

The Carbon Cycle: Ocean and Biosphere

EES 3310/5310

Global Climate Change

Jonathan Gilligan

Class #10: Wednesday, February 9 2022

Black History Month: Great Black Climate Scientists

J. Marshall Shepherd

- Born in Canton Georgia
- BS, MS, and PhD in meteorology from Florida State University
 - First African-American to get a Ph.D. in Meteorology from Florida State
- Distinguished Professor of Geography and Atmospheric Sciences at University of Georgia
- Deputy Director of NASA Global Precipitation Mission
- Chair of NASA Earth Sciences Advisory Committee 2017–2020
- President of the American Meteorological Society (2013)
- Elected to National Academy of Sciences, National Academy of Engineering, American Academy of Arts and Sciences (2021)

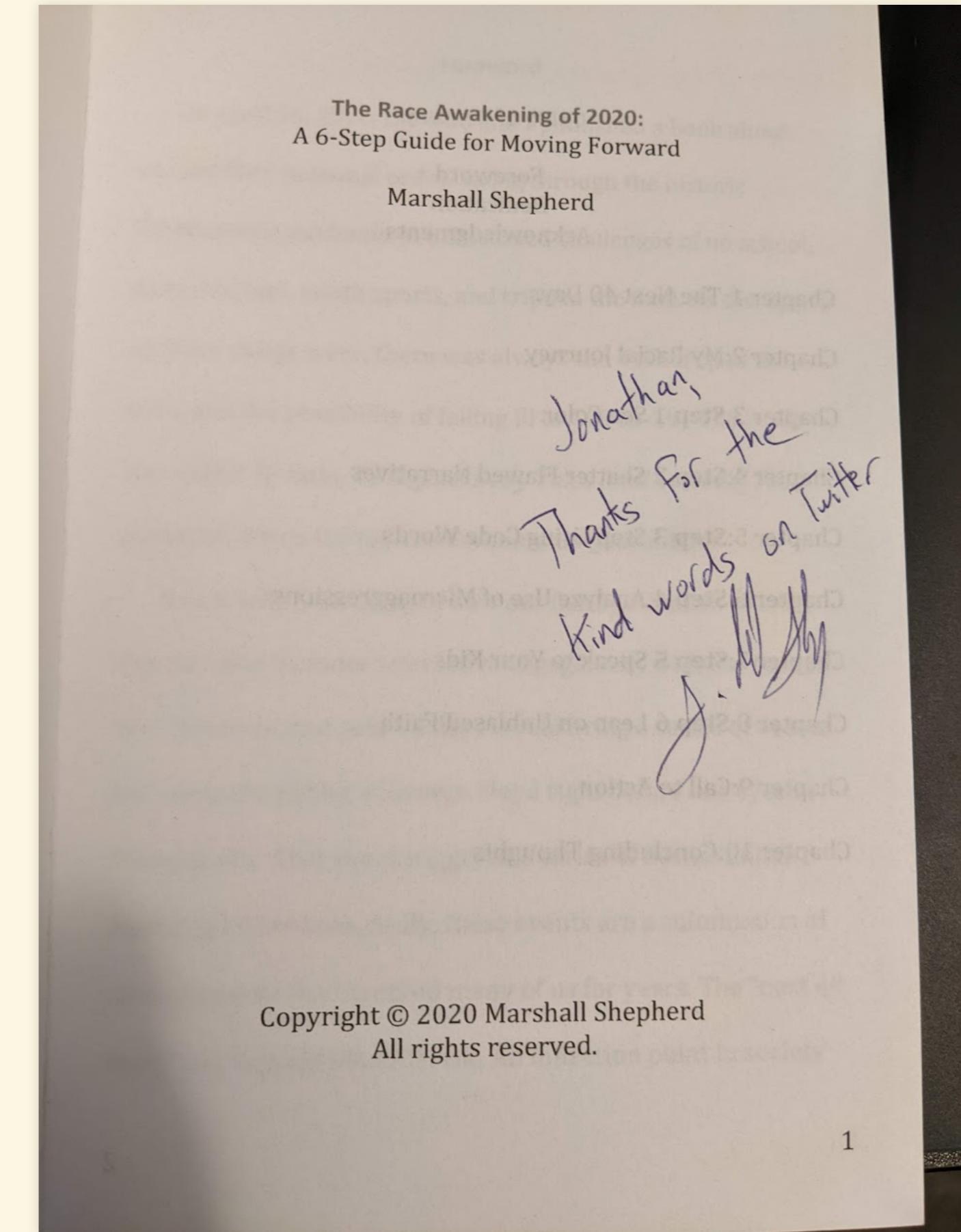
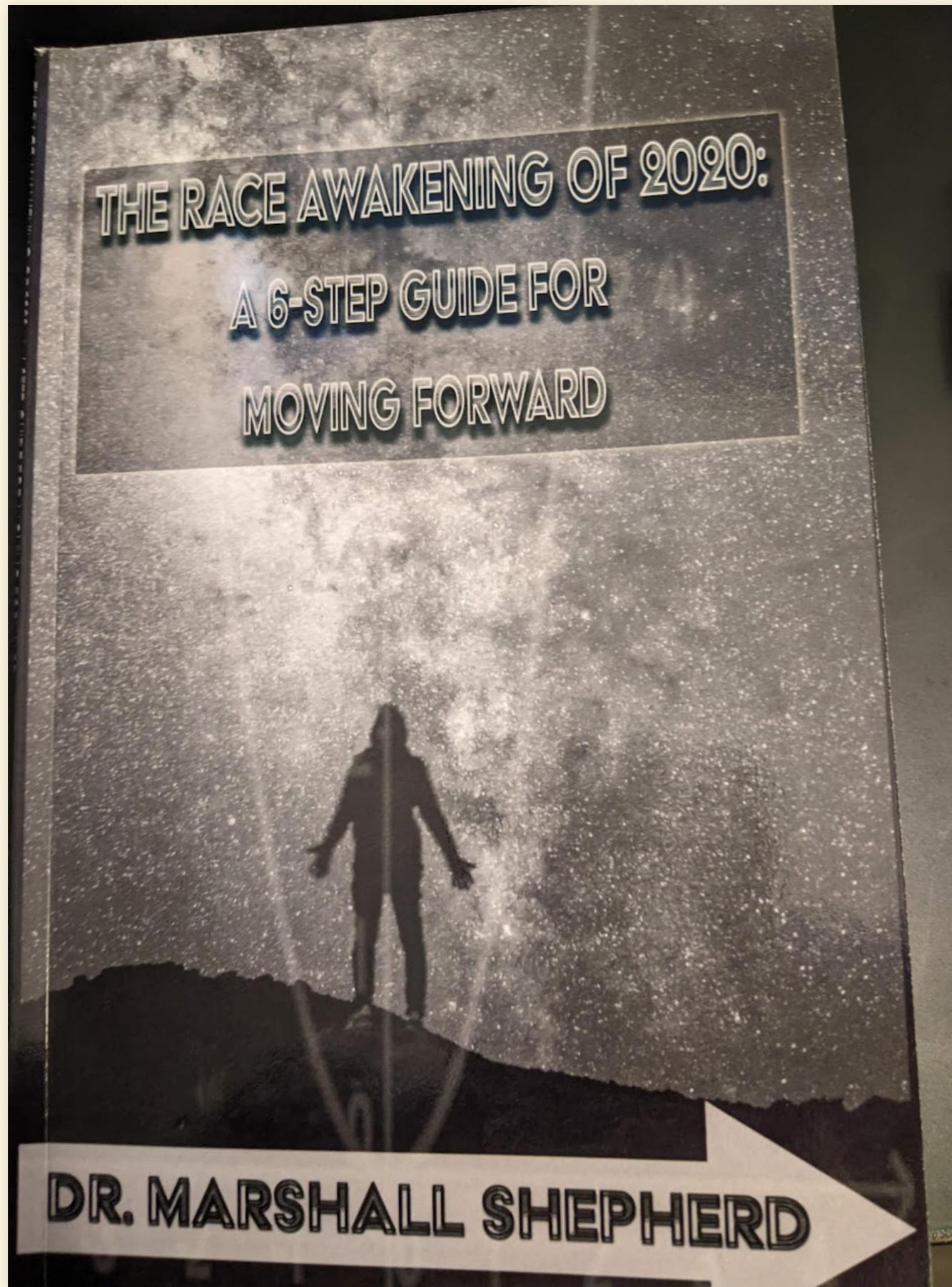


J. Marshall Shepherd

- Host, Weather Channel WxGeeks, award-winning Sunday science show
- 2020 Mani L. Bhaumik Award for Public Engagement with Science, American Association for the Advancement of Science
- 2019 Climate Communication Award, American Geophysical Union
- 2018 American Meteorological Helmut Landsburg Award for pioneering research on urban climates
- Seven awards from NASA for outstanding scientific achievement
- U.S. Presidential Early Career Award for pioneering research in weather and climate science (2004)



J. Marshall Shepherd



Biosphere Feedbacks

Hydrological Cycle

- Transpiration in plants:
 - Roots take water from ground
 - Leaves emit water vapor
 - Evaporation cools the air
 - Can be an important source of water vapor

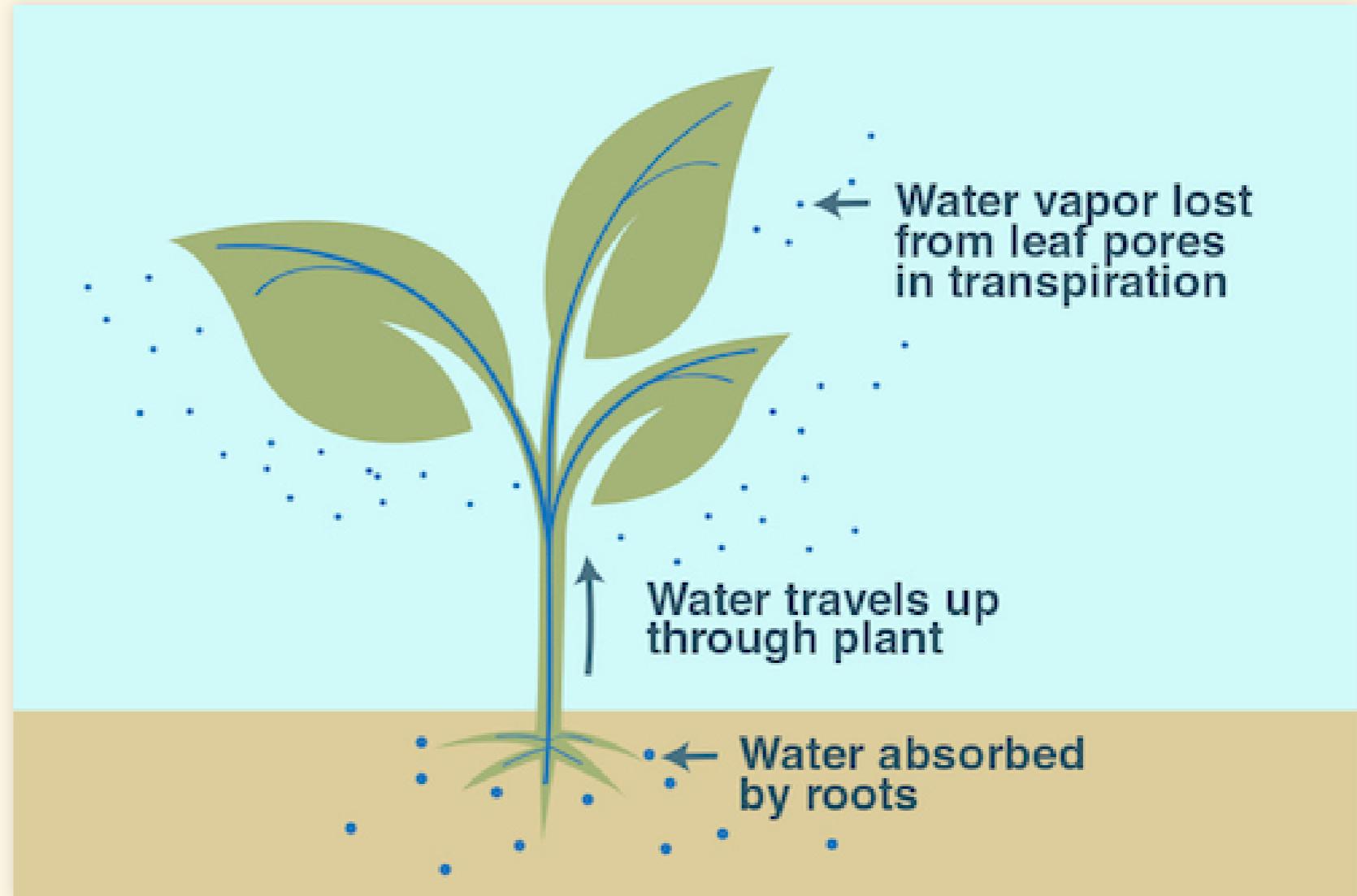


Image credit: NASA/JPL-Caltech <https://climatekids.nasa.gov/heat-islands/>

Transpiration and CO₂

- Transpiration occurs through “stomata” in leaves
- Tradeoff: stomata
 - Allow plant to get CO₂
 - Cause plant to lose water
- More CO₂ in atmosphere:
 - Fewer stomata
 - Less transpiration

