Ocean circulation

Ocean Movements

- **World Water Day – March 22**
- The movements that occur in oceans are categorized as: **waves, tides and currents.**

- Waves are formed due to **friction** between wind and surface water layer. The stronger the wind, the bigger the wave. They die out quickly on reaching the shore or shallow waters.
- Horizontal currents arise mainly due to **friction** between wind and water. Rotation of earth, Coriolis force and differences in water level gradient also play a major role.
- Vertical currents arise mainly due to density differences caused by temperature and salinity changes.
- Tsunami, storm surge and tides are **tidal waves** [waves with large wavelengths that have greater intensity and destructive power]. Waves and Tides will be dealt in separate posts. For now, we will take a look at ocean currents only.
- Usually temperature distribution and salinity are discussed first. But here, I will begin with ocean currents as they bear a greater influence on both temperature distribution and salinity distribution.

Ocean currents

- Ocean currents are the most important ocean movements because of their **influence on climatology** of various regions.
- Ocean currents are like river flow in oceans. They represent a **regular** volume of water in a **definite** path and direction.
- Ocean currents are influenced by two types of forces namely:

1. primary forces that initiate the movement of water;
2. Secondary forces that influence the currents to flow.

- The primary forces that influence the currents are:

1. **heating by solar energy;**
2. **wind;**
3. **gravity;**
4. **Coriolis force.**

- The secondary forces that influence the currents are:

1. **Temperature difference;**
2. **Salinity difference**

Primary Forces Responsible For Ocean Currents

Influence of insolation

- Heating by solar energy causes the water to expand. That is why, near the equator the ocean water is about 8 cm higher in level than in the middle latitudes.
- This causes a very slight gradient and water tends to flow down the slope. The flow is normally from east to west.

Influence of wind (atmospheric circulation)

- Wind blowing on the surface of the ocean pushes the water to move. Friction between the wind and the water surface affects the movement of the water body in its course.
- Winds are responsible for both magnitude and direction [Coriolis force also affects direction] of the ocean currents. Example: **Monsoon winds** are responsible for the seasonal reversal of ocean currents in the Indian ocean.
- The oceanic circulation pattern roughly corresponds to the earth's atmospheric circulation pattern.
- The air circulation over the oceans in the middle latitudes is mainly anticyclonic [Sub-tropical High Pressure Belt] (more pronounced in the southern hemisphere than in the northern hemisphere due to differences in the extent of landmass). The oceanic circulation pattern also corresponds with the same.
- At higher latitudes, where the wind flow is mostly cyclonic [Sub-polar Low Pressure Belt], the oceanic circulation follows this pattern.
- In regions of pronounced monsoonal flow [Northern Indian Ocean], the monsoon winds influence the current movements which change directions according to seasons.

Influence of gravity

- Gravity tends to pull the water down to pile and create **gradient variation**.

Influence of Coriolis force

- The Coriolis force intervenes and causes the water to move to the **right** in the northern hemisphere and to the **left** in the southern hemisphere.
- These large accumulations of water and the flow around them are called **Gyres.** These produce large circular currents in all the ocean basins. One such circular current is the **Sargasso Sea.**

Secondary Forces Responsible For Ocean Currents

- **Temperature difference** and **salinity difference** are the secondary forces.
- Differences in water density affect **vertical mobility** of ocean currents (vertical currents).
- Water with high salinity is denser than water with low salinity and in the same way cold water is denser than warm water.
- Denser water tends to sink, while relatively lighter water tends to rise.
- Cold-water ocean currents occur when the cold water at the poles sinks and slowly moves towards the equator.
- Warm-water currents travel out from the equator along the surface, flowing towards the poles to replace the sinking cold water.

Types of Ocean Currents

Based on depth

- The ocean currents may be classified based on their depth as **surface currents** and **deep water currents**:

1. surface currents constitute about 10 per cent of all the water in the ocean, these waters are the upper **400 m** of the ocean;
2. Deep water currents make up the other 90 per cent of the ocean water. These waters move around the ocean basins due to variations in the density and gravity.

- Deep waters sink into the deep ocean basins at high latitudes, where the temperatures are cold enough to cause the density to increase.

Based on temperature

- Ocean currents are classified based on temperature: as **cold currents** and **warm currents**:

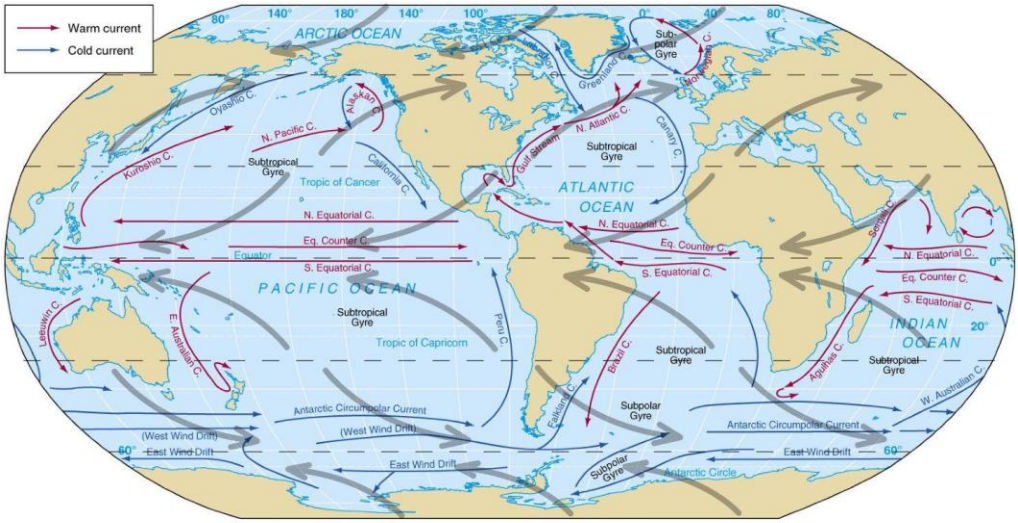
1. Cold currents bring cold water into warm water areas [from high latitudes to low latitudes]. These currents are usually found on the **west coast of the continents** (currents flow in clockwise direction in northern hemisphere and in anti-clockwise direction in southern hemisphere) in the low and middle latitudes (true in both hemispheres) and on the east coast in the higher latitudes in the Northern Hemisphere;
2. Warm currents bring warm water into cold water areas[low to high latitudes] and are usually observed on the east coast of continents in the low and middle latitudes (true in both hemispheres). In the northern hemisphere they are found on the west coasts of continents in high latitudes.

