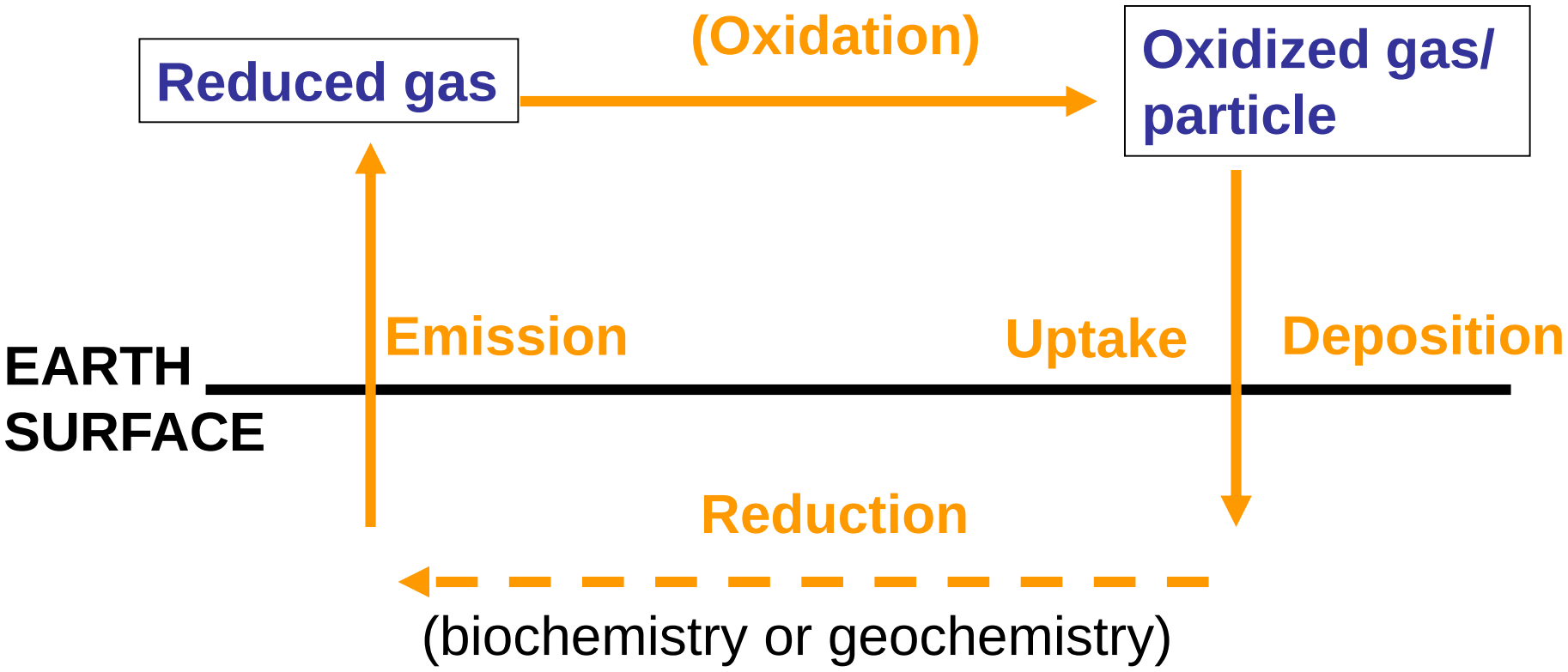
This Week: Global Biogeochemical Cycles - Carbon

- **Short-term biosphere-driven cycles**
  - Terrestrial biosphere
  - Marine biosphere
- **Long-term inorganic cycles**
  - Weathering-volcanism thermostat

Global Biogeochemical Cycles



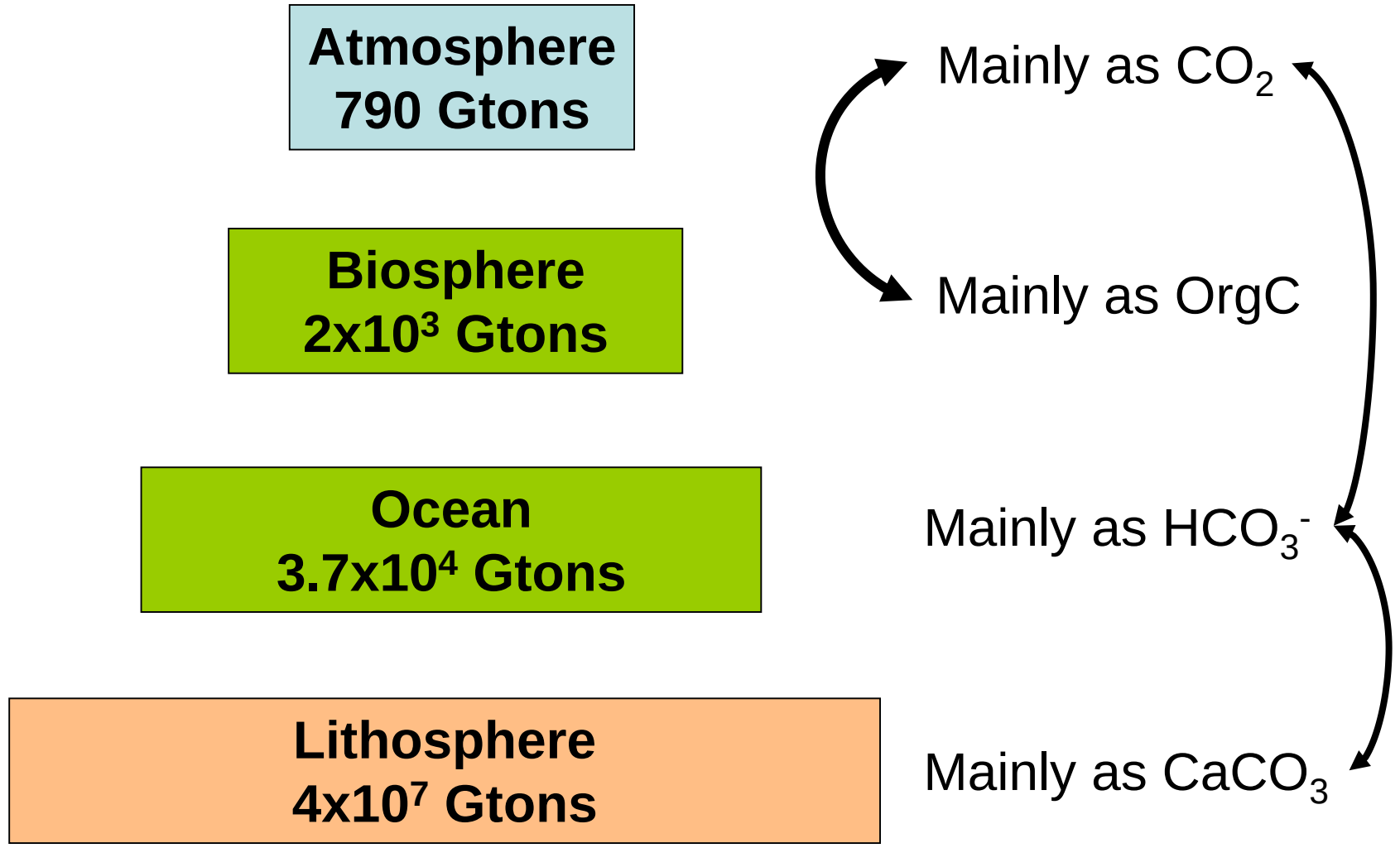
Mass Units of Geologic Scale

- 1 Gigaton = $1x10^9$ tons = $1x10^{12}$ kg
- $1x10^{12}$ kg = 1 x 10^{15} g = 1 Petagram

→1 Gigaton = 1 Petagram

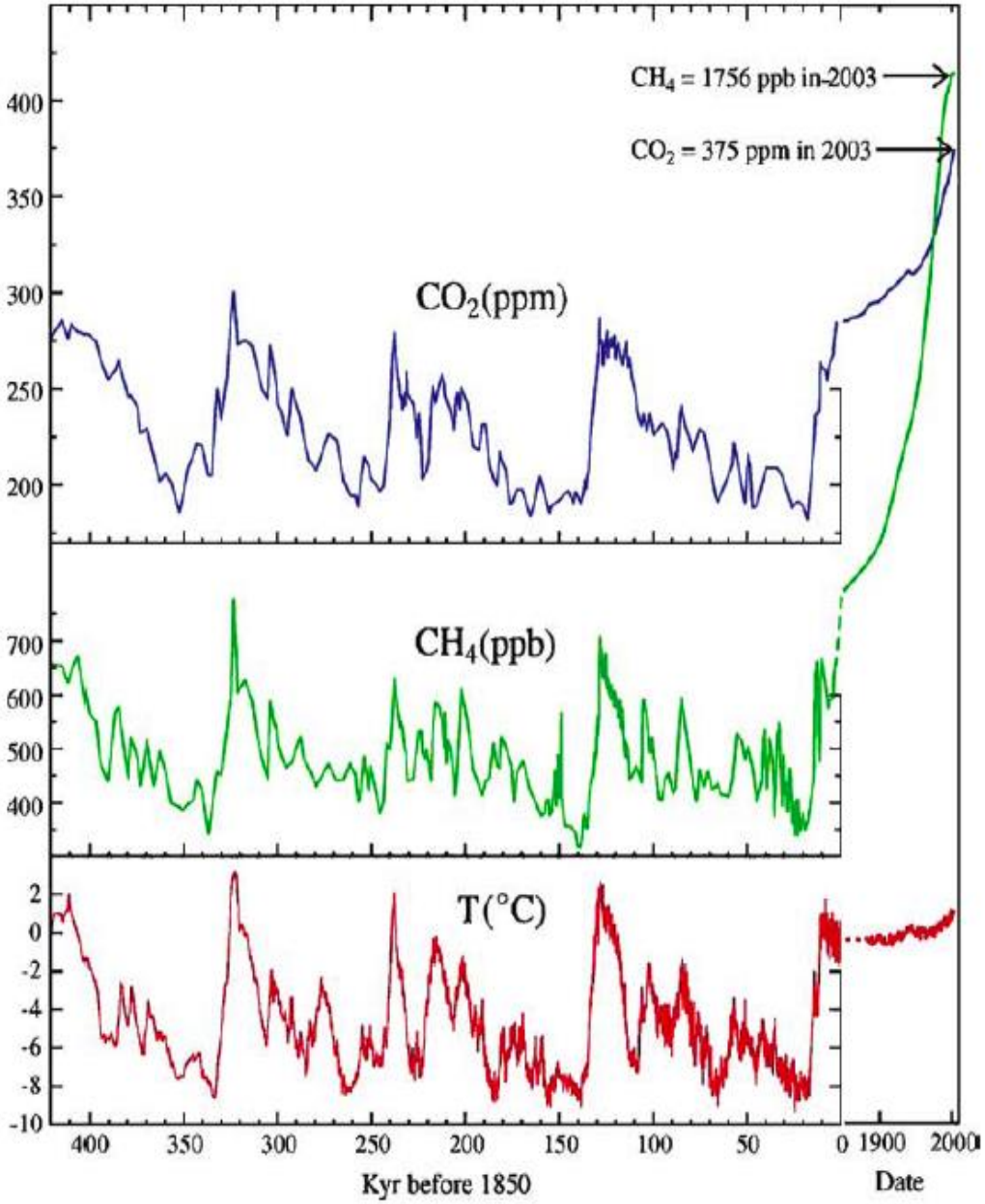
→ 1 ppm of atm. CO_2 ~ 2 Gtons C

Reservoirs of Carbon



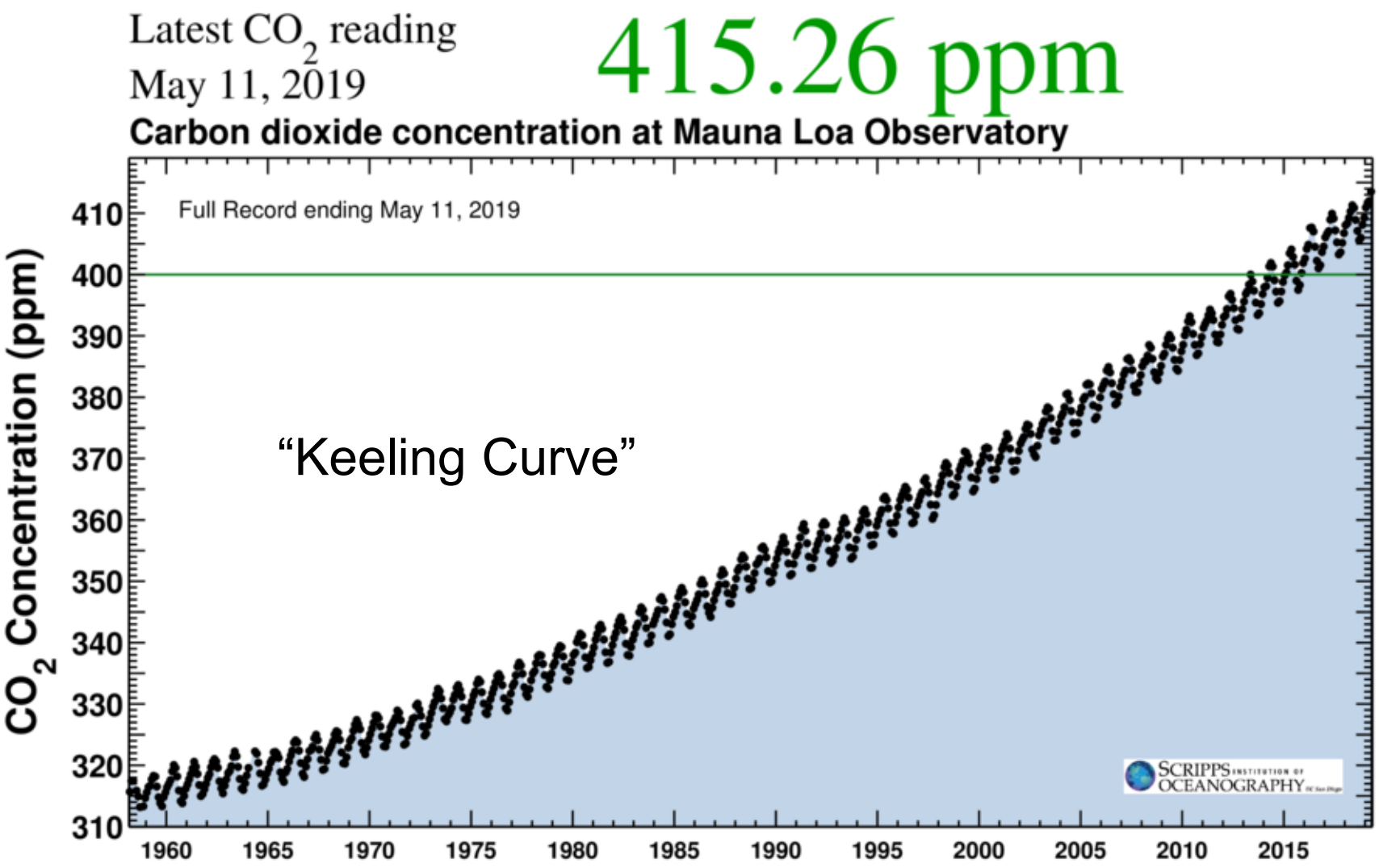
Carbon in the atmosphere and oceans mostly *inorganic*