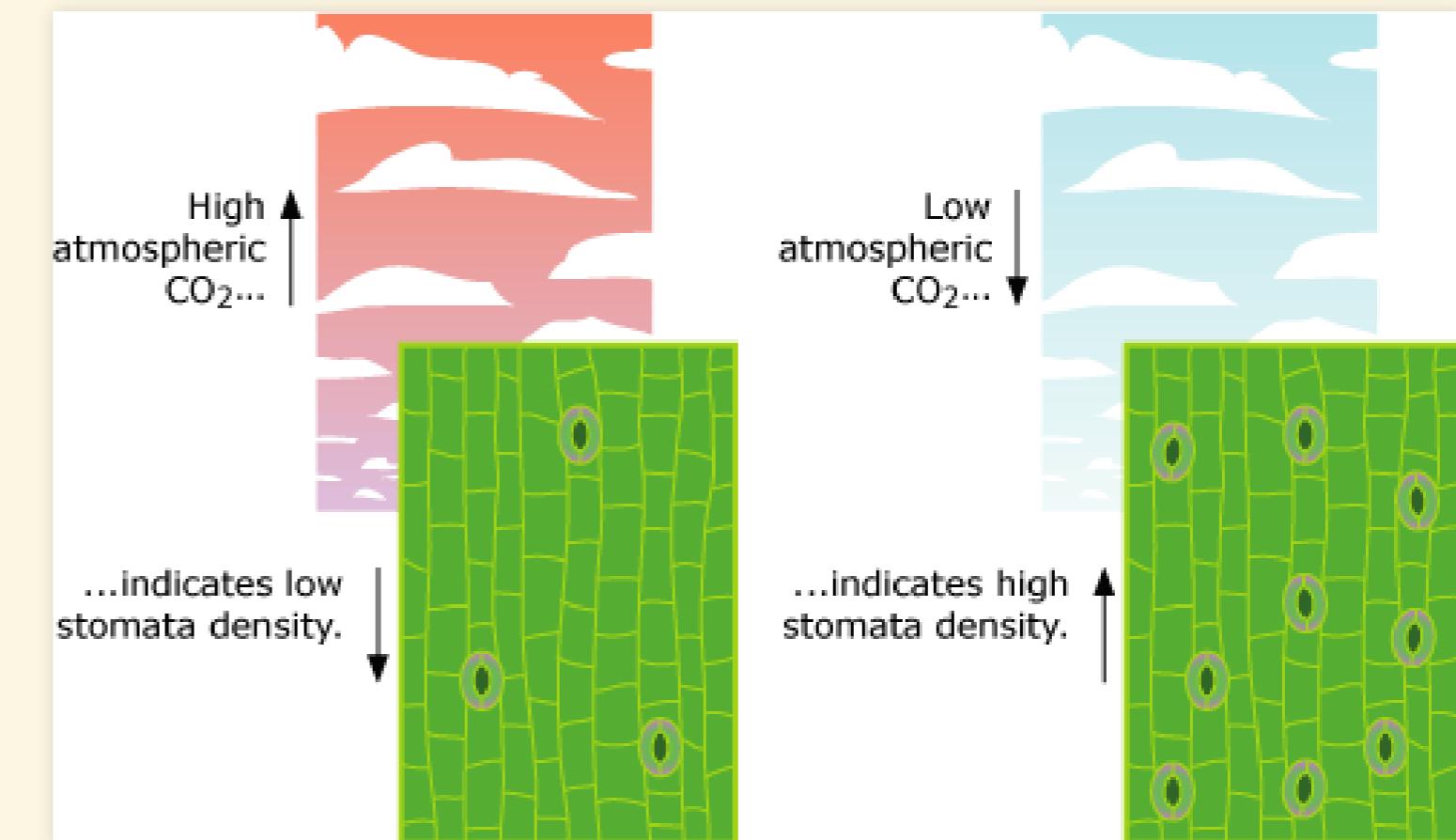
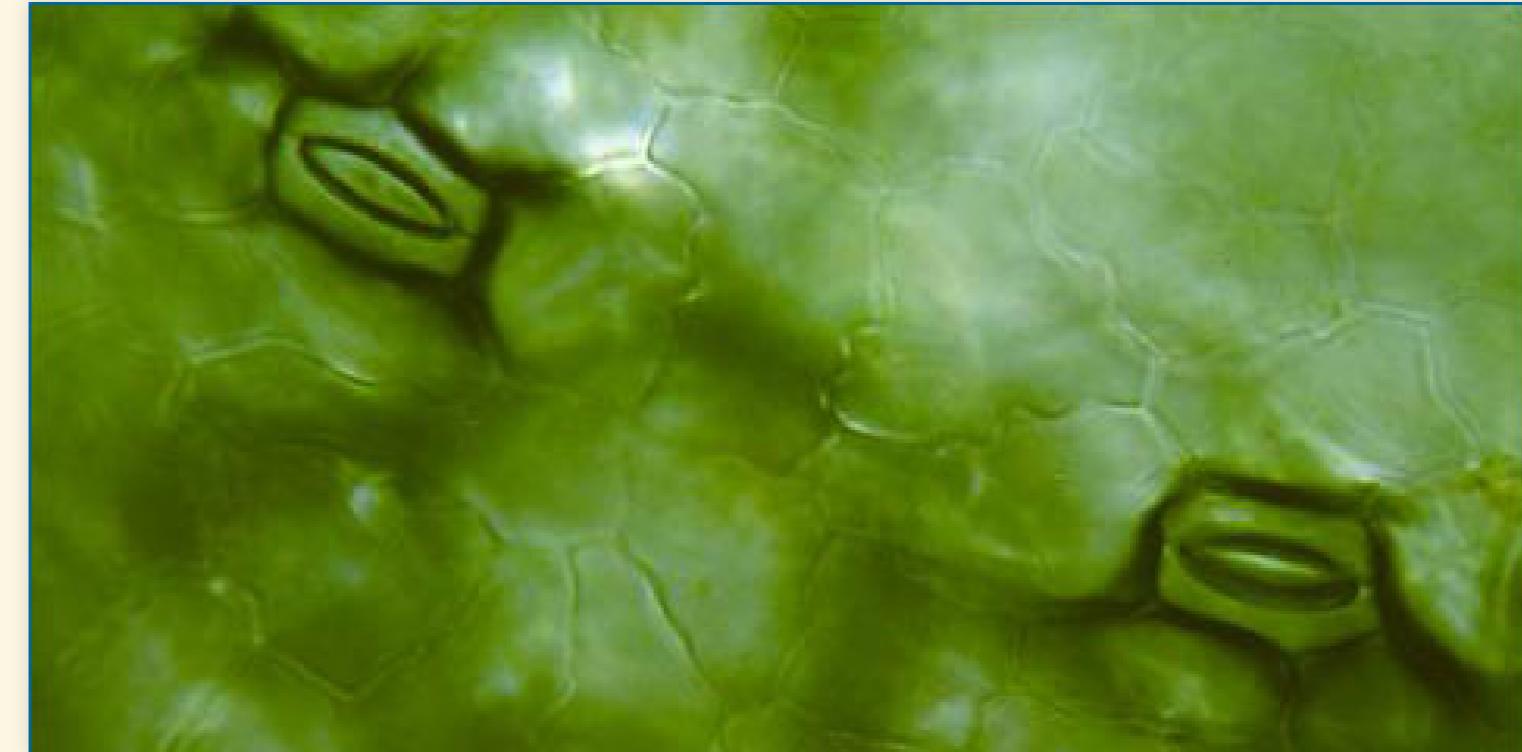


Image credit:

- Photo of stomata on duckweed: Micrographia <http://www.micrographia.com/specbiol/plan/planaq/plaq0100/lemnna-01.htm>.
- Diagram of response to CO₂: University of California Museum of Paleontology's Understanding Evolution <http://evolution.berkeley.edu>.

Carbon Cycle Feedbacks

- Dead organic matter in ground (leaves, roots, etc.) stores carbon
- Warming temperatures accelerate decomposition
 - Bacterial/fungal metabolism
- Huge amounts of dead organic matter in arctic tundra & permafrost
 - Concerns about accelerated greenhouse gas emissions as ground thaws & warms

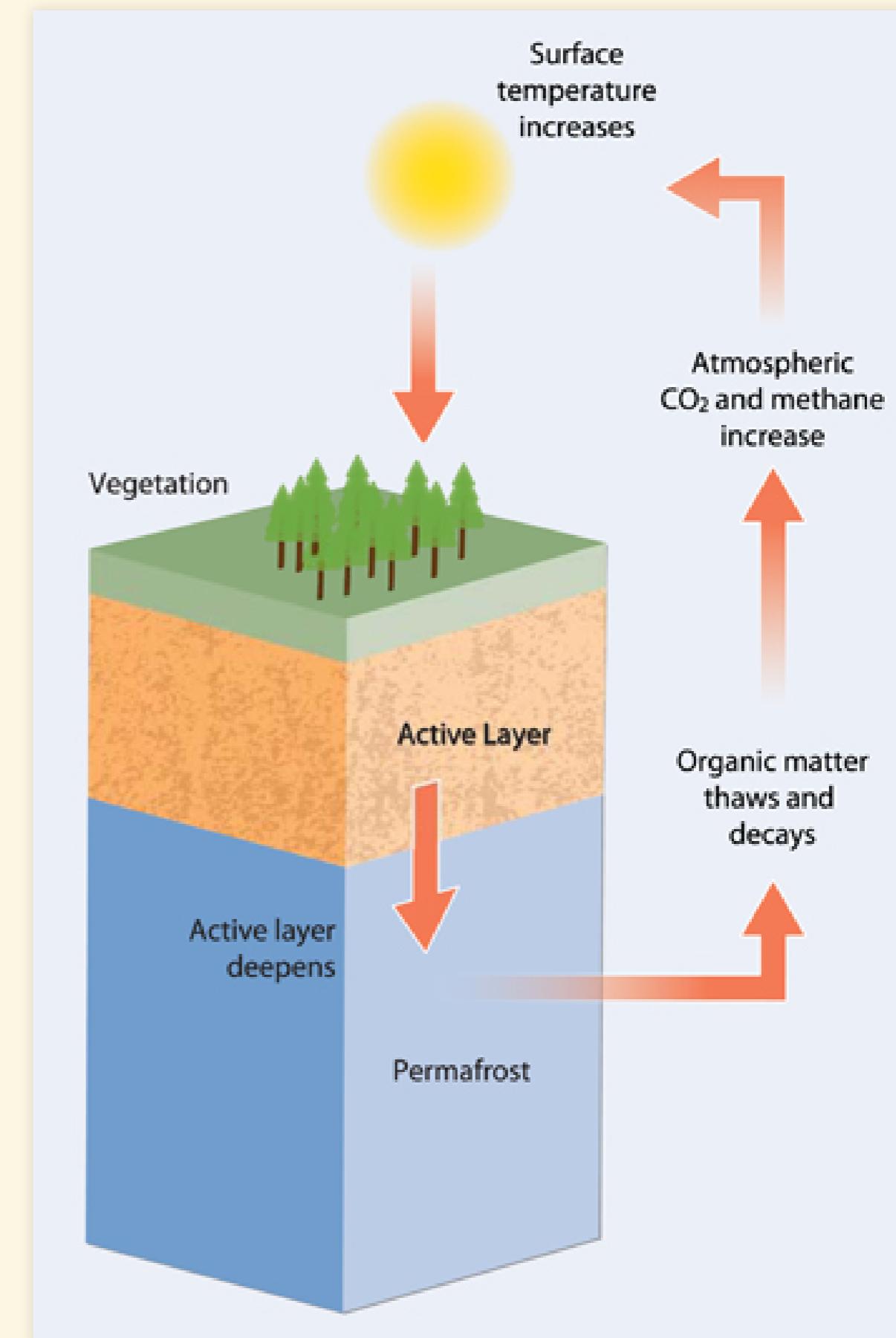
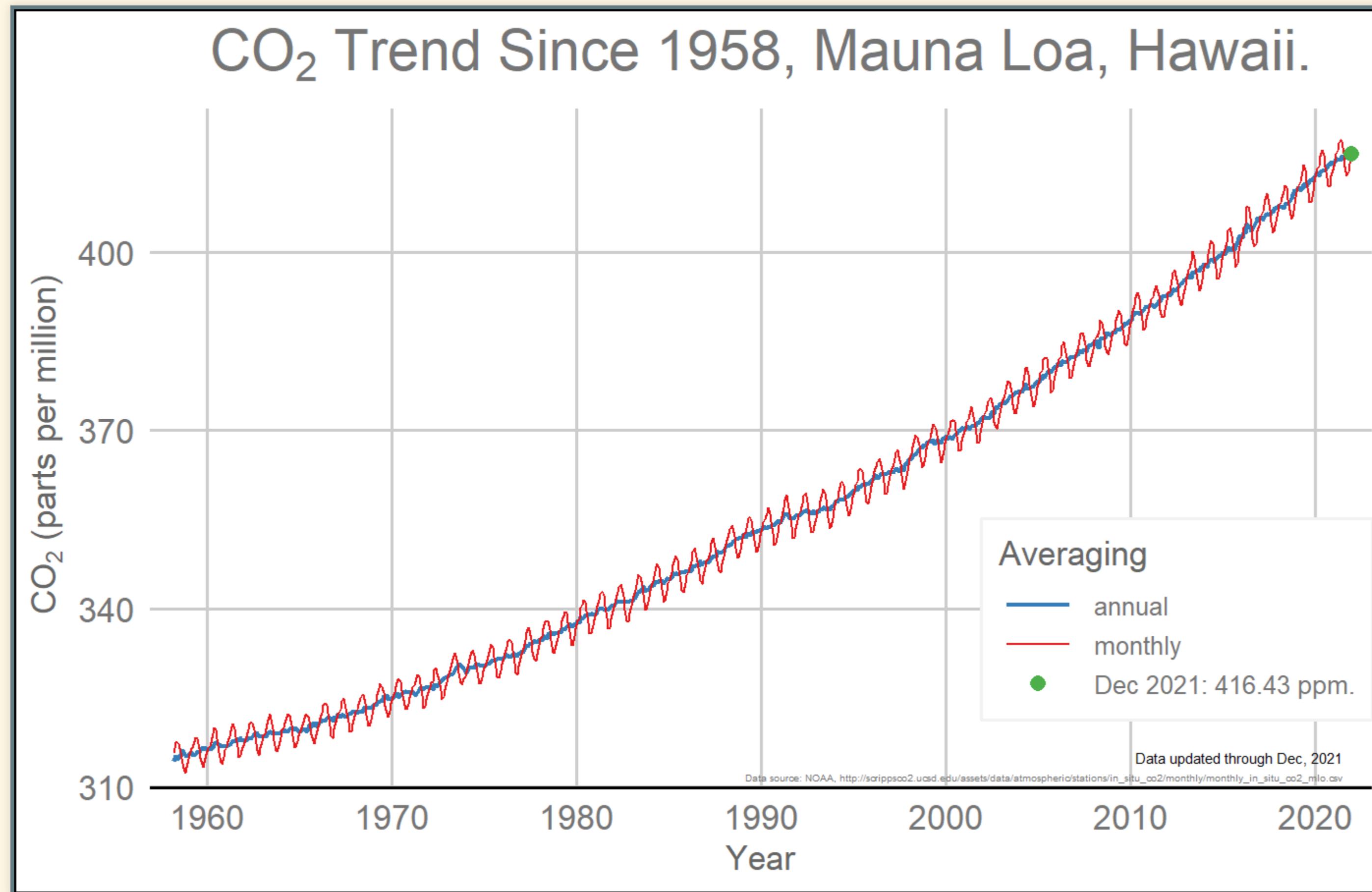


Image credit: K. Schaefer *et al.*, Environ. Res. Lett. **9**, 085003 (2014). doi: 10.1088/1748-9326/9/8/085003

CO₂ in the Atmosphere



Carbon Chemistry

What does the oxidation state tell you about a molecule containing carbon?

