Today:

- first look at an "upper-air" map (in relation to Thurs./Fri. weather)
- main atmos. gases
- logic for recognising "constant" vs. variable gases
- terminology of biogeochem. budget
- nitrogen cycle

** the term "constant gas" (sometimes, "permanent gas") assumes one has averaged over a period long enough to smooth out small variations implicit in the existenc eof biogeochem. cycle

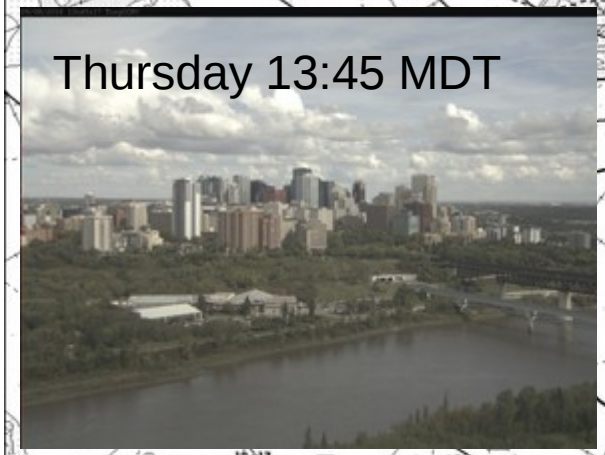
** water vapour is the *most* variable (spatially and temporally) of the common gaseous components (from 0% to about 4%, locally), because of its participation in the geographically and seasonally varying hydrologic cycle

TABLE 2.1 | The composition of Earth's atmosphere.

Constant Gases **	Per Cent of Dry Air by Volume	
Nitrogen (N_2)	78.08	78%
Oxygen (O_2)	20.95	21%
Argon (Ar)	0.93	1%
Neon (Ne)	0.00182	
Helium (He)	0.00052	
Hydrogen (H_2)	0.00006	
Variable Gases		
Water Vapour (H_2O) **	0.25	on avrg.
Carbon Dioxide (CO_2)	0.039	390 ppm
Methane (CH_4)	0.0002	2 ppm
Nitrous Oxide (N_2O)	0.00003	
Carbon Monoxide (CO)	0.000009	
Ozone (O_3)	0.000004	
Chlorofluorocarbons (cfcs)	0.00000002	

- weak wind, high humidity over C. Alberta
- compare with Fig 15.18
- wind blowing parallel to height contours
- $\text{speed} \propto \frac{1}{\text{contour spacing}}$

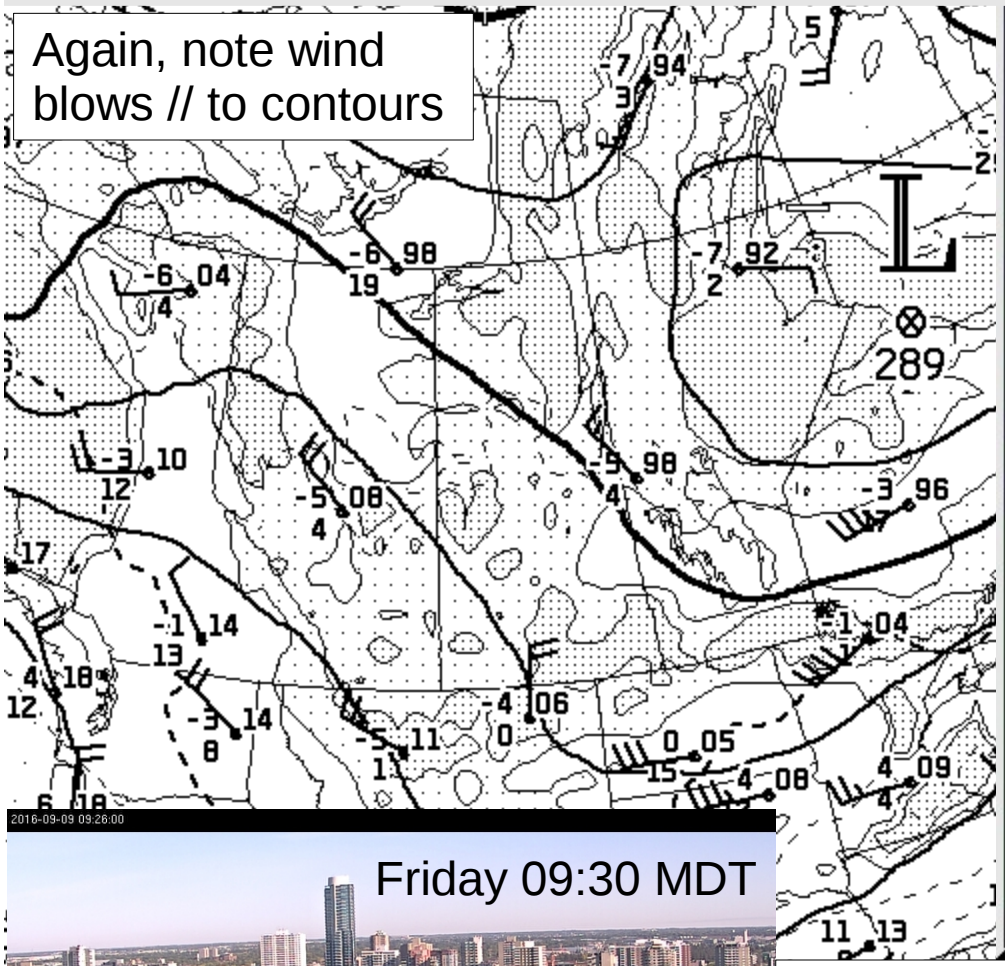
- lines are iso-lines of the height of the 700 hPa surface ("height contours")
- roughly 300 dam (=3000 m) above sea level
- shading represents moist air (dew point depression, $T - T_D$)