Slow Carbon Variations



Large (but slow) natural changes

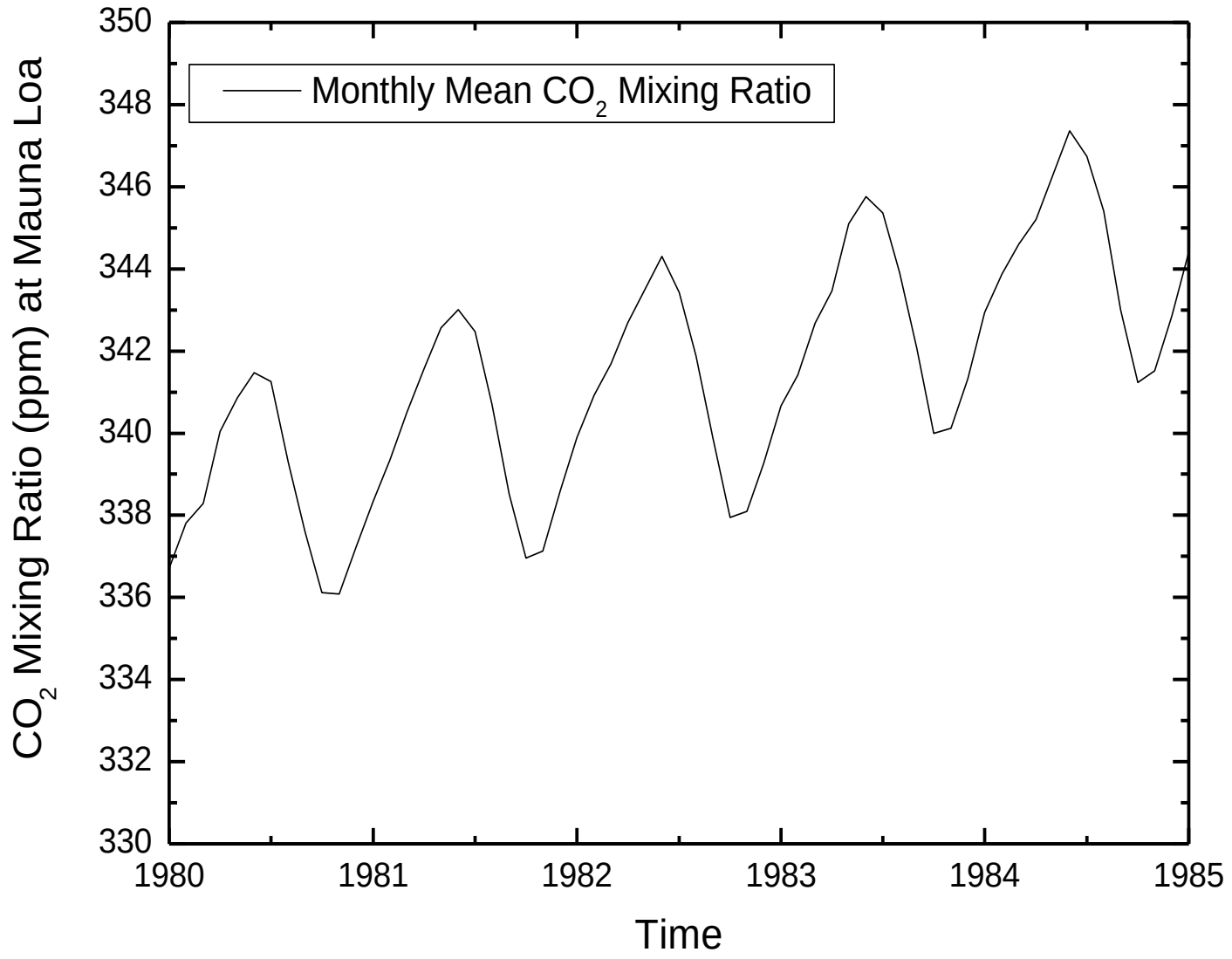
Modern Era Atmospheric Carbon



"Keeling Curve"

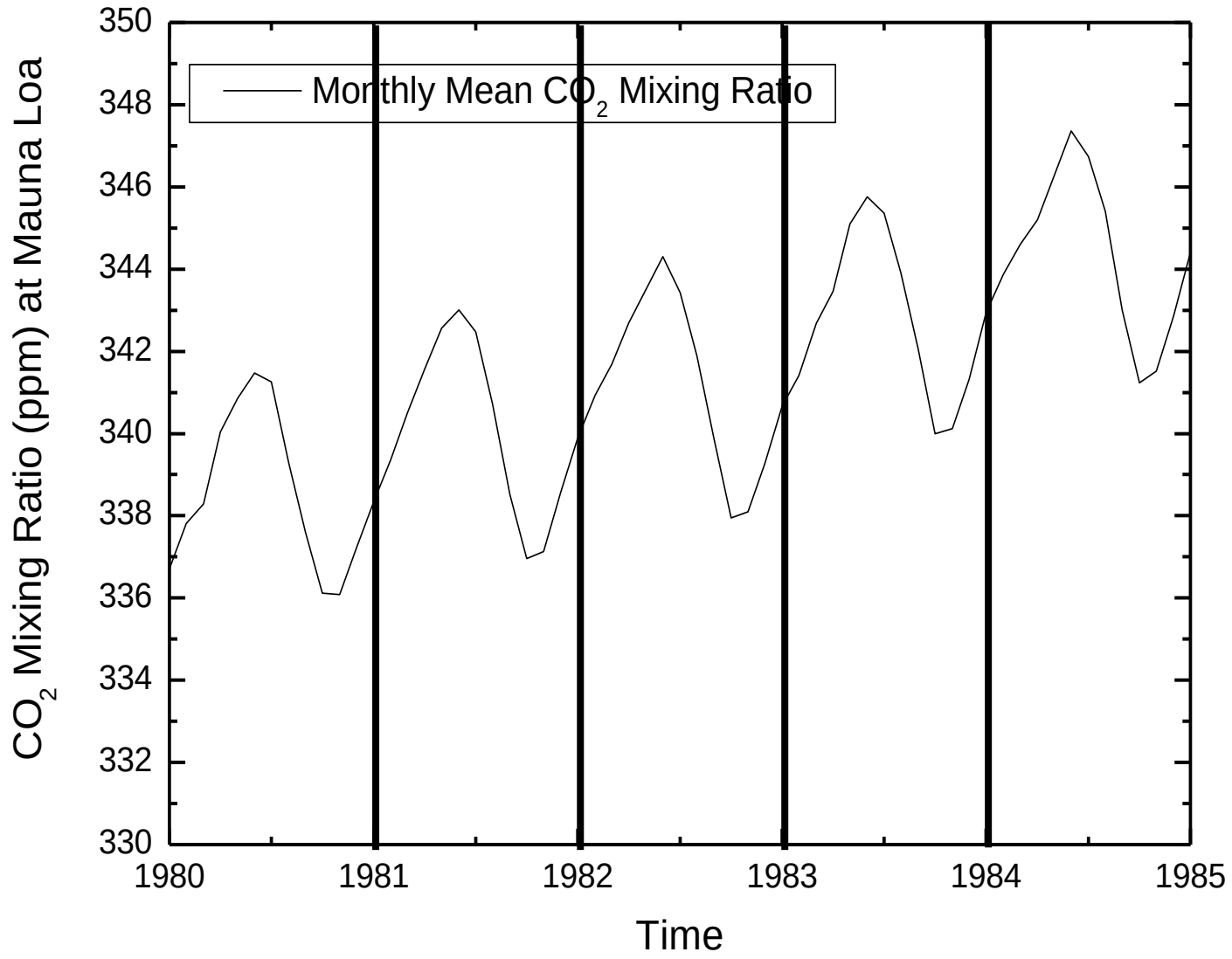
https://scripps.ucsd.edu/programs/keelingcurve/

Fast Carbon Variations: CO_2 Seasonal Cycle



Atmosphere responds to biosphere on short timescales

Fast Carbon Variations: CO_2 Seasonal Cycle



Atmosphere responds to biosphere on short timescales

Fast Flows of C: Organic Carbon Cycle

- Photosynthesis: solar energy is harnessed to convert InorgC (CO_2) into OrgC

$$nCO_2 + nH_2O + \text{Sunlight} \rightarrow nCH_2O + nO_2$$

(CH_2O: surrogate for carbohydrates)

- Respiration/Decay: aerobic conversion of OrgC → InOrgC

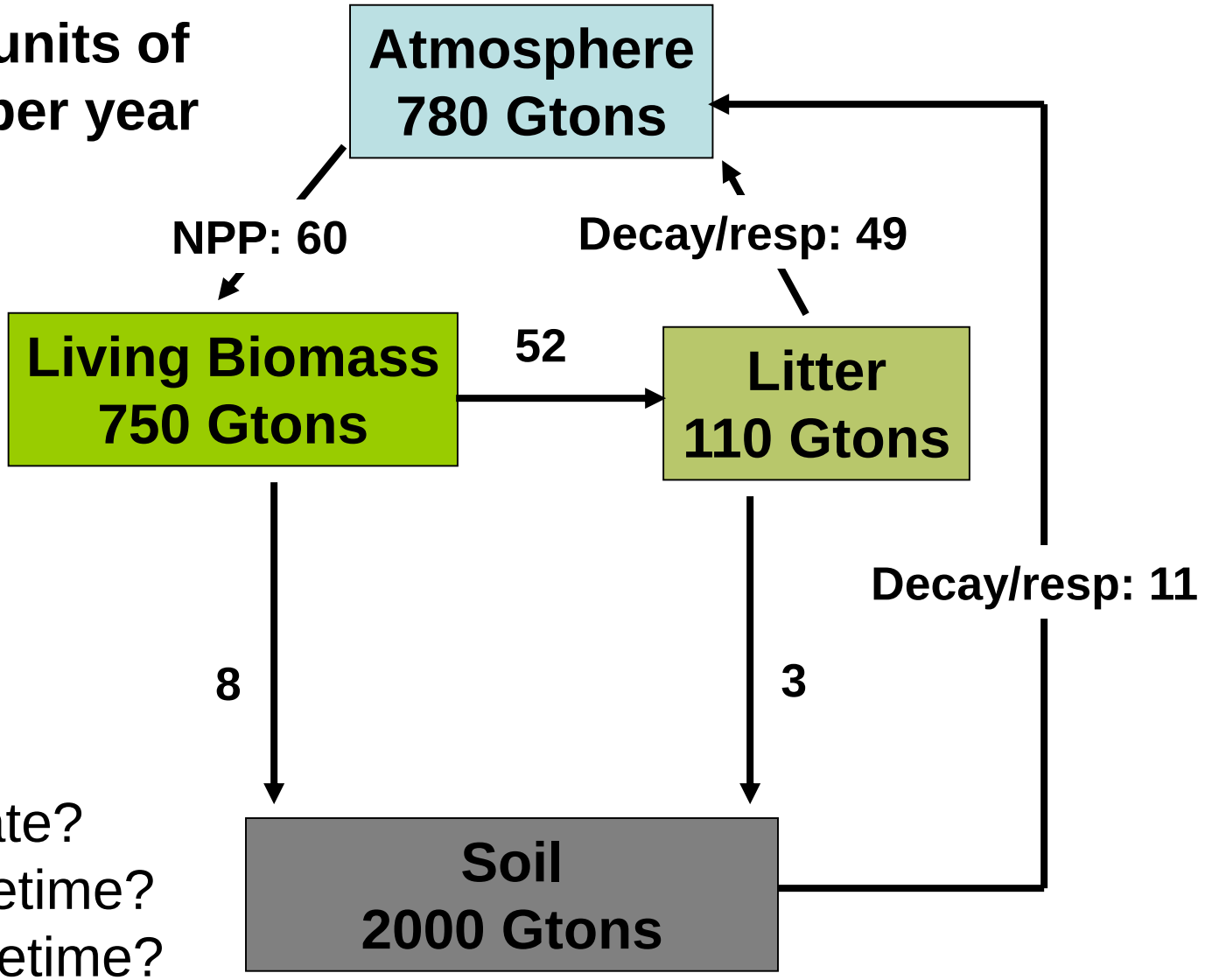
$$nCH_2O + nO_2 \rightarrow nCO_2 + nH_2O + \text{Energy}$$

