

# The Carbon Cycle: Mineral Weathering

EES 3310/5310

Global Climate Change

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Class #11: Wednesday, February 17 2021

# Ice Ages

# 25,000 years ago



Image credit: Ron Blakey

# 25,000 years ago

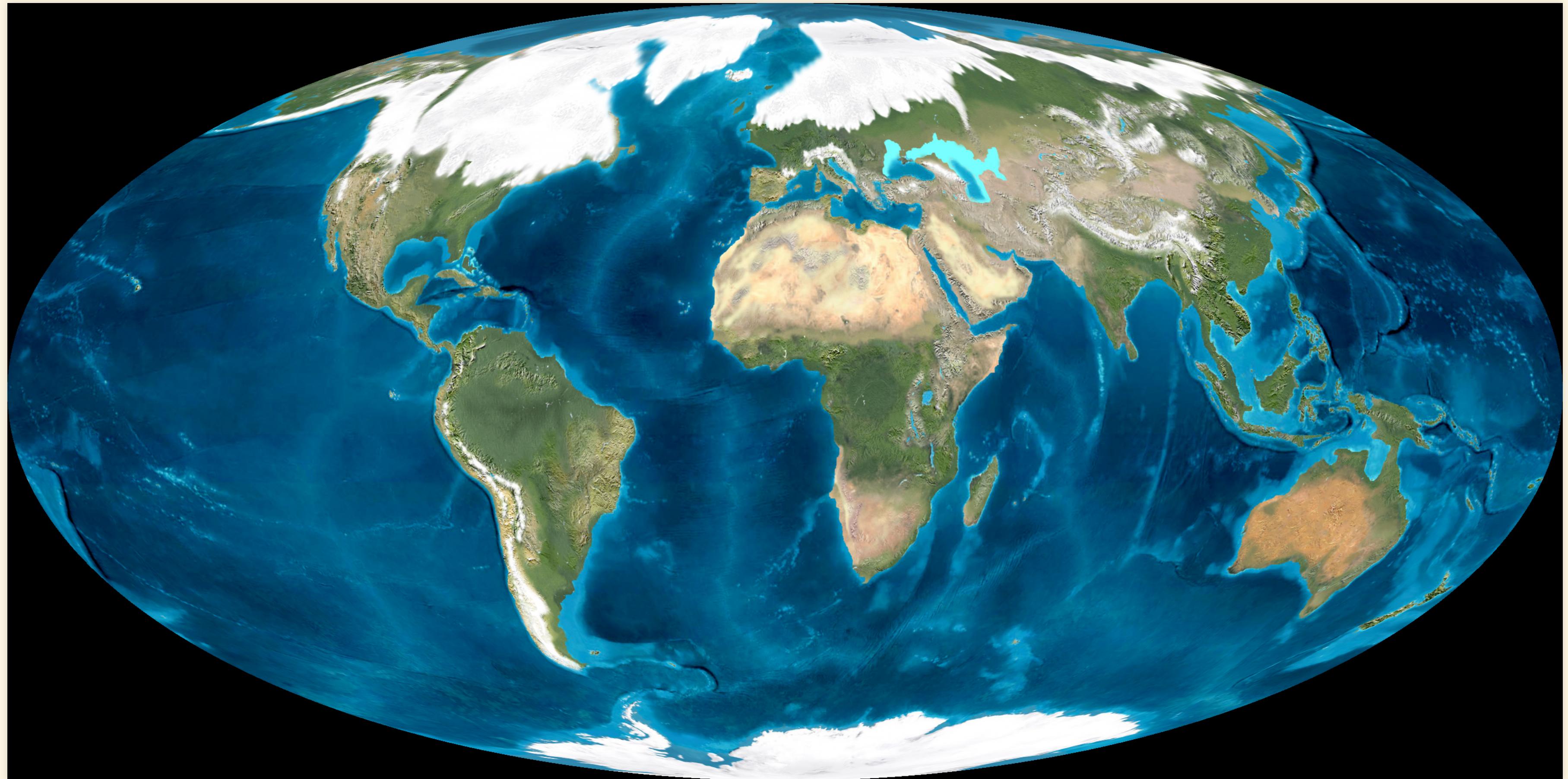
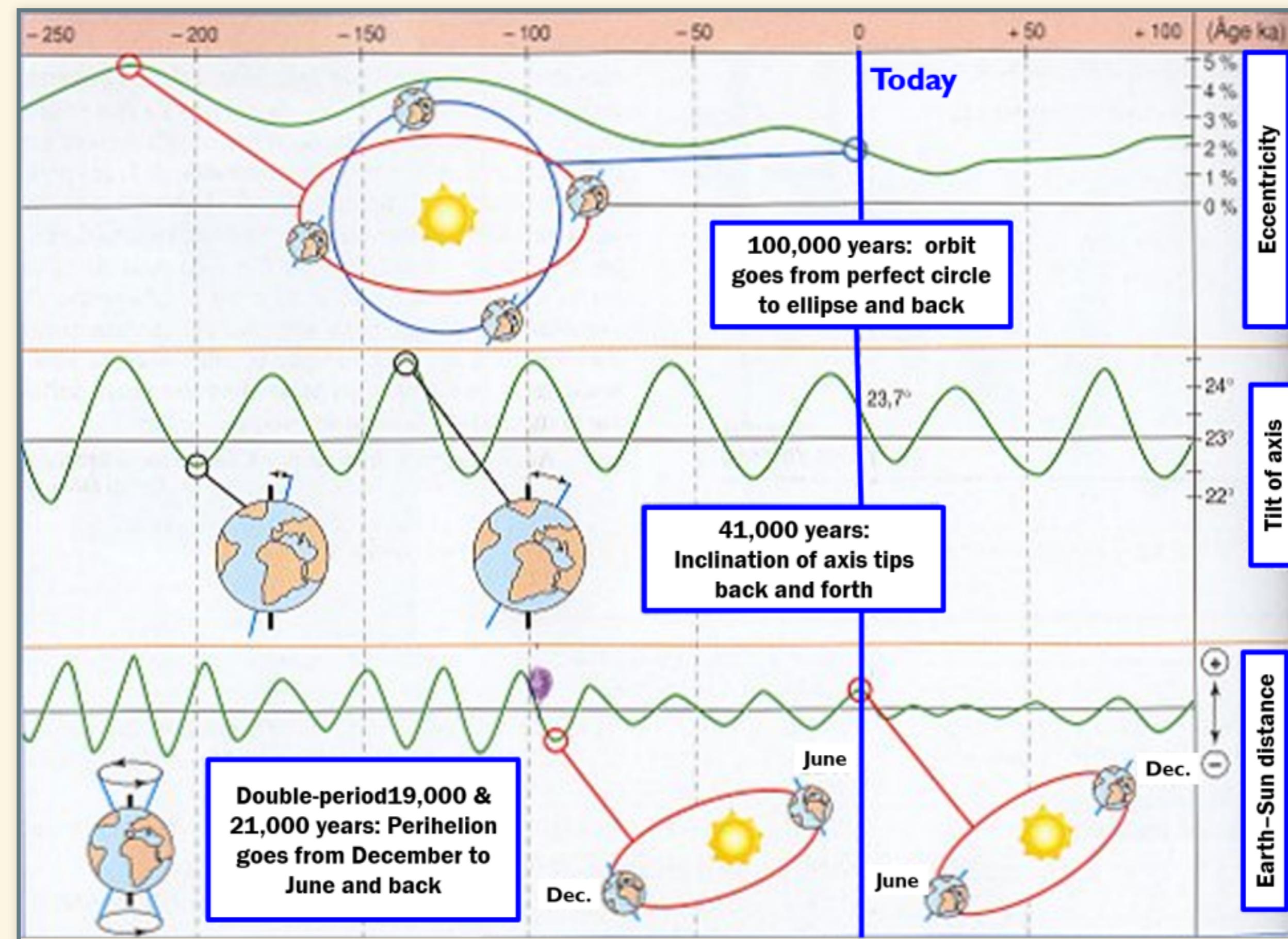
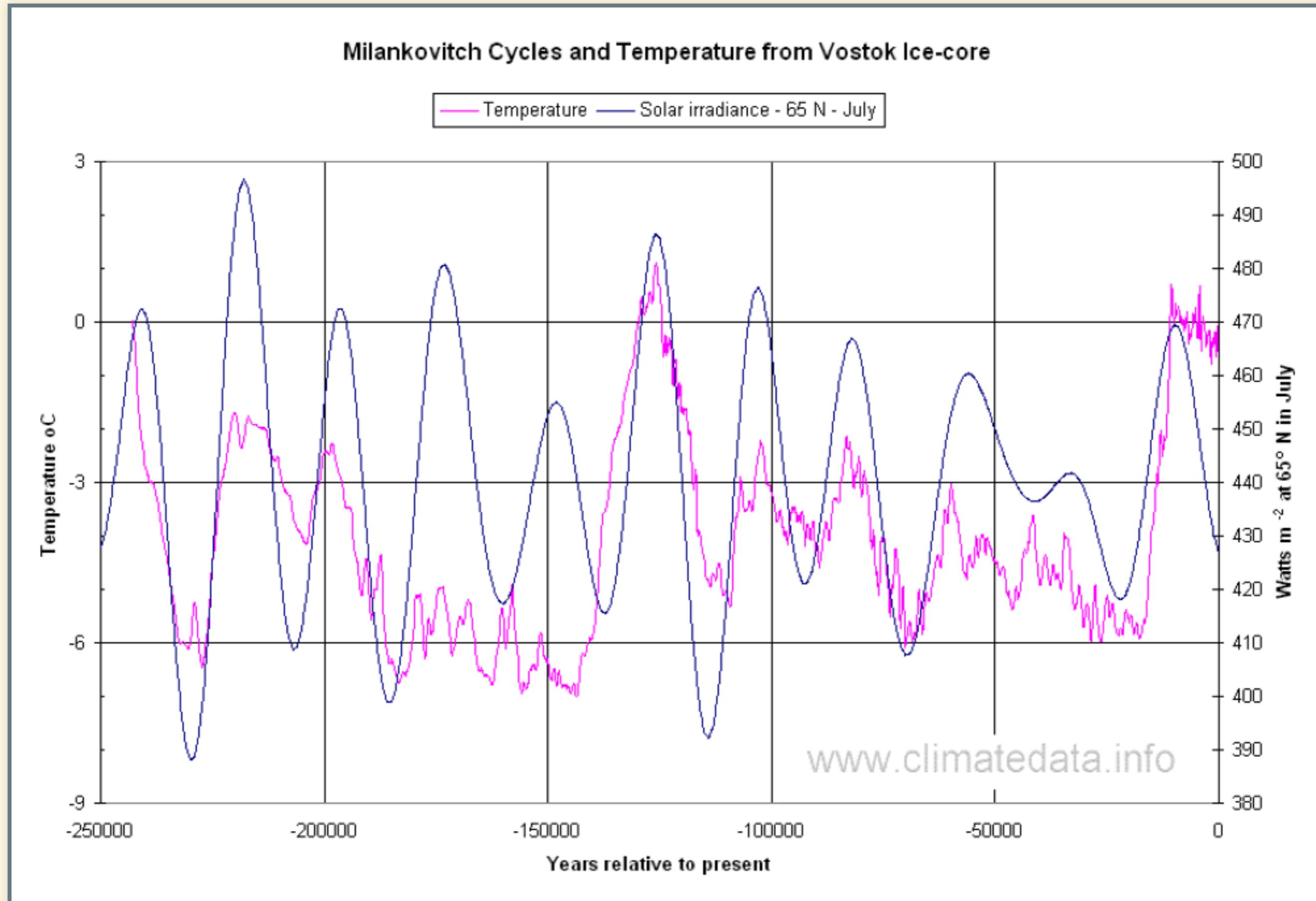


