Planetary Atmospheres

April 2, 2012

What Can We Observe?

- Mass
- Radius
- Temperature
- Albedo
- Atmospheric Lines
- Surface Properties

What Determines the Properties of a Planet?

- Energy flux from the Sun
- Planet with minimal atmosphere (e.g., Moon)

$$T_{eq} = (1-a)^{1/4} T_* \sqrt{\frac{R_*}{2D}}$$

- Atmosphere changes things....

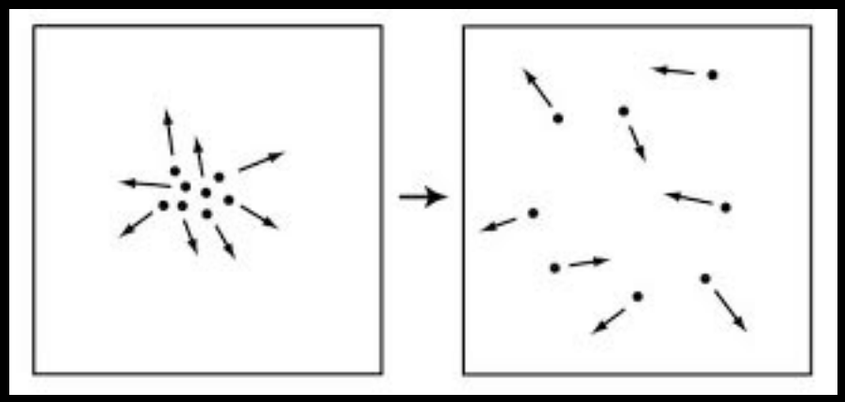
Thermodynamics

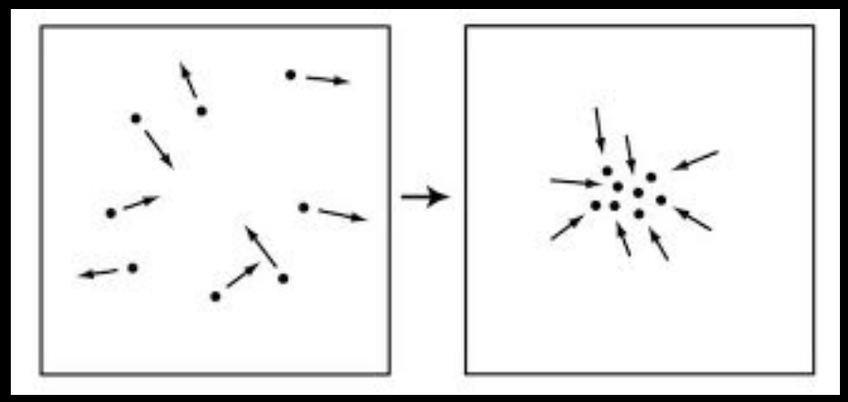
- Energy is conserved
- Entropy always increases (In an energetically closed system, heat flows from the hotter part of the system to the colder part of the system)
- There is a minimum temperature T = 0