- The energy you can get from burning it.
- Whether the carbon came from natural or human sources.
- Large oxidation state → large greenhouse effect.
- Large oxidation state → small greenhouse effect.

Carbon

Oxidation states:

Chemical State	Oxidation
Simple carbon	0
Bound to oxygen	+2
Bound to hydrogen	-1

Examples

Chemical	Oxidation	Name
CH_4	-4	methane
C_n	0	coal, graphite, diamond
$(\text{CH}_2)_n$	-2	long-chain alkane
CO_2	+4	carbon dioxide
$(\text{CH}_2\text{O})_n$	0	carbohydrate

Carbon

Category	Oxidation State	Examples
Mineral carbon	≥ 0	C : 0 (coal) CO_2 : +4
Organic carbon	≤ 0	CH_4 : -4 (methane) $(\text{CH}_2\text{O})_6$: 0 (sugar)

Energy:

- Negative oxidation → greater energy
- Positive oxidation → lower energy
- Photosynthesis:
 $\text{CO}_2 + \text{H}_2\text{O} + \text{energy} \Rightarrow \text{CH}_2\text{O} + \text{O}_2$
- Respiration:
 $\text{CH}_2\text{O} + \text{O}_2 \Rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{energy}$

Carbon

Energy:

- Negative oxidation → greater energy
- Positive oxidation → lower energy
- Photosynthesis:
 $\text{CO}_2 + \text{H}_2\text{O} + \text{energy} \Rightarrow \text{CH}_2\text{O} + \text{O}_2$
- Respiration:
 $\text{CO}_2 + \text{H}_2\text{O} + \text{energy} \Leftarrow \text{CH}_2\text{O} + \text{O}_2$

History of oxidation on earth:

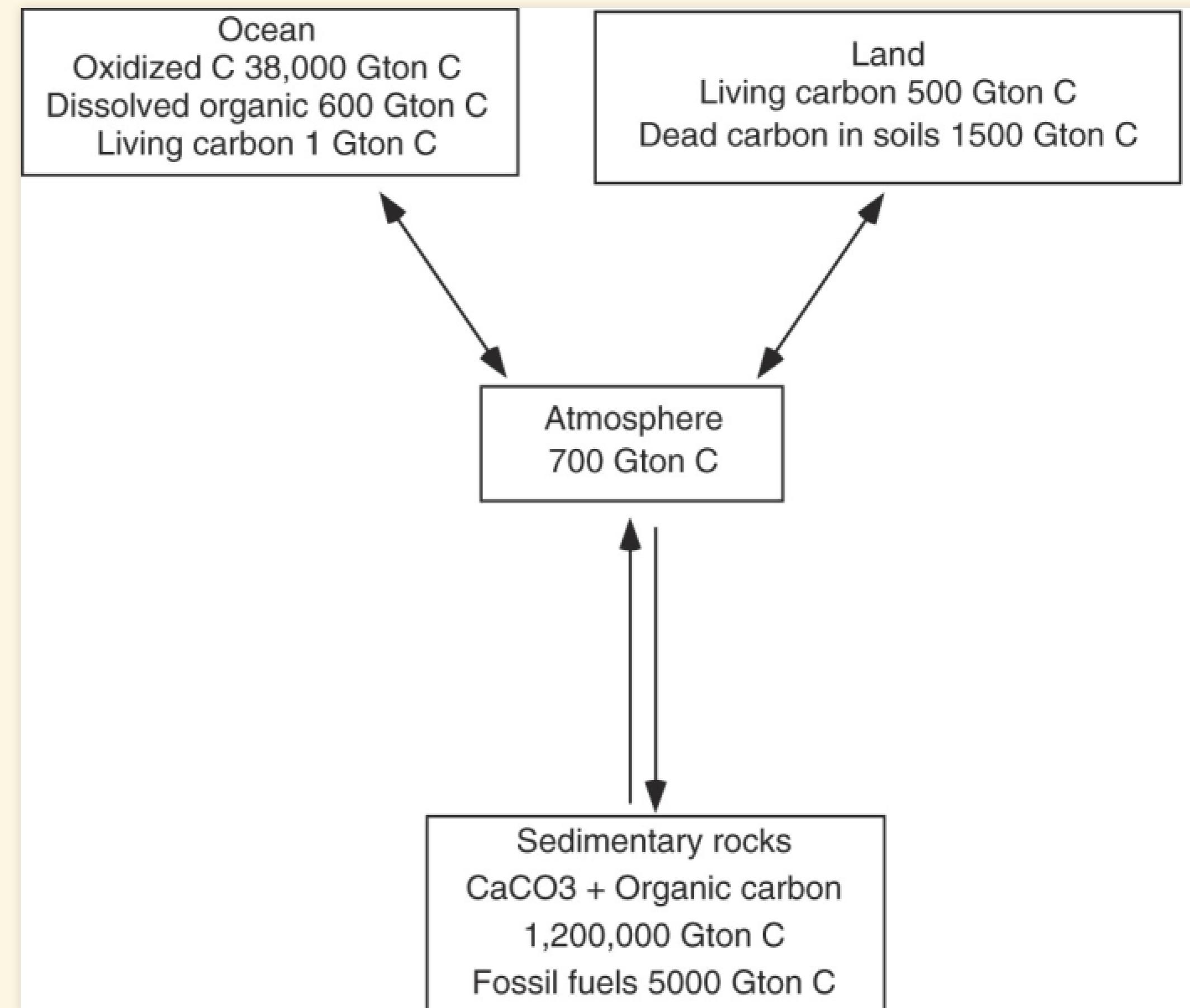
- Buried organic carbon could suck up all the oxygen in the atmosphere many times over.

Where is most of the carbon on earth?

1. The atmosphere.
2. The oceans.
3. Living and dead biomass at the land surface.
4. Deeply buried biomass.
5. Fossil fuels.
6. Carbonate rocks.

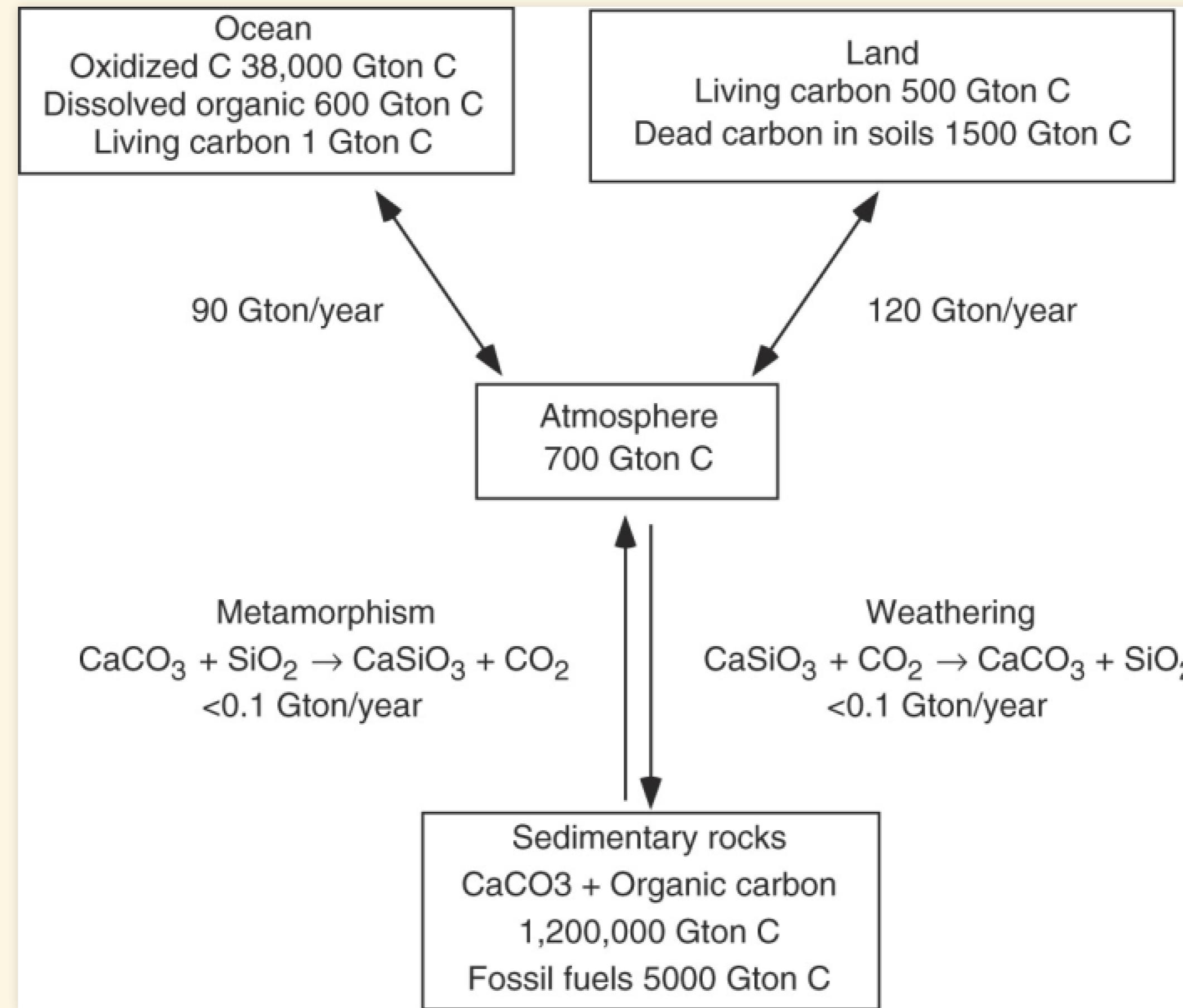
Carbon Reservoirs

Carbon Reservoirs



- GTon = gigaton
= 1 billion metric tons

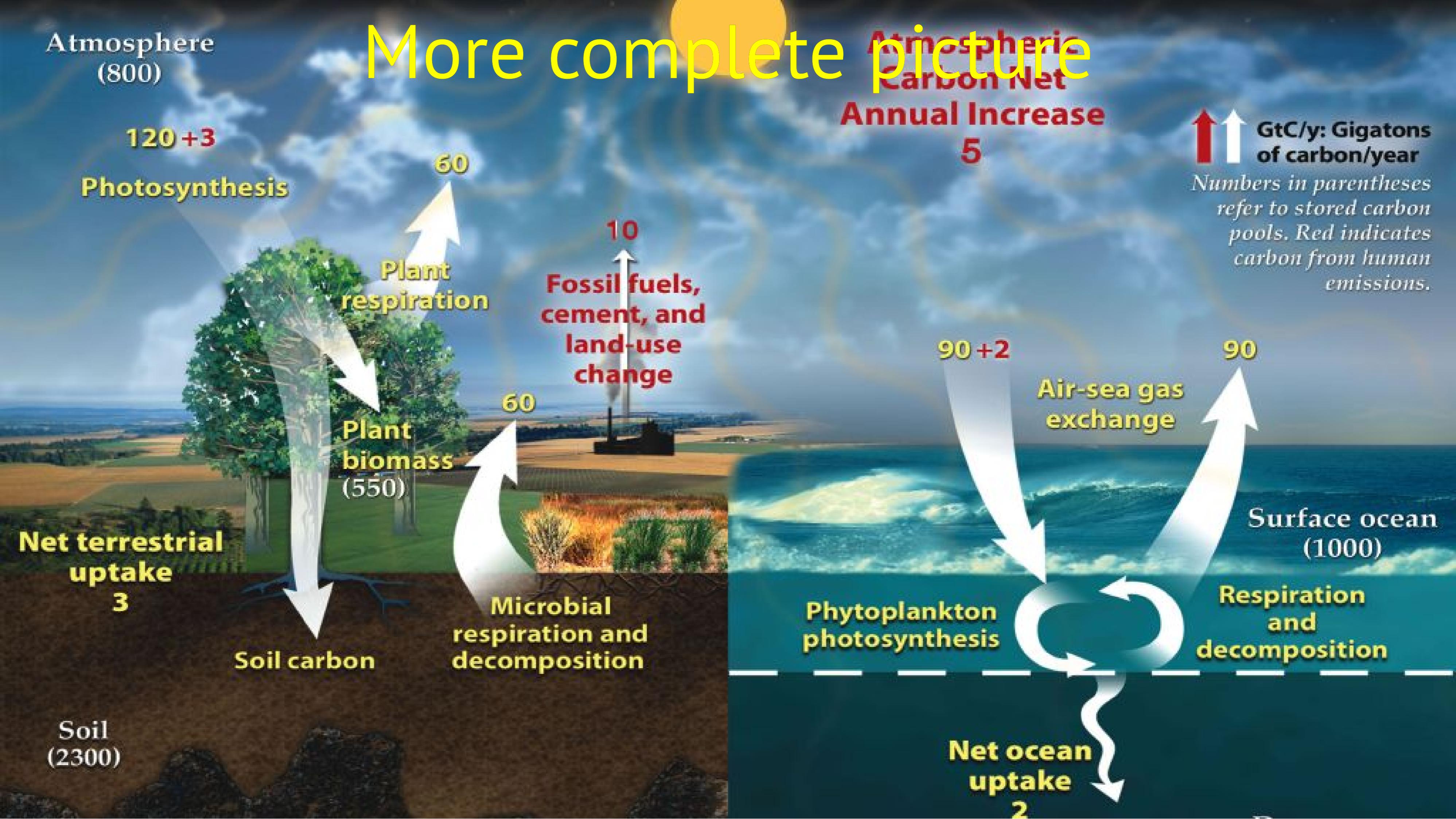
Carbon Pathways



The Planet's Lungs

- The land breathes
 - 1 year
- The oceans breathe
 - Hundreds to thousands of years
- The rocks breathe
 - Hundreds of thousands to millions of years