Image credit: Ron Blakey

# Causes



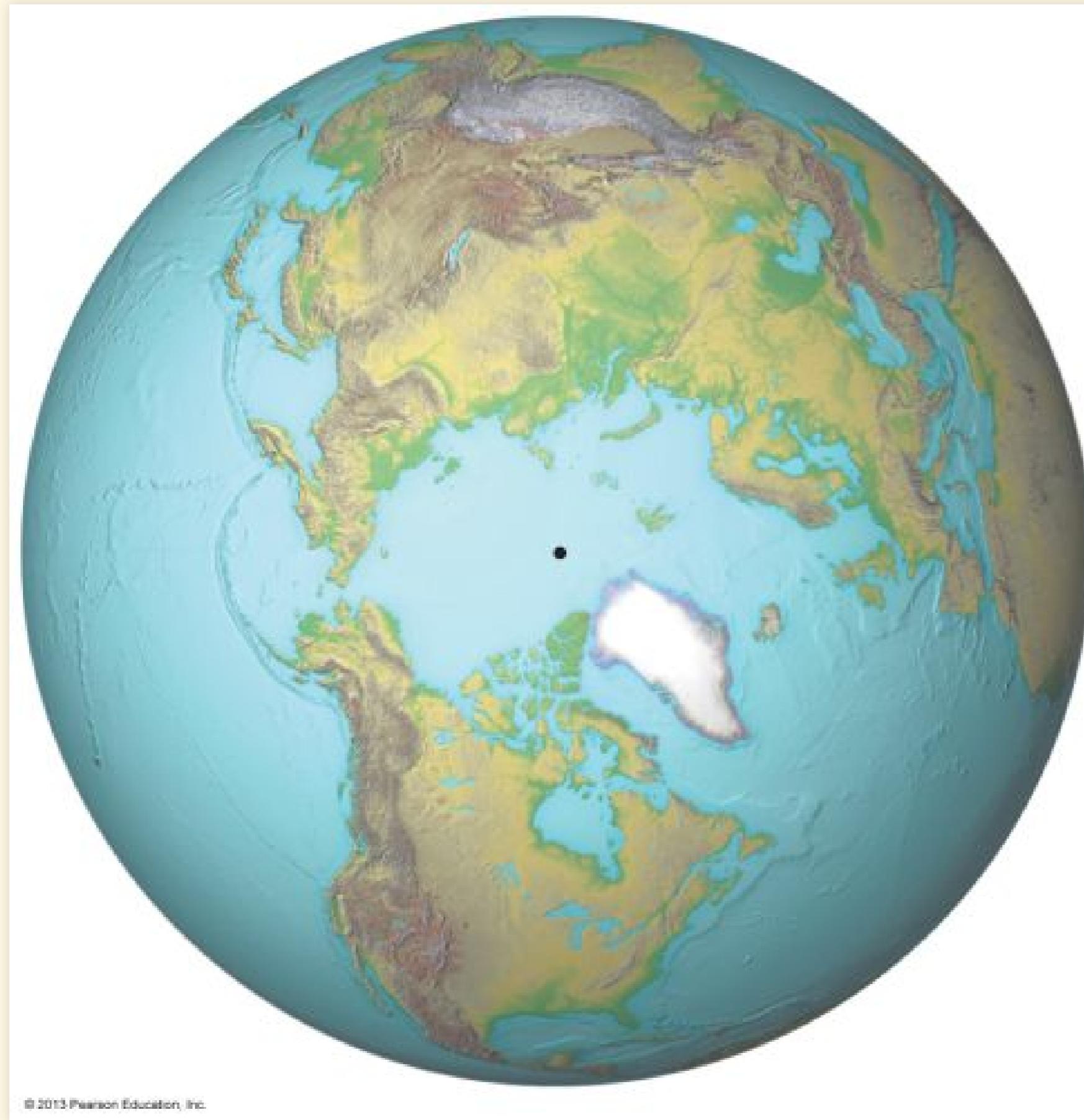
# Timing of Ice Ages



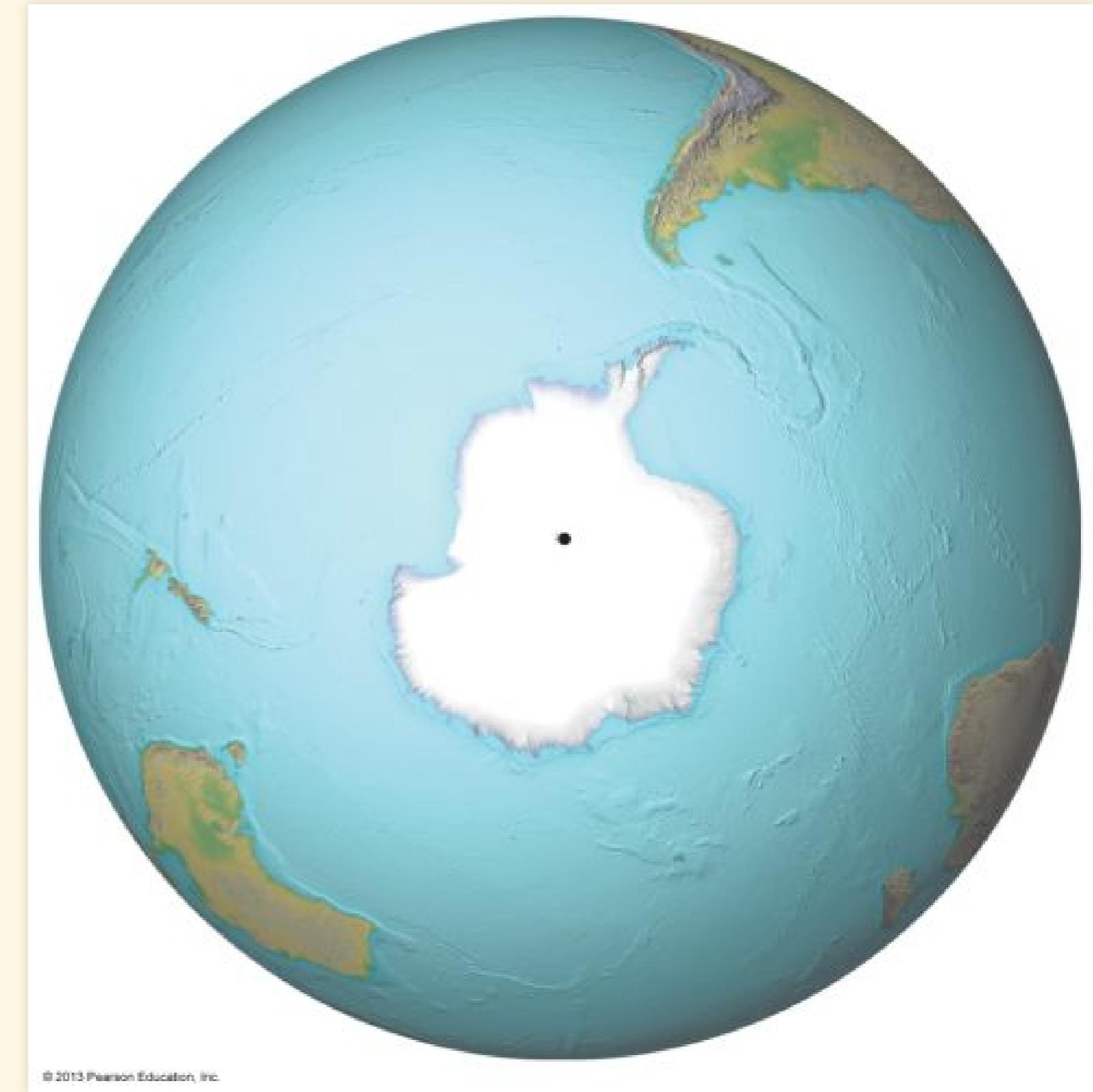
# Question

Why would the summer sunlight in the far northern hemisphere be so important?

