Lecture 15: Ocean Circulation

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Now we will learn the basics of how water moves in the ocean. If your body was the ocean, you might think of ocean currents as your circulatory (blood) system and the tides as your breath. Now these aren't meant to be literal metaphors. Your blood makes a complete loop through your entire body in about 1 minute (for most people while they are resting). If we follow drop of water as it move from the surface of the ocean, into deep water circulation, it can take over 1000 years for that water to make the full circuit – more on that later. Similarly, the tides don't facilitate exchange of oxygen and waste across the tidal interface the way that oxygen and CO_2 is exchanged at the surface of your lungs. Instead the
rising and falling of the tides (https://www.youtube.com/watch?v=tzcGFUsL4HM)

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is like the regular and rhythmic rising and falling of your ribs.

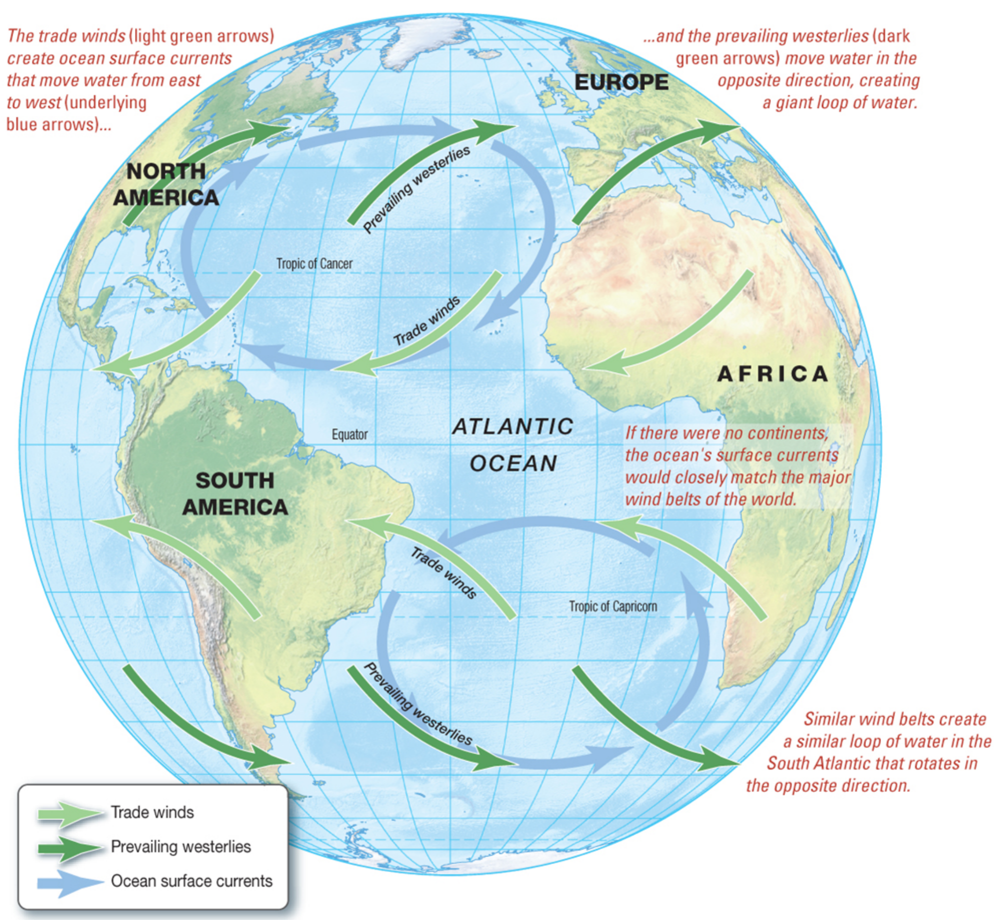
We will leave the tides alone for now and talk about the major Ocean Currents. Most of you will be familiar with the term 'Gulf Stream'. You have probably heard about this 'stream' when you are listening to weather forecasts while you were planning a recent weekend getaway to the shore, or a trip south to Florida. Ocean currents move water all around the planet and when they do, have the capacity to change the way that moisture, temperature and energy is exchanged between the ocean and the atmosphere and in turn, influence the weather. The Gulf Stream, for example, is a major controlling influence on weather along the Atlantic coast because it brings warm water from the Gulf of Mexico northward into regions of colder water. A crazy scheme developed by Ben Franklin and his pals during the Revolutionary war. Franklin, being the clever fellow that he was – figured out the path of the Gulf Stream and realized it was the reason England is warmer than would be expected given its latitude. Their crazy plan (that of course never went into action) was to divert this stream of warm water, preventing it from reaching England and throwing them back into a mini ice age. Crazy scheme – but it shows just how well Franklin appreciated the power of ocean currents on weather and climate.