More complete picture



Complete Carbon Cycle

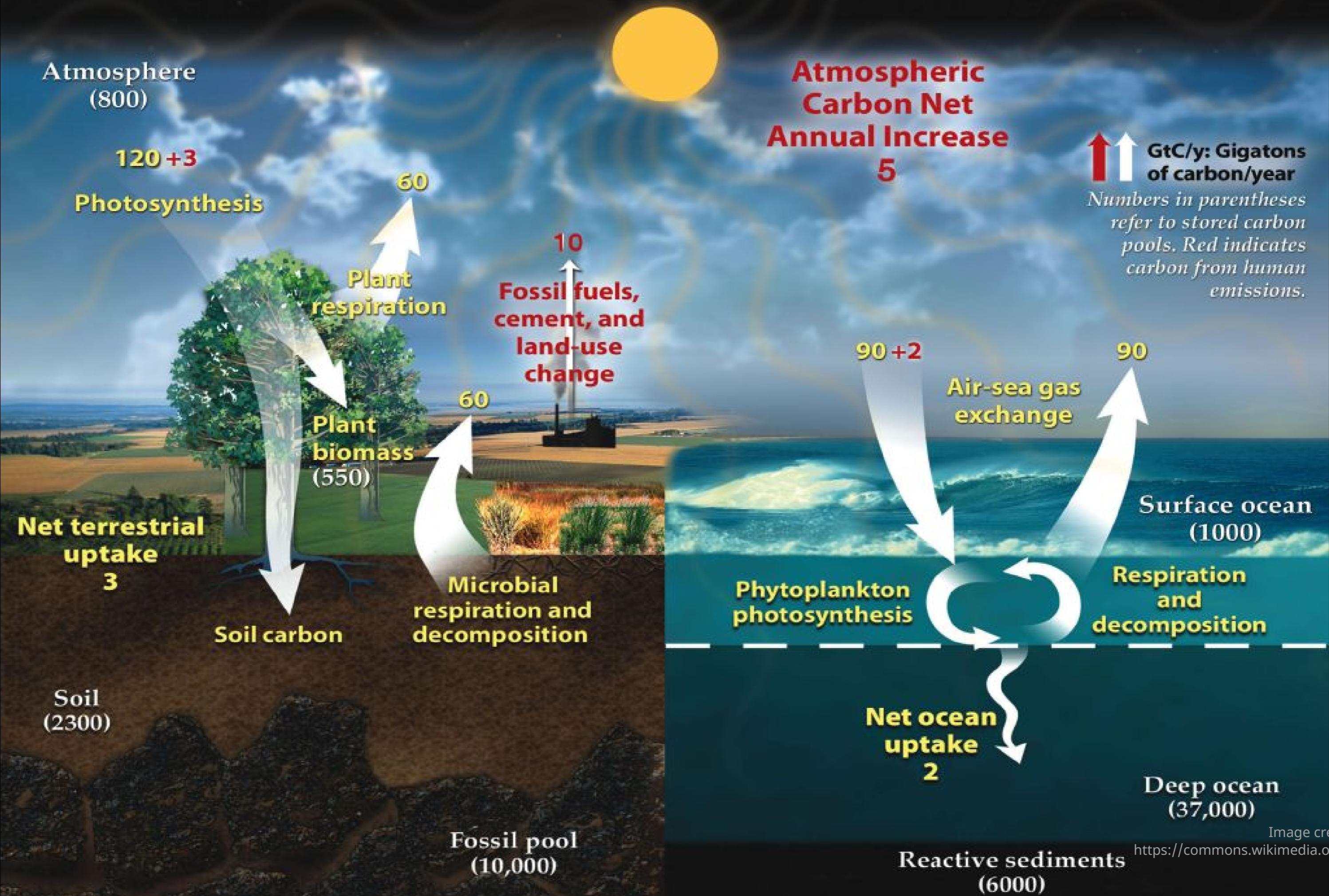
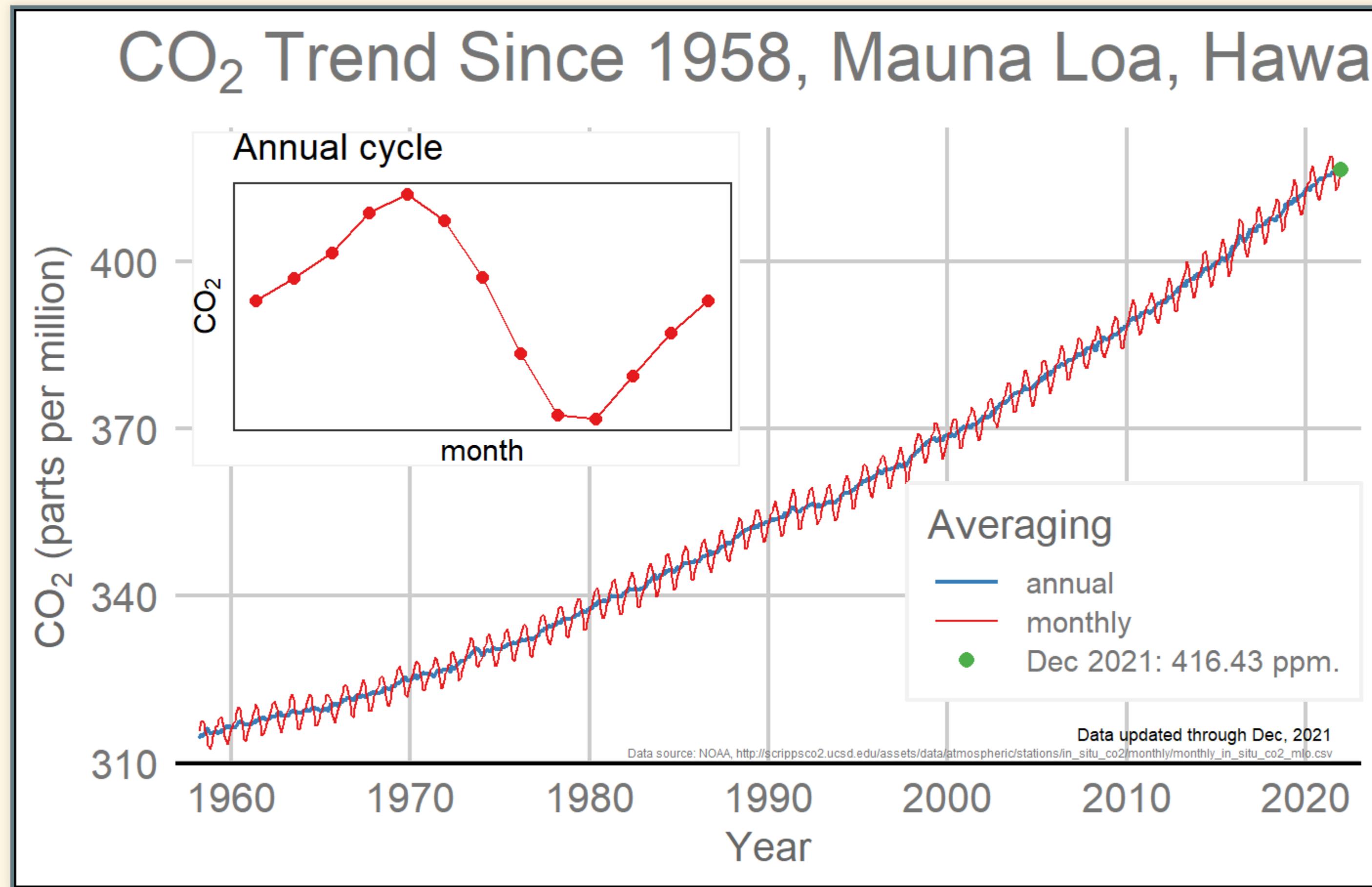


Image credit: NASA Earth Observatory

https://commons.wikimedia.org/wiki/File:Carbon_cycle.jpg

CO₂ Over Time



Why the difference in wiggles?

a. Hawaii

b. New Zealand

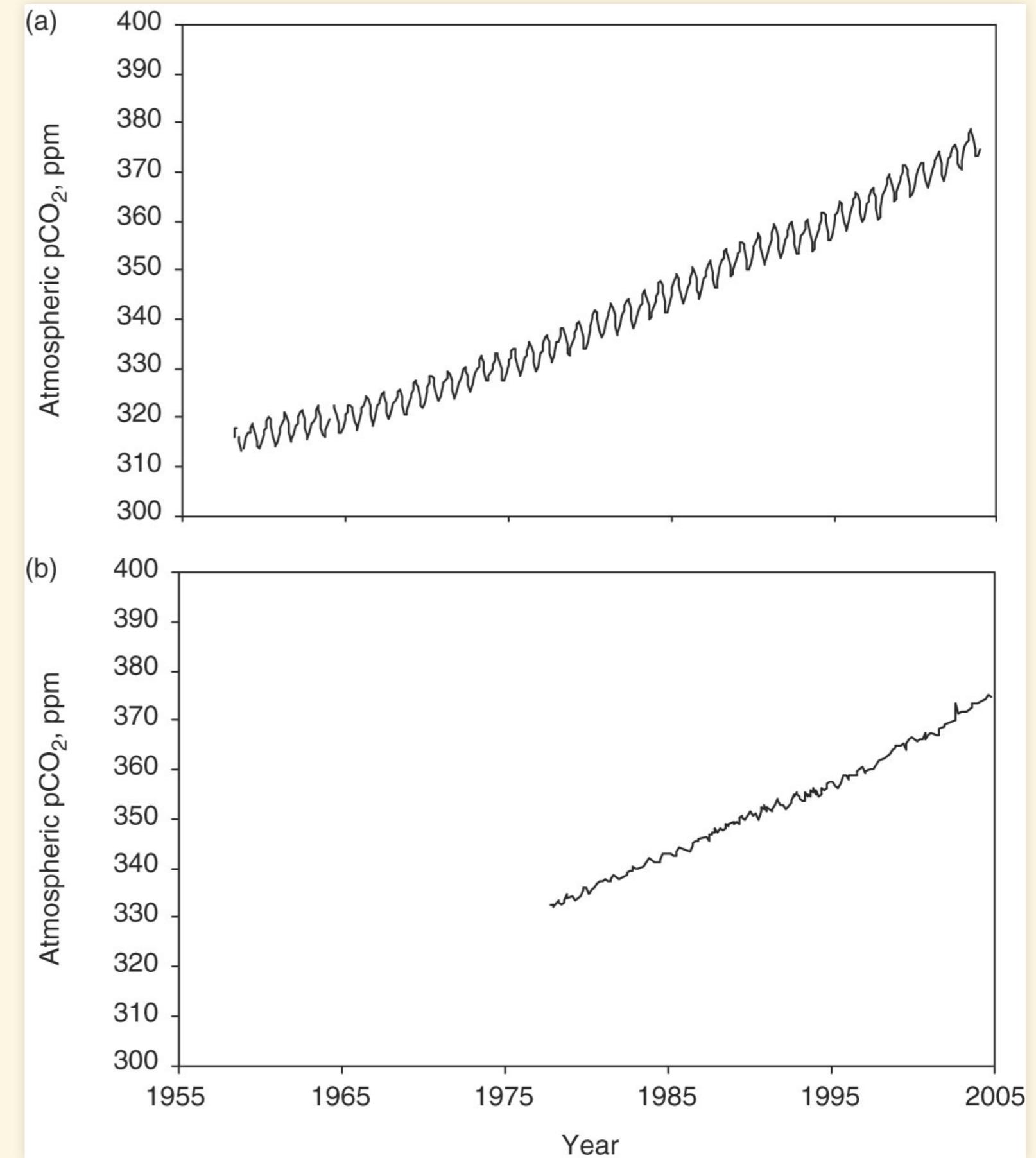
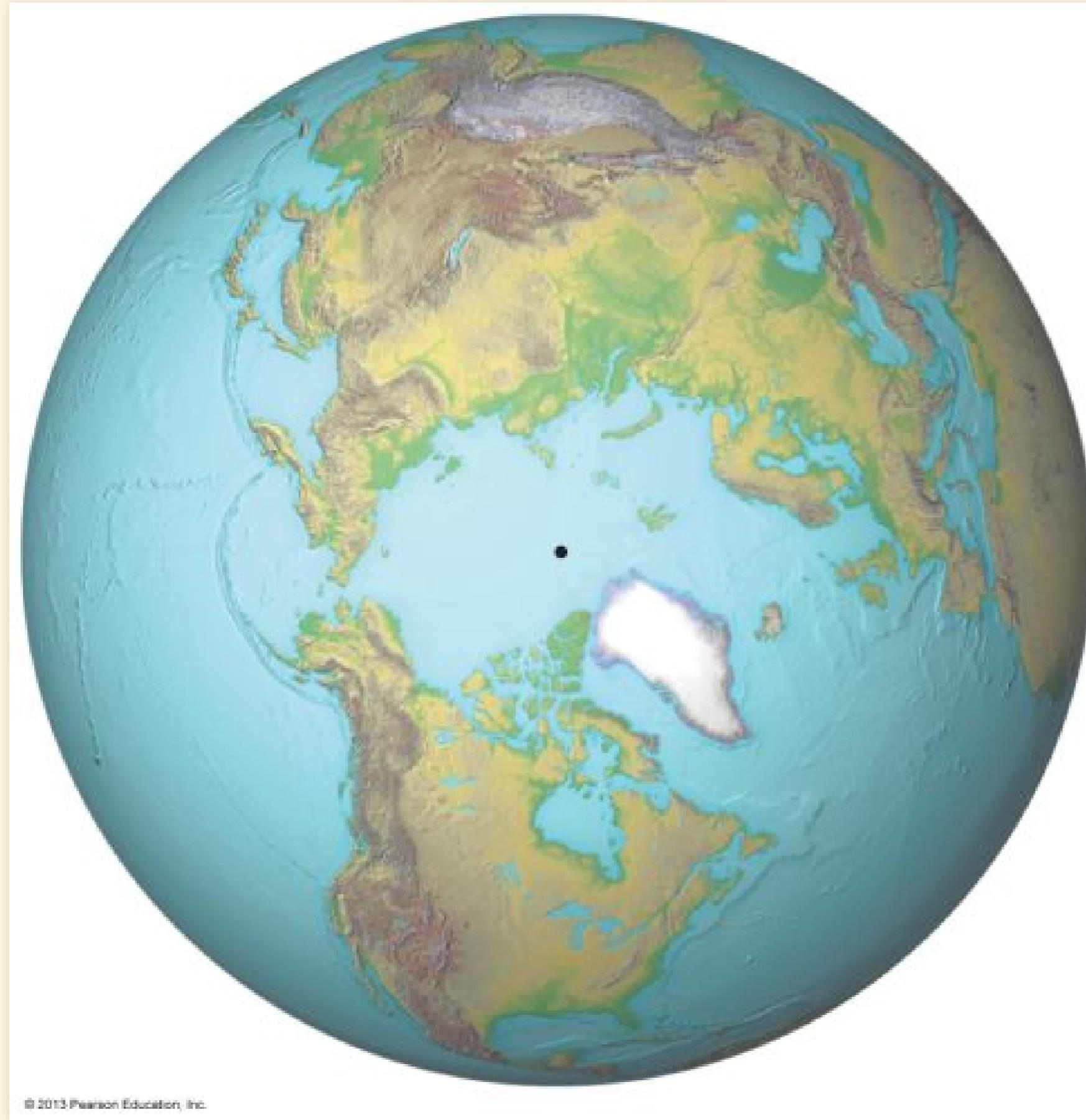
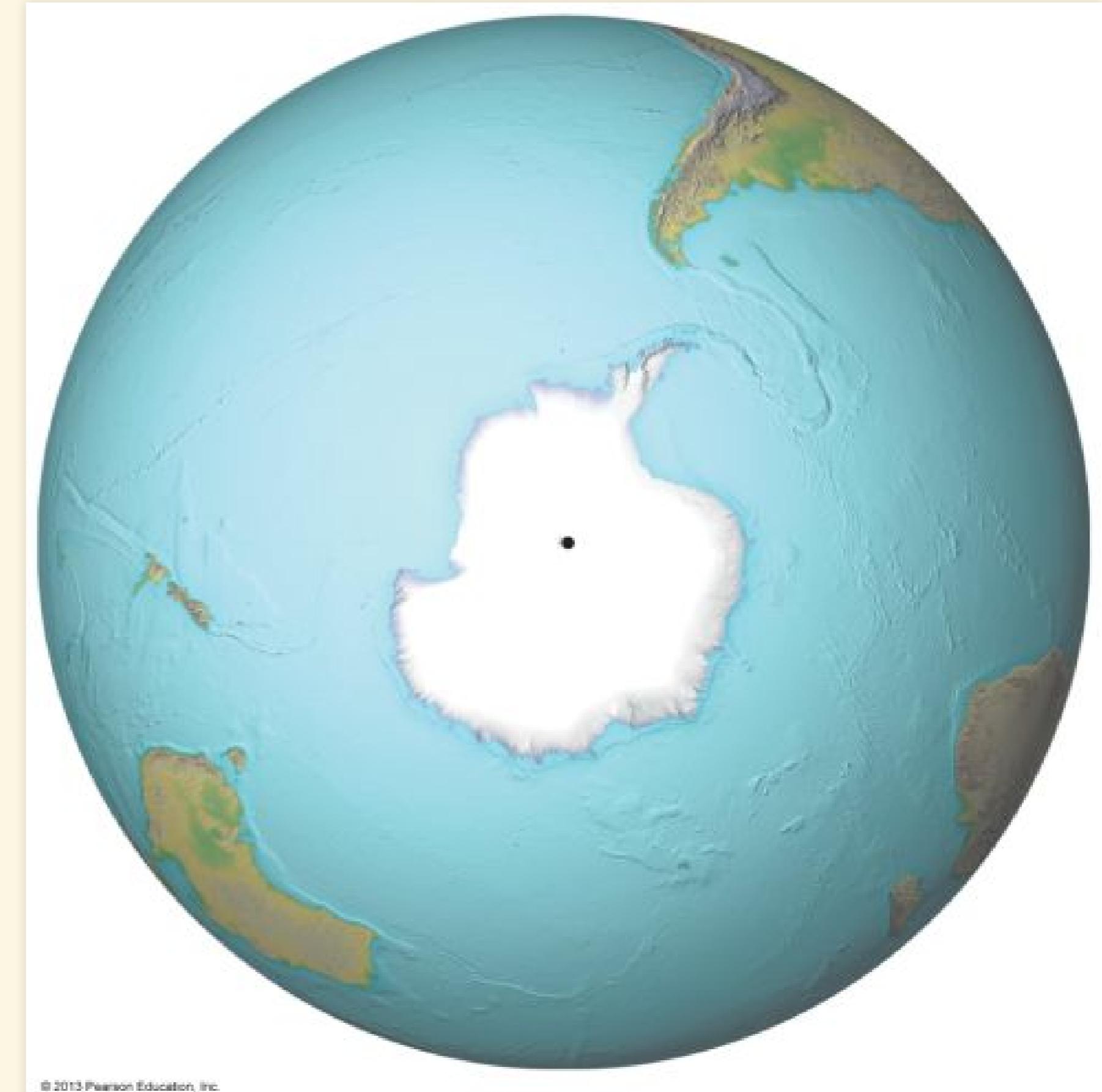


