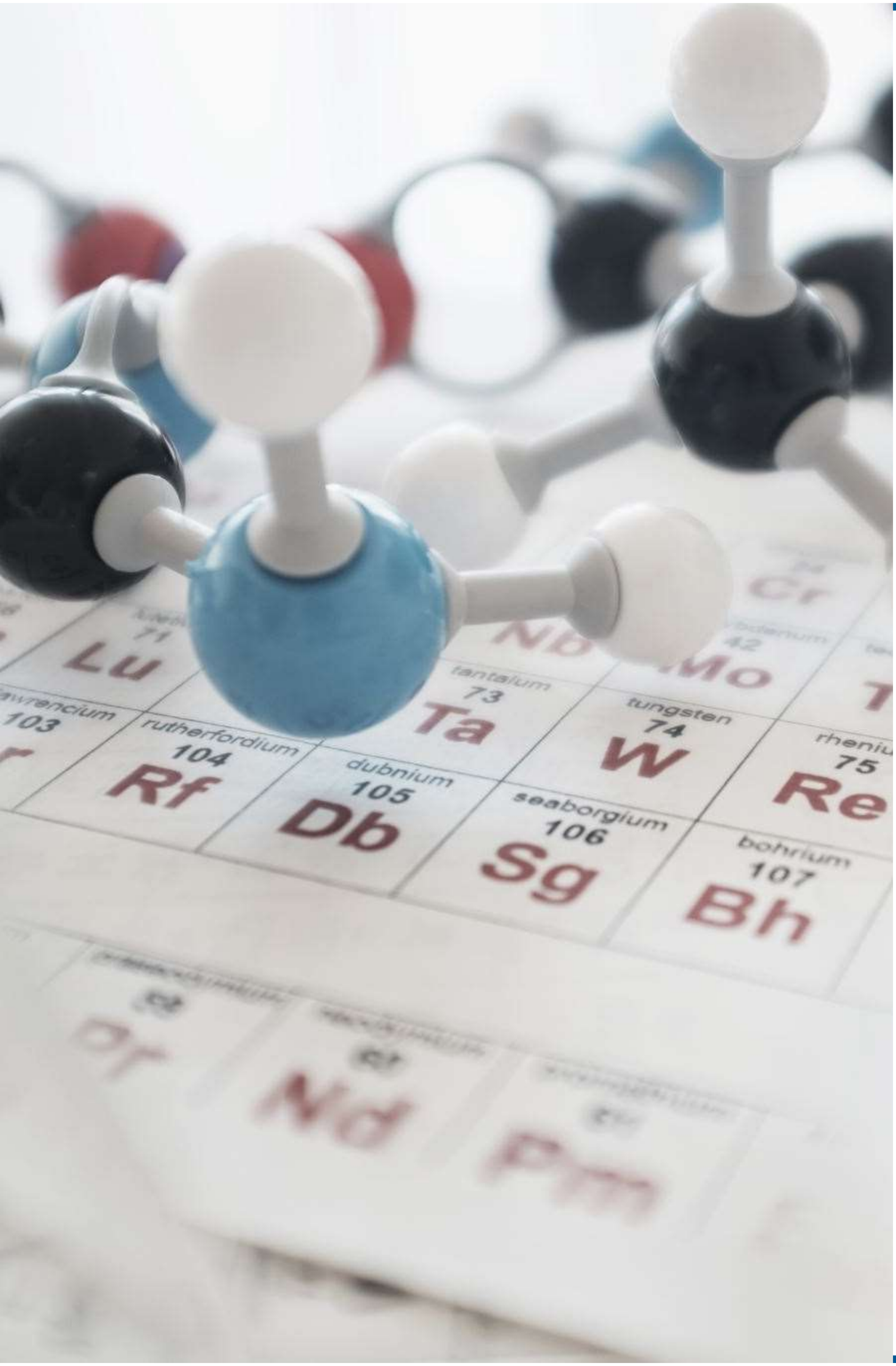
Simple Climate models

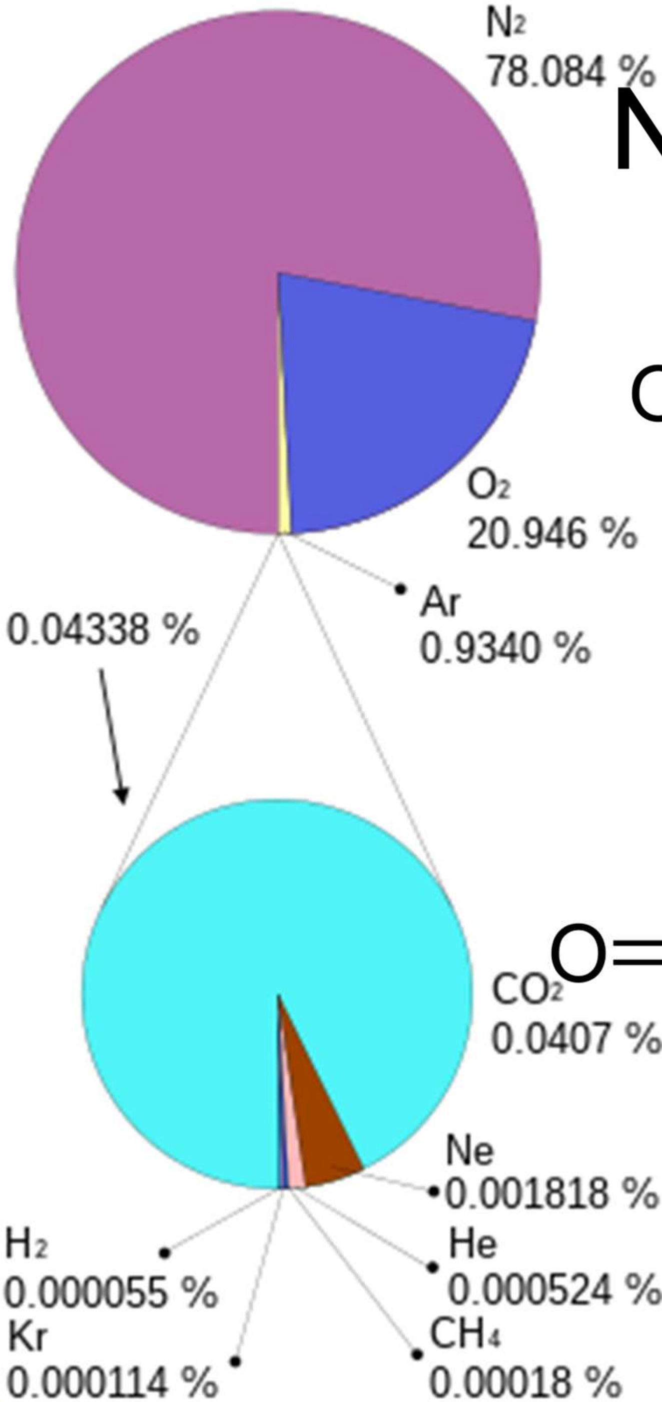
UNIT-2

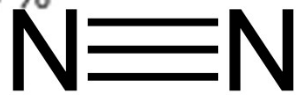
Simple Climate models	Source of energy
	Energy loss
	Greenhouse effect
	Carbon cycle
	atmosphere–land-biosphere–ocean carbon exchange

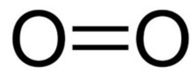


Carbon Cycle

Composition of the Atmosphere

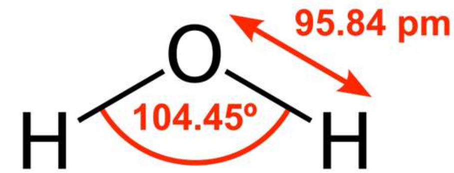




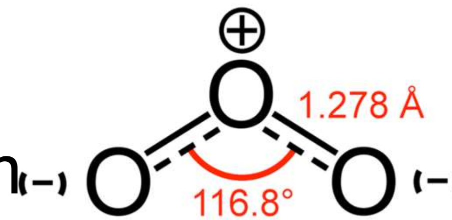


= 407 ppm

plus
water
H_2O ~ 0.4 %



ozone
O_3 ~ 0.0-0.07 ppm



N_2O
Hydrocarbons
Natural chemicals

http://en.wikipedia.org/wiki/File:Atmosphere_gas_proportions.svg

Composition of the Atmosphere

- Air has approximately 78% nitrogen
- Water vapor is the most abundant and important greenhouse gas in our atmosphere
- The largest part of this remaining 0.05% is carbon dioxide or CO_2, which made up 0.039% of the atmosphere
- Nitrous oxide or N_2O, which is present in today's atmosphere at concentrations of about 0.3 ppm.
- *Halocarbons* include chlorofluorocarbons and hydrochlorofluorocarbons, which are synthetic industrial chemicals used as refrigerants
- Natural chemicals such as methyl chloride. They are present in today's atmosphere at a concentration of a few parts per billion
- Ozone - its abundance is about 10 ppb or parts per billion, whereas its abundance can reach 10 ppm in the stratosphere