General Characteristics of Ocean Currents

- Characteristics of Ocean Currents arise due to the interplay of the above-mentioned factors.

The general movement of the currents in the northern hemisphere is clockwise and in the southern hemisphere, anti-clockwise.

- This is due to the **Coriolis force which is a deflective force and follows Ferrel's law**.
- A notable exception to this trend is seen in the northern part of the Indian Ocean where the current movement changes its direction in response to the **seasonal change in the direction** of monsoon winds.



The warm currents move towards the cold seas and cool currents towards the warm seas.

- In the lower latitudes, the warm currents flow on the **eastern shores** and cold on the western shores [food for imagination].
- The situation is reversed in the higher latitudes. The warm currents move along the western shores and the cold currents along the eastern shores.
- **Convergence:** warm and cold currents meet.
- **Divergence:** a single current splits into multiple currents flowing in different directions.

The shape and position of coasts play an important role in guiding the direction of currents.

- The currents flow not only at the surface but also below the sea surface (due to salinity and temperature difference).
- For instance, heavy surface water of the Mediterranean Sea sinks and flows westward past Gibraltar as a sub-surface current.

Effects of Ocean Currents

Ocean currents have a number of direct and indirect influences on human activities.

Desert formation

- Cold ocean currents have a direct effect on **desert formation** in west coast regions of the **tropical and subtropical continents**.
- There is **fog** and most of the areas are **arid due to desiccating effect (loss of moisture).**

Rains

- Warm ocean currents bring rain to coastal areas and even interiors. Example: Summer Rainfall in **British Type climate**.
- Warm currents flow parallel to the east coasts of the continents in tropical and subtropical latitudes. This results in warm and rainy climates. These areas lie in the western margins of the subtropical anti-cyclones.

Moderating effect

- They are responsible for moderate temperatures at coasts. [North Atlantic Drift brings warmness to England. Canary cold current brings cooling effect to Spain, Portugal etc.]

Fishing

- Mixing of cold and warm ocean currents bear richest fishing grounds in the world.
- Example: Grand Banks around Newfoundland, Canada and North-Eastern Coast of Japan.
- The mixing of warm and cold currents help to replenish the oxygen and favor the growth of **planktons**, the primary food for fish population. The best fishing grounds of the world exist mainly in these mixing zones.

Drizzle

- Mixing of cold and warm ocean currents create foggy weather where precipitation occurs in the form of drizzle [Newfoundland].

Climate

Results in

- Warm and rainy climates in tropical and subtropical latitudes [Florida, Natal etc.],
- Cold and dry climates on the western margins in the sub-tropics due to desiccating effect,
- Foggy weather and drizzle in the mixing zones,
- Moderate clime along the western costs in the sub-tropics.

Tropical cyclones

- They pile up warm waters in tropics and this warm water is the major force behind tropical cyclones.

Navigation

- Currents are referred to by their “drift”. Usually, the currents are strongest near the surface and may attain speeds over five knots (1

knot = ~1.8 km). [At depths, currents are generally slow with speeds less than 0.5 knots].

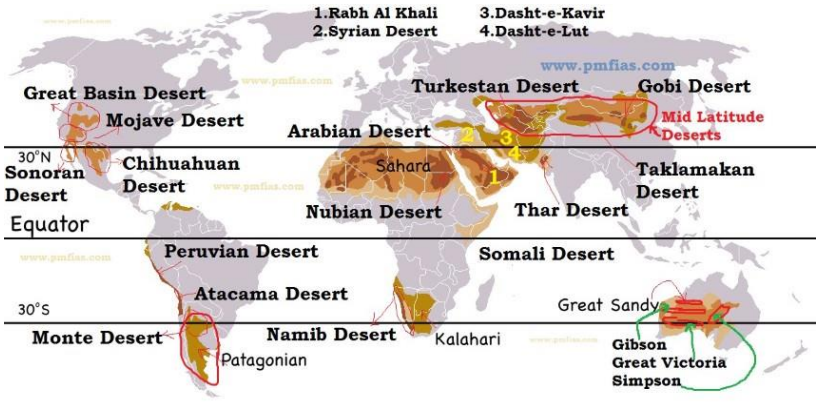
- Ships usually follow routes which are aided by ocean currents and winds.
- Example: If a ship wants to travel from Mexico to Philippines, it can use the route along the North Equatorial Drift which flows from east to west.
- When it wants to travel from Philippines to Mexico, it can follow the route along the doldrums when there is counter equatorial current [we will study this in next post] flowing from west to east.