- NET Primary Productivity (NPP) = P − (R + D)



Terrestrial Biosphere OrgC Cycle

Flows in units of Gtons C per year

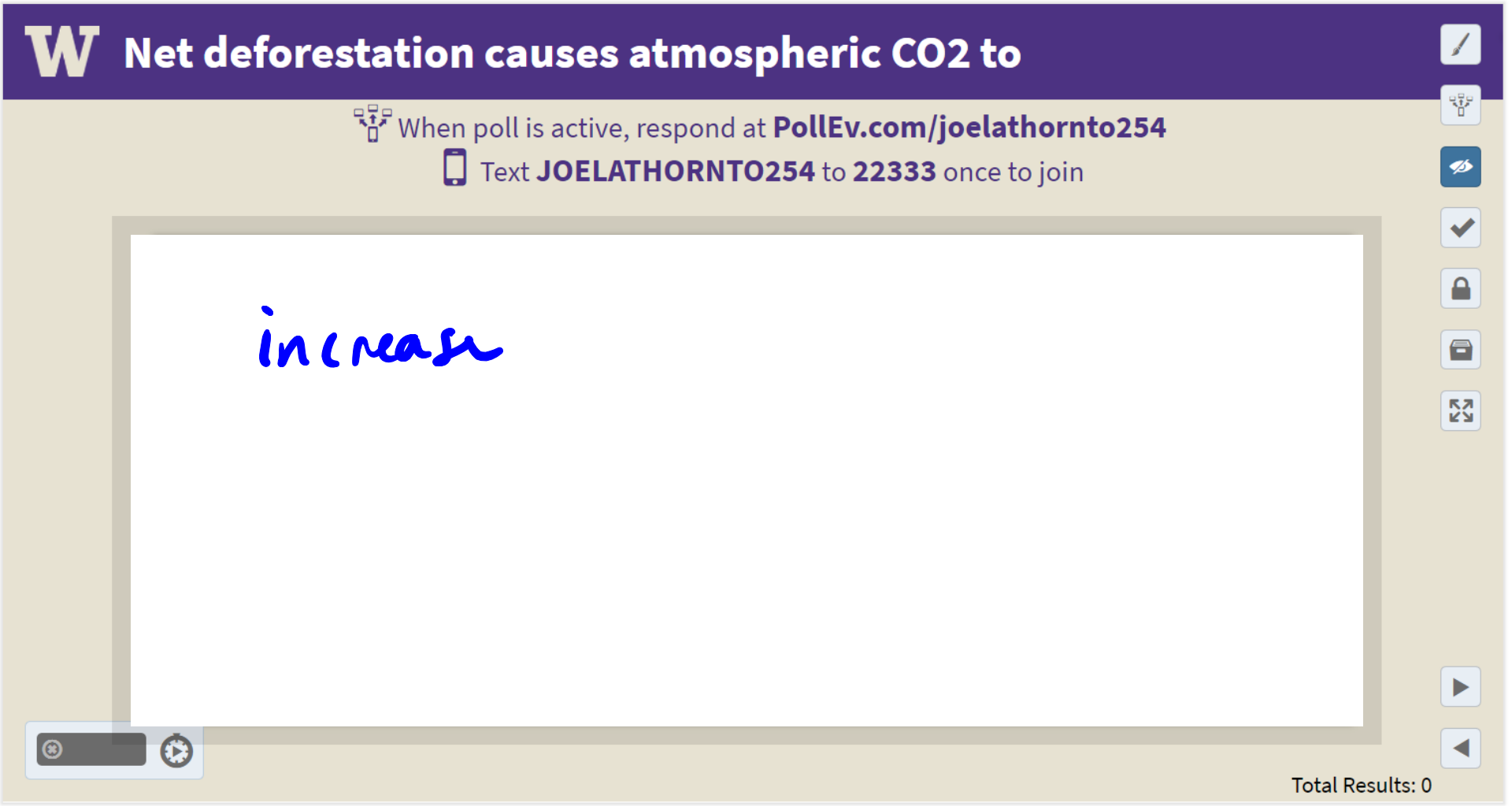


Steady State?
Longest lifetime?
Shortest lifetime?



W. Brazil (Whitaker/Reuters)

Poll Question



Poll Question

Humans are part of the terrestrial biosphere. We eat OrgC and respire CO2. Population will increase in the future, thus, just by breathing we will increase atmospheric CO2.

When poll is active, respond at **PollEv.com/joelathornto254**

Text **JOELATHORNTO254** to **22333** once to join

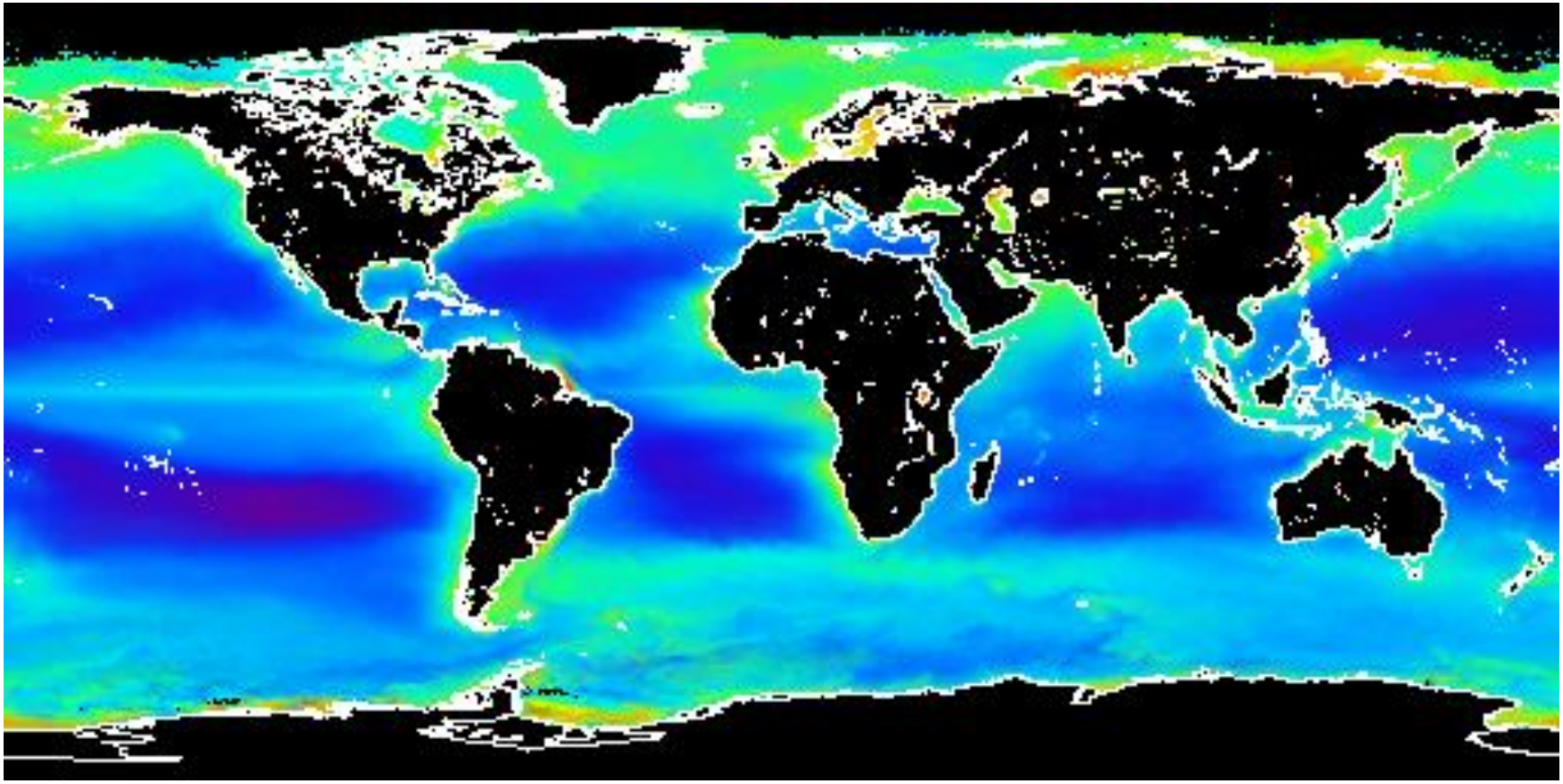
not in net (leaving out energy req. to grow food)

Total Results: 0

Marine Productivity

Global map of ocean color from SEAWIFS satellite chlorophyll →phytoplankton (where the nutrients are)

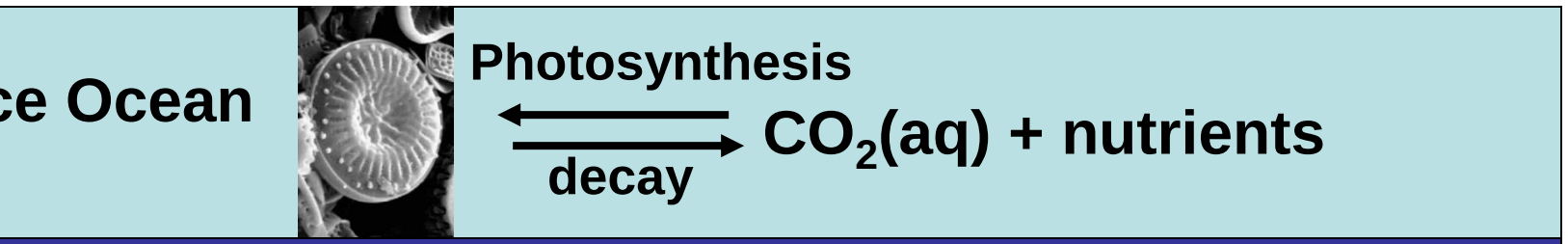
remember upwelling and convection?



