Ocean Currents

There are many parallels between the atmosphere and the oceans. Both are composed of fluids, air or water, which are free to flow under the influence of temperature differentials. Like the atmosphere has winds, so the ocean has currents. As with the wind, these currents are a means to redistribute solar energy from one place to another. Just as the atmosphere has surface winds and upper atmospheric circulation, the oceans also have surface currents and deep water currents. Also like the winds, many of these currents have established "permanent" patterns, which can last for tens of thousands of years. Our climate is very much dependent on ocean currents, since the redistribute massive amounts of heat energy from one part of the Earth to another. A disruption of ocean currents would lead to dramatic changes in the climate.

Ocean currents have a serious impact on our lives in other ways as well. They are responsible for the accumulation of nutrients in rich patches, which are prime fishing grounds. Many species of marine life take advantage of ocean currents for their seasonal migrations. Even modern problems such as the accumulation of debris in "garbage patches" on the oceans is driven by currents.

The movement of ships is also impacted by currents - traveling along a current saves fuel, while traveling against it costs more fuel. In the old days of sail ships, this impact could be even more serious -- the Agulhas Current in the southwest Indian Ocean was a serious obstacle to Portuguese sailors trying to reach India.

The volume of water carried by ocean currents is tremendous. It is measured in units called Sverdrup, where 1 Sverdrup is a flow rate of 1 million cubic meters of water per second. To give an idea of how large this circulation is, the total flow of fresh water from all the rivers in the world is about 1 Sverdrup. Meanwhile the flow of just one single ocean current - the Gulf Stream - varies from 30 Sverdrup to 150 Sverdrup, depending upon its location. This is why an oceanic current which is just a few degrees warmer or colder than the surrounding water can carry enormous amounts of heat energy from one location to another.

Typically, ocean currents are divided into two types: surface currents (which usually extend no more than about 400 meters below the surface), and deep water currents (also known as the thermohaline circulation) which occur in much deeper layers of the ocean.

Causes of Ocean Currents

There are several causes for ocean currents, including:

Solar Activity

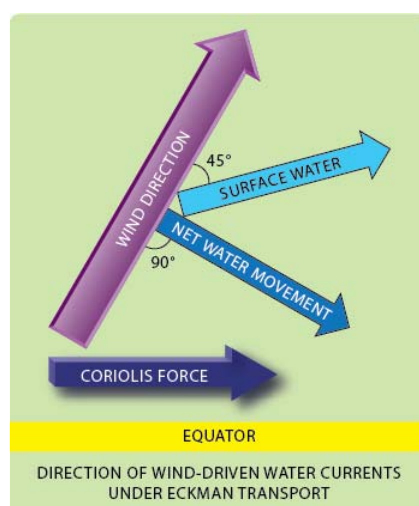
This is the single most important cause. The Sun provides the bulk of the energy which drives the circulation of water in the oceans, either directly or indirectly (through winds). The uneven distribution of solar energy across the globe (highest at the equator, decreasing towards the poles) produces an uneven heating of water in the ocean. Like air, hot water expands. The differential heating is so pronounced that sea level at the equator is about 8 cm higher than at temperate latitudes.

Gravity

The equatorial bulge of the oceans caused by the expansion of water under equatorial heat creates a slope, and water tends to run downhill under the force of gravity. This is one of the major reasons for surface water flow from the equator towards higher latitudes.

