The Carbon Cycle: Ocean and Biosphere

EES 3310/5310

Global Climate Change

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Class #10: Monday, February 15 2021

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

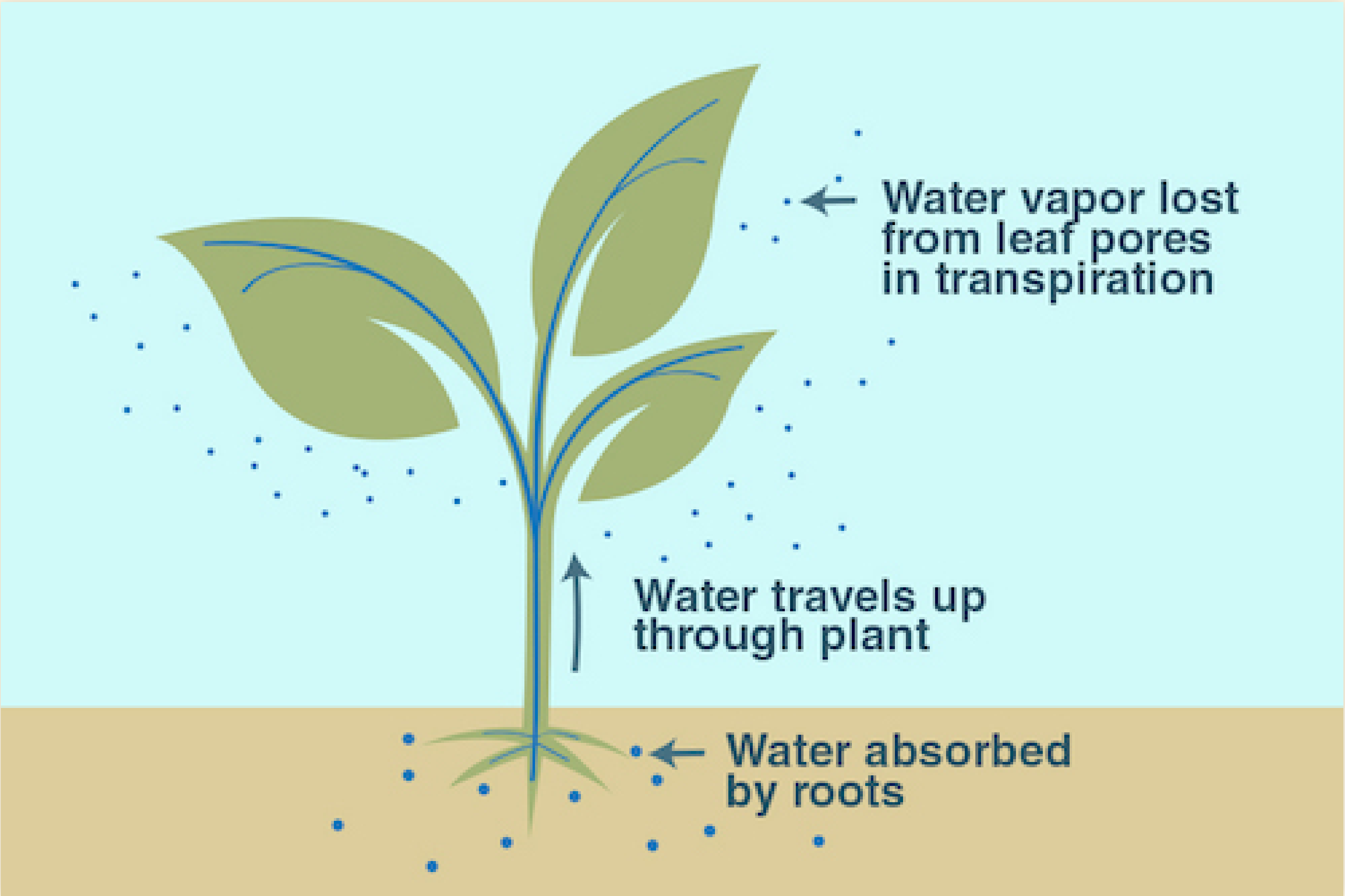


Image credit: NASA/JPL-Caltech https://climatekids.nasa.gov/heat-islands/

Transpiration and CO_2

- Transpiration occurs through "stomata" in leaves
- Tradeoff: stomata
  - Allow plant to get CO_2
  - Cause plant to lose water
- More CO_2 in atmosphere:
  - Fewer stomata
  - Less transpiration

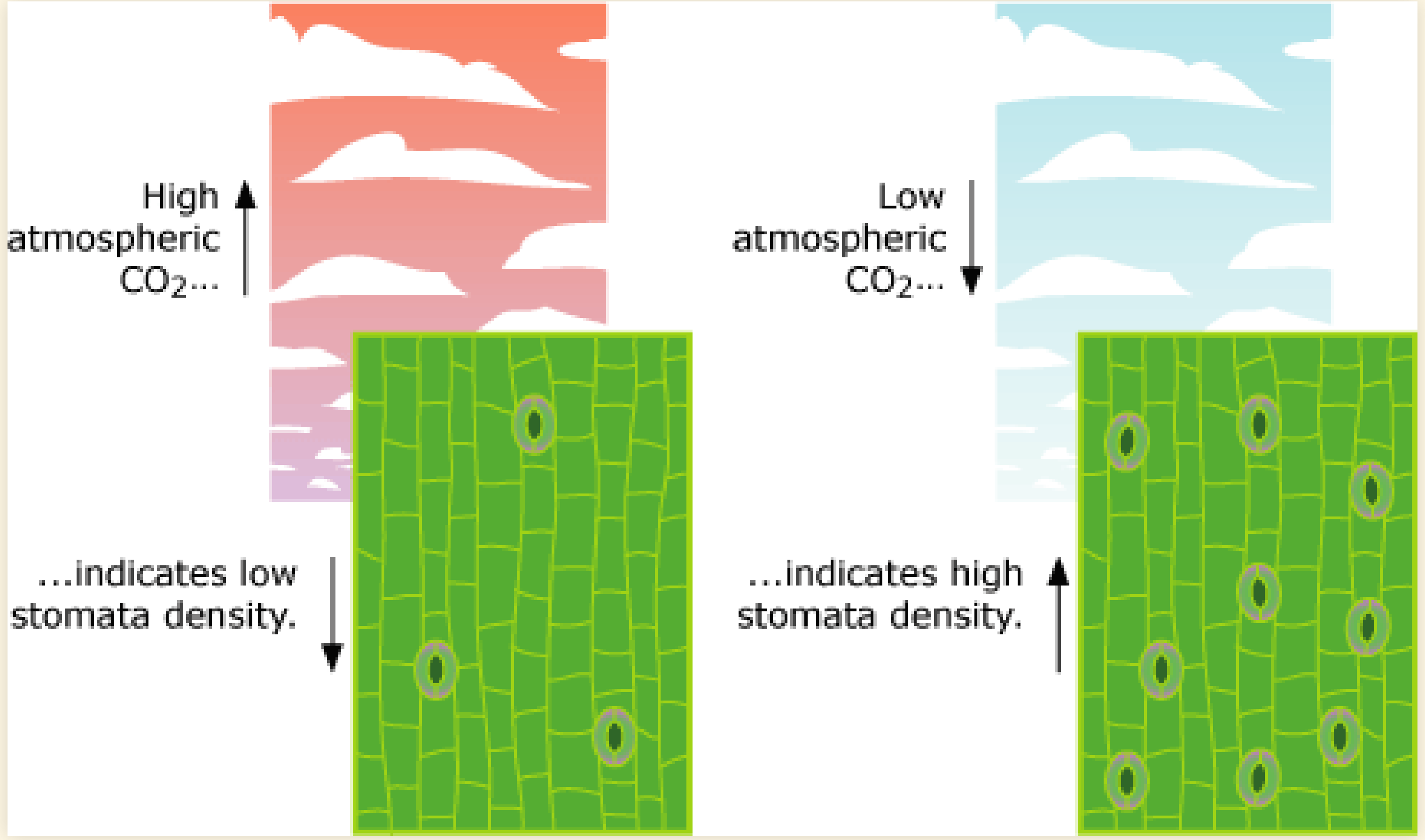


Image credit:
- Photo of stomata on duckweed: Micrographia http://www.micrographia.com/specbiol/plan/planaq/plaq0100/lemna-01.htm.
- Diagram of response to CO_2: University of California Museum of Paleontology's Understanding Evolution http://evolution.berkeley.edu.

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

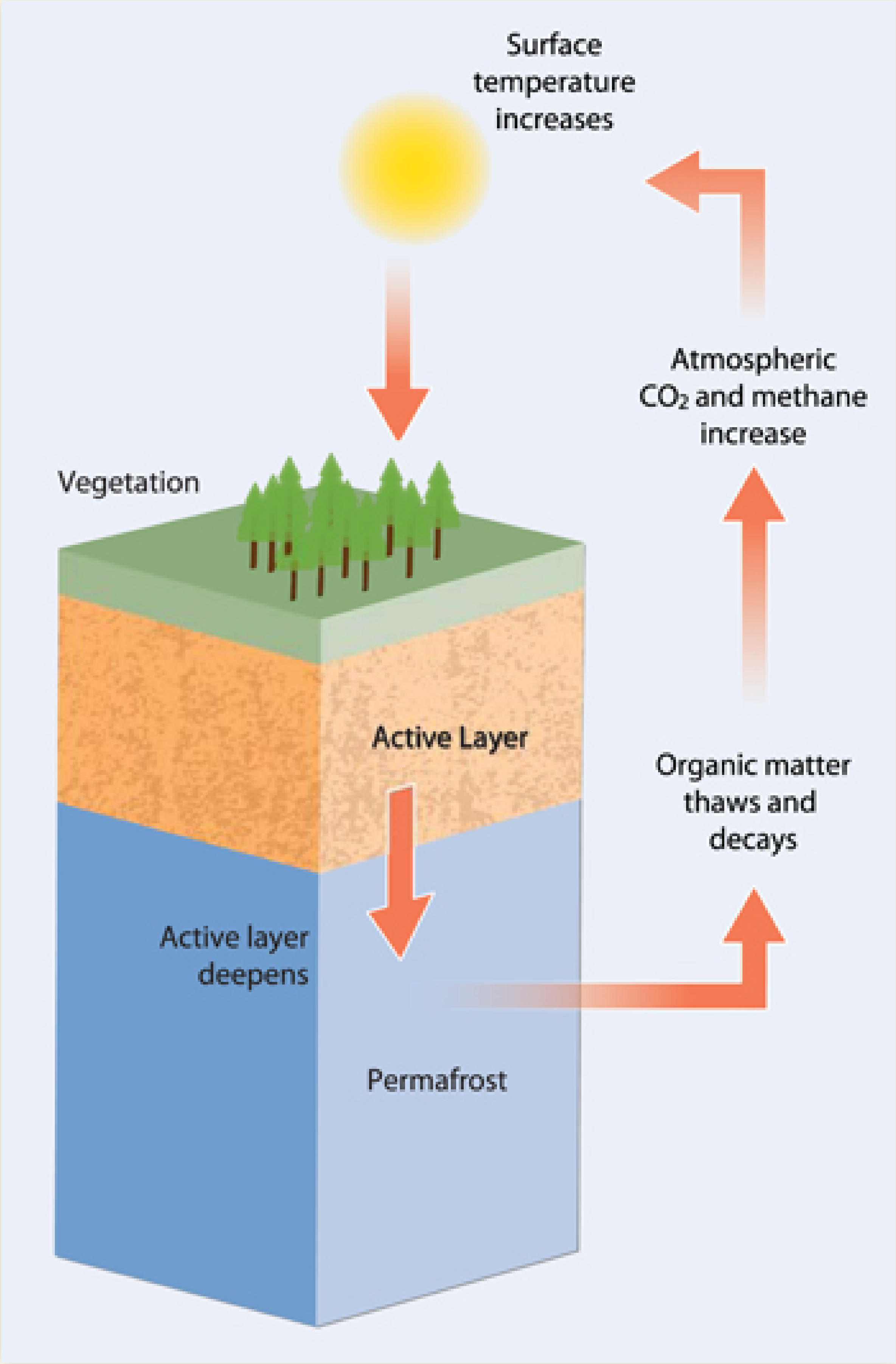
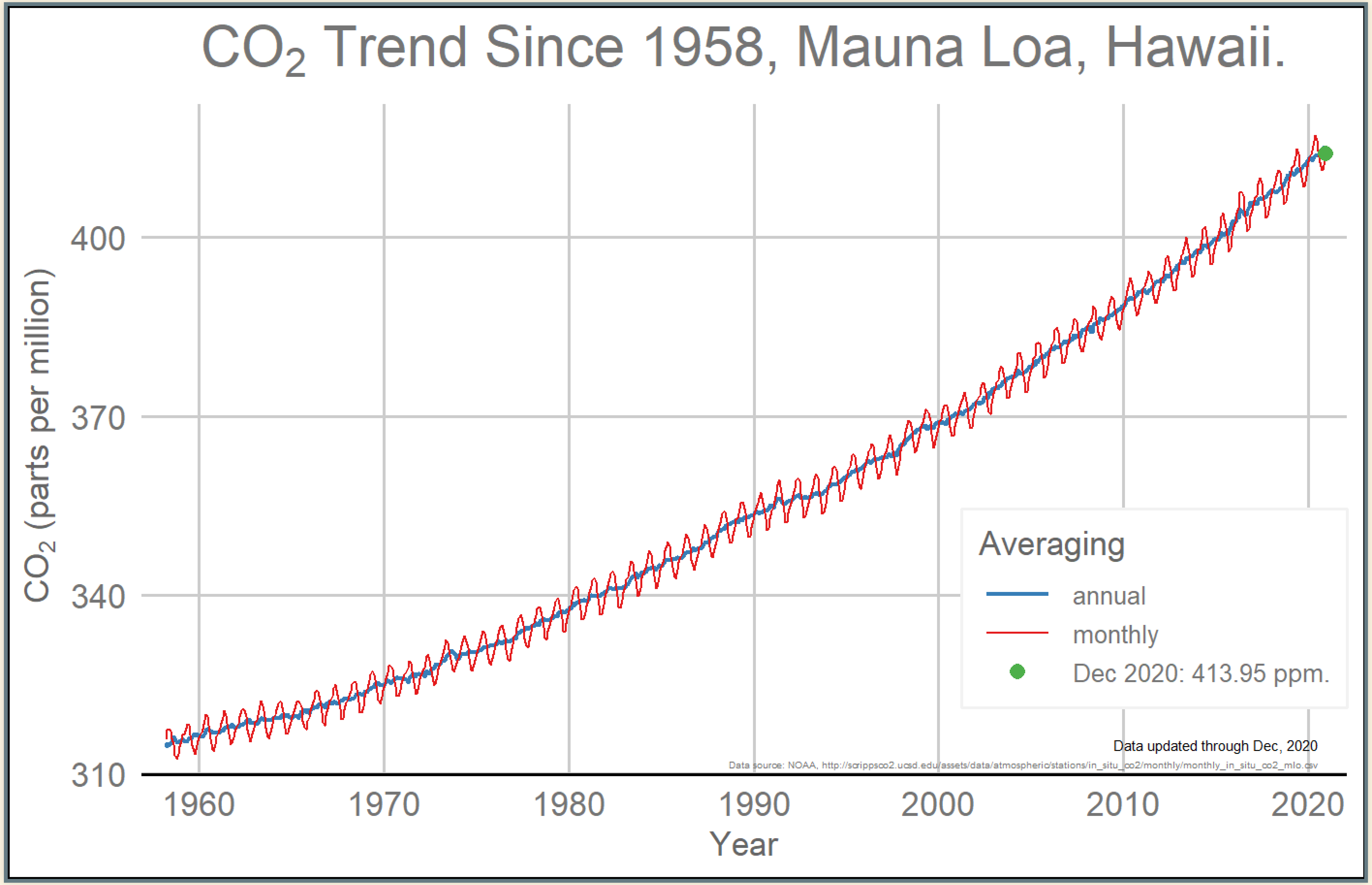


Image credit: K. Schaefer *et al.*, Environ. Res. Lett. **9**, 085003 (2014). doi: 10.1088/1748-9326/9/8/085003

CO_2 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 $\rightarrow$ 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
CH_4	−4	methane
$(CH_2)_n$	−2	long-chain alkane
CO_2	+4	carbon dioxide
$(CH_2O)_n$	0	carbohydrate

Carbon

Category	Oxidation State	Examples
Mineral carbon	≥ 0	$CO_2 : +4$
Organic carbon	≤ 0	$CH_4 : -4$ (methane) $(CH_2O)_6 : 0$ (sugar)

Energy:

- Negative oxidation $\rightarrow$ greater energy
- Positive oxidation $\rightarrow$ lower energy
- Photosynthesis:
  $CO_2 + H_2O + \text{energy} \Rightarrow (CH_2O)_n + O_2$
- Respiration:
  $(CH_2O)_n + O_2 \Rightarrow CO_2 + H_2O + \text{energy}$

