Climate System II
(Winter 2021/2022)

7th lecture:

Biogeochemical Cycles

(turnover times and circulation of biochemical tracers: carbon, nitrogen, sulfur, phosphorus)

Gerrit Lohmann, Martin Werner

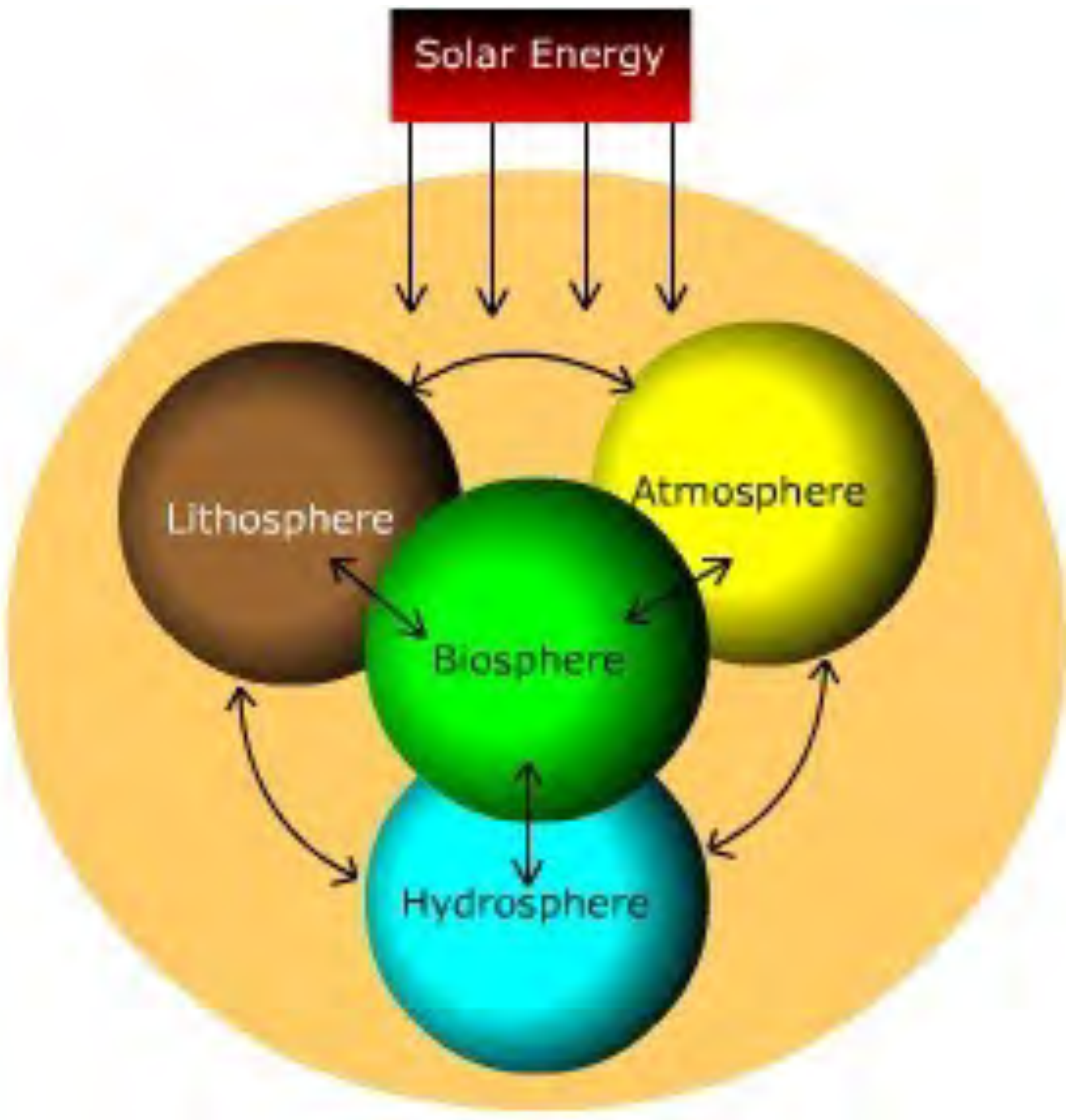
Tuesday, 10:00-11:45

(sometimes shorter, but then with some exercises)

https://paleodyn.uni-bremen.de/study/climate2021_22.html

What are biogeochemical cycles?

- **Earth system has four parts**
  - ***atmosphere***
  - ***hydrosphere***
  - ***lithosphere***
  - ***biosphere***
- **Biogeochemical cycles**
  - ***The chemical interactions (cycles) that exist between the atmosphere, hydrosphere, lithosphere, and biosphere***
- **Abiotic (physio-chemical) and biotic processes drive these cycles**

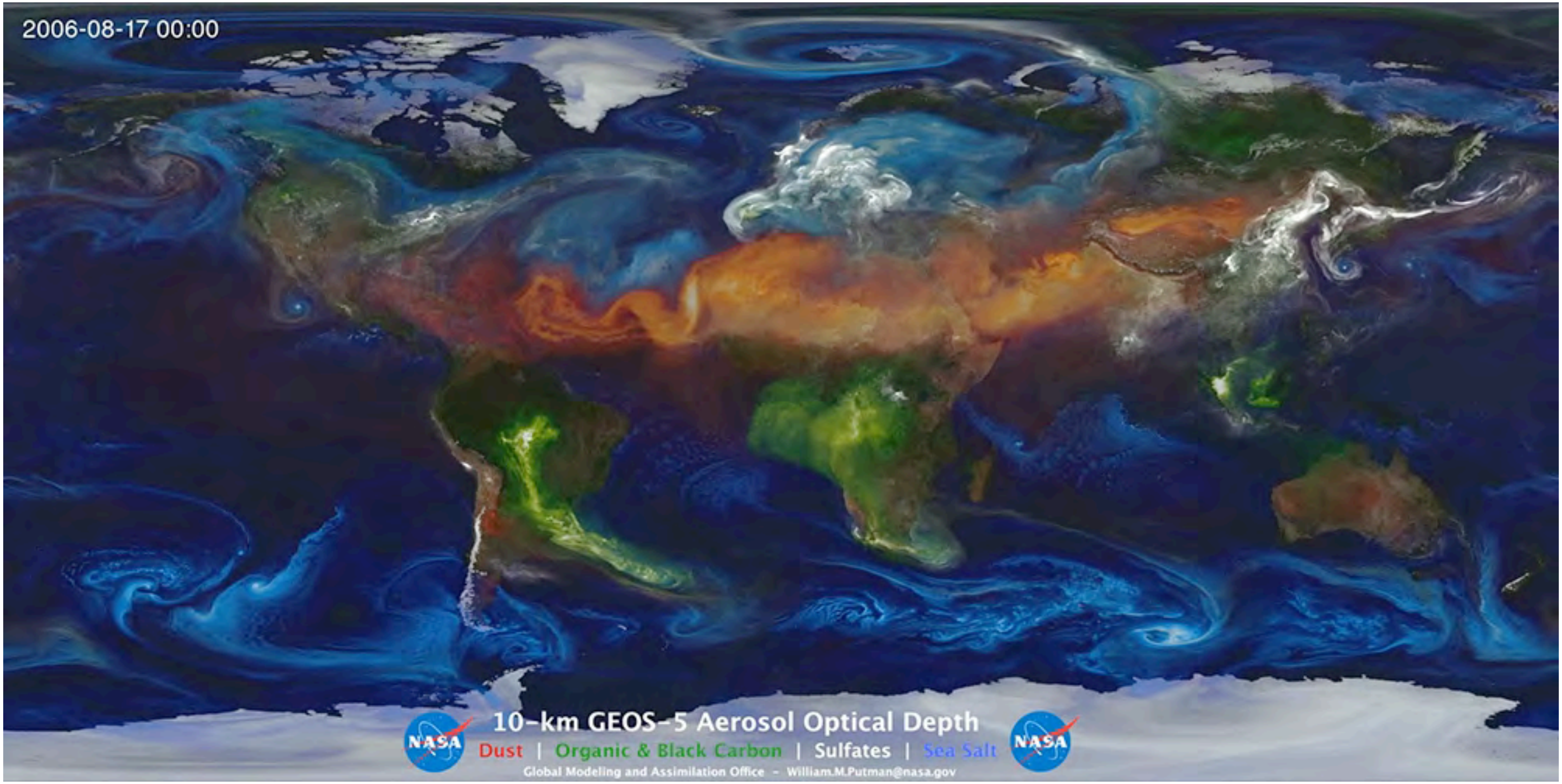


Biogeochemical cycles - key elements

Six nutrient elements make up 95% of the biomass mass on earth and form the biochemical foundation for life.

- **Carbon (CO_2, CH_4, CO)**
- **Nitrogen (N_2O, NO, NO_2, NH_3)**
- **Sulfur (SO_2, COS, H_2S, H_2SO_4)**
- **Phosphorous**
- **Hydrogen**
- **Oxygen**
- **Water**

Transport of biogeochemical aerosols and dust



Animation 1. Aerosol optical thickness of black and organic carbon (green), dust (red-orange), sulfates (white), and sea salt (blue) from a 10 km resolution GEOS-5 "nature run" using the GOCART model. The animation shows the emission and transport of key tropospheric aerosols from August 17, 2006 to April 10, 2007.

