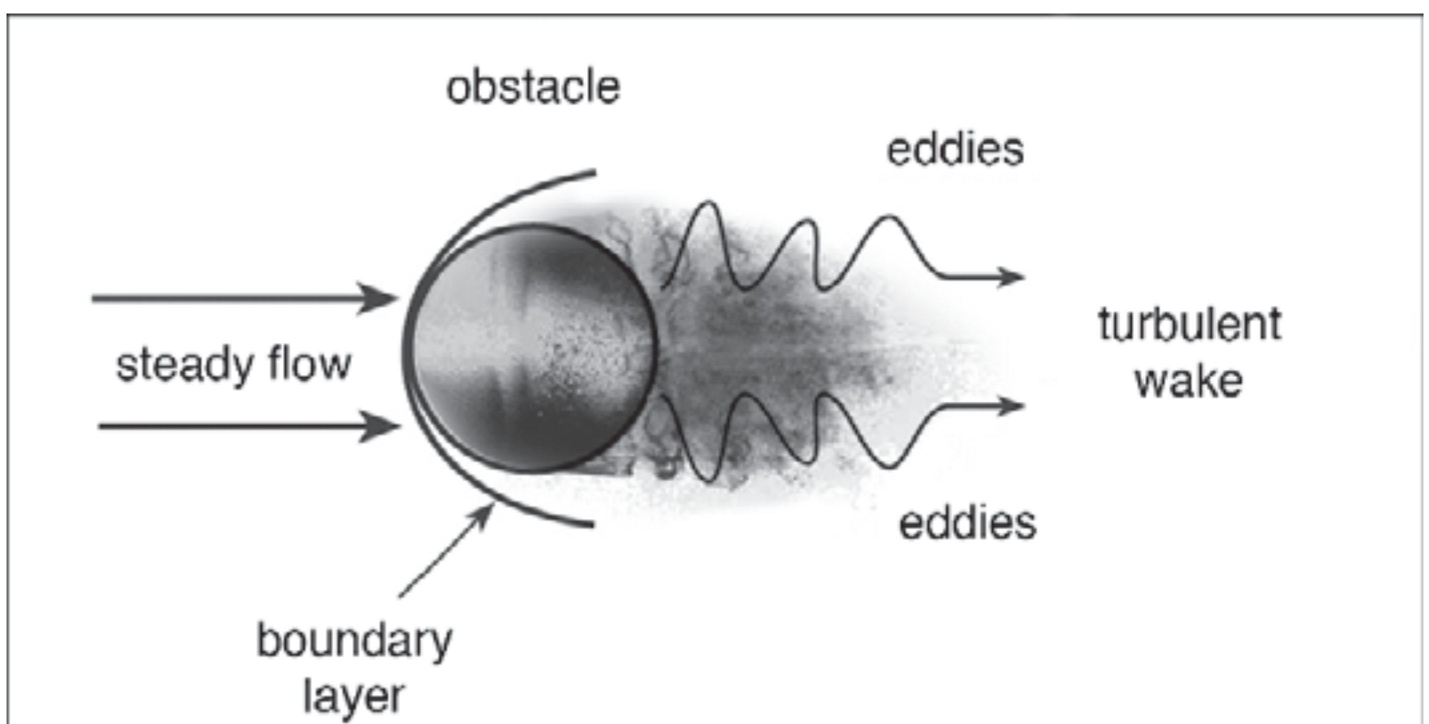
ATM 2106: Fluid on earth and air characteristics

March 6, 2019

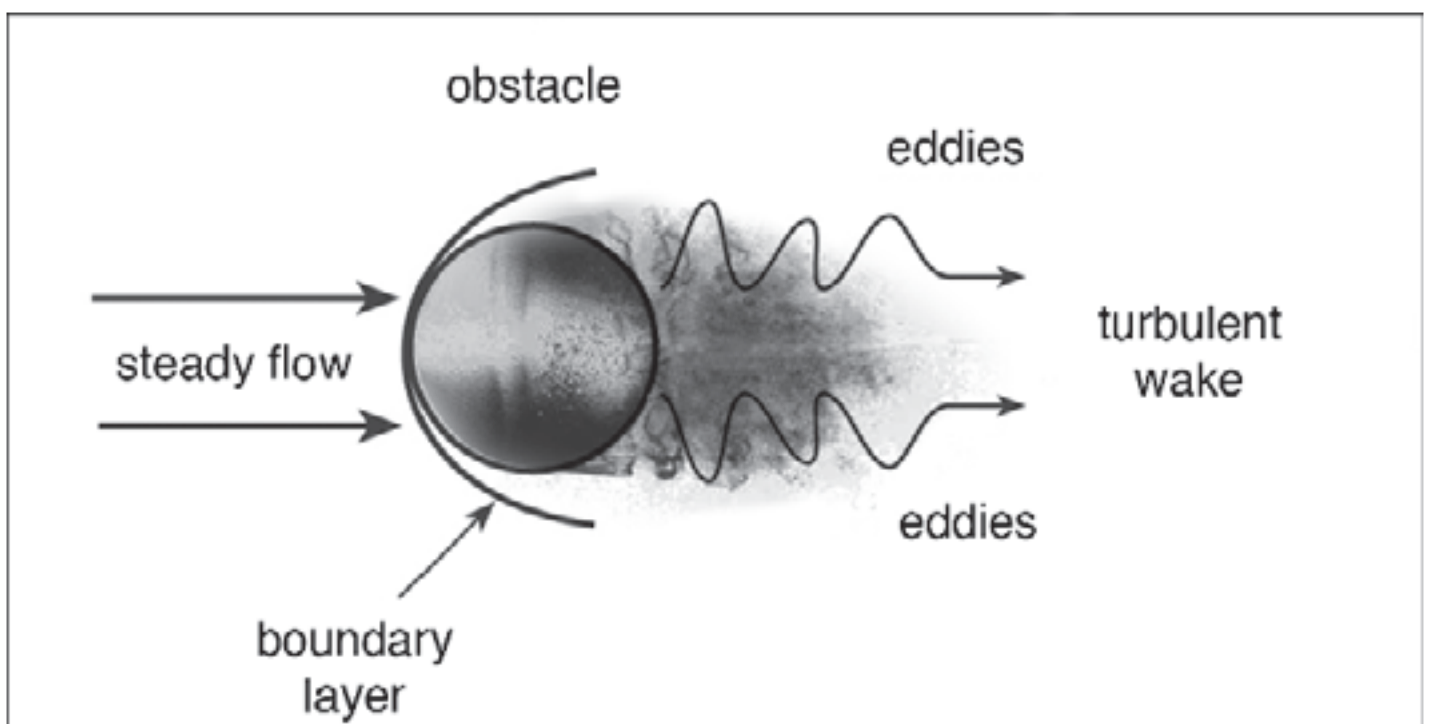
Fluid dynamics on earth

- Fluid dynamics is commonly studied in engineering.
- Typically, people consider a fluid of constant density as in the figure.
- The energy drives the turbulent wake comes from kinetic energy in the fluid.



