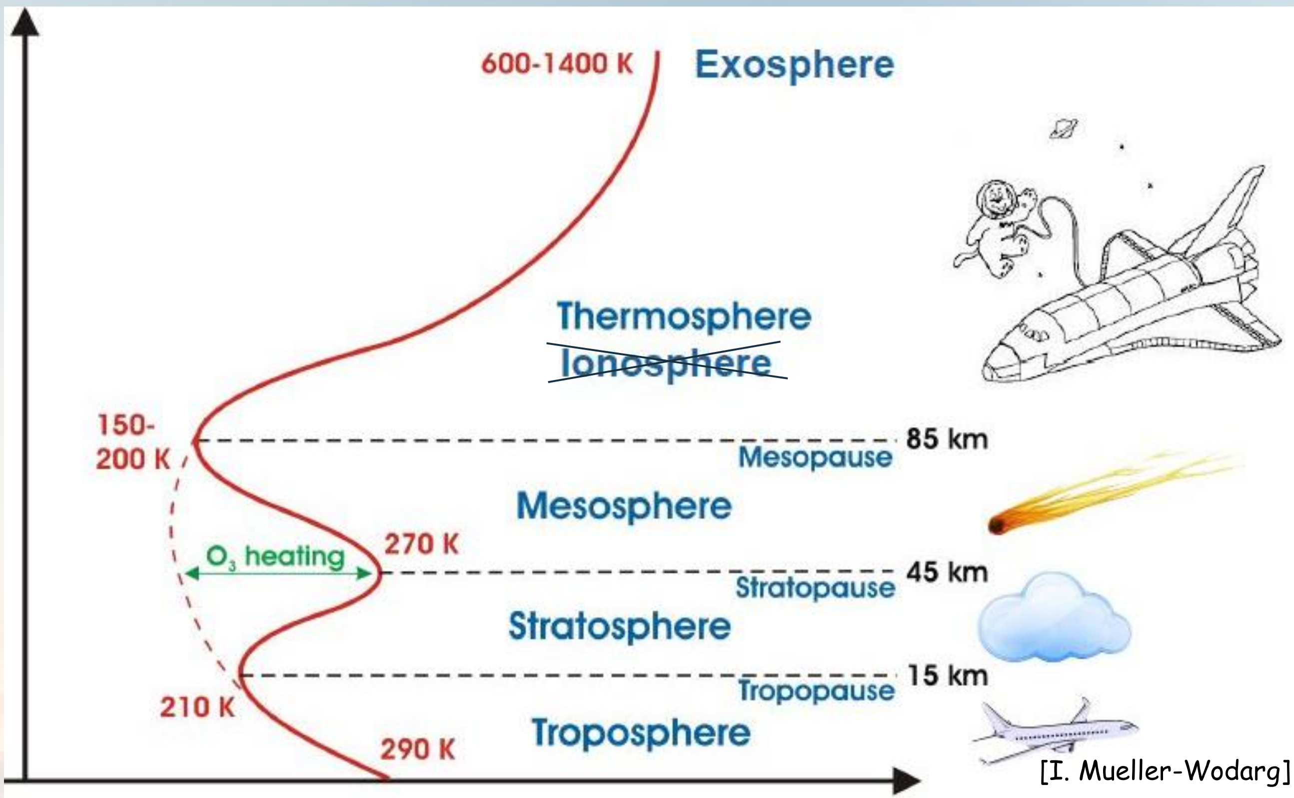
The neutral atmosphere



[I. Mueller-Wodarg]

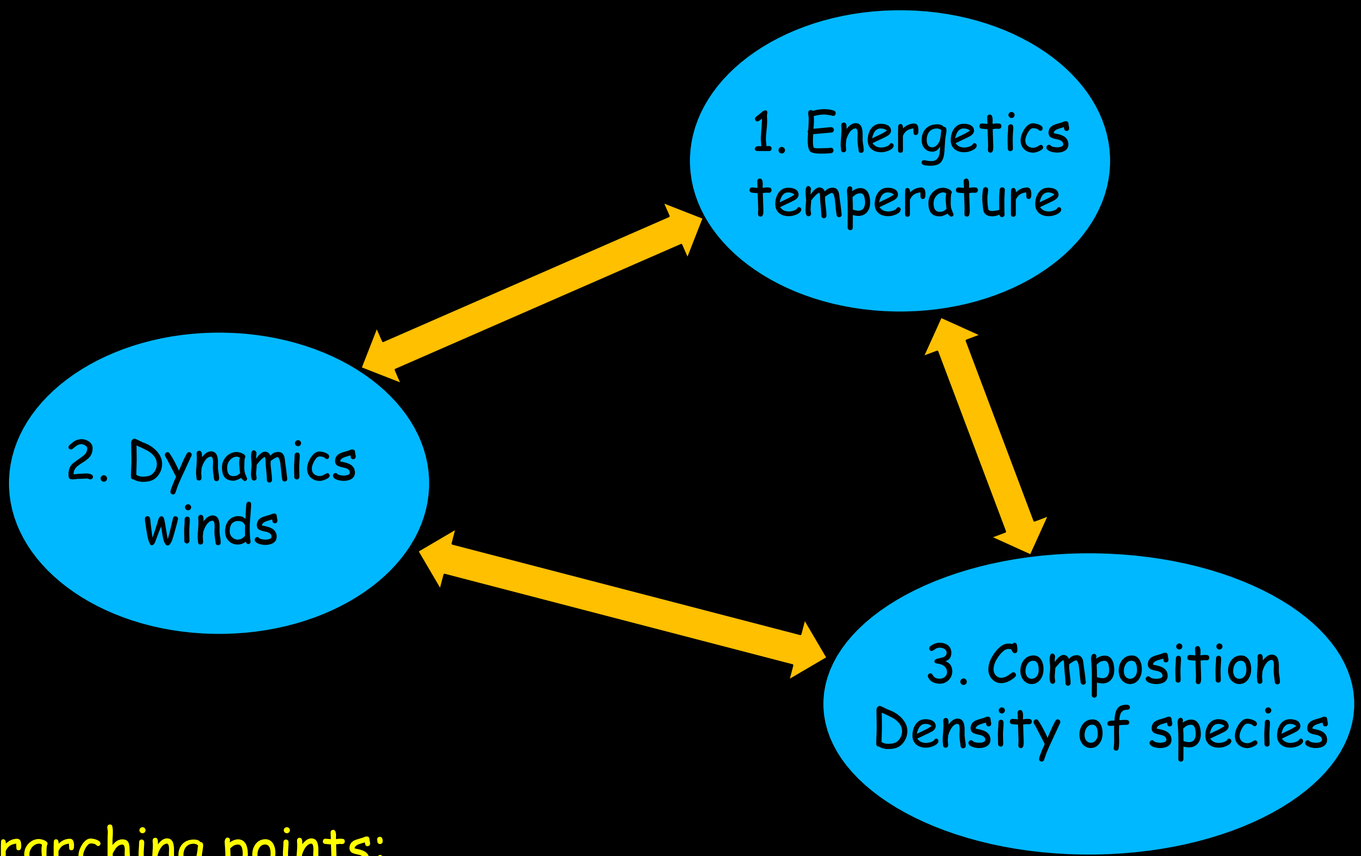
Astrid Maute

High Altitude Observatory, NCAR

CEDAR workshop, Santa Fe, June 2019

The National Center for Atmospheric Research is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

