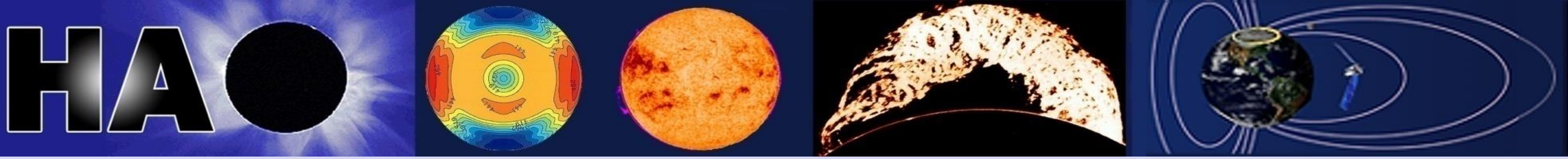
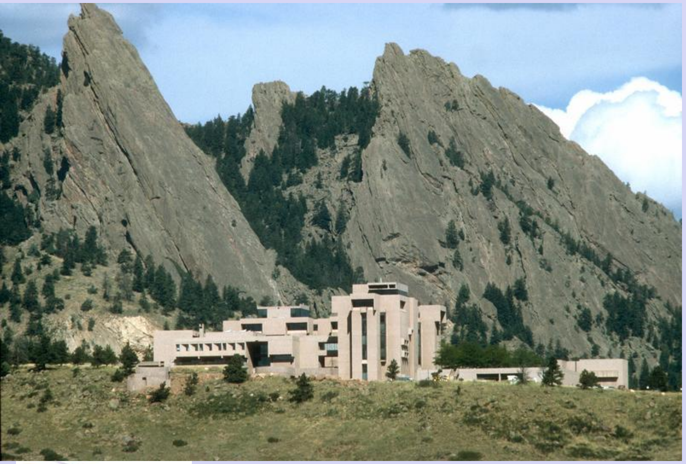


Thermospheric Winds

Astrid Maute
High Altitude Observatory (HAO)
National Center for Atmospheric Science (NCAR)
Boulder CO, USA

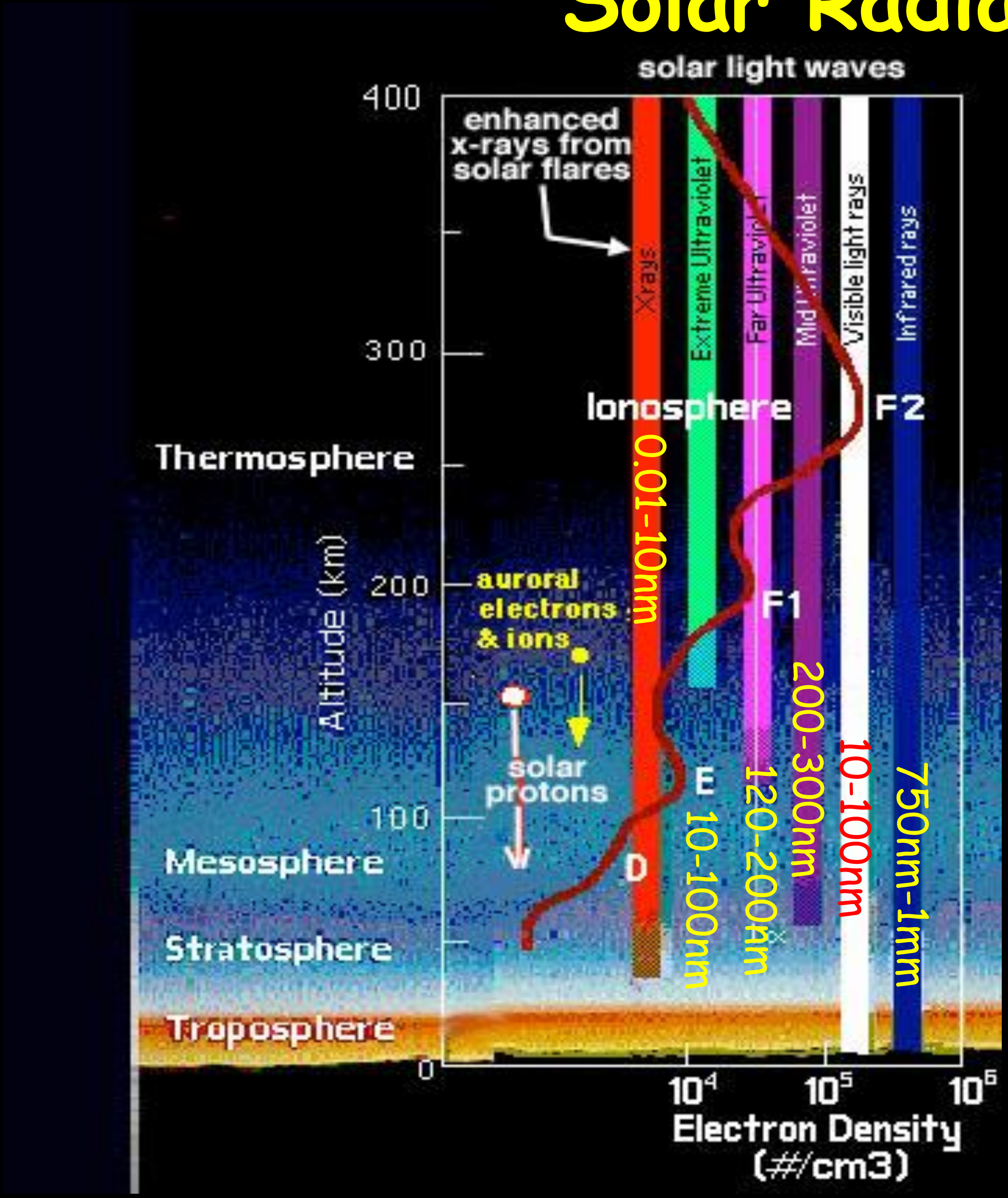


June 2016

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



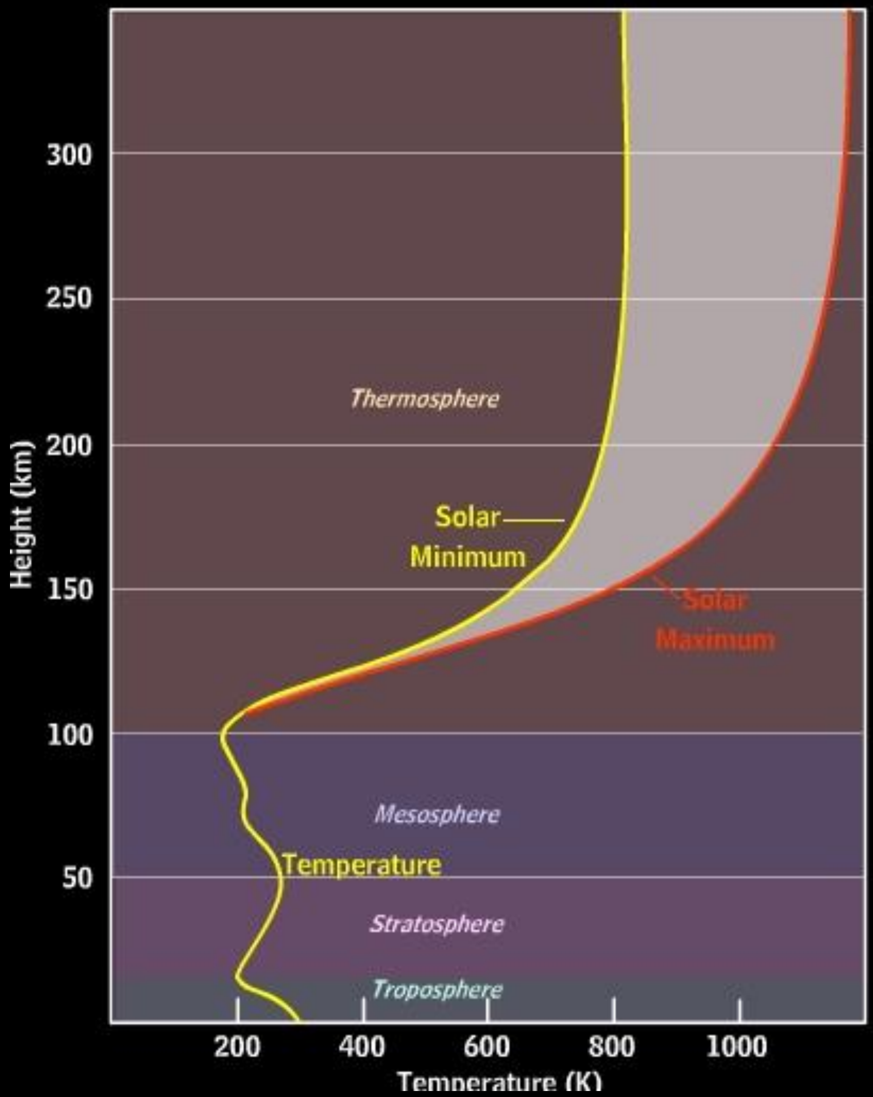
Total Solar Irradiance:
1368 +/- 0.5 W/m^2
Deposition Surface

