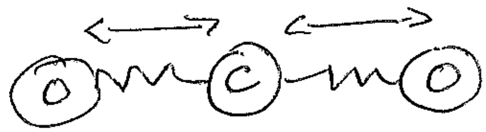
11 Sep 2017 – LEE

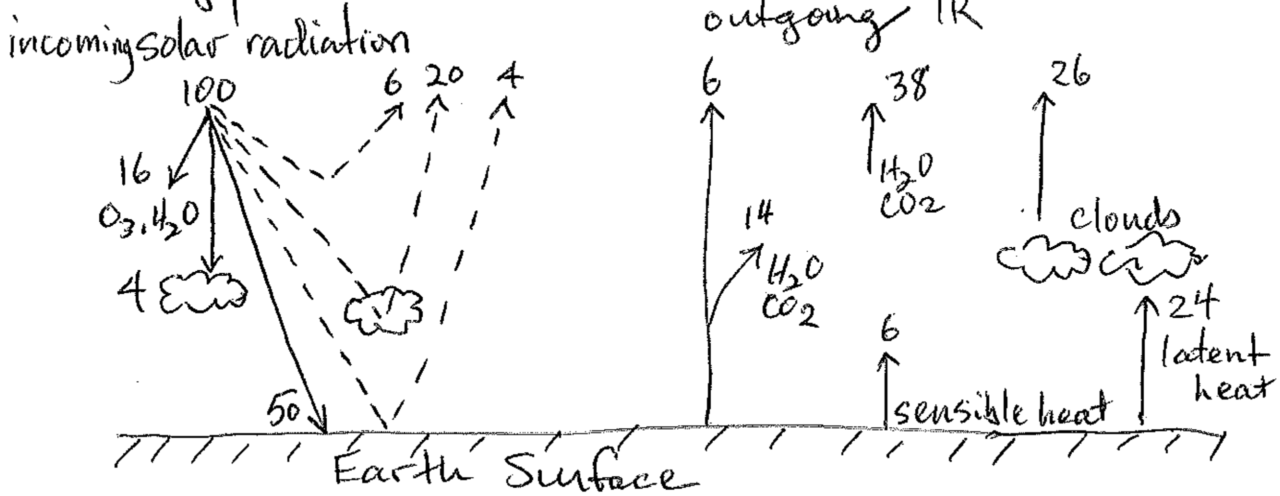
INTRODUCTION TO CARBON CYCLING

CO_2 greenhouse gas – necessary to keep planet warm



vibrational modes sensitive to infrared

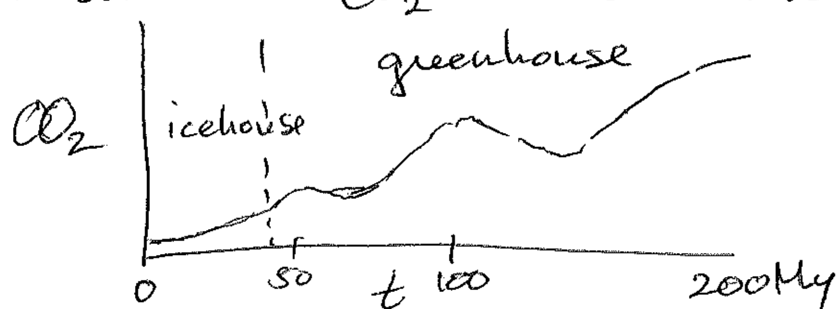
energy balance



without CO_2, Earth's surface T would be ~-25°C

incoming solar radiation ~ 300 W/m^2
compare to geothermal heat flow 80 mW/m^2

WHAT CONTROLS CO_2 THROUGH TIME?



CARBON COMES IN DIFFERENT FORMS (OXIDATION STATES)

C^{-4}	CH_4	methane
C^{0}	graphite, diamond, $[CH_2O]$	
C^{+2}	CO	carbon monoxide
C^{+4}	CO_2, $CaCO_3$	