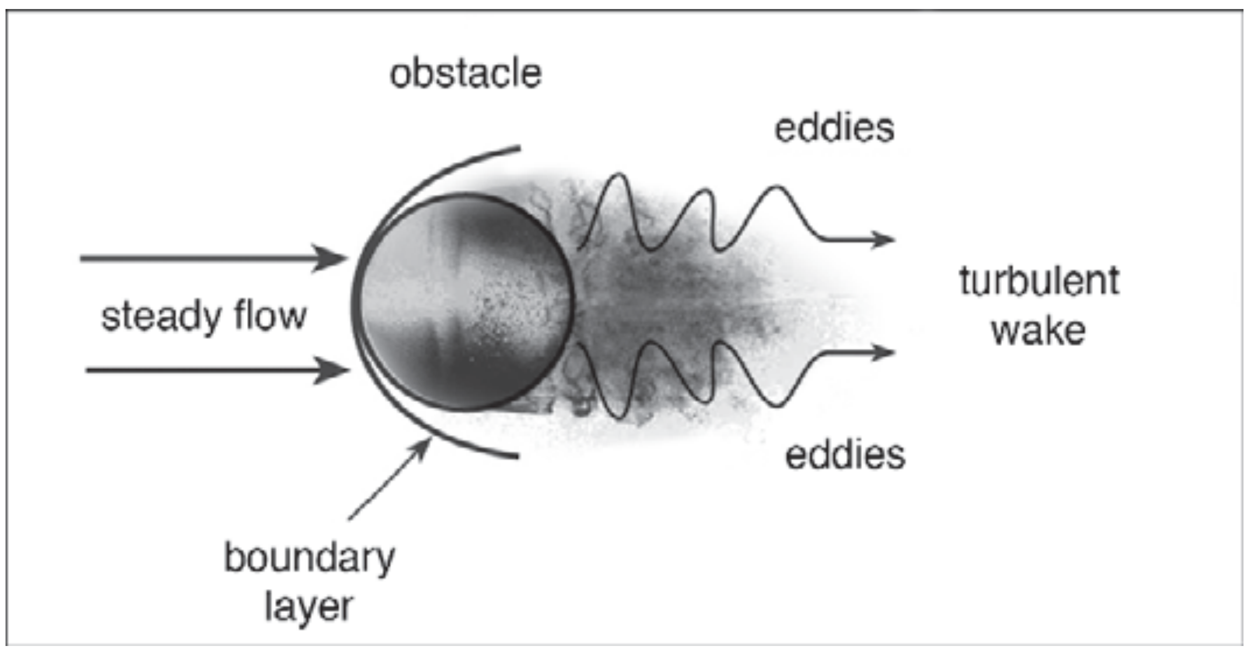
Fluid dynamics on earth

- This type of problems can be studied experimentally or mathematically (Fluid dynamics class by Prof. Noh).
- But it is not directly applied to the atmosphere or the ocean because of the assumption of the constant density.
- Or more precisely, $\rho = \rho(P)$



Fluid dynamics on earth

- There is a resemblance to the atmosphere…



the distribution of water vapor over Africa and the Atlantic Ocean

- But there is a fundamental difference between them.