Marine Biosphere Organic Carbon Cycle

Marine Organic C Cycle

$CO_2(g)$



Marine Organic C Cycle

$CO_2(g)$

Surface Ocean



Photosynthesis

$CO_2(aq)$ + nutrients

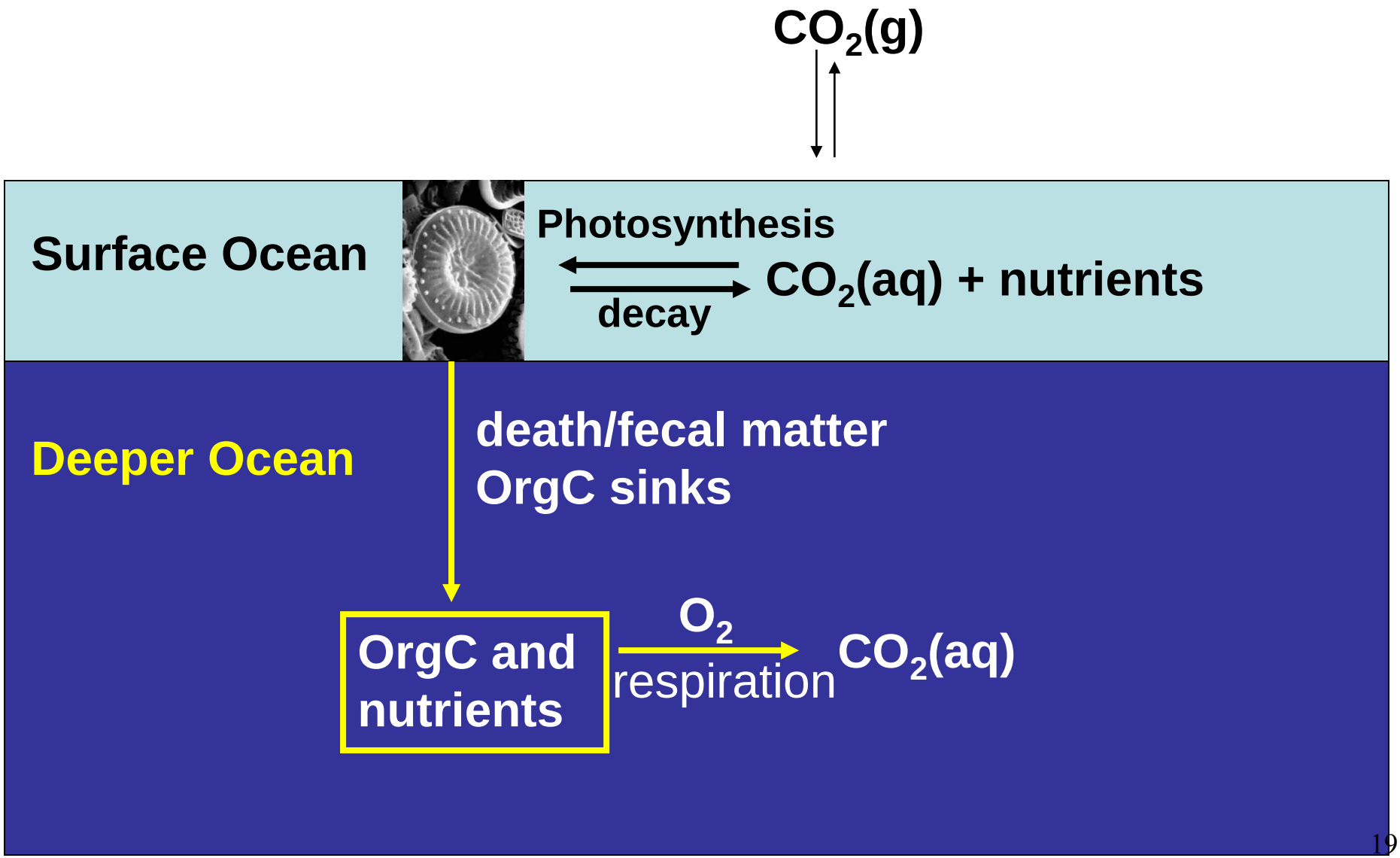
decay

Deeper Ocean

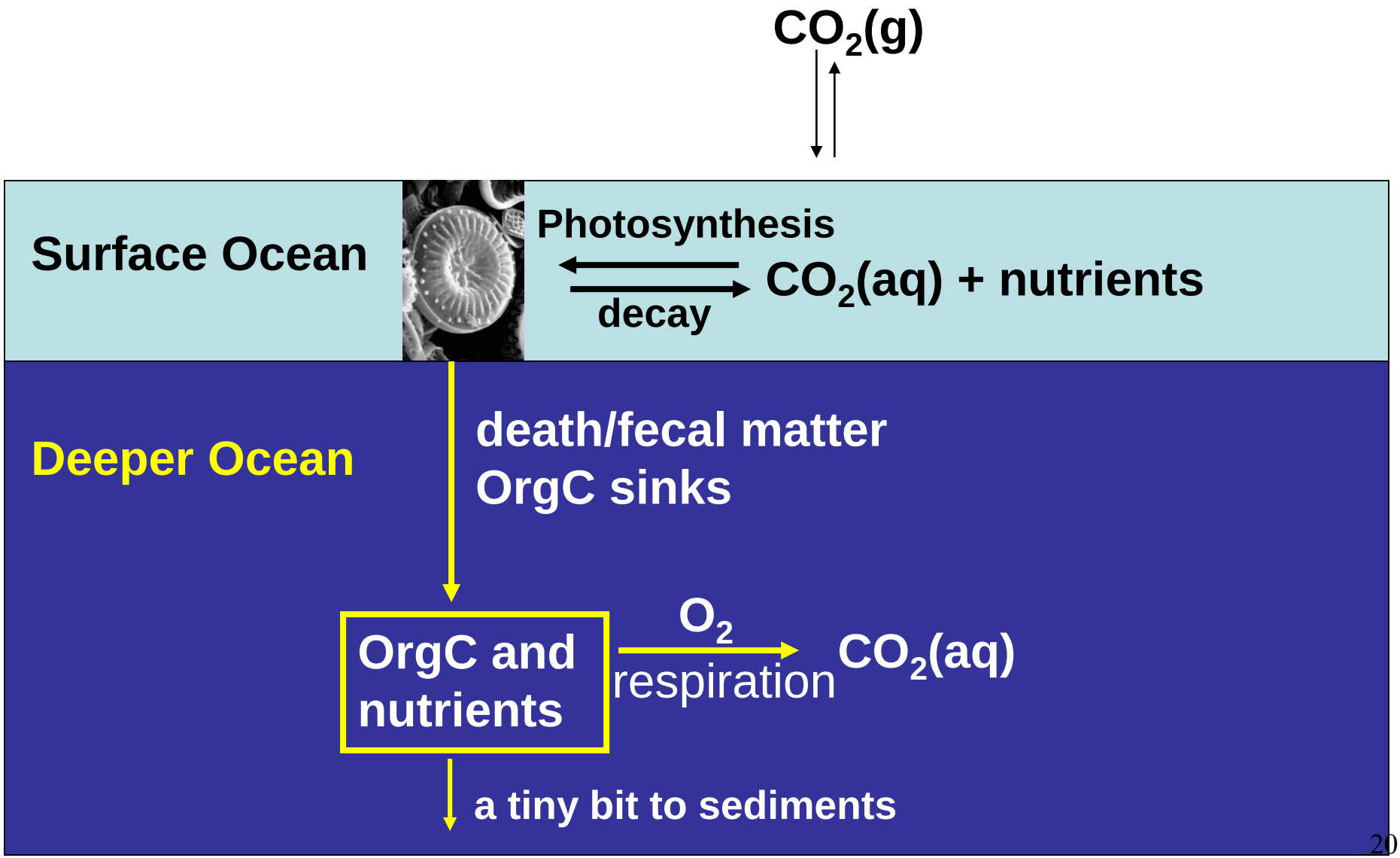
death/fecal matter
OrgC sinks

OrgC and nutrients

Marine Organic C Cycle



Marine Organic C Cycle

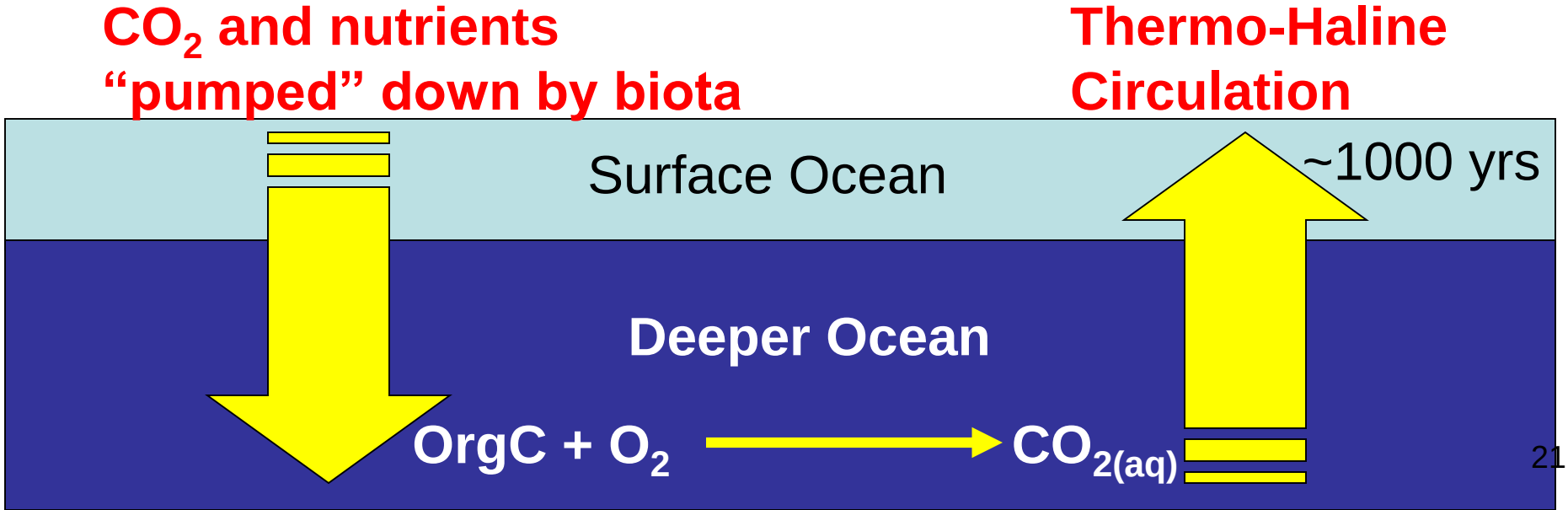


Marine Biological OrgC Pump: Key Points

1. Surface ***depleted*** (relatively) in C and nutrients

2. Deep ocean ***enriched*** in C and nutrients

3. Sinking of OrgC net pumps atm. CO_2 into ocean
–a net sink of CO_2 on ~1000 year timescale



Poll Question

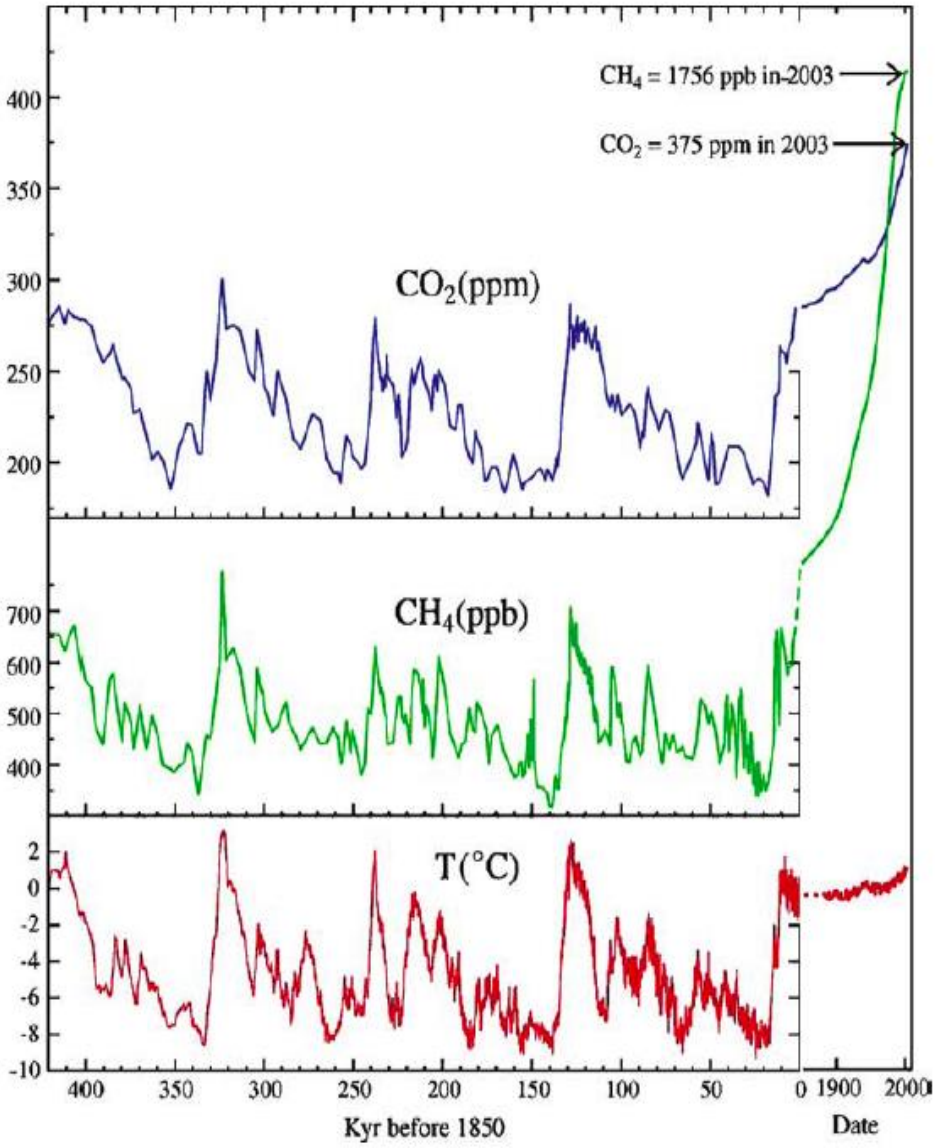
Suppose global T decreases. This cooling leads to less precipitation (right?), less precipitation leads to drier soils and thus more windblown soil dust, which contains, Iron (Fe), a critical nutrient for phytoplankton.