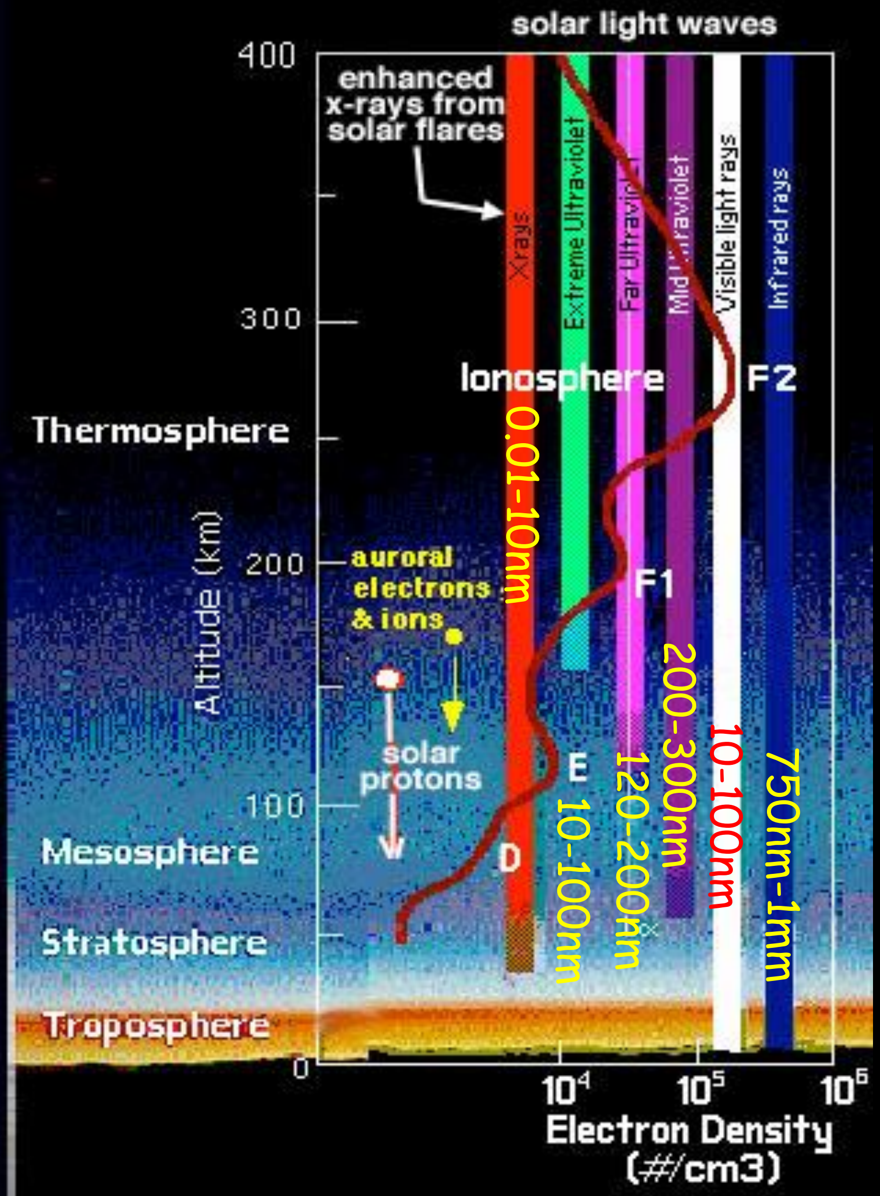
Outline



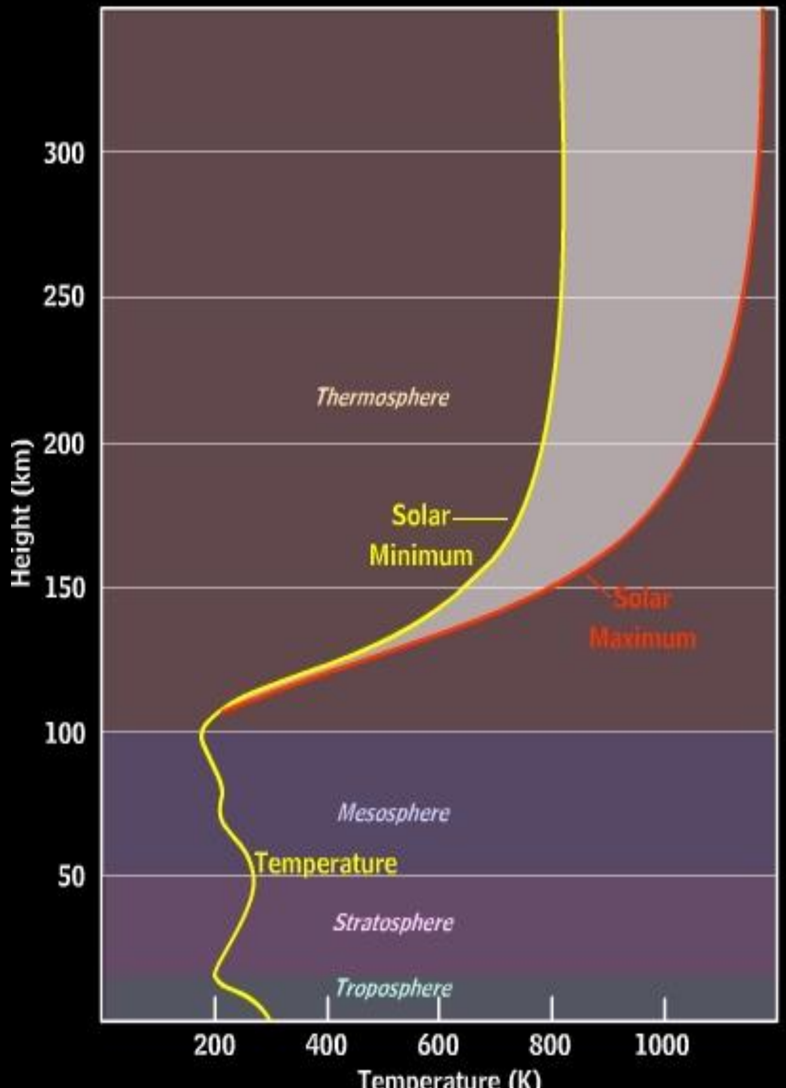
Overarching points:
Energetics, dynamics, and composition are interconnected
Atmospheric regions are coupled

CEDAR – Coupling, Energetics, and Dynamics of Atmospheric Regions

Solar Radiation & thermal structure

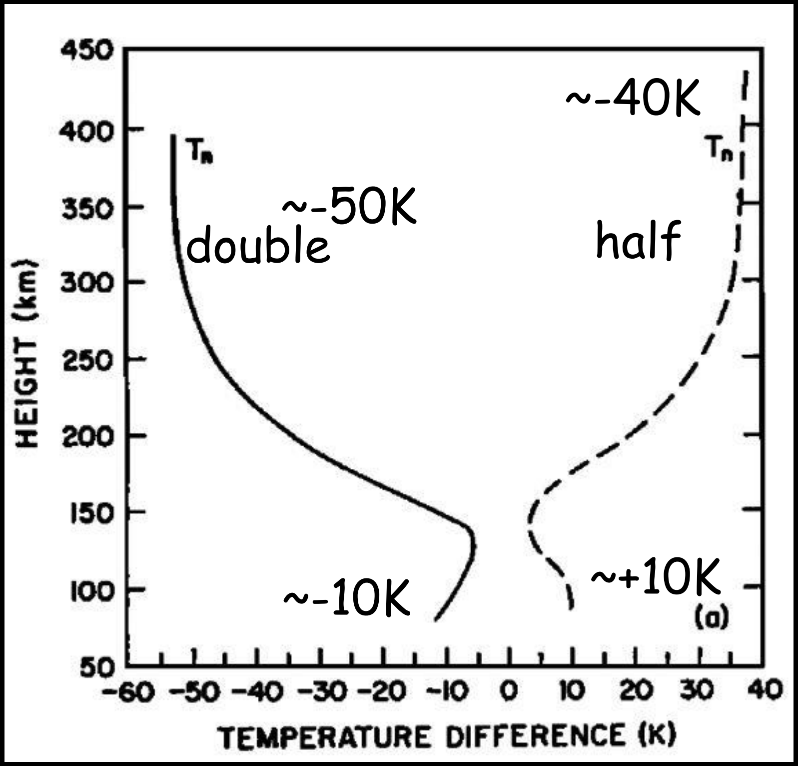


Neutral temperature [K]



Climate change effects

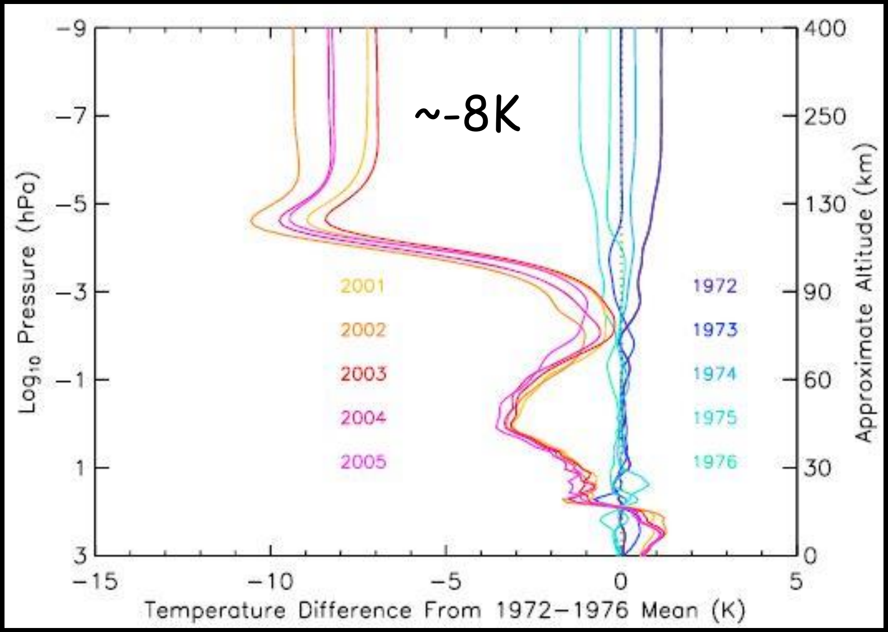
Global mean model



[Roble & Dickinson, 1989]

CO_2 & CH_4 concentration specified at ~60 km
(1950 global mean values: 330ppmv & 0.1ppmv)

Whole atmosphere model (WACCM-X)



