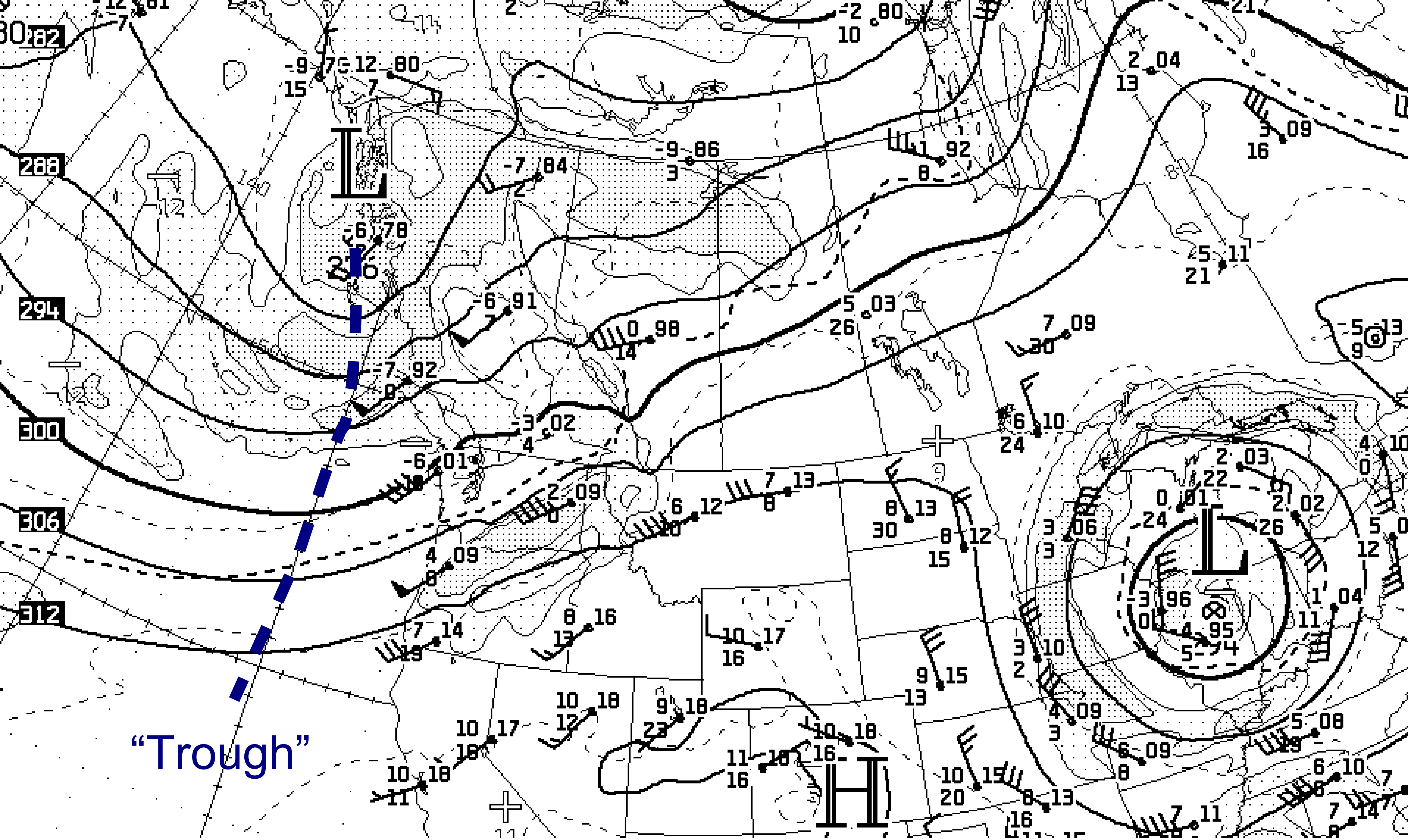
28 Sept., 2011

Complete Ch 3 – still to cover – influences on temperature on larger scales

- A global energy budget and "Earth's Equilibrium Temperature" (Section 3-2, p75)
- Latitudinal variability in net radiative forcing
- Other geographic influences (sea/land, elevation…)

Begin Ch 4 – Atmospheric Pressure and Wind



- solid lines, height contours
- dashed lines isotherms
- heavy stippling, $T - T_d \leq 2^{o}C$
- notice wind blows parallel to the height contours

MSC 700 hPa analysis, valid 12Z Tues 27 Sept. 2011

Why might we consider earth's global climatological temperature T_{eq} to be at equilibrium (Sec. 3-2)?

Because there is a stabilizing feedback. Let ΔT_{eq} be the change in T_{eq} over time interval Δt . Then,

area of earth's shadow

area of earth's surface

$$\frac{\Delta T_{eq}}{\Delta t} \propto \pi R^2 (1-a) S_0 - 4\pi R^2 \epsilon \sigma T_{eq}^4$$

Rate of change $\propto$	gains	minus	losses

R is earth's radius, S_0 is the solar constant, *a* (=0.3) is the planetary albedo, ε (≈1) is the planetary emissivity and σ is the Stefan-Boltzmann constant. The proportionality constant involves the heat capacity of the earth-atmosphere system. (In reality *a*,ε may depend on T_{eq}).