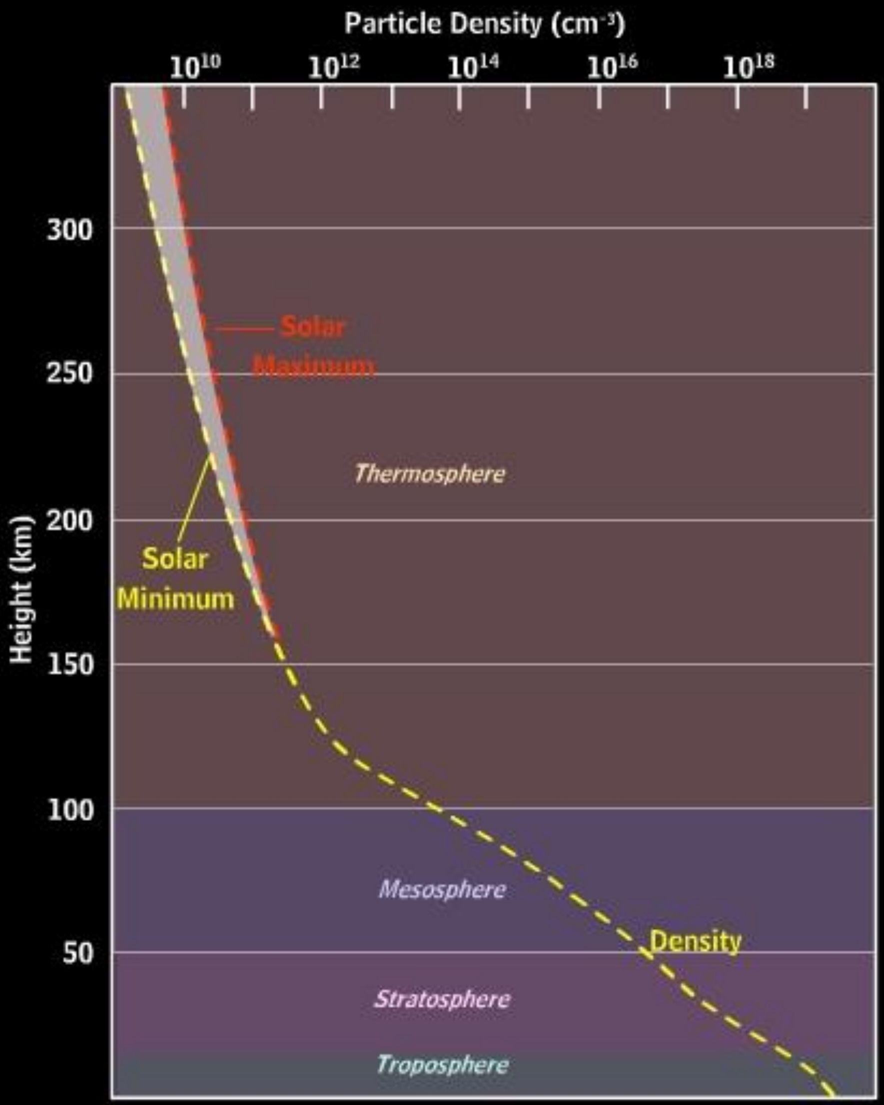
EUV 10-100nm
0.003+/- 0.001 W/m^2
Deposition: 100-500 km

FUV 120-200nm
0.1 W/m^2
Deposition: 50-120 km

UV 200-300nm
16 +/- 0.1 W/m^2
Depostion 0-50 km

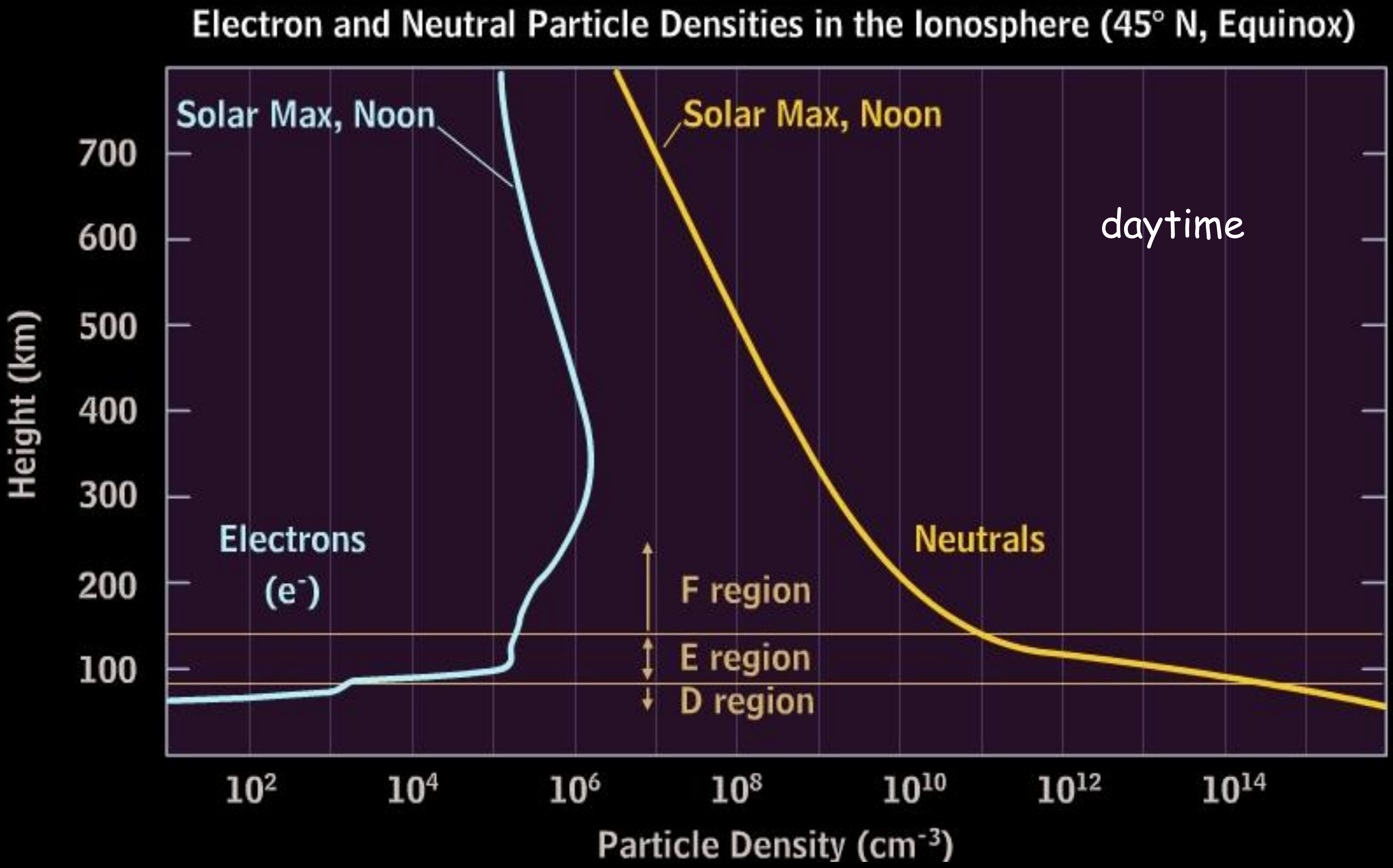
The Thermosphere





(Comet module: Aurora)

Thermosphere & Ionosphere



daytime

(Comet module: Aurora)

Momentum Equation

$$\frac{D\boldsymbol{U}_h}{Dt} = -\frac{1}{\rho}\nabla_h p - 2\Omega \times \boldsymbol{U}_h + \frac{1}{\rho}\nabla(\mu\nabla\boldsymbol{U}_h) - \nu_{\mathrm{ni}}(\boldsymbol{U}_h - \boldsymbol{V}_i)$$

pressure gradient

Coriolis

viscosity

ion drag

$$\frac{D}{Dt} = \frac{\partial}{\partial t} + \boldsymbol{U}\cdot\nabla$$

advection

local derivative

Hydrostatic equation

$$\frac{dp}{dz} = -\rho g$$

Equation of state

$$p = \rho R T$$

$\mathrm{U_h}$ horizontal neutral velocity
$\mathbf{V}_\mathrm{i}$ ion velocity
p pressure
ρ neutral density
Ω Earth rotation rate
ν_{ni} ion-neutral collision frequency
μ viscosity coefficient

