Energetics and Composition in the Thermosphere

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Major Species Continuity Equations (O and O\textsubscript{2})

\[
\frac{\partial \Psi}{\partial t} = -\frac{e^2}{\tau} \frac{\partial}{\partial Z} \left[ \frac{m}{m_{N_2}} \left( \frac{T_{00}}{T_n} \right)^{0.25} \tilde{\alpha}^{-1} L \tilde{\Psi} \right] + S - R +
\]

\[
e^2 \frac{\partial}{\partial Z} \left[ K(Z)e^{-z} \frac{\partial}{\partial Z} \left( 1 + \frac{1}{m} \frac{\partial m}{\partial Z} \right) \tilde{\Psi} \right] - \left( \tilde{V} \cdot \nabla \tilde{\Psi} + w \frac{\partial \tilde{\Psi}}{\partial Z} \right)
\]

\[
\Psi_{N_2} = 1 - \Psi_O - \Psi_{O_2}
\]

S is the loss of O\textsubscript{2} through photodissociation and the loss of O through three body recombination. Short term changes in O and O\textsubscript{2} are dominated by the transport processes (e.g., Rees, 1989), so only these will be discussed here.
Neutral Energy Equation

\[
\frac{\partial T}{\partial t} = \frac{ge^Z}{P_0C_p} \frac{\partial}{\partial Z} \left[ K_T \frac{\partial T}{\partial Z} + K_E H^2 C_p \rho \left[ \frac{g}{C_p} + \frac{1}{H} \frac{\partial T}{\partial Z} \right] \right] - \nabla \cdot \nabla T - w \left( \frac{\partial T}{\partial Z} + \frac{RT}{C_p m} \right) + \frac{(Q - L)}{C_p} + F_{DH}
\]

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 \((\text{NO}, \text{O}^{(3)P} \text{and} \text{CO}_2)\)

- **Downward heat conduction**
- **Heat advection**
- **Joule heating**
- **Compressional heating and cooling by expansion**
Minor Species Continuity Equations (NO and N(4S))

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

\[
e^Z \frac{\partial}{\partial Z} \left[ e^{-Z} K_E(Z) \left( \frac{\partial}{\partial Z} + \frac{1}{m} \frac{\partial m}{\partial Z} \right) \tilde{\Psi} \right] - \left( \tilde{V} \cdot \nabla \tilde{\Psi} + w \frac{\partial \tilde{\Psi}}{\partial Z} \right)
\]

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 $U, V, W, T, \Psi_{O_2}, \Psi_O$

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

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

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

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

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 $8 \times 10^6$
The Thermosphere/ionosphere System
What Drives the Temperature Structure of the Thermosphere

Roble et al., 1987
Forcing the Thermosphere

Daily Average Power Values for Solar Cycles 21-23

Power (GW)

Year


Joule Power

Solar Power

Particle Power

14 Jul 1982
13 Mar 1989
10 May 1992
6 Nov 2001
30 Oct 2003

Knipp et al, 2004
Changes in Major Species Neutral Composition
N$_2$ mmr and forcing in quiet time
Compositional Forcing (storm)

N$_2$ mmr

Vertical Advection

Horizontal Advection

Molecular Diffusion
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)

Joule

Advection

Compression and expansion

Conduction
Changes in Low Latitude Thermal Forcing

Compression and Expansion

Conduction

Quiet

Storm
Temperature Evolution during the AGU Storm
Compositional Disturbances During Geomagnetic Storms

Prolss (1981, 2011)

Strickland et al.
Compositional Changes Caused by Storms
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.
Causes of Temperature Changes

Qjoul (K/Day) UT 12

Qadv (K/Day) UT 12

Qstab (K/Day) UT 12

Qdown (K/Day) UT 12
Prolss (1981, 2011)