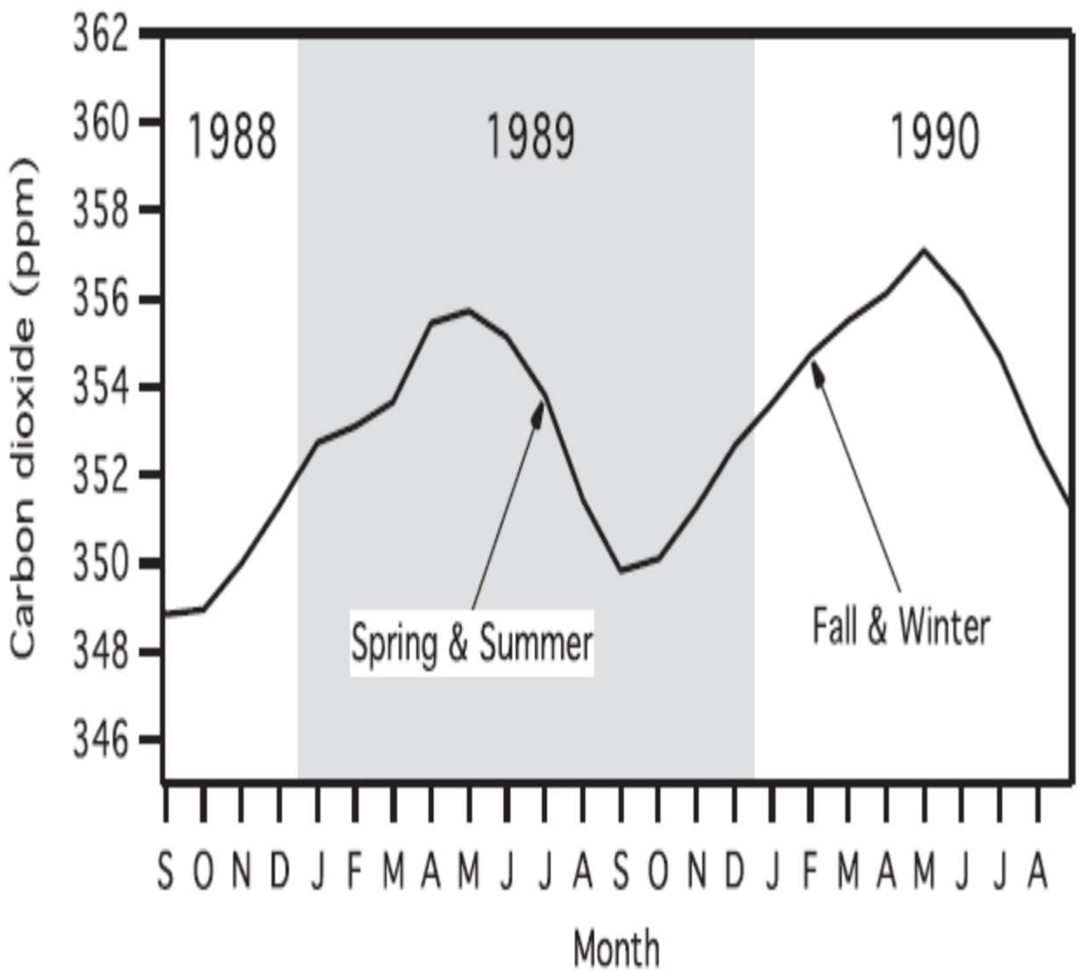
Composition of the Atmosphere

- As a greenhouse gas, methane is roughly 20 times more powerful than carbon dioxide on a per molecule basis
- The most powerful greenhouse gases on a per molecule basis are the halocarbons
- Most abundant gases diatomic nitrogen, diatomic oxygen, and argon, which together make up about 99.9% of the dry atmosphere, are not greenhouse gases at all
- differences in warming potential among various gases have important implications when designing policies to address climate change.
- Processes that regulate its atmospheric abundance are collectively known as the *carbon cycle*.

Atmosphere–land biosphere–ocean carbon exchange

Atmosphere–land biosphere exchange

Atmosphere–land biosphere exchange

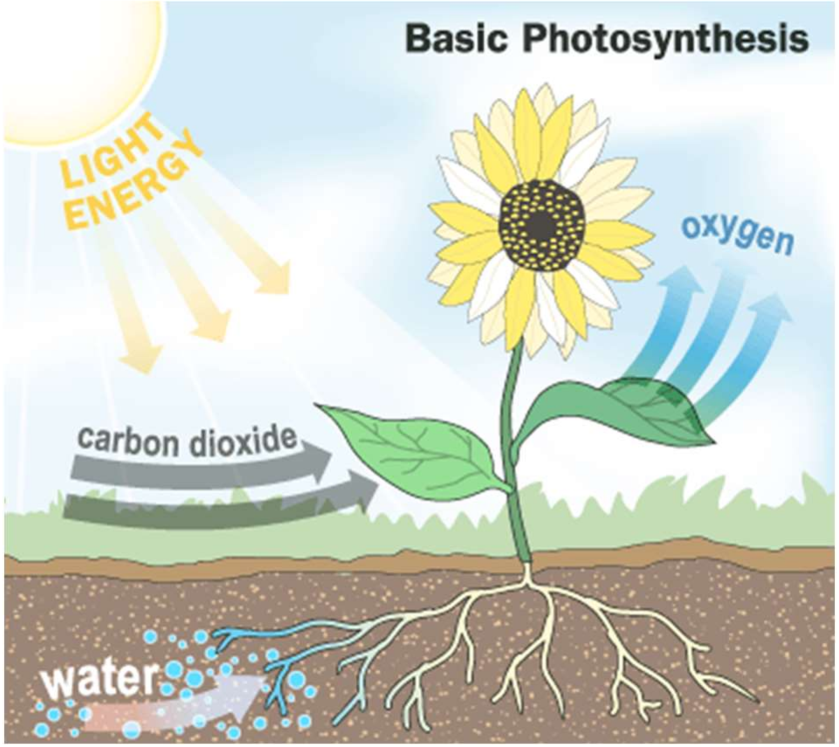


The atmospheric abundance of carbon dioxide from fall 1988 through fall 1990 (data measured at Mauna Loa, Hawaii, and obtained from the NOAA Earth System Research Laboratory/Global Monitoring Division).

