16. OCEAN CURRENTS

General Observations about Ocean Currents

Ocean current is the general movement of a mass of oceanic water in a definite direction, which is more or less similar to water streams flowing on the land surface of the earth. Ocean currents are most powerful of all the dynamics of oceanic waters because these drive oceanic waters for thousands of kilometers away. Ocean currents are divided on the basis of temperature into warm currents and cold currents.

On the basis of velocity, dimension and direction, they can be divided into drifts, currents and streams.

The forward movement of surface water of the oceans under the influence of prevailing winds is called drift whereas the ocean current involves the movement of Oceanic water in a definite direction with greater velocity.

Ocean stream involves movement of larger mass of ocean water like big rivers of the continent in a definite direction with greater velocity than the drifts and currents such as in Gulf Stream.

The currents in the oceans are originated due to combined effects of several internal as well as external factors, which control the origin and other characteristics of ocean current. They are related to different characteristics of ocean waters, rotational mechanism of the earth, external factors or atmospheric factors, topographic characteristics of the coasts and ocean basins. Besides, there are some factors which can modify the ocean currents.

- The factors relating to the earth's nature and its rotation include the gravitational force and deflective force by earth's rotation also known as Coriolis force.
- Oceanic factors include the pressure gradient, temperature variations and salinity differences. Ex- oceanic factors are atmospheric pressure and winds, evaporation and precipitation.
- Tides caused by the gravitational pull of the Moon and the Sun also play role in the forming of oceanic currents.
- The factors that can modify the currents are direction and shape of coastlines, bottom reliefs of the ocean basins, seasonal variations and rotation of the earth.
- Ocean circulation is driven by winds and by differences in water density. Along with the winds, ocean currents distribute the tropical heat worldwide, thus they play a very important role in maintaining Earth's heat balance.
- Please note that water at the poles travels in slow creeps below the surface water towards equator, which is called Ocean Creep. Ocean Creep is not a surface movement of water. It is an undercurrent flow occasioned by the sinking of cold and heavy water. The water, on becoming cold, contracts and its density increases.
- Those currents that flow from the Equator towards the poles are warmer than the surrounding water and so they are called warm currents. The ocean currents that flow from the polar areas towards the Equator are cooler compared to the surrounding water, so they are called cold currents. The actual difference in temperature of warm and cold currents is only a few degrees.
- The cold currents are usually found on the west coast of the continents in the low and middle latitudes in both the hemispheres and on the east coast in the middle latitudes in the Northern Hemisphere.
- The warm currents are usually observed on the east coast of the continents in the low and middle latitudes in both the hemispheres. In the Northern Hemisphere they are found on the west coasts of the continents in the high latitudes.
- The main effect of temperature differences on the earth occurs in a north-south direction i.e. from equator to poles. Warm equatorial waters therefore move slowly along the surface towards the poles while heavier cold waters of the polar areas creep slowly towards the Equator along the bottom of the sea. Thus, the difference in the temperature of the ocean waters causes ocean currents. They are convectional currents giving rise to a transfer of heat energy in the ocean waters from the areas of excess to the areas of deficit heat energy.
- The density of the ocean water varies from place to place, a movement in the ocean waters occurs due to this.

- A gyre is any large system of rotating surface ocean currents, particularly those involved with large wind movements. Gyres are caused by the Coriolis Effect; planetary vorticity along with horizontal and vertical friction, which determine the circulation patterns from the wind curl (torque).

Coriolis Effect and Coriolis Force

Coriolis Effect is a deflection of moving objects when they are viewed in a rotating reference frame. In a reference frame with clockwise rotation, the deflection is to the left of the motion of the object-, in one with counter-clockwise rotation, the deflection is to the right. Coriolis Effect is causes ONLY in a rotating reference frame. The deflective force causes by the Coriolis Effect is caused Coriolis force. It has its own say in many geographical phenomena, most important being the deflection of the general direction of ocean currents.