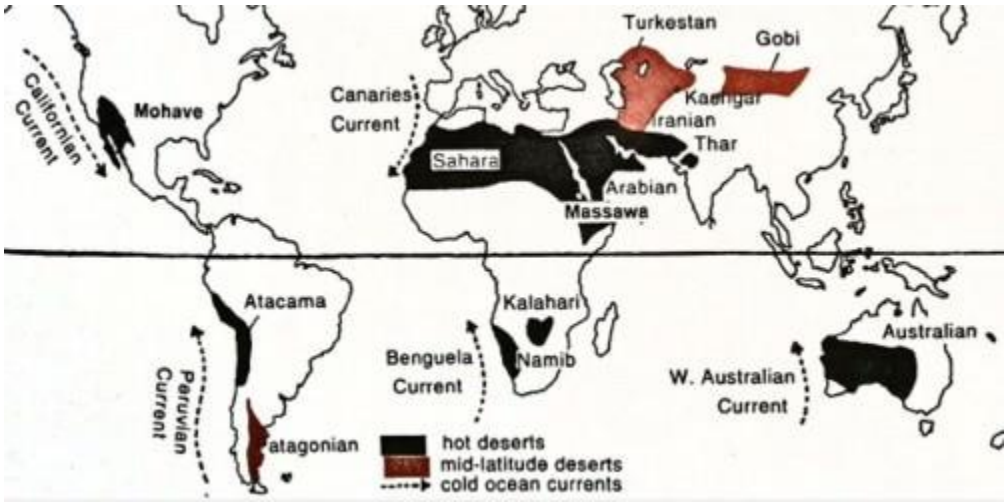
Desert Formation and Ocean Currents

Major hot deserts are located between 20-30 degree latitudes and on the western side of the continents. Why?

- The aridity of the hot deserts is mainly due to the effects of off-shore Trade Winds, hence they are also called **Trade Wind Deserts.**
- The major hot deserts of the world are located on the western coasts of continents between latitudes 15° and 30°N. and S (Question asked in Previous Mains Exam).
- They include the biggest Sahara Desert (3.5 million square miles). The next biggest desert is the Great Australian Desert. The other hot deserts are the Arabian Desert, Iranian Desert, Thar Desert, Kalahari and Namib Deserts.
- The hot deserts lie along the Horse Latitudes or the Sub-Tropical High Pressure Belts where the air is descending, a condition least favorable for precipitation of any kind to take place.
- The rain-bearing Trade Winds blow **off-shore** and the Westerlies that are on-shore blow outside the desert limits.
- Whatever winds reach the deserts blow from cooler to warmer regions, and their relative humidity is lowered, making condensation almost impossible.

- There is scarcely any cloud in the continuous blue sky. The relative humidity is extremely low, decreasing from 60 per cent in coastal districts to less than 30 per cent in the desert interiors. Under such conditions, every bit of moisture is evaporated and the deserts are thus regions of permanent drought. Precipitation is both scarce and most unreliable.
- On the western coasts, the presence of cold currents gives rise to **mists and fogs** by chilling the on-coming air. This air is later warmed by contact with the hot land, and little rain falls.
- The **desiccating effect** of the cold Peruvian Current along the Chilean coast is so pronounced that the mean annual rainfall for the Atacama Desert is not more than 1.3 cm.





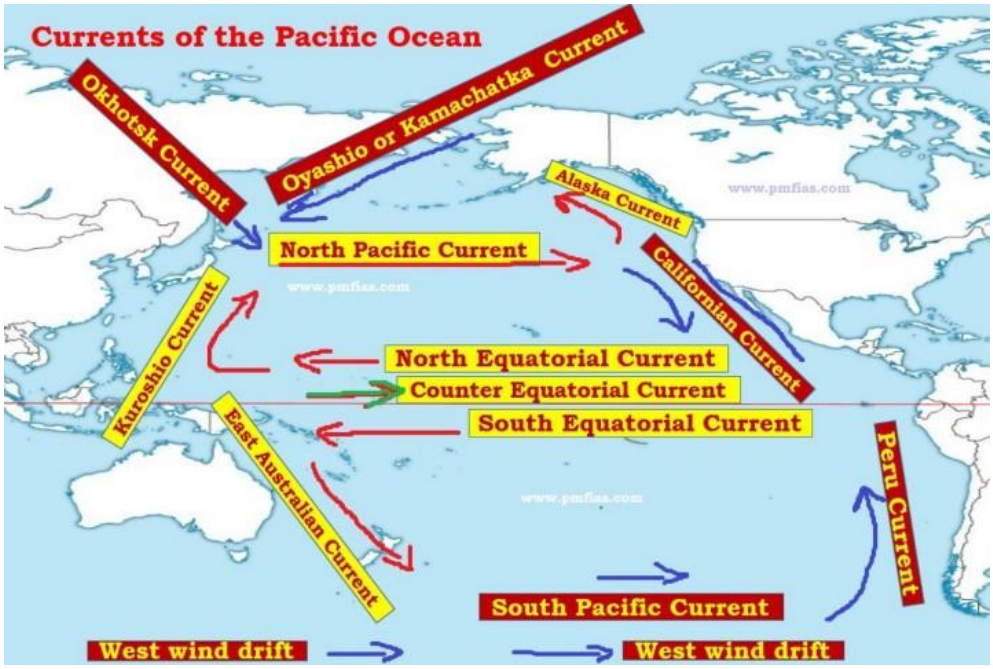
Pacific Ocean Currents

Equatorial Pacific Ocean Currents

- Under the influence of **prevailing trade winds [tropical easterlies]**, the **north equatorial current** and the **south equatorial current** start from the eastern pacific (west coast of Central America) and traverses a distance of 14,500 km moving from **east to west.**

Counter equatorial current

- This raises the level of western pacific (near Indonesia and Australia) ocean by few centimeters. And this creates a **counter-equatorial current** which flows between the north equatorial current and the south equatorial current in **west-east** direction.



