

# The Carbon Cycle: Ocean and Biosphere

EES 3310/5310

Global Climate Change

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Class #10: Wednesday, January 29 2020

# 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

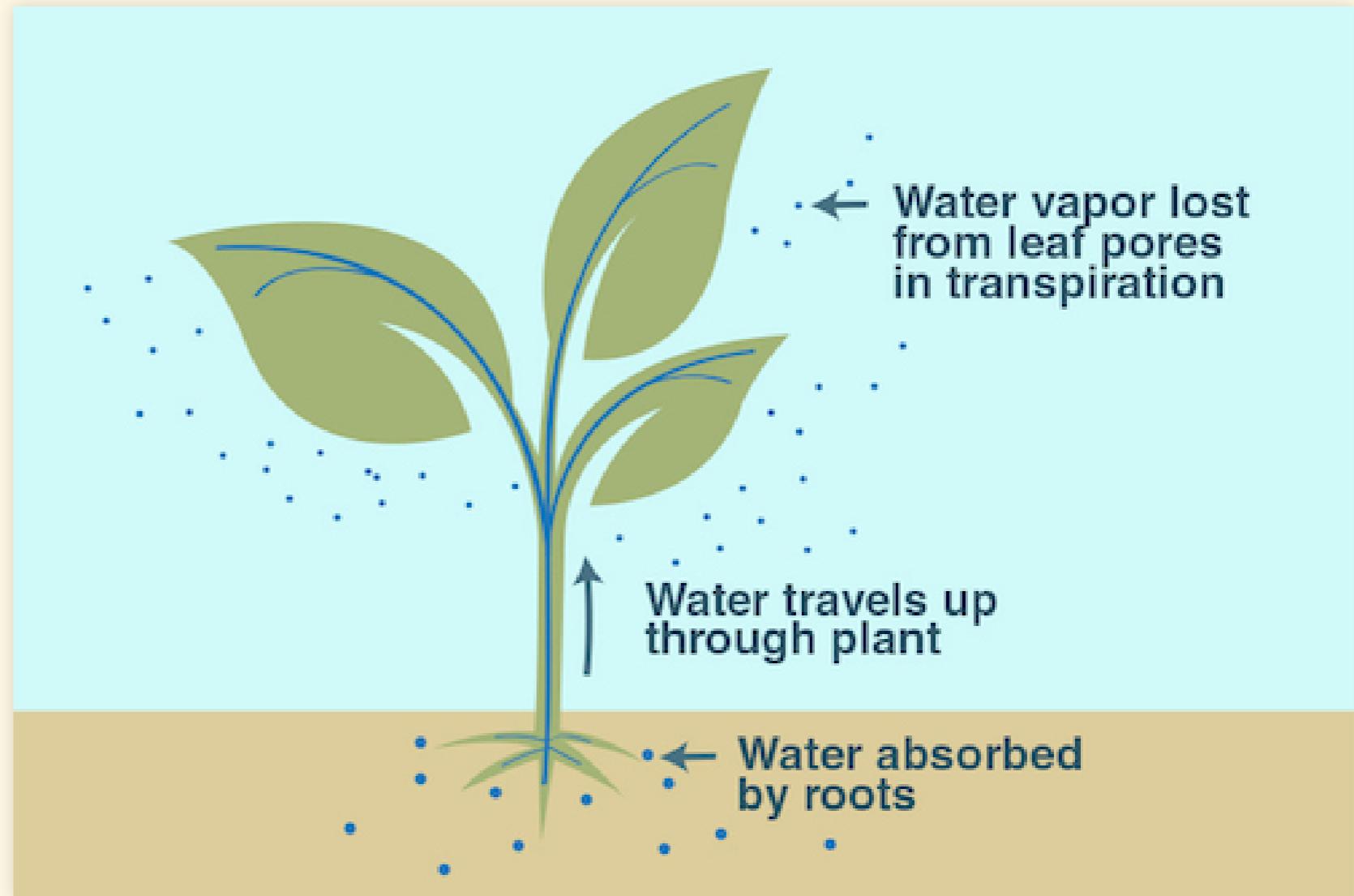


Image credit: NASA/JPL-Caltech <https://climatekids.nasa.gov/heat-islands/>

# Transpiration and CO<sub>2</sub>

- Transpiration occurs through “stomata” in leaves
- Tradeoff: stomata
  - Allow plant to get CO<sub>2</sub>
  - Cause plant to lose water
- More CO<sub>2</sub> in atmosphere:
  - Fewer stomata
  - Less transpiration

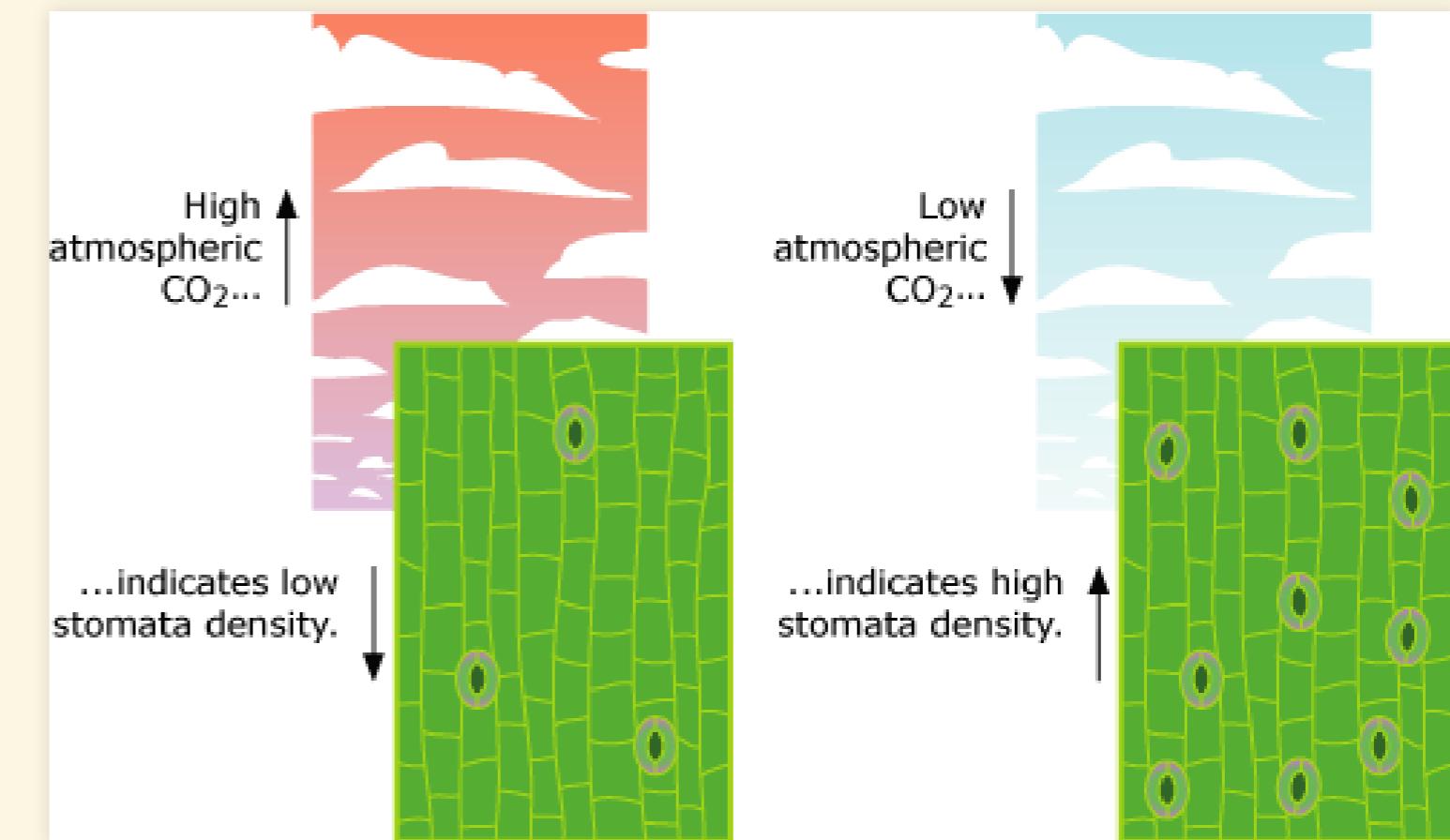
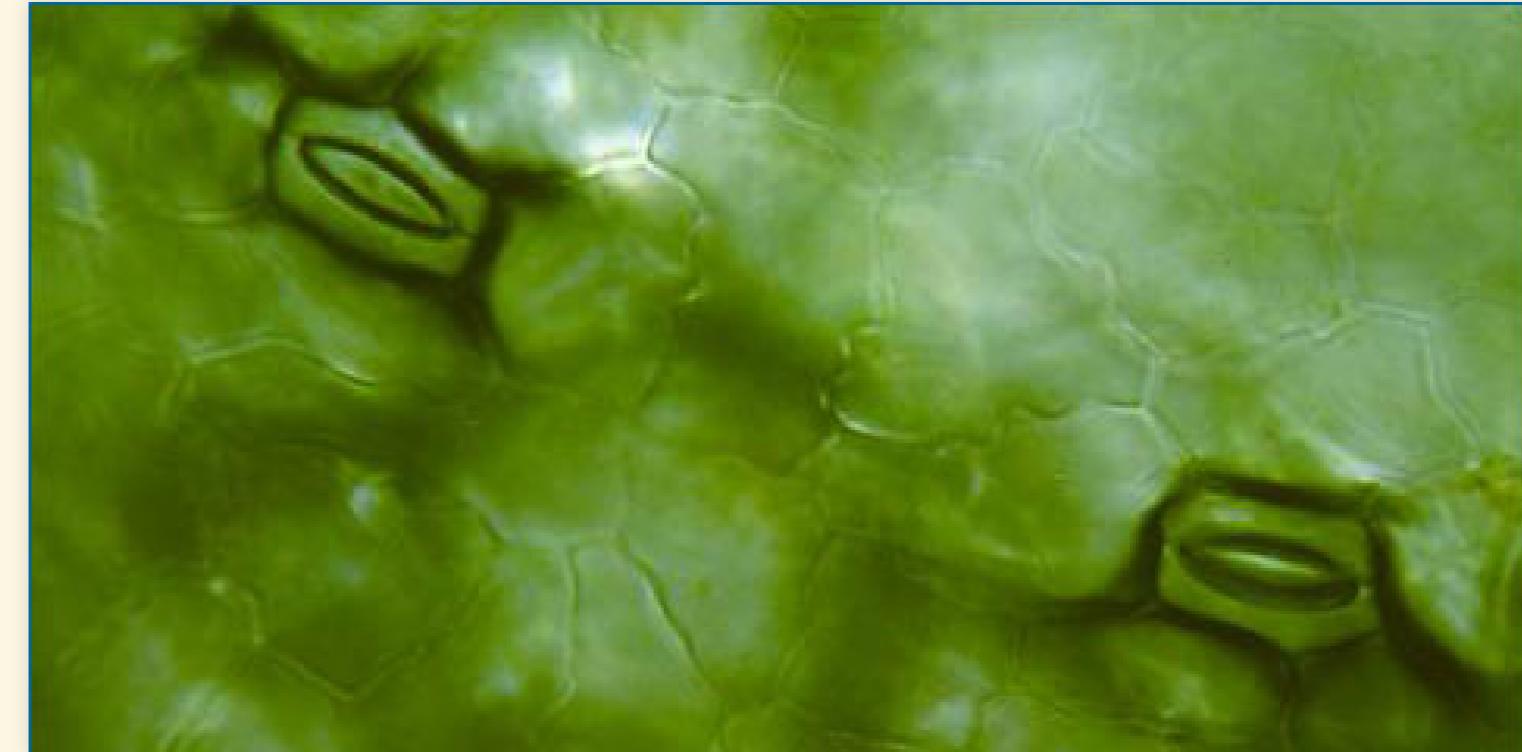


Image credit:

- Photo of stomata on duckweed: Micrographia <http://www.micrographia.com/specbiol/plan/planaq/plaq0100/lemn0-01.htm>.
- Diagram of response to CO<sub>2</sub>: 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

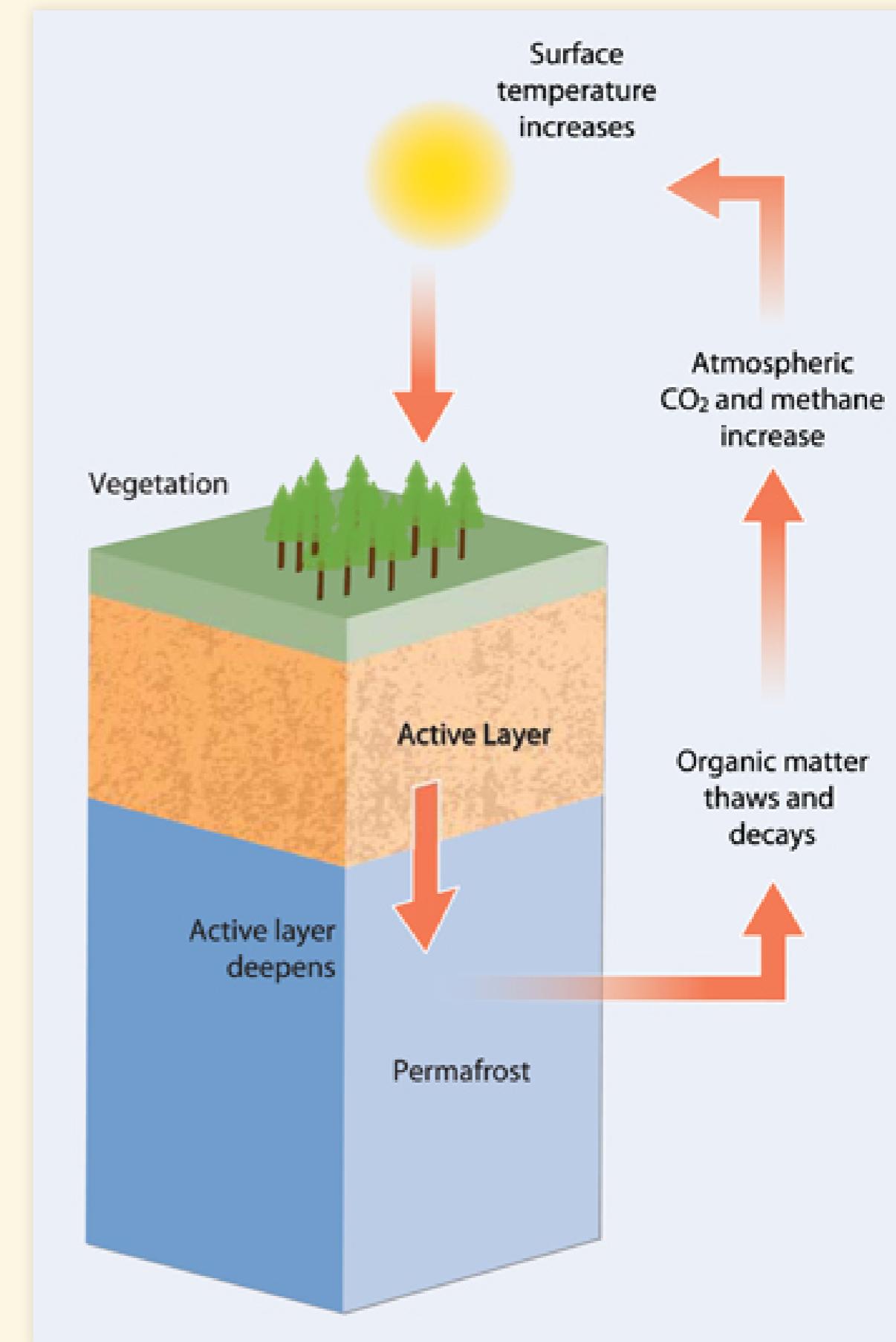
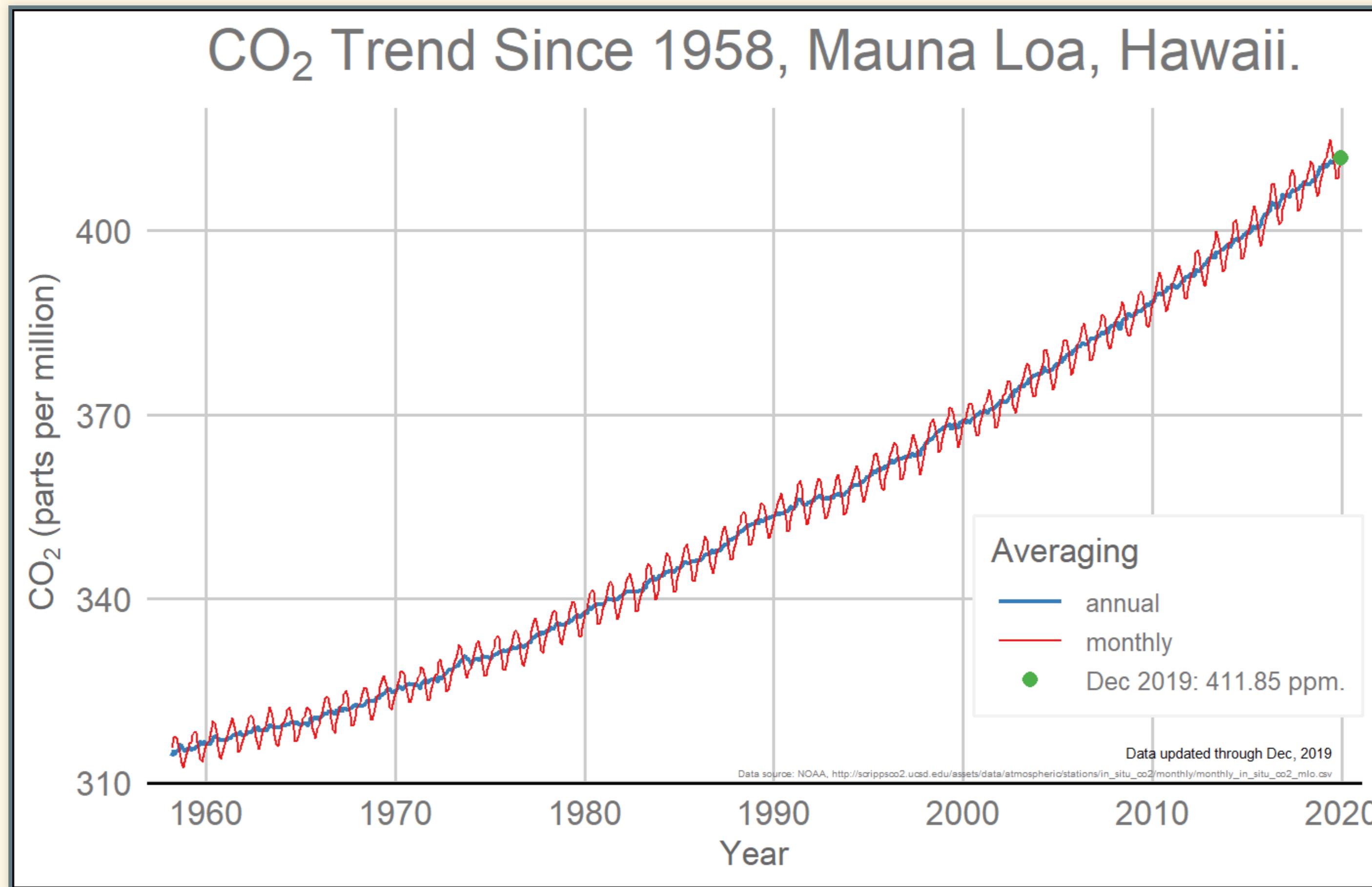