Important Observations:

- The currents flowing from equator towards the North Pole and from North Pole towards the equator are deflected to their right while the currents flowing north- south and south-north in the southern hemisphere are deflected towards their left.
- The rotational force of the earth causes movement of ocean water near the equator in opposite direction to 'the west to east rotation of the earth and thus equatorial currents are generated. These currents flow from east to west. Some ocean water moves in the direction of the rotation of the earth i.e. from west to east and thus counter equatorial currents are also formed.
- Please note that the magnitude of the deflection, or "Coriolis effect," varies significantly with latitude. The Coriolis Effect is zero at the equator and increases to a maximum at the poles. The deflection is proportional to wind speed: that is, deflection increases as wind strengthens. The resultant balance between the pressure force and the Coriolis force is such that, in the absence of surface friction, air moves parallel to isobars (lines of equal pressure). This is called the geotropic wind.
- The Coriolis force explains why winds circulate around high and low pressure systems as opposed to blowing in the direction of the pressure gradient.

Impact of Physical Properties of Ocean on Ocean Currents

Local variations in the physical properties of the ocean such as pressure gradient, temperature differences, salinity differences, density variations etc. generate ocean currents.

Temperature

The amount of insolation received at the earth's surface and consequent temperature decreases from equator towards the poles. Due to high temperature in the equatorial region the water density decreases because of greater expansion of water molecules whereas the density of sea water becomes comparatively greater in the polar areas. Consequently water moves due to expansion of volume from equatorial region (of higher temperature] to polar areas (colder areas] of relatively very low temperature.

There is movement of ocean water below the water surface in the form of subsurface current from colder polar areas to warmer equatorial areas in order to balance the loss of water in the equatorial areas. Thus, the poleward surface current and Equatorward subsurface currents form a complete circulatory system of ocean water. The Gulf Stream and Kuroshio warm currents moving from equator towards north are examples of such currents.

Salinity

Oceanic salinity affects the density of ocean water and density variation causes ocean currents. Salinity increases the density of ocean water. If two areas having equal temperature are characterized by varying salinity, the area of high salinity will have greater density than the area of low salinity. The denser water sinks and moves as subsurface current whereas less saline water moves towards greater saline water as surface current. In other words, ocean currents on the water surface are generated from the areas of less salinity to the areas of greater salinity. Such system of surface and subsurface currents caused by salinity variation is originated in open and enclosed seas. For example, the current flowing from the Atlantic Ocean to the Mediterranean Sea via Gibraltar Strait is caused because of the difference in salinity.

The salinity of the Mediterranean Sea is much higher than the adjoining Atlantic Ocean. Consequently, water sinks in the Mediterranean Sea. In order to compensate the loss of water Atlantic water flows as surface current into the Mediterranean Sea. The sinking

water in the Mediterranean Sea moves as subsurface current towards the Atlantic Ocean. Similarly, such system of surface and subsurface currents is generated between the Red Sea and the Arabian Sea via Bab-el-Mandeb Strait.

The salinity of the Baltic Sea is lowered due to the flow of fresh water by the rivers but the level of water is raised. With the result water moves northward as a surface current into the North Sea and subsurface current moves from the North Sea to the Baltic Sea.

Impact of Air Pressure and Winds on Ocean Currents

Air pressure on the oceanic water causes ocean currents through density variations. The areas of high atmospheric pressure are characterized by low volume of water and thus lowering of water level. Contrary to this the areas of low atmospheric pressure record higher volume of water and higher water level. Thus, water moves as surface current from the areas of higher water level (Low pressure areas] to low water level areas (high pressure areas).

Prevailing or planetary winds (e.g., trade winds, westerlies and polar winds) play major roles in the origin of ocean currents. The wind blowing on the water surface also moves water in its direction due to its friction with the water. Most of the ocean currents of the world follow the direction of prevailing winds. For example, equatorial currents flow westward under the influence of N.E. and S.B. trade winds. The Gulf Stream in the Atlantic and the Kuroshio in the Pacific move in northeastern direction under the influence of the westerlies. There is seasonal change in the direction of currents in the Indian Ocean twice a year (after every 6 months) due to seasonal change in the direction of monsoon winds. Friction caused by the wind sets the sea water in motion.

Types of Oecan Current

Ocean currents are of two type's viz. Surface Currents and Deep Currents. Surface currents affect surface water above the pycnocline (<10% of ocean water]. These currents are primarily driven by major wind belts. The Deep currents affect deep water below pycnocline (90% of ocean water] and are primarily driven by density differences. The deep currents are larger and slower than surface currents.