Three factors aid the formation of Counter-Equatorial current

1. Piling up of water in the western pacific due to trade winds.
2. The presence of doldrums (equatorial low pressure belt) in between the north equatorial current and the south equatorial current. Doldrums are narrow regions with calm (lower) atmospheric conditions. Such conditions aid the backward movement of piled up western pacific waters.
3. Piling of water in the western part of oceans due to rotation of earth (this is a very general point).

Kuroshio current

- The north equatorial current turns northward off the Philippines to form the **Kuroshio current.** Most of it lies in the **sub-tropical high pressure belt** and its northern part is under the influence of **westerlies.**

Oyashio **Current and Okhotsk current**

- There are two more cold currents in the northern Pacific, **Oyashio flows** across the east coast of Kamchatka Peninsula to merge with the warmer waters of Kuroshio, and the Okhotsk current flows past **Sakhlain Islands** to merge with the Oyashio current off Hokkaido (Northern Japanese Island).

North-Pacific current

- From the south-east coast of Japan, under the influence of prevailing westerlies, the **Kuroshio current** turns eastwards and moves as the North-Pacific current, reaches the west coast of North America, and bifurcates into two.

Alaska and Californian current

- The northern branch flows anti-clockwise along the coast of British Columbia and Alaska and is known as the **Alaska current**. The water of this current is relatively warm as compared to the surrounding waters in this zone.
- The southern branch of the current moves as a cold current along the west coast of USA and is known as the **Californian current**. The Californian current joins the north equatorial current to complete the circuit.

East Australian current

- Following the pattern in the northern hemisphere, the south equatorial current flows from east to west and turns southwards as the East Australian current. It then meets the South pacific current near Tasmania which flows from west to east.

Peru current or Humboldt Current

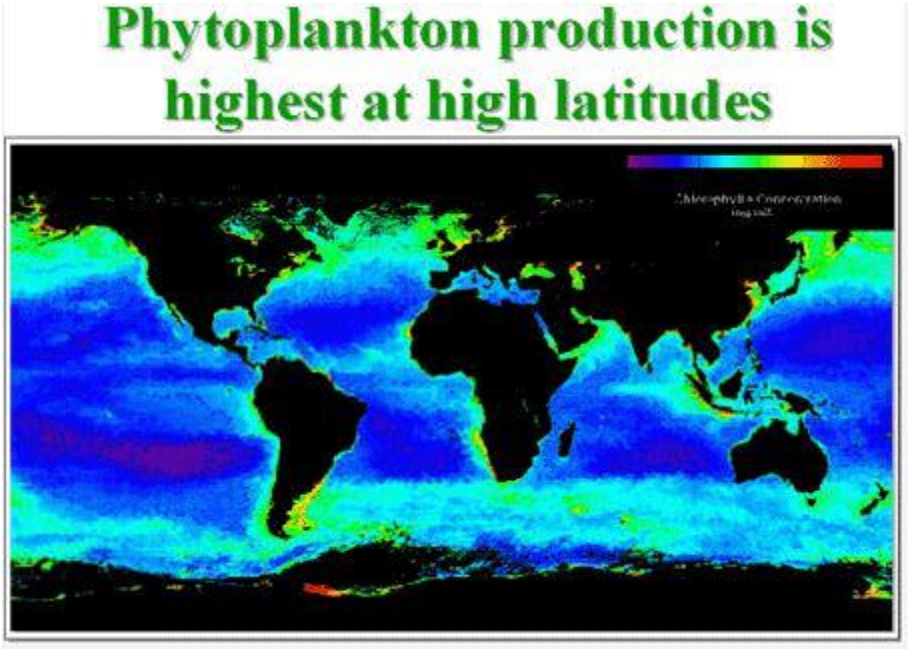
- Reaching the south-western coast of South America, it turns northward as the Peru current. It is a cold current, which finally feeds the south equatorial current, thus completing the great circuit.
- And the zone where Peru Cold current meets the warm equatorial ocean waters is an important fishing zone. Why? Read the topic below.

Phytoplankton and Fishing

Mixing zones of Cold and Warm Ocean Currents [Grand Banks] and cold water upwelling zones [Peru coast] are the most productive fishing grounds on earth. Why?

- Phytoplankton are the **primary producers** in the marine food chain and hence they are called the **'grass of the sea'**.
- Phytoplankton are predominantly **microscopic, single celled** organisms.
- Some species of algae are large, multicellular and live on the ocean bottom. However, they are insignificant players in the marine ecosystem compared to the phytoplankton as they only inhabit a narrow zone around the coast.

Why are cold and warm current mixing zones the good fishing grounds? Why are tropical waters highly *un*productive?



- Algae and other plants are able to **photosynthesize** to produce **organic material** from inorganic nutrients.
- And the organic material forms the building block for all animals higher up in the food chain.
- Almost all biomass in the ocean is derived from the **phytoplankton** and to a lesser extent the **benthic algae** *(found on the bottom of a sea or lake)*.
- However, there is a fundamental problem phytoplankton in the open ocean have to face. They **need both sunlight and nutrients** (such as **nitrate** and **phosphate**) to be able to photosynthesize.
- Sunlight is only available in the uppermost layers.
- During photosynthesis, the nutrients are quickly used up by phytoplankton so they are not available for long periods in the upper layers under normal circumstances.

This is indeed the case in tropical waters, and as a result they are very unproductive.

- To escape this problem the seawater needs to be **mixed regularly** to bring the nutrient rich deep waters up to the sunlight zone where the phytoplankton can grow.

This is one of the reasons why cold and warm currents convergence zones [mixing happens – the collision of currents causes mixing] and upwelling zones are very productive.