Winds

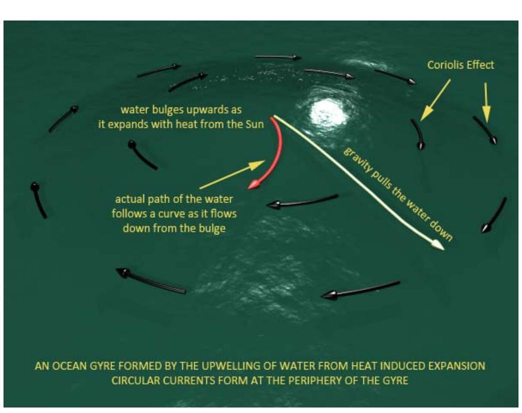
Winds produce a flow of water at the ocean surface due to friction between the wind and the surface of the oceans. Since the oceans are largely flat expanses unobstructed by topography, winds can blow for long distances, for prolonged periods of time. Friction between the air and the surface of the water is sufficiently high that a wind blowing for about 10 hours can produce a surface current in the water at about 2% of the wind velocity. So a steady wind blowing in a certain direction at 20 miles per hour for about 10 hours will produce a surface water current at about 0.4 miles per hour. The direction of the water current is not the same as that of the wind flow. The direction of the water current is affected by a phenomenon known as Eckman Transport.



DIRECTION OF WIND-DRIVEN WATER CURRENTS UNDER ECKMAN TRANSPORT

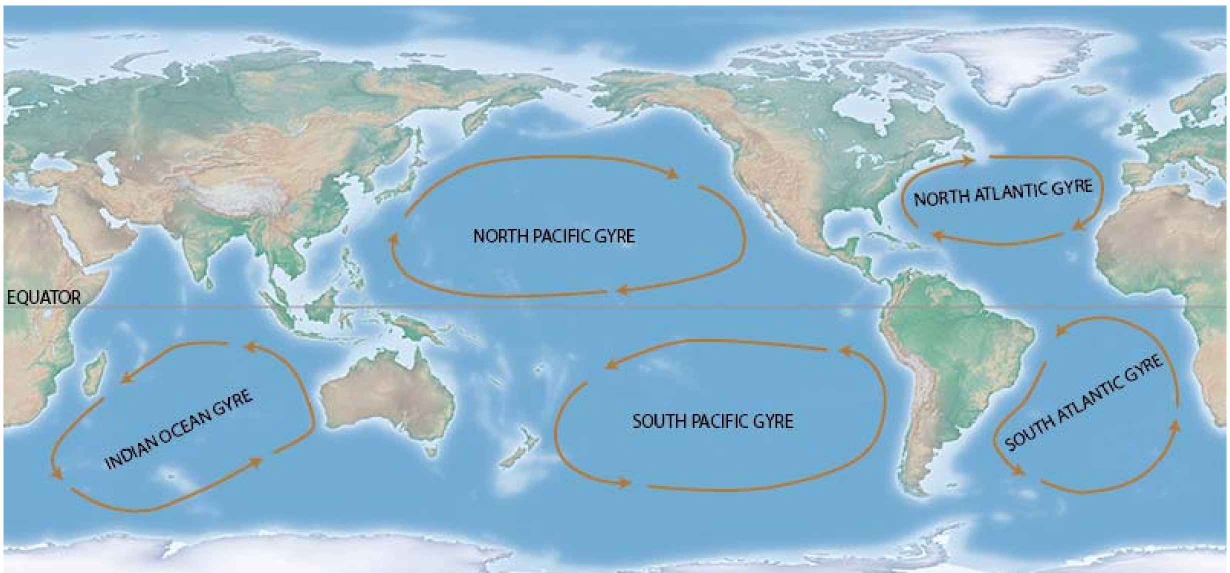
Briefly, a column of water can be thought of as consisting of many layers. Wind friction affects the topmost layer, pulling the water in the direction of wind flow. This top layer of water tends to pull layers of water beneath, but because of the Coriolis force (described in the section below), the water actually moves at an angle to the side. In progressively deeper layers, the sideways movement is enhanced, so the entire water column can been thought of as moving in a spiral. The net flow of water is almost at right angles to the wind.

Coriolis Force and Ocean Gyres



AN OCEAN GYRE FORMED BY THE UPWELLING OF WATER FROM HEAT INDUCED EXPANSION CIRCULAR CURRENTS FORM AT THE PERIPHERY OF THE GYRE

Because of the Coriolis Effect, currents tend to flow in curves rather than in straight lines. When the space for movement is restricted (such as by land bounding the oceans), these curves can close in on themselves, and cause a circular flow of water around a center. Such circular flows are called oceanic gyres. There are many permanent gyres in the world's oceans. Gyres are usually bounded by the shallow waters of continental shelves. There are five major gyres in the world's oceans, which are delimited by the continents around them.