Carbon

Energy:

- Negative oxidation $\rightarrow$ greater energy
- Positive oxidation $\rightarrow$ lower energy
- Photosynthesis:
  $CO_2 + H_2O + \text{energy} \Rightarrow (CH_2O)_n + O_2$
- Respiration:
  $CO_2 + H_2O + \text{energy} \Leftarrow (CH_2O)_n + O_2$

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

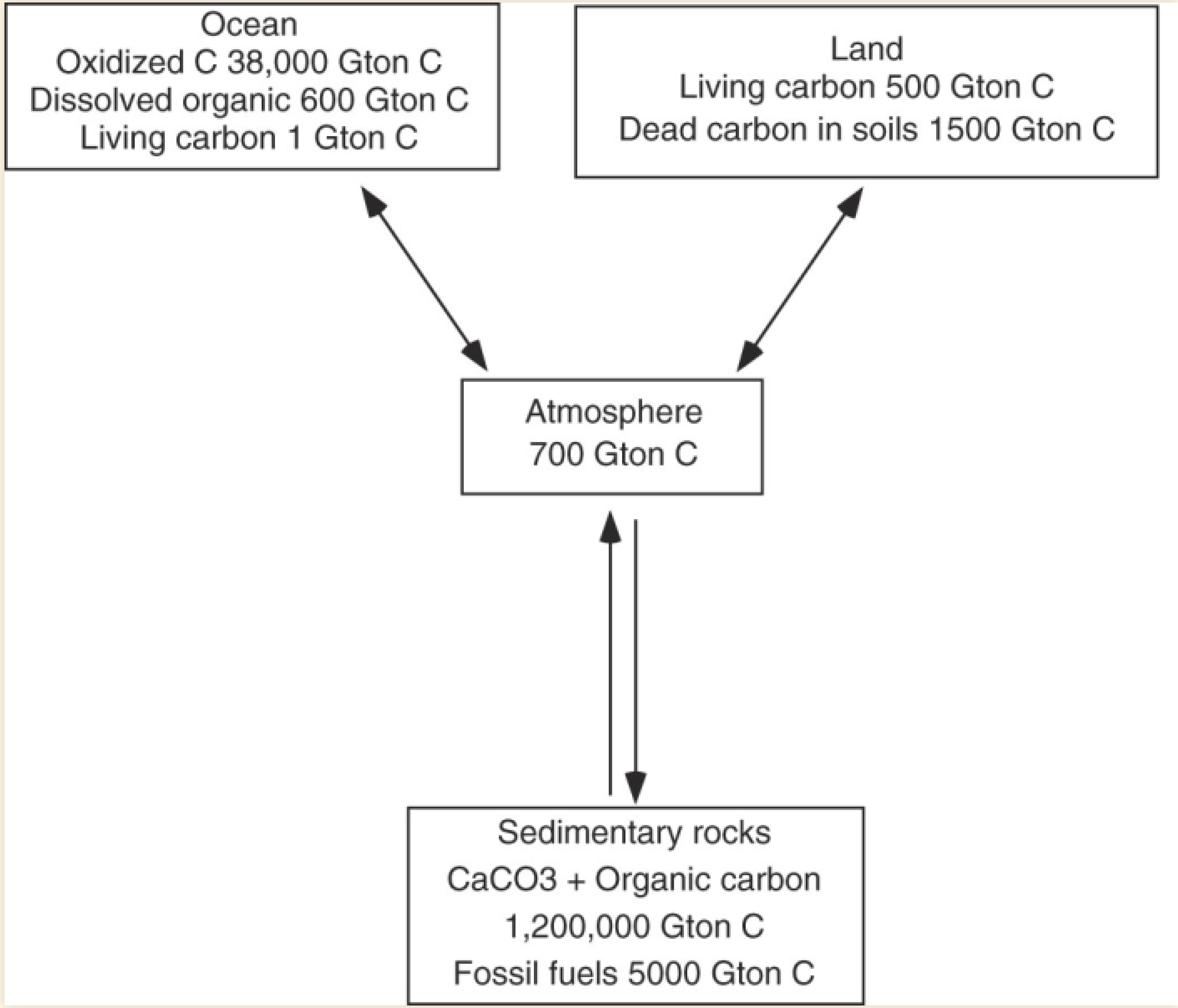


Image credit: D. Archer, *Global Warming: Understanding the Forecast*

Carbon Pathways

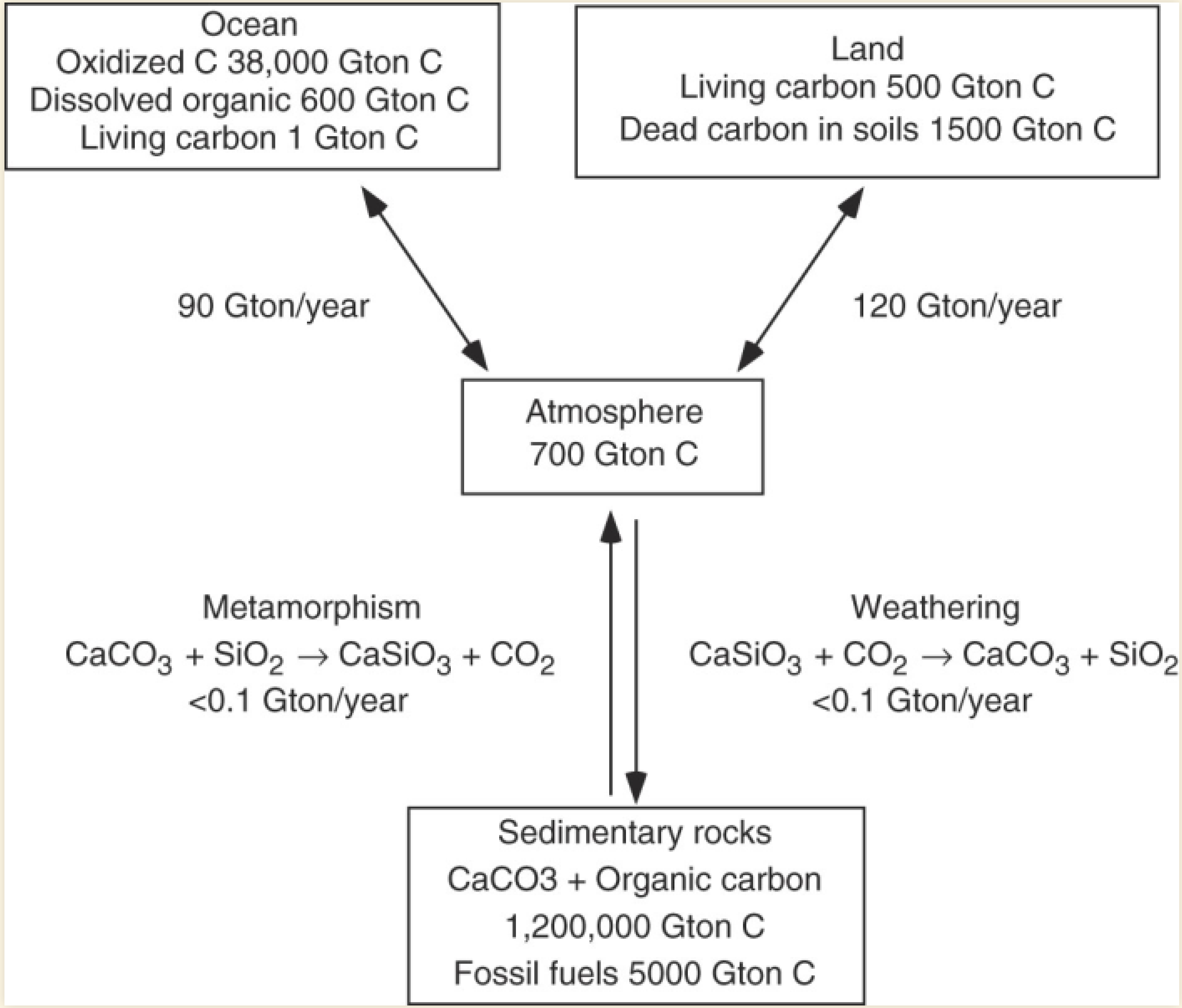
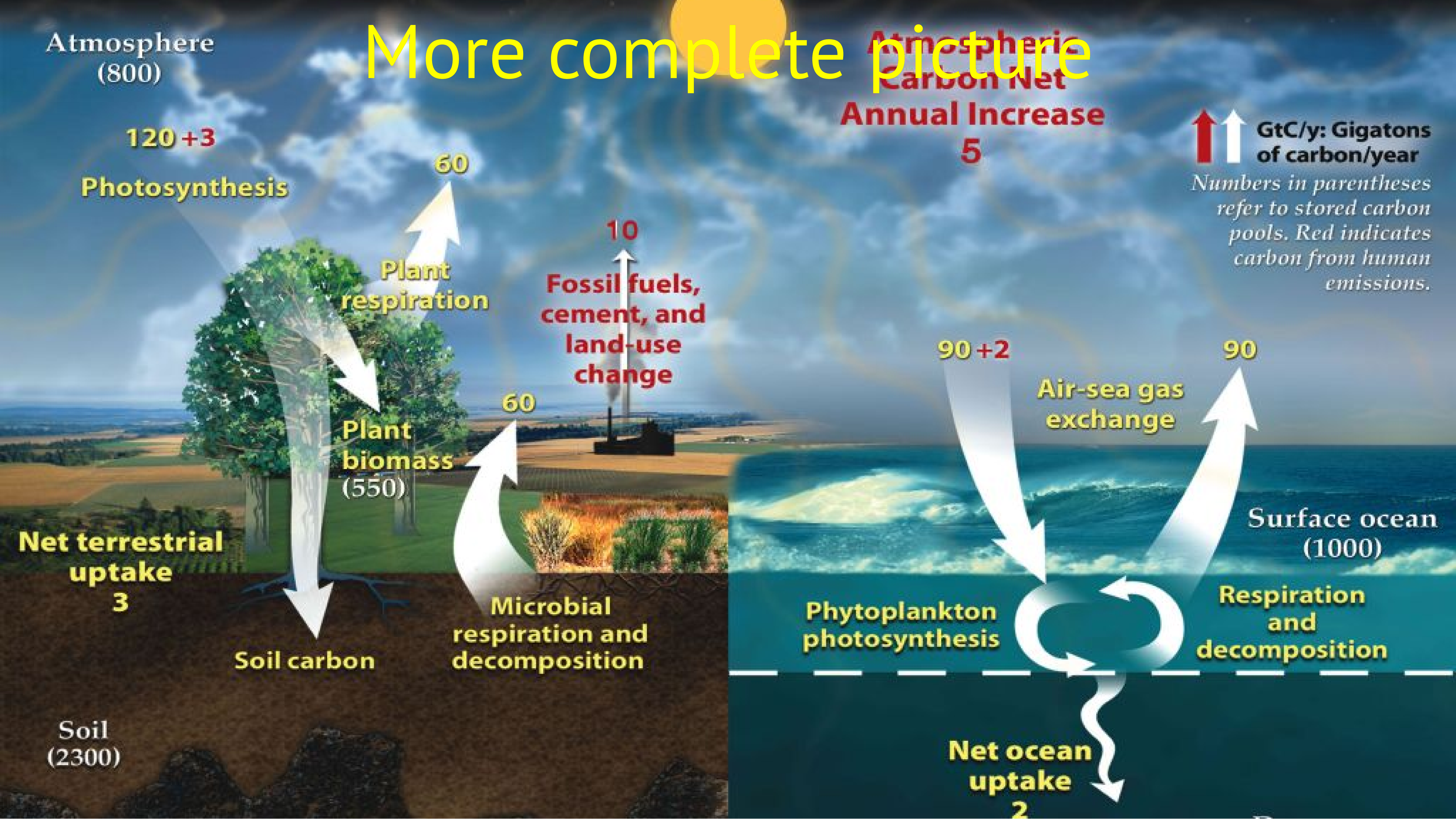


Image credit: D. Archer, *Global Warming: Understanding the Forecast*

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

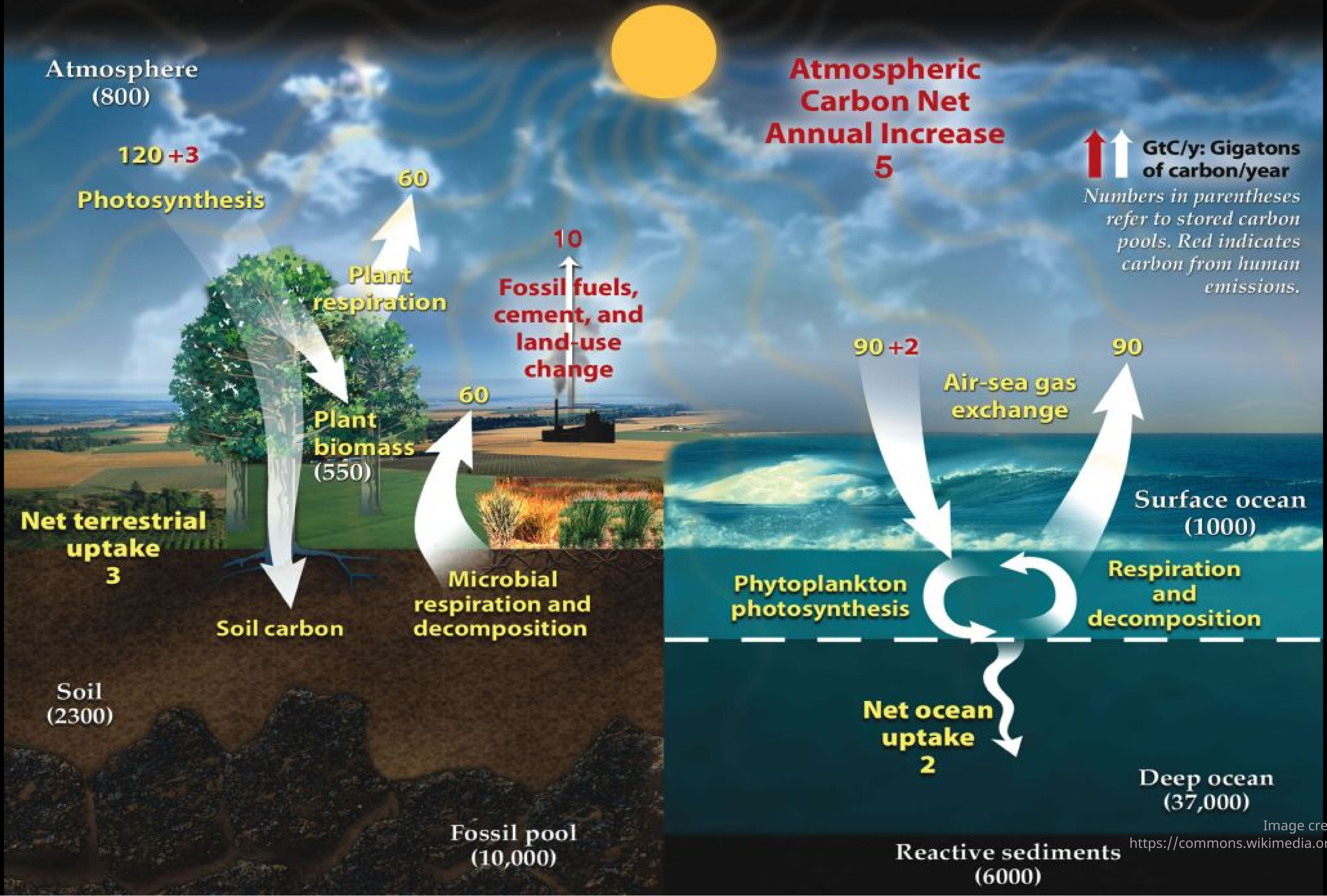
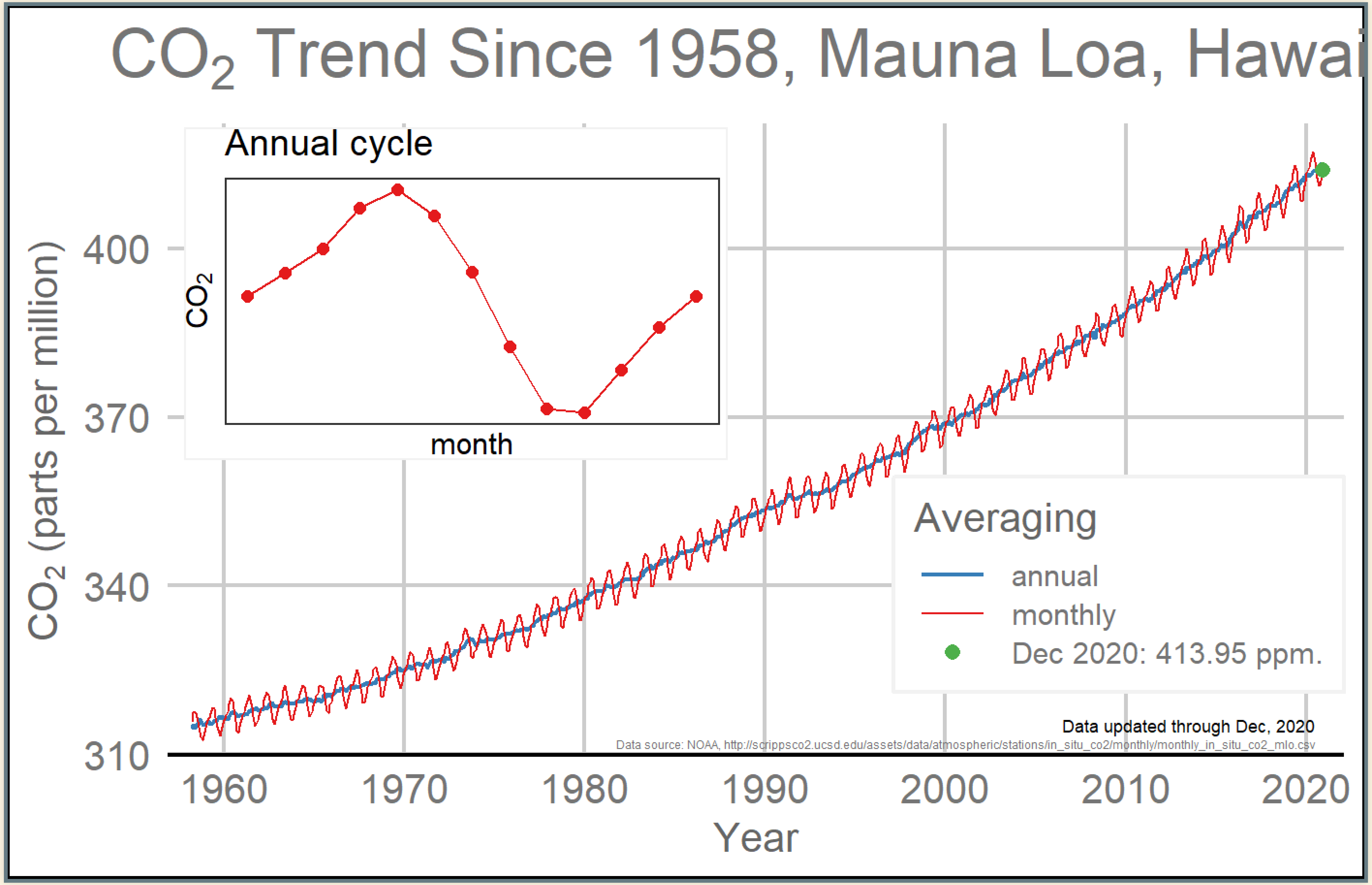


