CHAPTER 9
CIRCULATION OF THE OCEAN

MASS FLOW OF OCEAN WATER IS DRIVEN BY WIND AND GRAVITY

- The ocean currents are affected by 2 kinds of forces:
  - Primary forces:
    - Start water moving and determine its velocity (speed)
      - Wind (primary force responsible for surface currents)
      - Thermal expansion and contraction of water
      - Density differences between water layers
  - Secondary forces:
    - Factors that influence the direction and nature of its flow
      - Coriolis effect
      - Gravity
      - Friction
      - Shape of the ocean basins themselves

Surface currents - Horizontal flow of water at the ocean's surface
- About 10% of the water in the world ocean (uppermost 400 meters –1,300 ft)
- Driven by thermal expansion and wind friction
- Move water above the pycnocline

Thermohaline circulation - Water circulation produced by difference's in temperature and/or salinity (and therefore density).
- Water beneath the pycnocline
- Circulation is slower
- Depends on action of gravity on adjacent water masses of different densities

1. SURFACE CURRENTS ARE DRIVEN BY THE WINDS

- The winds are the primary force-- trade winds and westerlies **(Fig. 9.1, p.250)**
- Tug of wind on the ocean surface begins a more rapid mass flow of water
- The water flowing beneath the wind forms a surface current.
- Because of the Coriolis effect, in the NH, the surface currents flow to the right of the wind direction; and in the SH, the currents flow to the left.
- Intervening continents and basin topography often block continuous flow and help to deflect the moving water into a circular pattern called a **gyre**. **(Fig. 9.2, p.250)**
- **Gyre -** Circuit of mid-latitude currents around the periphery of an ocean basin. Most oceanographers recognize 5 gyres plus the West Wind Drift.

1.1 Surface Currents Flow around the Periphery of Ocean Basins

- What explains these circuit currents -- and formation of "gyres" -- Why do wind driven currents move at angle to the direction of the wind?
  - **Ekman spiral -** A theoretical model of effect on water of wind blowing over the ocean. Because of the Coriolis effect, the surface layer is expected to drift at an angle of 45^{o} to the right of the wind in the Northern Hemisphere and 45^{o} to the left in the Southern Hemisphere. Water at successively lower layers drifts progressively to the right (N), or left (S), through not as swiftly as the surface flow. **(Fig. 9.5, p.252)**

  - **Ekman transport -** Net water transport, the sum of layer movement due to the Ekman spiral. Theoretical Ekman transport in the Northern Hemisphere is 90^{o} to the right of the wind direction. **(Fig. 9.5, p.252)**

1.2 Seawater Flows in Six Great Surface Circuits (Geostrophic Gyres)

- **Geostrophic Gyres** – Describing a gyre or current in balance between the Coriolis effect and gravity; literally "turned by Earth".
- Because of the patterns of driving winds and the present positions of continents, the gyres are largely independent of each other in each hemisphere.
  - Within the current circuits (gyres), there are 2 current circuits in the Northern Hemisphere (**North Atlantic Gyre and North Pacific Gyre**) and 4 current circuits in the Southern Hemisphere (**South Atlantic Gyre; South Pacific Gyre; Indian Ocean Gyre; and the West Wind Drift or Antarctic Circumpolar Current**)

(Fig. 9.8, p.255)

- Five of these six great current circuits in the world ocean, are "**geostrophic gyres**": the North Atlantic gyre, the South Atlantic gyre, the North Pacific gyre, the South Pacific gyre, and the Indian Ocean gyre. The West Wind Drift (Antarctic Circumpolar Current) is the exception.

1.3 Boundary Currents Have Different Characteristics

- Because of the different factors that drive and shape them, the currents constituting gyres have different characteristics.
  - May be classified as:
    - Western boundary currents
    - Eastern boundary currents
    - Or transverse currents

1.3.1 <u>Western Boundary Currents</u>

- The fastest and deepest currents
- Found at the western boundaries of ocean basins (off the east coasts of continents)
- Narrow, fast, deep currents that move warm water poleward in each of the gyres
- There are 5 large western boundary currents:
  - The Gulf Stream (North Atlantic)
  - The Japan or Kuroshio Current (North Pacific)
  - The Brazil Current (South Atlantic)
  - The Agulhas Current (Indian Ocean)
  - The East Australian current (South Pacific)
- The volume of water transported in western boundary currents is extraordinary
- Water in a current, especially a western boundary current, can move for surprisingly long distances within well-defined boundaries.
- Ocean currents lack well-defined banks, and friction with adjacent water can cause a current to form waves along its edges. Western boundary currents meander as they flow poleward-- the looping meander sometimes form turbulent rings, or **eddies**, that can separate from the main flow and move away from the current ; some can reach diameters of more than 1,000 km (625 miles)

