

# The Carbon Cycle: Ocean and Biosphere

EES 2110

Introduction to Climate Change

Jonathan Gilligan

Class #13: Friday, February 10 2023

# 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)

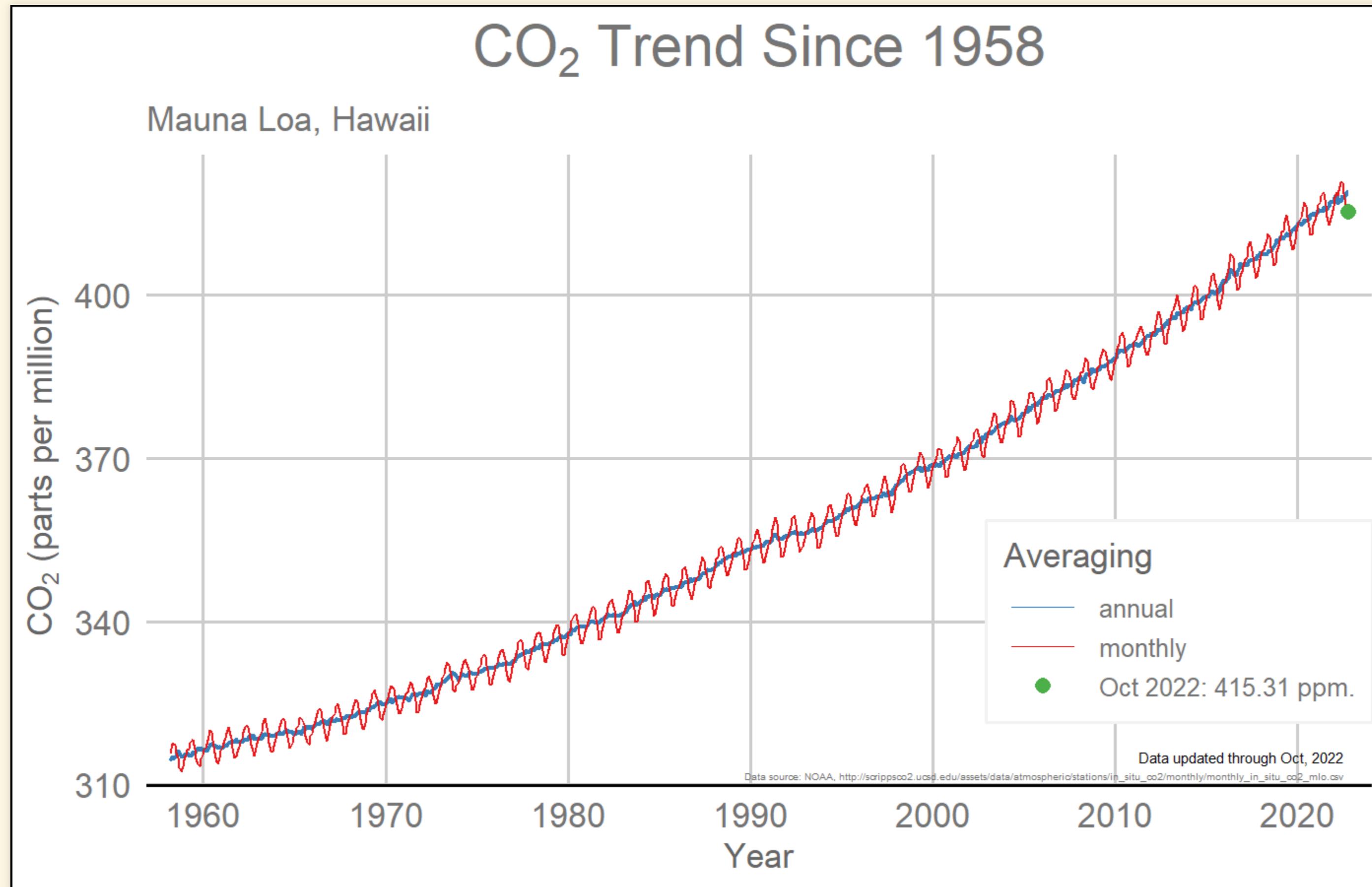


# J. Marshall Shepherd

- 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)



## ## CO<sub>2</sub> in the Atmosphere {#keeling}



# 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  $\rightarrow$  large greenhouse effect.
- Large oxidation state  $\rightarrow$  small greenhouse effect.

# Carbon

## Oxidation states:

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

# Examples

Chemical	Oxidation	Name
$\text{CH}_4$	-4	methane
$\text{C}_n$	0	coal, graphite, diamond
$(\text{CH}_2)_n$	-2	long-chain alkane
$\text{CO}_2$	+4	carbon dioxide
$(\text{CH}_2\text{O})_n$	0	carbohydrate

# Carbon

Category	Oxidation State	Examples
Mineral carbon	$\geq 0$	$\begin{aligned} & \text{C} & : \text{+0} \\ & \text{CO}_2 & : +4 \end{aligned}$
Organic carbon	$\leq 0$	$\begin{aligned} & \text{methane} & : -4 \\ & \text{sugar} & : -6 \end{aligned}$

## Energy:

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

# Carbon

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## History of oxidation on earth:

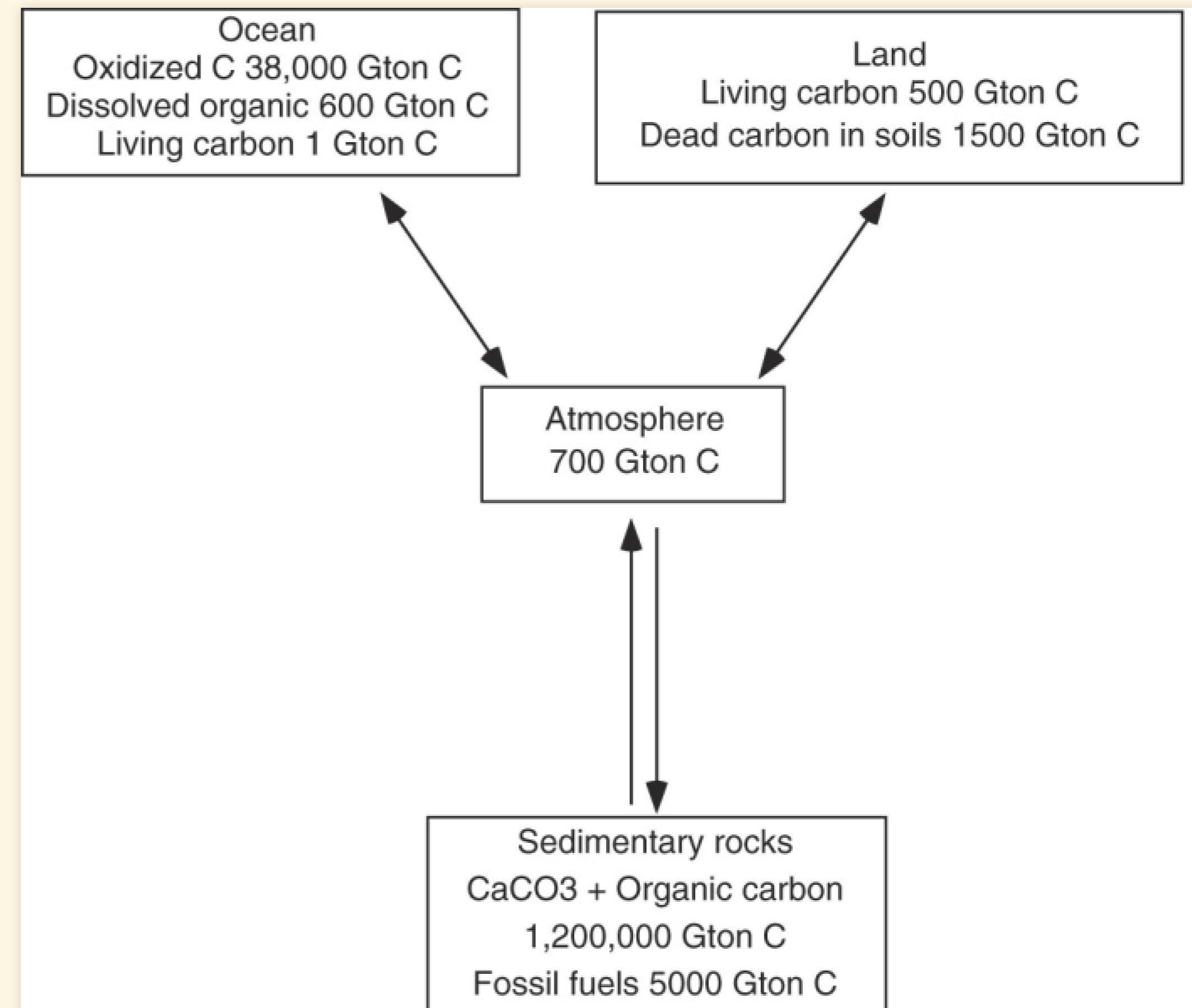
- Buried organic carbon could suck up all the oxygen in the atmosphere many times over.