Image credit: K. Schaefer *et al.*, Environ. Res. Lett. **9**, 085003 (2014). doi: 10.1088/1748-9326/9/8/085003

# CO<sub>2</sub> in the Atmosphere



# Carbon Chemistry

# What does the oxidation state tell you about<br/>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
$\text{CH}_4$	-4	<b>methane</b>
$(\text{CH}_2)_n$	-2	<b>long-chain alkane</b>
$\text{CO}_2$	+4	<b>carbon dioxide</b>
$(\text{CH}_2\text{O})_n$	0	<b>carbohydrate</b>

# Carbon

Category	Oxidation State	Examples
Mineral carbon	> 0	$\text{CO}_2$ : +4
Organic carbon	$\leq 0$	$\text{CH}_4$ : -4 (methane) $(\text{CH}_2\text{O})_6$ : 0 (sugar)

## Energy:

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

# Carbon

## Energy:

- Negative oxidation → greater energy

- Positive oxidaton → lower energy

- Photosynthesis:



- Respiration:



## History of oxidation on earth:

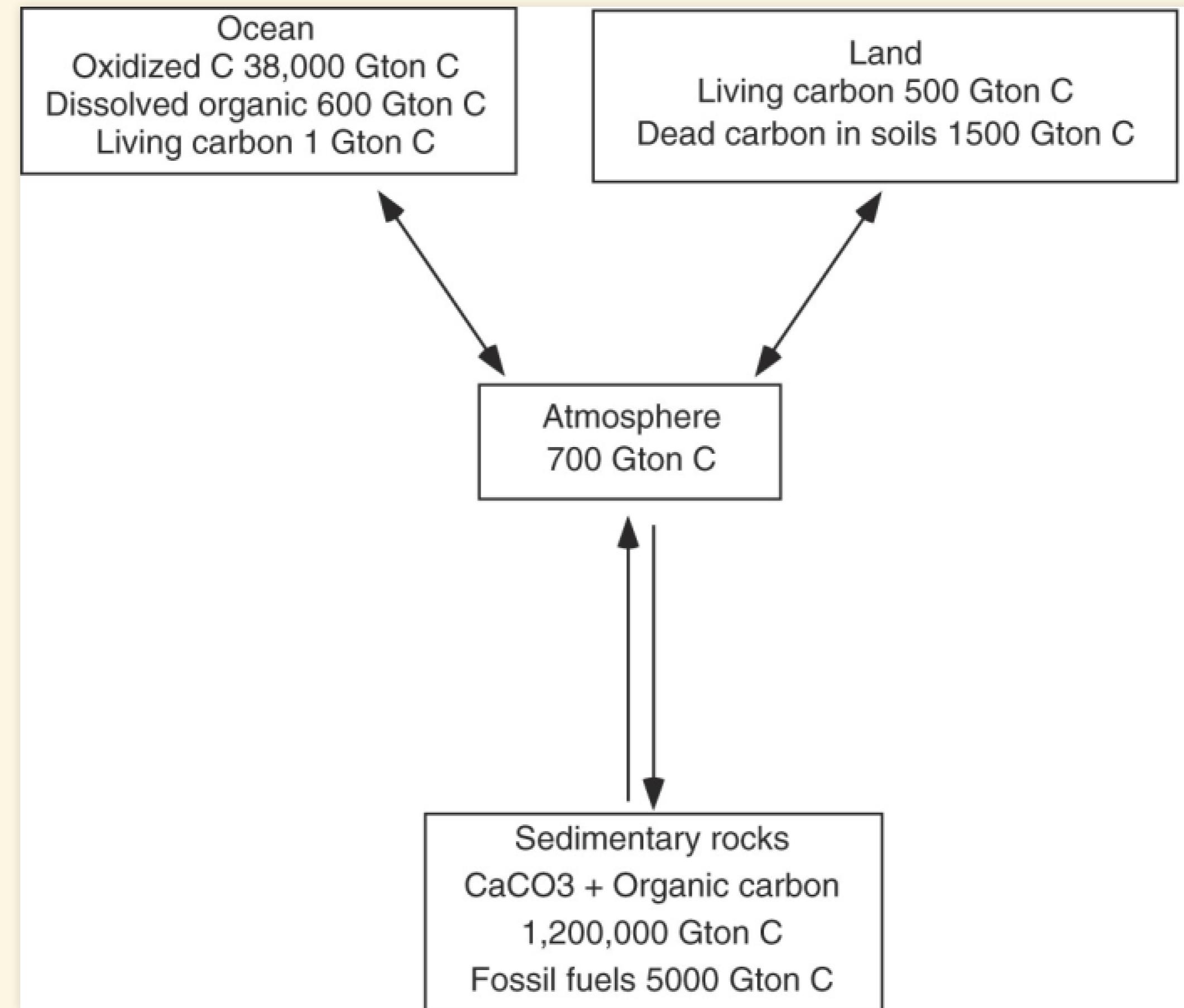
- Buried organic carbon could suck up all the oxygen in the atmosphere many times over.

# Where is most of the carbon on earth?

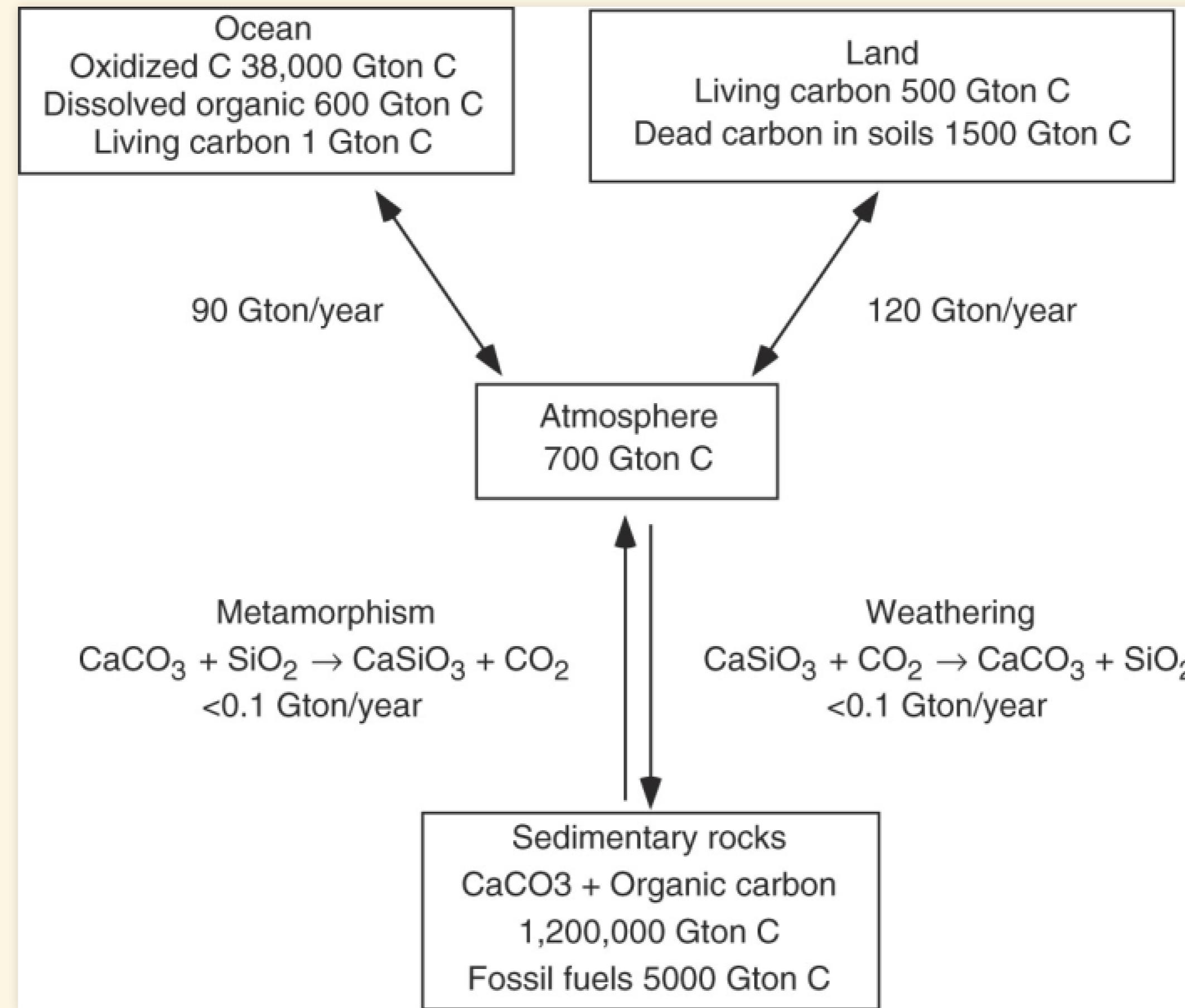
1. The atmosphere.
2. The oceans.
3. Living and dead biomass at the land surface.
4. Deeply buried biomass.
5. Fossil fuels.
6. Carbonate rocks.