(http://gmao.gsfc.nasa.gov/research/aerosol/modeling/nr1_movie/)

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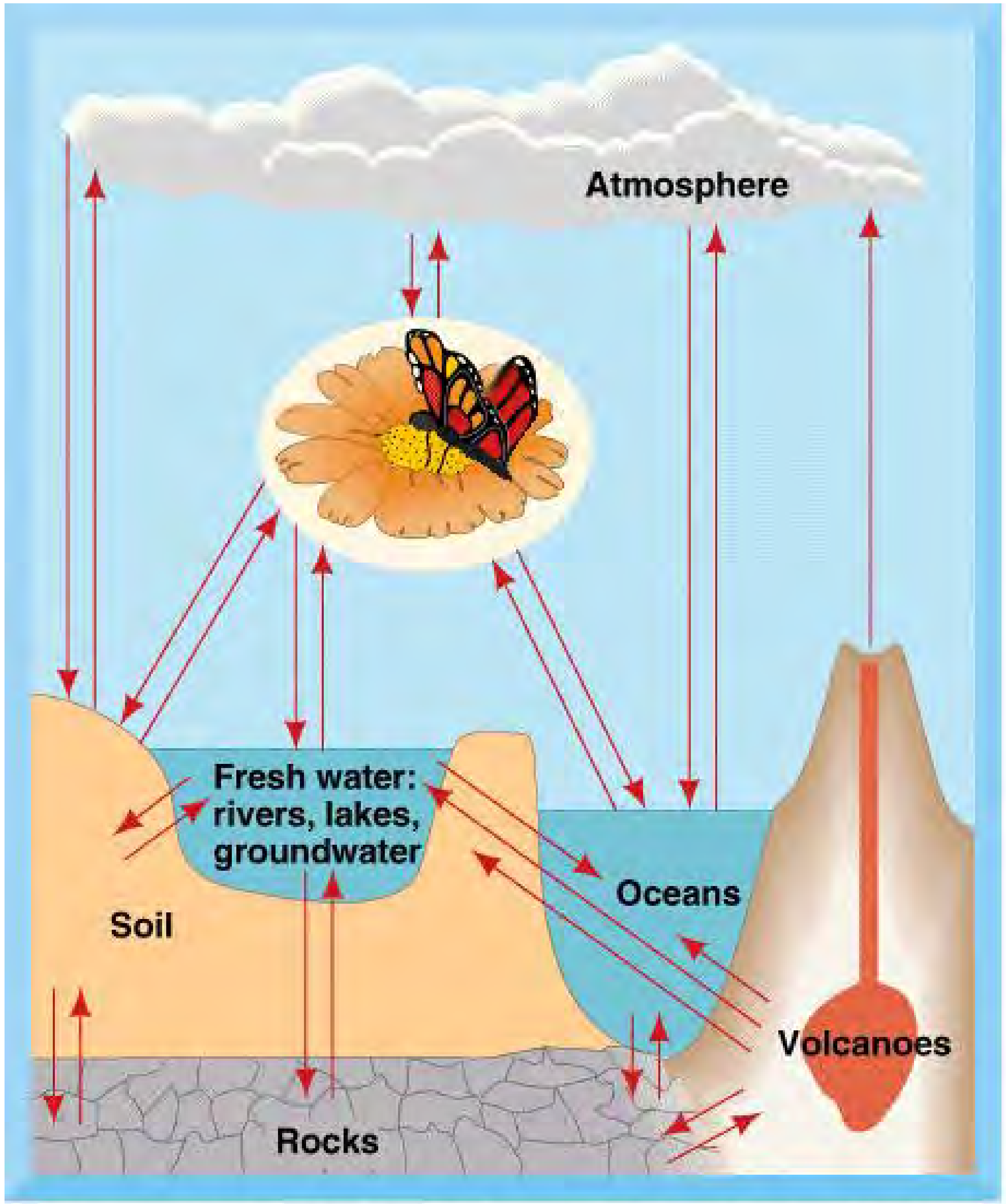
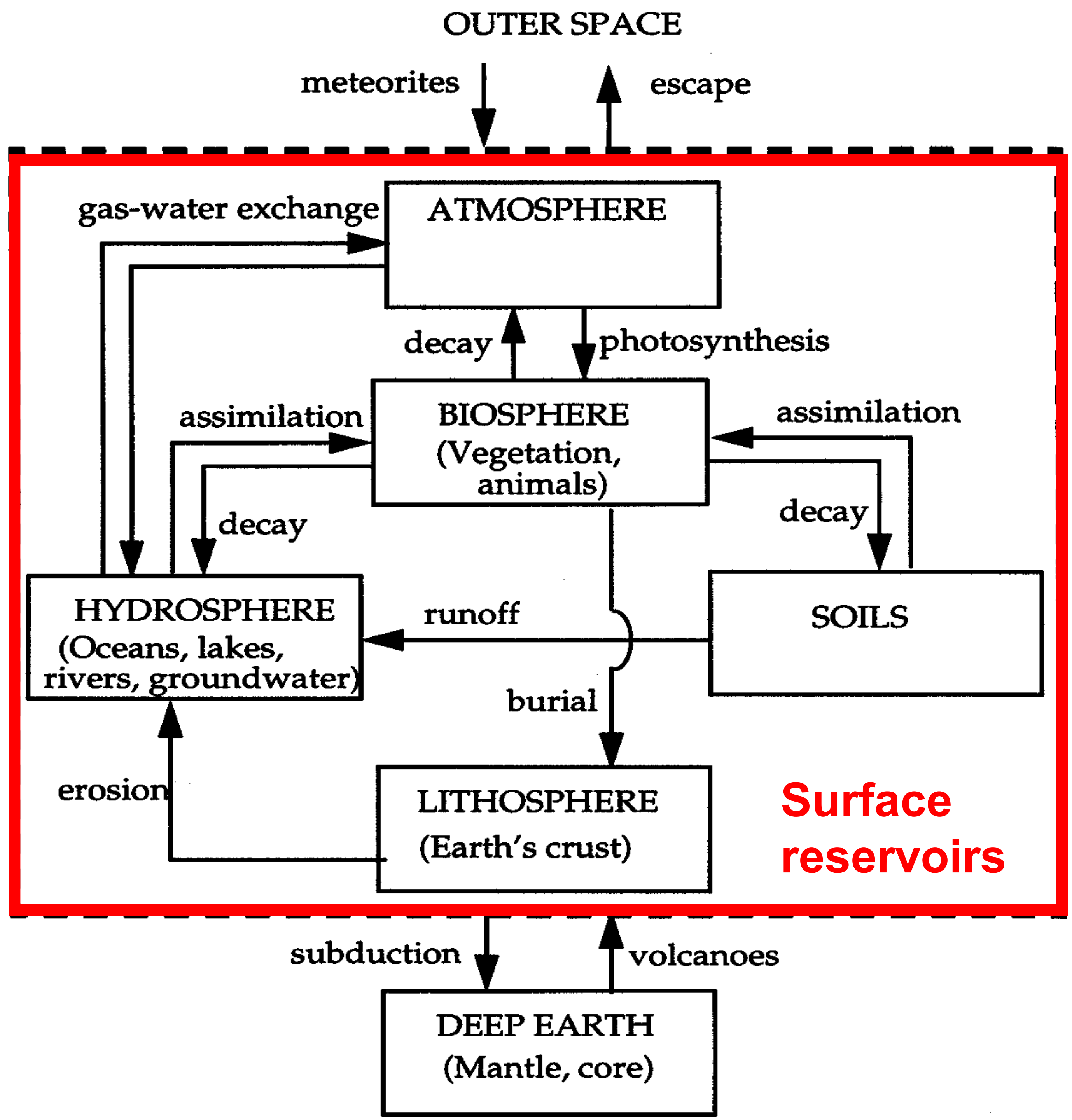
Biogeochemical cycles: Common features of all key elements

- **each element typically occurs in all four parts of the Earth System** **(e.g. water, carbon, nitrogen, etc.)**

- **each biogeochemical cycle can be described by**
    - ***pools***
    - ***fluxes in and out of pools***
    - ***chemical or biochemical transformations***