# Northern vs. Southern Hemisphere



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# Ice Age Feedbacks

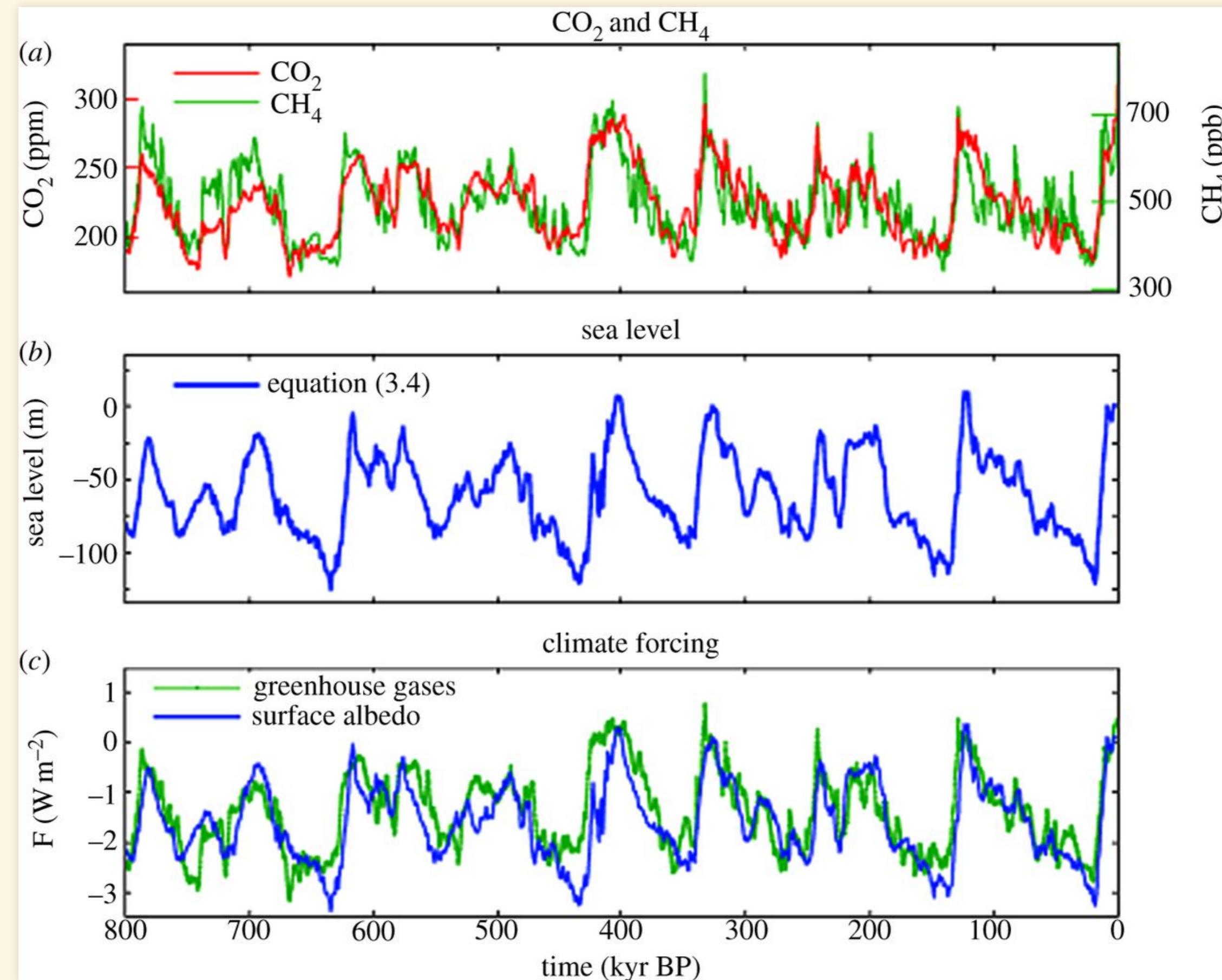
# Ice Age Feedbacks

- 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

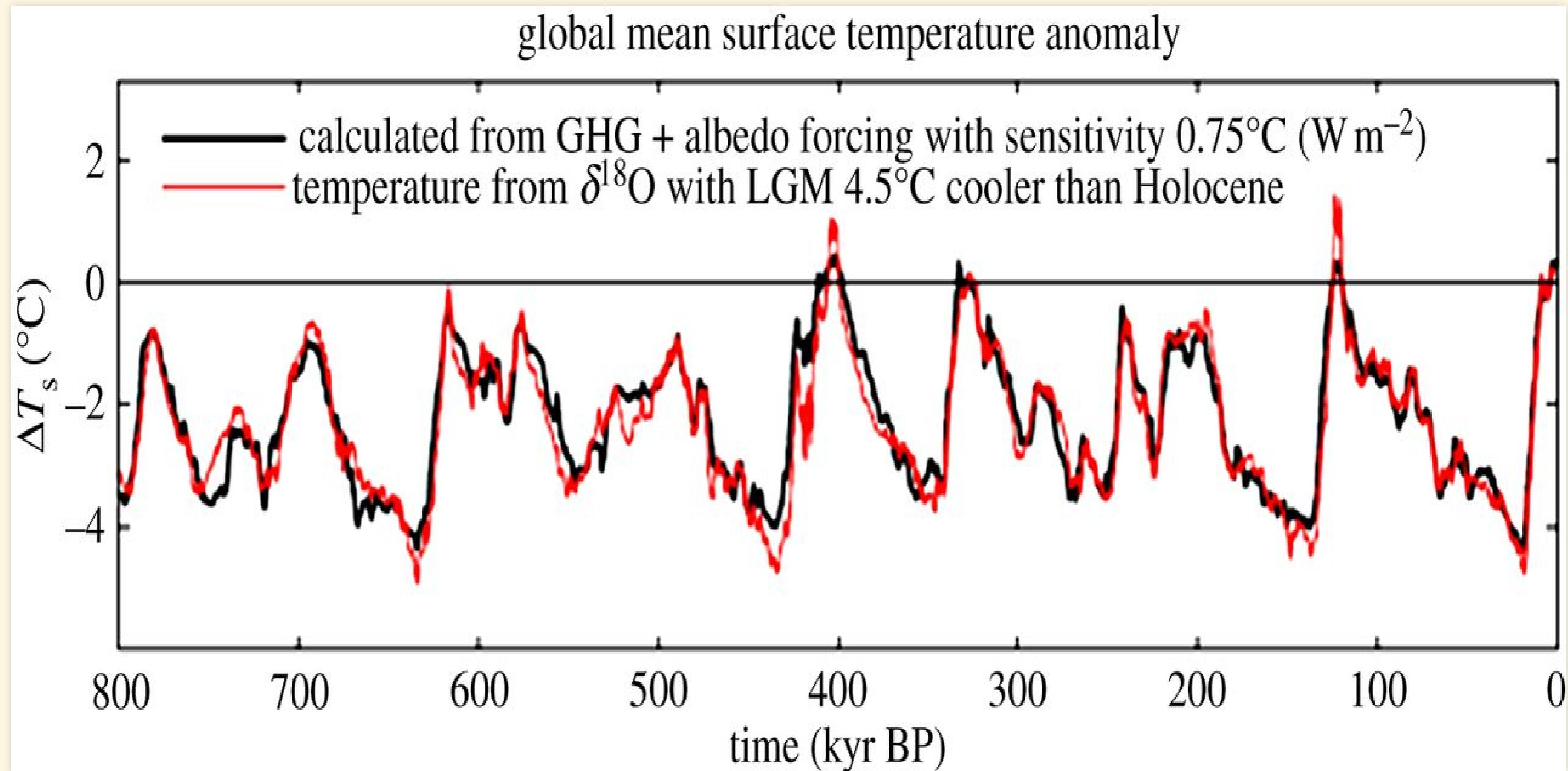
# Ice-Age Feedbacks:

- Temperature starts to fall
  - Glaciers grow → higher albedo
  - $\text{CO}_2$  drops → weaker greenhouse
  - Colder
- Temperature starts to rise
  - Glaciers retreat → higher albedo
  - $\text{CO}_2$  rises → stronger greenhouse
  - Warmer
- Without  $\text{CO}_2$  and ice-albedo feedbacks, ice-ages couldn't happen
- Ice ages can't happen with today's  $\text{CO}_2$  levels.

# Theory of Feedbacks



# Theory vs. Observations



# The Carbon Dioxide Theory of Climatic Change

By GILBERT N. PLASS

The Johns Hopkins University, Baltimore, Md.<sup>1</sup>

(Manuscript received August 9 1955)

