

Space Science: Atmospheres

Part- 7c-07

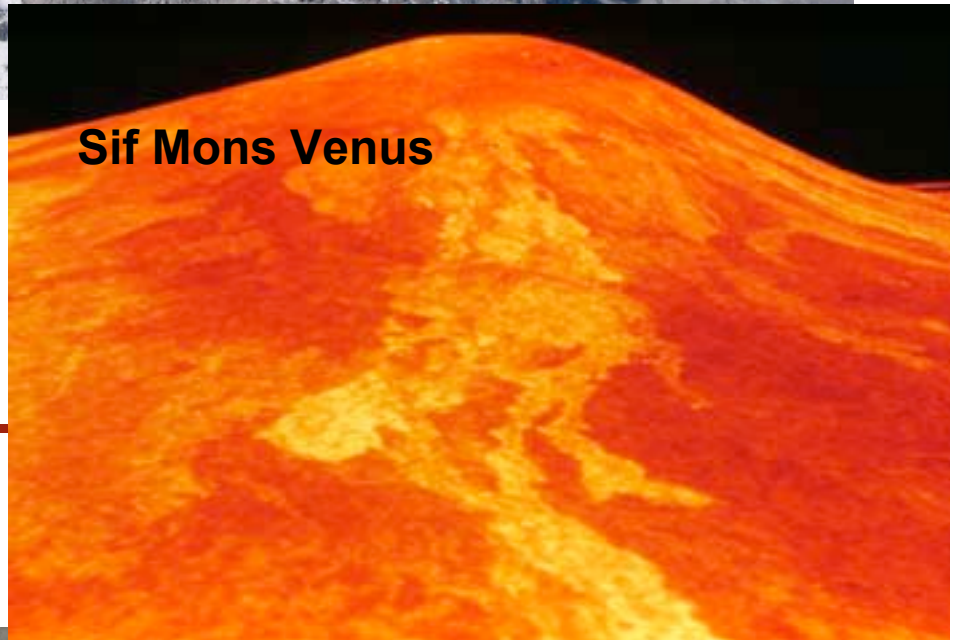
CO₂ Cycle

O₂ Cycle

Mt. St. Helens



Sif Mons Venus



**Do Gases
evolve from
interior? Yes
H₂O, CO₂, SO₂, etc.
+ silicates**

**Remember
there is also
Plate
Tectonics:**

Recycles

Olympus Mons



Atmospheric Sources

Volcanoes/ Outgassing

H₂, H₂O, CO₂, H₂, S, SO₂ ...

Impacts

Comets, meteors, micrometeorite

LOSSES

Surface

Condensation/ Reactions

Escape

Jeans

Hydrodynamic/ Blow off

Photo-Dissociation

Solar Wind + Solar Fields

Inventory of H₂O

Greenhouse

Venus --- gas

Earth --- water

Mars --- ice

We discussed the lack of H₂O on Venus and Mars -sort of.

Inventory of CO₂

Earth:

Atmosphere ~2.4x10¹⁸gm

Ocean ~1.3 x10²⁰gm

Biosphere ~1 x10¹⁹gm

Buried ~3.6x10²³gm

Venus:

Atmosphere ~4.4x10²³gm!

Surface/ Buried ??

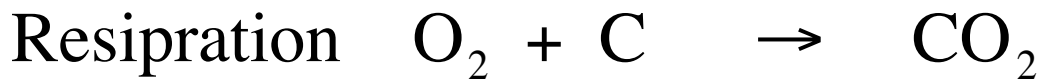
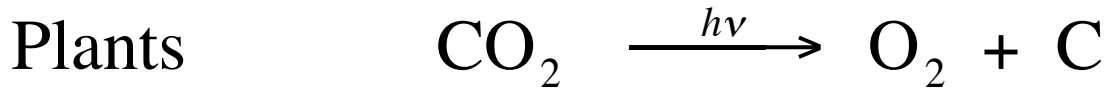
Mars:

Atmosphere ~ 3.0 x10²⁰gm

(scaled by mass to Venus ~0.005)

Surface/ Buried?

Photo synthesis + Respiration



Ocean: dissolves $\text{CO}_2 \rightarrow$ bicarbonate
bicarbonate $\rightarrow \text{CO}_2$ release
Near Equilibrium