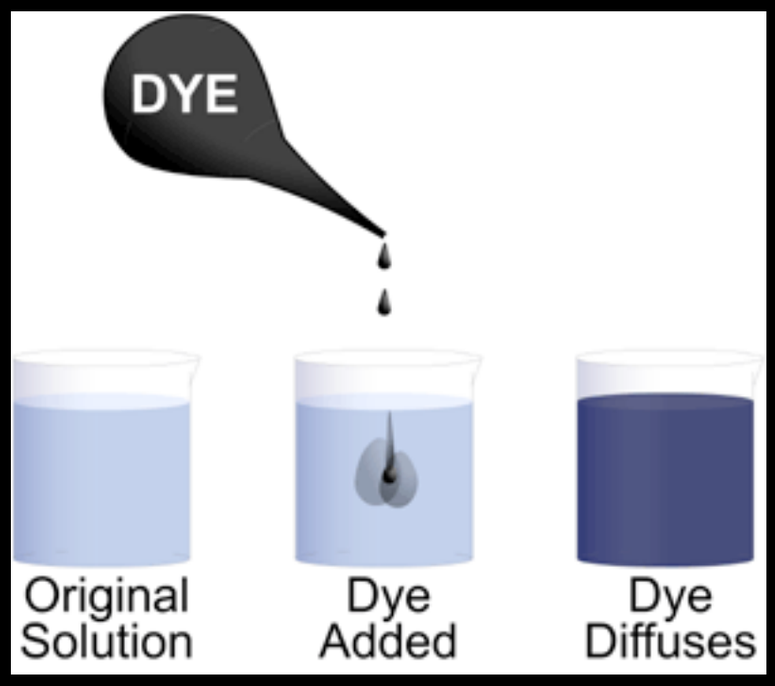
Alternative Version

- You can't win
- You can't even break even
- You can't leave the game

Entropy







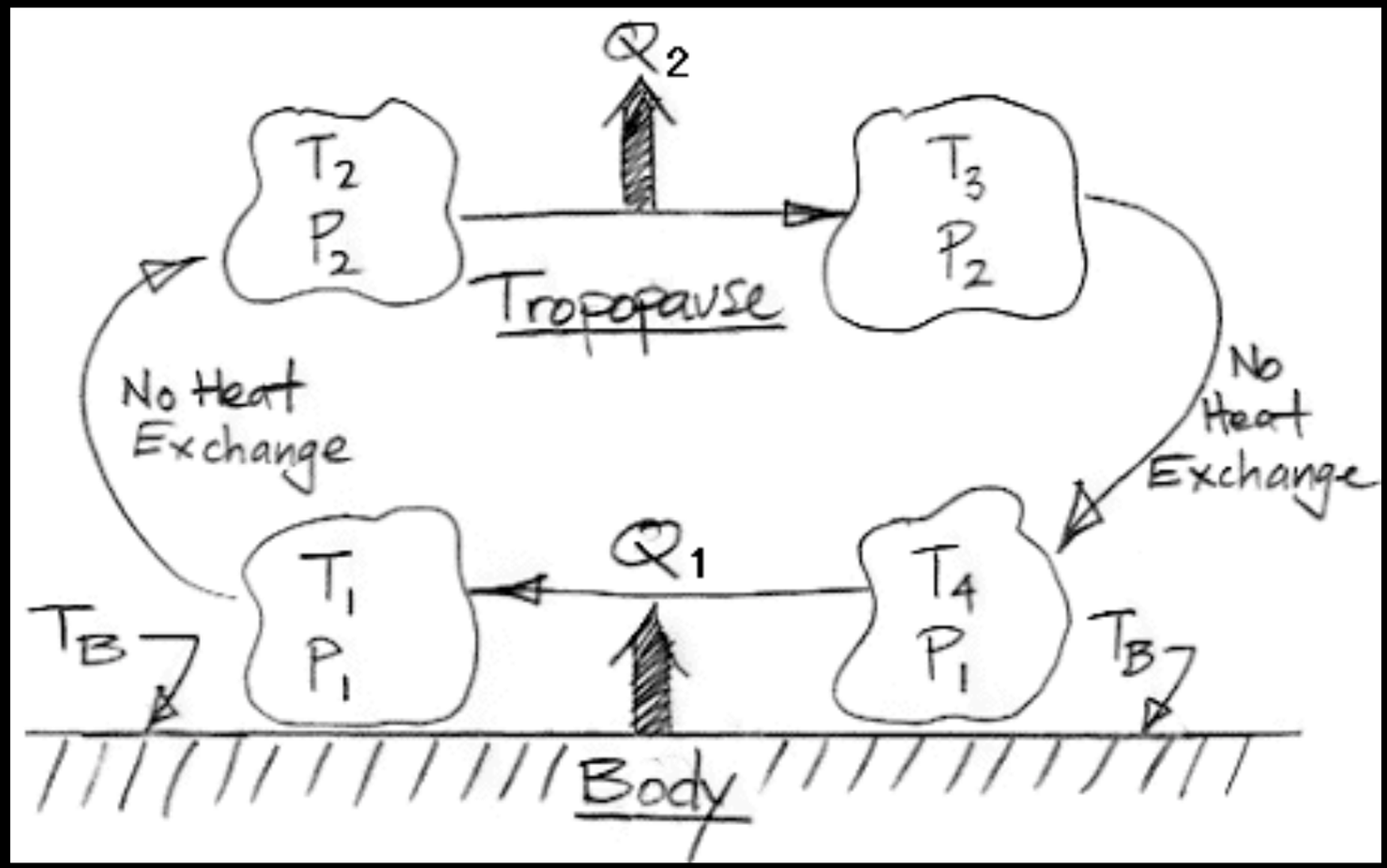
Entropy of an Ideal Gas

$$p = nkT$$