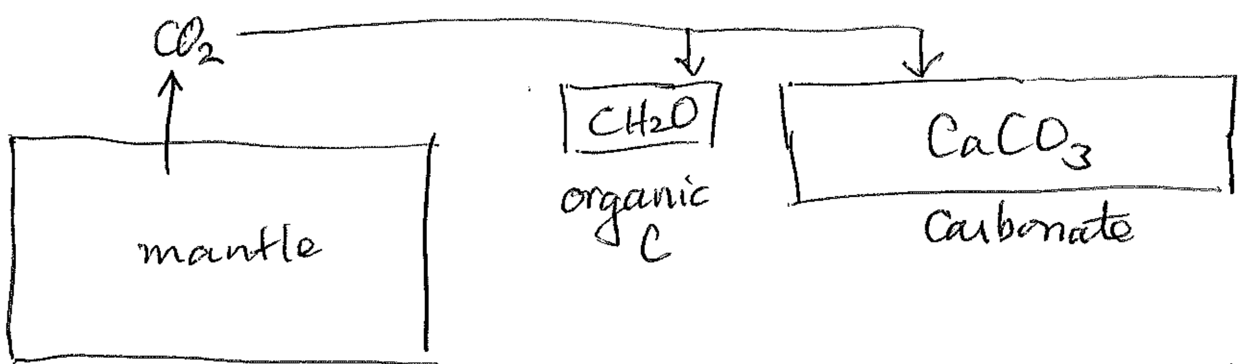
↓ increase oxidation state + oxygen

$$C + \tfrac{1}{2}O_2 = CO_2$$

$$CH_2O + O_2 = CO_2 + H_2O$$

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

Today's Earth



Photosynthesis $CO_2 + H_2O + \text{Sun} = CH_2O + O_2$ (← organic C)

free oxygen is produced

Carbonate precipation ⟶

Carbonate Precipitation

$$CO_2(g) = CO_2(L)$$

$$CO_2 + H_2O = H_2CO_3$$

$$H_2CO_3 = H^+ + HCO_3^-$$

$$Ca^{2+} + HCO_3^- = CaCO_3 + H^+$$

or

$$\boxed{Ca^{2+} + CO_2 + H_2O = CaCO_3 + 2H^+}$$

↑ if Ca^{2+} exists

← dissolution

→ precipitation

CO_2

$f_{org} = 20\%$ ↙ ↘ 80%

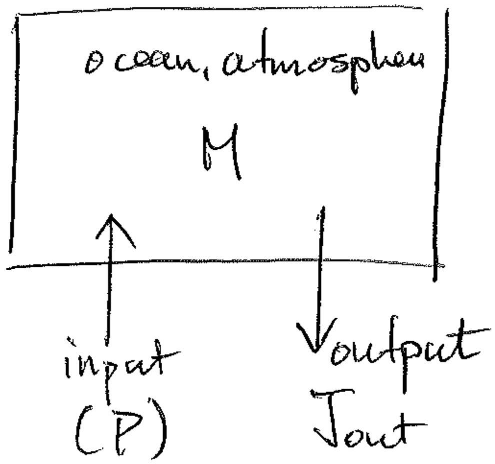
organic C (CH_2O) | Carbonate ($CaCO_3$)

↓

production of O_2

↓

changes N, S, P, Fe cycling



$$\frac{dM}{dt} = P - J_{out}$$

Jout should be proportional to mass of C in ocean/atmosphere M

$$J_{out} \sim M$$

$$J_{out} = k M$$

↑ rate constant 1/s

$1/k$ = residence time

= response time

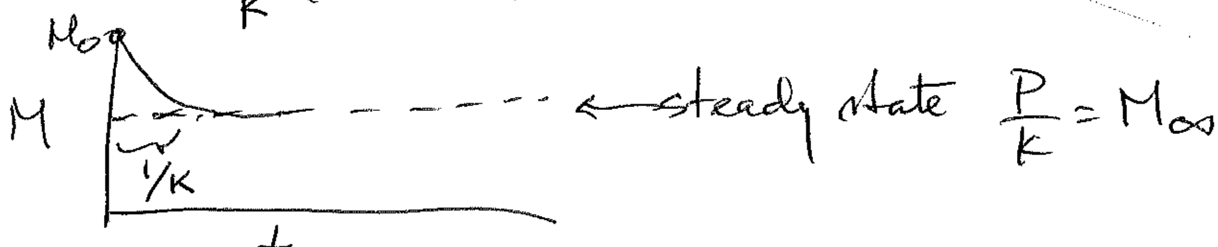
Response time

$\tau = \frac{M}{J_{out}} = \frac{M}{J_{in}}$ at steady state

if P is constant

$$\frac{dM}{dt} = P - kM$$

$$M = \frac{P}{k}(1 - e^{-kt}) + M_0 e^{-kt}$$



$$\frac{dM}{dt} = P - kM$$

- negative feedback

k is a measure of <u>efficiency</u> of C burial

negative feedback which buffers system.