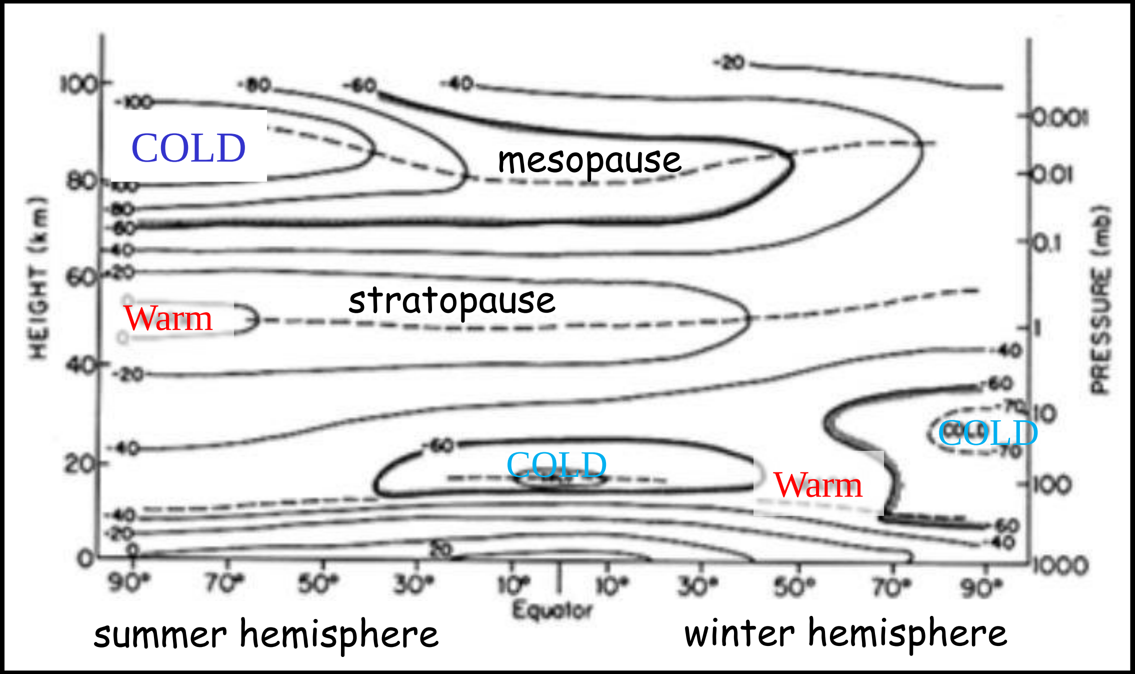
[Solomon et al., 2018]

CO_2, CH_4, CFC concentration specified surface
(CO_2 from 330ppmv to 375ppmv)

Stan Solomon's science highlight on Monday
"CEDAR and climate change" workshop on Wednesday

Coldest place: summer mesopause

Schematic of zonal mean temperatures [°C]



[Holton, 1976]

Clouds at ~80 km height!

Noctilucent clouds

NLC: Portland July2009

(Picture from Varnas)

Heating in the mesosphere mostly due to absorption of radiation by ozone which is stronger in the summer than the winter hemisphere which creates a meridional circulation. Upwind over the polar summer region causes temperature to drop due to expansion. Gravity wave breaking deposit eastward momentum increasing the upwind and the cooling.

Xinzhao Chu's prize lecture

Momentum Equation

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

pressure gradient — Coriolis — viscosity — ion drag

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

advection

local derivative

U_h horizontal neutral velocity
V_i ion velocity
p pressure
ρ neutral density
Ω Earth rotation rate
ν_{ni} ion-neutral collision frequency
μ viscosity coefficient

Hydrostatic equation

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

Equation of state

$$p = \rho R T$$

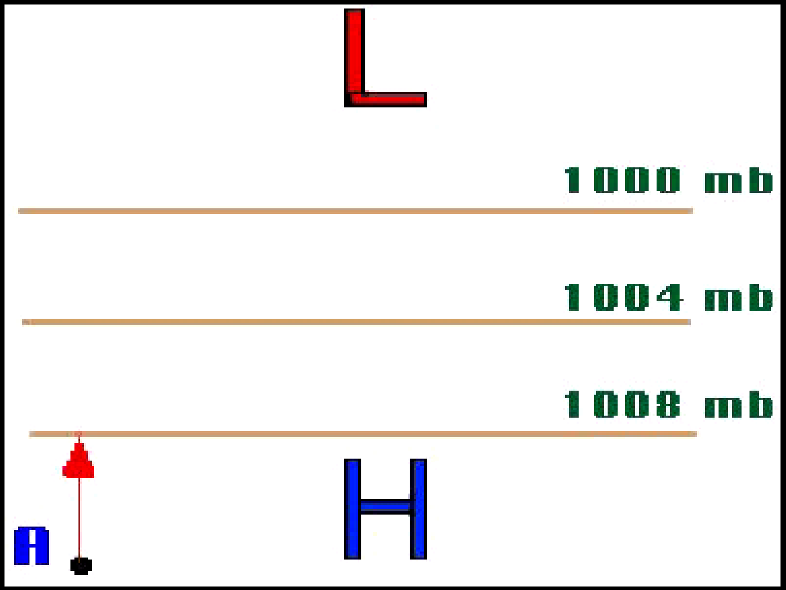
P, V_i External forces
T neutral temperature
z height
g gravitational acceleration
R = k_B/m with k_B Boltzman constant

Geostrophic approximation

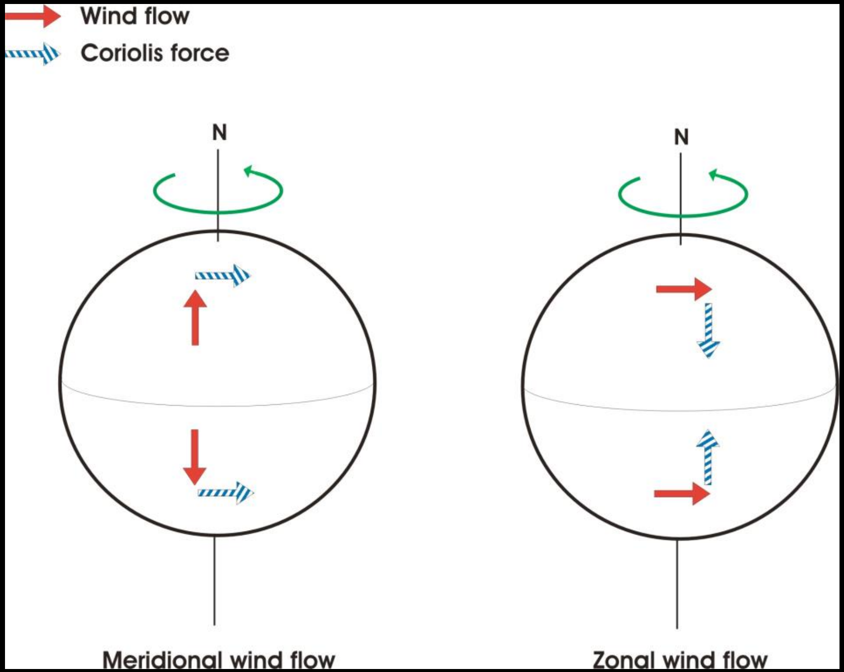
$$\frac{DU_h}{Dt} = -\frac{1}{\rho}\nabla_h p - 2\Omega \times U_h + \frac{1}{\rho}\nabla(\mu\nabla U_h) - \nu_{ni}(U_h - V_i)$$

pressure gradient

Coriolis



[University of Illinois]



[Forbes CEDAR 2007]

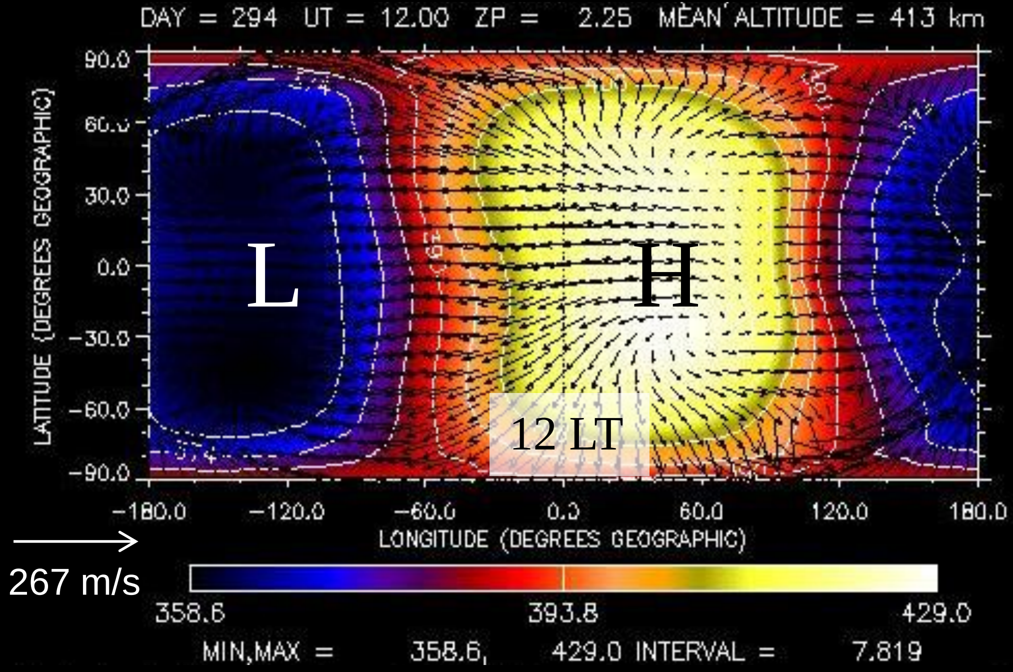
Pressure gradient force is balanced by Coriolis force
Wind flows along isobars
Valid up to mesosphere