$$dS = c_p \frac{dT}{T} - R\frac{dp}{p} = c_p d\ln\left(Tp^{-R/c_p}\right)$$

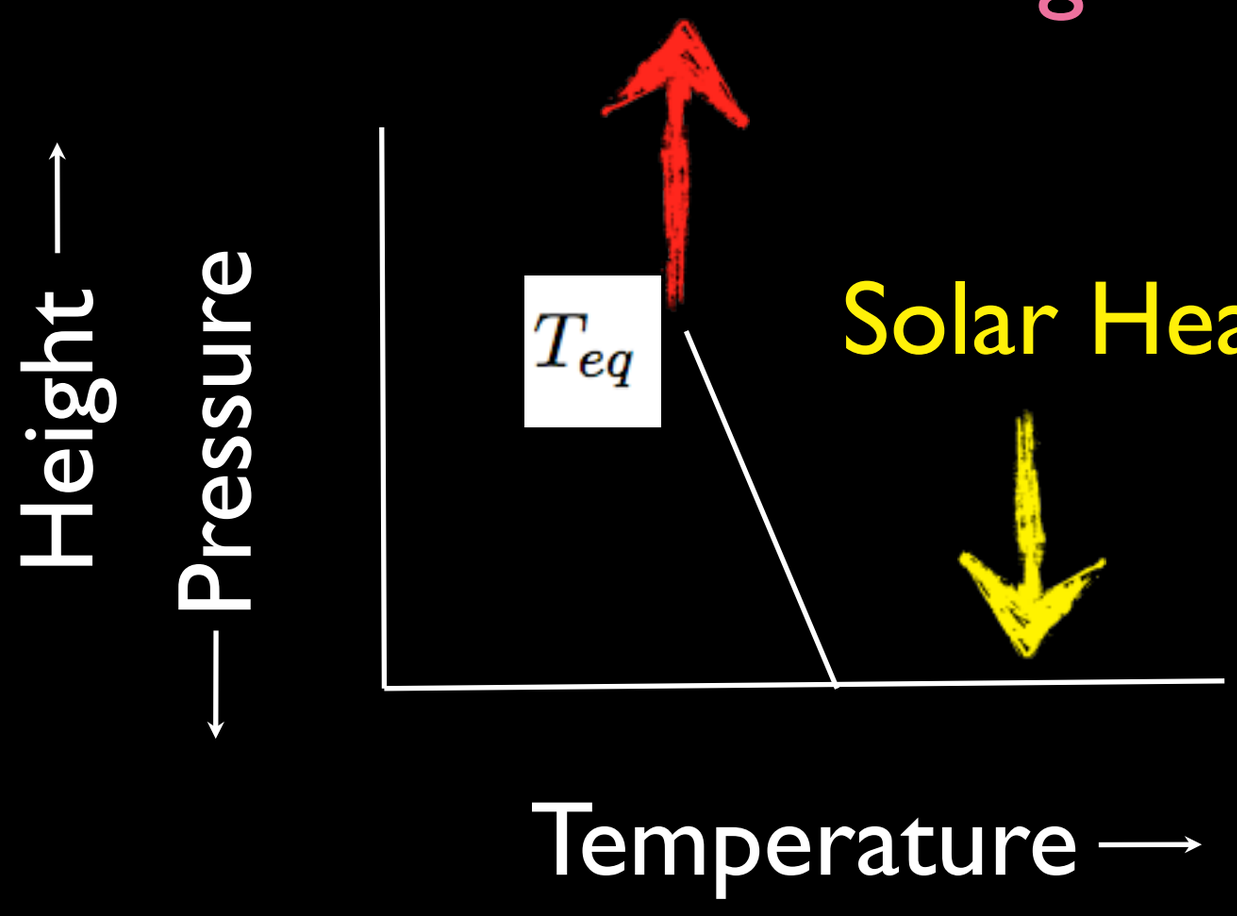
$$T(p) = T_0\left(\frac{p}{p_0}\right)^{R/c_p}$$

Convection


Q2
T2
P2
T3
P2
Tropopause
No Heat Exchange
No Heat Exchange
T1
P1
Q1
T4
P1
TB
TB
Body

