Class 7: The Carbon Cycle

- How is carbon circulated through the atmosphere and the Earth?
- How are humans interfering with the carbon cycle?

Learning Objectives

1. Identify Earth's carbon sinks, sources, and reservoirs. (1)
2. Explain why atmospheric carbon dioxide concentrations fluctuate in a consistent manner throughout the year. (2)
3. Identify and explain some of the feedback systems inherent in the carbon cycle due to climate change (2,3)
4. Diagram the interactions over time between various stocks and flows of carbon cycle (4)

Review: Forcings and Feedbacks

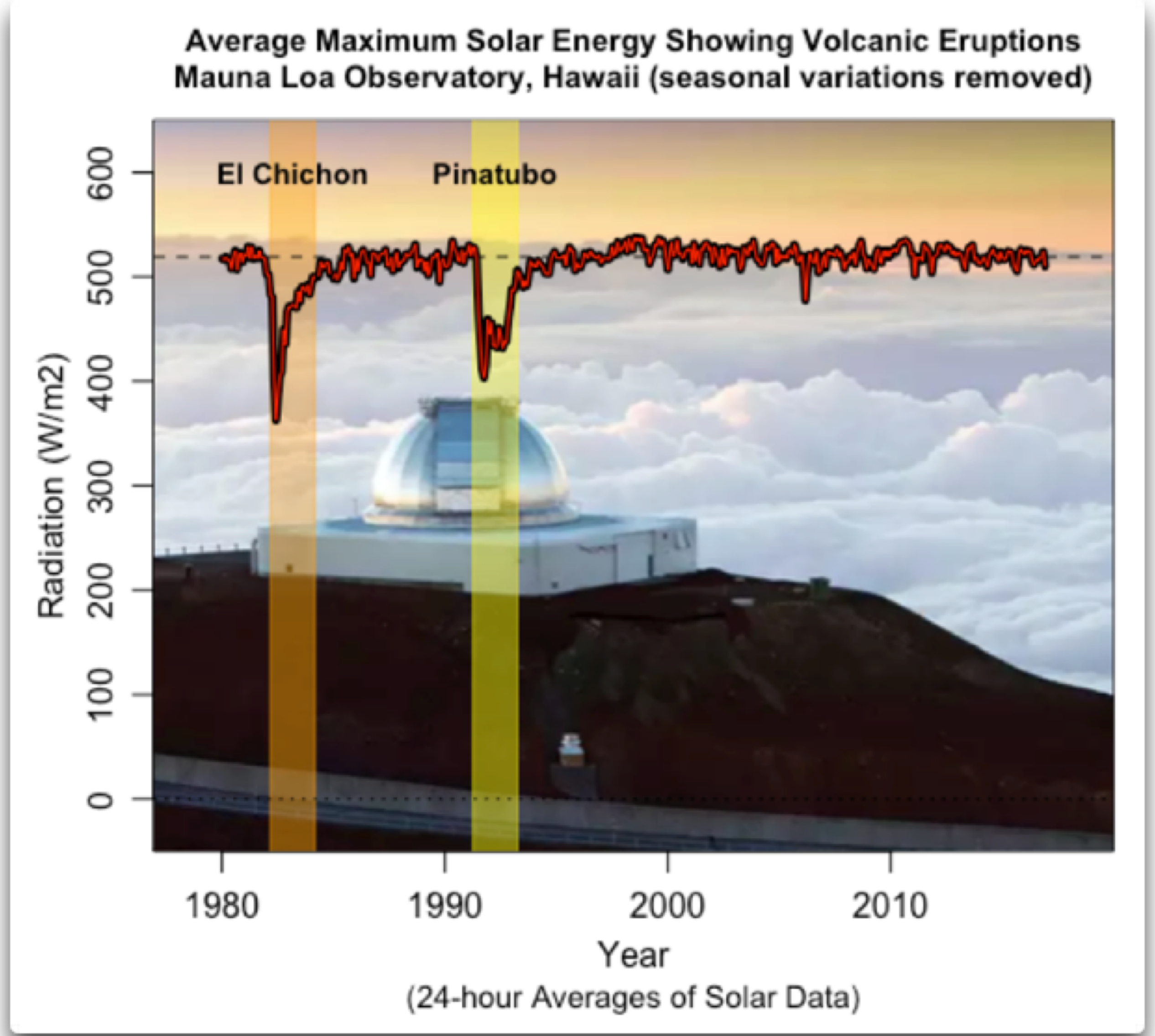
Climate Forcing:

Something that ‘pushes’ the climate system in one direction

Review: Forcings and Feedbacks

Climate Forcing:

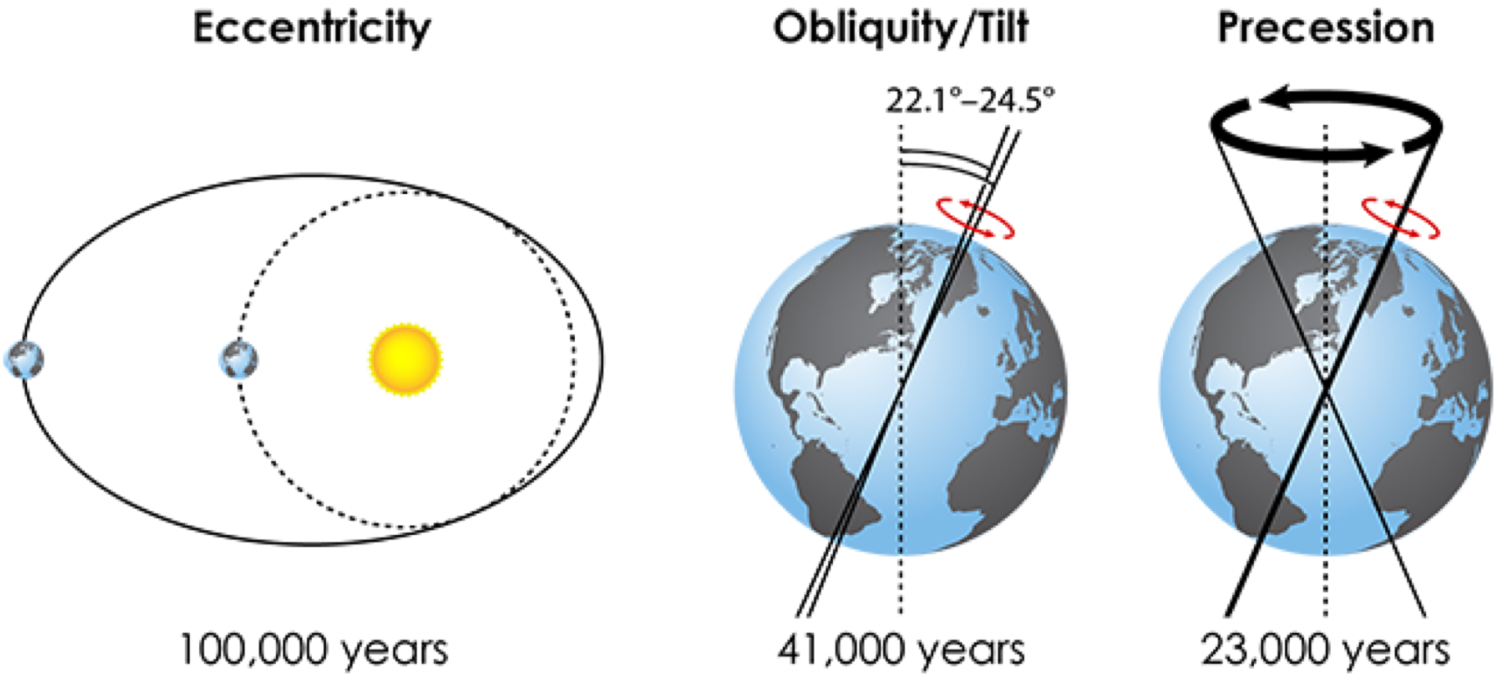
Example: explosive volcanoes reduce incoming solar radiation



Review: Forcings and Feedbacks

Climate Forcing:

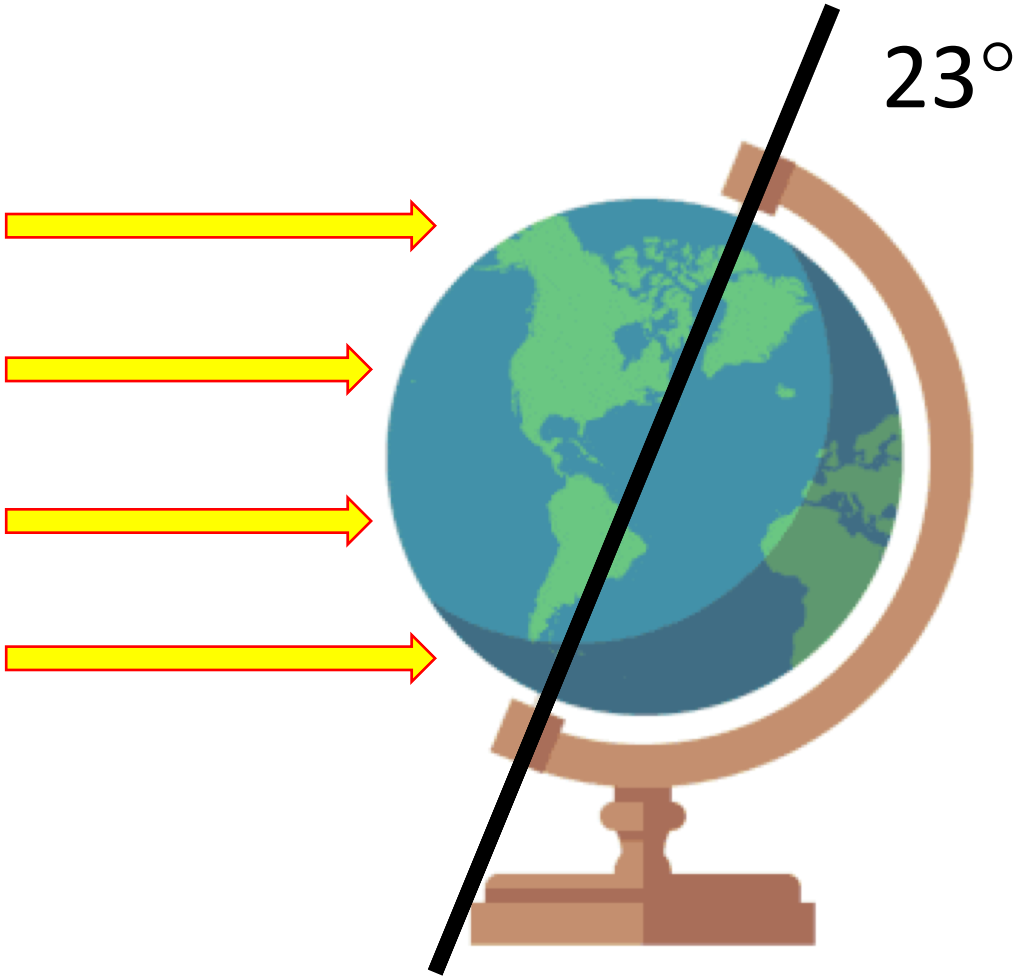
Example: Earth's orbital cycles… affect how much solar radiation is received at different latitudes



Review: Forcings and Feedbacks

Orbital cycles:

Do not affect how much radiation is hitting Earth, but where and when that radiation is focused



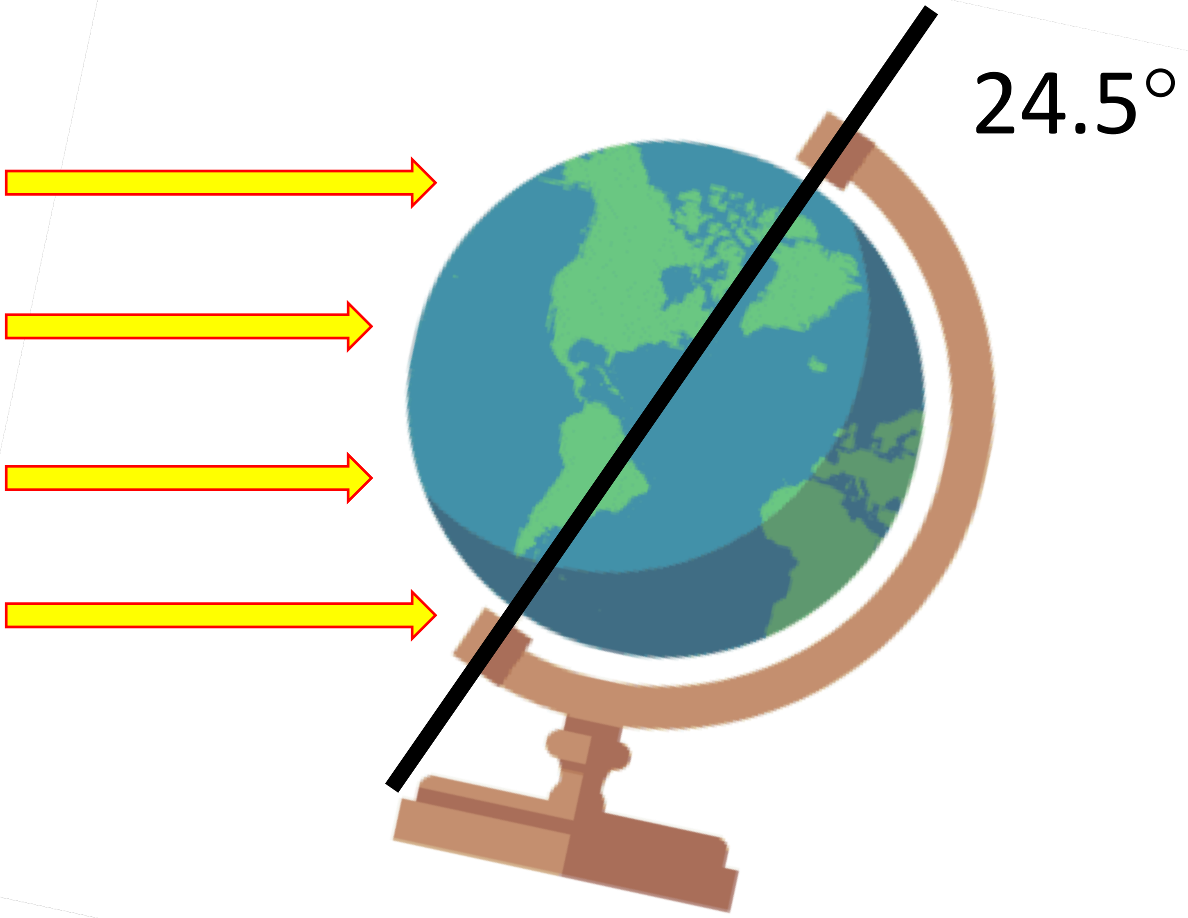
Review: Forcings and Feedbacks

Orbital cycles:

Do not affect how much radiation is hitting Earth, but where and when that radiation is focused

Example:

- More axial tilt = more intense seasons



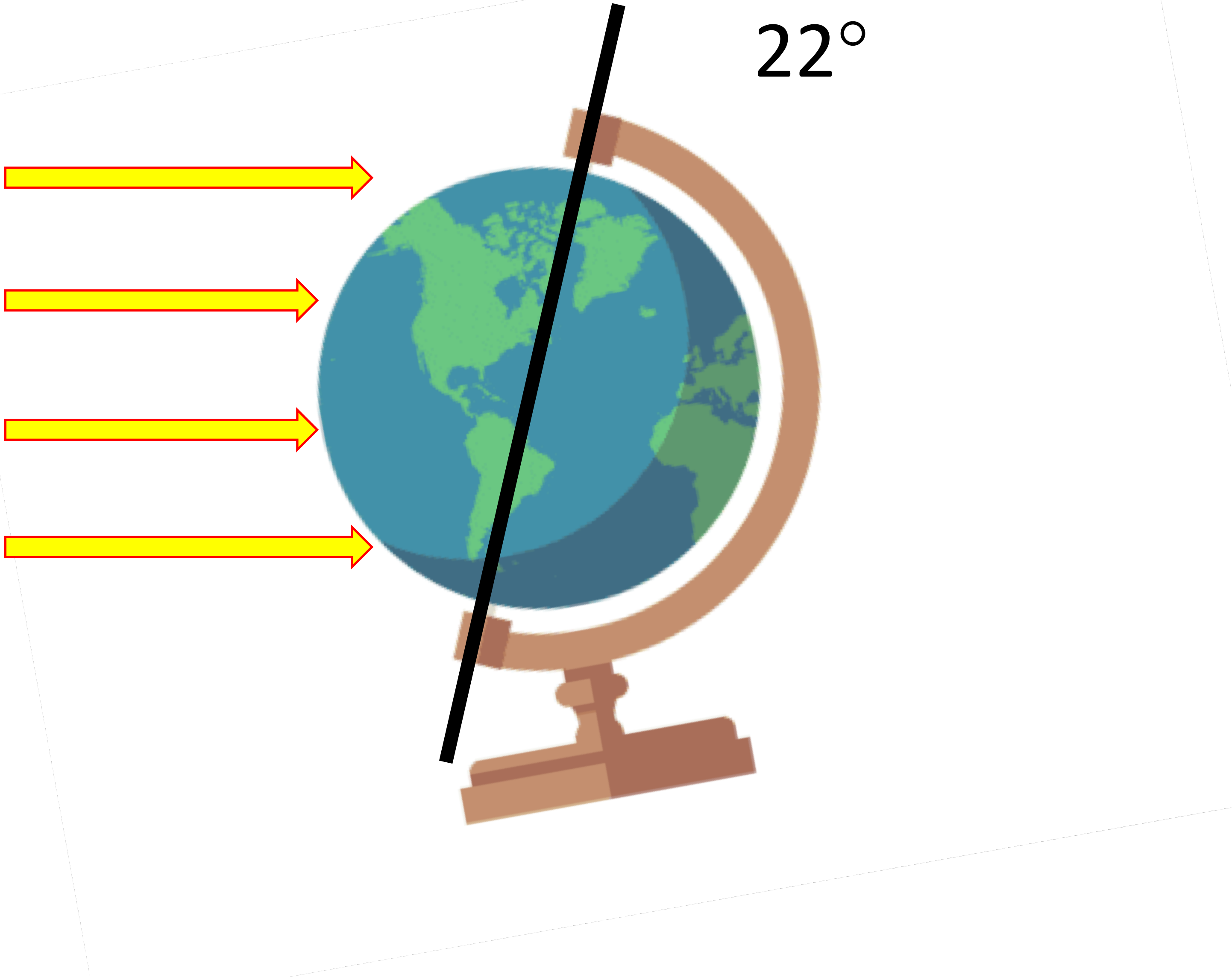
Review: Forcings and Feedbacks

Orbital cycles:

Do not affect how much radiation is hitting Earth, but where and when that radiation is focused

Example:

- More axial tilt = more intense seasons (and vice versa)



Review: Forcings and Feedbacks

Orbital cycles:

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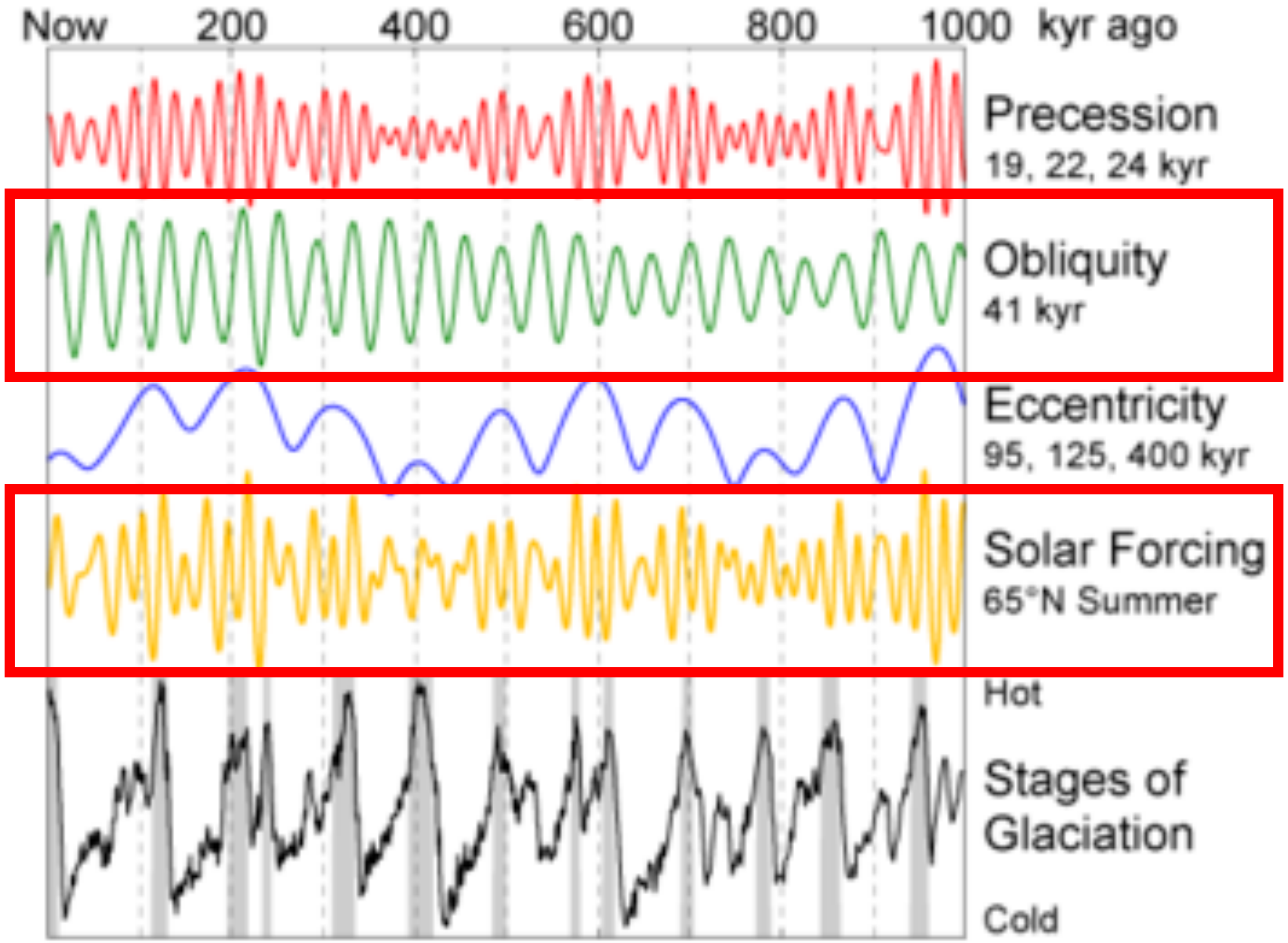
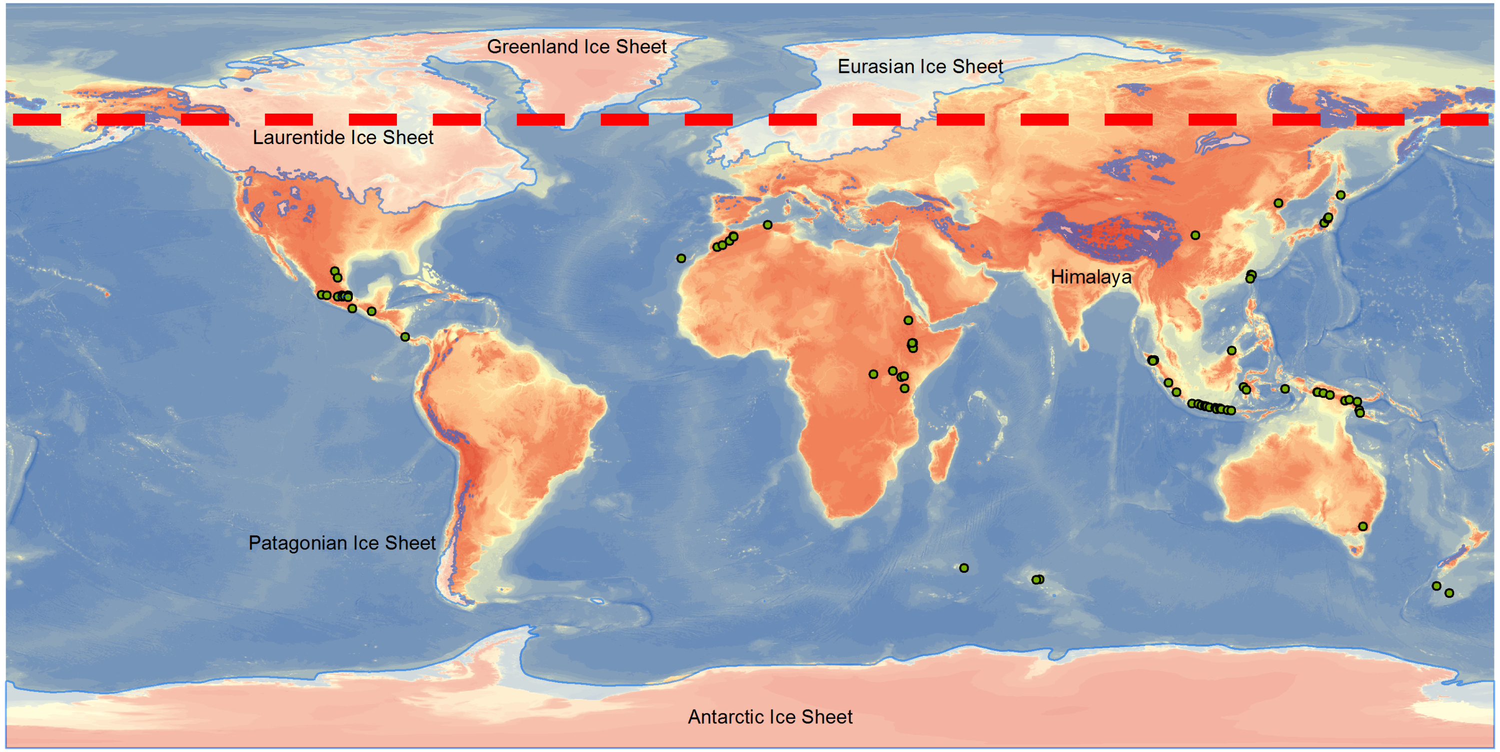


Review: Forcings and Feedbacks

Orbital cycles:

For reconstructing climate, we look at solar radiation received during summer at 65°N

This is where big ice sheets form!



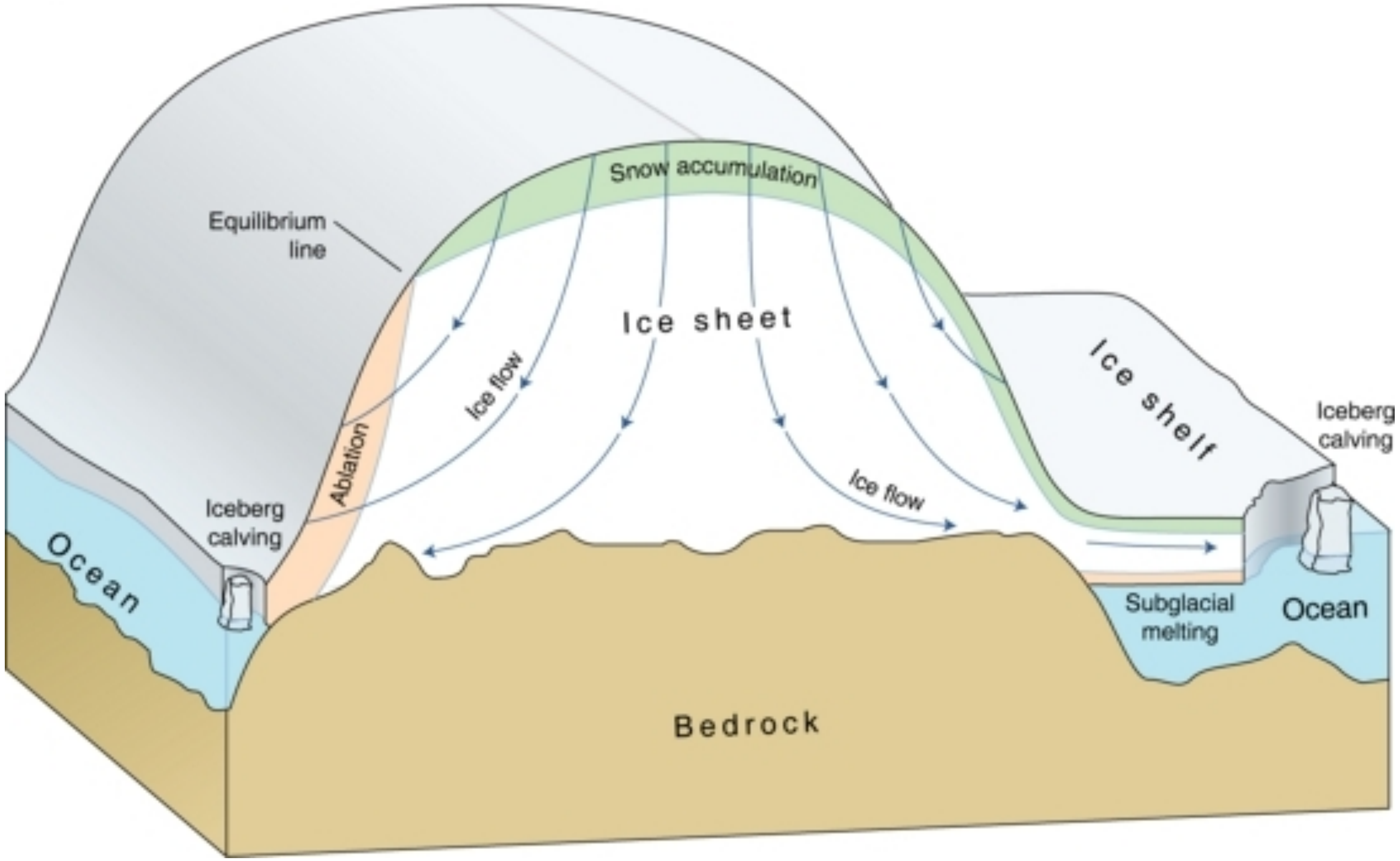
Review: Forcings and Feedbacks

Feedbacks:

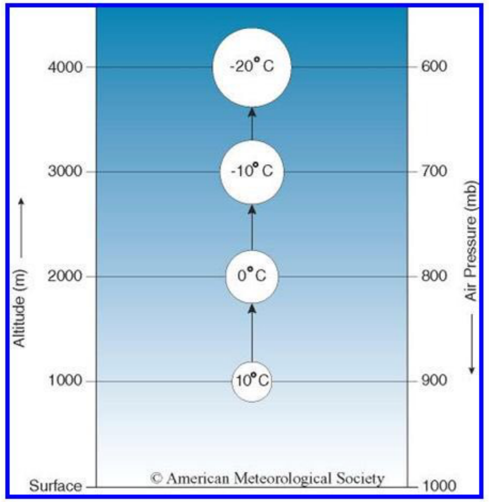
Internal dynamics that amplify (positive) or diminish (negative) a forcing

Review: Forcings and Feedbacks

Positive feedback example - Greenland Ice Sheet lowering, exposed to more warm air, further melting



Adiabatic Processes



Dry adiabatic lapse rate describes the expansional cooling of ascending unsaturated air parcels

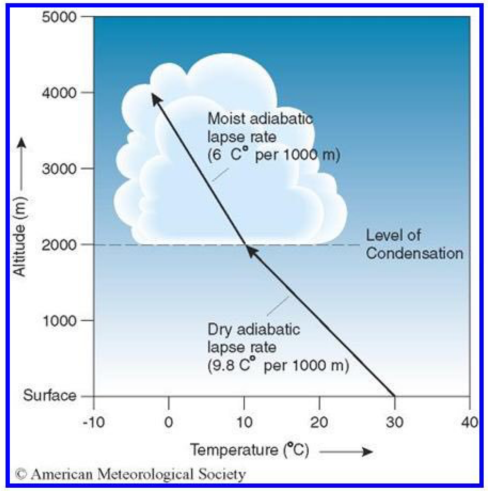


Illustration of dry and moist adiabatic lapse rates

Review: Forcings and Feedbacks

Feedbacks:

Positive feedback example – West Antarctic ice retreat, allowing more ocean water under ice, enhanced melting

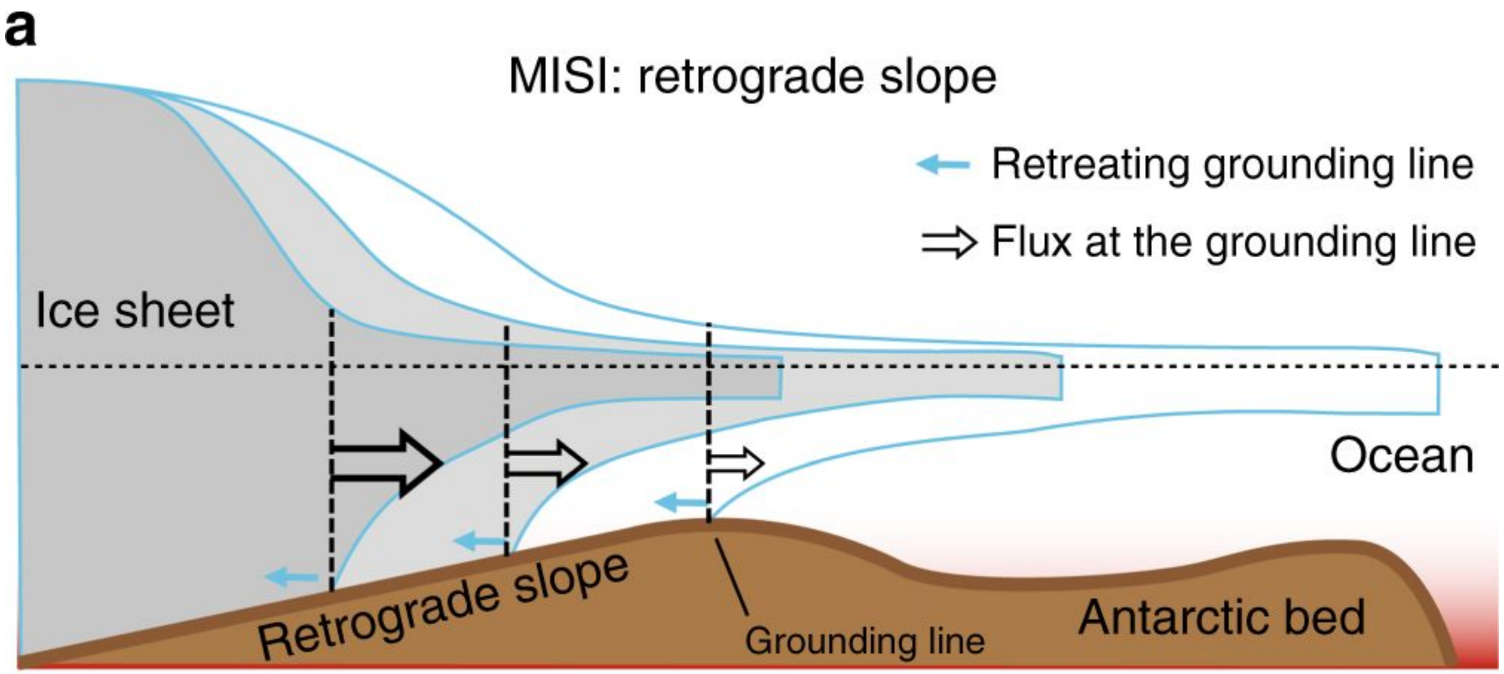


Image from Pattyn (2018), *Nature Communications*

Review: Forcings and Feedbacks

Feedbacks:

Negative feedback example – Mountain glaciers retreating, end up at higher elevations where it is colder

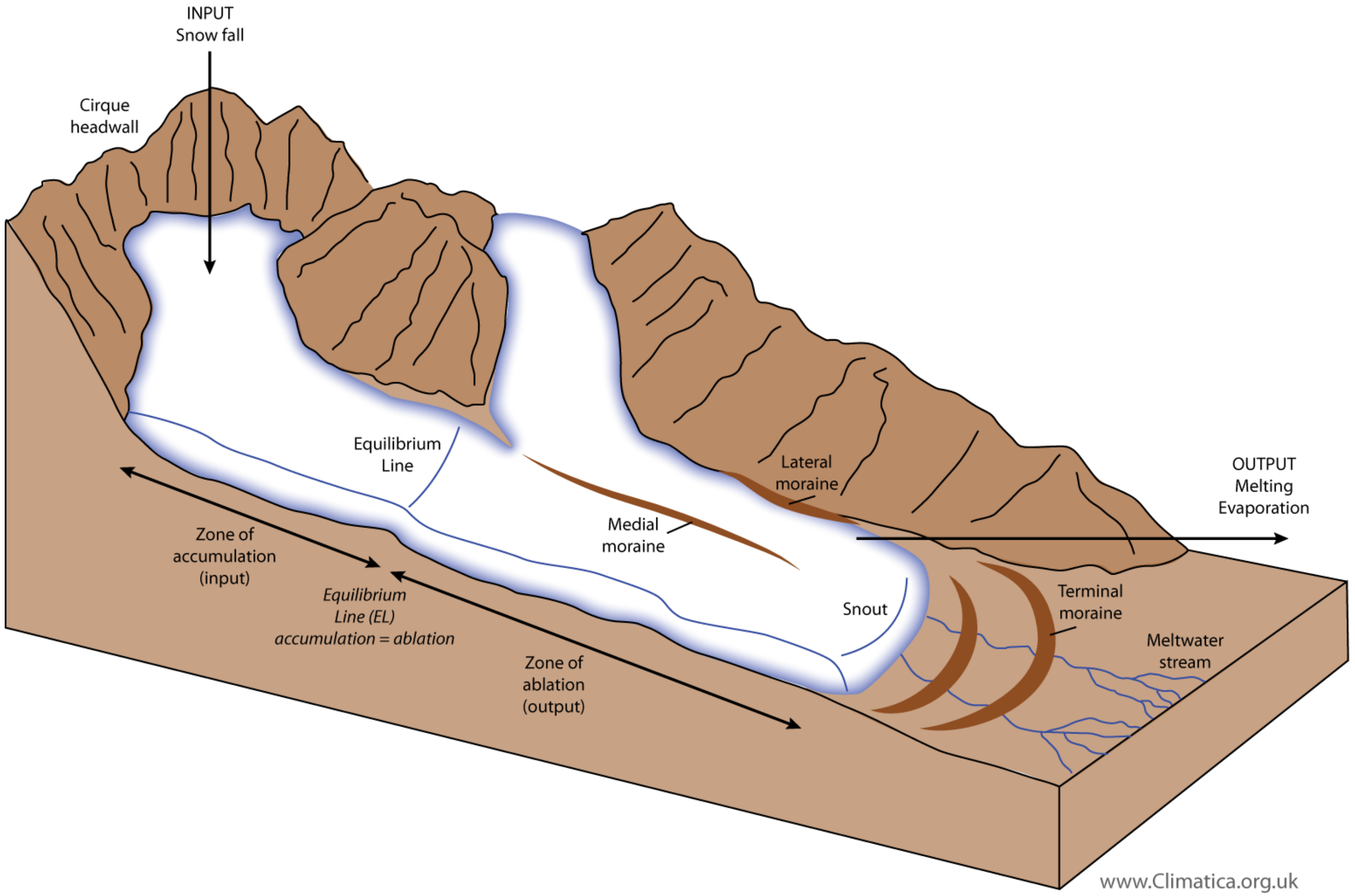


Image from *Climatica.org.uk*

Today's Class

Carbon Cycle: Reservoirs → Carbon Cycle: Exchanges → Human Impacts on Carbon Cycle → Carbon Cycle Feedbacks in a Warming World