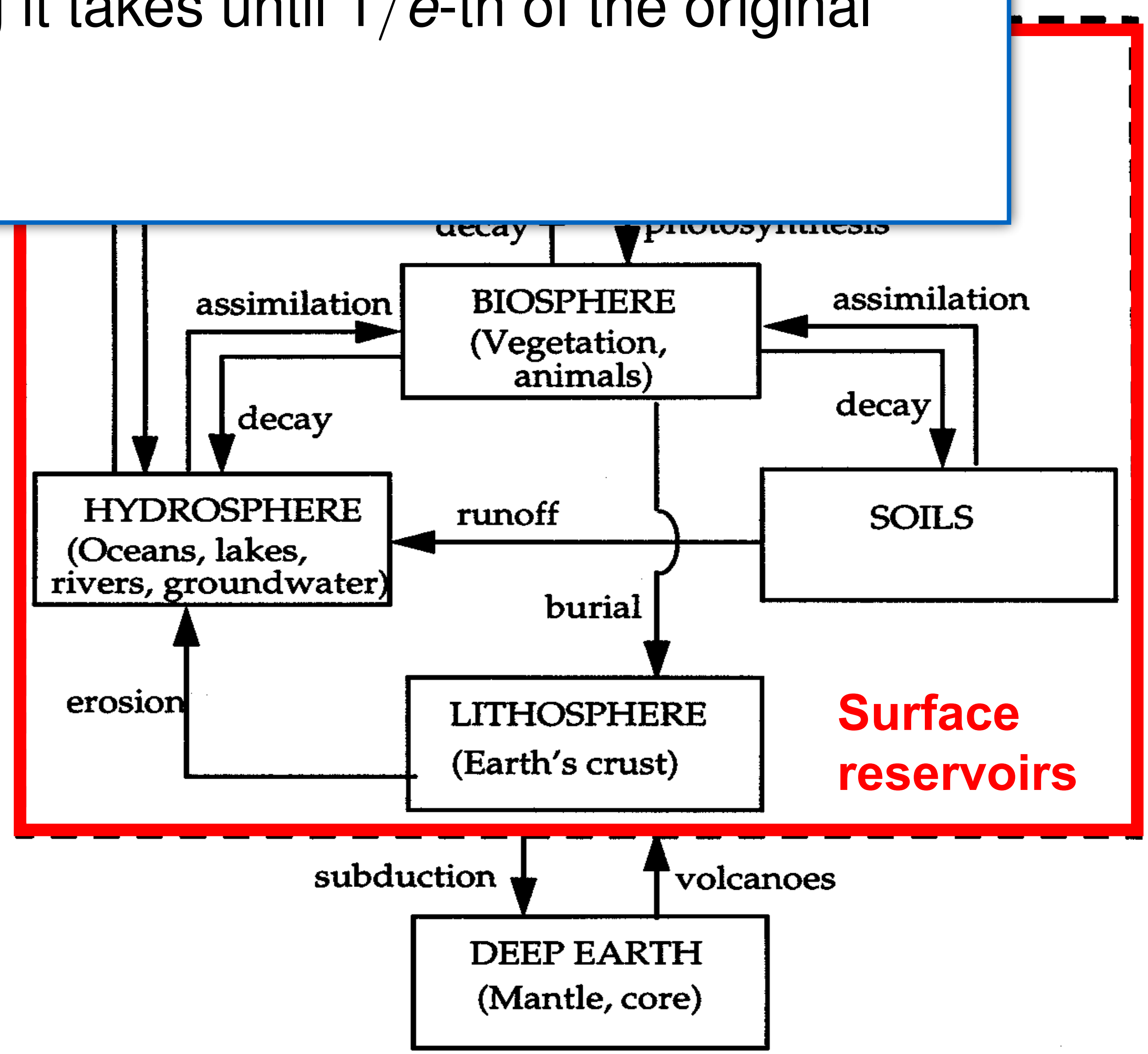

Atmosphere
Fresh water: rivers, lakes, groundwater
Oceans
Soil
Volcanoes
Rocks


OUTER SPACE
meteorites
escape
gas-water exchange
ATMOSPHERE
decay
photosynthesis
assimilation
BIOSPHERE (Vegetation, animals)
assimilation
decay
decay
HYDROSPHERE (Oceans, lakes, rivers, groundwater)
runoff
SOILS
burial
erosion
LITHOSPHERE (Earth's crust)
Surface reservoirs
subduction
volcanoes
DEEP EARTH (Mantle, core)

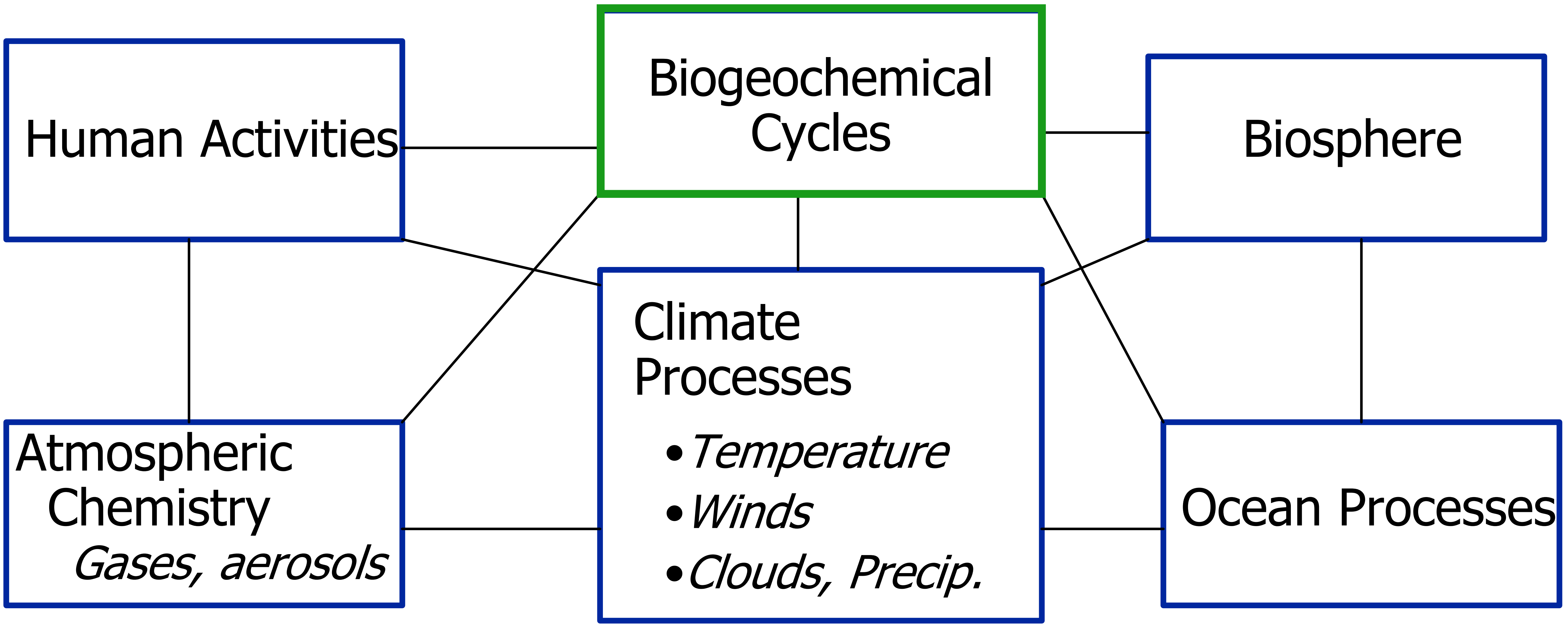
definition

turnover time τ is the size of a reservoir A, divided by the sum of all fluxes into (or out of) it $\sum F$, $\tau = A / \sum F$

- if there are only fluxes out of the reservoir, τ is how long it takes until the reservoir is empty
- if fluxes are balanced, τ is how long it takes until $1/e$-th of the original molecules is still in the reservoir



Biogeochemical cycles in climate research



Biogeochemical cycles are a key element for understanding our past and present climate!

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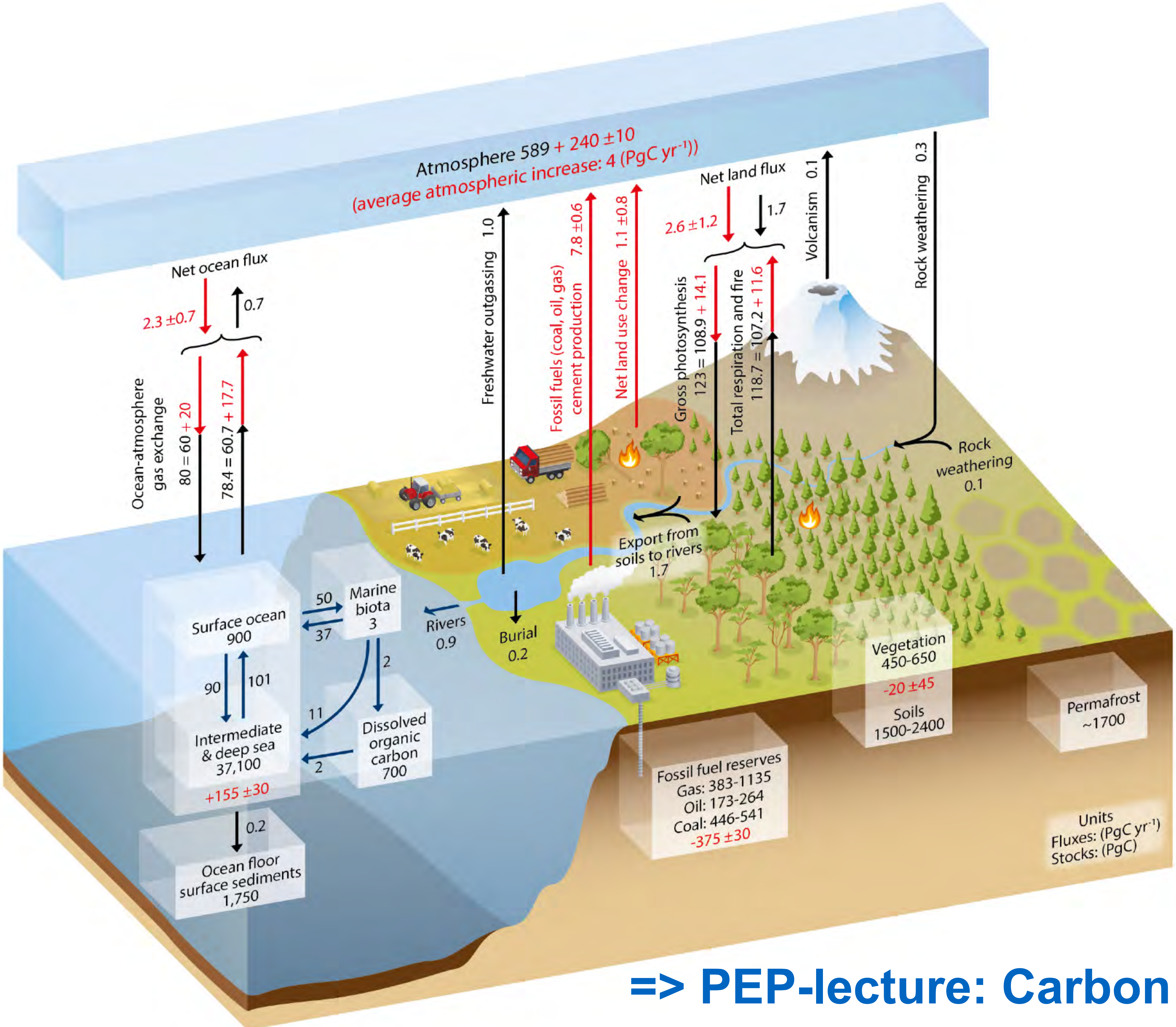
The global carbon cycle