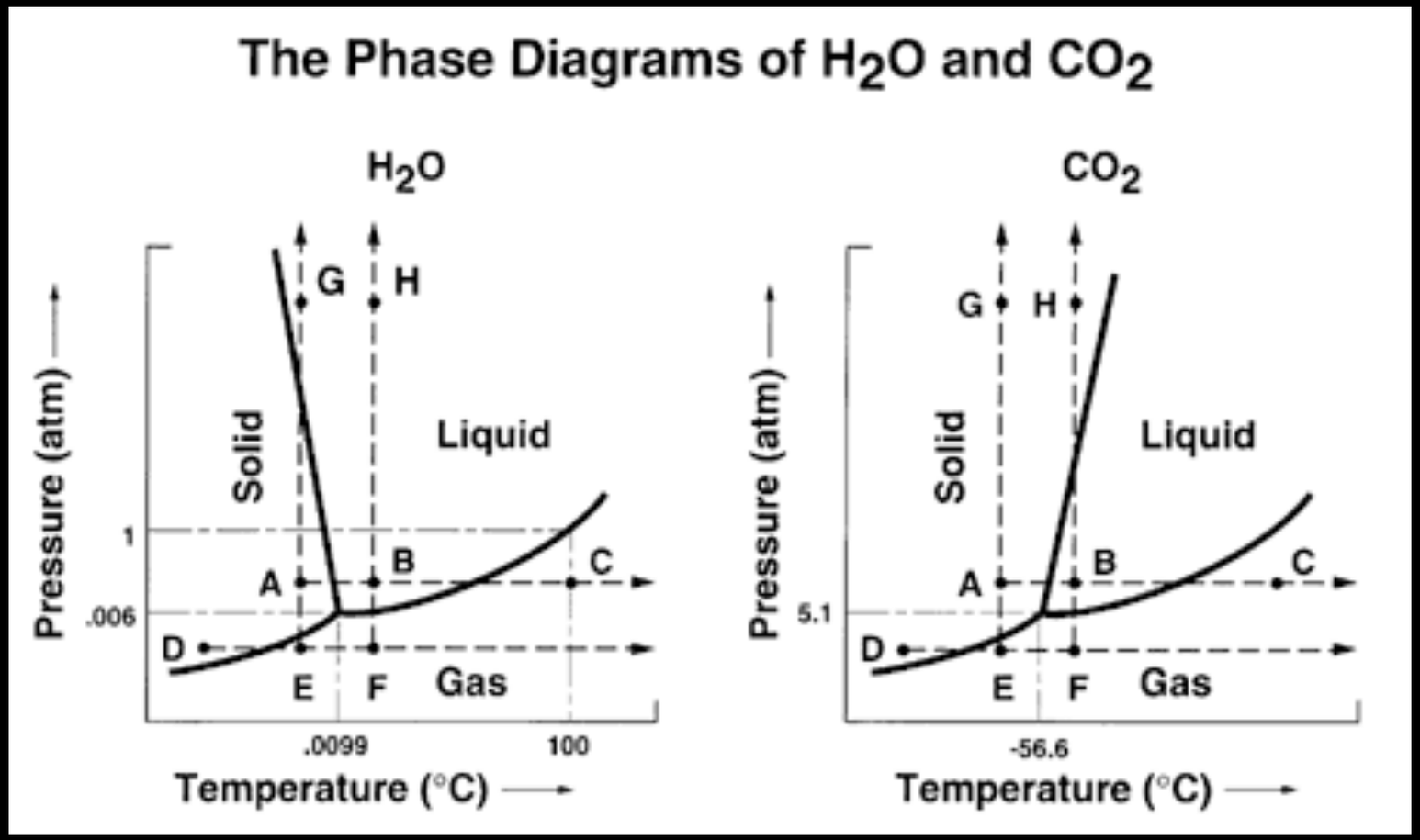
Simple Model of Troposphere

Thermal Cooling



$$T_s = T_{eq}\left(\frac{p_s}{p_{eq}}\right)^{R/c_p}$$

Phase Transitions



Latent Heat

- Lots of energy released in phase transitions, particularly for gases with Hydrogen bonds (H20, CH4, NH3)

	L (vap)	L (fusion)
H_2O	22.6×10^5	3.3×10^5
N_2	2×10^5	0.26×10^5
CO_2	3.97×10^5	2×10^5

Saturated Air

- In a multicomponent atmosphere, each component behaves "independently" as an ideal gas with its own saturation pressure

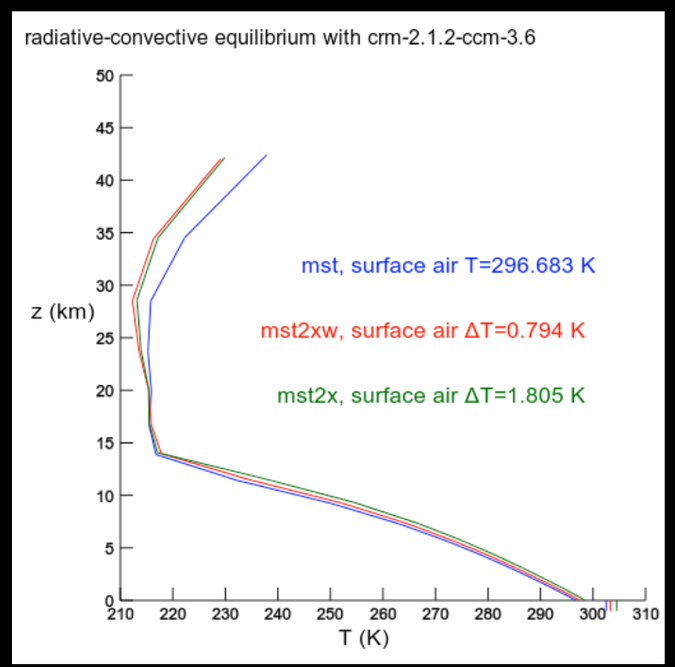
- Clausius-Clapeyron equation:

$$p_{sat}(T) = p_{sat}(T_0) \exp\left[\left(\frac{-L}{R_A}\right)\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$$