Burial --- land + Sea

Weathering

Carbon in 'rocks' is oxidized $\rightarrow \text{CO}_2$

Limestone (Ca CO_3) dissolves in water \rightarrow
bicarbonate

Burial in the Oceans

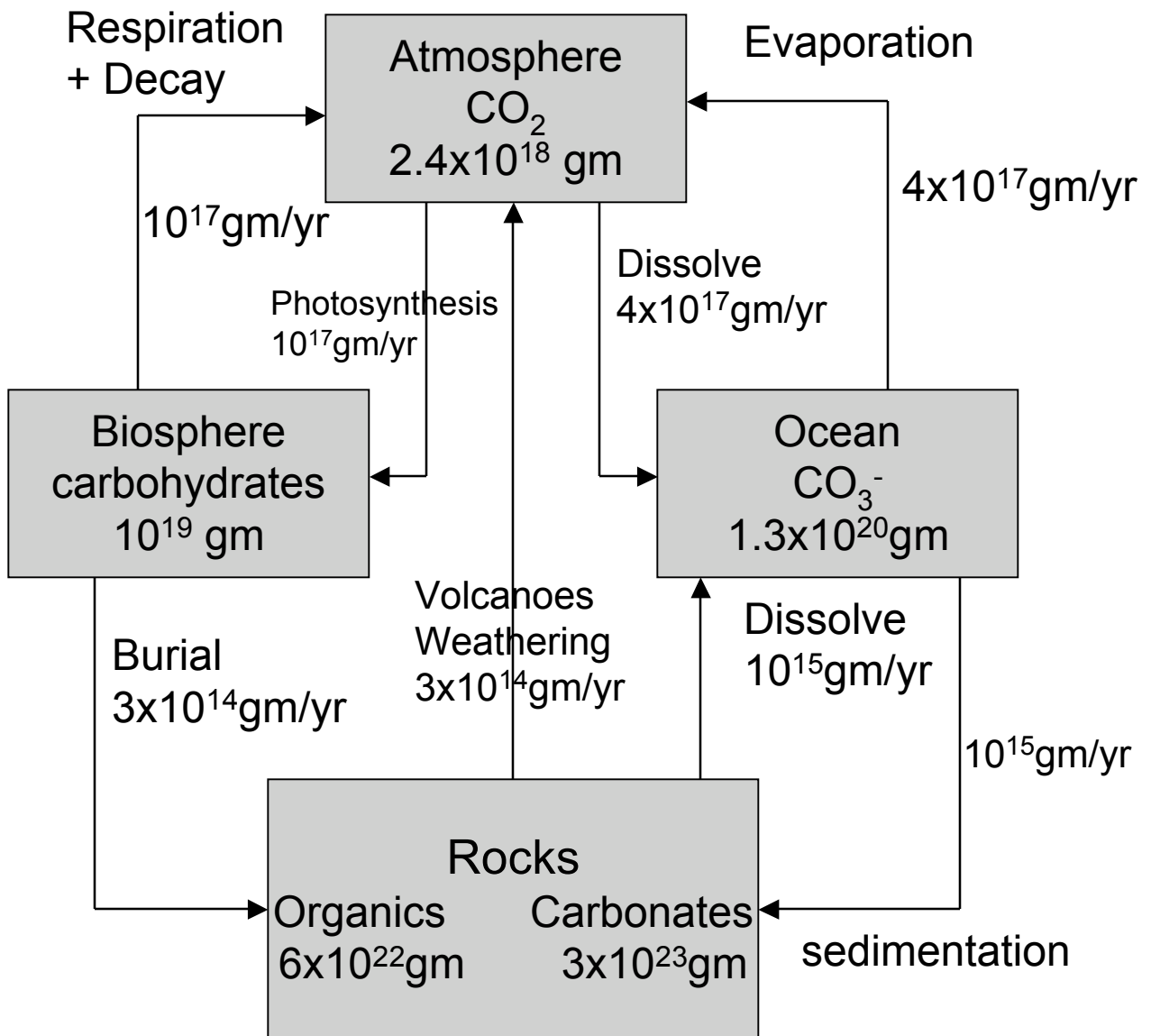