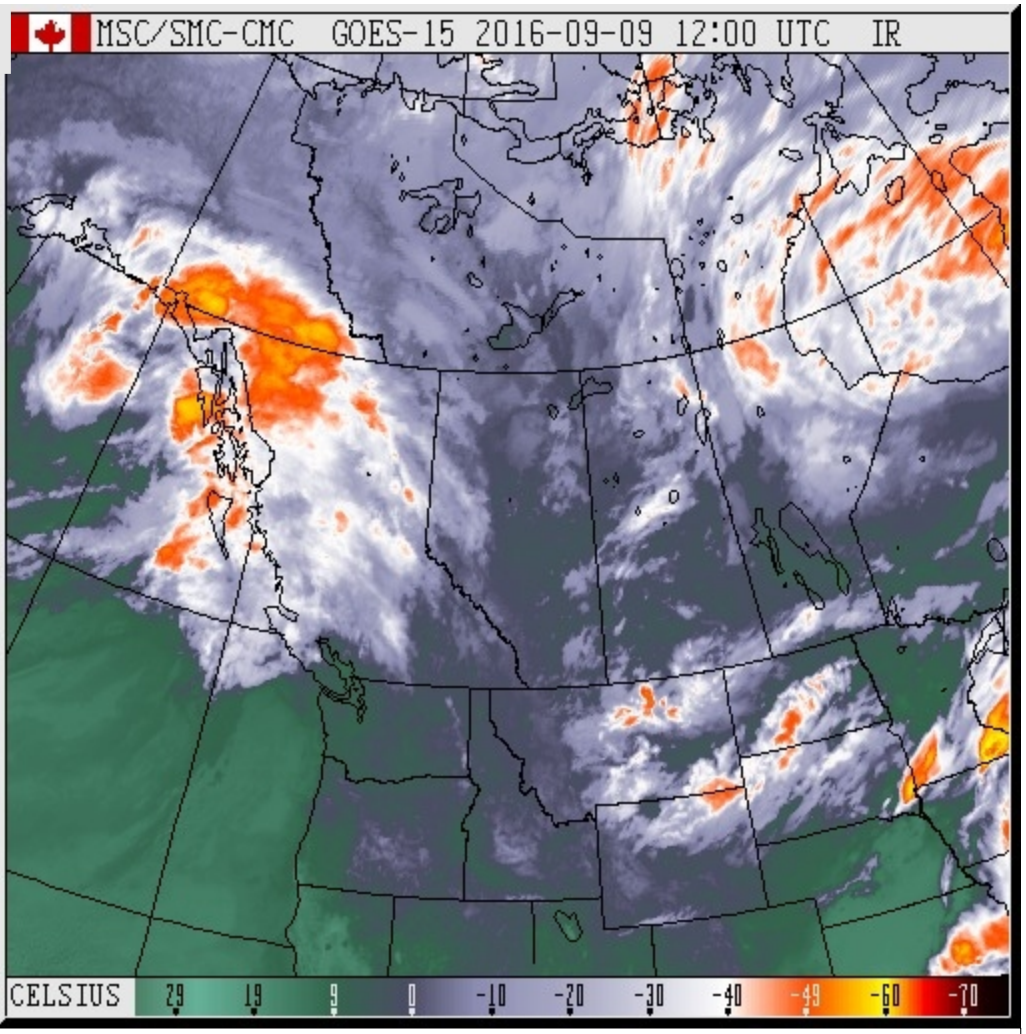


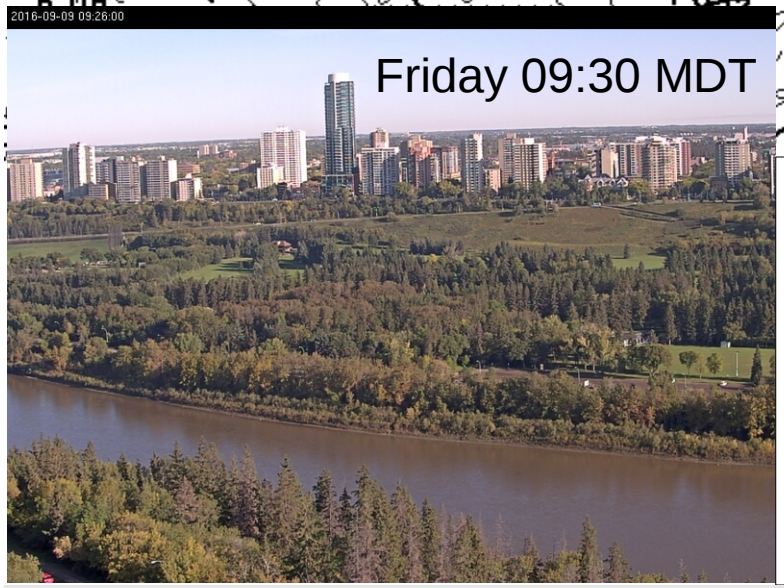
slack flow

ANALYSIS ANALYSE
12Z THU-JEU 08 SEP-SEP 16
700 hPa GEM HEIGHT-HAUTEUR TEMPERATURE T-TD
REGIONAL
HEIGHT - HAUTEUR ⊗ H L ...294, 300, 306... dam
TEMPERATURE -5, 0, 5... C
T-TD (C)
≤ 2 ≤ 5

CMC 700 hPa analysis 12Z Friday 9 Sept. 2016







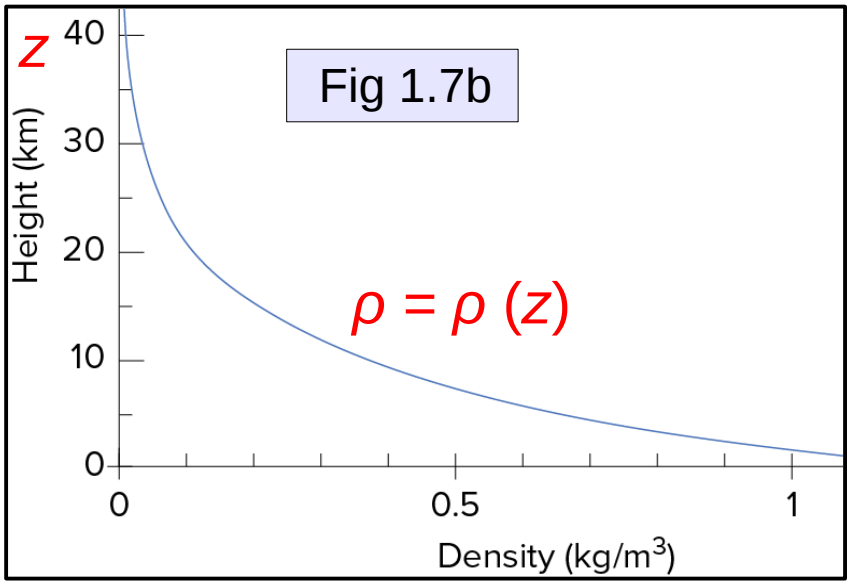
5:00 AM MDT Friday 9 Sept. 2016. Edmonton, today: Mainly sunny. Increasing cloudiness this afternoon.

- makes sense: presently dry (clear) aloft, but upper winds will "advect" (blow) humid (& cloudy) air onto C. Alberta?

- troposphere & stratosphere lie within the "homosphere"

- while proportions of the "constant" gases can (for most purposes) be treated as unvarying in the homosphere, their "partial densities" (mass per unit volume) decrease with height *z*, just like the total density