Image credit: NASA Earth Observatory
https://commons.wikimedia.org/wiki/File:Carbon_cycle.jpg

CO_2 Over Time



Why the difference in wiggles?

a. Hawaii

b. New Zealand

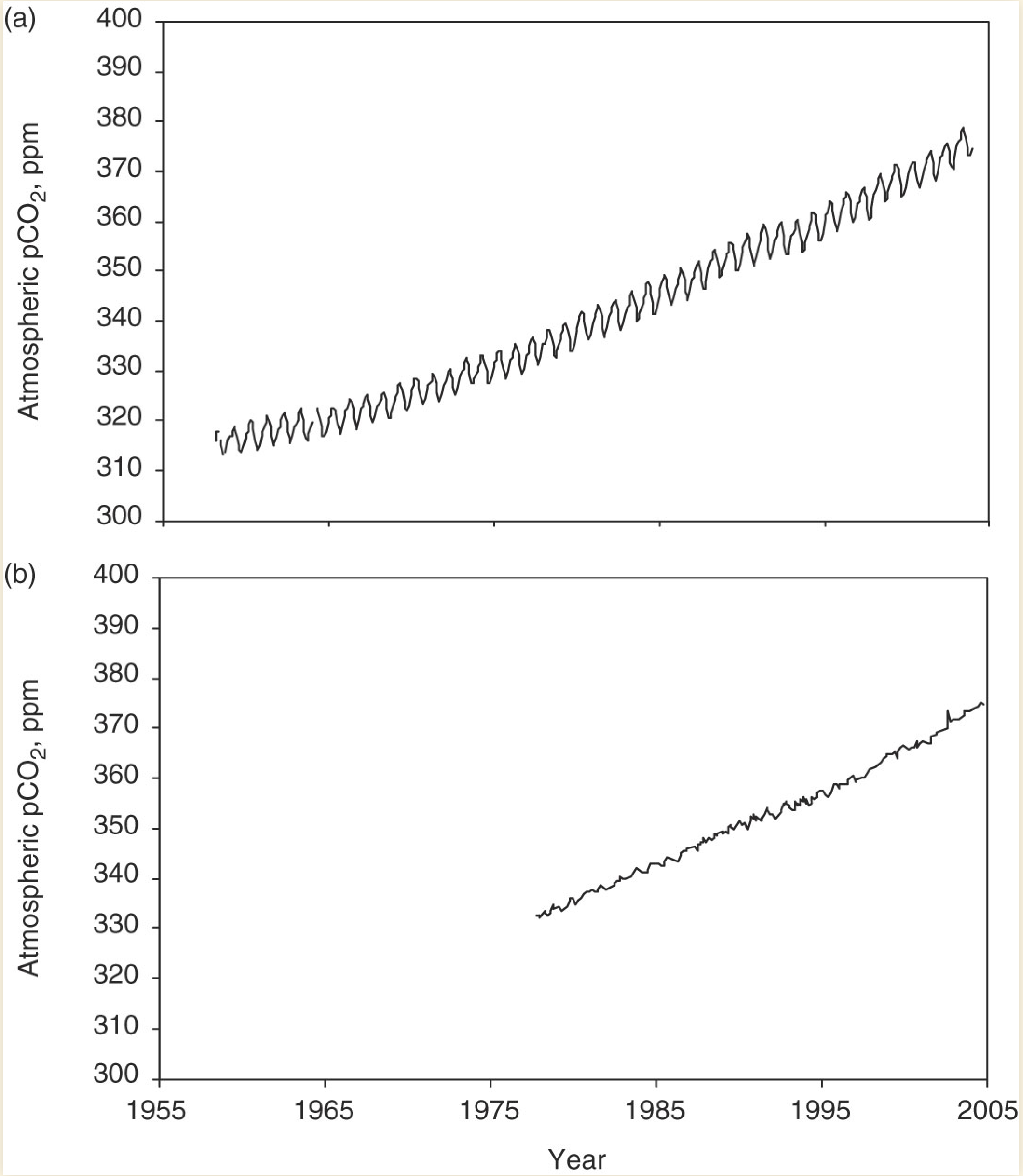
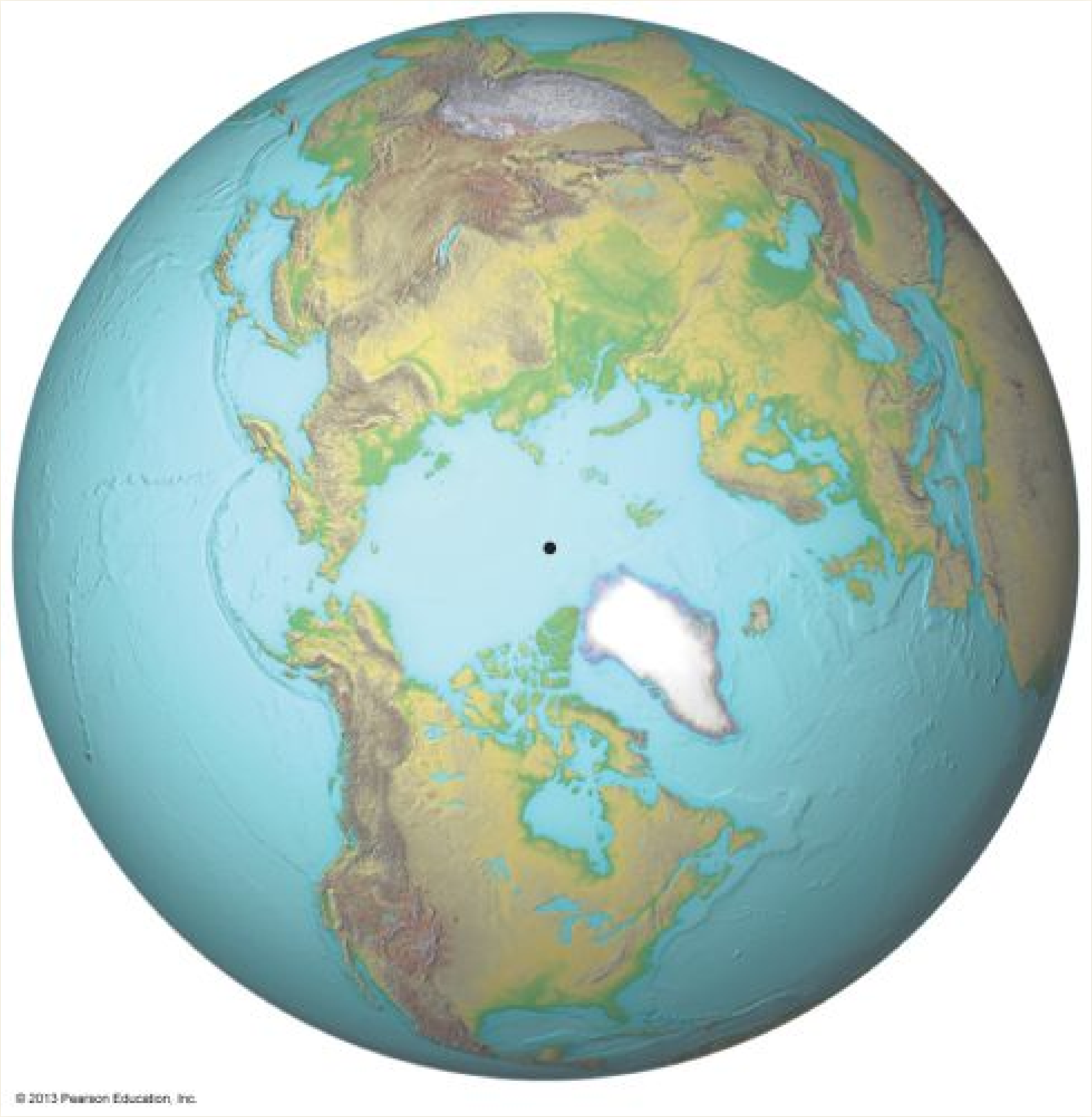


Image credit: D. Archer, *Global Warming: Understanding the Forecast*

Northern vs. Southern Hemisphere



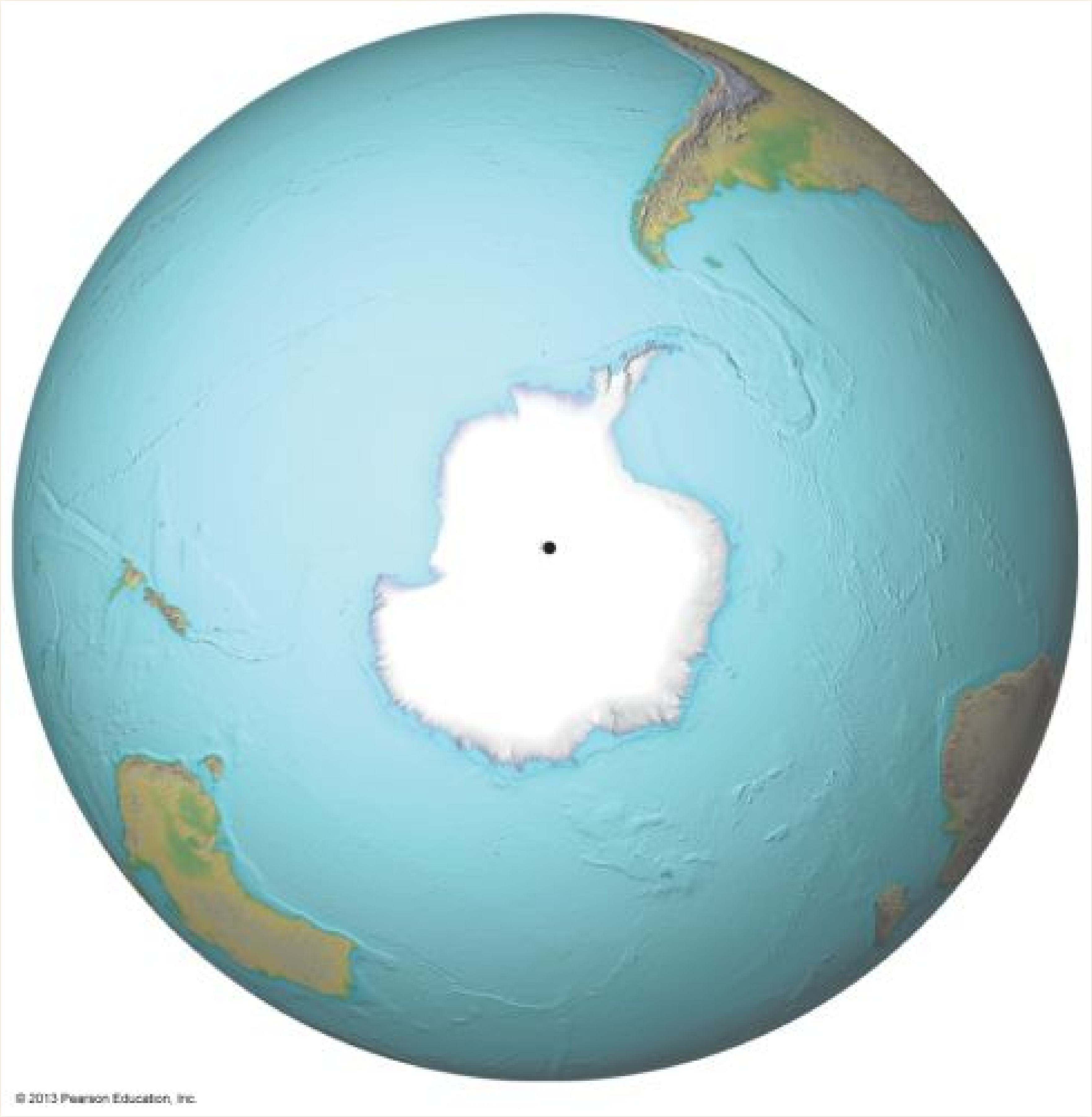


Image Credit: Pearson Education, Inc.