  - **Eddies -** A circular movement of water usually formed where currents pass obstructions, or between two adjacent currents flowing in opposite directions, or along the edge of a permanent current. **(Fig. 9.11, p.2256-257; Fig. 9.12, p.257)**

Gulf Stream: **(Fig. 9.10, p.256; Fig. 9.11, p.256-257)**

- Is the largest of the western boundary currents
- Off Miami, the Gulf Stream moves at an average speed of 2 meters per second (5 miles per hour) to a depth of over 450 m (1,500 feet).
- Average width is about 70 km (43 miles)
- Water within the current is usually warm, clear, and blue, often depleted of nutrients and incapable of supporting much life
- By contrast, water over the continental slope adjacent to the current is often cold, green, and teeming with life.

1.3.2 <u>Eastern Boundary Currents</u>

- Found in the eastern edge of ocean basins (off the west coast of continents)
- There are 5 eastern boundary currents:
  - The Canary Current (North Atlantic)
  - The Benguela Current (South Atlantic)
  - The California Current (North Pacific)
  - The West Australian Current (Indian Ocean)
  - The Peru or Humbolt Current (South Pacific)
- Eastern boundary currents are the opposite of their western boundary counterparts in nearly every way;
  - They carry cold water equatorward
  - They are shallow and broad, sometimes more than 1,000 km (625 miles) across
  - Their boundaries are not well defined
  - And eddies tend not to form
- Their total flow is less than that of their western counterparts

(Table 9.1, p. 258 -- Boundary Currents in the Northern Hemisphere)

1.3.3 Transverse Currents

- Most of the power for ocean currents is derived from the trade winds at the fringes of the tropics and from the mid-latitude westerlies.
- The stress of the winds on the ocean in these bands gives rise to the **tranverse currents.**
  - **Transverse currents -**East-to-West or west-to-east current linking the eastern and western boundary currents.
- Trade-wind-driven:
  - North and South Equatorial currents in the Atlantic and Pacific are moderately shallow and broad;
- Westerly winds:
  - Drive the eastward-flowing transverse currents of the mid-latitudes.
- Eastward-flowing currents are wider and flow more slowly than their equatorial counterparts.
- Intense westerly winds over the southern ocean drive the greatest of all ocean currents, the unobstructed **West Wind Drift (or Antarctic Circumpolar Current)**.
  - This current carries more water than any other

1.3.4 Westward Intensification (Fig. 9.13, p.259)

- Western boundary currents are concentrated because:
  - Water is pushed by the Trade winds and piles up at the western edge of the basin before turning swiftly poleward
  - The rotation of the Earth itself, offsets the water to the west because of the Earth's eastward rotation

1.4 Countercurrents and Undercurrents are Submerged Exceptions to Peripheral Flow

- Equatorial currents are typically accompanied by **Countercurrents** flowing on the surface in the opposite direction from the main current.
- At the meteorological equator (light winds), some backward flow of water occurs and flows away from the main equatorial currents to return on the surface to the east.
- Countercurrents can also exist "beneath" surface currents. These are sometimes referred to a **undercurrents**.
  - Undercurrents have been found under most major currents
  - Their volumes are often a significant percentage of the current above.

2 SURFACE CURRENTS AFFECT WEATHER AND CLIMATE

- Surface currents distribute tropical heat worldwide.
  - Warm water flows to higher latitudes, transfers heat to the air and cools, moves back to low latitudes, absorbs heat again, and the cycle repeats.
- The greatest amount of heat transfer occurs at mid-latitudes
- This combination of water flow and heat transfer from and to water influences climate and weather in several ways.
  - The North Atlantic Current (derived from the Gulf Stream) warm the western coast of Europe (**Fig. 9.17, p.262)**
  - At lower latitudes on an ocean's eastern boundary-- where cold currents are descending from the North and heading South, the land situated east of the predominating Westerlies are usually cool, foggy and mild (Ex: California current carrying cold water from the north, comes close to the coast of San Francisco)

