CHAPTER 1
THE OCEANS

Introduction

Oceans cover about 71% of the earth's surface area, and it is one major part of the earth system. The total mass of the hydrosphere is about 1.37×10^{21} kg. The oceans help in the processes of the atmosphere by the transfer of mass, momentum and energy through its surface. Oceans receive water and dissolved substances from the land. This dissolved substances settle down as sediments, which ultimately become rocks. At a lower level physical oceanography and meteorology are merging. The ocean provides the feedback leading to slow changes in the atmosphere.

In a broad sense, oceans provide us food (fishes etc.), affects weather and help in ocean transport, marine navigation. Ocean beds are sources for oil and gas extraction and are used for boating, fishing, navigation, surfing, swimming, recreation and extracting energy from waves. Because of these activities we are interested in the study of sea waves, currents, winds and temperature. It is a known fact that of natural disasters tropical cyclones (which form over the oceans) cause highest damage. We study the oceans to predict the formation, intensification, movement and ferocity of tropical systems to mitigate its adverse effects. In addition to tropical cyclones, the studies contribute for transport of heat energy from ocean to atmosphere in tropical latitudes to extra-tropical latitudes. Marine voyages also require the help of ocean studies. We shall study briefly the composition of sea water and exchanges that occur across the sea-air interface and motion of the sea in deep and shallow waters and discuss the effects of the wind on ocean currents.

1.1 Composition of Sea Water

From a very very long time men living near the sea obtained common salt for cooking by evaporating/boiling of sea water. It is now known that there are a number of salts dissolved in sea water. The dipolar nature of water molecule is responsible to dissolve salts by breaking and the ions of the salt are completely free from one another. More than 99% of sea salts contain six ions/atoms which are given below. The common salt (NaCl-Sodium chloride) dissolved material comprises about 85%.

Approximate composition percentage of sea water

Salt	Atoms	Ions
Chloride	55	55
Sodium	30	30
Sulphate	4	8
Magnesium	3	4
Calcium	1	1
Potassium	1	1

The above composition is more or less same throughout the global sea water.

Salinity: The number of grams of dissolved material in 1000 gm of sea water is called salinity. The average salinity of sea water is about 35 gm/kg or about 3.5% by weight.

Dissolved earth material enters ocean waters mainly through rivers on land entering into seas in the form of ions. Besides these ions, rivers carry eroded particles of soil and rock which are deposited as sediments on the sea floor. Dissolved salts in sea water differs from the average composition of the earth's crust, this is because certain elements are dissolved more readily than others and some chemicals are removed from ocean waters by living organisms. The shells and skeletons of living organisms in sea contain calcium (Ca) and silicate (SiO_2) and sea plants and animals too remove some elements from the sea/ocean water.

Sea plants, animals consume very little soluble sodium chloride (NaCl) hence they accumulate in sea water at a faster rate than other ions. Sea waters dissolve most types of ions except calcium. Calcium carbonate ($CaCO_3$) is deposited near sea shores, which form limestone rocks.

1.2 The Exchange of Earth Materials between Sea and Atmosphere

Earth's matter exists in three states viz solid, liquid and gas. The structure of solids is crystalline or amorphous. Liquid state matter exists as molecules or group of molecules. The gaseous state matter exists in molecular form but they are widely separated. The three states of matter generally changes one form to another with temperature (or heat).

As regards to exchange of matter between the oceans/seas and the atmosphere, some salts move from sea to the atmosphere as breaking waves toss the water droplets into the air, which generally evaporate leaving tiny salt crystals into the air. These crystals act as or become condensation nuclei. Sea plants release oxygen near surface, some escape into the air and the remaining goes to the depth of sea by currents. Water is exchanged between the sea and air. More than 80% of water vapour in the atmosphere is pumped from the oceans by way of evaporation. This occurs when the sea is warmer than air. The salinity of sea surface water is affected by the loss or gain of water which takes place in evaporation and precipitation processes. Thus the salinity of sea surface is greater in the vicinity of sub-tropical high pressure belts in both hemispheres.

There is no sharp boundary between the hydrosphere (sea) and the atmosphere. The waters of hydrosphere contains solid materials and gases in solution while the atmosphere contains solid and liquid particles. Salts from sea enters the atmosphere by breaking of sea waves. The evaporated tiny particles of salt act as condensation nuclei to form clouds. Oxygen and carbon dioxide are exchanged across air-sea interface. On land animals inhale oxygen and release (exhale) CO_2 from their bodies. Fish and other marine animals use O_2 that is dissolved in sea water which is replaced by O_2 (oxygen) of the atmosphere.

Plants absorb CO_2 and release O_2. Sea plants release O_2 near sea surface, some of which escape to the atmosphere. The remainder is carried to the depths of the sea by ocean currents. Water is exchanged between sea and the atmosphere as water vapour. About 80% of the water vapour in the atmosphere enters from the ocean by evaporation. This occurs readily when sea is warmer than the air. This water vapour returns to the sea when condensed in the atmosphere (in the form of precipitation) flows through river and falls into the sea. Some water is retained on land. The salinity of sea surface water is affected by evaporation and precipitation processes. By evaporation of water salinity increases, while with precipitation salinity decreases. Because of this salinity of ocean surface water is greater in sub-tropical anticyclone high pressure belts (where evaporation is more than precipitation water content).