Fate of CO_2 Emissions

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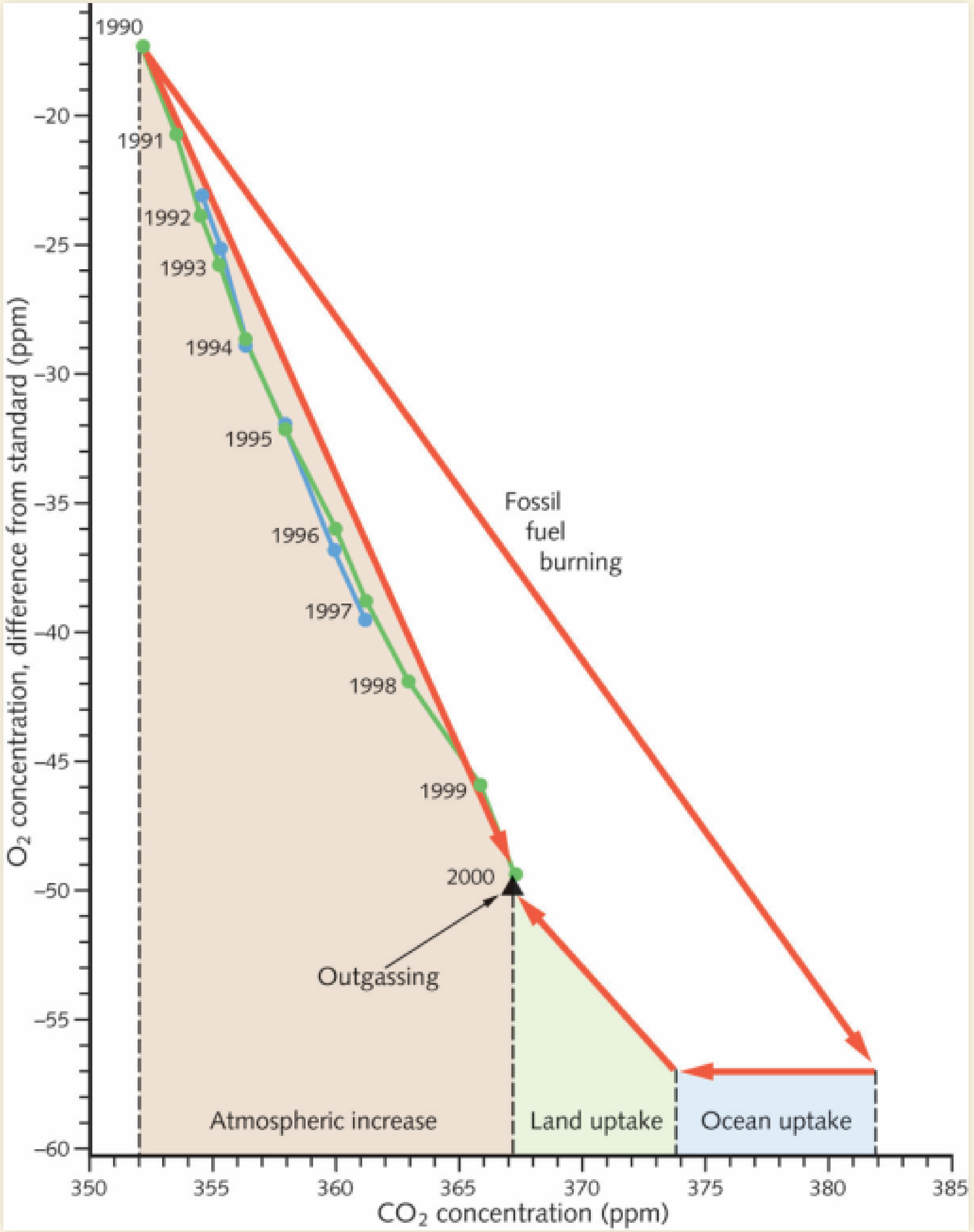

Image credit: J. Houghton, _Global Warming: The Complete Briefing, 4th ed. (Cambridge, 2009), Fig. 3.4

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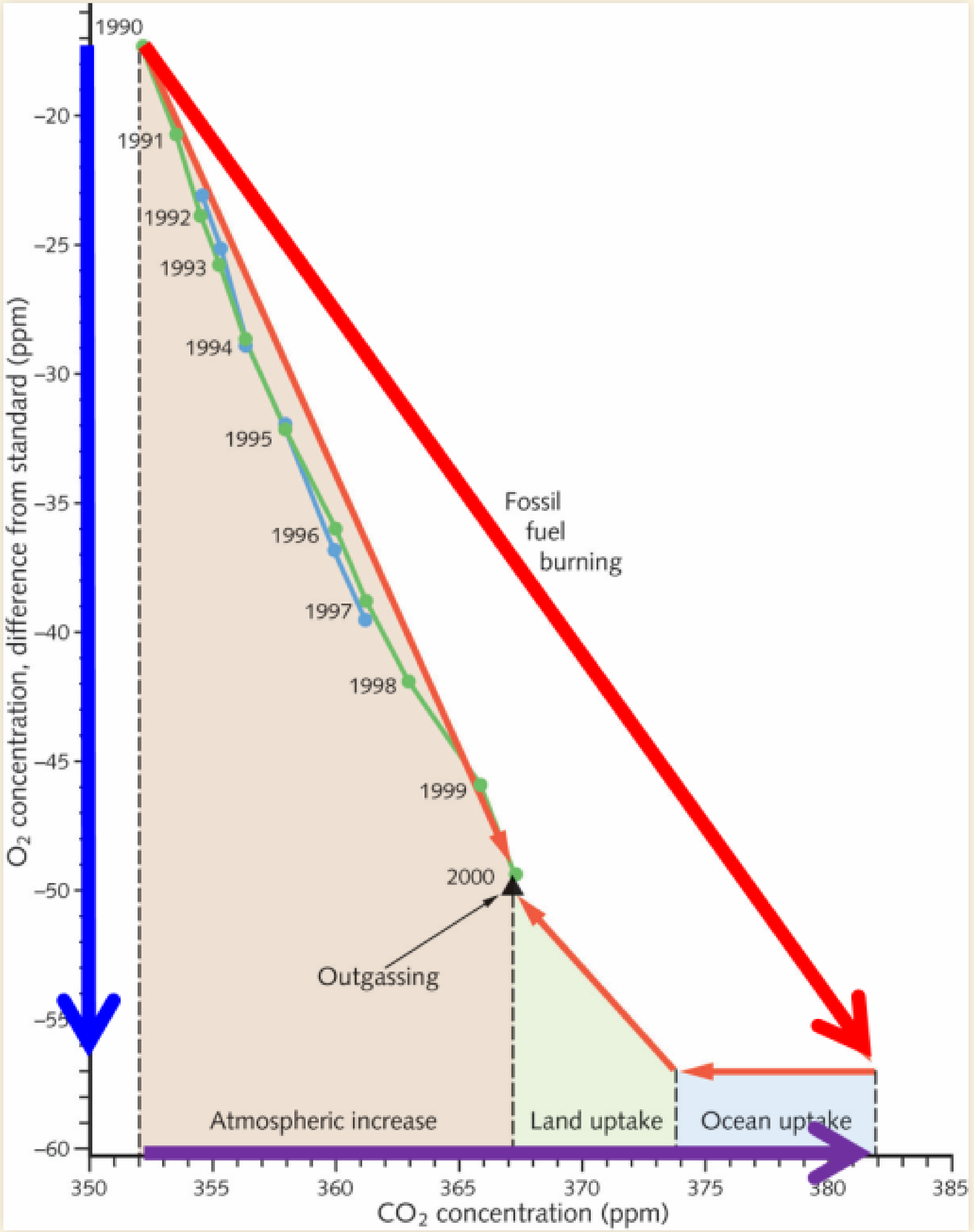

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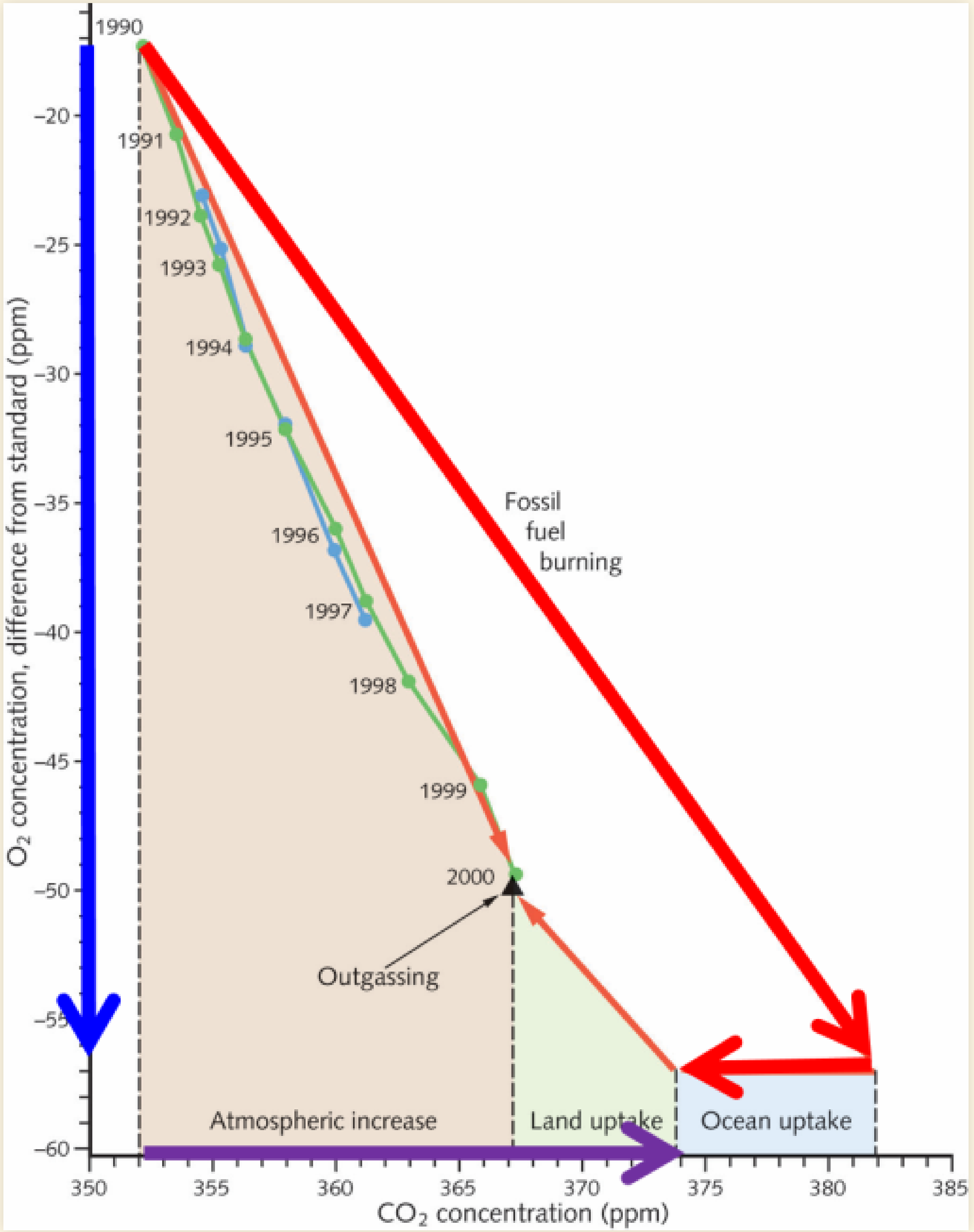

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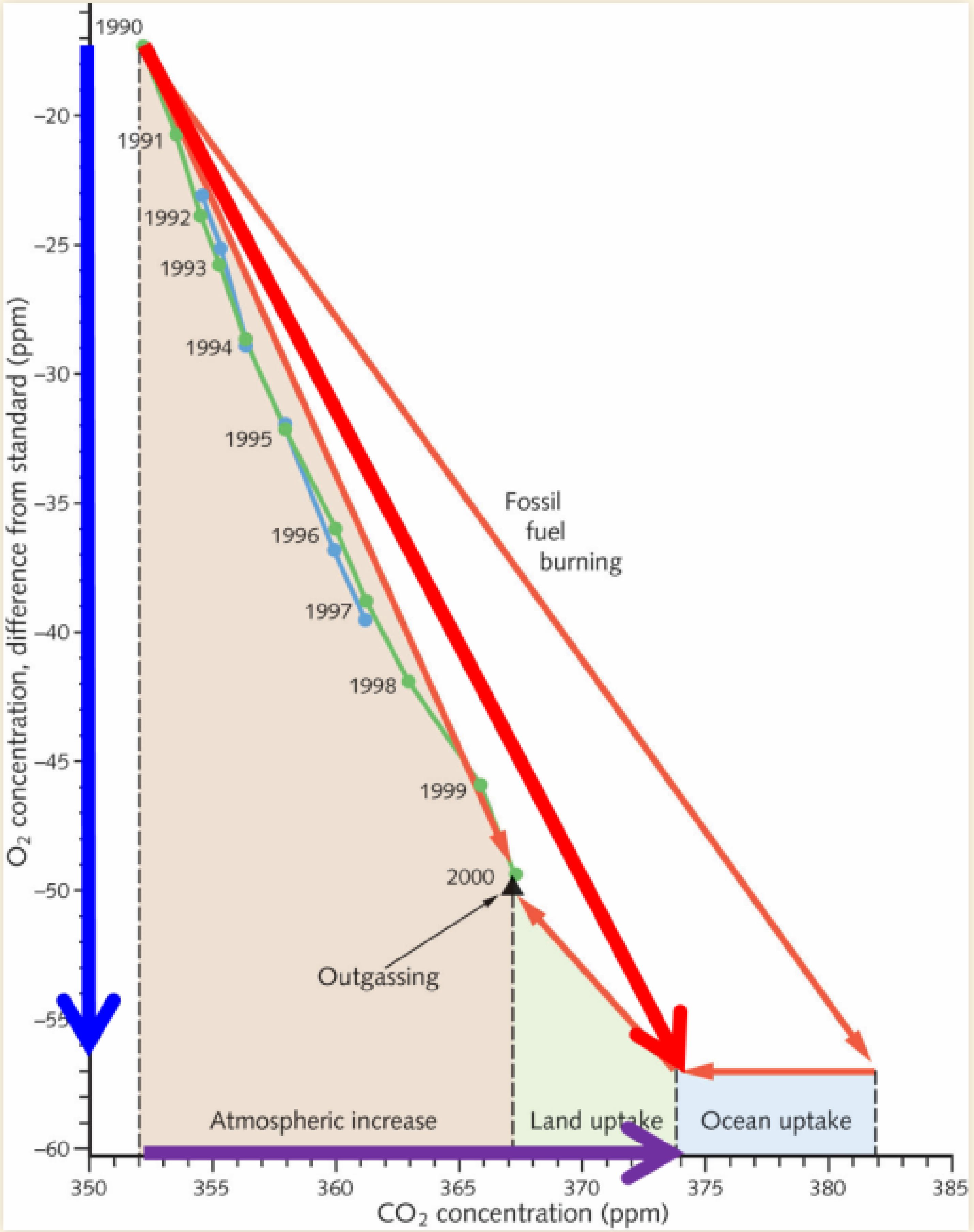

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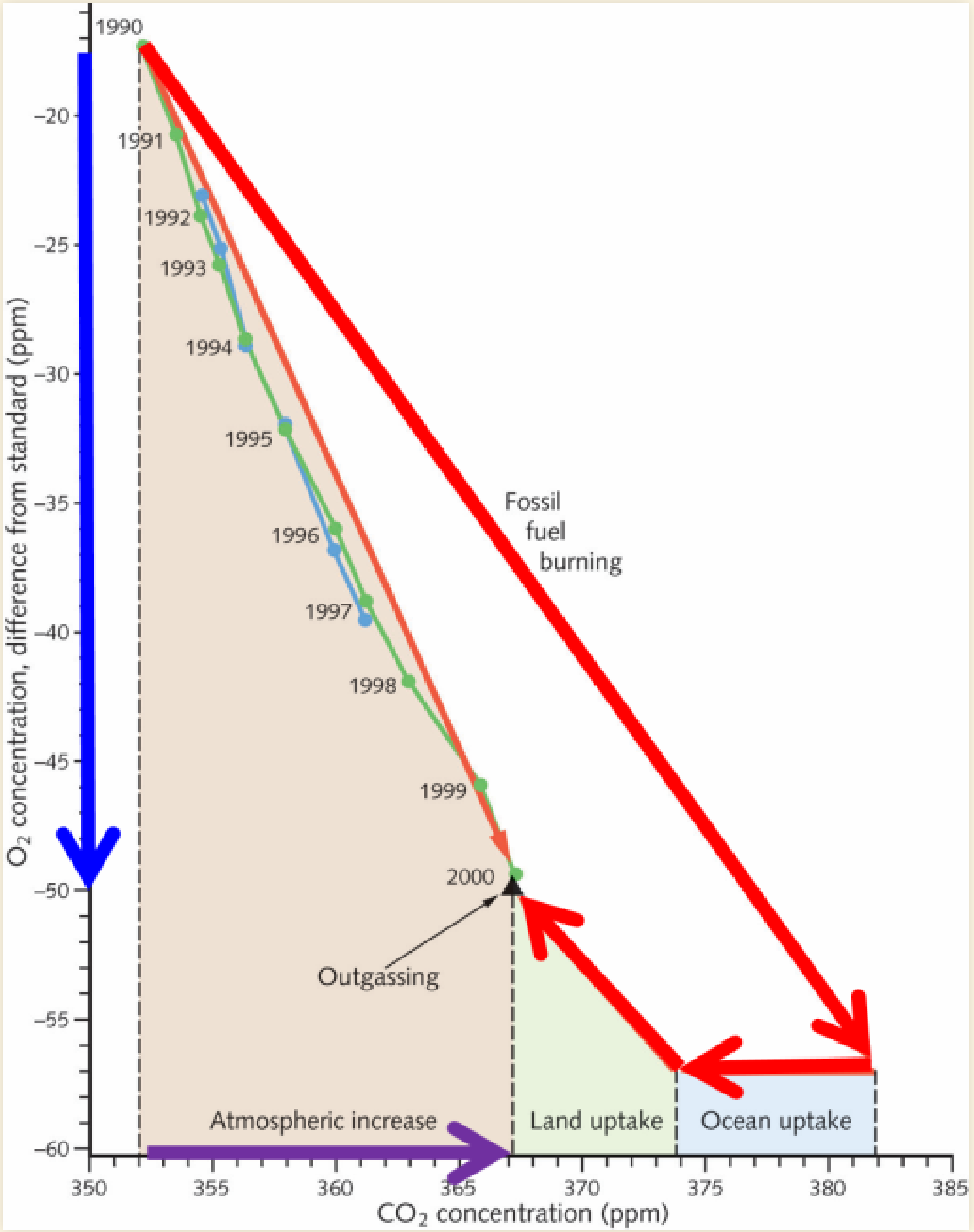