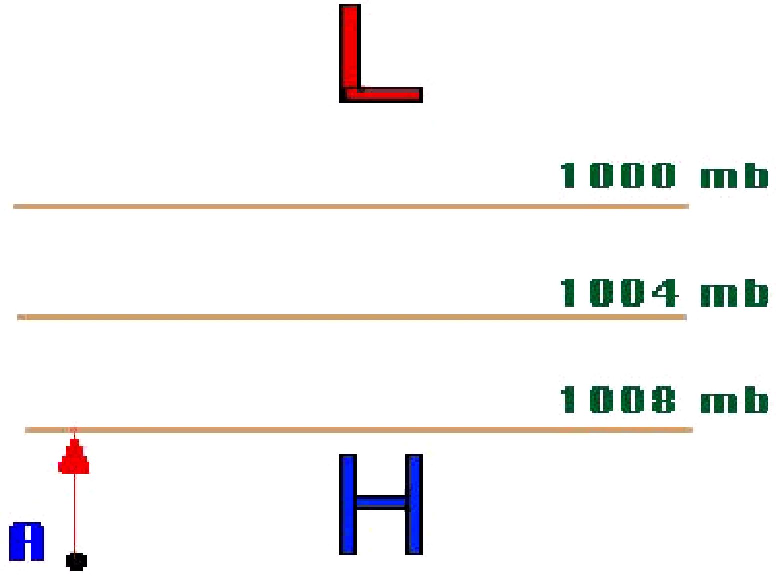
T neutral temperature
z height
g gravitational acceleration
R =k_B/m with k_B Boltzman constant

Geostrophic approximation

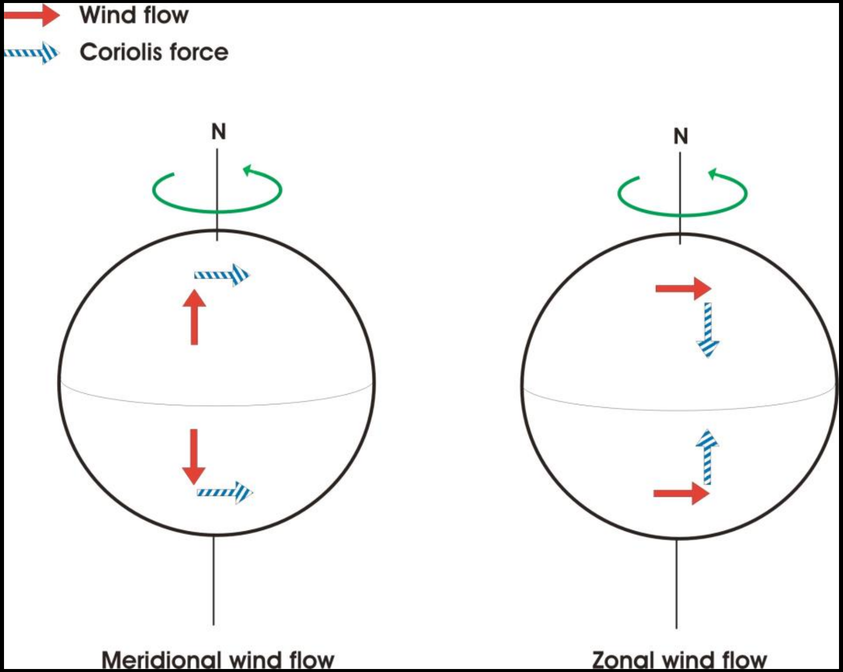
$$\frac{D\boldsymbol{U}_h}{Dt} = \boxed{-\frac{1}{\rho}\nabla_h p} - \boxed{2\Omega \times \boldsymbol{U}_h} + \frac{1}{\rho}\nabla(\mu\nabla\boldsymbol{U}_h) - \nu_{\mathrm{ni}}(\boldsymbol{U}_h - \boldsymbol{V}_i)$$

pressure gradient

Coriolis



[University of Illinois]



[Forbes CEDAR 2007]

Pressure gradient force is balanced by Coriolis force

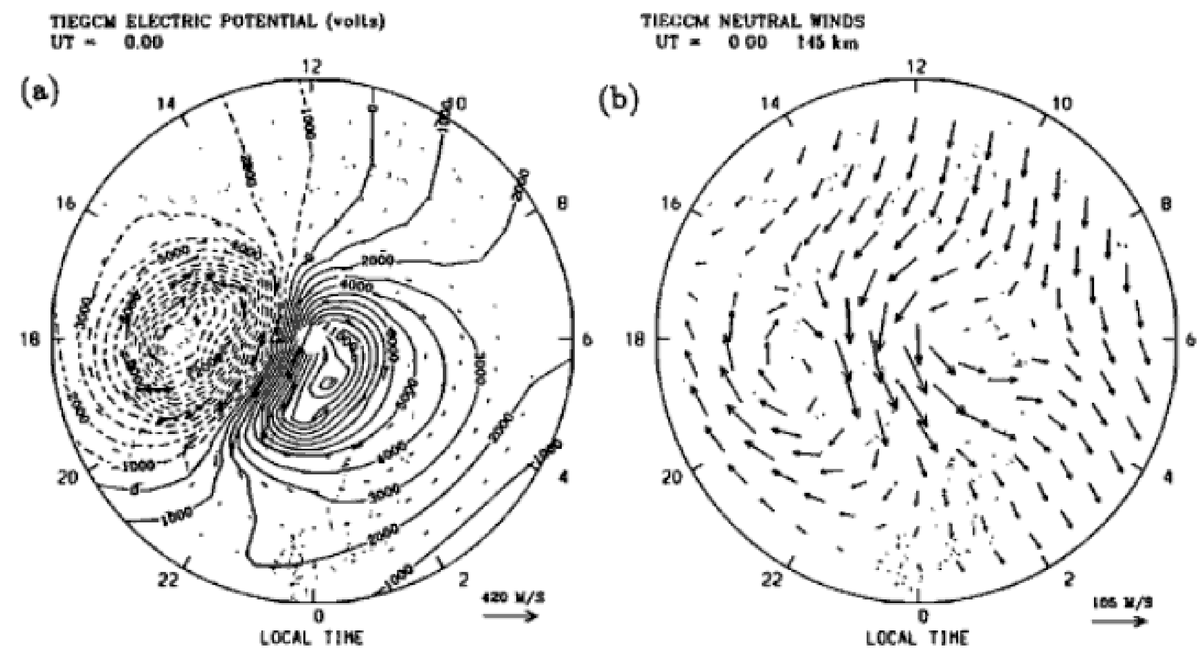
Wind flows along isobars

Valid up to mesosphere

Effects at High Latitude

$$\frac{D\boldsymbol{U}_h}{Dt} = -\frac{1}{\rho}\nabla_h p - 2\Omega \times \boldsymbol{U}_h + \frac{1}{\rho}\nabla(\mu\nabla\boldsymbol{U}_h) - \boxed{\nu_{\mathrm{ni}}(\boldsymbol{U}_h - \boldsymbol{V}_i)}$$

ion drag



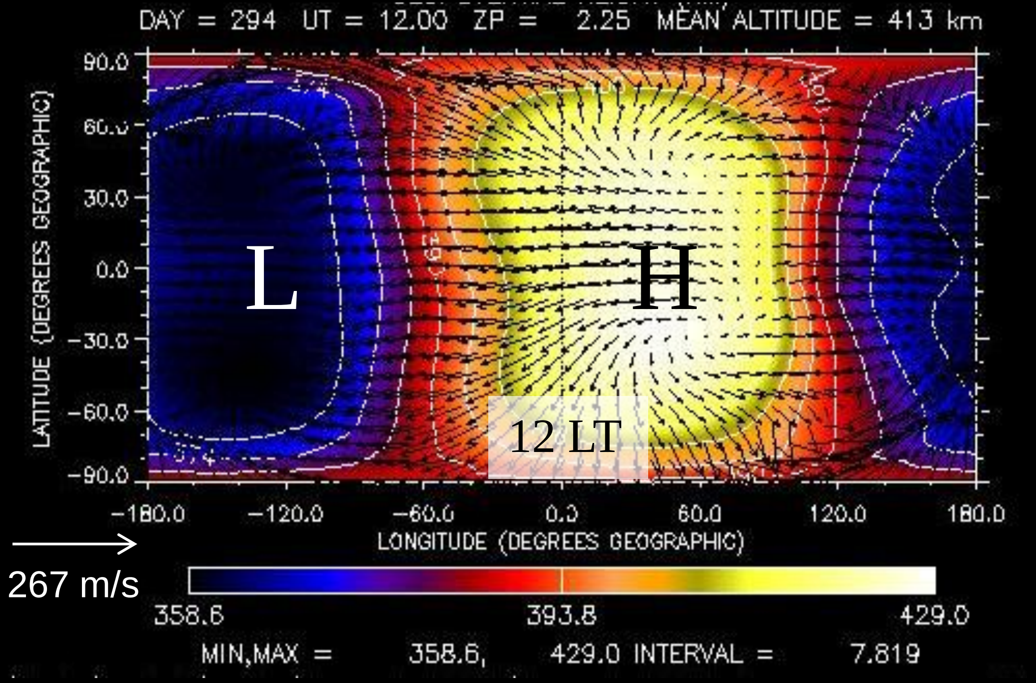
[Richmond 1994]

If the ion-neutral collision frequency ν_{ni} is sufficiently large, and if the ion drift $\mathbf{V}_i$ is sufficiently large and acts over a sufficient length of time, then the neutral gas circulation will begin to mirror that of the plasma.