- Carbon dioxide varies by 6 ppm or so, reaching a maximum in May and a minimum in September

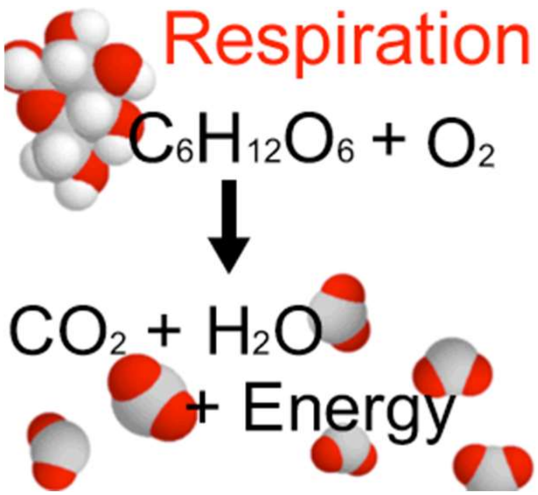
Photosynthesis

$$CO_2 + H_2O + \text{sunlight} \rightarrow CH_2O + O_2$$



CH_2O is a combination of carbon and water, and molecules made up of this unit are generally referred to as carbohydrates

Respiration



Bacteria, fungi, animals and humans derive their energy from respiration (oxidation) of organic carbon

Atmosphere–land biosphere exchange

- The atmosphere contains approximately 740 gigatonnes of carbon (GtC). A gigatonne is 1 billion metric tons, where 1 metric ton is 1,000 kg or 2,200 lbs.
- 1 GtC = 3.67 $GtCO_2$
- The atmosphere contains roughly 2,700 $GtCO_2$ (billion metric tons of carbon dioxide).
- The land biosphere contains 2,000 GtC or so, stored in living plants and animals, and in organic carbon in soils (e.g., decaying leaves).
- During a given year, photosynthesis removes approximately 100 GtC from the atmosphere.
- Respiration closely balances this, transferring 100 billion tons of carbon back to the atmosphere.
- Thus, over a year, there is no net change in carbon dioxide in the atmosphere or land biosphere as a result of photosynthesis or respiration

Atmosphere–land biosphere exchange

- During the northern hemisphere's spring and summer (May–September), when plants are growing and trees are leafing, global photosynthesis exceeds respiration and there is a net drawdown of carbon dioxide out of the atmosphere and into the land biosphere;
- During the northern hemisphere's fall and winter (October–April), plant material that was produced during the spring and summer decays, releasing carbon back into the atmosphere in the form of carbon dioxide.
- This means that global respiration exceeds photosynthesis and there is a net transfer of carbon from the biosphere into the atmosphere

Atmosphere–ocean carbon exchange

- One of carbon dioxide's most important properties is that it readily dissolves in water.
- Once it has dissolved in water, carbon dioxide can be converted to *carbonic acid* (H_2CO_3) by means of this reaction

$$CO_2 + H_2O \rightarrow H_2CO_3$$

- The carbonic acid can then be converted into other forms of carbon.
- Because of the conversion of carbon dioxide to many other forms of carbon, the ocean can absorb an enormous amount of carbon dioxide from the atmosphere.
- Carbon is returned to the atmosphere in a reaction
- This is followed by the escape of carbon dioxide back into the atmosphere.

$$H_2CO_3 \rightarrow CO_2 + H_2O$$

Atmosphere–ocean carbon exchange

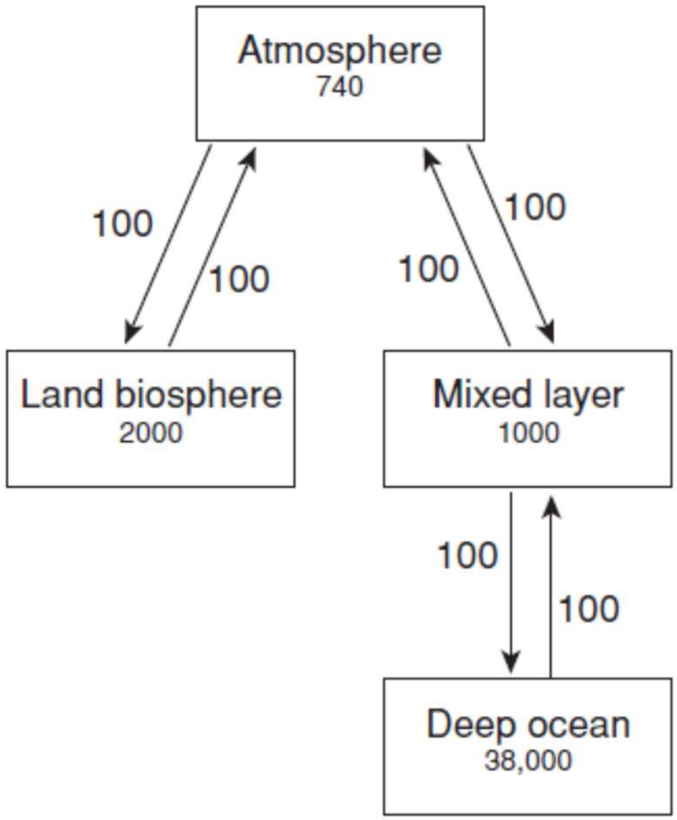
- Consider the ocean as being split into two parts. The first part is the top 100 m or so of the ocean, which exchanges carbon very rapidly with the atmosphere.
- This part of the ocean is sometimes referred to as the *mixed layer* because it is well mixed by winds and strong weather events, such as hurricanes.
- This layer contains approximately 1,000 GtC. Below this lies the vast majority of the ocean, and this *deep ocean* exchanges carbon with the mixed layer.
- The deep ocean also contains most of the ocean's carbon, approximately 38,000 GtC, or 50 times or so more carbon than is in the atmosphere