As oceanographers, you like to measure things! How would you measure currents? There are a number of ways that this is done. Some of them measure water movement directly, through the use of floating devices that are tracked as they move over time. These drifters are carried along in currents and show the ocean currents. There are some amazing global programs that openly share data about some of the more high tech floats (called Argos). Check out this **interactive map** (https://maps.biogeochemical-argo.com/adoptafloat/) to see where some of these are in the world, and their recent paths. High tech isn't absolutely necessary – when shipping containers spill floating cargo at sea, the paths of rubber duckies or running shoes have even been used to track surface ocean currents. We can also identify currents by tracking certain temperature and salinity characteristics of water masses – we will dig into this concept in a bit.

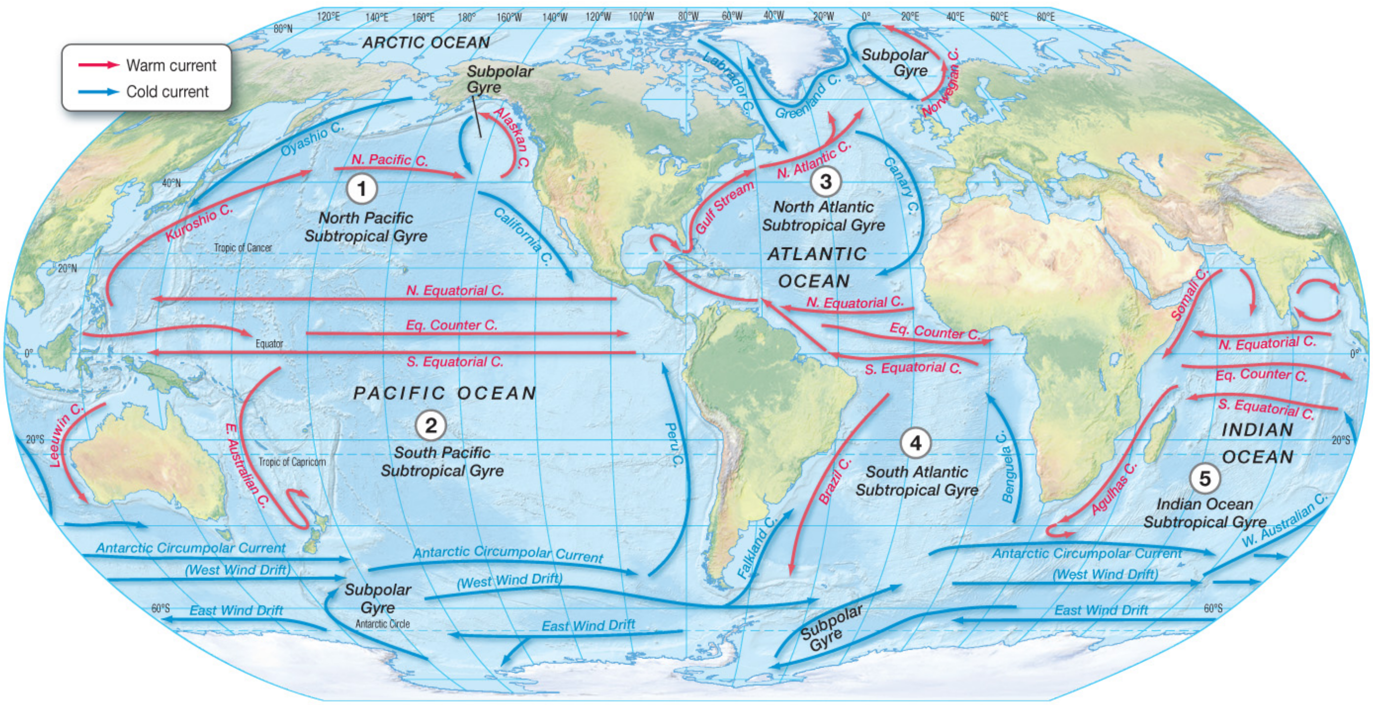
Ocean currents are of two types. There are *surface currents* generated by wind near the ocean surface, gravity, and the Coriolis effect, and *deep currents* that are slower moving and deeper in the water column (below 400 m). Surface currents mostly occur in water above the pycnocline and involve largely (but not exclusively) horizontal water movement. Deep currents are driven by density differences, are influenced by gravity and occur in water below the pycnocline (which is most of the water in the ocean) and involves horizontal and vertical water movement. Both of these currents are super important to your understanding of ocean motion, and you already know all about the Coriolis effect so we won't review that here. If you can't recall what Coriolis is all about, check out the Air-Sea interactions lectures before moving on here.