# Carbon Reservoirs

# Carbon Reservoirs



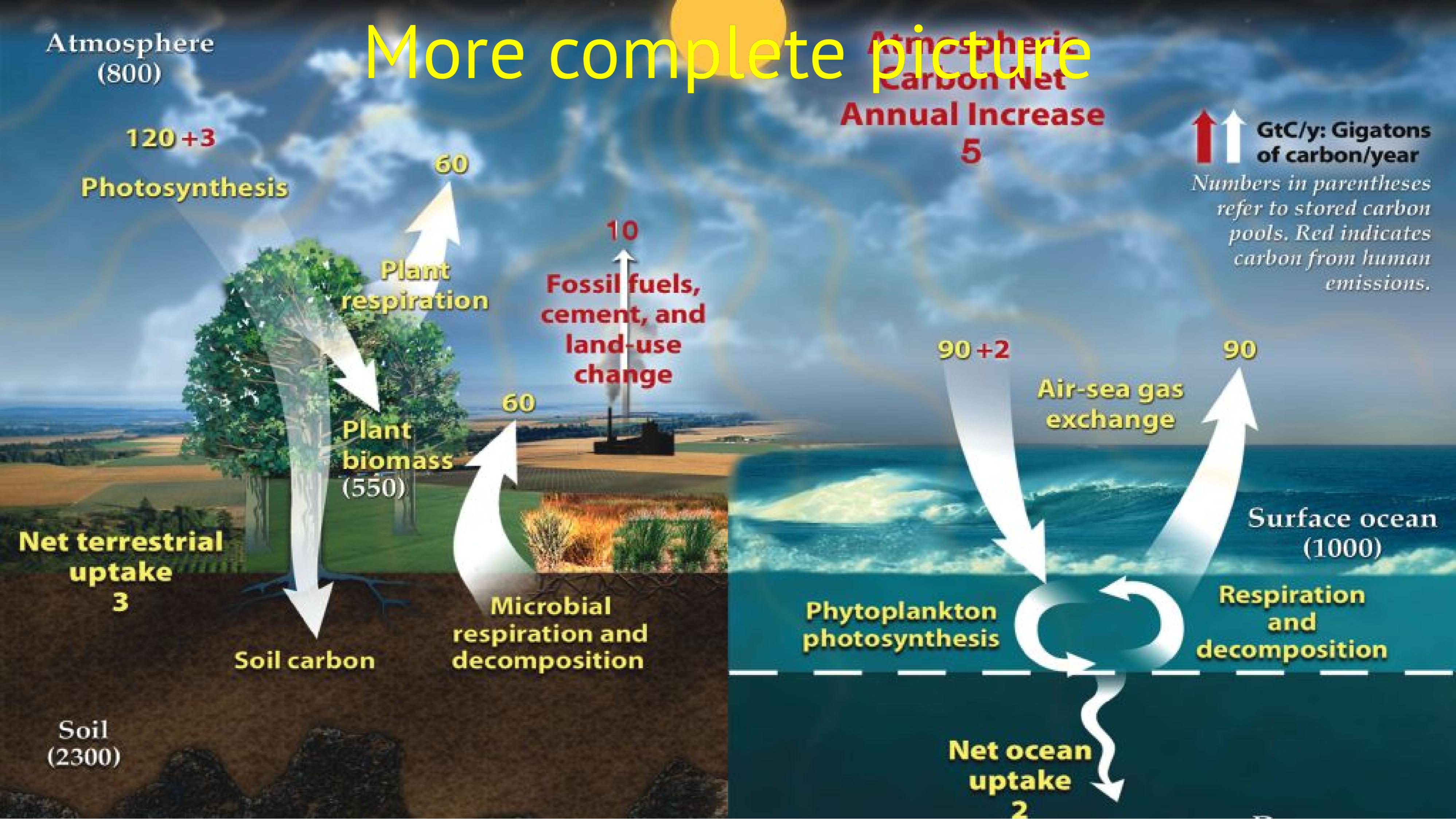
# Carbon Pathways



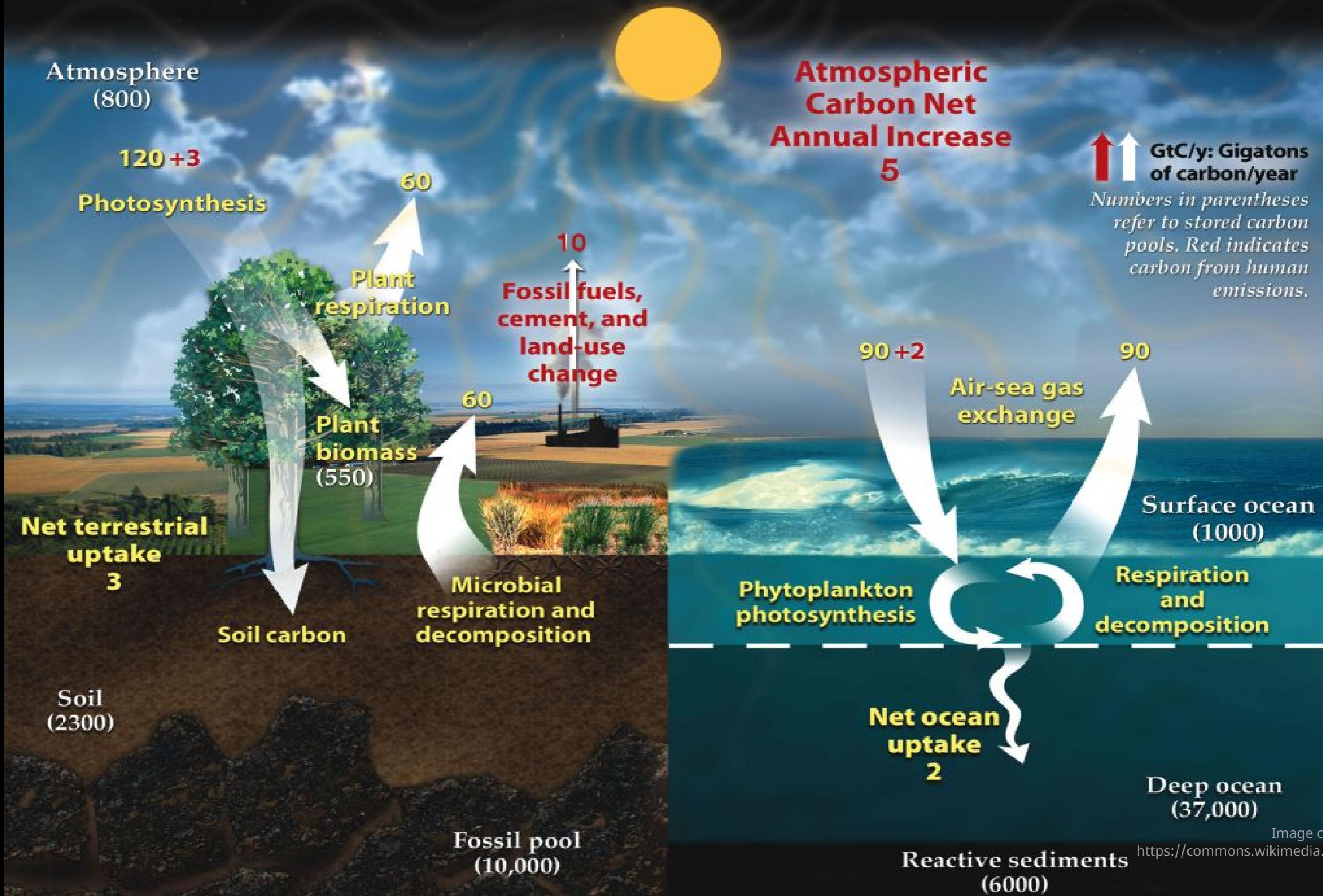
# The Planet's Lungs

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

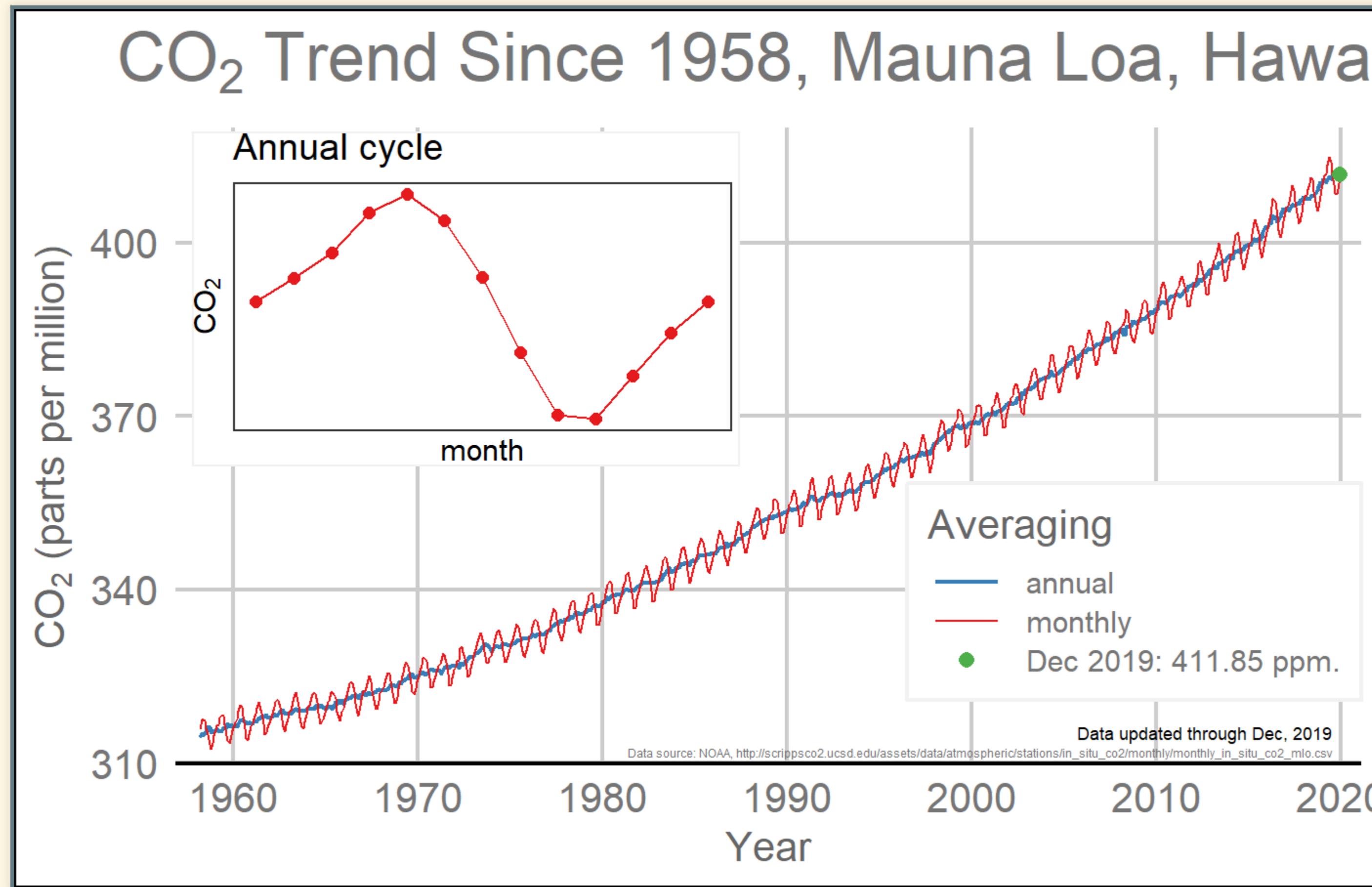
# More complete picture



# Complete Carbon Cycle



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



# Why the difference in wiggles?

a. Hawaii

b. New Zealand

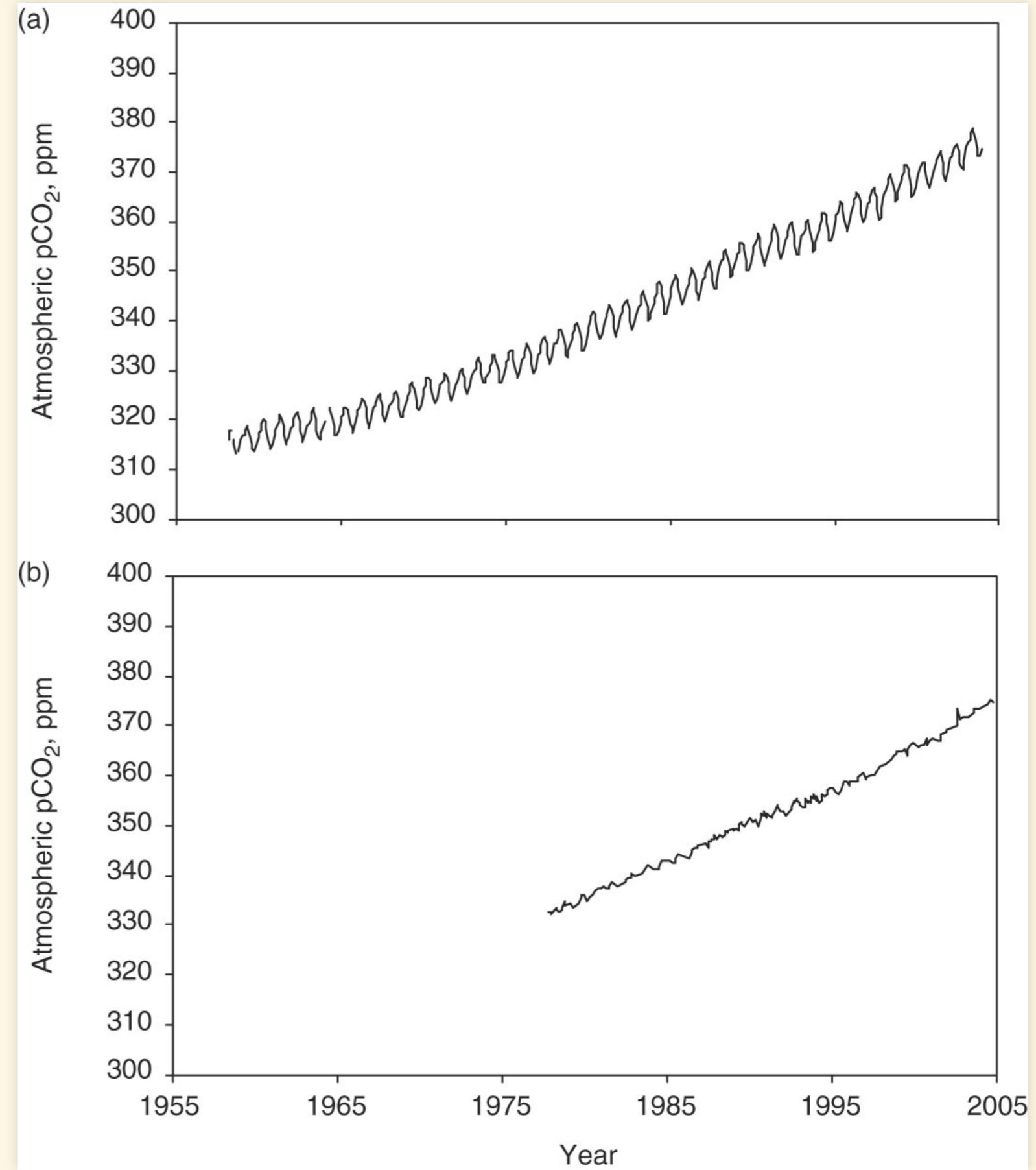
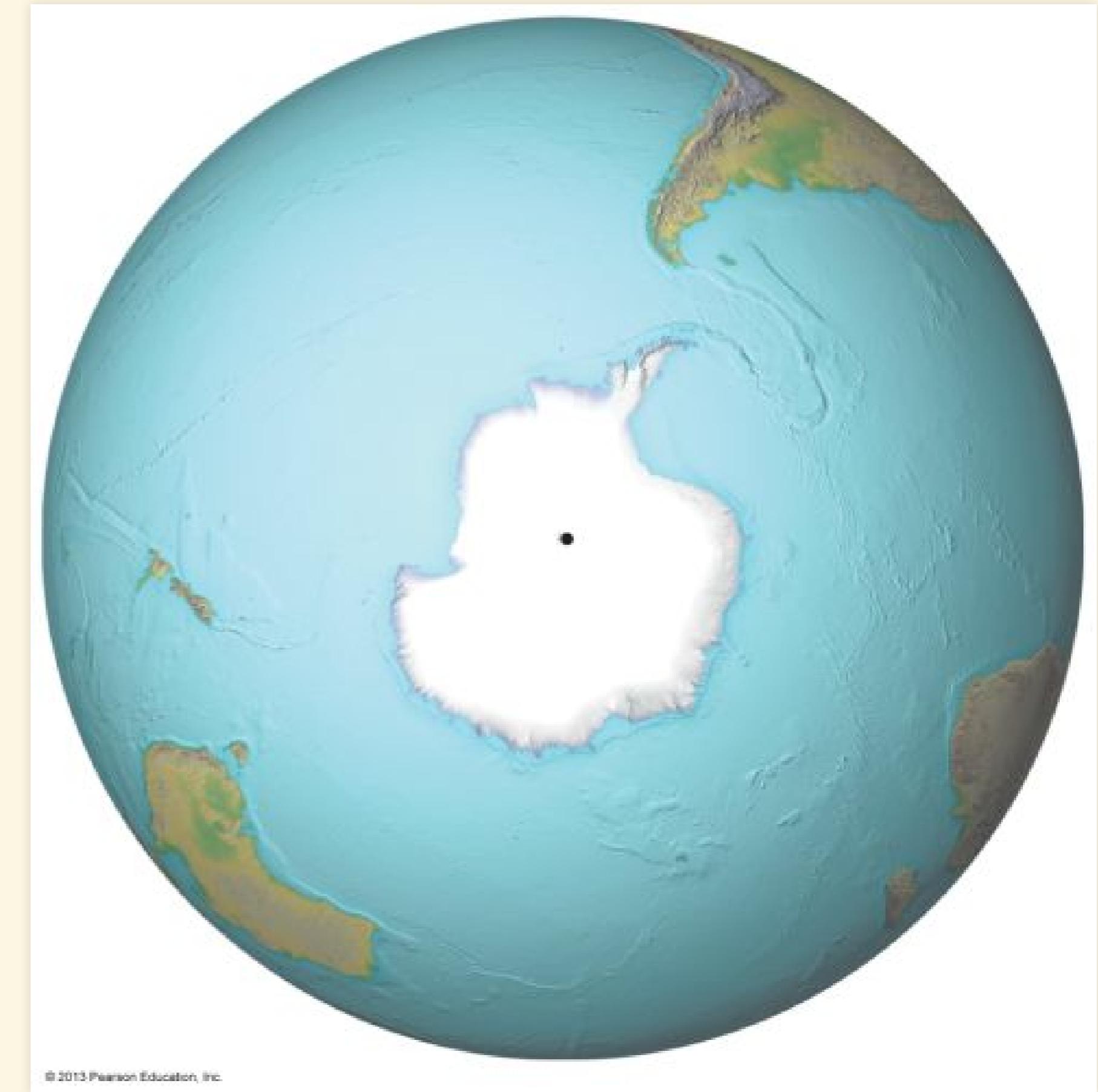
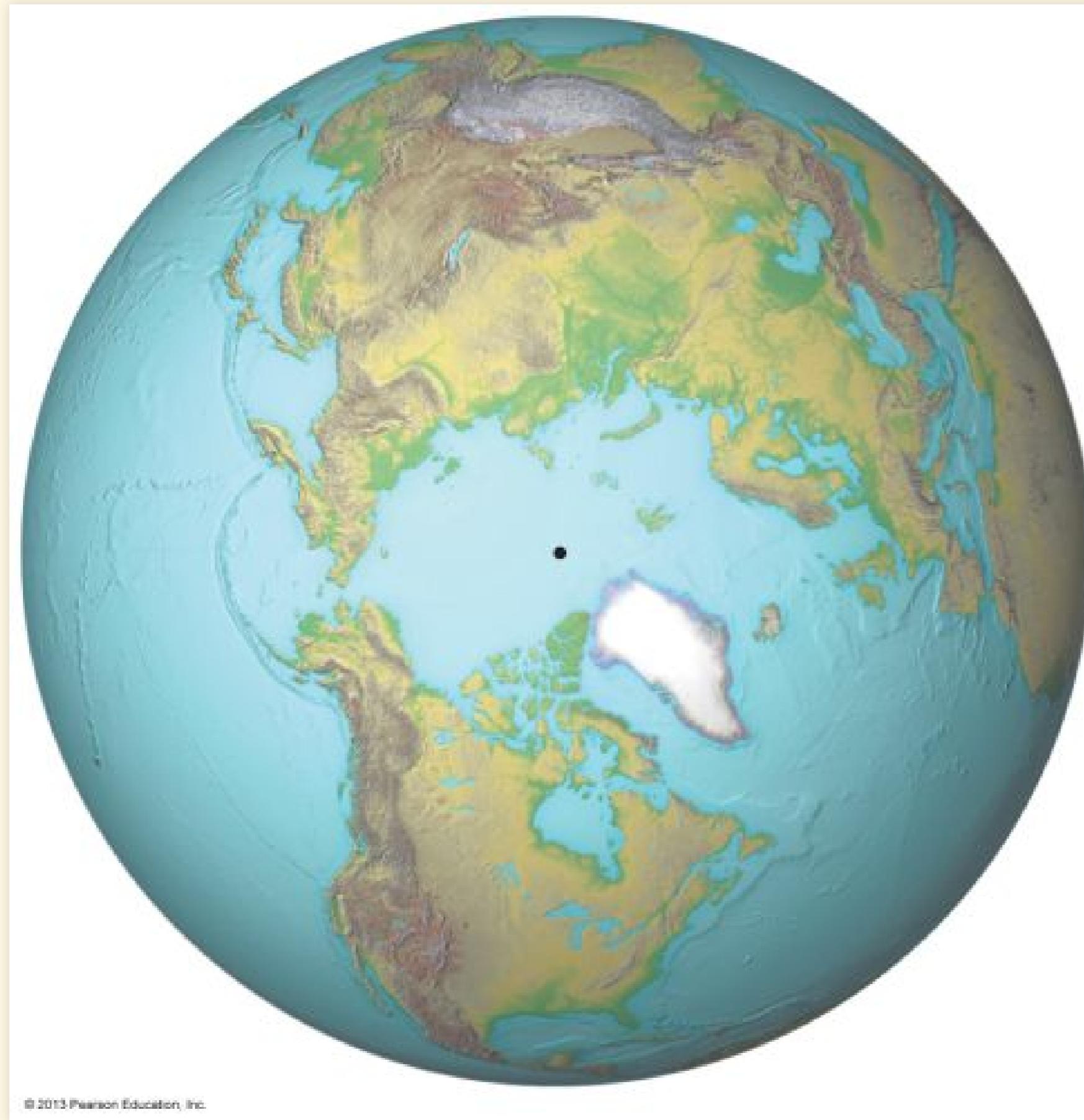


Image credit: D. Archer, *Global Warming: Understanding the Forecast*

# Northern vs. Southern Hemisphere



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Image Credit: Pearson Education, Inc.