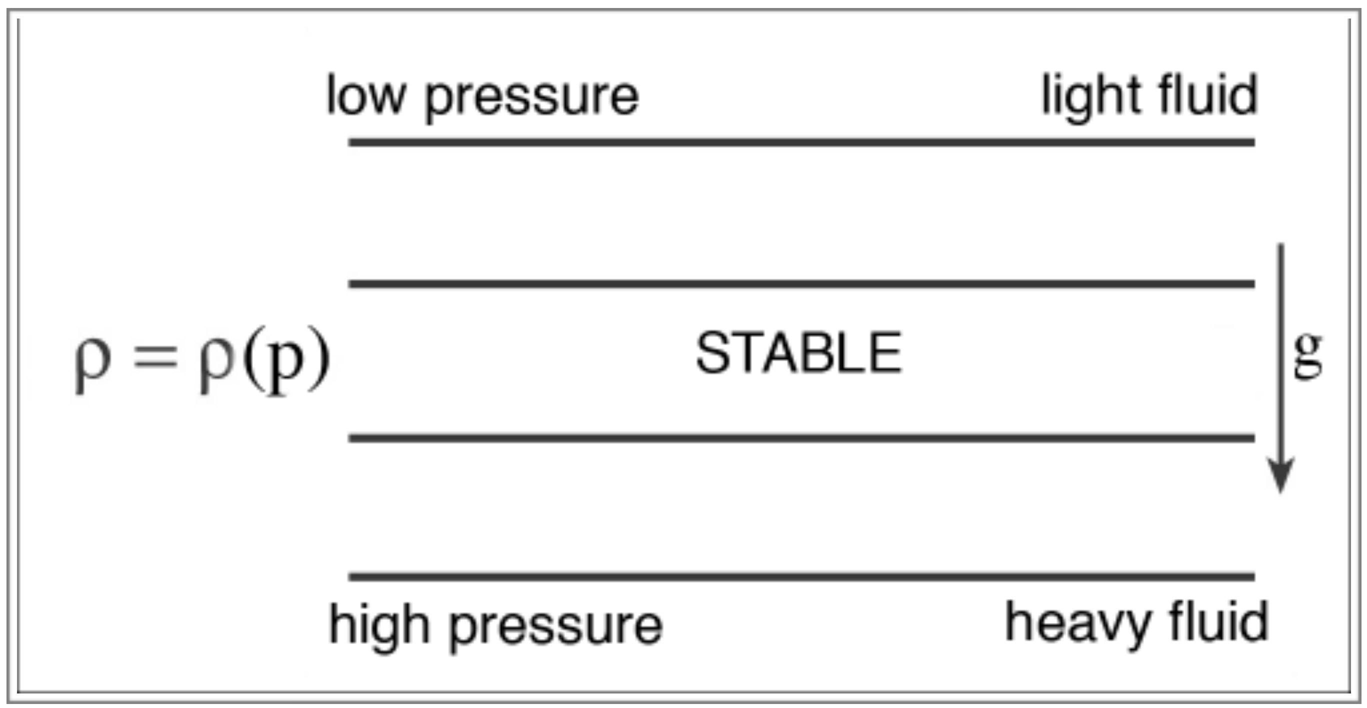
Fluid dynamics on earth

- 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



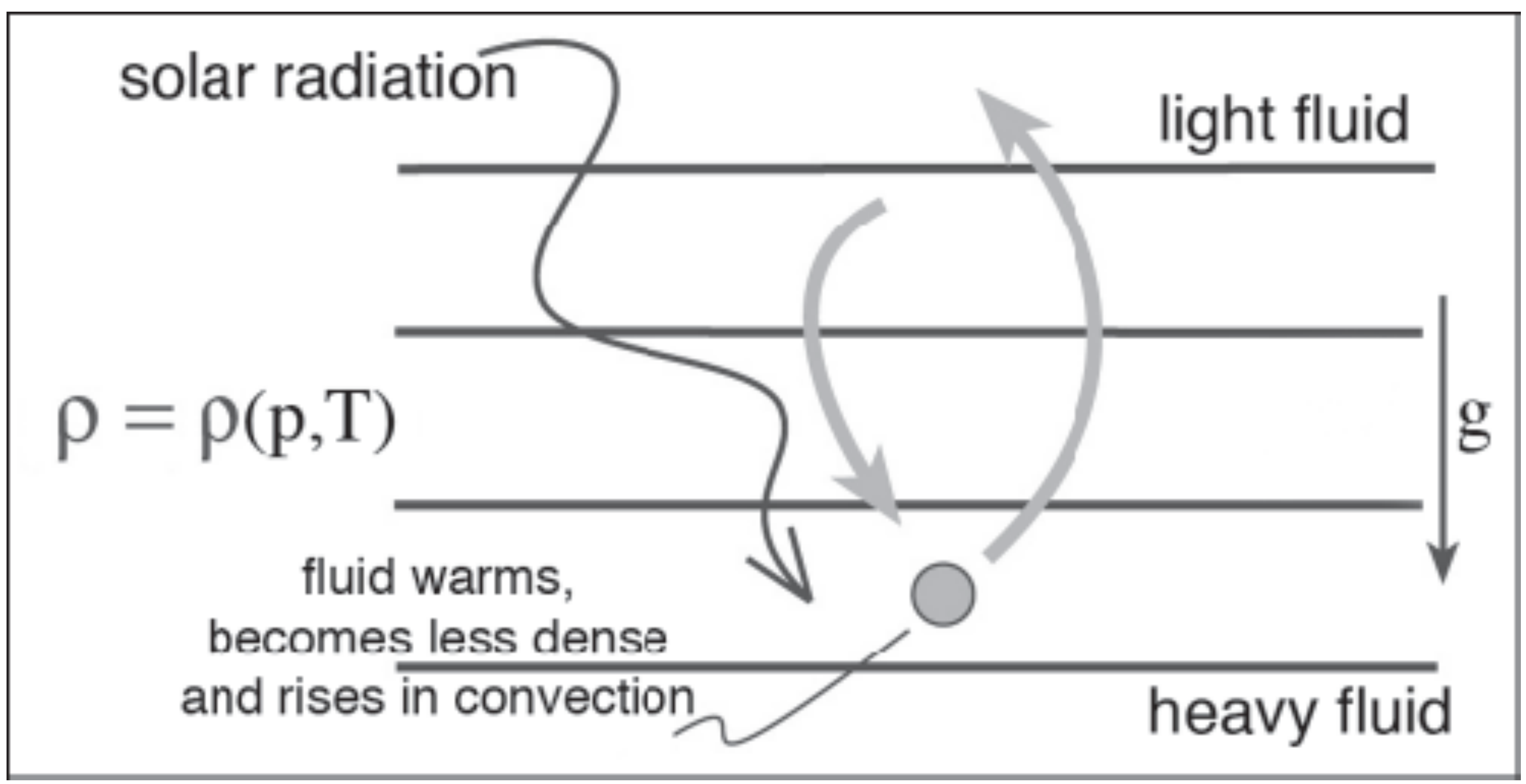
Fluid dynamics on earth

- Our earth is a lot more dynamic place!
- The key component is

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

Fluid dynamics on earth

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



Fluid dynamics on earth

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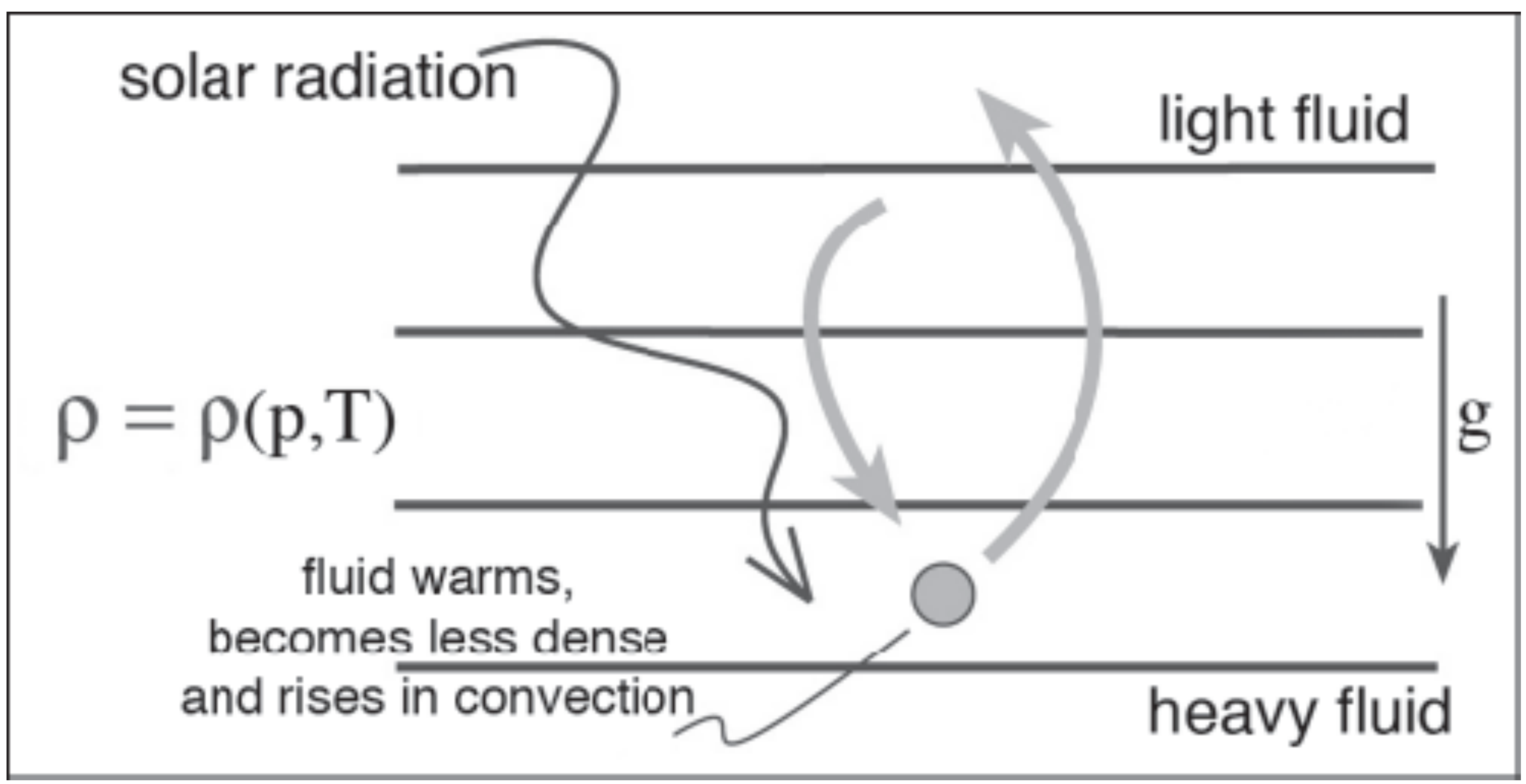
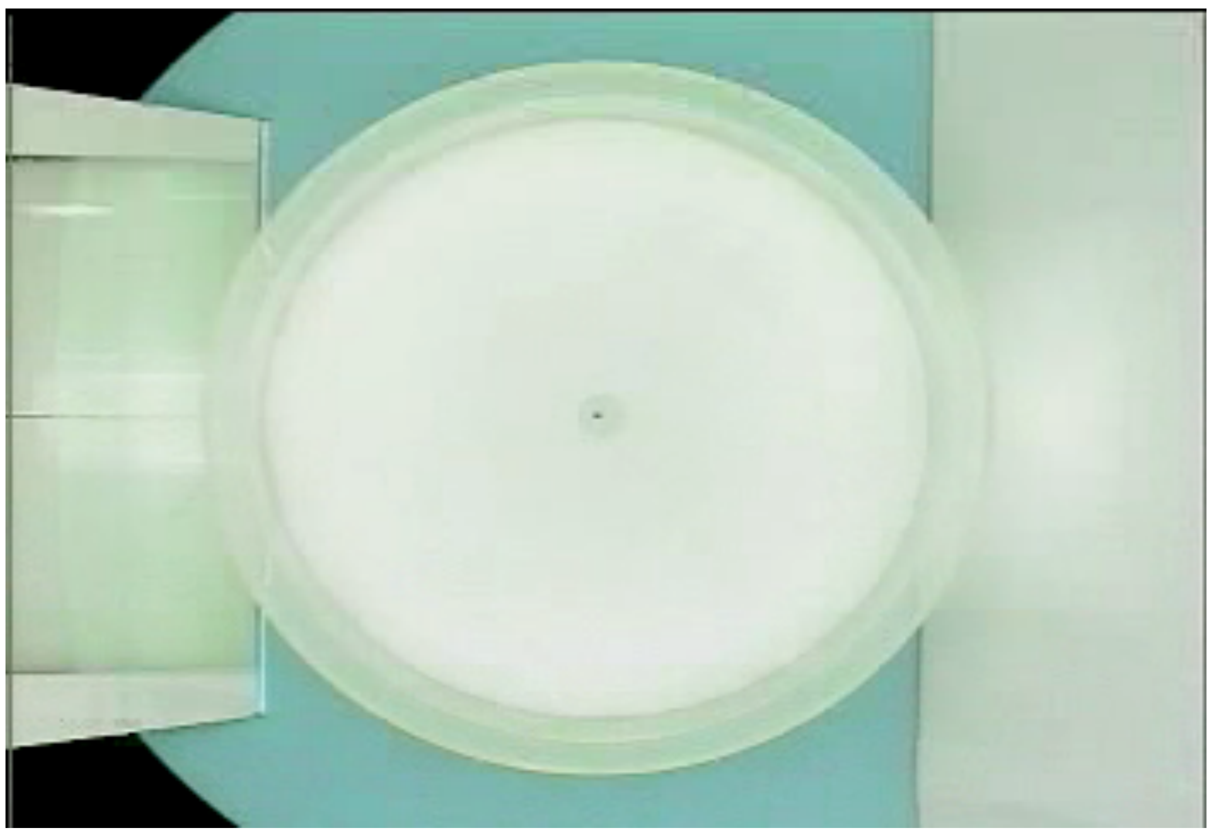