When poll is active, respond at **PollEv.com/joelathornto254**

Text **JOELATHORNTO254** to **22333** once to join

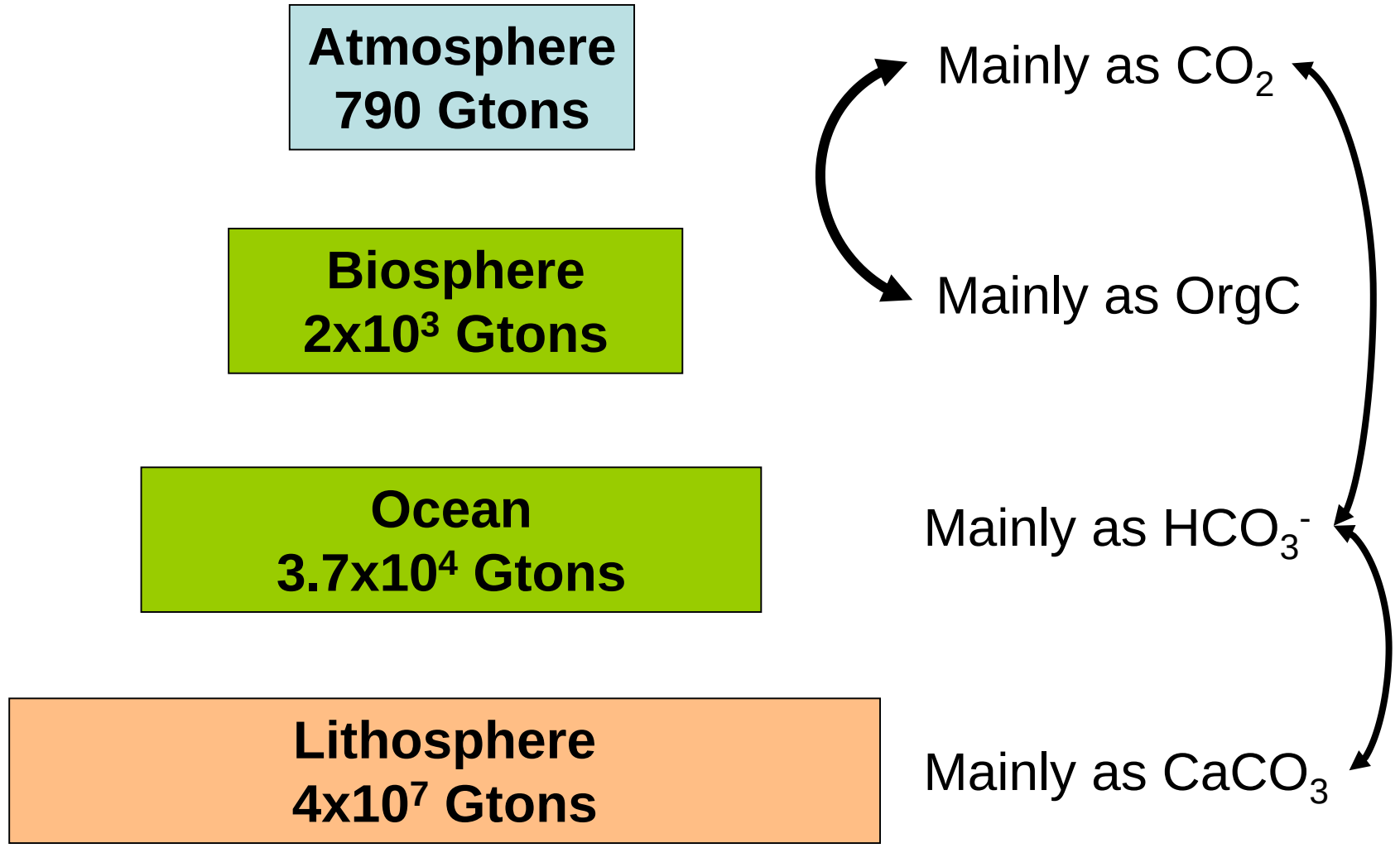
Total Results: 0

Slow Carbon Cycles



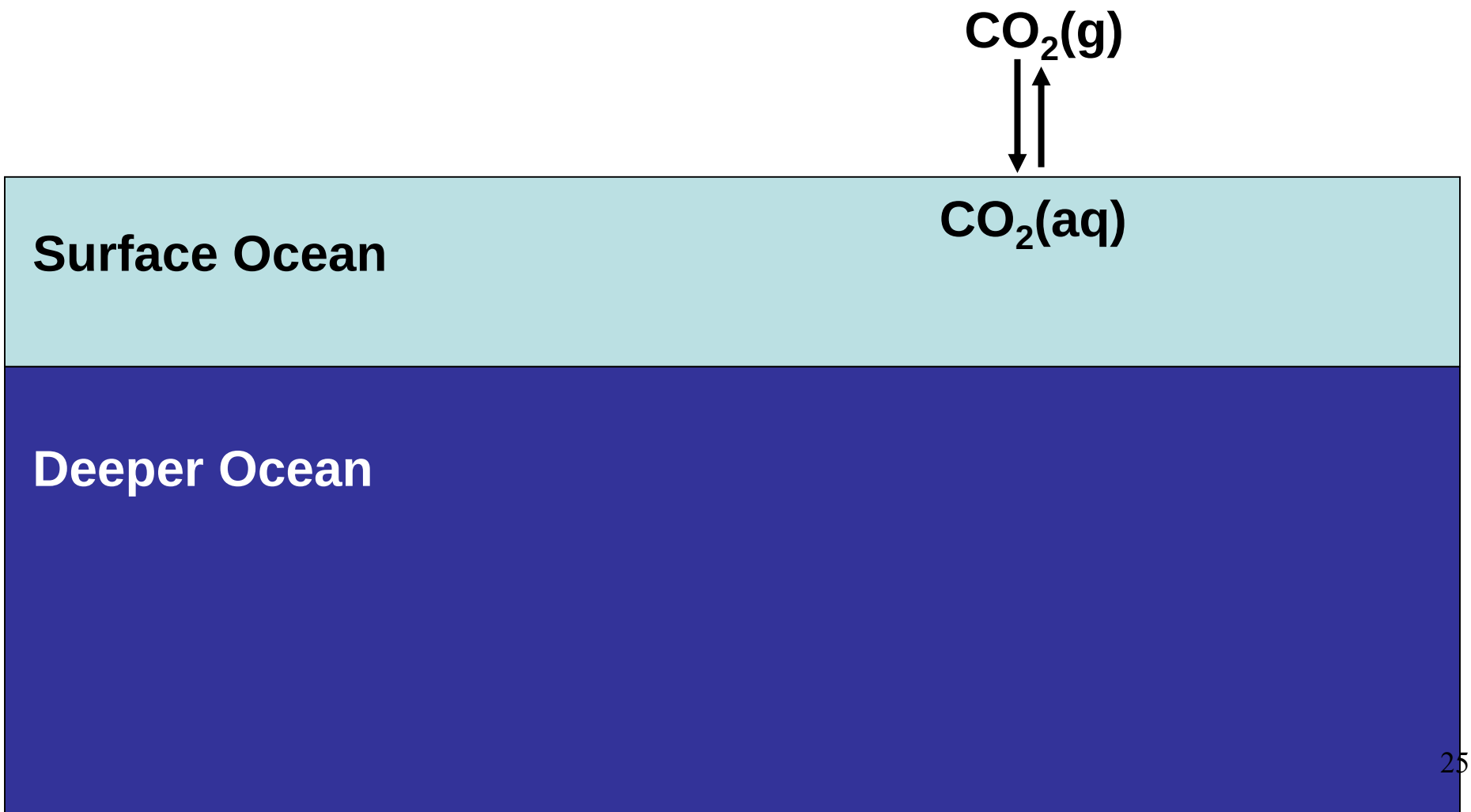
Large (but slow) natural changes carbon

Reservoirs of Carbon

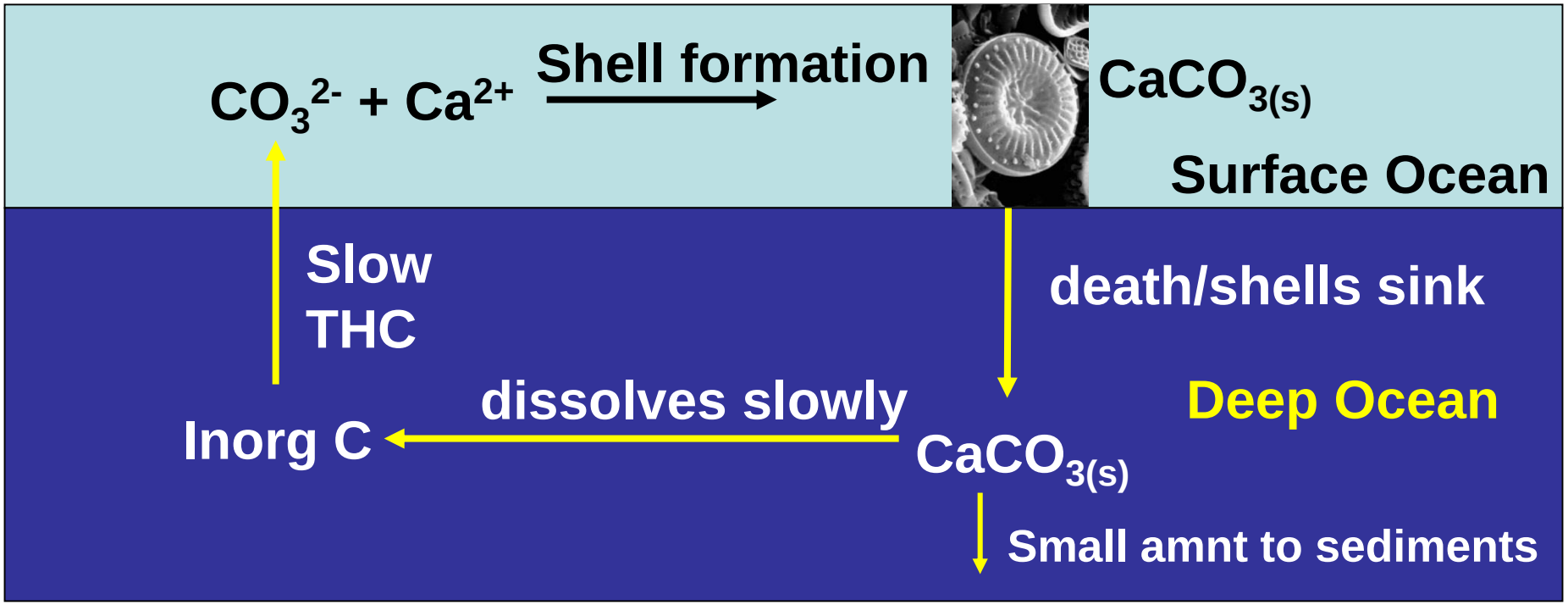


Carbon in the atmosphere and oceans mostly *inorganic*

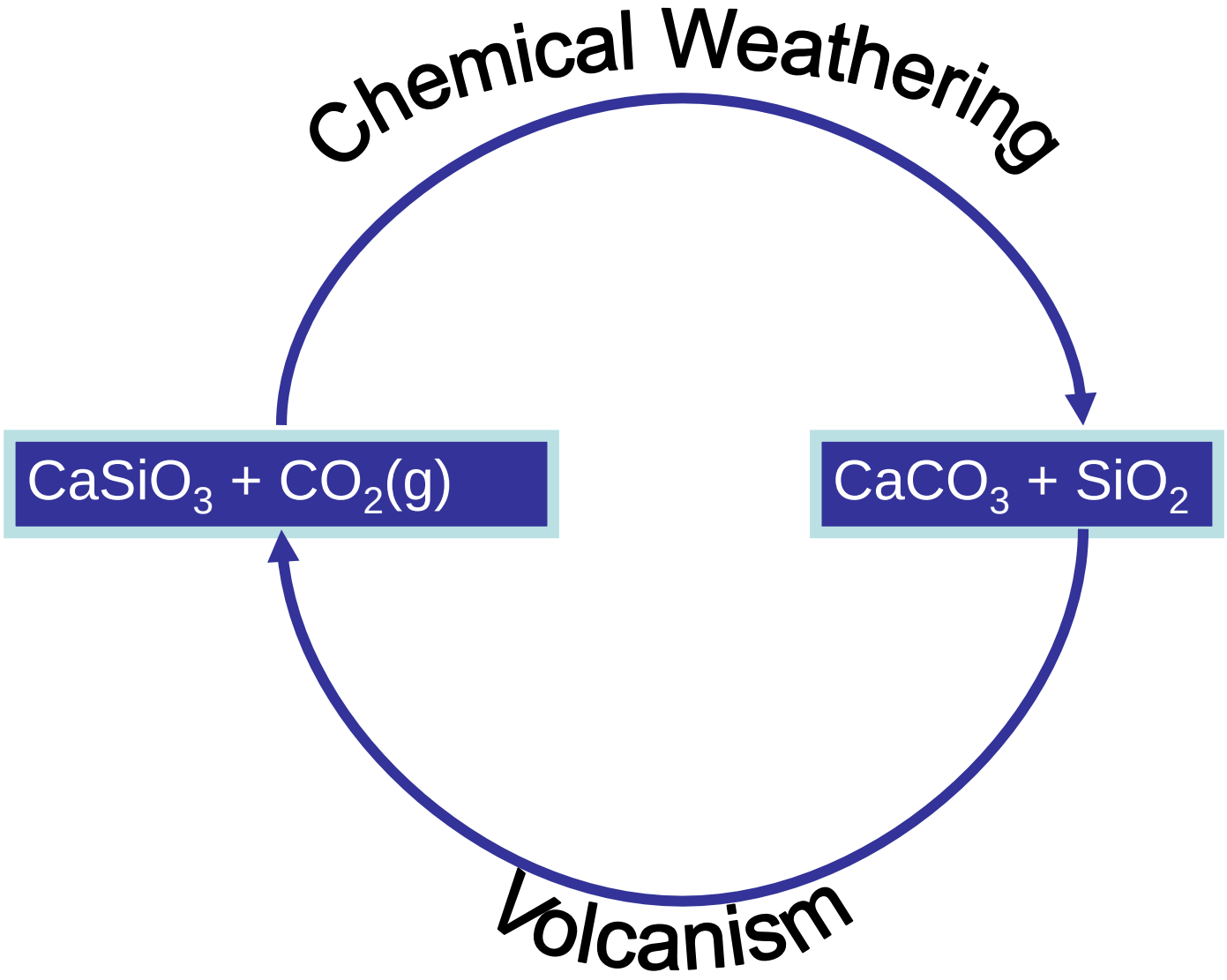
CO_2 Dissolution Into Ocean Water



Shell Formation (A Short-term InorgC Cycle)