At earth's (hypothetical) equilibrium temperature, there is balance:

Both sides of the equation are zero, thus setting the right hand side to zero

$$C\,\frac{\Delta T_{eq}}{\Delta t} = 0 \propto \pi R^2 (1-a) S_0 - 4\pi R^2 \epsilon \sigma T_{eq}^4$$

Common factors cancel

Set *a* =0.3 and ε=*1* to obtain earth's (radiative) equilibrium temperature (Sec. 3-2),

T_{eq} = 255 K

(However this entirely neglects the effect of the atmosphere – true global-annual mean surface temperature is about 288 K)

Latitudinal variation in annual net radiation on local unit area of horizontal surface

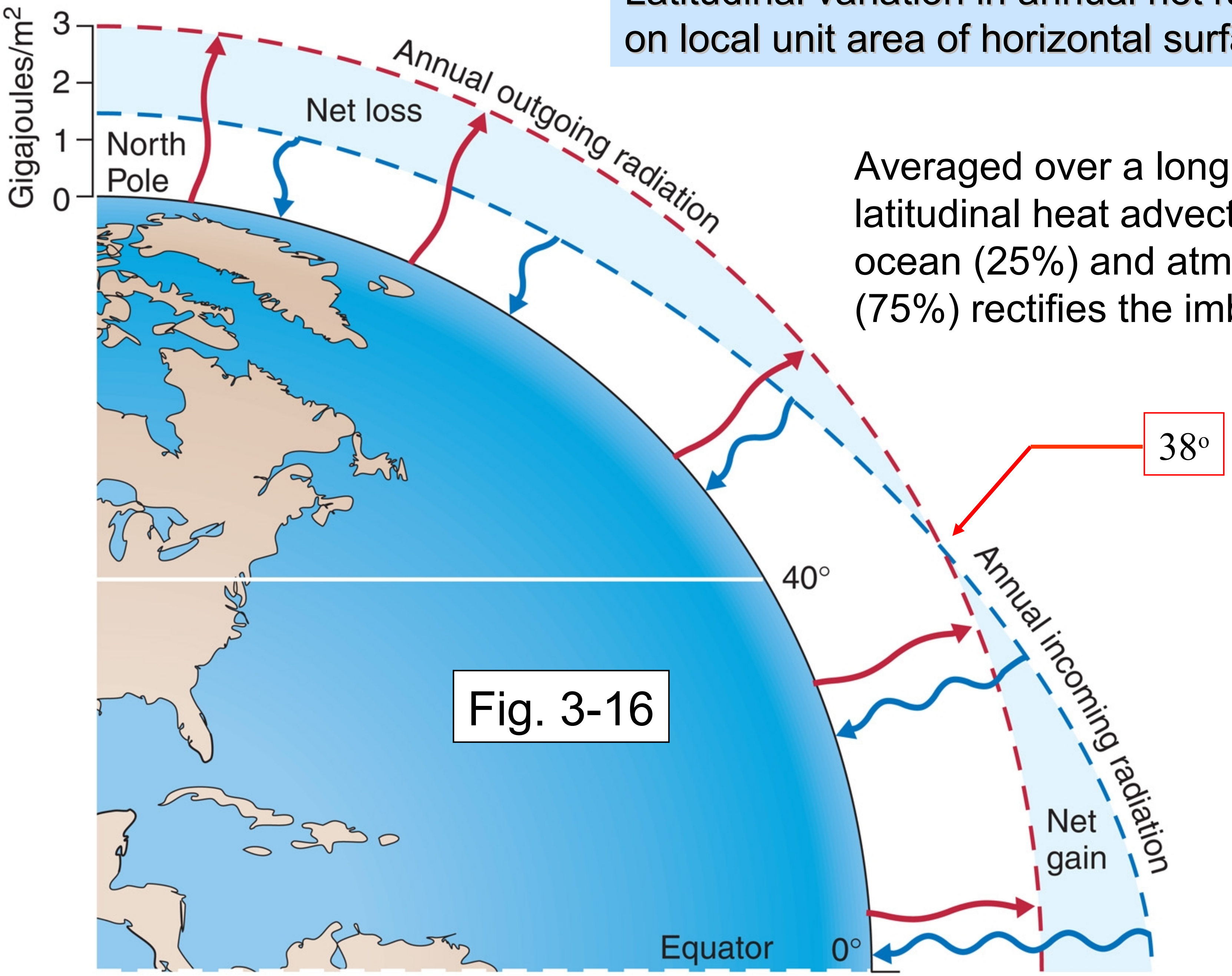


Fig. 3-16

Averaged over a long period, latitudinal heat advection by ocean (25%) and atmosphere (75%) rectifies the imbalance

Global Temperature Distribution – factors controlling temperature on regional & global time & space scales

- Latitude – modulates solar radiation (solar elev., daylength)
- Distribution of land & water – ocean currents advect heat**