# Fate of CO<sub>2</sub> Emissions

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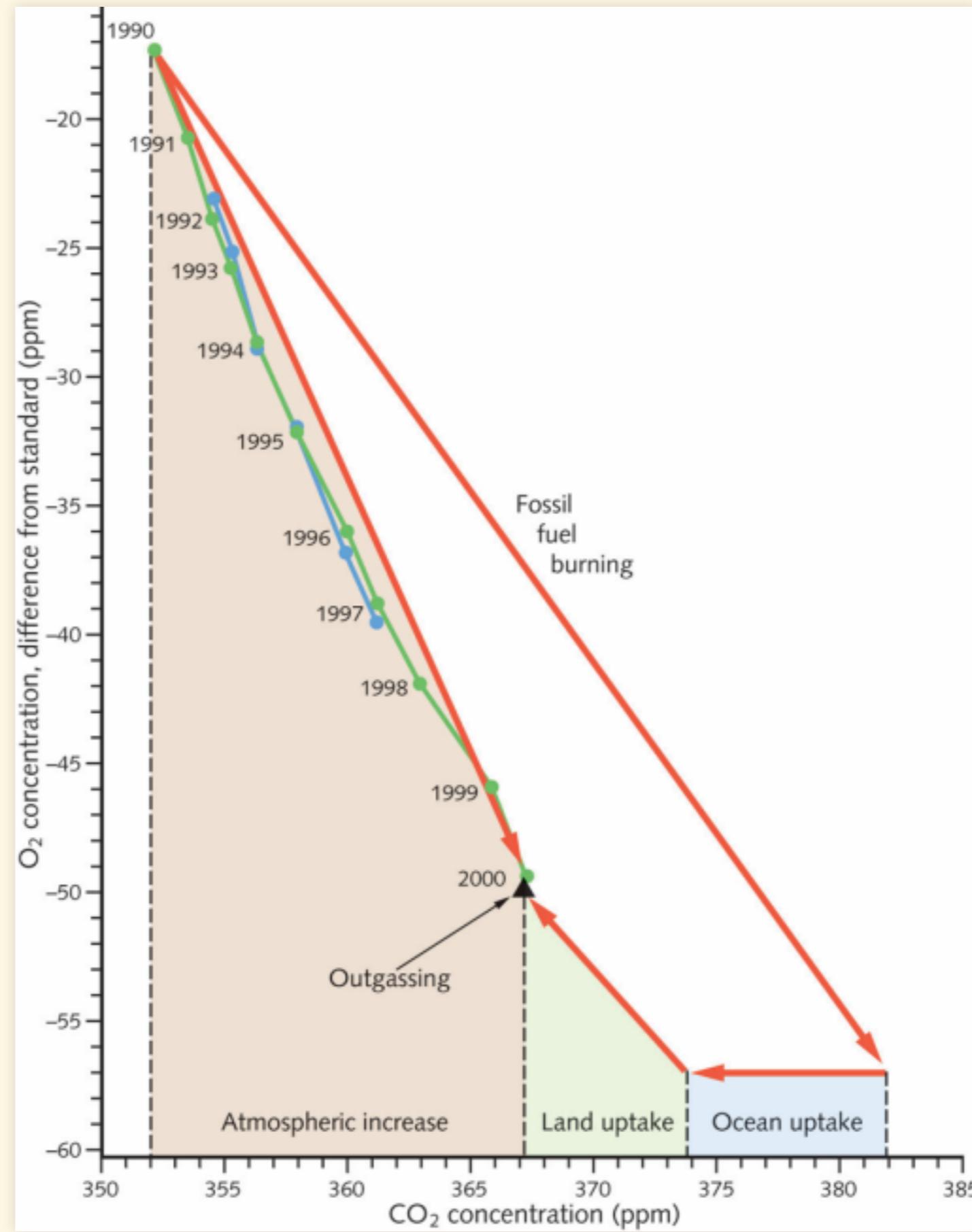


Image credit: J. Houghton, *Global Warming: The Complete Briefing*, 4th ed. (Cambridge, 2009), Fig. 3.4

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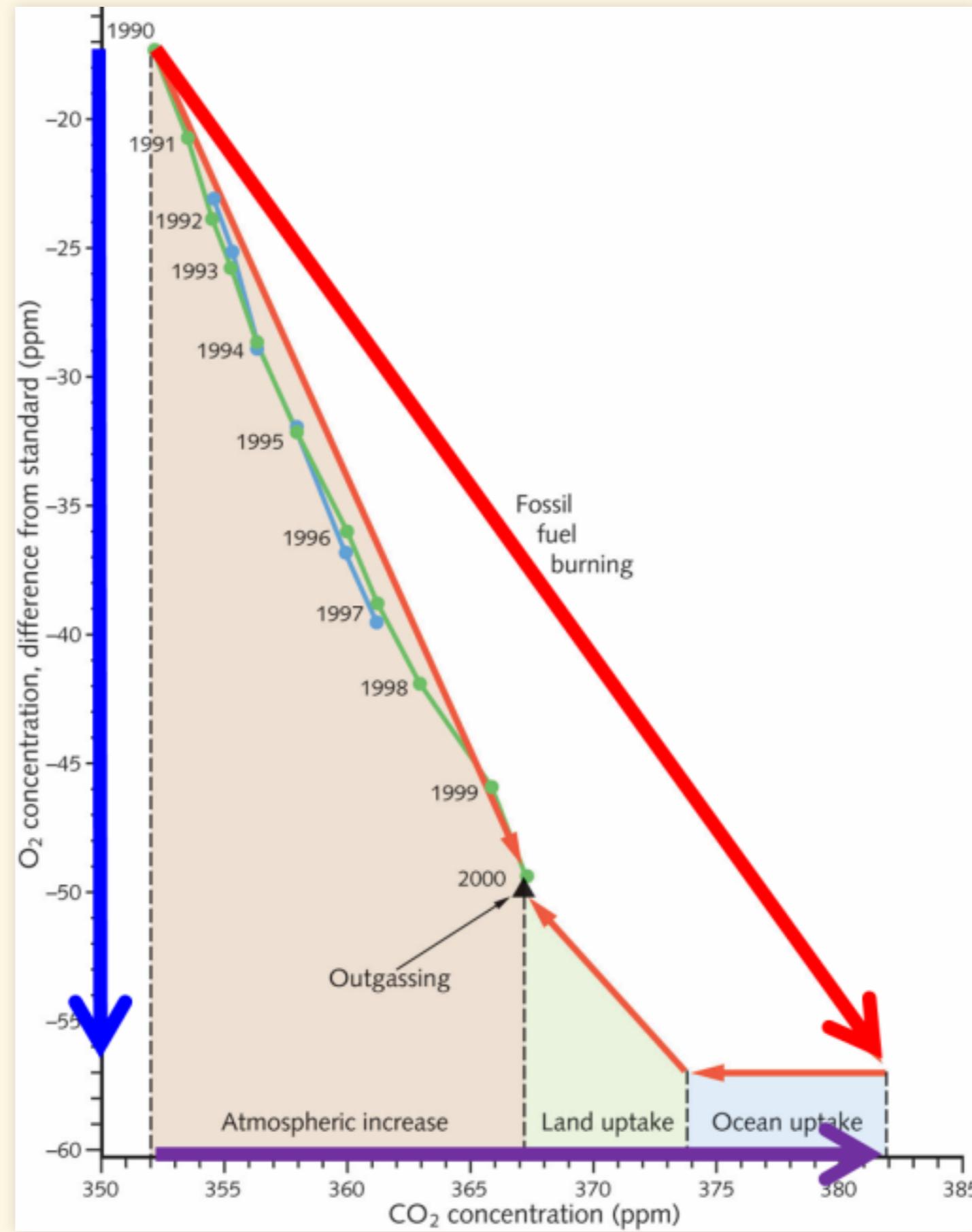


Image credit: J. Houghton, *Global Warming: The Complete Briefing*, 4th ed. (Cambridge, 2009), Fig. 3.4

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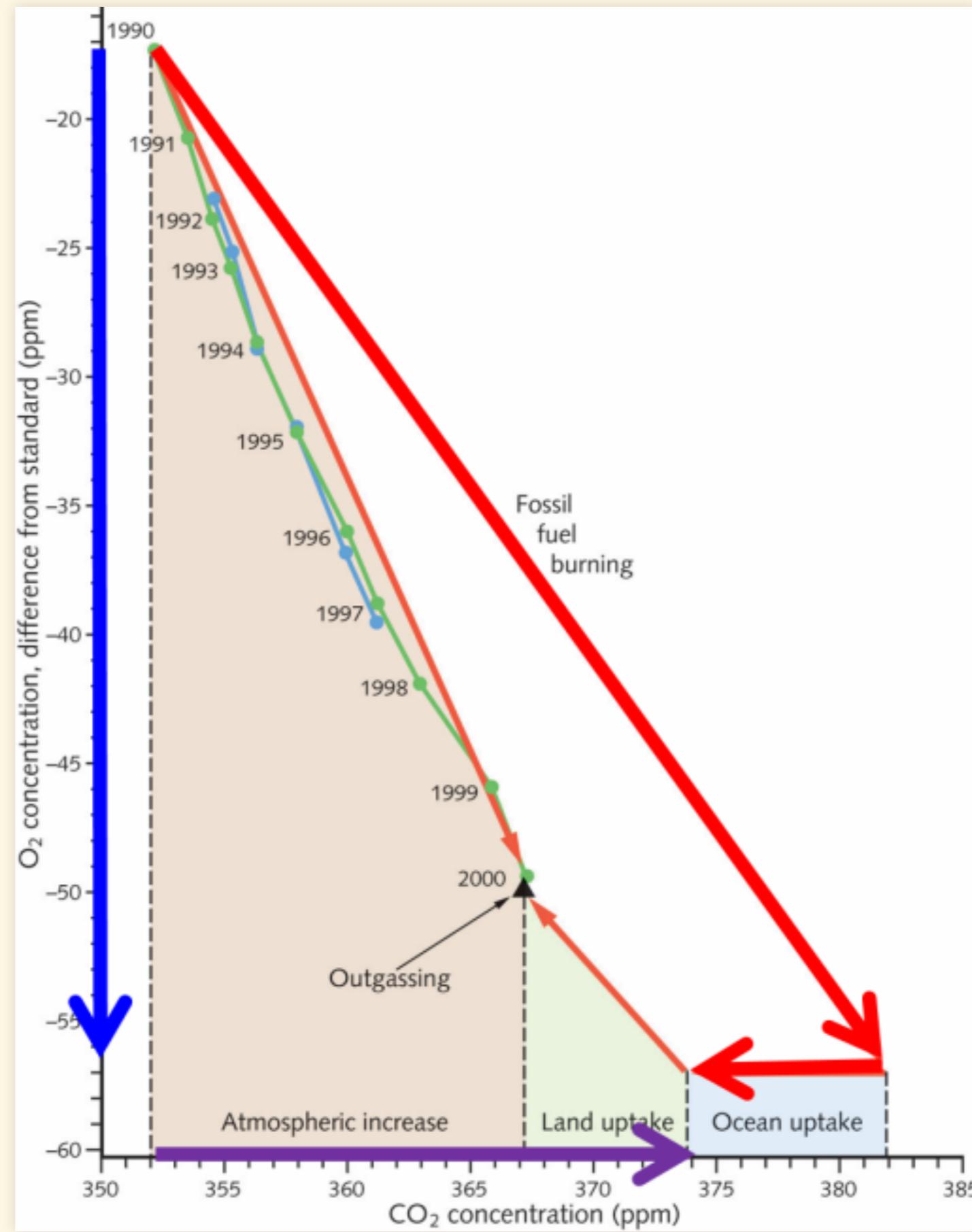


Image credit: J. Houghton, *Global Warming: The Complete Briefing*, 4th ed. (Cambridge, 2009), Fig. 3.4

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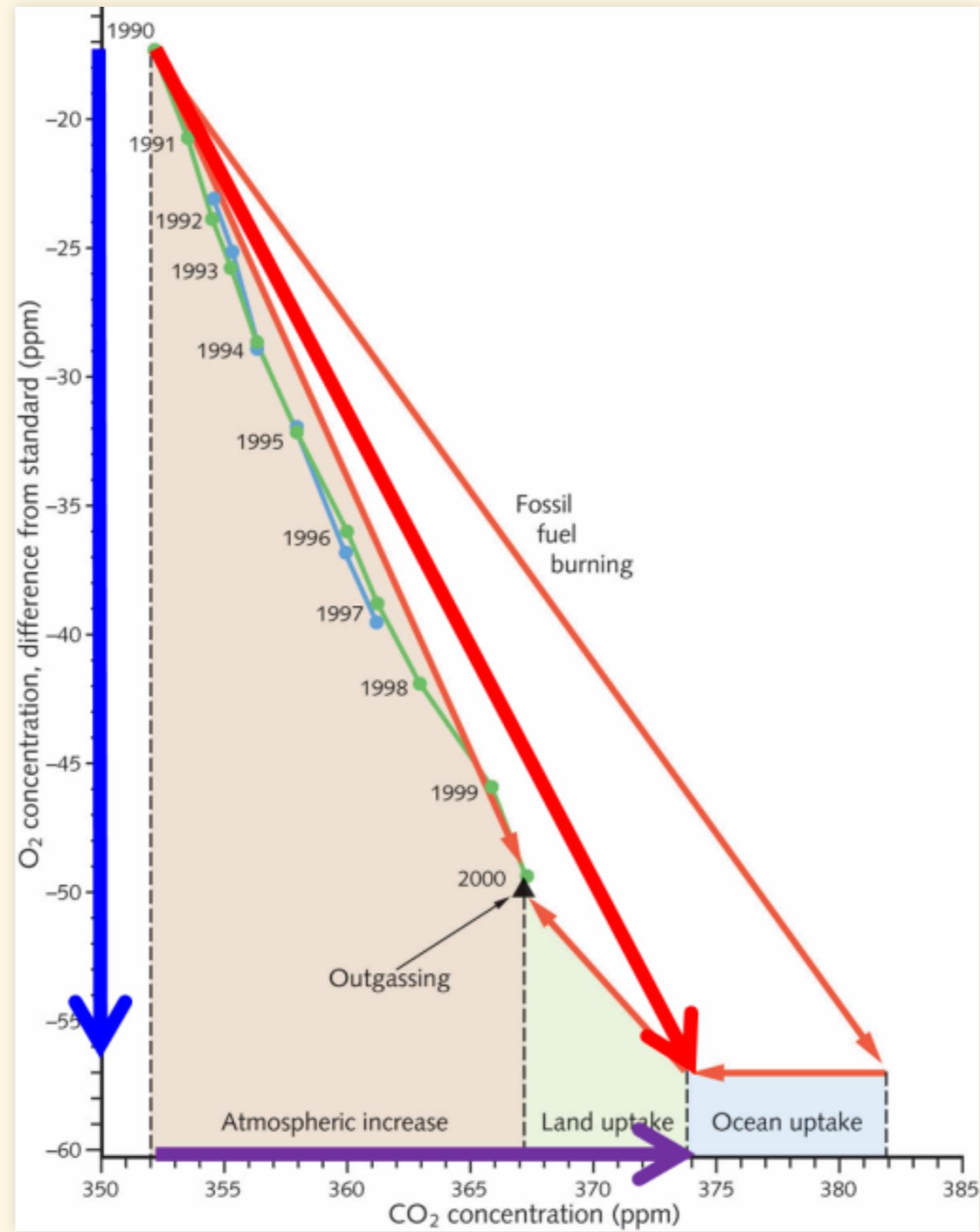


