The Carbon Cycle: Mineral Weathering

EES 2110

Introduction to Climate Change

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Class #15: Monday, February 13 2023

Ice Age Feedbacks

Ice Age Feedbacks

- Orbital cycles match timing of ice ages
- Changes in sunlight are too small to explain temperature changes
- There must be positive feedbacks to amplify them

Ice-Age Feedbacks:

- Temperature starts to fall
  - Glaciers grow \(\rightarrow\) greater albedo
  - \(\COO\) drops \(\rightarrow\) weaker greenhouse
  - Colder
- Temperature starts to rise
  - Glaciers retreat \(\rightarrow\) smaller albedo
  - \(\COO\) rises \(\rightarrow\) stronger greenhouse
  - Warmer
- Without \(\COO\) and ice-albedo feedbacks, ice-ages couldn’t happen
- Ice ages can’t happen with today’s \(\COO\) levels.

Theory of Feedbacks

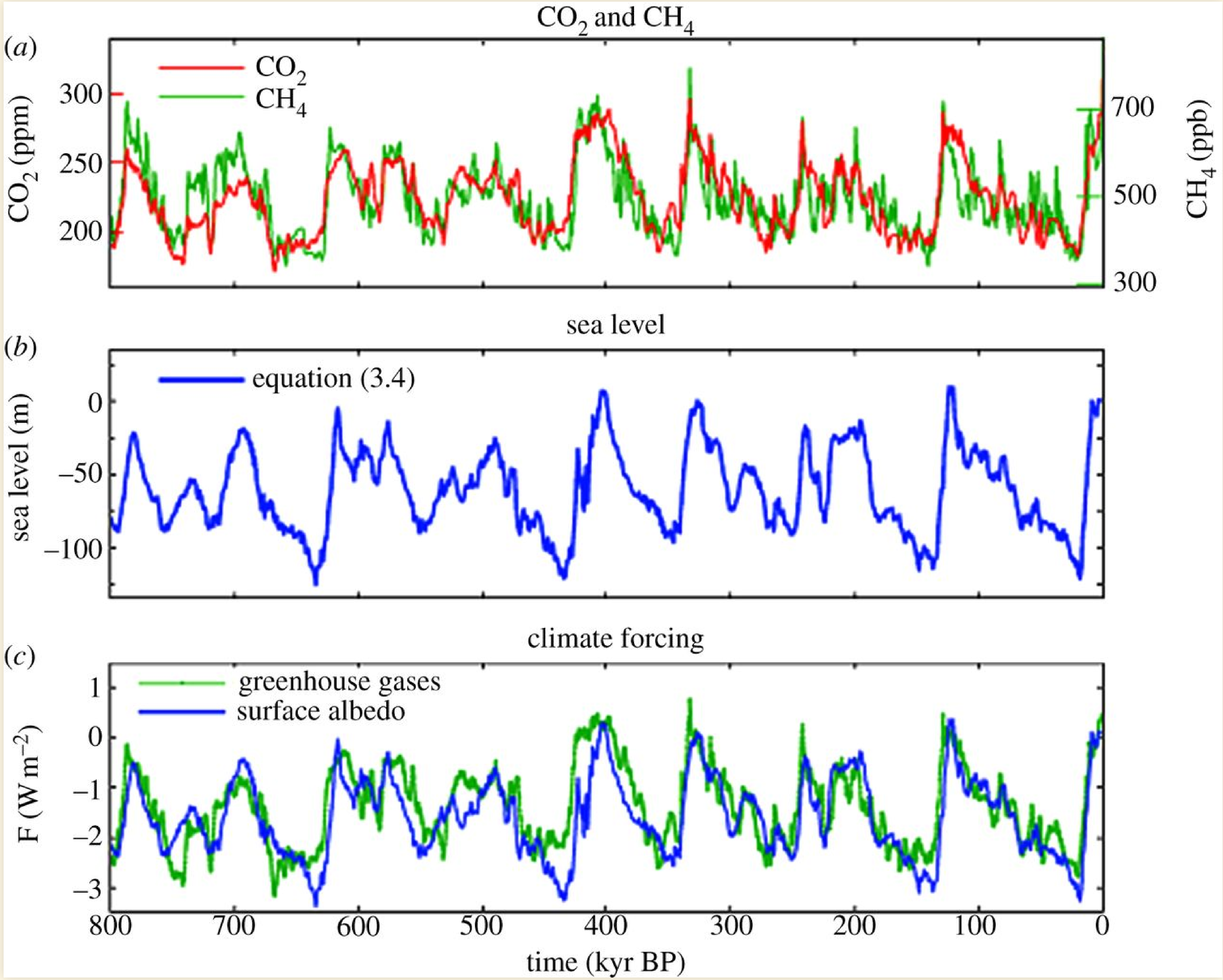
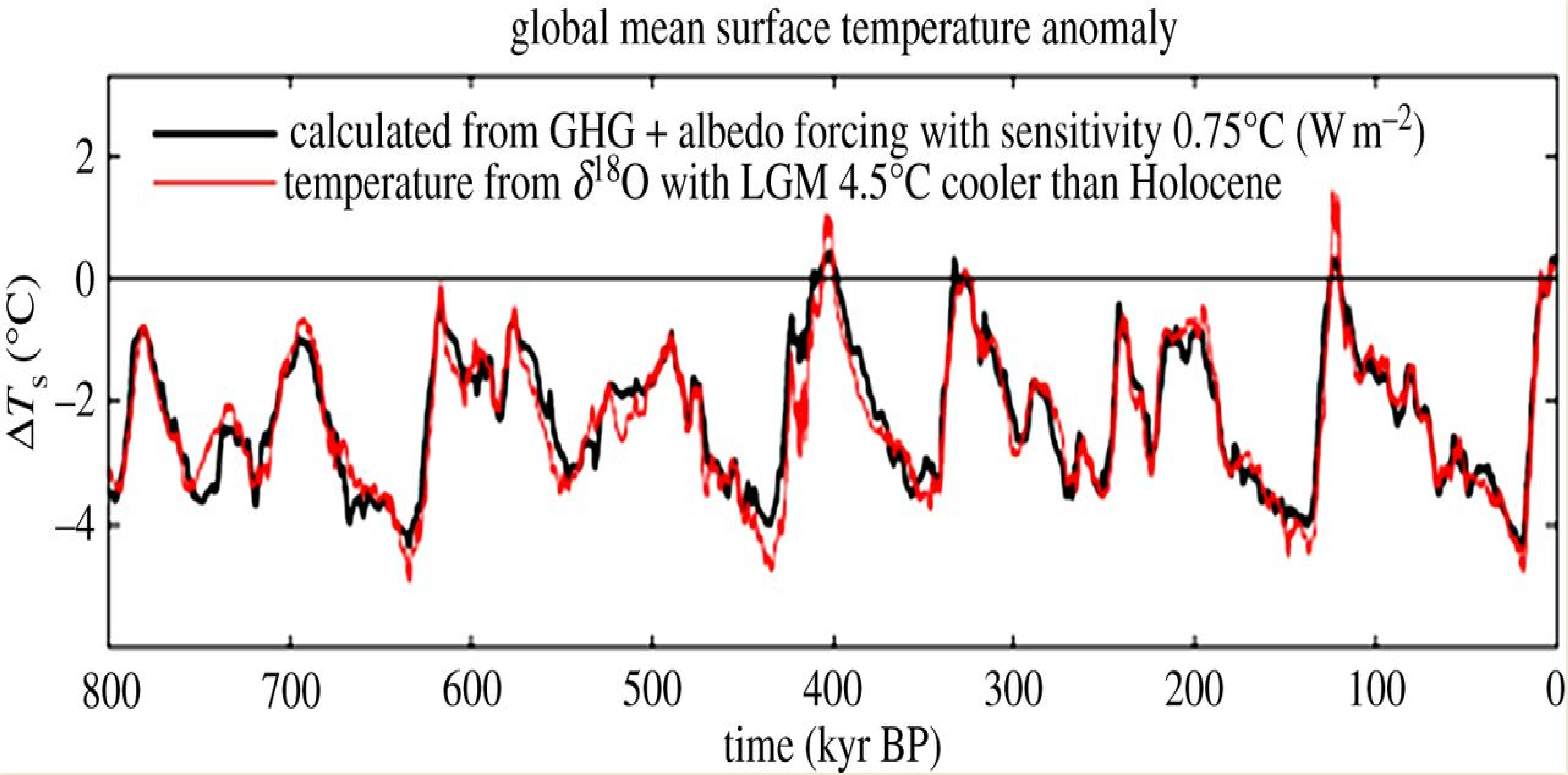