Carbon Reservoirs

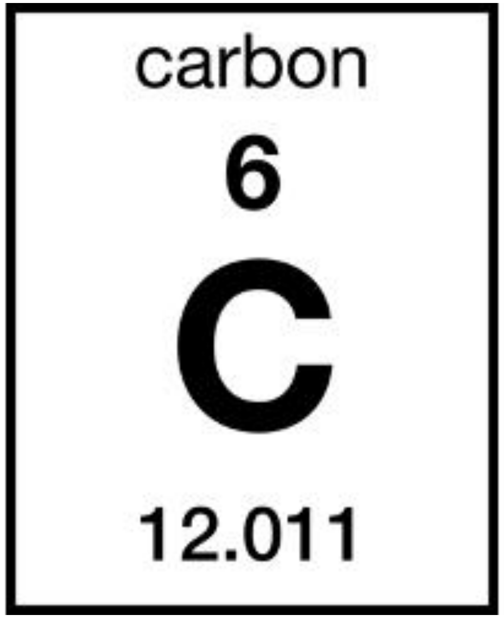
Quick Lesson on Units:

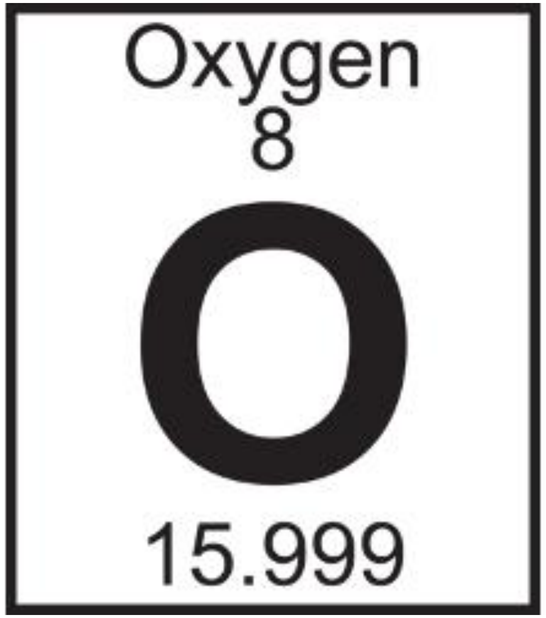
Gigaton = 1 billion tons
(~140 million bull elephants)

Gigatons of Carbon vs.
Gigatons of Carbon Dioxide

GtC vs. $GtCO_2$

12   12+16+16 = 44



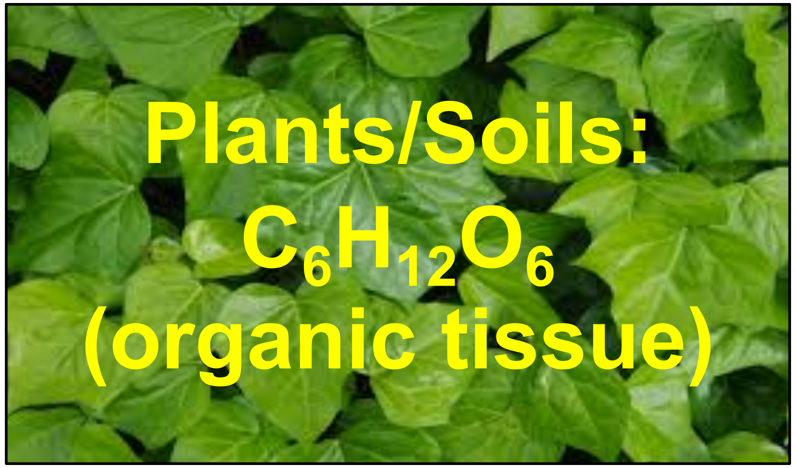


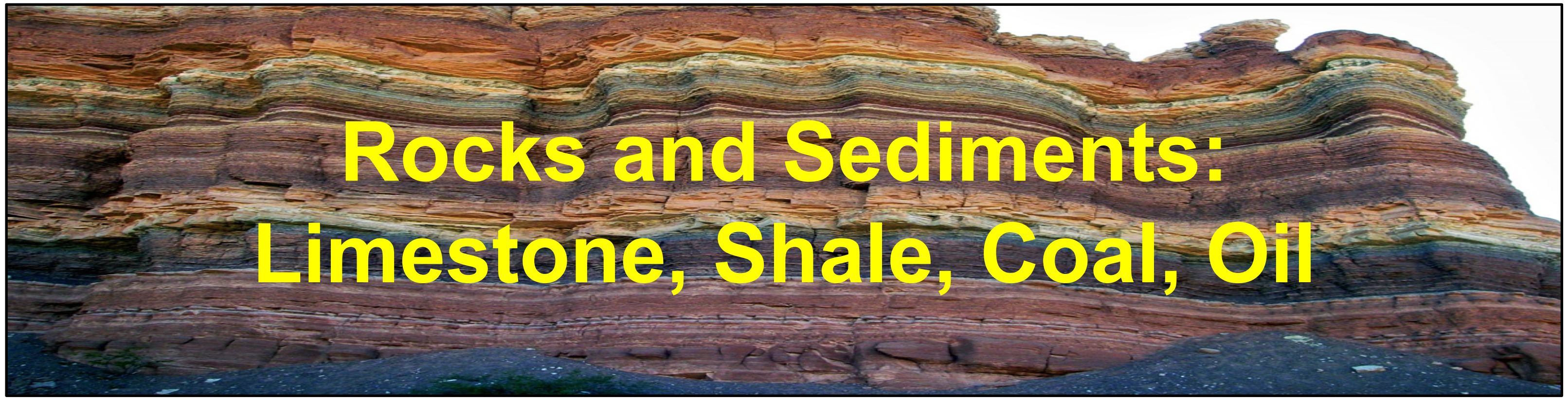
3.7X

Carbon Cycle: Reservoirs

Carbon Reservoirs

Carbon is present on Earth in many forms!





Carbon Reservoirs (GtC)

Atmosphere (600, Preindustrial)

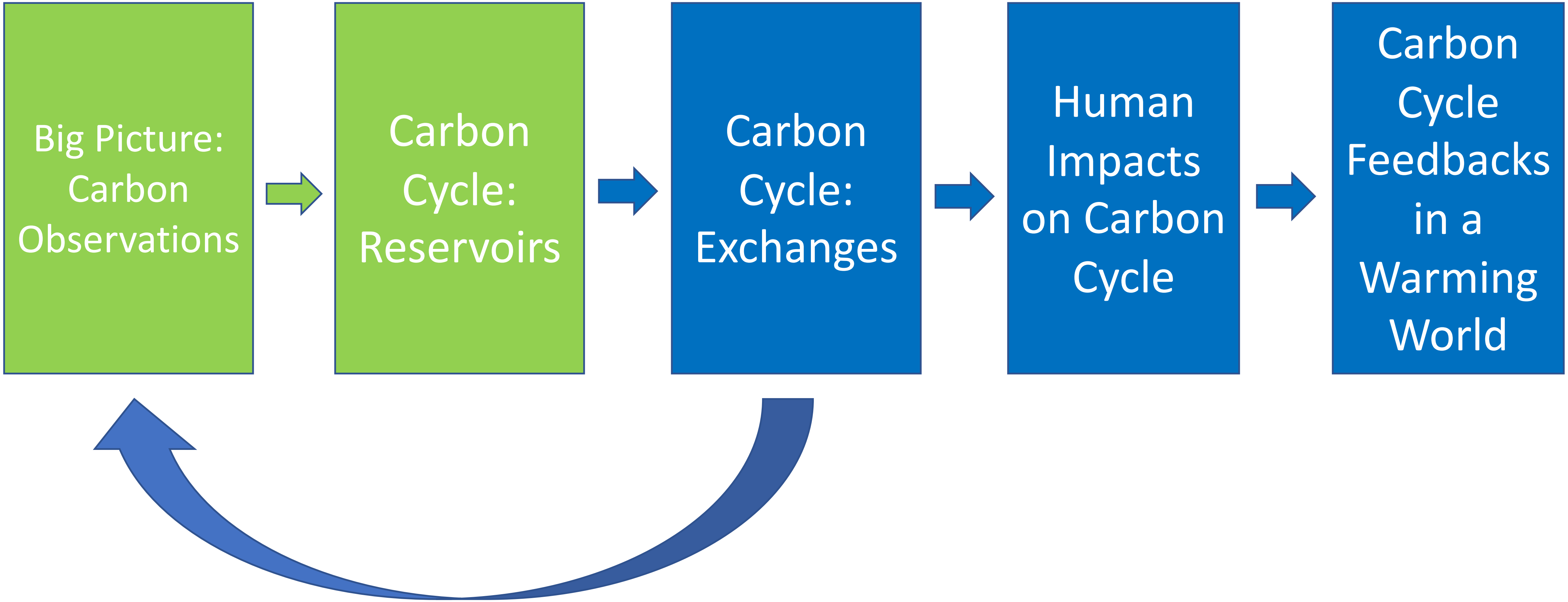
Surface Ocean (1,000)

Plants/Soils (2,000)

Deep Ocean (40,000)

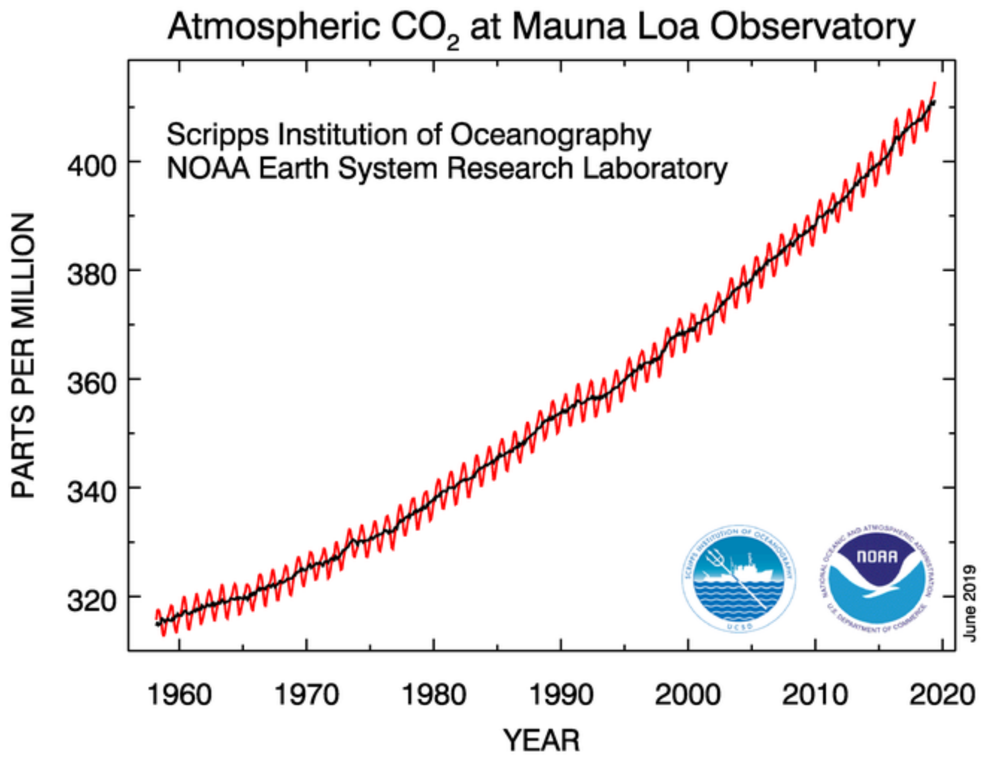
Rocks and Sediments (66,000,000)

Check In


Big Picture: Carbon Observations
Carbon Cycle: Reservoirs
Carbon Cycle: Exchanges
Human Impacts on Carbon Cycle
Carbon Cycle Feedbacks in a Warming World

Carbon Cycle: Exchanges

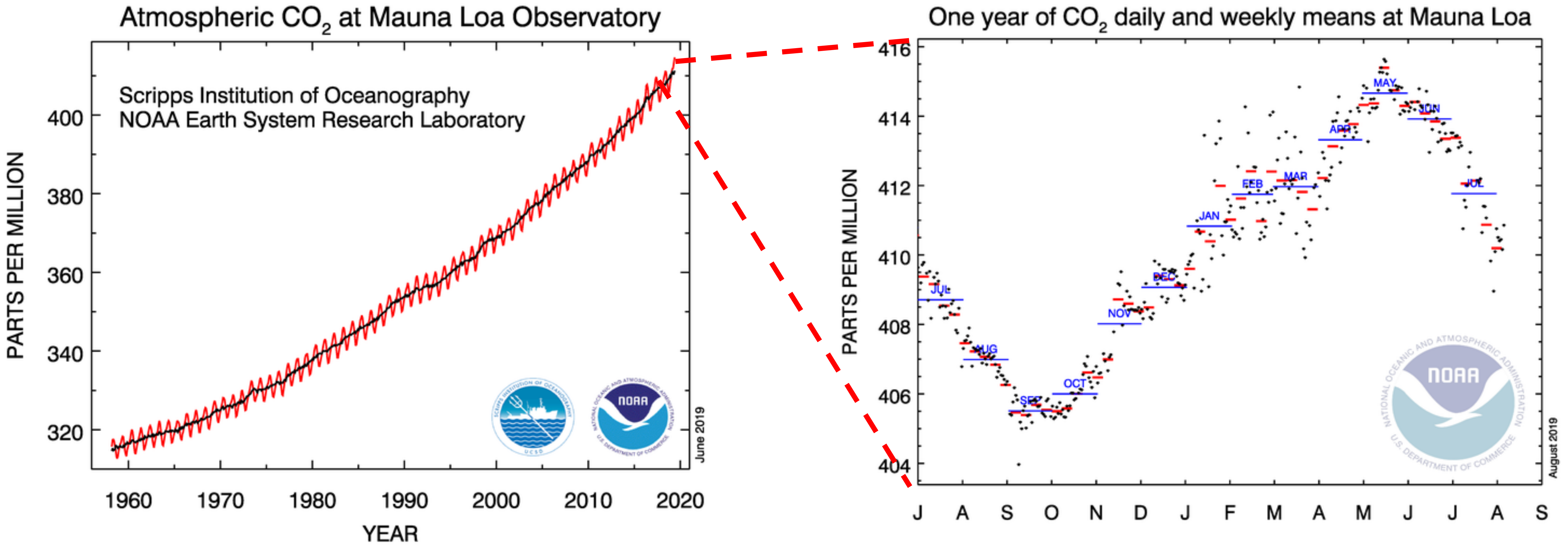
Mauna Loa Observatory



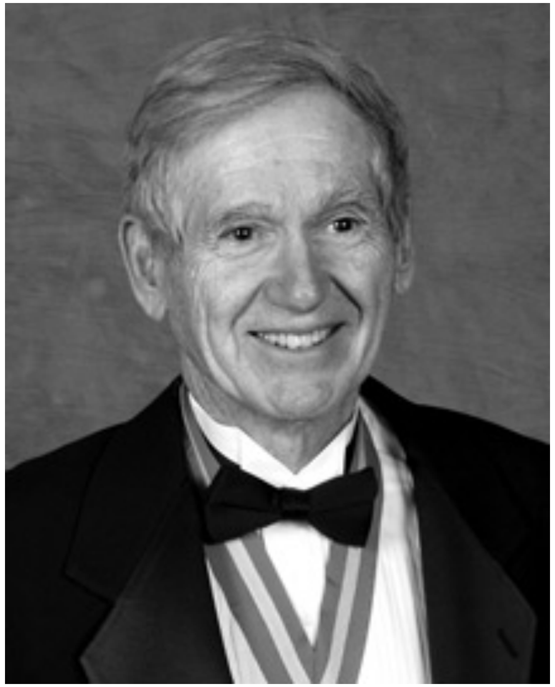
The Mauna Loa observatory is a gas measuring station located high up on the Mauna Loa volcano (11,140 feet above sea level). Its location in the middle of the Pacific and high above local emission sources makes it ideal for sampling 'global average' air. It has been continually recording since 1958!

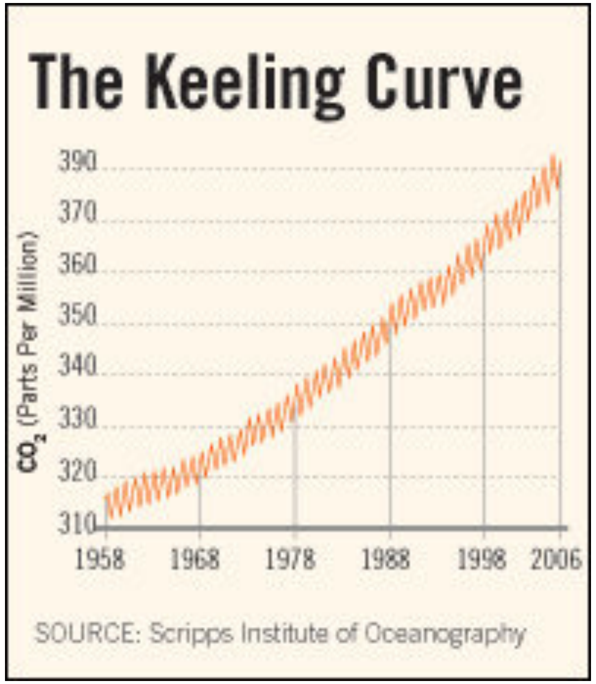
Think, Pair, Share

This plot of atmospheric CO_2 shows a pattern of annually increasing and decreasing concentration on top of the overall rising trend. What process(es) do you think could be responsible for this pattern?