Surface Currents

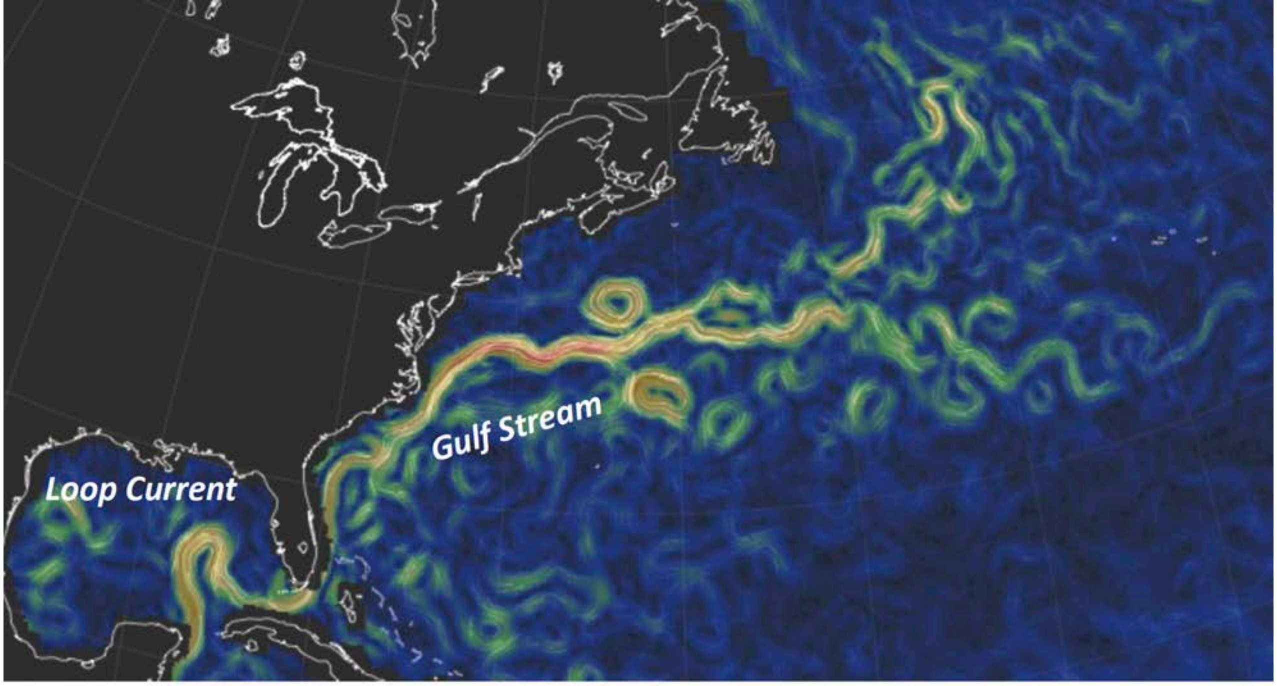
The surface currents are primarily driven by major wind systems that drag the surface water along through friction. You can do an experiment on your own by blowing across the top of your bowl of soup – you will see that the liquid at the surface moves in the direction you are blowing. These winds that drive surface currents are relatively predictable because they are driven by unequal heating of the air around the planet. At the equator, the sun heats the air (well, really it heats the ocean, that then heats the air) which rises and moves towards cooler regions (recall the circulation cells in the atmosphere we just learned about). This sets up a series of relatively predictable (on a global size scale that is) series of air mass movements along the surface of the planet. We already discussed these trade winds and prevailing westerlies – those are the predictable winds I am talking about. See below as a reminder.



