Topic: The carbon budget on land, ocean and atmosphere
3.1.1.3 Water and carbon cycles

What you need to know
What drives change in the global carbon budget on land
What drives change in the global carbon budget in the oceans
What drives change in the global carbon budget in the atmosphere
How changes to the carbon cycle affects global climate

Carbon systems

A systems approach allows us to consider not just the links between various components, but quantify the relationships and understand how feedback effects operate.

The key elements of a system are:

Inputs: quantities feeding in to the system
Outputs: quantities exiting the system
Stores/stocks: where quantities are contained for a sustained period in part of the system
Fluxes/Flows: transfer of quantities from one environment to another
Processes: mechanisms that generate change (such as photosynthesis)
Components: the 'givens' that systems operate upon (such as 'plants' that photosynthesize)
Controls: components that determine volume, scale, intensity and rate of system processes.

Within an overall system, there may be distinct sub-systems operating that have processes or components that are characteristic to them. The overall global carbon system can be subdivided into the sub-systems of carbon operating on land, in oceans and in the atmosphere. They are all inter-related in that carbon is cycled between them, but are distinctive sub-systems in themselves.

The carbon cycle on land (terrestrial)

- Dominated by photosynthesis of plants absorbing CO2 from the atmosphere.
- Carbon is stored within biomass, such as tropical and temperate forests.
- Carbon is transferred to the soil via leaf litter, roots and plant debris upon decomposition.
- Bacterial action in decomposition releases CO2 back to the atmosphere.
- Carbon is cycled quite rapidly through organic (living) systems between the atmosphere, vegetation (dominant biomass) and soils and is called the Fast Carbon Cycle.
- Human impact on this sub-cycle is considerable. The clearing of natural vegetation for urbanisation and agriculture is a major change to the biomass component and affects the carbon exchange between atmosphere and soil. Clearing vegetation by burning releases much stored carbon to the atmosphere very rapidly.

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The carbon cycle in the oceans

- Carbon is stored in the oceans as dissolved CO2, as bicarbonate ions in solution, and as the tissues (especially calcium carbonate skeletons and shells) of marine organisms.
- The inputs of carbon are from the atmosphere (dissolved CO2) in a direct exchange with ocean surfaces, as bicarbonate ions brought by rivers as a result of the weathering of carbonate terrestrial rocks, and a small input from subterranean volcanoes.
- Phytoplankton ('plant' plankton) in surface waters absorb CO2 in photosynthesis. They are fed on by zooplankton ('animal' plankton).
- A carbon pump operates within oceans transferring carbon from upper layers to the sea bed. A constant 'snow' of carbon deposits sinks with gravity as a result of marine organisms dying and zooplankton feeding on phytoplankton and discharging excrement.
- Carbon accumulates as/within ocean sediments in shallow seas (in deeper oceans it is often re-dissolved) leading to the natural sequestration of carbon by removing it to a long-term store within ocean-bed deposits.
- Human impacts on the oceans are only now becoming understood, but the warming of oceans as a result of climate change is believed to have a considerable impact on the ocean carbon cycle. Warmer seas are less able to absorb CO2 from the atmosphere and cause a reduction in phytoplankton activity.

The carbon cycle in the atmosphere

- Atmospheric carbon is usually in the form of carbon dioxide (CO2) or methane (CH4). Both are natural greenhouse gases, with methane being over 20 times more powerful in absorbing solar radiation, but much shorter-lived in the atmosphere, than CO2 (about 12 years as opposed to 50).
- Carbon dioxide combines with water molecules in clouds to form carbonic acid, and naturally-acidic rain. This leads to terrestrial weathering and can contribute to ocean acidification.
- Outputs from the atmosphere include absorption by surface vegetation and by oceans in the atmosphere-ocean gas exchange.
- Human impacts on the carbon cycle are most directly implicated in increasing atmospheric CO2 through the burning of fossil fuels.

How changes to the carbon cycle affect global climate

Carbon dioxide is essential in the earth's atmosphere to produce a planet habitable for life. Its capacity to absorb short-wave solar radiation has generated a temperature suitable for life to develop at this distance from the sun. However, anthropogenic (human) activity, particularly since the start of the Industrial Revolution, has resulted in increasing amounts of CO2 being released and a reduced capacity for natural systems to absorb it into other stores.

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Fossil fuels are naturally sequestered stores of carbon accumulated over millions of years and locked away in sub-surface strata for yet more millions of years. But exploiting them and burning them in large quantities for the past 200 years, human activity is effectively taking carbon from a long-term store of the slow carbon cycle, and creating a huge input into the fast carbon cycle.

The input of CO2 into the atmosphere from the burning of coal, oil and gas is faster than natural processes can remove it. There is evidence that plant growth increases with higher atmospheric CO2 levels, but only to a point and this levels off quite rapidly. Oceans have absorbed the bulk of human-generated CO2, but that rate is also thought to be slowing as phytoplankton thrive in cooler water and by raising ocean temperatures, their photosynthesis is reduced. In addition, increasingly acidic seas make it more difficult for molluscs and shell-forming marine creatures to extract the bicarbonate ions they need to convert into calcium carbonate.

Feedback loops

In a systems approach, change in the outputs can be redirected back at the inputs. This may either dampen down the initial change process (negative feedback loop) or amplify and intensify it (positive feedback loop). Human impact on the carbon cycle appears, worryingly, to be leading to a positive feedback effect. As a result, many climate scientists talk of a ‘tipping point’, whereby if atmospheric carbon dioxide is permitted to pass a certain level, then a positive feedback cycle will be instigated that means further increases of atmospheric carbon are virtually inevitable. The feared consequence will be human-induced ‘runaway global warming’.