Ocean processes are non-linear and turbulent. Ocean (like atmosphere) is a stratified fluid on the rotating earth. The air and water (both fluids) have many similarities in their fluid dynamics but there are some important differences. Water is practically incompressible. Atmospheric moisture plays very important role in water (in terms of latent heat). In case of ocean thermodynamics there is no counter part. All oceans are bounded by countries (laterally). The ocean circulation is forced in a different way as compared to atmosphere. Atmospheric motion is transparent to incoming solar radiation (i.e., insolation) and heated from below (i.e., at surface of the earth). Ocean exchange heat and moisture with atmosphere at the ocean upper surface. Convection in the ocean is by buoyancy loss from above. Wind stress over the surface drives ocean circulation, particularly upper one kilometer of depth. The wind driven and buoyancy driven circulations are inter wind. Ocean circulations affect climate and paleoclimate. As noted earlier about 71% of the earth's surface is occupied by oceans, with an average depth of about 3.7 km. Ocean basins are very complex, bottom topography notched (jagged) much more than land surface. Abyssal ocean currents are comparatively weak and temperature changes are very little. Because of this submarine ocean relief erosion is very very slow as compared to the mountains on land.

The ocean volume is about 3.2×10^{17} m^3, mass is 1.3×10^{21} kg and has huge (enormous) heat capacity, which is 1000 times the heat capacity of the atmosphere. Because of this (reason) it plays an important role in climate. The important features of ocean are given below.

Ocean surface area: 3.61×10^{14} m^2

Mean ocean depth: 3.7 km

Ocean Volume: 3.2×10^{17} m^3

Mean density of ocean water: 1.035×10^3 kg/m^3

Mass of the ocean: 1.3×10^{21} kg

The following table gives the albedo of different surfaces.

Surface	**Albedo (%)**
Ocean	2-10
Frost	6-18
Cities	14-18
Grass	7-25
Soil	10-20
Grass land	16-20
Desert land (sand)	35-45
Ice	20-70
Cloud (thin, thick status)	30, 60, 70
Snow (old)	40-60
Snow fresh	75-95

1.3 The Cryosphere

About 2% of the water on the surface of the earth is frogen and this is known as Cryosphere . In Greak Kryos - meaning "frost" or "cold". The Cryosphere includes: Ice-sheets, sea-ice, snow, glaciers and frozen ground (permafrost). Most of the ice is contained in the ice sheets over the land masses of Antarctica (89%) and Greenland (8%). These ice sheets store about 80% of the fresh water on the earth.

The Antarctica ice sheet average depth is about 2 km while the Greenland ice sheet is about 1.5 km thick. Climate is affected by the surface area covered by ice (not by the amount of ice). The albedo of ice varies 40-95%, about 70% in the mean, which reflects the incident radiation on it. The perennial (year-round) ice cover 11% of the land area and 7% of the ocean area.

Two forms of ice observed in Antarctica ocean.

(i) Sea ice, which is formed by freezing of sea water and

(ii) Ice bergs, which are broken off pieces of glaciers. Sea ice is important because it regulates the exchange heat, moisture and salinity in polar oceans and insulates relatively warm ocean water from the cold polar atmosphere.

1.3.1 Sea Icing

The physical properties of sea ice depends on the salt content. Salt content is a function of the rate of freezing, age, thermal history. The composition of salts in sea ice more or less same as in brine. For practical purposes the chlorinity and salinity of sea ice have the same meaning as for water (although the salts are not uniformly distributed in the ice).

The sea ice of salinity 10 ‰ at 3 ^{o}C is a mush (soft pulp) having 200 gm of brine per kilogram. Sea ice contains small bubbles of gas which changes the properties. The gases occur as small bubbles in the ice. The ice which has been frozen rapidly contain large gas quantity and in this case bubbles represent gases originally in solution in the water or in old ice (that has undergone partial thawing and has been refrozen in which case atmospheric air is trapped in the ice)

Pure water at 0 ^{o}C has density 0.9998674 kg/m^3 and pure ice at 0 ^{o}C has density 0.91676 kg/m^3. The specific heat of ice depends on temperature and changes in narrow limits. Whereas sea ice varies largely and depends on the salt content and temperature. The change in sea ice temperature depends on either melting or freezing and the amount of heat required depends on the salinity of the ice.

The specific heat of pure ice is less than that of pure water. The very high specific heat of ice of high salinity at the initial (near) freezing point is due to the formation of ice from the enclosed brine or its melting. The latent heat of fusion of pure ice at 0 ^{o}C and at atmosphere pressure is 79.67 cal/gm.

The vapour pressure of sea ice has not been determined but it could be very near to that of pure ice, which is given below.