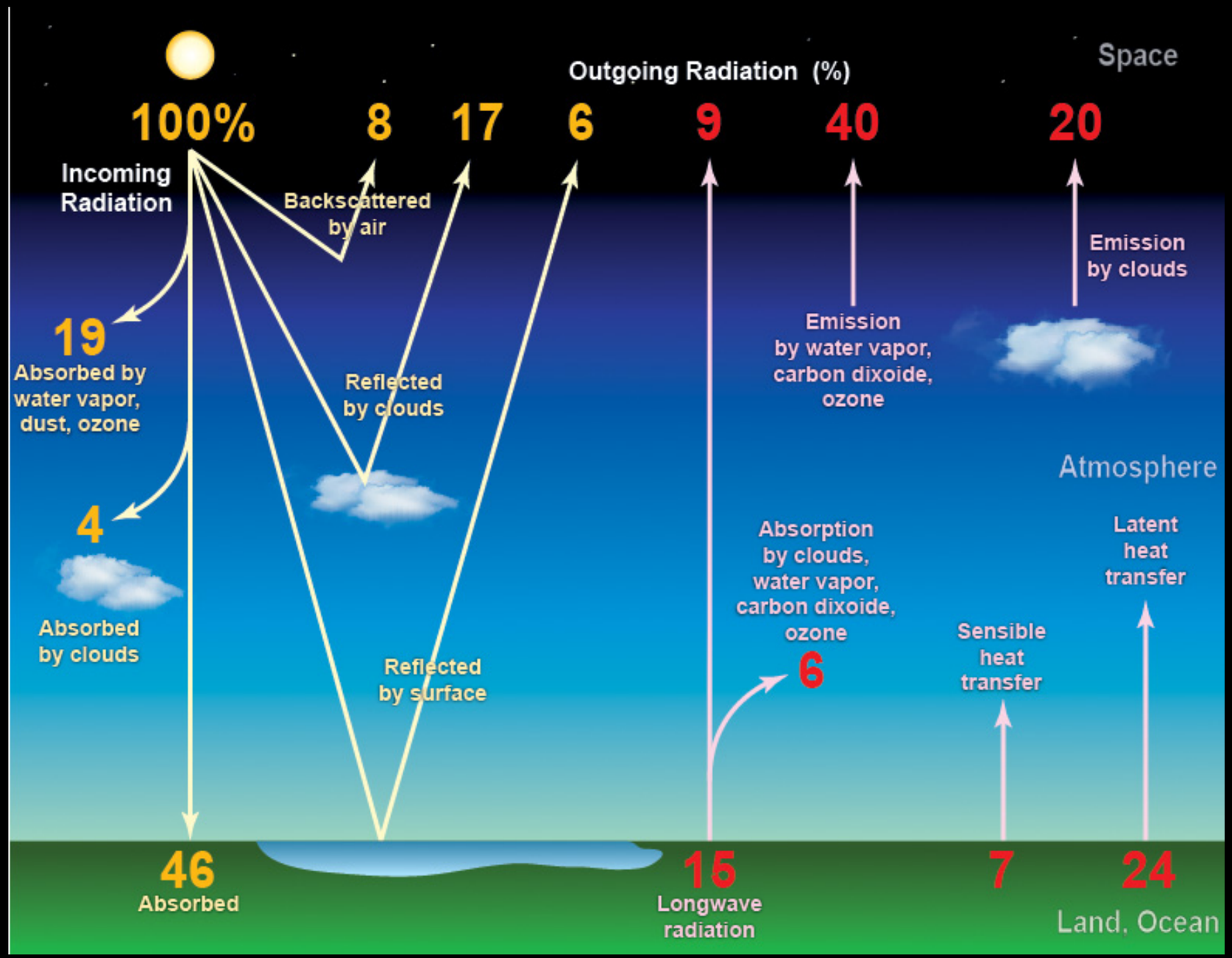
For Water L/R= 5420 K

Moist Adiabat

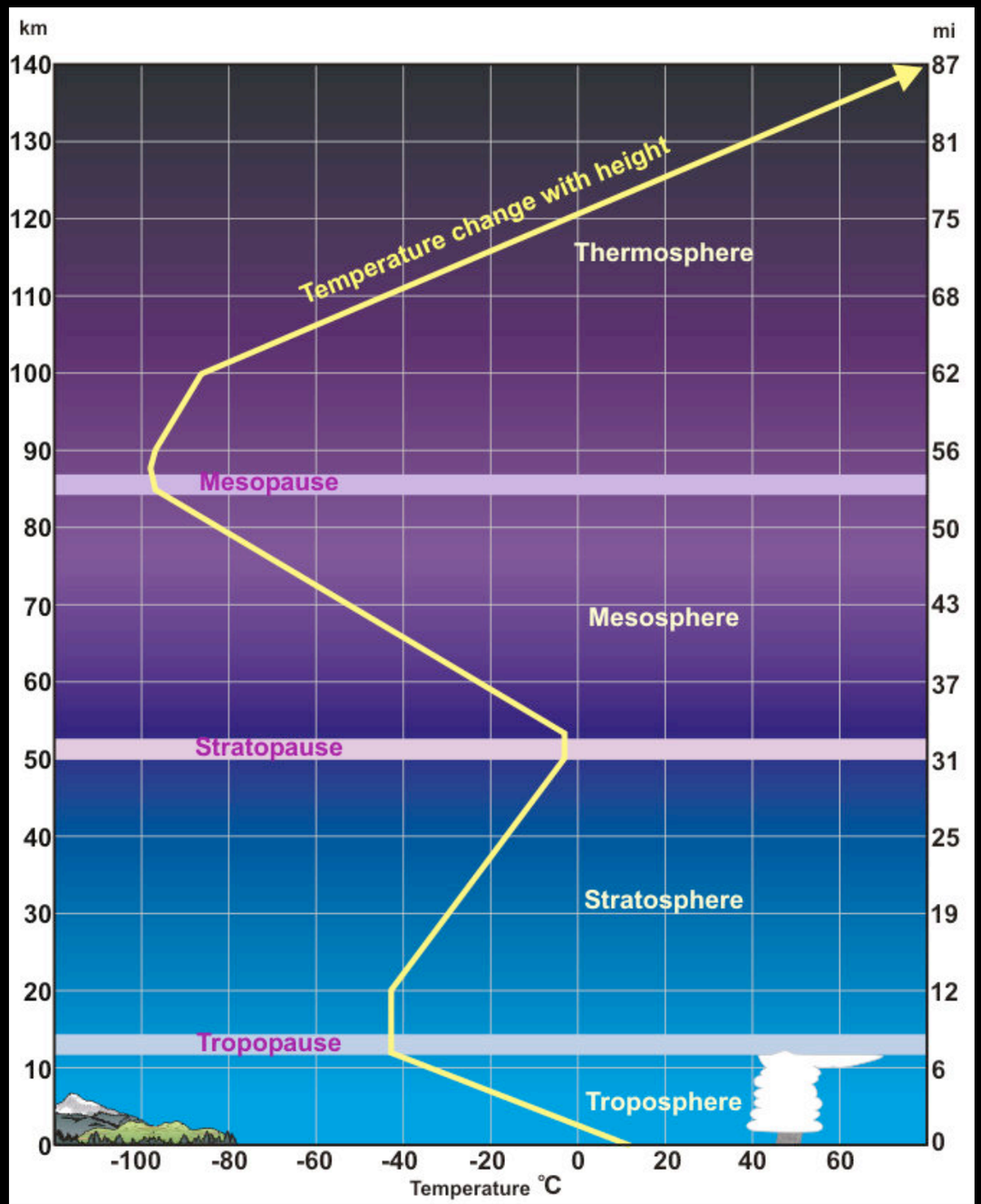
- Latent Heat serves as a source of energy release in the atmosphere.
- Rising gas cools and deposits energy in the atmosphere establishing an equilibrium profile that follows the "moist adiabat": air stays saturated (e.g., Tropics)



