MODULE 9
OCEAN & MARINE MET

Project
Strengthening Meteorological Information Service and Early Warning System (Component A)

BANGLADESH METEOROLOGICAL DEPARTMENT

LOCAL TRAINING

Prepared by:
Grant Thornton Consulting Bangladesh Ltd.

AIMS AND OBJECTIVES

- Participants will become familiar with the different terms about Ocean & Marin Met.
- They can demonstrate tools of oceanography.
- They can demonstrate Scales of Motion.
- They can demonstrate knowledge of the Ocean Elements.
- Participants can demonstrate Atmosphere & Ocean, including Action of Ocean on Atmosphere and Reverse.

DELIVERY AND DESCRIPTION

Methodology

This module is designed in such a way that the participants get explicit idea regarding the Oceanography and its terms and concepts. Besides, we also wish that the participants will be enhance their official works. To achieve this objective, we have made the sessions based on the most important topics of Ocean & Marin Met. that are used in everyday life.

Key learning outcomes

By the end of the course, delegates will have a knowledge and understanding of:

- Interpret, describe, and explain the basic and different terms about Ocean & Marin Met.
- Use an understanding of Types of Oceanography and Tools of Oceanography.
- Analyse and interpret Scales of Motion in Oceanography.
- Demonstrate Transfer between Atmosphere & Ocean of Momentum.
- Explain the various elements the of Ocean, including Waves, Tides, Seabed, Storm Surges.

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CHAPTER 1 : OCEANOGRAPHY

1.1 Introduction

Oceanography, scientific discipline concerned with all aspects of the world's oceans and seas, including their physical and chemical properties, their origin and geologic framework, and the life forms that inhabit the marine environment. Oceanography is the sum of these several branches. Oceanographic research entails the sampling of seawater and marine life for close study, the remote sensing of oceanic processes with aircraft and Earth-orbiting satellites, and the exploration of the seafloor by means of deep-sea drilling and seismic profiling of the terrestrial crust below the ocean bottom. Greater knowledge of the world's oceans enables scientists to more accurately predict, for example, long-term weather and climatic changes and also leads to more efficient exploitation of the Earth's resources. Oceanography also is vital to understanding the effect of pollutants on ocean waters and to the preservation of the quality of the oceans' waters in the face of increasing human demands made on them.

Oceanography has been transformed through the use of fluorescence to assay biology. Light-absorbing pigments cause many organisms to naturally fluoresce. Primarily, but not exclusively, these pigments are associated with photosynthesizing organisms, such as algae, aquatic vascular plants, and aerobic anoxygenic photosynthetic (AAP) bacteria. Fluorescence is most commonly detected as the emission that follows 'active' excitation using an actinic light source. One of the major breakthroughs for oceanography occurred in the 1960s with the detection of actively induced chlorophyll *a* fluorescence *in situ*. Chlorophyll *a* is contained by all algae and cyanobacteria and thus provides a measure of abundance. However, at typical environmental temperatures the chlorophyll *a* fluorescence emission signature largely originates from oxygen evolving photosystem II (PSII). Consequently, the chlorophyll *a* fluorescence signal contains information that can be used to characterize the photosynthetic activity of this complex. Recent technological advances have provided twenty-first-century oceanography with an array of active chlorophyll *a* induction fluorometers that are used routinely to assess photosynthetic physiology. In addition, enhanced capacities within remote sensing platforms has enabled researchers to make major steps in using 'passive' fluorescence from chlorophyll *a*, the fluorescence that is stimulated as a result of natural excitation by the sun (solar-stimulated), to assess global photosynthetic activity.

1.2 Types of Oceanography

Traditionally, oceanography has been divided into four separate but related branches:

- Physical Oceanography,
- Chemical Oceanography,
- Marine Geology,
- Marine Ecology.

1.2.1 Physical Oceanography

Physical oceanography deals with the properties of seawater (temperature, density, pressure, and so on), its movement (waves, currents, and tides), and the interactions between the ocean waters and the atmosphere. Physical oceanographers study the interaction between the ocean and its boundaries -- land, seafloor and atmosphere -- and the relationship between the sea, weather and climate. Questions about how the oceans work in a physical sense include investigations into water qualities such as temperature, salinity and density, and influential factors such as wind speed, air temperature, tides and interaction with nearby land and underwater formations.

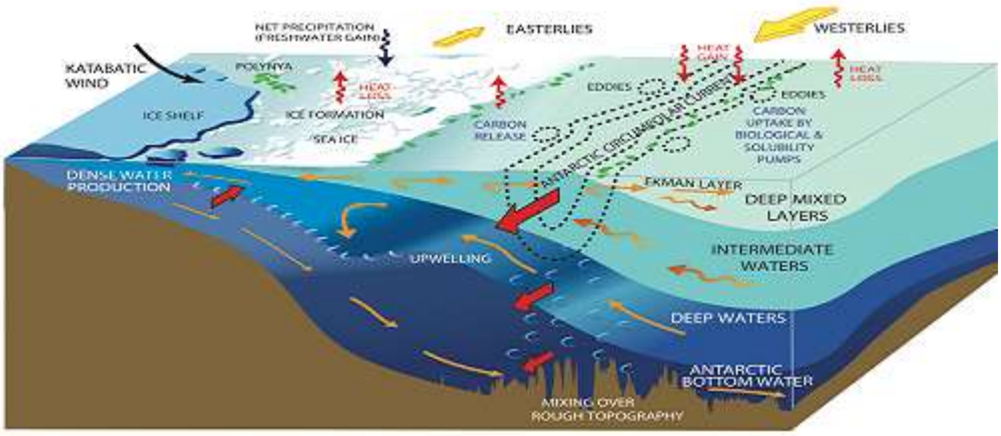


Figure: Physical Oceanography

1.2.2 Chemical Oceanography

Chemical oceanography has to do with the composition of seawater and the biogeochemical cycles that affect it. One important aspect of chemical oceanography is the study of pollutants. This work may lead chemical oceanographers to the deep ocean, coastal bays and estuaries, or inland rivers, streams and lakes. Sources of pollutants range from the obvious (sewage, oil or fuels, ocean dumping) to sources that are harder to detect or trace (agricultural or lawn runoff containing chemical fertilizers, leaking septic systems, road runoff or storm drain overflows). Chemical oceanographers study the impact of such pollutants by examining how they interact with seawater, marine life and sediments. Chemicals and pollutants introduced to a marine environment may behave very differently depending on environmental conditions such as salinity, wind, rainfall, temperature and transport methods. Transport methods include land-based (for example, surface runoff or groundwater), water-based (rivers and streams), and atmosphere-based (rain and dust). As the population discovers new ways to use the oceans -- be it for food, transportation, energy or waste disposal -- chemical oceanographers will play an important role in improving our knowledge about the impact of these activities on the ocean and its ability to sustain them.

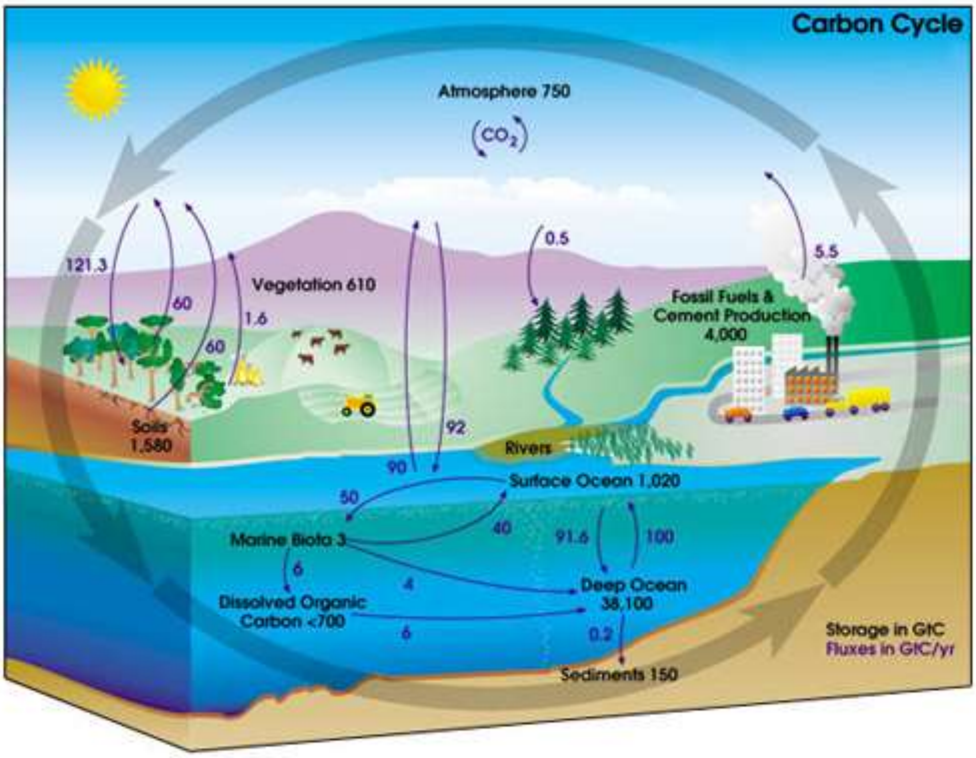


Figure: Chemical Oceanography

1.2.3 Marine Geology

Marine geology focuses on the structure, features, and evolution of the ocean basins. Geology is the study of the Earth. This includes how the Earth was formed, how the Earth has changed since it was formed, the materials that make up the Earth, and the processes that act on it. It involves geophysical, geochemical, sedimentological and paleontological investigations of the ocean floor and coastal zone. Marine geology has strong ties to geophysics and to physical oceanography.

In practice, the principal focus of marine geology has been on marine sedimentation and on the interpretation of the many bottom samples that have been obtained through the years. The advent of the concept of seafloor spreading in the 1960s, however, broadened the scope of marine geology considerably. Many investigations of midocean ridges, remanent magnetism of rocks on the seafloor, geochemical analyses of deep brine pools, and of seafloor spreading and continental drift may be considered within the general realm of marine geology.

More than half of our nation's population lives within 50 miles of the coast. Healthy coastal and offshore resources are vital to our nation's economy. The USGS studies coastal change, hazards that impact coastal areas, ocean resources, and coastal and marine ecosystems.

