Atmosphere: #1
Intro and fundamentals

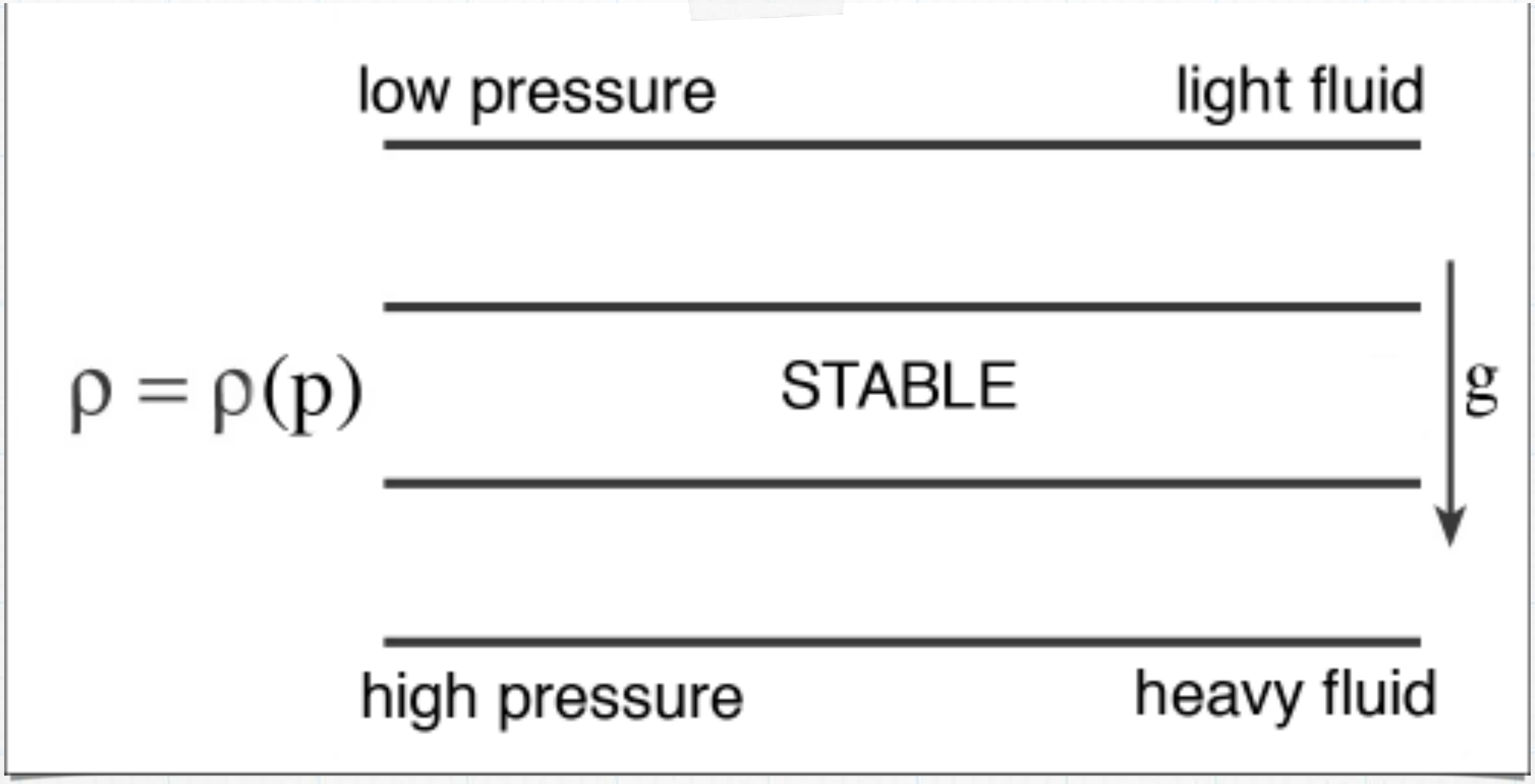
Fluid dynamics on earth

- Let's consider that the atmosphere and ocean is no different from the classical fluid dynamic problem.

$$\rho = \rho(p)$$

- Because of gravity, pressure increases downward.
- In a stable state, light fluid is always on top of heavy fluid.
- Also, assume that there is no obstacles to bend the fluid.
- What do you expect to see?