marine organisms

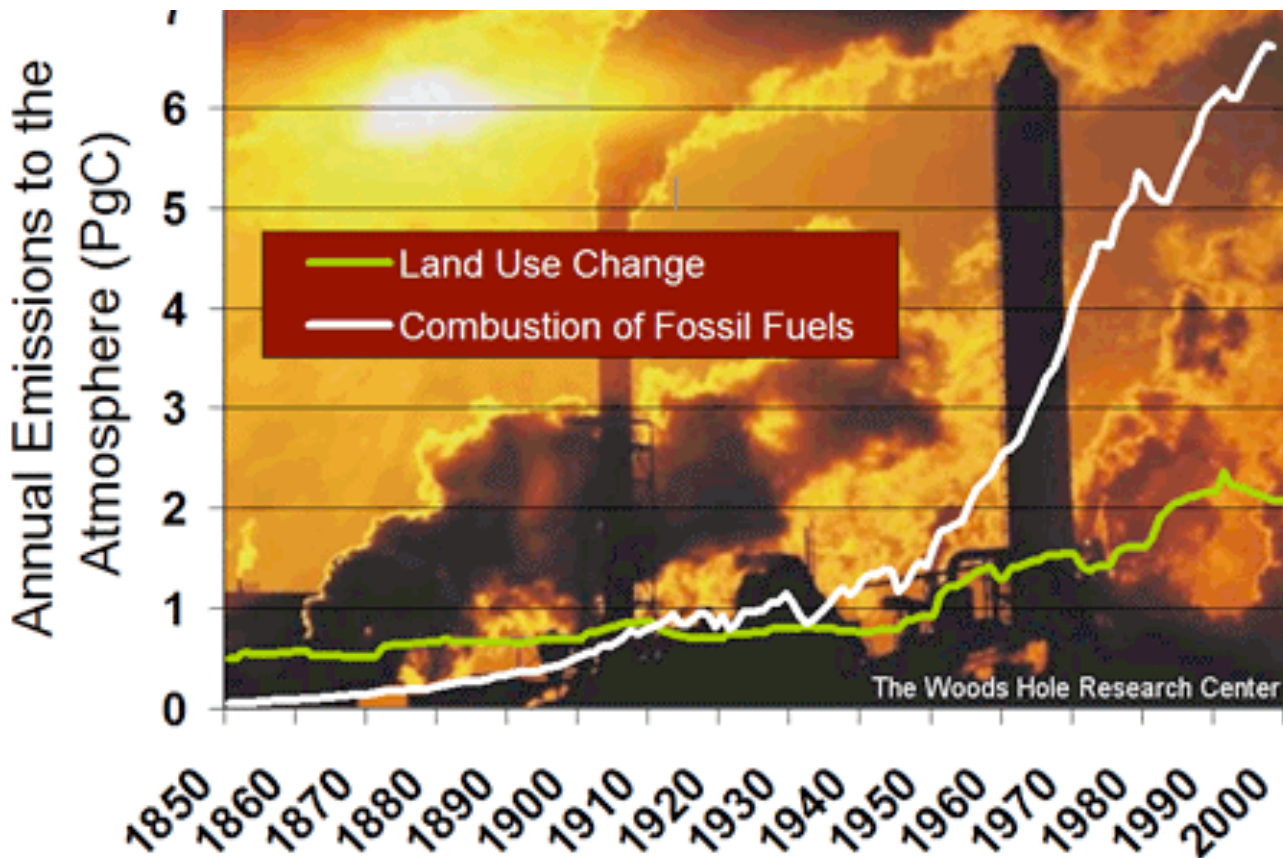
then



CO₂ Cycle on Earth (G+W)

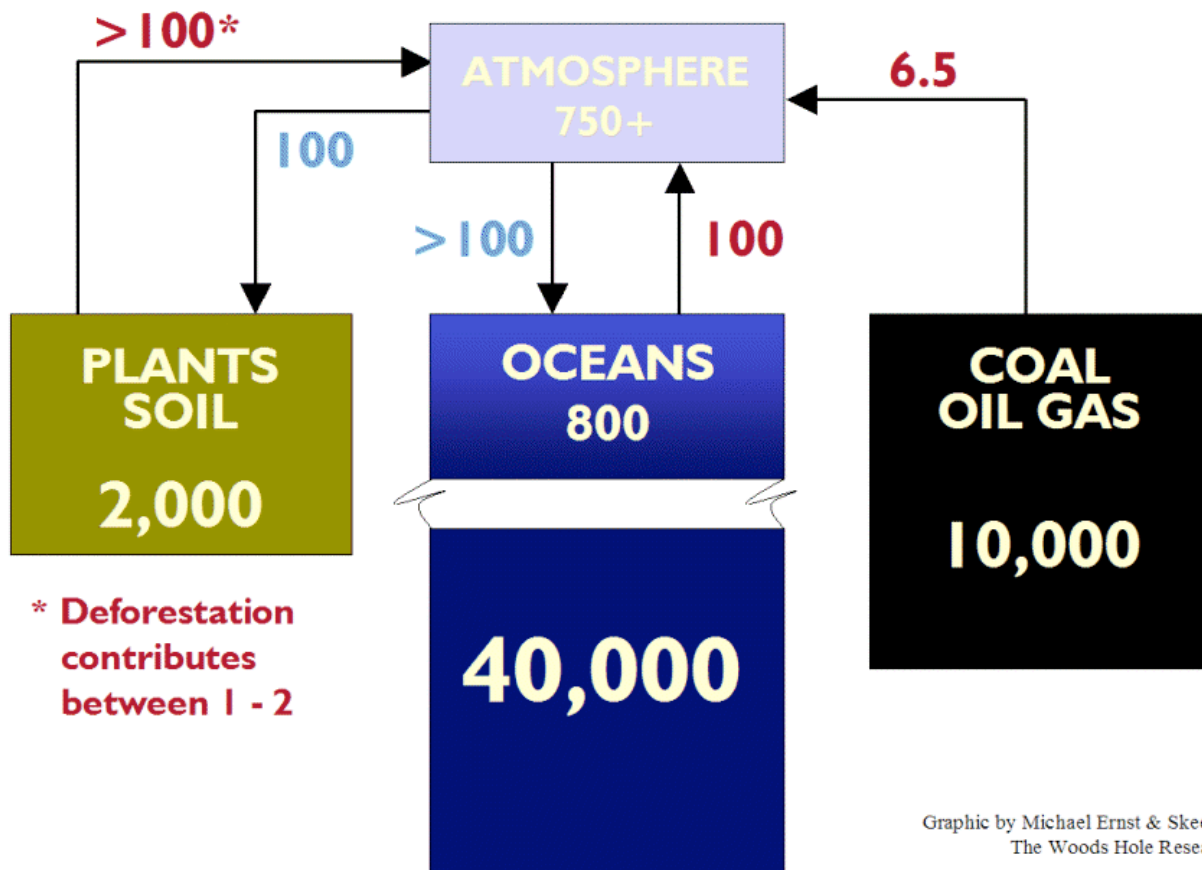


CO₂ ~ 3.6×10^{23} gm
H₂O ~ 1.6×10^{24} gm



Global Flows of Carbon

(Petagrams of Carbon/Year)