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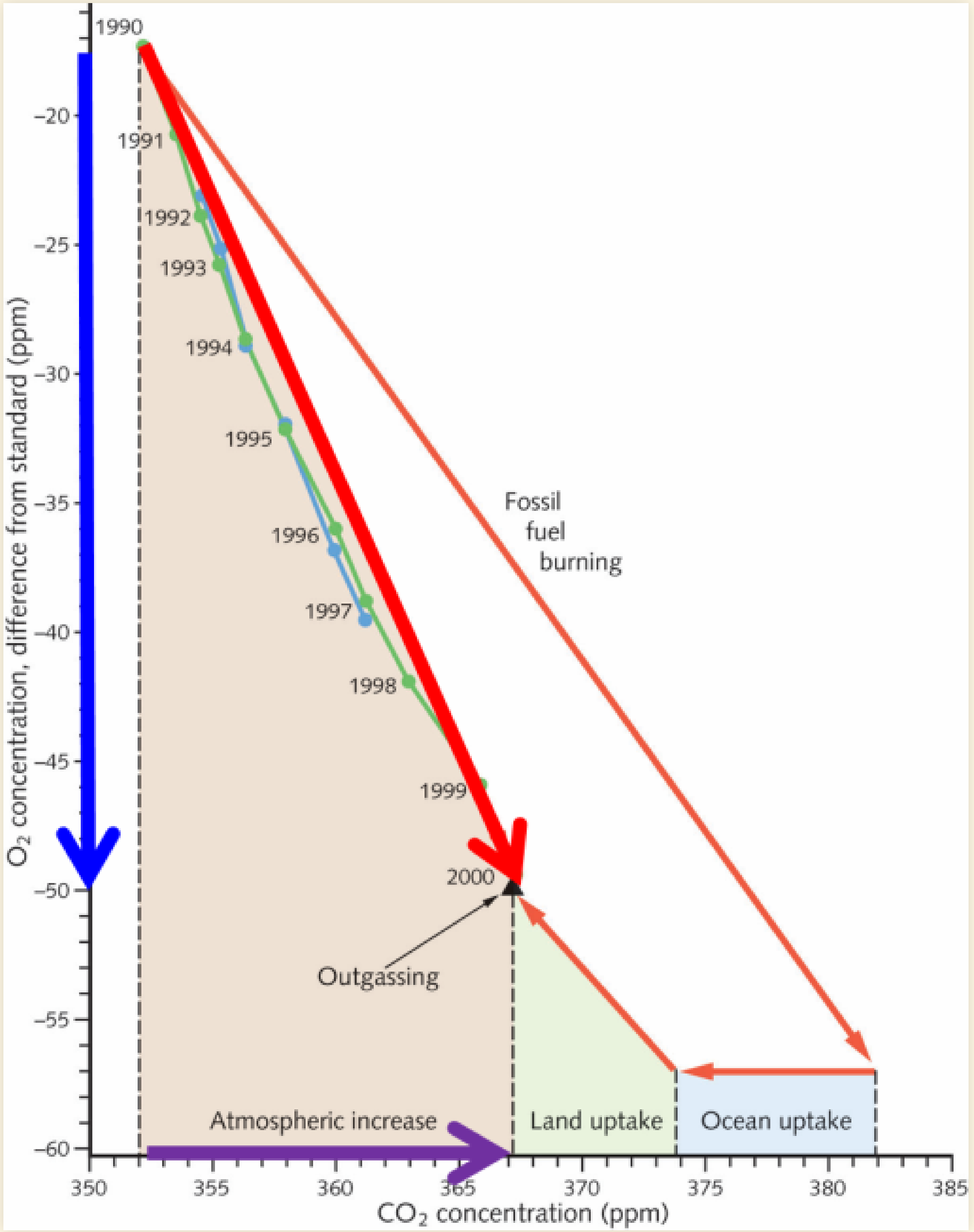

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Fate of CO_2 Emissions

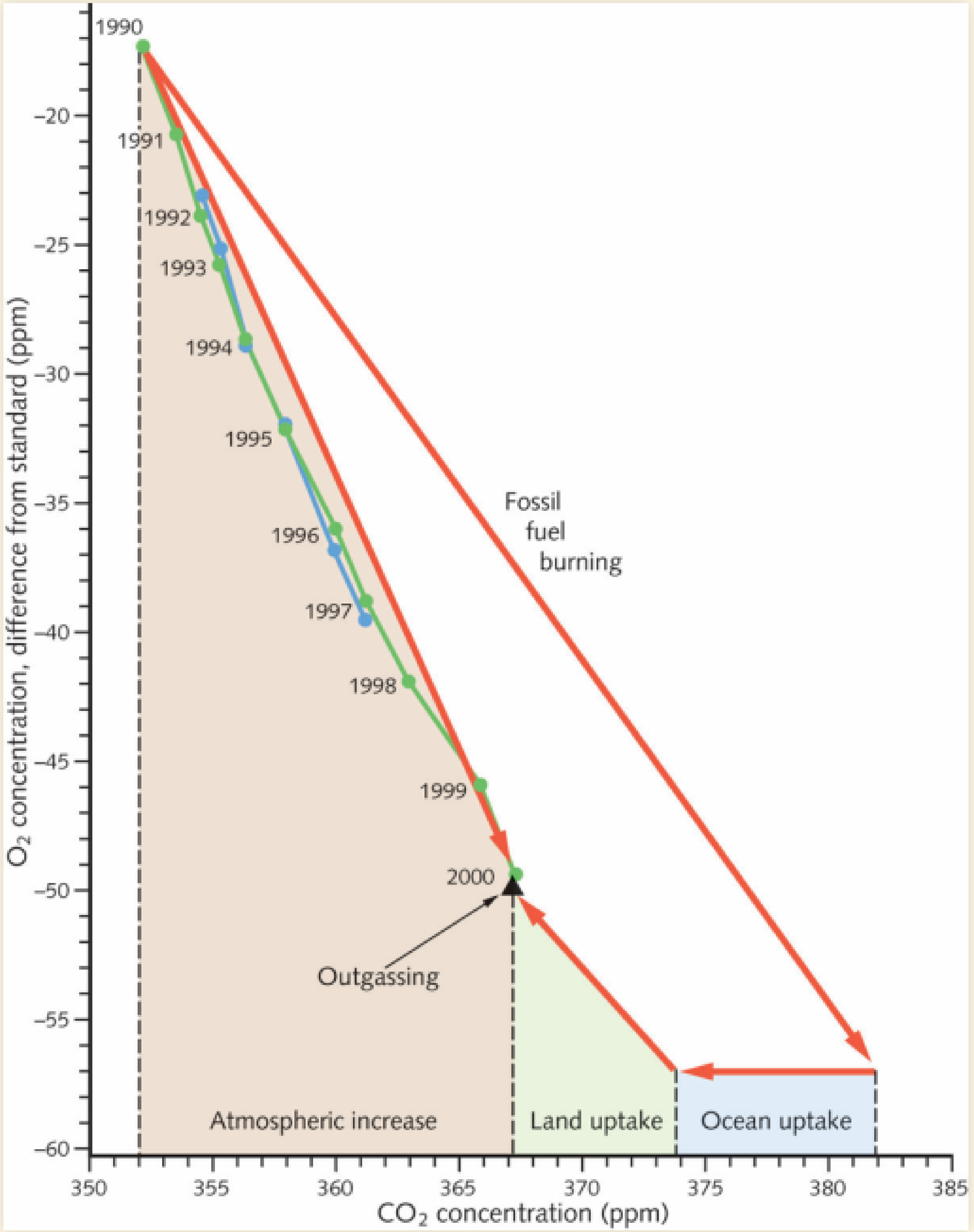
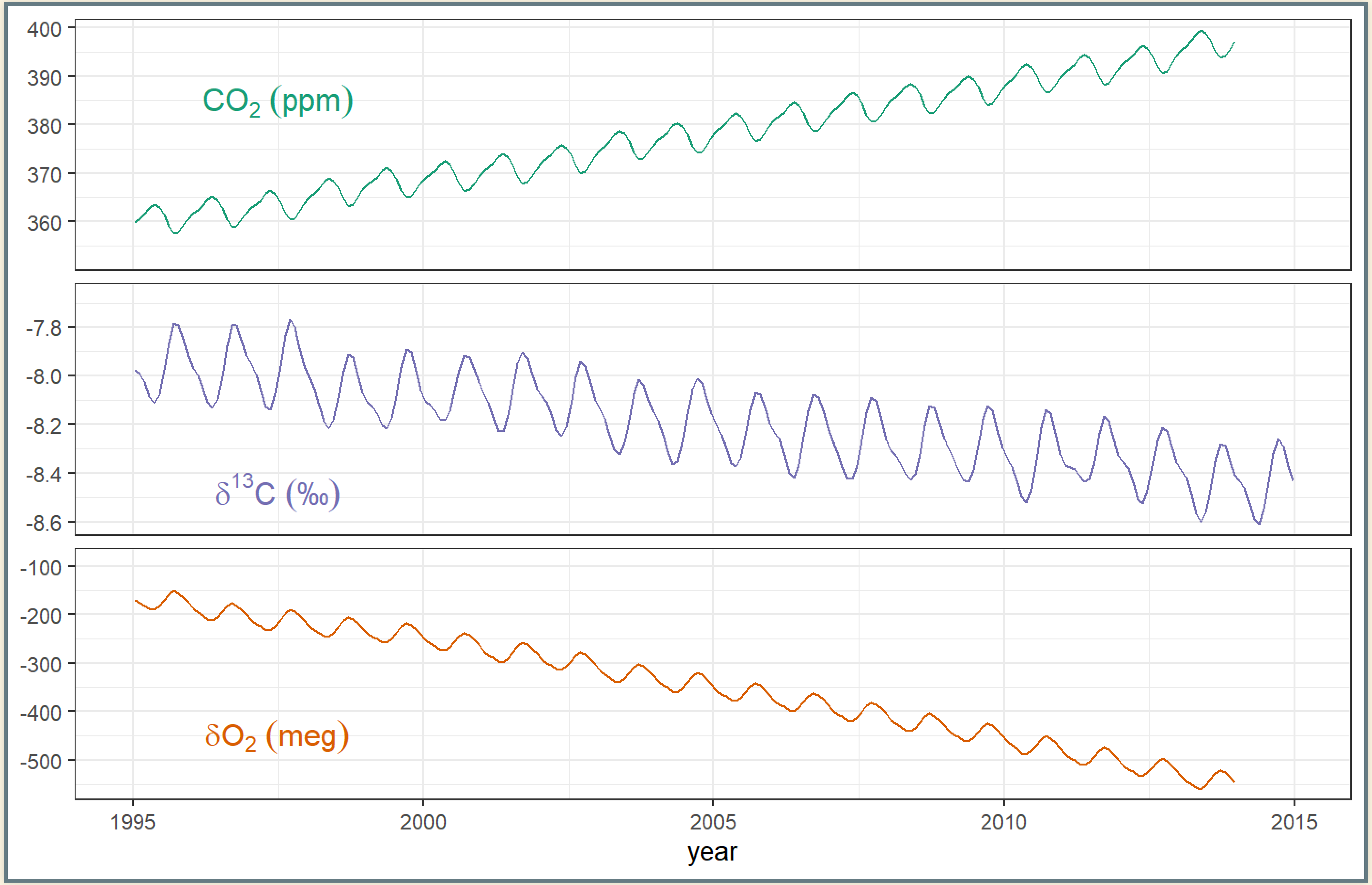


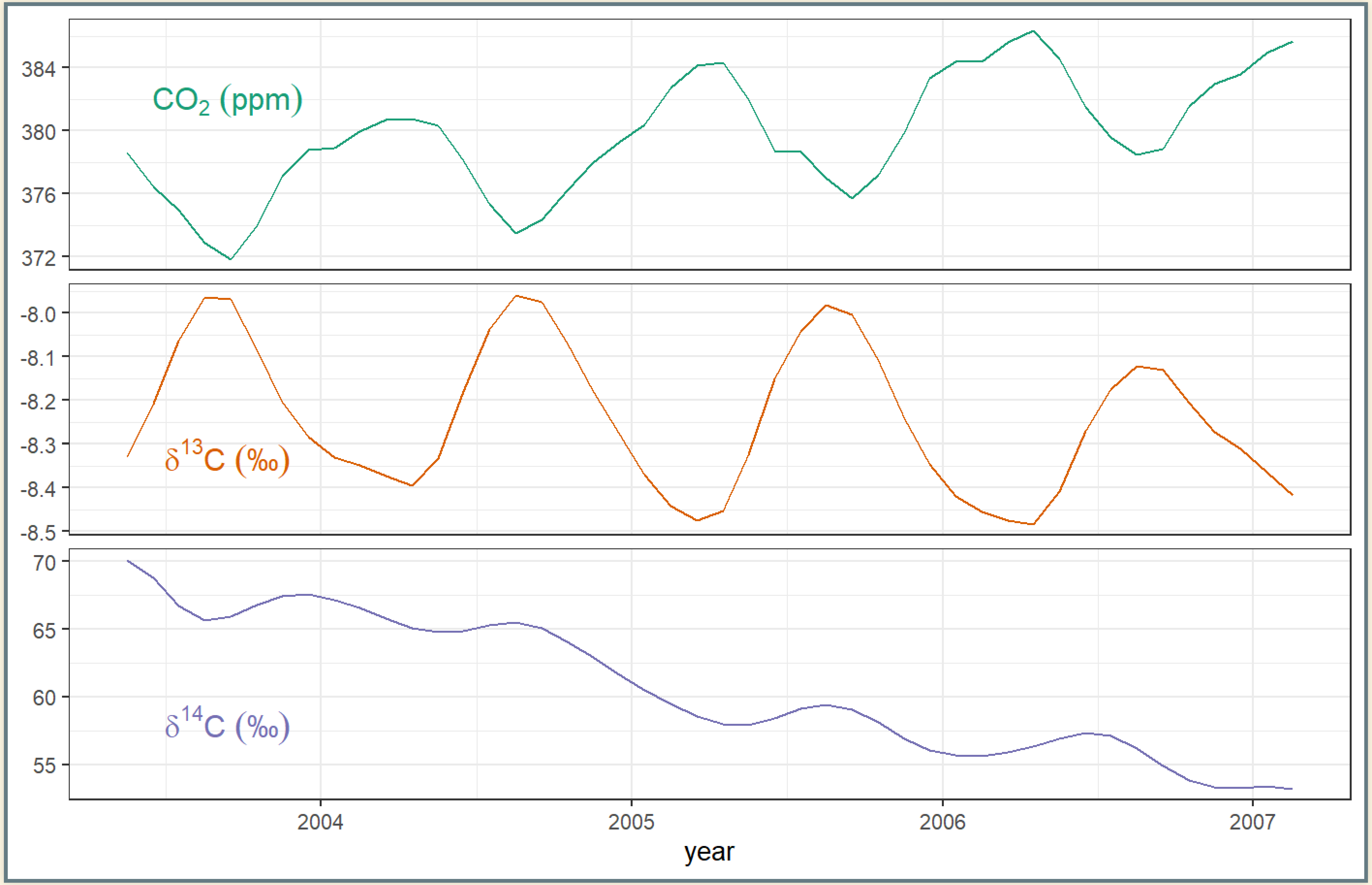
Image credit: J. Houghton, _Global Warming: The Complete Briefing, 4th ed. (Cambridge, 2009), Fig. 3.4