- Furthermore, in surroundings where atmospheric temperatures are often colder than oceanic temperatures, the top layers of the ocean are cooled by the atmosphere.
- This increases the density of the surface waters and causes them to sink and therefore causes mixing [nutrient deficient water sinks and nutrient rich water is upwelled].

Atlantic Ocean Currents

- The behavior of the Atlantic Ocean Currents is quite significant because of their influence on the climate of North-western Europe, climate of North-Western Africa and fishing in the Grand banks region.
- Equatorial Atlantic Ocean Currents
- Antilles current
- Gulf Stream and North Atlantic Drift
- Norwegian current
- Sargasso Sea
- Grand Banks-Richest Fishing Grounds on Earth
- Brazil current
- Benguela current

Equatorial Atlantic Ocean Currents

- Under the influence of **prevailing trade winds [easterly trade winds]**, the north equatorial current and the south equatorial current start from the eastern Atlantic (west coast of Africa), moving from east to west.
- This raises the level of western Atlantic (north of the Brazil bulge) ocean by few centimeters. And this creates a **counter-equatorial current** which flows between the north equatorial current and the south equatorial current in **west-east** direction.

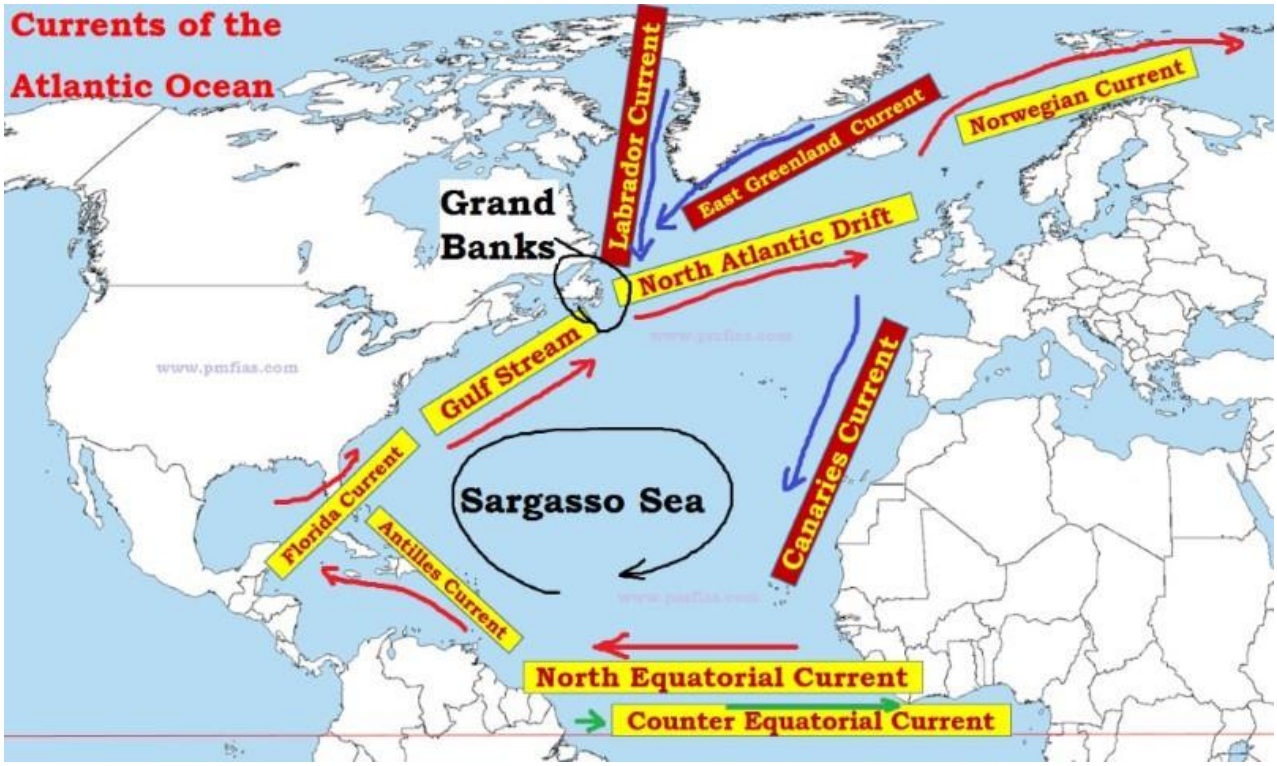
Antilles current

- The south equatorial current bifurcates into two branches near **Cape de Sao Roque (Brazil).**
- Part of the current enters the Caribbean Sea along with north equatorial current into the Mexican Gulf, while the remainder passes along the eastern side of the West Indies as the **Antilles current.**

- There is a rise in water level in the Mexican Gulf because of large amounts of water brought by the Mississippi river and branches of north and south equatorial currents.

Gulf Stream and North Atlantic Drift

- **Antilles current** creates a current that flows out through the Strait of Florida as **Florida current**, which mixes with Antilles current from the south.
- This combined current moves along the east coast of USA and is known as the Florida current upto the Cape Hatteras and as the Gulf Stream beyond that.
- Near the Grand Banks, the Gulf Stream mixes with cold Labrador and East Greenland currents and flows eastward across the Atlantic as the North Atlantic Drift.
- Here, westerly movement of North Atlantic Drift is due to the influence of **westerlies.**



Norwegian current

- The North Atlantic Current breaks up into two branches on reaching the eastern part of the ocean.
- The main current, continuing as the North Atlantic Drift, reaches the British Isles from where it flows along the coast of Norway as the **Norwegian current** and enters the Arctic Ocean.
- Norwegian current is **very important** as it keeps ocean to the north of Norway partly **free from ice** and also moderates the extremes of climate. It is because of this current, Russia is able to move cargo in summers through **Arctic ocean (Barents Sea).**
- The southerly branch flows between Spain and Azores as the cold Canary current.
- This current finally joins the north equatorial current completing the circuit in the North Atlantic.
- The **Sargasso Sea**, lying within this circuit, is full of large quantities of seaweed and is an important geographical feature.