Image credit: J. Houghton, *Global Warming: The Complete Briefing*, 4th ed. (Cambridge, 2009), Fig. 3.4

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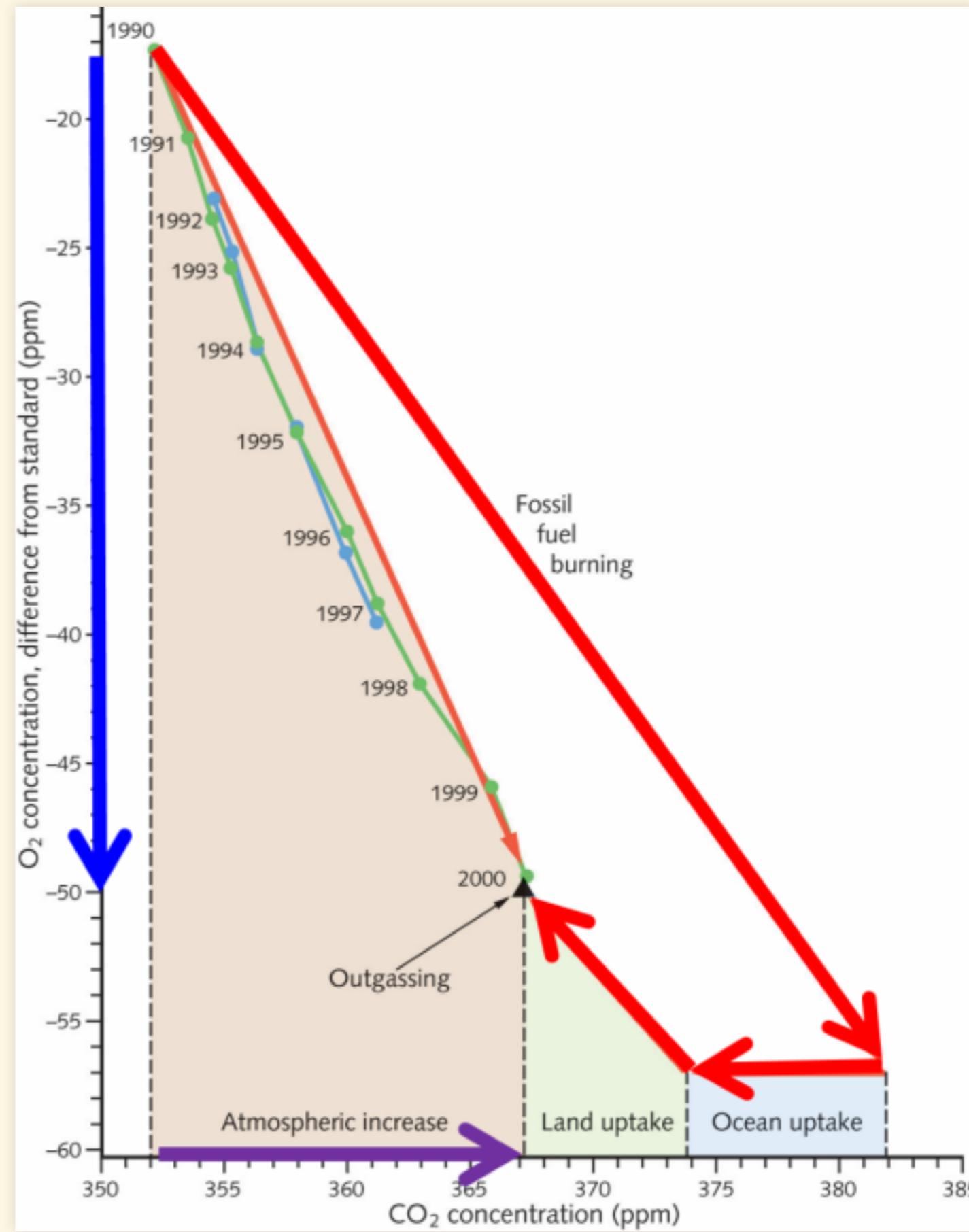


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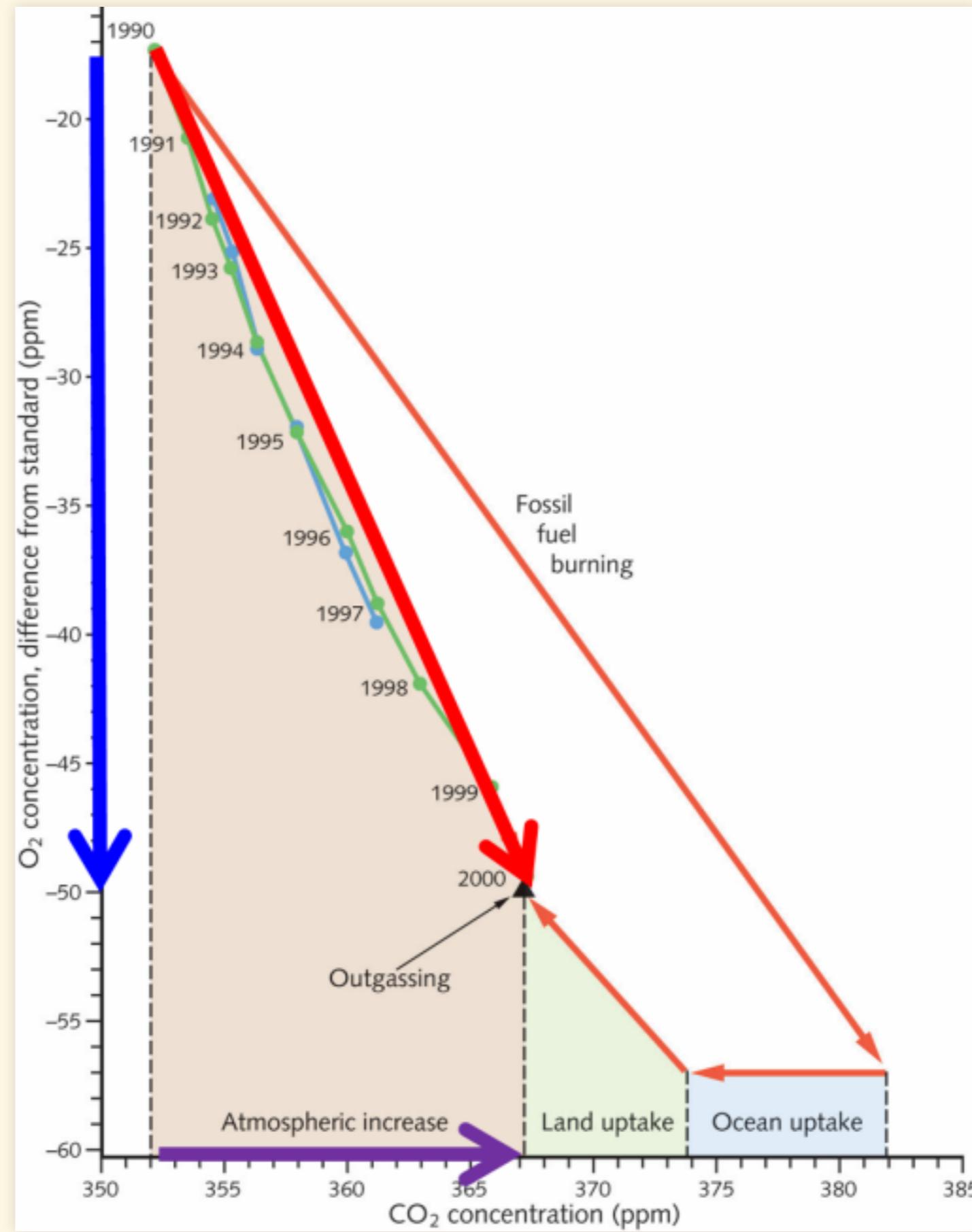


Image credit: J. Houghton, *Global Warming: The Complete Briefing*, 4th ed. (Cambridge, 2009), Fig. 3.4

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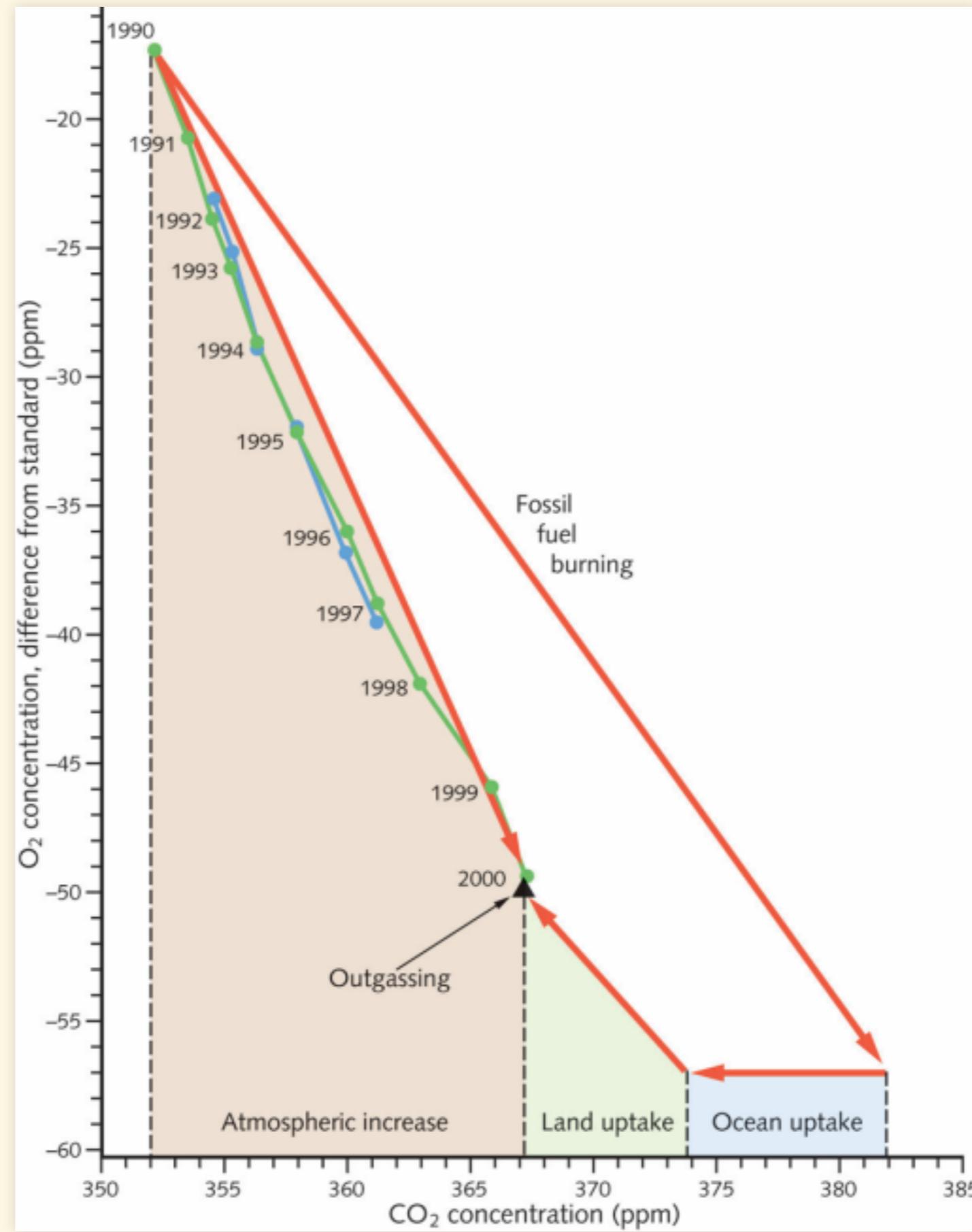
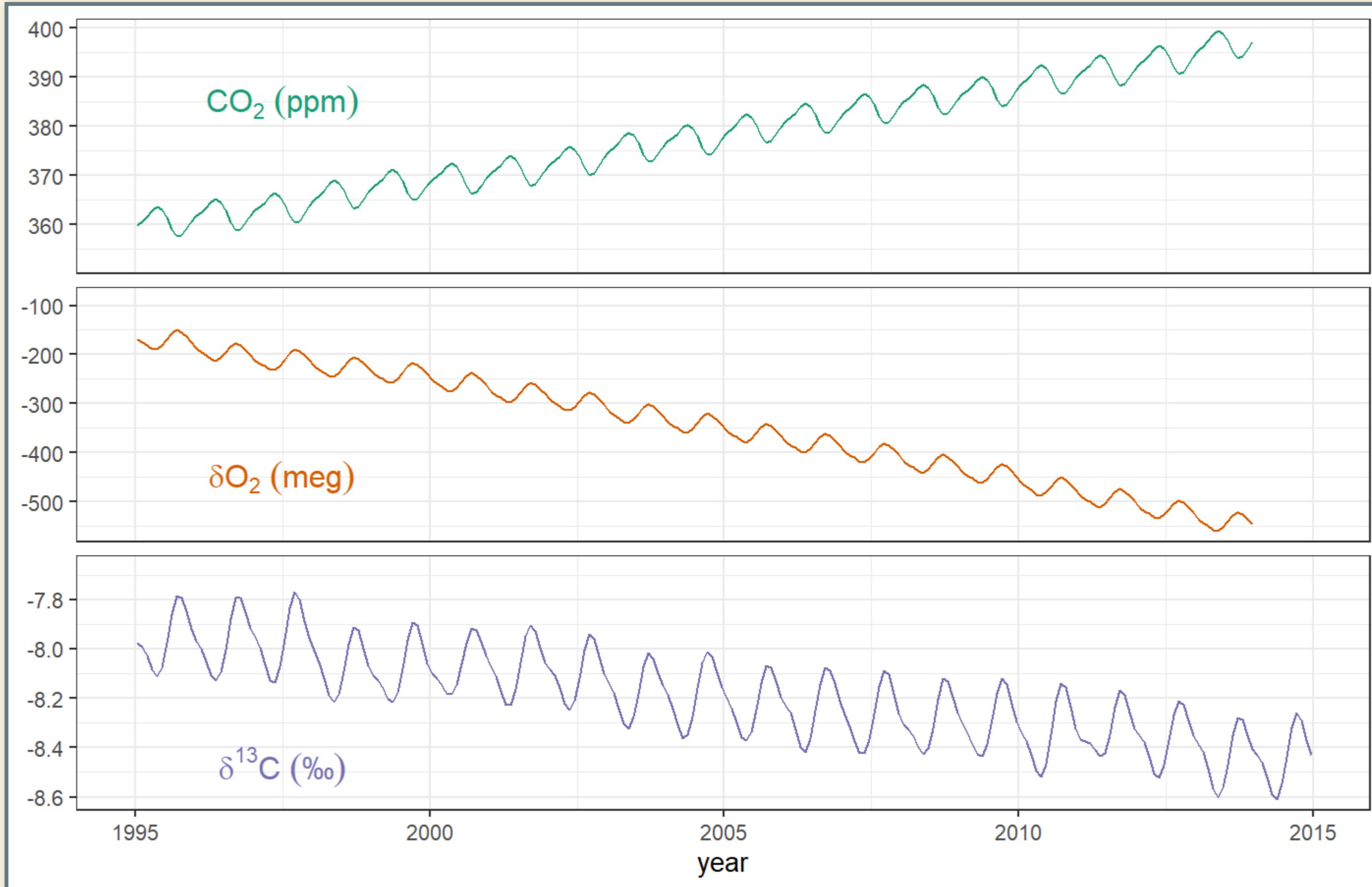