The stress of wind blowing across the sea causes a surface layer of water to move. Due to the low viscosity of water, this stress is not directly communicated to the ocean interior, but is balanced by the Coriolis force within a relatively thin surface layer, 10-200m thick. This layer is called the Ekman layer and the motion of this layer is called the Ekman transport. Because of the deflection by the Coriolis force, the Ekman transport is not in the direction of the wind, but is 90° to the right in the Northern Hemisphere and 90° toward the left in the Southern Hemisphere. The amount of water flowing in this layer depends only upon the wind and the Coriolis force and is independent of the depth of the Ekman layer and the viscosity of the water. The major surface currents are shown below:

Currents of The Atlantic Ocean

North Equatorial Current (warm)

North equatorial current is a significant Pacific and Atlantic Ocean current that flows east-to-west between about 10° north and 20° north. This current is generated because of upwelling of cold-water near the west coast of Africa. This warm current is also pushed westward by the cold Canary current. On an average, the north equatorial warm current flows from east to west but this saline current is deflected northward when it crosses the mid-Atlantic Ridge near 15°N latitude. It again turns southward after crossing over the ridge. This current, after being obstructed by the land barrier of the east coast of Brazil, is bifurcated into two branches viz. Antilles current and Caribbean current. The Antilles current is diverted northward and flows to the east of West Indies islands, and helps in the formation of Sargass Sea eddy while the second branch known as the Caribbean current enters the Gulf ofMexico and becomes Gulf Stream.

South Equatorial Current (warm)

The South Equatorial Current is a significant Pacific, Atlantic, and Indian Ocean current that flows east-to-west between the equator and about 20 degrees south. In the Pacific and Atlantic Oceans, it extends across the equator to about 5 degrees north. South equatorial current flows from the western coast of Africa to the eastern coast of South America between the equator and 20°S latitude. This current is more constant, stronger and of greater extent than the north equatorial current. In fact, this current is the continuation of the cold Benguela current. This warm current is bifurcated into two branches due to obstruction of land barrier in the form of the east coast of Brazil.

The northward branch after taking north-westerly course merges with the north equatorial current near Trinidad while the second branch turns southward and continues as Brazil warm current parallel to the east coast of South America. This current is basically originated under the stress of trade winds.

Equatorial Counter Current

Equatorial Counter Current is a significant ocean current in the Pacific and Indian oceans that flows west-to-east at approximately five degrees north. The Counter Currents result from balancing the westward flow of water in each ocean by the North and South Equatorial currents.

In El Nino years, Equatorial Counter current intensifies in the Pacific Ocean. The Equatorial Counter current flows from west to east in between the westward flowing strong north and south equatorial currents. This currents is less developed in the west due to stress of trade winds. In fact, the counter current mixes with the equatorial currents in the west but it is more developed in the east where it is known as the Guinea Stream. The Equatorial Counter current carries relatively higher temperature and lower density than the two equatorial currents. Several ideas have been put forth to explain the origin of the Equatorial Counter current. According to some scientists this current is originated because of the influence of the westerlies which blow from west to east in the calm zone of the doldrums or in the convergence zone of the north east and south east trade winds.

Gulf Stream

The Gulf Stream is a system of several currents moving in north-easterly direction. This current system originates in the Gulf of Mexico around 20°N latitude and moves in north easterly direction along the eastern coast of North America and reaches the western coasts of Europe near 70°N latitude. This system, named Gulf Stream because of its origin in the Mexican Gulf, consists of

1. Florida current from the strait of Florida to Cape Hatteras,
2. Gulf Stream from Cape Hatteras to the Grand Bank, and
3. North Atlantic Drift (current) from Grand Bank to the Western European coast.

North Equatorial Current flows westward off the coast of northern Africa. When this current interacts with the northeastern coast of South America, the current forks into two branches. One passes into the Caribbean Sea, while a second, the Antilles Current, flows north and east of the West Indies. These two branches rejoin north of the Straits of Florida. Thus, Florida current is in fact, the northward extension of the north equatorial current.

Hydrosphere and Atmosphere

This current flows through Yucatan channel into the Gulf of Mexico, thereafter the current moves forward through Florida Strait and reaches 30°N latitude. Thus, the Florida warm current contains most of the characteristics of the equatorial water mass.