3. WIND CAN CAUSE VERTICAL MOVEMENT OF OCEAN WATER

- The wind-driven *horizontal* movement of water can sometimes induce *vertical* movement in the surface water. This movement is called **wind-induced vertical circulation**.
  - Upward movement of water is known as **upwelling**;
    - The process brings deep, cold, usually nurient-ladden water toward the surface
  - Downward movement of water is called **downwelling**

3.1 Nutrient-Rich Water Rises near the Equator (Fig. 9.18a&b, p.263)

- **Equatorial upwelling –** Upwelling in which water moving westward on either side of the geographical equator tends to be deflected slightly poleward and replaced by deep water often rich in nutrients.
- Upwelling is an important process because this deep water is often rich in the nutrients needed by marine organisms for growth.

3.2 Winds Can Induce Upwelling near Coasts (Fig. 9.20, p.264)

- **Coastal upwelling –**Upwelling adjacent to a coast, usually induced by wind
- Wind blowing parallel to shore or offshore can cause coastal upwelling

- Coastal upwelling occurs when the surface water is replaced by deep water rising along the shore.
- Again because the new surface water is often rich in nutrients, it result in increased biological productivity.

- Upwelling can also influence weather.
  - Wind blowing from the north along the California coast causes offshore movement of surface water and subsequent coastal upwelling.
  - The overlying air becomes chilled, contributing to fog banks and cool summers.
- Wind-induced upwelling is also common in the Peru Current, along the west coast of Antartica's Palmer Peninsula, in parts of the Mediterranean, and near some large Pacific islands.

3.3 Wind Can Also Induce Coastal Downwelling (Fig. 9.21, p.265)

- Water driven toward a coastline will be forced downward, returning seaward along the continental shelf.
- This downwelling helps supply the deeper ocean with dissolved gases and nutrients, and it assists in the distribution of living organisms.
- Unlike upwelling, downwelling has no direct effect on the climate or productivity of the adjacent coast.

3.4 Langmuir Circulation Affects the Ocean Surface (Fig. 9.22, p.265)

- **Langmuir Circulation –** A series of parallel, counter-rotating circulation cells with long axes aligned parallel to the direction of the generating wind. (in Pinet 2000)
- Streaks of foam, seaweed, or debris, known as *windrows*, collect in areas where adjacent vortices converge, while regions of divergence remain relatively clear.

4. EL NINO and LA NINA ARE EXCEPTIONS TO NORMAL WIND AND CURRENT FLOW

El Nino

- Surface winds across most of the tropical Pacific normally move from east to west.
- The trade winds blow from the normally high-pressure area over the eastern Pacific (near Central and South America) to the normally stable low-pressure area over the western Pacific (north of Australia) **(Fig. 9.23, p.266)**
- These pressure areas change places at irregular intervals (not known why): high pressure builds in the western Pacific, and low pressure dominates the eastern Pacific
  - Winds across the tropical Pacific then reverse direction and blow from west to east: (the Trade winds weaken or reverse)
  - This change in atmospheric pressure (and thus wind direction) is called the **Southern Oscillation**.
- The trade winds normally drag huge quantities of water westward along the ocean's surface on each side of the equator, but as the winds weaken these equatorial currents crawl to a stop.
  - Warm water that has accumulated at the western side of the Pacific can then return east along the equator toward the coast of Central and South America. **(Fig. 9.24, p.267)**
  - The phenomena of the Southern Oscillation and El Nino are coupled; so the terms are often combined to form the acronym **ENSO**, for El Nino/Southern Oscillation.
- Effects:
- Normally, a current of cold water, rich in upwelled nutrients, flows north and west away from the South American continent **(Fig. 9.23, p.266)**. With the event of the ENSO, the upwelling is stopped by the flow westward in the equatorial east Pacific; i.e. The normal northward flow of the cold Peru Current is interrupted or overridden by the warm water. **(Fig. 9.24, p.267)**
  - The great biological productivity of the ocean off the coasts of Peru and Chile is halted-- creating massive die off or migration of birds and fish
  - Because of the Low-pressure in an area that has usually a high-pressure, there is more evaporation, thus, more precipitation-- often massive floods-- and massive loss in agriculture etc...