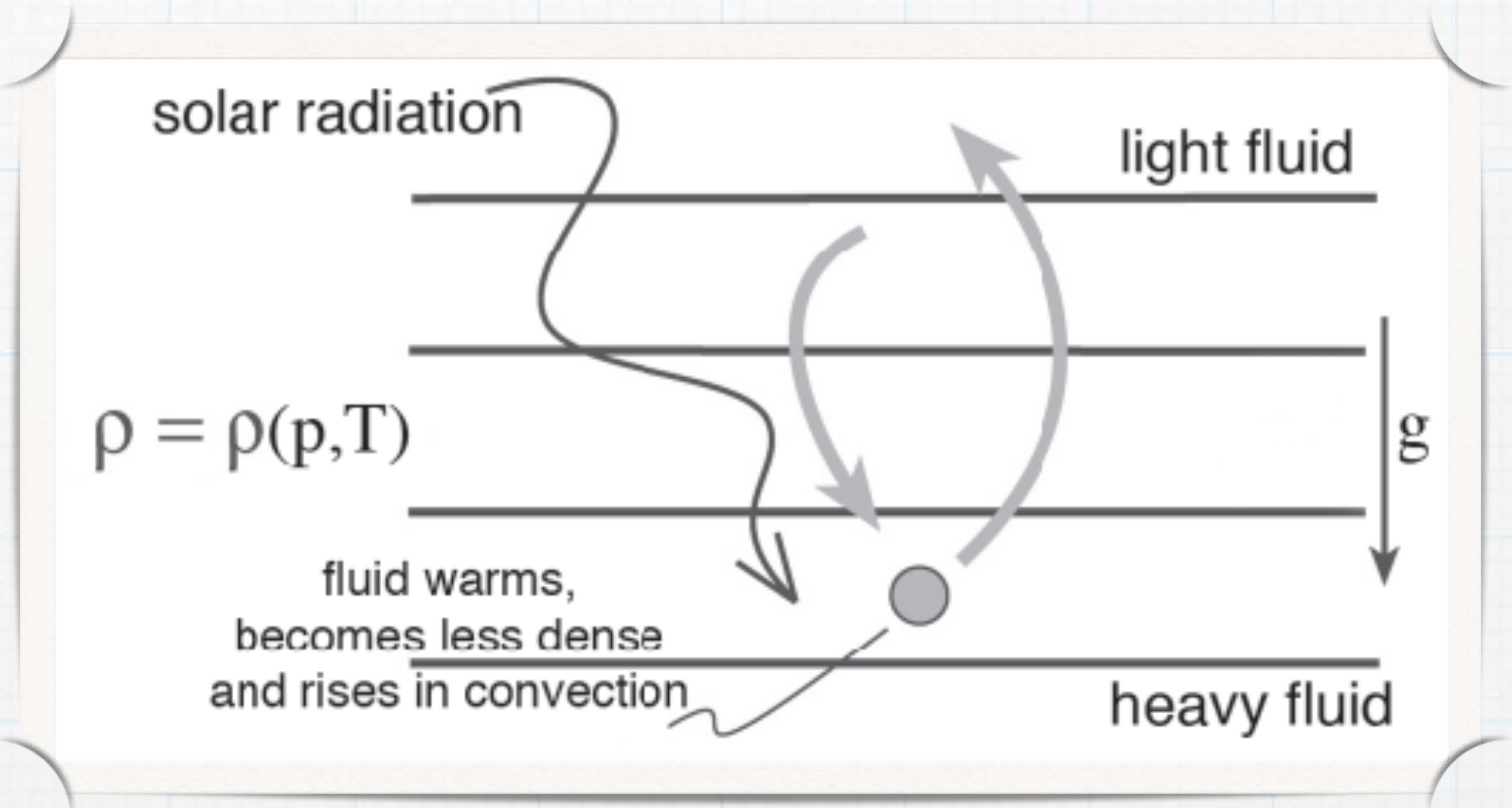
Fluid dynamics on earth



Fluid dynamics on earth

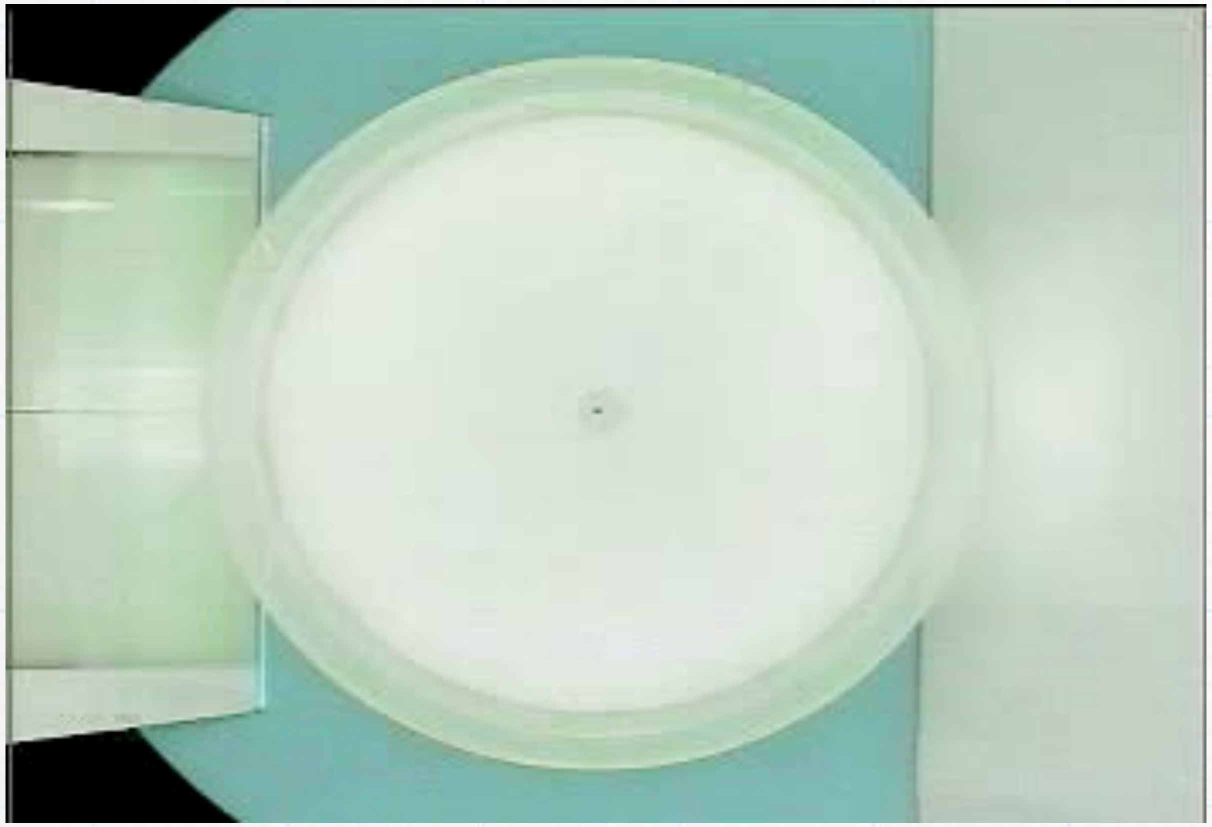
- Heating and cooling change the density of the fluid, making dynamical motions.
- Thermal energy can be converted to kinetic energy.
- The density of the fluid also depends on temperature