# 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.

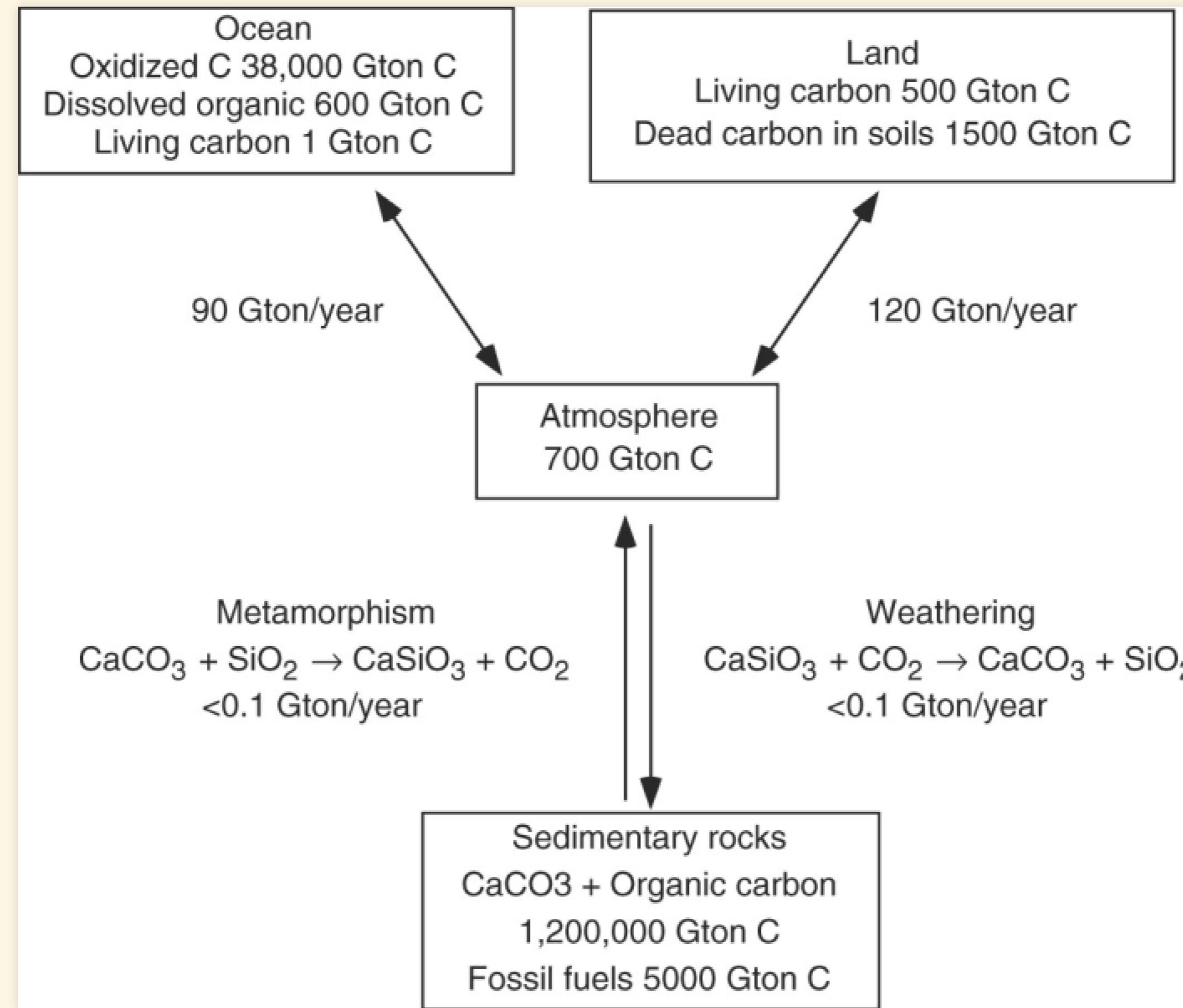
# Carbon Reservoirs

# Carbon Reservoirs



- GTon = gigaton  
= 1 billion metric tons

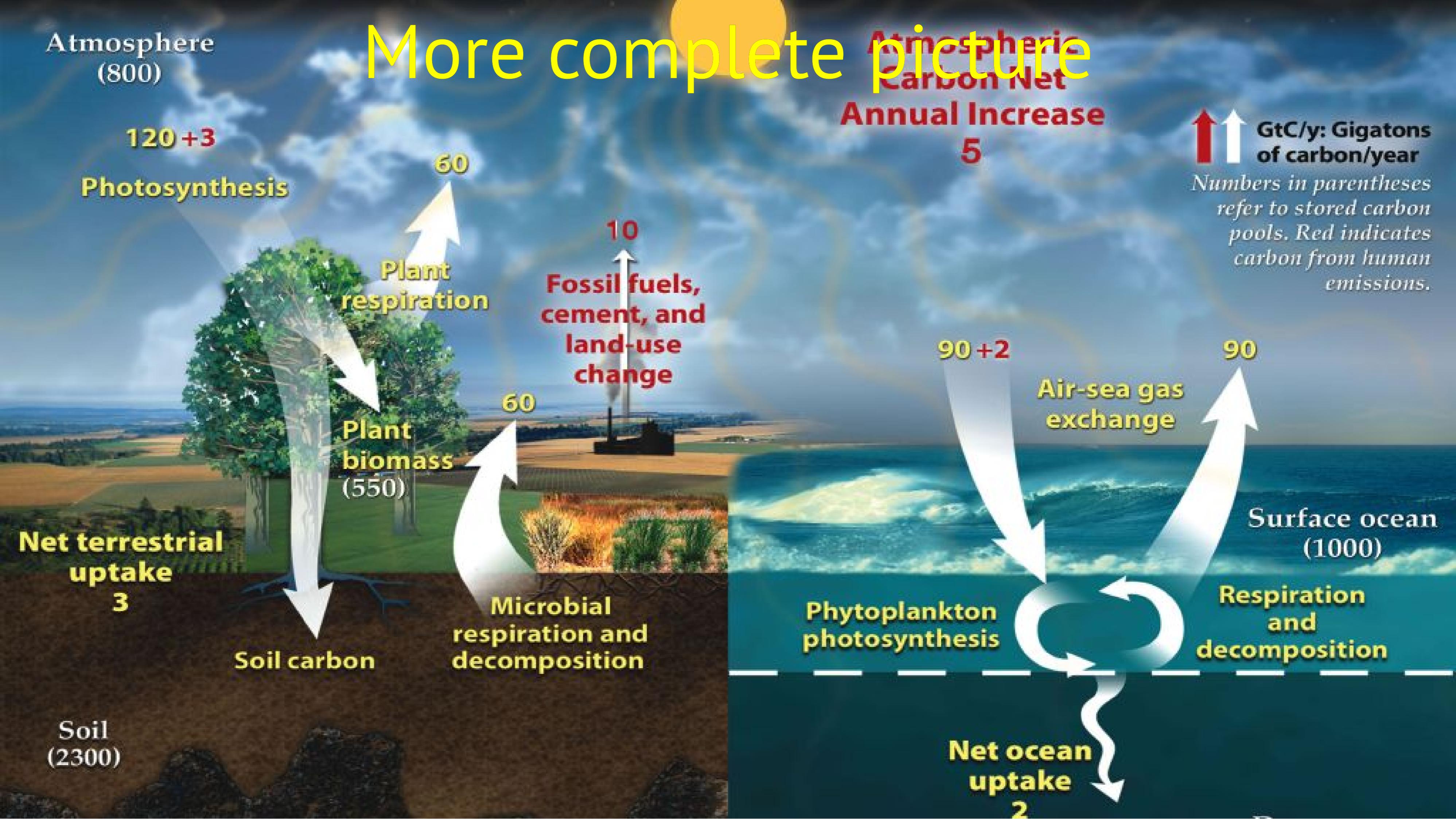
# Carbon Pathways



# 