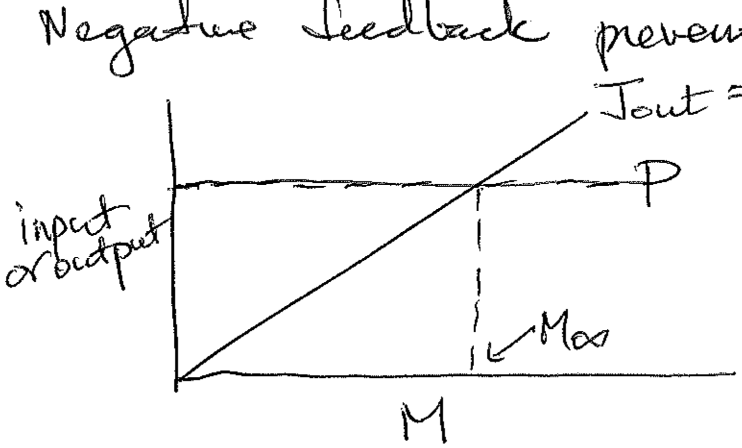
k is often called the <u>weathering feedback</u>

$CaSiO_3 + CO_2 = CaCO_3 + SiO_2$ (net rxn)

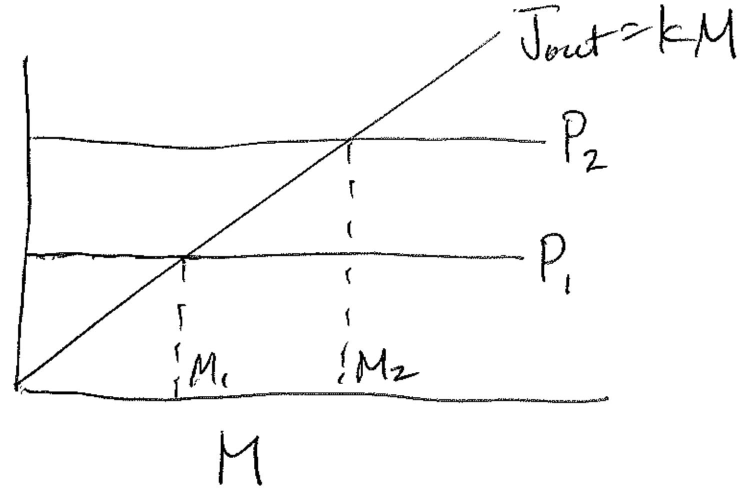
↑ CO_2 in form of acid rain dissolves calcsilicates

P is production of volcanic gases or any other origin

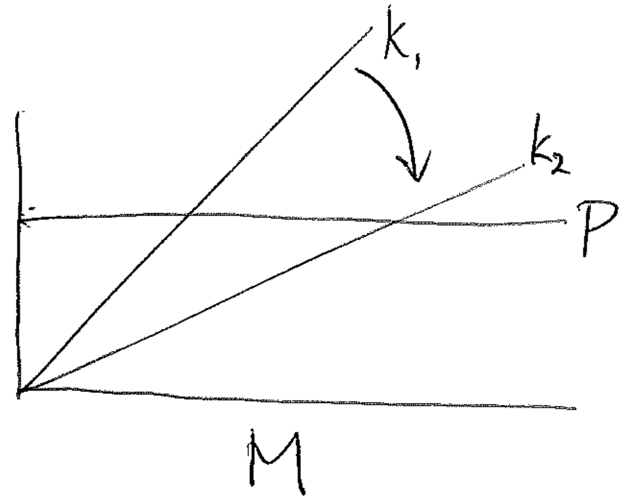
Negative feedback prevents runaway



- in a linear system increase M by increasing P or by changing k



increase P to increase M



P constant

- change efficiency of k

if k_1 decreases to k_2
M_1 increases to M_2

P controlled by degassing from mantle

k - silicate weathering → carbonate precipitation

- more orogeny erosion ↑ k
- higher T ↑ k
- more basalt ↑ k
- cool ↓ k
- more rain ↑ k