5. THERMOHALINE CIRCULATIONAFFECTS ALL THE OCEAN'S WATER

- Slow circulation of water at great depths driven by density differences rather than by wind energy (such as the surface currents)
- Because density is largely a function of water temperature and salinity, the movement of water is due to differences in density and is called **thermohaline circulation**.
- Responsible for most of the vertical movement of ocean water

5.1 Water Masses Have Distinct, Often Unique Characteristics

- Ocean water masses are stratified by differences in density
- Denser masses being the deepest
- Each water mass is identified by its specific temperature and salinity
- Distinct water masses do not mix, but flow above or beneath each other
- Temperate and tropical latitudes, we fine the following water masses:
  - Surface water: to a depth of about 200 meters (650 feet)
  - Central water: to the bottom of the main thermocline (which varies with latitude)
  - Intermediate water: To about 1500 meters (5000 Feet)
  - Deep water: water below intermediate water but not in contact with the bottom, to a depth of about 4000 m (13000 feet)
  - Bottom water: water in contact with the seafloor
- The different water masses initially formed at the "surface" by specific conditions of heating, cooling, evaporation, and dilution.

5.2 Thermohaline Flow and Surface Flow: The Global Heat Connection

- The swift and narrow currents along the western margins of ocean basins (western boundary currents) carry warm tropical surface waters toward the poles.
  - In a few places, the water loses heat to the atmosphere and sinks to become deep water and bottom water.
  - This sinking is most pronounced in the North Atlantic. The cold, dense water moves at great depths toward the Southern Hemisphere and eventually wells up into the surface layers of the Indian and Pacific Oceans. (It takes almost 1000 years to complete the circuit.)
- A simplified outline of the global circuit is shown in **Figure 9.31, p.274-275**.
  - 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.
  - Also, this whole slow-moving system is important in transporting water and heat.

5.3 The Formation and Downwelling of Deep Water Occurs in Polar Regions (Fig. 9.32, p.278)

Antarctic Bottom Water (ABW): (Fig. 9.32, p.278)

- Salinity 34.65 ppt
- Temperature: -0.5^{o}C (30^{o}F)
- Density 1.0279 g/cm^3
- This is the densest of all water masses of the world ocean waters – forms the bottom water of the different oceans of the globe
- It is produced near the Antarctic coasts – mostly around the Weddell Sea (very high salinity because of the formation of "brine" and very cold environment)
- As the ability to migrate north along the seafloor

North Atlantic Deep Water (NADW): (Fig. 9.32, p.278)

- Less dense than the ABW and floats above it
- Not in contact with the ocean floor – thus, it constitute the Deep water (rather than the "Bottom water")
- Originates in the North Atlantic Ocean – surface water where the weather is cold and ice forms --- brine and cold dense mass of water is formed

Mediterranean Deep Water: (Fig. 9,32, p.278; Fig. 9.33, p.279)

- Another Deep water mass
- forms in the Mediterranean
- Contrary to the 2 previous water mass, this deep water mass is relatively composed of warm water but with a very high "salinity" of about 38ppt
- It spreads into the Atlantic at about 1500 - 2000 m

- These water masses coming from the surface are well oxygenated and furnish oxygen to the ocean depths

- Water masses slowly mix with the surrounding water as they flow away from their sources, losing their individual identity, as they grow older.

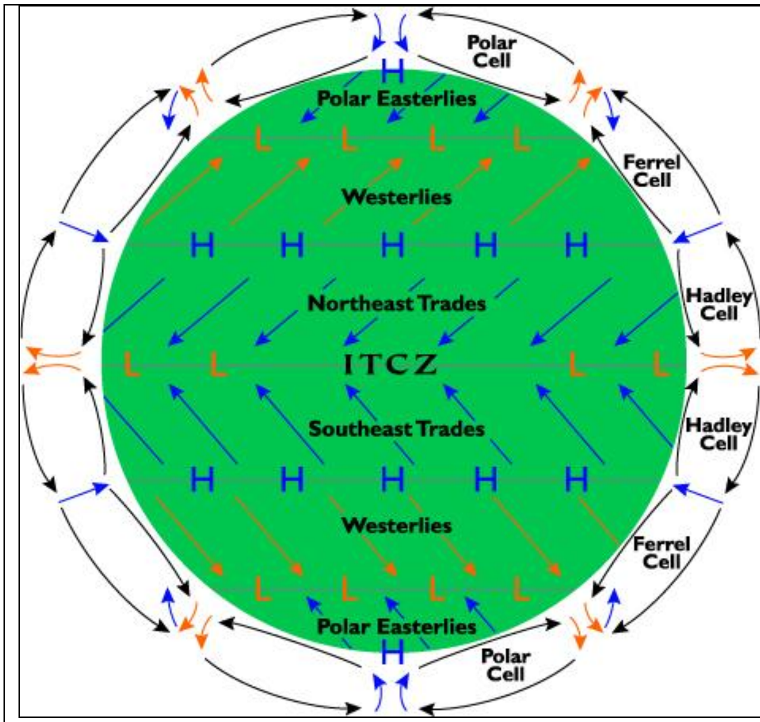
5.4 Water Masses May Converge, Fall, travel Across the Seabed, and Slowly Rise (Fig. 9.31, p.274-275)