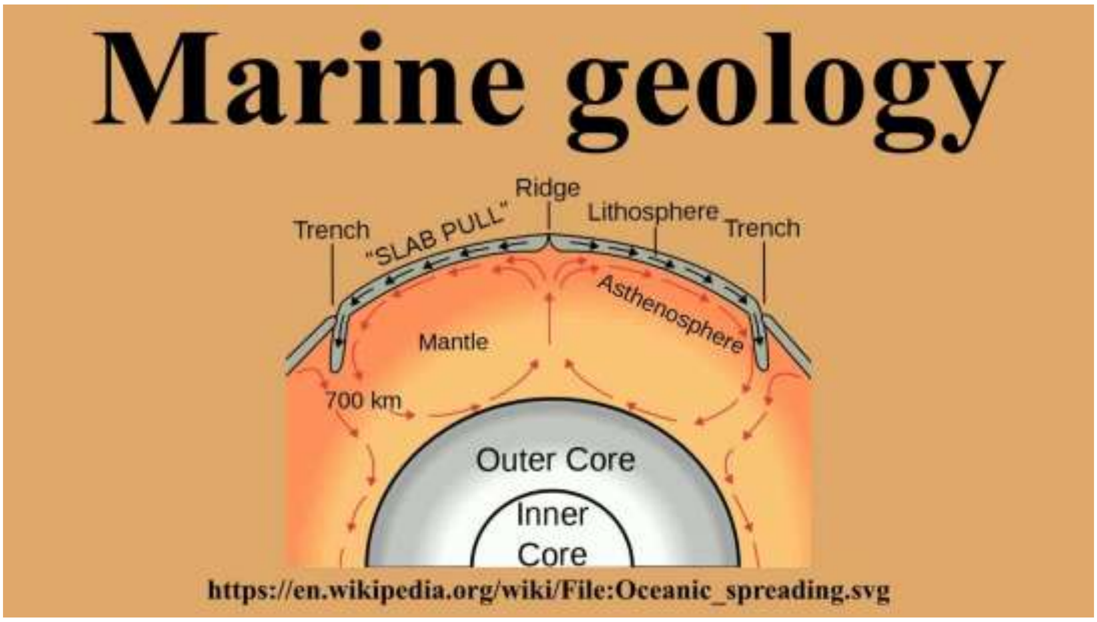


Figure: Marine geology

1.2.4 Marine Ecology

Marine ecology, also called biological oceanography, involves the study of the plants and animals of the sea, including life cycles and food production. The study of marine ecology also includes the influence of geology, geography, meteorology, pedology, chemistry, and physics on marine environments. The impact of human activity such as medical research, development, agriculture, fisheries, and forestry is also studied under marine ecology. In some ways, marine ecology is more complex than the relatively straightforward study of a particular organism or environment because of the numerous interconnections, symbiotic relationships, and influence of many factors on a particular environment.

Marine ecology overwhelmingly concerns those benthic or demersal populations that are found in association with solid substrata. Such populations are frequently distributed patchily, along with the habitats they occupy. Our knowledge of pelagic populations is less extensive, and although they also appear to be patchily distributed, it is unclear to what extent habitat factors usually drive this patchiness.

Although it might be logical for marine ecology and fisheries management science to interact closely, there has been a long history of marine ecology borrowing concepts and theories from terrestrial ecology. The recent adoption of metapopulation theory is a case in point.

Metapopulation theory, in its terrestrial context, is highly relevant to the description and exploration of sets of small populations scattered over small patches of suitable habitat—a condition that applies to a broad and growing range of species as human impacts continue to reduce and to subdivide patches of formerly more contiguous habitat. It deals explicitly with the dynamics of small populations that interact through dispersal of individuals among them, and considers dynamics both at the local population and at the wider metapopulation scale. Terrestrial ecologists use metapopulation theory to model actual populations, as a framework for guiding research questions, and as a paradigm against which to view population ecology.

Although marine and terrestrial systems have in common the fact that populations are patchily distributed, it is clear that marine systems differ from terrestrial ones. In marine systems, the causes of the patchy distributions are not always so clearly related to patchiness of habitat, and most human impacts tend to reduce, rather than increase, patchiness of habitat. Nevertheless, it is clear that there are many situations in which metapopulation theory has much to offer marine ecology. Time will tell how useful this theory becomes in marine ecology and management.

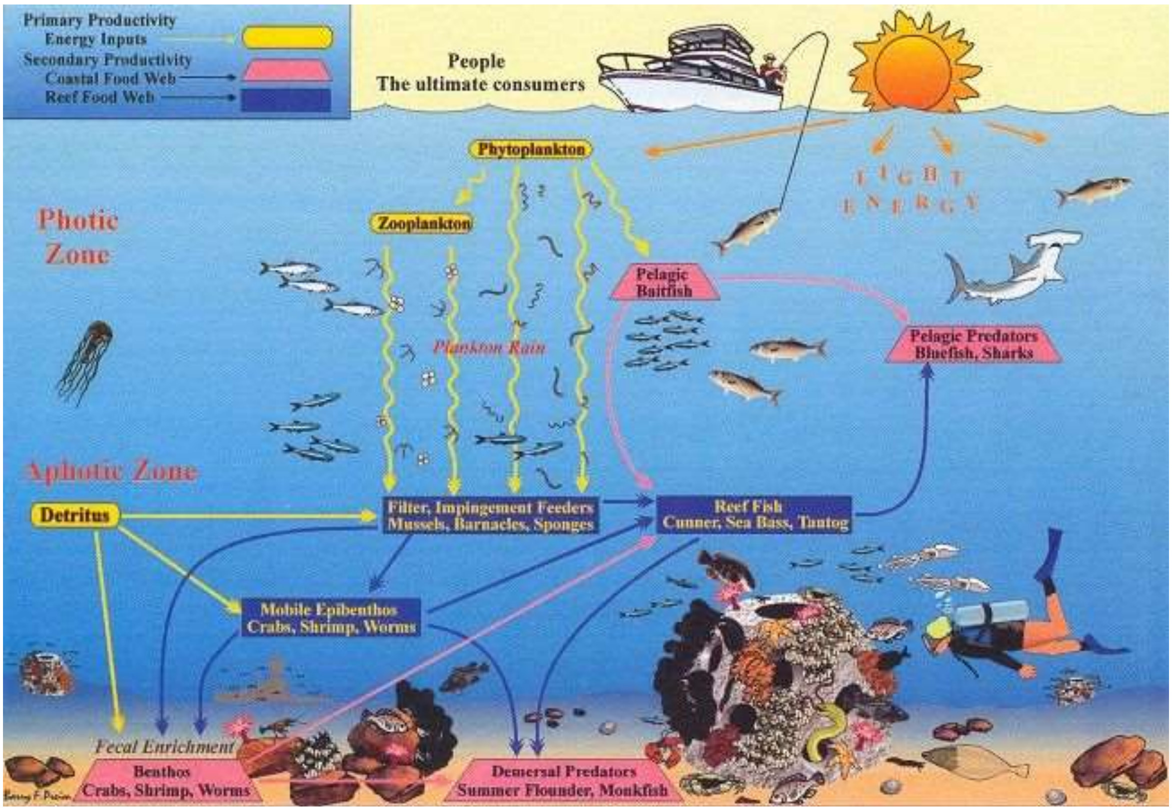


Figure: Marine Ecology

1.3 Tools of Oceanography

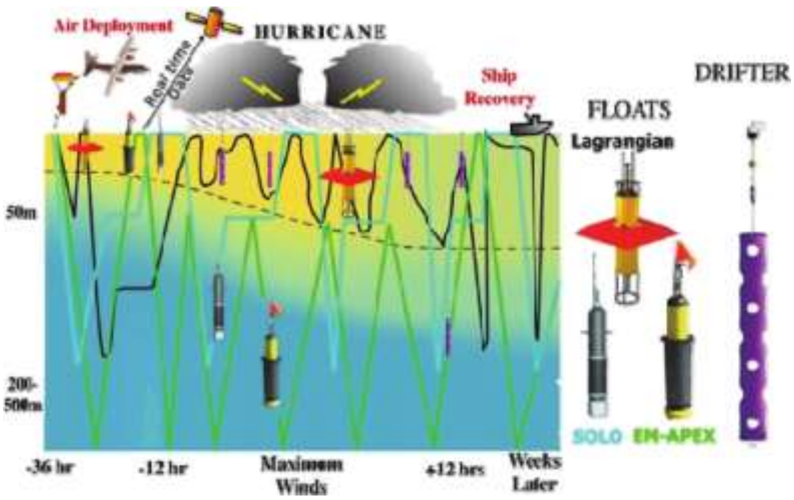
Since the ocean itself is not a convenient place to conduct research, scientists collect samples of water, sediment, flora, and fauna for study in laboratories aboard ship or ashore. Another approach is to create instruments or even automated laboratories to operate autonomously on the seafloor or in the water column. Oceanographic tools must carry out their missions in corrosive seawater and under high pressure in the deep sea. They must mesh with ships' winches and cranes and be of a size and weight manageable on the wet, unsteady, windswept deck of a research vessel. At the same time, they must be very precise. Some of the tool's oceanographers employ are described here.

1.3.1 Water Sampling

Water sampling devices range from a *bucket* dropped over the side of a ship to large *water bottles* sent thousands of meters toward the seafloor on a wire. Probably the most commonly used water sampler is known as a *CTD/rosette*: it is a framework designed to carry 12 to 36 sampling bottles (typically ranging from 1.2- to 30-liter capacity) and a conductivity/ temperature/ depth sensor that sends information to the laboratory so that the water bottles can be closed selectively as the instrument ascends. A standard rosette/CTD cast, depending on water depth, requires two to five hours of station time. New methods for this kind of sampling are being developed in order to reduce station time. The largest water bottles, called *Gerard barrels*, collect 250 liters. Particles in the water samples may be quantified with a *transmissometer* sent down the wire or attached to a CTD/rosette. Aboard the ship, a *flow cytometer* may be used to analyze particles in the form of single-celled organisms for optical properties indicative of their physiology and structure.

1.3.2 Floats and Drifters

Floats can be weighted to be neutrally buoyant at a particular depth, where they drift in the current while emitting periodic sounds. Such floats have been tracked for years by moored sound receivers to provide a long-term look at ocean currents. Trajectories of individual floats show how the water moves horizontally, and trajectories of groups of floats show how the water is mixed by eddies. This information is important for understanding how water tracers and pollutants are transported by the ocean. More recently, the sound sources have been moored while the floats act as receivers, surfacing at the end of an approximately two-year lifetime to report their data via satellite to a shore station. Other floats drift for two months, surface to transmit data to a satellite, and descend again for another two months of data collection. They can repeat this process for up to five years. Other combinations of these techniques are under development. Drogued surface drifters used for current studies also report position and data periodically via satellite transmission. Drifting sediment traps are used to study surface



layer sedimentation, and such instruments as an acoustic backscattering device for collecting long-term data on plankton distribution are mounted on drifting buoys.

1.3.3 Moorings

Instruments can be moored in the ocean for months or years to collect samples or data. Anchors are connected to holding lines with acoustic couplings that are released to recall the instruments. Flotation holds the instruments and their tether line upright in the water column and brings them to the surface on release. *Currents meters*, which may employ rotors, electric fields, acoustic/electromagnetic techniques, or acoustic Doppler profiling to track water motion, are often deployed on moorings. As scientists try to understand movement of materials through the oceanic system, they moor *sediment traps* at various depths for many months to collect samples of particles sinking through the water column. subsurface moorings are also used to suspend *settling plates* above the deep-sea floor to collect larval forms of benthic animals.

1.3.4 Satellites

While not exactly "seagoing" instruments, Earth-orbiting satellites play an important role in modern oceanography. Their use for relaying data from instruments at sea to ship or shore is expected to increase with time. Receipt of data in "real time," that is, as it is being taken, enables researchers to monitor the performance of equipment in the field (and send a ship to service it, if necessary), to make decisions about an experiment underway, and to distribute data quickly. Two-way communication via satellite allows control of remote instruments. In addition, receipt of satellite data useful for directing experiments at sea allows oceanographers to make efficient use of precious ship time. Cruises designed to study biological productivity may be guided by information from ocean color scanners that detect reflected light and interpret it in terms of chlorophyll content, which denotes phytoplankton production. Satellite-based instruments useful to oceanographers studying ocean circulation include *altimeters*, which register variations in sea level slope that indicate current flow, and *infrared sensors* that show currents, eddies, and other circulation features.