These trade and westerly winds pass along the surface of the earth, causing friction. The energy from the wind's friction doesn't penetrate very deeply into the water column (the energy dissipates rapidly) and so the influence of the wind is limited to the surface water (largely limited to the water above the pycnocline). This movement of surface water, if uninterrupted, would continue to follow the winds, but a couple of other forces constrain them. The currents are interrupted and directed by the continents that get in the way (this causes what are called boundary currents). These big surface currents make massive loops that operate as gyres. In the figure above, two of these are shown with the blue arrows. In the map below, five major ocean gyres are shown with the numbers on the map. The currents encircling them are the boundary currents. The five major gyres are (1) North Pacific Subtropical Gyre, (2) South Pacific Subtropical Gyre, (3) North Atlantic Subtropical Gyre, (4) South Atlantic Subtropical Gyre, (5) Indian Ocean Subtropical Gyre. Take a moment to find each one, and then see if you can find some smaller subpolar gyres on the map. There are also smaller subpolar gyres that rotate opposite to the direction of the subtropical gyre it sits next to.



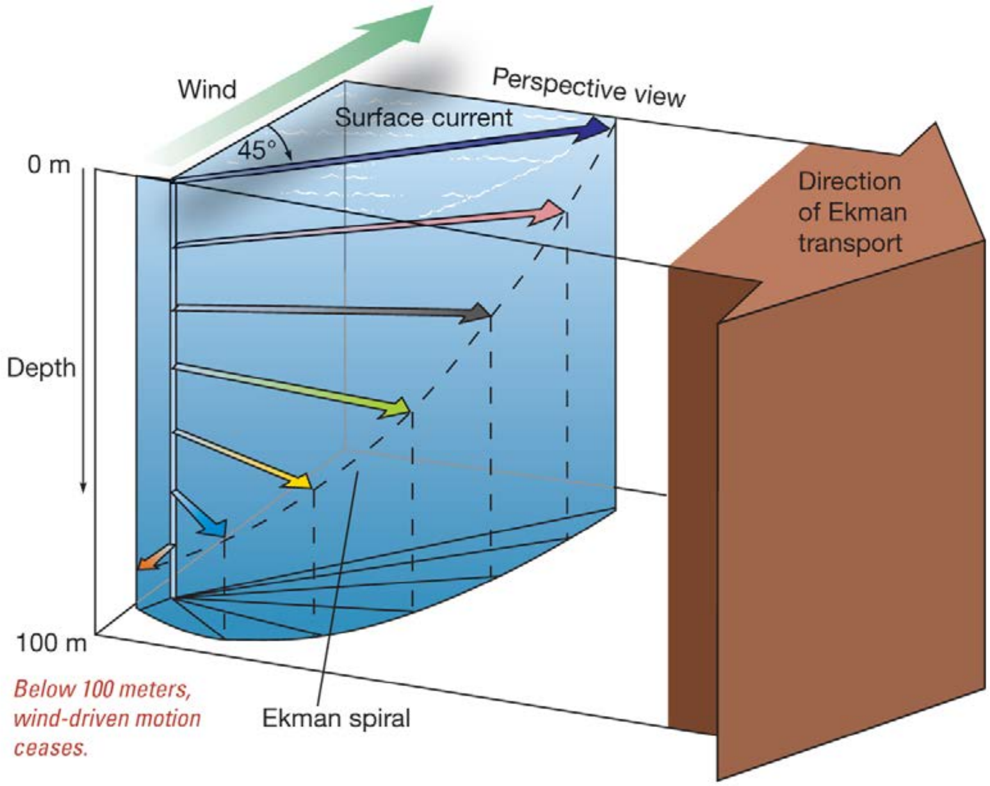
When you look at the boundary currents in particular, you will see that there is a pattern to the types of current that encircle the subtropical gyres. There are currents that sit on the western side of the gyre (if the gyre was a clock face, these are located from 6:00 to 12:00). These Western boundary currents are warm, narrow, relatively deep (but still surface) and fast. Don't get confused about what is being called West here - we are talking about currents that are on the Western edge of the gyre itself. On the other side of the gyre are the Eastern boundary currents, which are cold, slow, shallow and wide. Our beloved Gulf Stream is an example of a Western boundary current- think about those characteristics that define the Western boundary currents – what does it tell you about the Gulf Stream? Turns out that the temperature and location of the Gulf Stream and the Loop Current (it is found in the Gulf of Mexico – see the map below to see these currents) are really important to hurricane formation and strength. Touch back to the previous lecture if that doesn't ring a bell about why that would be the case.