## *Abstract*

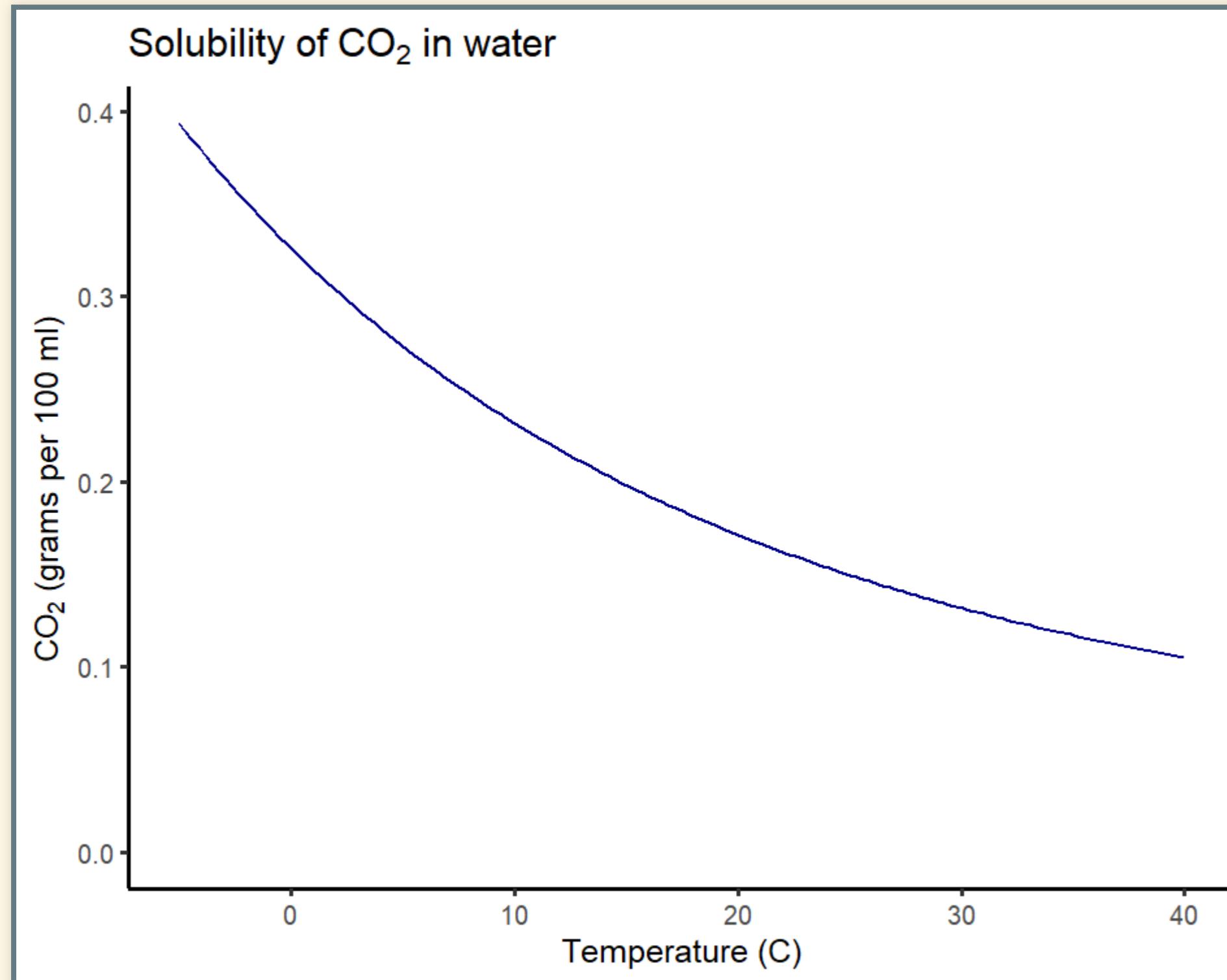
The most recent calculations of the infra-red flux in the region of the 15 micron CO<sub>2</sub> band show that the average surface temperature of the earth increases 3.6° C if the CO<sub>2</sub> concentration in the atmosphere is doubled and decreases 3.8° C if the CO<sub>2</sub> amount is halved, provided that no other factors change which influence the radiation balance. Variations in CO<sub>2</sub> amount of this magnitude must have occurred during geological history; the resulting temperature changes were sufficiently large to influence the climate. The CO<sub>2</sub> balance is discussed. The CO<sub>2</sub> equilibrium

*assuming that the average temperature change is calculated with and without  $\text{CaCO}_3$  equilibrium*

predicted by the CO<sub>2</sub> theory. When the total CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> theory predicts that this warming trend will continue, at least for several centuries.

The Oceans Breathe

# The Oceans Breathe



## Solubility pump:

- Temperature rises:
  - CO<sub>2</sub> moves from ocean to atmosphere.
- Temperature falls:
  - CO<sub>2</sub> moves from atmosphere to ocean.