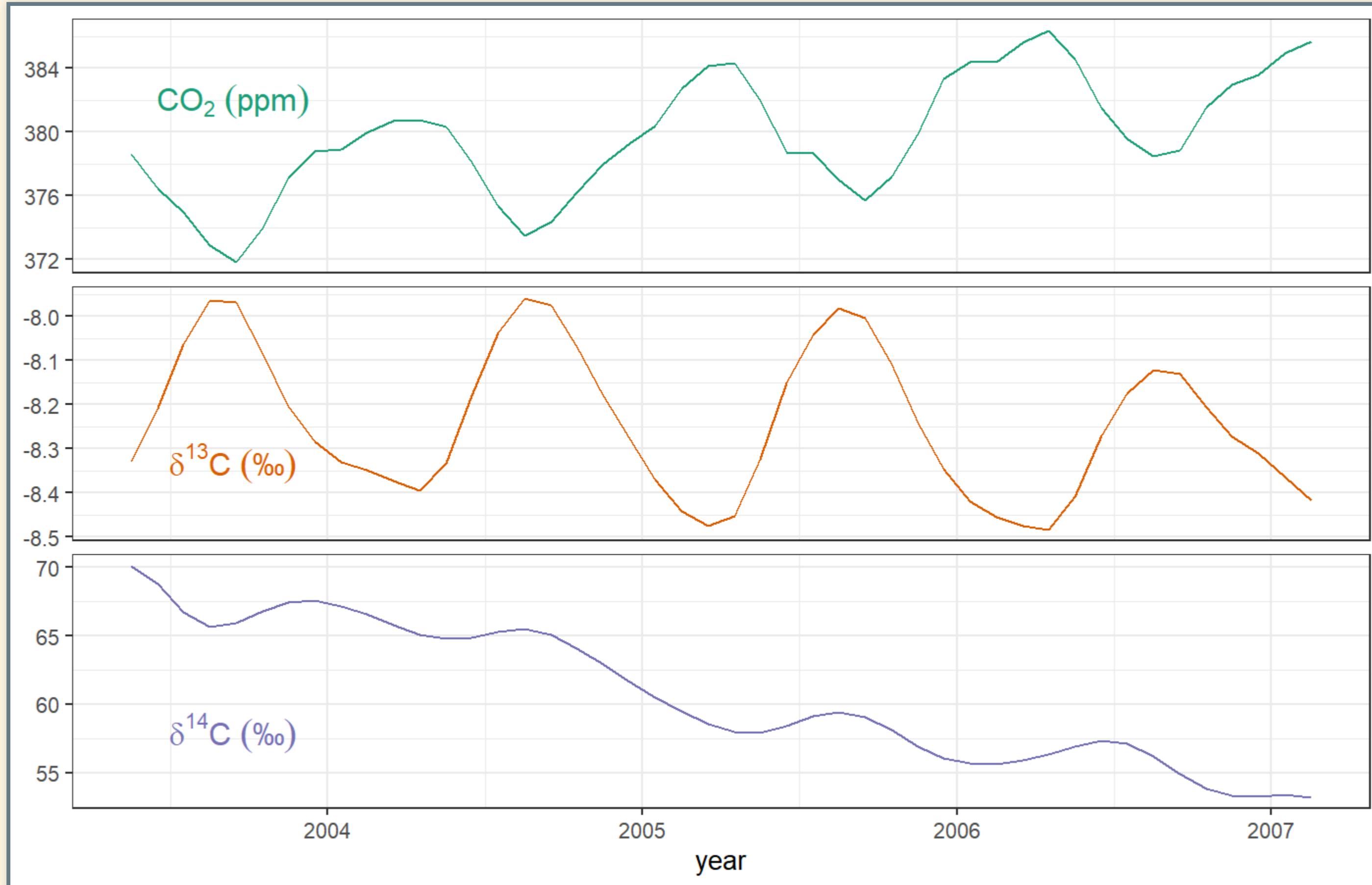
Image credit: J. Houghton, *Global Warming: The Complete Briefing*, 4th ed. (Cambridge, 2009), Fig. 3.4

# Source of CO<sub>2</sub>

# Source of CO<sub>2</sub>: O<sub>2</sub> and <sup>13</sup>C



# Source of CO<sub>2</sub>: $^{13}\text{C}$ and $^{14}\text{C}$



# Fossil Fuels vs. CO<sub>2</sub>

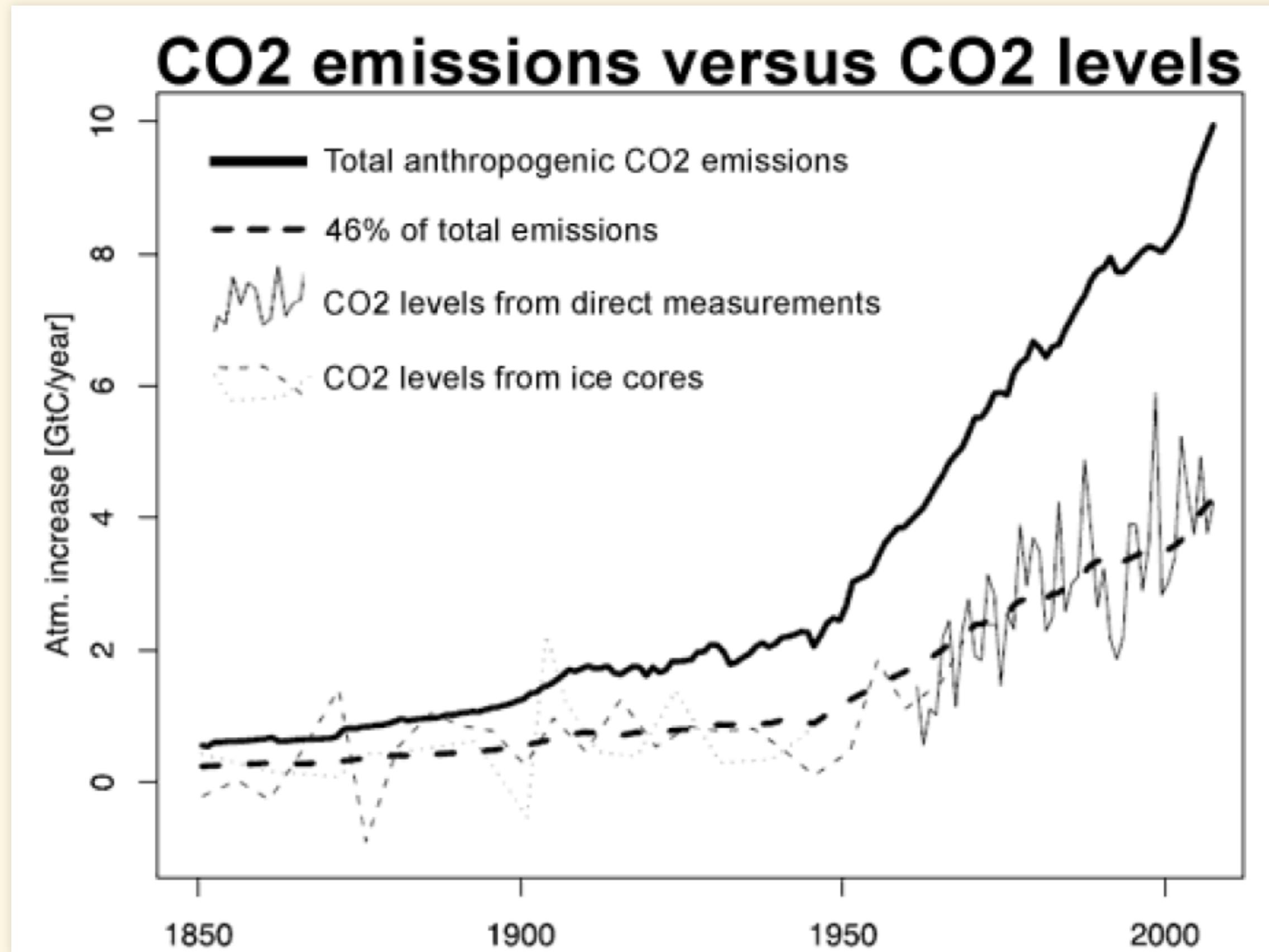


Image credit: W. Knorr, Geophys. Res. Lett. 36, L21710 (2009) doi: 10.1029/2009GL040613

- Concentrations match 46% of fossil fuel consumption

# Assessing the Evidence

- Decreasing O<sub>2</sub>: CO<sub>2</sub> produced by burning.
  - Not a mineral source (volcanoes).
- <sup>13</sup>C/<sup>12</sup>C: CO<sub>2</sub> must have biological origin.
- <sup>14</sup>C: 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