$$\rho = \rho_{N2} + \rho_{O2} + \rho_{Ar} + \ldots$$



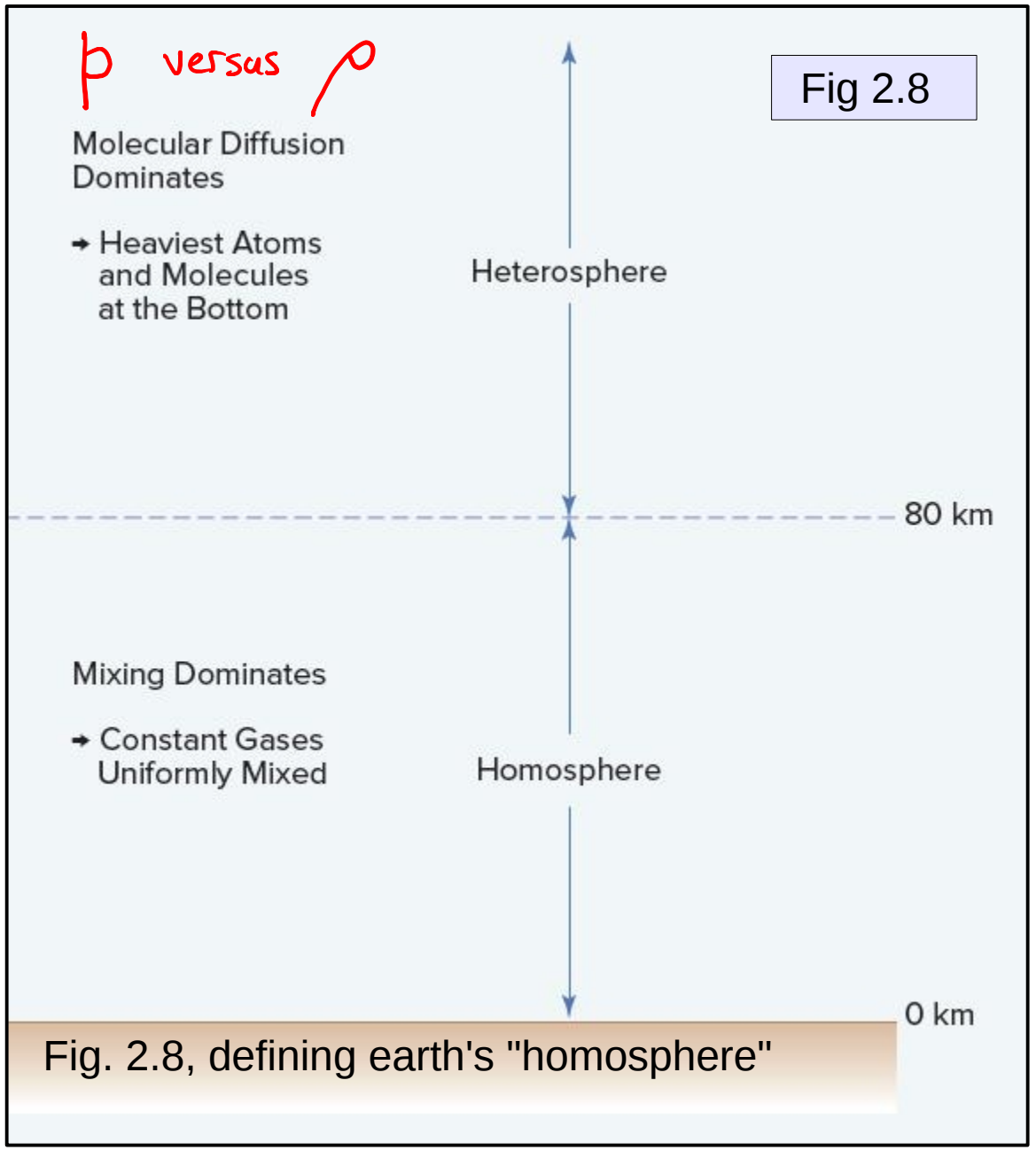
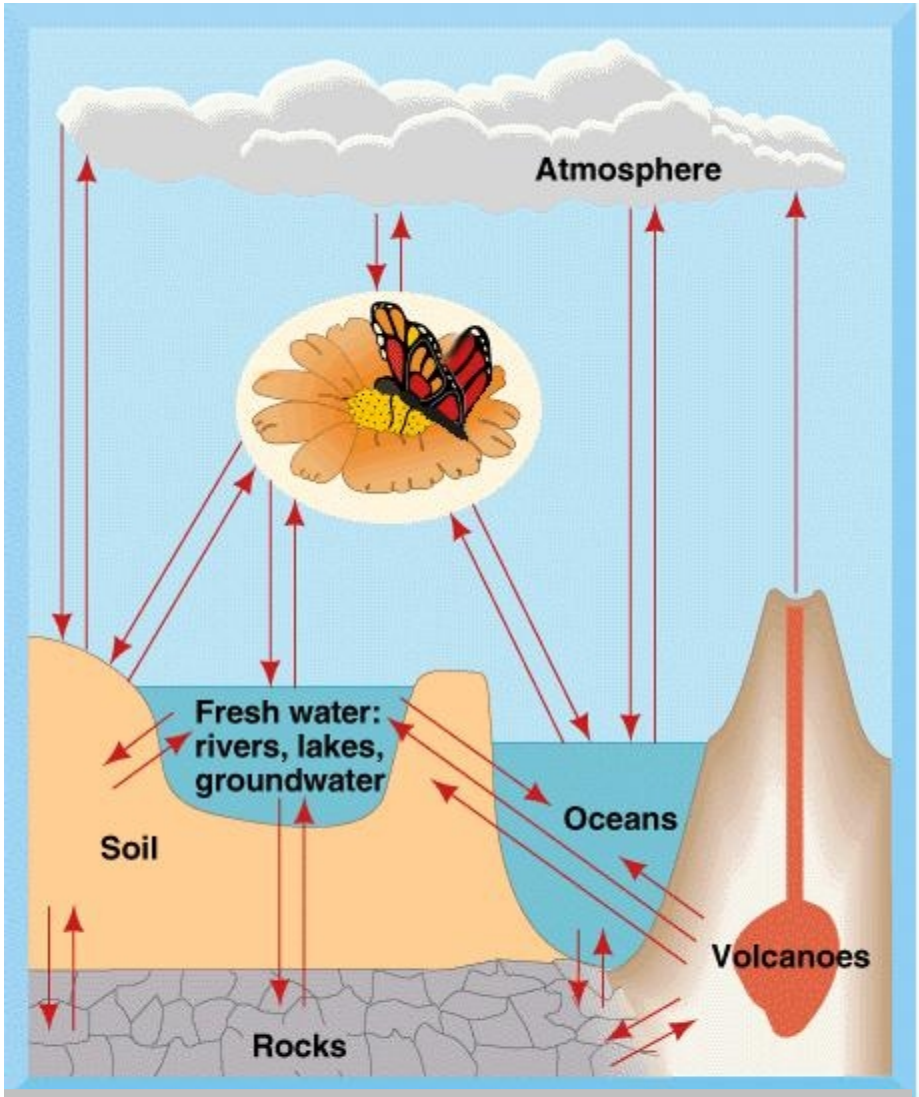