Image credit: J. Hansen *et al.*, Phil. Trans. Royal Soc. A **371**, 20120294 (2013) doi:10.1098/rsta.2012.0294

Theory vs. Observations



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The Carbon Dioxide Theory of Climatic Change

By GILBERT N. PLASS

The Johns Hopkins University, Baltimore, Md.[1]

(Manuscript received August 9 1955)

Abstract

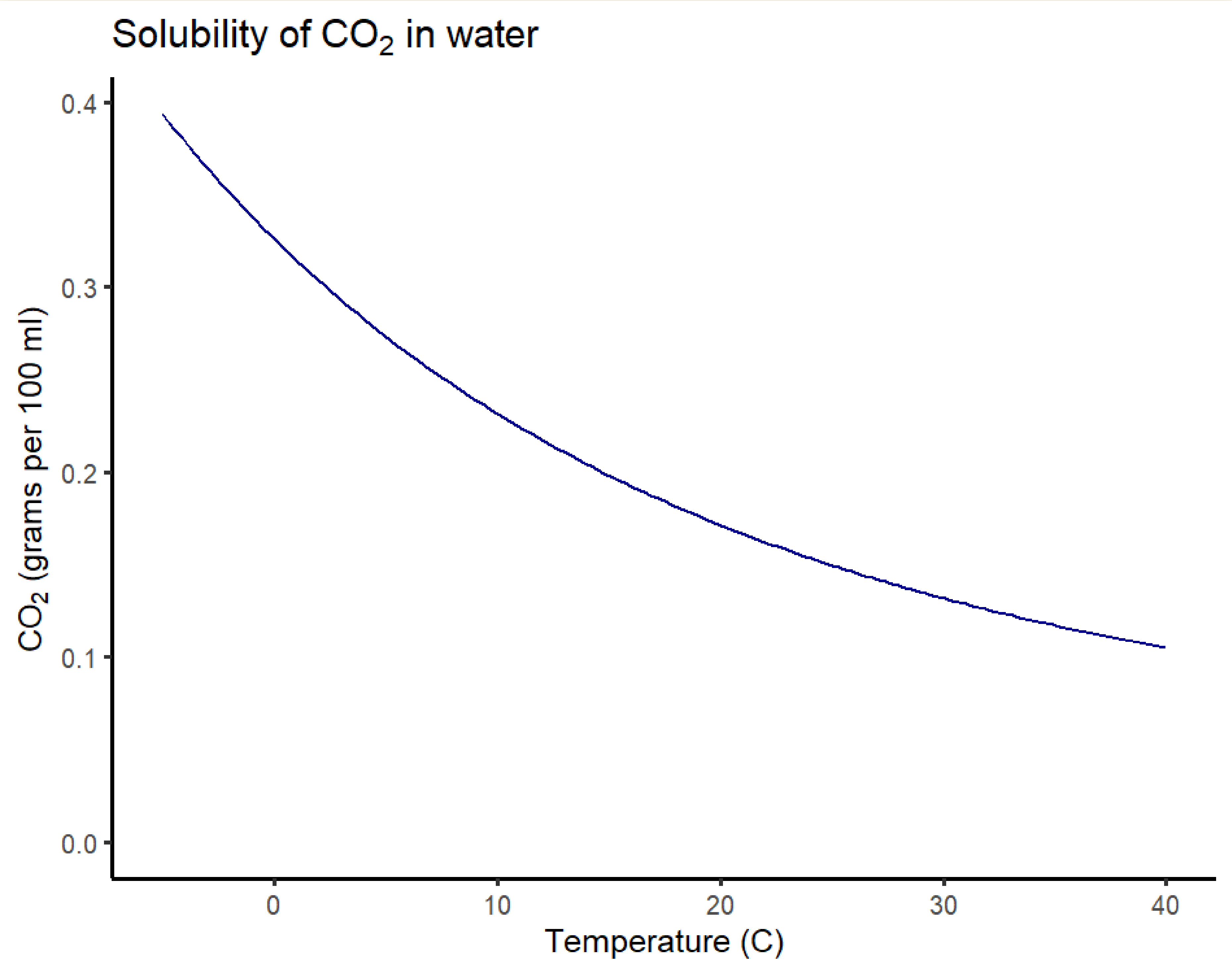
The most recent calculations of the infra-red flux in the region of the 15 micron CO_2 band show that the average surface temperature of the earth increases 3.6° C if the CO_2 concentration in the atmosphere is doubled and decreases 3.8° C if the CO_2 amount is halved, provided that no other factors change which influence the radiation balance. Variations in CO_2 amount of this magnitude must have occurred during geological history; the resulting temperature changes were sufficiently large to influence the climate. The CO_2 balance is discussed. The CO_2 equilib-