Upper Thermosphere

$$\frac{D\boldsymbol{U}_h}{Dt} = \underbrace{-\frac{1}{\rho}\nabla_h p}_{\text{pressure gradient}} - 2\Omega \times \boldsymbol{U}_h + \underbrace{\frac{1}{\rho}\nabla(\mu\nabla \boldsymbol{U}_h)}_{\text{viscosity}} - \underbrace{\nu_{\mathrm{ni}}(\boldsymbol{U}_h - \boldsymbol{V}_i)}_{\text{ion drag}}$$

Geopotential height and wind vectors at ~ 400 km

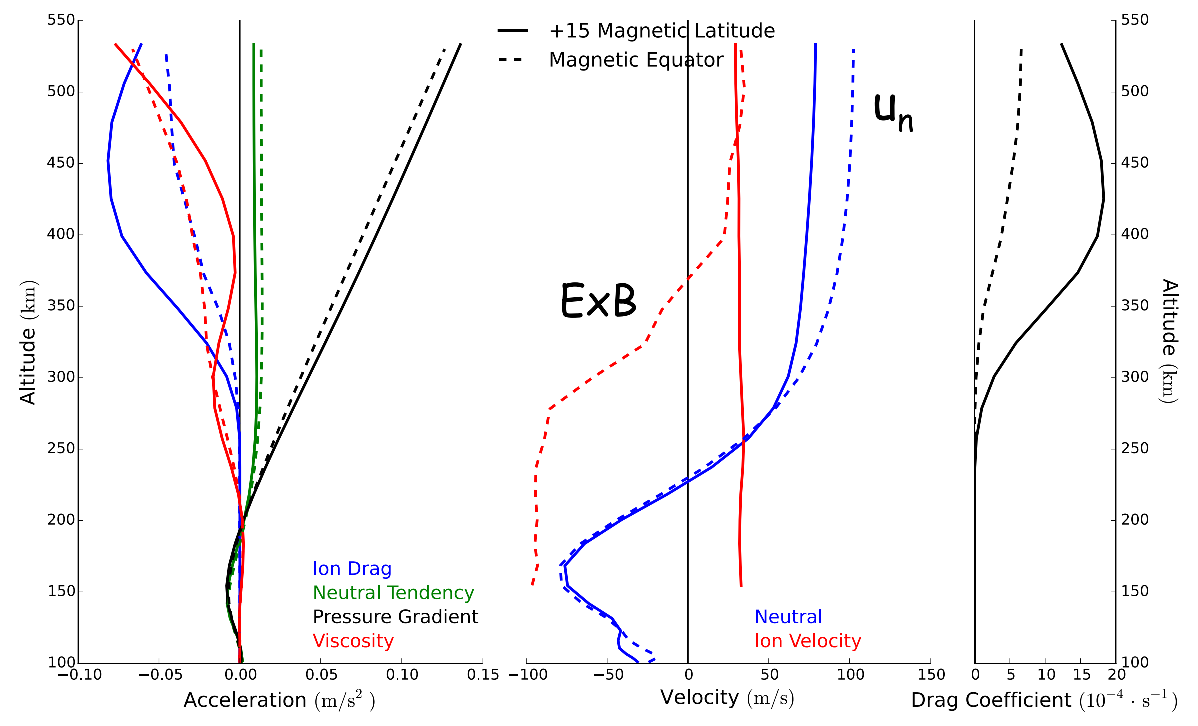


September equinox

In the upper thermosphere pressure gradient force, ion drag and viscous diffusion are important. The resulting wind tends to be across isobars.

Eastward acceleration terms at 19 LT

$$\frac{\partial U_h}{\partial t} + \cancel{U\cdot\nabla U_h} = -\frac{1}{\rho}\nabla_h p \cancel{- 2\Omega \times U_h} + \frac{1}{\rho}\nabla(\mu\nabla U_h) - \nu_{ni}(U_h - V_i)$$



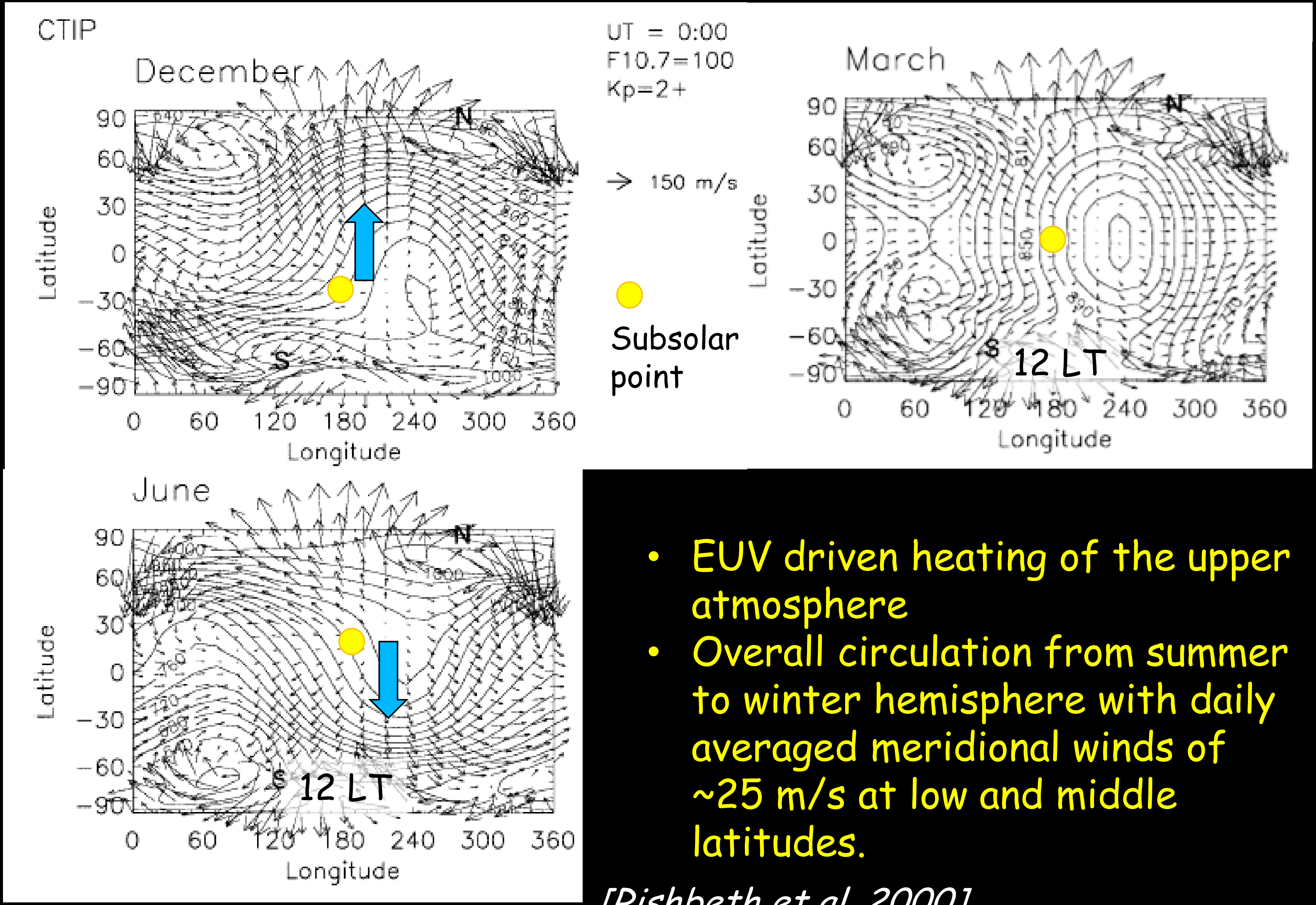
Acceleration terms at 19 LT at magnetic equator and equatorial ionization anomaly (EIA, 15° magnetic latitude)

[Evonosky et al., 2016]

- Ion drag and viscosity vary differently at the two latitudes but balance pressure gradient force.
- Neutral wind tendency δu/δt is small at both latitudes above 300km.