Source of CO_2

Source of CO_2: O_2 and ^{13}C



Source of CO_2: ^{13}C and ^{14}C



Fossil Fuels vs. CO_2

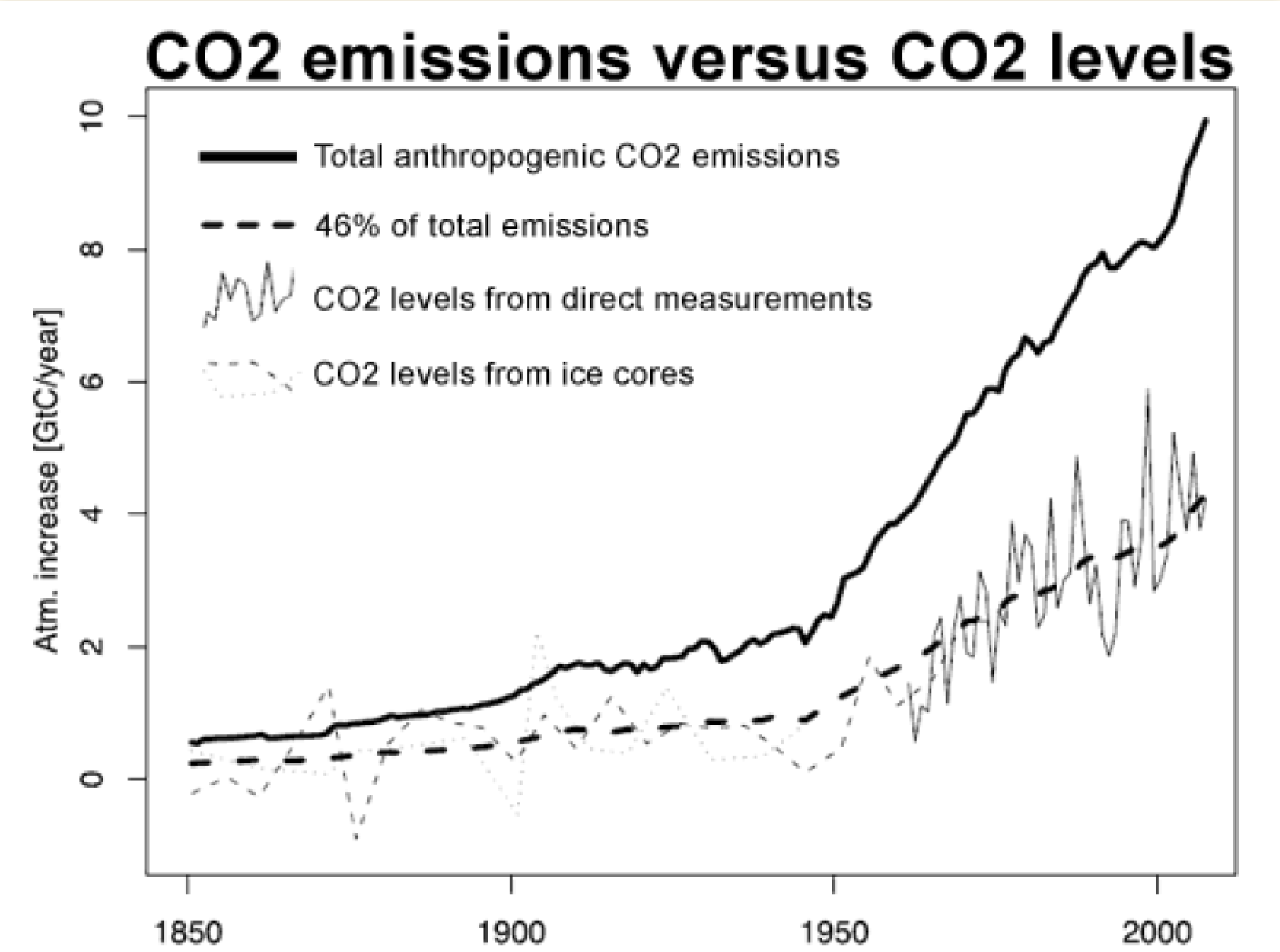


Image credit: W. Knorr, Geophys. Res. Lett. **36**, L21710 (2009) doi: 10.1029/2009GL040613

- Concentrations match 46% of fossil fuel consumption

Assessing the Evidence

- Decreasing O_2: CO_2 produced by burning.
  - Not a mineral source (volcanoes).
- $^{13}C/^{12}C$: CO_2 must have biological origin.
- ^{14}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

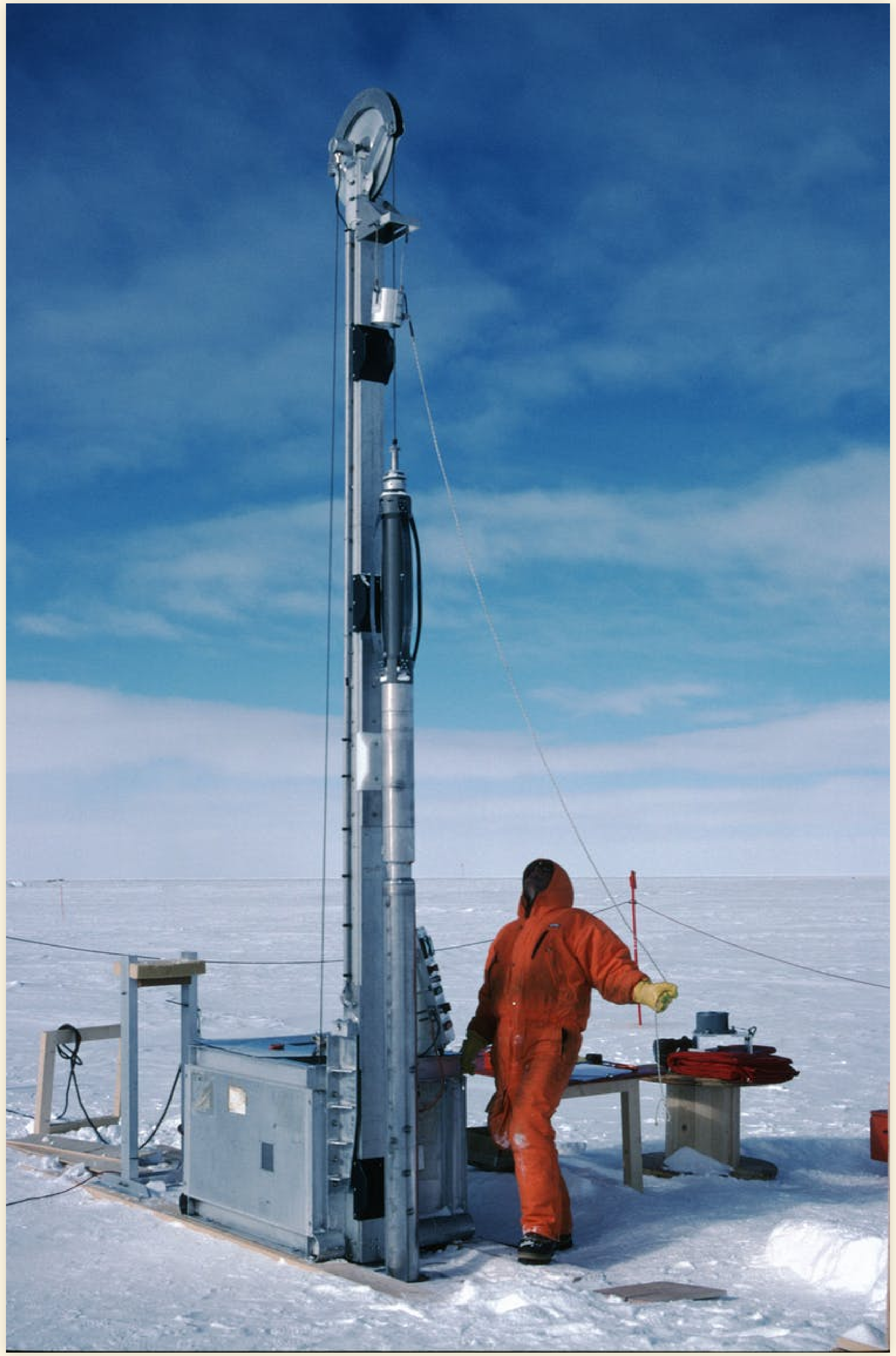


Image Credit: R Mulvaney/British Antarctic Survey

Ice Cores

Image credits: Pete Bucktrout/British Antarctic Survey

Inside the Ice Core

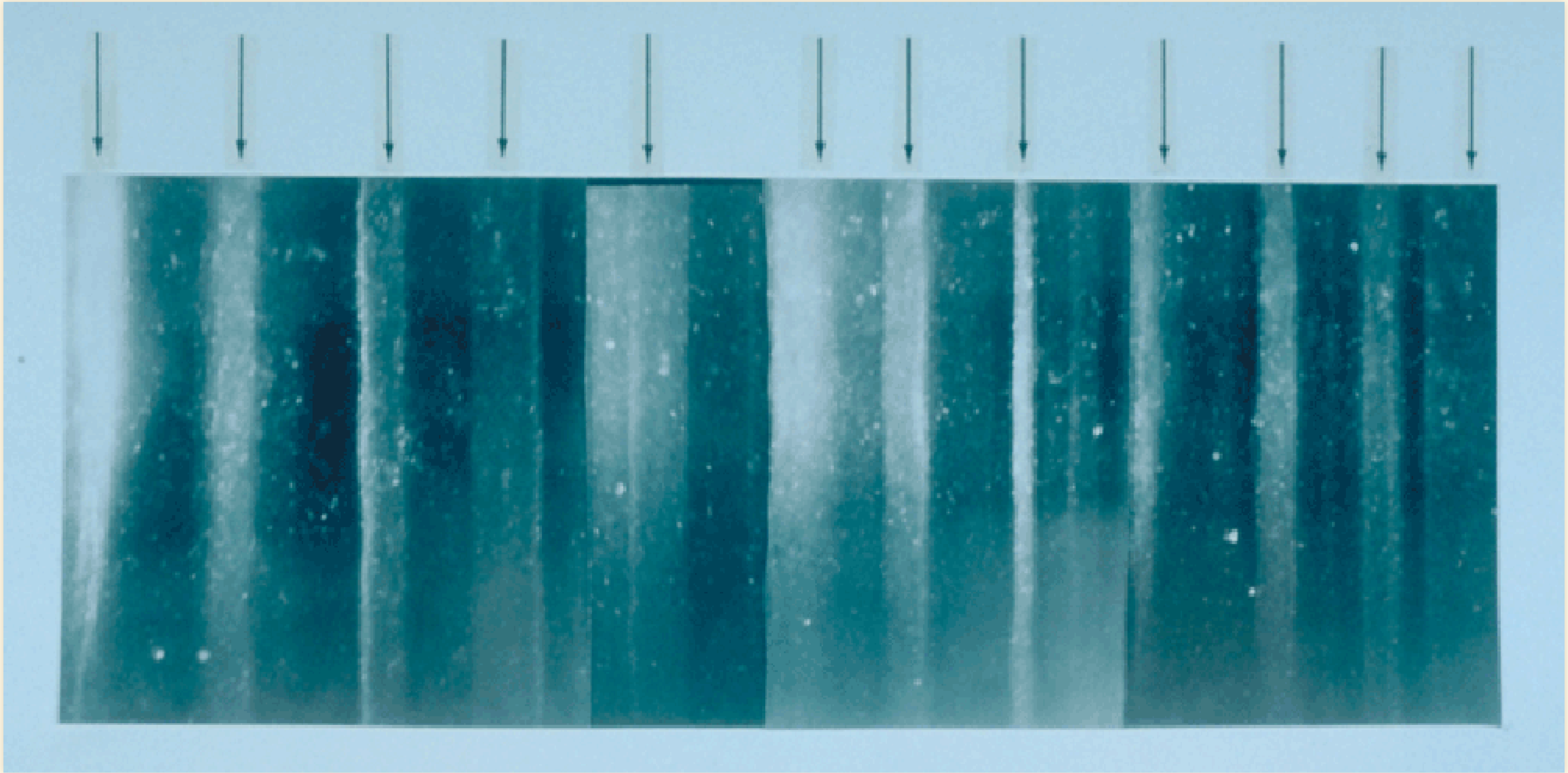


Image credit: National Ice Core Laboratory

Inside the Ice Core

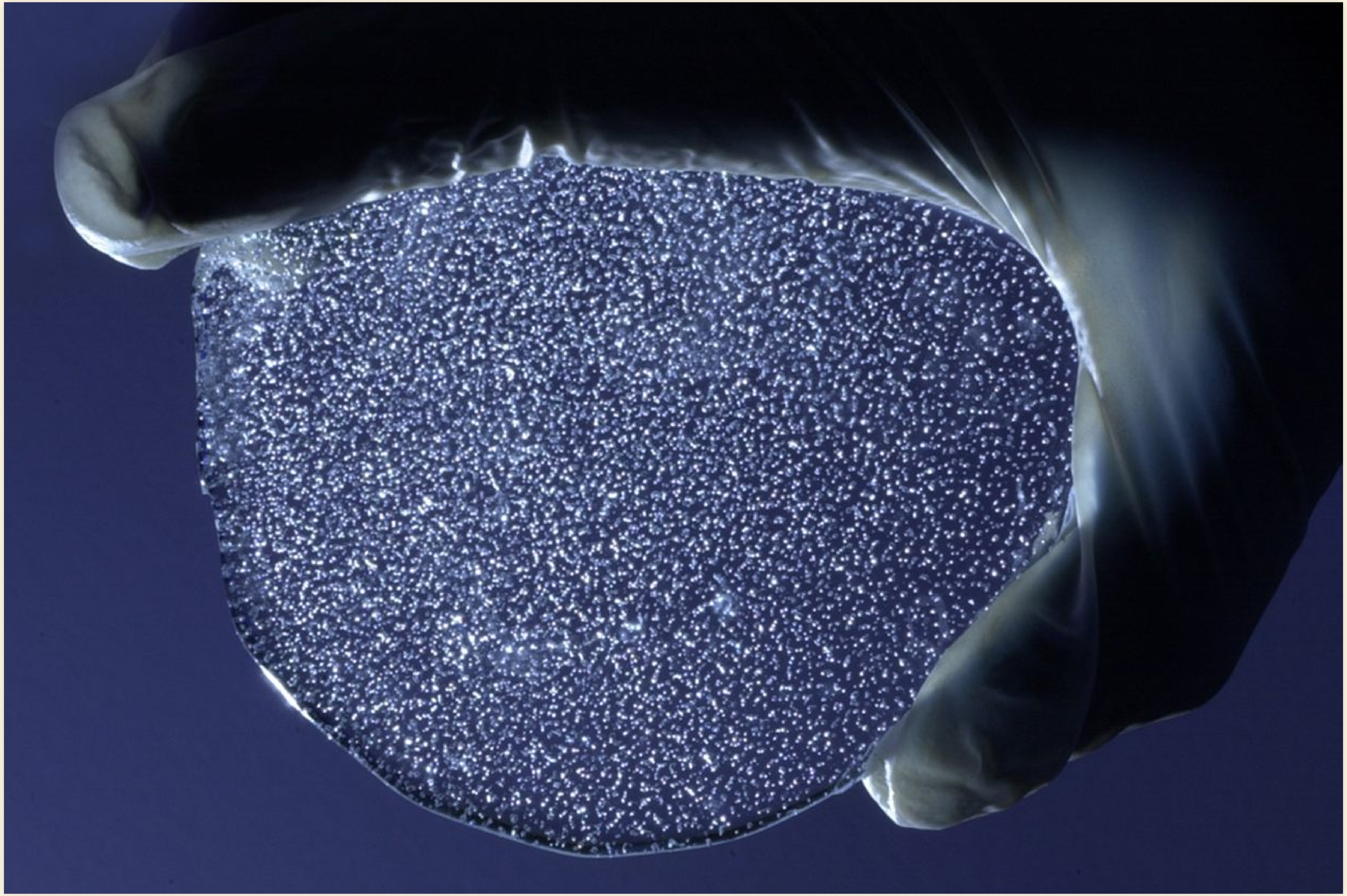
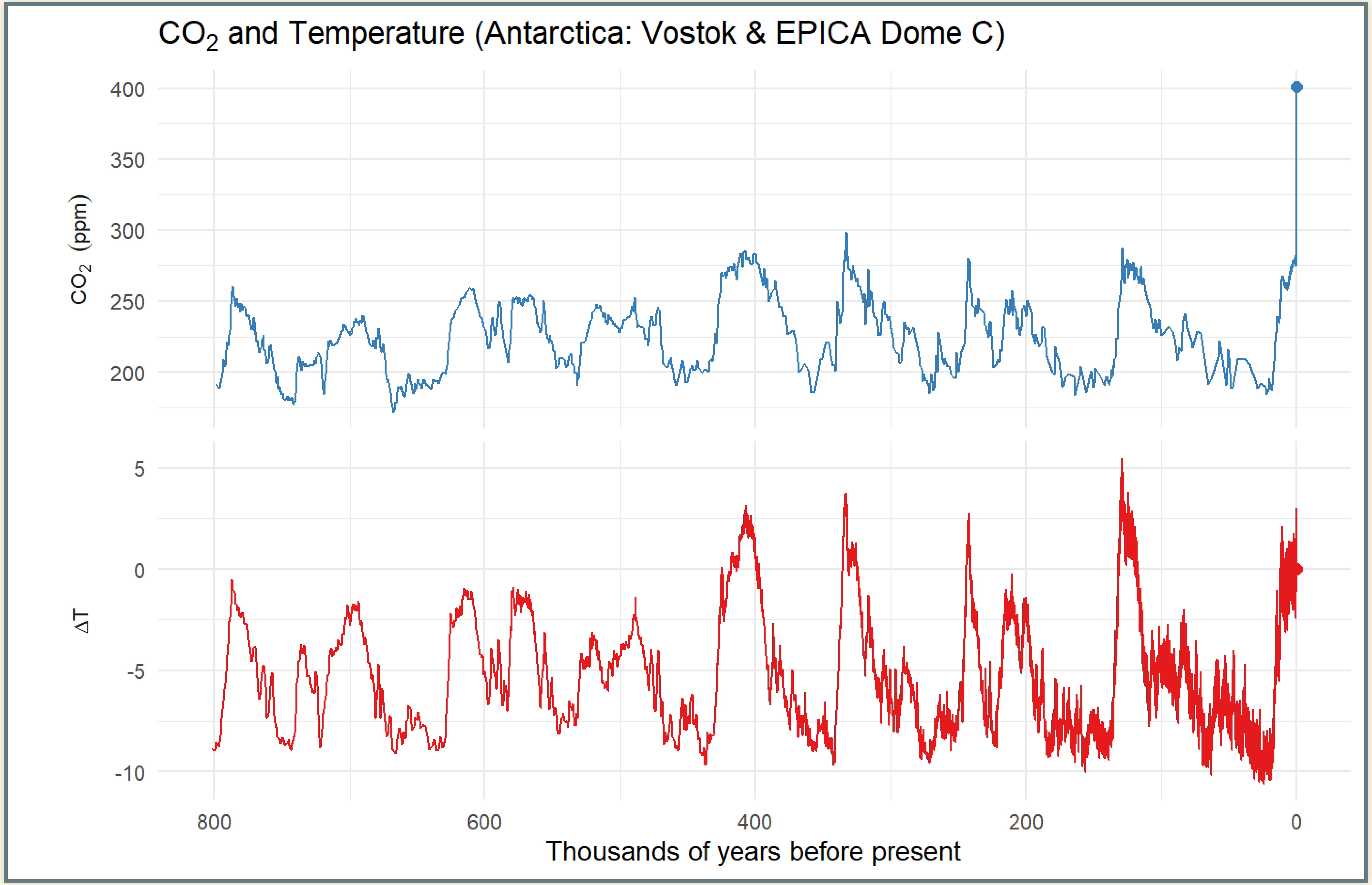