Upper Thermosphere

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

pressure gradient viscosity ion drag

Geopotential height and wind vectors at ~ 400 km



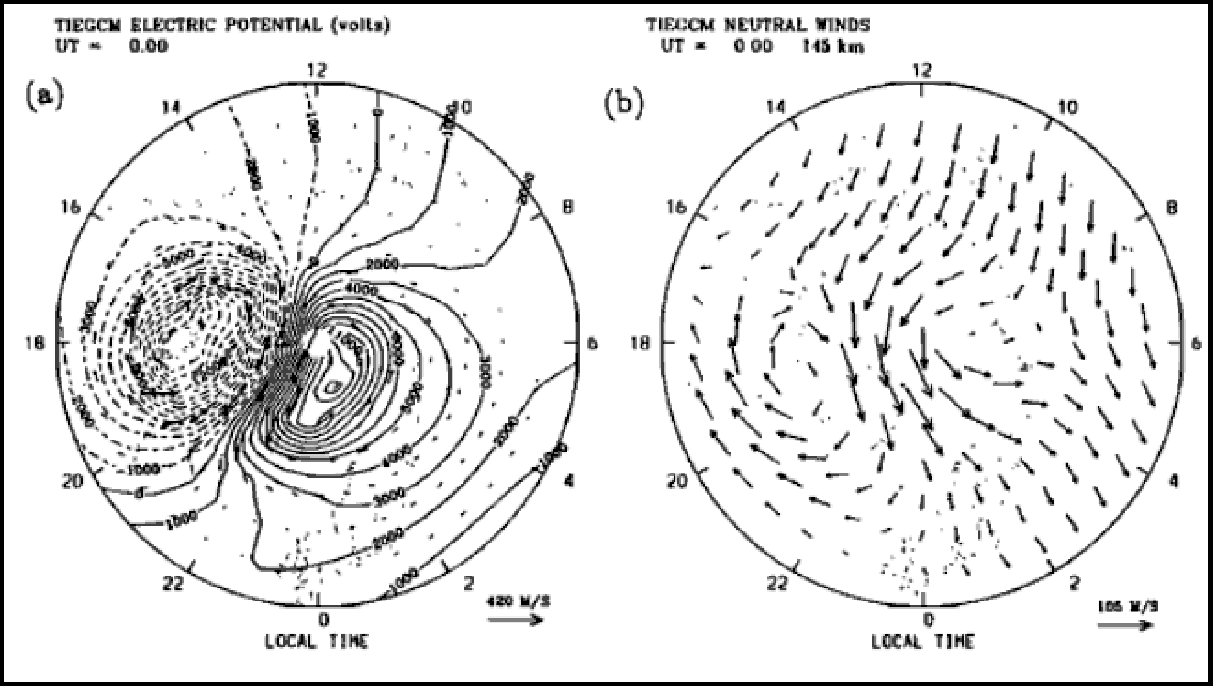
September equinox

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

Effects at High Latitude

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

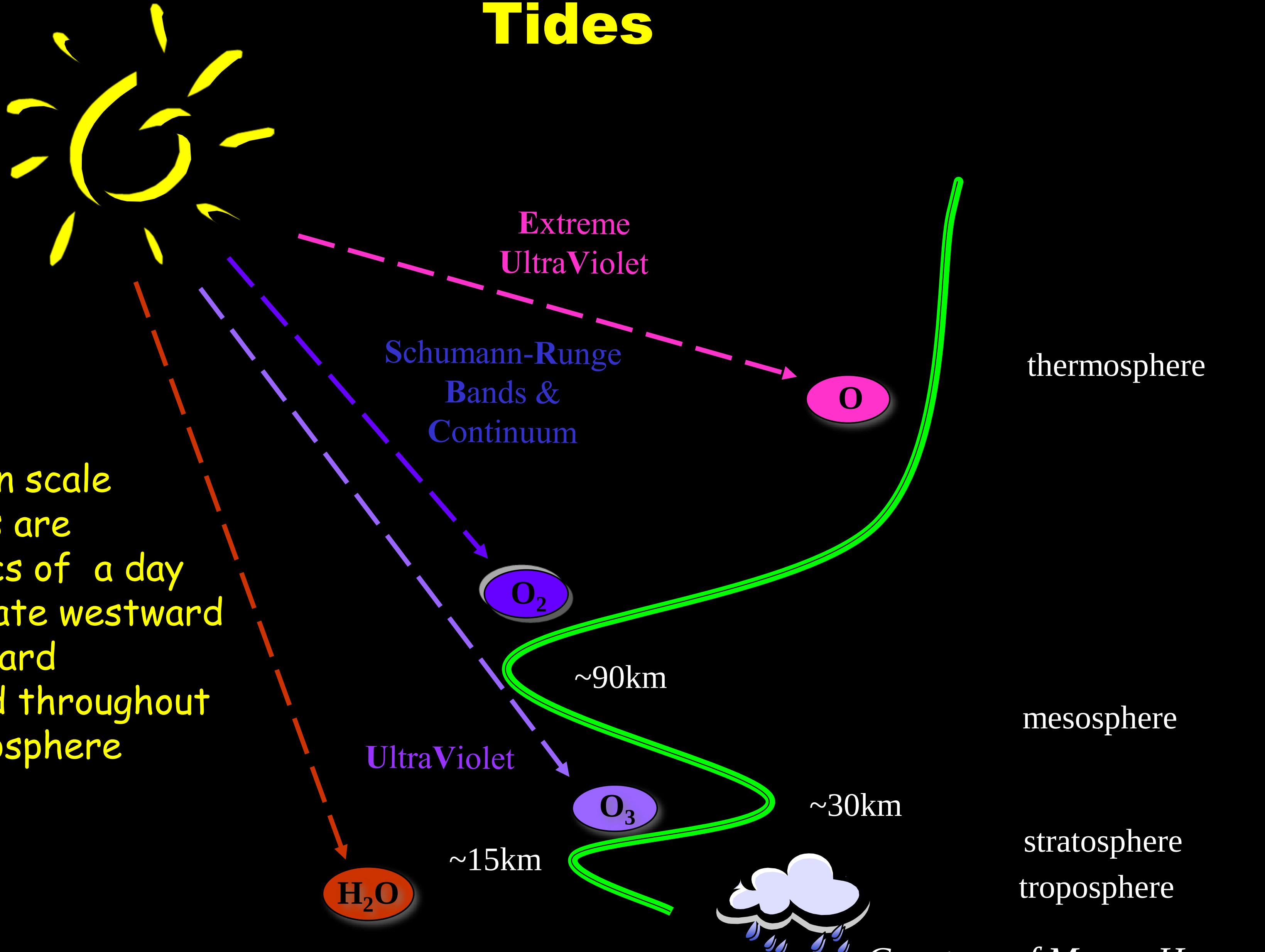
ion drag



[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.

Solar Radiation Excites Solar Atmospheric Tides



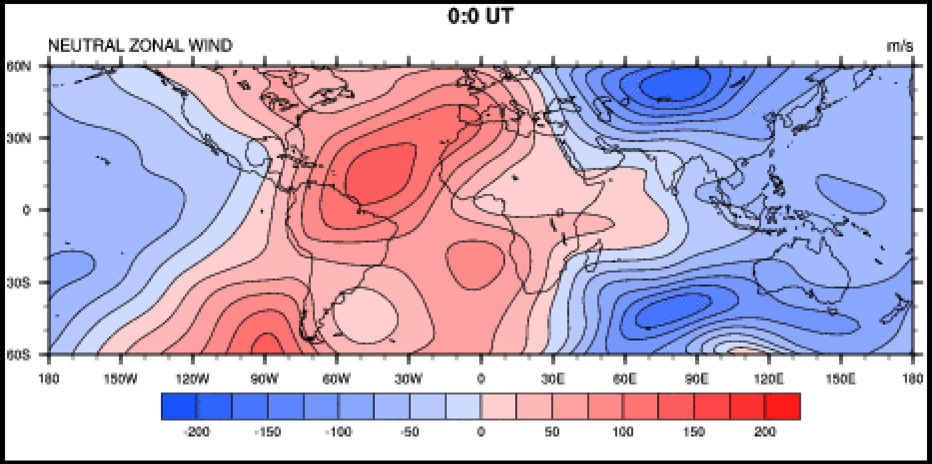
Tides:

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

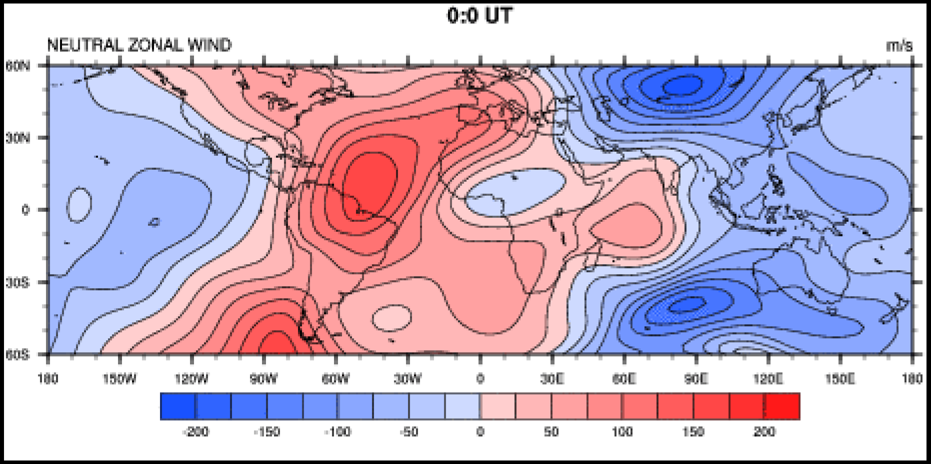
Courtesy of Maura Hagan

Migrating and non-migrating tides

Migrating tides



Migrating and nonmigrating tides



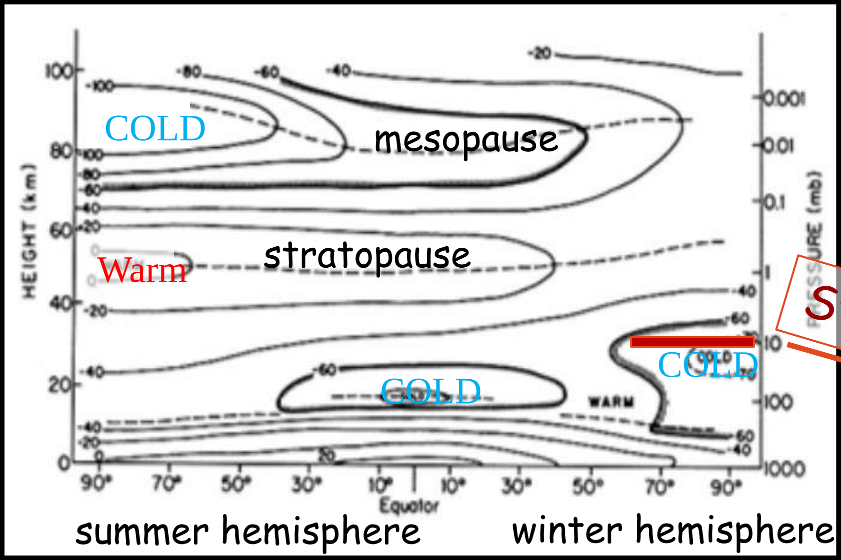
September equinox ~325 km
Solar minimum

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.

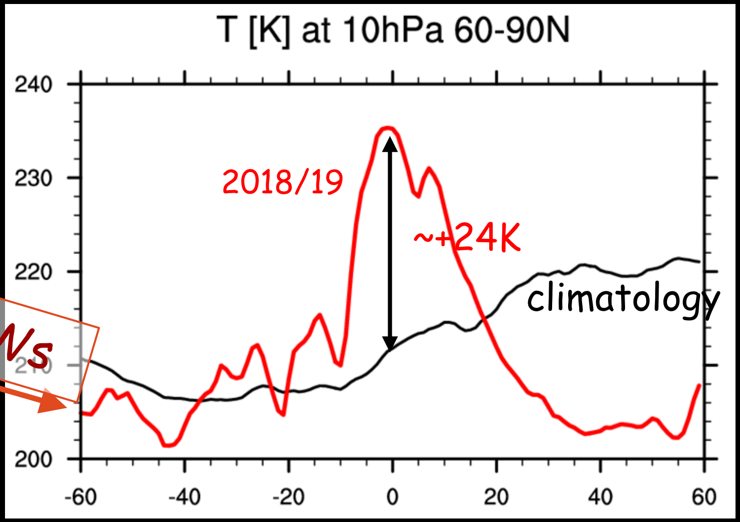
If the excitation depends on longitude a spectrum of tides is produced and can be expressed as a linear superposition of waves of various frequencies and zonal wavenumbers.

Planetary waves & polar vortex

Schematic latitude-height of zonal mean temperature [^oC]

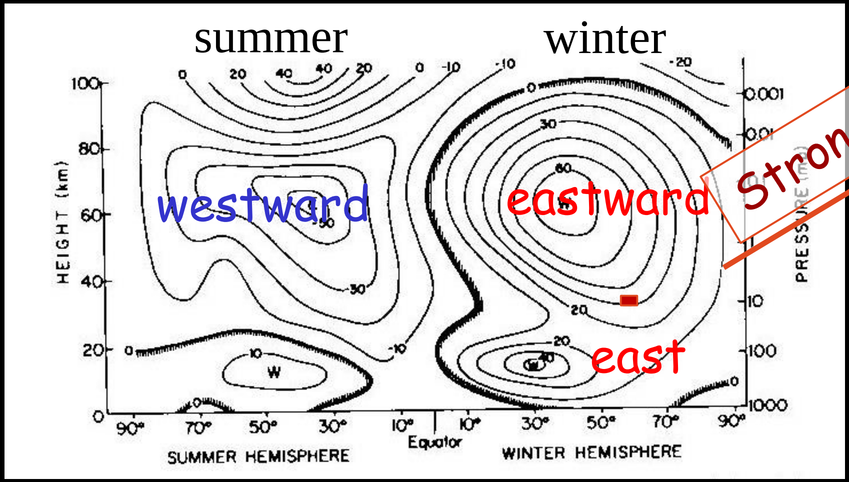


Disturbed middle atmosphere

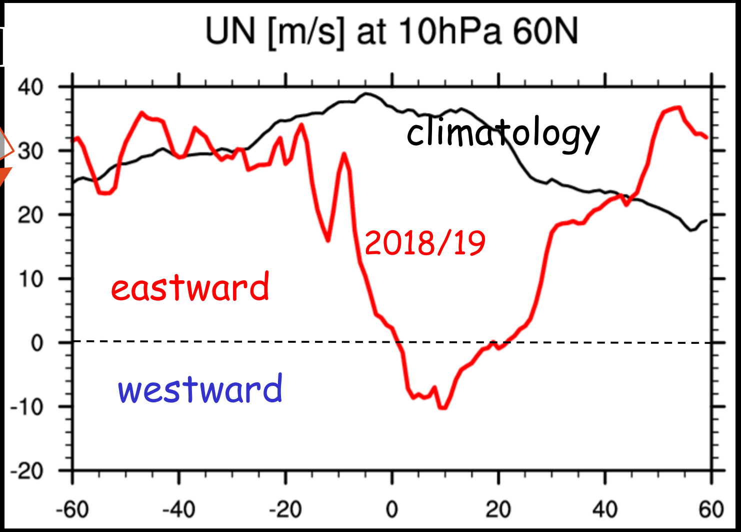


Strong PWs

Schematic latitude-height of zonal mean zonal wind [m/s]



Strong PWs



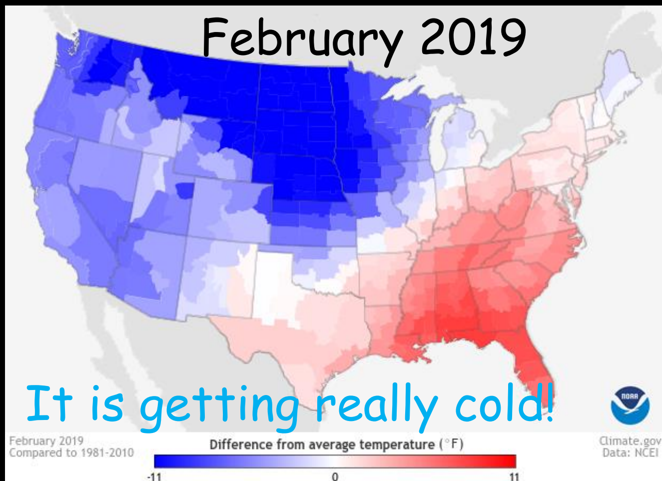
days from 1/1/2019

[Holton, 1976]