The trade winds blow westward in the tropics, and the westerlies blow eastward at mid-latitudes. This wind pattern applies a stress to the subtropical ocean surface with negative curl across the North Atlantic Ocean. The resulting Sverdrup transport is Equatorward. Because of conservation of potential vorticity caused by the northward-moving winds on the subtropical ridge's western periphery and the increased relative vorticity of northward moving water, transport is balanced by a narrow, accelerating poleward current, which flows along the western boundary of the ocean basin, outweighing the effects of friction with the western boundary current known as the Labrador Current. The conservation of potential vorticity also causes bends along the Gulf Stream, which occasionally break off due to a shift in the Gulf Stream's position, forming separate warm and cold eddies. This overall process, known as western intensification, causes currents on the western boundary of an ocean basin, such as the Gulf Stream, to be stronger than those on the eastern boundary.

As a consequence, the resulting Gulf Stream is a strong ocean current. It transports water at a rate of 30 million cubic meters per second through the Florida Straits. As it passes south of Newfoundland, this rate increases to 150 million cubic meters per second.

The average temperature of water at the surface is 24°C while the salinity is 3.6%. The temperature never falls below 6.5°C . The current becomes narrow while passing through the Florida strait but thereafter its width increases and current flows close to coast.

Canary Current (Cold)

The Canary current, a cold current, flows along the western coast of north Africa between Maderia and Cape Verde. In fact, this current is the continuation of North Atlantic Drift which turns southward near the

Spanish coast and flows to the south along the coast of Canaries Island. The average velocity of this current is 8 to 30 nautical miles per day. This current brings cold water of the high latitudes to the warm water of the low latitudes and finally merges with the north equatorial current. The Canary cold current ameliorates the otherwise hot weather conditions of the western coasts ofNorth Africa.

Labrador Current (Cold)

The Labrador Current, an example of cold current, originates in the Baffin Bay and Davis Strait and after flowing through the coastal waters of Newfoundland and Grand Bank merges with the Gulf Stream around 50°W longitude. The flow discharge rate of the current is 7.5 million ml of water per second. This current brings with it a large number of big icebergs as far south as Newfoundland and Grand Bank. These icebergs present effective hindrances in the oceanic navigation. Dense fogs are also produced due to the convergence of the Labrador cold current and the Gulf Stream near New-foundland.

Brazil Current (Warm)

The Brazil current is characterized by high temperature and high salinity. This current is generated because of the bifurcation of the south equatorial current because of obstruction of the Brazilian coast near Sun Rock. The northern branch flows northward and merges with the north equatorial current while the southern branch known as the Brazil current flows southward along the east coast of South America up to 40°S latitude. Thereafter it is deflected eastward due to the deflective force of the rotation of the earth and flows in easterly direction under the influence of westerlies. The Falkland cold current coming from south merges with Brazil current at 40° S.

Falkland Current (Cold)

The cold waters of the Antarctic Sea flows in the form of Falkland cold current from south to north along the eastern coast of South America up to Argentina. This current becomes most extensive and developed near 30°S latitude. This current also brings numerous icebergs from the Antarctic area to the South American coast.

South Atlantic Drift (Cold)

The eastward continuation of the Brazil current is called South Atlantic Drift. This current is originated because of the deflection of the Brazil warm current eastward at 40°8 latitude due to the deflective force of the rotation of the earth. The South Atlantic Drift, thus, flows eastward under the influence of the westerlies. This current is also known as the Westerlies Drift or the Antarctic Drift.

Benguela Current (Cold)

The Benguela current, a cold current, flows from south to north along the western coast of south Africa. In fact, the South Atlantic Drift turns northward due to obstruction caused by the southern tip of Africa. Further northward, this current merges with the South Equatorial Current.

Currents of The Pacific Ocean

North Equatorial Current (Warm)

The north equatorial current originates off the western coast of Mexico and flows in westerly direction and reaches the Philippines coast after covering a distance of 7500 nautical miles. This current is originated because of the Californian current and north-east monsoon. The volume of water continuously increases westward because numerous minor branches join this current from the north. A few branches also come out of the main current and turn towards - north and south. One branch emerges from the north equatorial current near Taiwan and flows northward to join Kuroshio current while the southern branch turns eastward to form counter equatorial current. It is significant to note that north equatorial current flows as a continuous current i n the north Pacific Ocean but there are seasonal variations in its northern and southern marginal areas. The velocity of the current ranges between 12 and 18 nautical miles per day. With the northward (northern summer) and southward south northward and southward but it always remains to the north of equator.