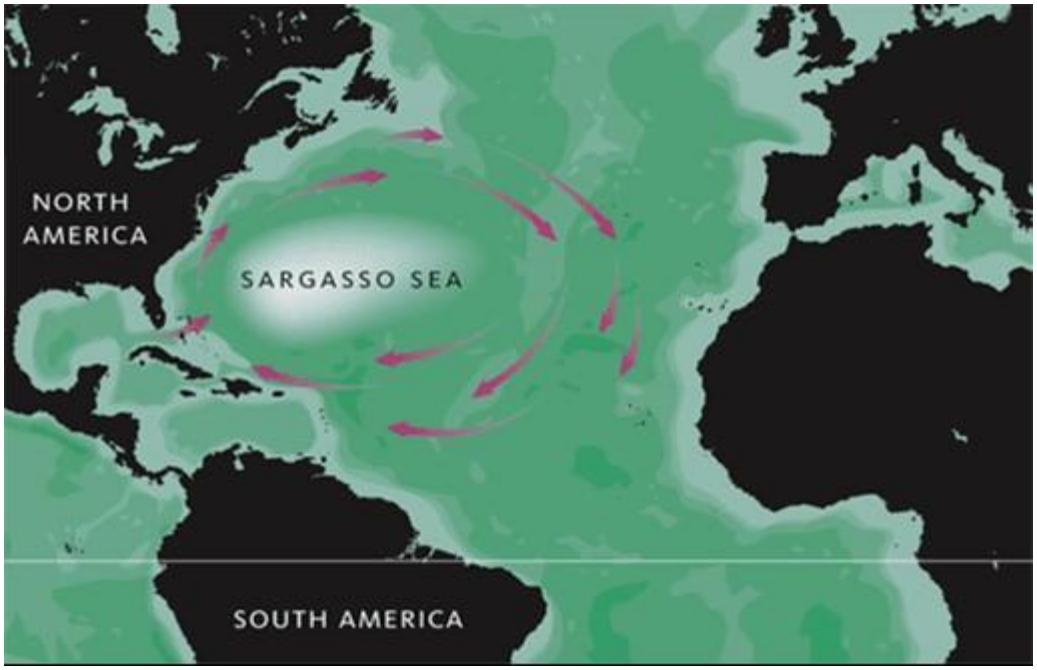
Sargasso Sea

- The Sargasso Sea is a region in the gyre in the middle of the North Atlantic Ocean.
- It is the only sea on Earth which has **no coastline.**
- It is bounded on the

1. west by the **Gulf Stream**;
2. north, by the **North Atlantic Current**;
3. east, by the **Canary Current**; and
4. south, by the **North Atlantic Equatorial Current**.

- This system of ocean currents forms the **North Atlantic Gyre**.
- All the currents deposit the marine plants and refuse they carry into this

sea.



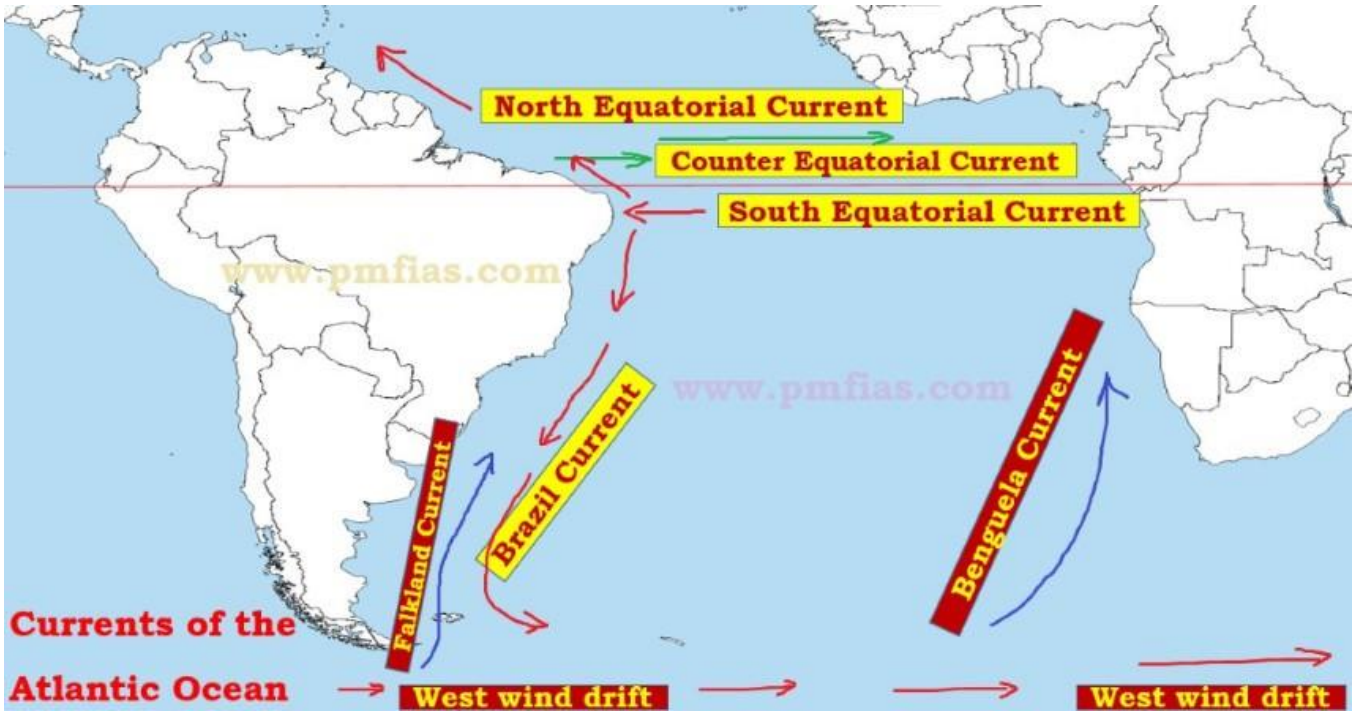
Grand Banks-Richest Fishing Grounds on Earth