Polar vortex talk by Lynn Harvey

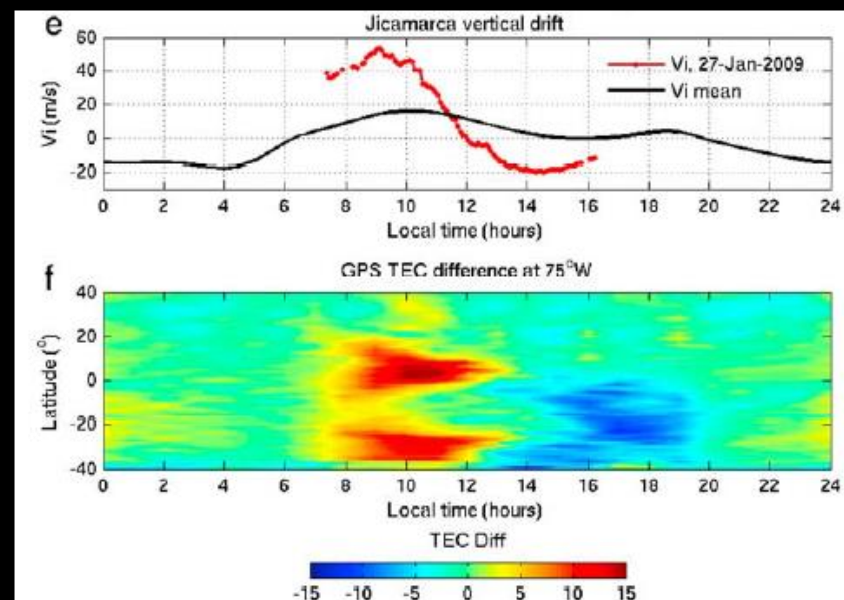
Effects of strong PW activity

Surface temperature anomaly [°F]

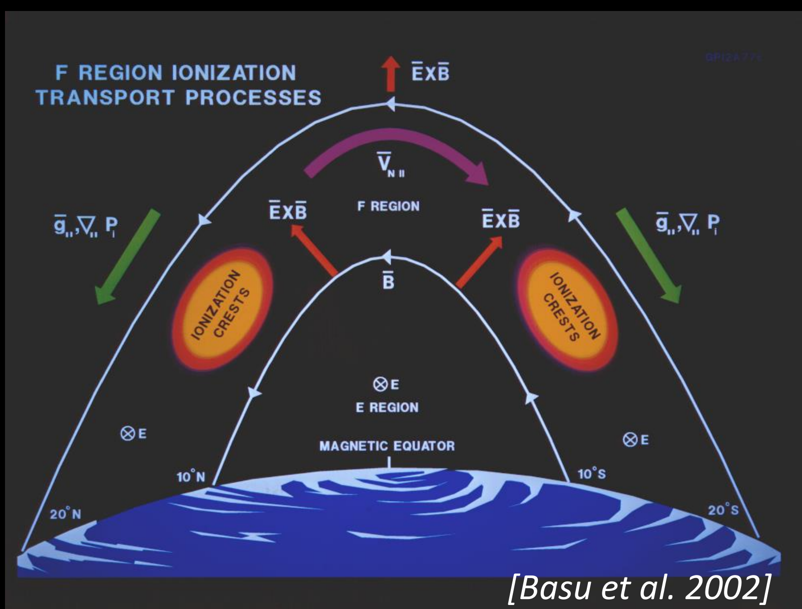


Middle atmosphere is disturbed

Global changes in the ionosphere



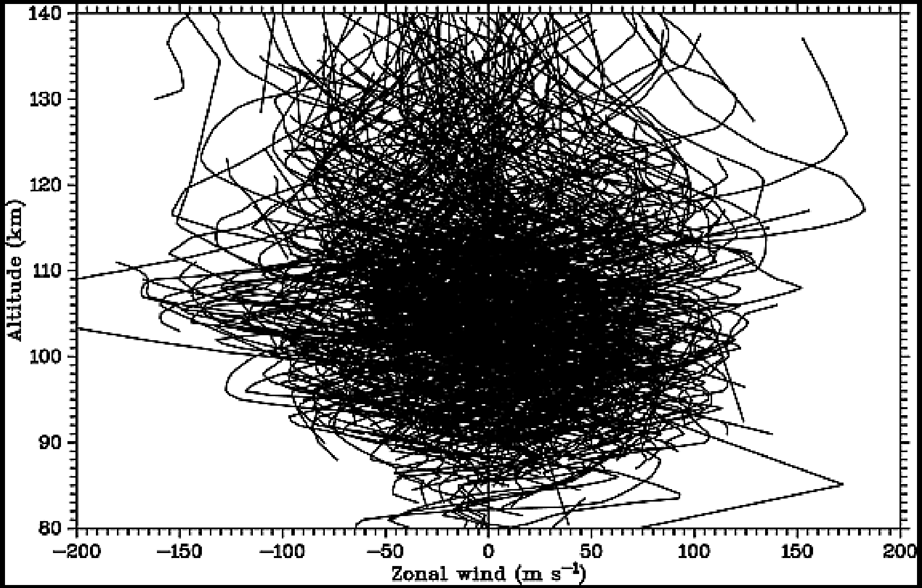
[Goncharenko et al., 2010]



[Basu et al. 2002]

Up to 100% changes in TEC

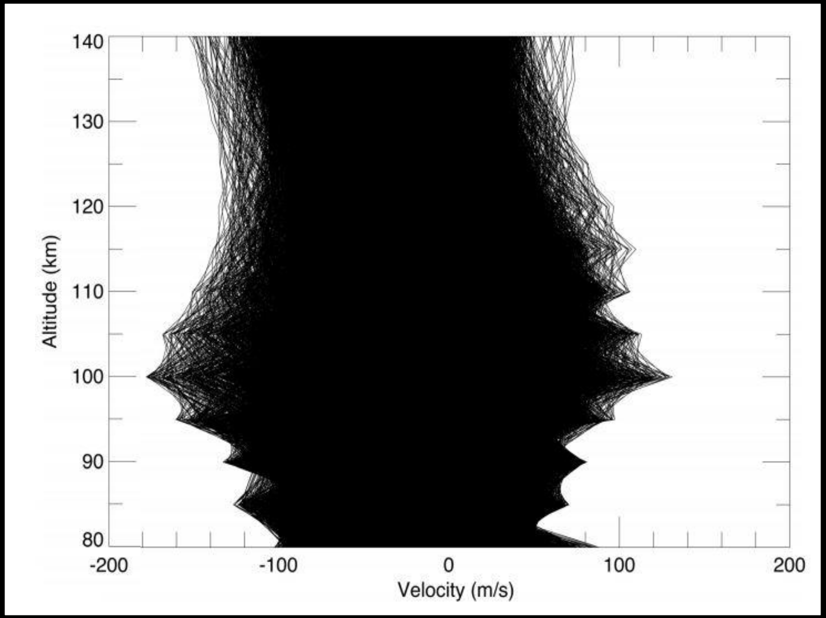
Variability of neutral wind in the MLT



[Larsen, 2002]

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

Zonal wind components from TIMEGCM forced by tropospheric weather through including NCEP reanalysis data at 30 km. Results are for 21 March, 1993 and all grid points equatorward of 52°

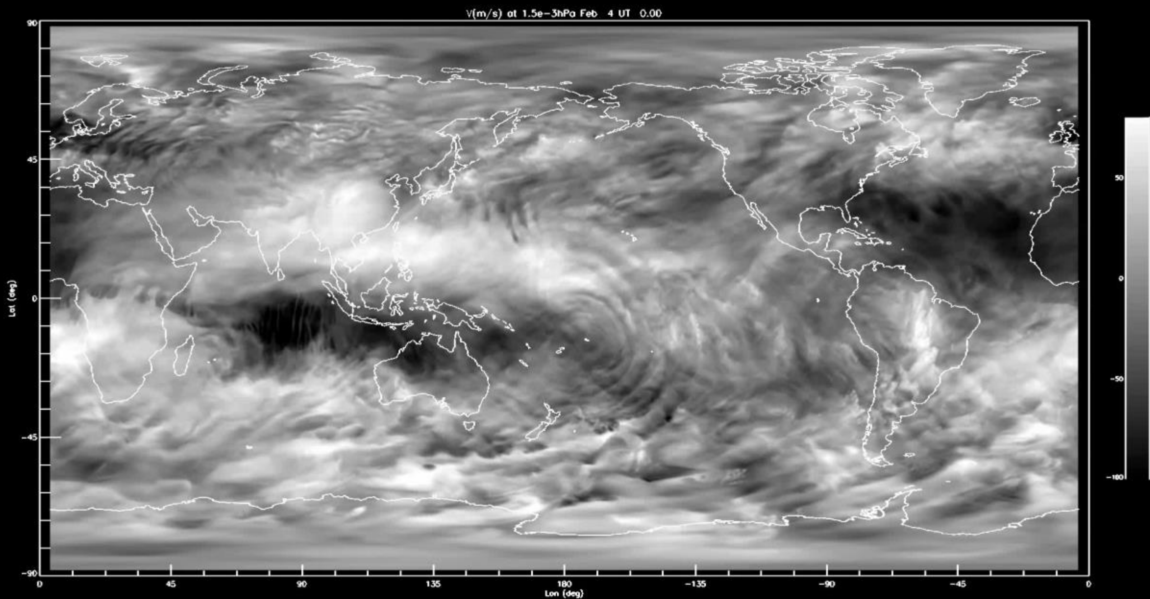


[Larsen & Fesen, 2009]