Dr. Charles (Dave) David Keeling (1928 – 2005)



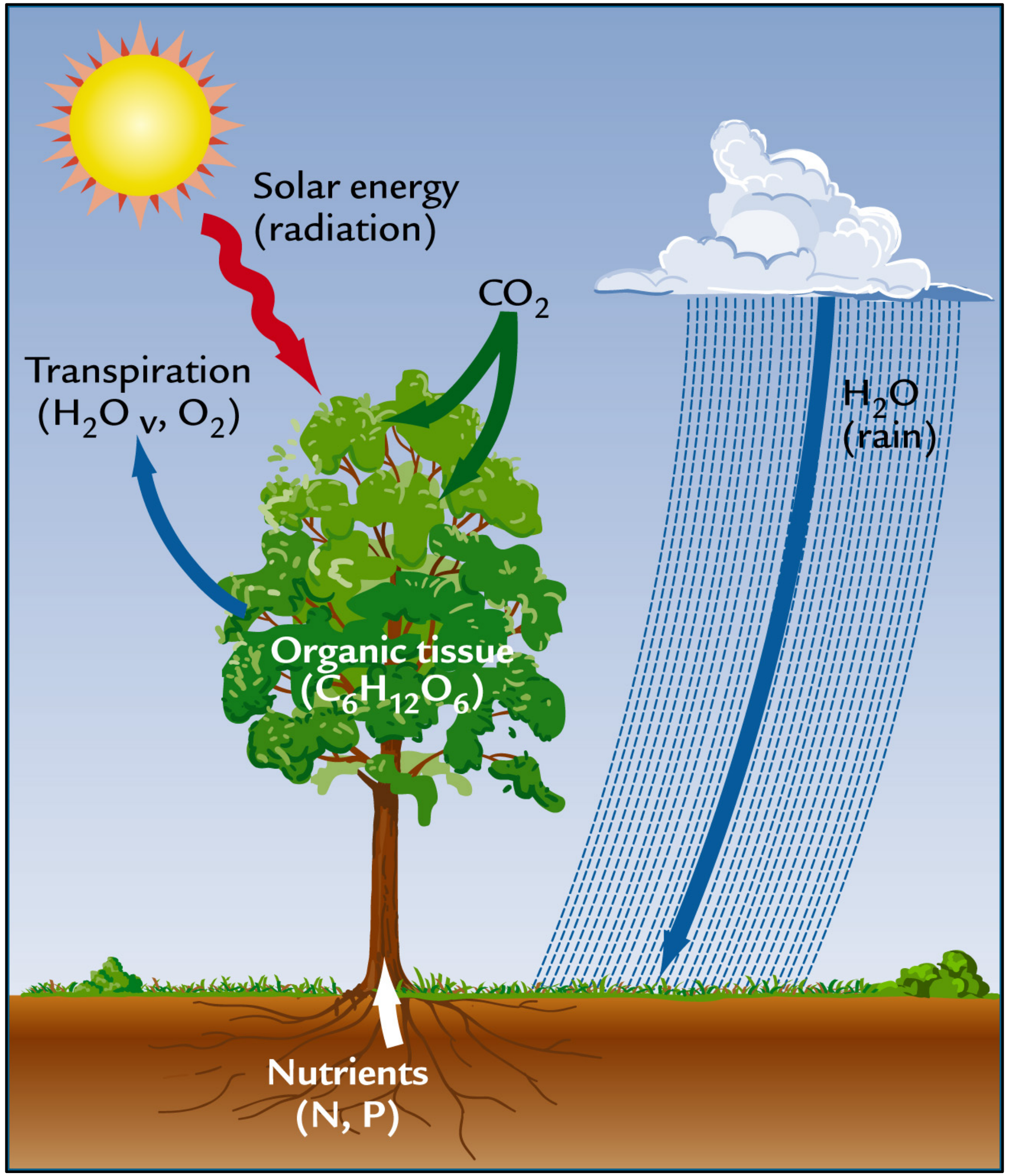


Dave Keeling was a chemist and physicist who developed a method to accurately measure gas concentrations in air. He began monitoring atmospheric CO_2 levels around the world and eventually secured funding to set up long-term monitoring stations in strategic locations. His Mauna Loa observatory has continually recorded CO_2 concentrations since 1958 and was the first warning sign that humans were increasing greenhouse gas concentrations.

Carbon Exchanges: Photosynthesis

Plants take CO_2 out of the atmosphere and emit oxygen and water vapor

- Photosynthesis: Absorbing CO_2 and solar radiation, creating 'food'
- Respiration: Plant breaks down 'food' for energy, releasing CO_2



Global-Scale Photosynthesis

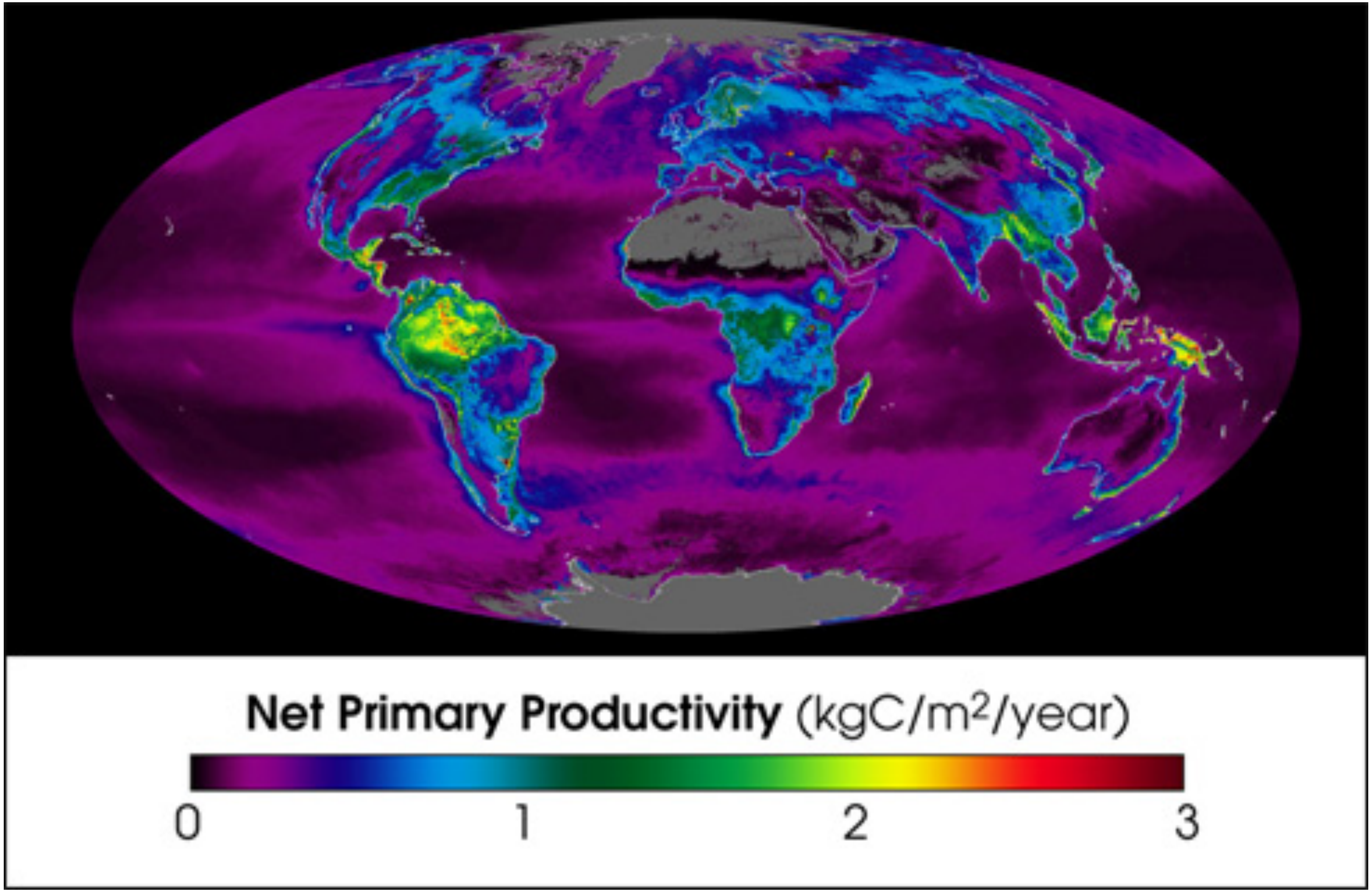
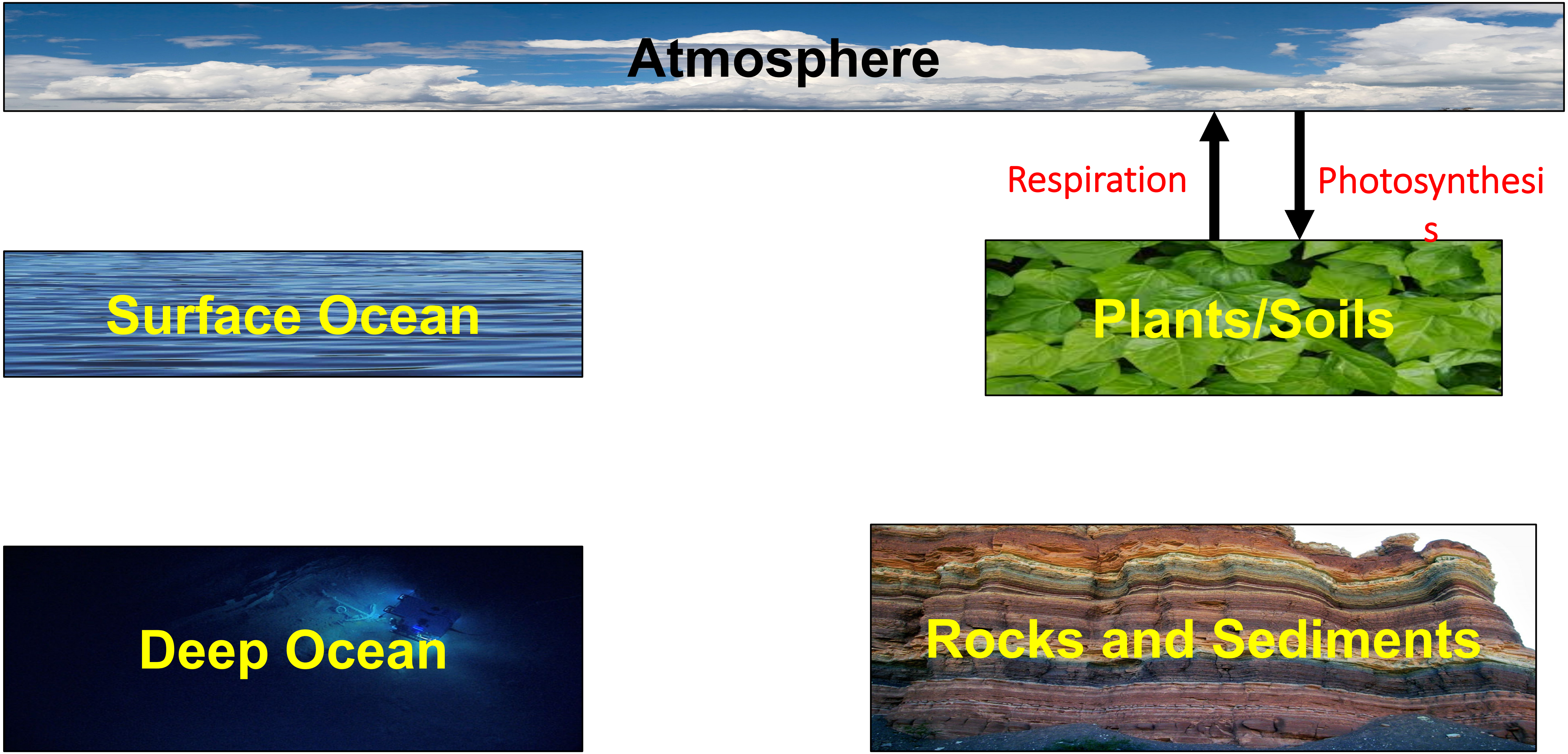
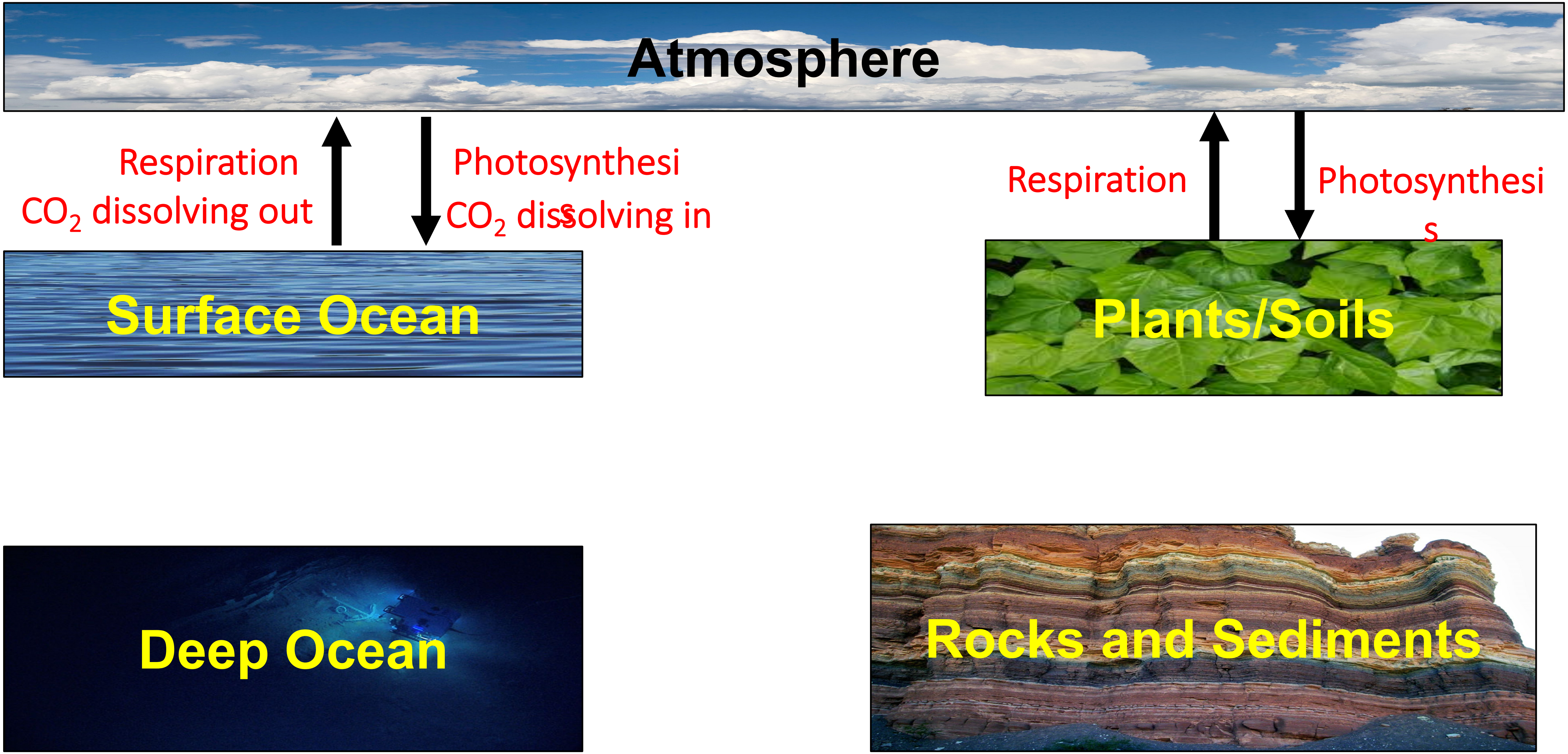


