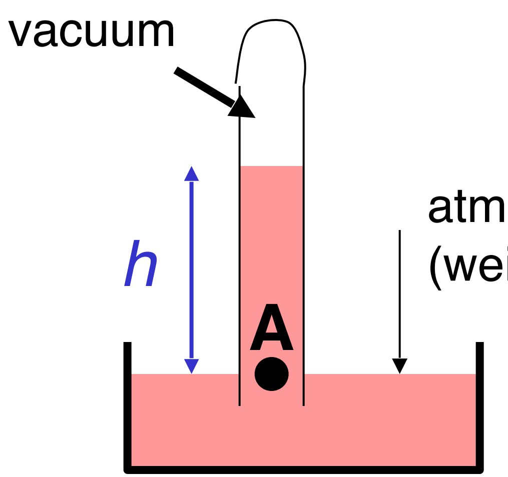
2. Atmospheric pressure

Measurement of atmospheric pressure with the mercury barometer



atmospheric pressure
(weight of atmosphere per unit area of surface)

Atmospheric pressure $p = p_A = \rho_{Hg} gh$

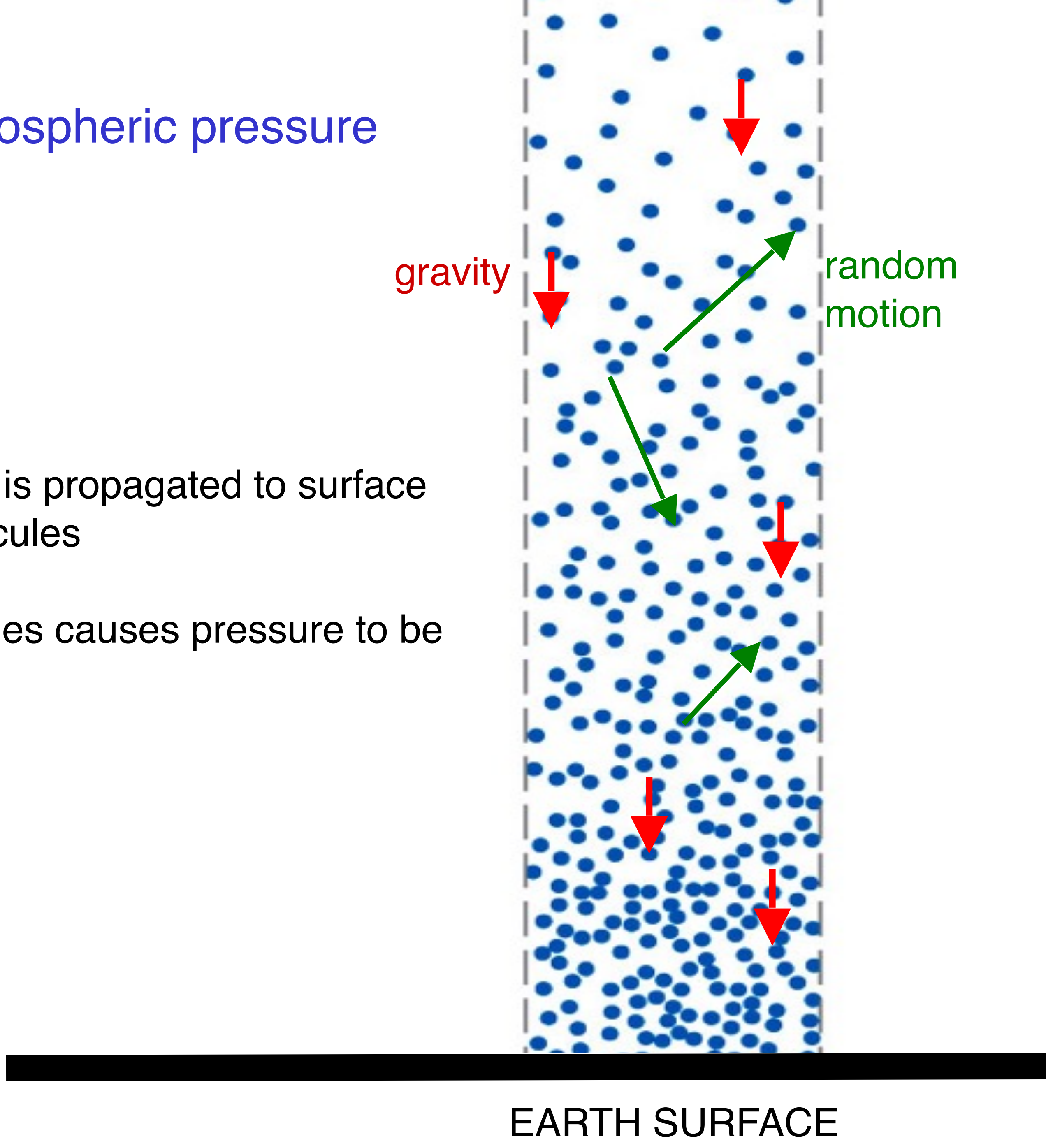
SI unit for pressure is the Pascal (Pa): 1 Pa = 1 kg m^{-1} s^{-2}