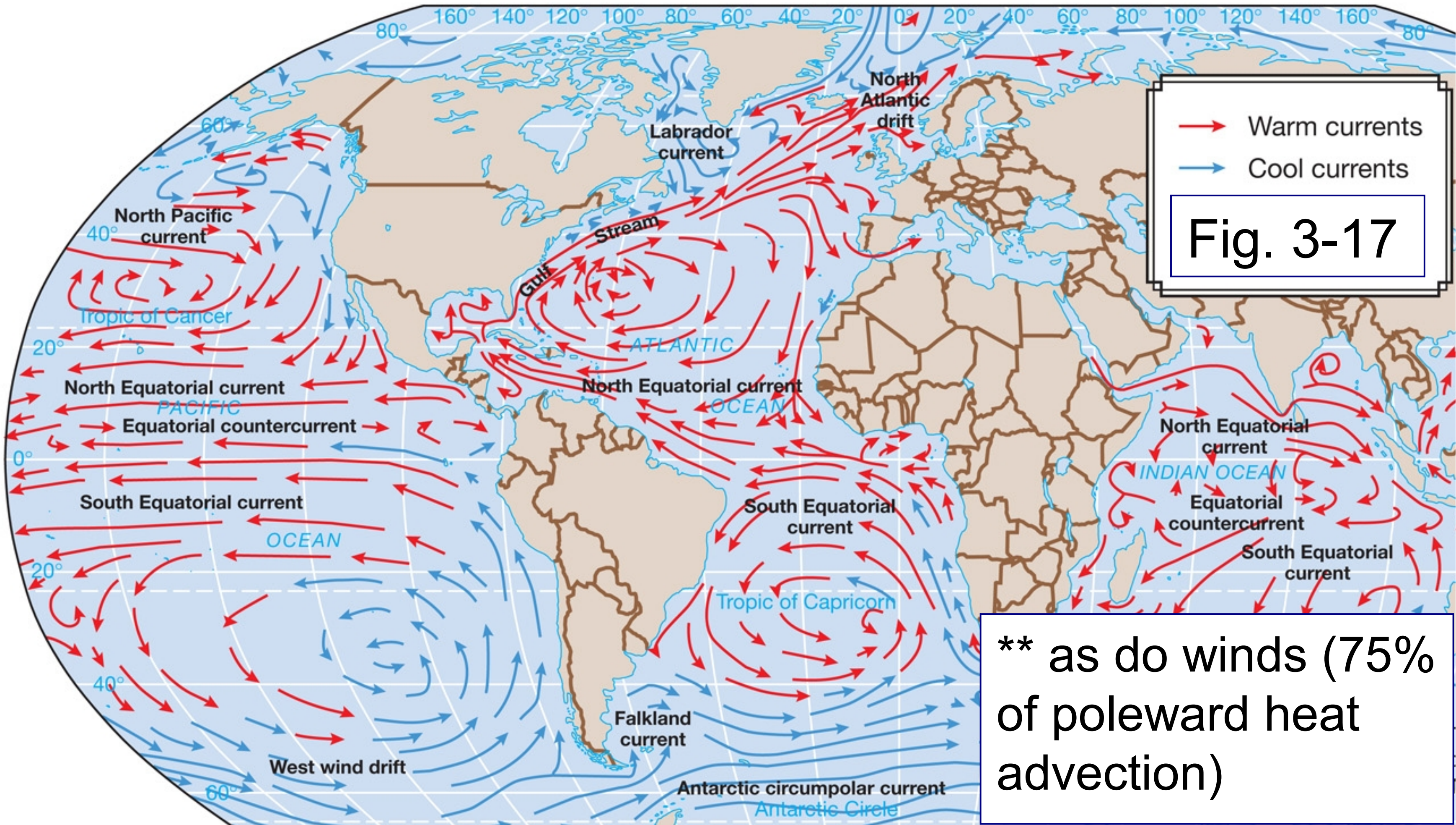


Fig. 3-17

** as do winds (75% of poleward heat advection)

Global Temperature Distribution – factors controlling temperature on regional & global time & space scales

- Distribution of land & water
  - surface thermal inertia, surface energy balance