=> PEP-lecture: Carbon Cycle

CO_2 sources and sinks

CO_2 sources

34.7 $GtCO_2$/yr
86%

14%
5.5 $GtCO_2$/yr

CO_2 sinks

17.9 $GtCO_2$/yr
44%

29%
11.5 $GtCO_2$/yr

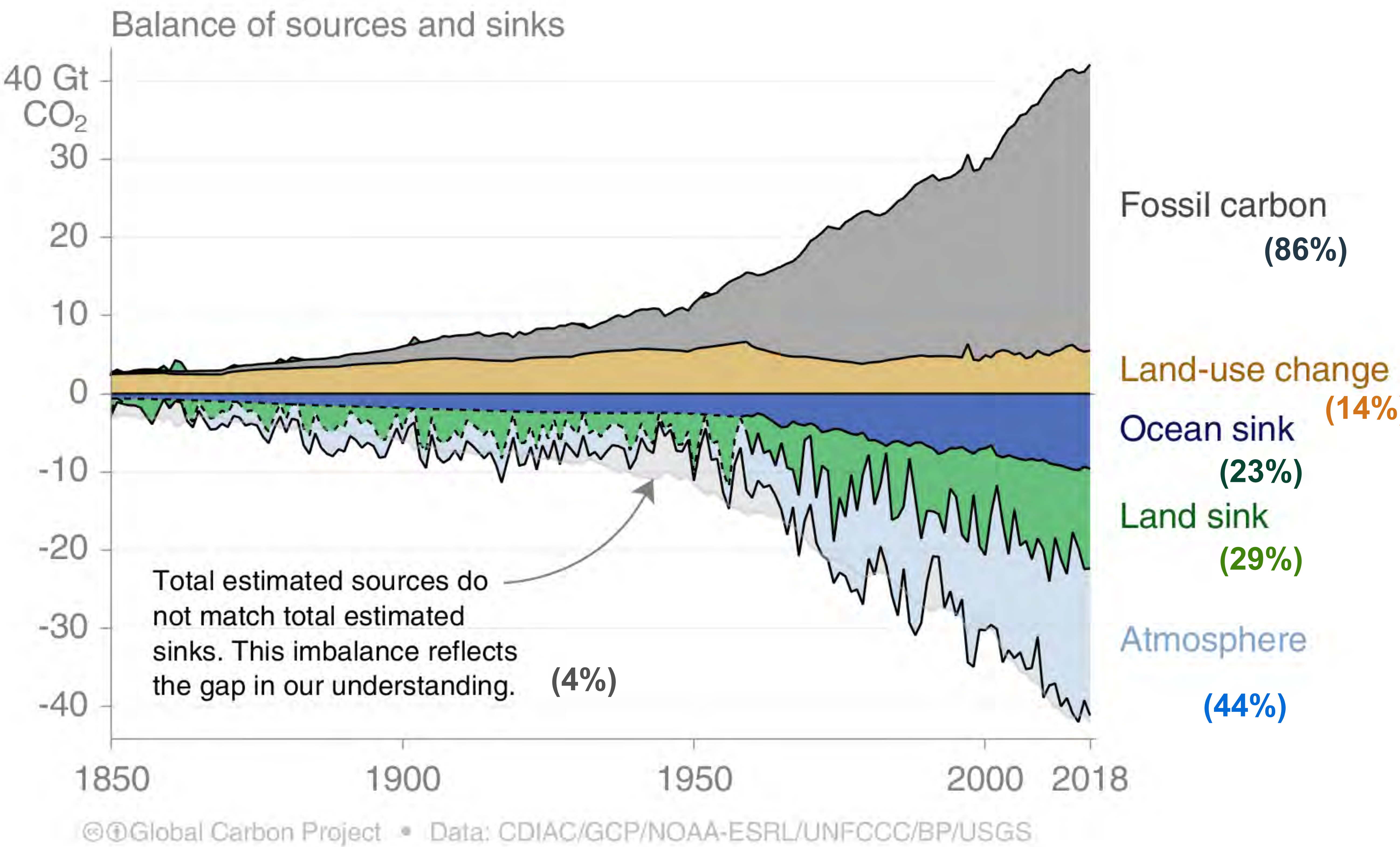
23%
9.2 $GtCO_2$/yr

CO_2 sources minus sinks: 4% 1.6 $GtCO_2$/yr

(all numbers for period 2009-2018)

[https://www.globalcarbonproject.org/carbonbudget/19/presentation.htm]

CO_2 sources and sinks



[[https://www.globalcarbonproject.org/carbonbudget/19/presentation.htm]]

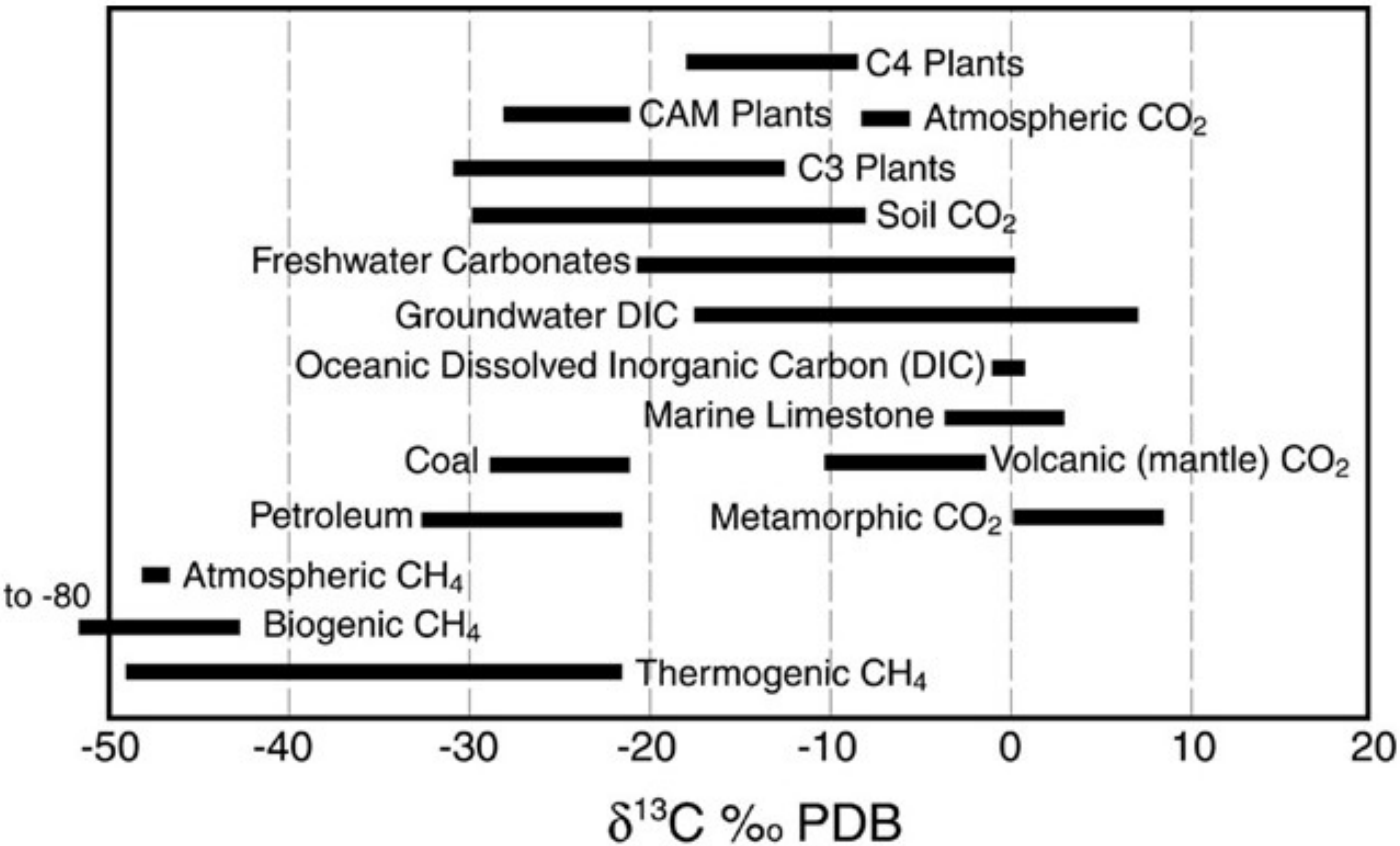
(percentage for years 2009-2018)

