- The major components of the earth's surface is the hydrosphere, which is covered by the oceans.(~70%)
- Average depth of oceans: 4000 m.

Role of the oceans in global climate change:

- The ocean carries not only a tremendous amount of mass and water but also a lot of energy.
- Q1: Why do the oceans carry a tremendous amount of energy?
  Ans:
  - ➔ The energy which is consumed by water is primarily determined by its heat capacity.
  - ➔ Definition: Heat Capacity(units : Joules/Kelvin)
    The amount of energy required to raise the temperature of an object by unti temperature interval under specified conditions.
  - ➔ For water, the heat capacity is higher compared to other objects.
- Due to the high heat capacity of liquid water, the uppermost 3 metres of the world ocean hold as much heat energy as the entire atmosphere.
- There is a dynamic equilibrium between the oceans and the atmosphere by constantly exchanging energy, water, and carbon. And human activities are currently shifting this balanced system.

The oceans-atmosphere coupling:

- The energy from the atmosphere is redistributed around the world on the ocean surface. This phenomenon is known as "The Great Ocean Conveyor Belt" or "Thermohaline circulation".
- Definition: Thermohaline circulation
  Refers to the part of the large scale ocean circulation that is driven by global density gradients created by temperature and salinity differences.
  - ➔ Thermo = temperature related.
  - ➔ Haline = salinity(amount of salt dissolved in a water body).
  - ➔ The ocean is naturally saline at approx. 3.5% salt.

- Thermohaline circulation animation link
  - ➔ Warm waters from the Atlantic move towards the arctic ocean.
  - ➔ There it becomes cold and its density increases, so it sinks.
  - ➔ This sunk water travels below the warm waters from the arctic ocean to the equator and then towards atlantic. These waters contain lots of salts and nutrients.
  - ➔ So, this movement of waters contains 2 key factors:
    (1) Temperature gradient,
    (2) Salinity.
  - ➔ The Great Ocean Conveyor Belt is a very large network of eddies, currents and gyres, largely driven by differences in temperature and salinity, which form density gradients.
  - ➔ For example, as warm, tropical water in the Atlantic Ocean travels northward towards Greenland, it cools. When this water forms sea ice, salt is left behind in the ocean, which increases salinity.

- ➔ Both the cooling of water and the increase in salinity serve to increase the density of the water, causing it to sink. This cool, salty, dense water then continues on a journey that distributes energy all over the globe, sometimes taking tens, hundreds, or even thousands of years to complete the cycle.
- ➔ This Ocean Conveyor Belt has been identified as an agent of dramatic historical climate changes, aiding in the activation and conclusion of past Ice Ages.

The oceans and the temperature:

- The vast majority of land-based rainfall can be traced back to oceanic evaporation.
- The oceans fuel major oceanic weather systems, such as hurricanes, cyclones and typhoons, warmer waters usually translate into higher energy storms.
- Important ocean based events which have impact on land region:
  (1) Monsoon,
  (2) Cyclones,
  (3) El- Nino, reverse process: La-Nina.
- El Niño-Southern Oscillation (ENSO) events are characterized by changes in sea surface temperatures (SST) in the tropical Eastern Pacific, changes in air pressure in the tropical Western Pacific, and other accompanying changes.
- Definition: El-Nino
  Refers to a typical climate change pattern that occurs across the tropical Pacific ocean roughly every 5 to 7 years.
  It is characterized by variations in,
  - ➔ the temperature of the surface of the tropical Eastern Pacific - warming or cooling known as El-Nino and La-Nina respectively
  - ➔ Air surface pressure in the tropical Western Pacific- the Southern Oscillation.
- ENSO causes extreme weathers like floods and droughts in many regions of the world.

Changes in the oceans:

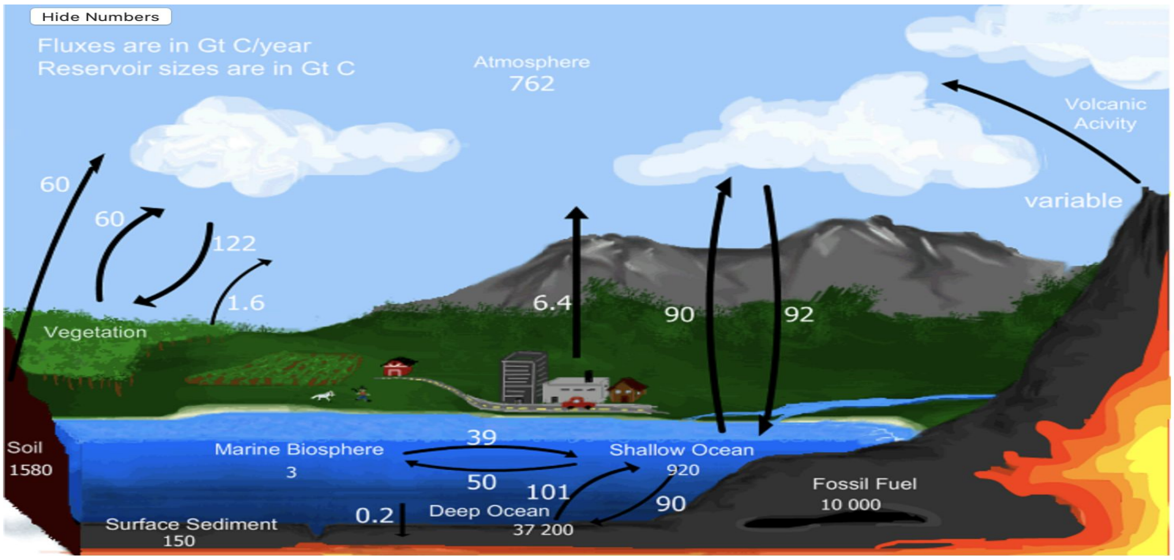
- The ocean is known as the long term memory of the Earth's climate because of its vast extent of waters.
- Oceanic changes are very slow compared to large daily(or even hourly) atmospheric fluctuations.(i.e Oceanic temperature variations lags by several years from atmospheric temperature variations)
- These changes can be measured in 2 ways:
  (1) By strategically inserting buoyes in the ocean.[unclear audio: timestamp = 20:37]
  (2) With the aid of satellites.

Carbon and the ocean:

- Carbon is naturally exchanged back and forth between the sea and atmosphere, with the oceans as a net carbon sink.
- Approximately half of all anthropogenic(resulting from or produced by human beings) carbon dioxide produced since the industrial revolution has been absorbed and sequestered by the oceans.

- Q2: How many gigatons of carbon are exchanged back and forth between the atmosphere and the ocean each year?
  Ans: From atmosphere to ocean : 92 Gt C/year
  From ocean to atmosphere : 90 Gt C/year
  Net Flux: from atmosphere to oceans.
- Q3: What is one problem associated with increased carbon in our oceans?
  Ans:
  - ➔ When carbon dioxide from the atmosphere dissolves in the ocean it enters a complex buffer system which is important in regulating the pH of the oceans .
  - ➔ As atmospheric carbon dioxide concentration increases, the pH of the oceans decreases. This change in pH has serious implications for the health of ocean ecosystems as carbonate, an important component in the shells of sea creatures such as mollusks, becomes less bioavailable.
  - ➔ Also, the addition of carbon to these ecosystems could drastically affect marine life, as these creatures are extremely sensitive to rapid environmental change due to their interconnected food networks, symbioses, and other relationships.
  - ➔ Humanity is also very dependent on marine life as much of the oxygen we breathe has oceanic origins, produced by marine photosynthesizers such as phytoplankton and various species of bacteria. In addition, humans rely on marine ecosystems for their livelihood, nourishment, and overall economic stability.
  - ➔ Therefore, if these ecosystems are forced out of balance by large increases in oceanic carbon, marine species will suffer and so will humanity.

[CO2 applet link]



Ocean Mixing:

- The distribution of carbon compounds in the ocean is highly variable. Shallow seas and surface waters are crowded with life and in contact with the atmosphere tend to have a different concentration of carbon than deeper waters.
- Carbon is transferred from the shallow ocean into the deep ocean through operation of ocean conveyor currents over a few thousands of years. As well, some of the

constituents of the marine biosphere release heavy carbon-containing waste that falls into the deep ocean, transferring the carbon it contains.
- Some of this carbon ends up as sediment on the ocean floor and enters into the long term carbon cycle through tectonic activity.

