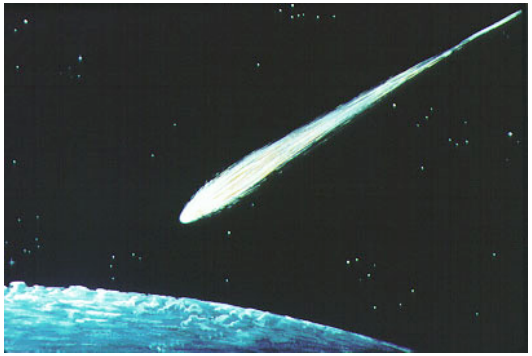
Biogeochemical Cycles

3 Fundamental Laws of Nature

- Conservation of Matter
- 1st Law of Thermodynamics
  (Conservation of Energy)
- 2nd Law of Thermodynamics
  (Entropy)

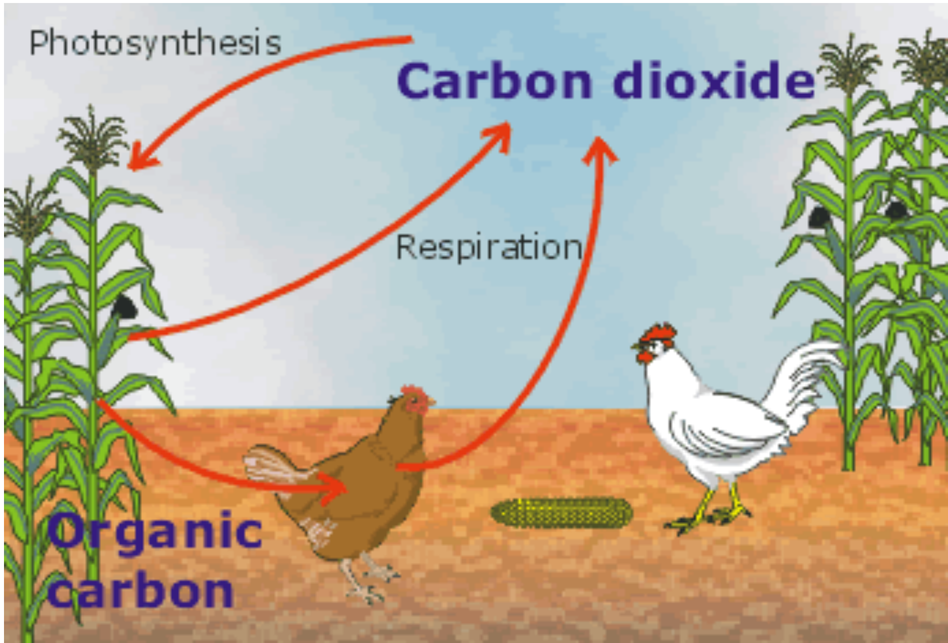
Earth:
Matter does not come and go

Earth is a Closed System to Matter



- Earth is a closed system with respect to elements like C, N, P, S etc
- When organisms die and decay, their body structures disintegrate and are reduced to constituent molecules
- Join the biogeochemical cycles
- Elements in the BC are either micro- (e.g. boron copper) or macro (CHONSP)

- Biogeochemical Cycles- Cycling of *energy*, and various *chemical elements* and compounds through the biosphere due to the feeding of organisms on each other
- This includes: carbon, nitrogen, phosphorus, water...almost anything that temporarily inhabits a living thing

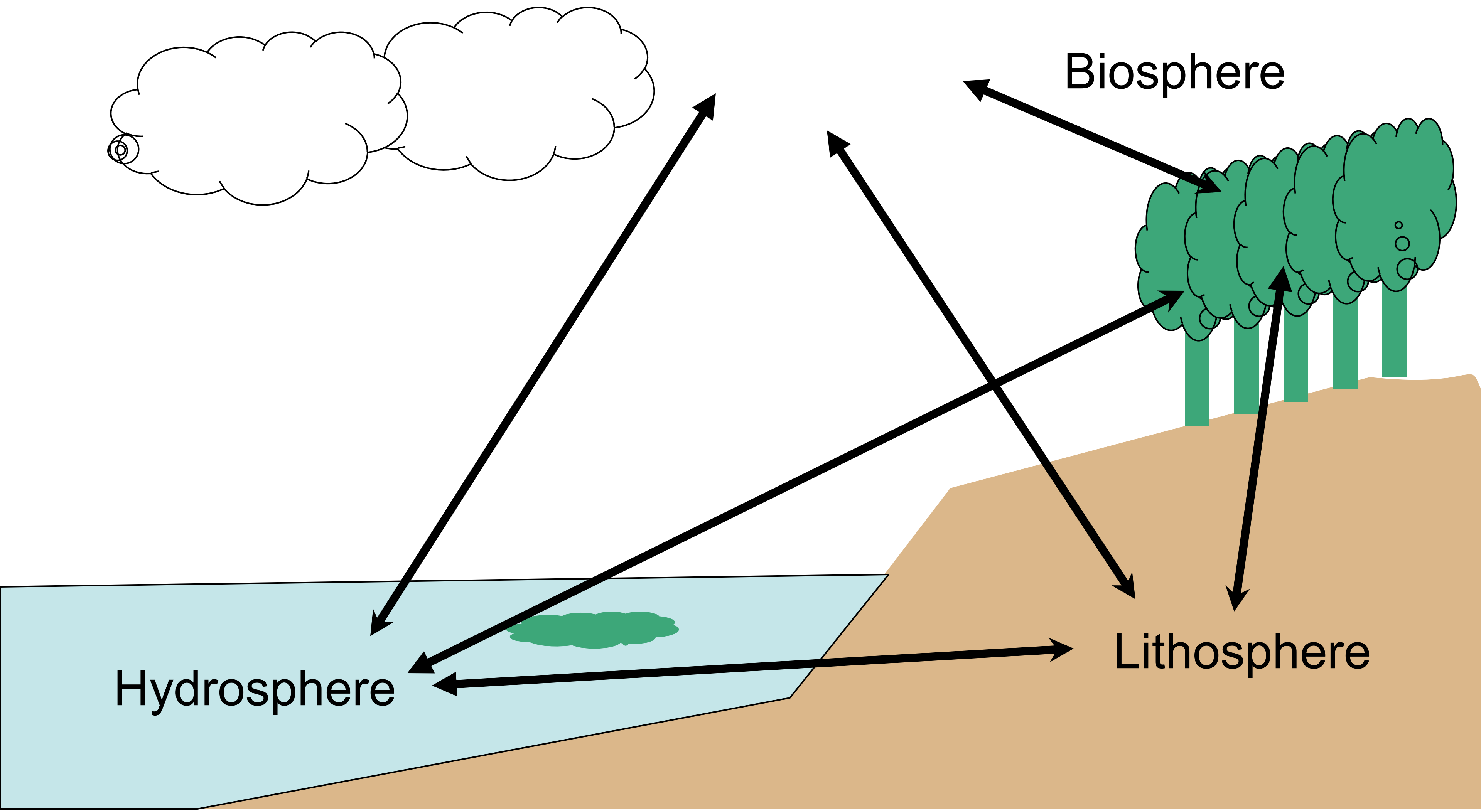


Importance

- Helps in the transformation of matter from one form to another thus enables utilization of matter in a form specific to a particular organism e.g. humans utilize water in liquid form-hydrological cycle; plants take nitrogen in two solid forms NH4+ and NO-3
- Transfer of molecules from one locality to another e.g. Nitrogen are highly concentrated in the atmosphere but transferred to the soil thru the nitrogen cycle
- Storage of elements; stored in their natural reservoirs and are released to organisms in small consumable amounts e.g. utilizing nitrogen in bits thru action of nitrogen fixing bacteria.

- Assists in functioning of ecosystems. Ecosystems function properly in a state of equilibrium, and whenever any imbalances occur, the ecosystem thru the biogeochemical cycle restores the equilibrium state; this may take a few days or years. The adjustment is such that the disturbing factor is eliminated.
- Biogeochemical cycles link living organisms with living organisms, living organisms with the non living, and non living organisms with nonliving. This is because all organisms depend on one another (rem Bazzaz's law??). Most especially the biotic and abiotic are linked by flow of nutrients engineered by the biogeochemical cycles.
- Biogeochemical cycles regulate the flow of substances. Since the the cycle pass thru different spheres, the flow of elements is regulated because each sphere has a particular medium and the rate at which elements flow flow is determined by the viscosity and density of the medium. Therefore elements in the BC flow at differing rates and this regulates the flow of the elements in those cycles

Biogeochemical Cycles: Reservoirs & Pathways



Some Major Cycles of Matter

- Water Cycle
- Rock Cycle
- Chemical Cycles
    - Carbon
    - Nitrogen
    - Phosphorous
    - Sulfur

The carbon cycle

- All living things are made of carbon. Carbon is also a part of the ocean, air, and even rocks. Because the Earth is a dynamic place, carbon does not stay still. It is on the move!
- In the atmosphere, carbon is attached to some oxygen in a gas called carbon dioxide.
- Plants use carbon dioxide and sunlight to make their own food and grow. The carbon becomes part of the plant. Plants that die and are buried may turn into fossil fuels made of carbon like coal and oil over millions of years. When humans burn fossil fuels, most of the carbon quickly enters the atmosphere as carbon dioxide.

- Carbon dioxide is a greenhouse gas and traps heat in the atmosphere.
- Without it and other greenhouse gases, Earth would be a frozen world.
- But humans have burned so much fuel that there is about 30% more carbon dioxide in the air today than there was about 150 years ago, and Earth is becoming a warmer place.
- In fact, ice cores show us that there is now more carbon dioxide in the atmosphere than there has been in the last 420,000 years.

- Carbon is the fourth most abundant element in the universe, and is absolutely essential to life on Earth.
- In fact, carbon constitutes the very definition of life, as its presence or absence helps define whether a molecule is considered to be organic or inorganic.
- Every organism on Earth needs carbon either for structure, energy, or, as is the case of humans, for both.
- Discounting water, you are about half carbon.
- Additionally, carbon is found in forms as diverse as the gas carbon dioxide (CO_2), and in solids like limestone ($CaCO_3$), wood, plastic, diamonds, and graphite

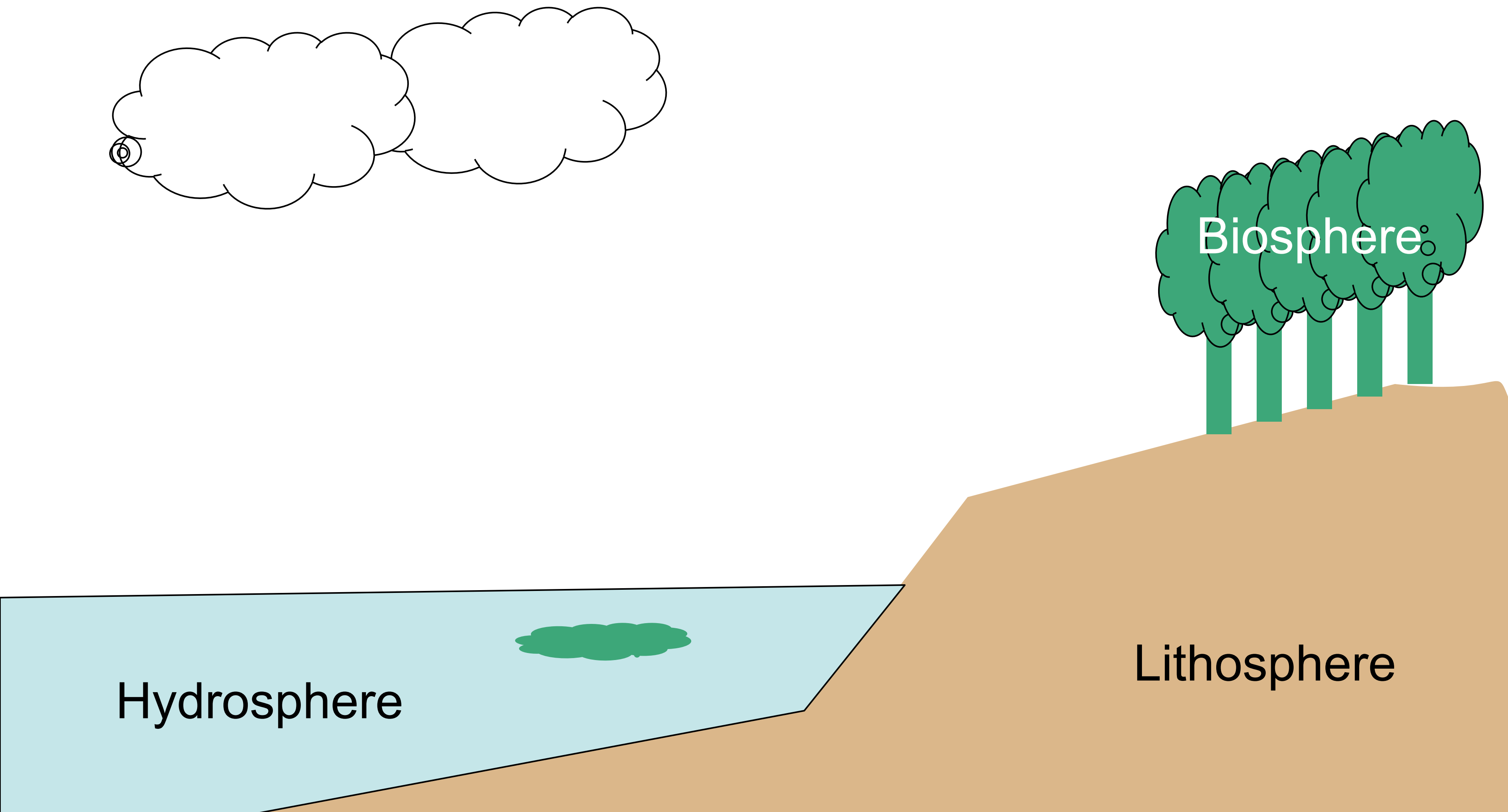
Process

- Carbon enters the atmosphere as **carbon dioxide** from respiration and combustion.
- Carbon dioxide is absorbed by producers to make **carbohydrates** in photosynthesis.
- Animals feed on the plant passing the carbon compounds along the food chain. Most of the carbon they consume is exhaled as **carbon dioxide** formed during respiration. The animals and plants eventually **die**.
- The dead organisms are eaten by **decomposers** and the carbon in their bodies is returned to the atmosphere as carbon dioxide. In some conditions decomposition is **blocked**. The plant and animal material may then be available as **fossil fuel** in the future for combustion.