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

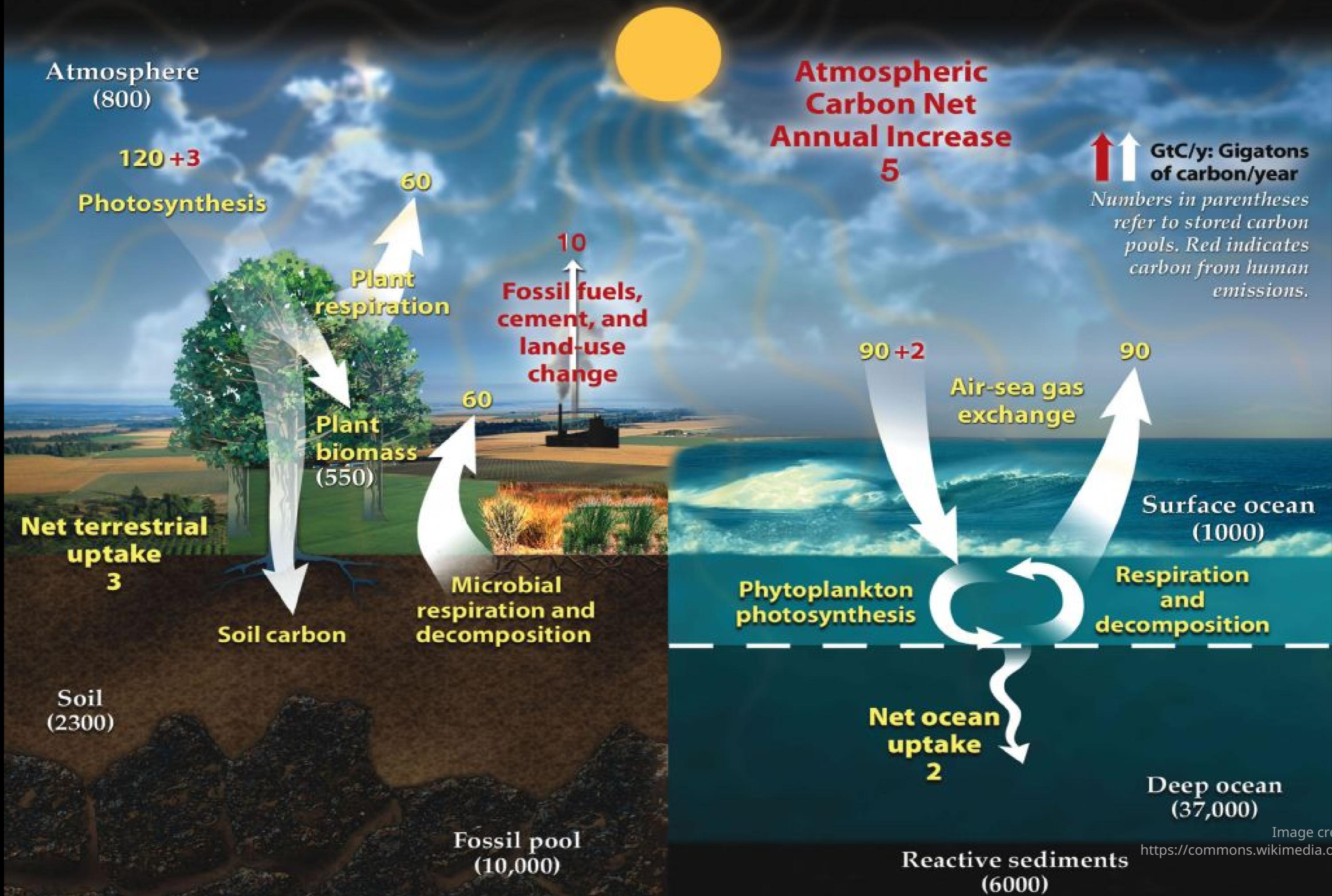
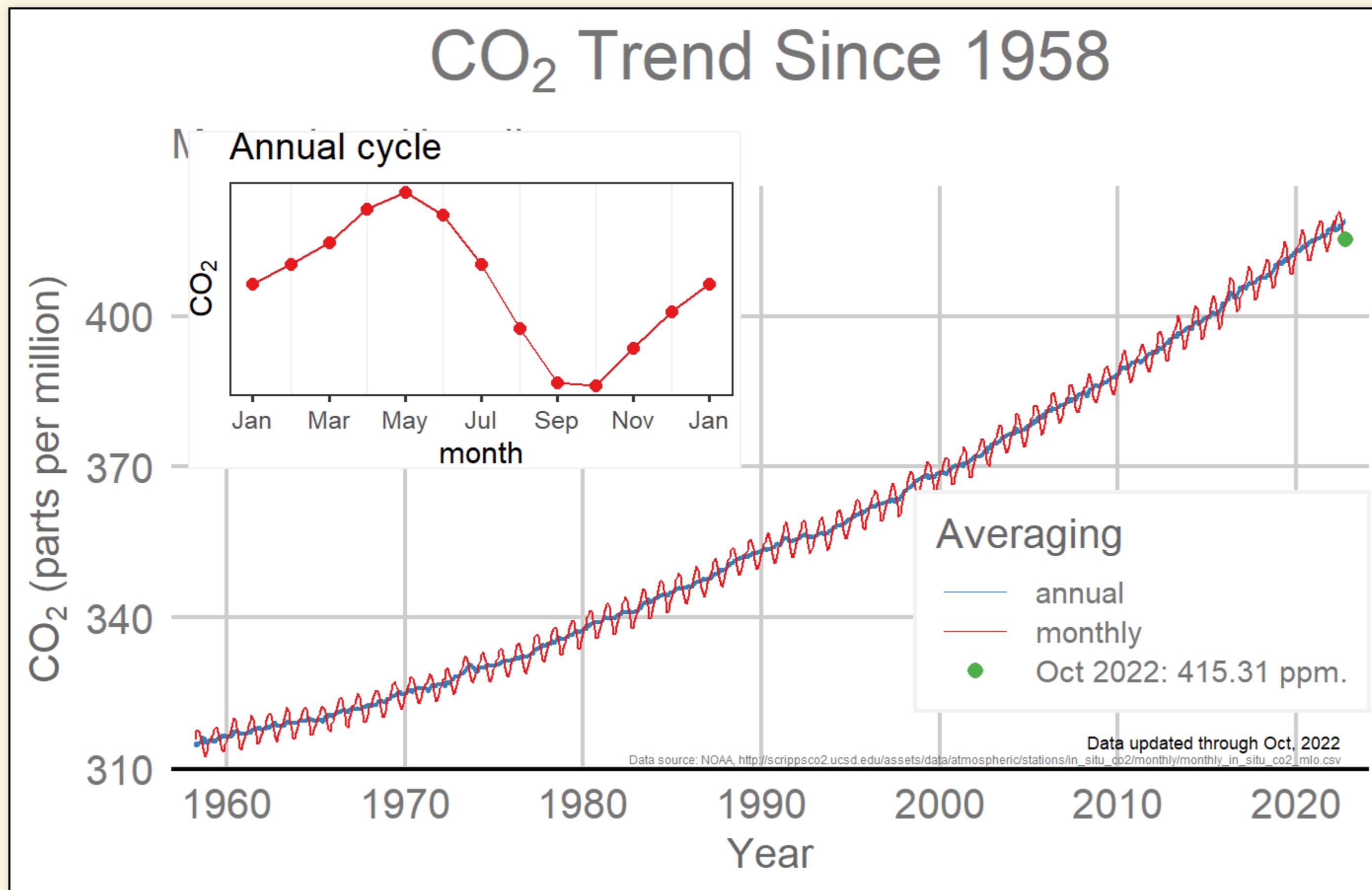


Image credit: NASA Earth Observatory

[https://commons.wikimedia.org/wiki/File:Carbon\\_cycle.jpg](https://commons.wikimedia.org/wiki/File:Carbon_cycle.jpg)