Carbon isotopes

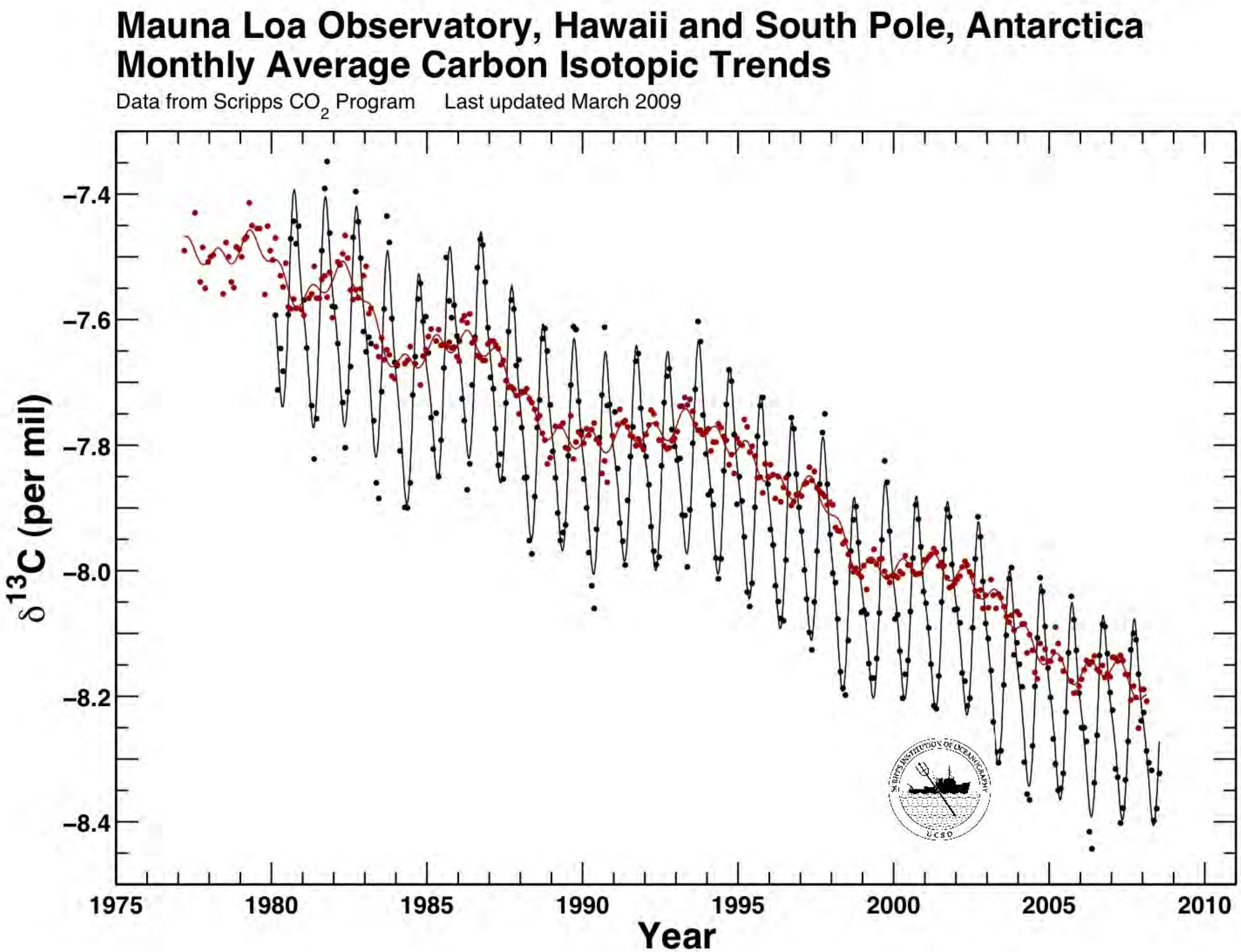
- **Relative abundance**
  - ^{12}C 98.89 % stable
  - ^{13}C 1.11 % stable
  - ^{14}C 1×10^{-10} % half-life=5276 years
- **^{12}C and ^{13}C are stable isotopes**
- **^{14}C is called radiocarbon**
  - Formed by cosmic radiation ($^{14}N + {}^{1}n \rightarrow {}^{14}C + {}^{1}p$)
  - Also formed in nuclear explosions

- ***During photosynthesis, plants preferentially uptake ^{12}C => the atmosphere will become enriched in ^{13}C***

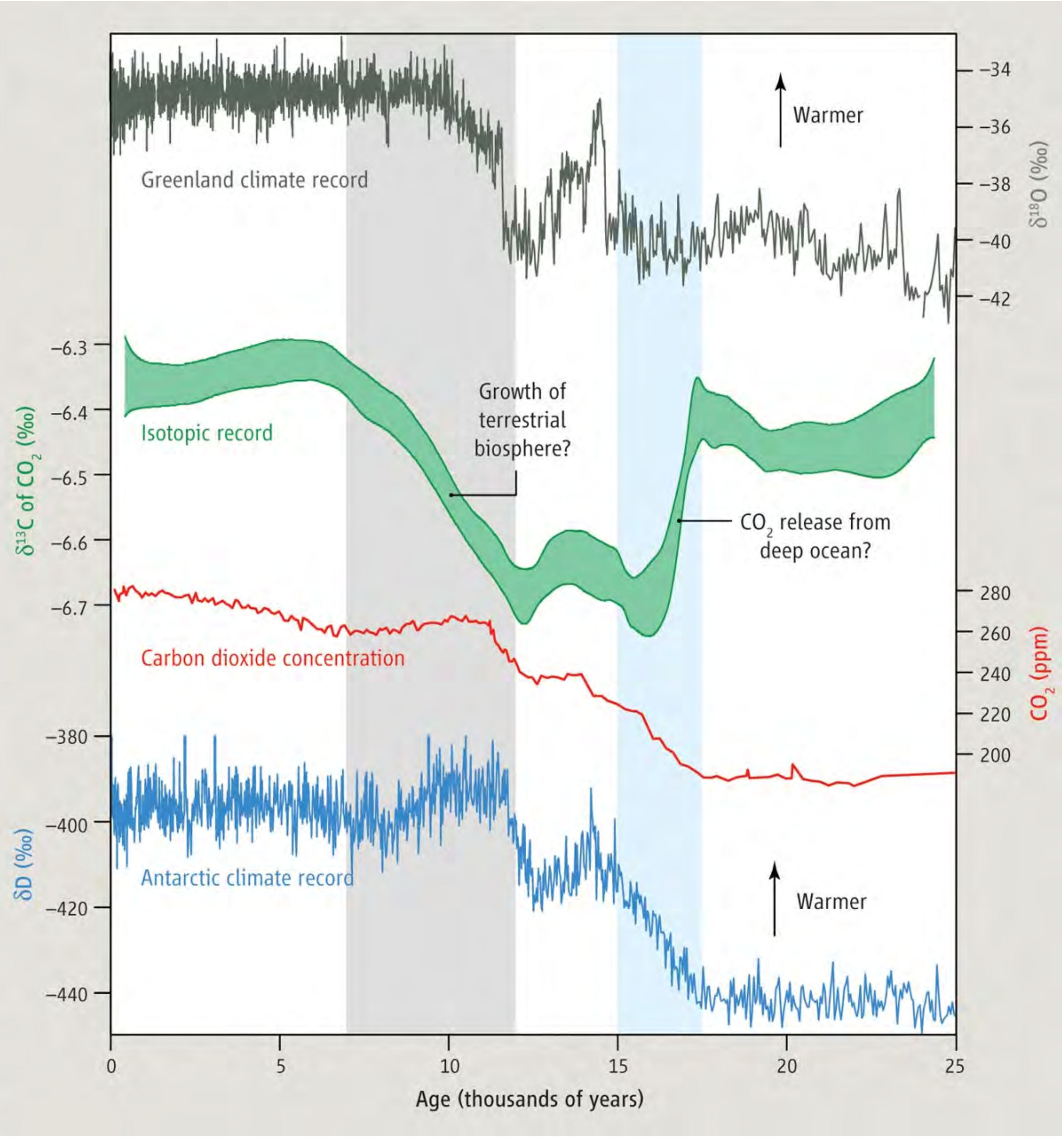
Variations of ^{13}C in different carbon pools



Variations of ^{13}C due to fossil fuel burning



Variations of ^{13}C since the last glacial maximum (LGM)



[Brook, The Ice Age Carbon Puzzle, Science, 2012]

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Nitrogen cycle: key points

- Nitrogen is in the atmosphere as N_2 (78%)
  - *NO, $N_2$0, NO_2 - other gases of nitrogen*
- N_2 is an inert gas and cannot be used by plants or animals
- N_2 can be converted to a usable form via
  - *Lightening*
  - *N-fixing micro-organisms (free living, assoc. with plant)*
  - *Industrial process (energy intensive)*
- Nitrogen is easily converted & lost from biological systems (e.g., fire)
- N_2O is the 3rd most important greenhouse gas