$$\rho = \rho(p, T)$$

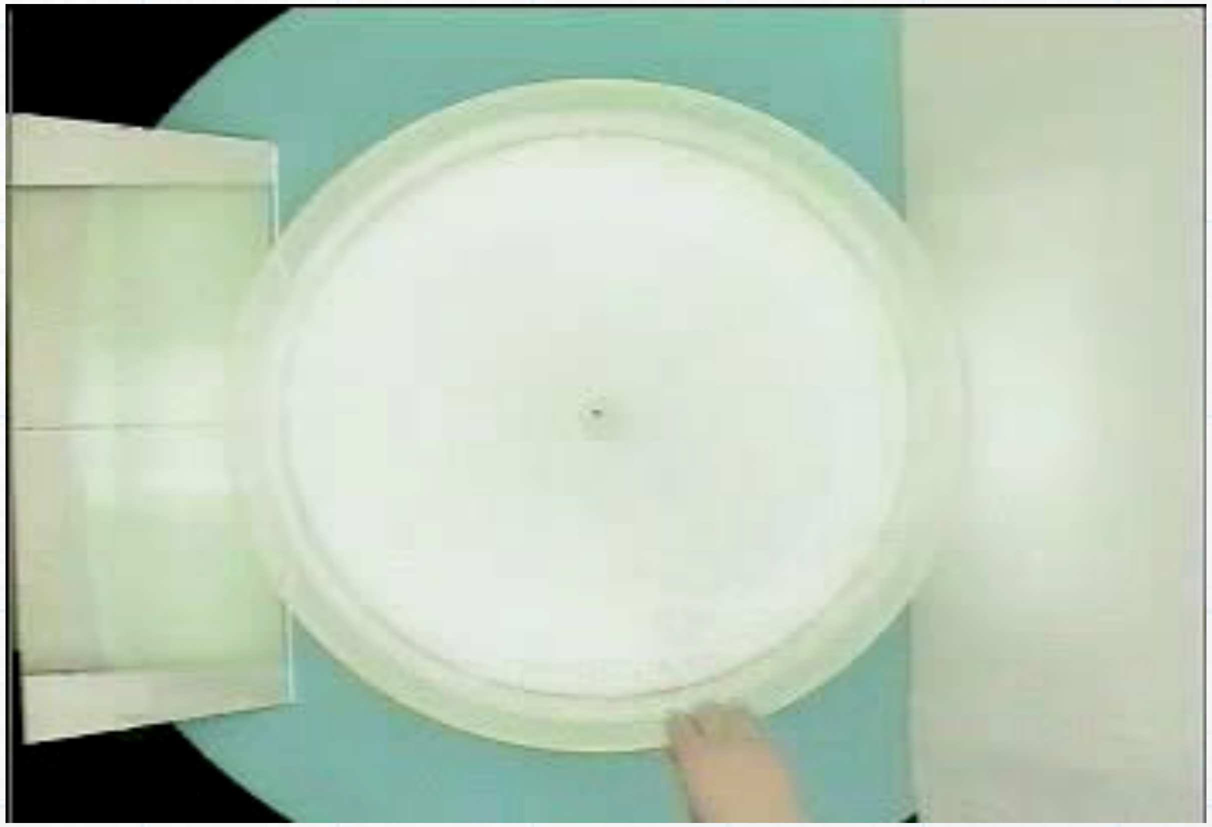


Fluid dynamics on earth

- The earth rotates!



Dissipation



Streaks of dye falling vertically

Flows of vertical columns

Fluid dynamics on earth

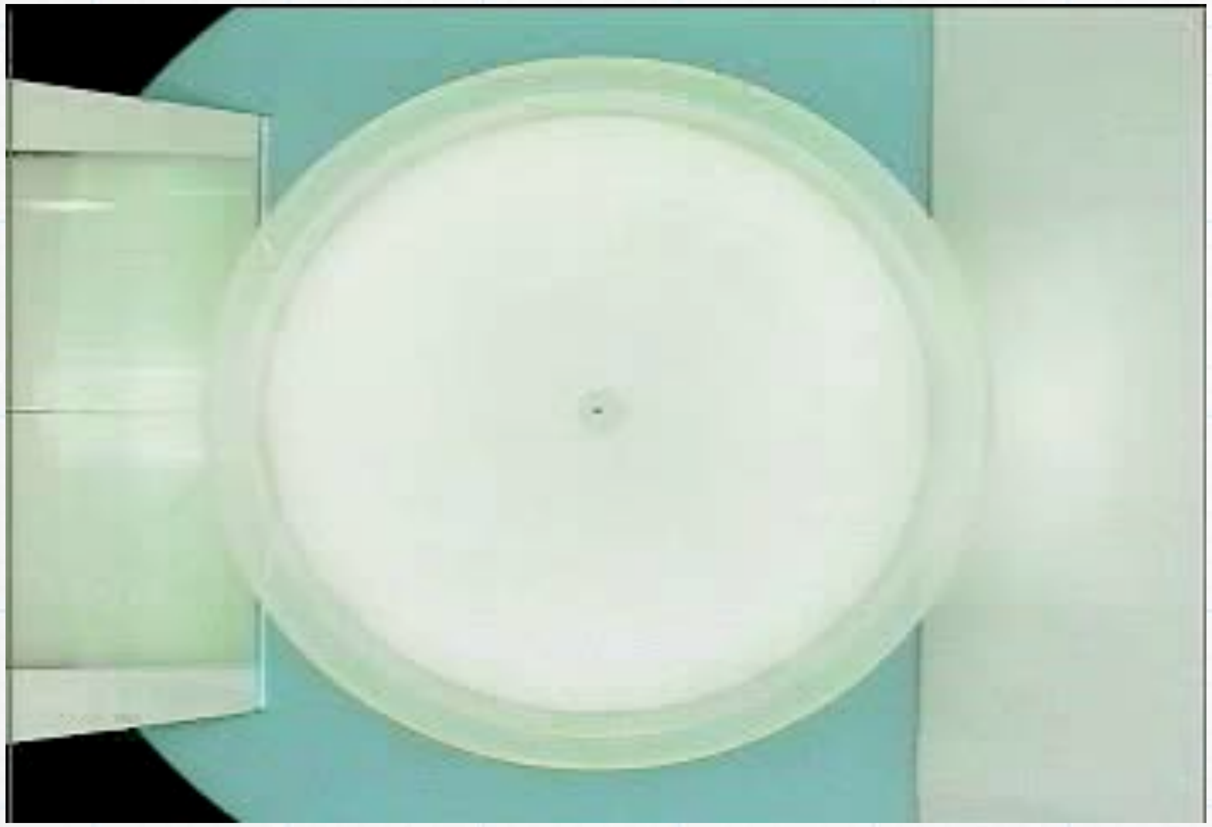
- Rotation does not always matter.
- Timescale of rotation: τ
- Timescale of the fluid: $\dfrac{L}{U}$

$$Ro = \tau \times \frac{U}{L}$$

- $Ro \gg 1$: The fluid is faster than rotation.
- $Ro \ll 1$: Rotation is faster than fluid.