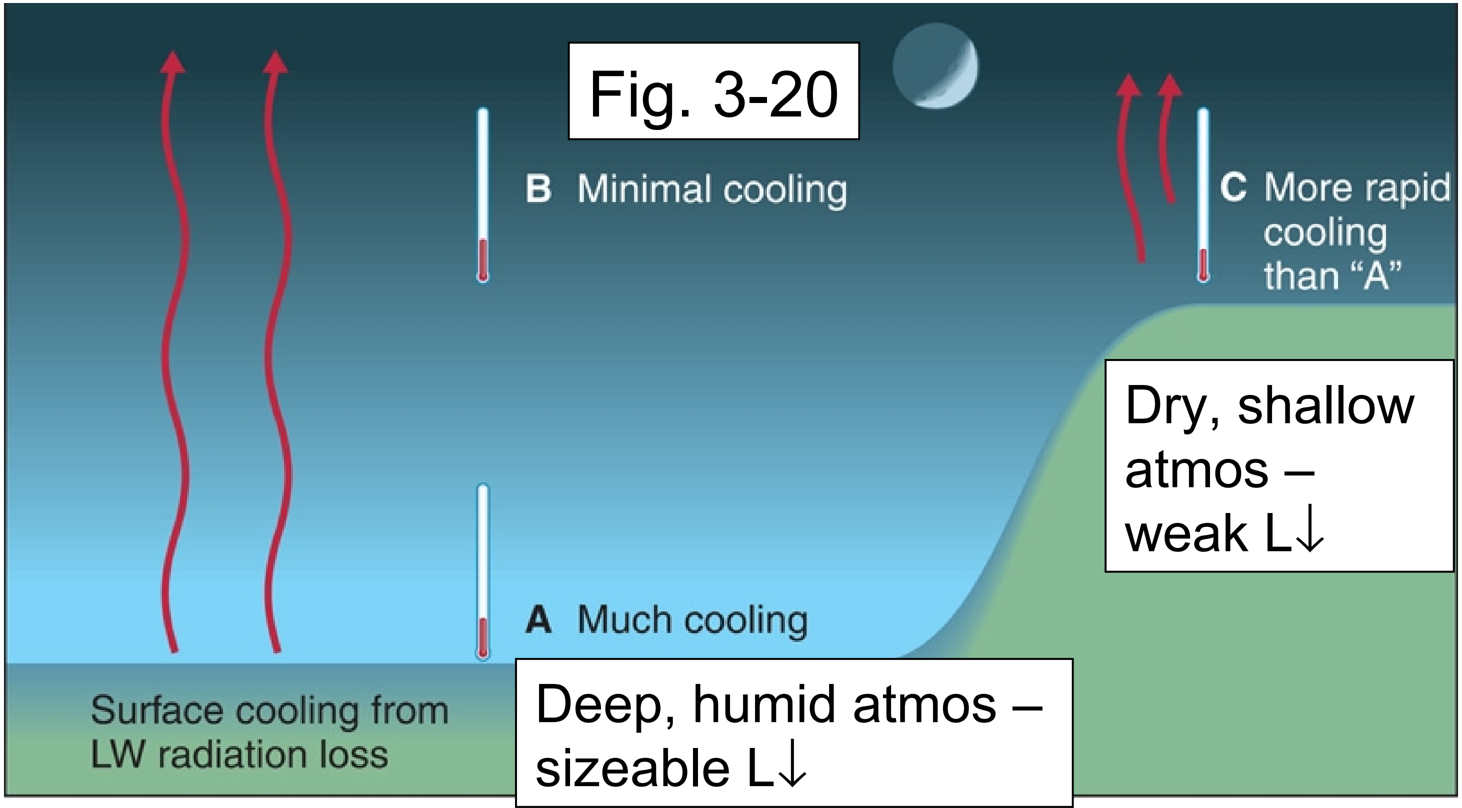
Why are water bodies "more conservative" (p78) in their temperature?

- solar radiation penetrates to some depth, so warms a volume
- much of available radiant energy used to evaporate water (Q_E)
- mixing of the water in the ocean/lake "mixed layer" ensures heat is deposited/drawn from a deep layer
- water has a higher specific heat capacity (4128 J kg^{-1} K^{-1}) than unsaturated soils (e.g. soil minerals ~ 1000 J kg^{-1} K^{-1})

Global Temperature Distribution – factors controlling temperature on regional & global time & space scales