The "Ultimate" InorgC Cycle

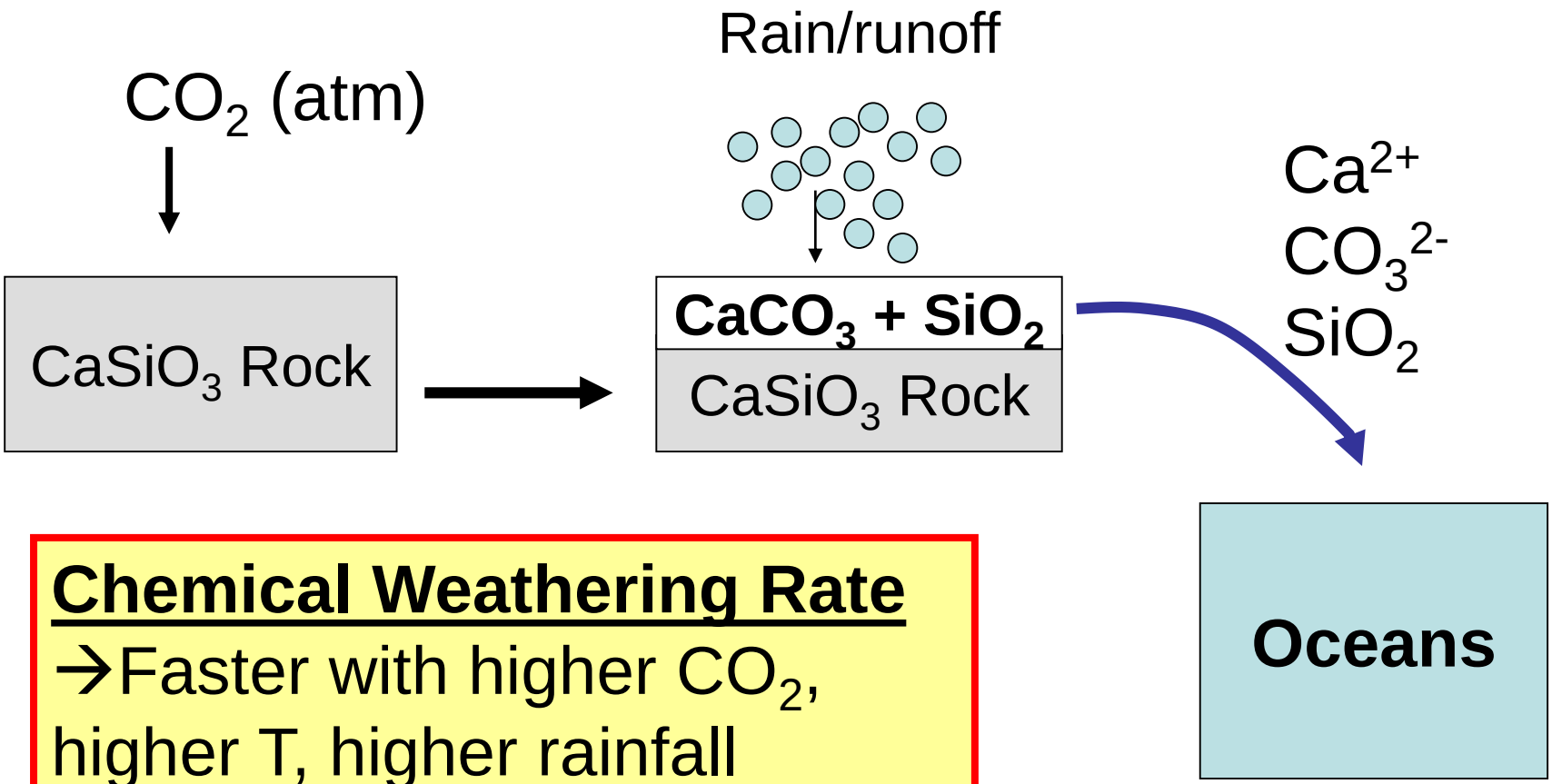


Weathering and Volcanism: Rocks Do Chemistry

Example of Weathering ($CaCO_3$ dissolution)



Silicate Weathering (simplified)

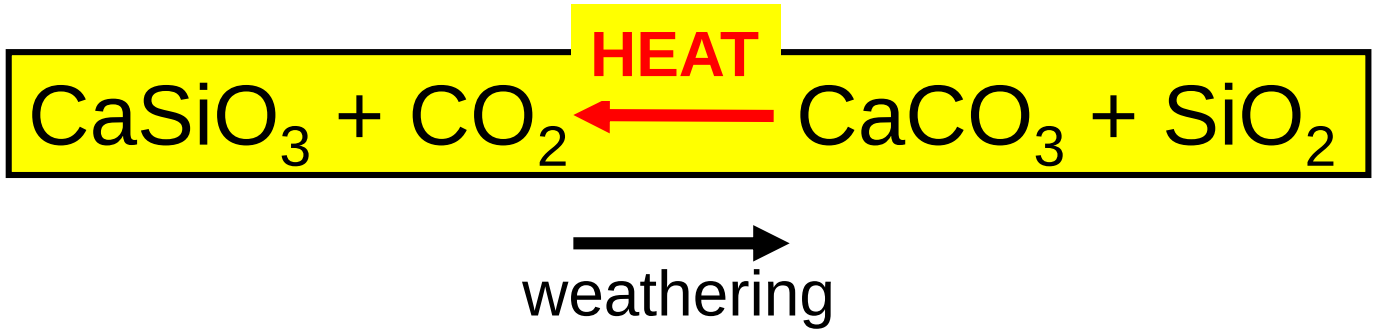


Chemical Weathering Rate

→Faster with higher CO_2, higher T, higher rainfall

Volcanic Degassing

Volcanism causes reverse of weathering



Tectonic activity converts $CaCO_3$ rocks back to silicate rocks ($CaSiO_3$) in the mantle (magma).

Released CO_2 finds way to atmosphere via vents

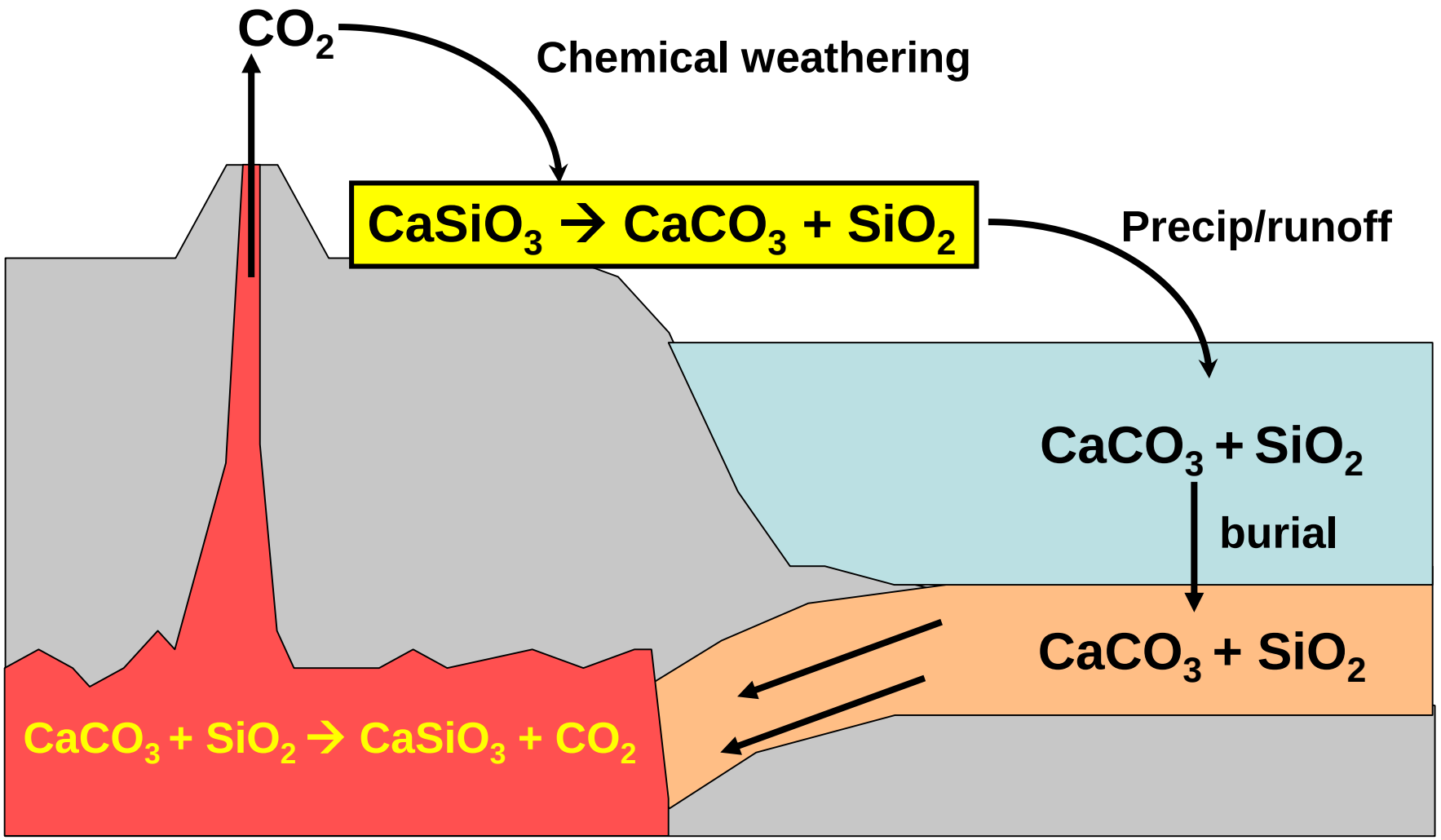
Volcanism in Action







Silicate Weathering – Volcanism Cycle

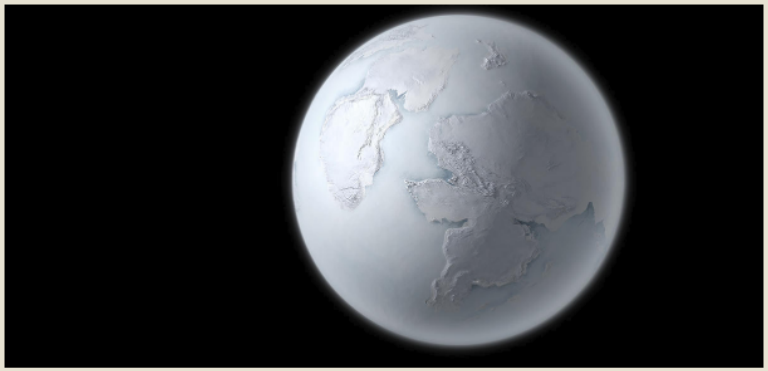


This cycle operates on 0.5 – 1 million year timescale.

Poll Question

Suppose there was a massive input of CO2 into the atmosphere, choose the best statement:

When poll is active, respond at **PollEv.com/joelathornto254** Text **JOELATHORNTO254** to **22333** once to join