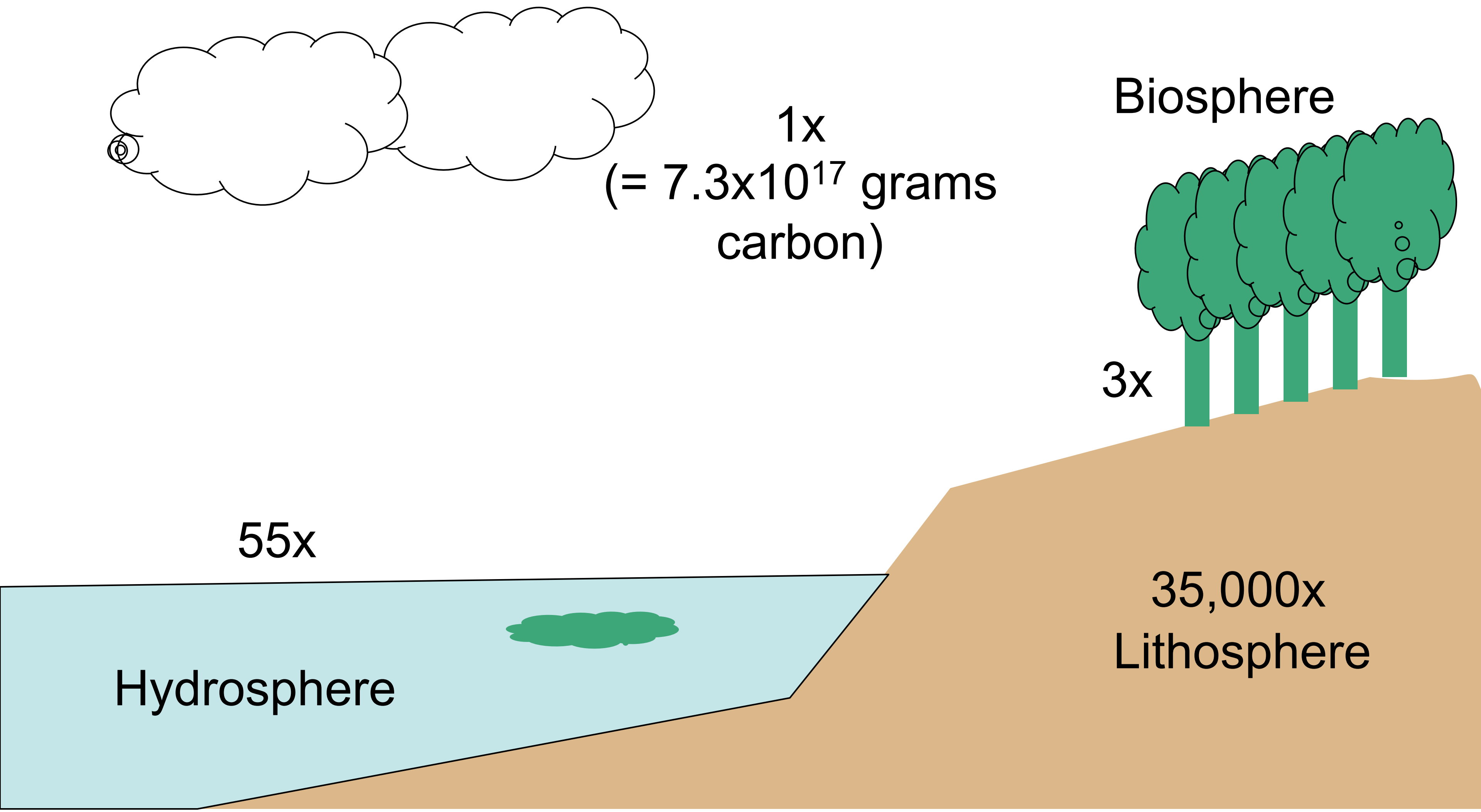
Carbon cycle in the sea - higher tier only

- In the sea, marine animals may convert some of the carbon in their diet to **calcium carbonate** which is used to make their **shells**.
- Over time the shells of dead organisms collect on the seabed and form limestone.
- Due to Earth movements this limestone may eventually become exposed to the air where it's weathered and the carbon is released back into the atmosphere as **carbon dioxide**.
- Volcanic action may also release **carbon dioxide**.