1.3.5 Meteorological Sensors

Exchanges across the air-sea interface, including heat and fresh water, couple the ocean and atmosphere and are of major interest in studies of global climate. A collaborative effort of scientists from several oceanographic institutions aims to provide accurate measurements at this interface particularly for the World Ocean Circulation Experiment (WOCE). Sensors being designed or upgraded for use either on research vessels or buoys include those to measure surface temperature, air temperature, wind speed and direction, barometric pressure, solar and long- wave radiation, humidity, and precipitation. From these measurements, accurate estimates of air-sea fluxes can be made. The sensor package includes the capability to telemeter some data on a regular basis via satellite to a central data facility.

1.3.6 Remotely Operated Vehicles

These robots, used for many years for simple oceanographic tasks, are increasingly sophisticated. Research vessels transport remotely operated vehicles (ROVs) to study sites and provide staging, servicing, and monitoring platforms for them. In the most sophisticated systems, the ROV is lowered on a cable alone or in a protective vehicle and then operates on a slack tether that decouples it from the ship's surface motion. Television cameras serve as "eyes" for the shipboard researchers, who receive television signals and control the vehicle via a fiber-optic cable. An ROV can explore, take photographs, collect samples, or handle instruments, operating around the clock for many consecutive days.

1.3.7 Shipboard Laboratories

The heart of any research voyage is the "main lab," where plans are made (and changed), samples are prepared and analyzed, data is received and processed, and the occasional party takes place. The laboratory is active day and night. It is seldom a tidy place - the lab configuration usually changes completely from one cruise to the next, and wires, sampling containers, tools, computers, and analytical instruments cram every available square centimeter. For some work, especially that requiring an extremely clean environment or specialized suites of equipment, portable vans may be outfitted and lifted aboard the research vessel to provide additional laboratory space. Scientists find it is increasingly important to analyze samples aboard ship rather than preserve them for processing ashore. Marine chemists, for example, often want to analyze many samples as soon as possible and to base tomorrow's work on today's sophisticated analysis.

Figure: Shipboard Laboratories

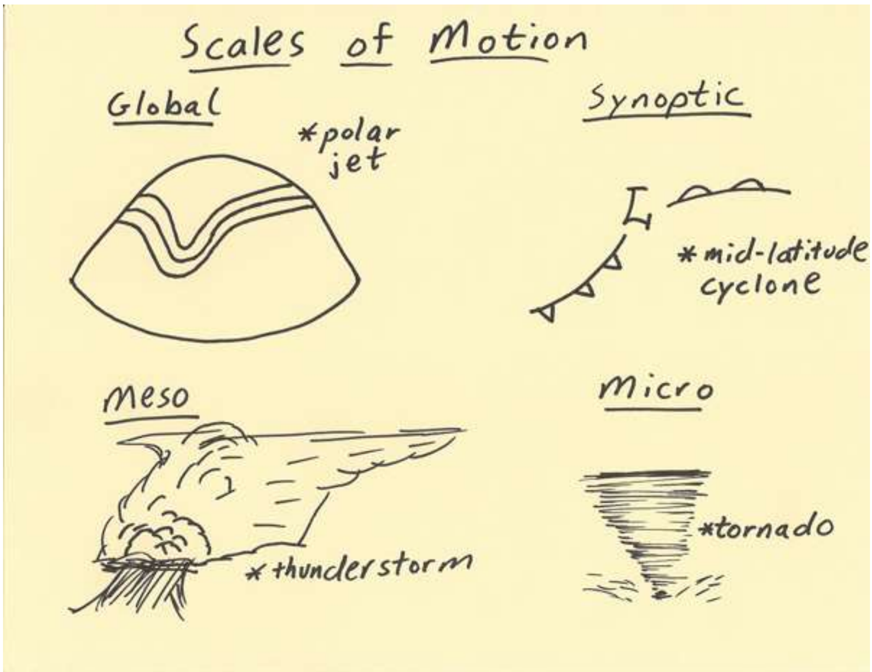
CHAPTER 2 : SCALES OF MOTION

2.1 Scales of Motion

Weather phenomena are analyzed at a variety of scales of motion. Four scales of motion that will be focused on in this writing from largest to smallest land area are the global scale, synoptic scale, mesoscale and microscale.

The global scale includes events that impact large areas of the global and last for weeks and even months at a time. Features such as the polar jet stream can be found just about any time somewhere. The polar jet stream is an example of a global scale phenomenon. Its influence circles the globe and influences the polar and middle latitudes with varying extent throughout the year. Another example of a global scale phenomenon is the position of subtropical highs. The position and strength of subtropical highs can influence weather across the globe.

The next scale is the synoptic scale. Phenomena on the synoptic scale can span over 1000s of kilometers and last for many days. Mid-latitude cyclones, hurricanes, and fronts are examples of synoptic weather events. A weather forecaster looks closely at the global scale and synoptic scale when making weather forecasts beyond 1 day out.



The mesoscale is the next scale that will be discussed. These weather phenomena typically last from an hour to a day and influence 10s to 100s of kilometers of distance. Examples of mesoscale weather events include thunderstorms (especially complexes of thunderstorms such as MCCs and squall lines), differential heating boundaries (i.e. sea breeze), and mesolows. A weather forecaster will integrate an increasing amount of mesoscale analyses into their forecasting technique when making short term forecasts such as over the next several hours to 1 day.

The last scale of motion that will be mentioned is the microscale. These events occur typically from minutes up to an hour and cover small distances such as less than 10 kilometers. Examples of microscale phenomena include tornadoes, rainbows, convective updrafts, and downdrafts. This scale is important since it is the scale most experienced with the eyes in-person. These are the weather events that are witnessed when going outside.

Scales of Motion

Scale	Time	Distance	Example
Planetary	Weeks, or longer	1000 to 40,000 km	Westerlies, trade winds
Synoptic	Days to weeks	100 to 5000 km	Cyclones
Mesoscale	Minutes to hours	1 to 100 km	Tornado, T-storm
Microscale	Seconds to minutes	< 1 km	Turbulence, wind gusts

2.2 Synoptic Scale of Motion

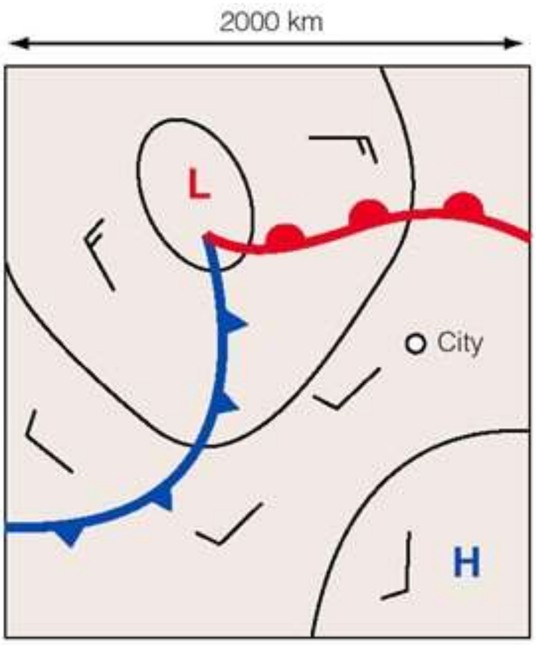


Figure: Synoptic Scale

The synoptic scale in meteorology (also known as large scale or cyclonic scale) is a horizontal length scale of the order of 1000 kilometers (about 620 miles) or more. This corresponds to a horizontal scale typical of mid-latitude depressions (e.g., extratropical cyclones). Most high- and low-pressure areas seen on weather maps (such as surface weather analyses) are synoptic-scale systems, driven by the location of Rossby waves in their respective hemisphere. Low-pressure areas and their related frontal zones occur on the leading edge of a trough within the Rossby wave pattern, while high-pressure areas form on the back edge of the trough. Most precipitation areas occur near frontal zones. The word *synoptic* is derived from the Greek word συνοπτικός (*synoptikos*), meaning seen together.

2.3 Mesoscale of Motion

Mesoscale meteorology is the study of atmospheric phenomena with typical spatial scales between 10 and 1000 km. Examples of mesoscale phenomena include thunderstorms, gap winds, downslope windstorms, land-sea breezes, and squall lines.

Figure: Mesoscale

2.4 Microscale of Motion

Local motion of winds and ocean currents over areas with sizes of 300 feet (100 meters) or less. An example of microscale motion is winds blowing past a chimney. The wind's speed generally increases with height above the earth's surface because: friction with the Earth's surface slows the air near the ground.

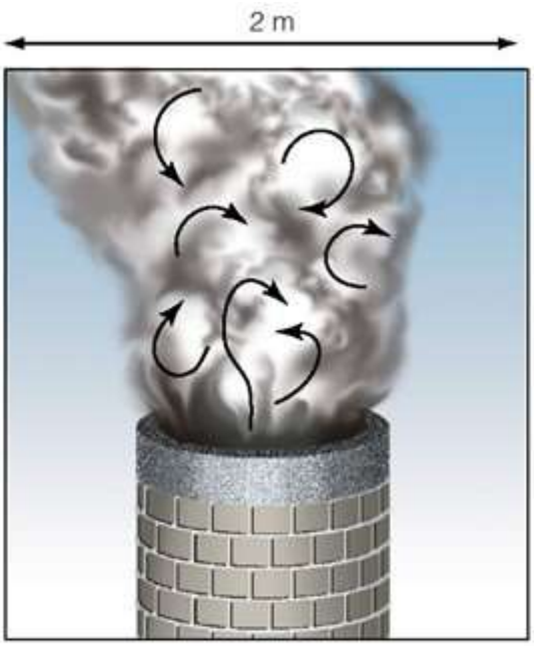


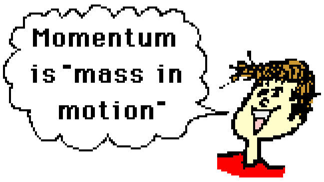
Figure: Microscale

2.5 Global Scale of Motion

The global scale includes events that impact large areas of the global and last for weeks and even months at a time. Features such as the polar jet stream can be found just about any time somewhere. The polar jet stream is an example of a global scale phenomenon.

2.6 Momentum Equations

Momentum is a commonly used term in sports. A team that has the momentum is on *the move* and is going to take some effort to stop. A team that has a lot of momentum is really *on the move* and is going to be *hard to stop*. Momentum is a physics term; it refers to the quantity of motion that an object has. A sports team that is *on the move* has the momentum. If an object is in motion (*on the move*) then it has momentum.



Momentum can be defined as "mass in motion." All objects have mass; so if an object is moving, then it has momentum - it has its mass in motion. The amount of momentum that an object has is dependent upon two variables: how much *stuff* is moving and how fast the *stuff* is moving. Momentum depends upon the variables mass and velocity. In terms of an equation, the momentum of an object is equal to the mass of the object times the velocity of the object.

Momentum = mass • velocity

In physics, the symbol for the quantity momentum is the lower case p. Thus, the above equation can be rewritten as

$$p = m \cdot v$$

where m is the mass and v is the velocity. The equation illustrates that momentum is directly proportional to an object's mass and directly proportional to the object's velocity.

The momentum equation an expression of Newton's second law of motion, represents the transient force balance on the fluid within a slice of the pipeline cross-section.

The left side, $\rho(\partial v / \partial t + v \partial v / \partial x)$, is mass times acceleration per unit volume of fluid (there is a velocity change in time, , as well as a change as it moves in distance,).

The right side (RHS) represents the forces acting on a unit mass of fluid.

The first RHS term, $-\partial p/\partial x$, is the net force imposed by the pressure gradient.