- The two cold currents—East Greenland current and the Labrador current—flow from the Arctic Ocean into the Atlantic Ocean.
- The Labrador current flows along part of the east coast of Canada and meets the warm Gulf Stream.
- The confluence of these two currents, one hot and the other cold, produce the famous **fogs around Newfoundland**.
- As a result of mixing of cold and warm waters, one of the world's most important fishing grounds is created.[Explained in the previous post: Pacific Ocean Currents – Fishing and Phytoplankton]

Brazil current

- In the South Atlantic Ocean, the south equatorial current, flowing from east to west, splits into two branches near **Cape de Sao Roque (Brazil).**

- The northern branch joins the north equatorial current (a part of it flows in Anatilles Current and other into Gulf of Mexico), whereas the southern branch turns southward and flows along the South American coast as the warm Brazil current.
- The south flowing Brazil current swings eastward at about latitude 35°S (due to westerlies) to join the **West Wind Drift** flowing from west to east.
- A small branch of West Wind Drift splits and flows between Argentinian coast and **Falkland Islands** and this current is called as **Falkland cold current**.
- It mixes with warm Brazil current at the southern tip of Brazil.



Benguela current

- A branch of the South Atlantic splits at the southern tip of Africa and flows along the west coast of South Africa as the cold Benguela current, which joins the south equatorial current to complete the circuit.

Table of Contents

Indian Ocean Currents

- Indian Ocean Currents and Monsoons
  - Winter Circulation
  - Summer Circulation – North Equatorial Current Counter-Equatorial Current are Absent
- Southern Indian Ocean Currents – Agulhas current, Mozambique current, West Australian current

- Indian ocean is **half an ocean**, hence the behavior of the North Indian Ocean Currents is different from that of Atlantic Ocean Currents or the Pacific Ocean Currents.
- Also, **monsoon winds** in Northern Indian ocean are peculiar to the region, which directly influence the ocean surface water movement [North Indian Ocean Currents].