REMEMBER: Climate change on orbital time scales

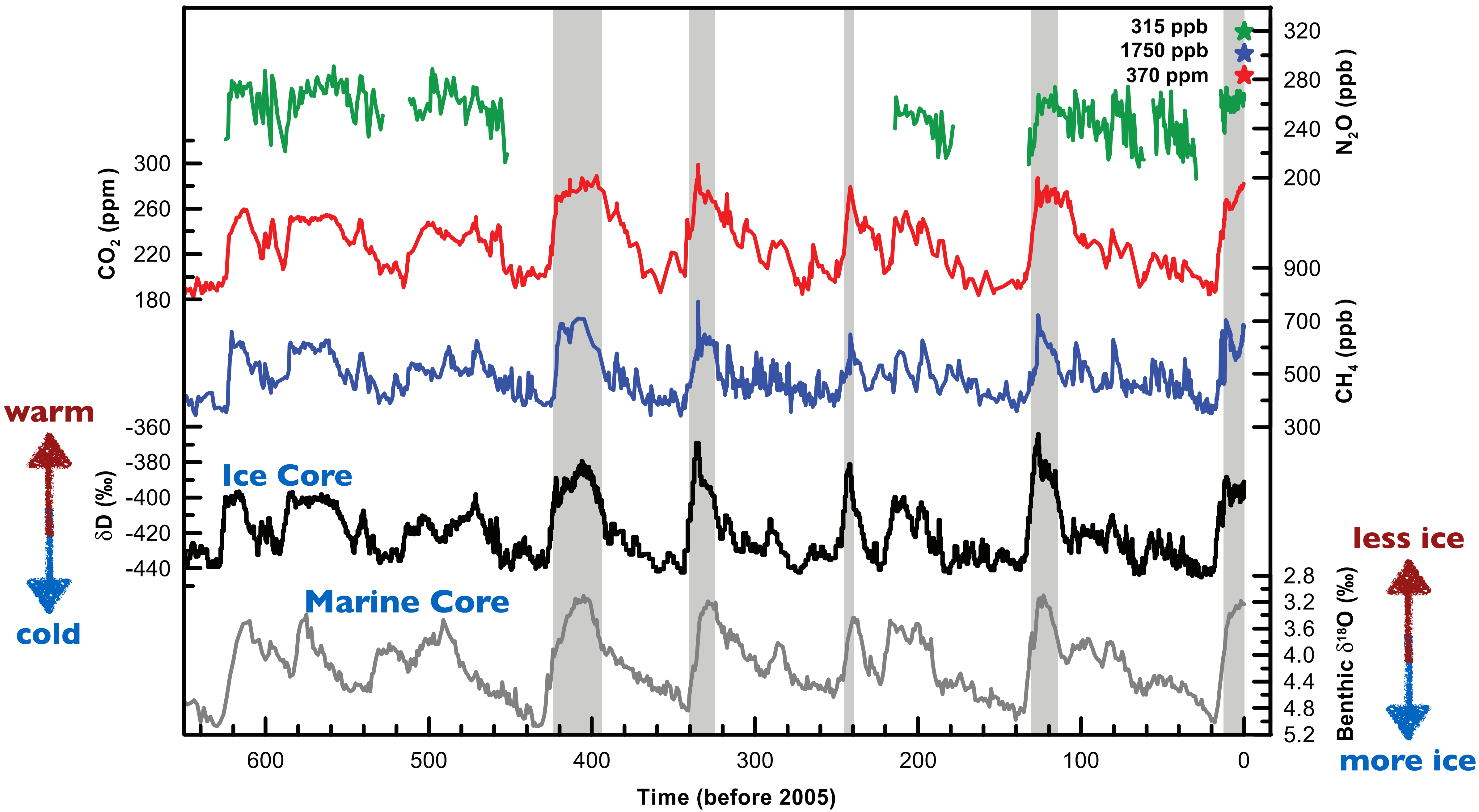
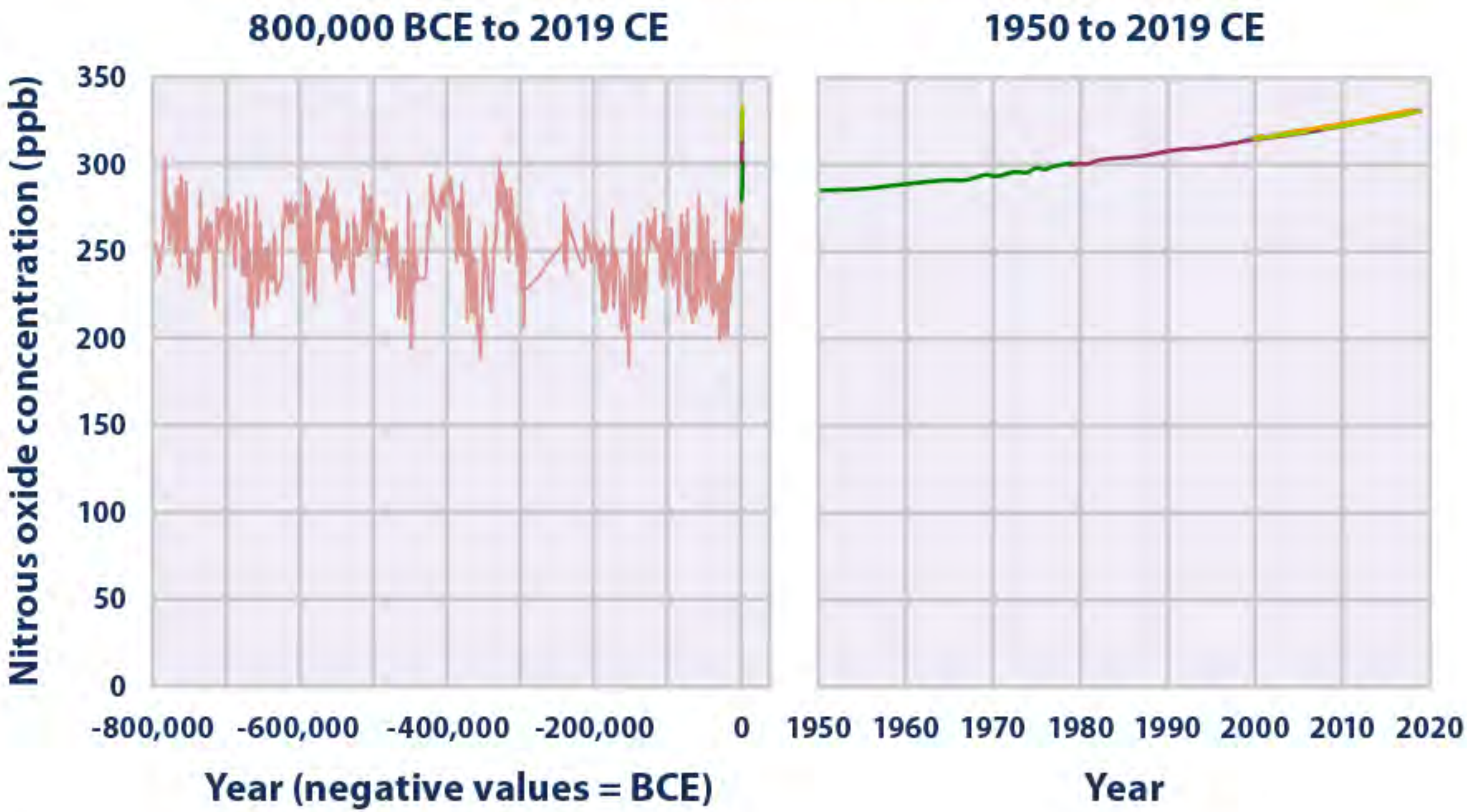


Figure 6.3. *Variations of deuterium (δD; black), a proxy for local temperature, and the atmospheric concentrations of the greenhouse gases CO_2 (red), CH_4 (blue), and nitrous oxide (N_2O; green) derived from air trapped within ice cores from Antarctica and from recent atmospheric measurements (Petit et al., 1999; Indermühle et al., 2000; EPICA community members, 2004; Spahni et al., 2005; Siegenthaler et al., 2005a,b). The shading indicates the last interglacial warm periods. Interglacial periods also existed prior to 450 ka, but these were apparently colder than the typical interglacials of the latest Quaternary. The length of the current interglacial is not unusual in the context of the last 650 kyr. The stack of 57 globally distributed benthic $\delta^{18}O$ marine records (dark grey), a proxy for global ice volume fluctuations (Lisiecki and Raymo, 2005), is displayed for comparison with the ice core data. Downward trends in the benthic $\delta^{18}O$ curve reflect increasing ice volumes on land. Note that the shaded vertical bars are based on the ice core age model (EPICA community members, 2004), and that the marine record is plotted on its original time scale based on tuning to the orbital parameters (Lisiecki and Raymo, 2005). The stars and labels indicate atmospheric concentrations at year 2000.*