Brian Harding's highlight on F-region winds, ITM modeling & wind obs. workshops

Gravity wave effects

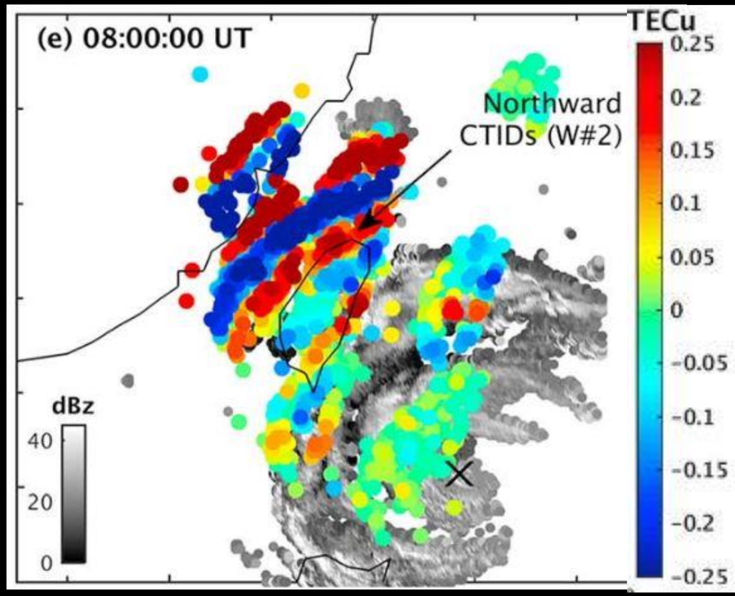
Meridional wind at ~95 km



[Liu et al., 2014]

High resolution Whole Atmosphere Community Climate Model (WACCM)

TEC from GNSS observations



[Chou et al., 2017]

Typhon Meranti over Taiwan on 13 September 2016

Several gravity wave related workshops (Monday) & TID workshop (Tues) & MSTID workshop (Wed)

Composition

$$\frac{d\boldsymbol{n}_i}{dt} = P_i - n_i L_i + \frac{\partial \Phi_i}{\partial z}$$

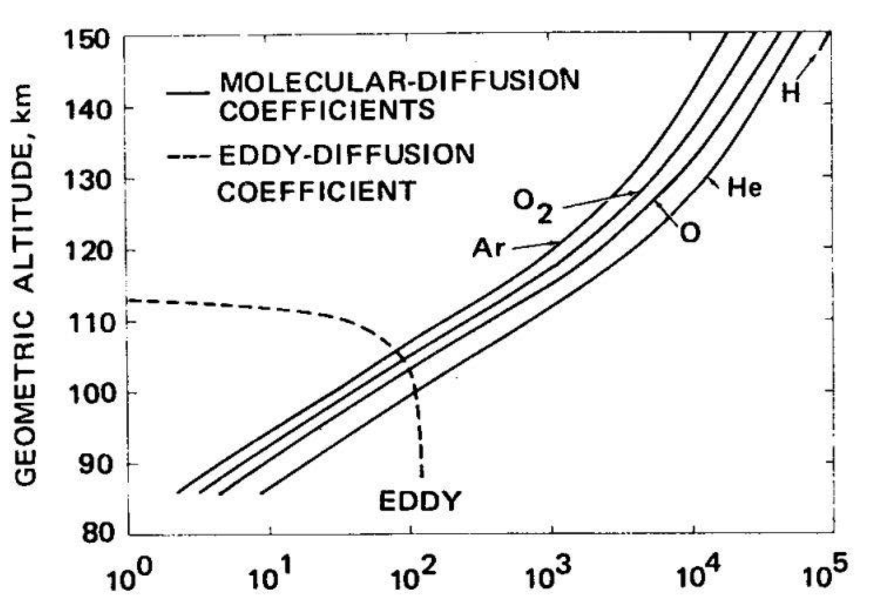
$$\frac{d\boldsymbol{n}_i}{dt} = \frac{\partial n_i}{\partial t} + U \cdot \nabla n_i$$

local derivative advection

P_i production through chemistry

L_i loss through chemistry

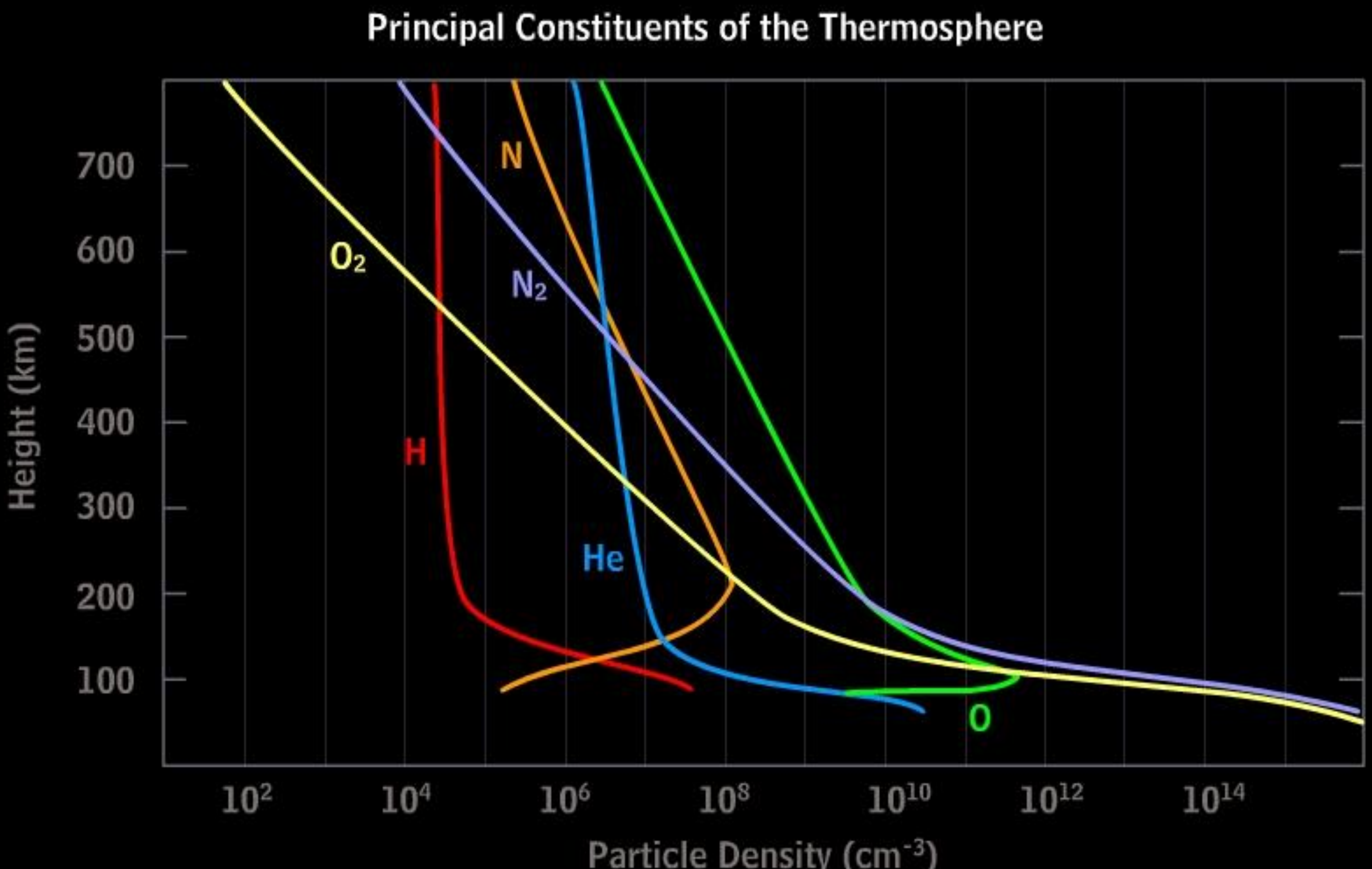
Φ_i flux (includes eddy diffusion, molecular diffusion, thermal diffusion)



Molecular-diffusion and eddy-diffusion coefficients [m^2/s]

