Thermospheric Winds

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Outline

- Thermosphere & ionosphere
- Momentum equation
- Special cases in different regions
- Global circulation with season and its effects
- Winds during geomagnetic storms - "Forcing from above"
- Coupling to the lower atmosphere: Tides & effects - "Forcing from below"
- Variability & observations
Solar Radiation

**Total Solar Irradiance:**

- **1368 +/- 0.5 W/m²**

**Deposition Surface**

- EUV 10-100nm
  - 0.003 +/- 0.001 W/m²
  - Deposition: 100-500 km

- FUV 120-200nm
  - 0.1 W/m²
  - Deposition: 50-120 km

- UV 200-300nm
  - 16 +/- 0.1 W/m²
  - Deposition 0-50 km
The Thermosphere

- Thermosphere
- Solar Minimum
- Solar Maximum
- Mesosphere
- Stratosphere
- Troposphere

Particle Density (cm\(^{-3}\))

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<tr>
<th>Height (km)</th>
<th>10(^{10})</th>
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Temperature

- Solar Maximum
- Solar Minimum

Density

- Mesosphere
- Stratosphere
- Troposphere

(Comet module: Aurora)
Thermosphere & Ionosphere

Electron and Neutral Particle Densities in the Ionosphere (45° N, Equinox)

- Solar Max, Noon
- Electrons (e⁻)
- Neutrals
- F region
- E region
- D region

Height (km)

10² 10⁴ 10⁶ 10⁸ 10¹⁰ 10¹² 10¹⁴

Particle Density (cm⁻³)

(daytime)

(Comet module: Aurora)
Momentum Equation

\[
\frac{DU_h}{Dt} = -\frac{1}{\rho} \nabla_h p - 2\Omega \times U_h + \frac{1}{\rho} \nabla (\mu \nabla U_h) - v_{ni}(U_h - V_i)
\]

- Pressure gradient
- Coriolis
- Viscosity
- Ion drag

\[
\frac{D}{Dt} = \frac{\partial}{\partial t} + U \cdot \nabla
\]

- Pressure
- Horizontal neutral velocity
- Ion velocity
- Pressure
- Neutral density
- Earth rotation rate
- Ion-neutral collision frequency
- Viscosity coefficient

Hydrostatic equation

\[
\frac{dp}{dz} = -\rho g
\]

Equation of state

\[
p = \rho RT
\]

- Neutral temperature
- Height
- Gravitational acceleration
- \(R = k_b/m\) with \(k_b\) Boltzman constant
Geostrophic approximation

\[
\frac{DU_h}{Dt} = -\frac{1}{\rho} \nabla_h \rho - 2\Omega \times U_h + \frac{1}{\rho} \nabla (\mu \nabla U_h) - v_{ni}(U_h - V_i)
\]

Pressure gradient balanced by Coriolis force.
Wind flows along isobars.
Valid up to mesosphere.

[University of Illinois]

Pressure gradient force is balanced by Coriolis force.
Wind flows along isobars.
Valid up to mesosphere.

[Forbes CEDAR 2007]
If the ion-neutral collision frequency $\nu_{ni}$ is sufficiently large, and if the ion drift $V_i$ is sufficiently large and acts over a sufficient length of time, then the neutral gas circulation will begin to mirror that of the plasma.
In the upper thermosphere pressure gradient force, ion drag and viscous diffusion are important. The resulting wind tends to be across isobars.
Ion drag and viscosity vary differently at the two latitudes but balance pressure gradient force.

Neutral wind tendency $\delta u/\delta t$ is small at both latitudes above 300km.

Tuesday: Poster EQIT-08 by Art Richmond
Global circulation: Seasonal Variations

- EUV driven heating of the upper atmosphere
- Overall circulation from summer to winter hemisphere with daily averaged meridional winds of ~25 m/s at low and middle latitudes.

[Rishbeth et al. 2000]
Thermosphere consist mainly of O and N$_2$ between ~120 – 500 km.

Upwelling occurs over the summer hemisphere (not focused on polar region).

Photo-ionization of O is a source of plasma while more molecular N$_2$ can increase the loss of plasma.

Enhanced O/N2 ratios tend to lead to enhanced F-region plasma densities.

[Forbes, 2007]
During geomagnetic storms there is an intensification of energy input into the high latitude region. The thermosphere heats and can generate “Traveling Atmospheric Disturbances (TAD)”. [Lu. et al., 2012]
Equatorward wind effect on plasma

\[ v_{\parallel Z} = \hat{v} \sin(I) \cos(I) \]

Equatorward neutral wind at midlatitude in the F-region tends to blow plasma up magnetic field lines into regions of reduced recombination and can lead to an increase in F-region density and height of the F-layer. The effect is largest for an inclination \( I = 45^\circ \).
Coupling to the lower atmosphere
Solar Radiation Excites Solar Atmospheric Tides

Tides:
- global in scale
- periods are harmonics of a day
- propagate westward or eastward
- excited throughout the atmosphere

[Courtesy of Maura Hagan]
Migrating and non-migrating tides

Migrating tides

September equinox ~325 km
Solar minimum

To an observer on the ground the heating and associated atmospheric change is moving westward with the apparent motion of the Sun. These tides are called “migrating” tides.

If the excitation depends on longitude a spectrum of tides is produced and can be expressed as a linear superposition of waves of various frequencies and zonal wavenumbers.
Latent Heat Release in Deep Convective Clouds Excites “Nonmigrating” Solar Tides

Raindrops form in deep tropical clouds releasing diurnally varying latent heat on the global scale exciting a spectrum of upward propagating nonmigrating tides.

Rain fall rate January 2002-2006

[Immel et al. 2006]

Directly penetrate and indirectly affect the thermosphere and ionosphere

[Zhang et al. 2010]
Variability of neutral wind in the MLT

MLT = Mesosphere-Lower-Thermosphere

Superposition of the zonal wind components for all the midlatitude and low-latitude chemical release wind profile data from four decades.

Empirical model

Zonal wind components corresponding to the chemical release wind profiles calculated with the empirical Horizontal Wind Model (HWM).

[Larsen, 2002]
High resolution modeling of winds at 95 km

Numerical model: meridional wind

High resolution Whole Atmosphere Community Climate Model (WACCM) [Liu et al., 2014]
Challenge of measuring neutral winds
Questions?