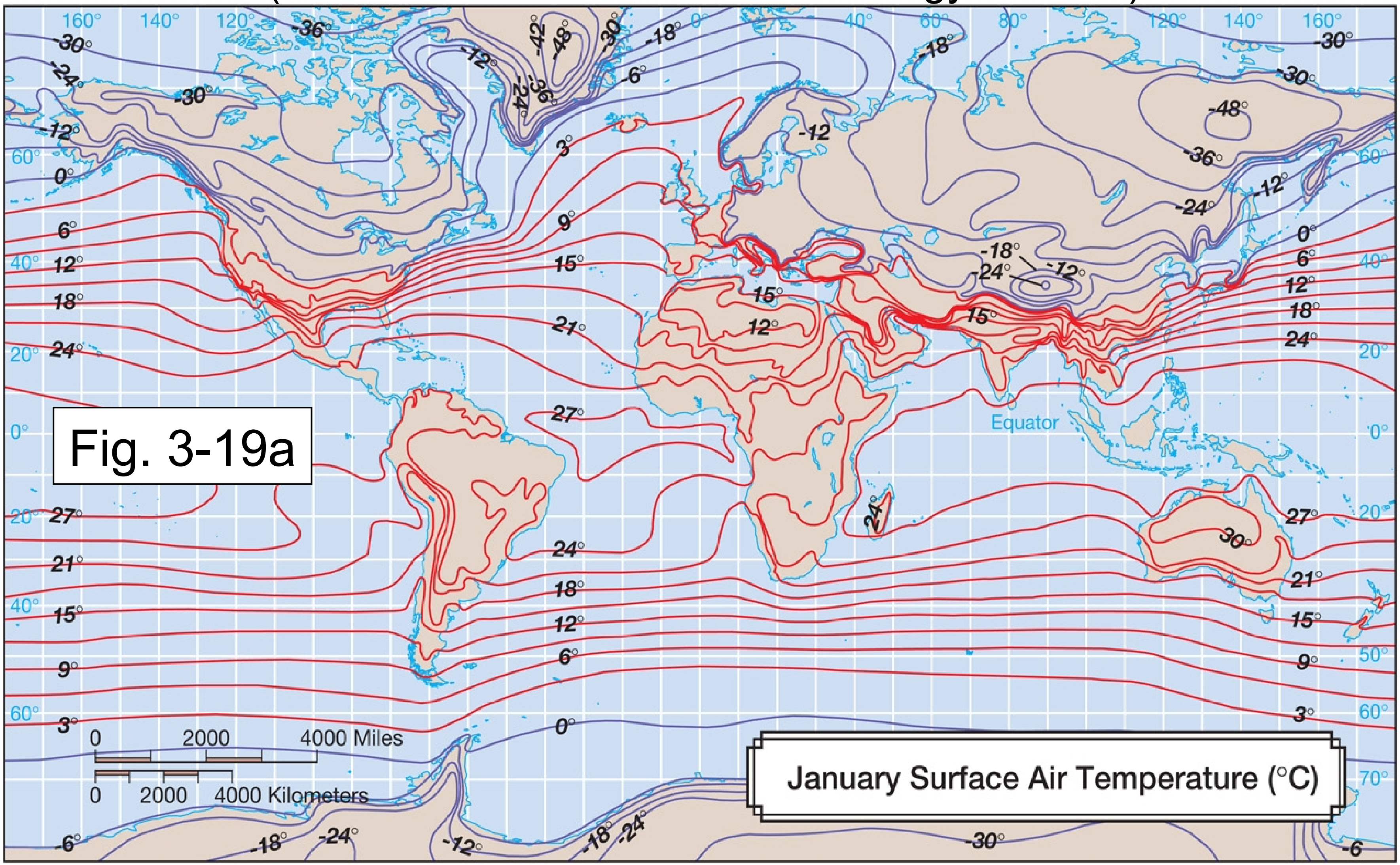
- Distribution of land & water
  - Topographic steering/blockage of winds
    e.g. isolation of winter continental interior from warmer ocean by intervening mountain range blocking advection by wind; mountain range extracts precipitation (rain shadow)… etc.

- Elevation & slope of terrain



- latitudinal temperature gradient is strongest in the winter hemisphere (during high lat. summer the lower midday sun is offset by long daylength)

- in summer (winter) temperature over continent is warmer (cooler) than over ocean (influence of latent heat flux in energy balance)



• northern hemisphere has a steeper winter latitudinal temperature gradient than the southern hemisphere (much greater proportion of ocean than land)