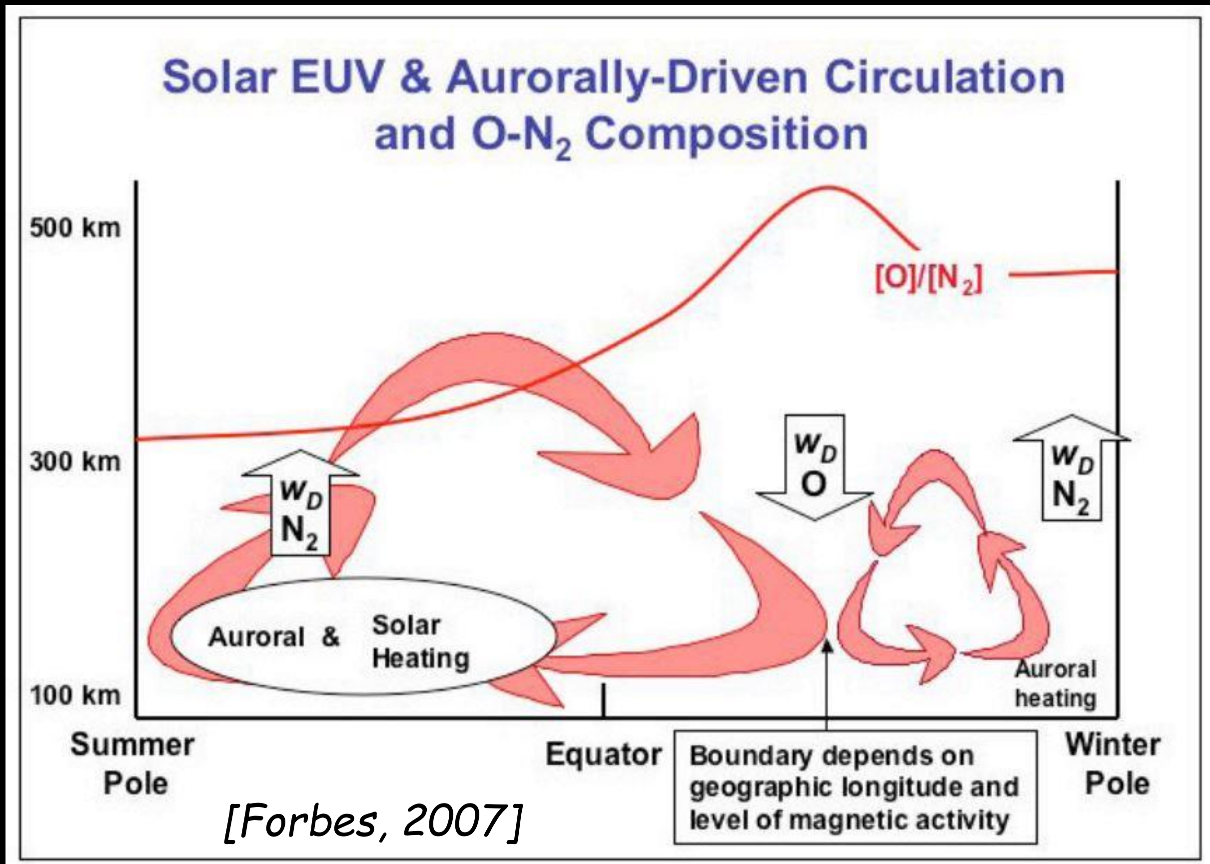
[US Standard Atmosphere, 1976]

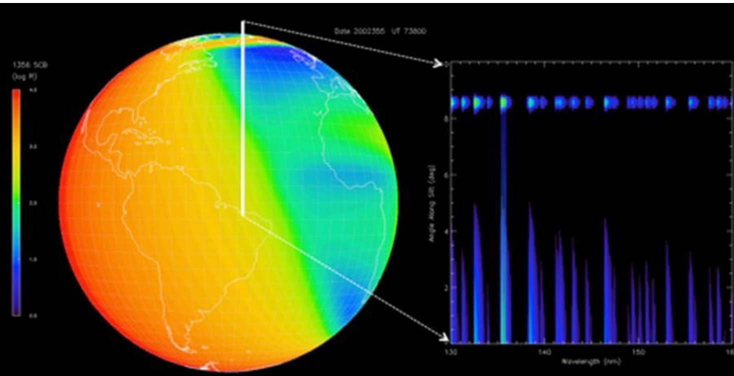
Thermospheric composition



[COMET]

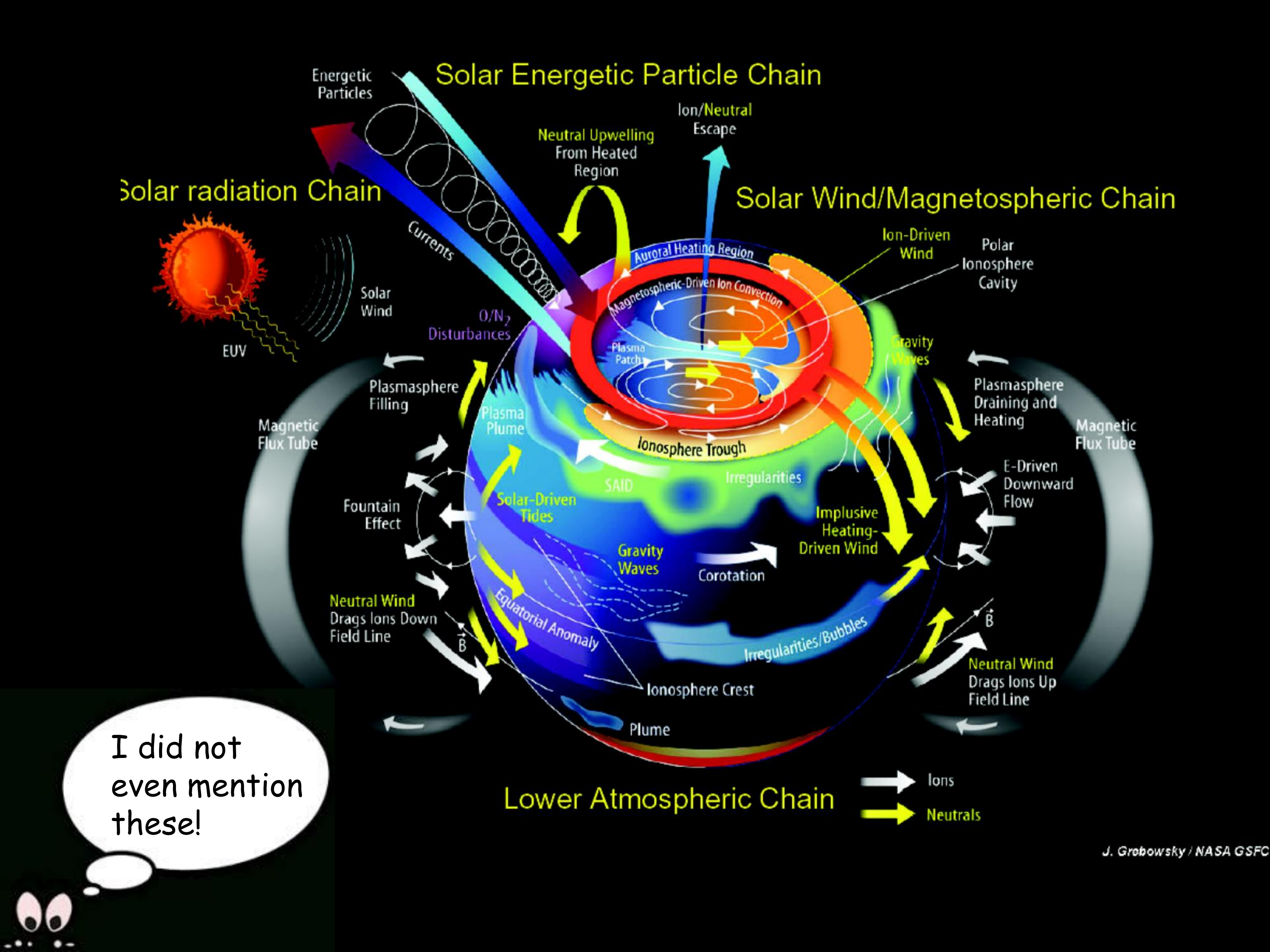
Solar EUV & auroral heating effect on O/N_2





- Upwelling occurs over the summer hemisphere and polar region.
- The diffusive equilibrium is disturbed and molecular rich air is transported up and equatorward through the meridional circulation.
- Diffusive equilibrium is restored- faster at higher than lower altitudes.
- Tend to lead to enhanced O/N_2 ratios and enhanced F-region plasma densities.

Richard Eastes' GOLD highlight


Solar Energetic Particle Chain
Energetic Particles
Ion/Neutral Escape
Neutral Upwelling From Heated Region
Solar radiation Chain
Solar Wind/Magnetospheric Chain
Currents
Solar Wind
EUV
O/N2 Disturbances
Auroral Heating Region
Magnetospheric-Driven Ion Convection
Ion-Driven Wind
Polar Ionosphere Cavity
Plasma Patch
Gravity Waves
Plasmasphere Filling
Plasma Plume
Plasmasphere Draining and Heating
Magnetic Flux Tube
Magnetic Flux Tube
Ionosphere Trough
SAID
Irregularities
E-Driven Downward Flow
Fountain Effect
Solar-Driven Tides
Implusive Heating-Driven Wind
Gravity Waves
Corotation
Neutral Wind Drags Ions Down Field Line
Equatorial Anomaly
Irregularities/Bubbles
Neutral Wind Drags Ions Up Field Line
Ionosphere Crest
Plume
Lower Atmospheric Chain
Ions
Neutrals
J. Grobowsky / NASA GSFC
I did not even mention these!