Double Atmosphere CO₂

Add 2.4×10^{18} gm CO₂

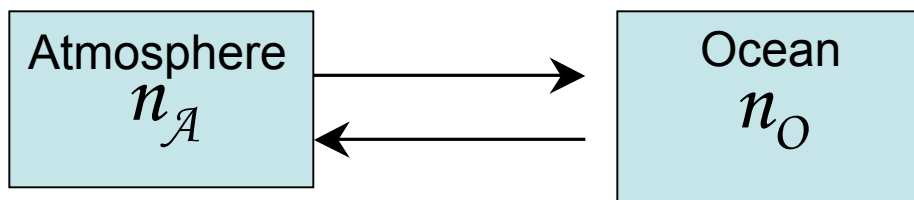
Vapor pressure of CO₂ up

Dissolves More → find new equilibrium

Experiment is being done

Since 1980 ~ 5×10^{17} gm CO₂,
added by fossil fuel burning

Look at fastest parts only



Rate Equation

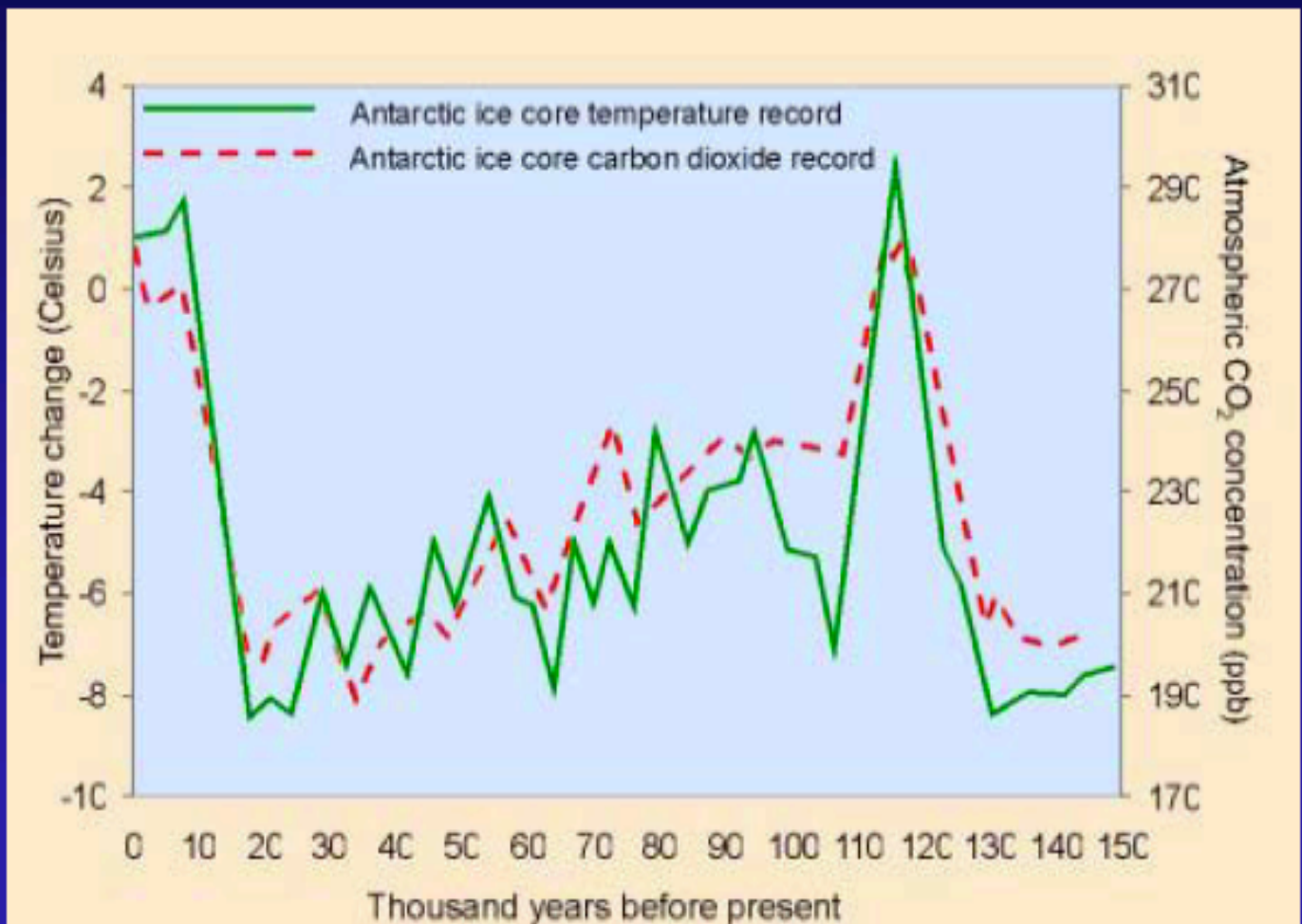
$$\frac{dn_A}{dt} = -\frac{n_A}{\tau_{\text{dis}}} + \frac{n_O}{\tau_{\text{evap}}} = -\frac{dn_O}{dt}$$