Image credit: Pete Bucktrout/British Antarctic Survey

The Oceans Breathe



Ice Ages

25,000 years ago

Image credit: Ron Blakey

25,000 years ago

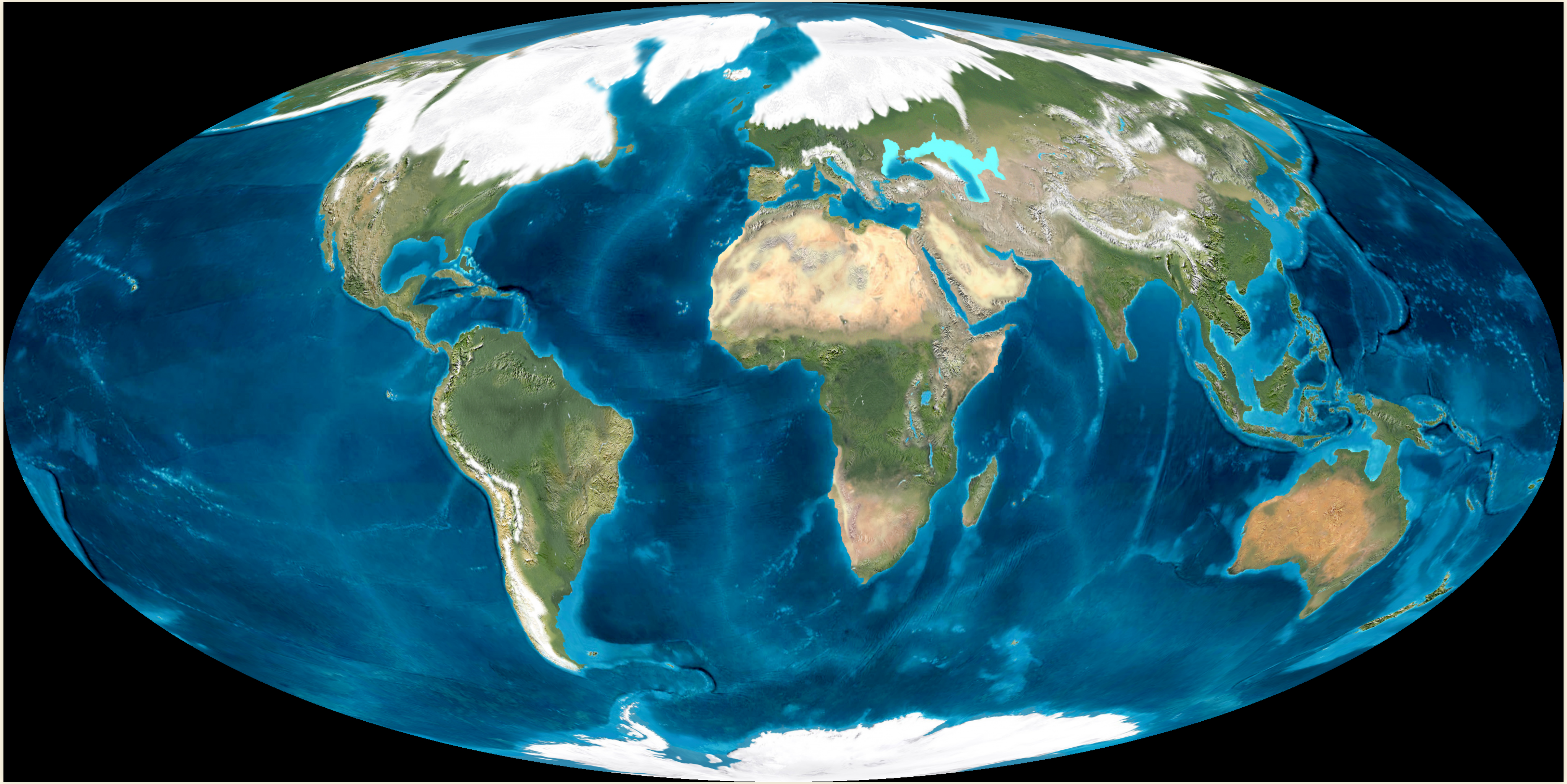
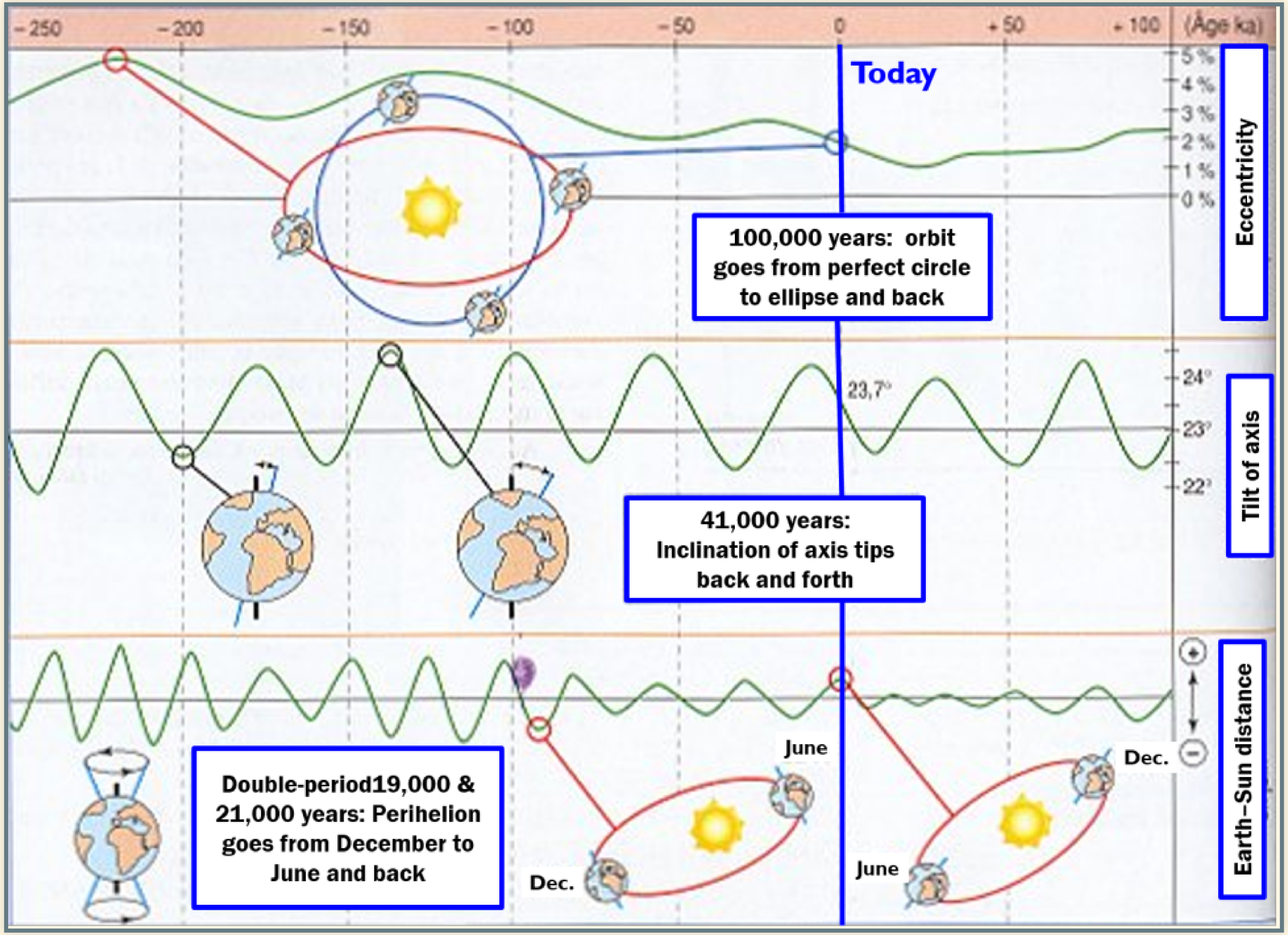


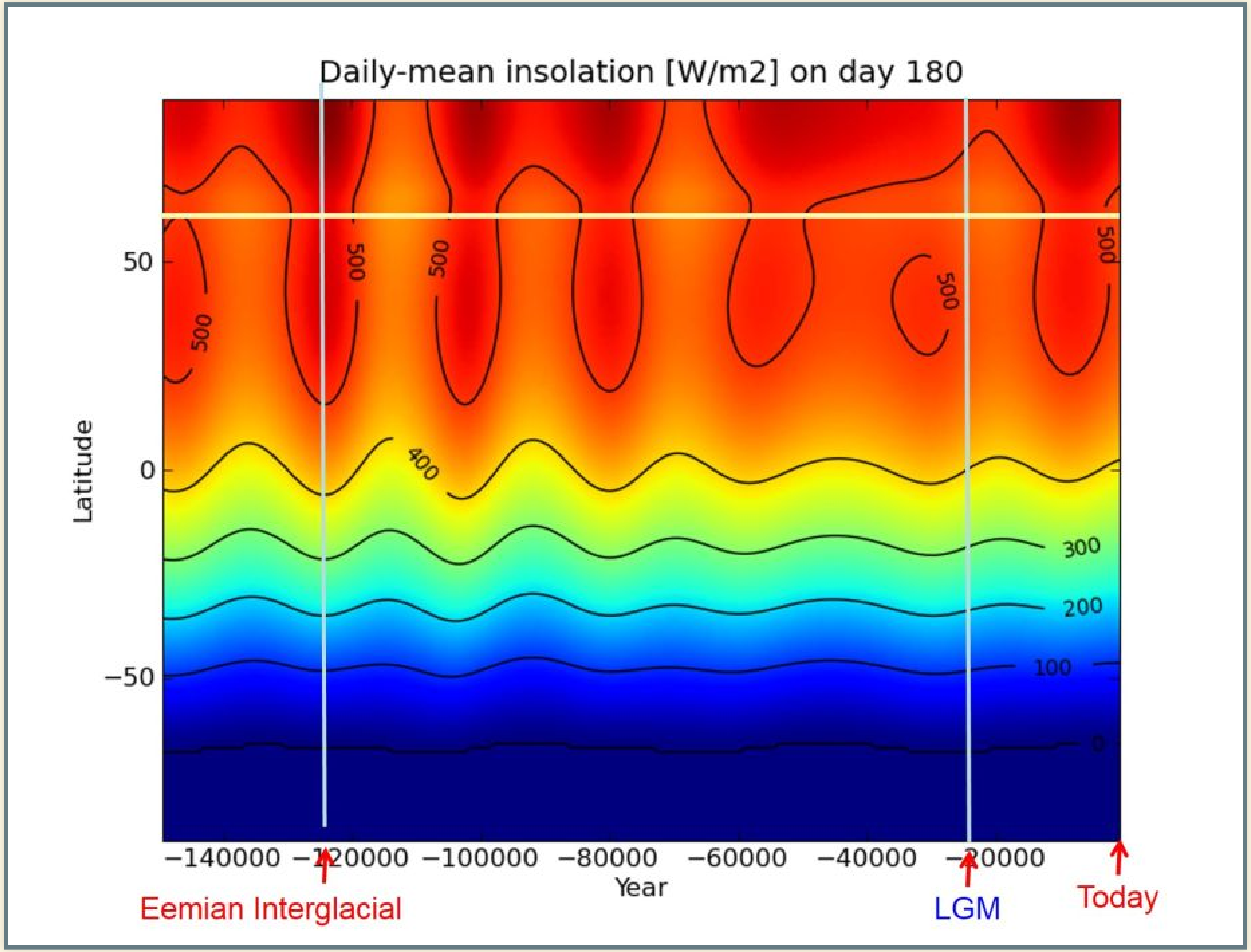
Image credit: Ron Blakey

Causes



- 250
- 200
- 150
- 100
- 50
0
+ 50
+ 100
(Âge ka)
Today
5 %
4 %
3 %
2 %
1 %
0 %
Eccentricity
100,000 years: orbit goes from perfect circle to ellipse and back
23,7°
24°
23°
22°
Tilt of axis
41,000 years: Inclination of axis tips back and forth
Double-period19,000 & 21,000 years: Perihelion goes from December to June and back
June
Dec.
June
Dec.
Earth–Sun distance

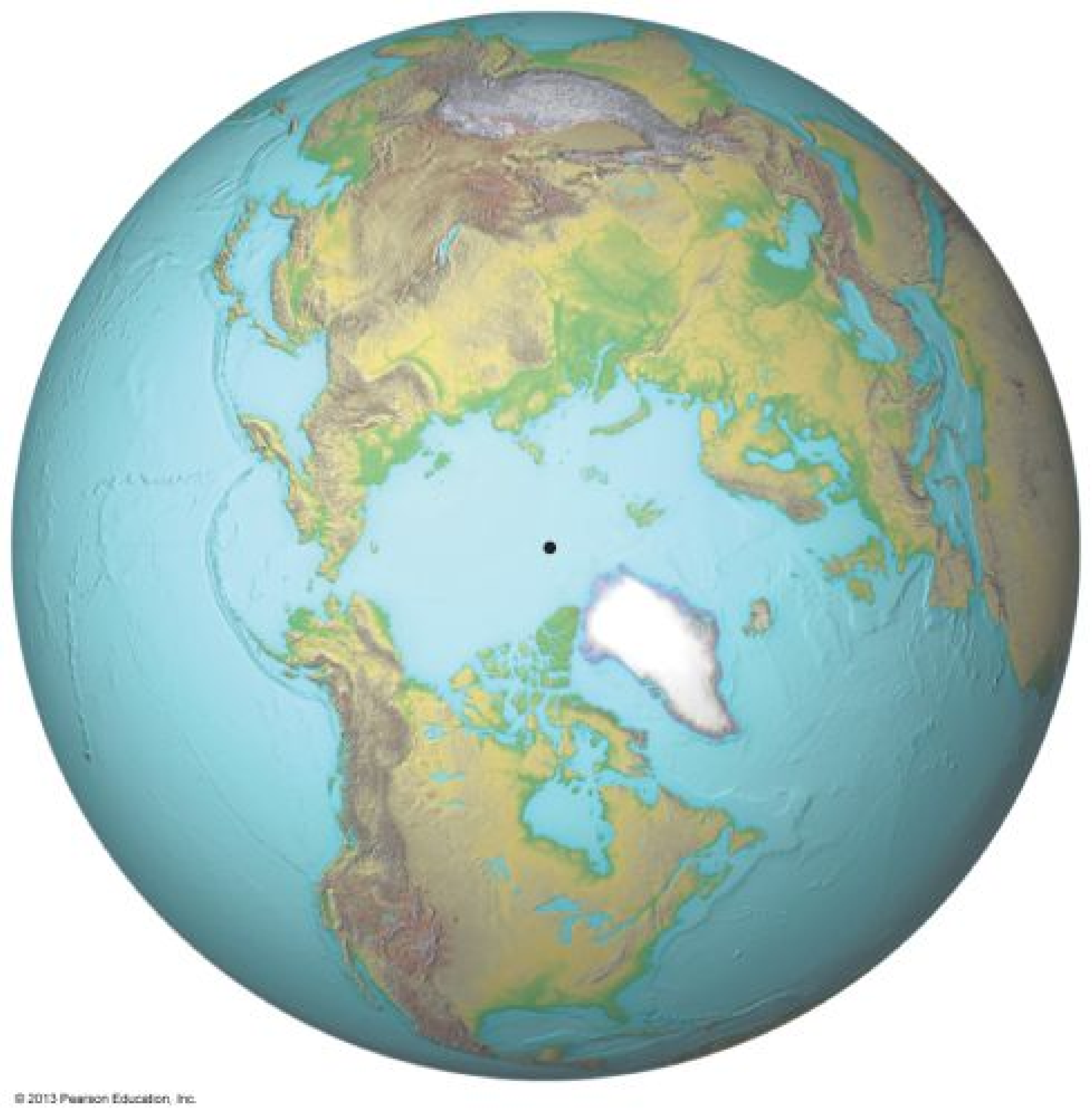
Insolation


Daily-mean insolation [W/m2] on day 180
Latitude
Year
50
0
−50
−140000
−120000
−100000
−80000
−60000
−40000
−20000
500
400
300
200
100
0
Eemian Interglacial
LGM
Today