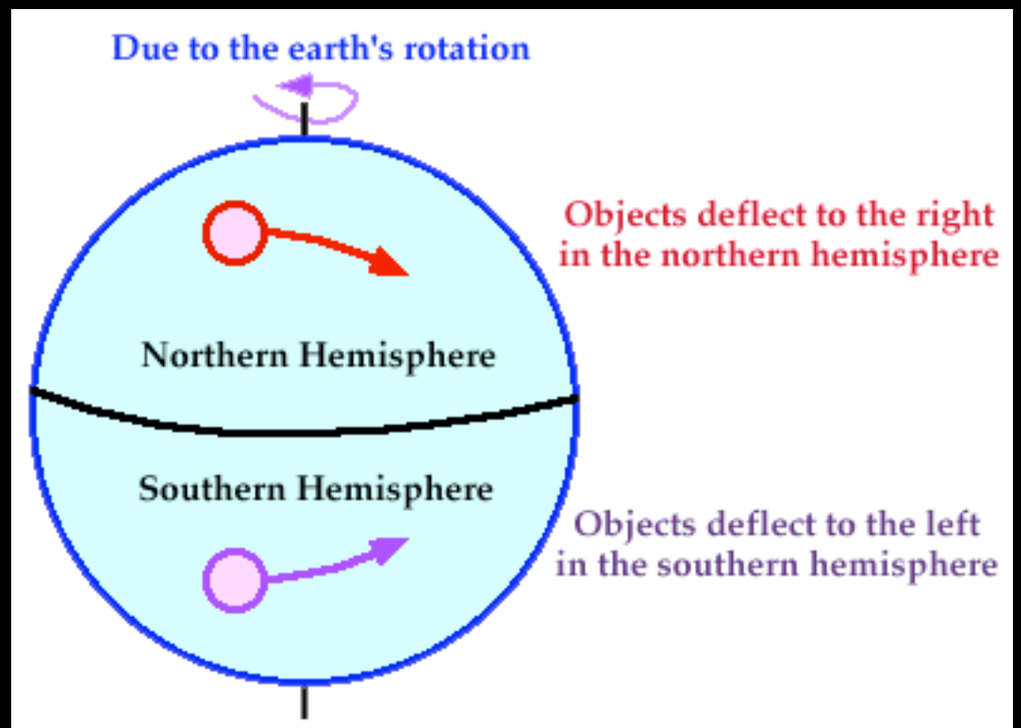
Thermal Balance Revisited

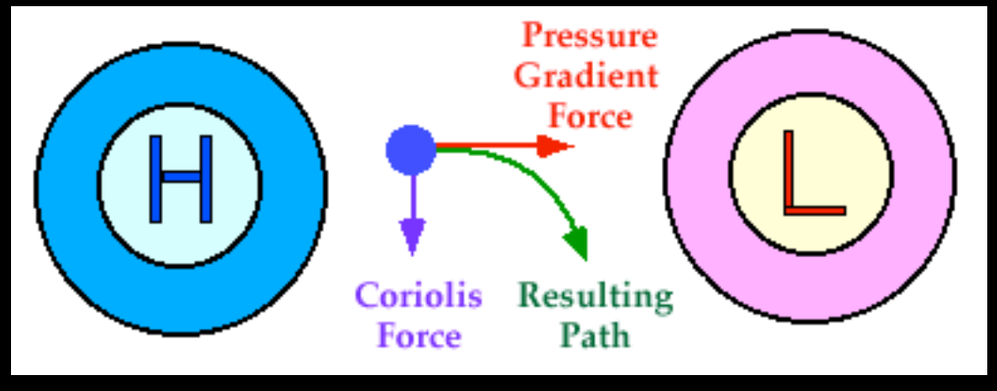


Temperature Structure of Earth's Atmopshere