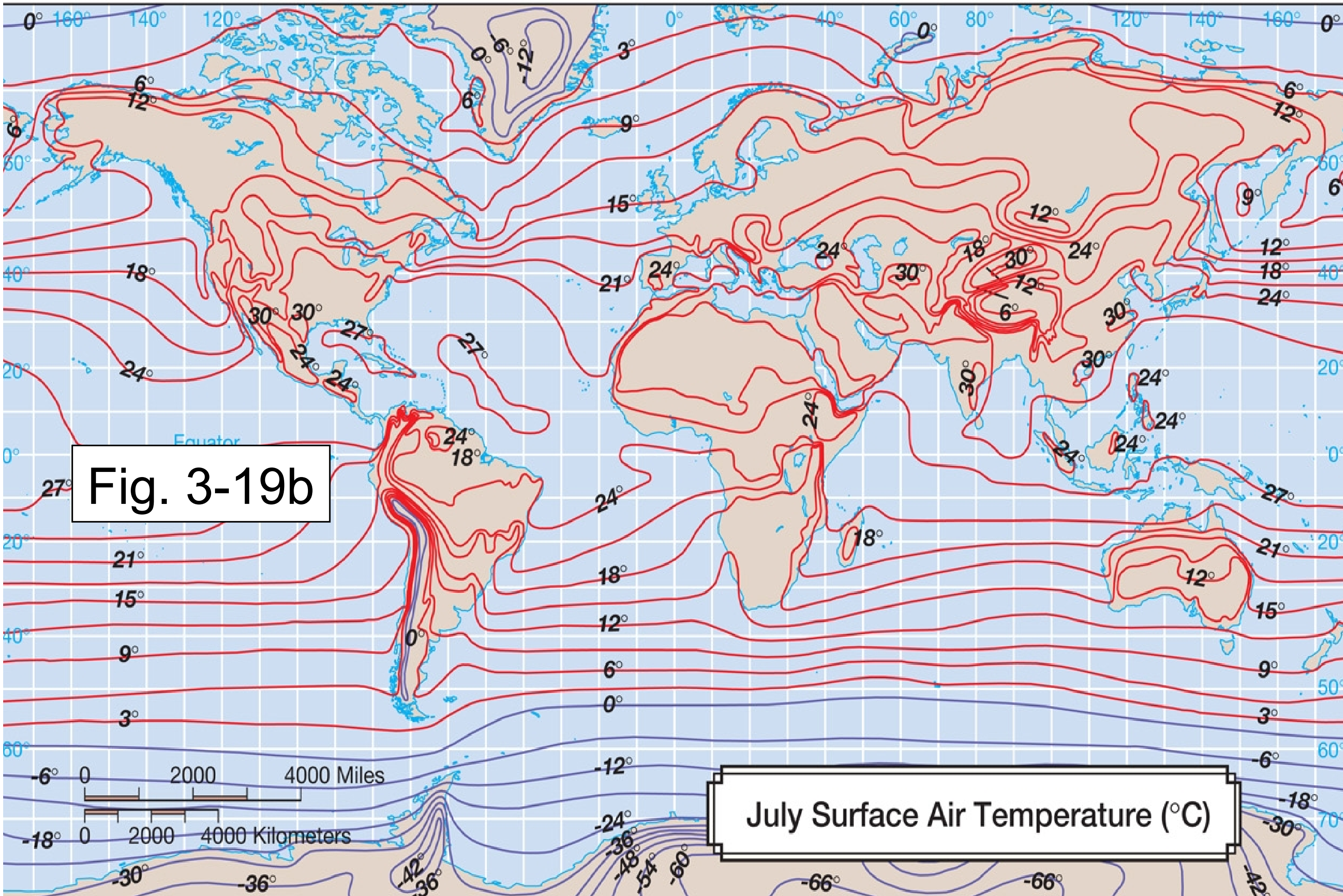
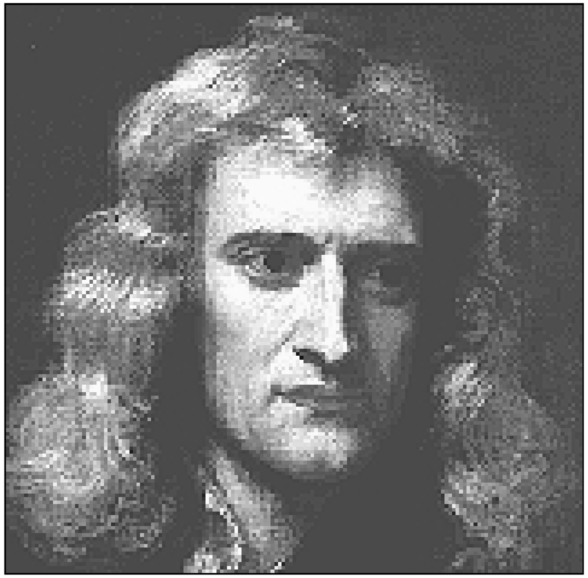


Fig. 3-19b

Ch. 4 Atmospheric Pressure and Wind

• we've covered some concepts from Ch4 already – e.g. definition and units of pressure, the cause of its height variation, its control over wind

• now we need a more quantitative view of the statics and the dynamics (forces and their balance) of the atmosphere. (Setup for Assignment 1)