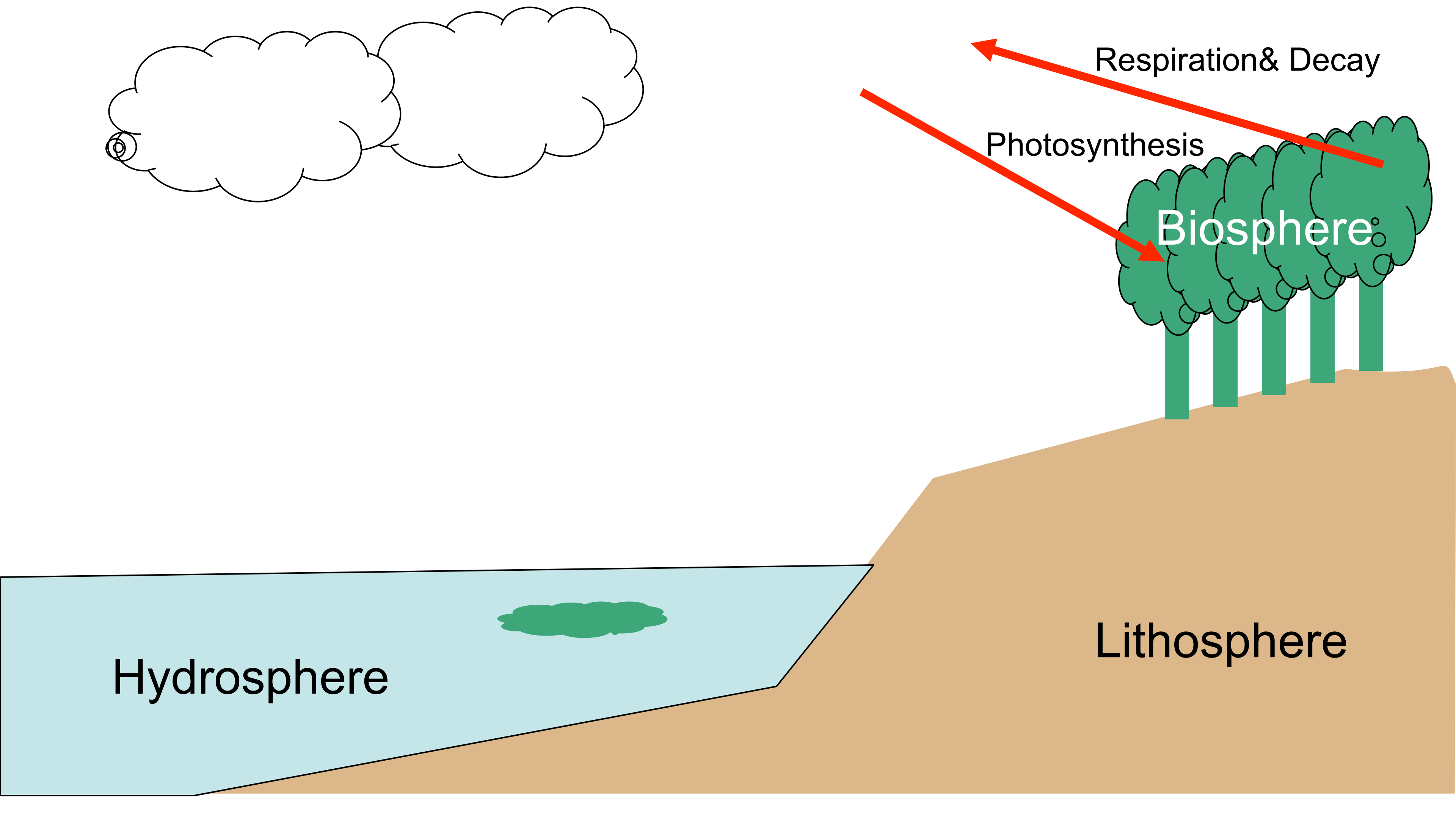
Carbon Cycle



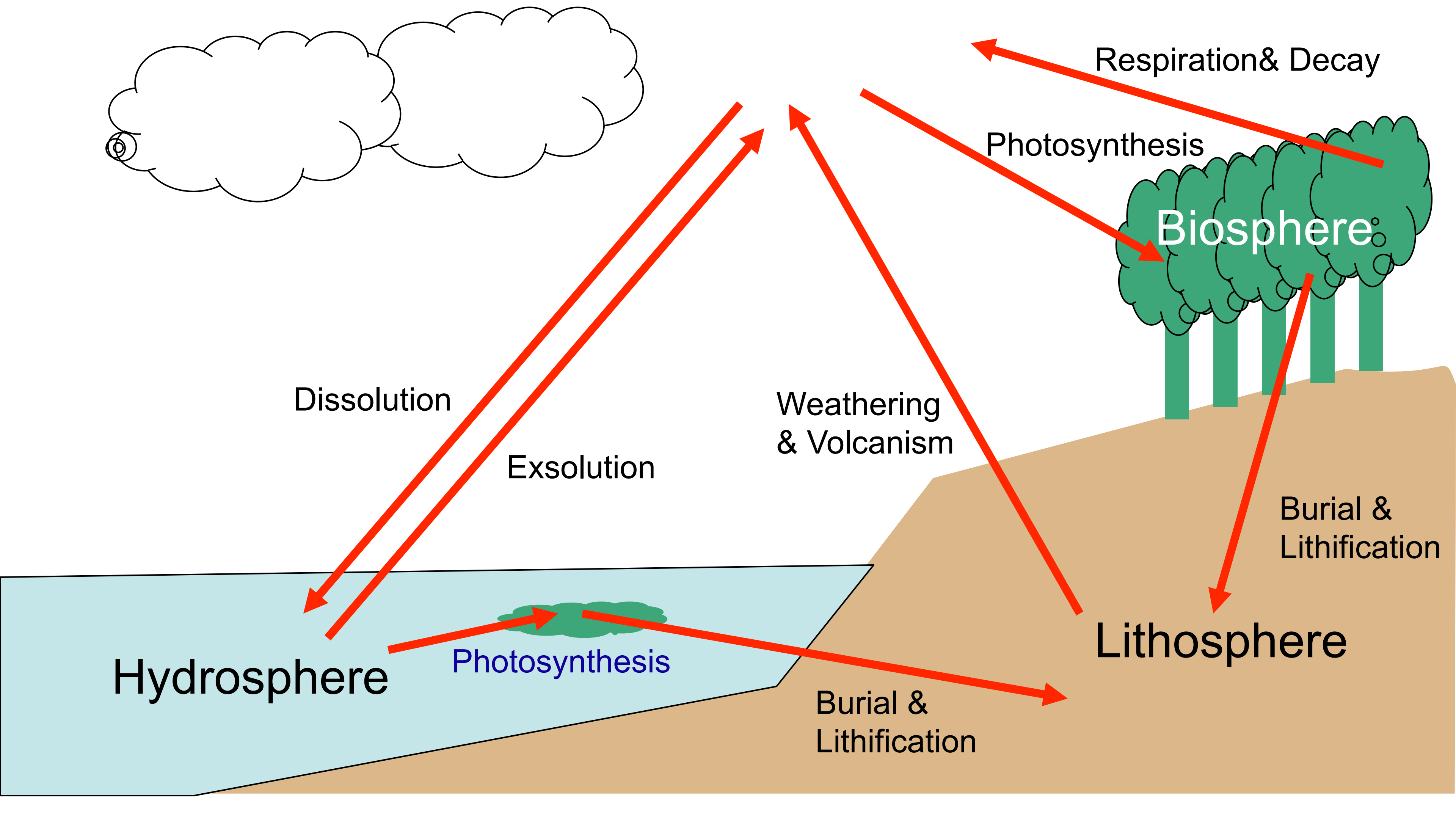
Carbon Cycle: Reservoirs



Carbon Cycle

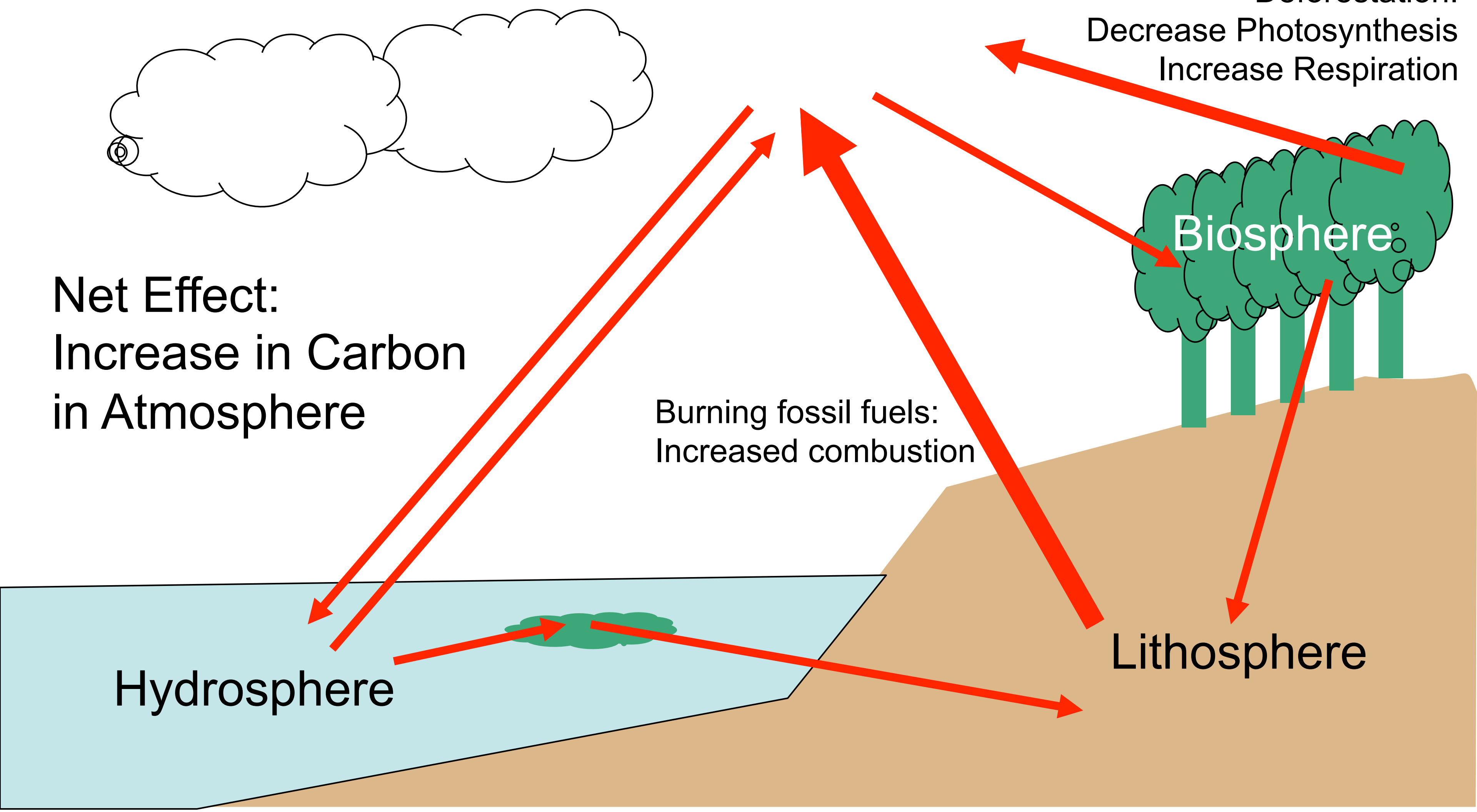


Carbon Cycle



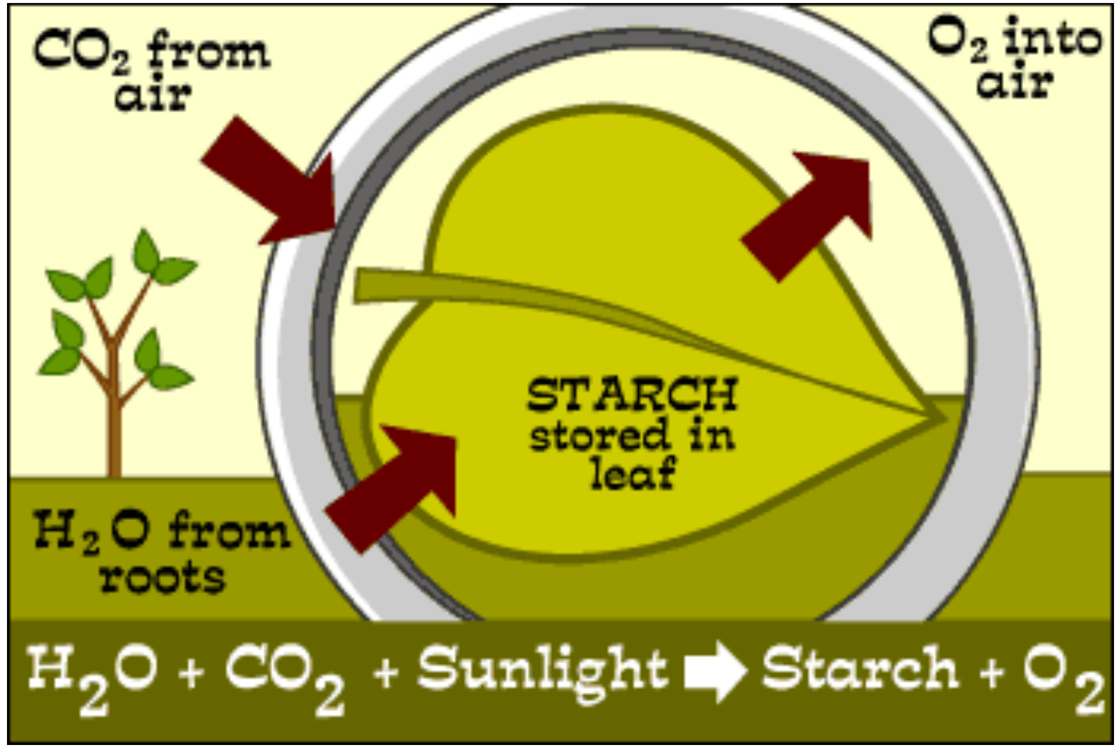
Carbon Cycle

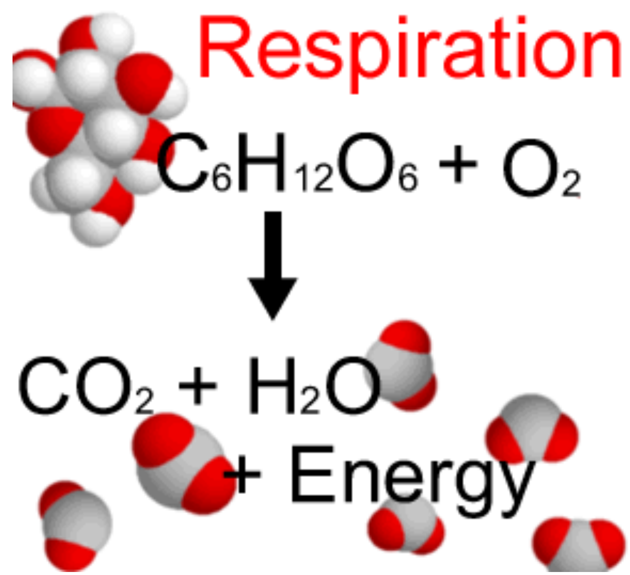
Human Impacts

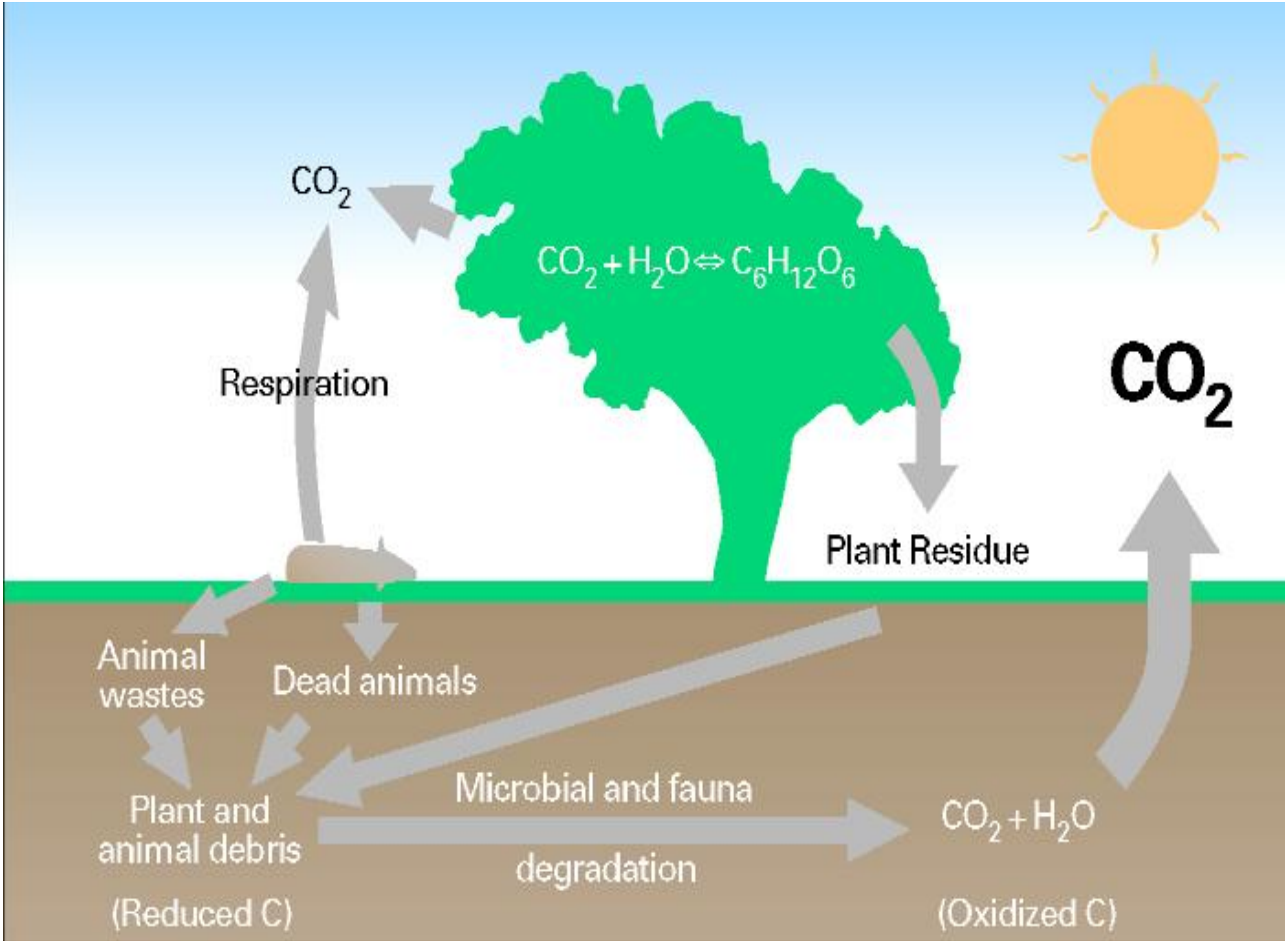


Carbon cycle

All organic matter eventually is oxidized (burned) and converted back to carbon dioxide and water.