Fluid dynamics on earth

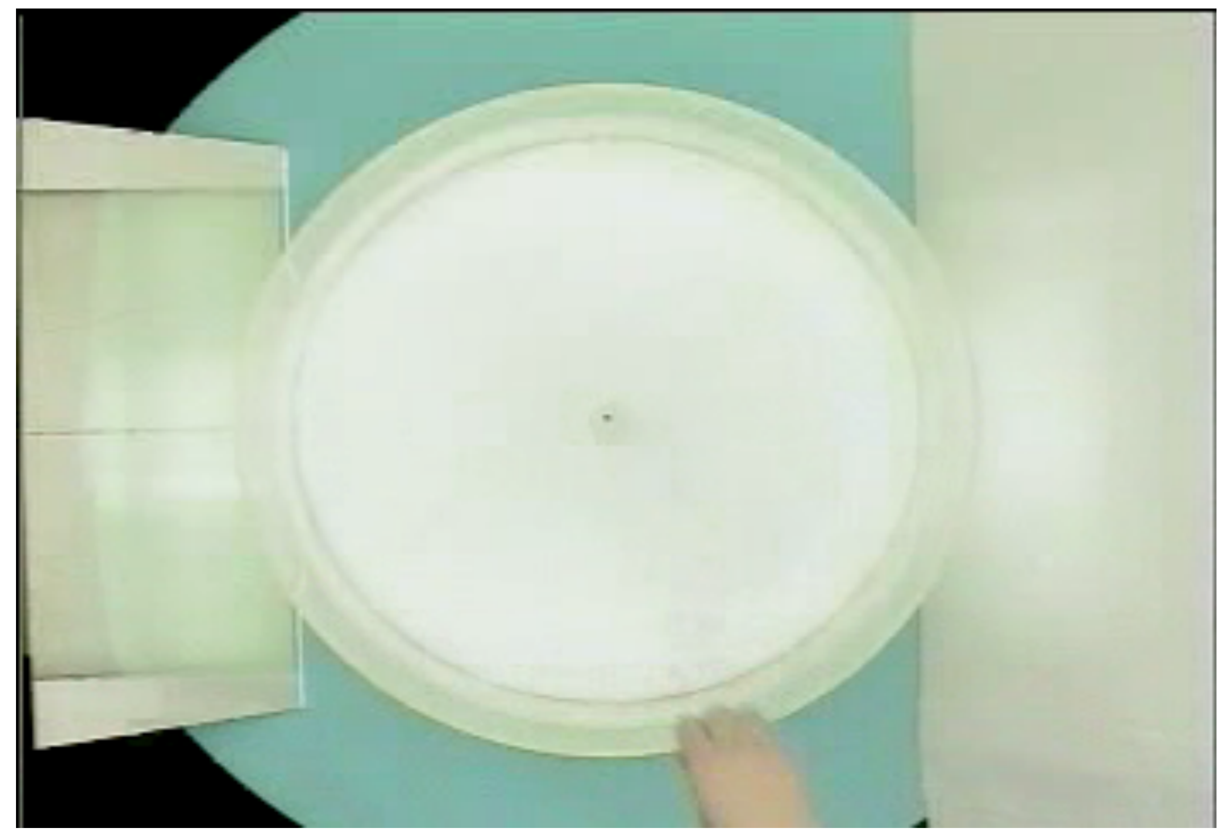
- Another important ingredient in fluid dynamics on earth is

rotation

Fluid dynamics on earth



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: $\dfrac{L}{U}$

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

Fluid dynamics on earth

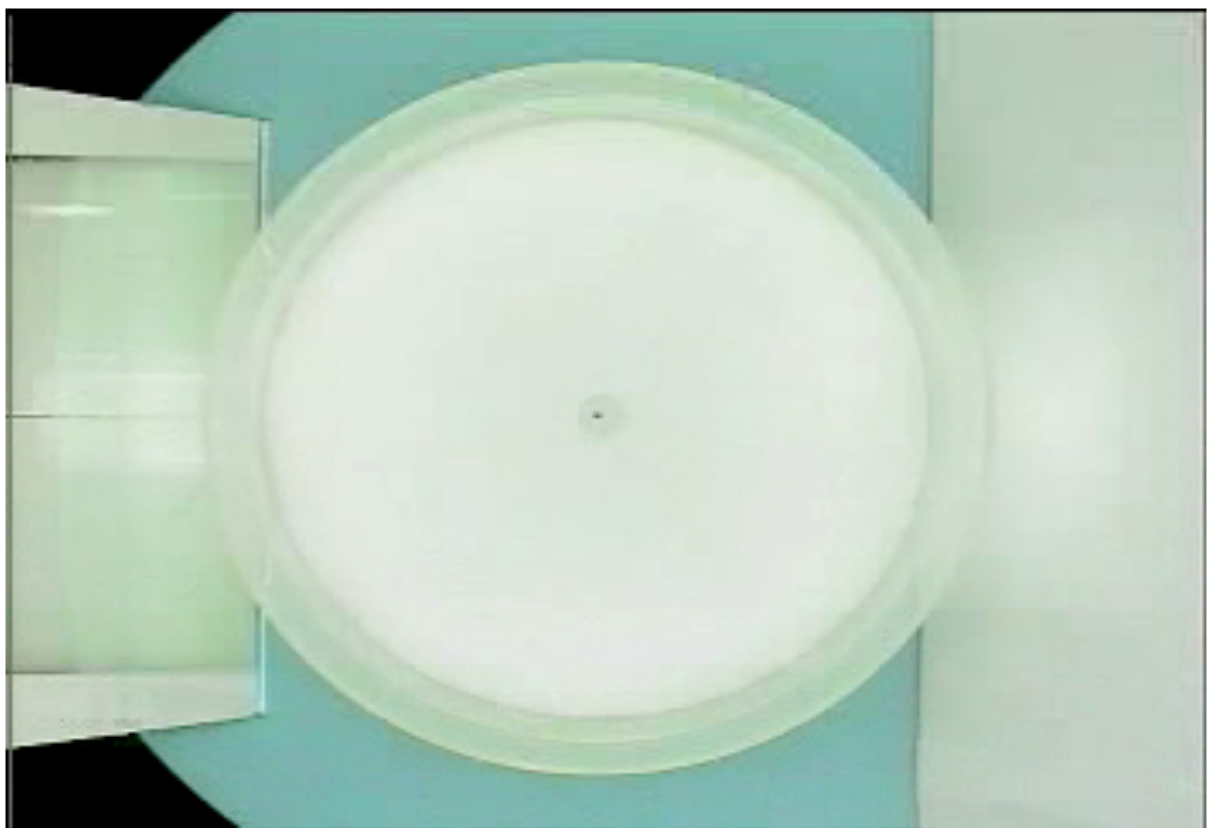
$Ro >> 1$: The fluid is faster than rotation.