The combined atmosphere–land biosphere–ocean system

The combined atmosphere–land biosphere–ocean system

- Approximately 100 GtC per year are continuously cycling between the atmosphere and land biosphere as plants absorb carbon dioxide as they grow and then release carbon dioxide when they die
- 100 GtC per year of carbon atoms are continuously dissolved into the ocean's mixed layer, while the same mass of carbon atoms comes out of the ocean and back into the atmosphere, thereby cycling between the atmosphere and ocean.
- The mixed layer is exchanging 100 GtC or so with the deep ocean

A schematic of exchange between the atmosphere, land biosphere, and ocean. Reservoirs are in GtC; fluxes are in GtC/yr.



The combined atmosphere–land biosphere–ocean system

- Turnover time for the atmosphere is the length of time that a carbon atom in the atmosphere will remain there before being transferred into one of the other two reservoirs
- *For Atmosphere*

  Turnover time =740 GtC/*(200* GtC/yr*)*=3.7 years ……**Residence time/lifetime**
- The turnover time of carbon in the *land biosphere*

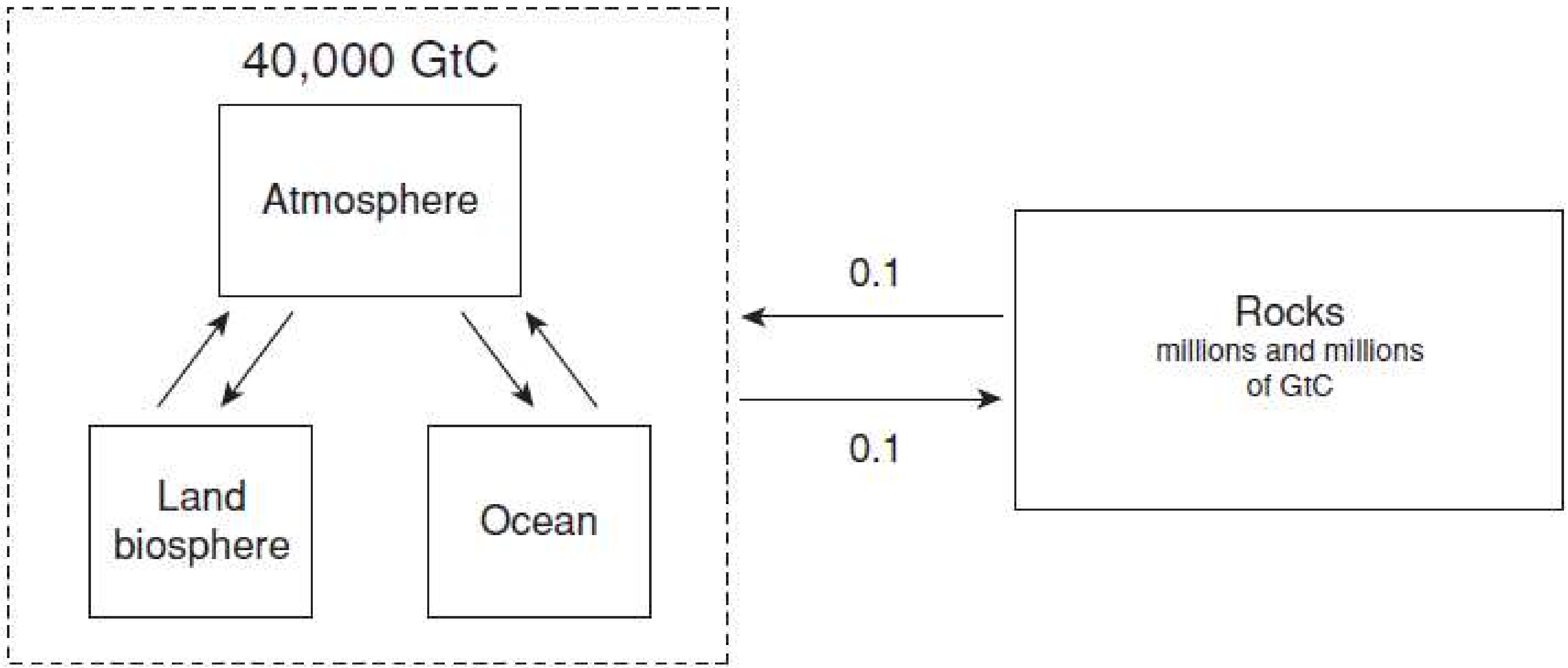
  2,000 GtC ÷ 100 GtC/yr = 20 years
- The turnover time for the mixed layer (Ocean)

  1,000 GtC ÷ 200 GtC/yr = 5 years
- The turnover time for the deep ocean

  38,000 GtC ÷ 100 GtC/yr = 380 years
- It takes several centuries for a carbon atom to make a round trip from the atmosphere through the mixed layer to the deep ocean, and back.