The second RHS term, $-\rho g \partial z/\partial x$, is the force of gravity on the element as it moves in the vertical direction (due to the slope of the pipeline).

The final term $-\rho f v|v|/2D$ is the frictional force that acts in a direction opposite to the velocity.

$$\rho\left(\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial x}\right) = -\frac{\partial p}{\partial x} - \rho g\frac{\partial z}{\partial x} - \rho\frac{fv|v|}{2D}$$

2.7 The Rossby Numbers

The Rossby number named for Carl-Gustav Arvid Rossby, is a dimensionless number used in describing fluid flow. The Rossby number is the ratio of inertial force to Coriolis force, terms and in the Navier–Stokes equations respectively.

A small Rossby number signifies a system strongly affected by Coriolis forces, and a large Rossby number signifies a system, in which inertial and centrifugal forces dominate.

Explicitly, the Rossby number is,

$$\mathrm{Ro} = \frac{U}{fL},$$

where U is the velocity scale, f is the Coriolis parameter, and L is the horizontal length scale. This number plays a fundamental role in defining the regime of large-scale geophysical fluid dynamics. Large-scale flows are defined as those that are significantly influenced by the earth's rotation and with sufficiently large L for Ro to be order one or less (e.g., flows with sufficiently small Rossby number are in geostrophic balance).

2.8 The Ekman Numbers

The Ekman number (Ek) is a dimensionless number used in fluid dynamics to describe the ratio of viscous forces to Coriolis forces. It is named after the Swedish oceanographer Vagn Walfrid

Ekman. When the Ekman number is small, disturbances are able to propagate before decaying owing to low frictional effects.
Explicitly, the vertical Ekman number is,

$$E_v = 2K_v/(fD^2),$$

in which K_v is the vertical eddy viscosity, f the Coriolis parameter, and D the characteristic vertical length scale.
The horizontal Ekman number is,

$$E_h = 2K_h/(fL^2),$$

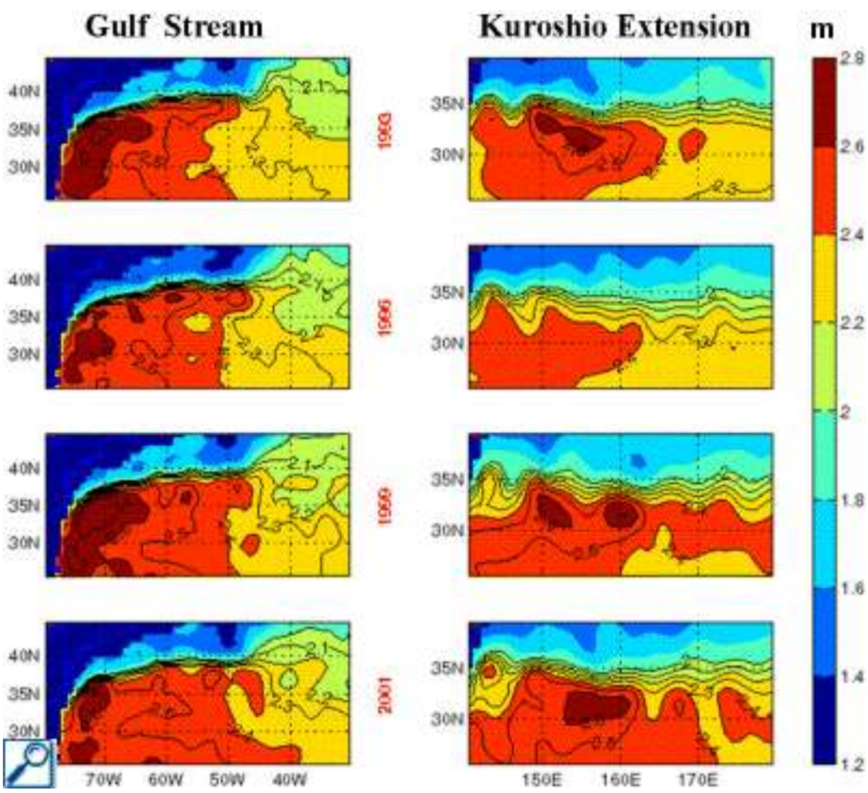
in which K_h is the horizontal eddy viscosity and L is the characteristic horizontal length scale. The Ekman number gives a measure of the rate at which stresses at a boundary (e.g., wind-induced stresses at the ocean surface) are communicated to the fluid interior.

2.9 Large-Scale Ocean Circulation

Thermohaline circulation (THC) is a part of the large-scale ocean circulation that is driven by global density gradients created by surface heat and freshwater fluxes. The water in these circuits transport both energy (in the form of heat) and mass (dissolved solids and gases) around the globe.
Satellite altimetry has provided the first direct measurement of the global ocean topography. Here we discuss the utility of such measurement for the determination of the oceanic general circulation. Because of the lack of detailed knowledge of the geoid, satellite-altimeter data have primarily been used to study the temporal variability of the ocean. The differences in sea-surface height measured along precisely repeating ground tracks or at ground-track crossovers reflect primarily the temporal change plus measurement errors, while the time-invariant geoid is canceled in the sea-surface height differences. The large variability of the ocean in space and time makes direct measurement of the oceanic general circulation, the long-term average of the flow field of the world's oceans, extremely difficult. The basic principle allowing the determination of the circulation from the ocean's density field is based on the fact that, in the open ocean at latitudes more than a few degrees from the equator, the large-scale oceanic flows are nearly in geostrophic and hydrostatic balance.
Density differences in ocean water contribute to a global-scale circulation system, also called the global conveyor belt. The global conveyor belt includes both surface and deep ocean currents that circulate the globe in a 1,000-year cycle.
A view of the global ocean circulation shows currents swirling around the hills and valleys at the sea surface. In the Northern Hemisphere, currents flow around hills in a clockwise direction and in an anticlockwise direction (the opposite occurs in the Southern Hemisphere) around valleys. These currents form gyres on either side of the equator. Planetary waves are other large-scale phenomena that are less easy to see on an instantaneous map, but nonetheless they too have a global impact.

The major ocean currents can raise sea surface height by up to a meter higher than the surrounding area. The deviation of the ocean surface elevation from the geoid is called ocean surface topography. This is used to calculate the speed and direction of ocean currents — provided that the geoid is understood independently with sufficient accuracy, which, since the CHAMP and GRACE gravimetry satellites were launched, is beginning to be the case. This understanding was enhanced further with the GOCE mission. After 4.5 years in orbit, it gathered enough data to map Earth's gravity with unrivalled precision. The 5th gravity field model based, EGM_TIM_RL05, with a mean global accuracy of 2.4 cm in terms of geoid heights and 0.7 mGal for gravity anomalies at a spatial resolution of 100 km.

Even without this knowledge, studies of the large-scale variations have been undertaken since the beginning of altimetry. Among other things, year-to-year variations in the extent of the Gulf Stream and Kuroshio currents have been observed, that can be correlated with changes in upper ocean heat content. These have an impact on ocean-atmosphere heat exchanges, with implications for decadal climate variations.

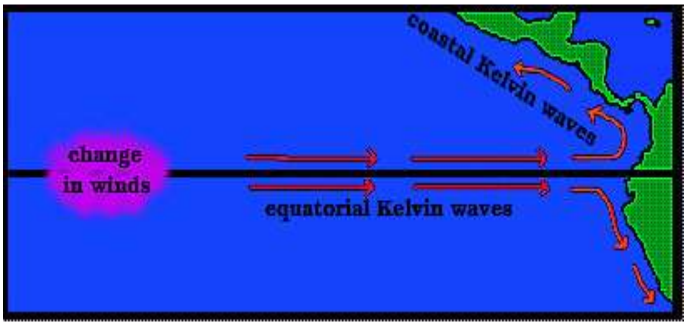


2.10 The Kelvin Waves

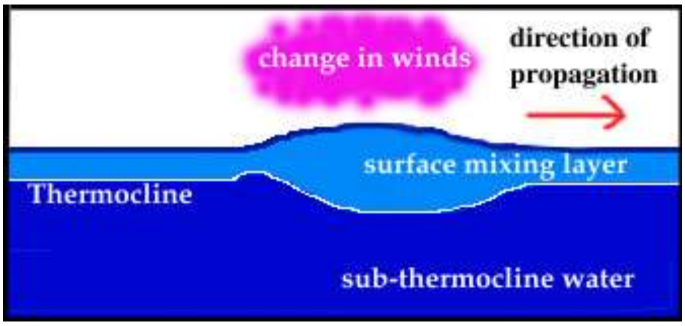
A Kelvin wave is a wave in the ocean or atmosphere that balances the Earth's Coriolis force against a topographic boundary such as a coastline, or a waveguide such as the equator. A feature of a Kelvin wave is that it is non-dispersive, i.e., the phase speed of the wave crests is equal to the group speed of the wave energy for all frequencies. This means that it retains its shape as it moves in the alongshore direction over time.

Kelvin wave (fluid dynamics) is also a long scale perturbation mode of a vortex in superfluid dynamics; in terms of the meteorological or oceanographical derivation, one may assume that the meridional velocity component vanishes (i.e. there is no flow in the north–south direction, thus making the momentum and continuity equations much simpler). This wave is named after the discoverer, Lord Kelvin (1879).

Internal coastal Kelvin waves can be generated by wind-induced, time-dependent coastal upwelling. Coastal upwelling (downwelling) is caused by an Ekman mass flux transported offshore (onshore) and forced by longshore winds. The disturbances can then propagate along the coast as boundary-trapped internal Kelvin waves.



There are two types of Kelvin waves, coastal and equatorial, and they are both gravity driven and non-dispersive. They are often excited by an an abrupt change in the overlying wind field, such as the shift in the trade winds at the start of El Niño.



Equatorial waves propagate to the east in the northern hemisphere, using the equator as a wave guide. Coastal Kelvin waves propagate around the northern hemisphere oceans in a counterclockwise direction using the coastline as a wave guide. These waves, especially the surface waves are very fast moving, typically with speeds of ~2.8 m/s, or about 250 kilometers in a day. A Kelvin wave would take about 2 months to cross the Pacific from New Guinea to South America.

2.11 Internal Waves

Internal waves are gravity waves that oscillate within a fluid medium, rather than on its surface. To exist, the fluid must be stratified: the density must change (continuously or discontinuously) with depth/height due to changes, for example, in temperature and/or salinity. If the density changes over a small vertical distance (as in the case of the thermocline in lakes and oceans or an atmospheric inversion), the waves propagate horizontally like surface waves, but do so at slower speeds as determined by the density difference of the fluid below and above the interface. If the density changes continuously, the waves can propagate vertically as well as horizontally through the fluid.

Internal waves, also called internal gravity waves, go by many other names depending upon the fluid stratification, generation mechanism, amplitude, and influence of external forces. If propagating horizontally along an interface where the density rapidly decreases with height, they are specifically called interfacial (internal) waves. If the interfacial waves are large amplitude, they are called internal solitary waves or internal solitons. If moving vertically through the atmosphere where substantial changes in air density influences their dynamics, they are called anelastic (internal) waves. If generated by flow over topography, they are called Lee waves or mountain waves. If the mountain waves break aloft, they can result in strong warm winds at the ground known as Chinook winds (in North America) or Foehn winds (in Europe). If generated in the ocean by tidal flow over submarine ridges or the continental shelf, they are called internal tides. If they evolve slowly compared to the Earth's rotational frequency so that their dynamics are influenced by the Coriolis effect, they are called inertia gravity waves or, simply, inertial waves. Internal waves are usually distinguished from Rossby waves, which are influenced by the change of Coriolis frequency with latitude.