Mean sea-level pressure:

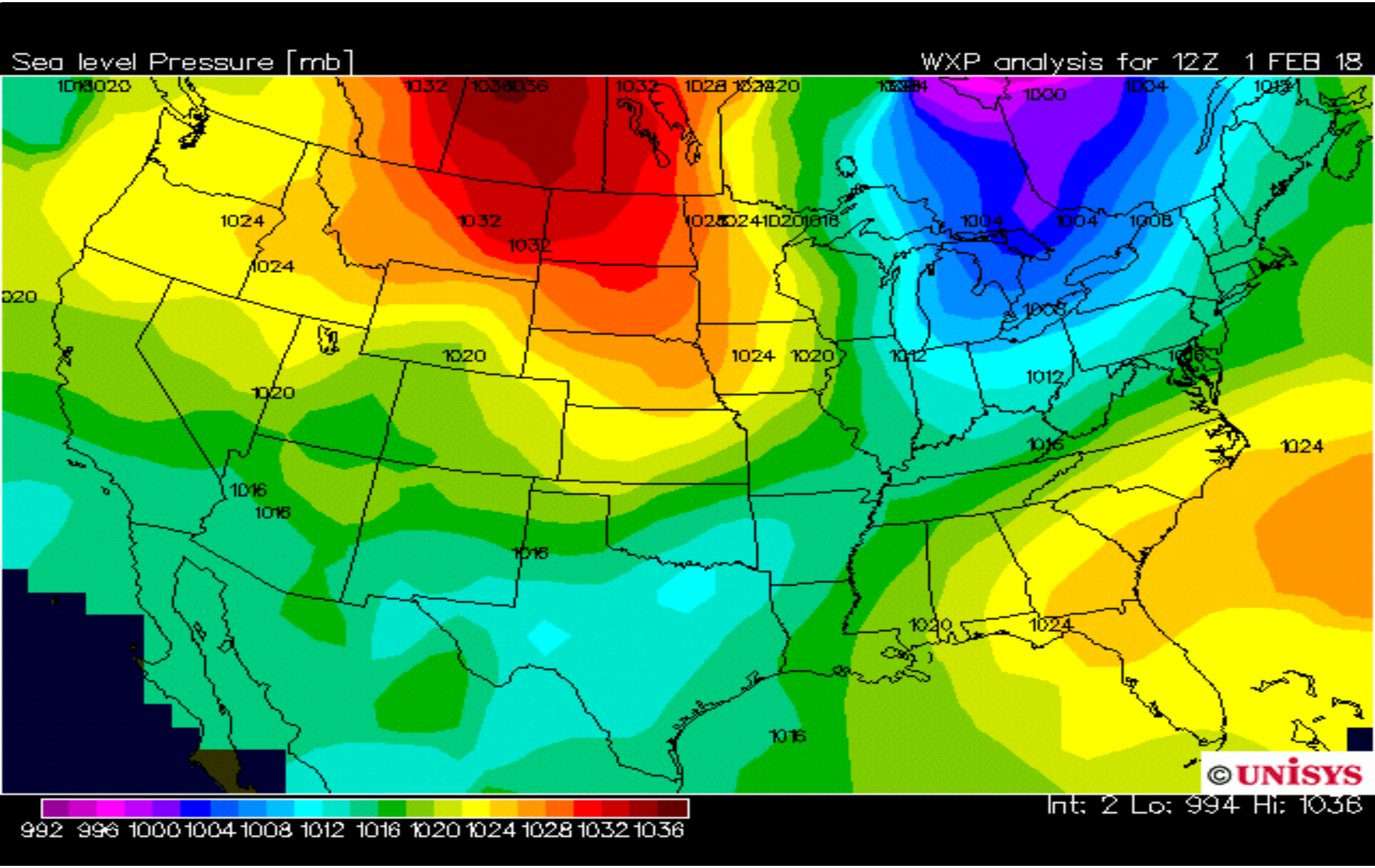
p = 1.013x10^5 Pa = 1013 hPa
= 1013 mb
= 1 atm
= 760 mm Hg (torr)