Figure from NASA

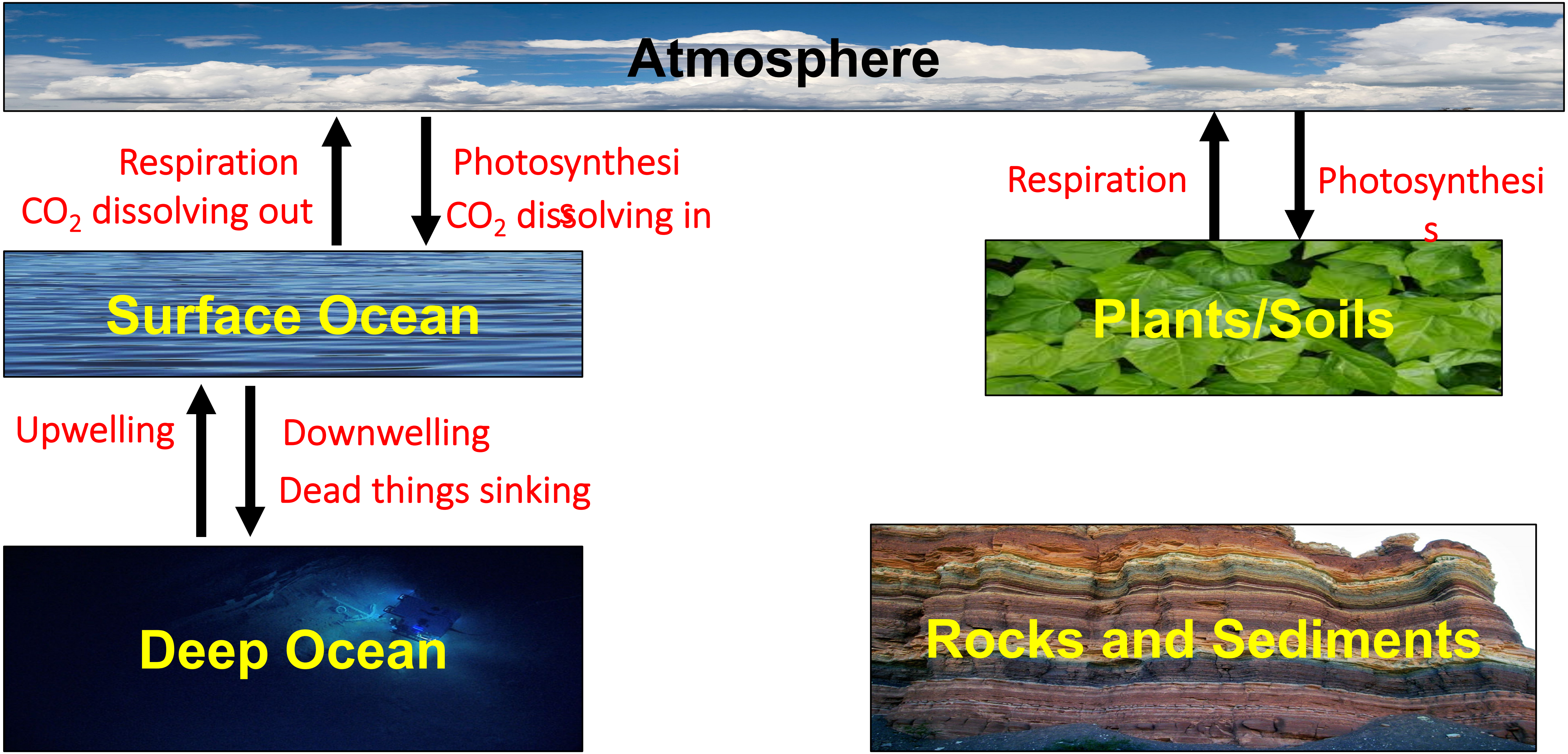
Carbon Exchanges



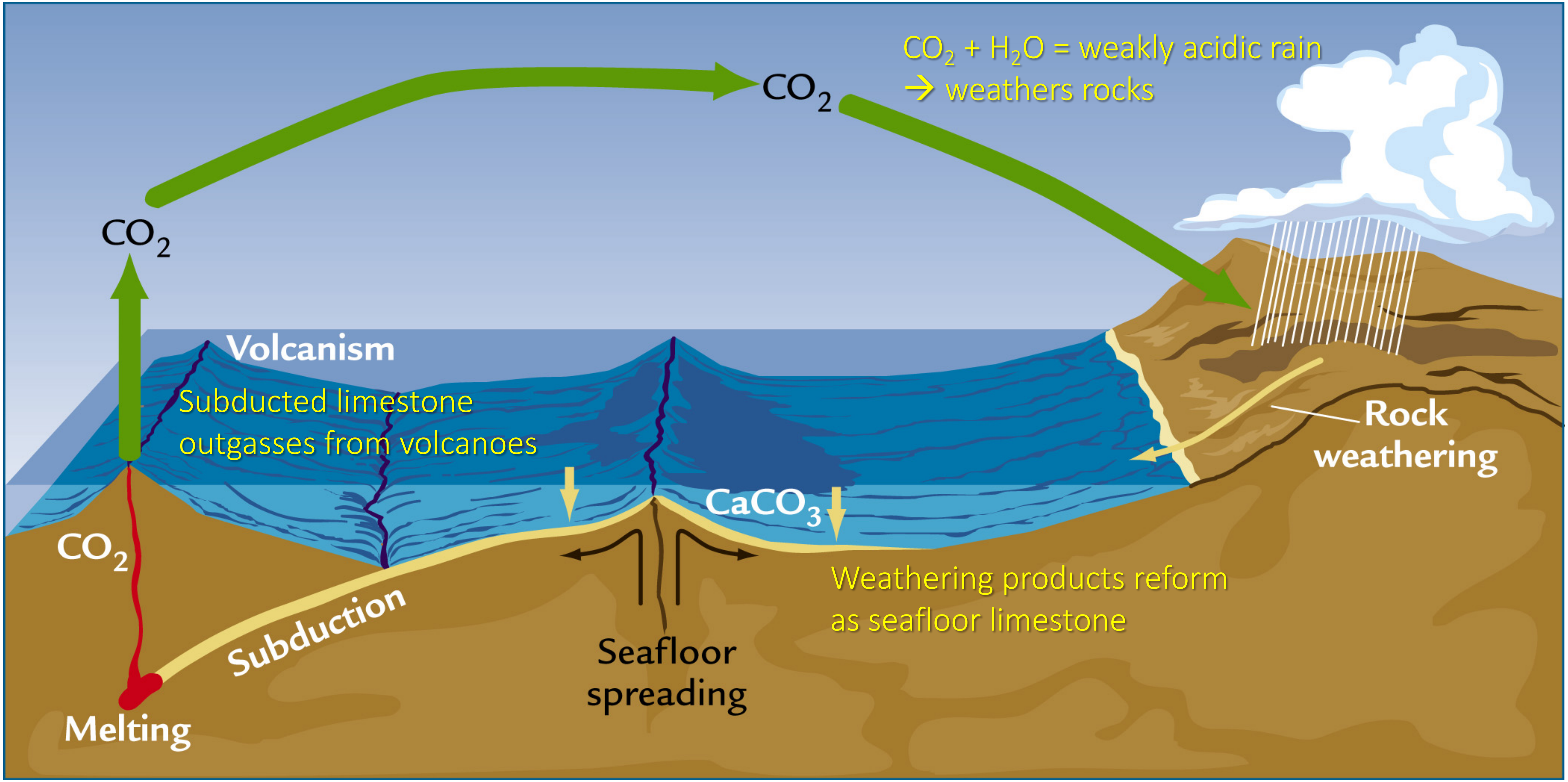
Carbon Exchanges



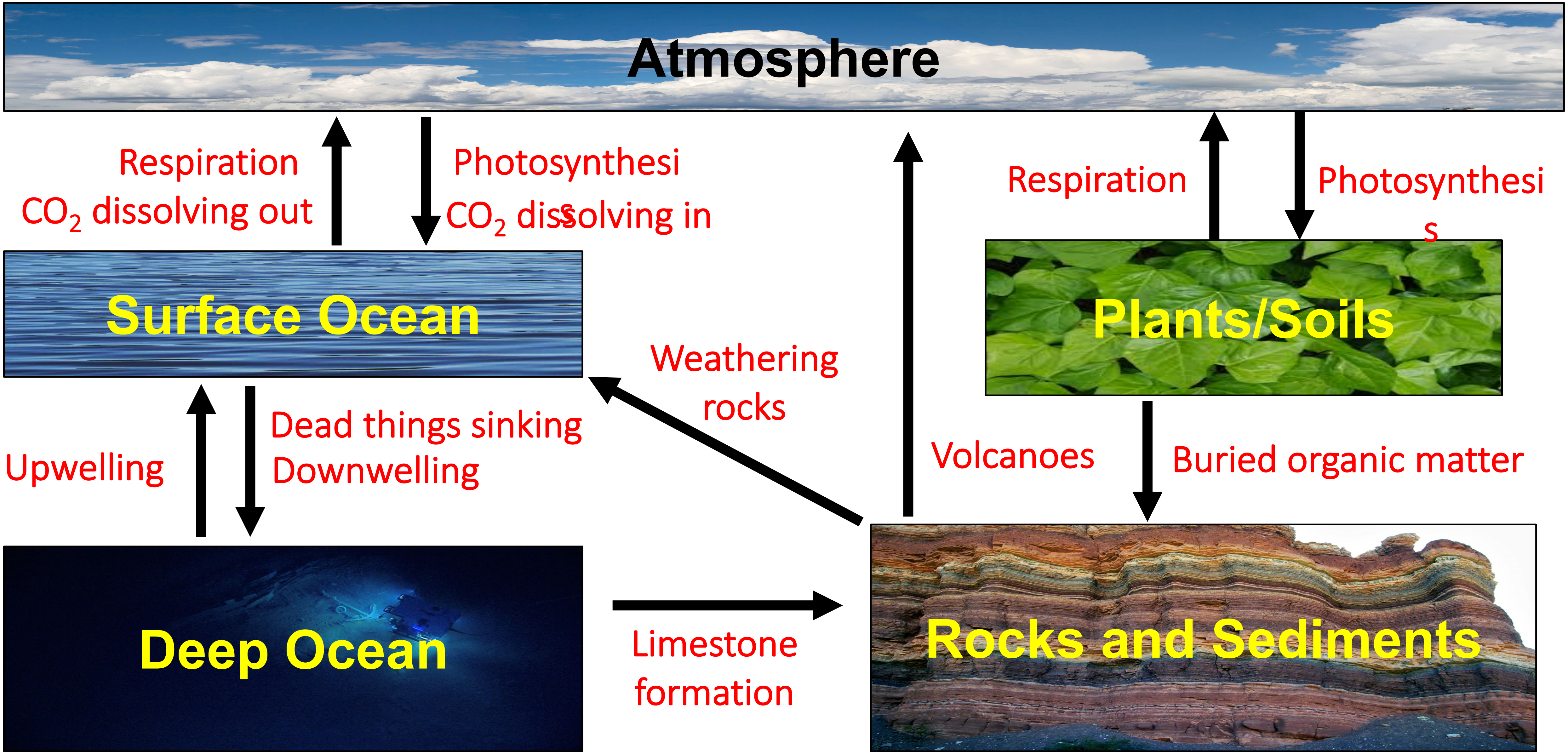
Carbon Exchanges

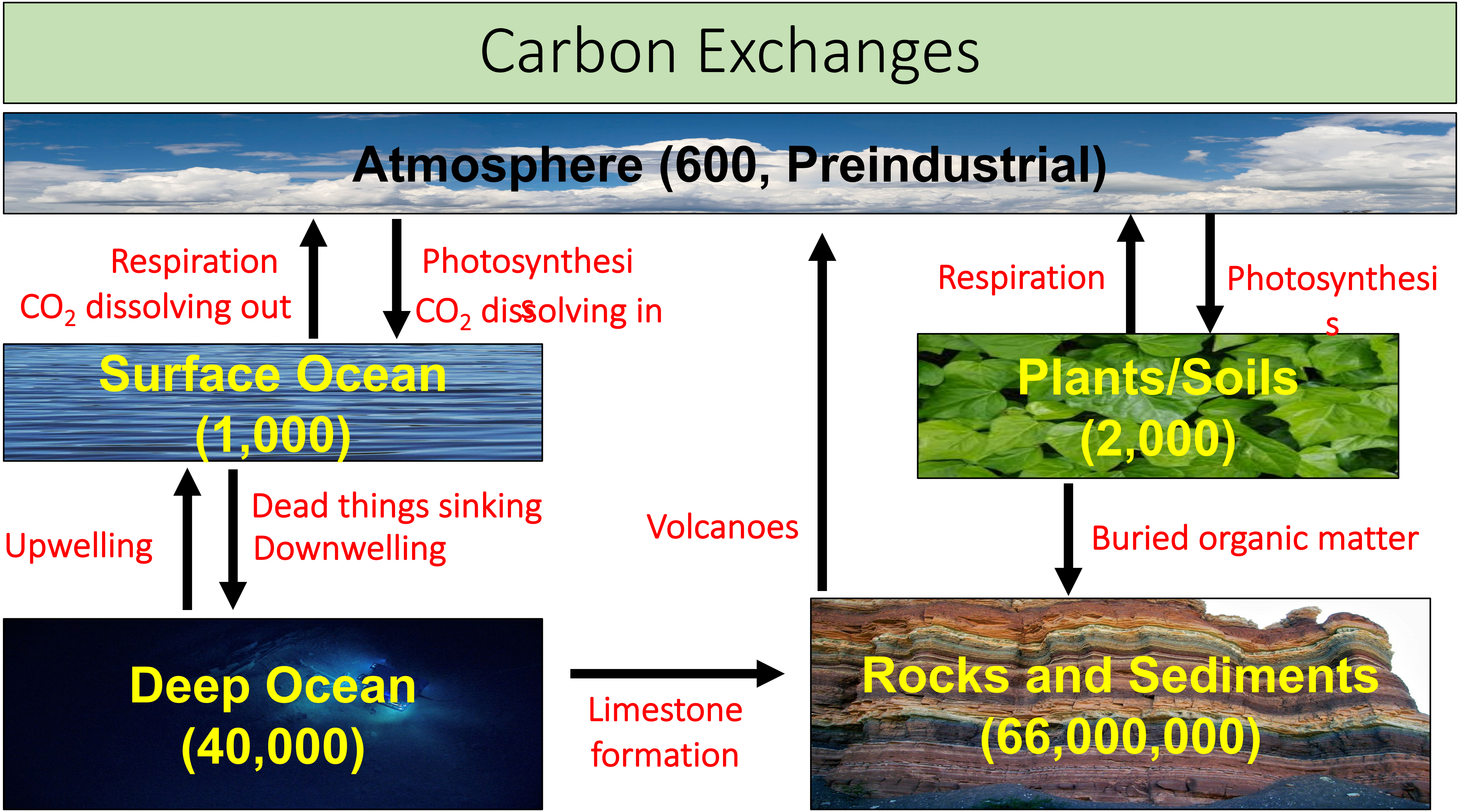


Carbon Exchanges

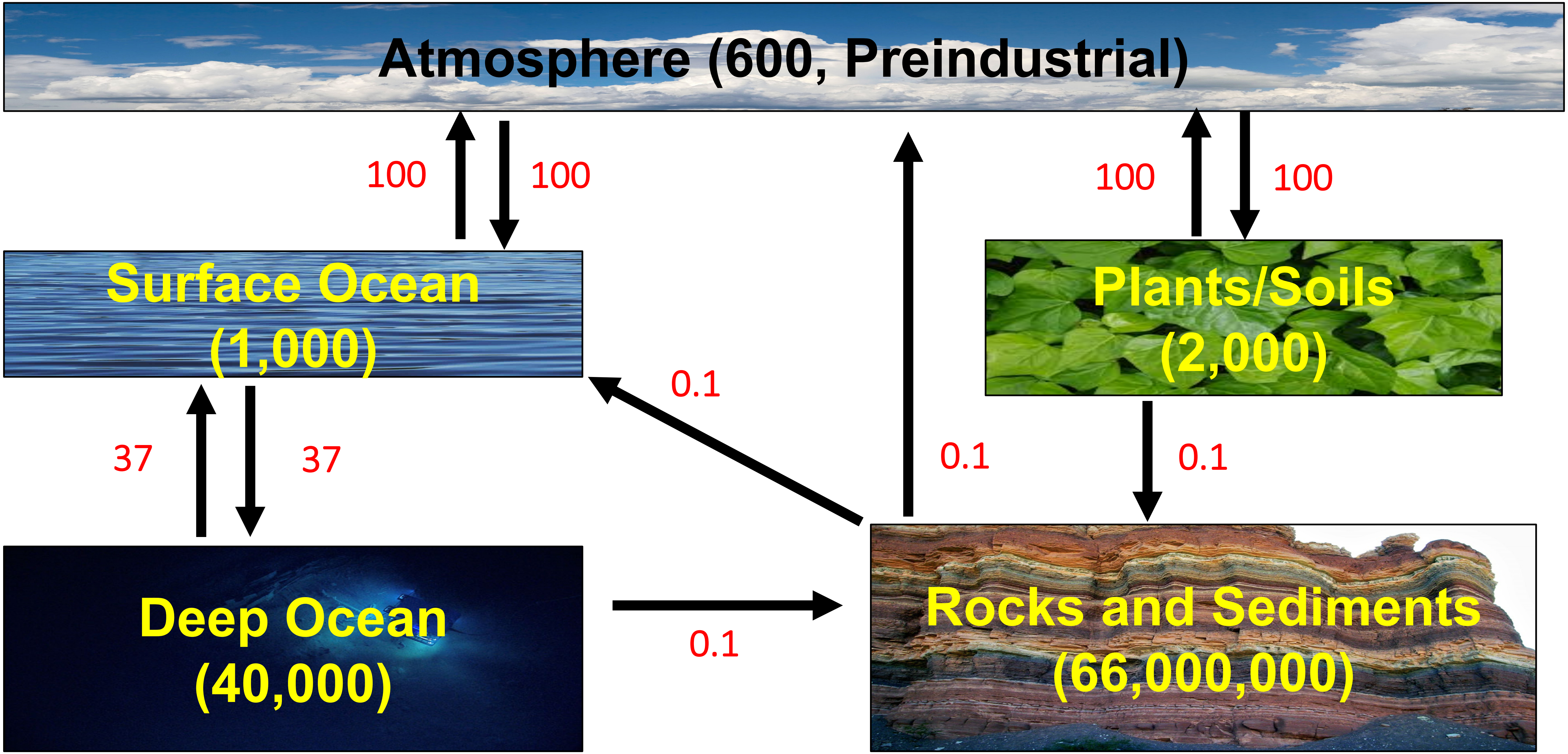


Carbon Exchanges




Carbon Exchanges
Atmosphere (600, Preindustrial)
Respiration
CO_2 dissolving out
Photosynthesis
CO_2 dissolving in
Respiration
Photosynthesis
Surface Ocean (1,000)
Plants/Soils (2,000)
Upwelling
Dead things sinking
Downwelling
Volcanoes
Buried organic matter
Deep Ocean (40,000)
Limestone formation
Rocks and Sediments (66,000,000)

Carbon Exchanges (GtC/year)