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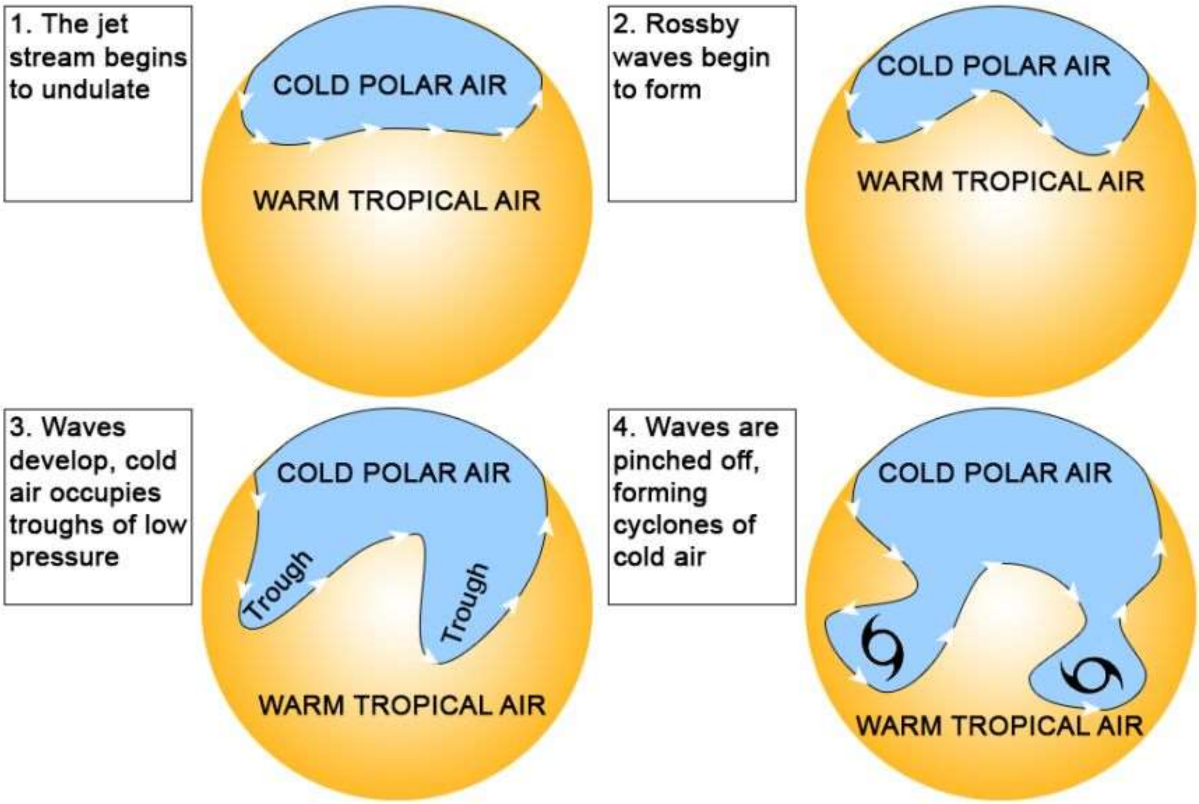
Figure: Internal Waves

2.12 Rossby Waves

Rossby waves, also known as planetary waves, are a type of inertial wave naturally occurring in rotating fluids. They were first identified by Carl-Gustaf Arvid Rossby. They are observed in the atmospheres and oceans of planets owing to the rotation of the planet. *Atmospheric* Rossby waves on Earth are giant meanders in high-altitude winds that have a major influence on weather. These waves are associated with pressure systems and the jet stream. Oceanic Rossby waves move along the thermocline: the boundary between the warm upper layer and the cold deeper part of the ocean.

Rossby waves have been well observed in the atmosphere for decades. The large scale of oceanic Rossby waves necessitates an array of observations spanning a noticeable fraction of an ocean basin to distinguish phase variations, and the data obtained from cruises and ships of opportunity have been inadequate for the task, despite some valiant efforts. Rossby waves were, therefore, remarkably difficult to observe in the ocean until recently. (Observing barotropic Rossby waves is likely to continue to be difficult: their high speed makes the design of an observation network almost impossible.) Thus, the theory of Rossby waves, discussed below, considerably predates their observation.



The launch of altimetric satellites changed all this dramatically. The barotropic Rossby waves remained essentially unobservable by satellites (the phases move so rapidly that they become indistinguishable between satellite passes). However, altimeter coverage proved ideal for the detection of surface signatures of baroclinic waves, which possessed surface height variations of a few centimeters and so were, at least for the TOPEX/Poseidon instrument, observable to the accuracy of the altimeter.

Satellite altimeters, to date, can only provide relative measures of sea surface height; in other words, they can report the variation of height accurately, but not the absolute value. For the purposes of observing wave propagation, this limitation presents no difficulties. Nonetheless, the ocean surface variation is made up of a superimposition of many different waves, direct responses to local forcing, and so on, so that the detection of Rossby waves still required massaging of the data.

CHAPTER 3 : ATMOSPHERE AND OCEAN

3.1 Transfer between atmosphere and ocean of momentum

Dependence of Exchange Rates on Air–Sea Velocity, Temperature, and Humidity Differences. Winds are produced in the atmosphere in response to radiative forcing. These winds transfer momentum to the ocean, producing ocean currents.

3.2 Heat

In oceanography and climatology, ocean heat content (OHC) is a term for the energy absorbed by the ocean, which is stored as internal energy or enthalpy. Changes in the ocean heat content play an important role in the sea level rise, because of thermal expansion.

The main source of ocean heat is sunlight. Additionally, clouds, water vapor, and greenhouse gases emit heat that they have absorbed, and some of that heat energy enters the ocean. Waves, tides, and currents constantly mix the ocean, moving heat from warmer to cooler latitudes and to deeper levels.

Ocean warming accounts for 90% of the energy accumulation from global warming between 1971 and 2010. About one third of that extra heat has been estimated to propagate to depth below 700 meters. Beyond the direct impact of thermal expansion, ocean warming contributes to an increased rate of ice melting in the fjords of Greenland and Antarctic ice sheets. Warmer oceans are also responsible for coral bleaching.

Physical characteristics of heat transport and ocean circulation impact the Earth's climate system. The heat capacity of the ocean is much greater than that of the atmosphere or the land. As a result, the ocean slowly warms in the summer, keeping air cool, and it slowly cools in winter, keeping the air warm.

Water has an especially high heat capacity at 4.18 J/g*C, which means it takes more heat to warm a gram of water. This is why, throughout the course of a warm summer day, the water in the ocean does not experience a significant change.

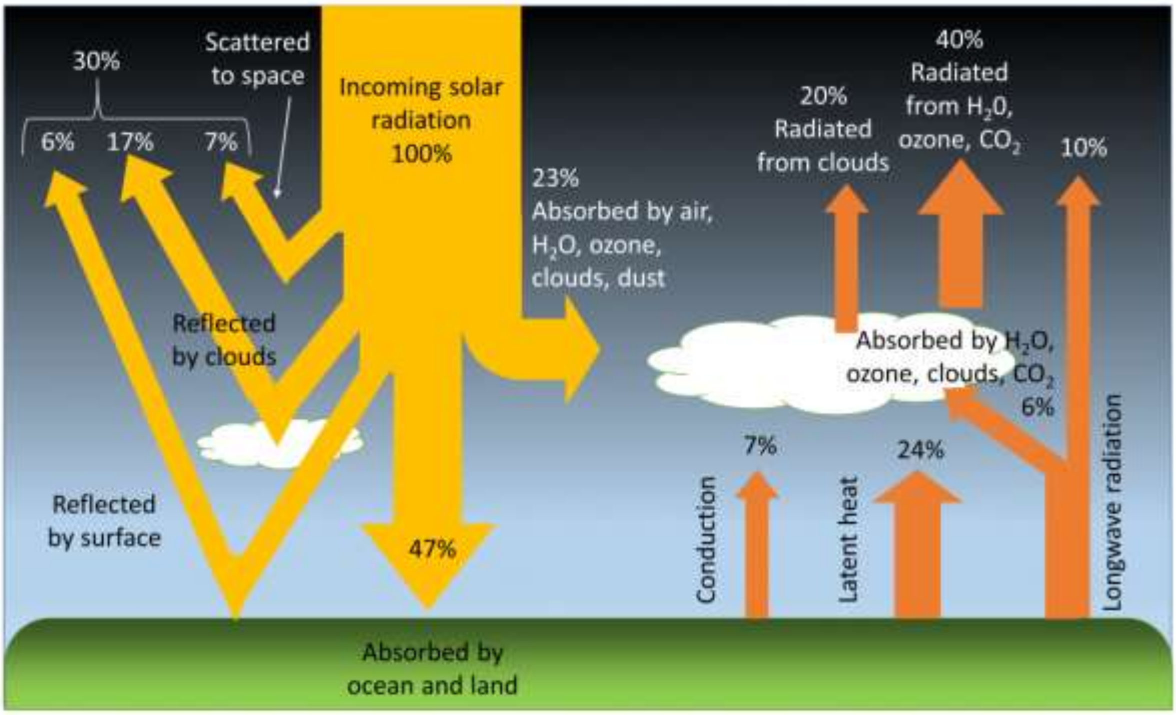


Figure: Earth's heat budget.

Of all of the solar radiation reaching Earth, 30% is reflected back to space and 70% is absorbed by the Earth (47%) and atmosphere (23%). The heat absorbed by the land and oceans is exchanged with the atmosphere through conduction, radiation, and latent heat (phase change). The heat absorbed by the atmosphere is eventually radiated back into space (PW).

3.3 Water vapor

Water vapor or aqueous vapor is the gaseous phase of water. It is one state of water within the hydrosphere. Water vapor can be produced from the evaporation or boiling of liquid water or from the sublimation of ice. Water vapor is transparent, like most constituents of the atmosphere.[4] Under typical atmospheric conditions, water vapor is continuously generated by evaporation and removed by condensation. It is less dense than most of the other constituents of air and triggers convection currents that can lead to clouds.

Being a component of Earth's hydrosphere and hydrologic cycle, it is particularly abundant in Earth's atmosphere, where it acts as the most potent greenhouse gas, stronger than other gases such as carbon dioxide and methane. Use of water vapor, as steam, has been important to humans for cooking and as a major component in energy production and transport systems since the industrial revolution.

Water vapor is a relatively common atmospheric constituent, present even in the solar atmosphere as well as every planet in the Solar System and many astronomical objects including natural satellites, comets and even large asteroids. Likewise the detection of extrasolar water vapor would indicate a similar distribution in other planetary systems. Water vapor is significant in that it can be indirect evidence supporting the presence of extraterrestrial liquid water in the case of some planetary mass objects.