Fig. 2.8, defining earth's "homosphere"



www.colorado.edu/GeolSci/courses/GEOL1070/chap04/chapter4.html

Biogeochemical budgets:

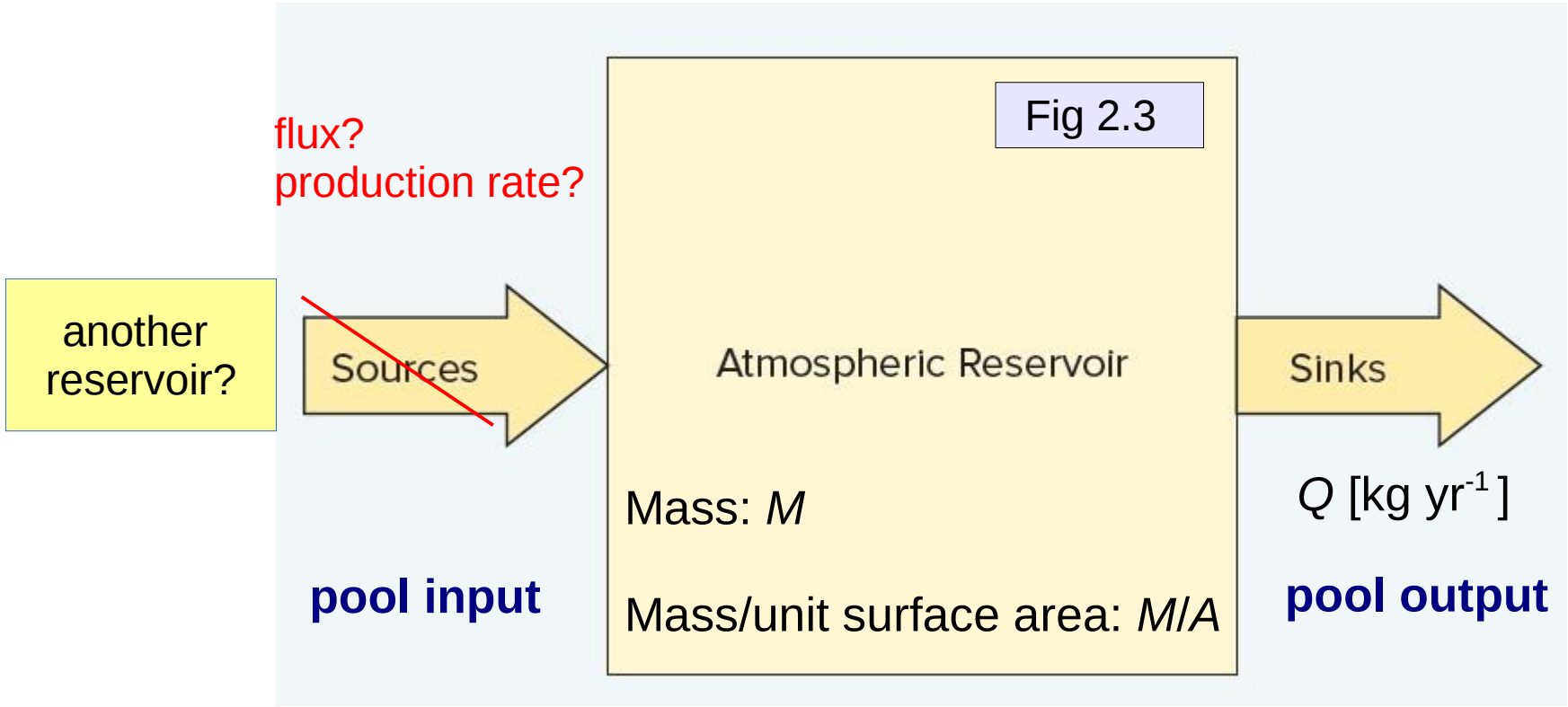
- Terminology:
  - reservoirs ("pools"), which may serve as "sources" and "sinks" for other reservoirs
  - interchanges (transport flows , "fluxes") to/from/between reservoirs
  - transformations (e.g. chem. reactions)
- must choose time scale & spatial volume for budget (e.g. annual, global vs. hourly, local)
- contemporary Global Climate Models ("Earth system models") incorporate biogeochem budgets for key gases

e.g. ocean reservoir stores carbon in organic and inorganic forms; functions as a "sink" for atmos. CO_2

Classification of a gas as "constant" or "variable" is related to its "residence time" –

$$\tau[\mathrm{yr}] = \frac{\text{Mass in pool}}{\text{Flux through pool}} = \frac{M}{Q} = \frac{M/A}{Q/A}$$

Eq 2.2



Definition of the residence time invokes an assumption of **steady state**: flux into reservoir = flux out of reservoir. That is, one treats pool input rate as equal to pool output rate, so that mass in the pool is static. Then *Q* is the flow (or "flux") *through* the pool.