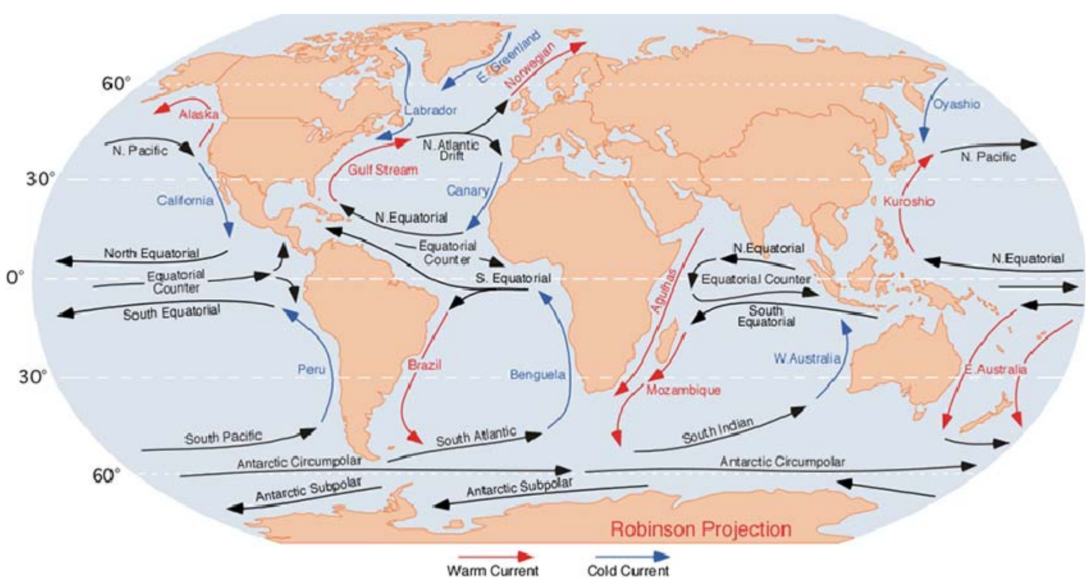


THE FIVE MAJOR OCEAN GYRES. CIRCULATION IS CLOCKWISE NORTH OF THE EQUATOR & ANTICLOCKWISE SOUTH OF THE EQUATOR.

These gyres are responsible for much of the world's surface currents. As you can see in the map above, much of the eastern coast of Africa has a current going from north to south, part of the Indian Ocean Gyre. This current was a great problem to early European navigators, trying to go around the Cape of Good Hope (the southern tip of Africa) to find a trade route to India. Early sailing ships tended to hug the coast, where the currents are strongest, and they didn't have a lot of motive power in the days of sail. Even today, ships use these currents to save fuel, since making way against the current is costly. Debris floating in the ocean also tends to converge in certain zones because of these currents. The North Atlantic Garbage Patch and the Great Pacific Garbage Patch are places where a lot of trash dumped into the oceans has aggregated.

These ocean currents affect marine life as well. The migrations of many organisms in the sea follows various currents in the oceans. Traveling along the path of a current is energy efficient and fast. They also affect the fishing industry. Obviously, fishing along the migration path of a commercial species can be a good idea, if implemented at the right time. Also, currents have an effect on nutrient levels in the ocean, which can affect the density and diversity of sea life. In areas where these surface currents move away from the coast, there is an upwelling of deep sea water (to replace the water caught and dragged along by the current). Deep sea waters are rich in nutrients, and so these places are very rich in marine life. Some of the world's best fishing areas are located in places where a current moves away from a shore.

Upwelling and downwelling also occur in the open ocean where winds cause surface waters to diverge (move away) from a region (causing upwelling) or to converge toward some region (causing downwelling). The five ocean gyres are the source of most of the ocean currents in the world. However, there are smaller currents that are produced as the result of local heating or cooling, or because of the presence of land forms (such as undersea mountain ranges, the presence of island chains, etc.) which cause the main currents to split into two. Here's a map of the major ocean currents:



Major Ocean Currents of the World. From Wikipedia.