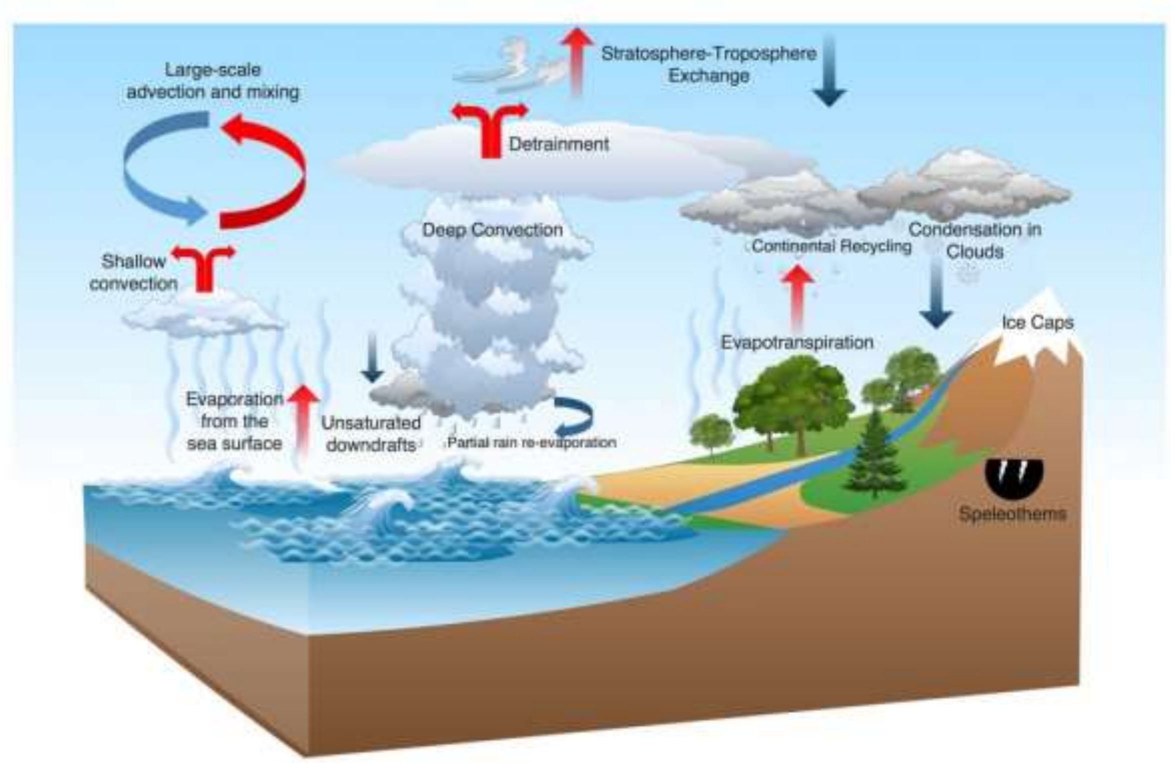


Figure: Water Vapor

Water is constantly cycling through the atmosphere. Water evaporates from the Earth's surface and rises on warm updrafts into the atmosphere. It condenses into clouds, is blown by the wind, and then falls back to the Earth as rain or snow. This cycle is one important way that heat, and energy are transferred from the surface of the Earth to the atmosphere and transported from one place to another on our planet.

Water vapor is also the most important greenhouse gas in the atmosphere. Heat radiated from Earth's surface is absorbed by water vapor molecules in the lower atmosphere. The water vapor molecules, in turn, radiate heat in all directions. Some of the heat returns to the Earth's surface. Thus, water vapor is a second source of warmth (in addition to sunlight) at the Earth's surface.

These maps show the average amount of water vapor in a column of atmosphere in a given month. The units are given in centimeters, which is the equivalent amount of water that could be produced if all the water vapor in the column were to condense. The lowest amounts of water vapor (0 centimeters) appear in white, and the highest amounts (6 centimeters) appear in dark blue. Areas of missing data appear in shades of gray. The maps are based on data collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on NASA's Aqua satellite.

The most noticeable pattern in the time series is the influence of seasonal temperature changes and incoming sunlight on water vapor. In the tropics, a band of extremely humid air wobbles north and south of the equator as the seasons change. This band of humidity is part of the Intertropical Convergence Zone, where the easterly trade winds from each hemisphere converge and produce near-daily thunderstorms and clouds. Farther from the equator, water vapor concentrations are high in the hemisphere experiencing summer and low in the one experiencing winter. Another pattern that shows up in the time series is that water vapor amounts over land areas decrease more in winter months than adjacent ocean areas do. This is largely because air temperatures over land drop more in the winter than temperatures over the ocean. Water vapor condenses more rapidly in colder air.

3.4 Gases

Seawater has many different gases dissolved in it, especially nitrogen, oxygen and carbon dioxide. It exchanges these gases with the atmosphere to keep a balance between the ocean and the atmosphere. Of the rarer gases, ammonia, argon, helium, and neon have been reported in sea water, and hydrogen is undoubtedly present in minute quantities. In the absence of dissolved oxygen, hydrogen sulphide may be present, and it is possible that in stagnating water other products of putrefactive decomposition, such as methane, may occur.

GASES IN AIR AND DISSOLVED IN SEA WATER AT EQUILIBRIUM WITH AIR

The percentage of gases in sea water is based on the total gases dissolved in sea water at equilibrium with air.

Gas	Chemical Symbol	Percentage in Air	Percentage in Sea Water
Nitrogen	N_2	78.08	62.6
Oxygen	O_2	20.95	34.3
Argon	Ar	0.934	1.6
Carbon Dioxide	CO_2	0.033	1.4
Neon	Ne	0.0018	0.00097
Helium	He	0.00052	0.00023
Methane	CH_4	0.00020	0.00038
Krypton	Kr	0.00011	0.00038
Carbon Monoxide	CO	0.000015	0.000017
Nitrous Oxide	N_2O	0.000050	0.0015
Xenon	Xe	0.0000087	0.000054

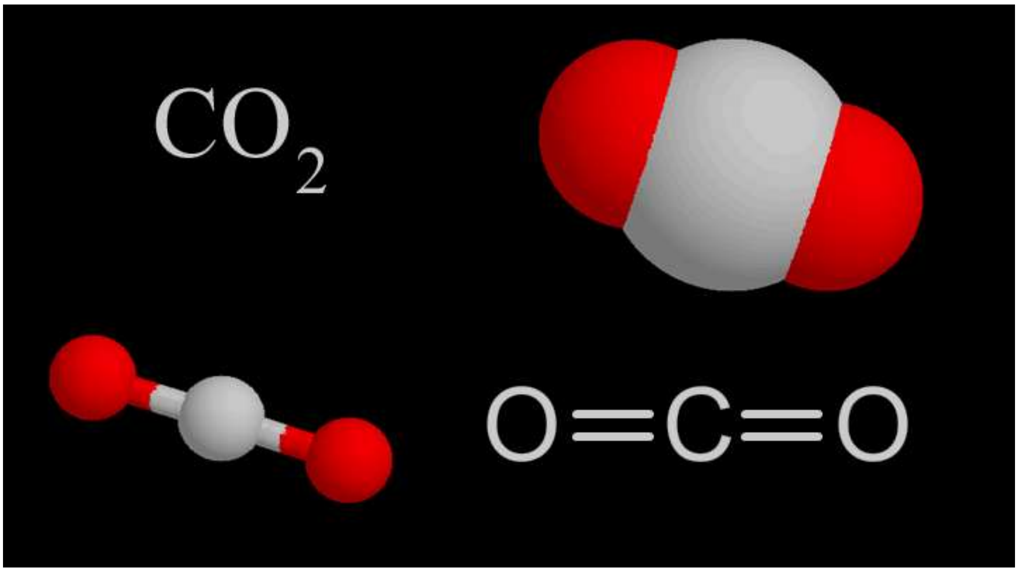
Greenhouse gases include carbon dioxide, methane, nitrous oxide and other gases that accumulate in the atmosphere and create the heat-reflective layer that keeps the Earth at a livable temperature. These gases form the insulation that keeps the planet warm enough to support life.

Some of the most common — and worrisome — greenhouse gases are:

- Carbon dioxide, which is emitted whenever coal, oil, natural gas and other carbon-rich fossil fuels are burned. Although carbon dioxide is not the most powerful greenhouse gas, it is the largest contributor to climate change because it is so common. In order to reduce carbon dioxide emissions, we need to reduce the amount of fuel we use in our cars, homes, and lives.
- Methane is caused by the decomposition of plant matter, and is released from landfills, swamps, rice paddies. Cattle also release methane. Although methane emissions are lower than carbon dioxide emissions, it is considered a major greenhouse gas because each methane molecule has 25 times the global warming potential of a carbon dioxide molecule.
- Nitrous oxide is released from bacteria in soil. Modern agricultural practices — tilling and soil cultivation, livestock waste management, and the use of nitrogen-rich fertilizers — contribute significantly to nitrous oxide emissions. A single nitrous oxide molecule has 298 times the global warming potential of a carbon dioxide molecule.
- Additional greenhouse gases include hydrofluorocarbons (1,430-14,800 time the global warming potential of carbon dioxide), sulfur hexafluoride (22,800 times the global warming potential of carbon dioxide), and water vapor.

3.5 Carbon Dioxide

Carbon dioxide is a chemical compound composed of one carbon and two oxygen atoms. It is often referred to by its formula CO2. It is present in the Earth's atmosphere at a low concentration and acts as a greenhouse gas. In its solid state, it is called dry ice.



CO2 is not poisonous; as a gas, CO2 itself will not hurt you. This is an important fact to remember, as carbon dioxide is a vital part of the environment. The human breathing mechanism actual revolves around CO2, not oxygen. Without carbon dioxide, humans wouldn't be able to breathe.

Carbon dioxide (CO_2) is an important heat-trapping (greenhouse) gas, which is released through human activities such as deforestation and burning fossil fuels, as well as natural processes such as respiration and volcanic eruptions. The first graph shows atmospheric CO_2 levels measured at Mauna Loa Observatory, Hawaii, in recent years, with average seasonal cycle removed. The second graph shows CO_2 levels during the last three glacial cycles, as reconstructed from ice cores.

Over the past 170 years, human activities have raised atmospheric concentrations of CO_2 by 47% above pre-industrial levels found in 1850. This is more than what had happened naturally over a 20,000-year period (from the Last Glacial Maximum to 1850, from 185 ppm to 280 ppm).

The time series below shows global distribution and variation of the concentration of mid-tropospheric carbon dioxide in parts per million (ppm). The overall color of the map shifts toward the red with advancing time due to the annual increase of CO_2.

Effects of CO2 in Human body:

Exposure to CO2 can produce a variety of health effects. These may include

- headaches,
- dizziness,
- restlessness,
- a tingling or pins or needles feeling,
- difficulty breathing,
- sweating,
- tiredness,
- increased heart rate,
- elevated blood pressure,
- coma,
- asphyxia, and
- convulsions.

Source of CO2:

We all know that it comes from burning of fossil fuels (coal, oil and natural gas), which produce carbon dioxide, which goes into the atmosphere, which makes the world warmer. What you may not know is that of the carbon dioxide we produce from fossil fuels, only about half stays in the atmosphere.

3.3.1 Carbon Dioxide in the Ocean and Atmosphere

Carbon dioxide (CO2) is considered a trace gas in the atmosphere because it is much less abundant than oxygen or nitrogen. However, this trace gas plays a vital role in sustaining life on Earth and in controlling the Earth's climate by trapping heat in the atmosphere.

The oceans play an important role in regulating the amount of CO 2 in the atmosphere because CO 2 can move quickly into and out of the oceans. Once in the oceans, the CO 2 no longer traps heat. CO_2 also moves quickly between the atmosphere and the land biosphere (material that is or was living on land).

Of the three places where carbon is stored—atmosphere, oceans, and land biosphere—approximately 93 percent of the CO_2 is found in the oceans. The atmosphere, at about 750 petagrams of carbon (a petagram [Pg] is 10^{15} grams), has the smallest amount of carbon.