predicted by the CO_2 theory. When the total CO_2 is reduced below a critical value, it is found that the climate continuously oscillates between a glacial and an inter-glacial stage with a period of tens of thousands of years; there is no possible stable state for the climate. Simple explanations are provided by the CO_2 theory for the increased precipitation at the onset of a glacial period, the time lag of millions of years between periods of mountain building and the ensuing glaciation, and the severe glaciation at the end of the Carboniferous. The extra CO_2 released into the atmosphere by industrial processes and other human activities may have caused the temperature rise during the present century. In contrast with other theories of climate, the CO_2 theory predicts that this warming trend will continue, at least for several centuries.

G.N. Plass, Tellus **8**, 140–154. (1956)

The Oceans Breathe

The Oceans Breathe



Solubility pump:

- Temperature rises:
  - CO_2 moves from ocean to atmosphere.
- Temperature falls:
  - CO_2 moves from atmosphere to ocean.

Positive feedback

Biological Pump

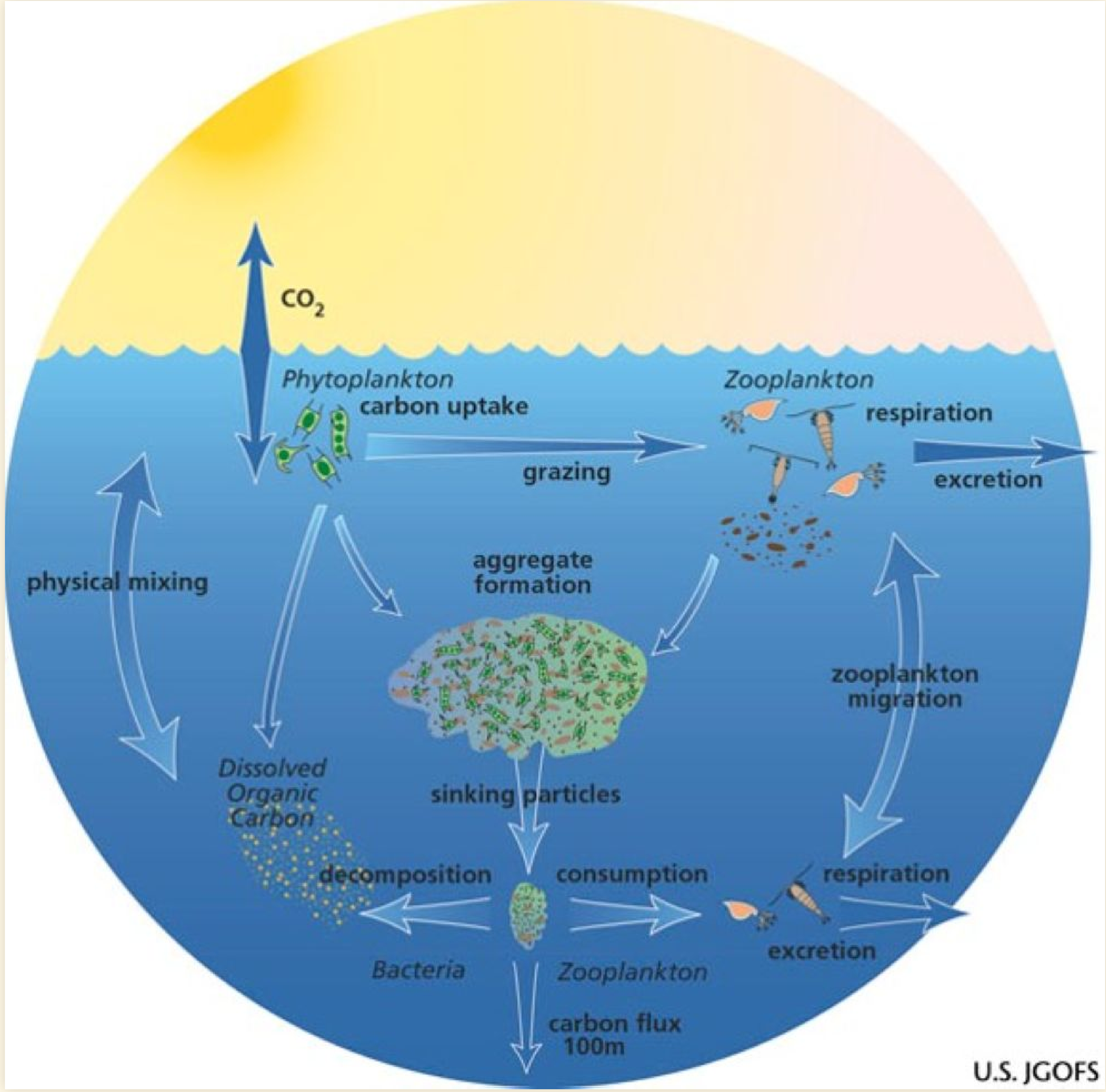


Image credit: US Joint Global Ocean Flux Study

Structure of the ocean

Structure of the ocean

Lower Atmosphere:

- Heated from bottom
  - Sunlight absorbed at bottom (ground)
- Warmer at bottom
- Unstable $\rightarrow$ well-mixed

Ocean:

- Heated from top
  - Sunlight absorbed at top (sea-surface)
- Warmer at top
- Thermocline as barrier to mixing
- Surface layer mixed by wind
- Deep ocean poorly mixed