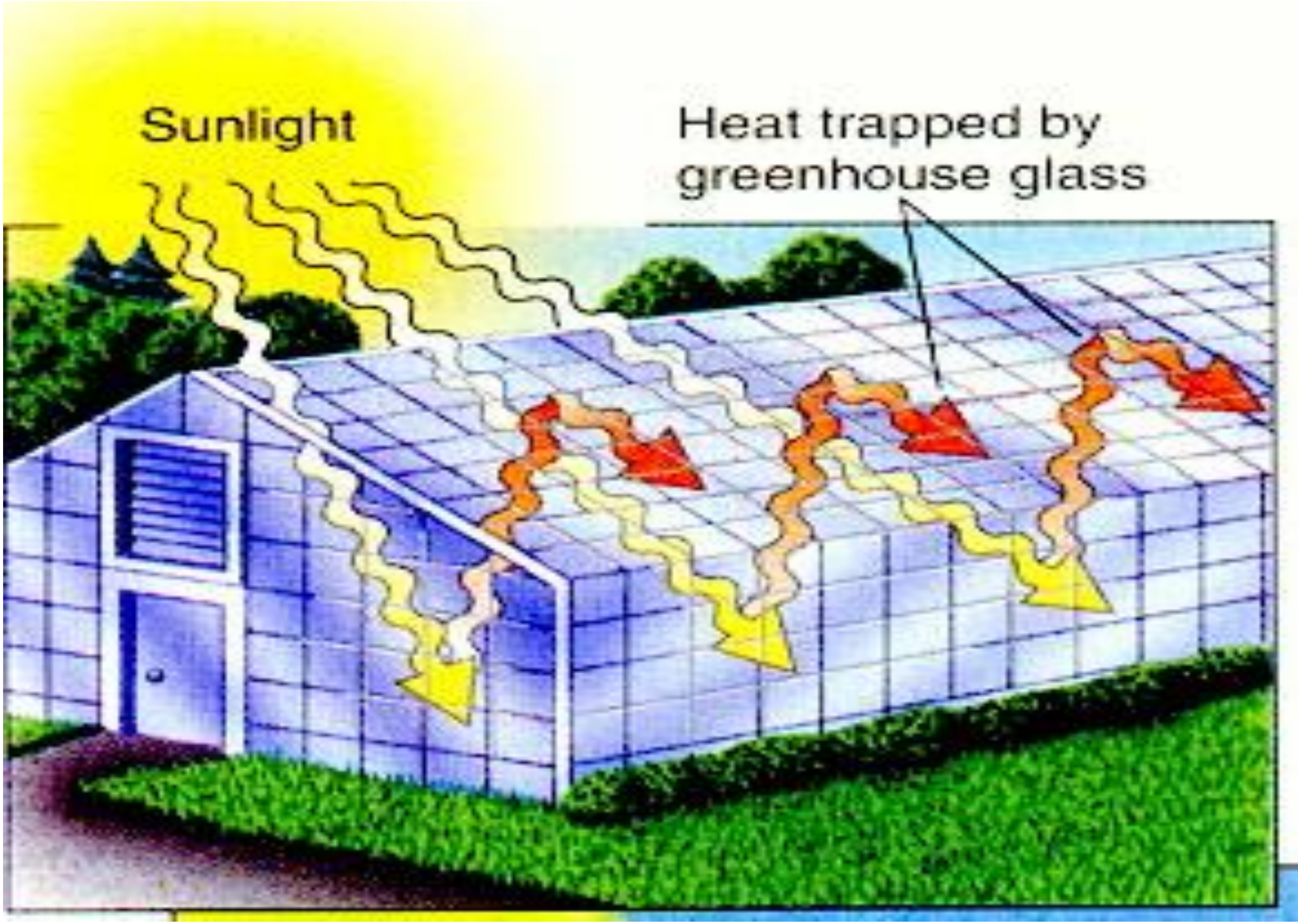


CO_2
$CO_2 + H_2O \Leftrightarrow C_6H_{12}O_6$
Respiration
CO_2
Plant Residue
Animal wastes
Dead animals
Microbial and fauna
degradation
Plant and animal debris
(Reduced C)
$CO_2 + H_2O$
(Oxidized C)

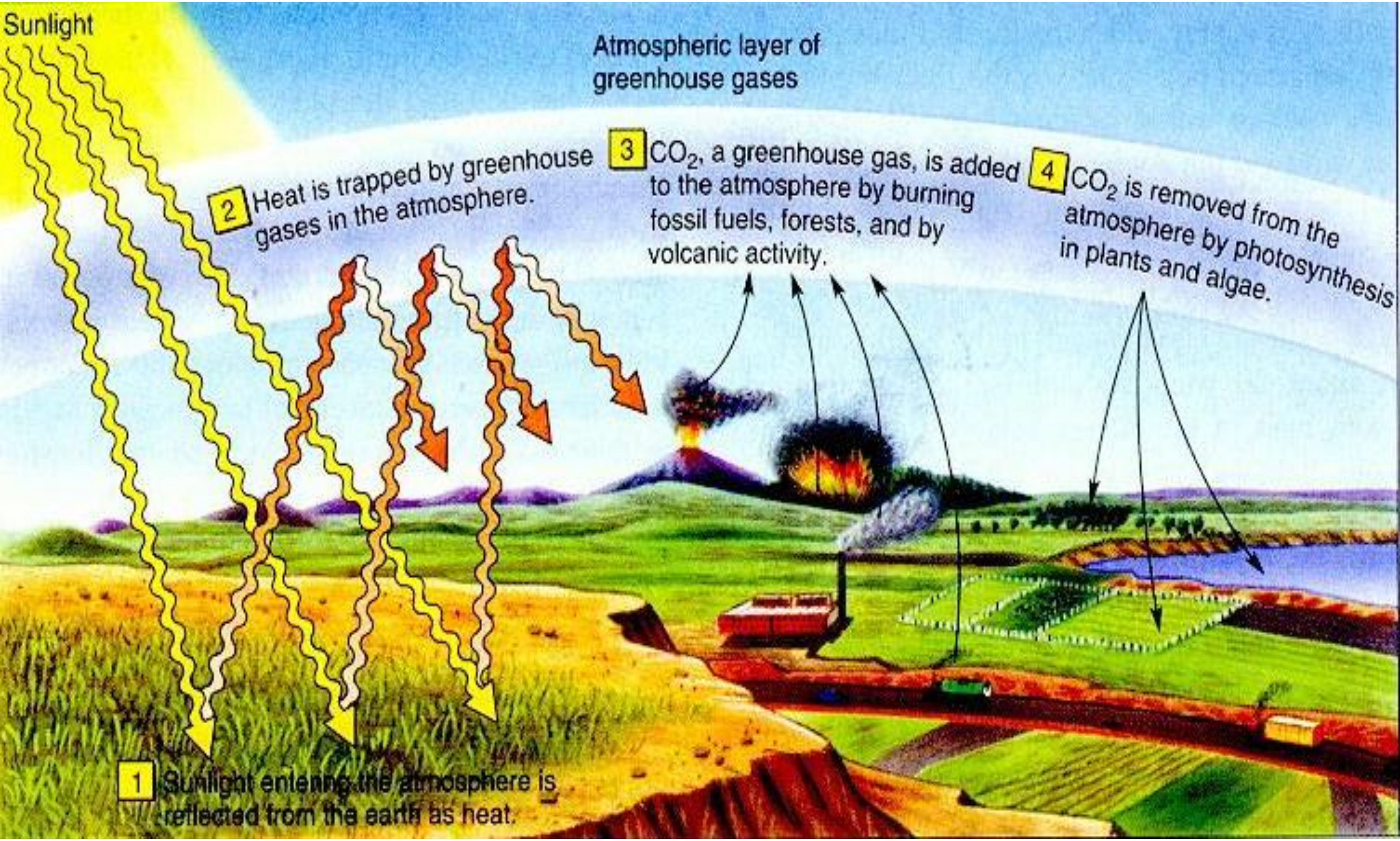
Carbon dioxide and global warming

- The use of fossil fuels and practice of deforestation to meet the world's energy demands has led to increasing concentrations of carbon dioxide (CO_2) and methane (CH_4) in the atmosphere.
- Both gases absorb terrestrial infrared radiation and have the potential to affect earth's climate by warming it.