# CO<sub>2</sub> Over Time

## CO<sub>2</sub> Trend Since 1958



# Why the difference in wiggles?

a. Hawaii

b. New Zealand

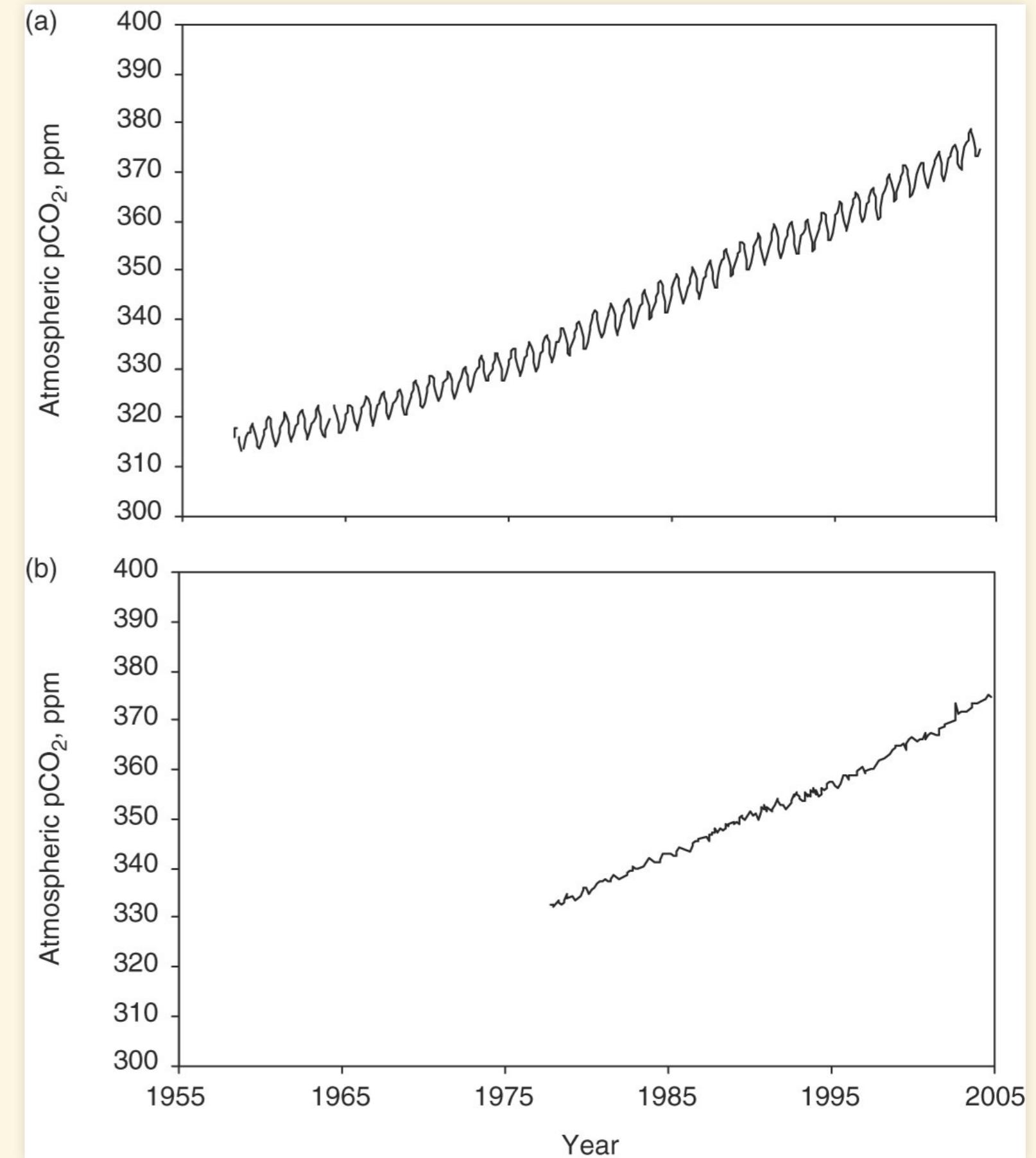
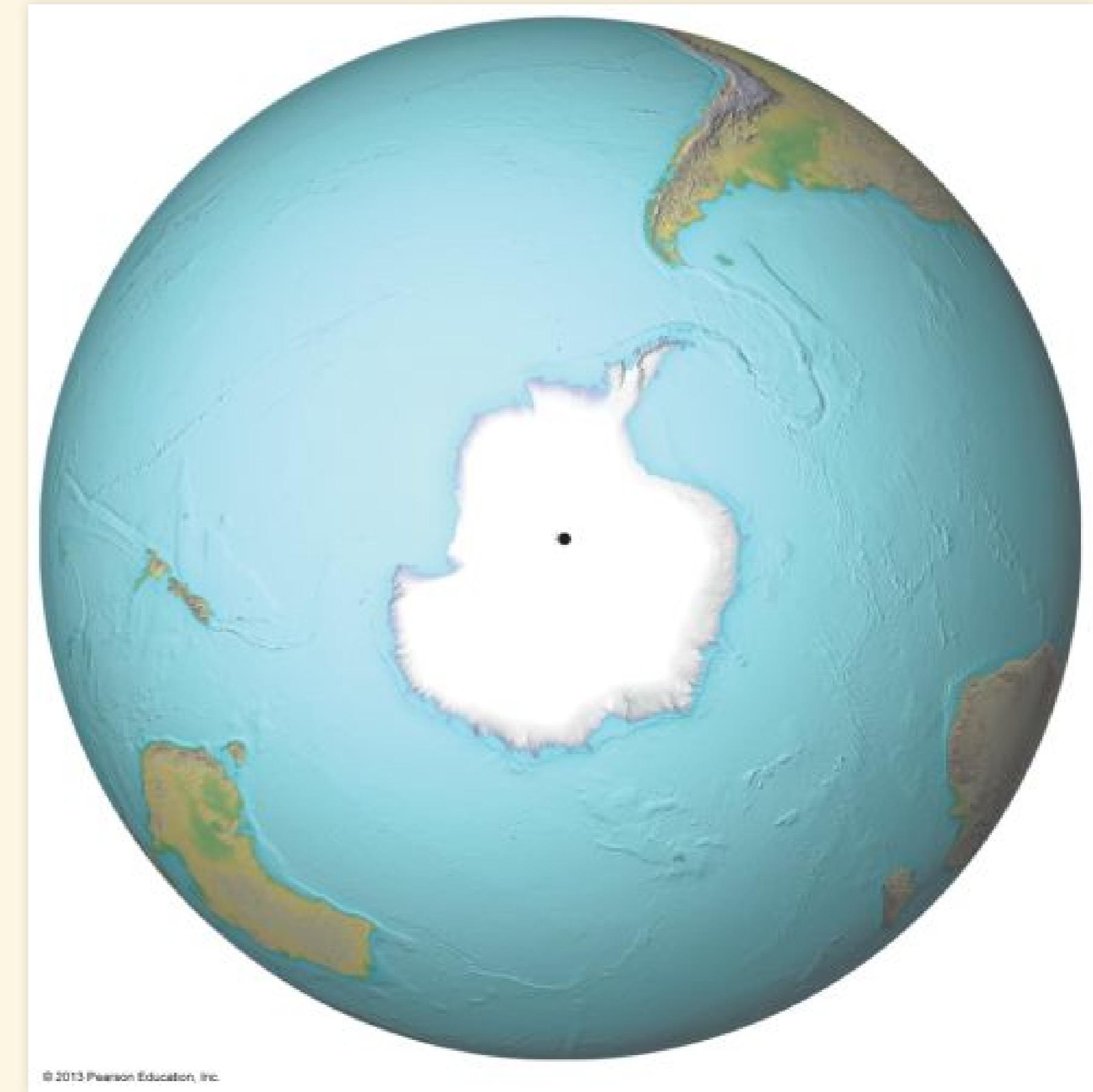
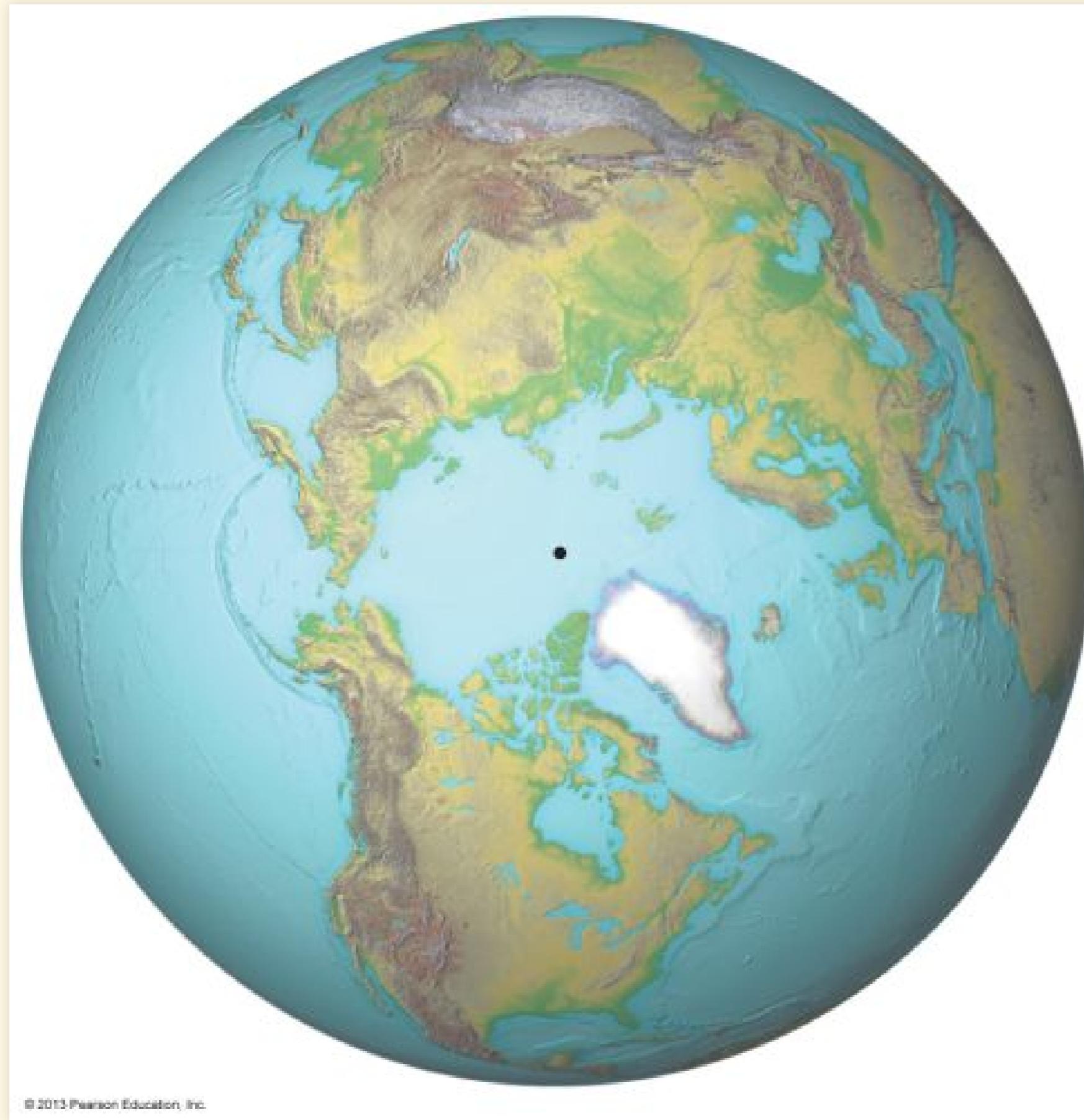


Image credit: D. Archer, *Global Warming: Understanding the Forecast*

# Northern vs. Southern Hemisphere



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Image Credit: Pearson Education, Inc.