Surface pressure: $$P_0\ [\mathrm{Pa}] = \frac{F}{A}\left[\frac{\mathrm{N}}{\mathrm{m}^2}\right] = \frac{M\ g}{A} = (M/A)\ g \approx 10^5$$

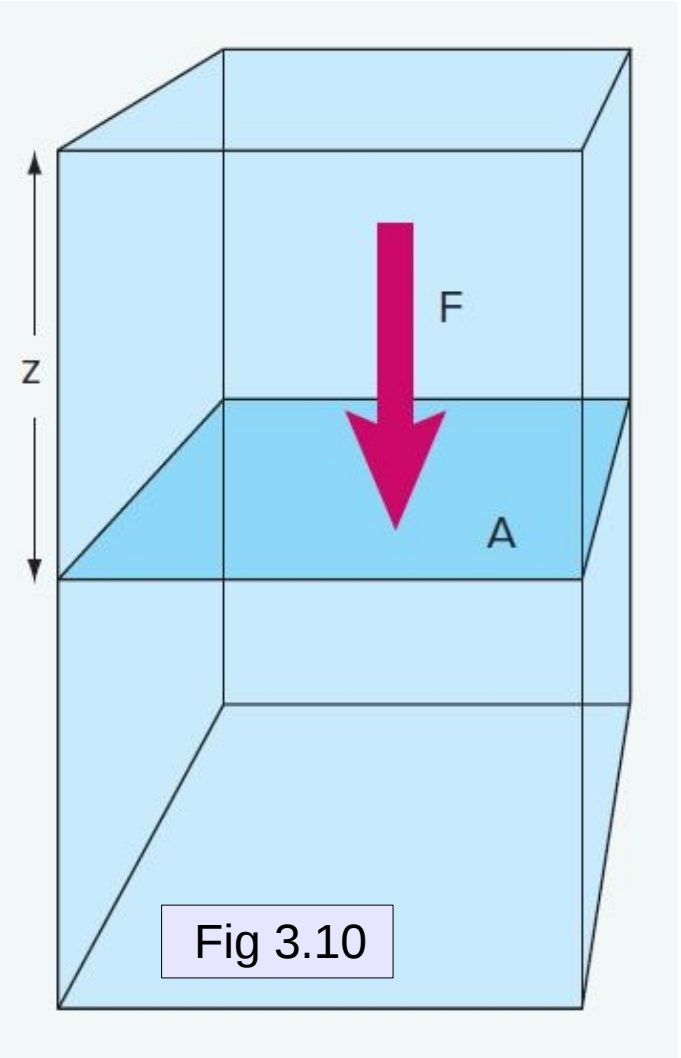


Fig 3.10

Mass: *M* Area: *A* Mass/unit surface area: *M*/*A*

- We conclude $\frac{M}{A} \approx 10^4\ \mathrm{kg\ m^{-2}}$
- Surface area of whole earth (mean radius *R*=6371 km)

$$A = 4\pi R^2 \simeq 5.1 \times 10^{14}\ \mathrm{m^2}$$

- Total mass of atmosphere (inferred from sfc pressure)

$$M \approx \frac{M}{A} \times A = 10^4 \times 5.1 \times 10^{14} \simeq 5 \times 10^{18}\ \mathrm{kg}$$

- Total mass of N_2?

$$M_{N_2} \approx 0.78\ M \simeq 4 \times 10^{18}\ \mathrm{kg}$$

- Given that (as just computed) $M_{N_2} \approx 4 \times 10^{18}\ [\text{kg}] = 4 \times 10^{9}$ million metric tons

  and given also that $\tau_{N_2} = 16 \times 10^{6}\ [\text{yr}]$ AND $\tau = \frac{M}{Q}$

  (mis-stated by Table 2.2)