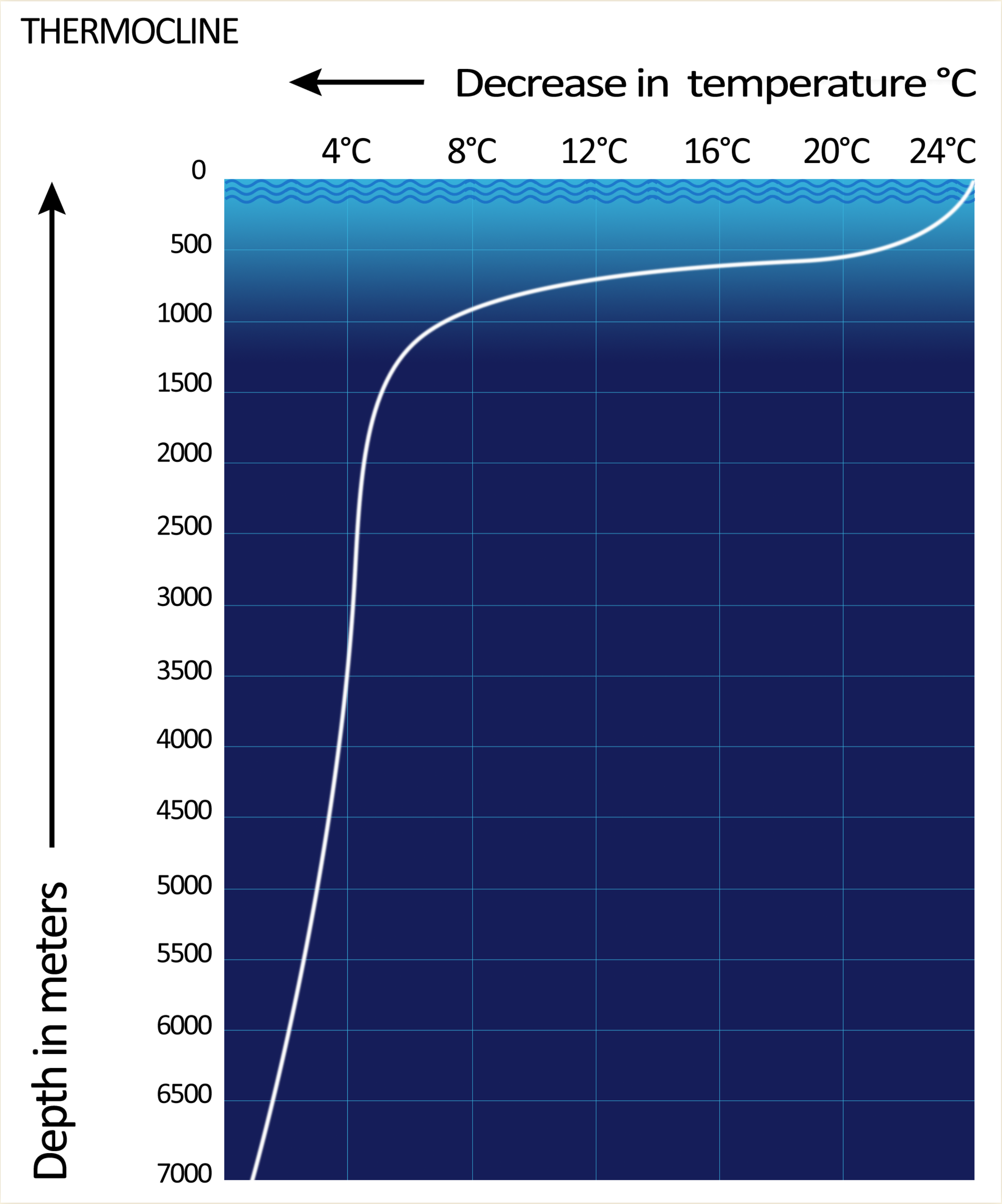


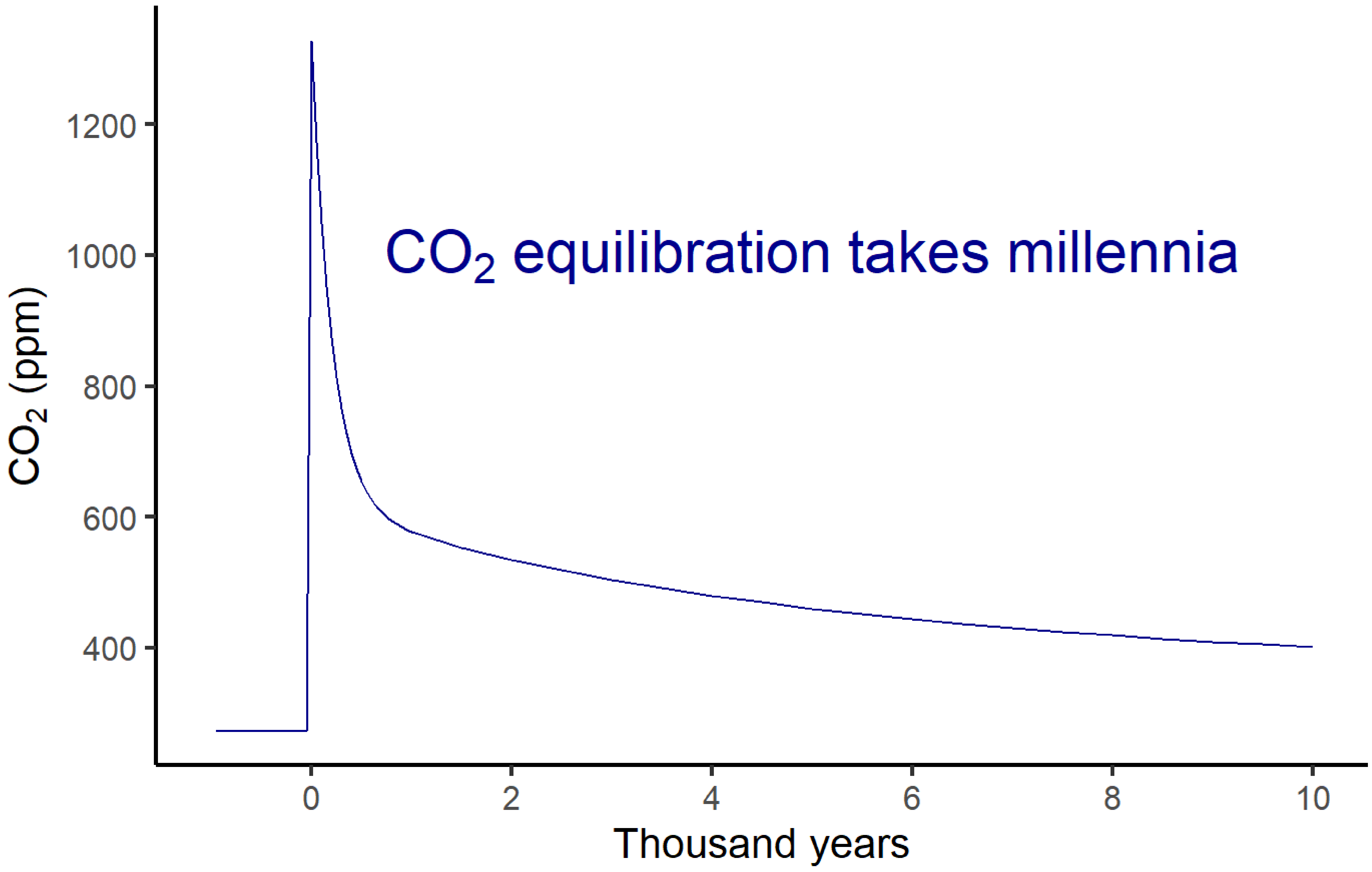
Image credit: Wikimedia

Ocean Carbon Cycle

Numbers:

- **Air $\Leftrightarrow$ Upper ocean:**
  - 1000 GT carbon in upper ocean
  - Very fast: 92 GT/year from atmosphere
- **Upper $\Leftrightarrow$ Deep ocean:**
  - 38,000 GT carbon in deep ocean
  - Slow: 6 GT/year from upper ocean

- GT = billion metric tons
  - 1 GT water is a cube 1 kilometer on each side
  - 1000 GT water is a cube 10 km (6 miles) on each side


CO2 equilibration takes millennia
1200
1000
800
600
400
CO2 (ppm)
0
2
4
6
8
10
Thousand years