Image credit: D. Archer, *Global Warming: Understanding the Forecast*

Northern vs. Southern Hemisphere



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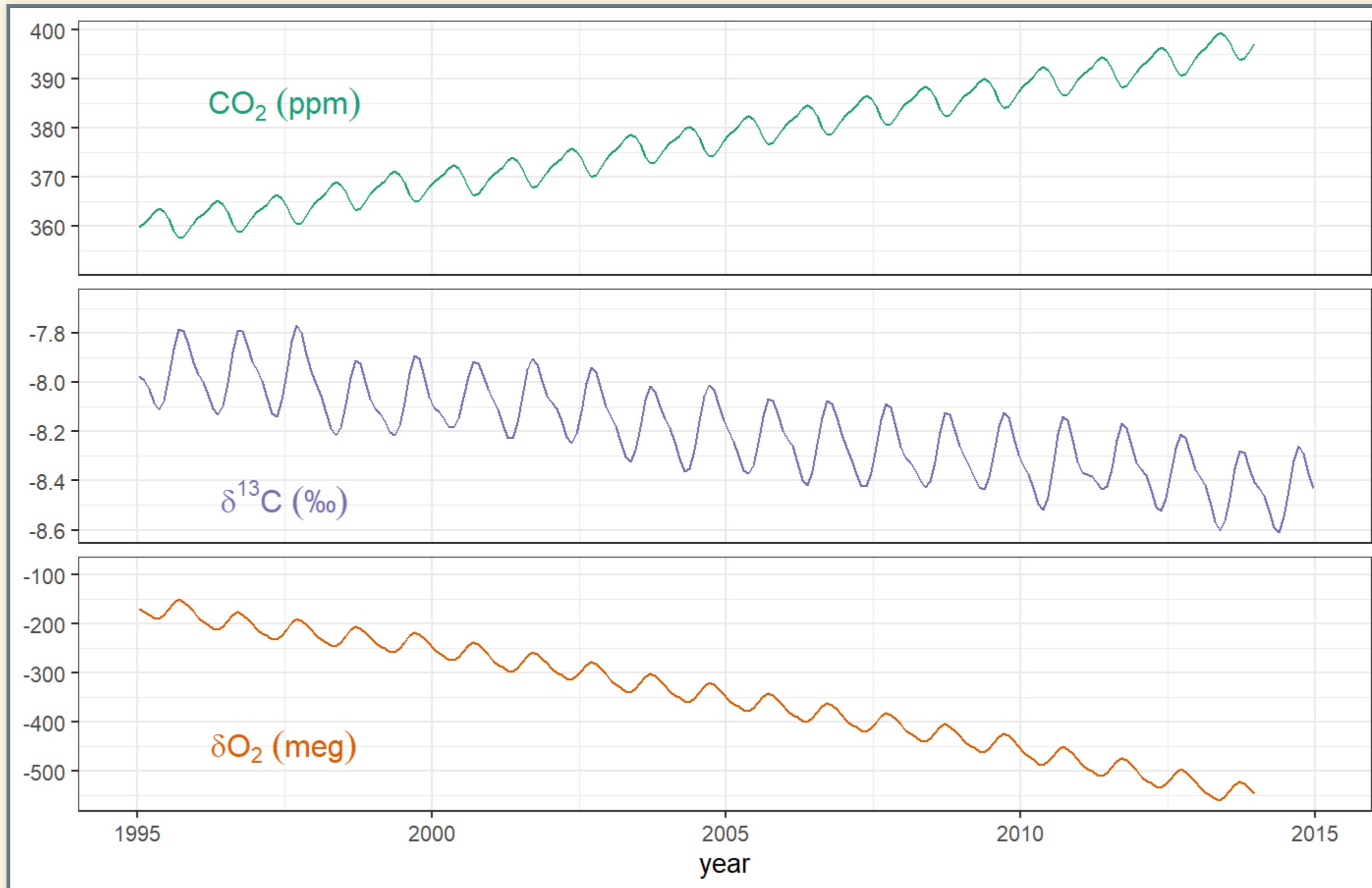


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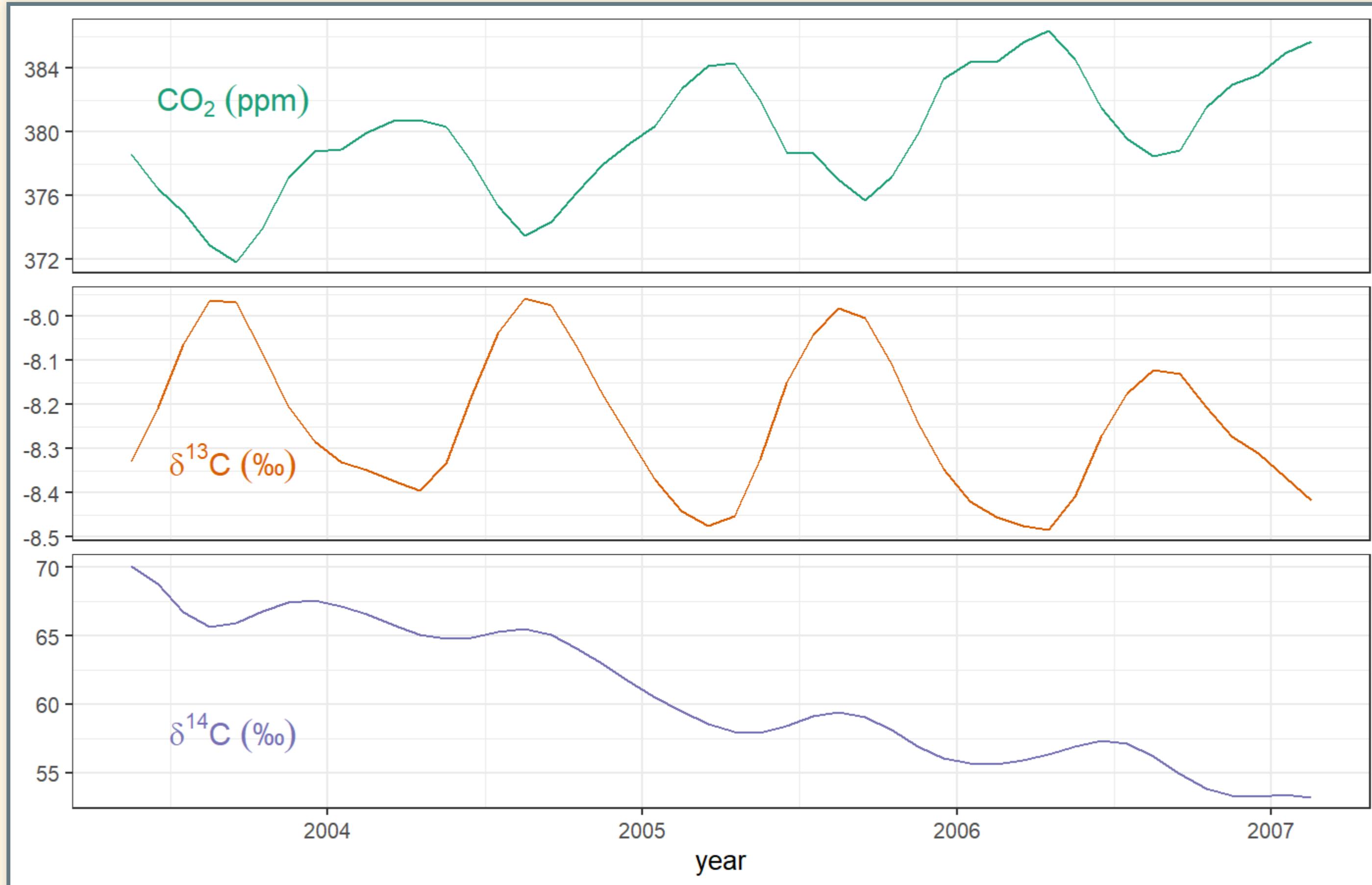
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Source of CO₂