The greenhouse effect

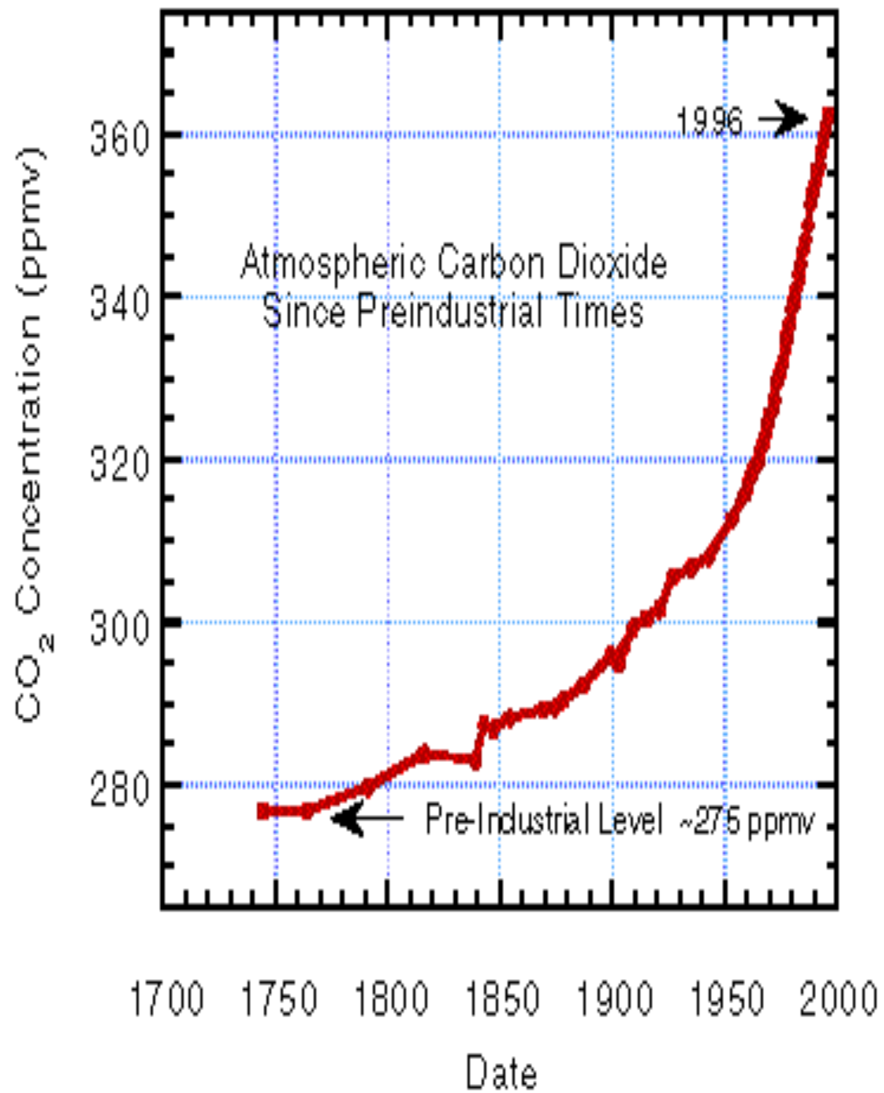


The greenhouse effect

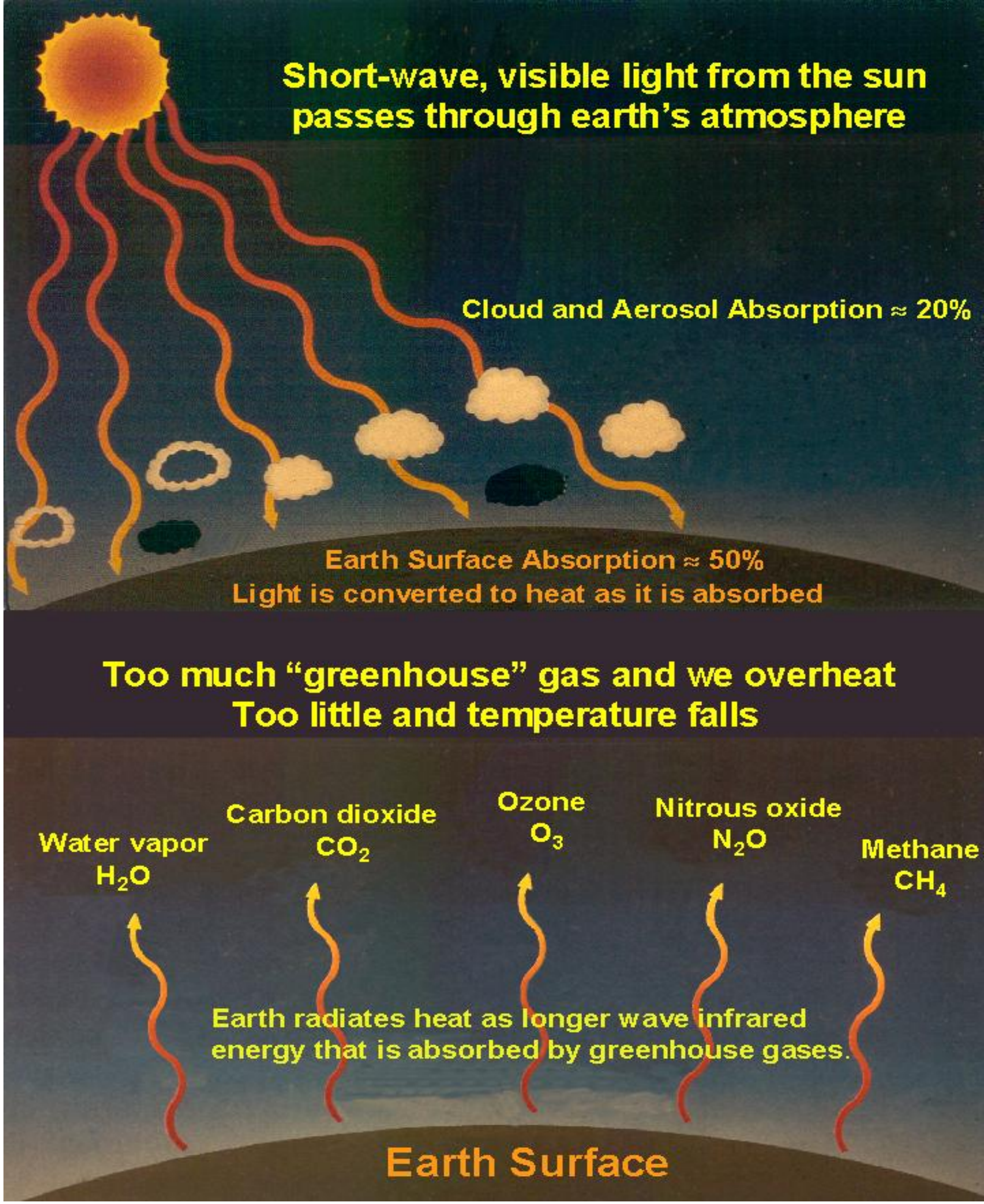


Source of atmospheric carbon

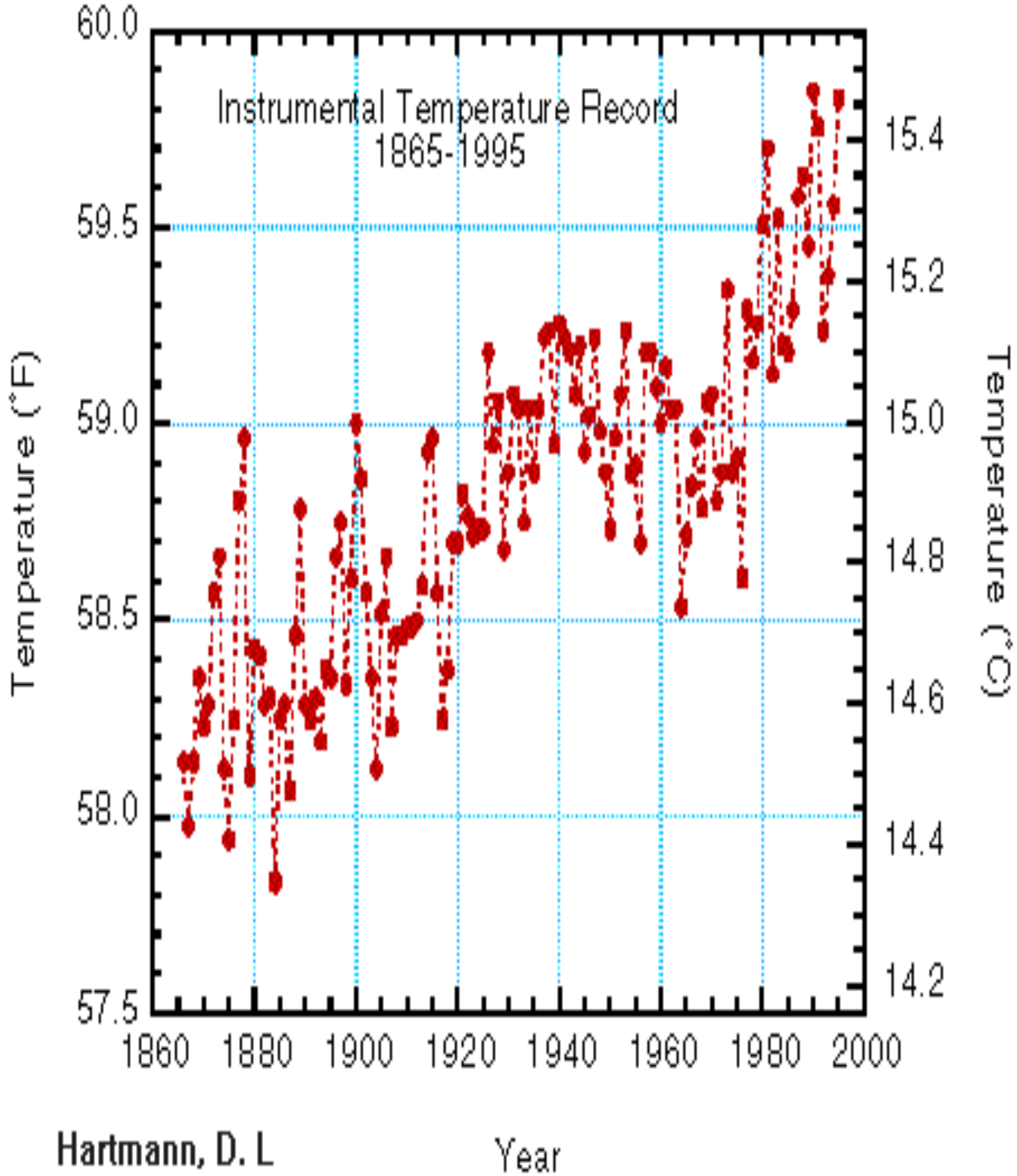
- *Atmospheric carbon represented a steady state system, where influx equaled outflow, before the Industrial Revolution*.
- Currently, it is no longer a steady state system because the influx exceeds the outflow.
- Therefore, we are experiencing an increase in atmospheric carbon, mainly in the form of CO_2



- Half of the solar energy that reaches Earth passes through the atmosphere and is absorbed at the surface.
- About 90% of the infrared radiation emitted by the surface is absorbed by the atmosphere before it can escape to space.

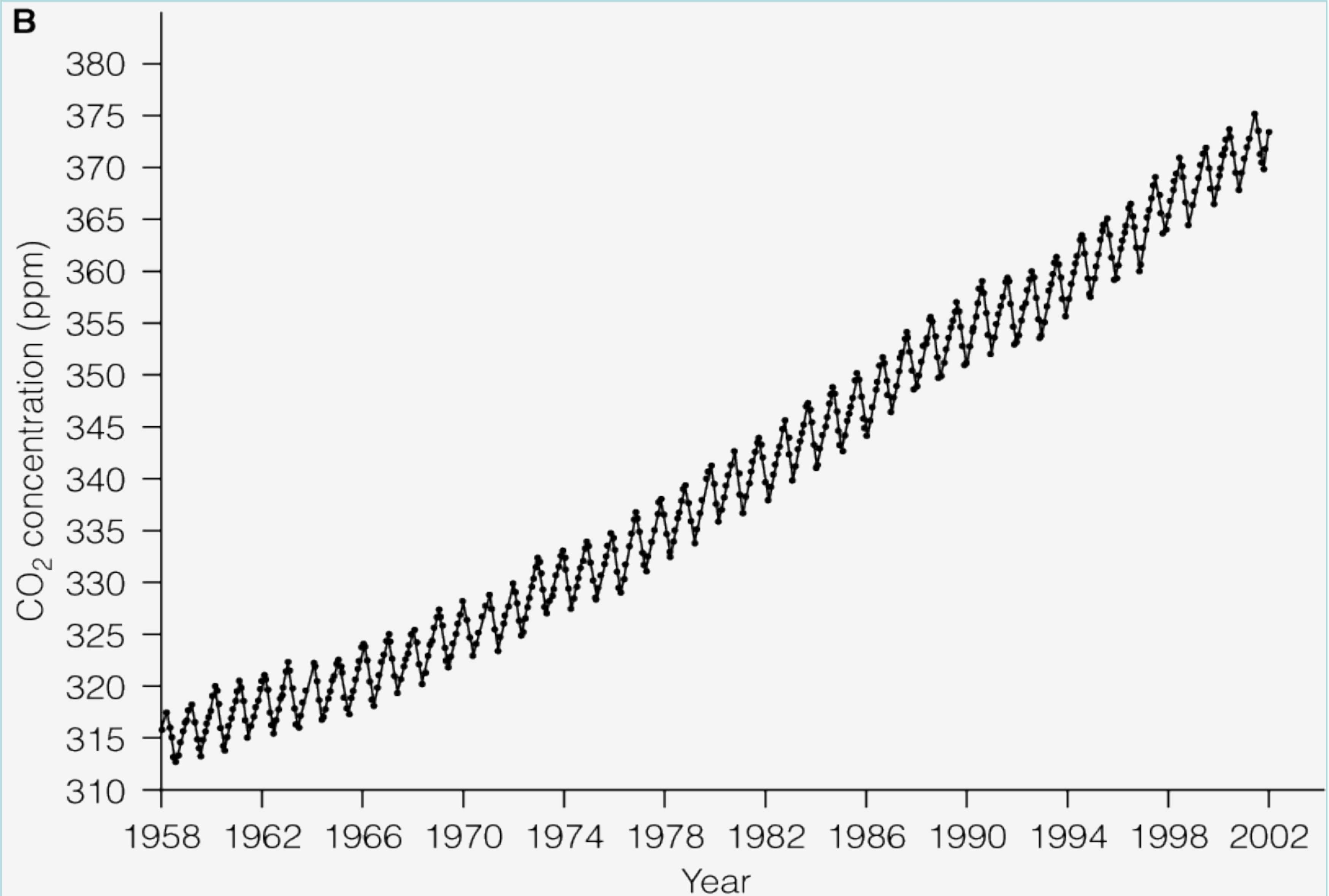


- The characteristics of the atmosphere that enable it to raise the temperature of the surface of Earth are:
- 1) atmosphere is transparent to sunshine
- 2) but is almost opaque to infrared radiation.
- So the atmosphere lets in the heat from the sun, but is reluctant to let it escape again due to the "greenhouse gasses"



Hartmann, D. L

- *“If CO2 is suddenly added to the atmosphere, it takes between 50 and 200 years for the amount of atmospheric CO2 to establish a new balance, compared to several weeks required for water vapor”*



Plot depicting the continuous increase in atmospheric CO2 from 1958 to 2002.

……………………………

Are you convinced about "Climate Change"

If yes or no… explain why?

Soil carbon sinks

- Large amounts of carbon have been released into the atmosphere through the conversion of grasslands and forests to agricultural and grazing land, as well as through unsustainable land practices.
- Soils can regain lost carbon by absorbing or "sequestering" it from the atmosphere. But the ability of soils to act as carbon "sinks“ depends on sound land management.

Facts:

- Carbon (C) enters the biosphere during photosynthesis:

$$CO_2 + H_2O \dashrightarrow C_6H_{12}O_6 + O_2 + H_2O$$

- Carbon is returned to the biosphere in cellular respiration:

$$O_2 + H_2O + C_6H_{12}O_6 \dashrightarrow CO_2 + H_2O + \text{energy}$$

Amount of CO_2 during the year:

- Every year there is a measurable difference in the concentration of atmospheric CO_2 in phase with the seasons.
- For example, in winter there is almost no photosynthesis therefore there is a high concentration of CO_2.
- During the growing season there is a measurable difference in the concentration of atmospheric CO_2 over parts of each day.
- For example, at sunrise photosynthesis begins with the uptake of CO_2, by afternoon plant respiration increases, at sunset photosynthesis stops so the concentration of CO_2 in the atmosphere increases.

Assignment 1

Discuss the influence of human activities on the Biogeochemical cycles (1 week)

Human induced changes in the global carbon cycle:

The Earth is getting warmer.

The 20th century has been the warmest in the last 600 years.

This century is about 1 degree Fahrenheit warmer than last century.

The balance of evidence suggests that burning of fossil fuel (eg. coal, oil, natural gas), which emits CO2 as a waste, is the cause.