Tuesday: Poster EQIT-08 by Art Richmond

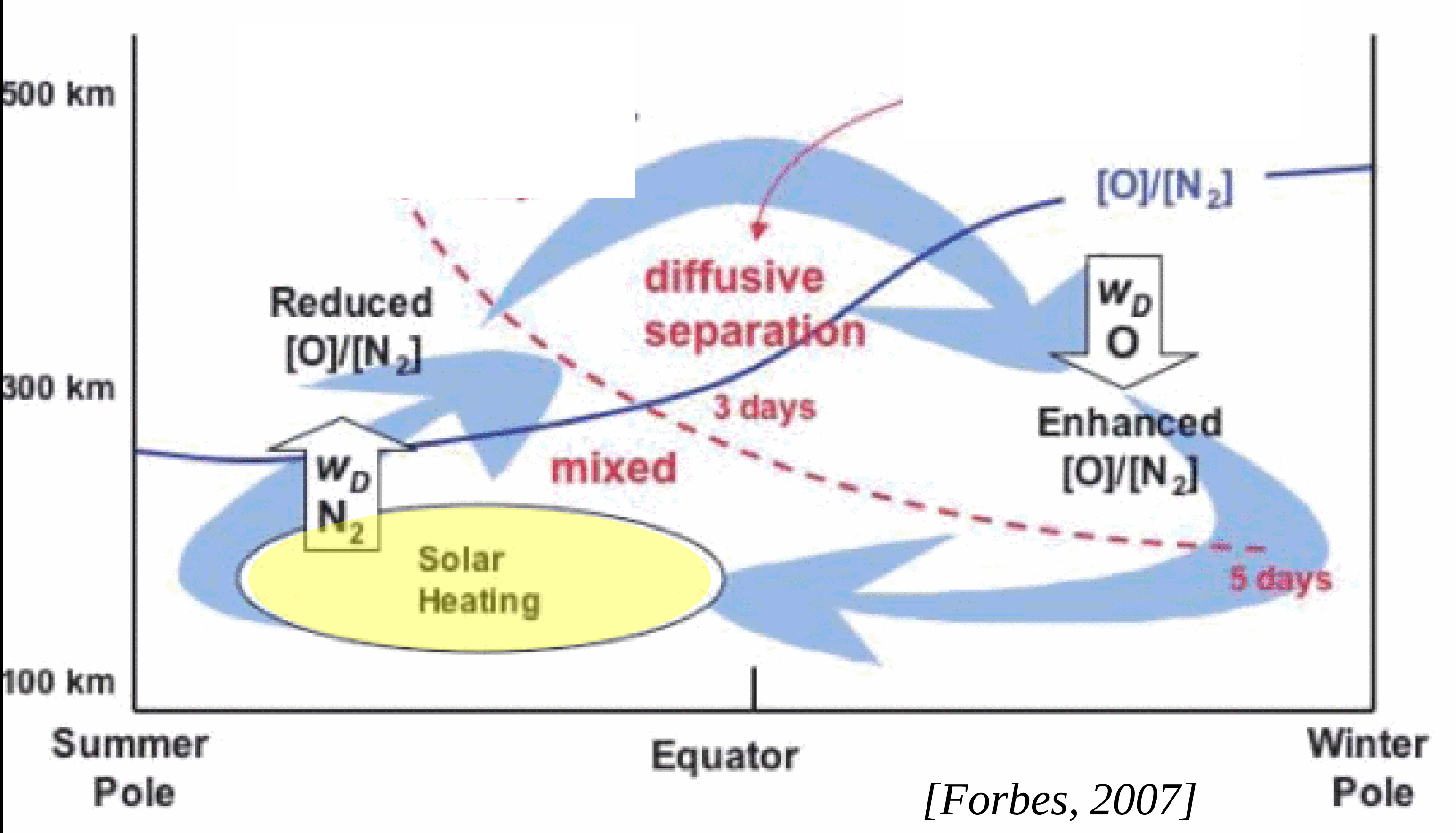
Global circulation: Seasonal Variations



- 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]

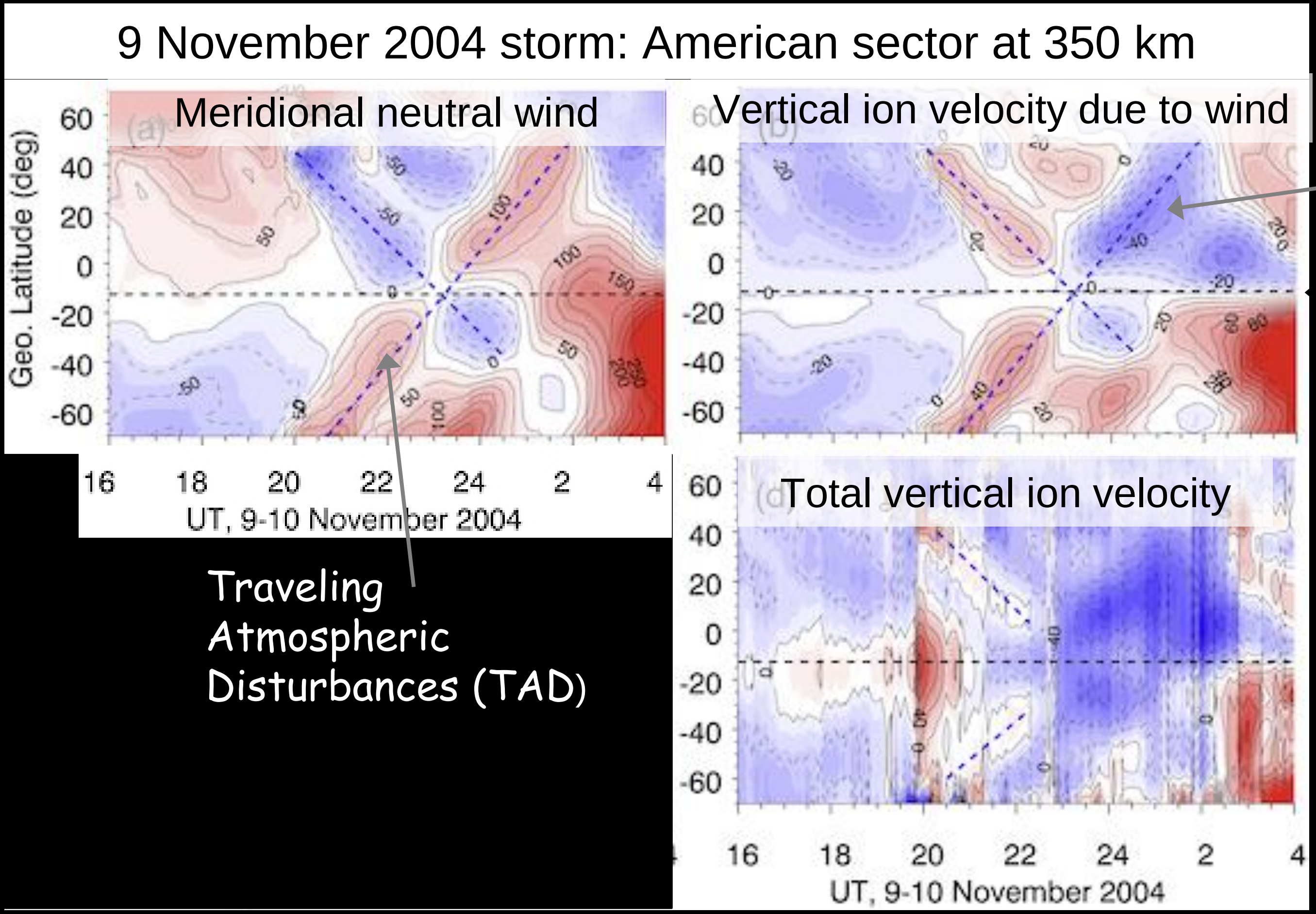
Solar EUV driven circulation effect on O/N2



[Forbes, 2007]

- 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.

Strom time winds at midlatitudes



Traveling Atmospheric Disturbances (TAD)

phase propagation of Traveling Atmospheric Disturbances (TAD)