Total Results: 0

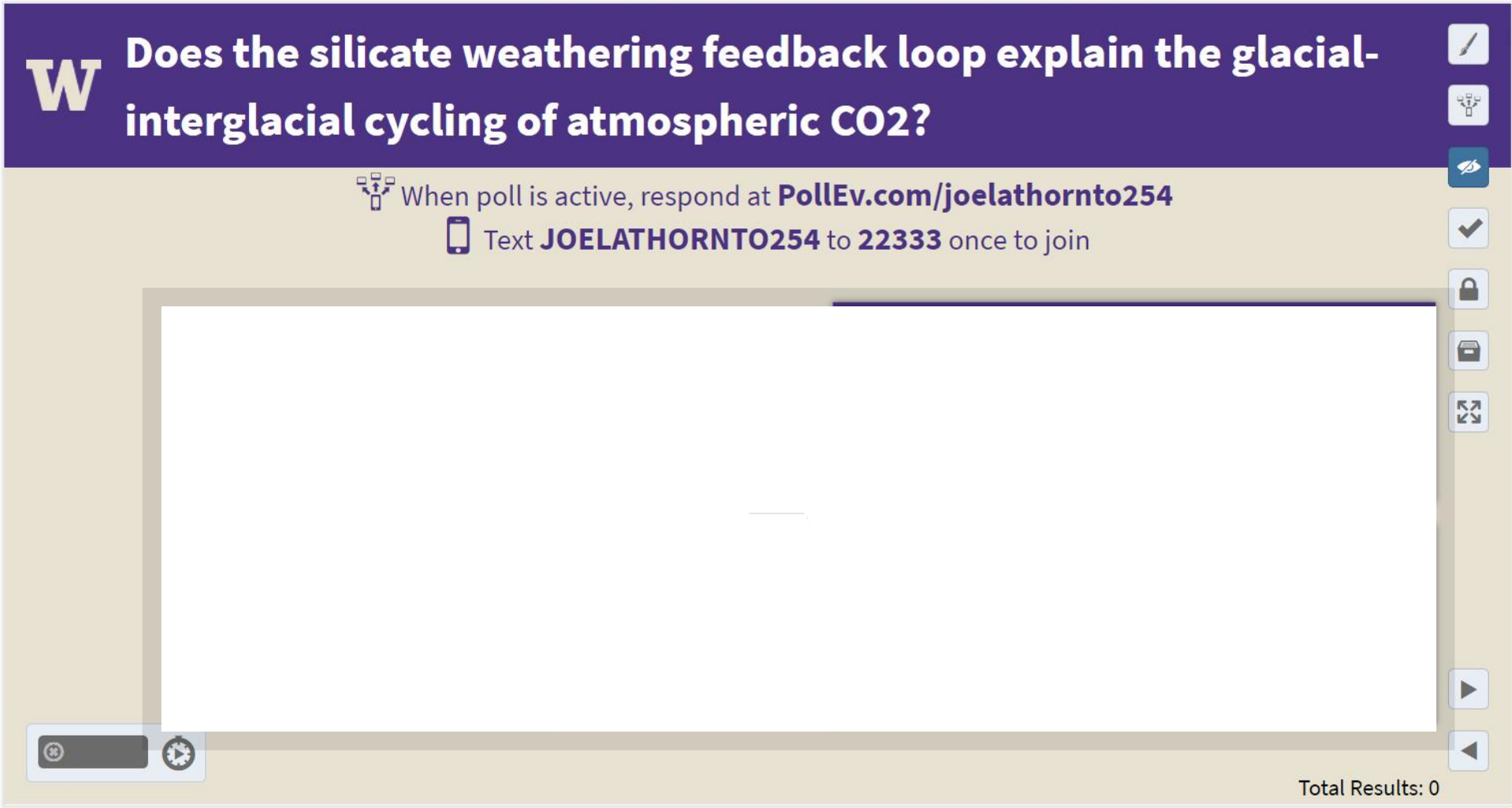
Silicate Weathering Feedback

Atmospheric CO_2

Silicate Weathering Rate

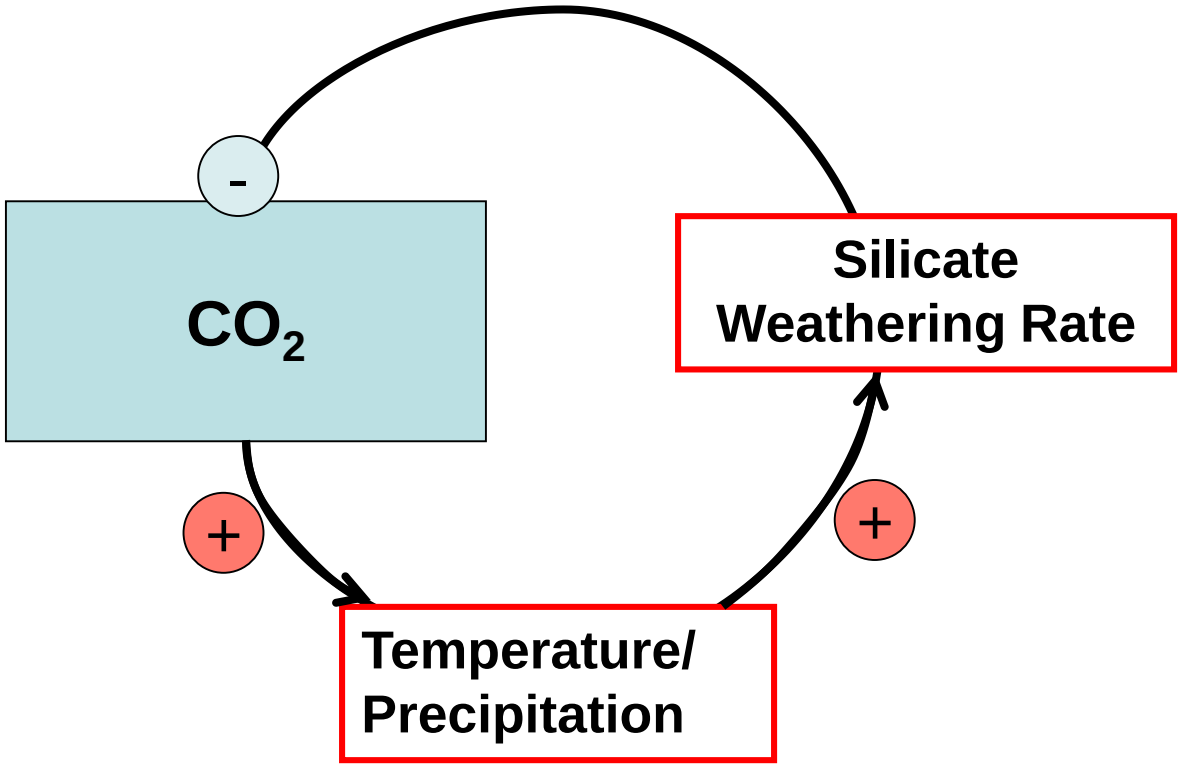
Temperature/ Precipitation

Poll Question

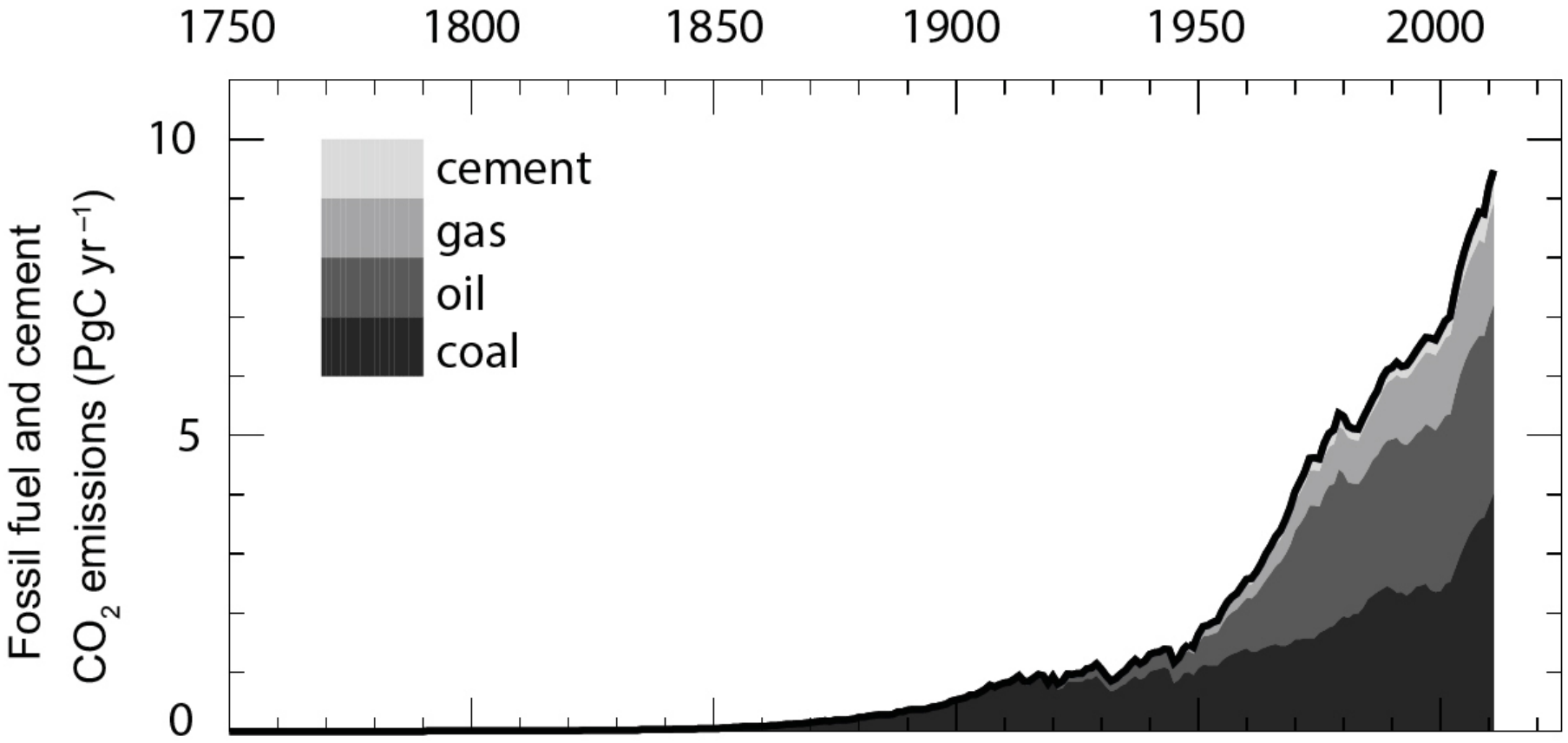


Silicate Weathering Feedback

Negative Feedback—Stabilizing Climate
(on *long time* scales 0.5 to 1 million years)

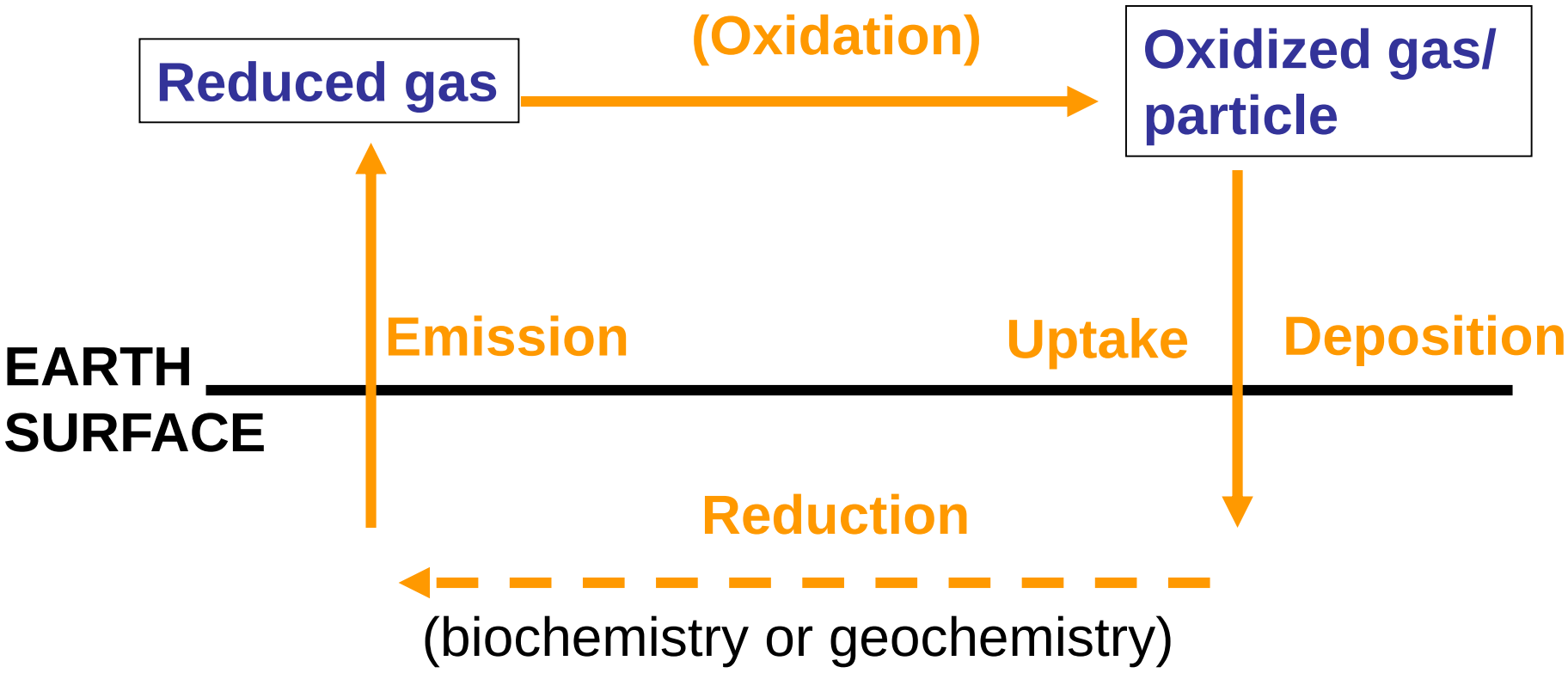


Anthropogenic CO_2 emissions since pre-industrial



IPCC 2014

Global Biogeochemical Cycles



Poll Question

Fossil fuel burning by humans injects ~ 8 Gt C per year into the atmosphere as CO2, which is a ___ over the natural input rate of Carbon from the sediments to the atmosphere.

When poll is active, respond at **PollEv.com/joelathornto254**

Text **JOELATHORNTO254** to **22333** once to join

Total Results: 0

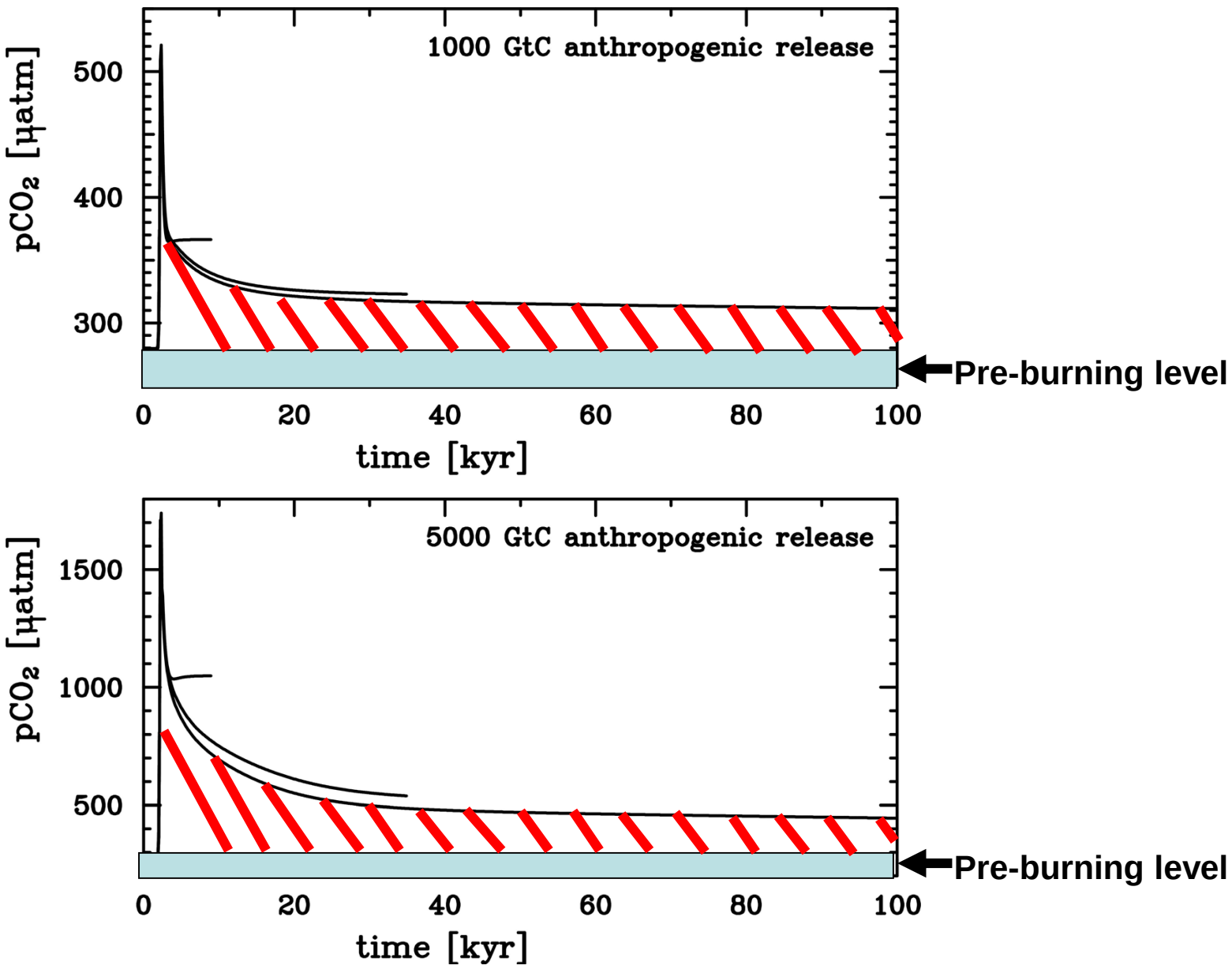
Poll Question

If we ceased fossil fuel burning and deforestation, how long would it take the Earth system to fully recover from our current perturbation?

