Ocean Circulation

I. Surface Currents
   a. About 10% of the ocean’s water is in surface currents, water flowing horizontally in the uppermost 400 m
      i. Driven mostly by wind friction
      ii. Most wind energy comes from the trade winds (easterlies) and westerlies
      iii. The moving water will ‘pile up’ in the direction the wind is blowing
          1. gravity will pull water down this slope, in the direction from which it came
          2. However, the Coriolis effect causes surface currents in the N.Hemisphere to be deflected to the right and to the left in the S. Hemisphere.
          3. Continents block the flow of the water, causing the currents to flow in large circular patterns called gyres.
   b. Gyres
      i. Example: N. Atlantic
      ii. Water flows clockwise around the N. Atlantic
      iii. The East/West winds flow to the right of the prevailing winds.
      iv. When driven by the wind, the topmost layer of the ocean in the N. Hemisphere flows at about 45° to the right of the wind direction.
         1. Layers below the top layer respond by being deflected in a similar manner.
         2. This trend continues to a depth of about 100 m below the surface
         3. This results in an Ekman Spiral
            a. Ekman spirals transport water 90° to the right of wind in the N. Hemisphere and to the left in the S. Hemisphere
            b. They are about 100 m deep.
      4. This causes a build up of water in the center of the ocean, which is really a hill of water about 2 m higher than the rest of the ocean.
      5. This hill is maintained by wind energy, friction with the surrounding continents, and the coriolis effect.
      6. Pressure gradients, from gravity, propel the currents of the gyre and hold them along the outside edges of the ocean basins.
   v. Geostrophic Gyres
      1. Gyres in balance between the pressure gradient and the Coriolis effect are called geostrophic gyres (Geo=earth; strophe=turning), and their currents are called geostrophic currents.
         a. Geostrophic gyres are largely independent of each other.
2. There are six great current circuits in the world ocean.
   a. Two in the S. Hemisphere and four in the S. Hemisphere
   b. Five are Geostrophic gyres
      i. N. Atlantic
      ii. S. Atlantic
      iii. N. Pacific
      iv. S. Pacific
      v. Indian
   c. The sixth and largest current system is the Antarctic Circumpolar Current and because it flows around the entire world it is not considered geostrophic.

vi. **Currents within Gyres**

1. **Western Boundary Currents**
   a. Located on the gyre’s western end
   b. Ex: **Gulf Stream (G.S.), Kuroshio, Brazil, Agulhas, East Australian**
   c. G.S. moves about 2 m/s (5 miles/h) off Miami
      i. That’s >160km/day
      ii. >450 m deep
      iii. Width about 70 km
   d. They transport warm water away from the equator
   e. Lots of water gets transported
      i. G.S. is at least 55 **Sverdrups (sv)**, one **sverdrup** is 1 million cubic meters/second (about ½ the size of the Louisiana Superdome), about 300 times the flow of the Amazon
   f. Really looks like a river in the sea.
      i. The water is distinctly different.
         1. Warmer
         2. Clearer
         3. Bluer
      ii. Often **eddy**, turbulent rings, form in the current and trap cold or warm water in the centers and then separate from the main stream

2. **Eastern Boundary Currents**
   a. There are five Eastern Boundary Currents
      i. Canary Current,
      ii. Benguela Current
      iii. California current
      iv. West Australian Current
      v. Humboldt or Peru current
   b. On the Eastern edge of the gyre.
c. They carry cold water toward the equator
d. They are shallow and broad
e. They carry less water than W.B.C.’s
   i. Canary current only carries about 16 sv’s

3. Transverse Currents
   a. These are currents that connect the E.B.C.’s and
      W.B.C.’s and are driven by winds
   b. The N. and S. Equatorial Currents in the Atlantic
      and Pacific are formed by the push of the trade
      winds.
   c. These currents are usually impeded by continents.
   d. However, in the S. Ocean there are no continents in
      the way and the transverse current forms the
      Antarctic Circumpolar Current.

4. Countercurrents and Undercurrents
   a. Equatorial Currents are usually accompanied by
      countercurrents flowing on the surface in opposite
      direction of the main flow.
   b. This backward flow is a reaction to the build up of
      water on one side of the ocean.
   c. Countercurrents also exist beneath surface currents
      i. Called undercurrents, they are 100 to 200
         m below the surface and can carry as much
         water as the surface currents.