Atmosphere–rock exchange

- Millions of gigatonnes of carbon – is stored in rocks, such as limestone ($CaCO_3$)



A schematic of exchange between the atmosphere–land biosphere–ocean reservoir and the rock reservoir

- Carbon dioxide is transferred from rocks directly into the atmosphere by volcanic eruptions. This process releases an average of roughly 0.1 GtC/yr
- Volcanic emissions of carbon dioxide are roughly balanced by a process known as *chemical weathering*, which removes about an equal amount of carbon from the atmosphere–land biosphere–ocean reservoir and transfers it back into rocks.

Atmosphere–rock exchange

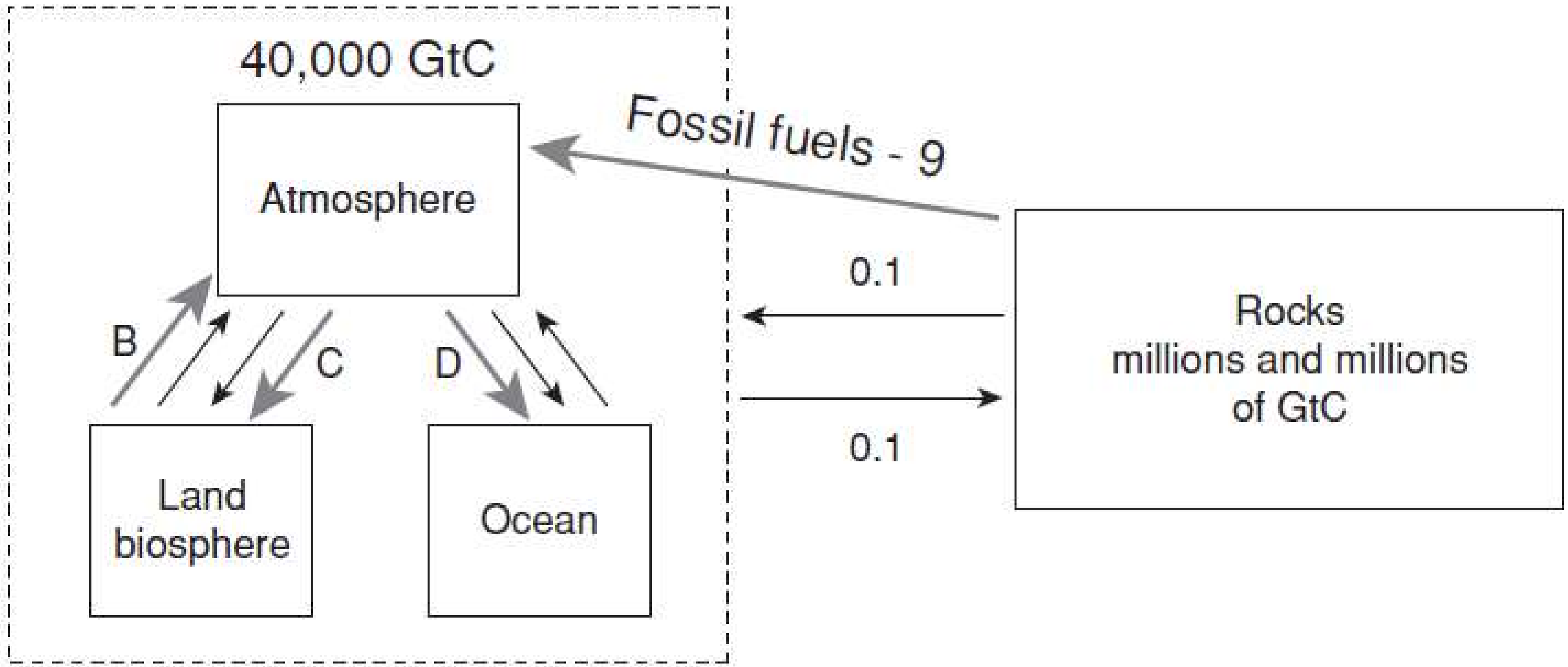
- Chemical weathering starts when carbon dioxide in the atmosphere dissolves into raindrops falling toward the surface through the process

$$CaSiO_3 + CO_2 \rightarrow CaCO_3 + SiO_2$$

- The carbon dioxide molecule consumed in this reaction came from the atmosphere, via rainwater, and it is transferred into a molecule of calcium carbonate or CaCO3, which is limestone and subsequently runs off with the rainwater and eventually reaches the ocean.
- The reaction also forms silicon dioxide (SiO2), the primary component of sand, quartz, and glass
- the molecules of calcium carbonate are deposited through various mechanisms on the sea floor.
- Over millions of years, *plate tectonics* carries this calcium carbonate deep within the Earth, where high temperatures and pressures turn the rock into magma.
- Eventually, this magma is transferred back to the surface by volcanism, thereby releasing the carbon dioxide back to the atmosphere and completing the cycle.