Carbon Exchanges

In general…

The bigger a carbon reservoir, the slower it exchanges carbon

In a stable climate, the carbon cycle is balanced

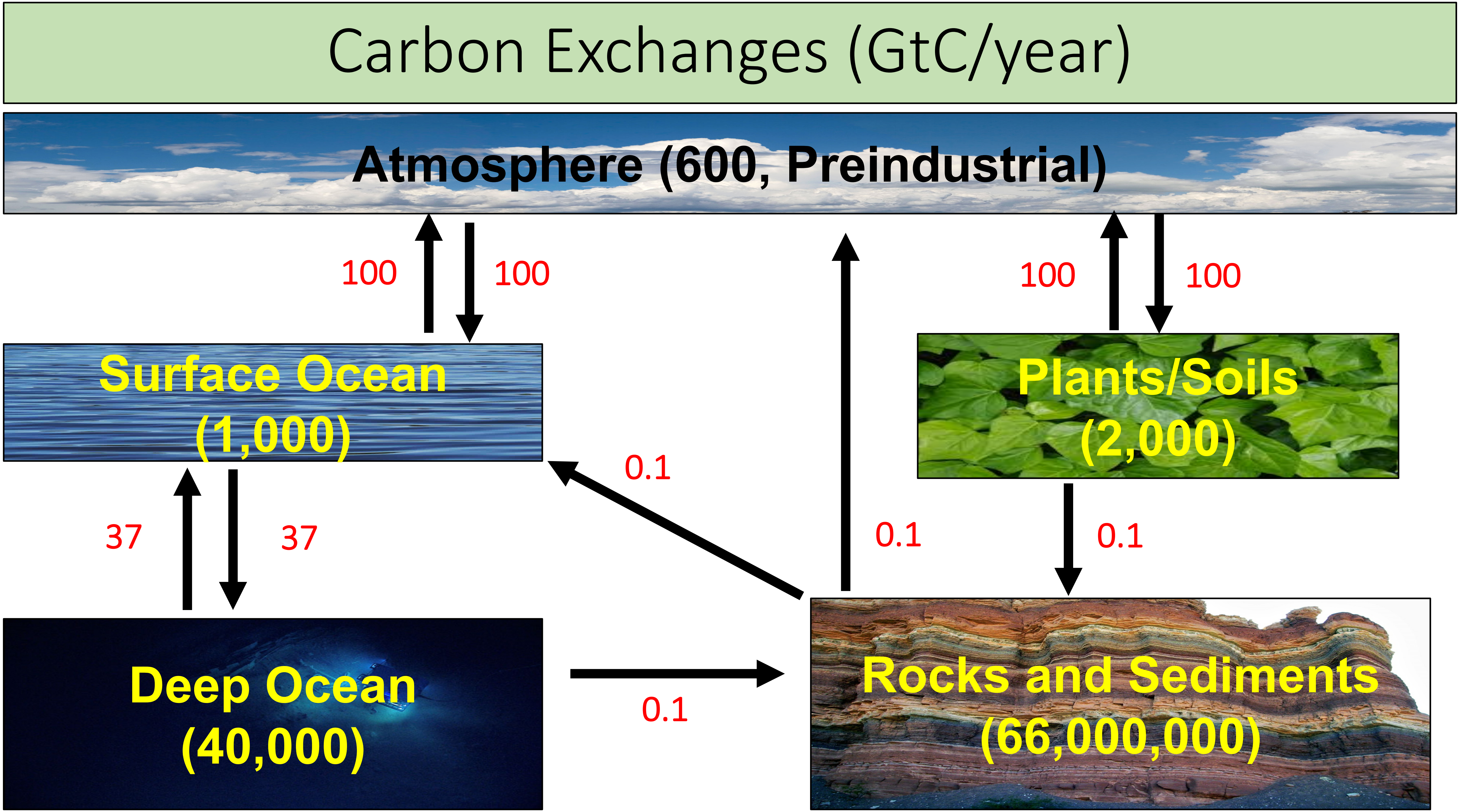
Today's Class

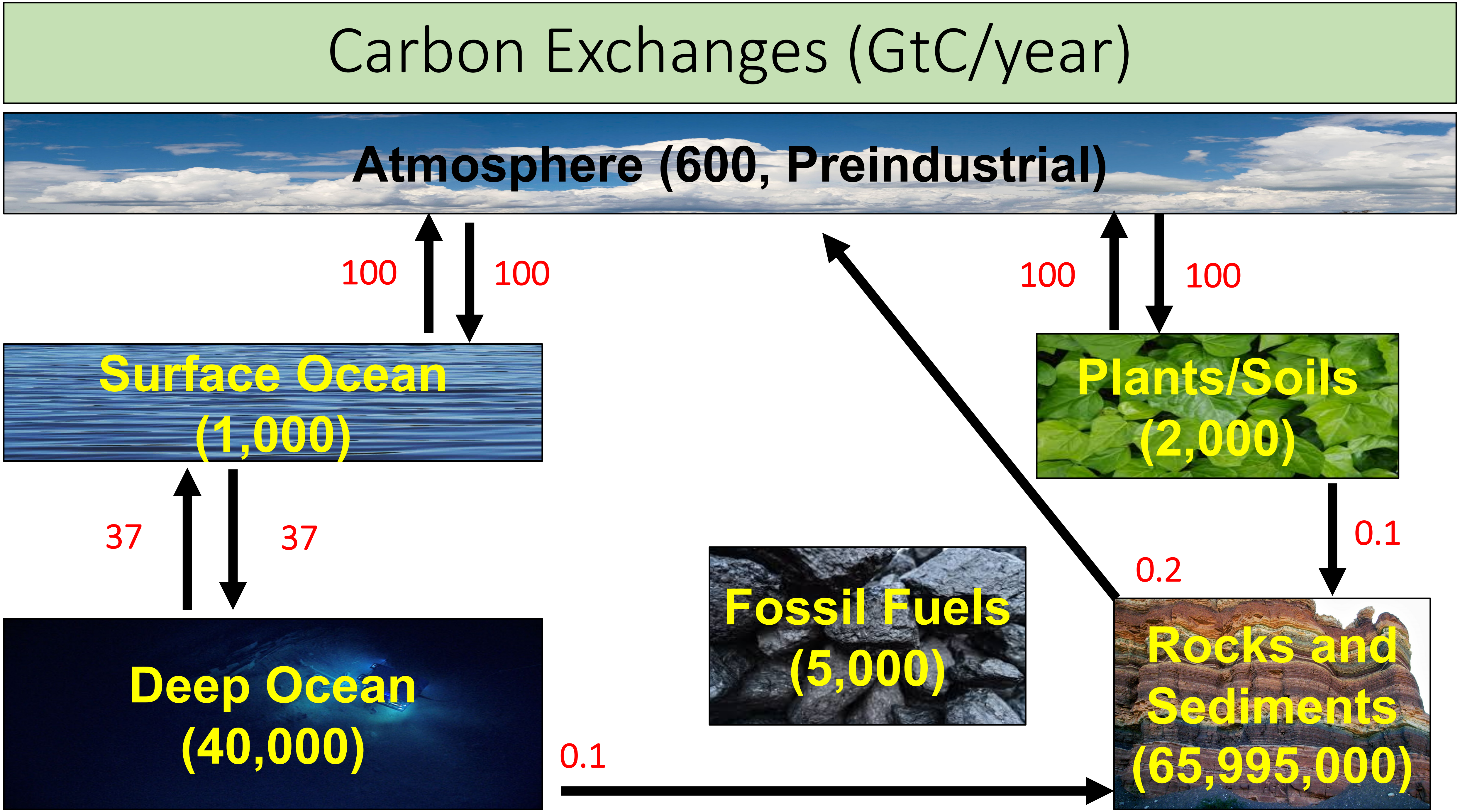
Carbon Cycle: Reservoirs → Carbon Cycle: Exchanges → Human Impacts on Carbon Cycle → Carbon Cycle Feedbacks in a Warming World

Think, Pair, Share

Humans are acting like an extra carbon exchange to the natural carbon cycle. From which reservoirs do you think we are removing carbon, and where are we adding it?

Human Impacts on the Carbon Cycle


Carbon Exchanges (GtC/year)
Atmosphere (600, Preindustrial)
100
100
100
100
Surface Ocean
(1,000)
Plants/Soils
(2,000)
0.1
0.1
0.1
37
37
Deep Ocean
(40,000)
0.1
Rocks and Sediments
(66,000,000)


Carbon Exchanges (GtC/year)
Atmosphere (600, Preindustrial)
100
100
100
100
Surface Ocean (1,000)
Plants/Soils (2,000)
37
37
0.1
0.2
Fossil Fuels (5,000)
Deep Ocean (40,000)
Rocks and Sediments (65,995,000)
0.1

Human Carbon Emissions

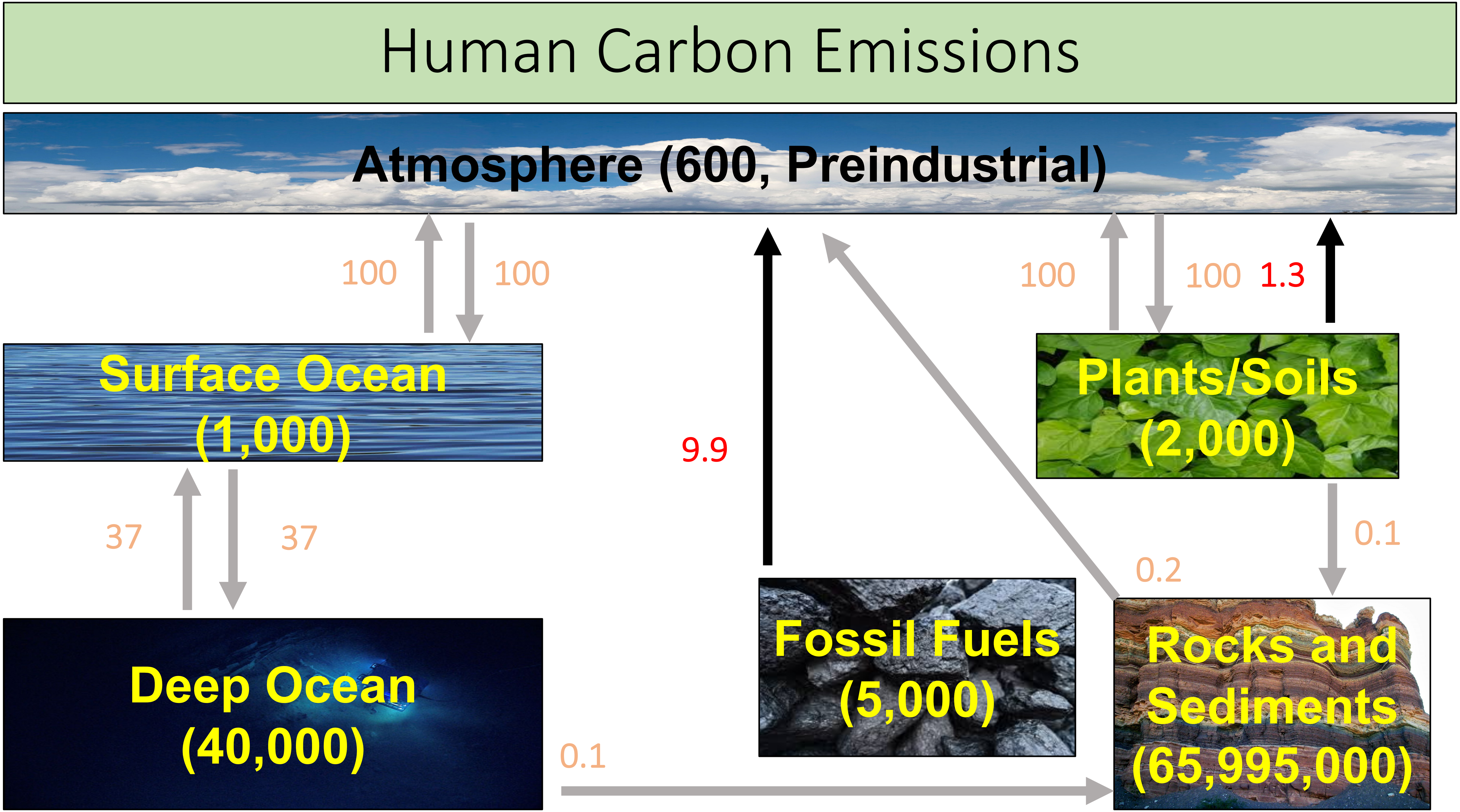
Burning Fossil Fuels

9.9 ± 0.5 GtC/y

Data from World Meteorological Organization

Land Use Change

1.3 ± 0.5 GtC/y


Human Carbon Emissions
Atmosphere (600, Preindustrial)
100
100
Surface Ocean (1,000)
37
37
Deep Ocean (40,000)
9.9
Fossil Fuels (5,000)
100
100
1.3
Plants/Soils (2,000)
0.1
0.2
Rocks and Sediments (65,995,000)
0.1

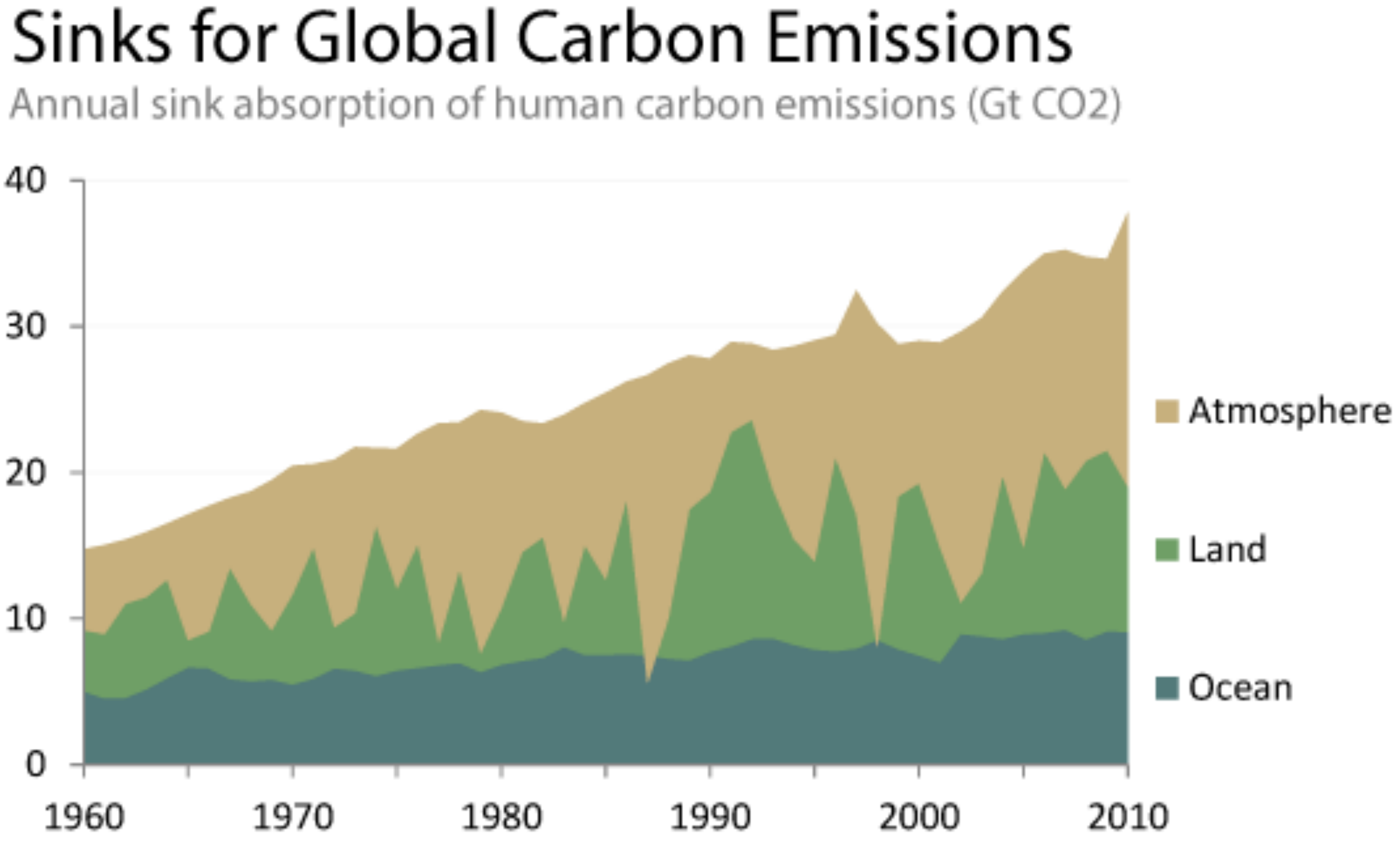


Figure from Global Carbon Project

2015:

Emissions:

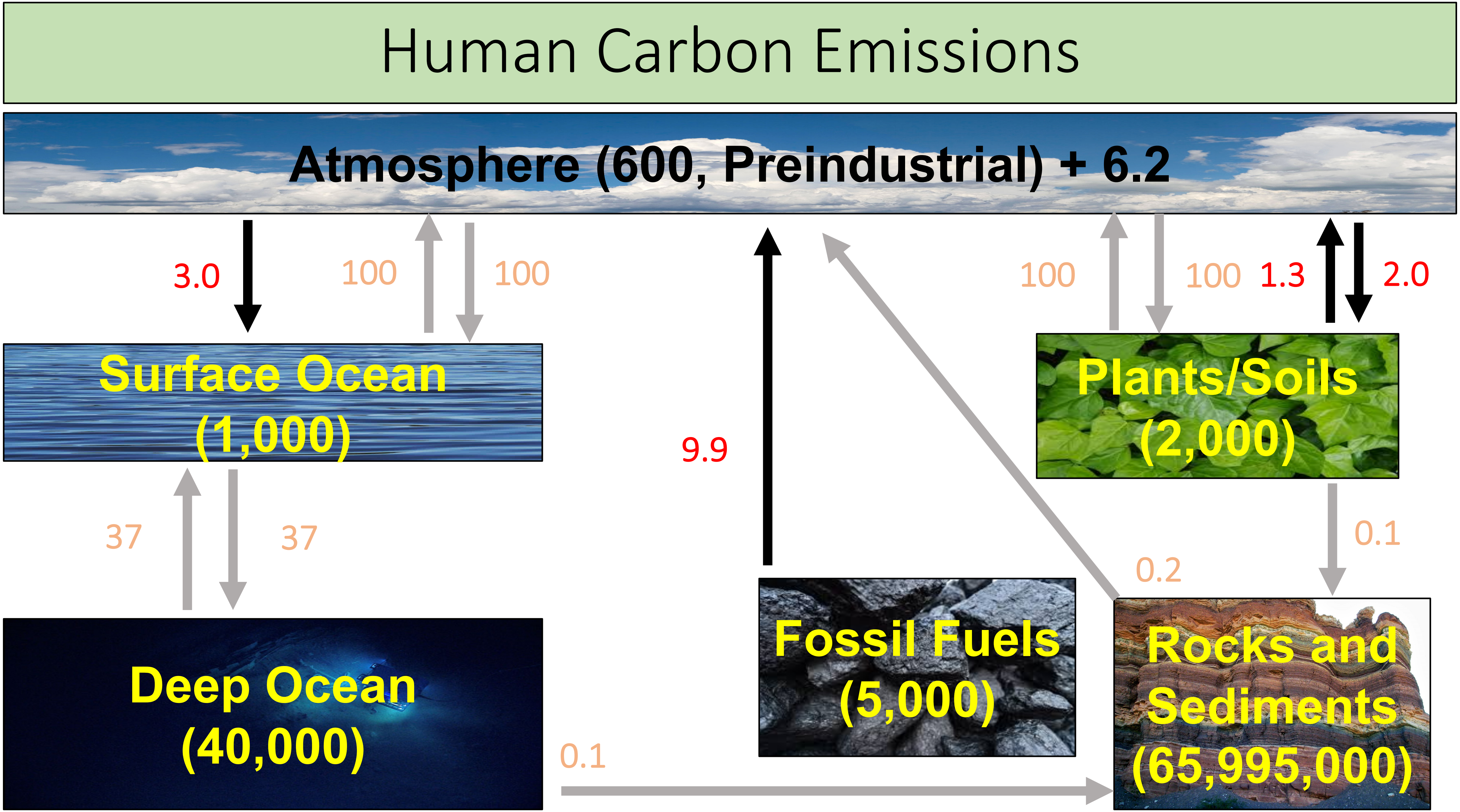
~11.2 GtC

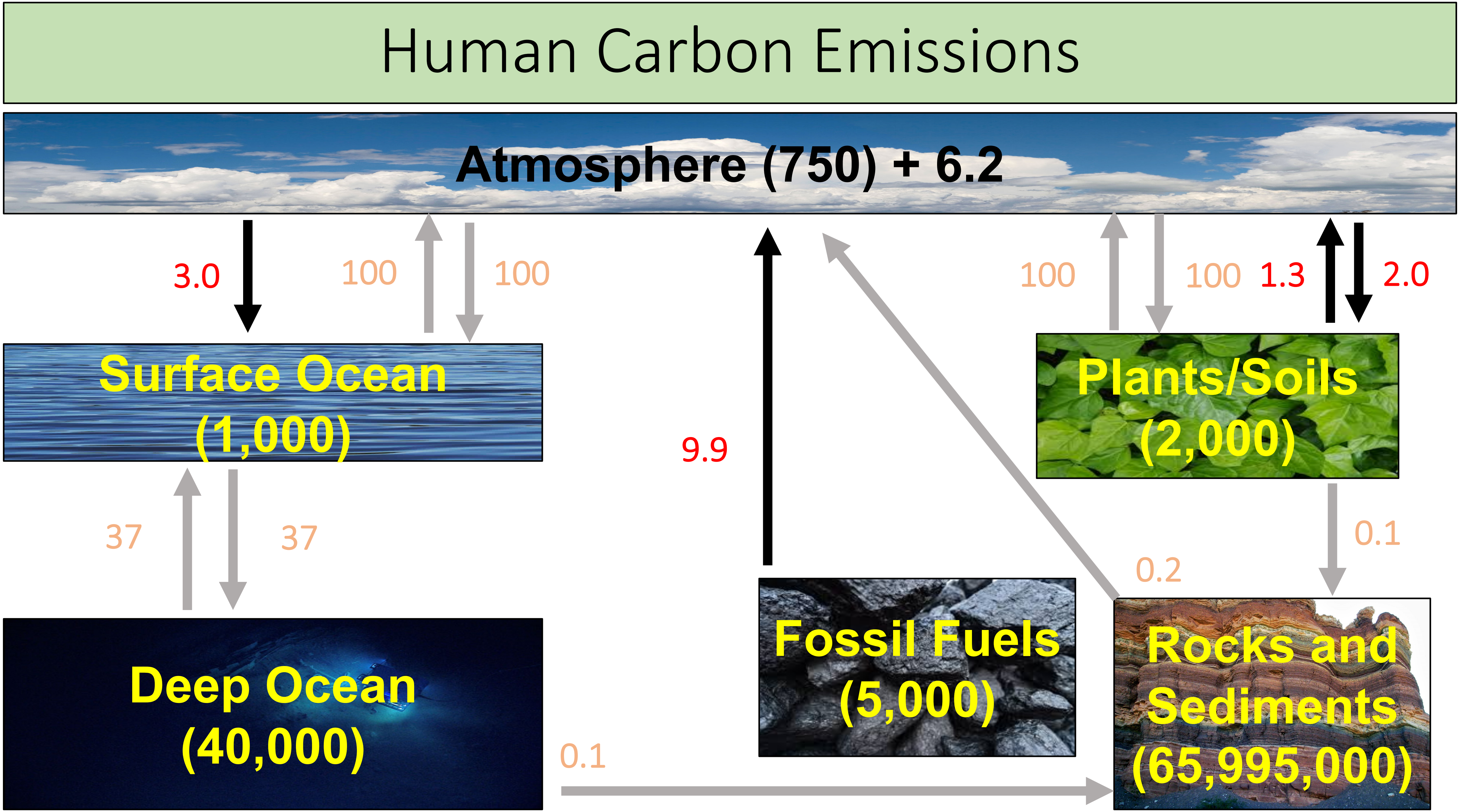
Atm: 6.2 ± 0.2

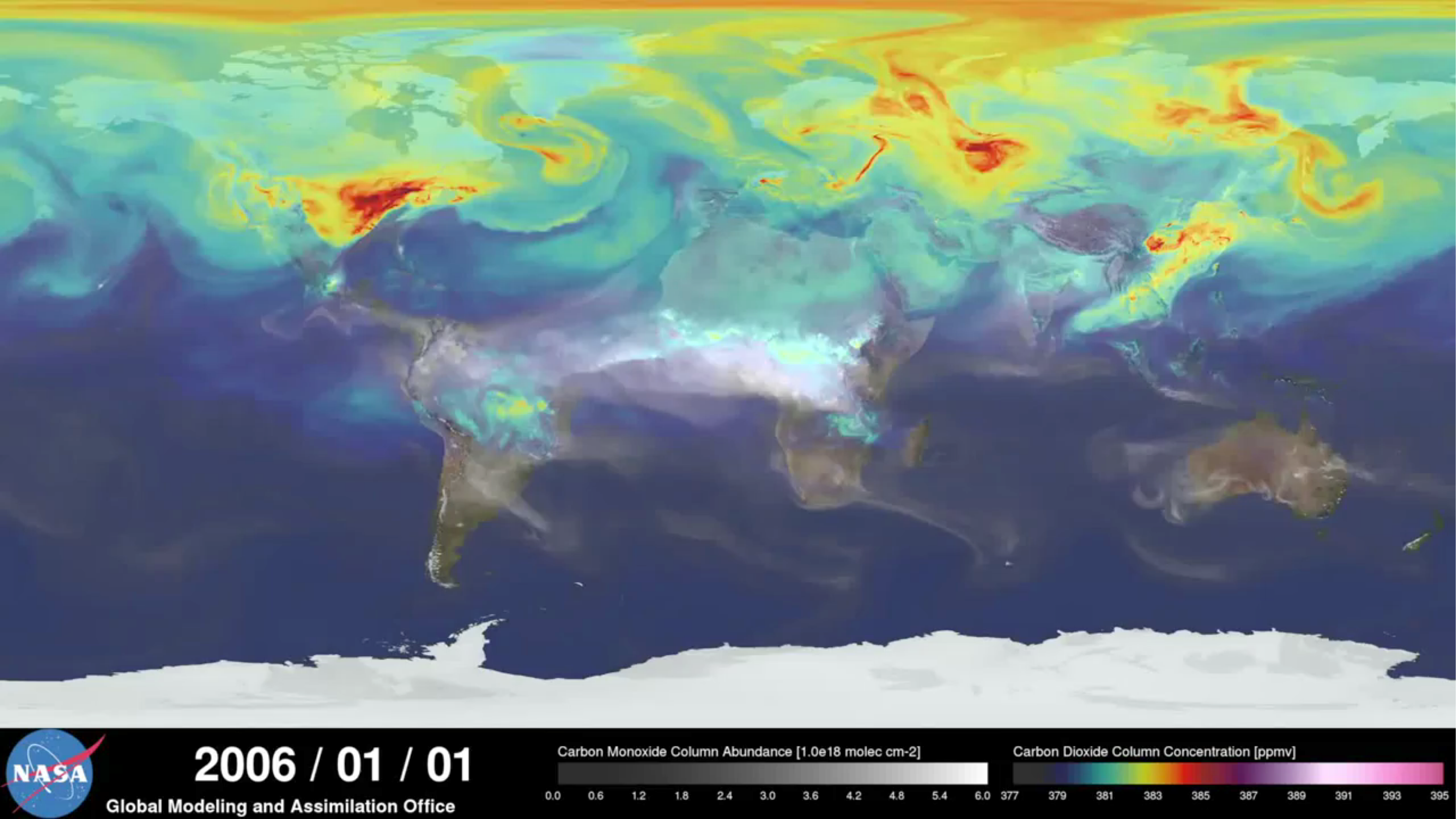
Ocean: 3.0 ± 0.5

Land: 2.0 ± 0.9

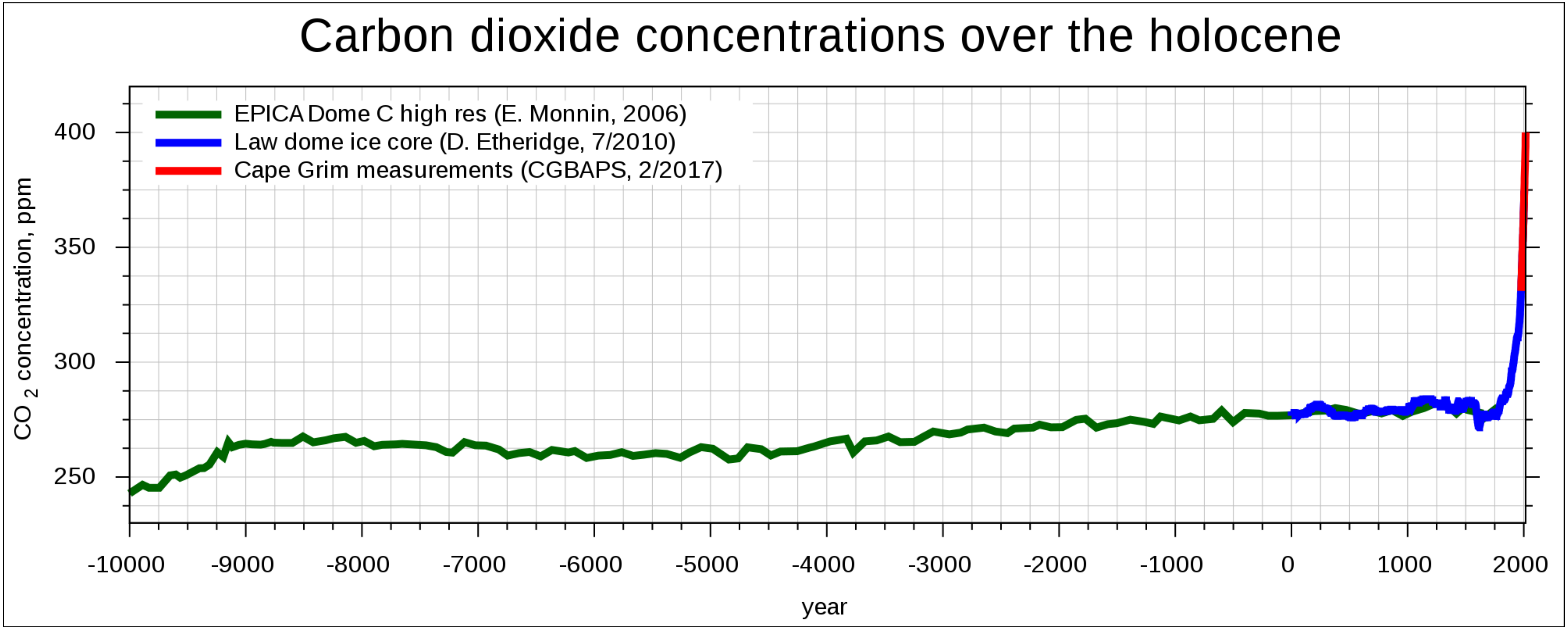
Data from WMO Annual Carbon Budget


Human Carbon Emissions
Atmosphere (600, Preindustrial) + 6.2
3.0
100
100
100
100
1.3
2.0
Surface Ocean
(1,000)
9.9
Plants/Soils
(2,000)
37
37
0.1
0.2
Deep Ocean
(40,000)
Fossil Fuels
(5,000)
Rocks and
Sediments
(65,995,000)
0.1


Human Carbon Emissions
Atmosphere (750) + 6.2
3.0
100
100
100
100
1.3
2.0
Surface Ocean
(1,000)
9.9
Plants/Soils
(2,000)
37
37
0.1
0.2
Deep Ocean
(40,000)
Fossil Fuels
(5,000)
Rocks and
Sediments
(65,995,000)
0.1


NASA
2006 / 01 / 01
Global Modeling and Assimilation Office
Carbon Monoxide Column Abundance [1.0e18 molec cm-2]
0.0 0.6 1.2 1.8 2.4 3.0 3.6 4.2 4.8 5.4 6.0
Carbon Dioxide Column Concentration [ppmv]
377 379 381 383 385 387 389 391 393 395

Human Carbon Emissions



We are disrupting a balanced system

Today's Class

Carbon Cycle: Reservoirs → Carbon Cycle: Exchanges → Human Impacts on Carbon Cycle → Carbon Cycle Feedbacks in a Warming World

Comprehension Check

Roughly what percentage of human-caused carbon emissions remain in the atmosphere?

A. 90 - 100%
B. 70 - 80%
C. 50 – 60%
D. 30 – 40%
E. 10 – 20%

Carbon Cycle Feedbacks in a Warming World

Carbon Cycle Feedbacks in a Warming World

1. (Negative Feedback)

Will more carbon in atmosphere lead to more carbon uptake by plants?

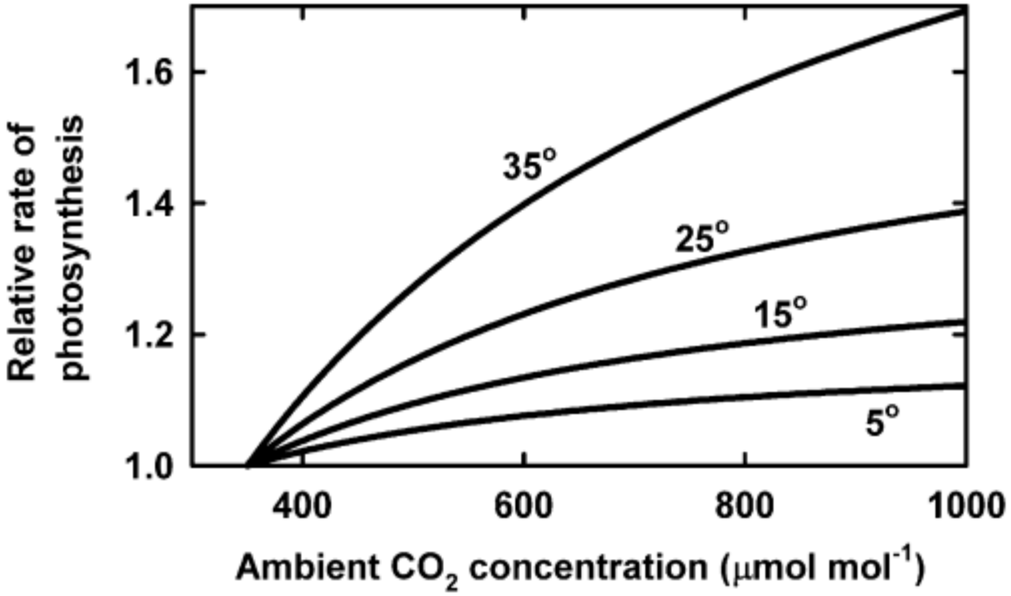
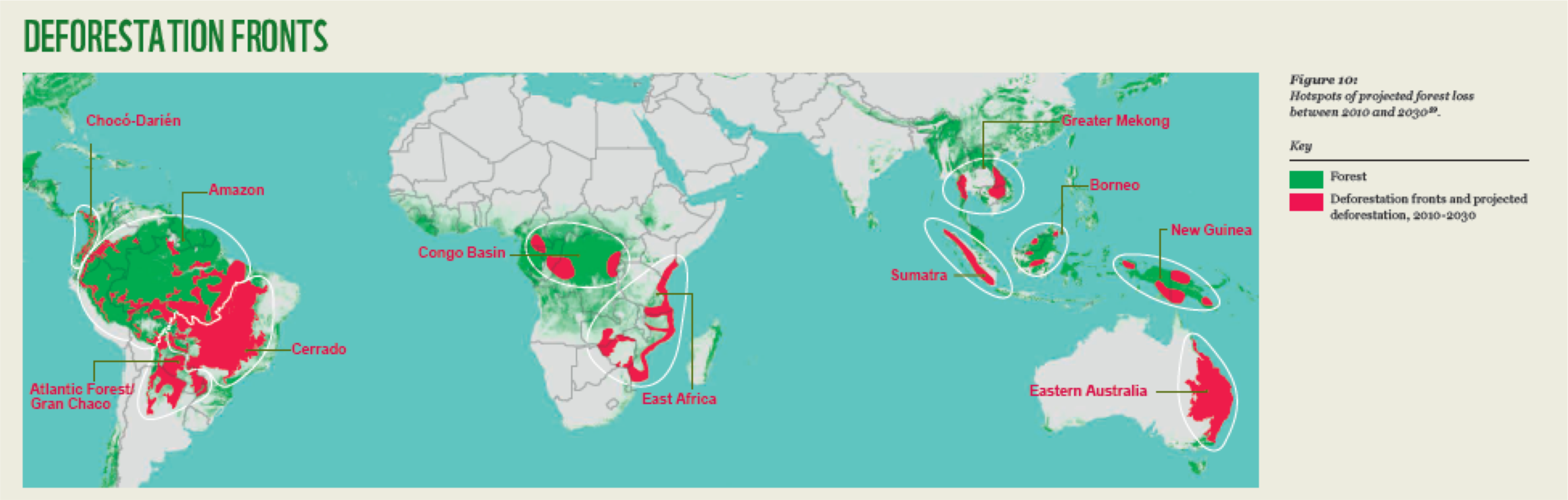


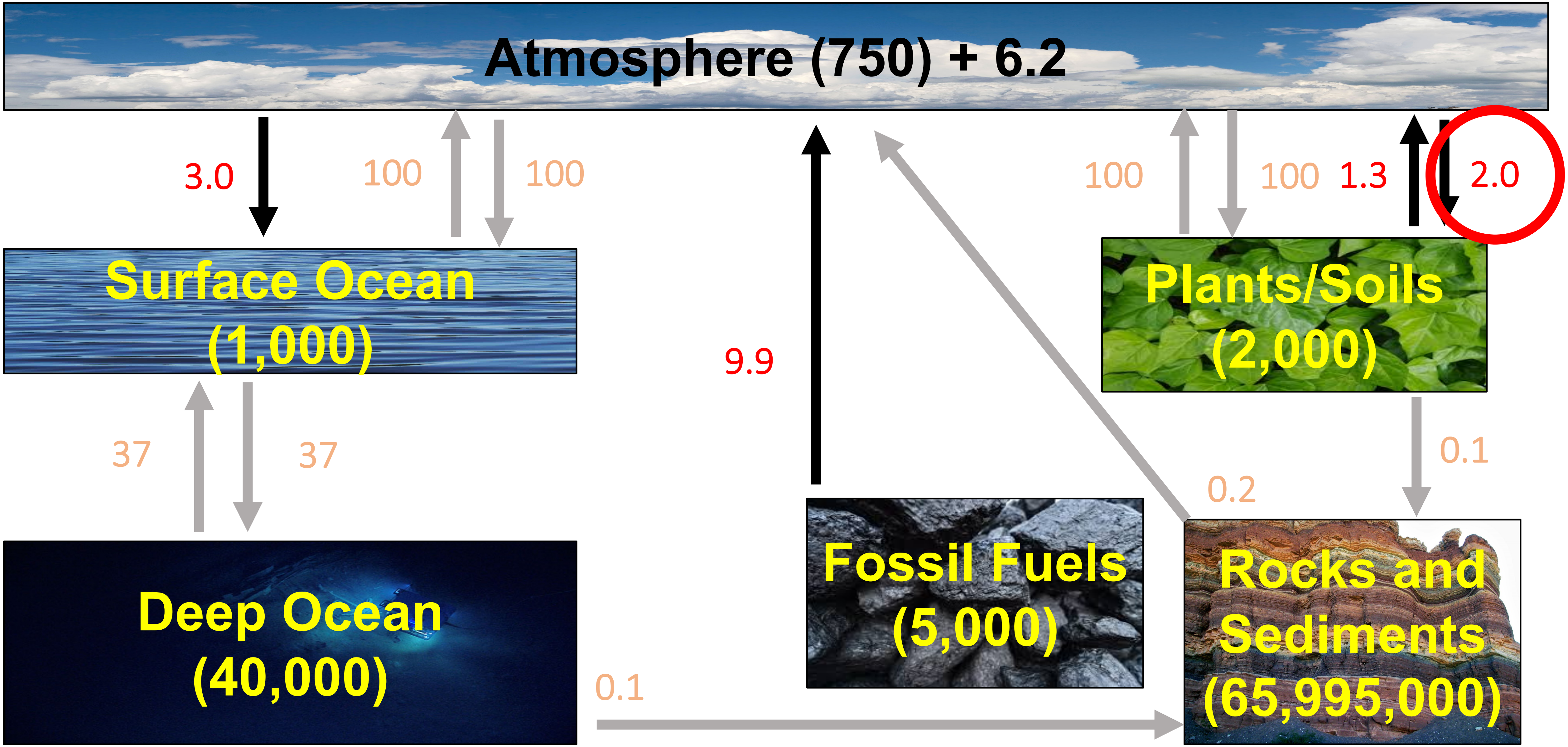
Figure from Kirschbaum, 2011, *Plant Physiology*

Carbon Cycle Feedbacks in a Warming World



Yes! This feedback should slow carbon increase in atmosphere… if we were not cutting down our forests

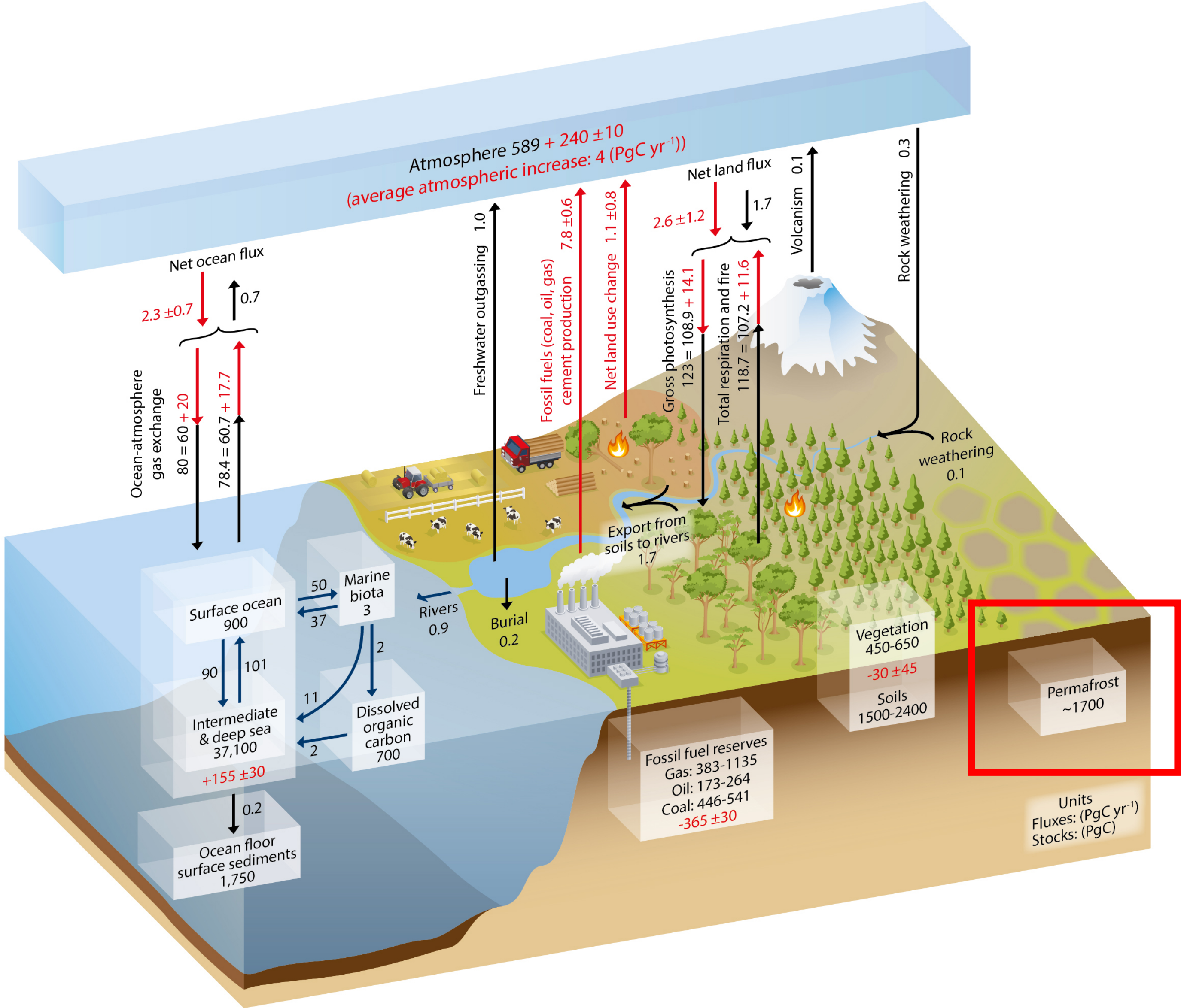
Carbon Cycle Feedbacks in a Warming World



