The Global Carbon Cycle

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Carbon cycle: Big picture questions

• What processes transfer carbon between the land, ocean and atmosphere?
• Why do different transfer processes dominate on different time scales?
• How does the carbon cycle mediate global climate?
• How are human activities changing the carbon cycle?
Carbon emissions and sinks

IPCC AR5, Figure 6.8

[Diagram showing carbon emissions and sinks from 1750 to 2000, with emissions, ocean sinks, and partitioning represented by different colors and lines.]
Challenges in teaching the carbon cycle
Following the path of a carbon atom

**Steady state**

- Size of reservoirs and inflows/outflows is constant

**Residence time**

- Average length of time spent in reservoir at steady state

Residence time = Reservoir size at steady state / Inflow or outflow rate

The organic carbon cycle
reservoir sizes in Gt C, fluxes in Gt C/yr
from The Earth System, Kump et al., 2010
Typical residence time of carbon in major earth reservoirs

$1 - 10^3$ years: land and ocean dominate

$10^3 - 10^6$+ years: geology dominates
Weathering, metamorphism and formation of calcium carbonate rocks control the carbon cycle over geologic time scales (>10,000-100,000 years)
What happens to a pulse of CO₂ added to the atmosphere?

**Land uptake**
(1-100 yrs)
Photosynthesis minus respiration

\[ 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{photons} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \]

**Ocean invasion**
(10-1000 yrs)
Seawater buffer reaction

\[ \text{CO}_2 + \text{CO}_3^{2-} + \text{H}_2\text{O} \rightleftharpoons \text{2HCO}_3^- \]

**Reaction with CaCO₃**
(10³-10⁴ yrs)

\[ \text{CO}_2 + \text{CaCO}_3 + \text{H}_2\text{O} \rightarrow \text{Ca}^{2+} + 2\text{HCO}_3^- \]

**Silicate weathering**
(10⁴-10⁶ yrs)

\[ \text{CO}_2 + \text{CaSiO}_3 \rightarrow \text{CaCO}_3 + \text{SiO}_2 \]

IPCC AR5, FAQ 6.1, Figure 2
Global carbon cycle

Black = pre-Industrial Era
Red = anthropogenic perturbations

IPCC AR5, Figure 6.1
What controls the ocean’s ability to take up CO$_2$?

Biological Pump Module by Katherine Heal

Chisholm, 2000
How will the biological pump change in the future?

- Which arrows (fluxes) control the biological pump? What processes do they represent?
- What red arrows (perturbations) might climate change add?