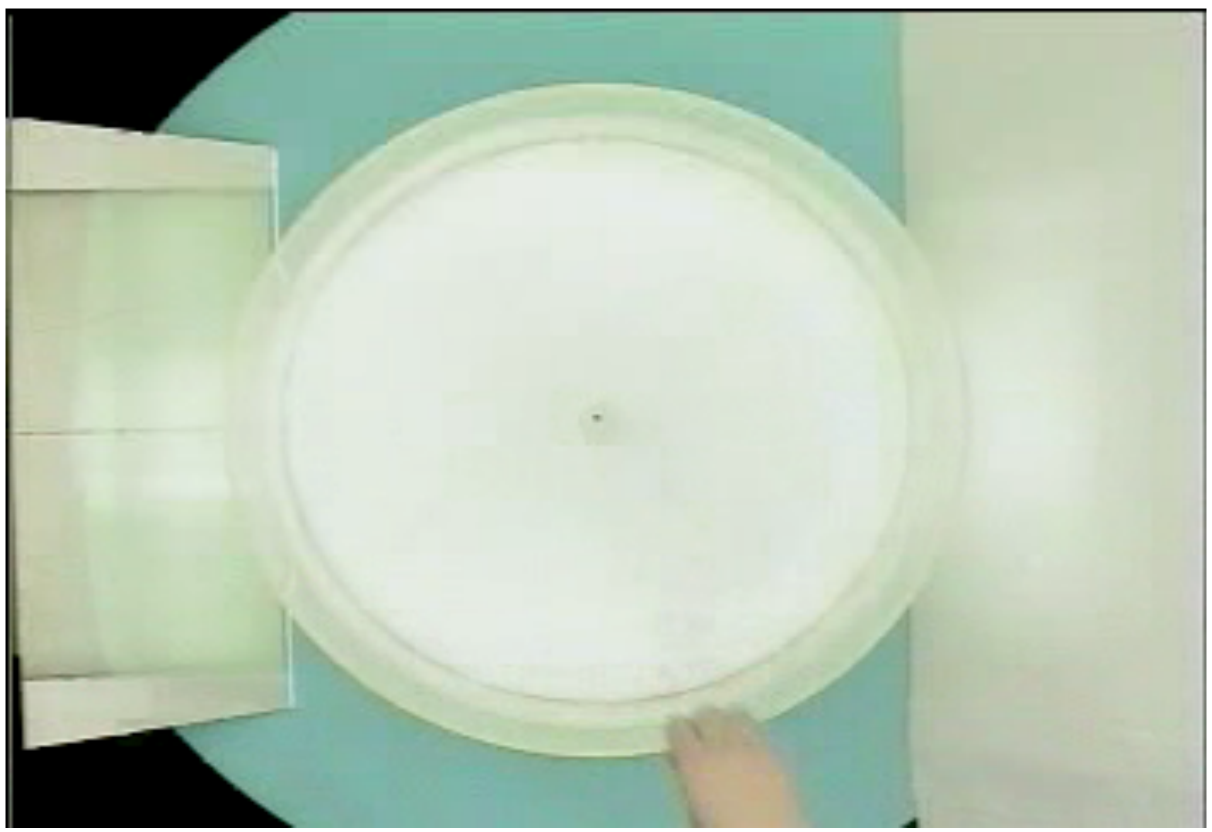
$Ro << 1$: Rotation is faster than fluid.

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

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!

Characteristics of the Atmosphere

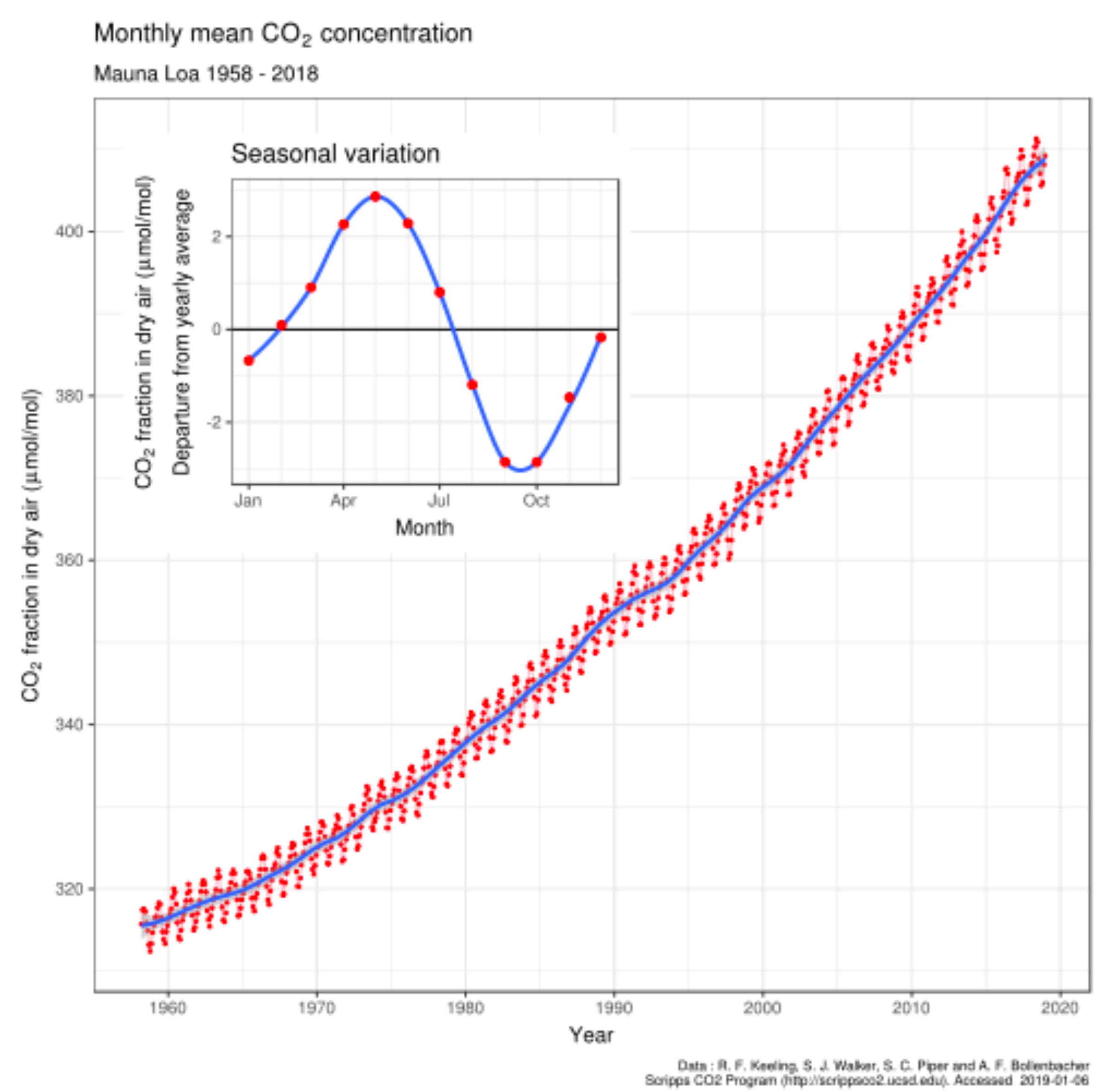
- Very thin
  - About 80% of the mass of the atmosphere in 10 km
  - 10 km << 6400 km
  - A constant gravity assumption
- Continuous around the globe
- Water vapor

TABLE 1.1. Some parameters of Earth.

Earth's rotation rate	Ω	$7.27 \times 10^{-5} s^{-1}$
Surface gravity	g	$9.81\ ms^{-2}$
Earth's mean radius	a	6.37×10^{6} m
Surface area of Earth	$4\pi a^2$	$5.09 \times 10^{14}\ m^2$
Area of Earth's disc	πa^2	$1.27 \times 10^{14}\ m^2$

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.