Current speed in North Atlantic and Gulf of Mexico

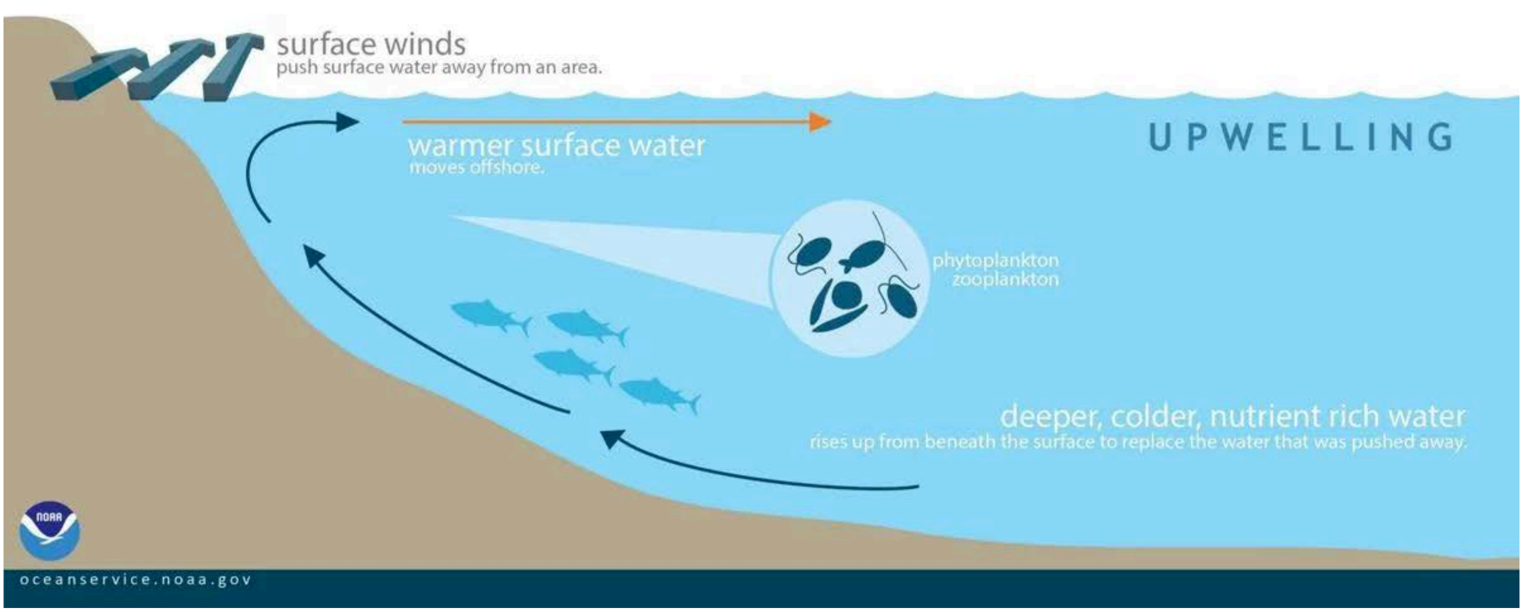
The trade winds, which blow out of the northeast in the Northern hemisphere, and out of the southeast in the Southern hemisphere (find them on the globe figure 2 above), cause specific water motion between the tropics. These currents are called equatorial currents. The north and south equatorial currents form the equatorial boundary current of the subtropical gyres and travel westward around the equator. Find those on the map of the global gyres above. These two parallel current push water in the same direction which causes it to literally pile up on the western side of a given ocean basin, which causes a countercurrent to flow in the opposite direction due to gravity. That countercurrent sits between the equatorial currents and is called the equatorial countercurrent (creative, huh!). The ocean area along the equator is greater in the Pacific basin than in the Atlantic, so the equatorial countercurrent is more apparent there.

Wind over the ocean surface causes friction that moves the surface water – ok, we got that. But now, what if I tell you that the direction of the movement of that surface water is 45 degrees to the right of the wind direction in the Northern hemisphere (under idealized conditions). You would say to me – of course it does because of Coriolis! Right-o. Coriolis causes the surface water movement to be to the right of the direction of the wind. The current at the surface moves as a thin layer on the surface, and it transfers movement to layers below it; however, the speed of water movement decreases with water depth. And what is even more fascinating, is that each layer as you move down in the water column deflects further and further to the right which creates a spiral of water movement. This spiral is called an Ekman spiral – named for the clever person who first discovered it. If you go deep enough on this spiral, you will find that the water motion at depth is actually opposite to the direction of the wind speed that initially created it. The other thing that happens, is when you look at all of the layers together, the net transport of water is actually at a right angle (90 degrees) to the wind that generated it. Now, that is 90 degrees to the right in the northern hemisphere, and 90 degrees to the left in the southern. The figure below shows how this sets up.