Fluid dynamics on earth

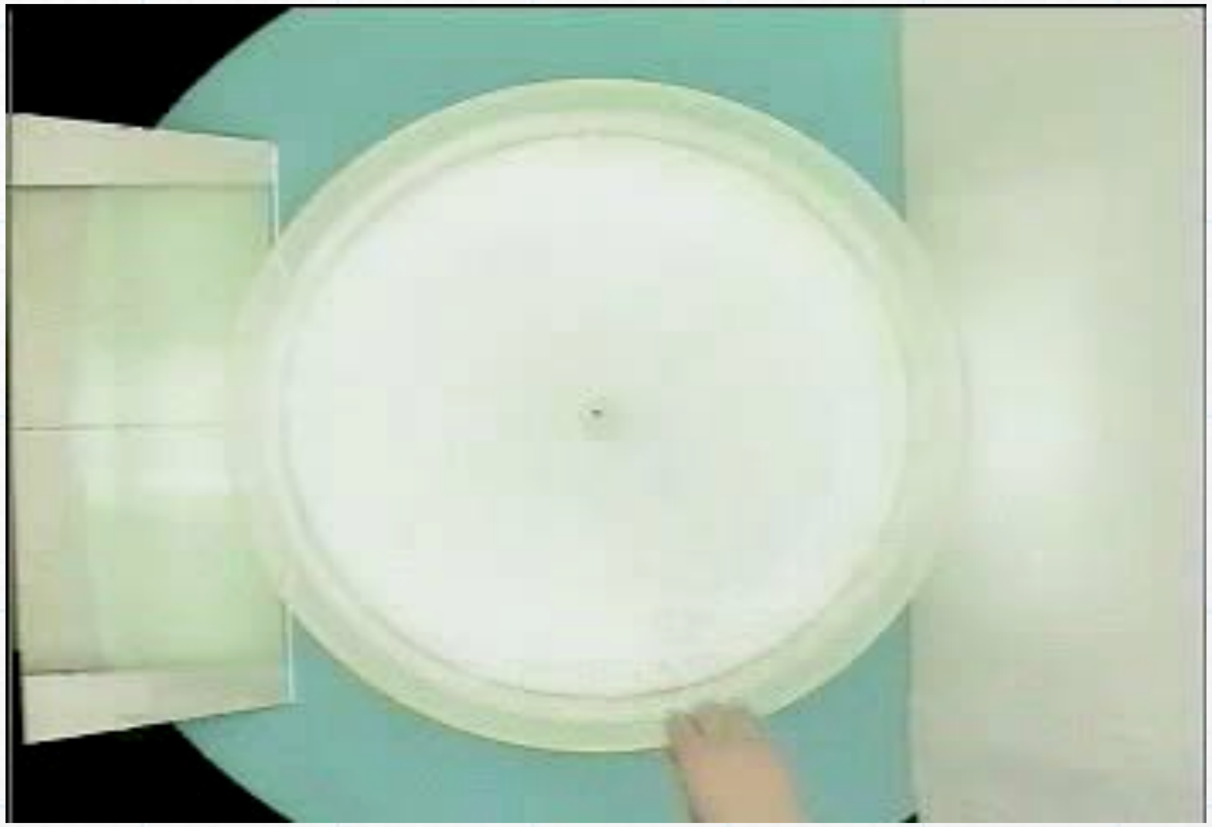
$$Ro = \tau \times \frac{U}{L}$$



$U \sim 1 \text{ cm s}^{-1}$

$L \sim 30 \text{ cm}$

$\tau \to \infty$



$U \sim 1 \text{ cm s}^{-1}$

$L \sim 30 \text{ cm}$

$\tau \sim 3 \text{ s}$

Fluid dynamics on earth

Atmosphere :

$$\tau \sim 1 \text{ day} \approx 10^5 \text{ s}$$

$$U \sim 10 \text{ m s}^{-1}$$

$$L \sim 5000 \text{ km}$$

Ocean :

