# C cycle

## Inorganic C processes in water

### CO2 in air is in equilibrium with CO2 in water. However, as soon as CO2 dissolves it undergoes equilibrium transformations to carbonic acid, and bicarbonate and carbonate ions. Carbonate can react with calcium to precipitate as solid calcium carbonate, including as solid parts of plants and animals

#### pH greatly affects this. Low pH (acidic) shifts equilibrium toward CO2 while high pH (alkaline) shifts it toward carbonate. At seawater pH of ~8, bicarbonate accounts for ~95% or more of inorganic C

#### lowering of pH leads to lower ability to precipitate CaCO3 and lower ability to store inorganic C in ocean

## models of C pools and flows

### in general, C found in atmospheric, terrestrial, oceanic, and geologic pools or reservoirs. Transformations occur between these pools

#### reservoir units are mass, whereas transformations are mass per time

### exchange of CO2 from atmosphere to land and sea are similar with land taking up and emitting slightly more CO2 per year than the sea. This means, photosynthesis on land is slightly higher than in sea, but on a semi equilibrium basis, i.e., before Man’s effect, CO2 uptake from the atmosphere by land and sea is equal to the release of CO2 back into the atmosphere from respiration (including decomposition).

### Currently, excess CO2 production from fossil fuel burning has pushed the system slightly out of equilibrium so that some of the fossil fuel CO2 accumulates in the atmosphere over time. Some also accumulates in the sea (primarily surface seawater) and on land as increased plant biomass.

### The oceanic budget includes a very large reservoir of C in the intermediate and deep sea, but the exchange of C with these pools is very slow and not rapid enough to take all the excess CO2 out of the atmosphere

### The terrestrial budget includes a large soil C pool, much of which is in high latitude wetland soils that are becoming mobile due to permafrost melting and longer warm seasons

### Different parts of the global C system work at different time spans

#### Exchange of C with land plants and the surface ocean are rapid and can be seen in seasonal changes in atmospheric CO2 concentrations. Land plants are responsible for the bulk of these seasonal changes

##### Land plants stick their leaves into the atmosphere while oceanic plants get their immediate C from the surface ocean bicarbonate pool

##### Seasonal changes are more pronounced in the N hemisphere since this is where 70% of land plants live

#### The deep ocean works at a pace of thousands of years, i.e., the deep ocean takes about 35,000 years to move a parcel of water from the N Atlantic to the mid to N Pacific

#### Fossil fuels take millions of years to form and are stored for millions of years. Their impact should be small

##### Man has taken this long-term process and made it a short term one. This is why the global system cannot keep up

## To examine the current C budget, we need to see where C comes from and where it goes, i.e., sources and sinks of C

### Since excess CO2 is coming from fossil fuel burning and deforestation, we need determine the fate of this C.

### Measurements of CO2 production from fossil fuels are precise as is the concentration of CO2 in the atmosphere and its rate of increase. However, the amount of C that is removed from the atmosphere by the sea is less precise and the amount that enters the terrestrial is even less precise.

### We also have a significant source of CO2 coming from terrestrial deforestation, but this is decreasing rapidly.

### The budget then becomes an accounting process, i.e., what are the sources and sinks and what pools get what amount?

### Since the sources from deforestation and fossil fuel burning are fairly well known, especially fossil fuels, and the oceanic uptake is known, but not extremely well, the uptake by land is usually determined as the difference since there is no other place for the C to go. This used to be called the “missing C”, but now is known better and is usually ascribed to land plant uptake (known as greening of the Earth).

### Presently, about 50% of the C sources end up in the atmosphere (which makes it a sink), while about 25% each goes to the ocean and land plant sinks.

#### A big job ahead is to try to understand how much these sinks might change over time.

##### Best current guess is that both land and sea sinks will decrease over time, making the atmospheric sink larger leading to more rapid increase in atmospheric CO2.

## Past CO2 varied as a function of Earth’s temp as affected by solar irradiance changes. CO2 (and CH4) were high during interglacial and low during glacial periods.

### CO2 is now more than 50% higher than it should be

### CH4 is about 3 times higher

## Methane also can enter the atmosphere from methane hydrates that form on land and in the sea under certain pressures and temperatures. Changes in these conditions could dissolve hydrates leading to massive CH4 release.

## Atmosphere

## Why does Temp decrease w/ altitude in troposphere but increase in stratosphere? What causes heating?

## Understand how and why heating of Earth varies with season and latitude and how both vertical and horizontal airflow work to create surface air flows that we live in. How does a spinning Earth affect this? How does this lead to global climate patterns?

## Be able to calculate residence time and understand relationship between reactivity, residence time and the variability in the concentration of gases.

## Differentiate primary and secondary aerosols including hetero- and homogenous aerosols

## Understand how gas and deposited material chemical distribution can be used to determine the source of materials

## Compare and contrast even and odd N compounds

## What controls long term O2 levels and where do the important traces gases come from?

## Compare and contrast the “good” and “bad” ozone

## How is ozone formed and what other O species is it involved in forming?