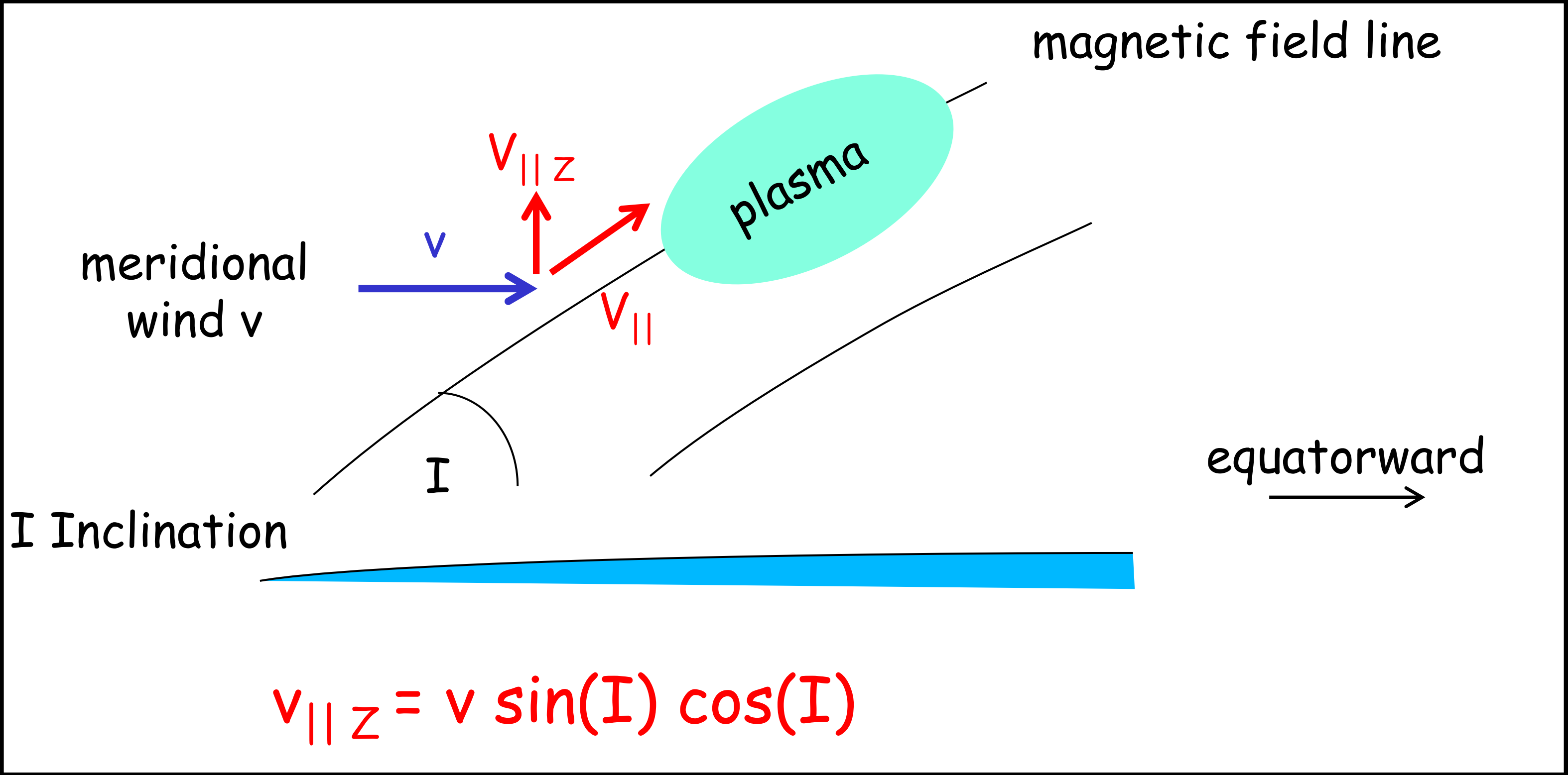
geomagnetic equator

geomagnetic equator

[Lu. et al., 2012]

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)”.

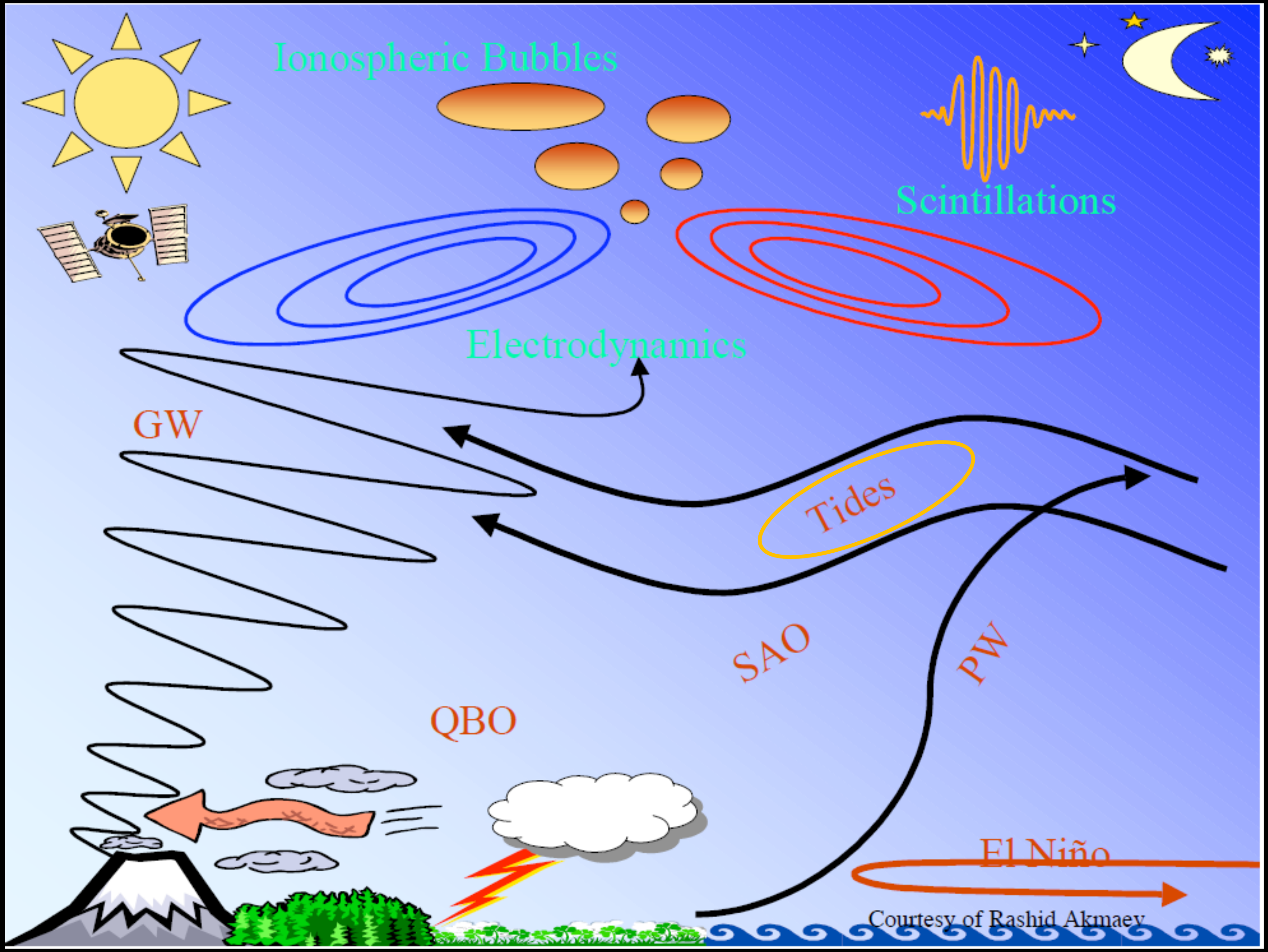
Equatorward wind effect on plasma



$$v_{|| z} = v \sin(I) \cos(I)$$

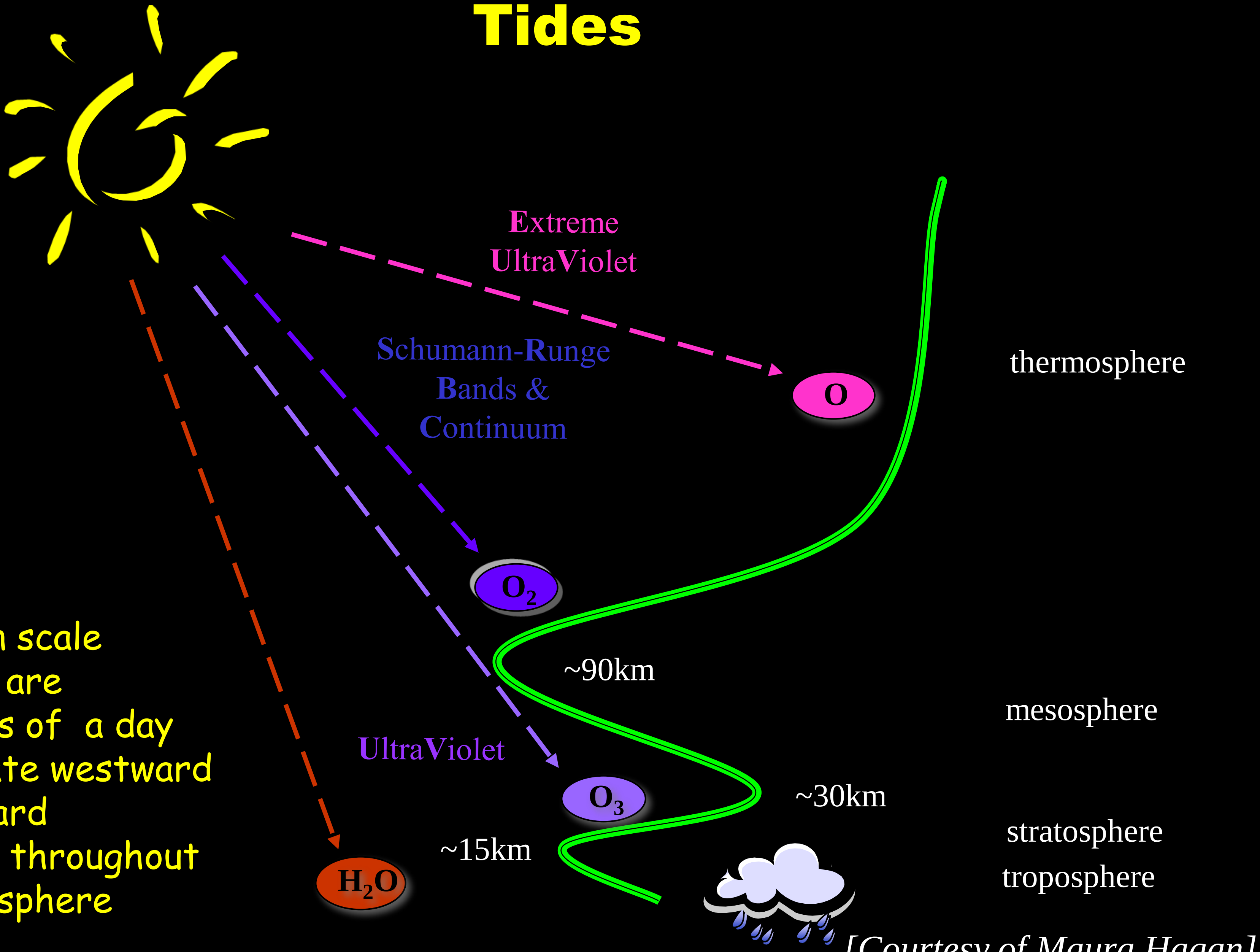
Equatorward neutral wind at midlatitude in the F-region tends to blow plasma up magnetic field lines into regions of reduced recombination and can lead to an increase in F-region density and height of the F-layer.
The effect is largest for an inclination I=45°.