$$\tau \sim 1 \text{ day} \approx 10^5 \text{ s}$$

$$U \sim 0.1 \text{ m s}^{-1}$$

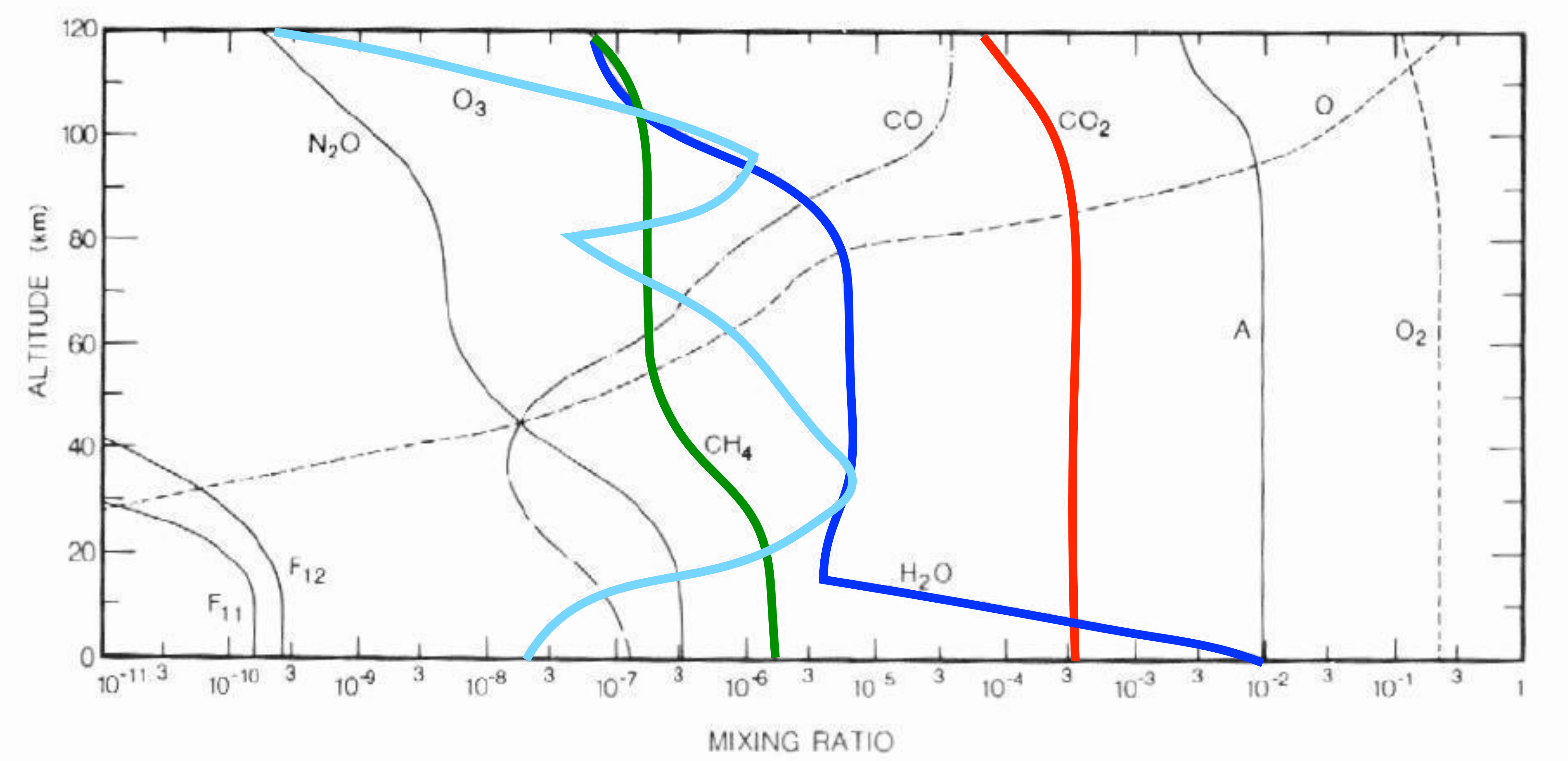
$$L \sim 1000 \text{ km}$$

Rotation is important in determining the fluid motion on earth!

Chemical composition of the atmosphere

Permanent Gases			Variable Gases			
Gas	Symbol	% by volume	Gas	Symbol	% by volume	Parts per million
Nitrogen	N_2	78.08	Water Vapor	H_2O	0~4	
Oxygen	O_2	20.95	Carbon dioxide	CO_2	0.036	360ppmV
Argon	Ar	0.93	Methane	CH_4	0.0017	
Neon	Ne	0.0018	Nitrous oxide	N_2O	0.00003	
Helium	He	0.0005	Ozone	O_3	0.000004	
Hydrogen	H_2	0.00006	Particles		0.000001	
Xenon	Xe	0.000009	Chlorofluro carbons		0.00000002	