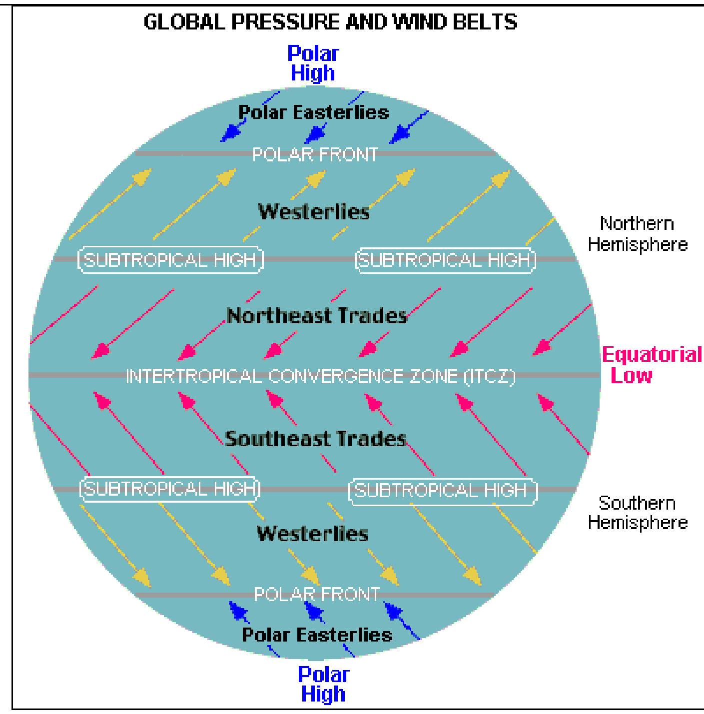
- The great quantities of dense water sinking at ocean basin edges must be offset by equal quantities of water rising elsewhere.
- The water sinks relatively rapidly in a small area where the ocean is very cold, but it rises much more gradually across a very large area in the warmer temperate and tropical zones.
- It then slowly returns poleward near the surface to repeat the cycle.
- Hundreds of years may pass before water masses complete a circuit or blend to lose their identities.

CLO 5. The student will be able to illustrate the interaction between the oceanic and the atmospheric circulation patterns and explain how it affects the climate patterns of the Earth. (Physical oceanography)

SLO 5.1 The student will be able to illustrate in a drawing the global atmospheric circulation cells or weather patterns; the location of the associated wind regimes; and the corresponding convergence and divergent zones.