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

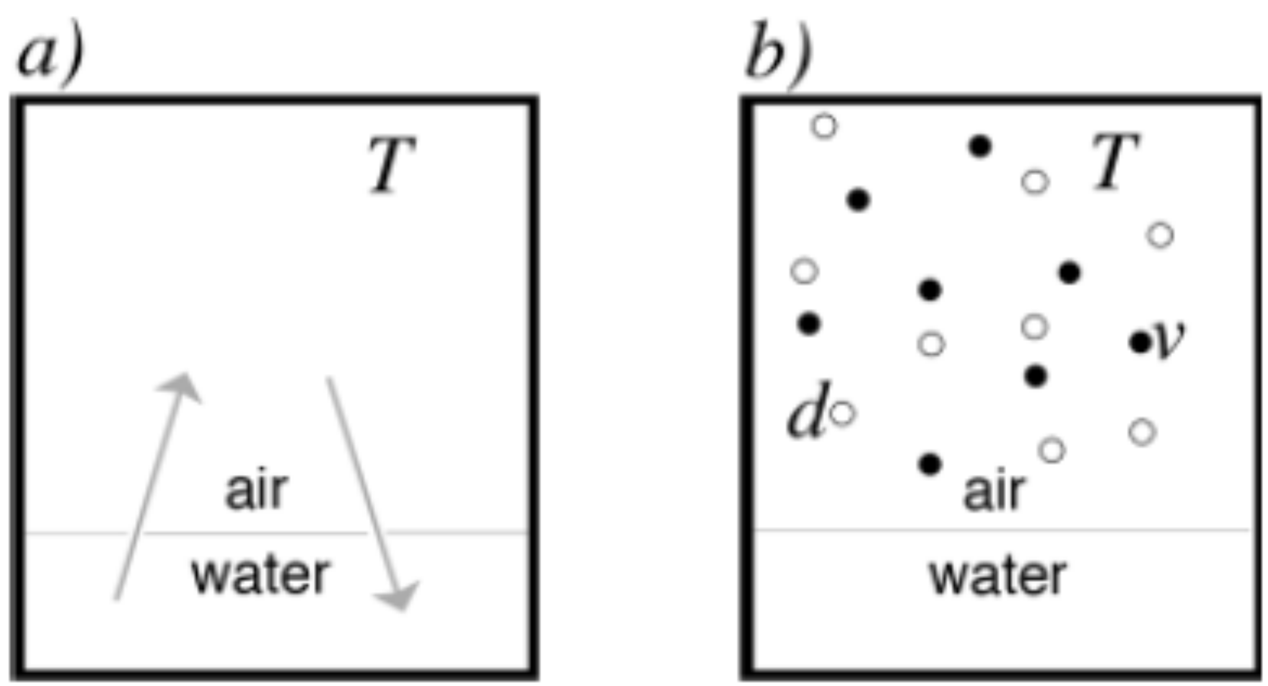
$$p = p_d + e$$

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

$$p \approx p_d$$

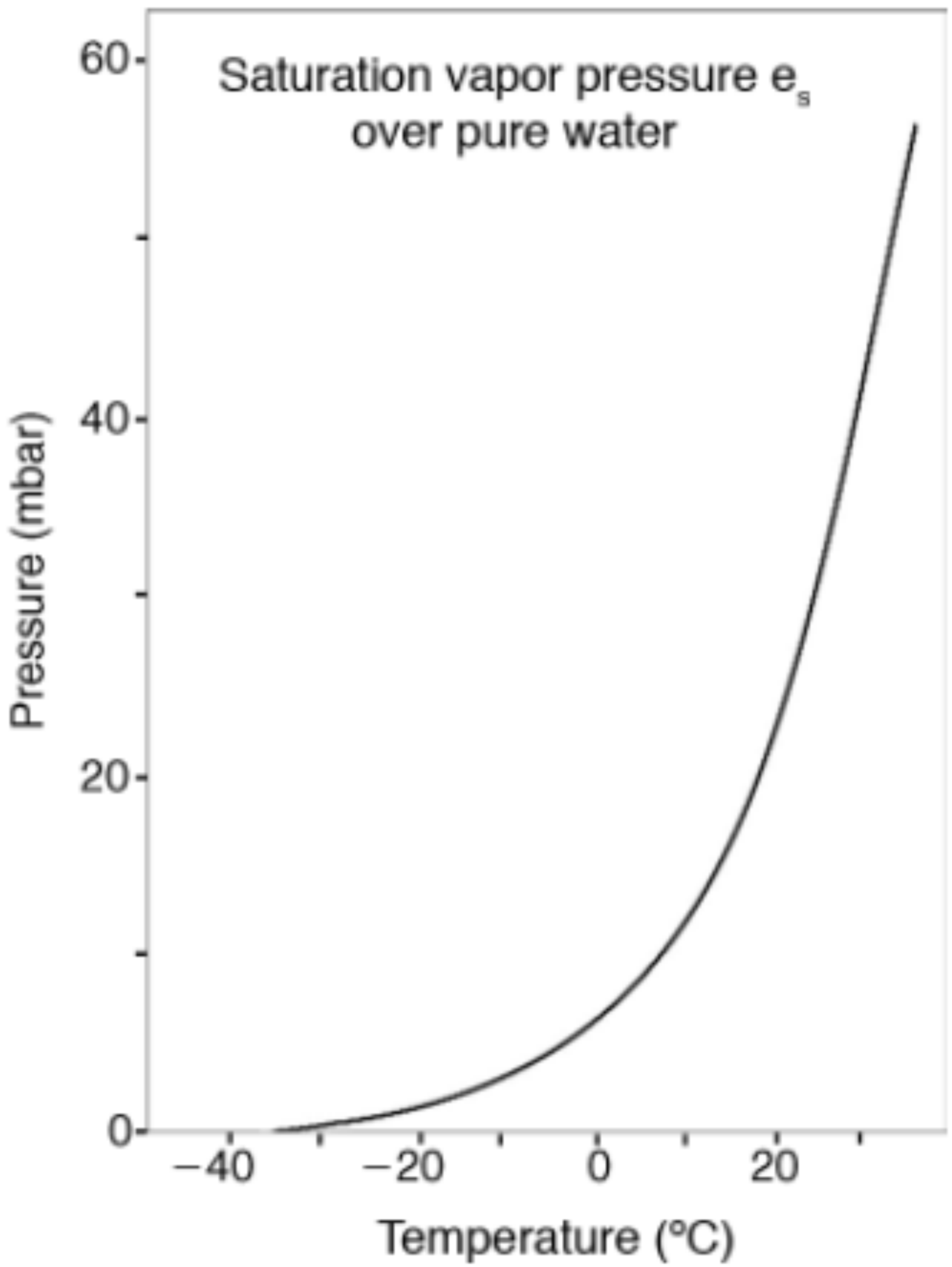
Physical properties of air: II. Moist air

- 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.