The Oceans Breathe  
Centuries to Millennia

# Studying Ancient Climates

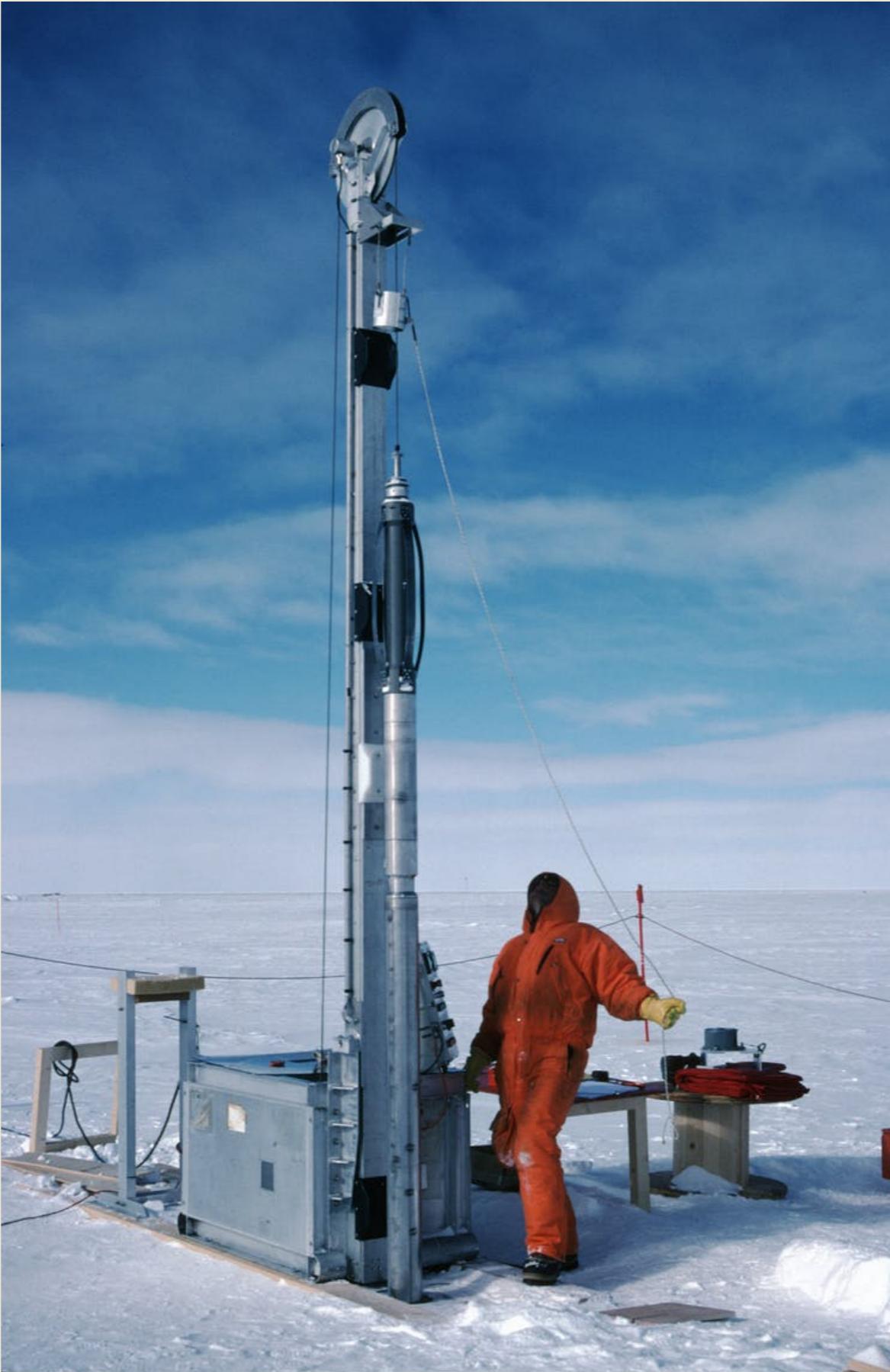


Image Credit: R Mulvaney/British Antarctic Survey

# Ice Cores



Image credits: Pete Bucktrout/British Antarctic Survey