- *Atmosphere* – is the volume of gases, water vapor, and airborne particles enveloping Earth.
- *Weather* – is the state of the atmosphere at a specific time and place
- *Climate* – is the long-term average of weather in an area
- The temperature and water content of air greatly influence its "density".; Warm air is less dense than cold air (molecules take more space/volume); Humid air is less dense than dry air at the same temperature because molecules of water vapor weigh less than the nitrogen and oxygen molecules that the water vapor displaces.
  - *These rising, expanding, cooling and falling compression, heating relationships are important in understanding atmospheric circulation, weather, and climate.*
- Air flows in large patterns shaped both by variations in:
  - Solar heating with latitude and ; Season; Rotation of the Earth
- *Wind* **-** Is the mass movement of air
- Earth's uneven solar Heating results in large-scale atmospheric circulation:
  - *Convection current* **-** A single-closed-flow circuit of rising warm material and falling cool material.
  - If the model was ideal: Air heated in the tropics would expand and become less dense; rise to high altitude; turn poleward and "pile up" as it converged near the poles; The air would then cool and contract by radiating heat into space, sink to the surface, and turn equator wards flowing along the surface back to the tropics to complete the circuit.
  - But the global circulation of air is governed by 2 factors:
    - Uneven solar heating and
    - The rotation of the Earth
- *Coriolis effect* -- the eastward rotation of the Earth on its axis deflects the moving air or water (or any moving object having mass) away from its initial course..The apparent deflection of a moving object from its initial course when its speed and direction are measured in reference to the surface of the rotating Earth. The object is deflected to the right of its anticipated course in the Northern Hemisphere and to the left in the Southern Hemisphere. The deflection occurs for any horizontal movement of objects with mass and has no effect at the equator.
- Both the uneven solar heating and the rotation of the Earth will modify the atmospheric circulation cells.
  - Instead of having one cell in each hemisphere circulating from the equator, reaching the poles and returning to the equator, three distinctive atmospheric circulation cells will be observed in each hemisphere.
  - Three circulation cells form in each hemisphere (Hadley cells; Ferrel cells; Polar cells)
- The atmospheric circulation generates large-scale surface wind patterns:
  - The bands of dependable surface winds are : trade winds; westerly; and polar easterlies
  - At the bands between circulation cells, the air is moving vertically and the surface winds are weak and erratic (i.e. at the Doldrums; the Horse latitudes; and the Polar Fronts).
  - These bands are zones of "*convergence*" when 2 wind regimes meet each other or zones of "*divergence*" when 2 wind regimes move away from each other.





- Since the Northern Hemisphere contains much less ocean surface than the Southern Hemisphere and since land masses have a lower heat capacity than the ocean, the seasonal difference in temperature in cell circulation are more extreme in the north (cell circulation is much more symmetrical in the Southern Hemisphere)
  - Consequently, the different proportions of land to ocean surface in the 2 hemisphere affects the position of the ITCZ (Intertropical Convergence Zone); the ITCZ, does not coincide with the "*geographical equator*" (0^o latitude); instead, it lies at the "*meteorological equator*" (thermal equator) situated about **5^o-8^o North of the geographic equator.**

SLO 5.2 The student will be able to sketch a world ocean view of the surface currents; describe the relationship between the wind, surface currents, Coriolis effect, Ekman transport, and their links to the formation of geostrophic gyres; list the five geostrophic gyres and the additional West Wind Drift; compare/contrast within a given geostrophic gyre, the western and eastern boundary currents, in terms of relative width, depth, speed, and water temperature.