In Equilibrium:

$$\frac{n_A^o}{\tau_{\text{dis}}} = \frac{n_O^o}{\tau_{\text{evap}}}$$

Carbon Concentration Long Term

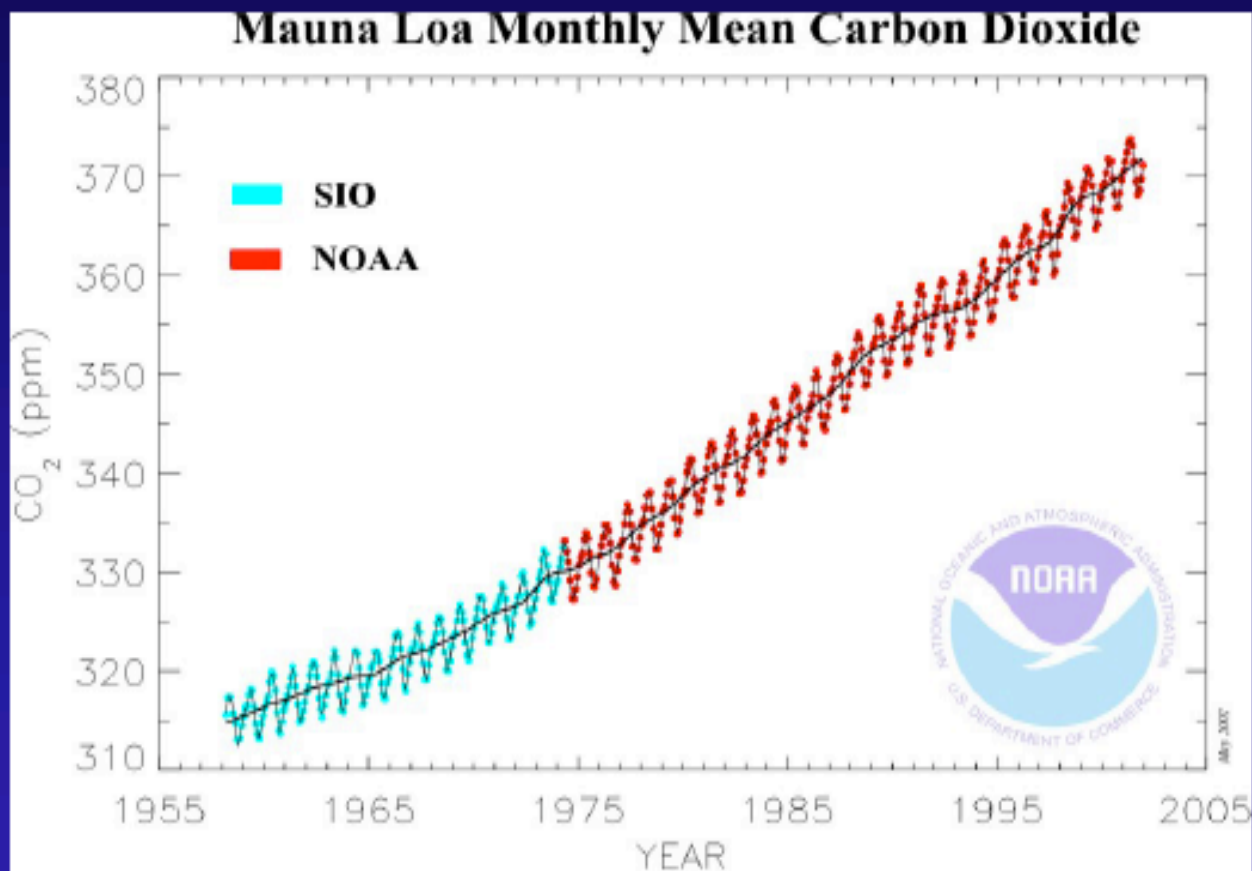
- Historical Record – Correlation of CO₂ and Temp



Carbon concentration vs. time

- Increase from 280 ppm (1860) to 370 ppm (present) – 31% increase

◆ Note: 370 ppm = 0.0370%



Atmospheric carbon dioxide monthly mean mixing ratios. Data prior to May 1974 are from the Scripps Institution of Oceanography (SIO, blue), data since May 1974 are from the National Oceanic and Atmospheric Administration (NOAA, red). A long-term trend curve is fitted to the monthly mean values. Principal investigators: Dr. Pieter Tans, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6678, ptans@cmdl.noaa.gov, and Dr. Charles D. Keeling, SIO, La Jolla, California, (616) 534-6001, cdkeeling@ucsd.edu.