5. Effect of currents on climate
   a. When you have warm water moving into colder
      regions it heats the atmosphere
      i. England is much warmer than Labrador,
         even though they are at comparable latitudes
   b. When you have cold water moving into warmer
      regions it cools the atmosphere
      i. Summers in Seattle are not as hot as
         summers in New York

   c. Upwelling and Downwelling
      i. In the Equatorial Pacific the trade winds cause the formation of
         the North and South Equatorial Currents
         1. These currents move warm water across the pacific from
            the East to the West.
            a. In the East, along the coasts of Peru and Chile, the
               water removal of water causes coastal upwelling
               and the lowering of the sea surface height
               i. Upwelling: process by which deep, cold,
                  nutrient-rich water is brought from depths to
                  the surface
               ii. Coastal Upwelling: the movement of
                   surface water away from a coast line causes
deeper water to be brought up in order to replace it.

iii. This deeper water is colder, because it is farther from the sun.

iv. The sea surface is lower because
   1. Water that removed
   2. The water the replaces it is colder, denser and therefore has a smaller volume

b. In the West, along the coasts of SE Asia and Micronesia, there is a build up of warm water.

ii. During an El Niño the trade winds weaken, stop all together, or even reverse direction.
   1. This change in the winds causes that pile of warm water in the Western Pacific to slosh back along the equator until it hits the South America
      a. The presence of that warm water creates a cap on the water column and effectively shuts down upwelling.
      b. Without the upwelling of nutrients, the productivity of the sea shuts down, thus destroying the fishery in Peru and Chile
   2. During a strong El Niño, the wave of warm equatorial water can be pushed along the coasts of North and South America, even as far north as Oregon.

iii. When water is driven toward a coastline it will be forced downward returning seaward along the continental shelf
   1. This downwelling supplies deeper ocean water with dissolved gases and nutrients

d. Vertical Motion and the Three-Layered Ocean
   i. The oceans are a three dimensional habitat and vary horizontally and vertically.
      1. Many of the changes in habitat are due to changes with depth.
      2. The three-dimensional structure of water is a function of its density
      3. That is why oceanographers measure the temperature and salinity of the water column.
   ii. Because the densest water sinks, the ocean is often layered, or stratified
      1. The surface water tends to stay where it is and float on the denser water below, so the water column is said to be stable, that is it is difficult to mix the layers.
      2. How stable the water is depends on the differences in density between the surface and the deep water.
iii. Occasionally, surface water becomes more dense than the water below it.
   1. The surface water sinks, displacing the less dense water below in a process known as overturn.
   2. This occurs when the density remains constant with depth.
   3. Water will descend to the depth determined by its density.

iv. The processes that change salinity in the open ocean, evaporation, precipitation and freezing, only occur at the surface, and the largest changes in temperature also occur mainly at the surface.
   1. Therefore, once surface water has sunk, it is imprinted with a characteristic temperature and salinity.
   2. Oceanographers use this to follow the movement, or circulation, of water masses over great distances, known as thermohaline circulation.

II. Thermohaline Circulation
   a. Thermohaline (thermo=temperature, haline=salt) circulation is the movement of water due to its density
      i. Responsible for the majority of non-surface water movement in the oceans, both vertical and horizontal
   b. Three-Layered Ocean
      i. Surface Layer – 100-200 m thick
         1. Much of it is mixed by wind, waves and currents, so it’s known as the mixed layer.
         2. There often exists a seasonal thermocline, or region of rapid temperature change, in this layer.
      ii. Intermediate Layer - from 200m to 1,500m
         1. Characterized by the permanent thermocline, the zone of transition between warm surface water and the cold water below.
         2. Do not confuse with seasonal thermocline.
         3. The permanent thermocline rarely breaks down and is a feature of the deep ocean, not of shelf regions.
      iii. Deep and Bottom Layers - below 1500m
         1. Technically these are two different kinds of water but they are both uniformly cold at about 4°C.
   c. T/S Diagrams
      i. Temperature/Salinity Diagrams (T/S Diagrams) are used to describe different water masses.
         1. Note that many combinations of temperature and salinity can yield the same density.
   d. Formation and Downwelling of Deep water
      i. Antarctic Bottom Water, the most distinctive of all water masses
         1. Formed in the Weddell Sea when ice freezes, extruding salt and making very cold, very salty water.
      ii. Other Deep water formation
1. **North Atlantic Deep Water** is formed when the relatively warm and salty N. Atlantic cools and sinks between Iceland and Greenland

2. Some dense deep water forms in the Arctic Ocean, but the bottom topography prevents most of it from escaping, except in a few places near Scotland, Iceland and Greenland

e. **Thermohaline Circulation Patterns**
   i. This sinking water must be balanced by rising water
   ii. The continual diffuse upwelling of deep water maintains the existence of the permanent thermocline found everywhere at low and mid-latitudes.
      1. This slow upward movement is estimated to be about 1 cm/per day over most of the ocean
   iii. Water masses butt against each other in **convergence zones** and the heavier water can slide beneath the lighter water

f. **Thermohaline Flow and Surface Flow: The Global Heat Connection**
   i. The transport of tropical water to the polar regions is part of **The Great Conveyor Belt** for heat.
      1. The slow, steady three-dimensional flow of water in the conveyor belt distributes dissolved gases and solids, mixes nutrients and transports the juvenile stages of organisms between ocean basins.