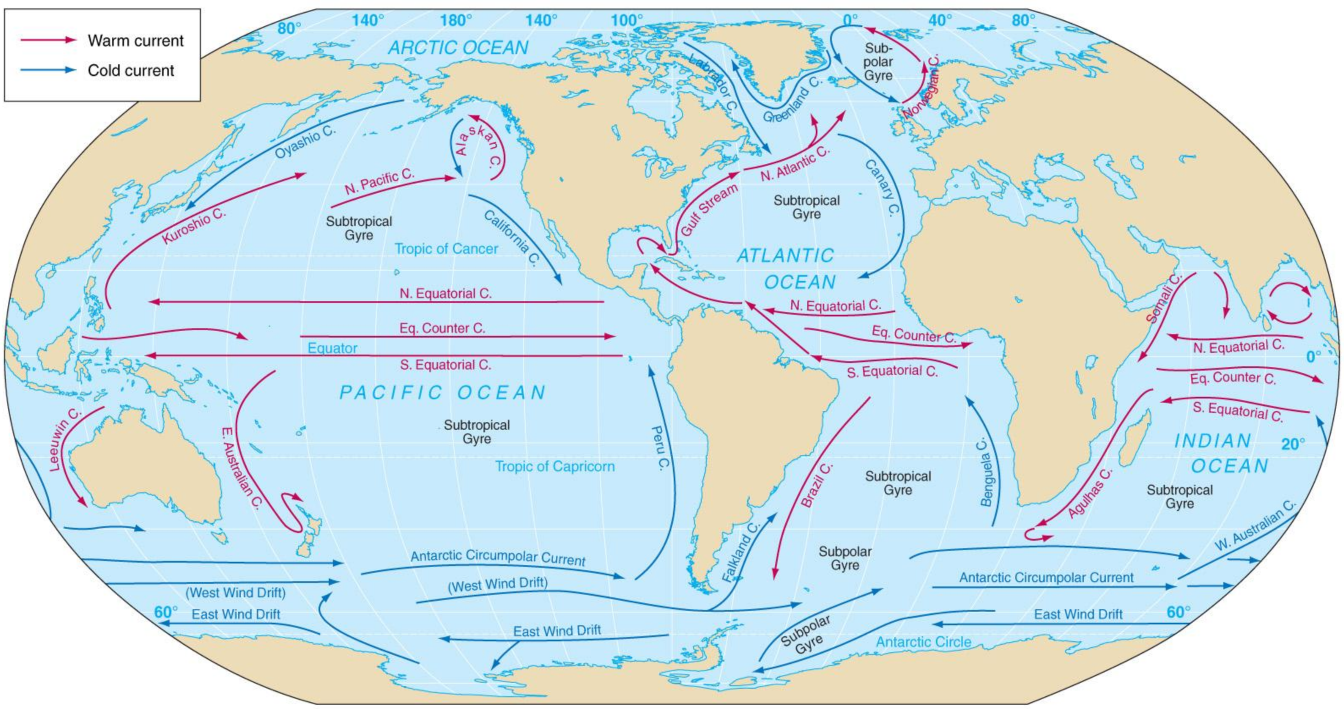
- Ocean circulation can be divided into "wind-induced surface currents", which influence about 10% of the total ocean's volume of water, (moves above the pycnocline); and "density-driven (thermohaline) subsurface flow, which affects the remaining 90%.

Surface currents are driven by the wind

- The large wind-powered circulation gyres (circuit currents) in each ocean consist of a system of geostrophic currents that rotate clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere. Geostrophic currents represent a dynamic balance between Coriolis deflection and pressure gradient.
  - *Gyre* - Circuit of mid-latitude currents around the periphery of an ocean basin. Most oceanographers recognize 5 geostrophic gyres (North Atlantic; South Atlantic; North Pacific; South Pacific; and, the Indian Ocean gyres) plus the West Wind Drift (Antarctic Circumpolar Current) which is a gyre but not geostrophic.
  - What explains these circuit currents (gyres) relies on the *Ekman spiral* **–**
  - *Ekman spiral* -- A theoretical model of effect on water of wind blowing over the ocean. Because of the Coriolis effect, the surface layer is expected to drift at an angle of 45^o to the right of the wind in the Northern Hemisphere and 45^o to the left in the Southern Hemisphere. Water at successively lower layers drifts progressively to the right (N), or left (S), though not as swiftly as the surface flow. The overall net transport is called the *Ekman transport***.** It is a net water transport of 90^o to the right of the wind direction in the NH and 90^o to the left of the wind in the SH.
- In both hemispheres, the pattern of current flow around the gyres is asymmetrical, with narrow, deep, swift transport in the western part of the gyre (*western boundary currents*), and broad, shallow, slow drift in the eastern part of the gyre (*eastern boundary currents*).

- *Western boundary currents* -- found at the western boundaries of ocean basins (off the east coasts of continents); narrow, fast, deep currents that move warm water poleward in each of the gyres; western boundary currents meander as they flow poleward-- the looping meander sometimes form turbulent rings, or *eddies*, that can separate from the main flow and move away from the current ; some can reach diameters of more than 1,000 km (625 miles) and last for several months or even years
  - There are 5 large western boundary currents:
    - The Gulf Stream (North Atlantic) --- the largest of the western boundary currents; moves at an average speed of 2 m/sec to a depth of over 450 m; average width is about 70 km; water within the current is usually clear, blue, often depleted of nutrients
    - The Japan or Kuroshio Current (North Pacific)
    - The Brazil Current (South Atlantic)
    - The Agulhas Current (Indian Ocean)
    - The East Australian current (South Pacific)