3.6 Oxygen

Oxygen is a very important gas in the ocean because of its role in biological processes. Marine plants such as phytoplankton, seaweed, and other types of algae produce organic matter from carbon dioxide and nutrients through photosynthesis, the process that produces oxygen. The upper 10 to 50 meters (33 to 164 feet) of the ocean can be highly supersaturated with oxygen owing to photosynthesis.

Photosynthesis by plants is restricted to the upper sunlit areas of the ocean, but organic matter settles from the surface layer to deeper waters where oxygen consumption by animals and bacteria is a major process. The oxygen content of deep ocean waters is renewed by a process called thermohaline circulation. When surface waters either cool or become more saline (salty), their density increases, and they sink to greater depths in the ocean where they can spread over vast distances.

On a global scale, these dense waters form in the North Atlantic Ocean near Iceland and Greenland, as well as near Antarctica. The dense waters spread throughout all the oceans over periods of tens and hundreds of years, transporting high oxygen concentrations in the deep sea.

3.7 Nitrogen

Nitrogen is an essential nutrient required in the photosynthetic production of organic matter by marine plants. Nitrogen gas in the atmosphere and dissolved in sea water cannot be used, however, by many types of plants. Nitrogen must be converted into forms such as nitrate (NO_3^-) or ammonia (NH_3) before it becomes a useful nutrient for most photosynthetic organisms. While the biological cycling of nitrogen is very important in the ocean, it has only a slight effect on the amount of nitrogen gas in sea water. Nitrogen in ocean waters is within 5 percent of equilibrium with the atmosphere.

3.8 Action of Ocean on atmosphere and the reverse

The ocean plays a central role in regulating the Earth's climate. The Fifth Assessment Report published by the Intergovernmental Panel on Climate Change (IPCC) in 2013 revealed that it has thus far absorbed 93% of the extra energy from the enhanced greenhouse effect, with warming now being observed at depths of 1,000 m. As a consequence, this has led to increased ocean stratification (prevention of water mixing due to different properties of water masses), changes in ocean current regimes, and expansion of depleted oxygen zones. Changes in the geographical ranges of marine species and shifts in growing seasons, as well as in the diversity and abundance of species communities are now being observed. At the same time, weather patterns are changing, with extreme events increasing in frequency.

Atmospheric warming is leading to the melting of inland glaciers and ice, causing rising sea levels with significant impacts on shorelines (coastal erosion, saltwater intrusion, habitat destruction) and coastal human settlements. The IPCC projects global mean sea level to increase by 0.40 [0.26–0.55] m for 2081–2100 compared with 1986–2005 for a low emission scenario, and by 0.63 [0.45–0.82] m for a high emission scenario. Extreme El Niño events are predicted to increase in frequency due to rising GHG emissions.

3.9 Role of the Ocean in Climate

The ocean is increasingly seen as a vital component of the climate system. It exchanges with the atmosphere large quantities of heat, water, gases, particles and momentum. It is an important part of the global redistribution of heat from tropics to polar regions keeping our planet habitable, particularly equatorward of about 30°. In this article we review recent work examining the role of the oceans in climate, focusing on research in the Third Assessment Report of the IPCC and later. We discuss the general nature of oceanic climate variability and the large role played by stochastic variability in the interaction of the atmosphere and ocean. We consider the growing evidence for biogeochemical interaction of climatic significance between ocean and atmosphere. Air – sea exchange of several radiatively important gases, in particular CO2, is a major mechanism for altering their atmospheric concentrations. Some more reactive gases, such as dimethylsulp hide, can alter cloud formation and hence albedo. Particulates containing iron and originating over land can alter ocean primary productivity and hence feedbacks to other biogeochemical exchanges. We show that not only the tropical Pacific Ocean basin can exhibit coupled ocean – atmosphere interaction, but also the tropical Atlantic and Indian Oceans. Longer lived interactions in the North Pacific and Southern Ocean (the circumpolar wave) are also reviewed. The role of the thermohaline circulation in long-term and abrupt climatic change is examined, with the freshwater budget of the ocean being a key factor for the degree, and longevity, of change. The potential for the Mediterranean outflow to contribute to abrupt change is raised. We end by examining the probability of thermohaline changes in a future of global warming.

3.10 The Ocean and Climate change

- The ocean is being disproportionately impacted by increasing carbon dioxide (CO2) and other greenhouse gas emissions (GHG) from human activities.
- This causes changes in water temperature, ocean acidification and deoxygenation, leading to changes in oceanic circulation and chemistry, rising sea levels, increased storm intensity, as well as changes in the diversity and abundance of marine species.
- Degradation of coastal and marine ecosystems threatens the physical, economic and food security of local communities, as well as resources for global businesses.

- Climate change weakens the ability of the ocean and coasts to provide critical ecosystem services such as food, carbon storage, oxygen generation, as well as to support nature-based solutions to climate change adaptation.
- The sustainable management, conservation and restoration of coastal and marine ecosystems are vital to support the continued provision of ecosystem services on which people depend. A low carbon emissions trajectory is indispensable to preserve the health of the ocean.

Importance:

The ocean and coasts provide critical ecosystem services such as carbon storage, oxygen generation, food and income generation. Coastal ecosystems like mangroves, salt marshes and seagrasses play a vital role in carbon storage and sequestration. Per unit of area, they sequester carbon faster and far more efficiently than terrestrial forests. When these ecosystems are degraded, lost or converted, massive amounts of CO_2 – an estimated 0.15-1.02 billion tons every year – are released into the atmosphere or ocean, accounting for up to 19% of global carbon emissions from deforestation. The ecosystem services such as flood and storm protection that they provide are also lost.

The impacts of ocean warming and acidification on coastal and marine species and ecosystems are already observable. For example, the current amount of CO_2 in the atmosphere is already too high for coral reefs to thrive, putting at risk food provision, flood protection and other services corals provide. Moreover, increased GHG emissions exacerbate the impact of already existing stressors on coastal and marine environments from land-based activities (e.g. urban discharges, agricultural runoff and plastic waste) and the ongoing, unsustainable exploitation of these systems (e.g. overfishing, deep-sea mining and coastal development). These cumulative impacts weaken the ability of the ocean and coasts to continue to perform critical ecosystem services.

The degradation of coastal and marine ecosystems threatens the physical, economic and food security of coastal communities – around 40% of the world population. Local fishers, indigenous and other coastal communities, international business organisations and the tourism industry are already seeing the effects of climate change particularly in Small Island Developing States (SIDS) and many of the Least Developed Countries (LDCs).

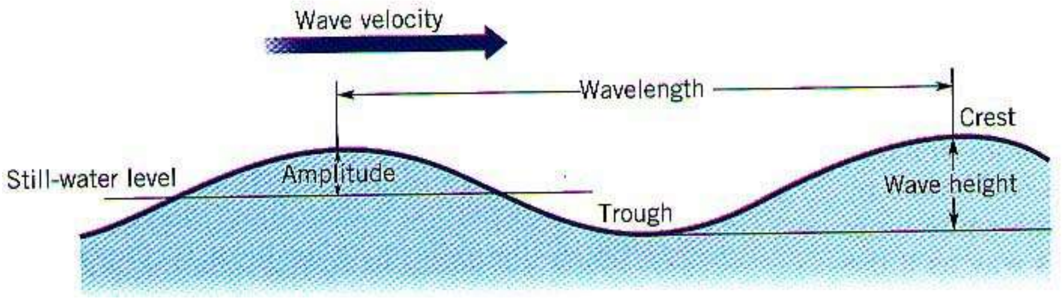
Weakened or even lost ecosystems increase human vulnerability in the face of climate change and undermine the ability of countries to implement climate change adaptation and disaster risk reduction measures, including those provided for in Nationally Determined Contributions (NDCs) under the Paris Agreement on climate change.

CHAPTER 4: THE OCEAN ELEMENTS

4.1 Waves

Waves are among the most familiar features in the ocean

It's important that you know some of their parts. The following list refers to the figure below:



Crest-the very top of the wave

trough-the hollow between two crests

wave height-the vertical distance between the top of one wave crest and the bottom of the next trough

wavelength-the horizontal distance between any one point on one wave and the corresponding point on the next

wave steepness-the ratio of height to length

amplitude-the maximum vertical displacement of the sea surface from still water level

(half the wave height)

period-the time it takes for one complete wavelength to pass a stationary point

wave speed-the velocity with which waves travel

deep water waves-waves that are in water that is deeper than half their wavelength

shallow water waves-waves that are in water that is shallower than 1/20 their wavelength (the important difference on these last two is whether or not the sea floor influences the motion of the wave)

4.2 Tides

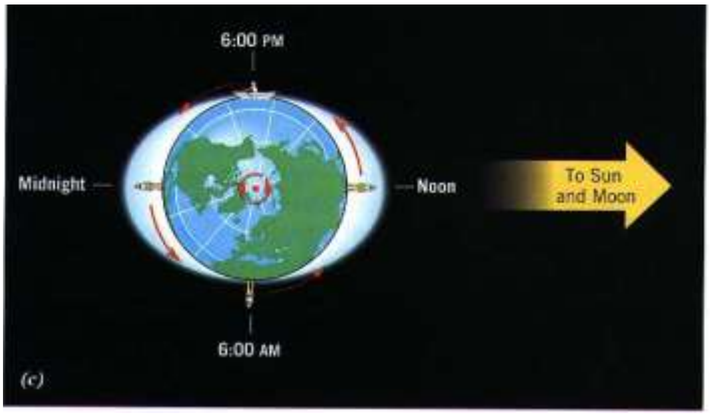
The biggest waves in our oceans are the tides. These are caused by the gravitational forces between the earth and the sun and the moon. The moon has the biggest influence because it is close. It essentially pulls up a bulge in the ocean on the side of the earth closest to it. It actually pulls up the land too, but not as much. There is also a bulge on the side opposite the moon. This one is tougher to understand. I've heard it explained two ways that seem to help:

1. Because of centrifugal force (more an effect of the earth and moon revolving together than an actual force), the ocean on the side of the earth opposite the moon is sort of thrown outward, like you are when you go around a bend in your car.

2. Imagine a race car, minivan, and bicycle starting a race. All three accelerate, and from the point of view of the minivan, the race car shoots out in front and the bicycle gets left behind. The way they spread out depends on the *differences* in rate of acceleration. Similarly, the side of the earth nearest the moon gets pulled out harder than the side away from the moon relative to the earth itself. The nearside shoots out ahead, and the backside gets left behind.

Twice daily tides like this are called semidiurnal tides. It is also possible to have only one high and one low tide per day. That would be a diurnal tide. Partly this depends on your latitude, but it turns out that some 400 variables go into predicting the tide at any one place, so it isn't nearly this simple.

The sun tugs on the oceans too, but since it's so far away, it has less influence than the moon. You can see the influence when the moon and sun and earth are all lined up. This would be during a full moon and a new moon. With both the sun and moon pulling the same direction, we get extra high tides and extra low tides (a big tidal range). These happen twice a month and are called spring tides. In between these, during the quarter phases of the moon, we get tides with the lowest ranges. These are called neap tides.



View of the Earth from above the North Pole. The tidal bulges are aligned with the Sun and Moon. As the Earth spins, we are carried through these bulges, thus experiencing two high tides and two low tides per day. In the case illustrated here, we would experience the high tides at noon and midnight, and the low tides at 6:00 PM and 6:00 AM, as indicated.