# Inside the Ice Core

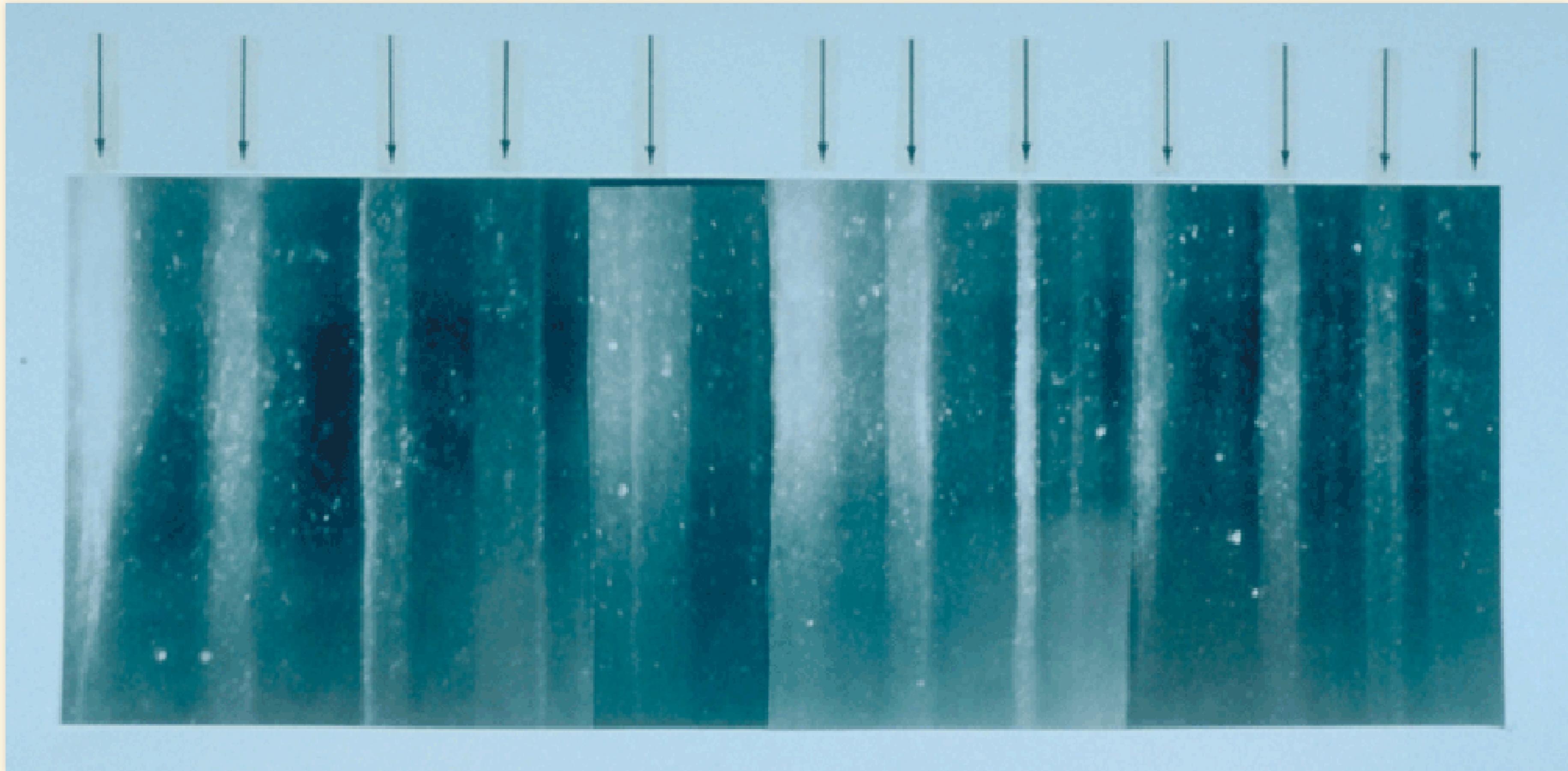


Image credit: National Ice Core Laboratory

# Inside the Ice Core

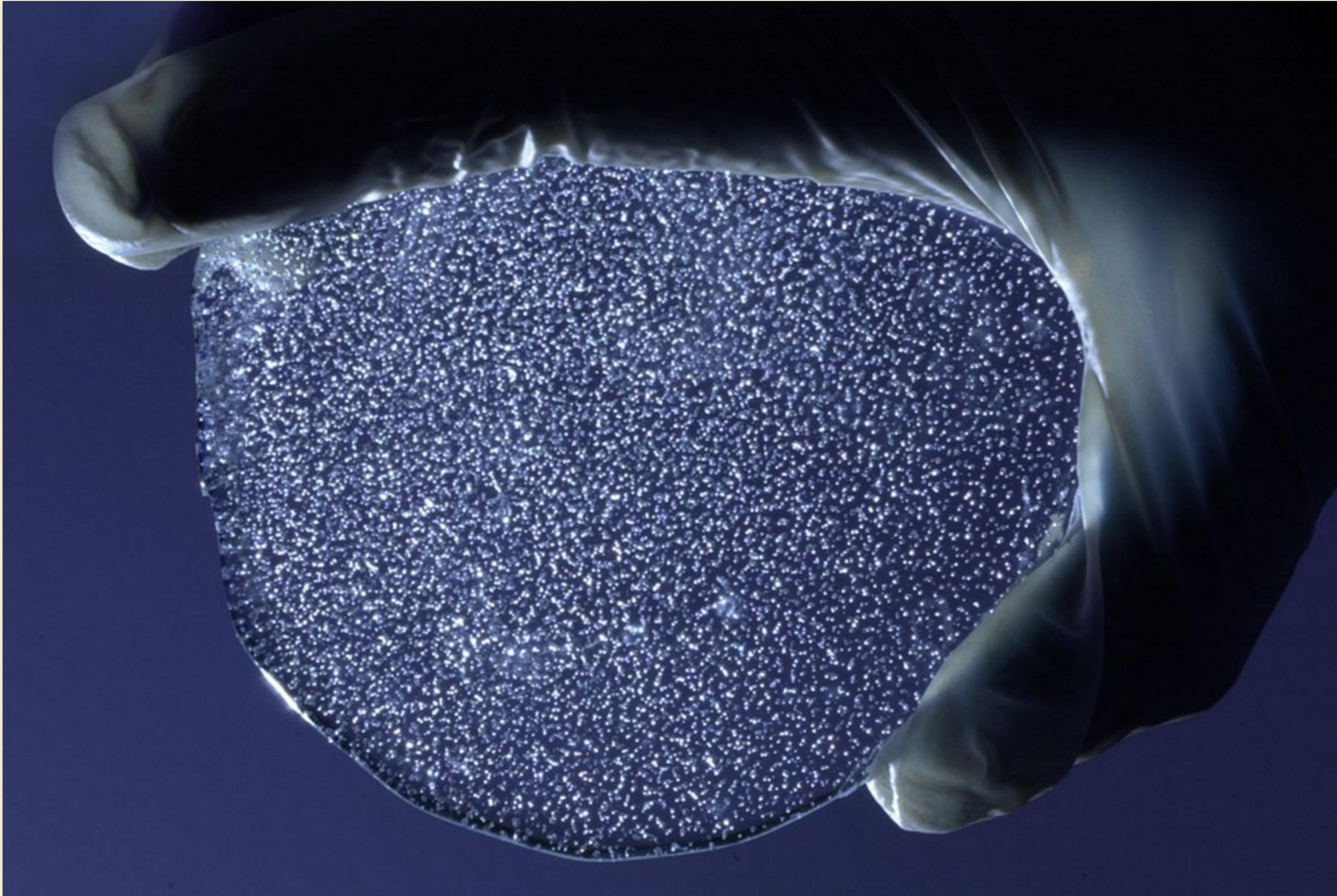
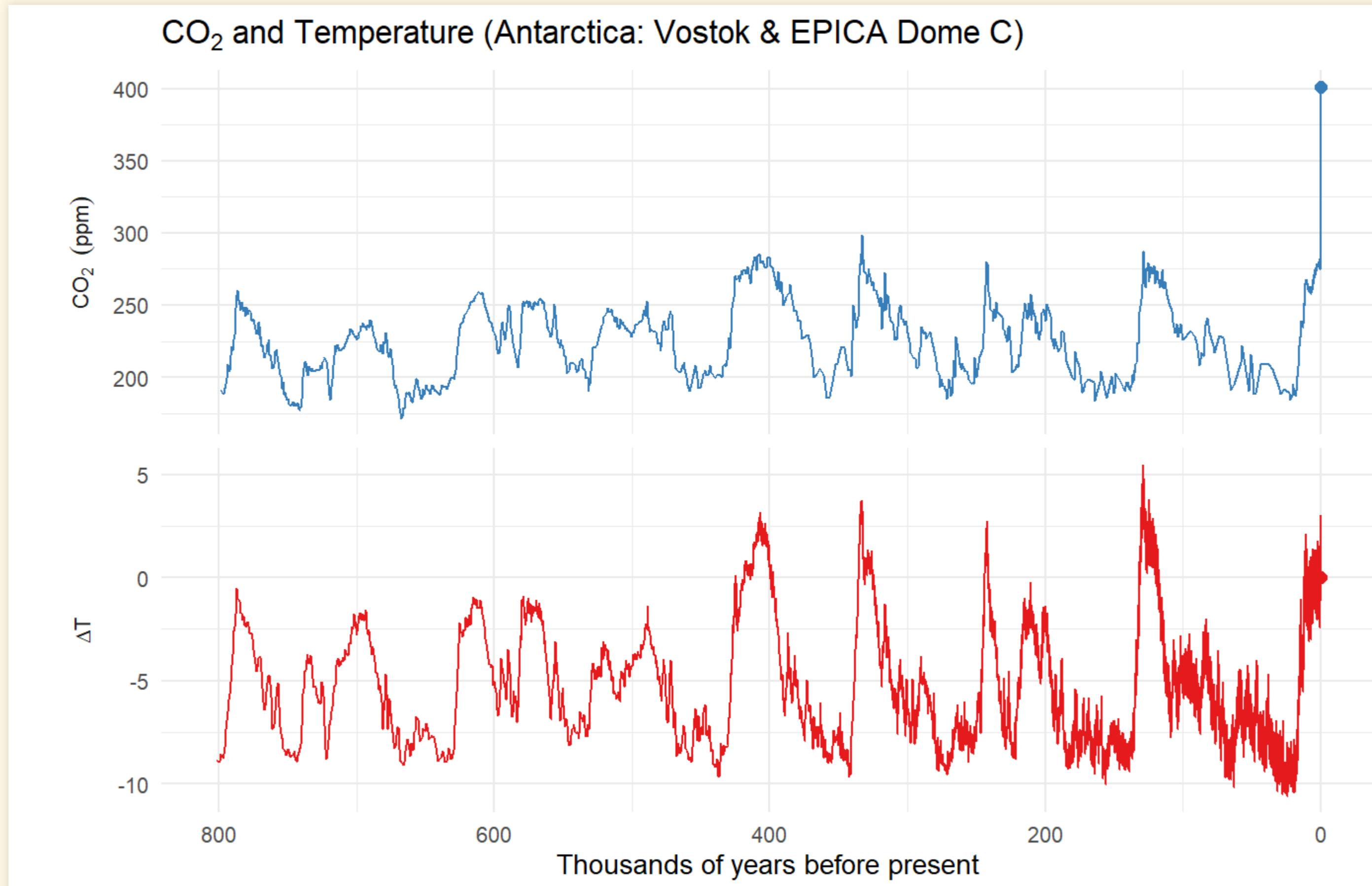