Chemical composition of the atmosphere

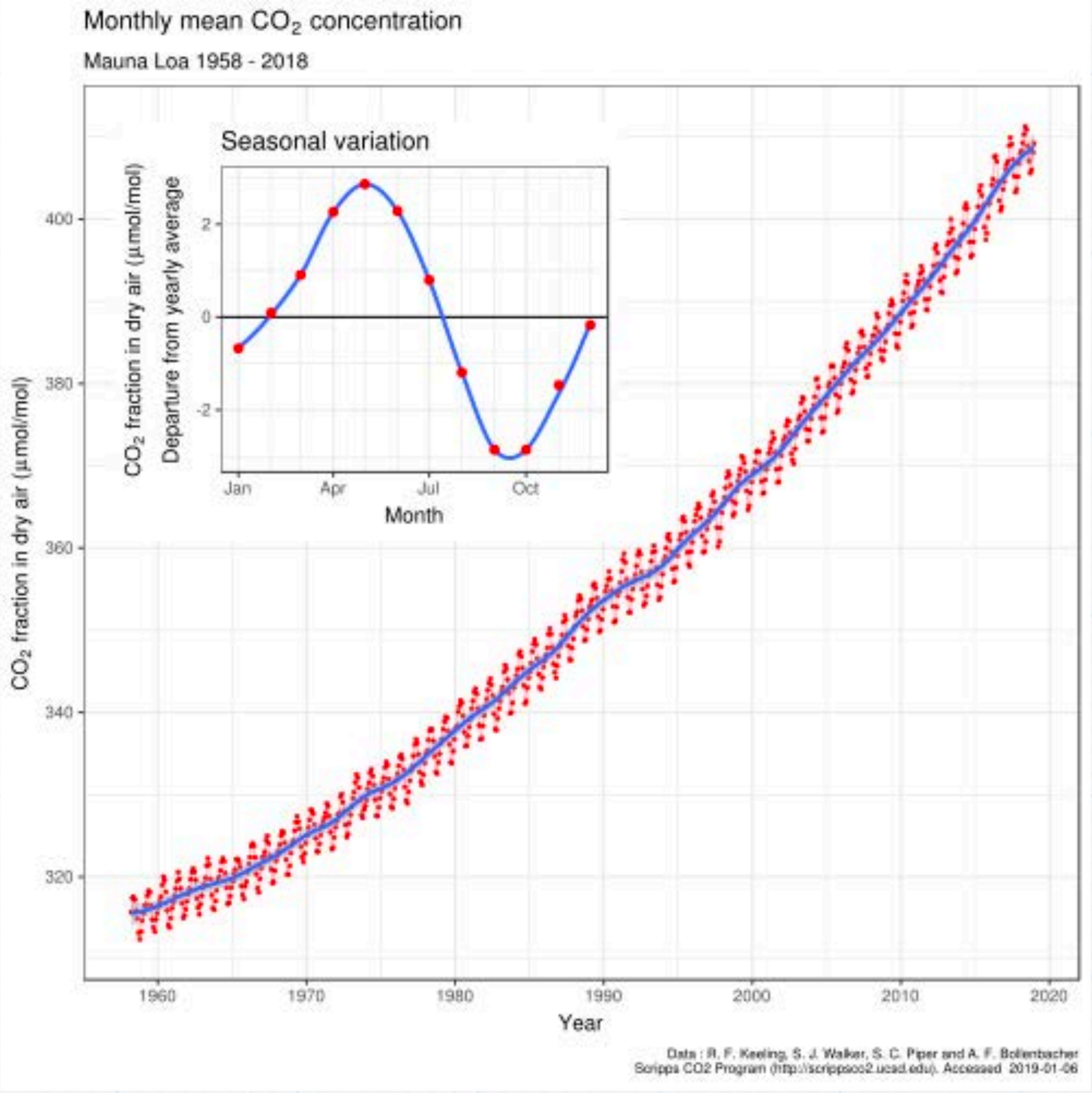


Vertical distribution of gases

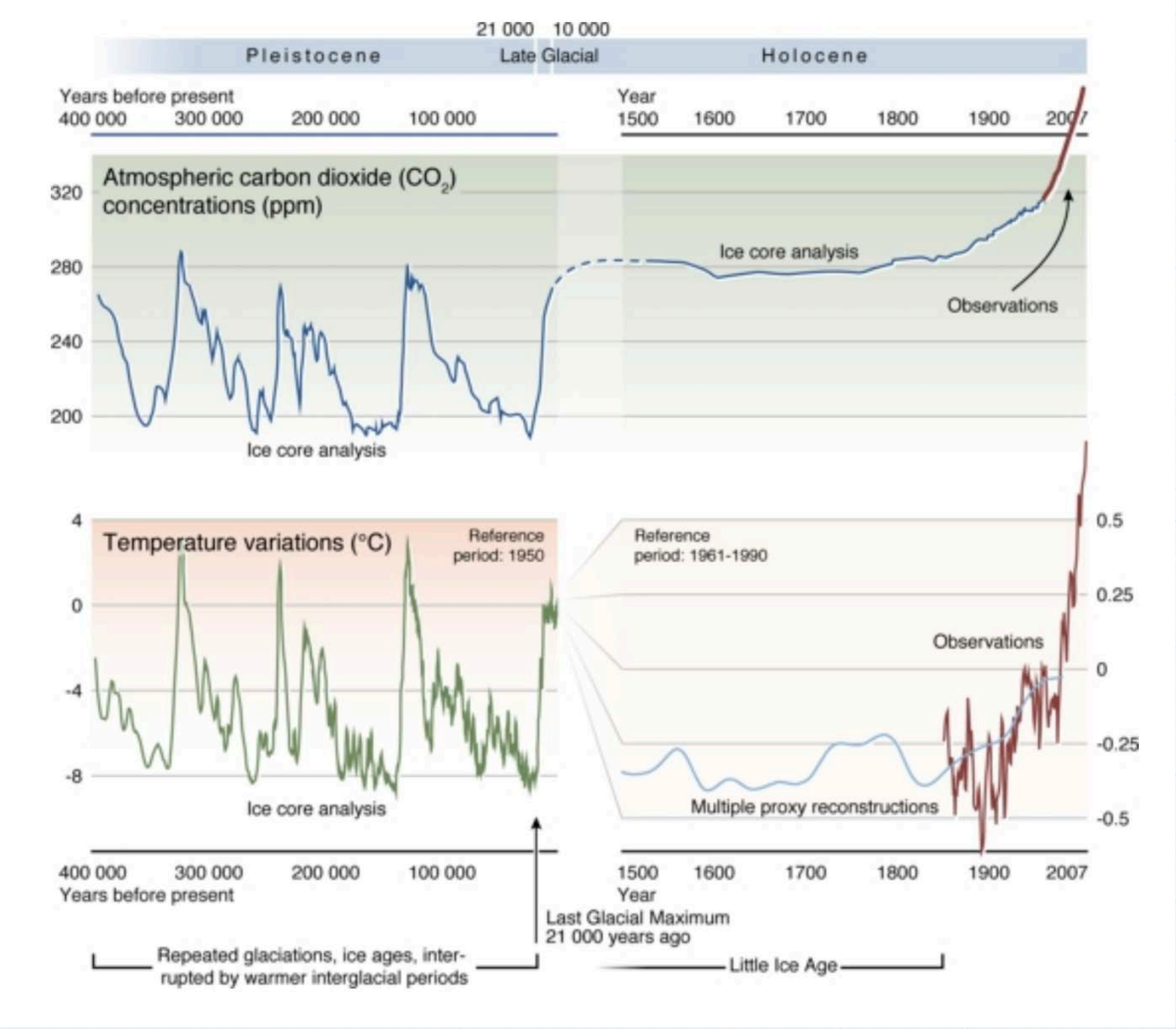
Goody and Yung, 1989

Characteristics of the Atmosphere

- Atmospheric water vapor is present in variable amounts.
- Important for radiative transfer (greenhouse effect)
- Another gas important for greenhouse effect is CO_2.



CO2 concentration and climate



From : http://pog.mit.edu/12.003//pdf_slides/Topic2.pdf

Physical properties of air: I. Dry air

- The atmosphere obeys the perfect gas law.

$$p = \rho R T$$

- Gas constant (*R*) for dry air:

$$R = 287 \text{ J kg}^{-1} \text{ K}^{-1}$$

- Air is compressible and we have to consider thermal expansion (to be covered later).

Physical properties of air: II. Moist air

- The air parcel can contain both water vapor and dry air.
- Then the partial pressure of water vapor, e, is

$$e = \rho_v R_v T$$

- The partial pressure of dry air, p_d, is

$$p_d = \rho_d R_d T$$

- The pressure of the mixture, p, is

$$p = p_d + e$$

- In practice, water vapor amount is so small, so

$$p \approx p_d$$

Physical properties of air: II. Moist air

- At a given temperature, *T*, there exists saturation vapor pressure.
- At saturation vapor pressure, e_S, the rate of evaporation is the same as the rate of condensation.