4.3 Seabed

The seabed (also known as the seafloor, sea floor, or ocean floor) is the bottom of the ocean, no matter how deep. All floors of the ocean are known as 'seabed's'. Earth materials in the surface seabed of the continental shelf is made up of a veneer of material falling out of suspension, such as dust from continents, biological material, sometimes ash and, more recently, human waste. Seafloor biological activity creates debris, for instance from reefs.

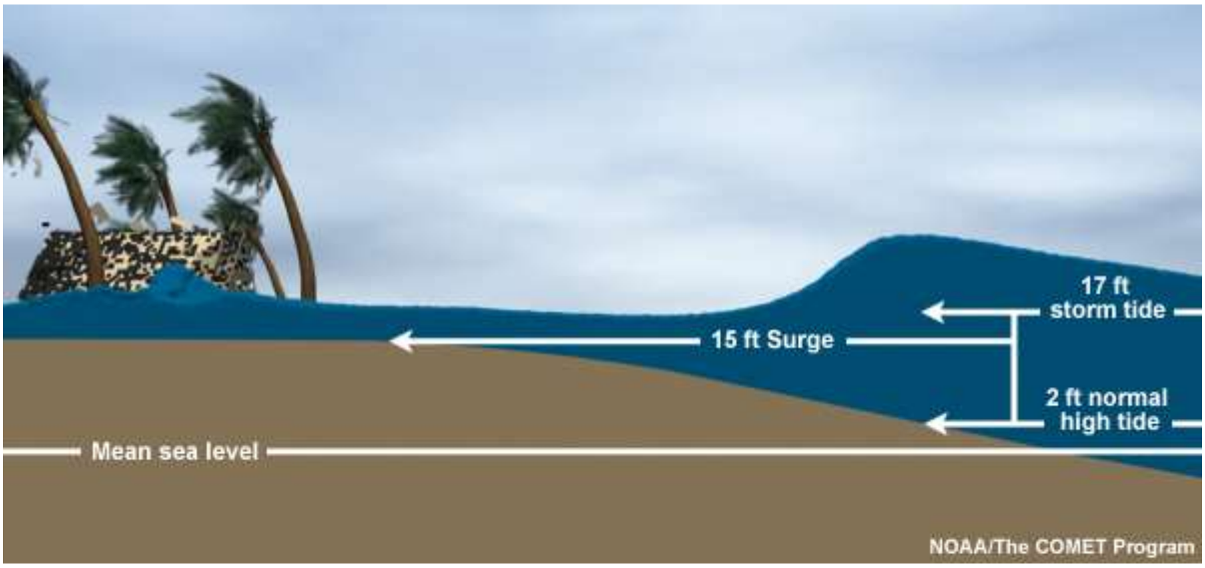
Figure: Seabed

4.4 Storm Surges

A storm surge is a rise in sea level that occurs during tropical cyclones, intense storms also known as typhoons or hurricanes. The storms produce strong winds that push the water into shore, which can lead to flooding. This makes storm surges very dangerous for coastal regions.

Climate change is likely to lead to higher storm surges as sea levels rise. Higher sea levels give storm surges a higher starting point – increasing their size and reach when they make landfall.

Storm *surge* is the abnormal rise in seawater level during a storm, measured as the height of the water above the normal predicted astronomical tide. The surge is caused primarily by a storm’s winds pushing water onshore. The amplitude of the storm surge at any given location depends on the orientation of the coast line with the storm track; the intensity, size, and speed of the storm; and the local bathymetry.



4.5 The role of the seabed regarding waves, tides & storm surges

Features of the Seabed/Seafloor:

Before scientists invented sonar, many people believed the ocean floor was a completely flat surface. Now we know that the seafloor is far from flat. In fact, the tallest mountains and deepest canyons are found on the ocean floor; far taller and deeper than any landforms found on the continents. The same tectonic forces that create geographical features like volcanoes and mountains on land create similar features at the bottom of the oceans.

Look at Figure 4.23. If you follow the ocean floor out from the beach at the top left, the seafloor gently slopes along the continental shelf. The sea floor then drops off steeply along the continental slope, the true edge of the continent. The smooth, flat regions that make up 40% of the ocean floor are the abyssal plain. Running through all the world's oceans is a continuous mountain range, called the mid-ocean ridge ("submarine ridge" in Figure 4.23). The mid-ocean ridge is formed where tectonic plates are moving apart from each other, allowing magma to seep out in the space where the plates pulled apart. The mid-ocean ridge system is 80,000 kilometers in total length and mostly underwater except for a few places like Iceland. Other underwater mountains include undersea volcanoes (called seamounts), which may rise more than 1,000 meters above the ocean floor. Those that reach the surface become volcanic islands, such as the Hawaiian Islands. Deep oceanic trenches are created where a tectonic plate dives beneath (subducts) another plate.

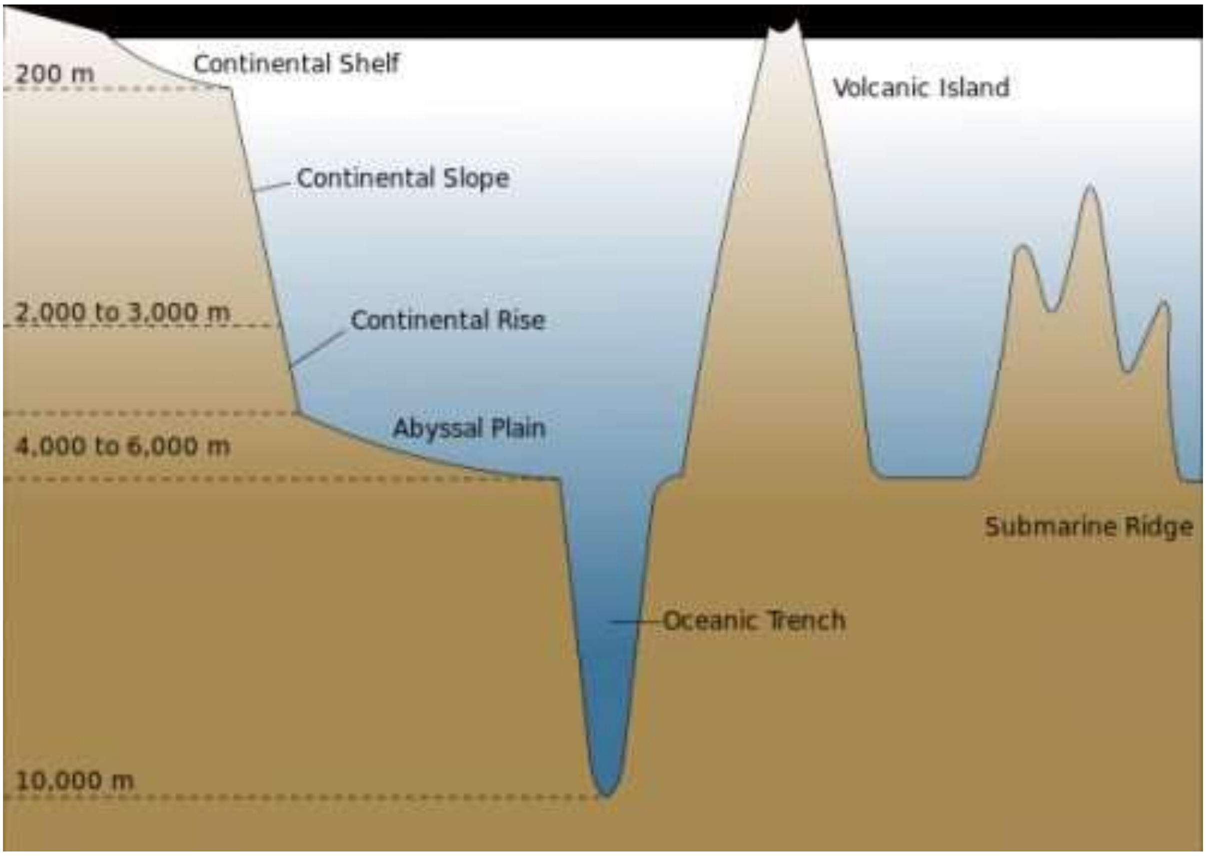


Figure 4.23: The seafloor is as varied a landscape as the continents.

4.5.1 The role of the International Seabed Authority

General

The purpose of this Chapter is to investigate the role of the International Seabed Authority, whether it is responsible for protection and regulation of living resources of the Area. This Chapter will briefly introduce the ISA and further will focus on its mandate. The question at hand is to what extent will this mandate be appropriate to ensure the effective management of living resources of the Area? To this end, the scope of prescriptive and enforcement jurisdiction of the Authority with respect to protection of living resources will be examined.

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Paragraph 5 of the Preamble UN General Assembly Resolution 2749 (XXV) declares that "an international regime applying to the area and its resources and including appropriate international machinery should be established."[141] ISA is an autonomous international organization which is responsible for the organizing and controlling activities in the Area specifically administering its resources. It is established under LOSC and the 1994 Agreement. Both instruments contain norms that rule its functioning. Article 156 of the LOSC establishes the Authority which shall function in accordance with Part XI. In the same Article there is an important statement in paragraph 2 that: "All States Parties are ipso facto members of the Authority."[142] Therefore, it can be concluded that under LOSC no specific conditions are required for States to be members of the Authority. Adherence of a State to the Convention automatically turns it into a member of the Authority. Further, Article 157 defines the nature and fundamental principles of the Authority. The Authority is invoked for organizing and controlling the activities in the Area, with the specific aim of administering its resources. Paragraph 2 has substantial meaning, it is read as follows: "the powers and functions of the Authority shall be those expressly conferred upon it by [LOSC]. The Authority shall have such incidental powers, consistent with [LOSC], as are implicit in and necessary for the exercise of those powers and functions with respect to activities in the Area."143 From the wording of Article 157(2) it might be assumed that the Authority has an extensive competence. The Authority has both main powers (those expressly conferred by LOSC) and supplementary powers (incidental powers). "Incidental powers" can be characterized as unwritten powers that are necessary for the Authority to effectively perform such powers and functions as are expressly conferred upon it.144 Further, regarding the functions and powers of the Authority, Article 152 in paragraph 1 states that: "The Authority shall avoid discrimination in the exercise of its powers and functions[…]".145 This indicates that Authority within its competence shall provide equitable treatment to all States without exceptions. But paragraph 2 contains deviation from this principle and stipulates that the Authority is under permission to pay special consideration for developing States. In the special circumstances, Authority will provide for more favorable treatment to developing State than industrialized State. LOSC establishes the organization of the Authority in Article 158. An Assembly, a Council and a Secretariat are established as the principal organs of the Authority and Enterprise established separately. In conformity with Article 153(1) activities in the Area referring to exploration and exploitation of the resources of the Area "shall be organized, carried out and controlled[…]in accordance with[…]the rules, regulations and procedures of the Authority."146 Part XI focuses on the mineral resources and mining activity. As consequence it can be presumed that Authority's mandate can be characterized as mining oriented. However, it has been concluded that living resources located in the Area are legally part of the regime of Part XI. Therefore, the Authority shall administer these resources as well as minerals. Moreover, Article 145 requires, the Authority to adopt rules, regulations and procedures with respect to activities in the Area in order to ensure effective protection for the marine environment.147 Nevertheless, the problem at hand is that Article 145 does not explicitly prescribe that the Authority must protect living resources. It obliges to protect the marine environment as a whole.

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