Molecular view of atmospheric pressure

- Weight of all air molecules is propagated to surface by random motion of molecules
- Random motion of molecules causes pressure to be applied in all directions



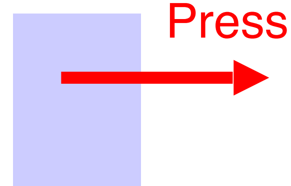
“Sea level” pressure map



weather.unisys.com

Sea-level pressure has narrow range:1013 ± 50 hPa everywhere

Consider a pressure gradient at sea level operating on an elementary air parcel *dxdydz*:

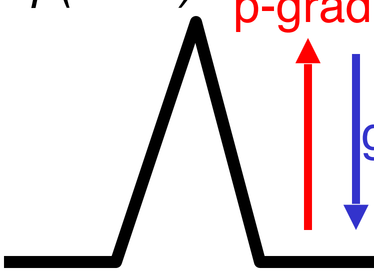


$$dF = (p(x) - p(x+dx))dydz$$

Acceleration $a = -\frac{1}{\rho_a}\frac{dp}{dx}$ where ρ_a is air density

For Δp = 10 hPa over Δx = 100 km, $a \approx 10^{-2}$ m s^{-2} ⇨ 100 km/h wind in 3 h!
Wind transports air to from high to low pressure, decreasing Δp

On mountains, however, the surface pressure is lower, and the pressure-gradient force along the Earth surface is balanced by gravity:



⇨This is why weather maps show “sea level” isobars even over land; the fictitious “sea-level” pressure assumes an air column to be present between the surface and sea level

Total mass m_a of the atmosphere

Radius of Earth: 6380 km

Mean pressure at Earth's surface: 984 hPa

$$m_a = \frac{4\pi R^2 p_{surface}}{g} = 5.13\times 10^{18}\,\mathrm{kg}$$

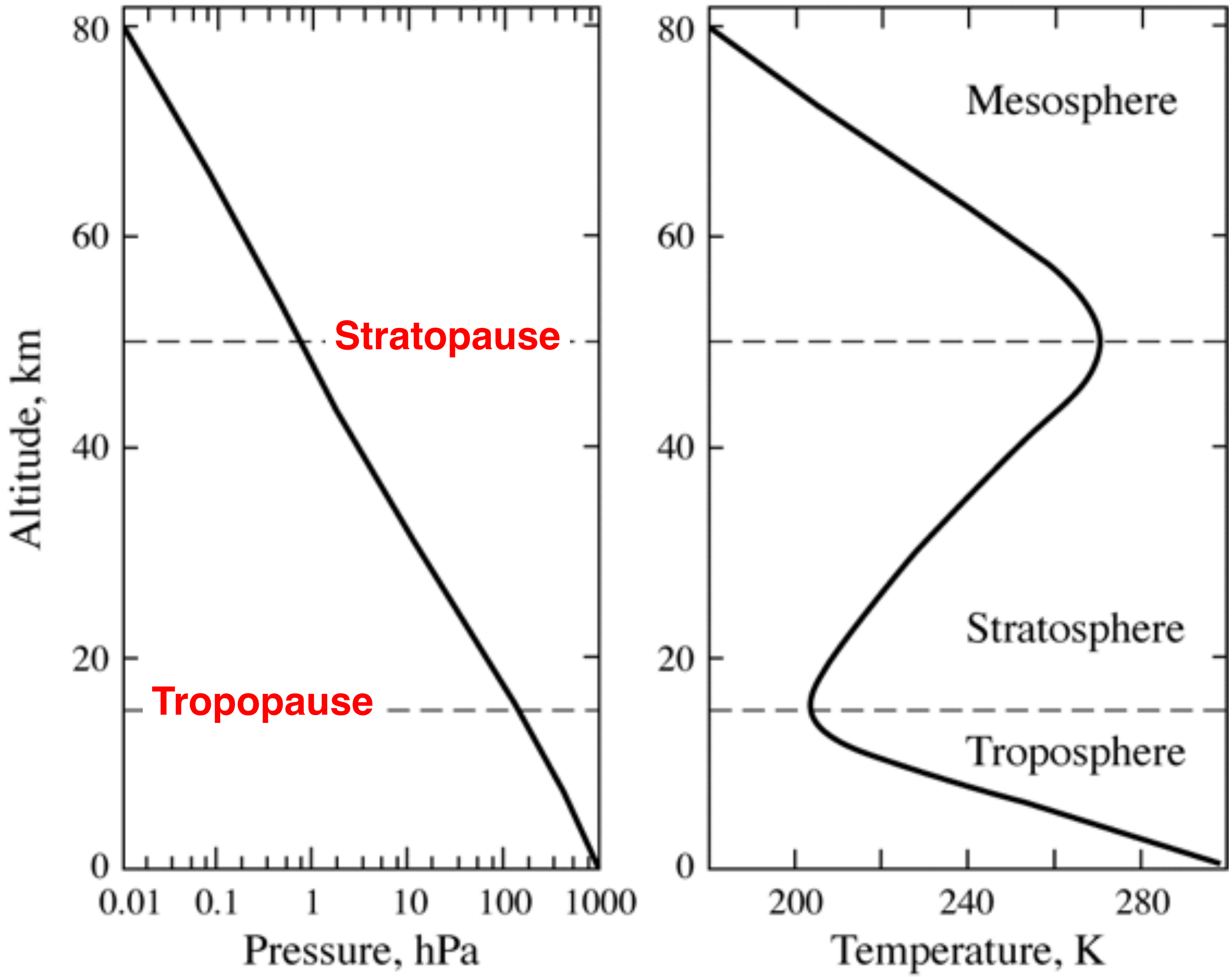
Total number of moles of air in atmosphere:

$$N_a = \frac{m_a}{M_a} = 1.8\times 10^{20}\ \mathrm{moles}$$

Mol. wt. of air: 29 g $mole^{-1}$ = 0.029 kg $mole^{-1}$

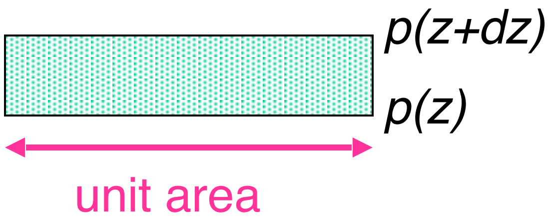
Vertical profiles of pressure and temperature

mean values for 30^{o}N, March



Barometric law describes the decrease of pressure with altitude

- Consider elementary slab of atmosphere:



$$p(z) = p(z+dz) + \rho_a g dz \quad \Rightarrow \quad \boxed{\frac{dp}{dz} = -\rho_a g}$$

hydrostatic equation

Ideal gas law: $\rho_a = \dfrac{pM_a}{RT} \quad \Rightarrow \quad \dfrac{dp}{p} = -\dfrac{M_a g}{RT} dz$

Assume T = constant, integrate:

$$\boxed{p(z) = p(0)e^{-z/H}}$$

with scale height $H = \dfrac{RT}{M_a g} \approx 7.4$ km ($T = 250$ K)

barometric law

$$\boxed{n_a(z) \approx n_a(0)e^{-z/H}}$$

$$p(z+H) = \frac{p(z)}{e}; \qquad p(z+5\text{km}) \approx \frac{p(z)}{2}$$

Application of barometric law: the sea-breeze effect

(a) Initial equilibrium: $T_L = T_S$, $p_L = p_S$

(b) Sun heats land: $T_L > T_S \Rightarrow H_L > H_S \Rightarrow p_L(z) > p_S(z)$:
high-altitude flow from land to sea

(c) High-altitude flow from land to sea $\Rightarrow p_L(0) < p_S(0)$:
surface flow from sea to land

Questions

1. The Badwater Ultramarathon held every July starts from the bottom of Death Valley (100 m below sea level) and finishes at the top of Mt. Whitney (4300 m above sea level). This race is a challenge to the human organism! By what percentage does the oxygen number density decrease between the start and the finish of the race?

2. Why does it take longer to boil an egg in Denver than in Boston?