Source of CO₂: O₂ and ¹³C



Source of CO₂: ^{13}C and ^{14}C



Fossil Fuels vs. CO₂

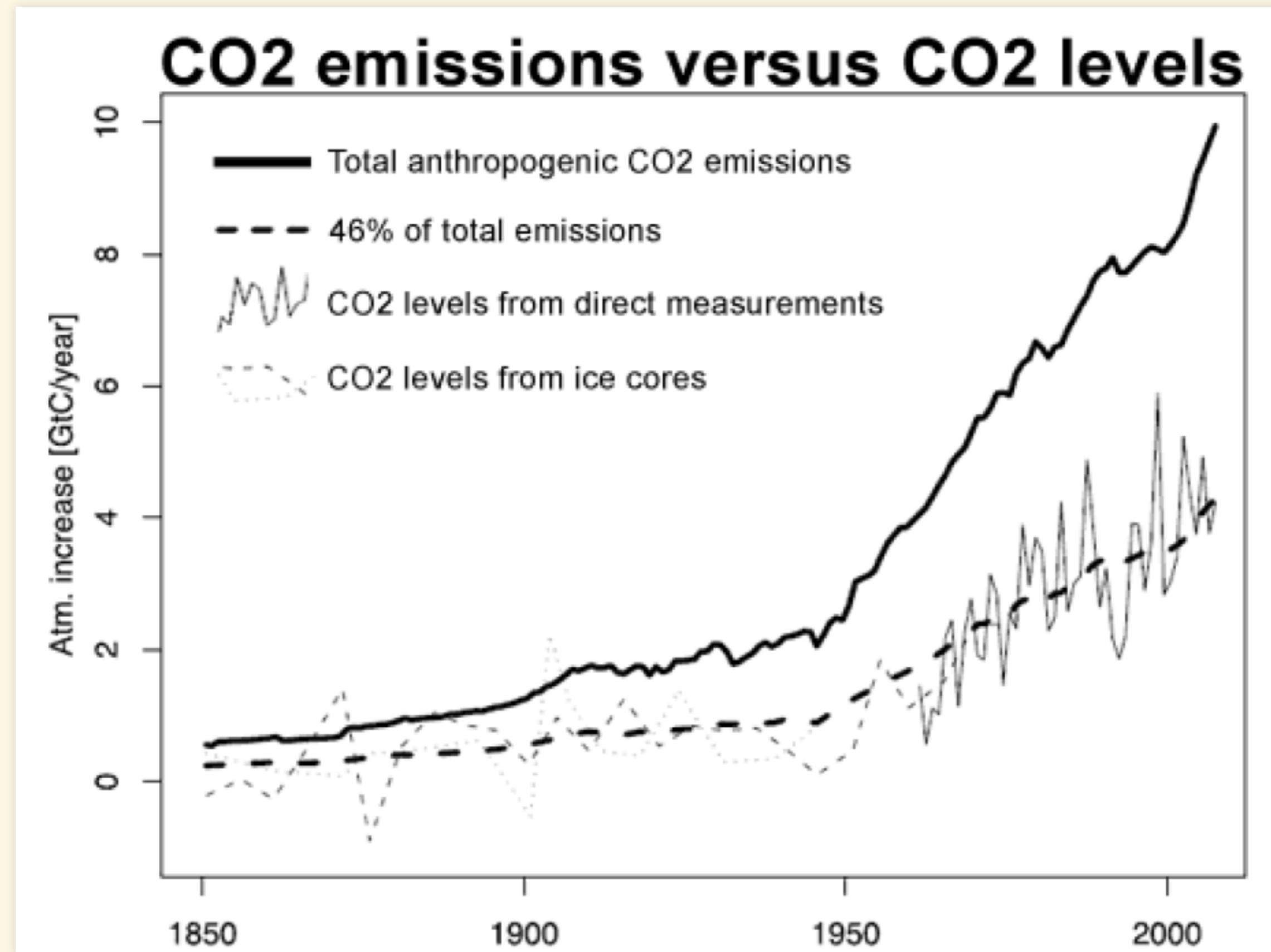


Image credit: W. Knorr, Geophys. Res. Lett. **36**, L21710 (2009) doi: 10.1029/2009GL040613

- Concentrations match 46% of fossil fuel consumption

Assessing the Evidence

- Decreasing O₂: CO₂ produced by burning.
 - Not a mineral source (volcanoes).
- ¹³C/¹²C: CO₂ must have biological origin.
- ¹⁴C: The fuel must be thousands of years old.
- Possible sources: Burning billions of tons per year of very old organic matter.
- Rate of rise matches fossil fuel consumption.
- **Therefore: Dominant source must be fossil fuels.**