Image credit: Pete Bucktrout/British Antarctic Survey

# The Oceans Breathe



# Ice Ages

# 25,000 years ago



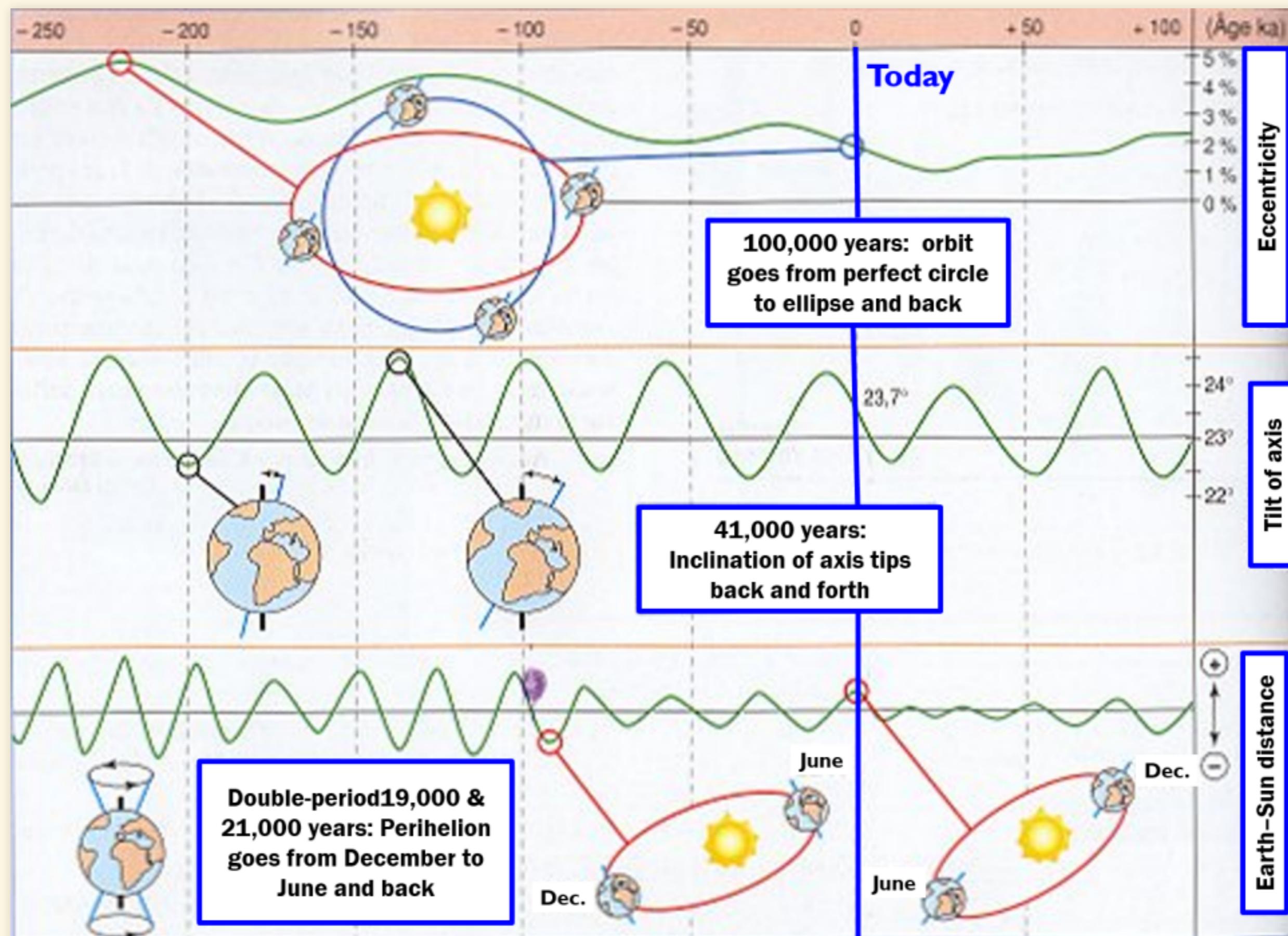
Image credit: Ron Blakey

# 25,000 years ago

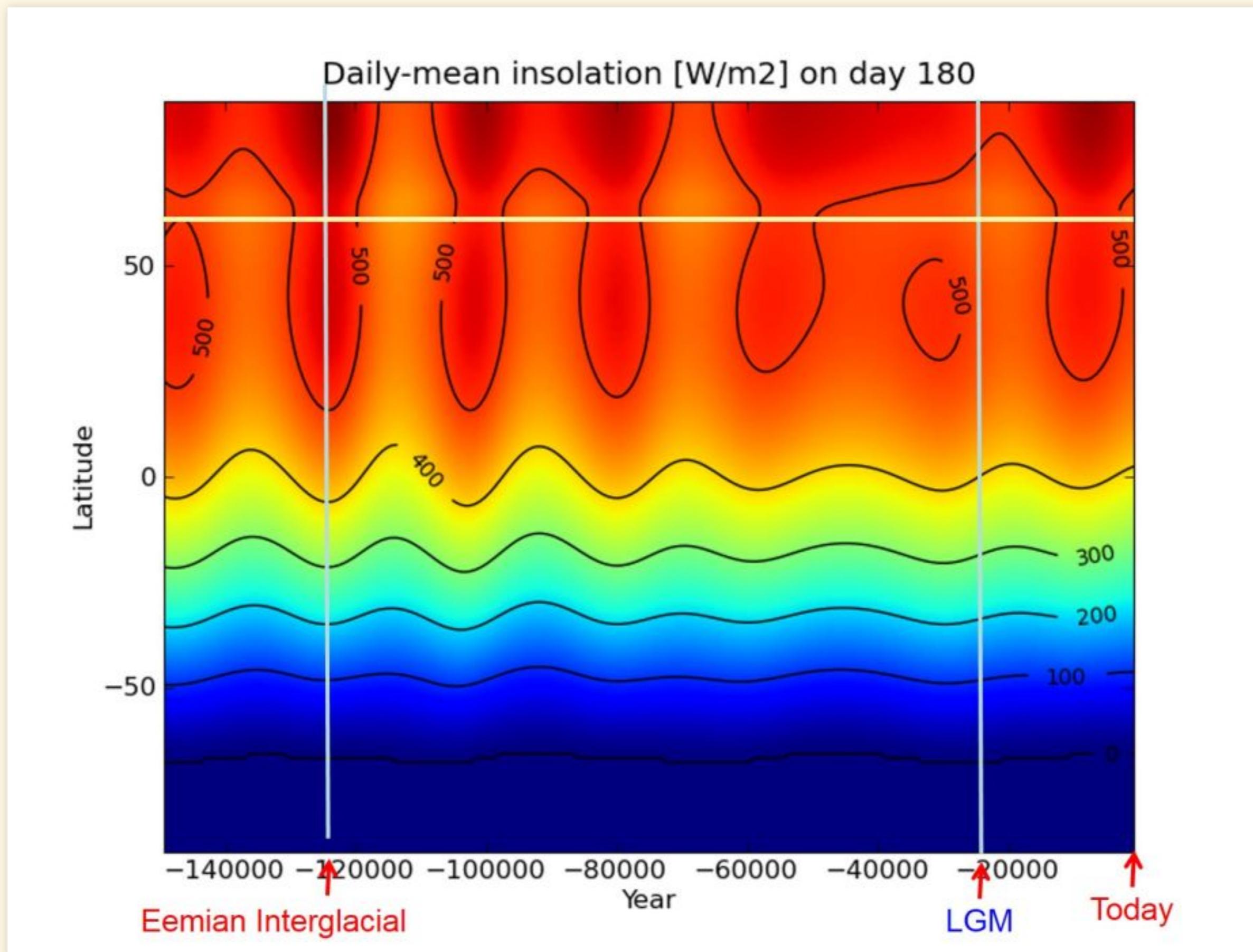


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# Causes



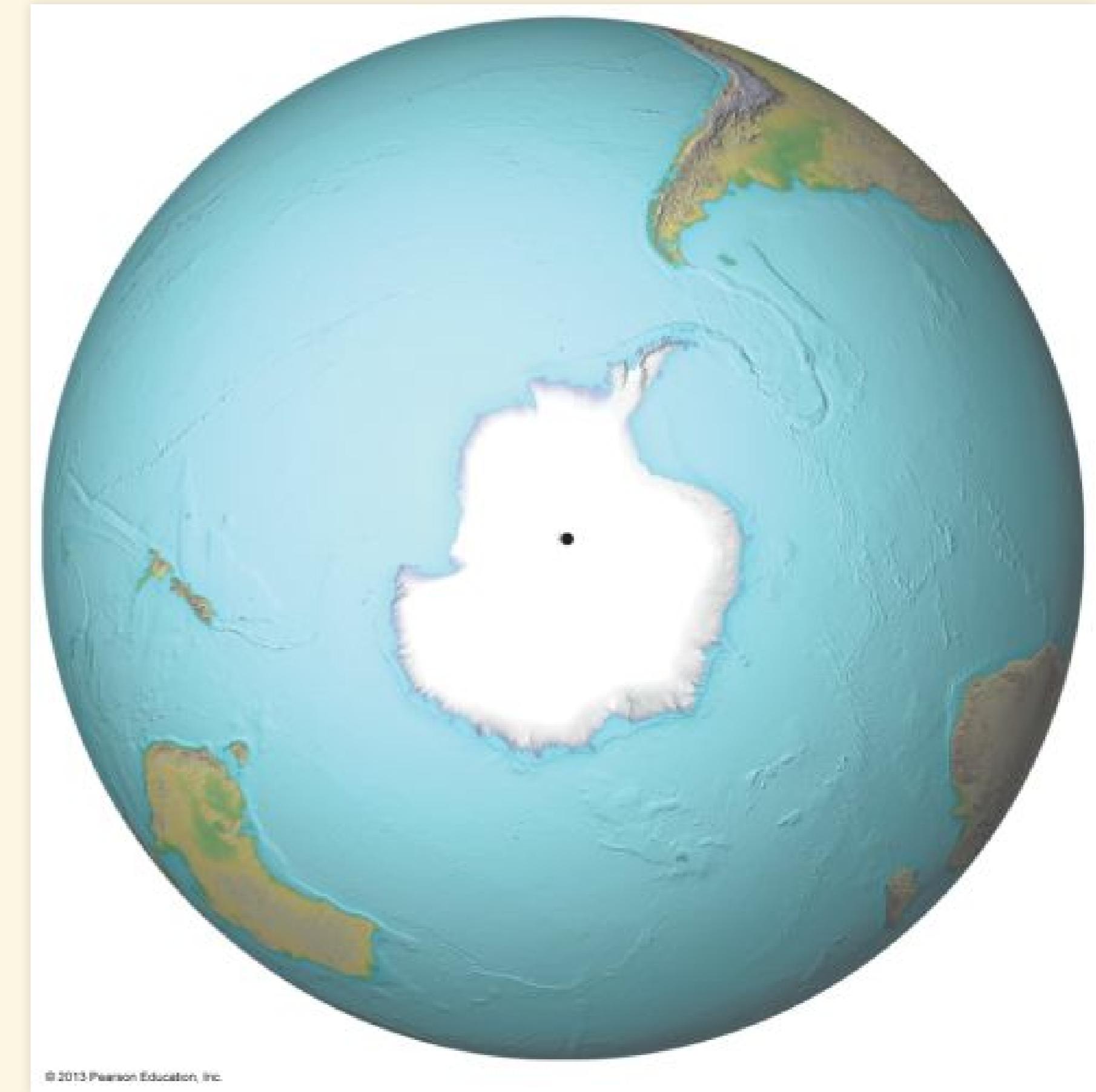
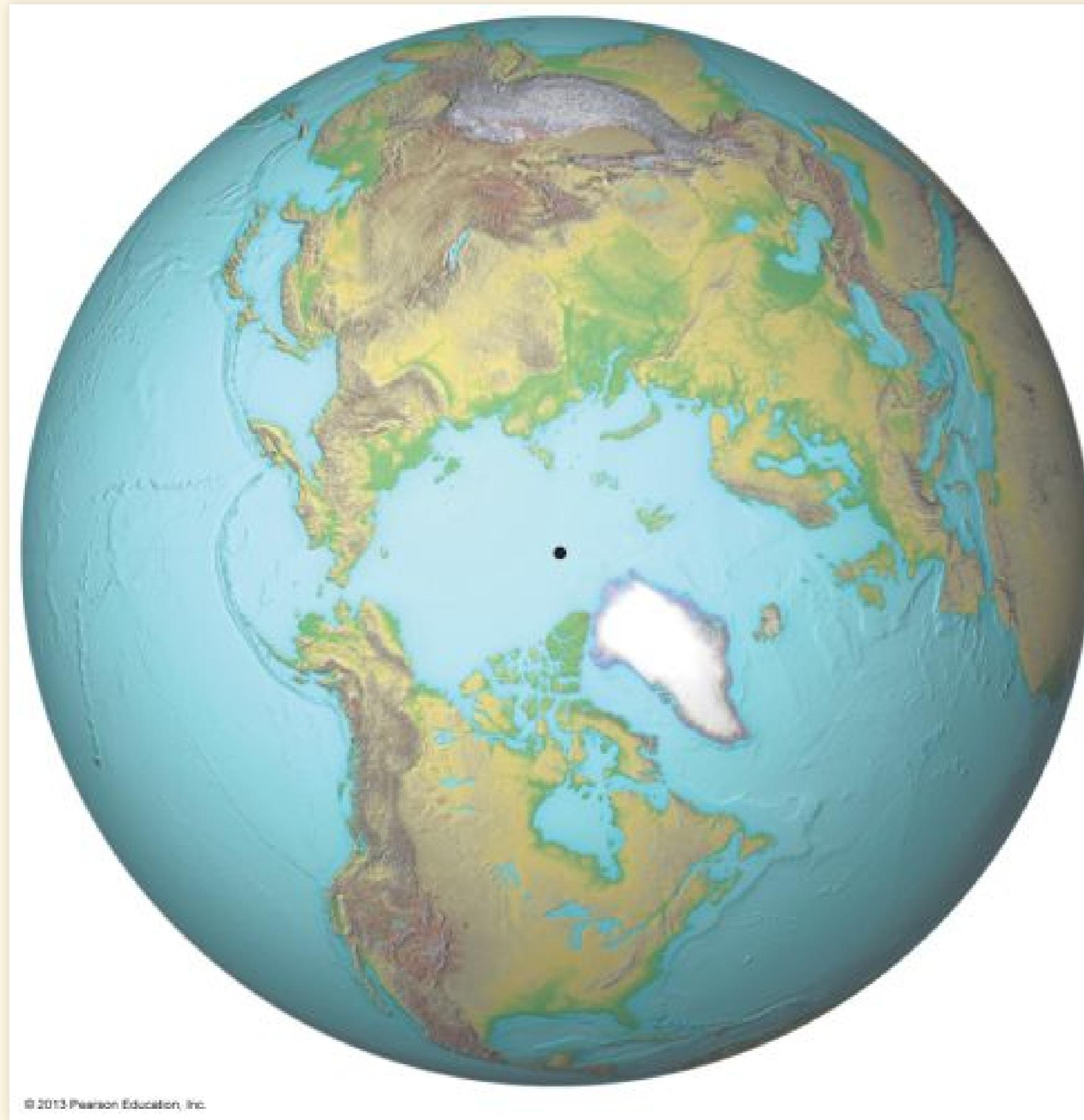
# Insolation