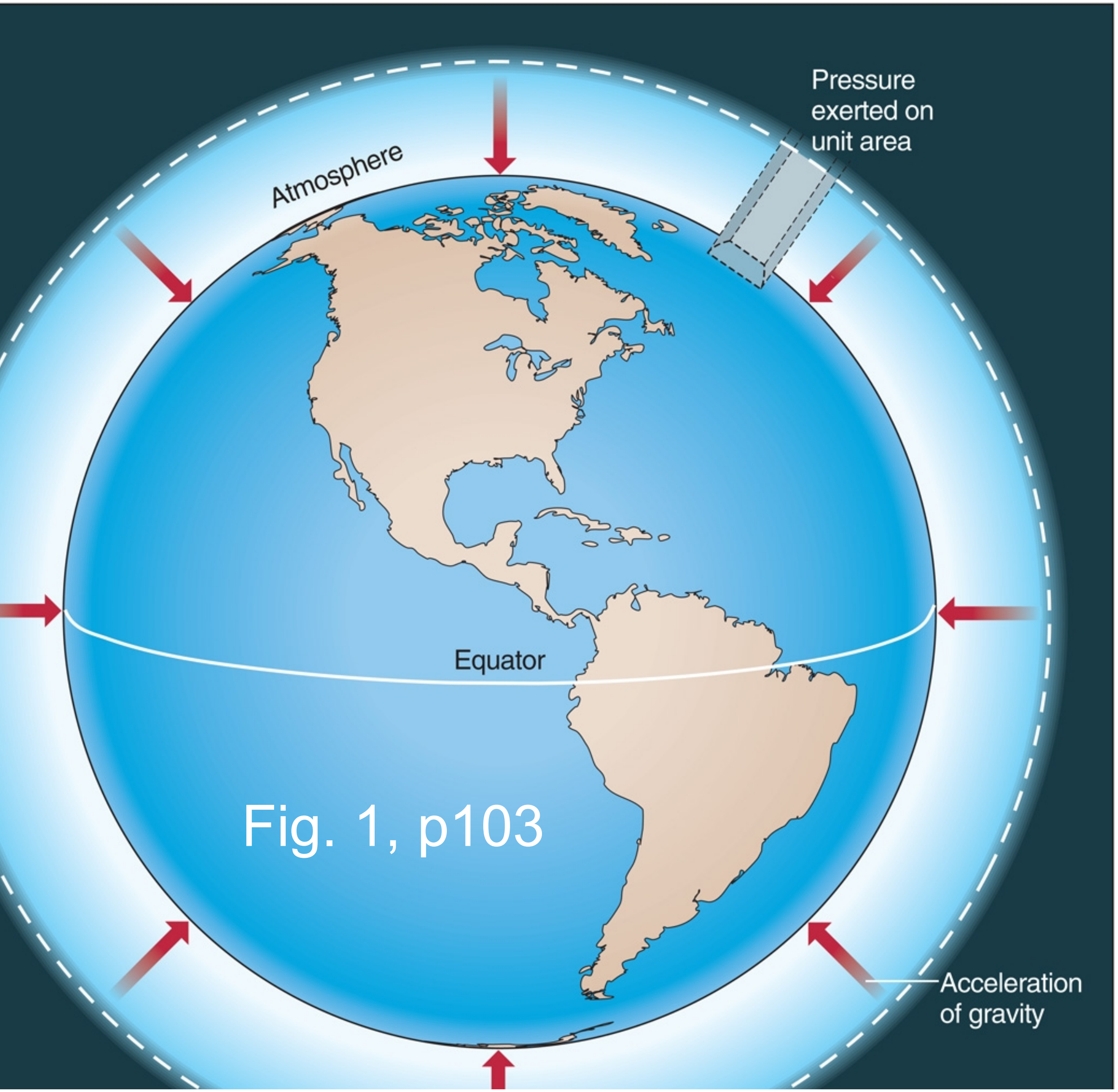
Sir Isaac Newton
1642 - 1727

• we'll begin by looking in more detail at hydrostatic pressure variation in the vertical

• next focus on *horizontal* pressure gradients and learn to think instead of the corresponding "height gradients"

• then cover the theoretical relationship between wind speed and the height gradient

In the macroscopic view, pressure at the base of a static air column is controlled by overlying mass



$$p = \frac{M\ g}{A}$$

- But simultaneously,there is a valid microscopic view – the pressure at every point is related to the temperature and density at that point...

The Equation of State (ideal gas law, p105)

$$p = \rho \; R \; T$$

p , pressure [Pa]

ρ , density [kg m^{-3}]

R , 287 [J kg^{-1} K^{-1}] , specific gas const. for dry air

T , temperature [K]

Convert pressure to Pascals and temperature to Kelvin, for use in this equation

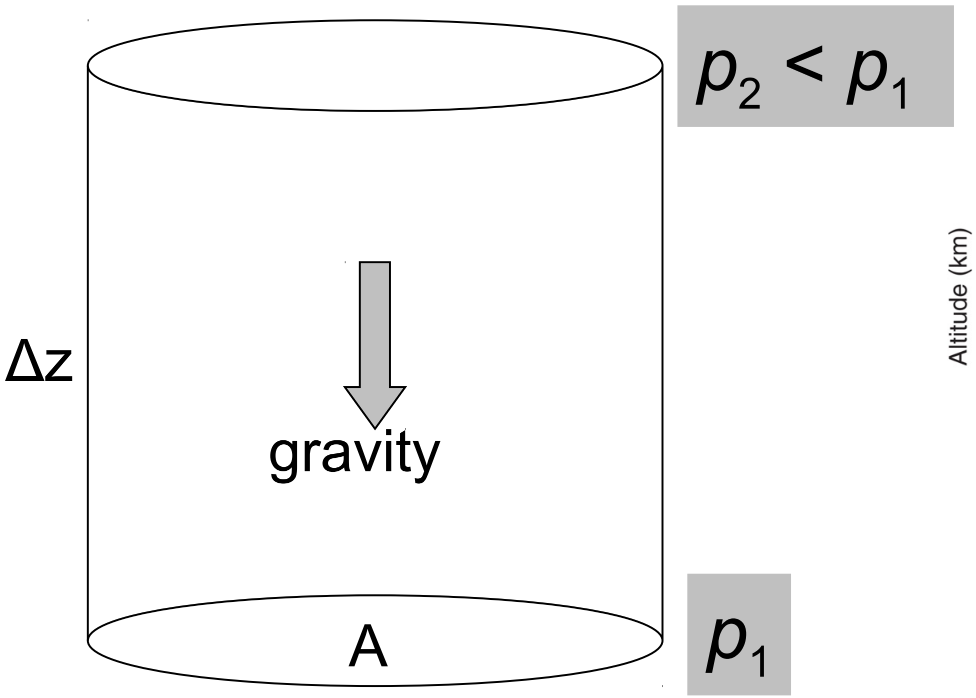
Question: these paragliders are flying at a height of 1000 m above sea-level. A pilot's instrument reports