- Carbon move into the rock reservoir when plants are rapidly buried in sediment before they can decay
- Once buried and subjected to the great heat and pressure found deep within the Earth, this dead plant material can be converted to fossil fuels, which humans extract and burn for energy – thereby returning the carbon to the atmosphere
- A carbon atom will remain in the atmosphere–land biosphere–ocean system for approximately 40,000 GtC÷(0.1 GtC/yr) = 400,000 years before it is transferred into the rock reservoir
- As the large size of the rock reservoir and the relatively small rate of exchange between the rocks and the atmosphere, it takes many, many millions of years for a carbon atom to travel through the rock reservoir and reemerge into the atmosphere
- As continents move, patterns of rainfall can change, and new rock can be exposed to the atmosphere, both of which can change the rate of chemical weathering
- Therefore, the rate that carbon dioxide is removed from the atmosphere.
- For example, approximately 40 million years ago the Indian subcontinent collided with the Asian continent, forming the Himalayas and the adjacent Tibetan Plateau. Changing wind patterns brought heavy rainfall onto the expanse of the newly exposed rock, and the resultant chemical weathering drew down atmospheric carbon dioxide over a period of tens of millions of years.

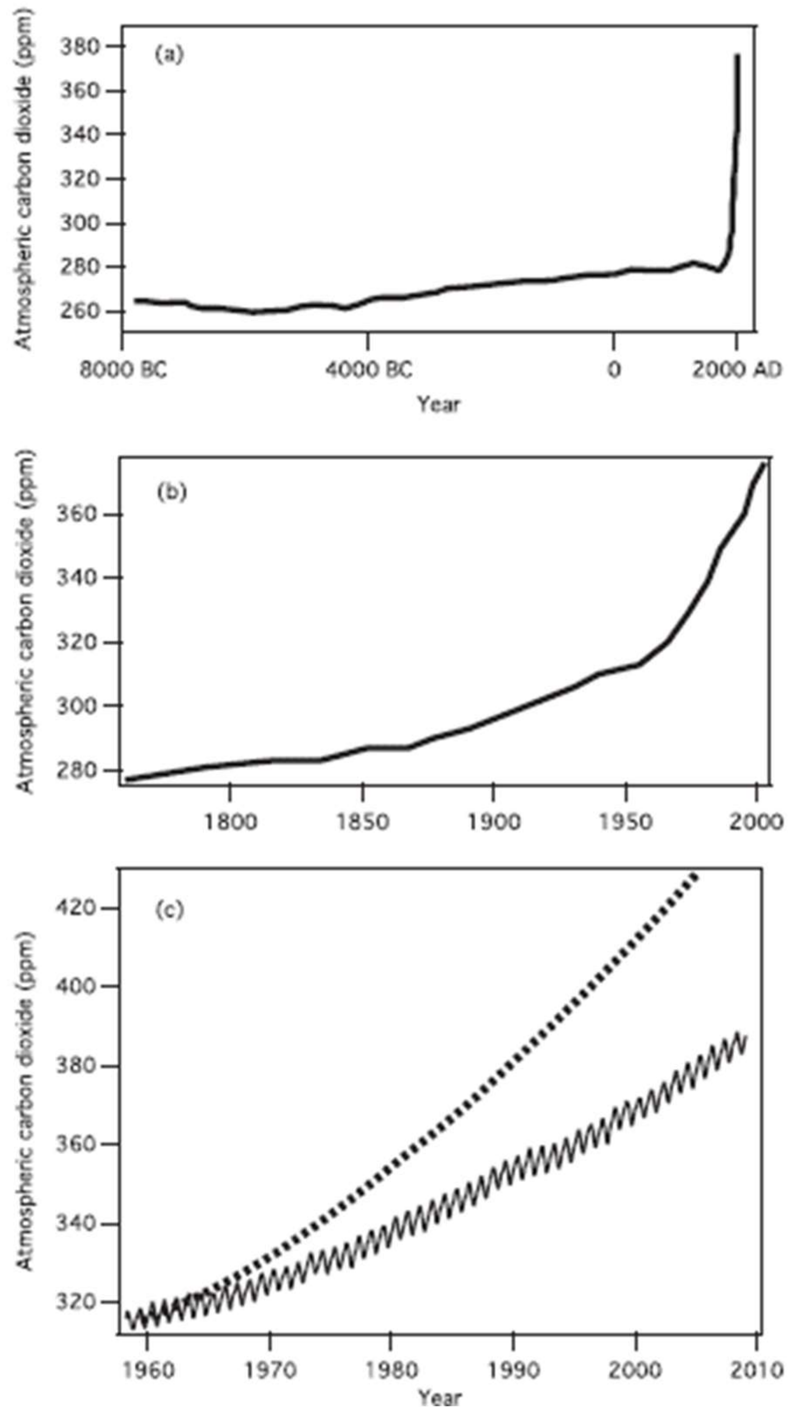
How are humans perturbing the carbon cycle?