CO2 is a "Green House" gas - it traps heat at the Earth's surface. (H2O vapor and methane are also examples of green house gases)

Signs that the climate is warming:

Plants start blooming 8 days earlier in spring than 11 years ago.

Birds from the United Kingom lay eggs earlier.

Buds on trees appear earlier and leaves fall later in the Northern Hemisphere.

Alaska, North West Canada, and Siberia have warmed up as much as 5 degrees Fahrenheit in the last 30 years

The nitrogen cycle

- Most plants get the nitrogen they need from soil.
- Many farmers use fertilizers to add nitrogen to the soil to help plants grow larger and faster.
- Both nitrogen fertilizers and forest fires add huge amounts of nitrogen into the soil and nearby lakes and rivers.
- Water full of nitrogen causes plants and algae to grow very fast and then die all at once when there are too many for the environment to support.

- Although nitrogen is very abundant in the atmosphere, it is largely inaccessible in this form to most organisms!!!!

The nitrogen cycle consists of 4 major steps: *nitrogen fixing*, *decomposition*, *nitrification* and *denitrification*.

Nitrogen fixation

- When bacteria in the soil takes nitrogen from the air, it becomes nitrates and can move through the food chain.
- For example, legume like clovers, peas and beans, their roots can take N_2 from the air and transform into another form called nitrates.
- In addition lightning transforms N2 into NO2, which goes into the soil to form nitrates. Also, synthetic fertilizer from farming can bring nitrate to the soil.
- Overall, nitrogen fixation takes unreactive nitrogen from the air and fixes it into a usable form.

Decomposition and Ammonification

- After nitrogen fixation, roots of plants absorb the nitrate. In the plant, they are in the form of protein and nucleic acids. In turn, animals eat these plants who break them down.
- When animals produce waste or die, this waste decays and bacteria consumes this dead organic matter.
- As a result, the nitrogen in this waste is in the form of ammonium (NH_4^+).
- This is a key process in the nutrient cycle that constantly exchanges inorganic and organic matter back and forth in an environment.

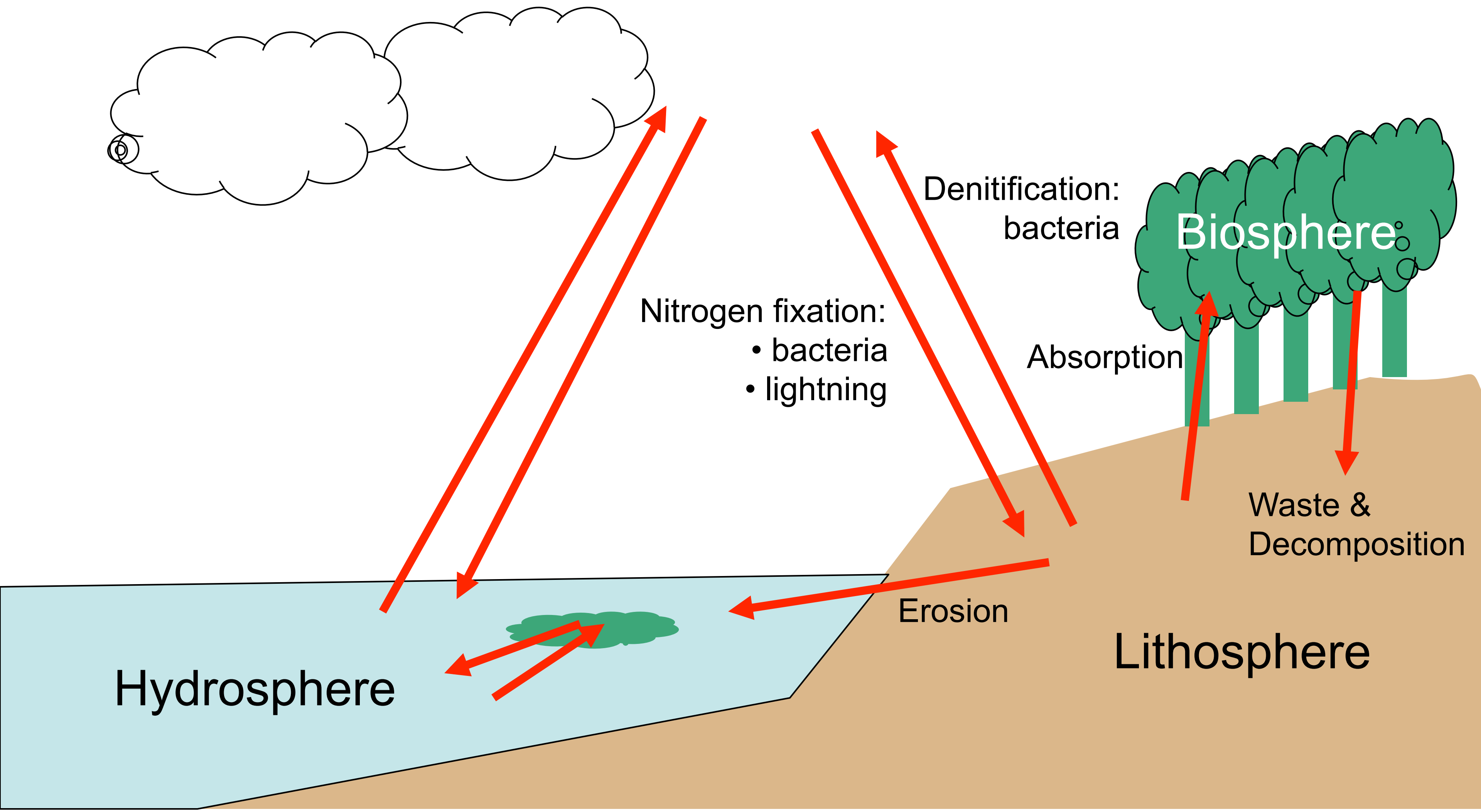
Nitrification

- However, it’s difficult for plants to use ammonium. So this waste (ammonium) is again broken down by bacteria through a process called ‘nitrification’.
- Nitrification takes the ammonium and transforms it into nitrates in the soil. And again, plants can absorb nitrate and moves through the food chain.
- If you deplete the soil from nitrogen, this deprives the plants from growing. Because bacteria convert dead plant material to nitrates, plants absorb it as food.

Denitrification

- Through the denitrification process, nitrates are converted nitrogen gas again. So it leaves the soil to go back into the atmosphere.
- Overall, denitrification turns nitrates (NO_3) in the soil to nitrogen (N_2) which is returned to the air.

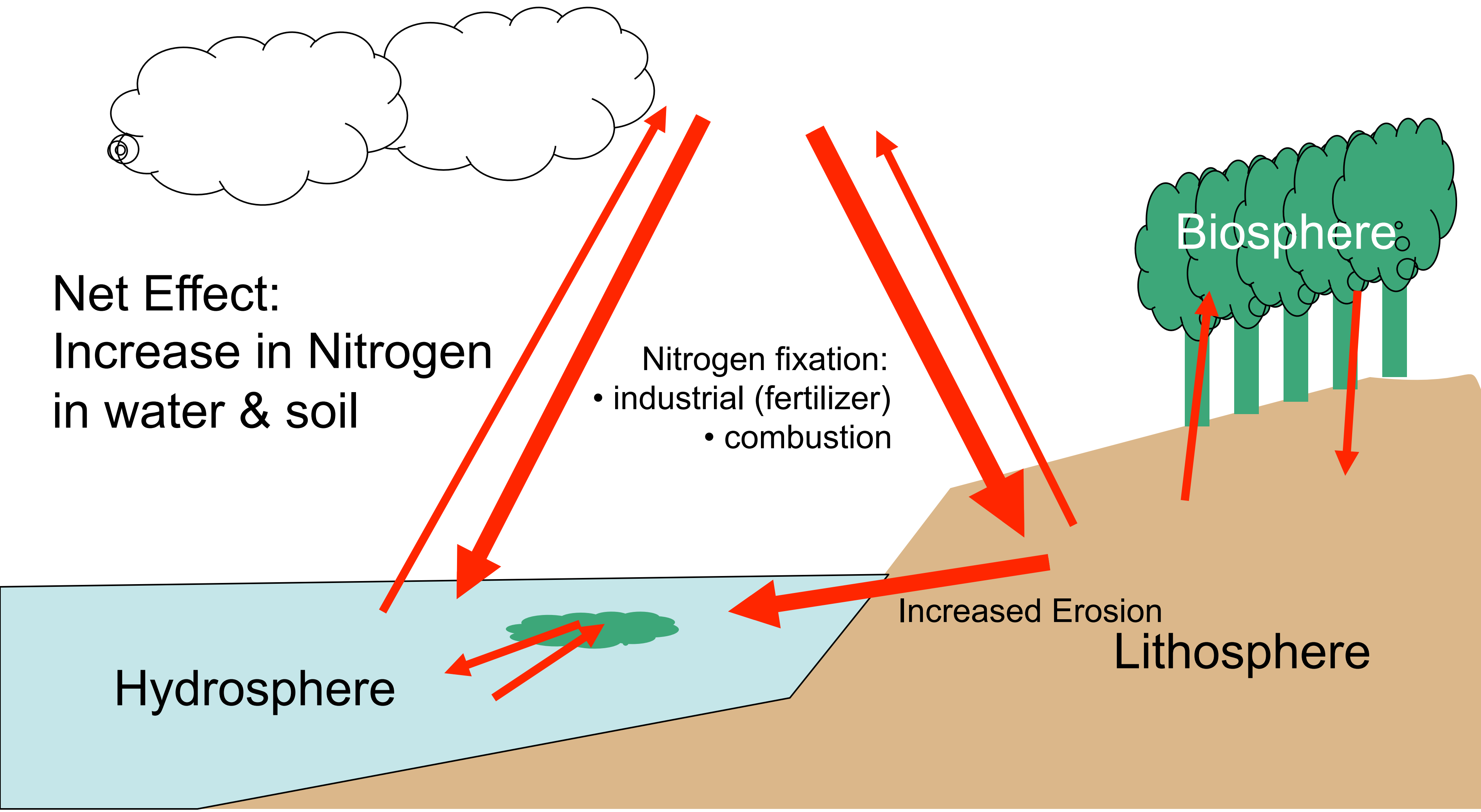
Nitrogen Cycle



Nitrogen-Fixing Bacteria in Root Nodules

Human Impacts

Nitrogen Cycle



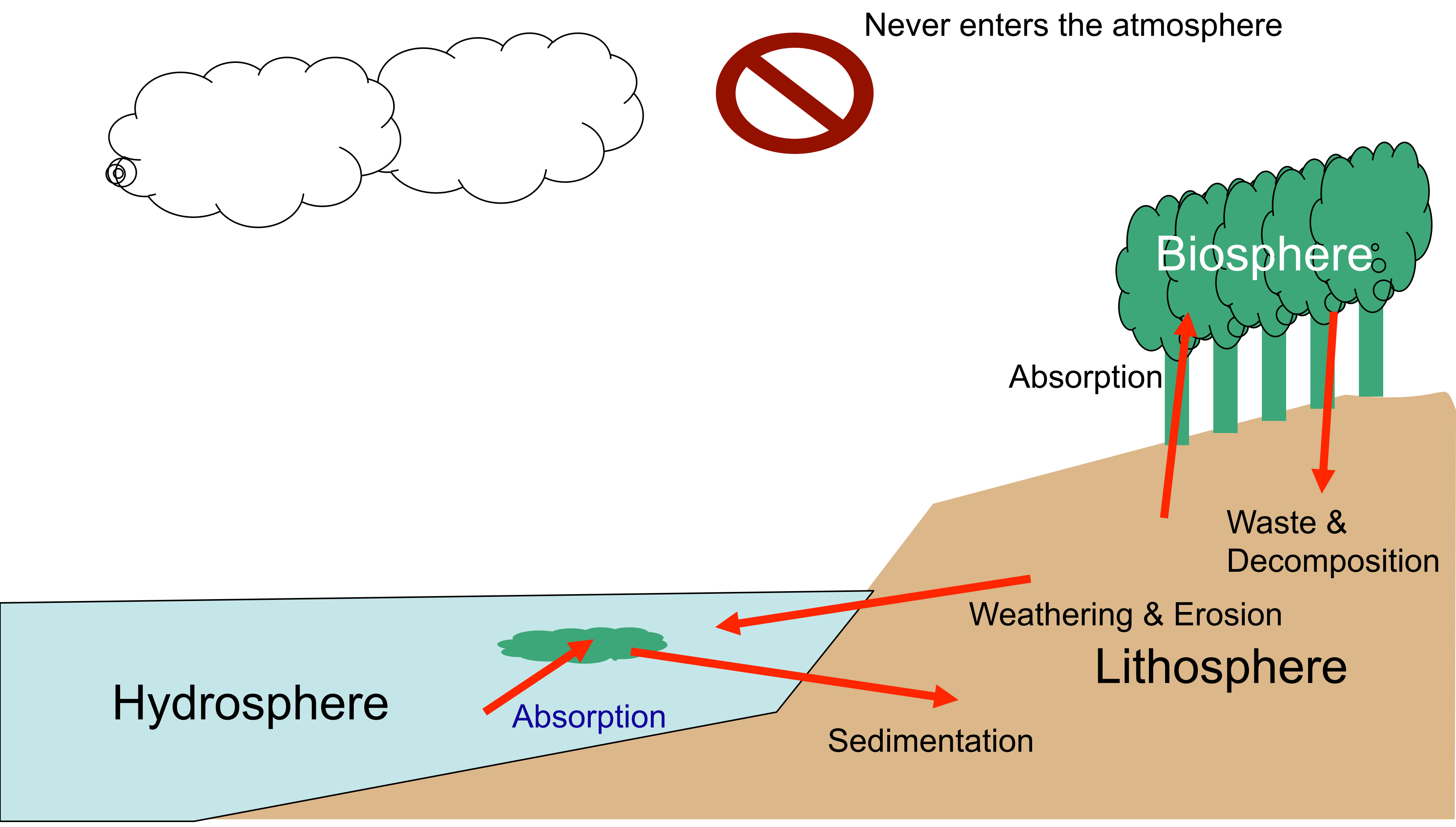
Nitrogen cycle

Facts:

- Nitrogen (N) is an essential constituent of protein, DNA, RNA, and chlorophyll.
- N is the most abundant gas in the atmosphere, but it must be fixed or converted into a usable form.
- **Nitrogen Fixation Methods:**
- 1) High energy fixation- a small amount of atmospheric nitrogen is fixed by lightening. The high energy combines N and H2O resulting in ammonia (NH3) and nitrates (NO3). These forms are carried to Earth in precipitation.
- 2) Biological fixation: achieves 90% of the nitrogen fixation. Atmospheric nitrogen (N2) is split and combined with hydrogen (H) atoms to form ammonia (NH3).

- **Who performs nitrogen fixation?**
- symbiotic bacteria (eg. Rhizobium spp.) living in association with leguminous (plants in the pea family), and root-noduled non-leguminous plants (eg. Alnus spp.).
  - free-living anaerobic bacteria
  - blue-green algae (cyanobacteria)
- Once NH3 is in the soil it combines with H+ ions to form ammonium ion (NH4), or without it to form NO3.
- NH4+ and NO3 are readily absorbed by plants.

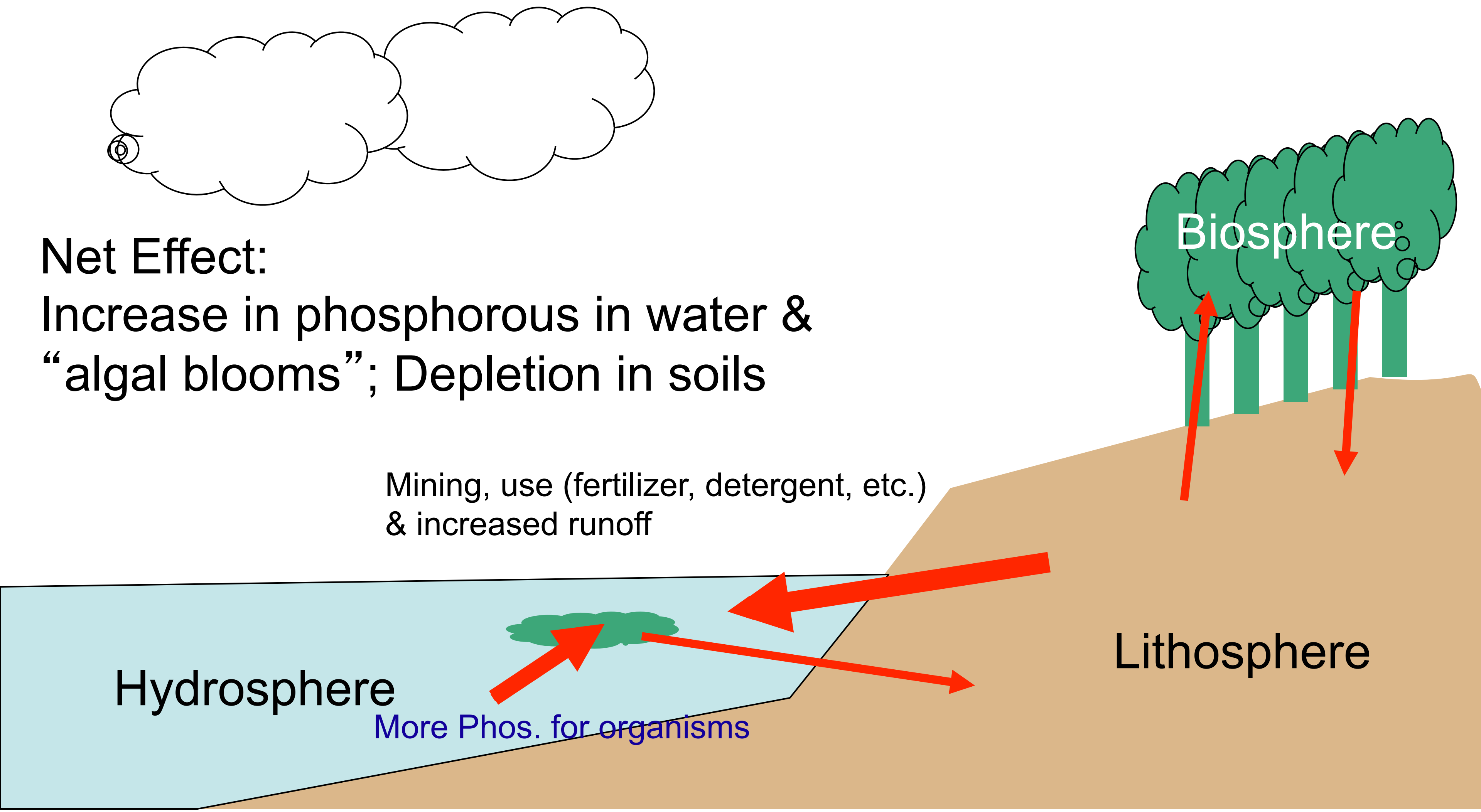
Phosphorous Cycle



Human Impacts

Phosphorous Cycle

Net Effect:
Increase in phosphorous in water & "algal blooms"; Depletion in soils

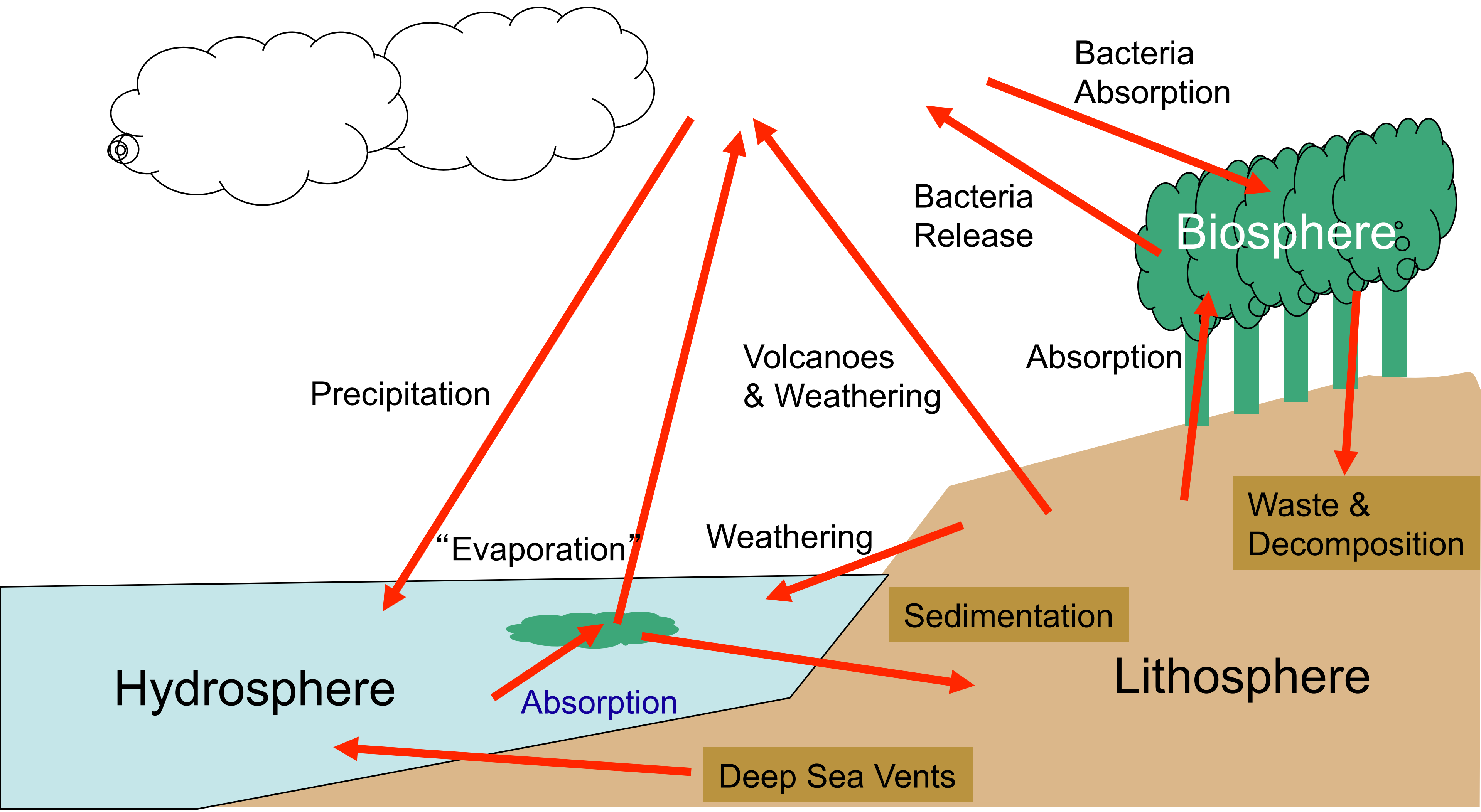


Phosphorus cycle

<u>Facts:</u>

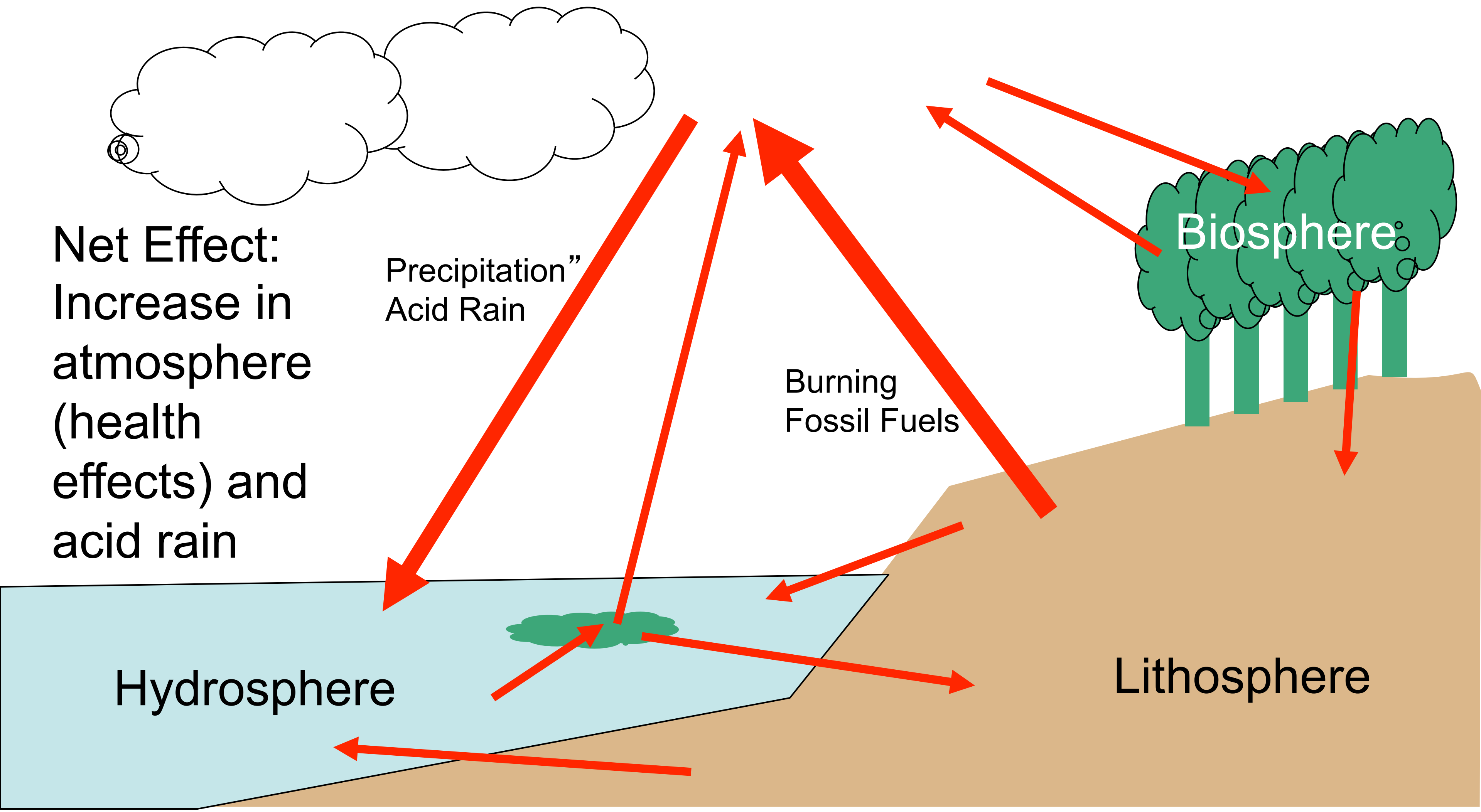
- **Component of DNA, RNA, ATP, proteins and enzymes**
- **Cycles in a sedimentary cycle**
- **A good example of how a mineral element becomes part of an organism.**
- **The source of Phosphorus (P) is rock.**
- **It is released into the cycle through erosion or mining.**
- **It is soluble in H2O as phosphate (PO4)**
- **It is taken up by plant roots, then travels through food chains.**
- **It is returned to sediment**