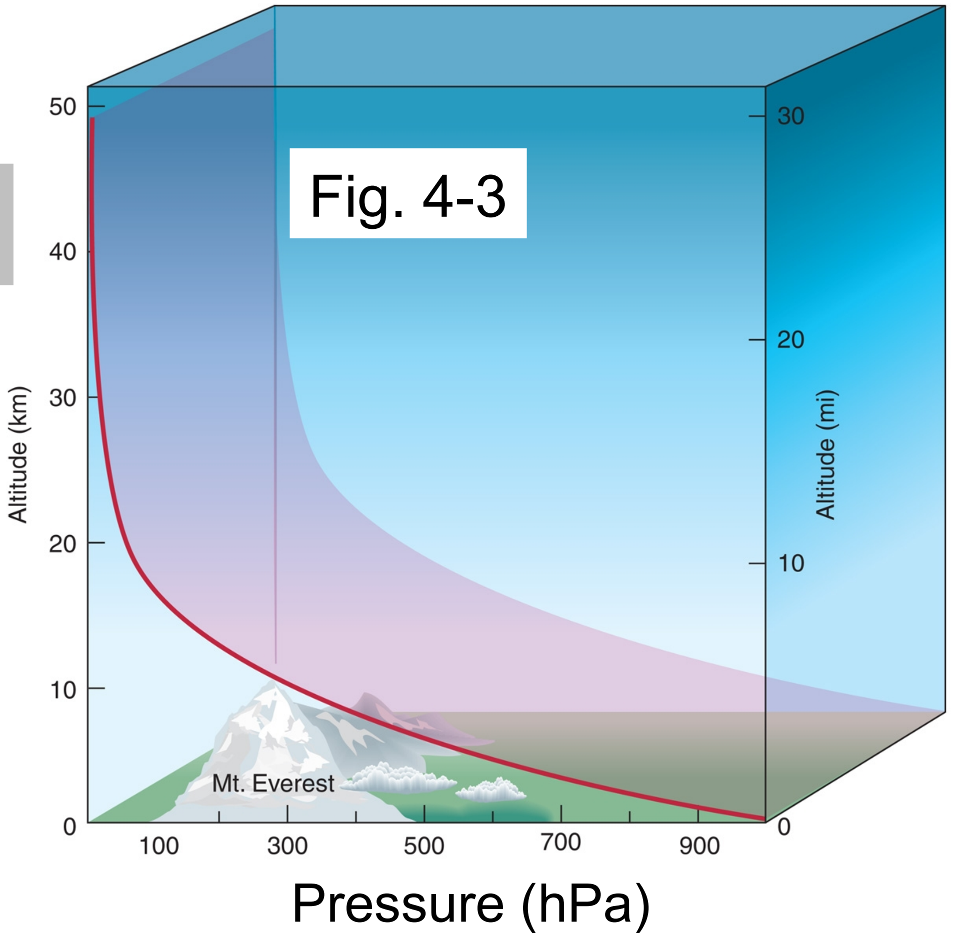
$$p = 900[\text{hPa}],$$
$$T = 25[^\circ\text{C}].$$

The air density at flight level is?

$$\rho = \frac{p}{R\ T} = \frac{90000}{287\,x\,(273.15+25)} =$$

Local hydrostatic equilibrium (Sec. 4-3, p112)





- gravity pulls down
- pressure pushes up harder than down
- introducing area A and depth Δz of column, result of a force balance is:

The hydrostatic equation (Sec. 4-3, p112)

Gives the change in pressure (Δp) associated with an increase (Δz) in height

$$\frac{\Delta p}{\Delta z} = -\rho g \quad \left[\frac{Pa}{m} \text{ or } Pa \; m^{-1} \right]$$

ρ = air density [kg m^{-3}] (approximately 1, near ground)
g = grav. accel'n = 9.81 [m s^{-2}] (approximately 10)

Thus: near ground, pressure increases by an amount Δp = - 10 Pa for each 1 m increase in height

100 Pa (= 1 hPa)	per 10m
100 hPa	per 1 km

Question: if those paragliders descend 100 m, estimate the pressure at their new flight level:

p_1, T_1 (known) $\rightarrow$ p_2, T_2

$p_1 = 900$ hPa,
$T_1 = 25°C$

Importance of the hydrostatic equation:

• although the atmosphere obviously is not static, it turns out that in the real atmosphere variation of pressure with height is closely approximated by the hydrostatic equation – particularly if we consider the pressure (and related properties) to have been averaged on horizontal planes over areas of order 100 km x 100 km (the "synoptic scale" view). Most Numerical Weather Prediction (NWP) models and all Dynamical Climate models (GCM's) treat the pressure distribution as hydrostatic – a big simplification to the vertical force balance

• next, as a precursor to considering the balance of horizontal forces, let's consider horizontal pressure gradients... their cause, and their representation as "height gradients"