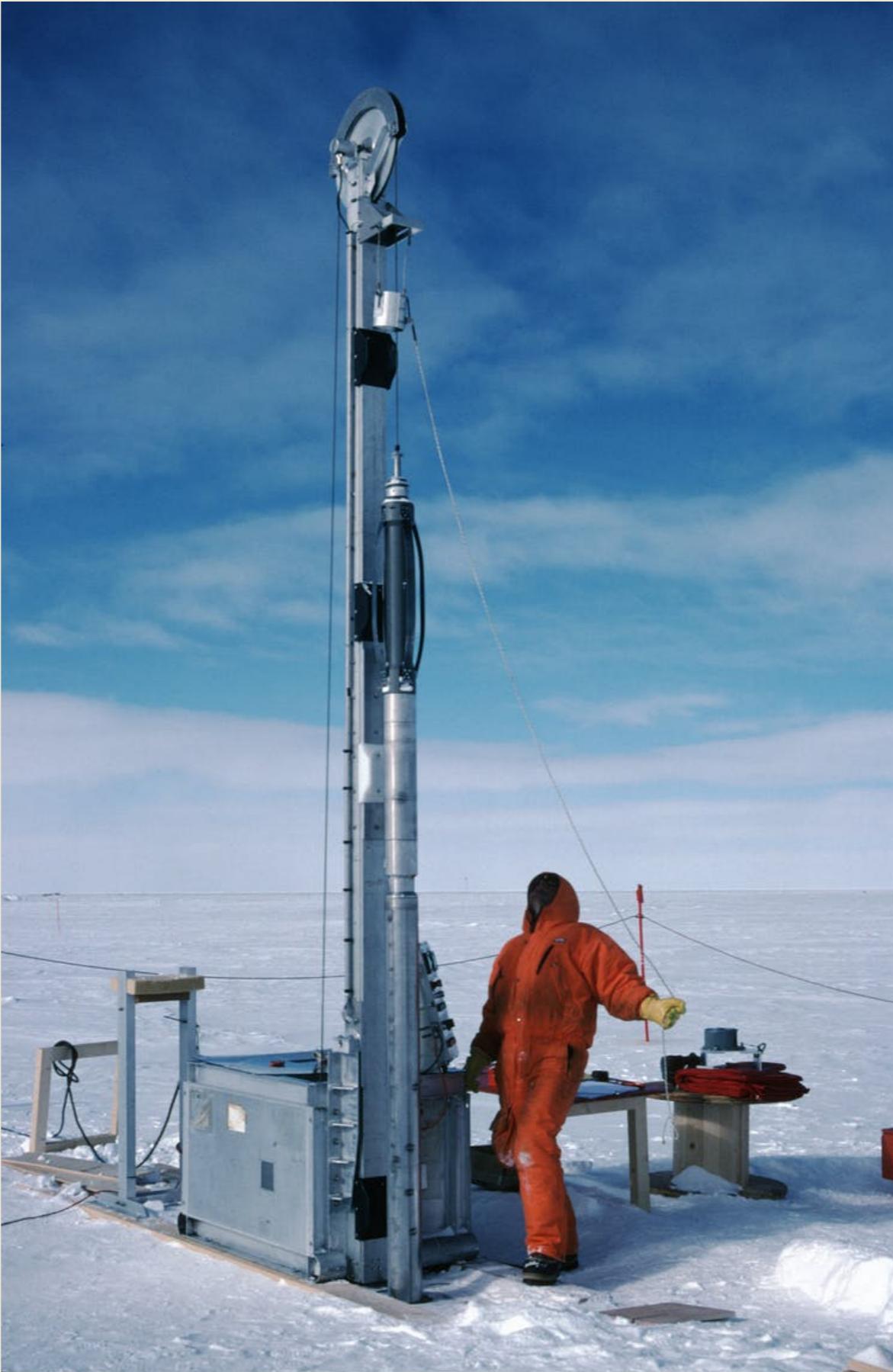


Image Credit: R Mulvaney/British Antarctic Survey

# Ice Cores



Image credits: Pete Bucktrout/British Antarctic Survey

# Inside the Ice Core

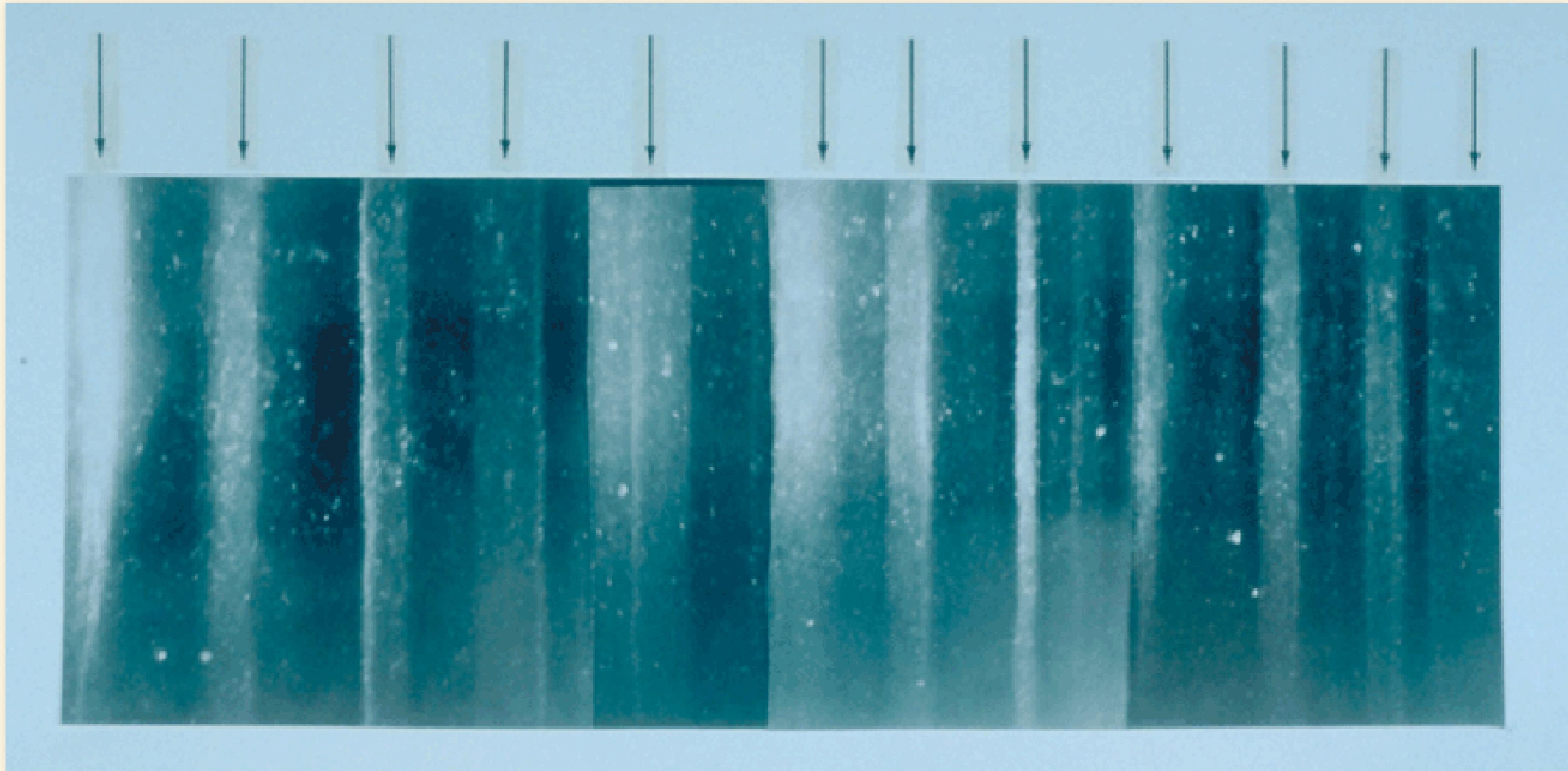


Image credit: National Ice Core Laboratory

# Inside the Ice Core

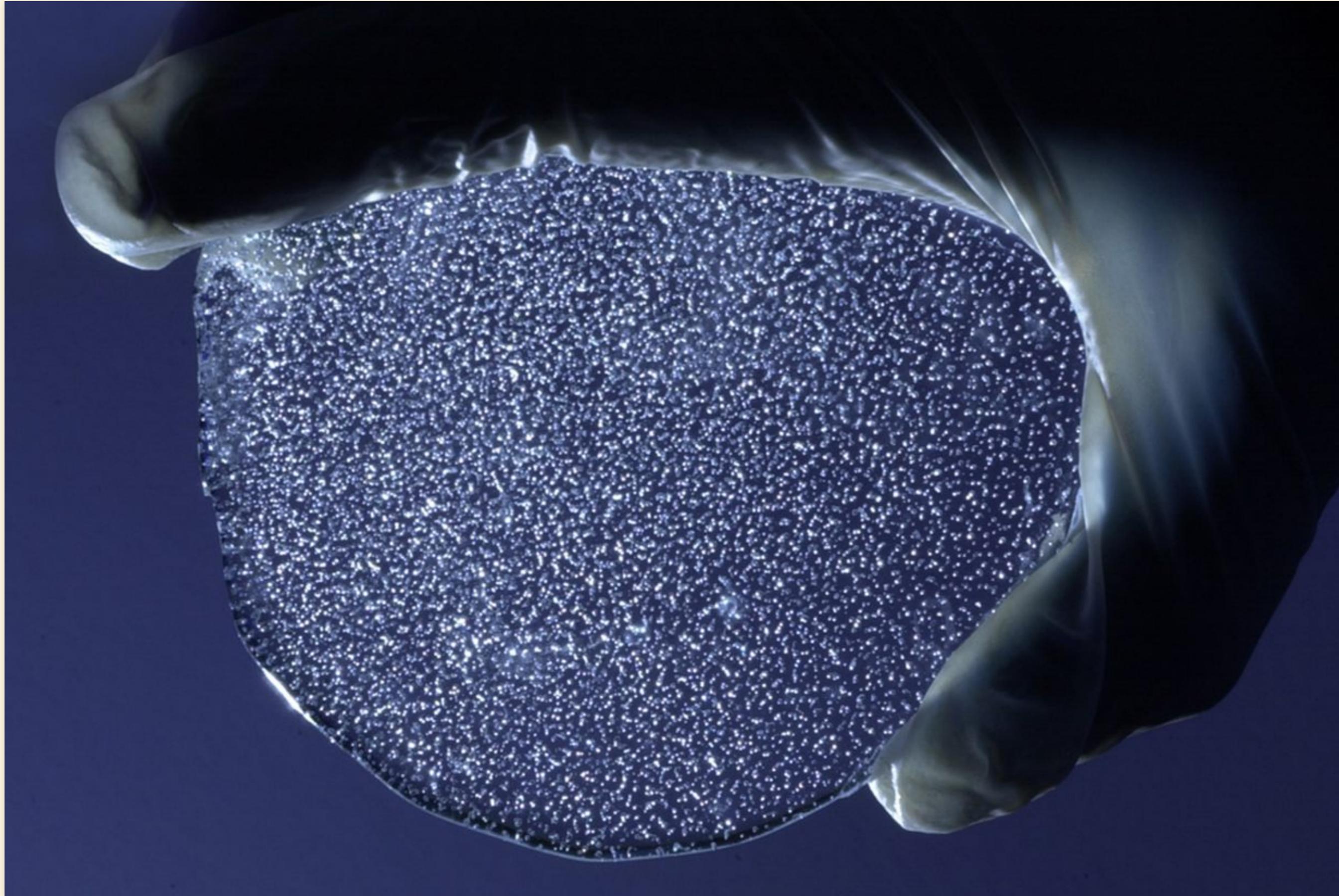
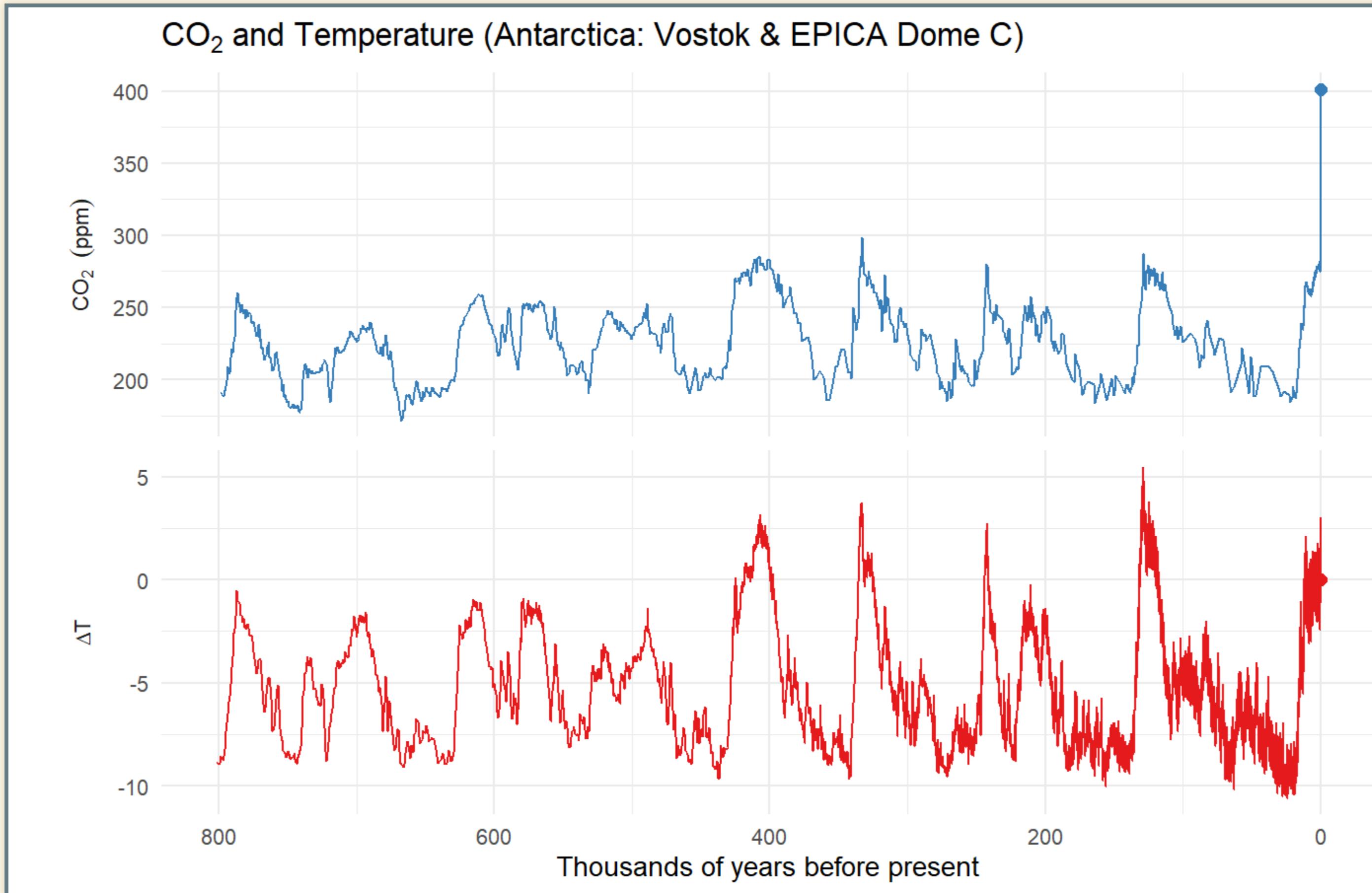