Sulfur Cycle



Human Impacts

Sulfur Cycle



Net Effect: Increase in atmosphere (health effects) and acid rain

Sulfur cycle

Facts:

- **Component of protein**
- **Cycles in both a gas and sedimentary cycle.**
- **The source of Sulfur is the lithosphere(earth's crust.**
- **Sulfur (S) enters the atmosphere as hydrogen sulfide (H_2S) during fossil fuel combustion, volcanic eruptions, gas exchange at ocean surfaces, and decomposition.**
- **H_2S is immediately oxidized to sulfur dioxide (SO_2)**
- **SO_2 and water vapor makes H_2SO_4 (a weak sulfuric acid), which is then carried to Earth in rainfall**
- **Sulfur in soluble form is taken up by plant roots and incorporated into amino acids such as cysteine. It then travels through the food chain and is eventually released through decomposition.**

Acid rain

- Acid rain refers to a mixture of deposited material, both wet and dry, coming from the atmosphere containing more than normal amounts of nitric and sulfuric acids. Simply put, it means rain that is acidic in nature due to the presence of certain pollutants in the air due to cars and industrial processes.
- It is easily defined as rain, fog, sleet or snow that has been made acidic by pollutants in the air as a result of fossil fuel and industrial combustions that mostly emits Nitrogen Oxides (NOx) and Sulfur Dioxide (SO2).
- Acidity is determined on the basis of the pH level of the water droplets. Normal rain water is slightly acidic with a pH range of 5.3-6.0, because carbon dioxide and water present in the air react together to form carbonic acid, which is a weak acid. When the pH level of rain water falls below this range, it becomes acid rain.
- When these gases react with water molecules and oxygen among other chemicals found in the atmosphere, mild acidic chemical compounds such as sulfuric and nitric acid are formed resulting to acid rain. Acid rain generally leads to weathering of buildings, corrosion of metals, and peeling of paints on surfaces. Erupting volcanoes contains some chemicals that can cause acid rain. Apart from this, burning of fossil fuels, running of factories and automobiles due to human activities are few other reasons behind this activity.

Forms of acid rain

- There are two forms in which acid deposition occurs – wet and dry. Both are discussed below:
- **Wet Deposition:** When the wind blows the acidic chemicals in the air to the areas where the weather is wet, the acids fall to the ground in the form of rain, sleet, fog, snow or mist. It removes acid from the atmosphere and deposit them on the earth’s surface. When this acid flows through the ground, it affects large number of plants, animals and aquatic life. The water from drain flows into rivers and canals which is them mixed up with sea water, thereby affecting marine habitats.
- **Dry Deposition:** If the wind blows the acidic chemicals in the air to the areas where the weather is dry, the acidic pollutants slip into dust or smoke and fall to the ground as dry particles. These stick to the ground and other surfaces such as cars, houses, trees and buildings. Almost 50% of the acidic pollutants in the atmosphere fall back through dry deposition. These acidic pollutants can be washed away from earth surface by rainstorms.
- It was discovered way back in 1800s during the Industrial Revolution. A Scottish chemist, Robert Angus Smith, was first to discover this phenomenon in 1852 as a relationship between acid rain and atmospheric pollution in Manchester, England. But it gained public attention mainly in 1960s. The term was coined in 1972 when the NY Times published reports about the climate change effects which started arising due to the occurrence of acid rain in the Hubbard Brook Experimental Forest in New Hampshire.

Causes of acid rain

- Both natural and man-made sources are known to play a role in the formation of acid rain. But, it is mainly caused by combustion of fossil fuels which results in emissions of sulfur dioxide (SO_2) and nitrogen oxides (No_x)

1. Natural Sources

- The major natural causal agent for acid rain is volcanic emissions. Volcanoes emit acid producing gases to create higher than normal amounts of acid rain or any other form of precipitation such as fog and snow to an extent of affecting vegetation cover and health of residents within the surrounding. Decaying vegetation, wildfires and biological processes within the environment also generate the acid rain forming gases. Dimethly sulfide is a typical example of a major biological contributor to sulfur containing elements into the atmosphere. Lighting strikes also naturally produces nitric oxides that react with water molecules via electrical activity to produce nitric acid, thereby forming acid rain.

2. Man-made sources

- Human activities leading to chemical gas emissions such as sulfur and nitrogen are the primary contributors to acid rain. The activities include air pollution sources emitting sulfur and nitrogen gases like factories, power generations facilities, and automobiles. In particular, use of coal for electrical power generation is the biggest contributor to gaseous emissions leading to acid rain. Automobiles and factories also release high scores of gaseous emissions on daily basis into the air, especially in highly industrialized areas and urban regions with large numbers of car traffic. These gases react in the atmosphere with water, oxygen, and other chemicals to form various acidic compounds such as sulfuric acid, ammonium nitrate, and nitric acid. As a result, these areas experience exceedingly high amounts of acid rain.
- The existing winds blow these acidic compounds over large areas across borders and they fall back to the ground in the form of acid rain or other forms of precipitation. Upon reaching the earth, it flows across the surface, absorbs into the soil and enters into lakes and rivers and finally gets mixed up with sea water.
- The gases i.e. i.e. sulfur dioxide (SO2) and nitrogen oxides (NOx) are primarily gases occurring from electric power generation by burning coal and responsible for acid rain.

Effects of acid rain

- **Effect on Aquatic Environment:** Acid rain either falls directly on aquatic bodies or gets run off the forests, roads and fields to flow into streams, rivers and lakes. Over a period of time, acids get accumulated in the water and lower the overall pH of the water body. The aquatic plants and animals need a particular pH level of about 4.8 to survive. If the pH level falls below that the conditions become hostile for the survival of aquatic life. Acid rain tendency of altering pH and aluminum concentrations greatly affects pH concentration levels in surface water, thereby affecting fish as well as other aquatic life-forms. At pH levels below 5, most fish eggs cannot hatch. Lower pHs can also kill adult fish. Acid rain runoff from catchment areas into rivers and lakes has also reduced biodiversity as rivers and lakes become more acidic. Species including fish, plant and insect types in some lakes, rivers and brooks have been reduced and some even completely eliminated owing to excess acid rain flowing into the waters.
- **Effect on Forests:** It makes trees vulnerable to disease, extreme weather, and insects by destroying their leaves, damaging the bark and arresting their growth. Forest damage due to acid rain is most evident in Eastern Europe – especially Germany, Poland and Switzerland.

- **Effect on Soil:** Acid rain highly impacts on soil chemistry and biology. It means, soil microbes and biological activity as well as soil chemical compositions such as soil pH are damaged or reversed due to the effects of acid rain. The soil needs to maintain an optimum pH level for the continuity of biological activity. When acid rains seep into the soil, it means higher soil pH, which damages or reverses soil biological and chemical activities. Hence, sensitive soil microorganisms that cannot adapt to changes in pH are killed. High soil acidity also denatures enzymes for the soil microbes. On the same breadth, hydrogen ions of acid rain leach away vital minerals and nutrients such as calcium and magnesium.
- **Vegetation Cover and Plantations:** The damaging effects of acid rain on soil and high levels of dry depositions have endlessly damaged high altitude forests and vegetation cover since they are mostly encircled by acidic fogs and clouds. Besides, the widespread effects of acid rain on ecological harmony have lead to stunted growth and even death of some forests and vegetation cover.
- **Effect on Architecture and Buildings:** Acid rain on buildings, especially those constructed with limestone, react with the minerals and corrode them away. This leaves the building weak and susceptible to decay. Modern buildings, cars, airplanes, steel bridges and pipes are all affected by acid rain. Irreplaceable damage can be caused to the old heritage buildings.

- **Effect on Public Health:** When in atmosphere, sulfur dioxide and nitrogen oxide gases and their particulate matter derivatives like sulfates and nitrates, degrades visibility and can cause accidents, leading to injuries and deaths. Human health is not directly affected by acid rain because acid rain water is too dilute to cause serious health problems. However, the dry depositions also known as gaseous particulates in the air which in this case are nitrogen oxides and sulfur dioxide can cause serious health problems when inhaled. Intensified levels of acid depositions in dry form in the air can cause lung and heart problems such as bronchitis and asthma.
- **Other Effects:** Acid rain leads to weathering of buildings, corrosion of metals, and peeling of paints on surfaces. Buildings and structures made of marble and limestone are the ones especially damaged by acid rain due to the reactivity of the acids in the rain and the calcium compounds in the structures. The effects are commonly seen on statues, old grave stones, historic monuments, and damaged buildings.

  Acid rain also corrodes metals like steel, bronze, copper, and iron.

Solutions to acid rain

Cleaning up Exhaust Pipes and Smokestacks

- Most of the electric power supporting the modern-day energy requirements comes from combusting fossil fuels such as oil, natural gas, and coal that generate nitrogen oxides (NOx) and sulfur dioxide (SO2) as the chief contributors to acid rain. Burning coal largely accounts for SO2 emissions while NOx emissions are mostly from fossil fuel combustions.
- Washing coal, use of coal comprised of low sulfur, and use of devices known as "scrubbers" can provide technical solution to SO2 emissions. "Scrubbing" also called flue-gas desulfurization (FGD) typically work to chemically eliminate SO2 from the gases leaving smokestacks. It can eliminate up to 95% of SO2 gases. Power generation facilities can also shift to using fuels that emit much less SO2 such as natural gas instead of burning coal. These methods are simply called emission reduction strategies.
- Similarly, NOx emissions from automobile fossil fuel combustions are mitigated upon by use of catalytic converters. Catalytic converters are fixed on the exhaust pipe system to reduce NOx emission. Improvement of gasoline that combusts cleaner is also a strategy for reducing emission of NOx gases.

- **Restoring Damaged Environments**
- Use of limestone or lime, a process called liming, is a practice that people can do to repair the damage caused by acid rain to lakes, rivers and brooks. Adding lime into acidic surface waters balances the acidity. It’s a process that has extensively been used, for instance in Sweden, to keep the water pH at optimum. Even though, liming is an expensive method and has to be done repeatedly. Furthermore, it only offers a short-term solution at the expense of solving the broader challenges of SO2 and NOx emissions and risks to human health. Nevertheless, it helps to restore and allow the survival of aquatic life forms by improving chronically acidified surface waters.
- **Alternative Energy Sources**
- Besides fossil fuels, there is a wide range of alternative energy sources that can generate electrical power. These include wind energy, geothermal energy, solar energy, hydropower, and nuclear power. Harnessing these energy sources can offer effective electrical power alternatives instead of using fossil fuels. Fuel cells, natural gas, and batteries can also substitute use of fossil fuel as cleaner energy sources. As of today, all energy sources have environmental and economic costs as well as benefits. The only solution is using sustainable energy that can protect the future.
- **Individual, National/State, and International Actions**
- Millions of people directly and indirectly contribute to SO2 and NOx emissions. Mitigation of this challenge requires individuals to be more informed about energy conservation and ways of reducing emissions such as: turning off lights or electrical appliances when not using them; use public transport; use energy efficient electrical appliances; and use of hybrid vehicles or those with low NOx emissions.

Assignment

Read and make notes on the Hydrological cycle

THE END