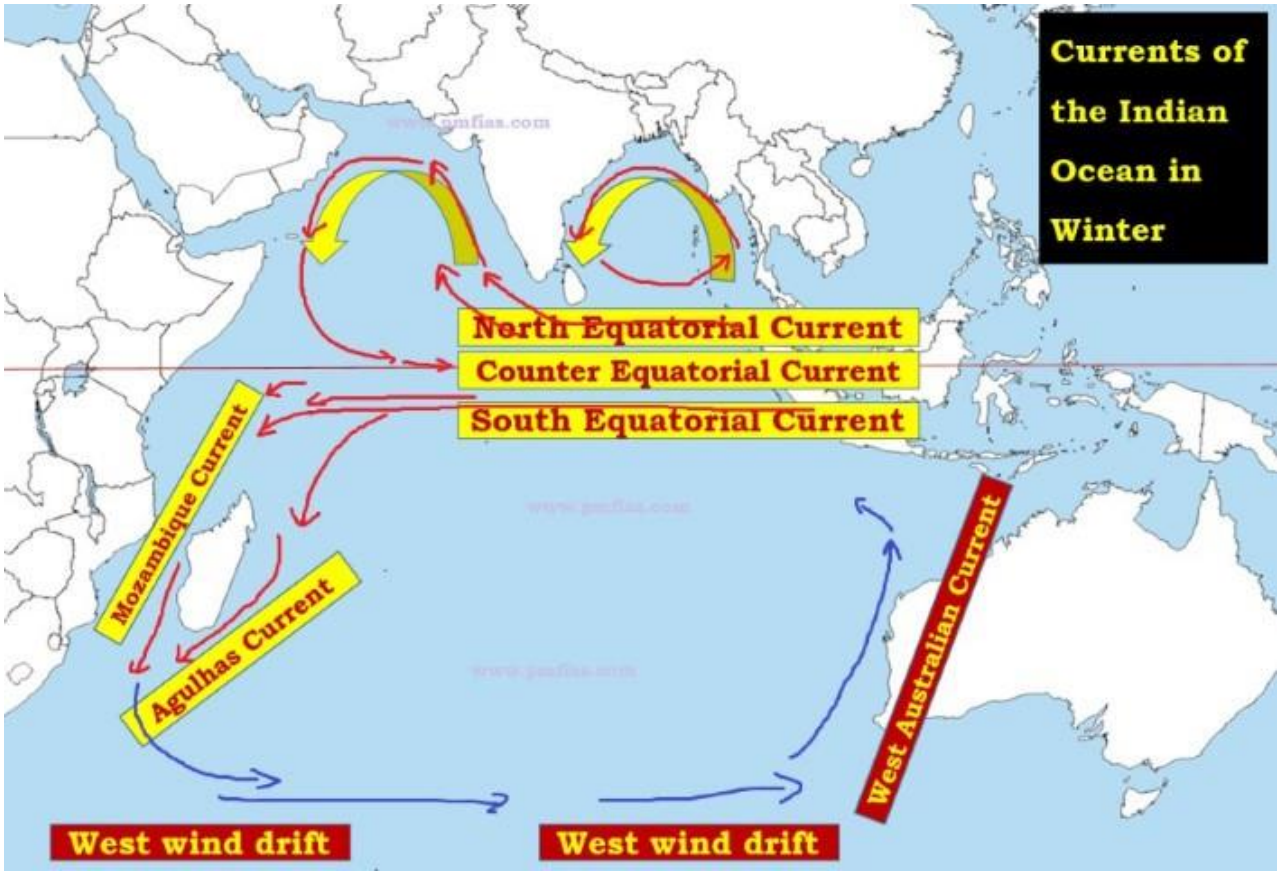
Indian Ocean Currents and Monsoons

- The currents in the northern portion of the Indian Ocean change their direction from season to season in response to the **seasonal rhythm of the monsoons**. The effect of winds is comparatively more pronounced in the Indian Ocean.

Winter Circulation

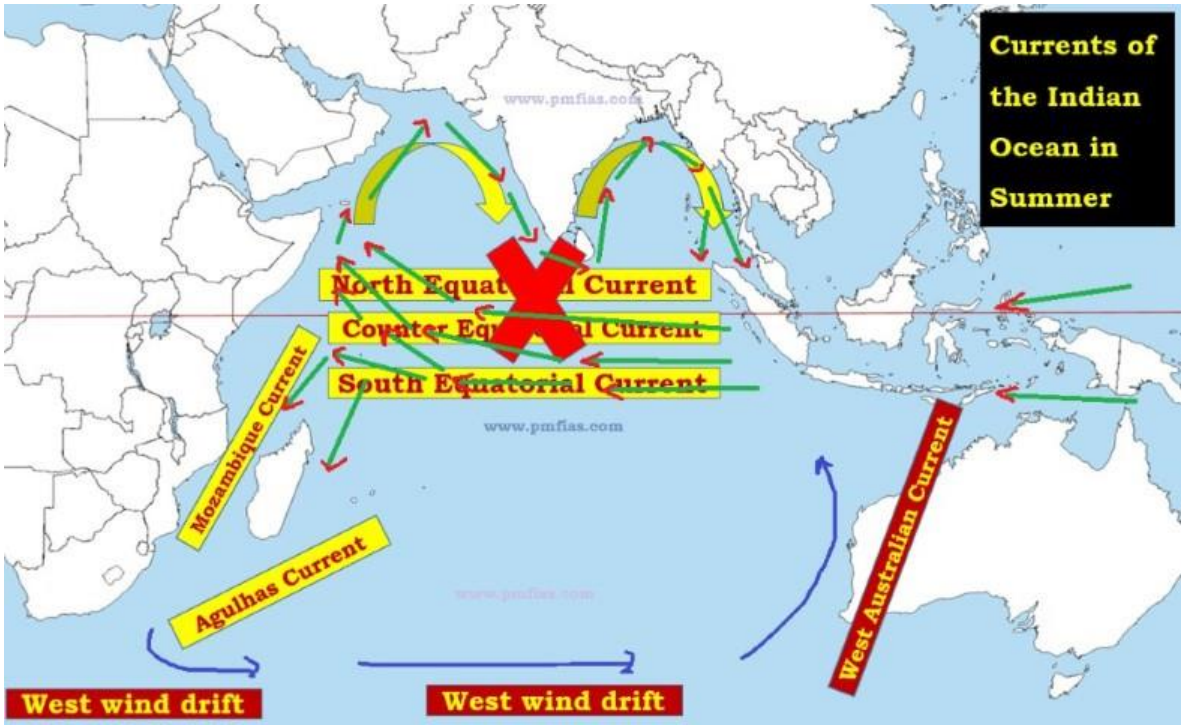
- Under the influence of **prevailing trade winds [easterly trade winds]**, the north equatorial current and the south equatorial current start from the south of Indonesian islands, moving from east to west.
- This raises the level of western Indian (south-east of horn of Africa) ocean by few centimeters. And this creates a **counter-equatorial current** which flows between the north equatorial current and the south equatorial current in **west-east** direction.
- The north-east monsoons drive the water along the coast of Bay of Bengal to circulate in an **anti-clockwise** direction.

- Similarly, the water along the coast of Arabian Sea also circulate in an **anti-clockwise** circulation.



Summer Circulation – North Equatorial Current Counter-Equatorial Current are Absent

- In summer, due to the effects of the strong south-west monsoon and the absence of the north-east trades, a strong current flows from west to east, which completely *obliterates the north equatorial current*. Hence, there is *no counter-equatorial current as well***.**
- Thus, the circulation of water in the northern part of the ocean is **clockwise** during this season.



Southern Indian Ocean Currents – Agulhas current, Mozambique current, West Australian current

- The general pattern of circulation in southern part of the Indian Ocean is quite similar to that of southern Atlantic and Pacific oceans. It is **less marked by the seasonal changes.**
- The south equatorial current, partly led by the corresponding current of the Pacific Ocean, flows from east to west.
- It splits into two branches, one flowing to the east of Madagascar known as **Agulhas current** and the other between Mozambique and Western Madagascar coast known as **Mozambique current**.
- At the southern tip of Madagascar, these two branches mix and are commonly called as the Agulhas current. It still continues to be a warm current, till it merges with the West Wind Drift.
- The **West Wind Drift**, flowing across the ocean in the higher latitudes from west to east, reaches the southern tip of the west coast, of Australia.

- One of the branches of this cold current turns northwards along the west coast of Australia. This current, known as the **West Australian current**, flows northward to feed the south equatorial current.