Estimate Time Constants and New Equilibrium

Fraction in Ocean $\approx 98\%$

Fraction in atmosphere $\approx 2\%$

$$\tau_{\text{evap}} \approx 1.3 \times 10^{20} \text{ gm} / 4 \times 10^{17} \text{ gm/yr} = 325 \text{ yr}$$

$$\tau_{\text{dis}} \approx 2.4 \times 10^{18} \text{ gm} / 4 \times 10^{17} \text{ gm/yr} = 6 \text{ yr}$$

Now Double

$$\eta_A(\infty) + \eta_O(\infty) = 2 \eta_A^o + n_O^o$$

New Equilibrium

$$\frac{\eta_A(\infty)}{\tau_{\text{dis}}} = \frac{\eta_O(\infty)}{\tau_{\text{evap}}}$$

Size of Increase

$$\Delta = \frac{n_A(\infty) - n_A^o}{n_A^o} = 1 / [1 + \tau_{\text{evap}} / \tau_{\text{dis}}] \approx 2\%$$

Double \Rightarrow $\sim 2\%$ increase

Find Effective Time Constant

$$n_T = 2 n_A^{\circ} + n_O^{\circ}$$

$$\frac{dn_A}{dt} = -\left(\frac{1}{\tau_{dis}} + \frac{1}{\tau_{evap}}\right)n_A + \frac{n_O}{t_{evap}}$$

$$\tau_{eff} = \left(\frac{1}{\tau_{dis}} + \frac{1}{\tau_{evap}}\right)^{-1}$$

$$\approx \tau_{dis} \approx \mathbf{6 \text{ years}}$$

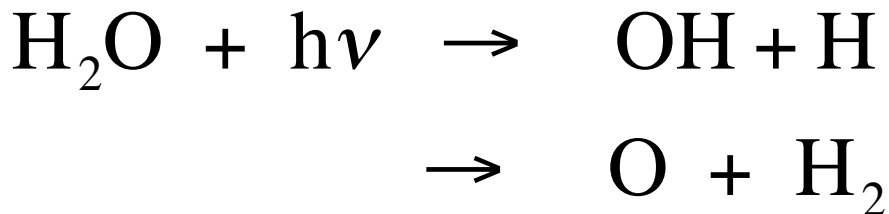
Actual change is: 10% in 6 years

Since ocean circulates (mixes) only slowly.

VENUS

Run away Greenhouse

H₂O does not condense



H₂ + H escape

Total CO₂ = 4.4x10²³g

Atmosphere – Surface: Equilibrium ?

Silicate Rocks + CO₂

e.g., CaSiO₃ + CO₂

Gives

Carbonate + Quartz

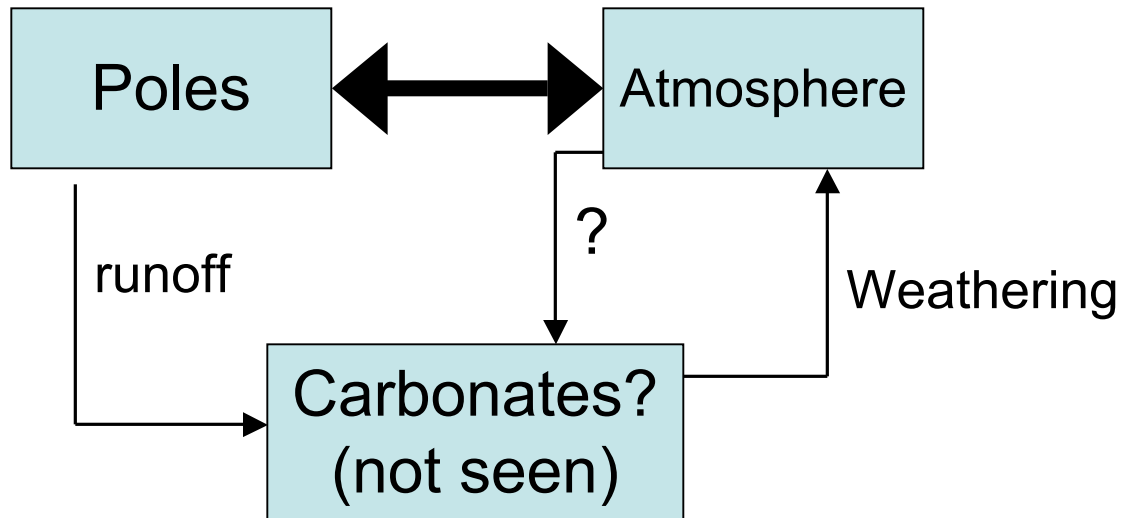
CaCO₃ + SiO₂

Old idea: passive?

Magellan: Surface Looks Active??

Also: there is some water->active volcanism?