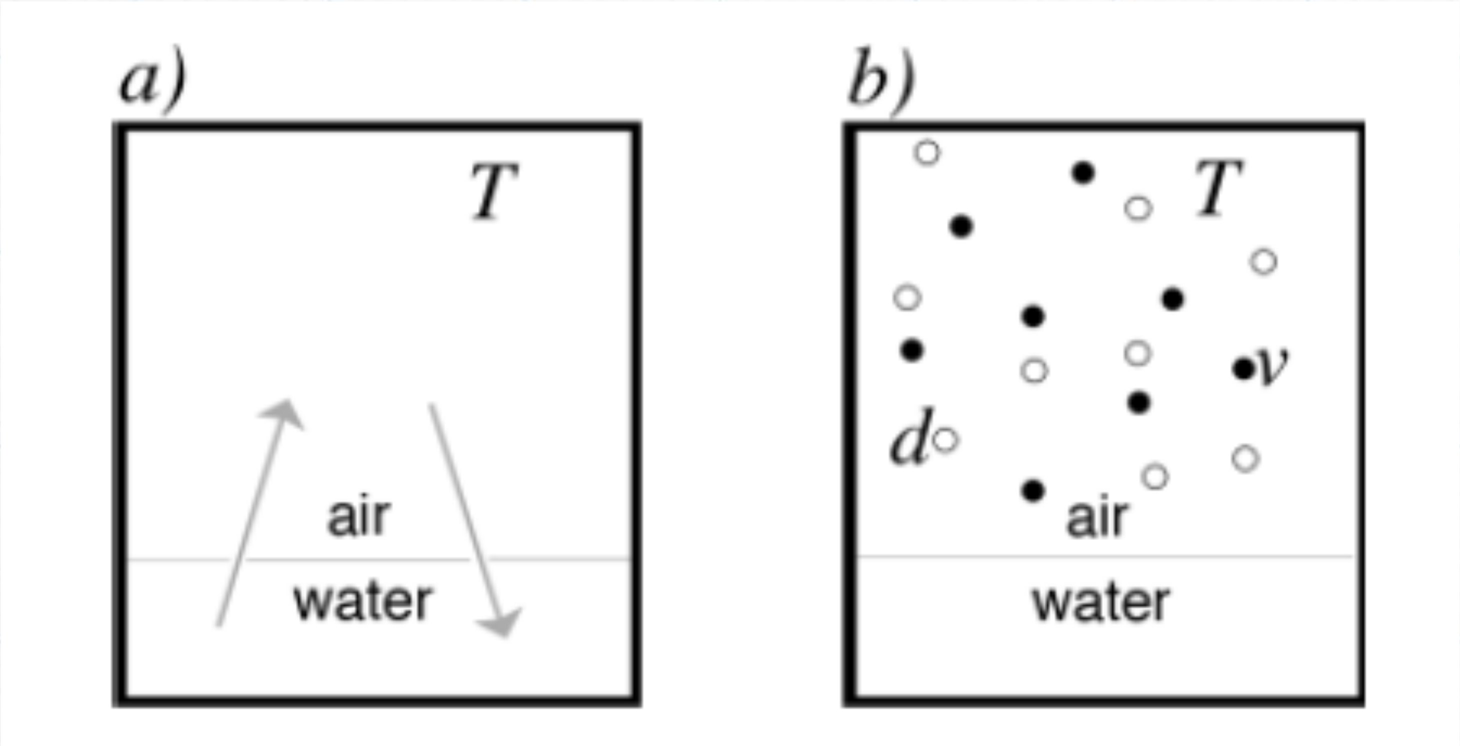


Figure 1.4, Marshall and Plumb (2008)

- What do you expect to see if $e > e_S$?