The Oceans Breathe
Centuries to Millennia

Studying Ancient Climates

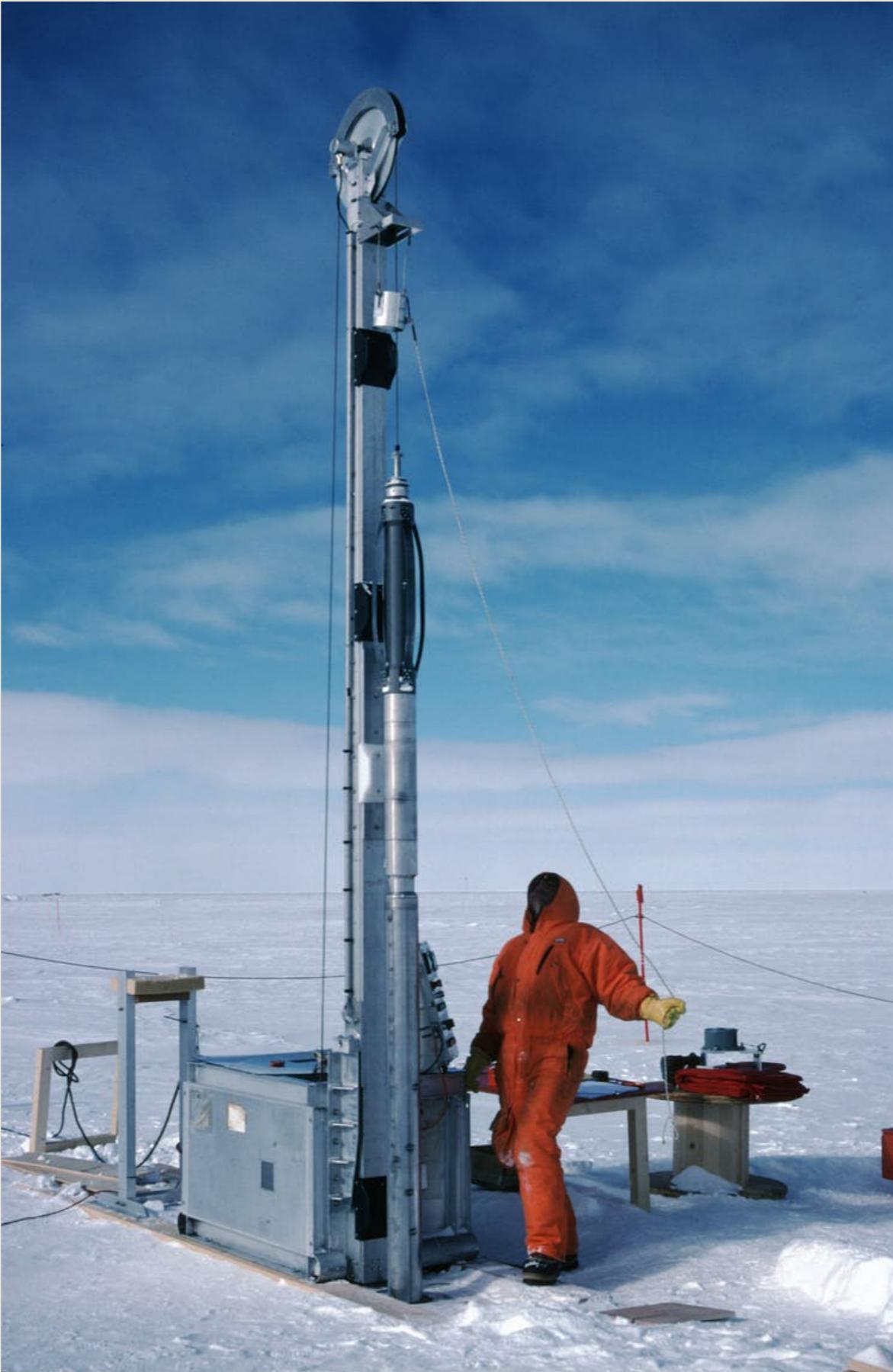


Image Credit: R Mulvaney/British Antarctic Survey

Ice Cores



Image credits: Pete Bucktrout/British Antarctic Survey

Inside the Ice Core

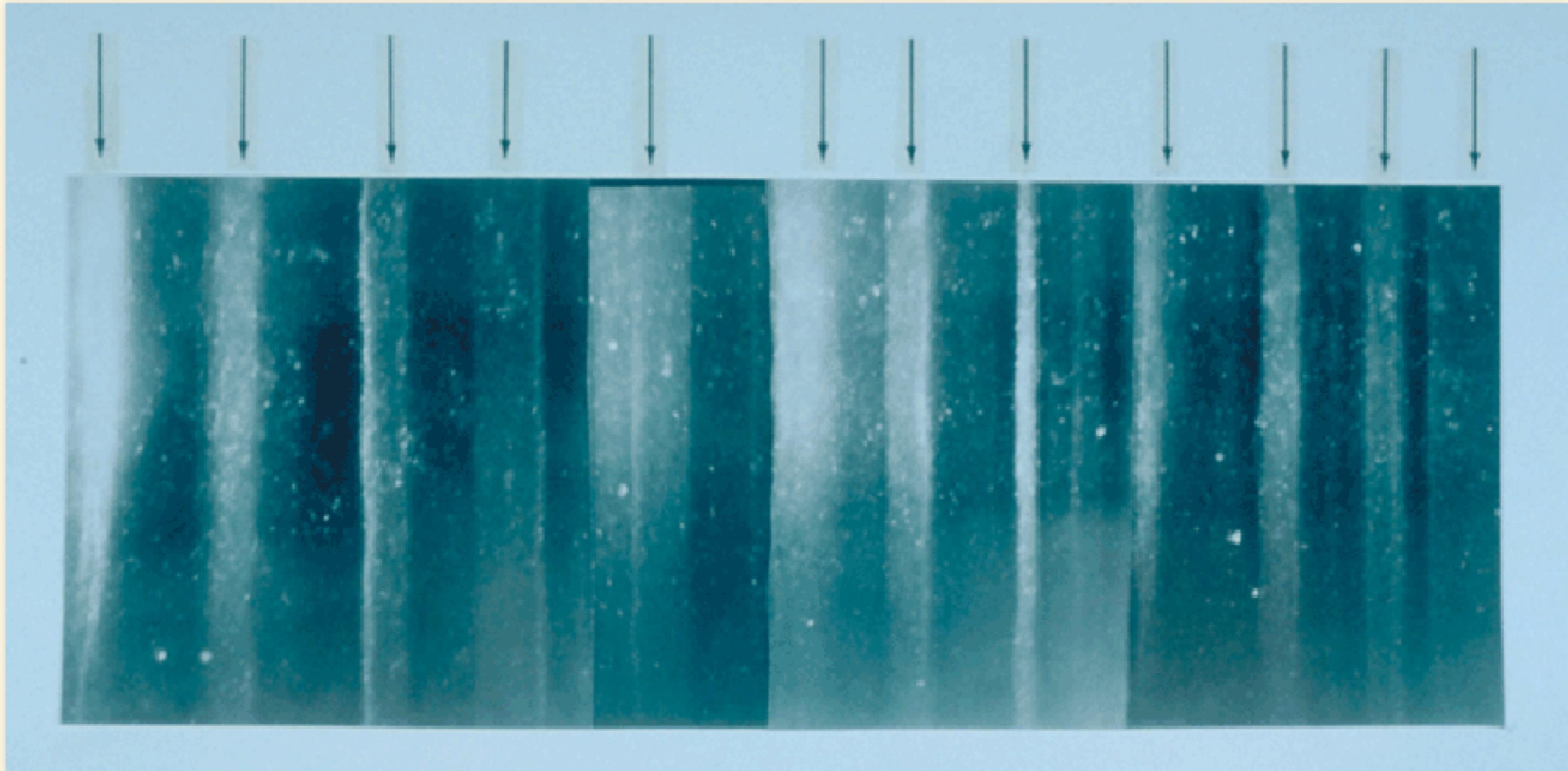


Image credit: National Ice Core Laboratory

Inside the Ice Core

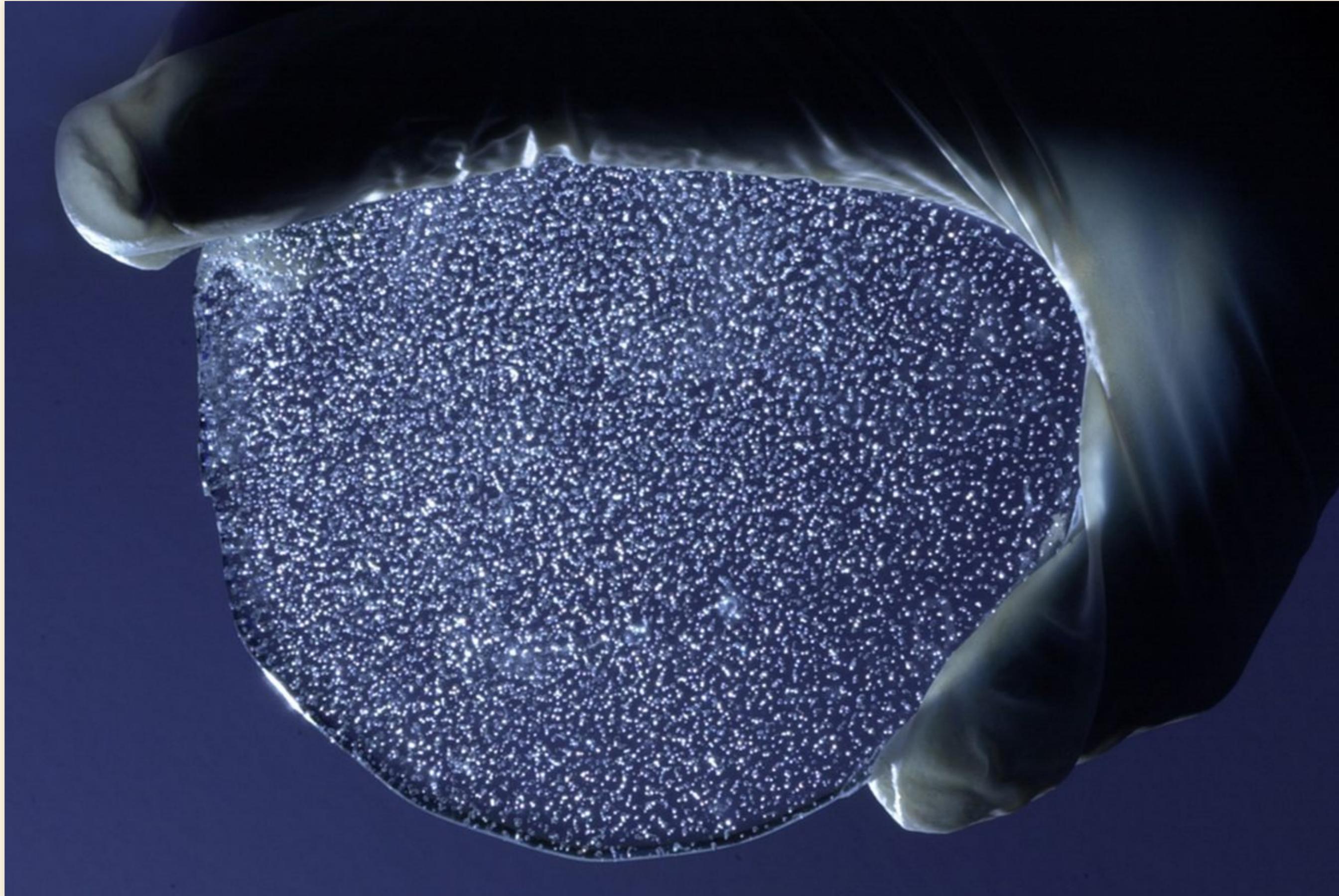
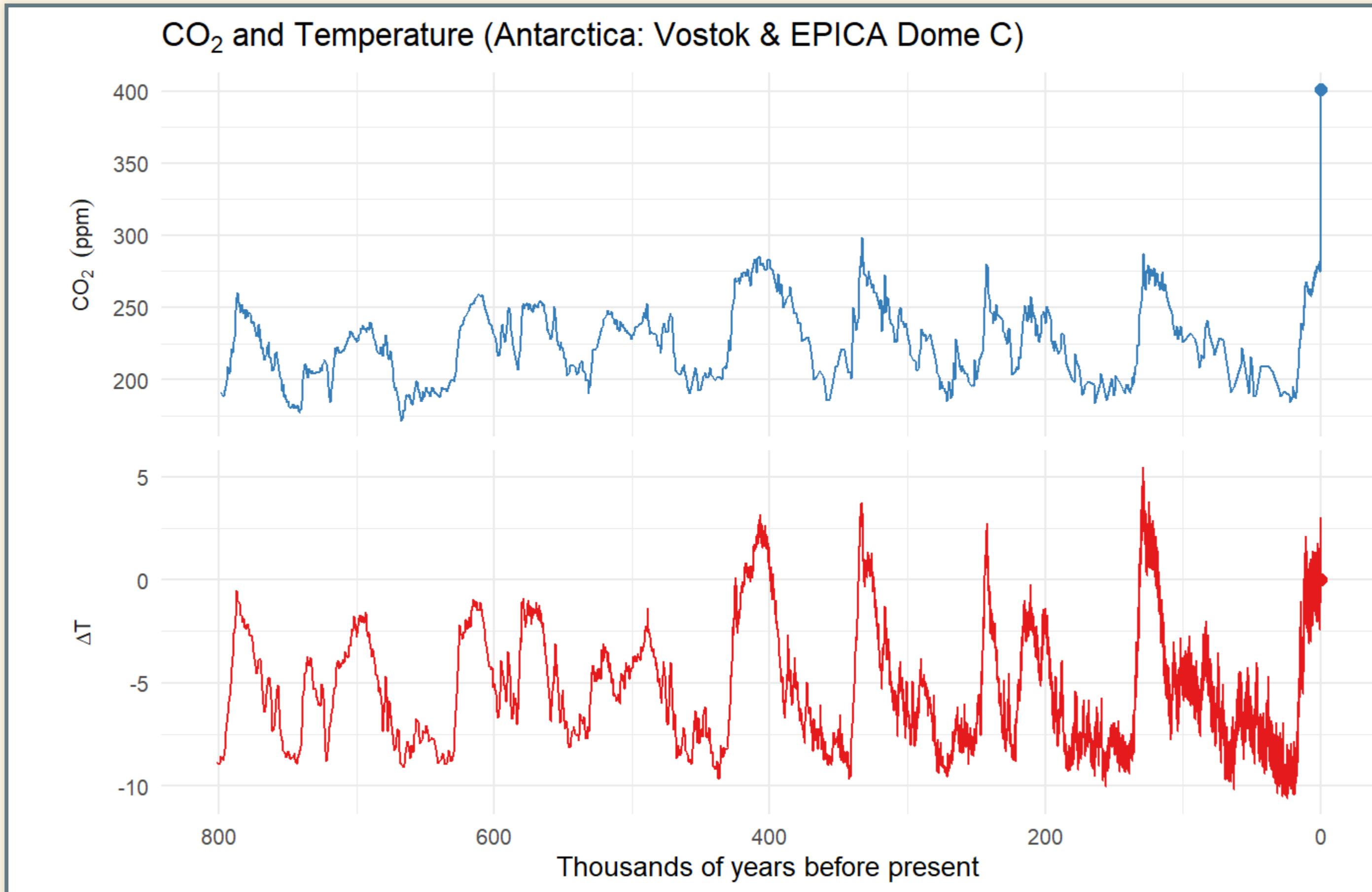