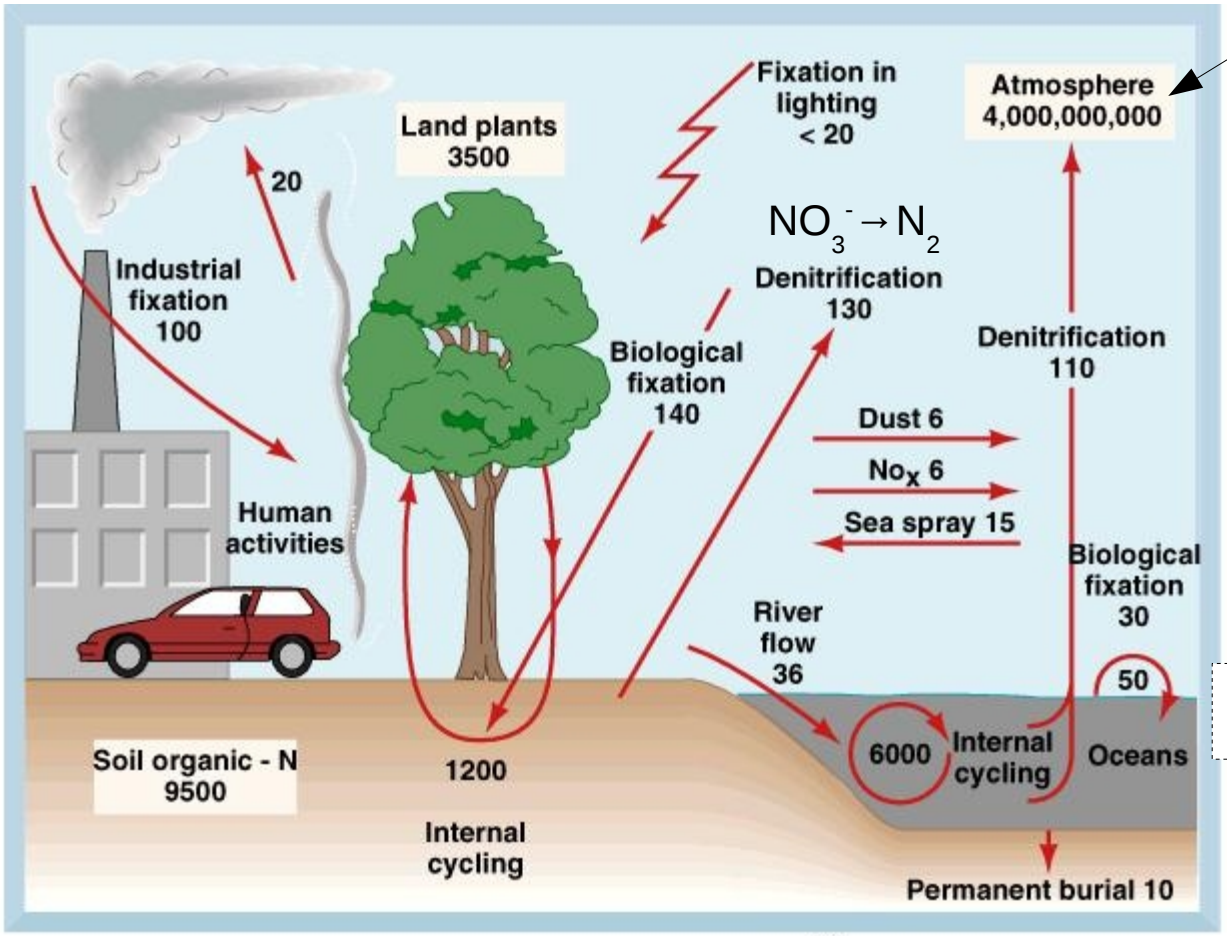
- we infer:

$$Q_{N_2} \approx 2.5 \times 10^{11}\ [\text{kg yr}^{-1}]$$

- and since sfc area of the earth A = 5.1 x 10^{14} m^2

$$\left[\frac{Q}{A}\right]_{N_2} \approx 5 \times 10^{-4}\ [\text{kg m}^{-2}\text{yr}^{-1}]$$

$$\left[\frac{Q}{A}\right]_{N_2} \approx 0.5\ [\text{g m}^{-2}\text{yr}^{-1}]$$



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Consistent with our previous calculation?

At 1.2 x 10^{12} kg/yr, the annual soil/plant "internal cycle" – uptake from soil by growing plants, leaf fall/decay – greatly exceeds net (aggregate) flux

$$\frac{Q}{A} = \frac{1.2 \times 10^{12}}{5.1 \times 10^{14}} \approx 2 \ [\mathrm{g\ m^{-2}\ yr^{-1}}]$$

Key natural processes:

- fixation by soil bacteria
- denitrification (other soil bact.)
- incorporation from soil by growing plants
- decay of plant material

Unit for pools: x 10^9 kg

Unit for fluxes: x 10^9 kg yr^{-1}

consistent with p7??

Annual gains by atmosphere: $Q^+_{N_2} = (20 + 130 + 110) \times 10^9 = 260 \times 10^9$ kg yr^{-1}

Annual losses by atmosphere: $Q^-_{N_2} = (100 + 20 + 140) \times 10^9$ kg yr^{-1}

- consider fractional change in mass of N_2 within the troposphere (regarded as well mixed over time scale of a day) over one summer day due to **biological fixation**

- tropopause at *P* ~ 30 kPa (300 hPa)
- troposphere contains ~ 70% of atmos. mass
- to a first approximation,