Mars CO₂



Principally : Atmosphere – Poles
Poles --- Permanent Ice Caps
--- Seasonal CO₂ Caps
--- Runoff to ground water

Vapor Pressure

Determined by temperature

Winter Pole

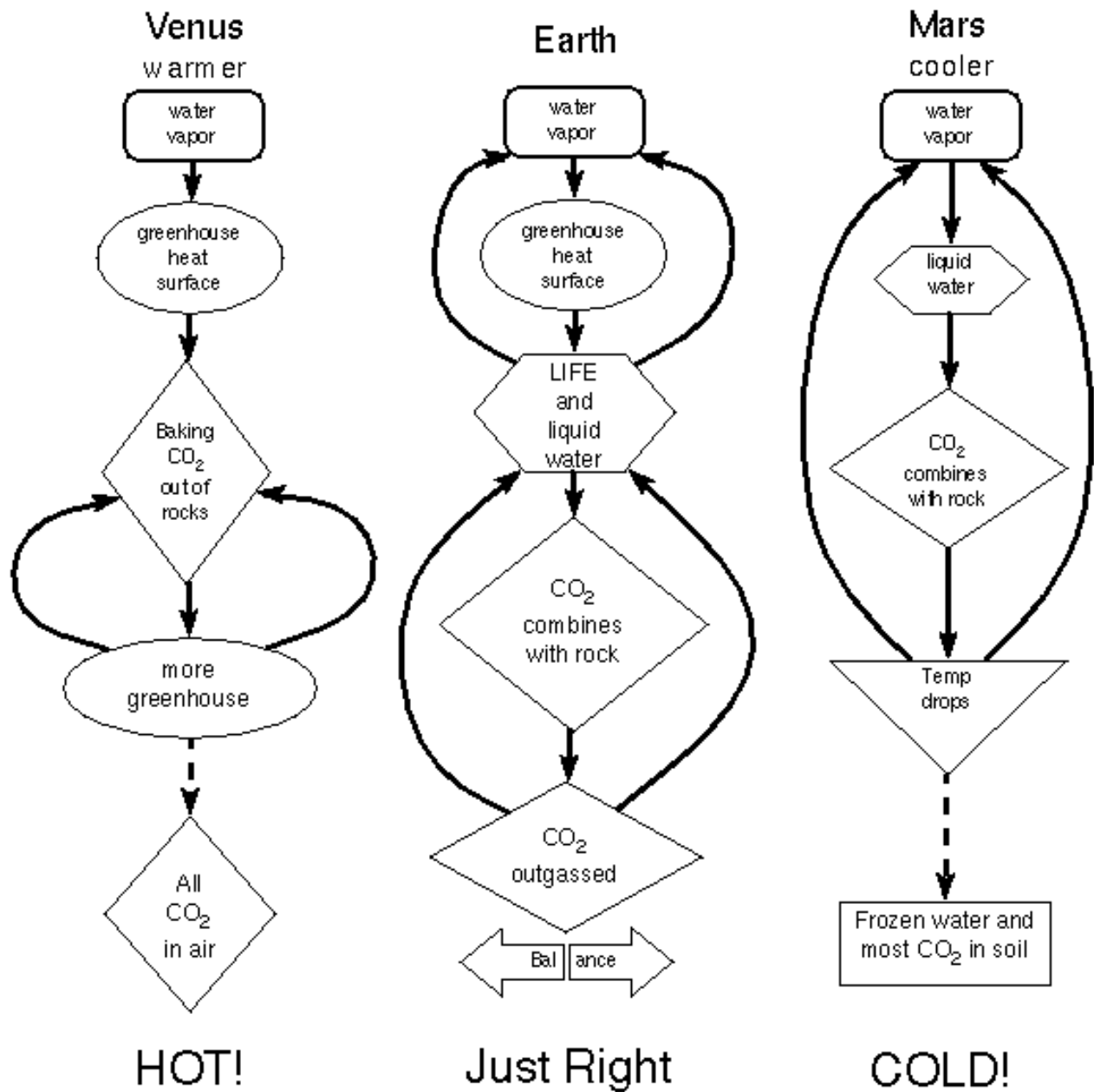
Orbital cycles are very important

Loss



(Europa / Mars)

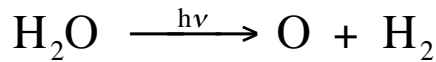
Where does the C go???



Venus has runaway greenhouse effect and no water left. Earth has life and liquid water keeping temperature balanced and most of its CO₂ in the rocks. Mars has runaway refrigerator with water frozen in permafrost layer and most of its CO₂ in the rocks or frozen on the surface.

Atmospheric O₂

In beginning – O oxidizes rocks + some O₂



carbonates in rocks (oxidized)

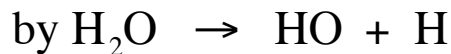
Little O₂, no O₃ ⇒ UV ⇒ **no organisms**

Present O₂ Cycle

Source of O₂ ?