**Positive feedback**

# Biological Pump

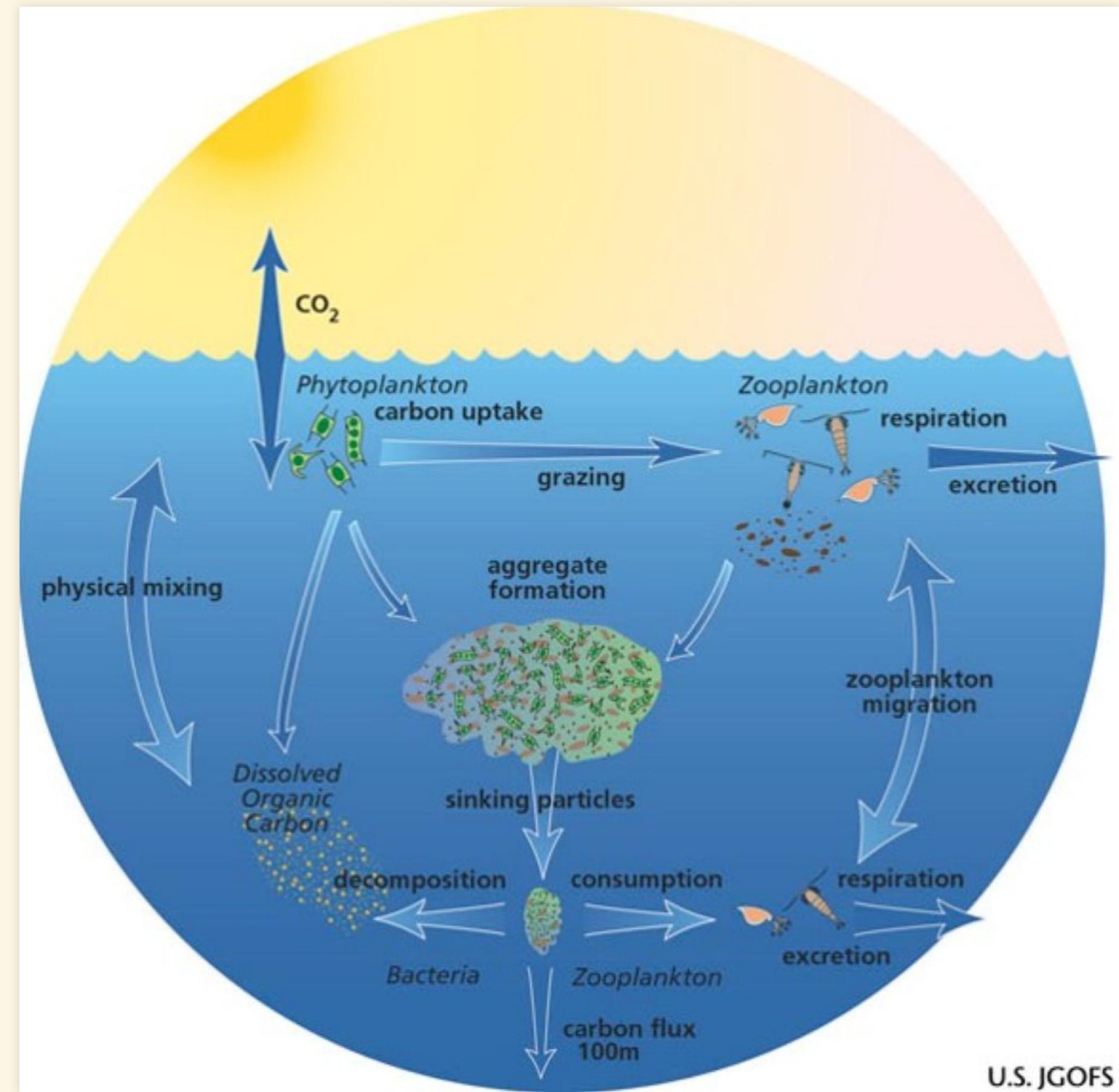


Image credit: US Joint Global Ocean Flux Study

# Structure of the ocean

# Structure of the ocean

## Lower Atmosphere:

- Heated from bottom
  - Sunlight absorbed at bottom (ground)
- Warmer at bottom
- Unstable → 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