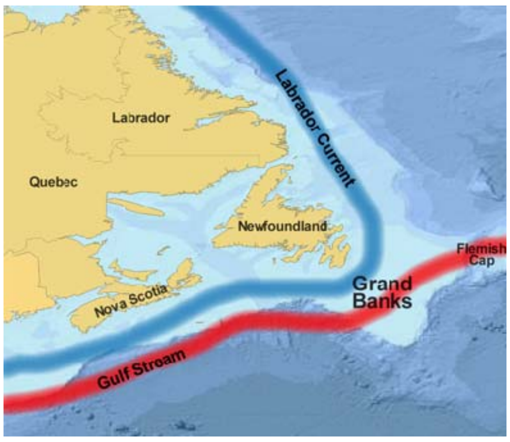
Gulf Stream

This is part of the north Atlantic gyre. This is a warm water current. Much of the warm water actually begins in the Gulf of Mexico, and exits to the Atlantic through the Florida Strait. There it meets warm water from the Caribbean, and together, this warm water flows northwards along the east coast of the US. The other branch of the North Atlantic Drift, however, heads northwards along the west coast of northern Europe, as the Norwegian Current. This is what warms much of Western Europe, far warmer than similar latitudes in Asia or Canada. This has allowed long growing seasons in Europe, extensive farming, and the development of thriving population centers so far north. Although its influence on Europe is more famous, it is also an important factor in the climate of Florida. The warm winters we see in Florida are due to the Gulf Stream.

Labrador Current

This is a cold current, part of the "Viking" gyre. If you recall reading above in the Gulf Stream section, the North Atlantic Drift breaks into two branches as it approaches the coast of Europe. The southerly branch rejoins the North Atlantic

Gyre, but the northerly branch (the Norwegian Current) shoots off northwards along the northern coast of Europe. As it nears Iceland, much of the water is deflected westwards, where it joins the East Greenland Current, which continues westwards until it reaches cold waters drifting southward off the northern coast of Canada, and becomes the Labrador Current.



The Labrador Current is a cold water current and therefore keeps the east coast of Canada (at least in the north) cold and sparsely inhabited. In fact, the tree line on the east coast of Canada stops at about 53° to 56° N latitude (there are no trees north of that). Compare that to some places in central Siberia, where the tree line extends as far north as 72°, a difference of about 15° of latitude.

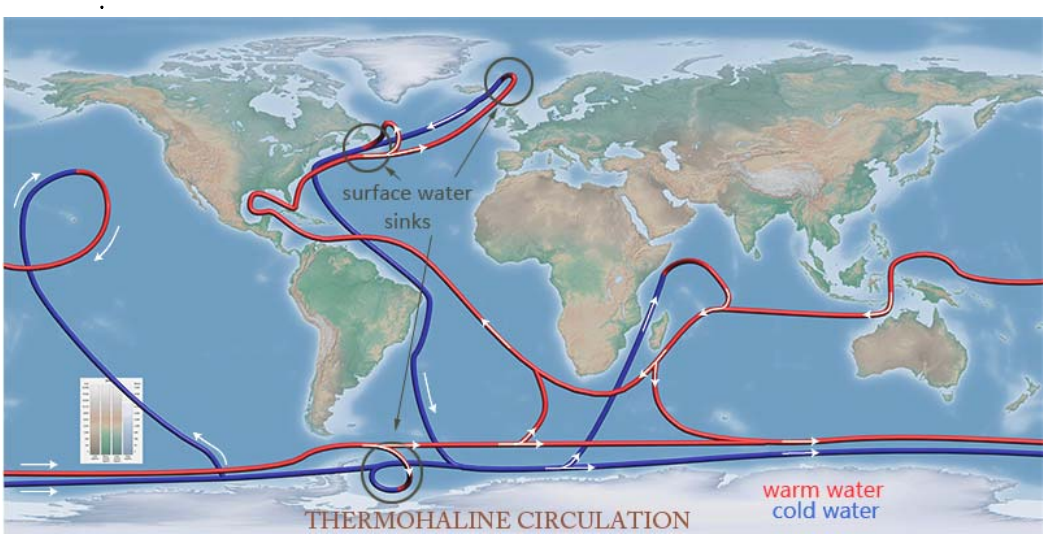
An interesting thing happens when the cold Labrador Current meets the warm Gulf Stream off the coast of Newfoundland and the Maritime Provinces. This meeting of a cold and warm current produces heavy fogs in the Grand Banks, as well as very rich fishing grounds. Normally, since currents on the east coast of North America are western boundary currents, the coastal regions are not as good for fishing as the west coast. However, because of the meeting of these two currents, the Grand Banks has some of the richest fishing regions in the world. They extend to the Flemish Cap, which is an underwater plateau off the Grand Banks. These shallow waters (as shallow as 400 feet in some spots) were free of glaciation during the last ice age, and possibly became a sanctuary for marine life during the ice age. They are still rich in many commercial species, including swordfish and halibut. The Labrador Current tends to carry down stuff from northern waters. Sometimes, this consists of icebergs, which can cause a shipping hazard in far southerly waters where icebergs are normally not expected.