- *Eastern boundary currents* -- Found in the eastern edge of ocean basins (off the west coast of continents); are the opposite of their western boundary counterparts --- carry cold water equatorward; are shallow and broad, sometimes more than 1,000 km (625 miles) across; boundaries are not well defined; eddies do not form; their total flow is less than that of their western counterparts
- There are 5 eastern boundary currents:
  - The Canary Current (North Atlantic)
  - The Benguela Current (South Atlantic)
  - The California Current (North Pacific)
  - The West Australian Current (Indian Ocean)
  - The Peru or Humbolt Current (South Pacific)
- *Transverse currents* -East-to-west or west-to-east current linking the eastern and western boundary currents.
- *West Wind Drift (Antarctic Circumpolar Current)* -- Intense westerly winds over the southern ocean drive the greatest of all ocean currents, the unobstructed West Wind Drift (or Antarctic Circumpolar Current).; this current carries more water than any other
- *Countercurrents* -- At the meteorological equator (light winds), some backward flow of water occurs and flows away from the main equatorial currents to return on the surface to the east (flowing on the surface in the opposite direction from the main current).
  - *Undercurrents* – are countercurrents that exist "beneath" surface currents; have been found under most major currents; their volumes are often a significant percentage of the current above.



SLO 5.3 The student will be able to define both upwellings and downwellings; explain what causes them; distinguish between the coastal and equatorial upwellings; and, relate the importance of upwellings in terms of primary productivity, marine life support, and economic interest for major world fisheries.

- The wind-driven *horizontal* movement of water can sometimes induce *vertical* movement in the surface water. This movement is called *wind-induced vertical circulation*.
  - Upward movement of water is known as **upwelling**; This process brings deep, cold, usually nurient-ladden water toward the surface; permits high primary productivity – and consequently can sustain major fishery grounds
  - **Equatorial upwelling –** Upwelling in which water moving westward on either side of the geographical equator tends to be deflected slightly poleward and replaced by deep water often rich in nutrients.
  - **Coastal upwelling –**Upwelling adjacent to a coast, usually induced by wind**;** Wind blowing parallel to shore or offshore can move the surface water offshore; this surface water is replaced by deep water rising along the shore; .again because the new surface water is often rich in nutrients, it result in increased biological productivity.
  - **Downwellings** -- Downward movement of water is -- Water driven toward a coastline will be forced downward, returning seaward along the continental shelf.; This downwelling helps supply the deeper ocean with dissolved gases and nutrients, and it assists in the distribution of living organisms.

SLO 5.4 The student will be able to define thermohaline circulation; discuss the origin, nature, and location of its associated major deep water current namely, the Antarctic Bottom Water and the North Atlantic Deep Water; explain what the "global conveyer belt" is; its significance for both life in the ocean and Earth's climate; describe the causes of an eventual shut down of the global conveyer belt system, and its consequences.

- Subsurface flow, known as *thermohaline circulation*, results from density variations produced by a difference in the temperature and salinity of water masses. When water masses converge, the more dense water sinks below and buoys up the less dense water. Most water that fills the depths of the oceans is near freezing and originated near the surface of the polar seas. Residence time for water in the deep sea is about 500 to 1,000 years. The water masses slowly mix with the surrounding water as they flow away from their sources, losing their individual identity as they grow older.
- Ocean basins exchange water on a regular basis. A "conveyer belt" model of this exchange suggests that warm water from the Pacific Ocean and Indian Ocean is exported to the Atlantic Ocean along the surface, where it cools and sinks, returning at depth back to the Pacific and Indian Ocean.

- The slow, steady, three-dimensional flow of water in the conveyor belt distributes dissolved gases including oxygen and solids, and mixes nutrients to the ocean depths. It equally transports the juvenile stages of organisms between ocean basins.

- *Antarctic Bottom Water (ABW)* -- This is the densest of all water masses of the world ocean waters; it forms the bottom water of the different oceans of the globe; it is produced near the Antarctic coasts – mostly around the Weddell Sea (very high salinity because of the formation of "brine" and very cold environment)
- *North Atlantic Deep Water (NADW)*-- Less dense than the ABW and floats above it; Not in contact with the ocean floor – thus, it constitute the Deep water (rather than the "Bottom water"); Originates in the North Atlantic Ocean – surface water where the weather is cold and ice forms --- brine and cold dense mass of water is formed
- *Mediterranean Deep Water (MDW)* -- Another Deep water mass; forms in the Mediterranean; Contrary to the 2 previous water mass, this deep water mass is relatively composed of warm water but with a very high "salinity" of about 38ppt; It spreads into the Atlantic at about 1500 - 2000 m