# Question

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

# Northern vs. Southern Hemisphere



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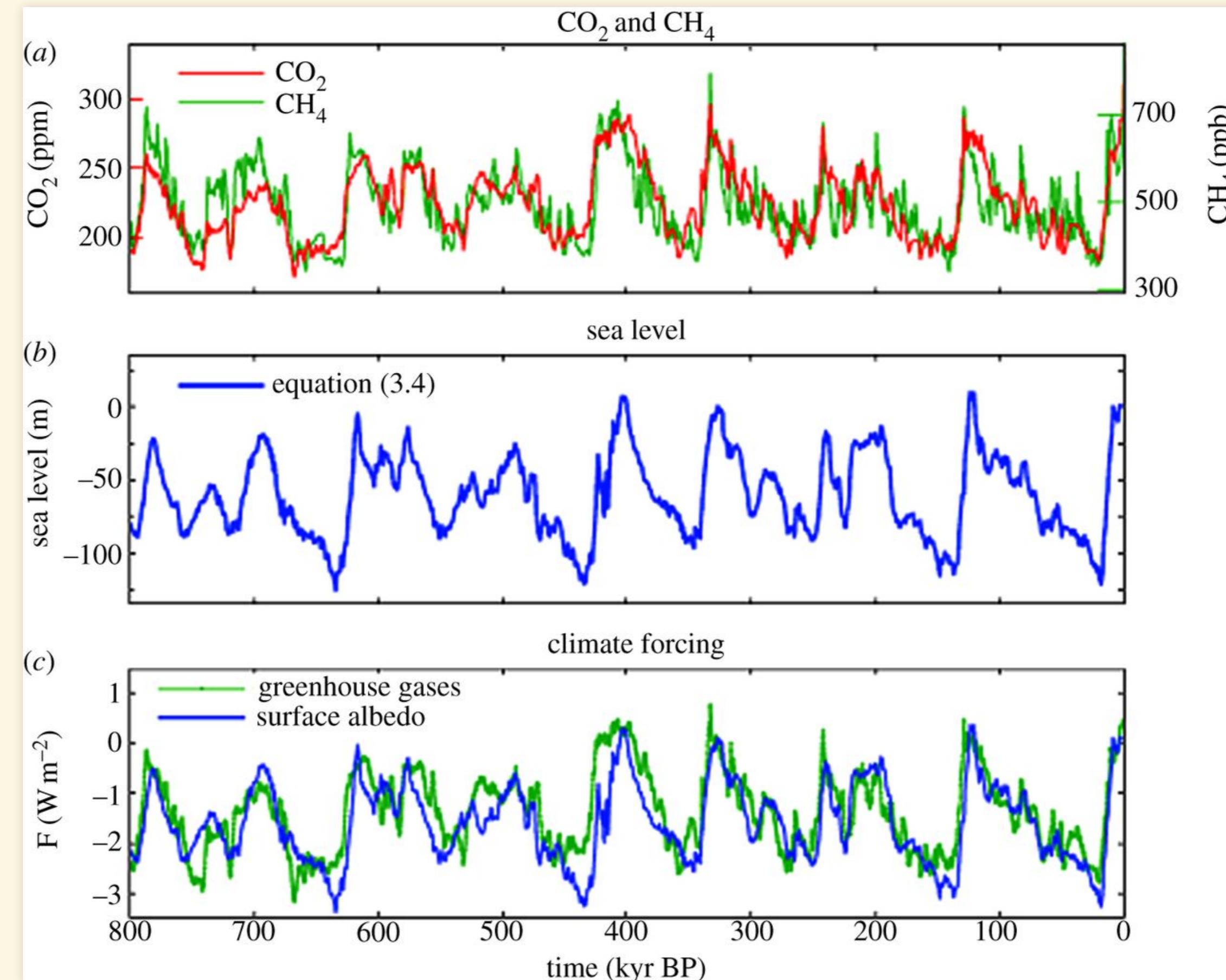
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# Ice Age Feedbacks

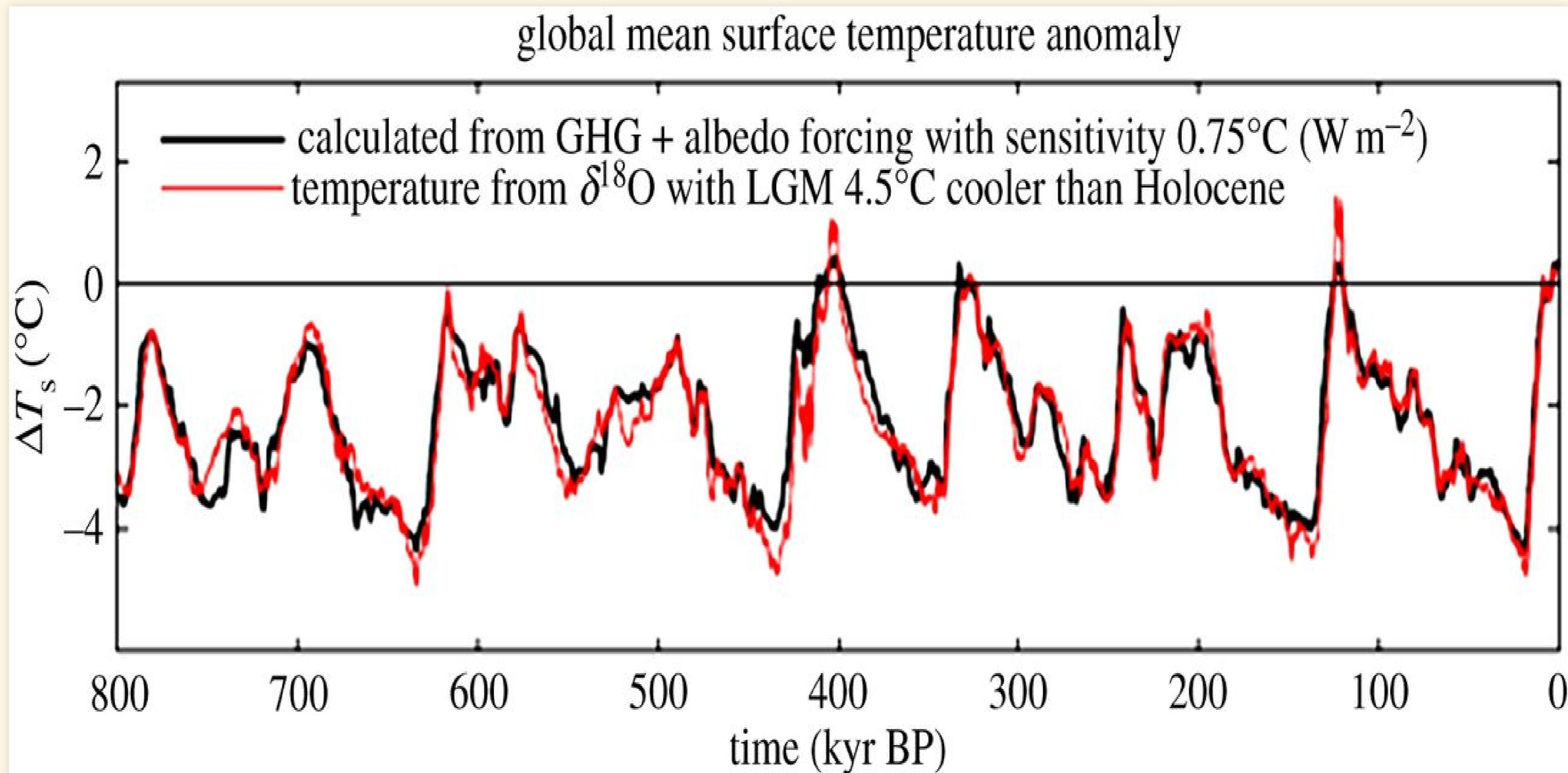
# Ice Age Feedbacks

- 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  $\rightarrow$  higher albedo
  - $\text{CO}_2$  drops  $\rightarrow$  weaker greenhouse
  - Colder
- Temperature starts to rise
  - Glaciers retreat  $\rightarrow$  higher albedo
  - $\text{CO}_2$  rises  $\rightarrow$  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.

# 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 CaCO<sub>3</sub> 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.