Coupling to the lower atmosphere



Courtesy of Rashid Akmaev

Solar Radiation Excites Solar Atmospheric Tides



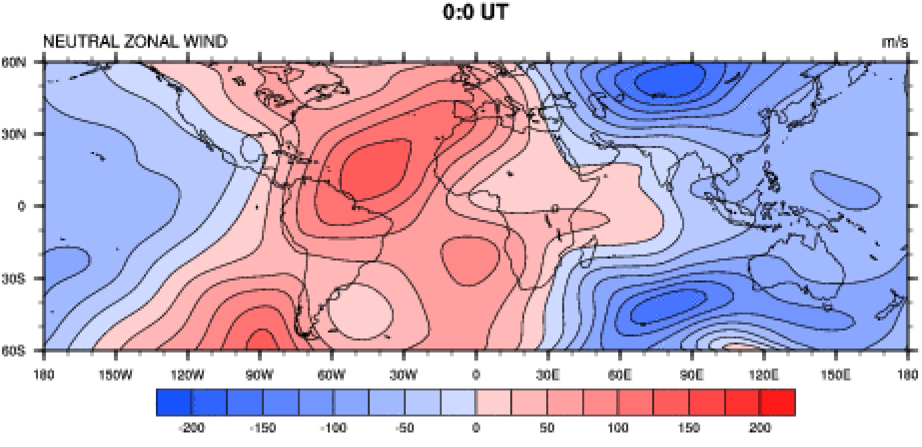
Tides:

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

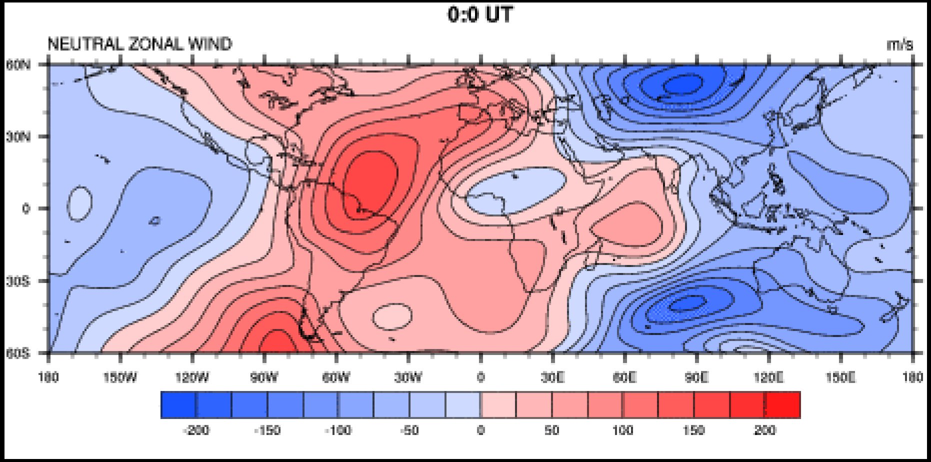
[Courtesy of Maura Hagan]

Migrating and non-migrating tides

Migrating tides



Migrating and nonmigrating tides



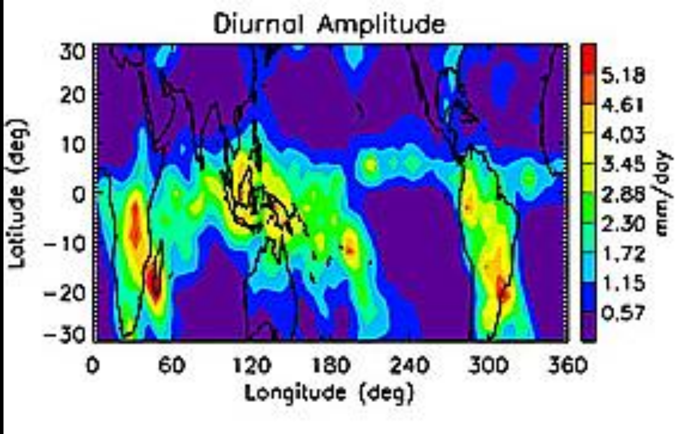
September equinox ~325 km
Solar minimum

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.

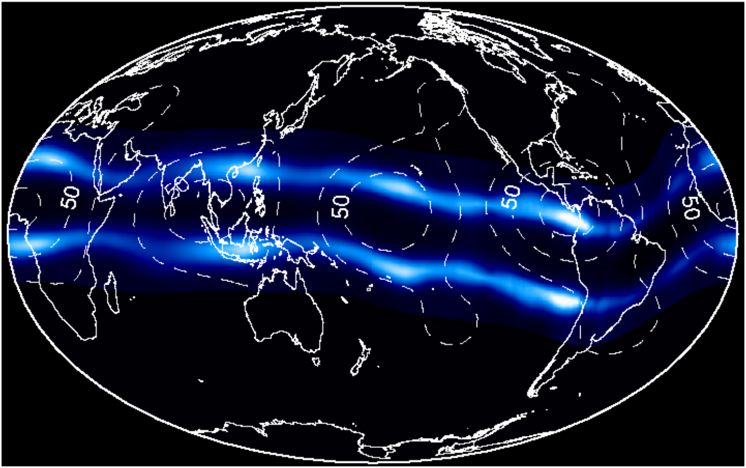
Latent Heat Release in Deep Convective Clouds Excites "Nonmigrating" Solar Tides

rain fall rate January 2002-2006



[Zhang et al. 2010]

IMAGE 135.6-nm O airglow at 20 LT



[Immel et al. 2006]