IPCC, 2007

REMEMBER: Climate change on orbital time scales

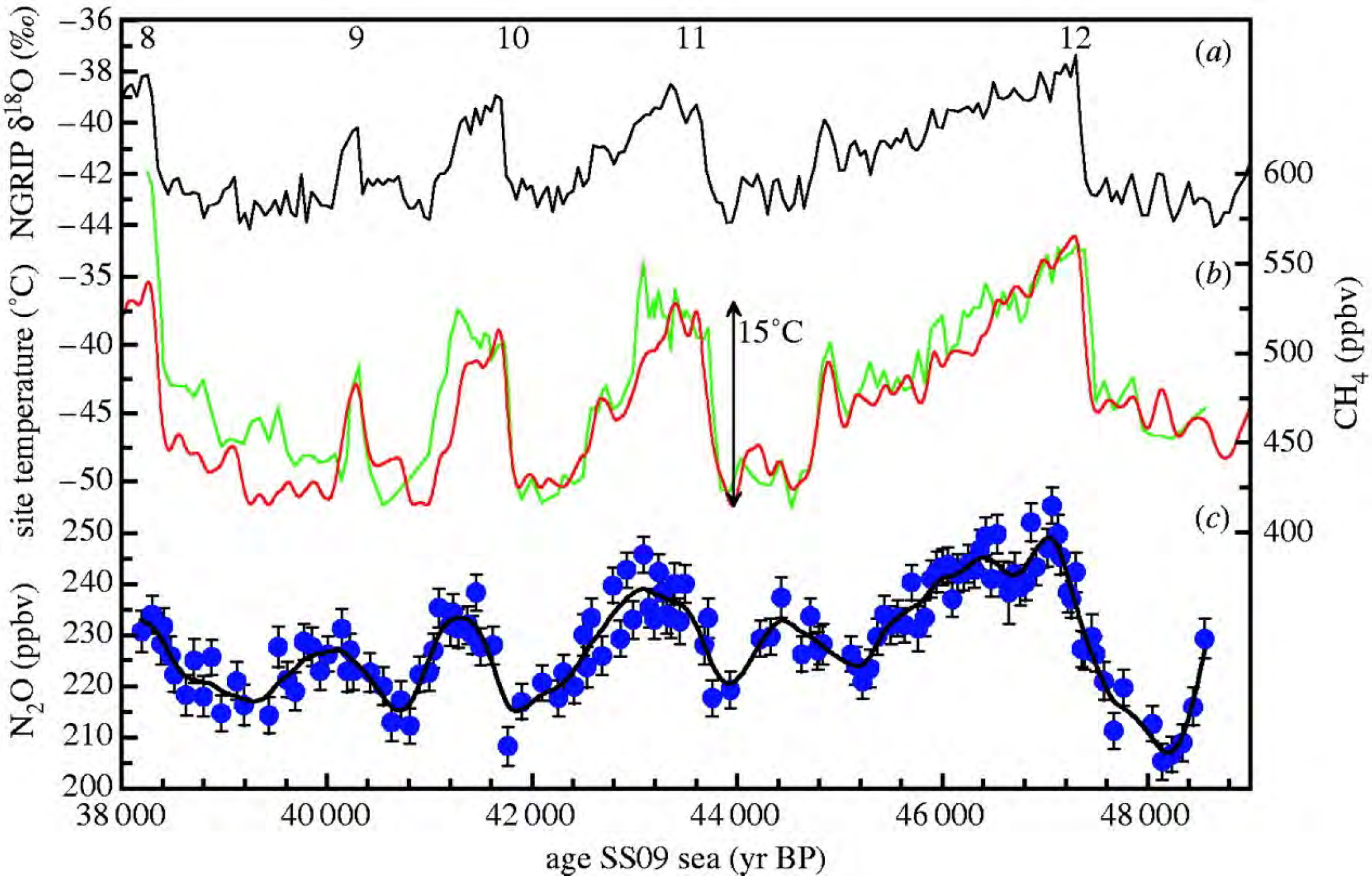


Data source: Compilation of six underlying datasets. See www.epa.gov/climate-indicators for specific information.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

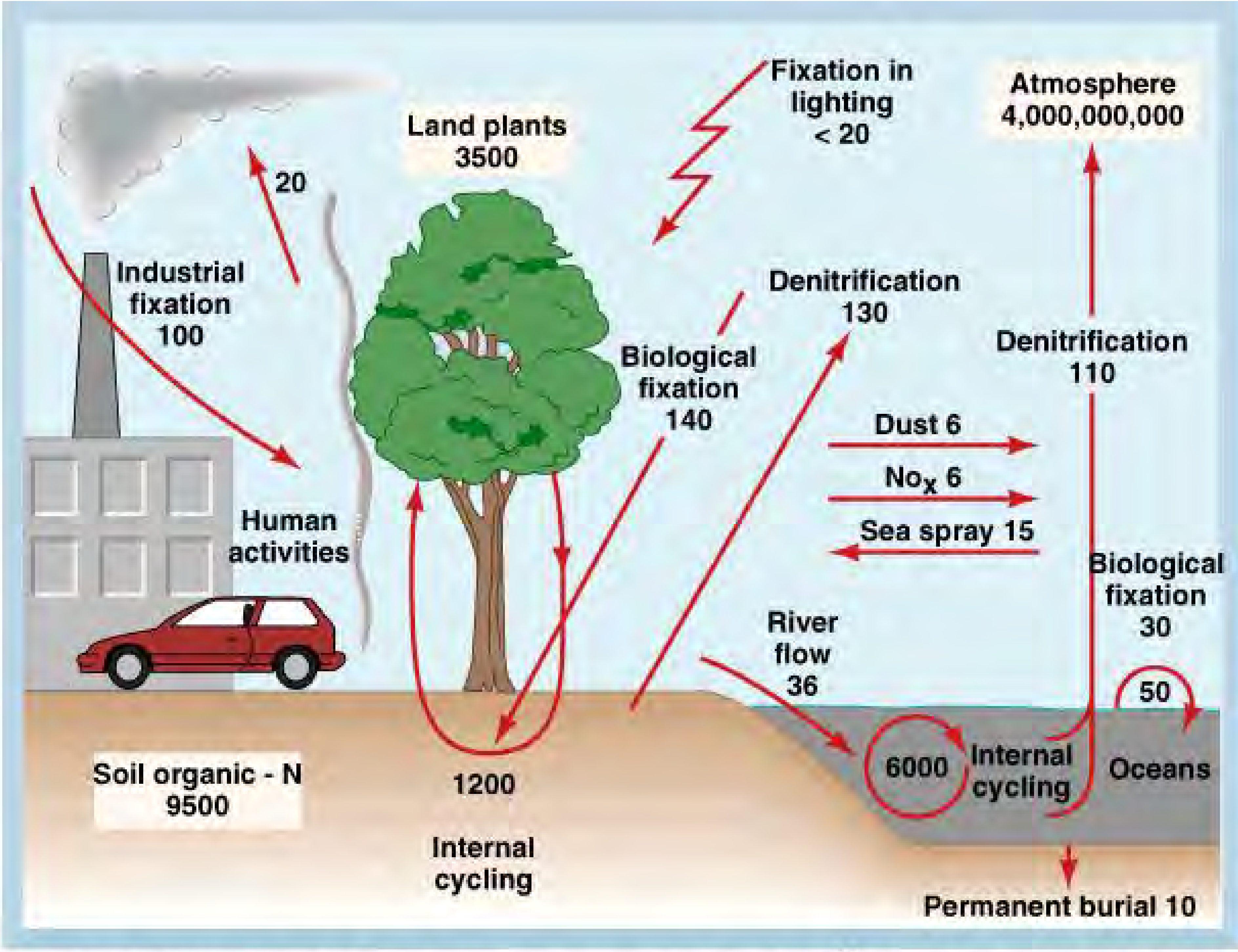
[https://www.epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases]

Oxygen isotope (North Greenland Ice Core Project Members 2004), temperature (red; Huber et al. 2006), CH4 (green) and N2O (Flückiger et al. 2004) data from NorthGRIP, Greenland over the period of 38–49 kyr BP on the SS09_sea time-scale (Johnsen et al. 2001).



Eric Wolff, and Renato Spahni Phil. Trans. R. Soc. A 2007;365:1775-1792

The global nitrogen cycle



The global nitrogen cycle. Pools (□)and annual (→) flux in $10^{12}gN_2$. Note that the industrial fixation of nitrogen is nearly equal to the global biological fixation. (*SOURCE:* Data from Söderlund, and T. Rosswall, 1982 , O. Hutzinger (ed.), *The Handbook of Environmental Chemistry*, Vol 1, Pt. B., Springer-Verlag New York, Inc., New York).