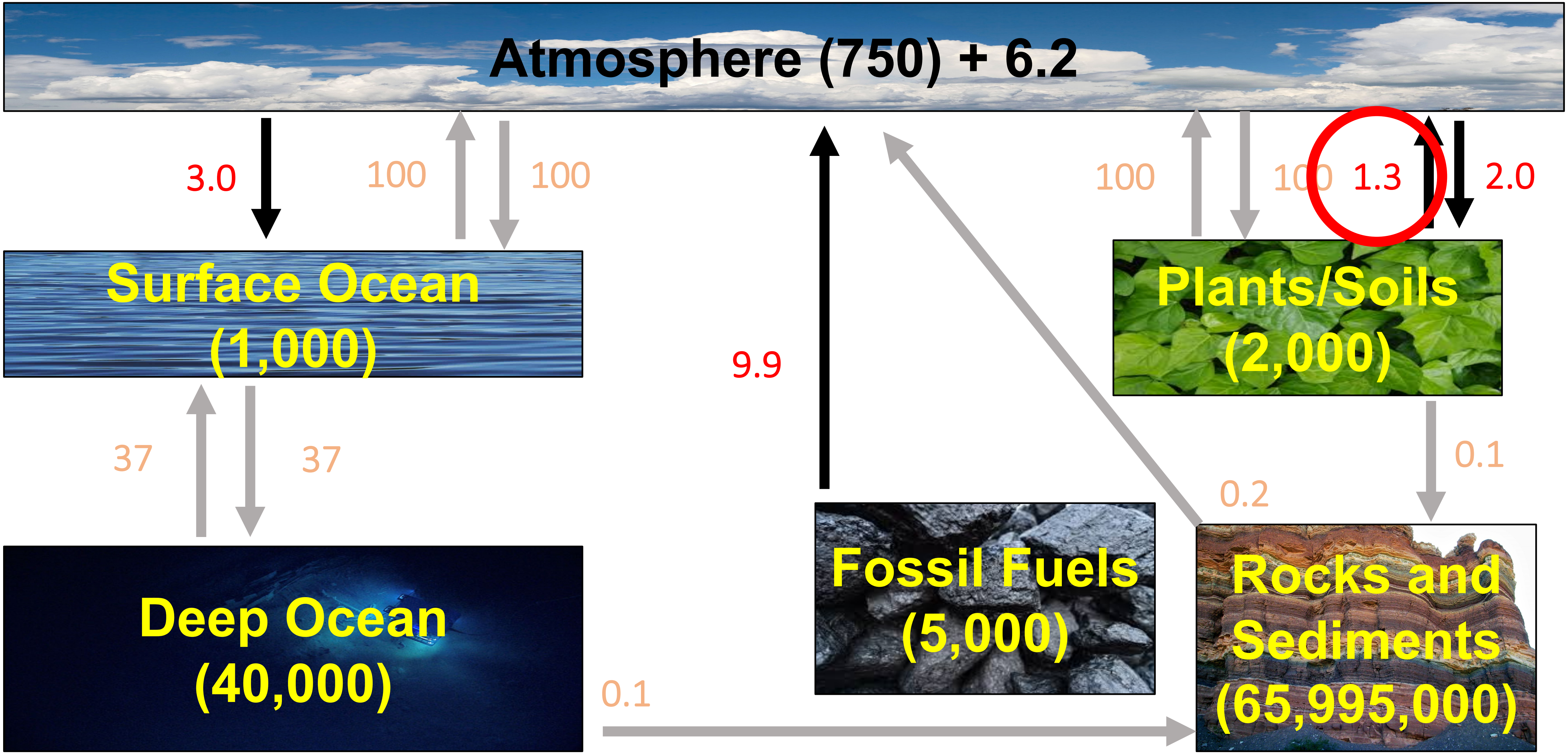
Carbon Cycle Feedbacks in a Warming World

2. (Positive Feedback)

Melting permafrost will increase carbon flux into atmosphere



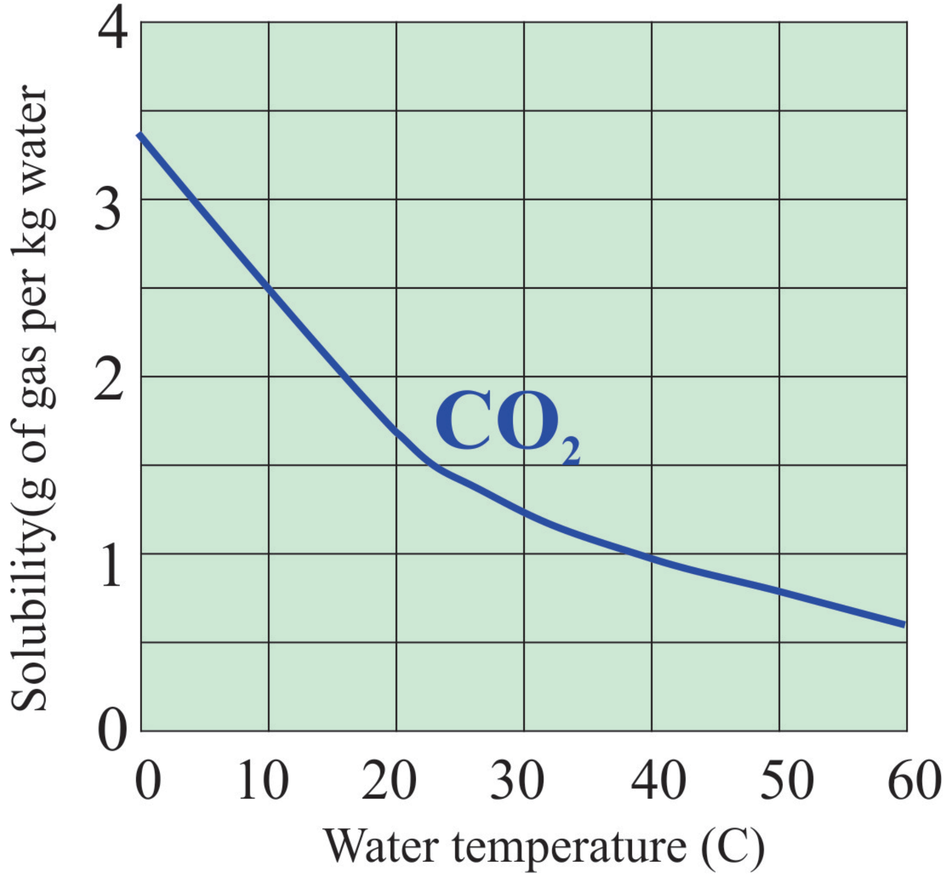
Carbon Cycle Feedbacks in a Warming World

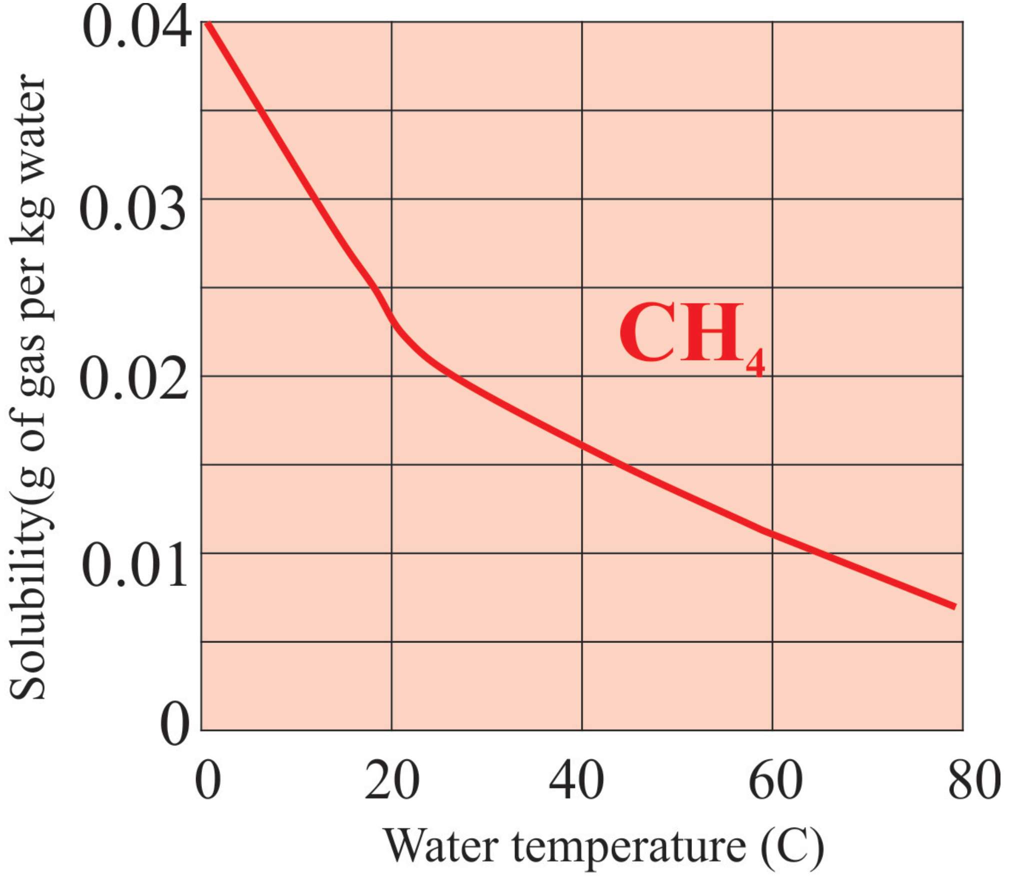


Carbon Cycle Feedbacks in a Warming World

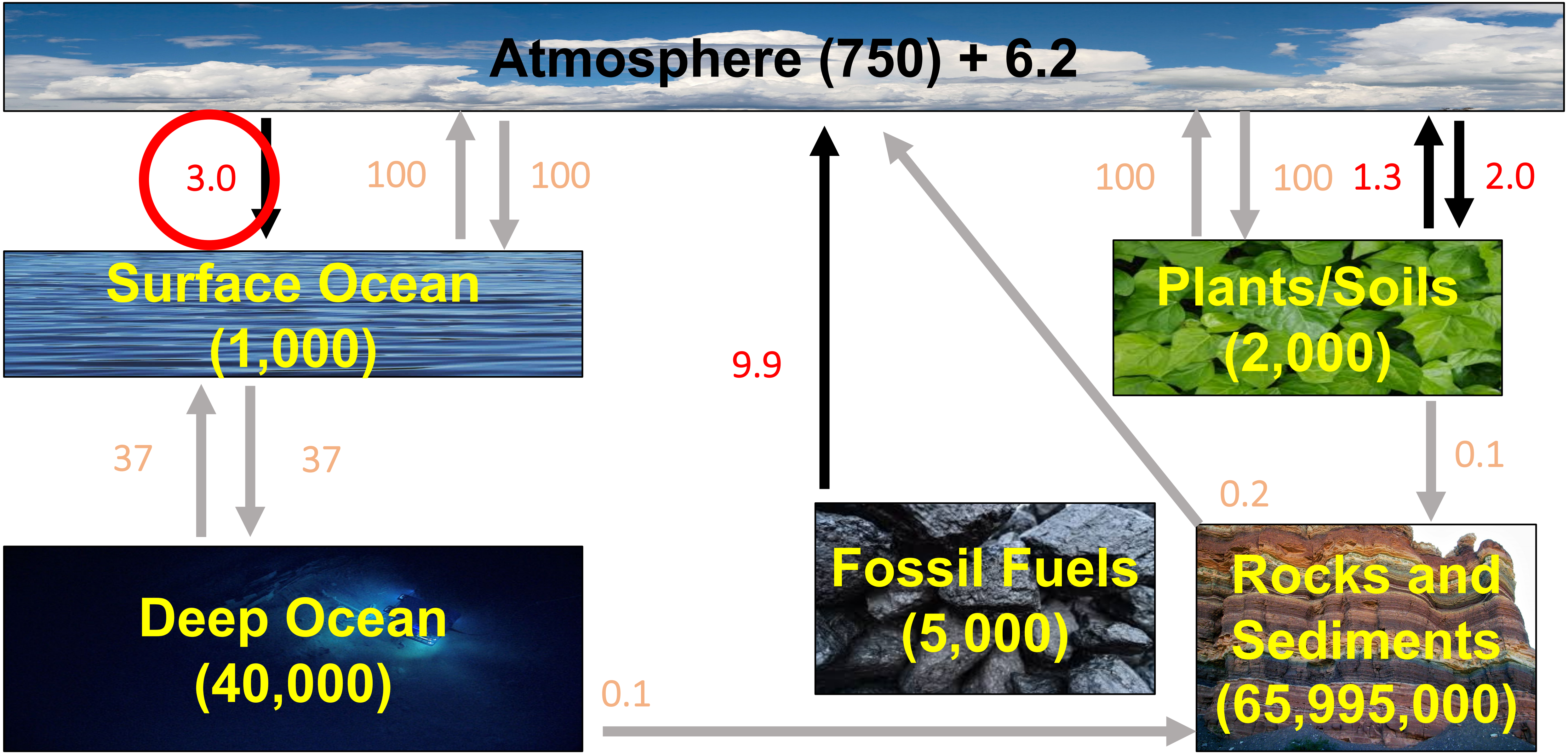
3. (Positive Feedback)

Less atmospheric carbon dissolves in warmer water





Carbon Cycle Feedbacks in a Warming World



Carbon Cycle Feedbacks in a Warming World

4. (Long Term Negative Feedback)

More chemical weathering (CO_2 removal from atmosphere) in a warmer climate

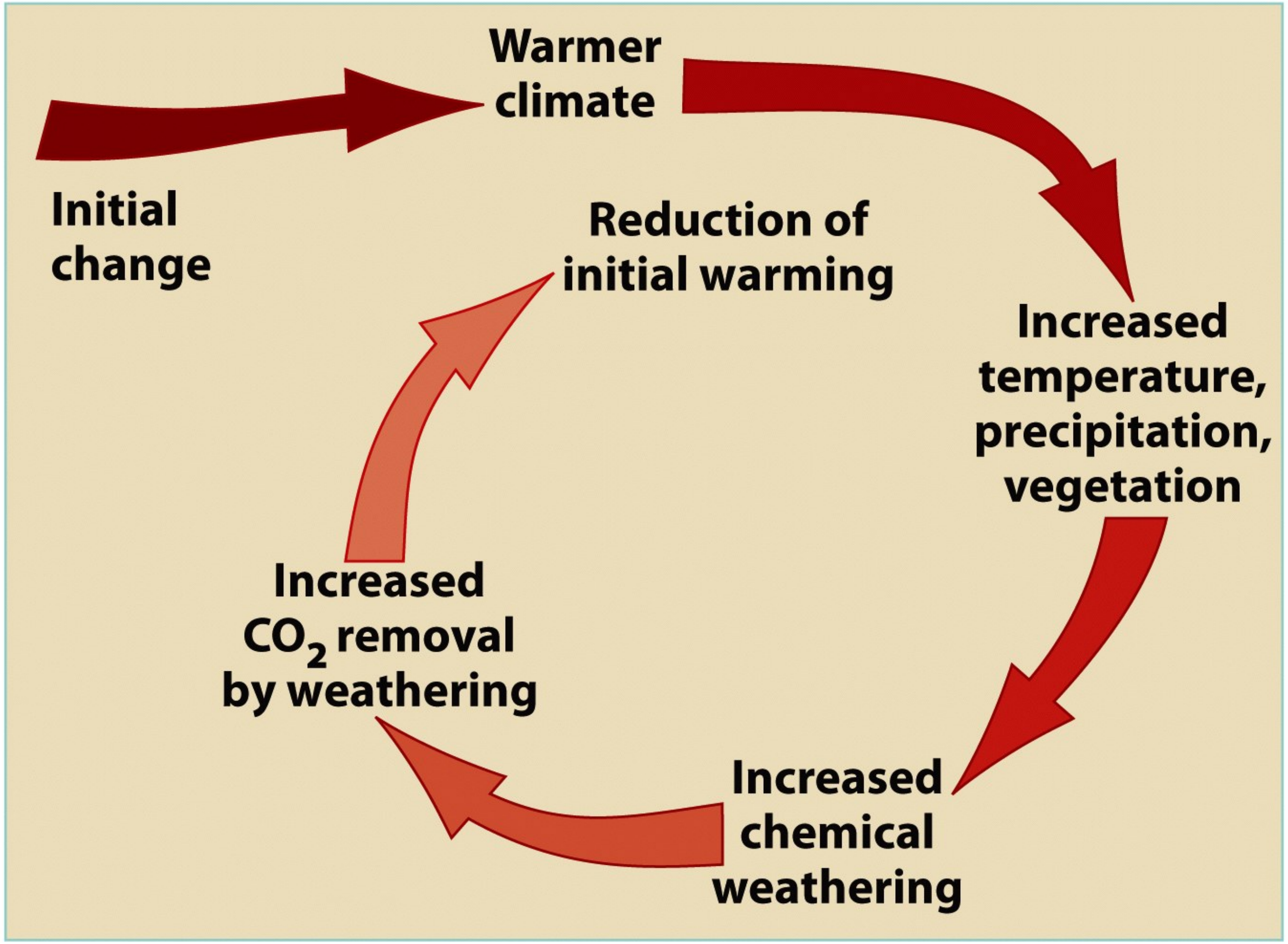


Figure 3-7a
Earth's Climate: Past and Future, Second Edition

Carbon Cycle Feedbacks in a Warming World

In Summary:

- Feedbacks in carbon cycle will amplify (positive feedback) or diminish (negative feedback) the amount of carbon increase in the atmosphere

- Negative feedbacks:
  - Increased plant photosynthesis with increasing atmospheric CO_2
  - Increased chemical weathering (long-term)

- Positive feedbacks:
  - Melting permafrost adding more carbon to atmosphere
  - Decreasing ocean uptake of carbon with increasing temperature