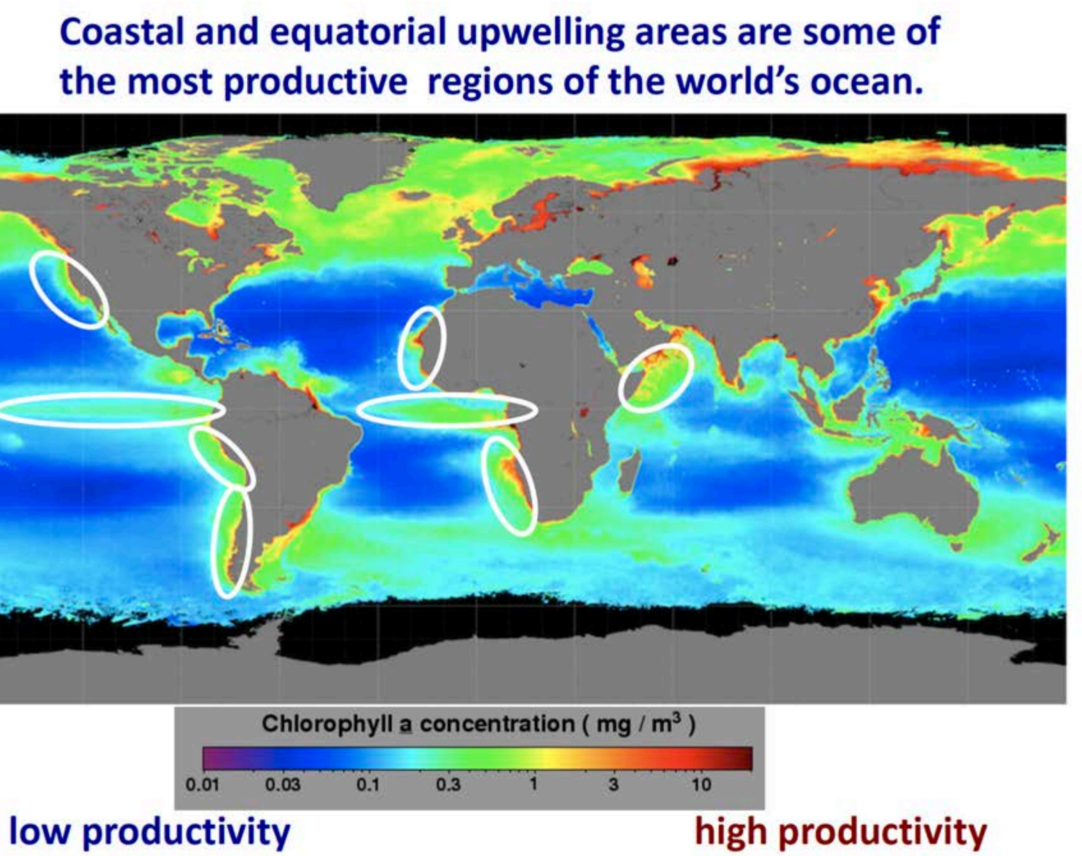


(a) Wind drives surface water in a direction 45 degrees to the right of the wind in the Northern Hemisphere. Deeper water continues to deflect to the right and moves at a slower speed with increased depth, causing the Ekman spiral.

This concept of Ekman transport is fundamental to a really important form of water motion in the ocean that helps support all kinds of biological processes (and sometimes might ruin your day at the beach!).When winds blow out of the south along the Jersey shore, you now know that due to Ekman transport moves water 90 degrees to the right of the wind direction, which would mean water moves away from the shore (do the mental picture of this to make sure you follow). When winds draw surface water away from the shore, deeper (often colder) water is pulled up towards the shore to fill in; this is called upwelling. The figure below shows how this happens. When that deeper water is drawn up near the shore, it brings with it nutrients that help fuel plankton blooms (fertilizer!) that feeds zooplankton that support animals higher up in the food chain (it also means that beachgoers get a much colder swimming experience). The opposite happens in downwelling. Wind pushes surface water onshore and this warm surface water meets the coast and is pushed down deeper.