Physical properties of air: II. Moist air

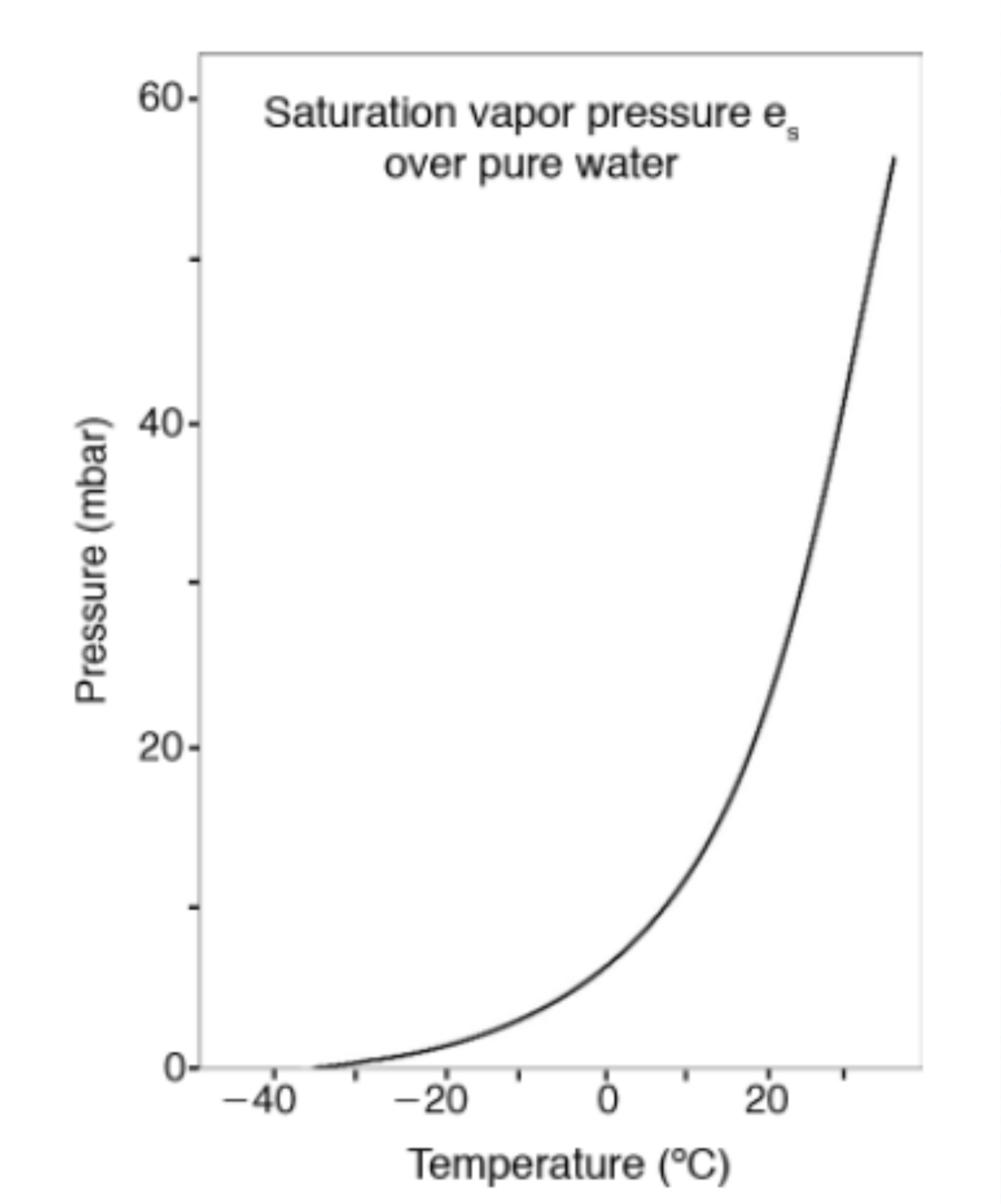


Figure 1.5, Marshall and Plumb (2008)

- e_s is a function of only temperature.
- **e_s is exponentially increases with temperature.**

$$e_s = Ae^{\beta T}$$

$$\begin{cases} A = 6.11 \text{ hPa}, \\ \beta = 0.067 \ {}^\circ\text{C}^{-1} \end{cases}$$

Physical properties of air: II. Moist air

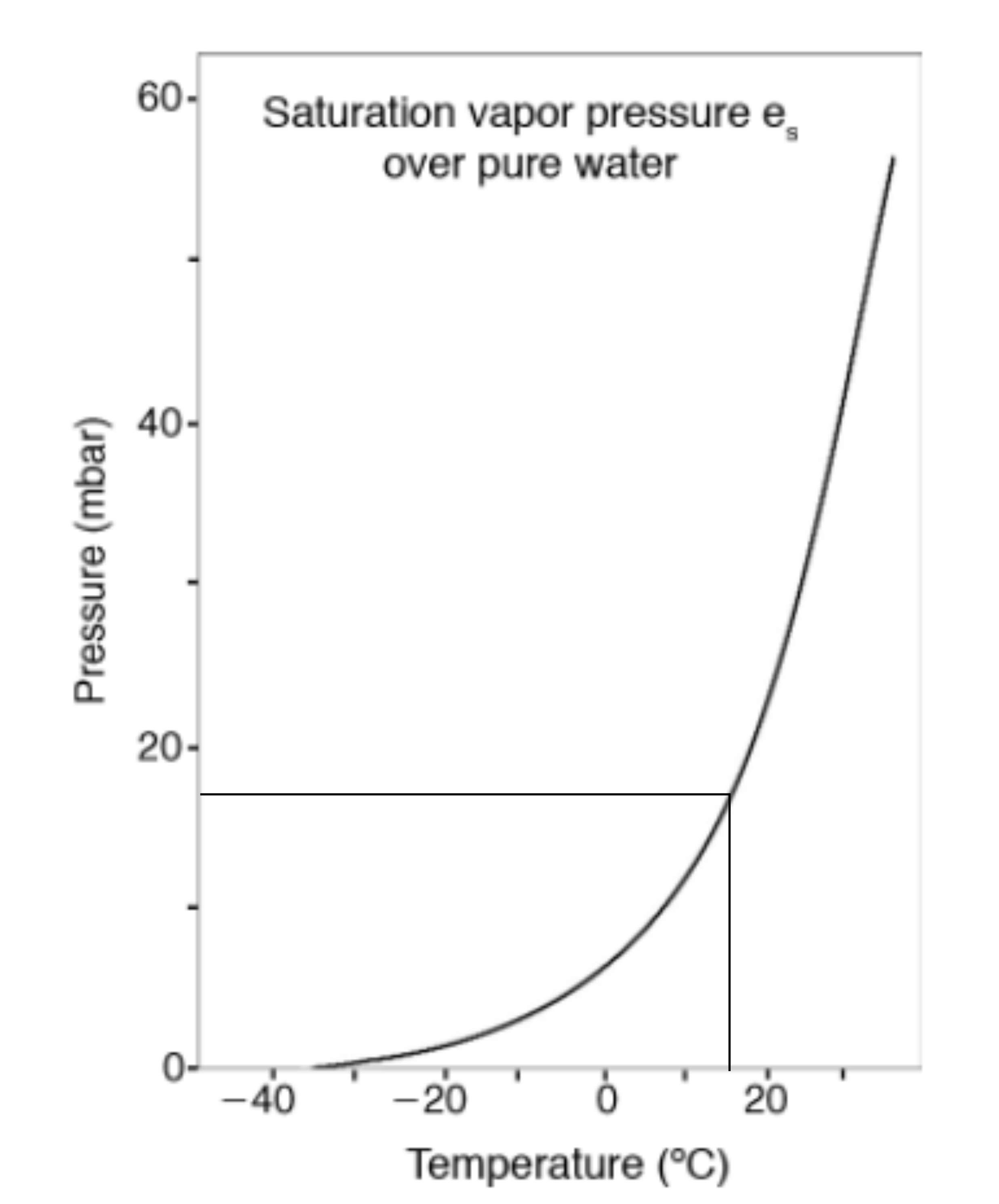


Figure 1.5, Marshall and Plumb (2008)

- The moisture content decays rapidly with height.
- Tropics tends to be more moist (wetter) than polar regions.
- Precipitation occurs when air cools.
- In last glacial maximum, the earth was drier and barrener than now.

Cloud formation