Question

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

Northern vs. Southern Hemisphere



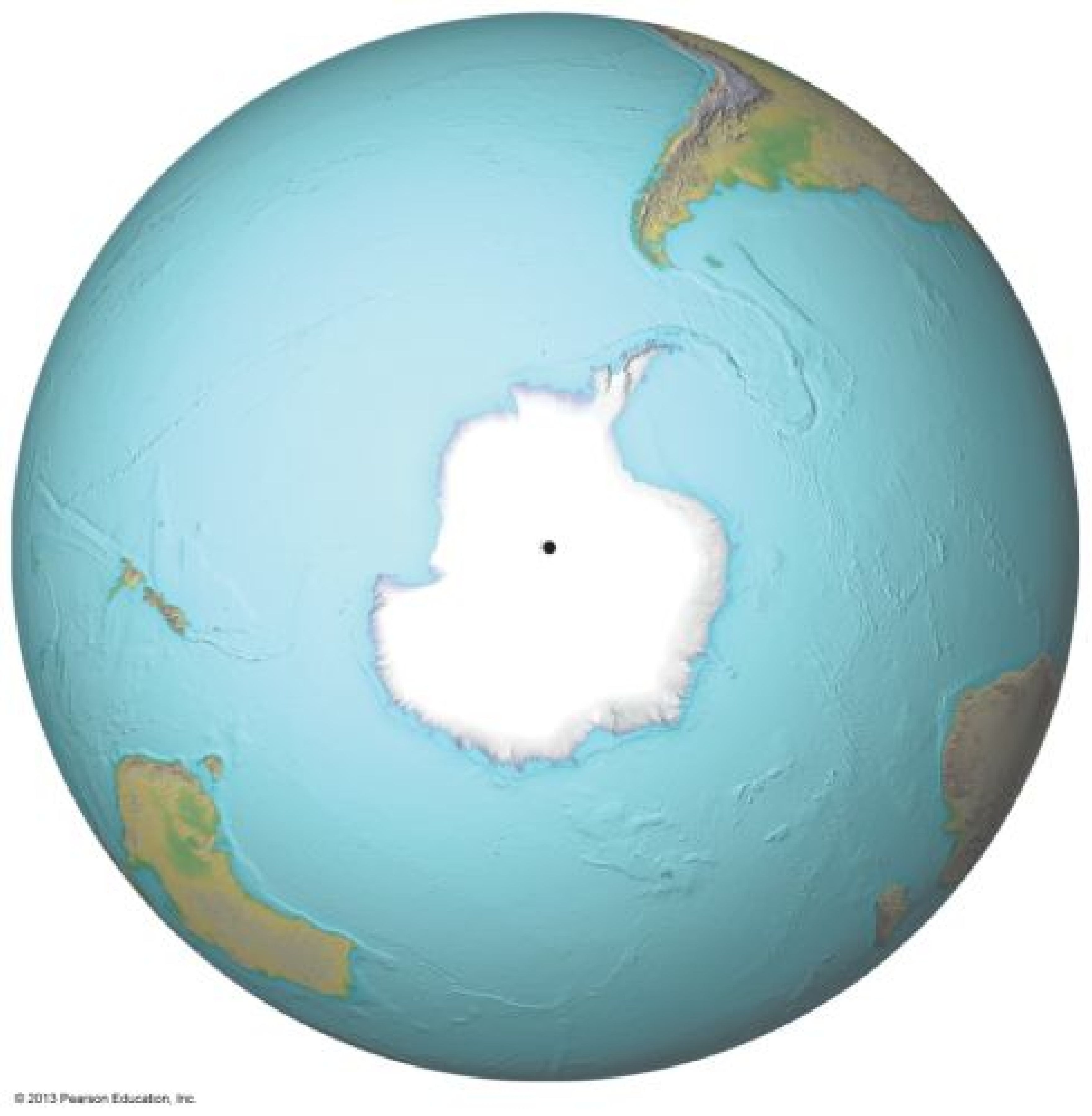
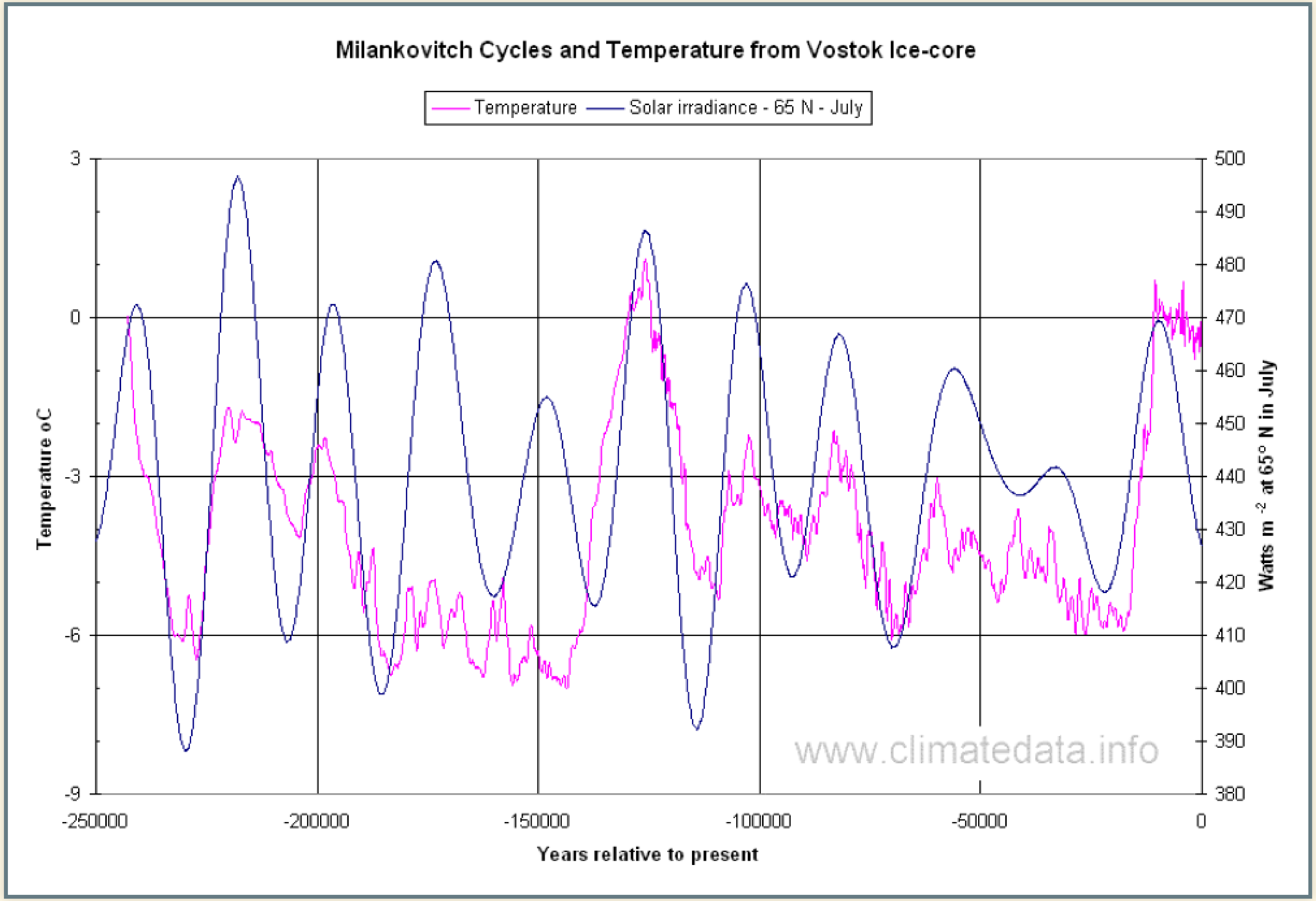


Image Credit: Pearson Education, Inc.

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

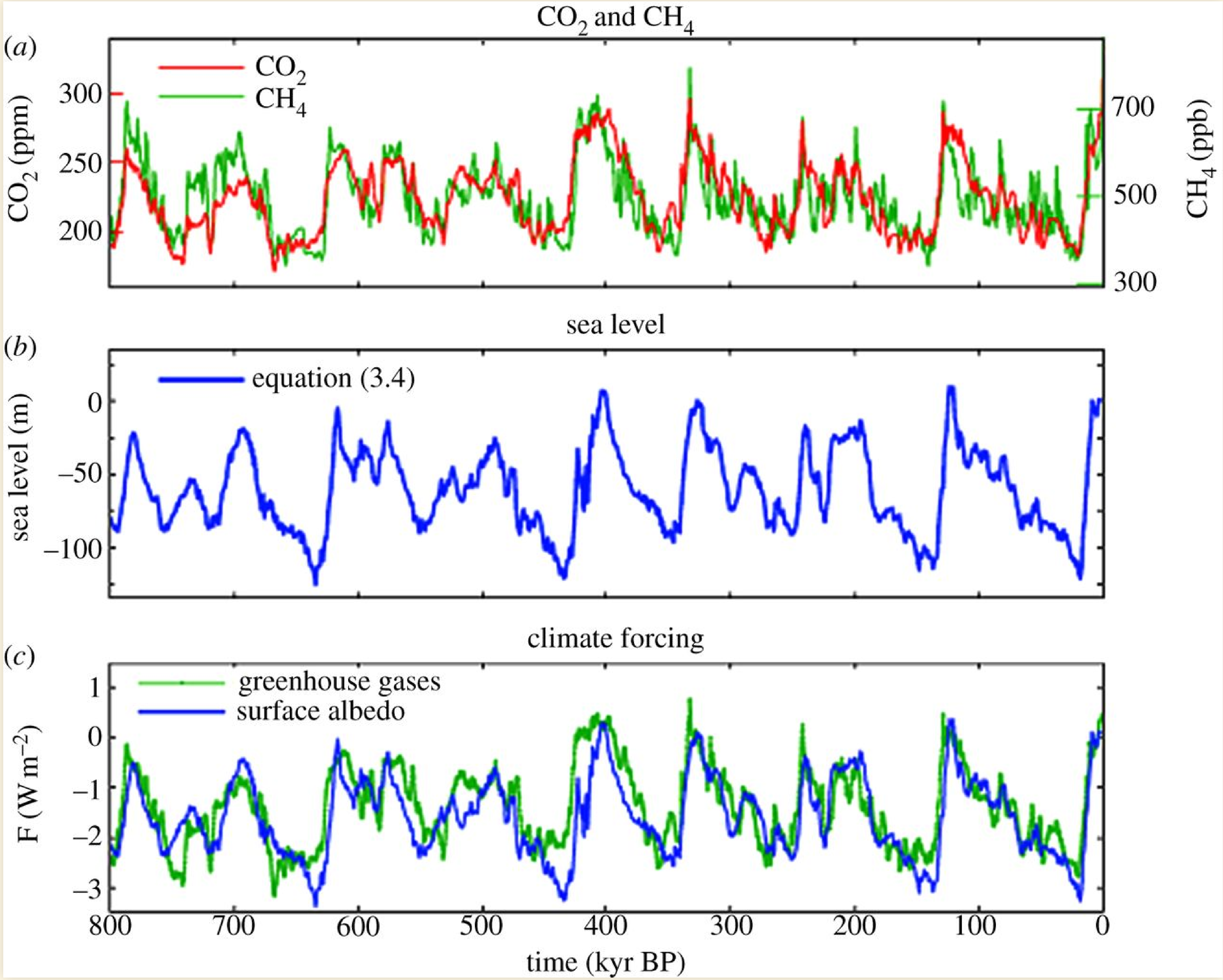


Image credit: J. Hansen *et al*., Phil. Trans. Royal Soc. A **371**, 20120294 (2013) doi:10.1098/rsta.2012.0294

Theory vs. Observations

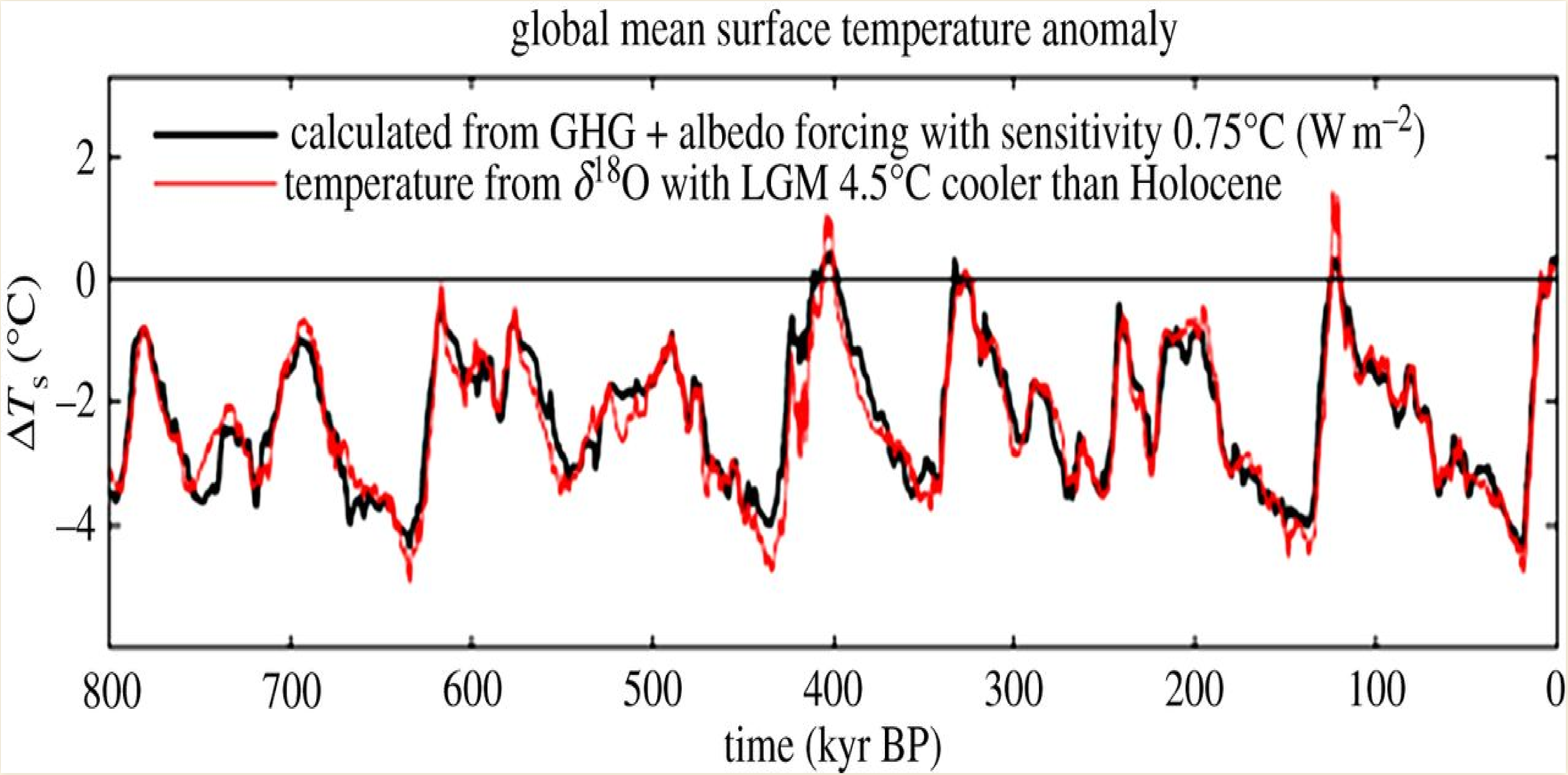


Image credit: J. Hansen *et al.*, Phil. Trans. Royal Soc. A **371**, 20120294 (2013) doi:10.1098/rsta.2012.0294

Ice-Age Feedbacks:

- Temperature starts to fall
  - Glaciers grow $\longrightarrow$ higher albedo
  - CO_2 drops $\longrightarrow$ weaker greenhouse
  - Colder
- Temperature starts to rise
  - Glaciers retreat $\longrightarrow$ higher albedo
  - CO_2 rises $\longrightarrow$ 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 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)