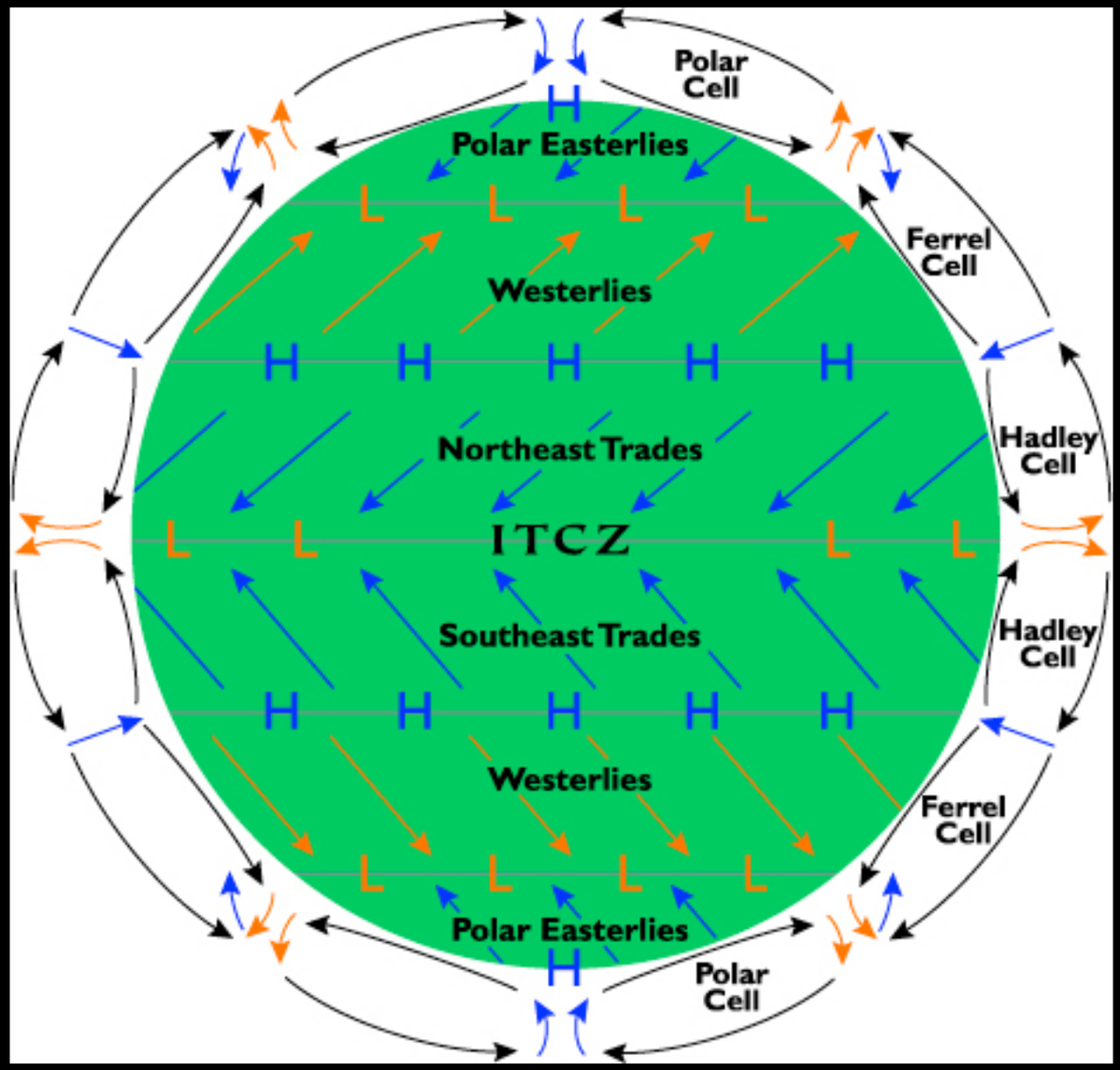


Coriolis Force

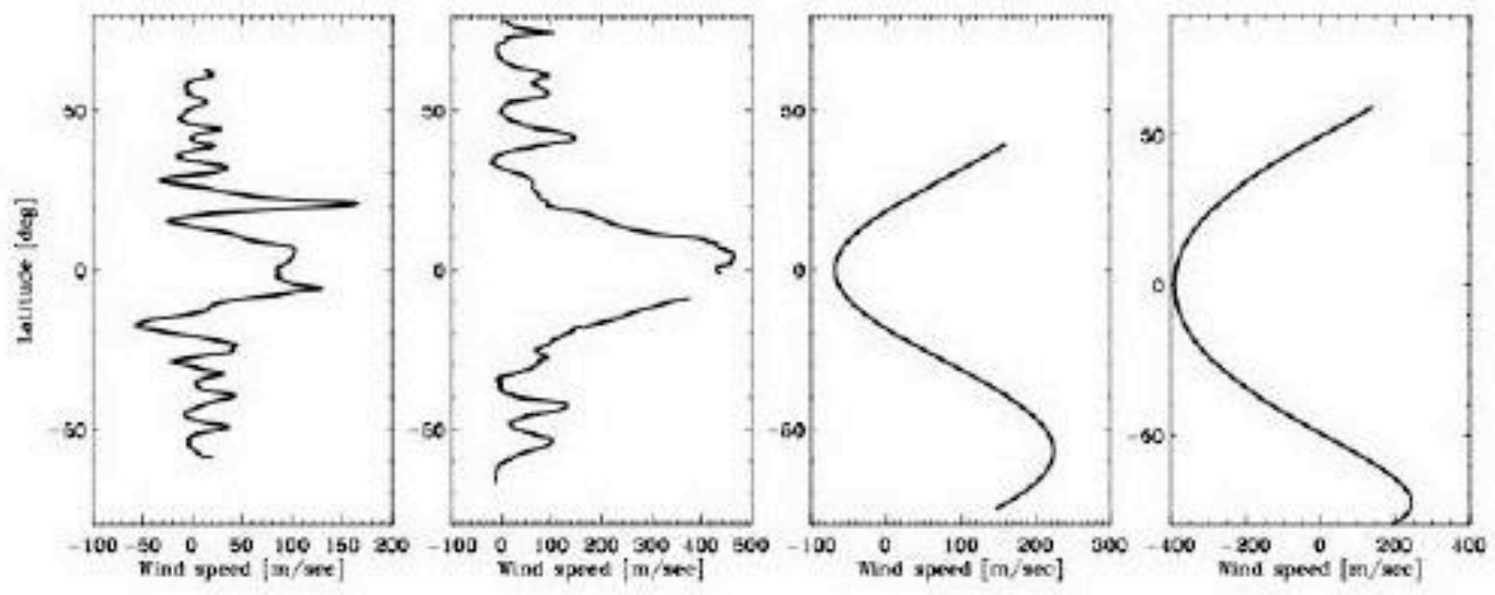




Hadley Zones



Circulation on Giant Planets



Jupiter's Red Spot