Basics of Ocean Circulation

Key Concepts:

Moving water tends toward a situation of equilibrium. Flows adjust to the forces acting on them so that those forces balance one another. The major forces that need to be considered with respect to moving water are:

Wind stress at the sea surface, internal friction, the Coriolis force and horizontal pressure gradient forces.

For boundary flows: friction with the seabed or coastline may need to be considered.

Ekman Motion: wind stress and internal Friction balanced by Coriolis force
Ekman Motion

Ideal Ocean:
- Inf. Deep
- Inf. Wide
- No variation in density
- Surface remains horizontal

Surface currents move 45° to the right/left of the wind in the NH/SH.
Mass transport in the Ekman Layer is 90° to the right/left of the wind in the NH/SH
Ekman Motion

**Coriolis Force:**

\[ m \times 2\Omega \sin(\phi) \times u \]

- \( m \): mass
- \( u \): speed
- \( \phi \): latitude
- \( \Omega \): angular velocity of Earth
- \( 2\Omega \sin(\phi) \): Coriolis Parameter (f)

**Ekman Surface Current Speed:**

\[ u_o = \frac{\tau}{\rho (A_z f)^{1/2}} \]

- \( u_o \): current speed
- \( A_z \): vertical eddy viscosity
- \( \tau \): wind stress
- \( \rho \): density of seawater
- \( f \): Coriolis Parameter

Remember that all physical variables and quantities have units!! Write the units of all quantities above, use the metric system.

Surface currents move **45°** to the right/left of the wind in the NH/SH.

Mass transport in the Ekman Layer is **90°** to the right/left of the wind in the NH/SH.
Ekman Motion

Depth Mean Current:

\[ u = \frac{\tau}{(D\rho f)} \]

- \( u_0 \) = current speed
- \( D \) = depth of the Ekman Layer
- \( \tau \) = wind stress
- \( \rho \) = density of seawater
- \( f \) = Coriolis Parameter

\[ D = (2\pi^2 A_z/f)^{1/2} \]

In the Ocean the thickness of the Ekman Layer is less than the thickness of the mixed layer (100 - 200 m).

Would you have an Ekman Layer extending up from the seabead?
This is Climatology!
(averages over a long period)

Figure shows:
1. Prevailing winds at the Earth’s surface & average position of the ITCZ for northern summer/southern winter (July - Top) and for northern summer/southern winter (January - Bottom),
2. positions of main regions of high (red/pink) and low (blue) low atmospheric pressure
Surface winds over the Pacific and Atlantic oceans for one day in 1999. Data obtained from satellite-borne instruments that measure microwave radar back-scattered from the sea-surface. (Wind speed is calculated from the estimated roughness of the sea-surface, and wind direction from the inferred orientation of wave crests)

Real winds at any one time look more like this!
Ocean Currents
Geostrophic gyres are gyres in balance between the pressure gradient and the Coriolis effect. Of the six great currents in the world’s ocean, five are geostrophic gyres. Note the western boundary currents in this map.
Boundary Currents Have Different Characteristics

**Western boundary currents** - These are narrow, deep, fast currents found at the western boundaries of ocean basins.

- The Gulf Stream
- The Japan Current
- The Brazil Current
- The Agulhas Current
- The Eastern Australian Current

**Eastern boundary currents** - These currents are cold, shallow and broad, and their boundaries are not well defined.

- The Canary Current
- The Benguela Current
- The California Current
- The West Australian Current
- The Peru Current
Nutrient-Rich Water Rises near the Equator

Equatorial upwelling.

The South Equatorial Current, especially in the Pacific, straddles the geographical equator. Water north of the equator veers to the right (northward), and water to the south veers to the left (southward). Surface water therefore diverges, causing upwelling. Most of the upwelled water comes from the area above the equatorial undercurrent, at depths of 100 meters or less.
Wind Can Induce Upwelling near Coasts

Coastal upwelling.

In the Northern Hemisphere, coastal upwelling can be caused by winds from the north blowing along the west coast of a continent. Water moved offshore by Ekman transport is replaced by cold, deep, nutrient-laden water. In this diagram, temperature of the ocean surface is shown in degrees Celsius.
Wind Can Also Induce Upwelling Coastal Downwelling

Coastal downwelling.

Wind blowing from the south along a Northern Hemisphere west coast for a prolonged period can result in downwelling. Areas of downwelling are often low in nutrients and therefore relatively low in biological productivity.
The global pattern of deep circulation resembles a vast “conveyor belt” that carries surface water to the depths and back again. Begin with the formation of North Atlantic Deep Water north of Iceland, which flows south through the Atlantic and then flows over (and mixes with) deep water formed near Antarctica. The combined mass circumnavigates Antarctica and then moves north into the Indian and Pacific ocean basins. Diffuse upwelling in all of the ocean returns some of this water to the surface. Water in the conveyor gradually warms and mixes upward to be returned to the North Atlantic by surface circulation.
Summary

• Ocean water circulates in currents caused mainly by wind friction at the surface and by differences in water mass density beneath the surface zone.

• Water near the ocean surface moves to the right of the wind direction in the Northern Hemisphere, and to the left in the Southern Hemisphere.

• The Coriolis effect modifies the courses of currents, with currents turning clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere.

• Upwelling and downwelling describe the vertical movements of water masses. Upwelling is often due to the divergence of surface currents; downwelling is often caused by surface current convergence or an increase in the density of surface water.
Summary

• Circulation of the 90% of ocean water beneath the surface zone is driven by gravity, as dense water sinks and less dense water rises. Since density is largely a function of temperature and salinity, the movement of deep water due to density differences is called thermohaline circulation.

• Water masses almost always form at the ocean surface. The densest (and deepest) masses were formed by surface conditions that caused water to become very cold and salty.

• Because they transfer huge quantities of heat, ocean currents greatly affect world weather and climate.