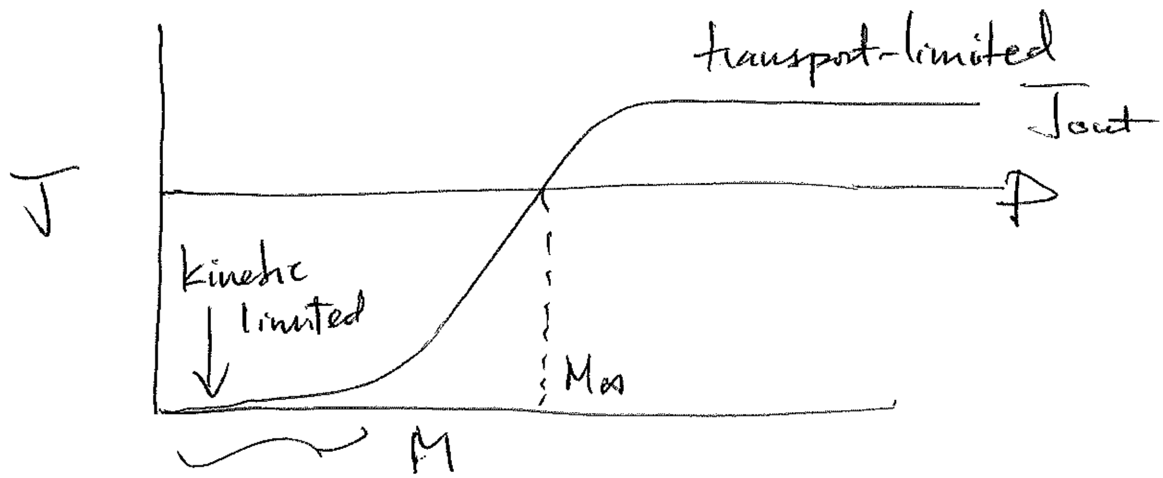
Runaway

J_{out} is not linear

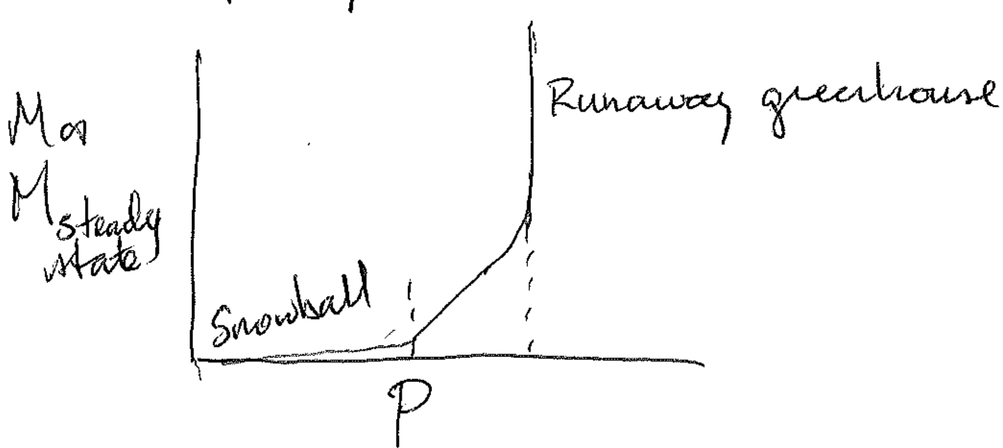
- transport limited
- threshold limited

for example, if erosion rates are too fast compared to chemical dissolution rates, weathering feed back decreases

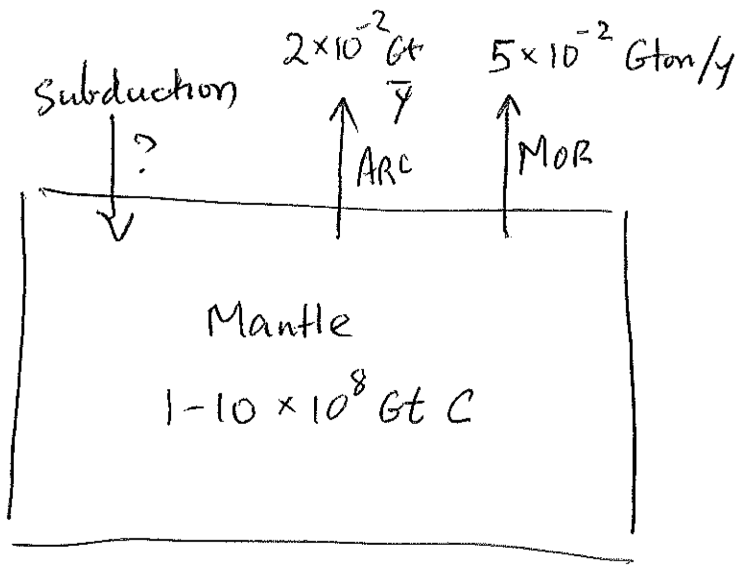
if weathering stops because kinetics freeze up... e.g. if T is too low, or water too low then k decreases