The Rocks Breathe

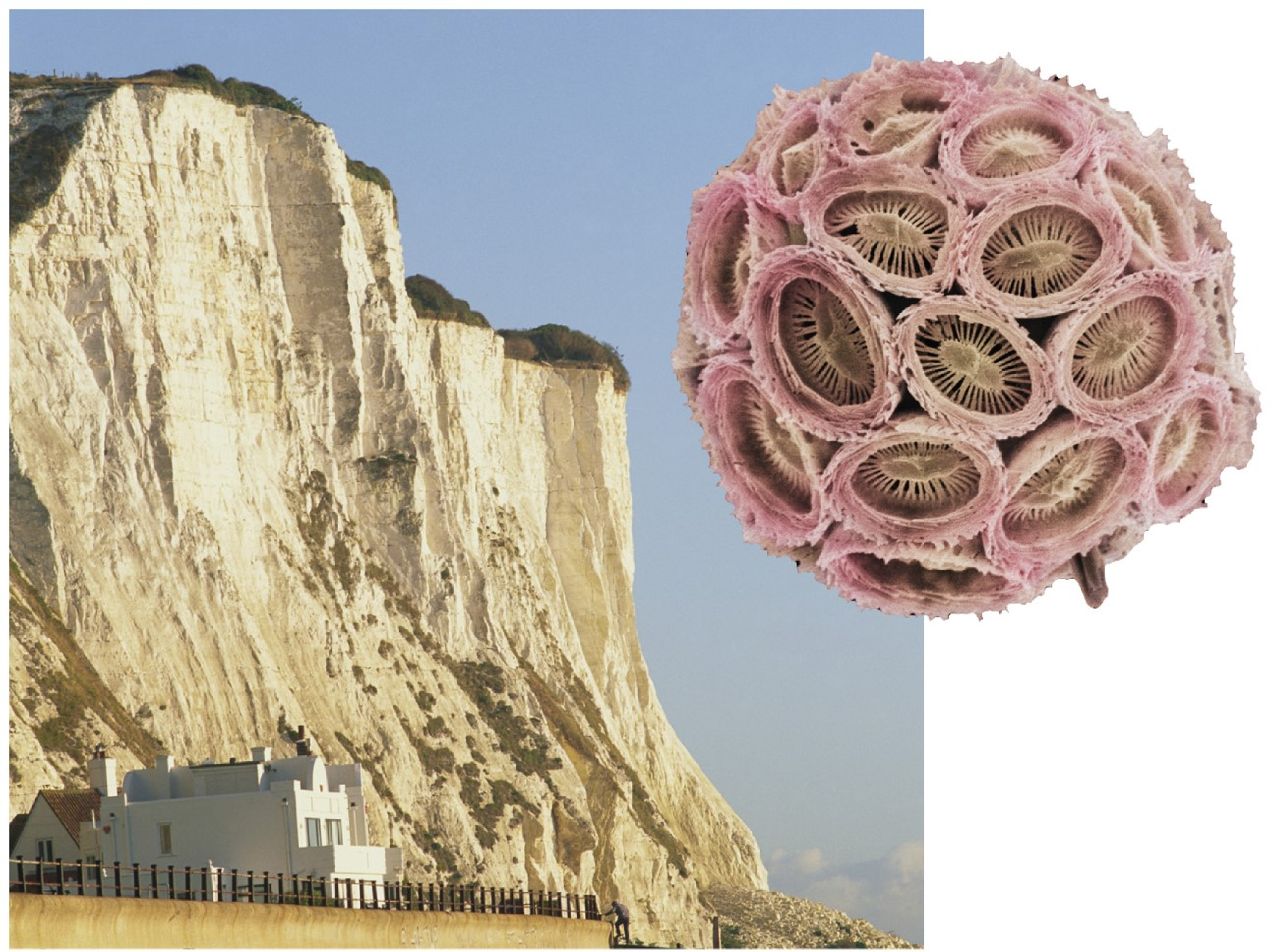
The Rocks Breathe

- Carbonate vs. Silicate minerals
- Urey Reaction: \[\mathrm{CaSiO_3} + \COO \Leftrightarrow \mathrm{CaCO_3} + \mathrm{SiO_2}\]
  - \(\Rightarrow\) **weathering** (reactions near surface)
  - \(\Leftarrow\) **metamorphism** (high temp./pressure deep beneath surface)
- Silicate minerals formed at high temperature (igneous)
- Carbonate minerals formed at low temperature (sedimentary)

Why this is important

- Rain falls on silicate minerals
  - CO_2 dissolves into rainwater
  - Dissolved CO_2 makes rainwater is acidic
- Acidic water dissolves silicate minerals
  - Dissolved ions ($\mathrm{Ca^{+2}}$, $\mathrm{SiO_3^{-2}}$, etc.)
- In oceans, plankton convert dissolved CO_2 & ions to calcite (calcium carbonate)
- Calcite ends up as limestone on sea floor
- **Bottom line:**
  - Weathering silicate minerals transforms atmospheric CO_2 to rocks on sea floor.
  - Detailed chemistry on Monday

From atmosphere to rocks



Weathering as Thermostat

CO_2 is balance of volcanic outgassing
and chemical weathering

- **Temperature rises:**
  - More rain, faster chemical reactions
  - Faster weathering
  - Atmospheric CO_2 falls
  - Temperature falls
- **Temperature falls**
  - Less rain, slower chemical reactions
  - Slower weathering
  - Atmospheric CO_2 rises
  - Temperature rises
- Net effect:
  - Keeps temperature stable near some “set point”
  - Set-point is determined by geology

Temperature of Earth

- As long as outgassing is constant, weathering acts as thermostat.
- Earth’s temperature has been remarkably stable over time.
- Change of volcanic outgassing changes “setting” of thermostat.

Temperature of Mars and Venus

- Mars used to be warm.
  - Now it is frozen.
  - Why?
    - Volcanic outgassing stopped.
      - All CO_2 converted to rocks.
      - No new CO_2 from volcanoes.
- Venus is scorching hot
  - Why?
    - Runaway greenhouse:
      - All water evaporated
      - Chemical weathering stopped
      - Volcanic outgassing/metamorphism converted all carbonate minerals to CO_2 gas.