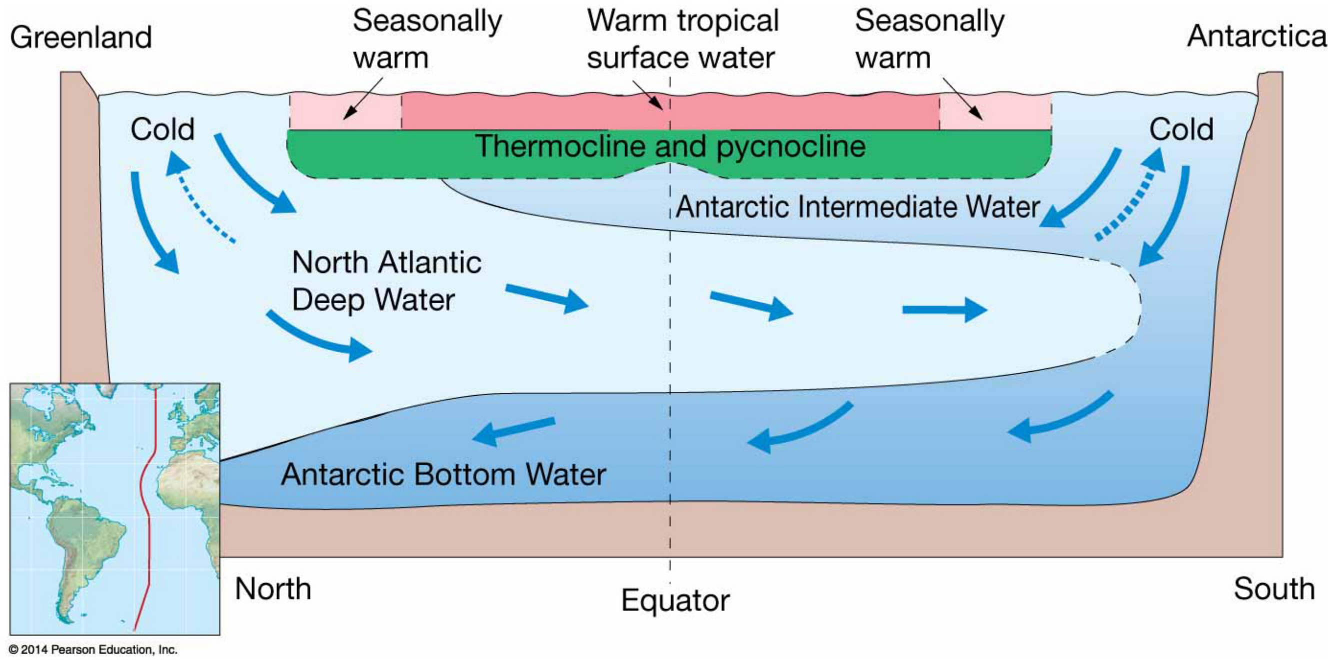
This same upwelling process happens at the equator because of Ekman transport of the equatorial currents, which leads to upwelling along the equator because the Ekman transport of the north and south equatorial currents move away from one another (logic that one out by thinking about Coriolis on each of them), which means that deeper water must be drawn up to infill. These currents along the equator are relatively constant, which means that the upwelling along the equator and the nutrients that are brought to the surface there create consistent phytoplankton blooms (we will learn more about plankton blooms soon). For now, have a look at the global map of productivity below – the areas of high productivity are circled and correspond to some of these coastal and equatorial upwelling areas. Pretty amazing!