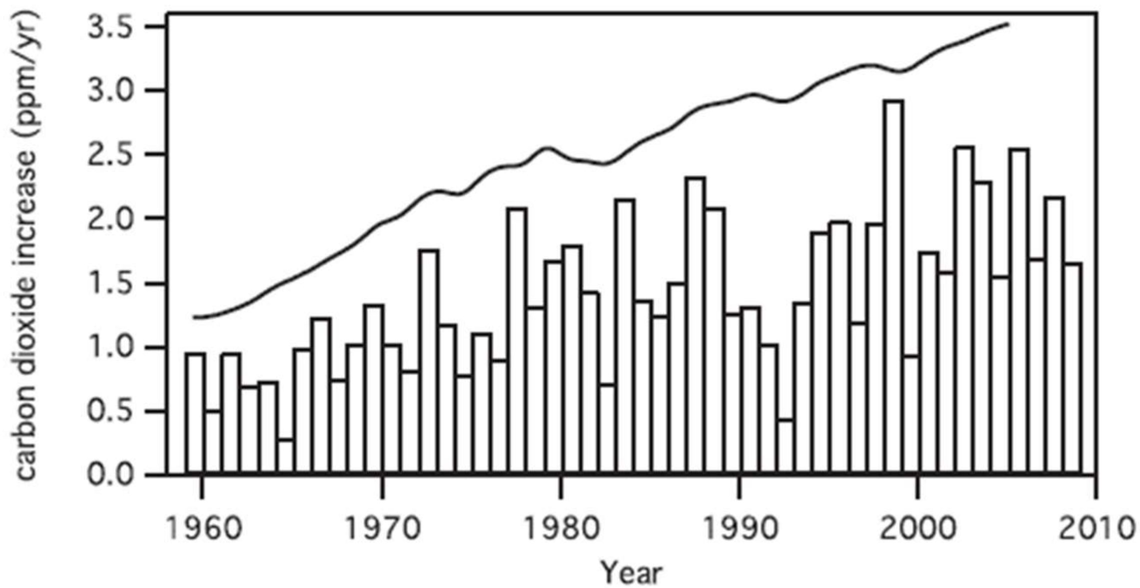
- Combustion of *fossil fuels:* In 2008, fossil fuel combustion released approximately 9 GtC to the atmosphere – roughly 90 times the natural flow rate of carbon from the rocks to the atmosphere.
- *Deforestation :* Deforestation is an important source of carbon dioxide for the atmosphere, and estimates are that it contributed approximately 1.5 to 2 GtC to the atmosphere per year during the 2000s

How are humans perturbing the carbon cycle?

- Figure a) shows the abundance of carbon dioxide over the past 10,000 years
- Over almost all of this time, the abundance remained in a narrow range, 260–280 ppm, but a sudden spike occurred in the past few hundred years
- Figure b) shows a close-up of the past 250 years. It shows that atmospheric carbon dioxide began rapidly increasing right at the beginning of the industrial revolution, when widespread economy-wide burning of fossil fuels began
- The rise in carbon dioxide is accelerating. Over the past 250 years, atmospheric carbon dioxide has increased by 100 ppm or so
- The first 50 ppm of the increase took more than 200 years, until the 1970s, whereas the second 50 ppm took only 30 years
- Figure b) shows high-resolution measurements of the abundance of carbon dioxide in our atmosphere over the past 50 years



- In the late 1950s, the increase in atmospheric carbon dioxide was less than 1 ppm/yr, while during the first decade of the 21st century, the increase was nearly 2 ppm/yr
- This reflects the increasing rate of fossil fuel consumption over the past half-century
- In 2008, for example, the combustion of fossil fuels led to the emission of approximately 8.7 GtC to the atmosphere
- Coal combustion contributed 40% of this, oil combustion contributed 36%, and most of the rest comes from natural gas (methane) combustion.



- Bars show the observed year-to-year increase in atmospheric carbon dioxide. The solid line shows what the annual increase would have been had 100% of the carbon dioxide emissions remained in the atmosphere

Methane

- Methane is another crucial carbon-containing gas is roughly 20 times more powerful of a greenhouse gas than carbon dioxide
- Atmospheric methane has both human and natural sources
- Cattle, as well as goats and sheep - about 80 million tons per year
- Rice paddies - 60 million tons per year
- Bacterial processes in landfills and other waste repositories - 60 million tons per year
- Methane from the petrochemical industry - 60 million tons per year
- Geologic methane from coal mines - 50 million tons per year
- Biomass burning - 50 million tons
- Human activities in the 2000s were approximately 350 - million tons.
- The annual total emission of methane from natural sources is roughly 200 million tons per year
- Natural emissions – 35%, human activities – 65%
- 70% bacterial fermentation of organic material (wetlands, rice agriculture, livestock, landfills, forests, oceans, and termites). 30% of the emissions are nonbiogenic,

Methane

- Methane’s contribution to global warming is approximately one fourth of the contribution of carbon dioxide
- As a result, reductions of methane emissions are frequently included in plans to address climate change
- Methane is removed from the atmosphere by oxidation, which follows the following schematic reaction

$$CH_4 + 2O_2 \rightarrow CO_2 + 2\,H_2O$$

- On average, a molecule of methane is destroyed by this reaction 10 years after it was emitted.
- If we stopped emitting methane today, within a few decades all of the human-emitted methane would be gone, and the atmospheric abundance would be back down to pre-industrial amounts