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

Physical properties of air: II. Moist air

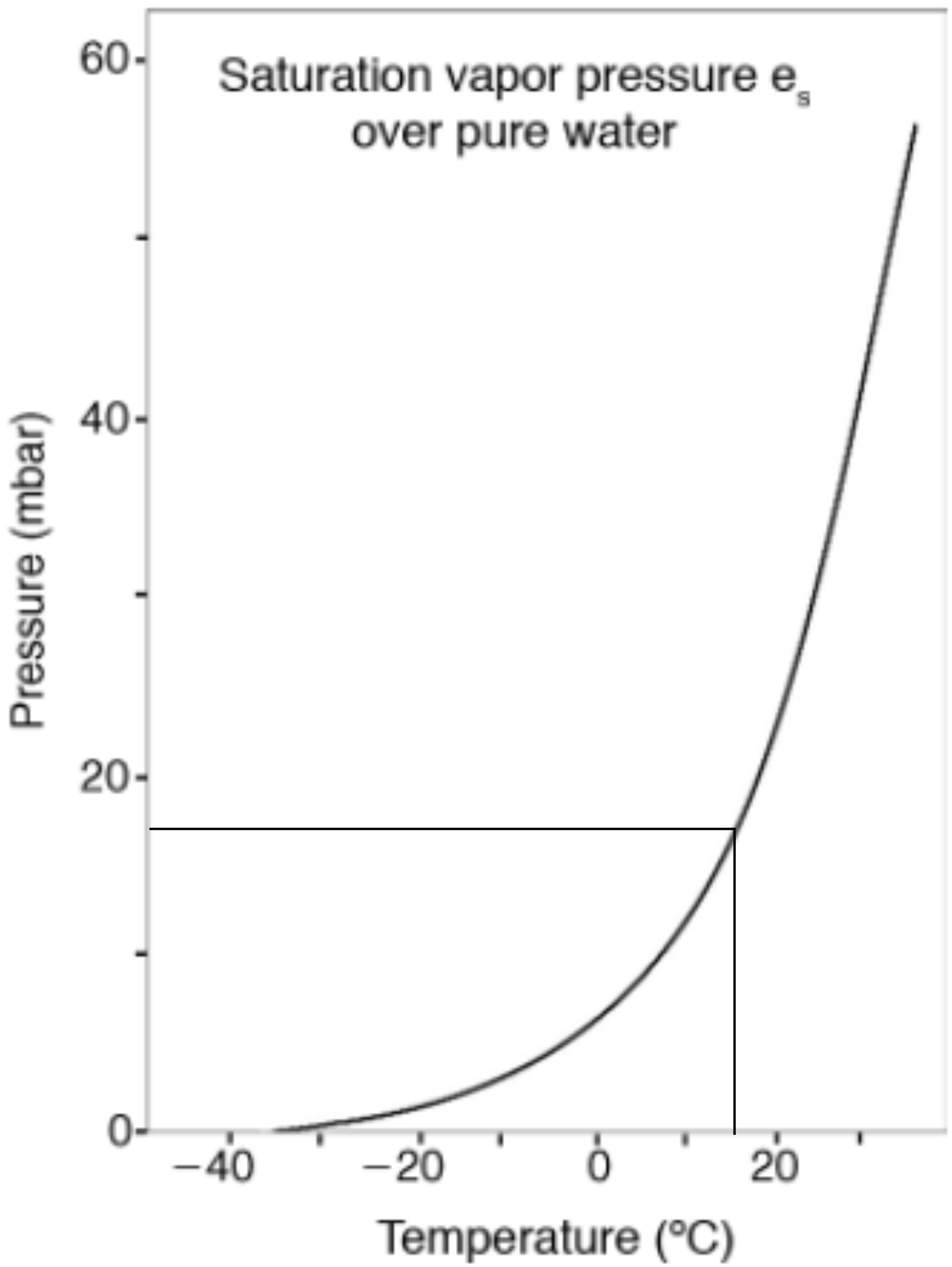


- e_s is a function of only temperature.
- **e_s is exponentially increases with temperature.**