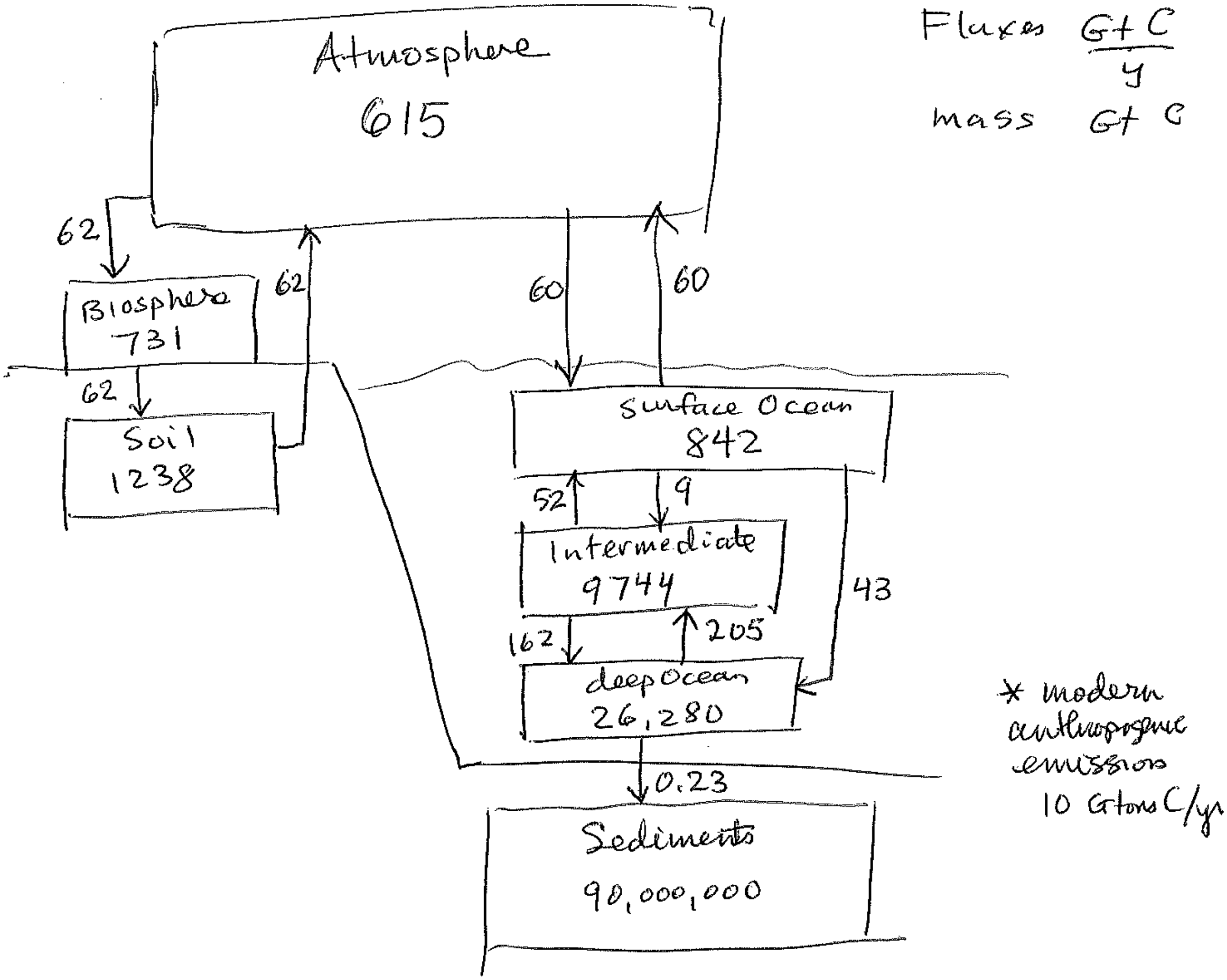
- perhaps $CO_2 \downarrow$, then $T \downarrow$ and precipitation $\downarrow$