Deep Water Currents

The currents we have talked about so far are surface currents, driven mostly by temperature, winds and gravity, and modified by things such as the Coriolis Effect, and by continental shorelines. However, in addition to these surface currents, there is also a deep water circulation in the oceans, referred to as the thermohaline circulation, or sometimes the "Oceanic Conveyer Belt". As the word "thermohaline" indicates (thermo = heat, haline = salts), this circulation is driven mostly by temperature and salinity of the water.

Although we talk about two separate circulations - surface and deep water, it's important to remember that the two systems are connected. Surface currents and deep water currents are connected by the upwelling and sinking of water at certain spots on the Earth, mostly near the poles. This vertical circulation (rising and sinking water) connects surface currents to deep water currents. Sinking of cold water to the deeper parts of the ocean is the main trigger for the Thermohaline circulation.

.



Thermohaline circulation in the world's oceans

Surface currents and the deep water Thermohaline circulation are very different. Surface currents tend to follow narrow channels and are much faster. Complete circuits of water along the major ocean gyres only takes 3-6 years. This is why a message in a bottle tossed into the ocean can cross the Atlantic in 2-3 years, if it happens to find a good path along the surface currents. Deep water currents, on the other hand, are very wide and kind of slowly seep along the ocean floors, wending their way between sea floor topography. They are much slower in comparison. A complete circuit around a deep water current could take 2000 years. Deep water currents are thought to be important in maintaining the Earth's energy balance over the long term, and therefore have a very long term impact on climate. They tend to move heat from the equator to the polar regions, and are probably the most important source of heat to the poles. This in turn regulates the amount of polar ice, which may in turn have long term effects like ice ages and warmer periods between ice ages. Since they are also the major means of exchanging water between the surface layers and the deep ocean, they are also very important for the Earth's carbon dioxide balance. The oceans are major carbon sinks, and the sinking of ocean waters carries a lot of dissolved carbon dioxide to the cold sea floor, where it tends to get sequestered.

Questions: Answer in the following space and on a separate sheet of paper if needed.

1. Name three things that ocean currents effect?
2. What is the Sverdrup rate?
3. What are the four things that cause surface ocean currents?
4. What is a gyre? What are the five main gyres?
5. What is the Ekman transport?
6. What is the Coriollis effect?
7. How do gyres effect sailors? Ocean debris? Migration of sea animals? Fishing industry?
8. What is upwelling and downwelling?
9. Two of the main ocean currents are described, list them and the effects of each current.
10. What are the two words used to describe the deep water currents?
11. What is the cause of this circulation?
12. Compare the time to complete a surface current vs. a deep water current.
13. What is effects does the deep water current have on climate?