Image credit: Pete Bucktrout/British Antarctic Survey

# The Oceans Breathe



# Ice Ages

# 25,000 years ago



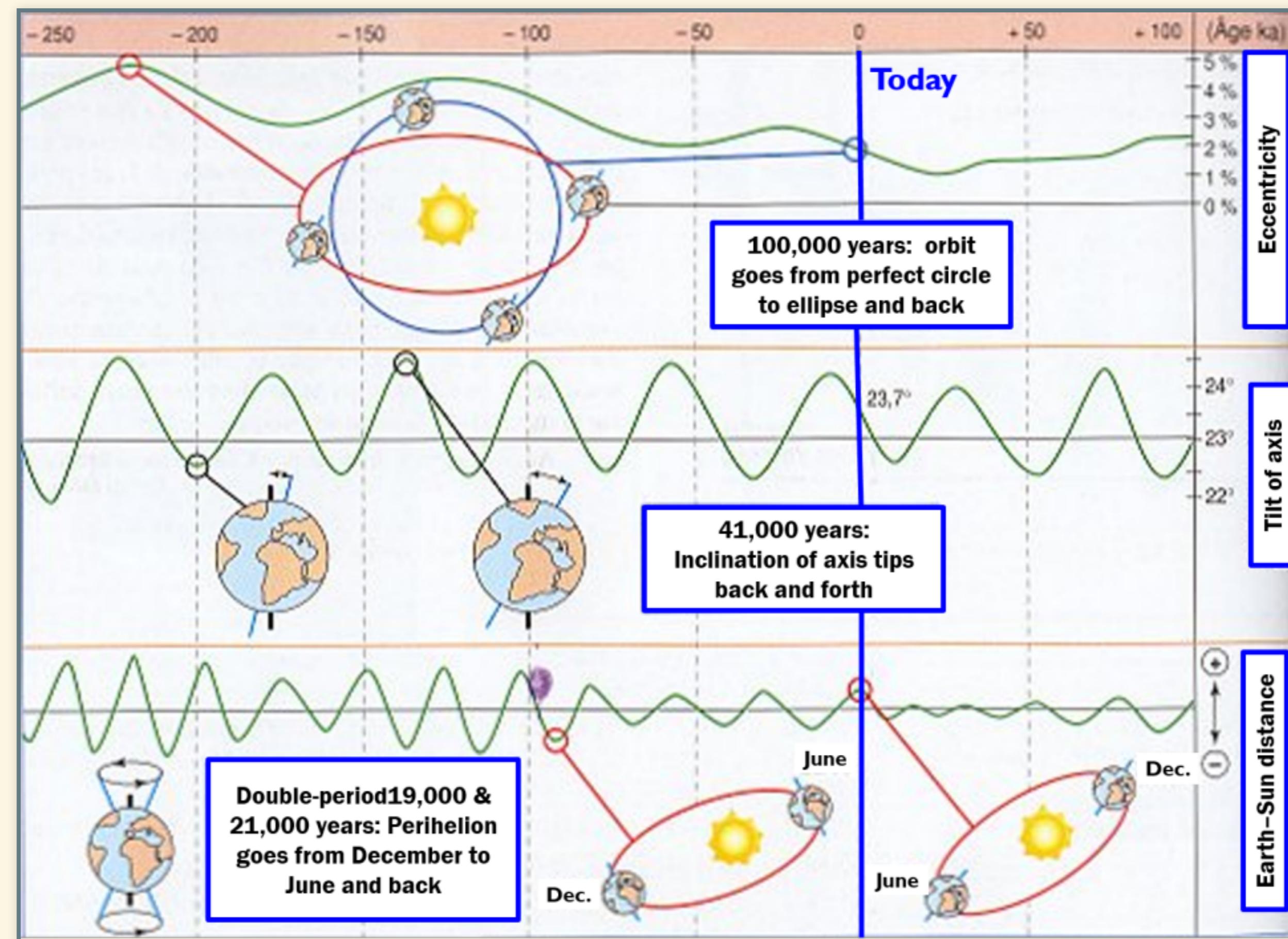
Image credit: Ron Blakey

# 25,000 years ago

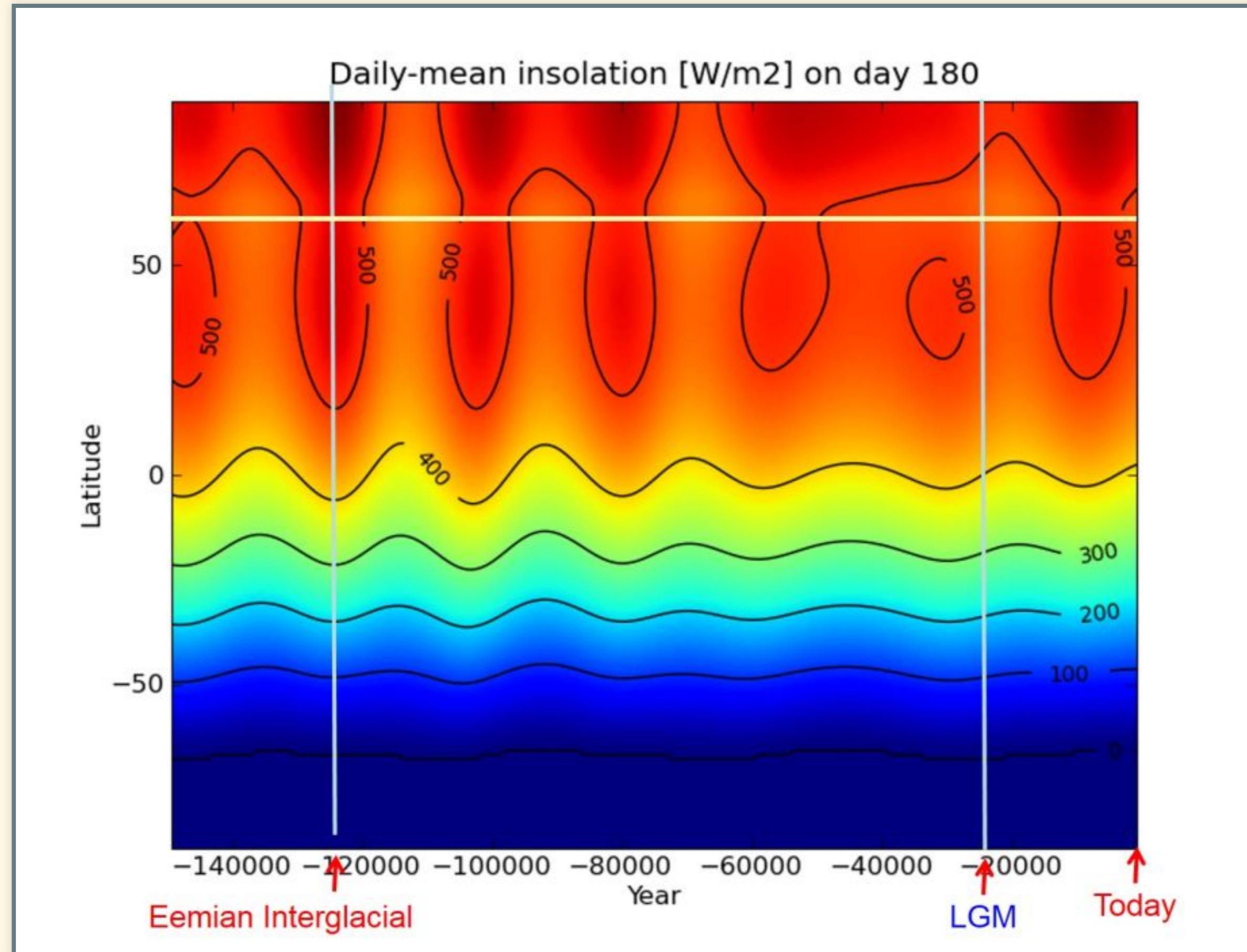


Image credit: Ron Blakey

# Causes



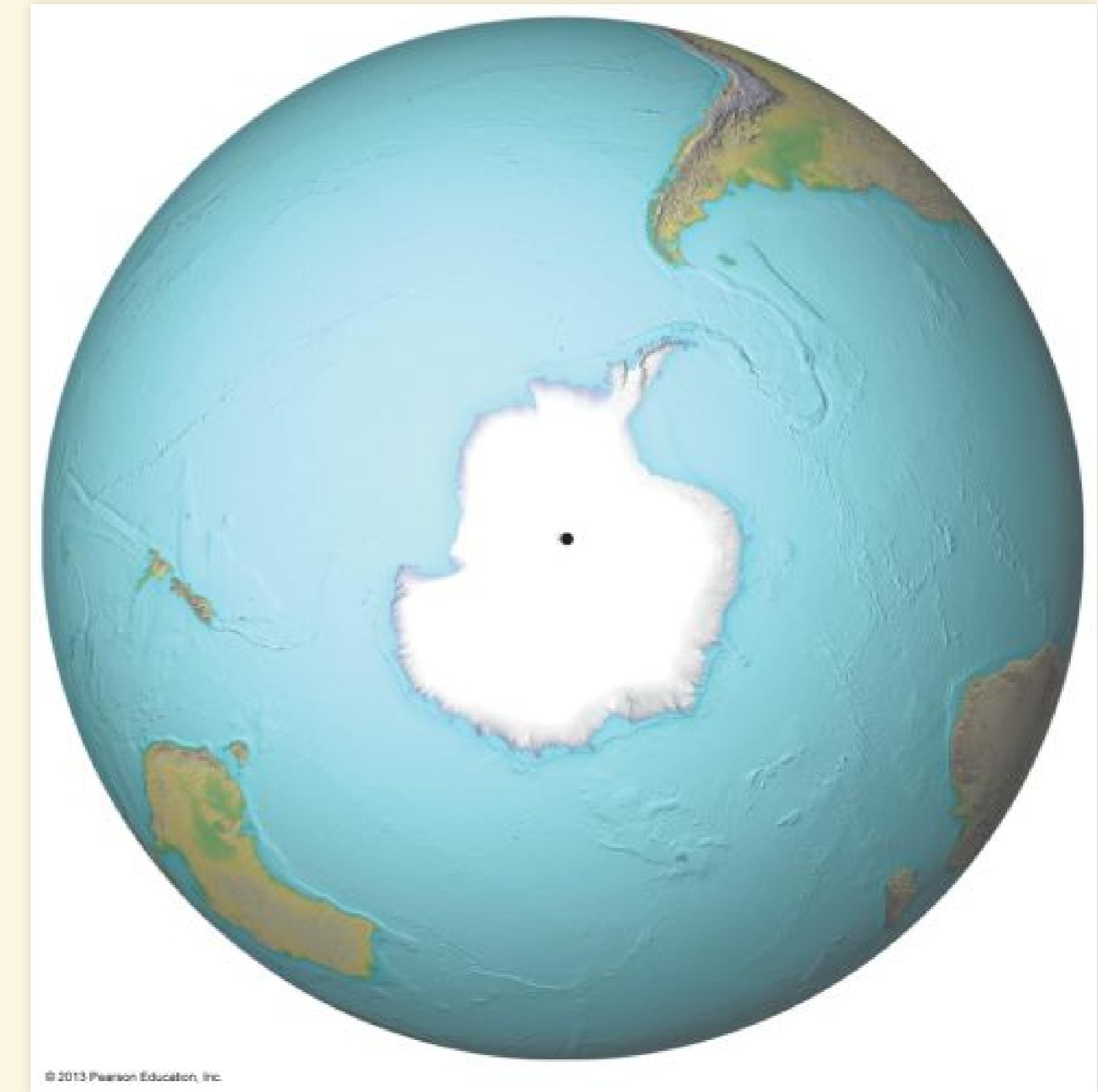
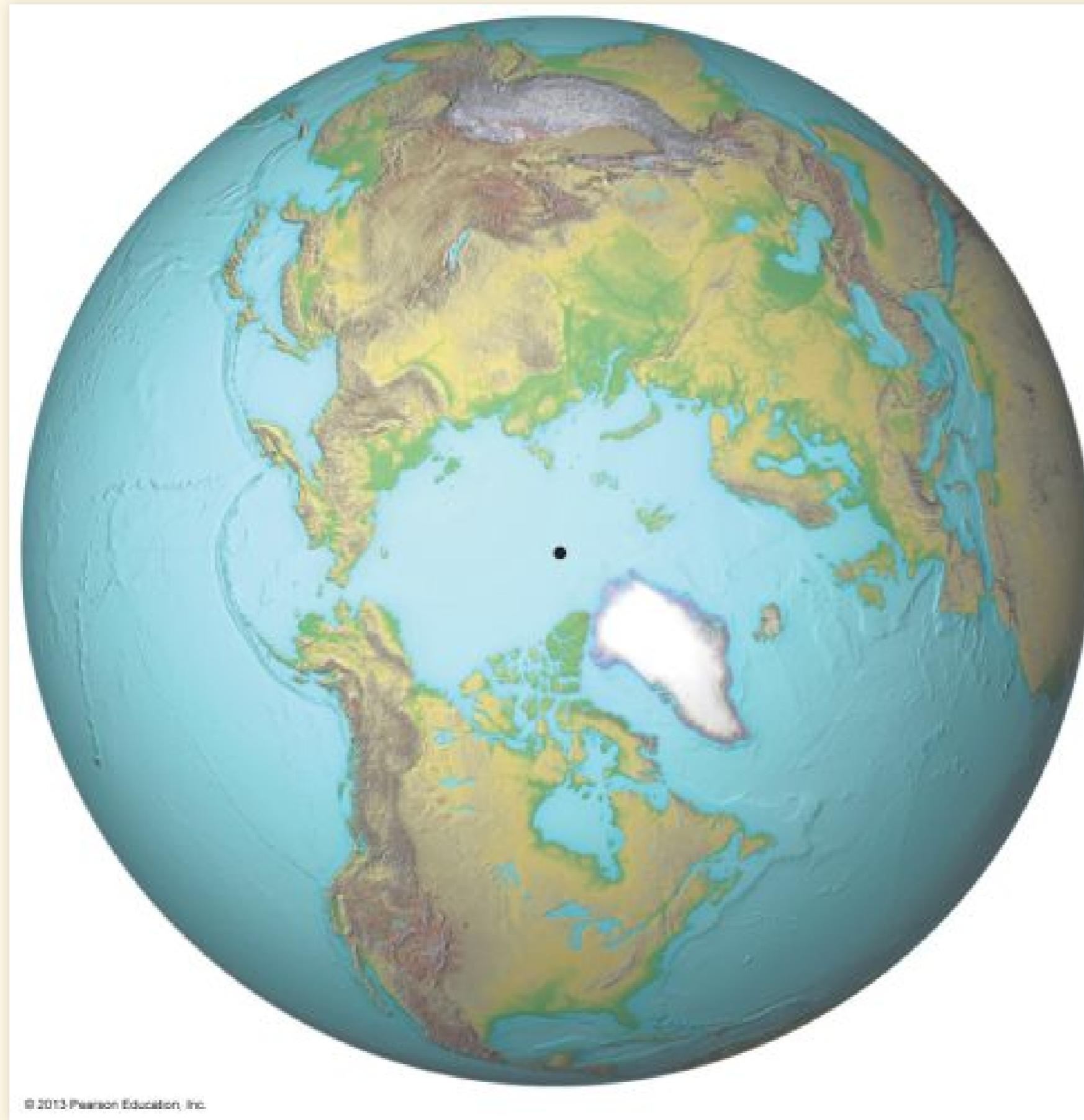
# Insolation



# Question

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

# Northern vs. Southern Hemisphere

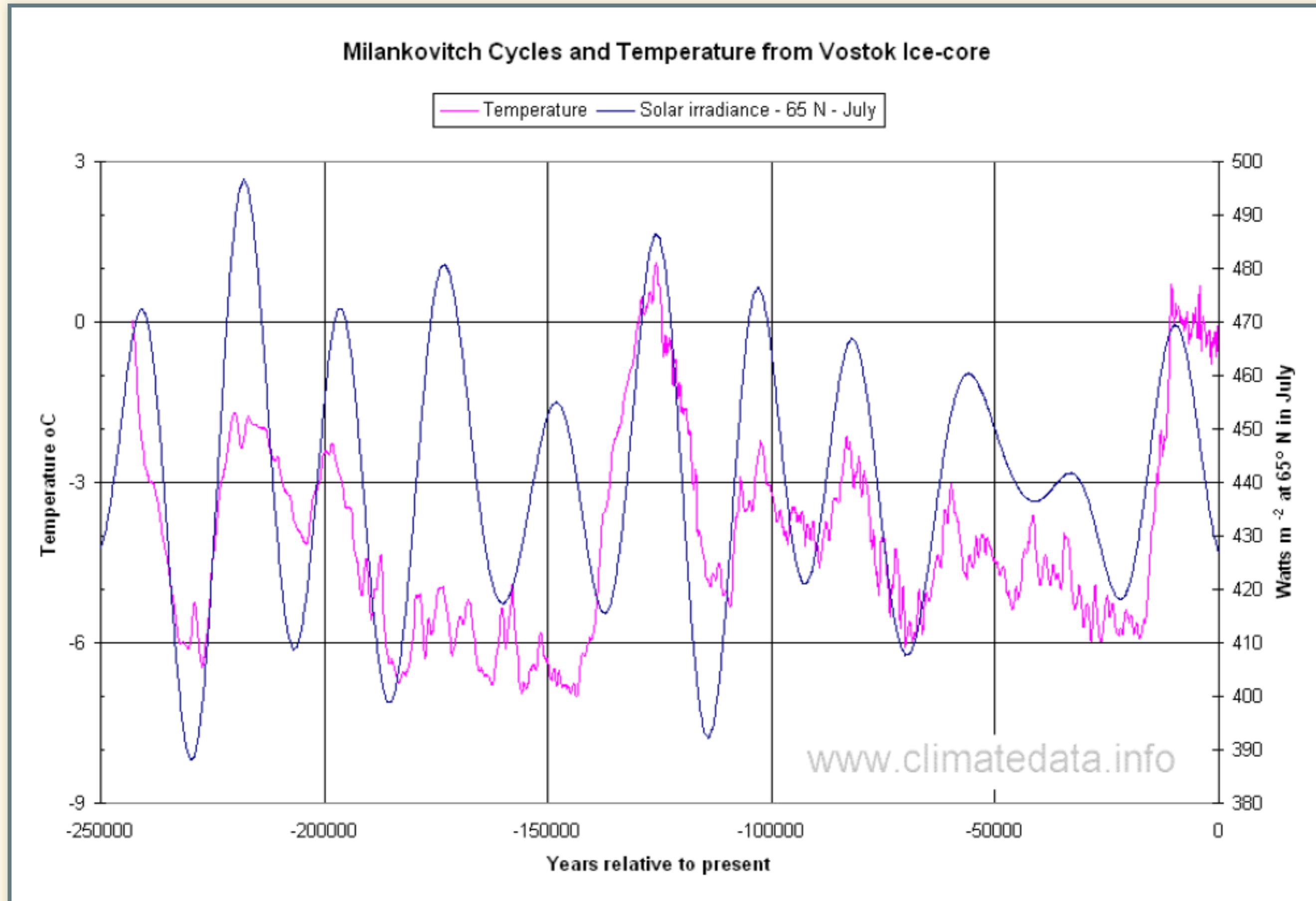


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# Timing of Ice Ages

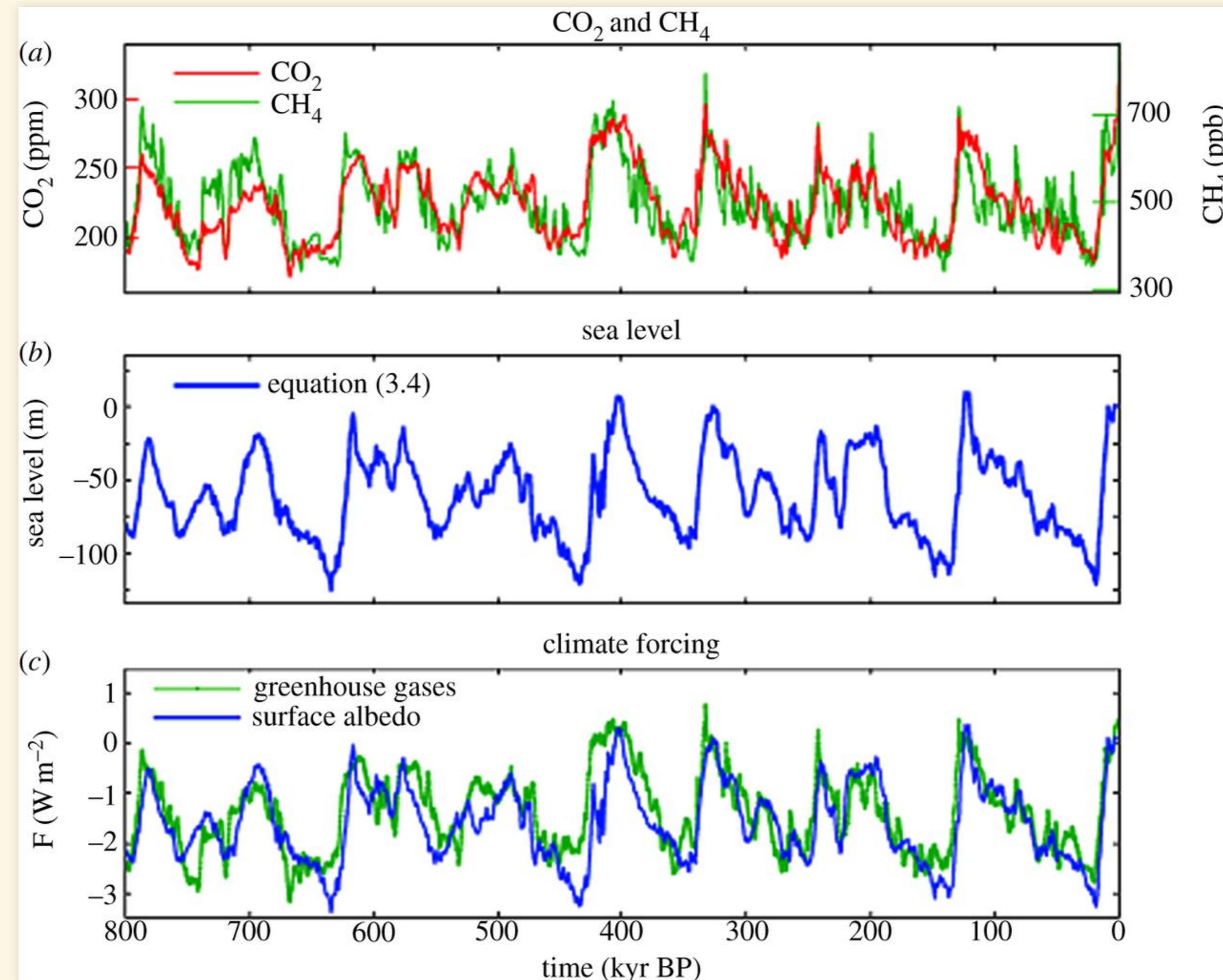


# Ice Age Feedbacks

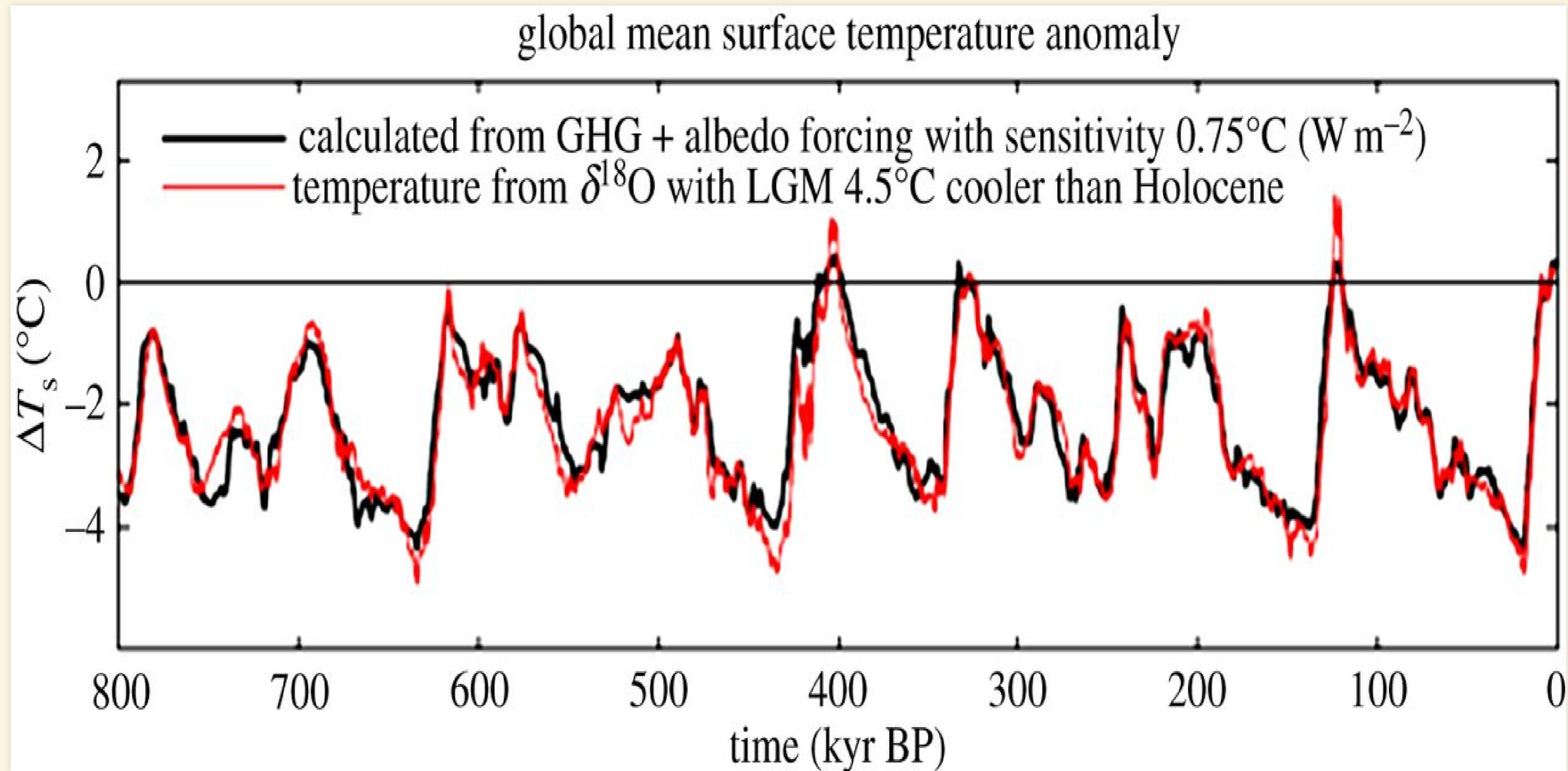
# Ice Age Feedbacks

- 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
  - $\text{CO}_2$  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.

# 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.