Deep Earth



τ. in mantle ~ 4 Gy or more



τ for ocean, atmosphere biosphere = 170,000 y

τ for soils = 20 y

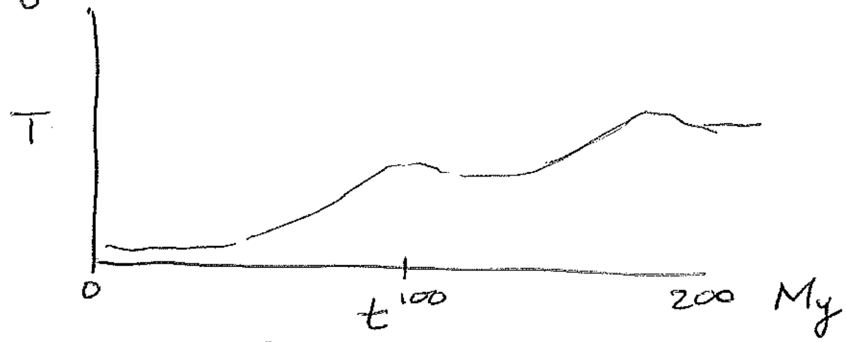
τ for total ocean = 614 y

τ surface ocean ~ 10 years

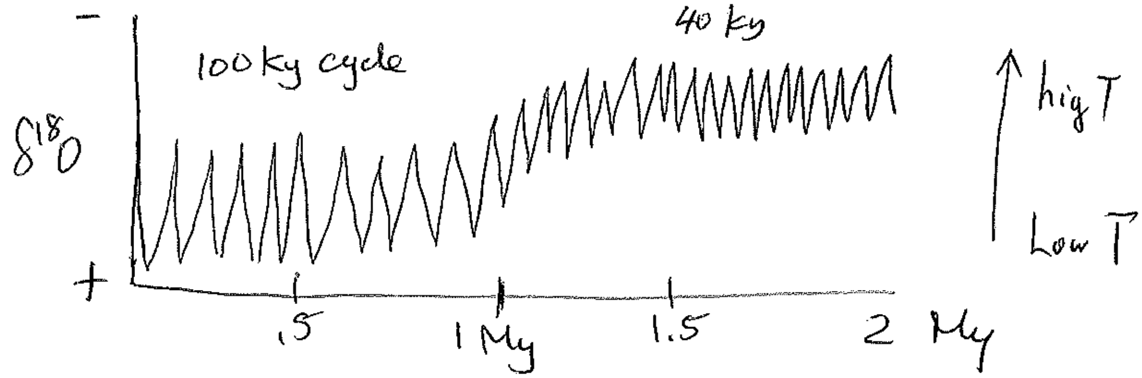
τ surface + intermediate

τ biosphere 10 years

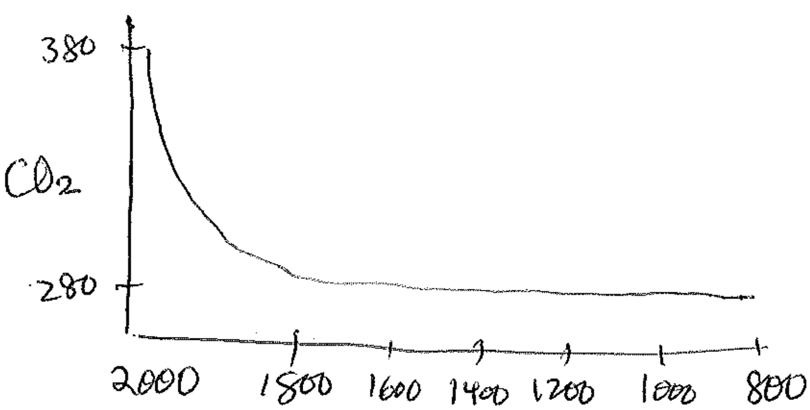
My timescales



100 ky timescales



Human timescales



Questions

- What is response time, residence time?
- What controls steady state?

>My timescale	$P(t)$	- tectonics
	k	- weathering
<100 ky timescales	$P(t)$	ocean degassing
	k	- biosphere and ocean uptake
	Solar insolation	
<1000 y	$P(t)$	biosphere, anthropogenic
	k	biosphere + ocean uptake