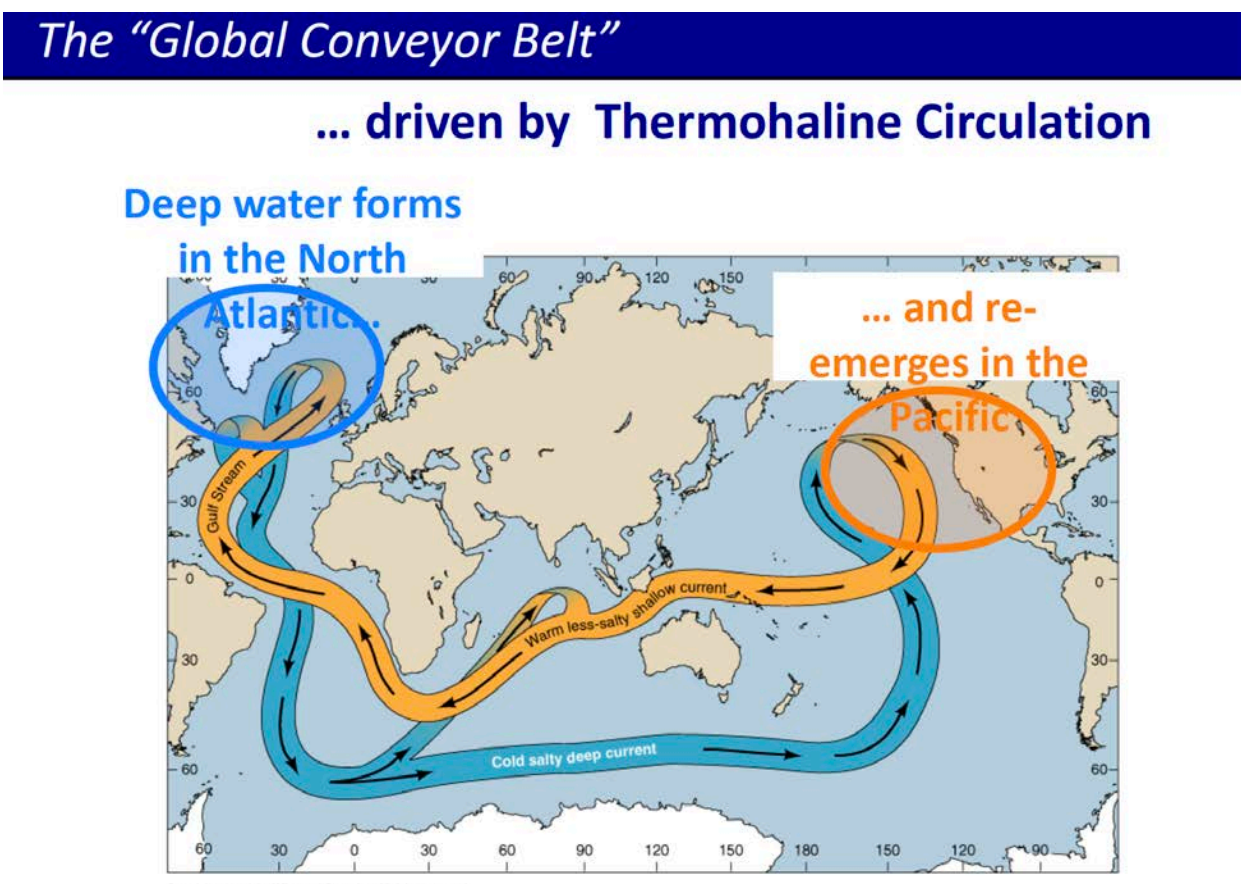
Here is a nice **video (http://scienceprimer.com/surface-currents-ekman-spiral-and-ekman-transport)** that explains Ekman sprials, Ekman transport, and upwelling.

Deep Currents

Deep ocean currents are driven by - brace yourself, this has been introduced before, and will continue to be an important theme - density. Cold water is already more dense, but it can also carry more salt and is therefore much more dense than warm water. In the polar regions, the water is cold and salty, making it dense and heavy, and sinks. As it sinks, it is replaced by warmer water from further south. Check out the image below. This shows an idealized global ocean -imagine that it shows a cross section of the ocean through the Atlantic basin from Greenland on the left to Antarctica on the right. It shows cold dense water at the poles sinking and moving along the bottom of the Atlantic basin.



The deep, dense cold water creeps along the ocean floor until it reaches a warmer part of the planet where it gets less dense and rises to become part of the warm current. These currents are driven by thermohaline circulation (thermos=temperature, and haline=salt). These currents are all connected and are sometimes called the Great Ocean Conveyor Belt. You will note in the image below that shows the path of the deep currents, that these move among all of the earth's ocean areas and is the way that the entire ocean is connected as one. One full circuit of this conveyor takes nearly 1600 years. This means that water that is coming up from the deepest parts of the ocean today at places where cold water moves up is nearly 500 years old!



So, now you know the ways that surface and deep ocean currents work. These currents help to move thermal energy around the world, and play a huge role in weather patterns and climate. Pretty amazing how the planet's circulation system works!