Temp ^{o}C	0	−10	−20	−30
Vapour pressure h Pa	6.11	2.61	1.04	0.39

The Latent heat of evaporation of pure ice is variable.

1.4 Some Physical Properties of Sea Water

The most abundant element of hydrosphere is oxygen. It comprises 88.9 % oxygen and 11.1 % nitrogen by weight. Waters of oceans, lakes and rivers contain dissolved elements of earth's crust in small amounts. Sea water has about 3.5% dissolved minerals, of which sodium and chlorine ions are the largest, whose combination is found sodium chloride (NaCl, common salt) and hence the salty taste to the sea water.

Liquid water made up of multiple groups of H_2O molecule having one, two or three elementary molecules called monohydrol, dihydrol and trihydrol. These forms depend on temperature, immediate past history of water and other factors. The degree of polymerization decreases with increasing temperature. Nuetral waters have variable amounts of heavy hydrogen (deutrium – isotope of hydrogen) and oxygen. This modifies the density and other properties of water. Fresh water or rain water have lower heavy isotopes as compared to sea water. The important properties of water are given below.

Density of pure water at 4 ^{o}C is 0.999×10^3 kg/m^3

While the average density of sea water is 1.035×10^3 kg/m^3

Specific heat (C_ω) 4.18×10^3 J/kg ^{o}K

Latent heat of fusion (L_f) 3.33×10^5 J/kg

Viscosity (μ) 10^{-3} kg/m, sec

$$\text{Kinetic viscosity } (\upsilon) = \frac{\text{viscosity of water}}{\text{density}} = 10^{-6}\,\text{m}^2/\text{sec}$$

Thermal diffusivity (K) 1.4×10^{-7} m^2/sec

Heat capacity of water is the highest as compared to all solids and liquids except liquid Ammonia. This does not allow extreme range of temperature but allows large quantity of heat transfer water to atmosphere.

Ocean temperature ranges from about –2 ^{o}C to + 30 ^{o}C, from 3 ‰ to 37 ‰, chlorinity 19.00 ‰ & froms 34.325 ‰.

Temperature, salinity of deep ocean and bottom ocean water vary 4 ^{o}C to – 1 ^{o}C, salinity 34.6 ‰ to 35 ‰ and high pressure. (‰ Stands for per thousand or per mile).

Sea water diurnal temperature range is less than 2 ^{o}C and maintains uniform (water) body temperature.

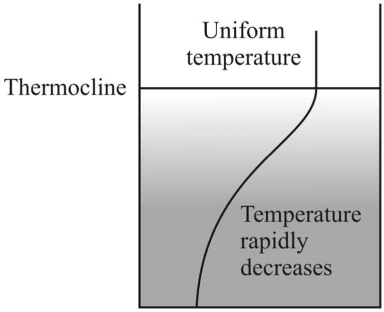
1.5 Energy Exchange Processes between Sea and Atmosphere Interface

In the process of evaporation of sea water, energy is transferred from the sea to the atmosphere. 80% of the worlds atmospheric water vapour goes from the sea (oceans). Energy that is required to evaporate sea water is derived from the insolation. This energy is transferred from sea to the atmosphere as latent heat of the water vapour. When water vapour condenses it releases latent heat to the atmosphere, which remains as a heat in the atmosphere.

A tropical cyclone resembles a great heat engine that derives its energy mainly from the transfer of sensible and latent heat from sea to air. The main input is water vapour, a form of latent heat.

The oceans cover about 71% of the earth's surface, and so a large part of insolation (incoming solar radiation) in shortwave radiation is absorbed by the oceans. The oceans then radiate back a great portion of terrestrial long wave radiation. This long-wave radiation by the oceans absorbed by the atmospheric greenhouse gases (like CO_2, O_3, water vapour, CH_4 etc). This energy heats the atmosphere.

In equatorial low latitudes more energy (insolation) is absorbed by the earth-atmosphere system than energy radiated back to the space as terrestrial radiation. Thus ocean surface warms the tropics. In contrast to this, at high latitudes where energy is deficit and sea surface temperatures are low in polar regions.



Most of the insolation (short wave radiation) is absorbed in the top few meters of the oceans. A part of this absorbed heat energy transmitted downwards by vertical mixing by the winds and waves. As a result there is a surface layer with a uniform temperature (in the sea). This layer may extend to about two to three hundred meters depth. Below this (surface) layer, temperature decreases rapidly for (another) a few hundred meters because warm surface waters do not reach this depth. In boundary (range of depth) where temperature changes rapidly with depth is called the thermocline. Thermocline tends to seal off vertical water movements in many parts of the ocean. This thermocline depth is also a zone of highest density gradient is called pycnocline. Below the thermocline temperature decreases gradually. Even in tropics the temperature of the ocean water at a depth of one kilometer is only a few degrees above freezing point.

The exchanges of matter and energy are related to the events of atmospheric circulation and its waters. Because of this the study of transfer processes that occur across air-sea interface is important, which helps in understanding of weather and its forecasting.