South Equatorial Current (Warm)

The south equatorial current is originated due to the influence of south-east trade winds and flows from east to west. This current is stronger than the north equatorial current. The average velocity is 20 nautical miles per day while the maximum velocity becomes 100 nautical miles a day. Numerous minor currents join this current, from the left and thus, the volume of water continuously increases west-ward, The current is bifurcated into northern and southern branches near New Guinea. The northern branch turns eastward and flows as counter equatorial current w rule the southern branch -moves towards the northern and north-eastern coasts of Australia.

Counter Equatorial Current (Warm)

The current flowing west to east between the north and south equatorial currents is termed counter equatorial current. Because of trade winds immense volume of water is piled up in the western marginal parts of the ocean, with the result there is general slope gradient of water surface from west to east. This higher water level in the west and descending slope gradient of water surface from west to east make the oceanic water flow in easterly direction in the name of counter equatorial current which is the most developed counter current in the Pacific Ocean. This counter equatorial current is extended up to the Panama Bay.

Kuroshio System (Warm)

The Kuroshio System consists of several currents and drifts is similar to the Gulf Stream system of the Atlantic Ocean. This system runs from Taiwan to the Bering Strait and consists of the Kuroshio current, the Kuroshio extension, the north Pacific drift, the Tsushima current and the counter Kuroshio current.

Oyashio Current (Cold)

The Oyashio cold current is also known as Kurile cold current. This cold current flows through the Bering Strait in southerly direction and thus transports cold water of the Arctic Sea into the Pacific Ocean. Near 50°N latitude this current is bifurcated into two branches. One branch turns east-ward and merges with the Aleutian and Kuroshio currents. The second branch moves upto the Japanese coasts. This current is comparable to the cold Labrador Current of the North Atlantic Ocean. The convergence of cold Oyashio (Kurile) and warm Kuroshio Current causes dense fogs which become potential hazards for navigation.

California Current (Cold)

The California current, an example of cold current, is similar to the Canary cold current of the Atlantic Ocean in most of its characteristics. In fact, this current is the eastward extended portion of the North Pacific drift. The cold California current is generated because of the movement of oceanic water along the Californian coast from north to south in order to compensate the loss of water which is caused due to large-scale transport of water off the coast of Mexico under the influence of trade winds in the form of the north equatorial current. This current after reaching the Mexican coast turns west-ward and merges with the north equatorial current.

Peru Current (Cold)

The cold current flowing along the western coast of South America from south to north is called Peru current or Humboldt current. This current is known as Peru coastal current near the coast w bile it is called Peru oceanic current off the coast. Mean annual temperature ranges between 14°C and 17°C and the average velocity of moving water is 15 nautical miles (27km] per day. The temperature of sea water increases from the coast towards the ocean.

East Australia Current (Warm)

South equatorial current is bifurcated near the Australian coast into northern and southern branches. The southern branch flows as east Australia current from north to south along the eastern coasts of Australia. New Zealand is surrounded by this current. It is deflected eastward near 40°S latitude due to deflective force of the earth and flows in easterly direction under the influence of the westerlies. This is a warm and more consistent current. It raises the temperature of east Australian coast for considerable distance southward.

Currents of The Indian Ocean

The current systems of the Indian Ocean are largely controlled and modified by landmasses and monsoon winds. Indian Ocean being surrounded by the Indian subcontinent, Africa and Australia does not present most favourable conditions for the development of consistent system of ocean currents. The currents in the northern Indian Ocean change their flow direction twice a year due to north-east and south-west monsoon winds.

North-East Monsoon Current (Warm)

North-east monsoon winds blow from land to the ocean during winter season in the northern hemisphere and thus westward blowing north-east monsoon currents are produced in Indian Ocean. This current flows to the south of 5°N latitude. Besides, some independent currents originate in the Bay of Bengal and Arabian sea and flow in south-westerly direction.

S.W. Monsoon Current (Warm)

There is complete reversal in the direction of monsoon winds during summer season. The north-easterly direction of winter monsoon winds becomes south-westerly during summer season in the northern hemisphere. This reversal of direction of monsoon winds also reverses the direction of ocean currents of Indian Ocean during summer season. North-east monsoon ocean currents disappear and south-west monsoon ocean currents are developed. The general direction of monsoon currents is from south-west to north-east but several minor branches emerge from the main branch and move in the Bay of Bengal and Arabian Sea. The Indian counter current developed during winter season disappears due to this current.