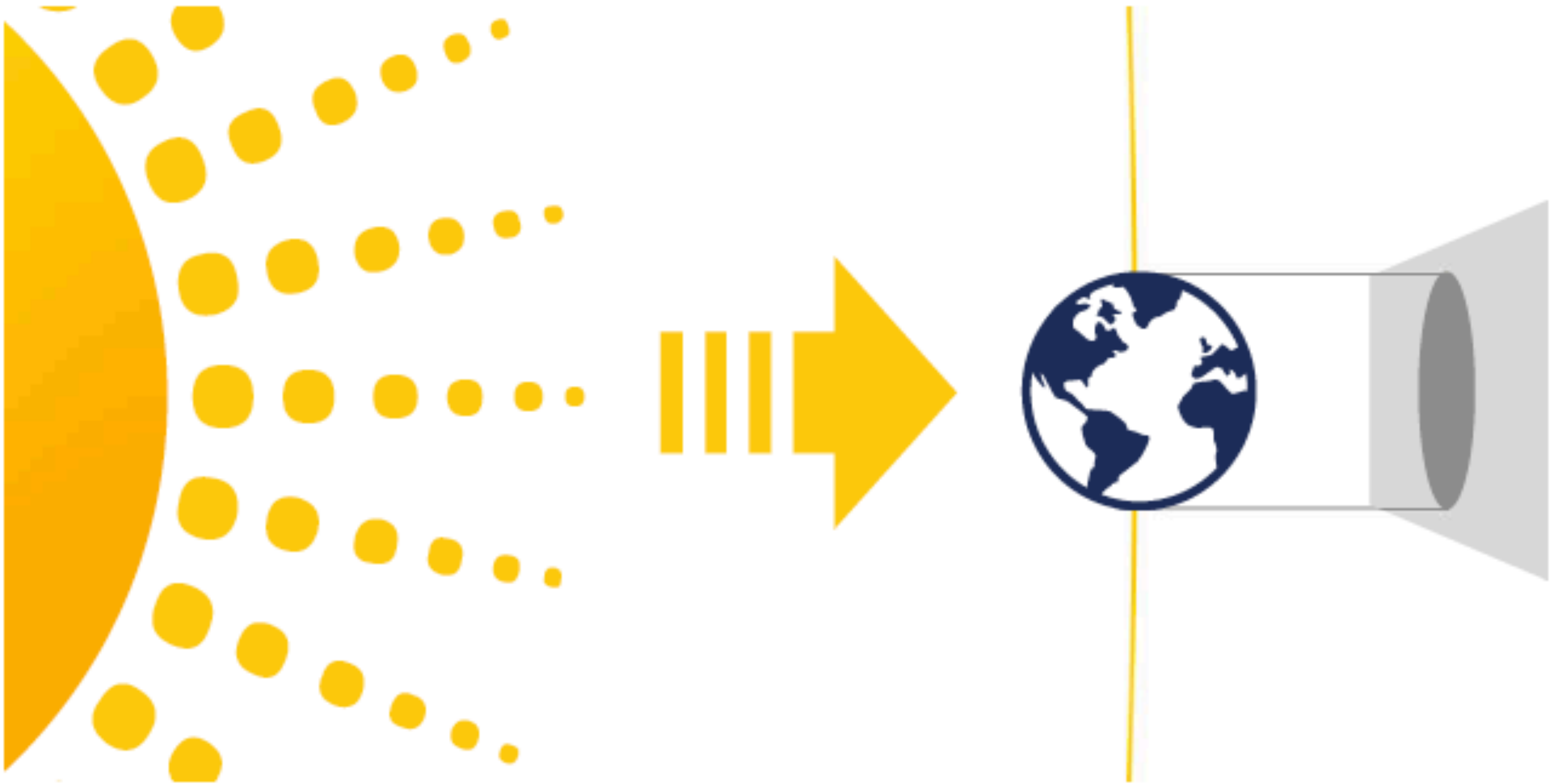
$$e_s = Ae^{\beta T}$$

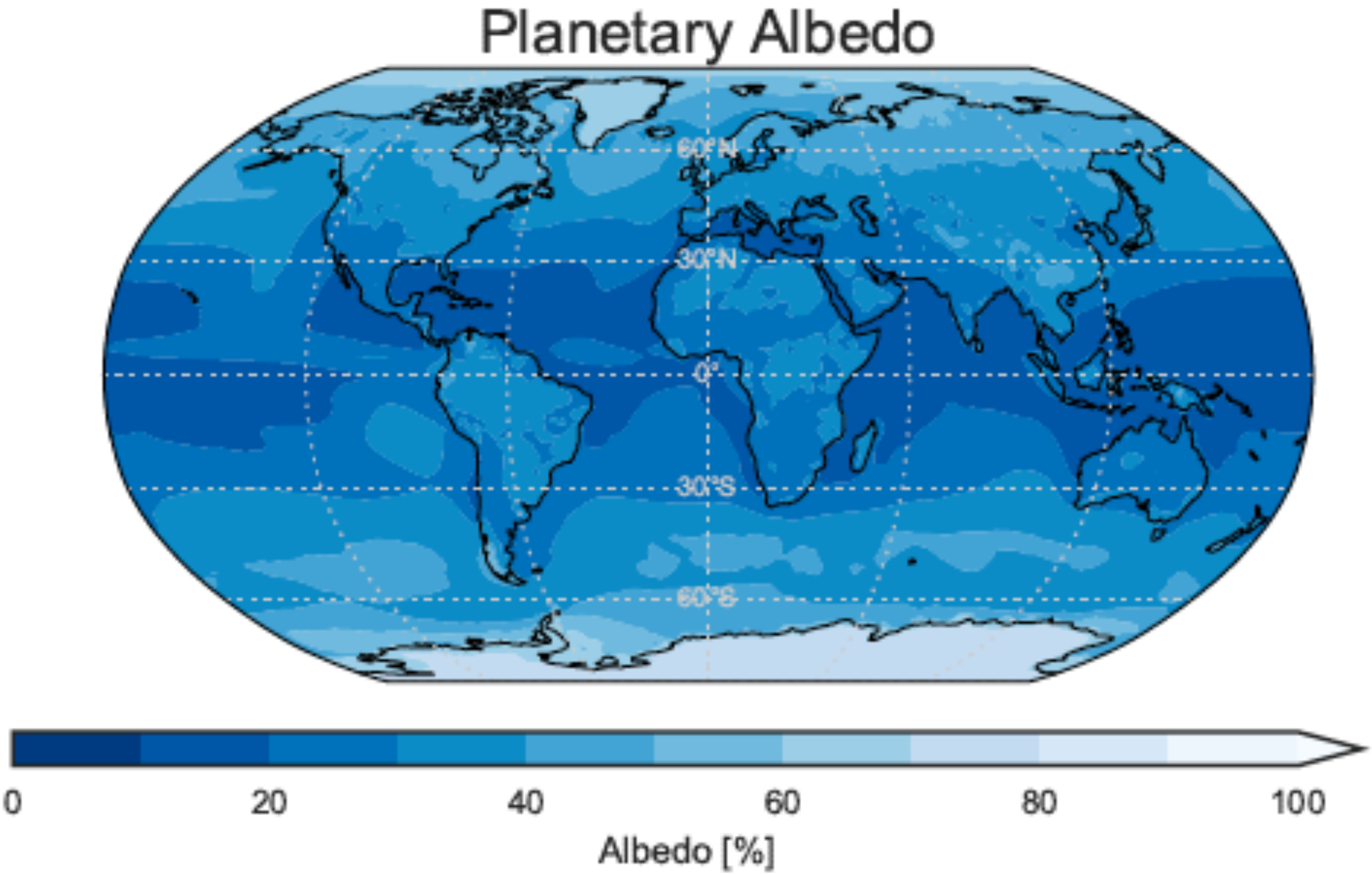
$$\begin{cases} A = 6.11 \text{ hPa}, \\ \beta = 0.067\ {}^\circ\text{C}^{-1} \end{cases}$$

Physical properties of air: II. Moist air



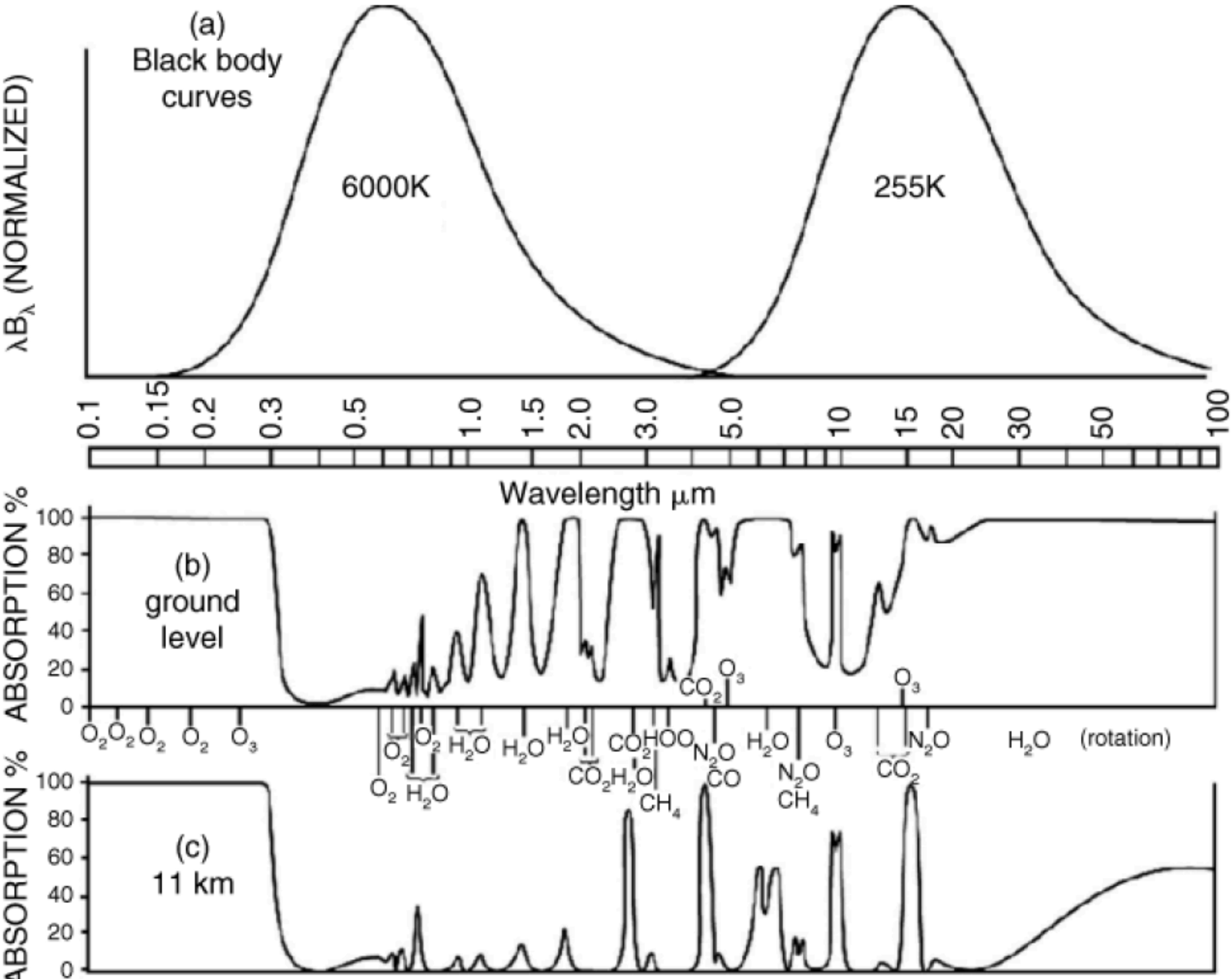
- The moisture content decays rapidly with height.
- Tropics tends to be more moist (wetter) than polar regions.
- Precipitation occurs when air cools.
- In last glacial maximum, the earth was drier and barrener than now.




Planetary Albedo
60°N
30°N
0°
30°S
60°S
0
20
40
60
80
100
Albedo [%]

Type of surface	Albedo (%)
Ocean	2–10
Forest	6–18
Cities	14–18
Grass	7–25
Soil	10–20
Grassland	16–20
Desert (sand)	35–45
Ice	20–70
Cloud (thin, thick stratus)	30, 60–70
Snow (old)	40–60
Snow (fresh)	75–95

Average ≃ 30%



(a)
Black body curves
6000K
255K
λB_λ (NORMALIZED)
0.1
0.15
0.2
0.3
0.5
1.0
1.5
2.0
3.0
5.0
10
15
20
30
50
100
Wavelength μm
(b)
ground level
ABSORPTION %
100
80
60
40
20
0
O_2 O_2 O_2 O_2 O_3
O_2 O_2 H_2O O_2 H_2O
H_2O H_2O CO_2 H_2O CO_2 H_2O CH_4
HOO
CO_2 O_3 N_2O CO
H_2O N_2O CH_4
O_3 O_3 CO_2 N_2O
H_2O (rotation)
(c)
11 km
ABSORPTION %
100
80
60
40
20
0