When poll is active, respond at **PollEv.com/joelathornto254**

Text **JOELATHORNTO254** to **22333** once to join

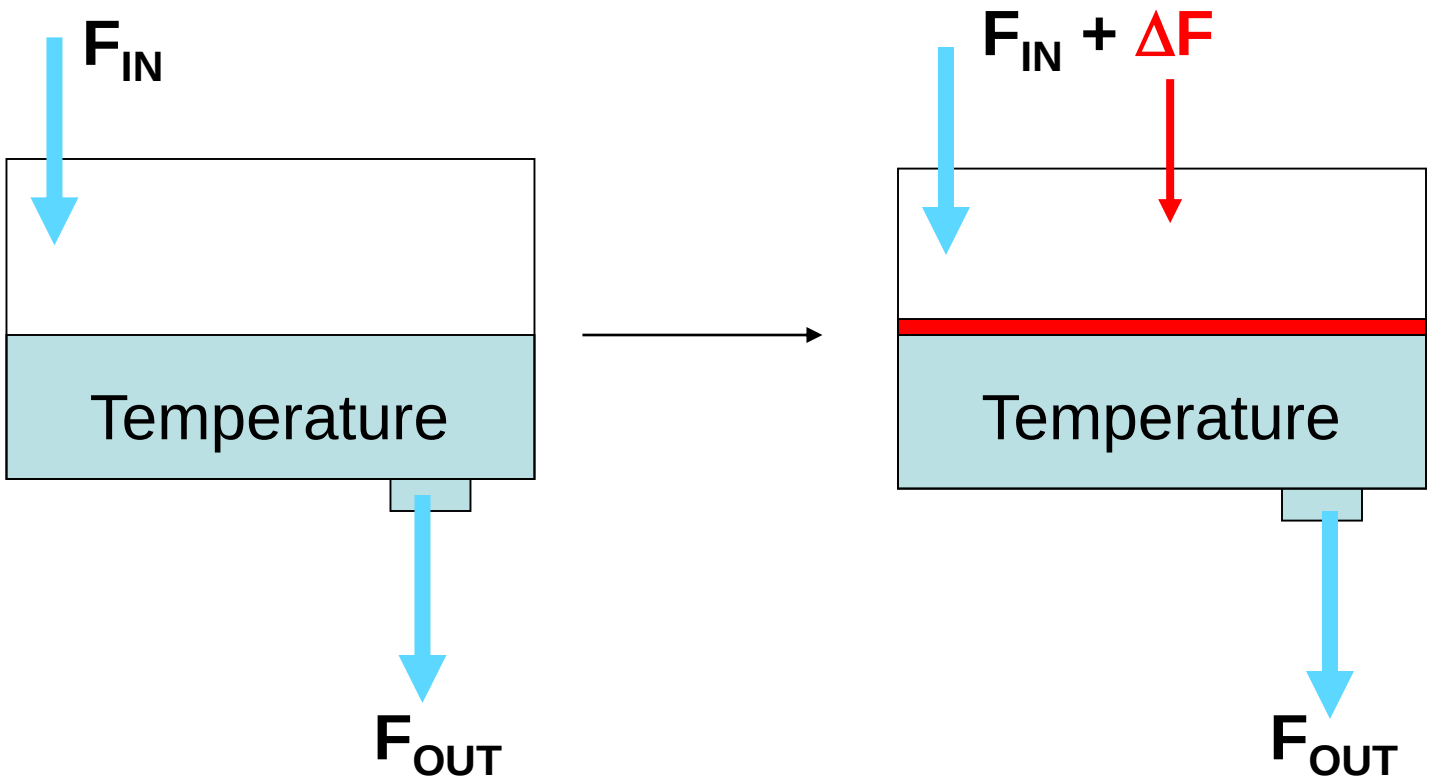
A Long View of Fossil Fuel Perturbation



Adapted From: Archer, *J. Geophys. Res.*

Climate Forcings

a perturbation that directly or indirectly affects Earth's energy budget



Radiative Forcings and Climate Sensitivity

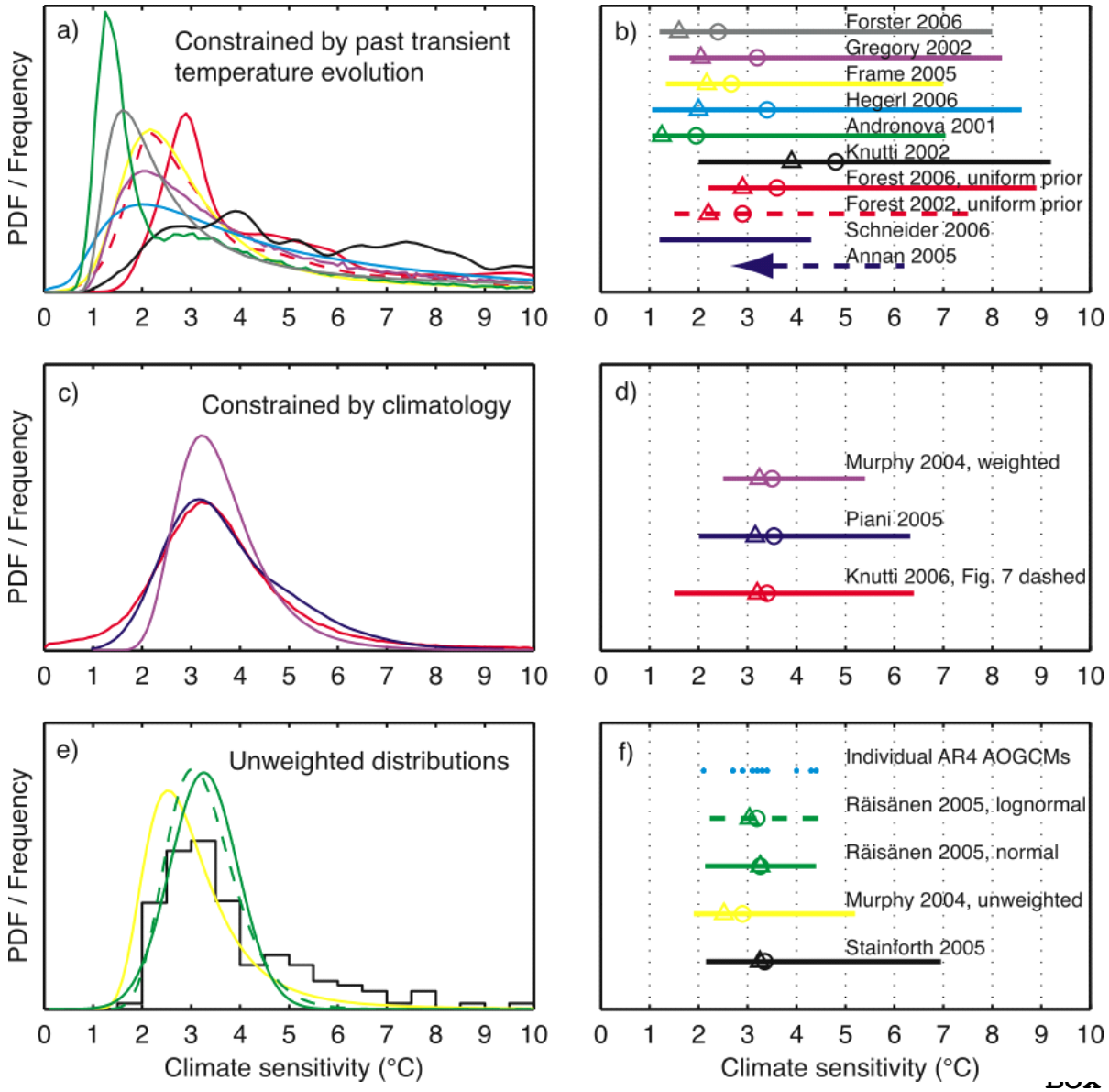
Climate Sensitivity-All about Feedbacks

$$\Delta T = \lambda \Delta F$$

λ is the ***climate sensitivity parameter***

→ ***units: K "per" W/m^2***
→ **amount of climate change for a forcing**
→ **λ determined by feedbacks!**

Estimates of Climate Sensitivity



T change for a 4 W/m² forcing (i.e. "double CO_2")

Most probable λ ~ 0.75 K/(W/m²)

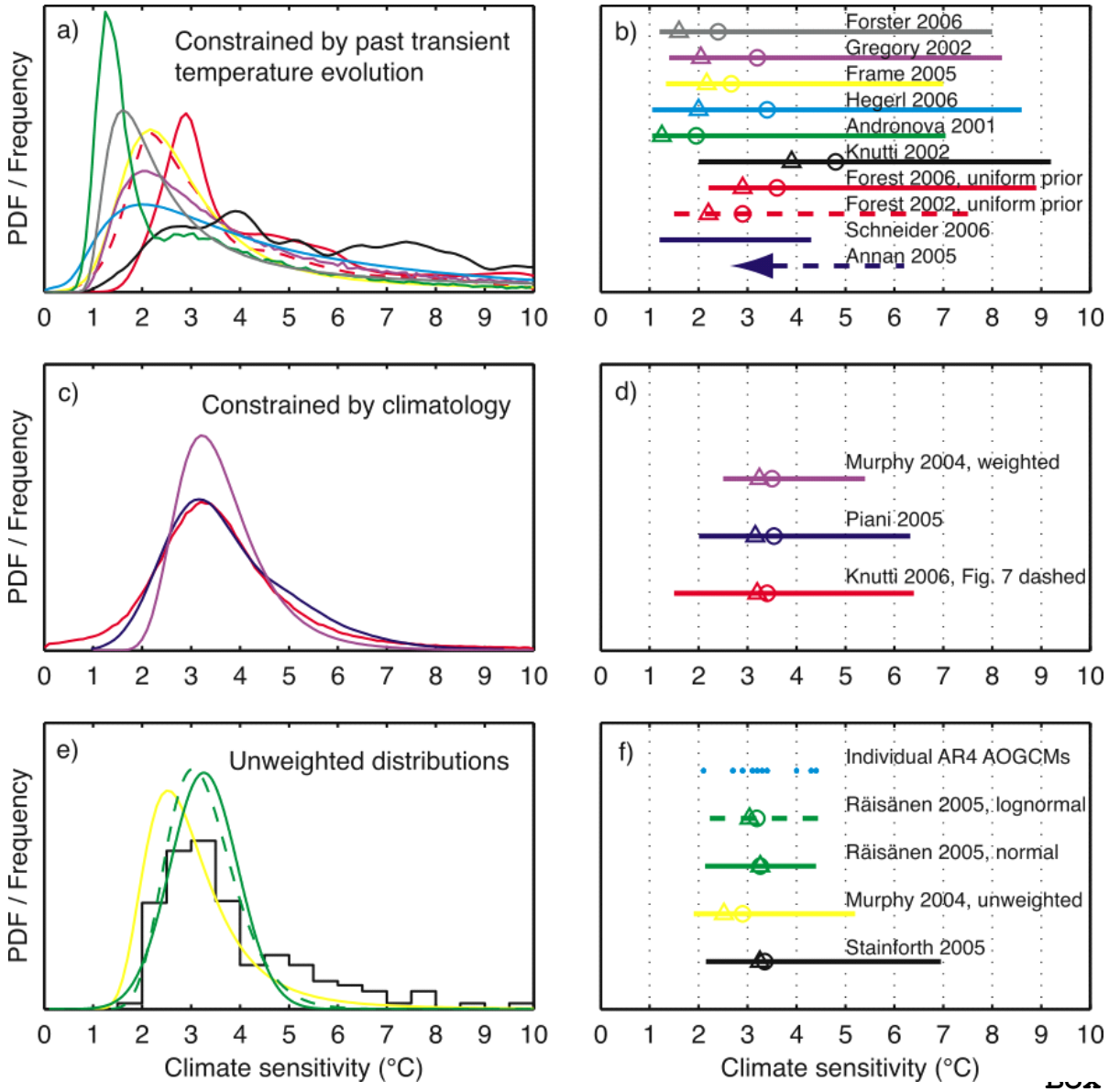
Poll Question

Globally averaged solar insolation varies by 0.2% every 100Kyr, equivalent to a -0.5 W/m2 forcing. From this info and the T record in the ice core, only, estimate a climate sensitivity parameter.

When poll is active, respond at **PollEv.com/joelathornto254** Text **JOELATHORNTO254** to **22333** once to join

Total Results: 0

Estimates of Climate Sensitivity



T change for a 4 W/m² forcing (i.e. "double CO_2")

Most probable λ ~ 0.75 to 1 K/(W/m²)