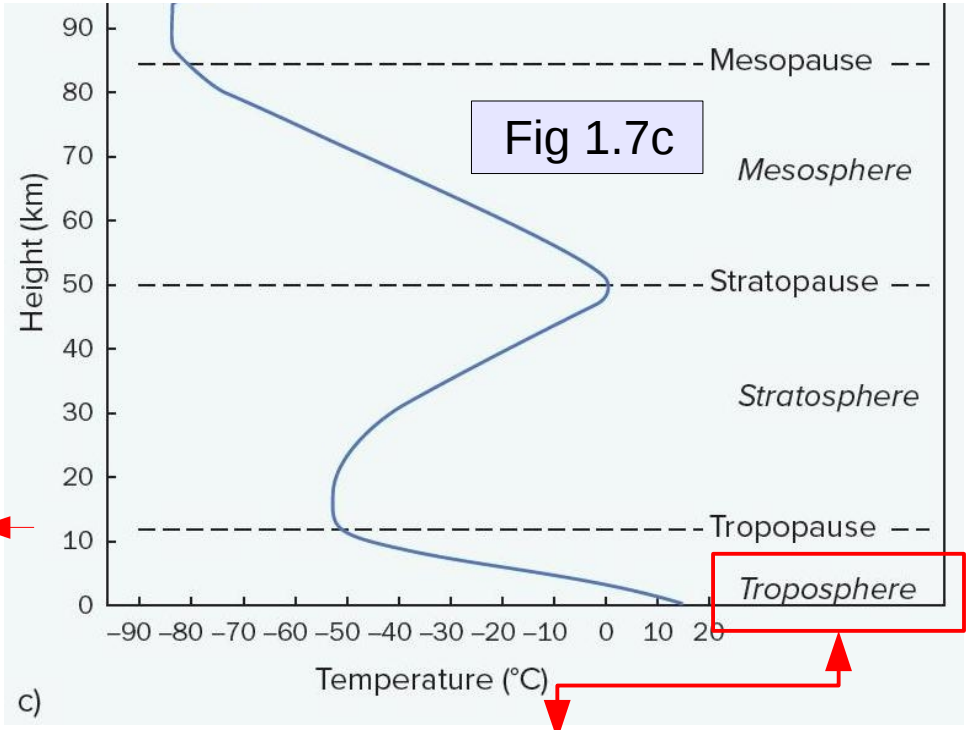
$$\left[\frac{\Delta M}{M}\right]_{N_2} \approx \frac{Q \times 1/365}{.7 \times (4 \times 10^{18})}$$

mass of atmos.

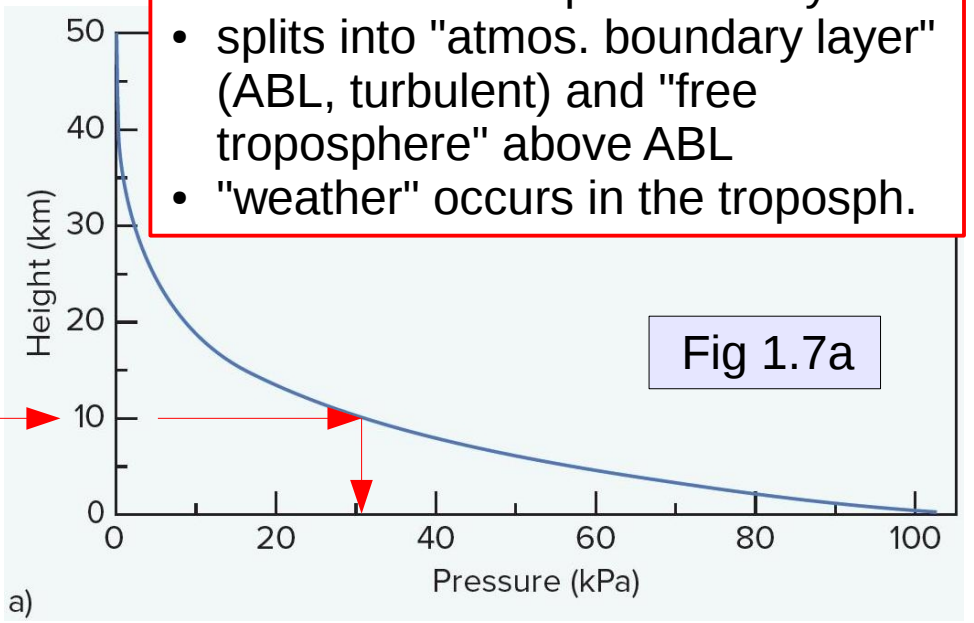
$$\approx \frac{(140 \times 10^9)\ \frac{1}{365}}{\text{kg/yr} \times \text{yr}}$$

$$\simeq 10^{-10}$$

- this justifies calling nitrogen a "constant" (or "permanent") gas



- well stirred over period ~ days
- splits into "atmos. boundary layer" (ABL, turbulent) and "free troposphere" above ABL
- "weather" occurs in the troposph.



Lecture of 9 Sept.

- concept of a constant pressure surface, and isolines of its height above sea level
- relationship of wind aloft to height contours
- strong correlation between cloud on satellite image & humidity at 700 hPa level
- proportions of the three main constant gases and three main variable gases
- simple-mindedness of "residence time" concept
- overview of global annual biogeochem cycle for nitrogen
- *next class we'll look at the biogeochem cycles for carbon dioxide, water and methane*