The Long Term Carbon Cycle:
- The Long-term carbon cycle takes place over hundreds of thousands of years.
- A significant portion of our planet's carbon is stored below the earth's surface at any one time. Exchanges between this vast reservoir and other portions of the carbon cycle take place very slowly. However, even at this slow pace, the long-term carbon cycle has played a key role in regulating atmospheric carbon dioxide concentration throughout much of earth's history. The weathering of rock, deposition of sediment, compression of biomass into fossil fuels, movement of tectonic plates and activity of volcanoes are important interfaces in the long-term carbon cycle.

Weathering and Sedimentation:
- As water erodes rock, chemical weathering takes place. The net effect of this process is the removal of carbon dioxide from the atmosphere through conversion into water soluble carbon compounds.
- Streams and rivers transport these soluble carbon compounds to the oceans, where they become involved in the complex carbon chemistry that occurs in the oceans. Some of this carbon is eventually deposited as sediment on the ocean floor.

Tectonic and Volcanic Activity:
- In subduction zones, places where one continental plate slides under another, some of the carbon deposited as sediment on the ocean floor is transported into the earth's crust. On the other hand, in spreading centers where tectonic plates are moving apart, carbon dioxide is released into the ocean.
- The subducted carbon may reappear much later as carbon dioxide gas in volcanic eruptions.
- Tectonic activity resulting in the exposure of new rock to the atmosphere or the removal of rock formerly accessible to the atmosphere can affect rates of chemical weathering.

Soil and decomposition:
- Soil contains a rich store of carbon in the form of various organic compounds.
- When plants and animals die they decompose. In the process some of their carbon is returned to the soil and some is converted into carbon dioxide by the organisms that help decompose the dead tissue.
- Over geological timescales organic matter in the soils may be transformed into fossil fuels, moving the carbon from the short to the long term cycle.

Cellular Respiration:
- Cellular respiration is a metabolic process that breaks down complicated biological molecules to provide the energy required to live. Carbon dioxide is produced as a by-product and is released into the atmosphere in small quantities each time you exhale.
  Reaction of cellular respiration: : $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + Energy.

Photosynthesis:

- Harnessing the sun's energy, plants convert atmospheric carbon dioxide into the biological molecules necessary for life by photosynthesis. In removing carbon from the atmosphere , earth's vegetation has the ability to store significant amounts of carbon. Each year the atmospheric carbon dioxide concentration fluctuates due to seasonal changes in the amount of photosynthesis occurring.
- Reaction: $6CO_2 + 6H_2O$ + Energy -> $C_6H_{12}O_6 + 6O_2$.

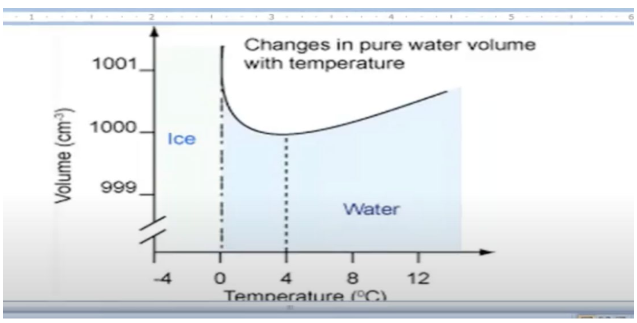
Land use change:

- A healthy forest stores carbon in the tissues of its resident plants. When this forest is cut down or burned(for whatever reasons) the carbon that was previously stored in vegetation is released into the atmosphere.

The oceans and climate change:

- The oceans are crucial in climate regulation due to: (1) worldwide span
  (2) immense heat capacity
  (3) vulnerability to change.

- Changes in ocean heat energy will have dramatic effects all over the globe.
  - Increased atmospheric temperatures will raise ocean temperatures as well as oceanic evaporation. Since tropical storms gather much of their energy from the ocean, the energy content of these storms will increase, leading to more intense storms, greater evaporation and precipitation, and extraordinary changes in ocean salinity.
  - Regional variations in temperature and salinity will have worldwide effects on the Great Ocean Conveyor Belt, which is one of the main energy distribution patterns. Any changes to this process will alter climate both regionally and worldwide.
  - Sea level rises due to thermal expansion of the sea water.
  - In the next century sea level rise upto 0.44 m can happen.



As seen from the graph, for temperature>4 degree C, volume of water increases in proportion to the temperature.

- There is also a 4th process(regional salinity) which is due to increase in atmospheric temperature which implies increase in temperature across oceanic surfaces.
  - Increase in temperature => more evaporation => increase in **regional salinity**.
  - Desalinization will also take place because of dilution of salinity on some other side.