Image credit: Pete Bucktrout/British Antarctic Survey

The Oceans Breathe



Ice Ages

25,000 years ago



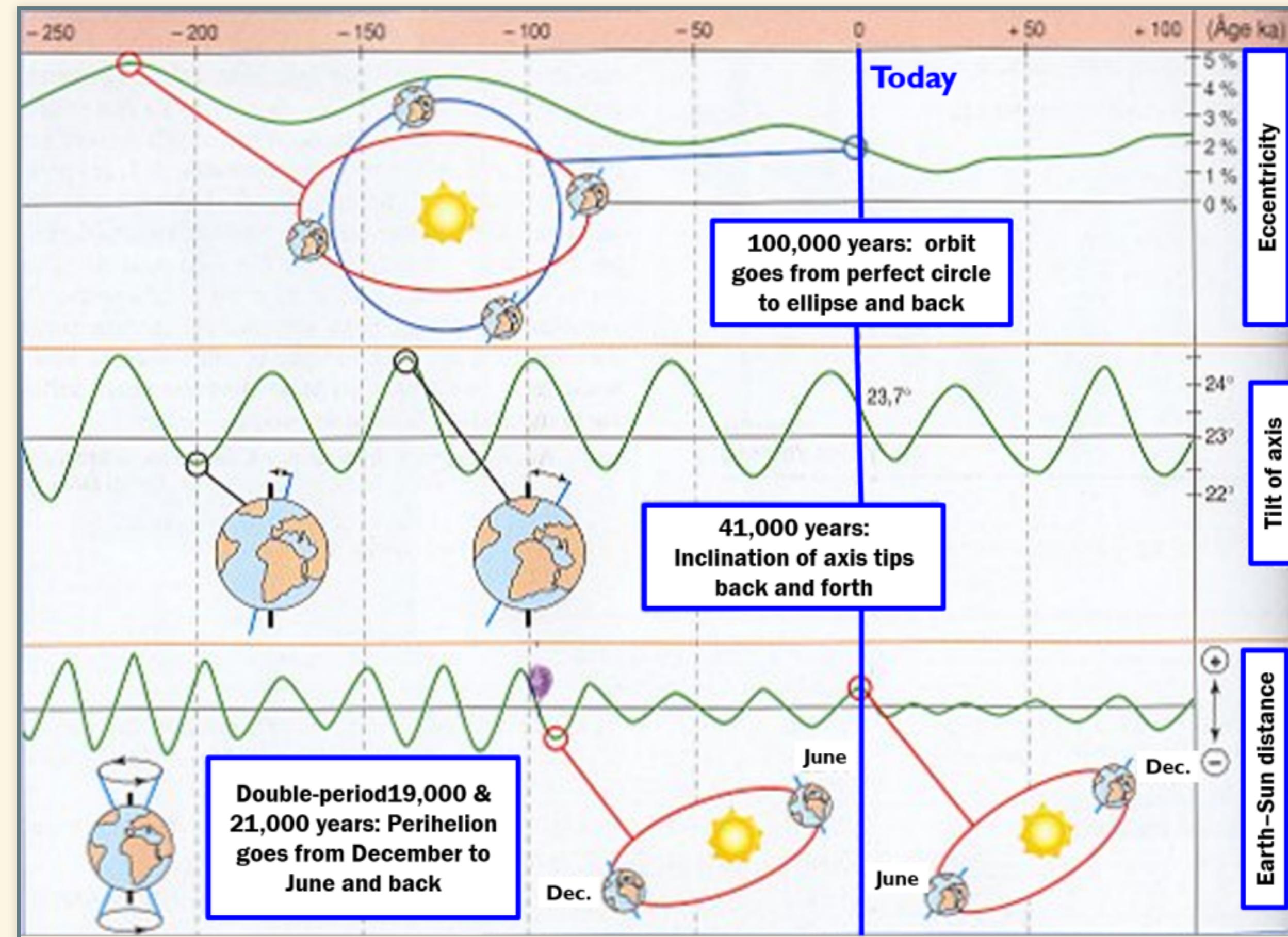
Image credit: Ron Blakey

25,000 years ago

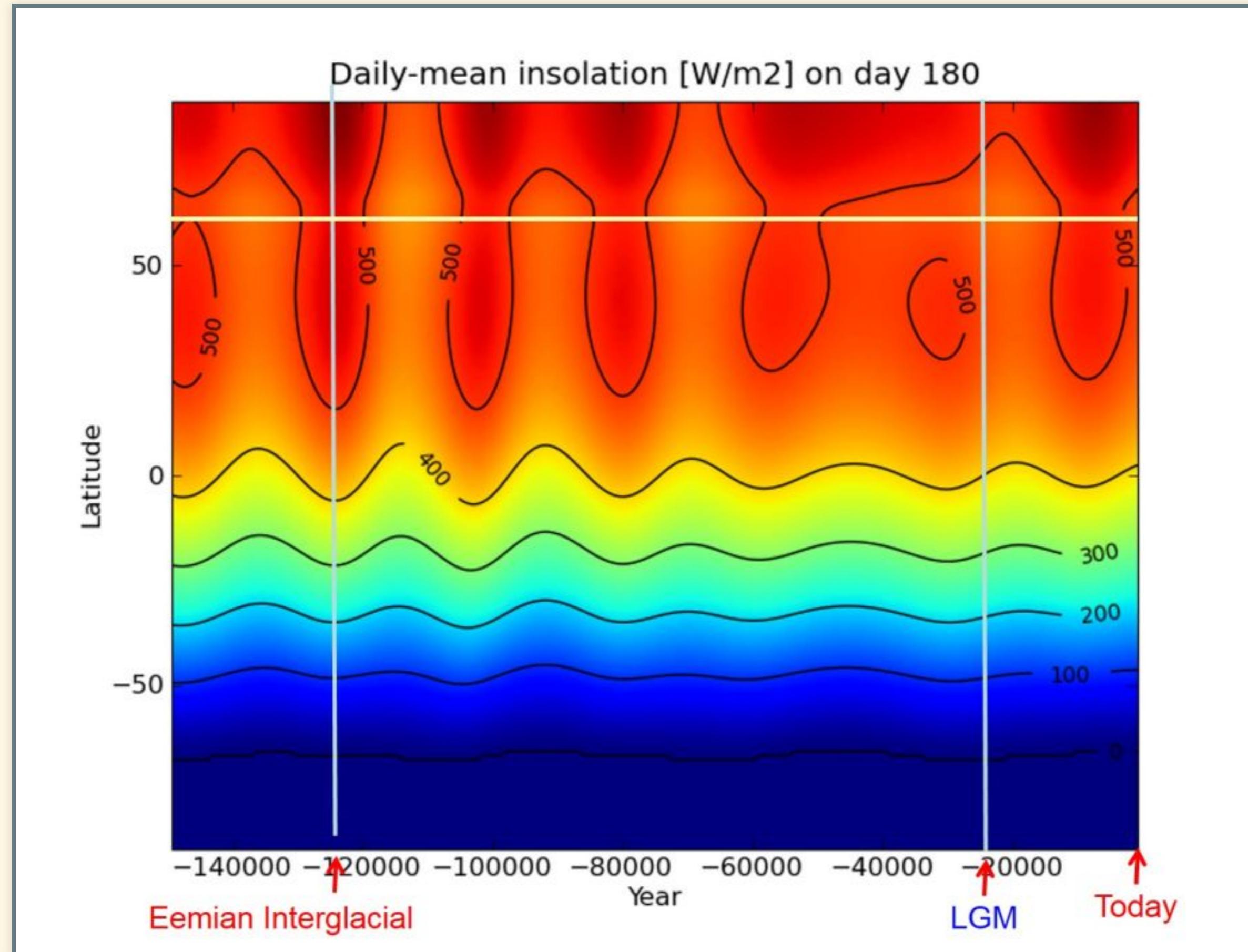


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Causes



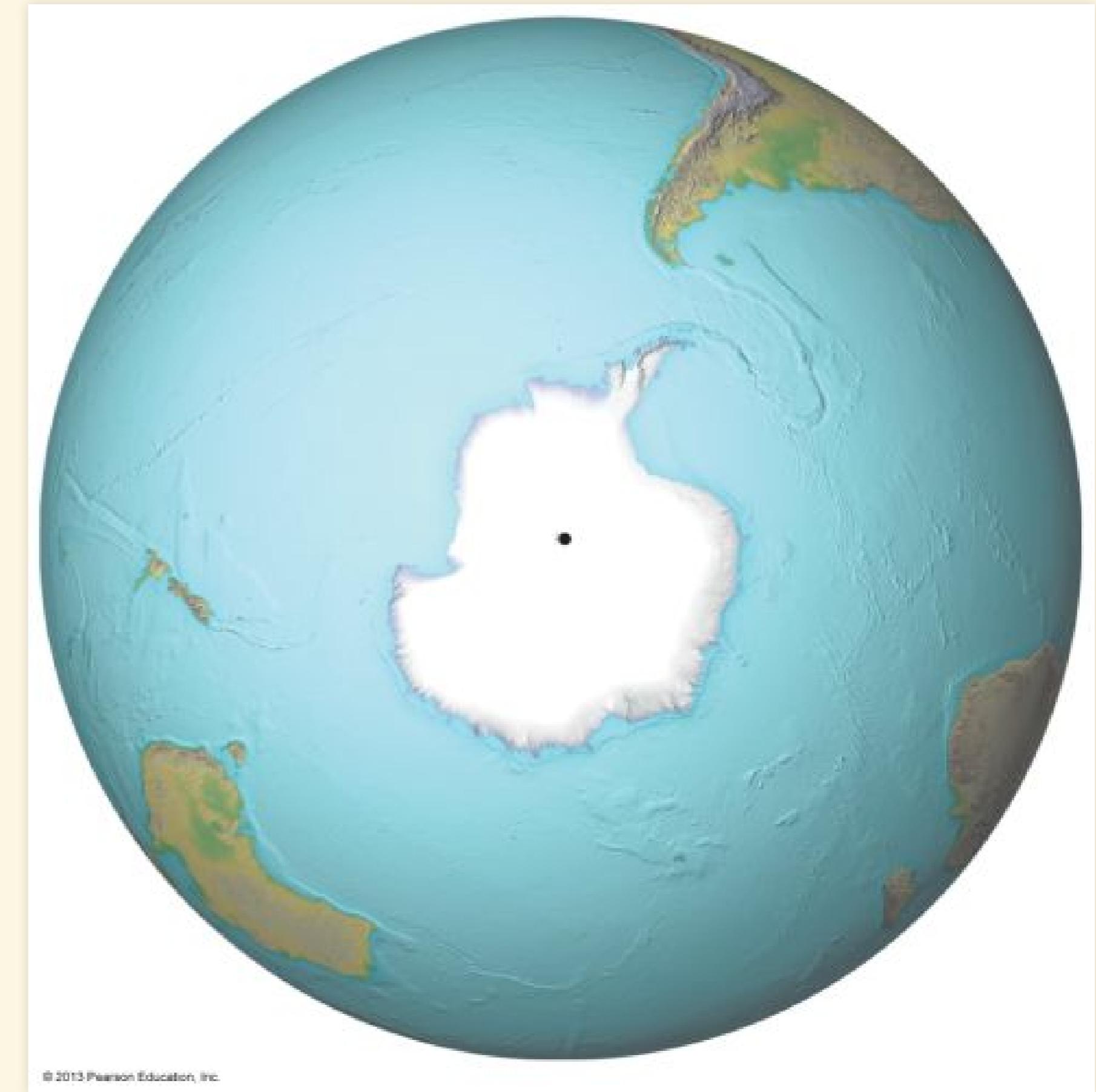
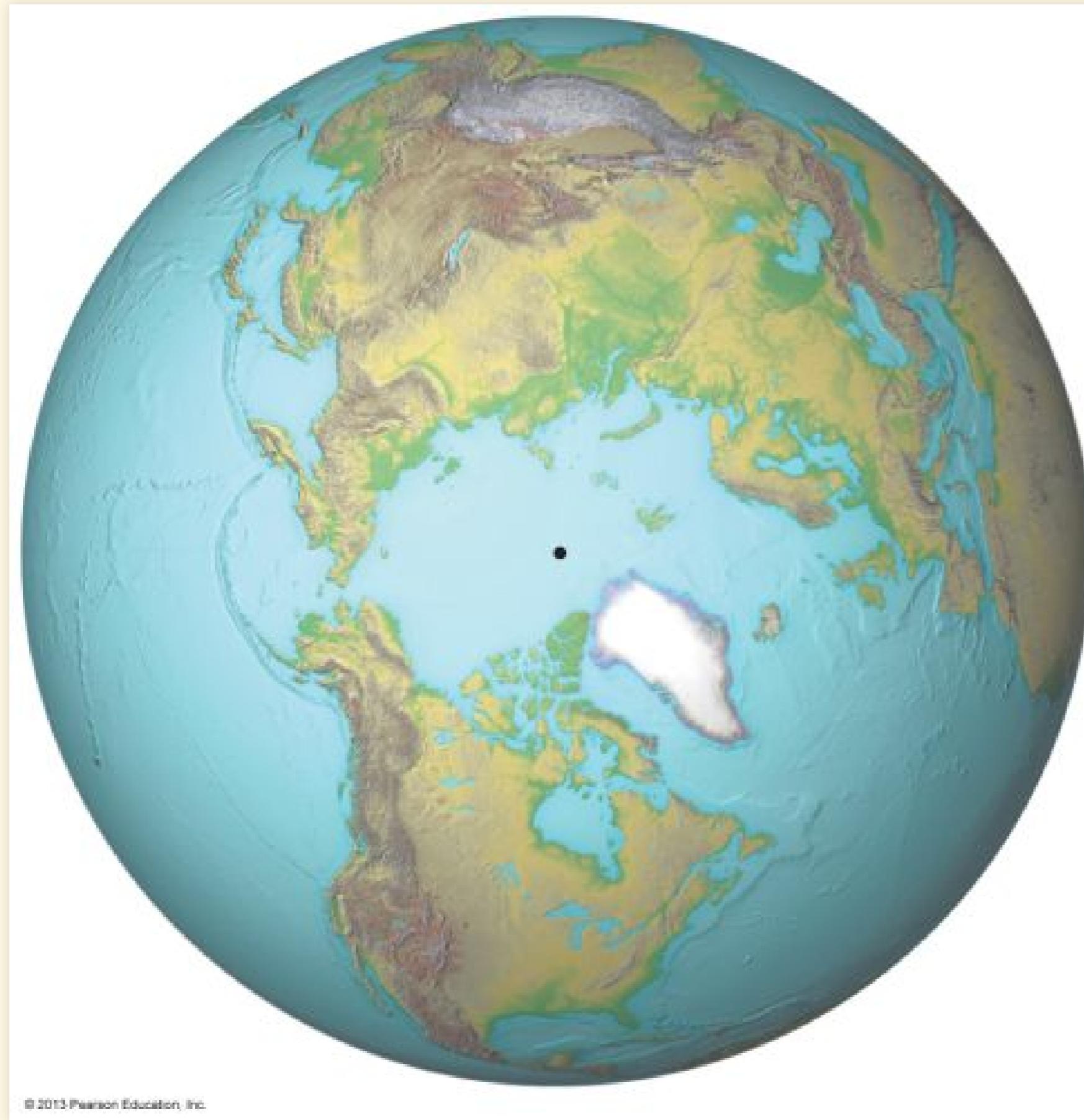
Insolation



Question

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

Northern vs. Southern Hemisphere



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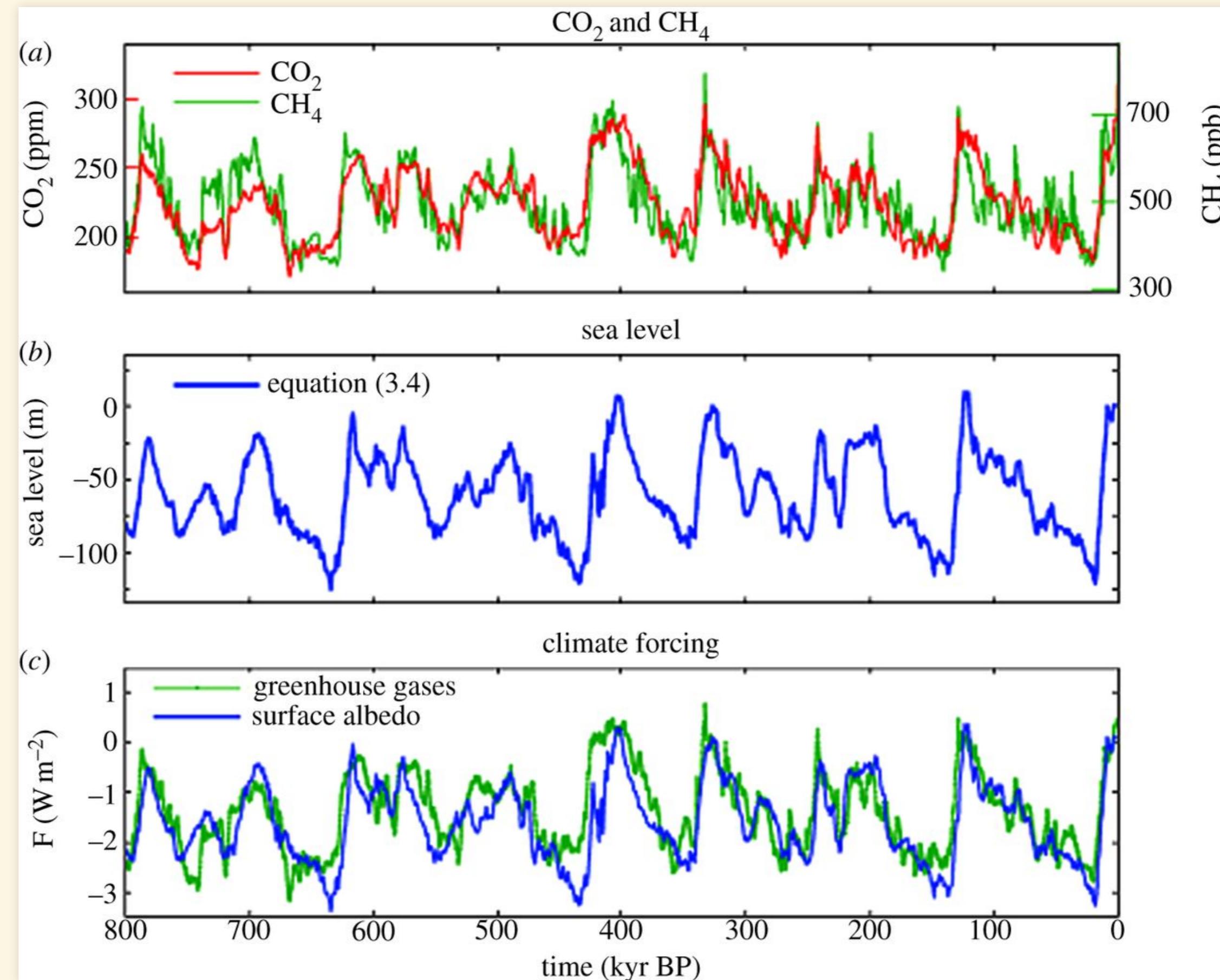
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Ice Age Feedbacks

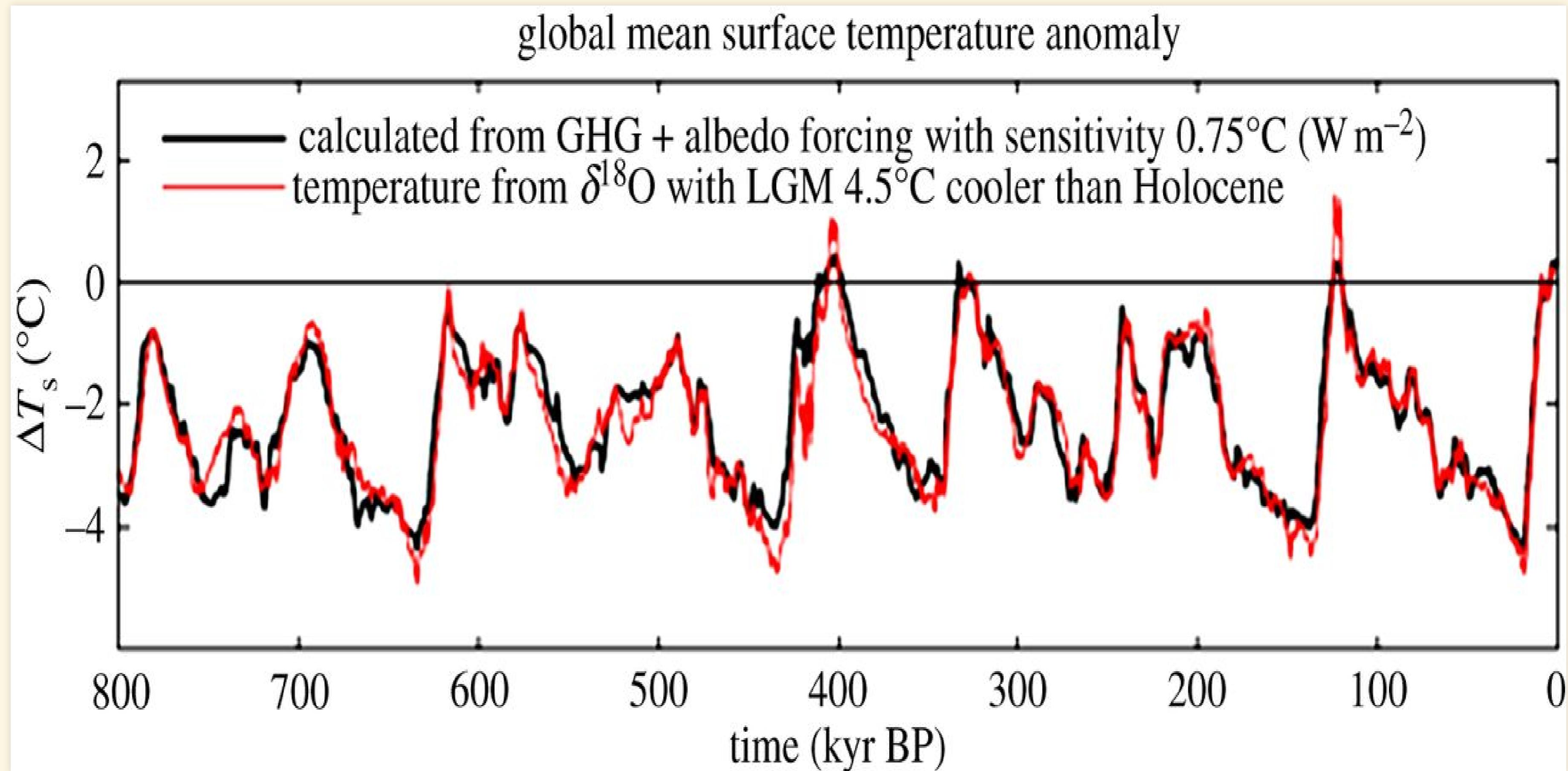
Ice Age Feedbacks

- 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

Theory of Feedbacks



Theory vs. Observations



Ice-Age Feedbacks:

- Temperature starts to fall
 - Glaciers grow → higher albedo
 - CO_2 drops → weaker greenhouse
 - Colder
- Temperature starts to rise
 - Glaciers retreat → higher albedo
 - CO_2 rises → stronger greenhouse
 - Warmer
- Without CO_2 and ice-albedo feedbacks, ice-ages couldn't happen
- Ice ages can't happen with today's CO_2 levels.

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 CO₂ band show that the average surface temperature of the earth increases 3.6° C if the CO₂ concentration in the atmosphere is doubled and decreases 3.8° C if the CO₂ amount is halved, provided that no other factors change which influence the radiation balance. Variations in CO₂ amount of this magnitude must have occurred during geological history; the resulting temperature changes were sufficiently large to influence the climate. The CO₂ balance is discussed. The CO₂ equilibrium

~~assuming that the average temperature change is calculated with and without CaCO₃ equilibrium~~
predicted by the CO₂ theory. When the total CO₂ 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 CO₂ 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 CO₂ 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 CO₂ theory predicts that this warming trend will continue, at least for several centuries.