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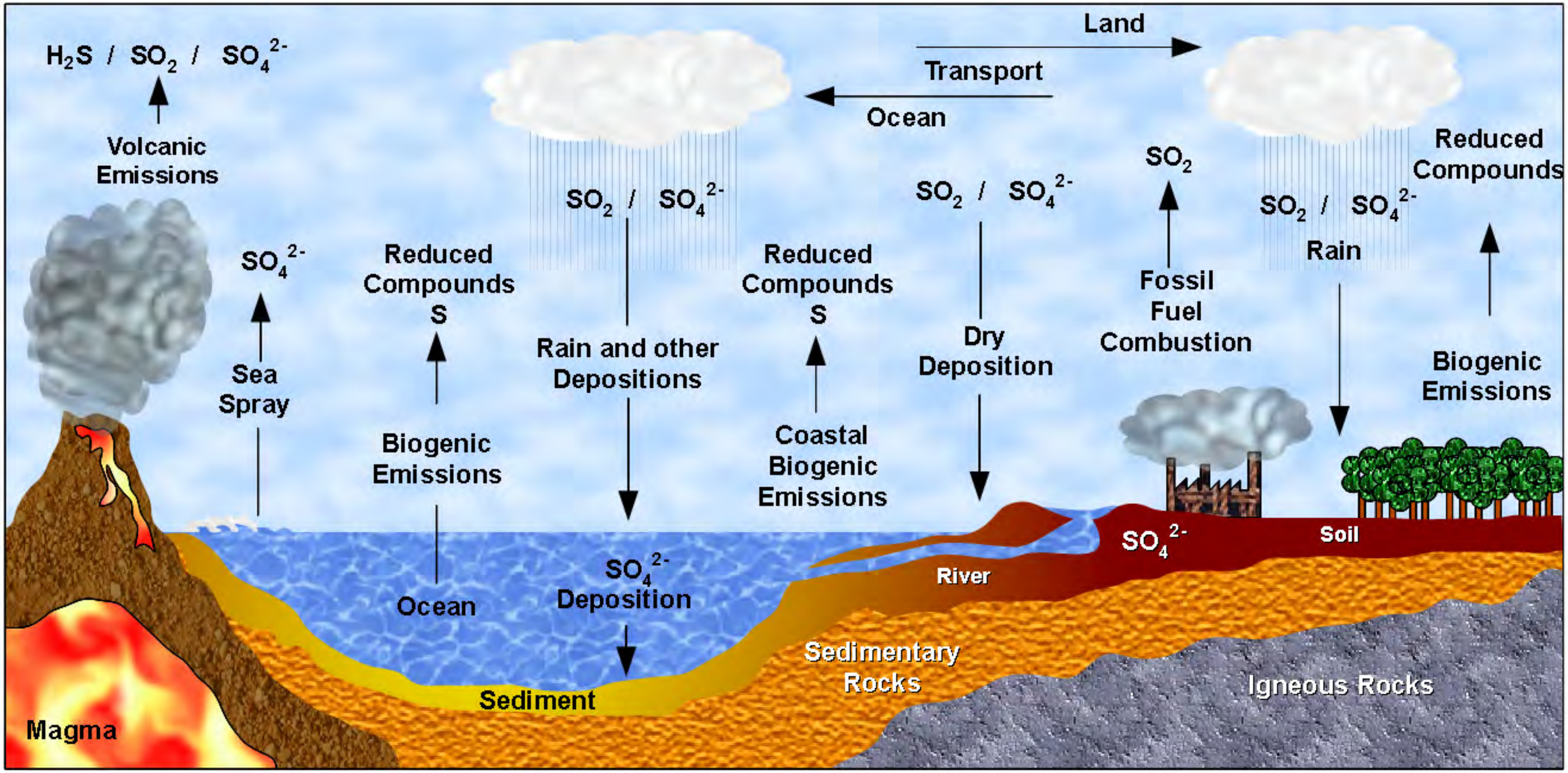
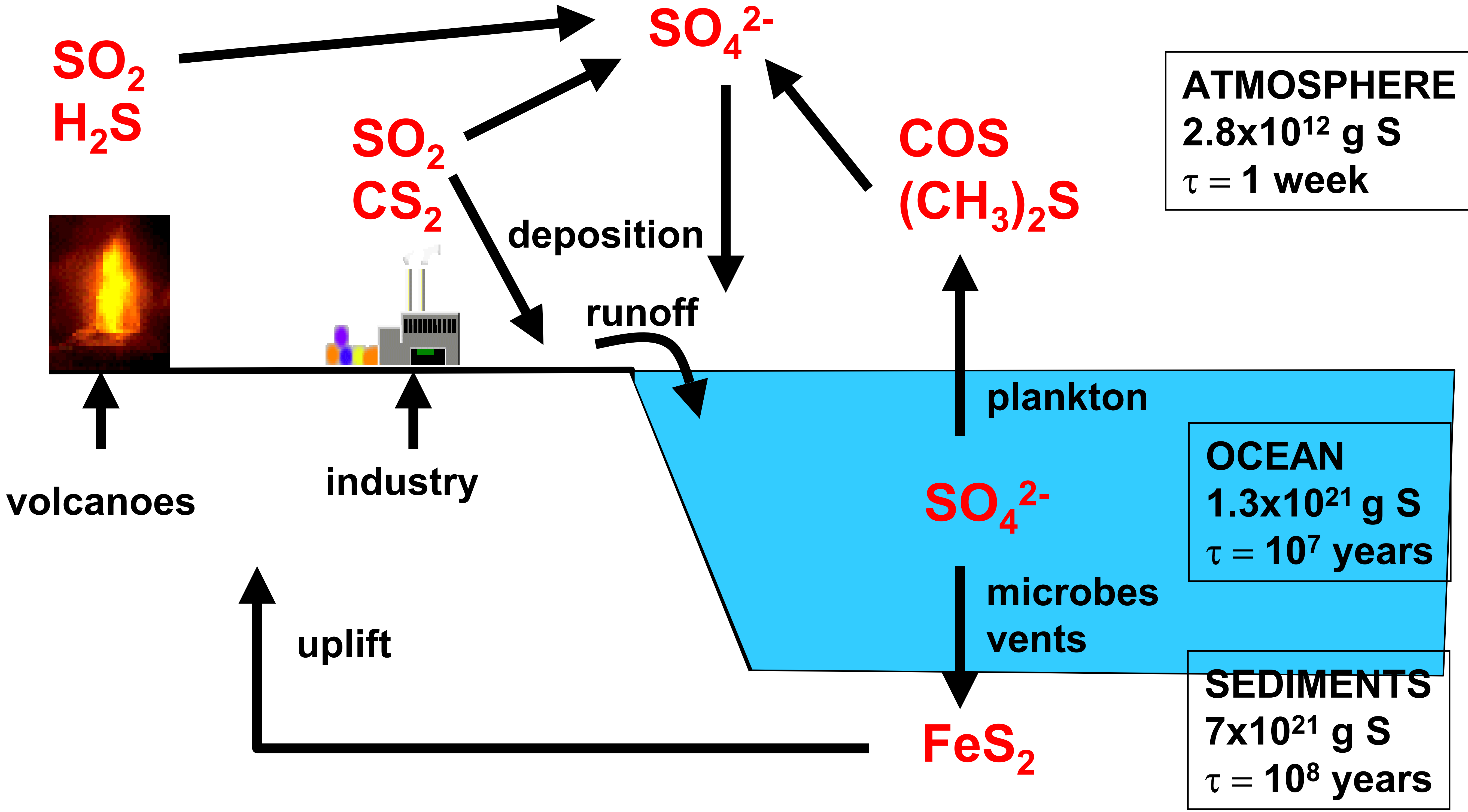
The importance of sulfur cycling

- **Sulfur, along with carbon, hydrogen, oxygen, nitrogen, and phosphorus, is one of the major constituents of living tissue.**
- **While this element is essential to life, it is also relatively abundant.**
- **It is therefore an** essential **plant nutrient, but not ordinarily a** limiting **plant nutrient.**
- **Plants take up SO_4^{2-} by reduction and incorporation into amino acids. It is released in many forms during decomposition.**

The global sulfur cycle



The global sulfur cycle



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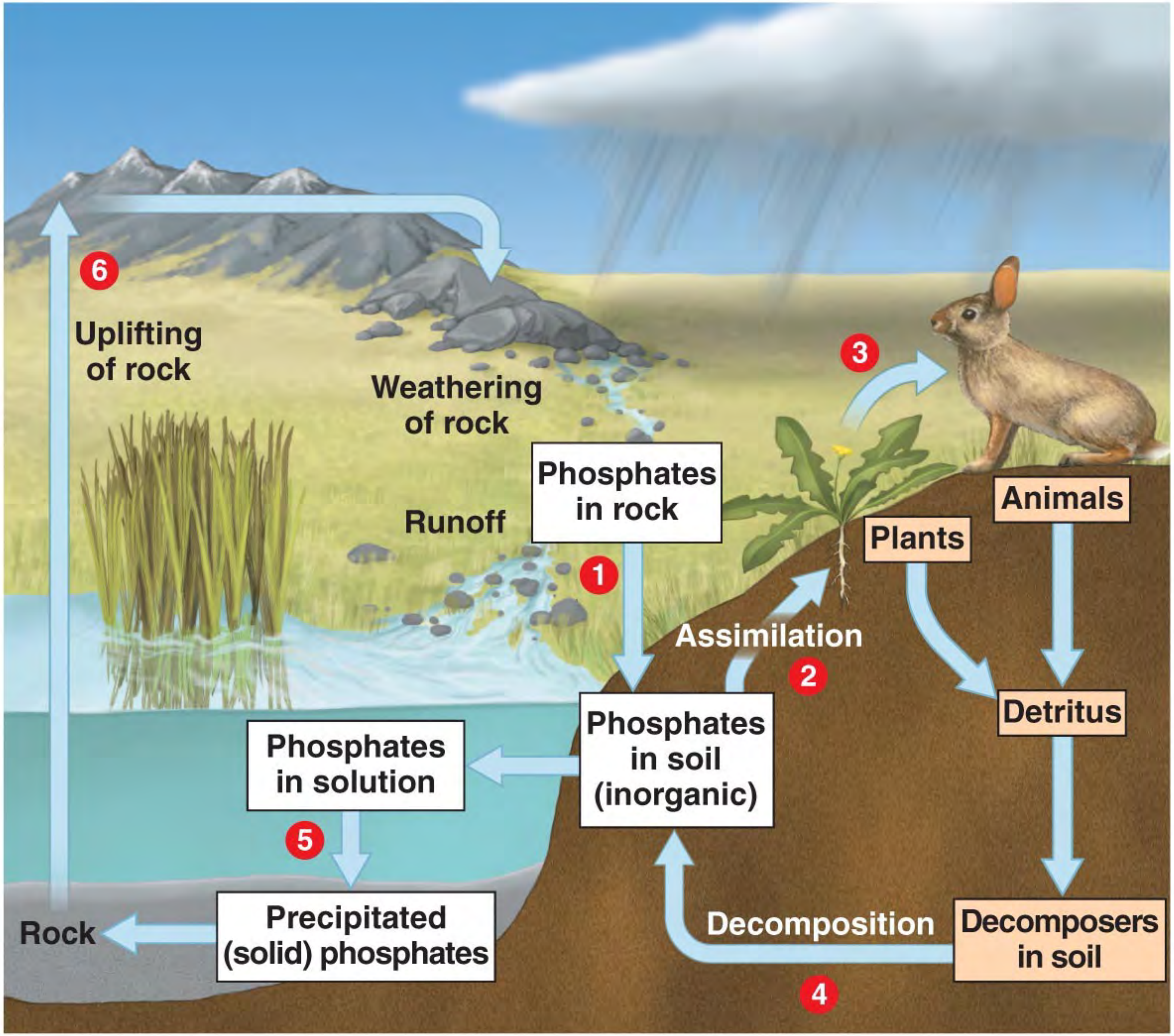
The phosphorus cycle



The phosphorus cycle - key points

- The phosphorus cycle has no atmospheric component
- The phosphorus cycle is largely restricted to solid and liquid components
- Unlike N cycle, major source of reactive P is not through microbial reactions
- Only 10% of P from rivers to oceans is available to marine biota; the rest is tied to soil and deposited quickly
- The major P sink is burial in marine sediments.
  Marine phosphorite deposits are mined and reintroduced to the P cycle by human activities.
- The phosphorus biomass reservoirs are derived from the carbon cycle and C:P ratios.

Global Phosphorus Reservoirs and Turnover Times

	10^{12} g P	Turnover time
Sediments	4×10^{9}	2×10^{8} y
Land	2×10^{5}	2000 y
Deep Ocean	8.7×10^{4}	1500 y
Terrestrial biota	3000	~50 y
Surface ocean	2700	2.6 y
Atmosphere	0.028	days

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End of lecture.

Slides available at:

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