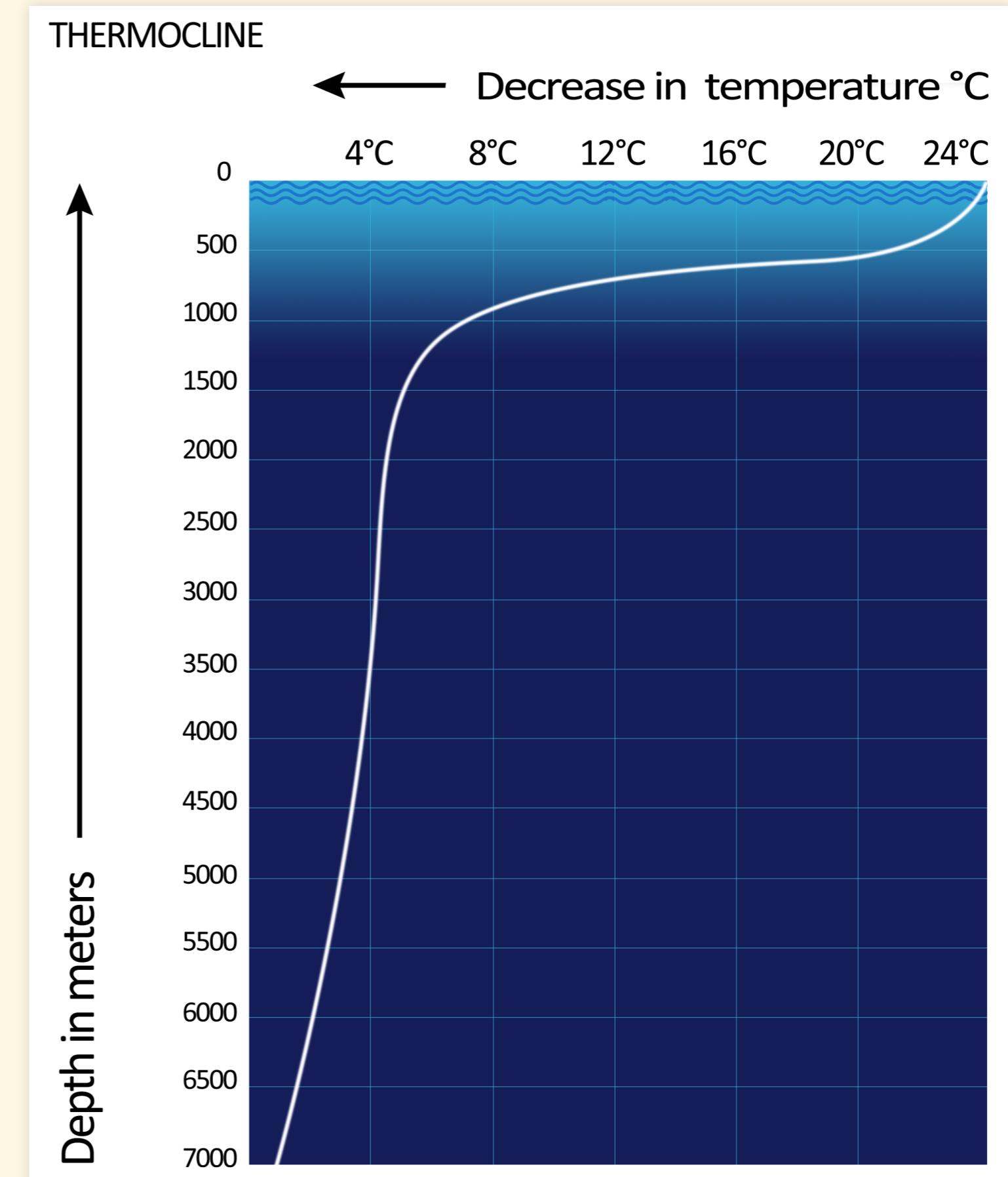
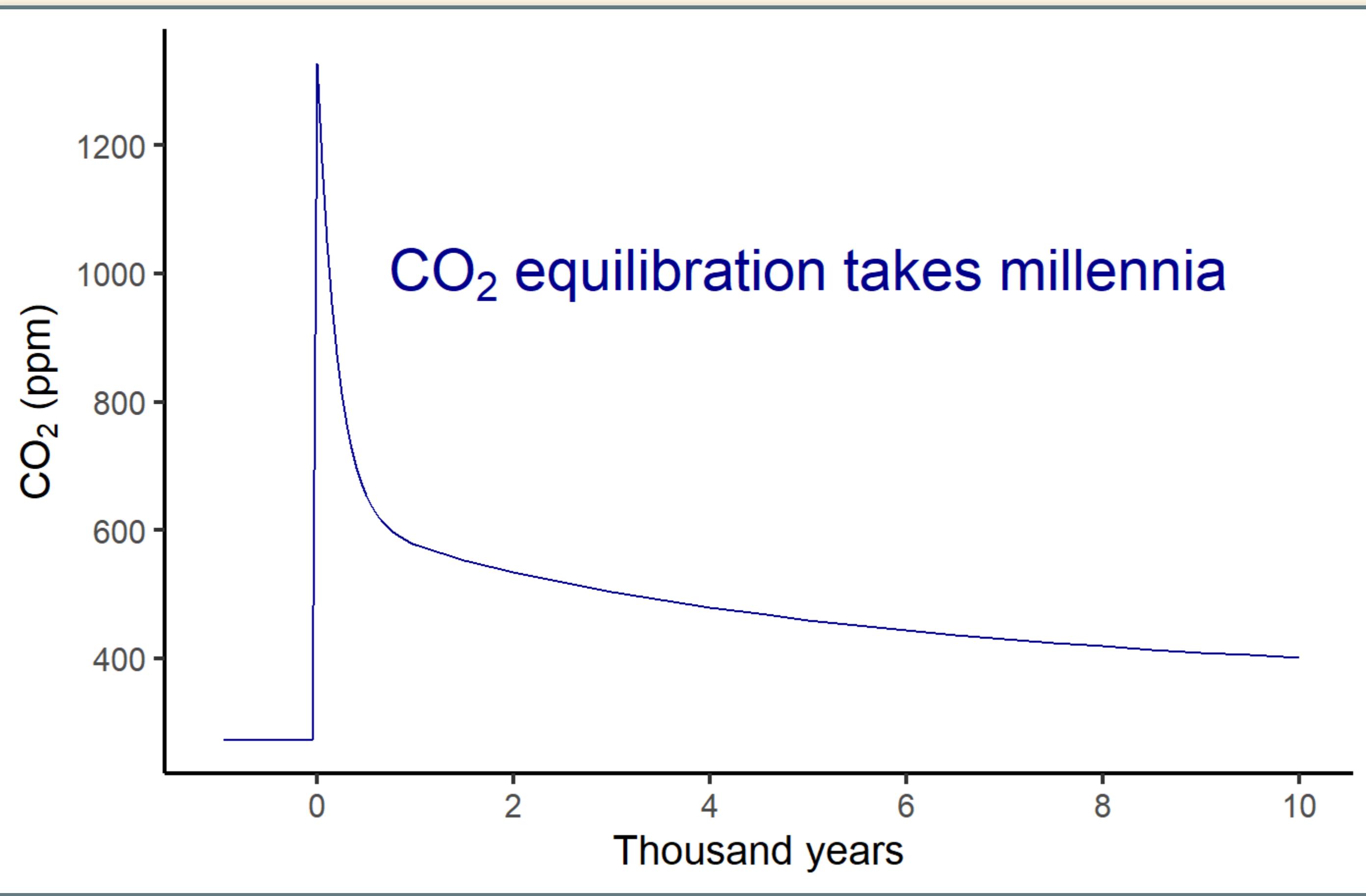


Image credit: Wikimedia

# 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



The Rocks Breathe

# The Rocks Breathe

- Carbonate vs. Silicate minerals
- Urey Reaction:



- $\Rightarrow$  **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
  - $\text{CO}_2$  dissolves into rainwater
  - Dissolved  $\text{CO}_2$  makes rainwater is acidic
- Acidic water dissolves silicate minerals
  - Dissolved ions ( $\text{Ca}^{+2}$ ,  $\text{SiO}_3^{-2}$ , etc.)
- In oceans, plankton convert dissolved  $\text{CO}_2$  & ions to calcite (calcium carbonate)
- Calcite ends up as limestone on sea floor
- **Bottom line:**
  - Weathering silicate minerals transforms atmospheric  $\text{CO}_2$  to rocks on sea floor.
  - Detailed chemistry on Friday

# Weathering as Thermostat

$\text{CO}_2$  is balance of volcanic outgassing  
and chemical weathering

- **Temperature rises:**
  - More rain, faster chemical reactions
  - Faster weathering
  - Atmospheric  $\text{CO}_2$  falls
  - Temperature falls
- **Temperature falls**
  - Less rain, slower chemical reactions
  - Slower weathering
  - Atmospheric  $\text{CO}_2$  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<sub>2</sub> converted to rocks.
    - No new CO<sub>2</sub> from volcanoes.
- Venus is scorching hot
  - Why?
    - Runaway greenhouse:
      - All water evaporated
      - Chemical weathering stopped
      - Volcanic outgassing/metamorphism converted all carbonate minerals to CO<sub>2</sub> gas.