H₂O ultimately

But condensation limits loss to space

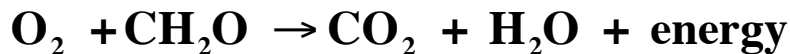


O₂ eventually produced by organisms

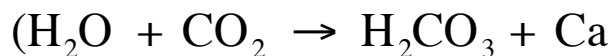
Photosynthesis



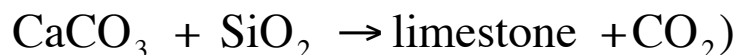
Respiration



Note: CO₂ stabilized by oceans



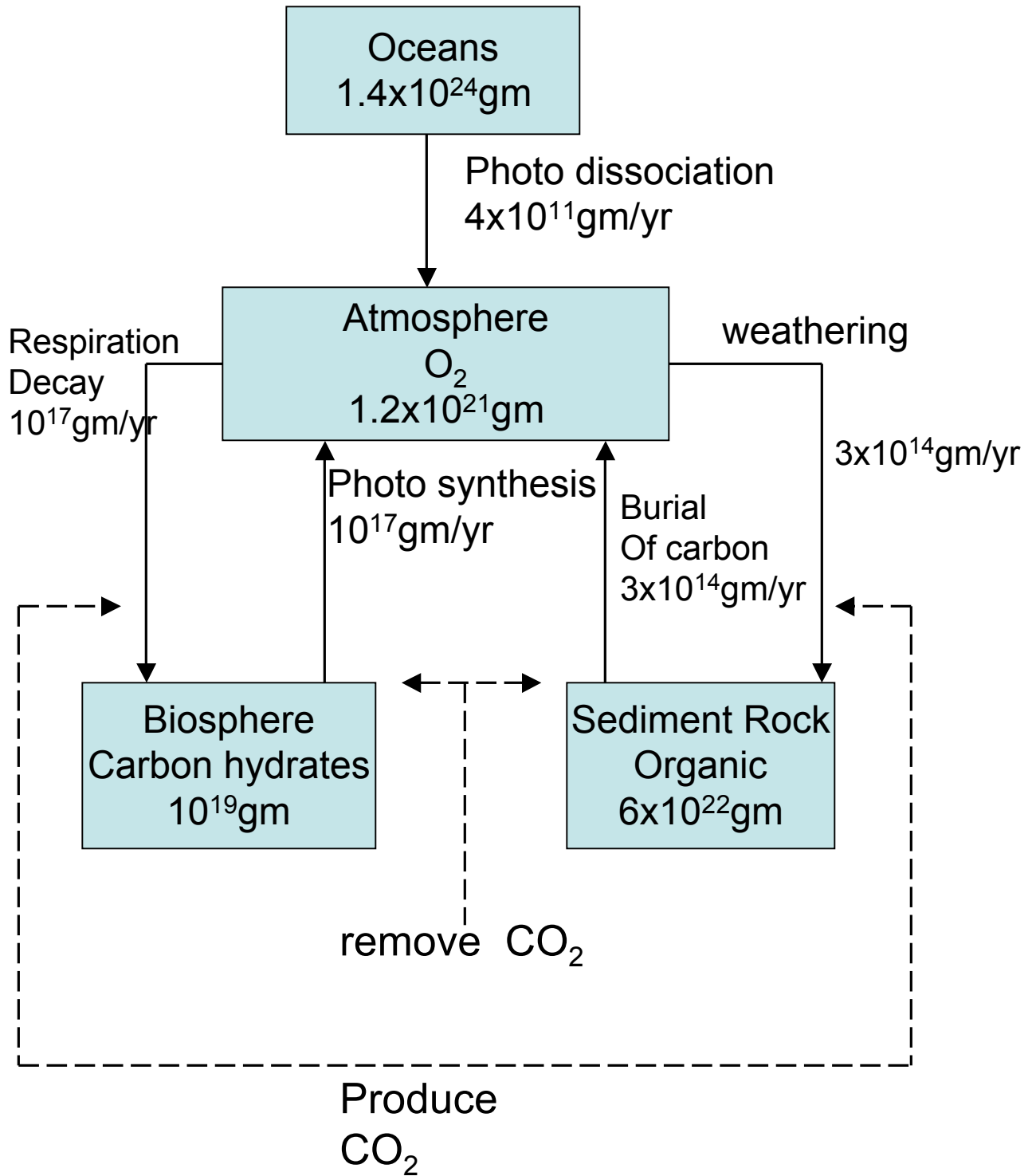
marine organisms



O₂ not so

(a fraction dissolves in ocean → biology).

Oxygen Cycle



Review

Composition

Solar, Giant Planets, Terrestrial Planets

Vertical Structure

Hydrostatic (scale height)

Diffusion/ homopause

Thermal Structure

Solar (Albedo)/ Internal Heating

Adiabatic Lapse (troposphere; potential temp.)

Thermal Conduction(thermosphere)

Radiation to Space (strato and mesospheres)

Chemistry

Absorption (optical pathlength)

Reaction rates

Ozone (EUV/UV: Chapman layers)

Ionospheres (ambipolar diffusion)

Radiation Transport

Greenhouse (IR vs. Visible)

Circulation/ Winds

Momentum Eq. (Rossby/Ekman numbers)

Boundary Layer (eddy viscosity)

Hadley Cells (bouyancy)

Geostrophic/ Cyclostrophic Flow

Zonal Winds/ Belts

Planetary/ Gravity Waves

Evolution / Escape

Escape (Jeans, Hydro., non-thermal)

Isotope ratios (heavy isotopes enhanced)

Fate of water and CO₂