raindrops form in deep tropical clouds

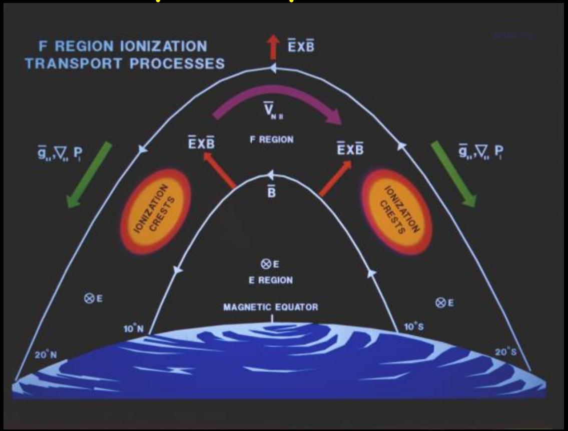
⬇

releasing diurnally varying latent heat on the global scale

⬇

exciting a spectrum of upward propagating nonmigrating tides

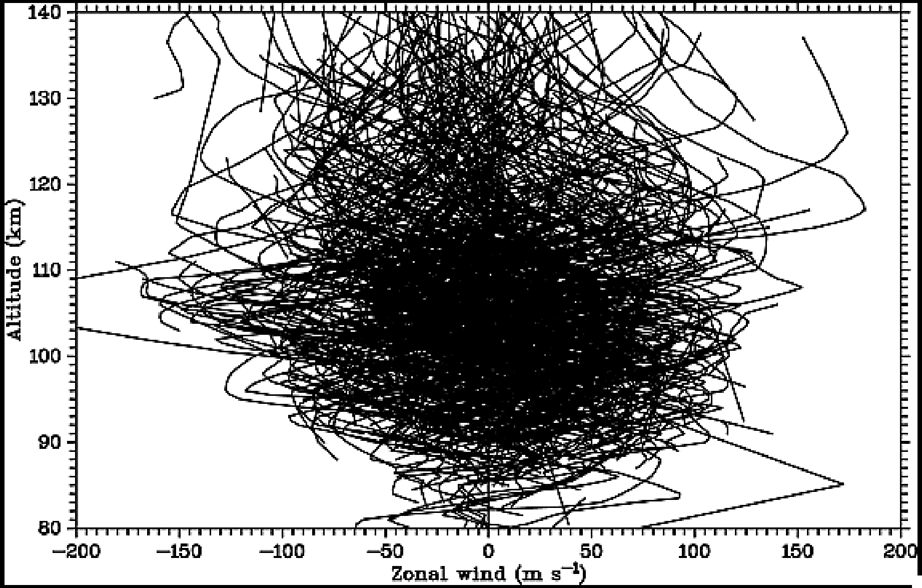
modulate the E-region dynamo process



directly penetrate and indirectly affect the thermosphere and ionosphere

Variability of neutral wind in the MLT

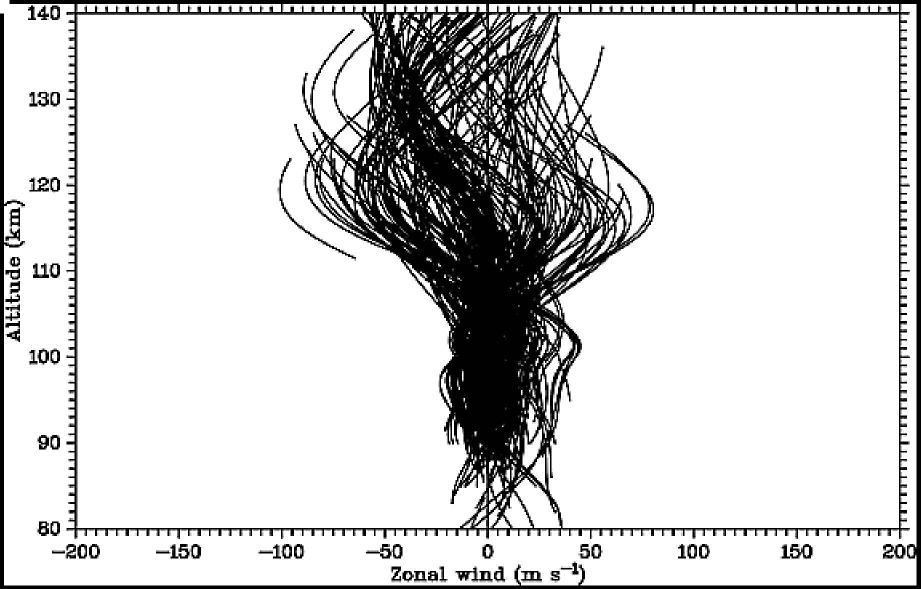
observations



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

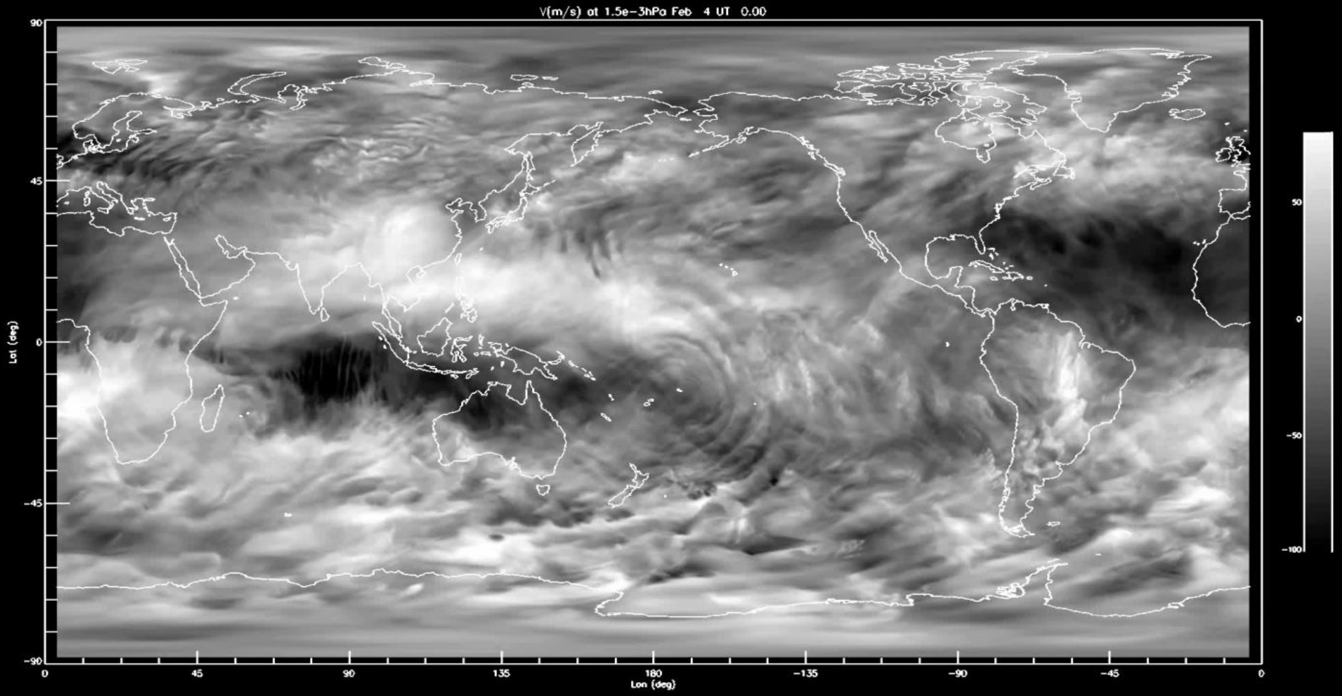


Zonal wind components corresponding to the chemical release wind profiles calculated with the empirical Horizontal Wind Model (HWM).

[Larsen, 2002]

High resolution modeling of winds at 95 km

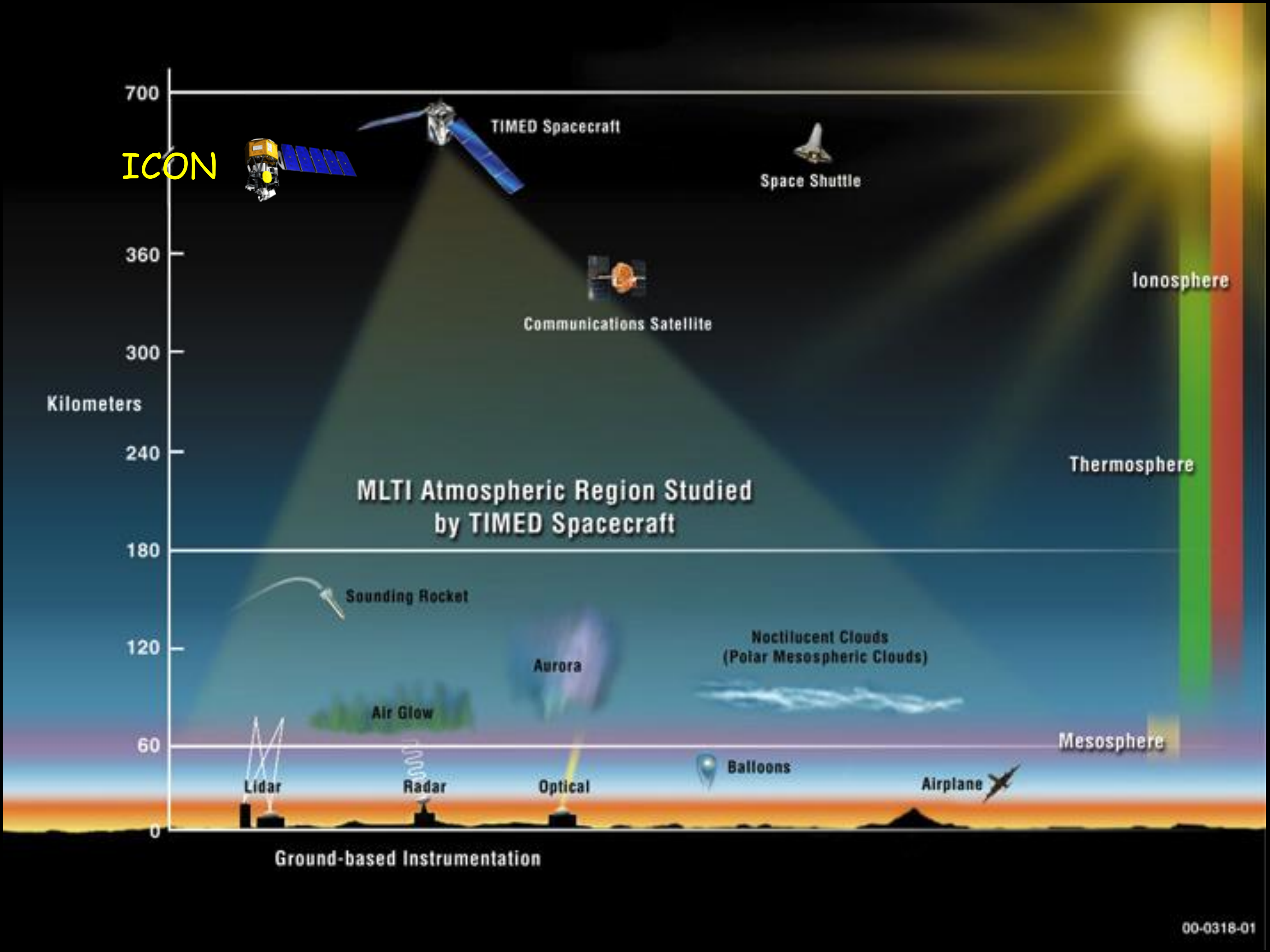
Numerical model: meridional wind



High resolution Whole Atmosphere Community Climate Model (WACCM)

[Liu et al., 2014]

Challenge of measuring neutral winds



Questions?