The World Ocean – III
Circulation, Waves, and Tides
Ocean Circulation

• **Surface ocean currents** are broad, slow drifts of surface water caused by friction between the ocean and air flowing over it
  – 50-100 m deep
  – Solar radiation provides heat energy, non-uniform heating generates winds, which drive the movement of surface ocean water

• **Ocean current direction** is also influenced by the **Coriolis force**
Ocean Circulation

(A) Angular velocity

(B) Coriolis Effect
Ocean Circulation

- **Ekman transport**
  - The *balance* of the *wind* on surface water and *Coriolis force* at depth
  - Generates a spiraling current pattern
  - Results in a *net direction* of water movement about 90˚ to the wind direction
  - Near coasts this leads to vertical movement of ocean water
    - *Upwelling* if net transport is away from land
    - *Downwelling* if net transport is toward land
Ocean Circulation

Wind

Surface current

20–45°

Net water movement (90° to wind direction)
Ocean Circulation

(A) Wind

Ekman transport

Upwelling

(B) Wind

Ekman transport

Downwelling
Ocean Circulation

• With geography, ocean current drivers set up the **major surface current systems** in the world ocean

• Each major ocean current is part of a large subcircular current system called a **gyre**
  – 2 in the Pacific
  – 2 in the Atlantic
  – 2 in the Indian
Ocean Circulation
FIGURE XI-3. A highly idealized representation of the prevailing winds and their effect on the surface currents of an imaginary rectangular ocean.
Fig. 12.1 In geostrophic flow, moving water is acted upon by the Coriolis force and deflected until an equal and opposing pressure gradient force is formed. When this balance is struck, the water moves at a right angle to the pressure gradient. The slope of the sea surface required to form this pressure gradient is $a/b$. The density surfaces take on a reverse slope $c/d$ which is much greater than the sea-surface slope and which is readily measured. The adjustment in the mass field allows the hydrostatic pressure at some depth to be constant; Pressure $A$ equals Pressure $B$ even though the columns of water are of unequal lengths.
Ocean Circulation

- On either side of the equator, ocean regions are dominated by westward-flowing North and South Equatorial currents.
- Along the equator is the eastward-flowing Equatorial Countercurrent.
- Near 60° latitude, the Antarctic Circumpolar Current circles the globe.
Ocean Circulation

- North Atlantic Deep Water (NADW) originates at the surface of the north Atlantic, flows downward, and spreads southward to the south Atlantic.
- Flowing beneath this is the colder, denser Antarctic Bottom Water (AABW).
- The sinking of dense, cold, saline surface water propels a global thermohaline circulation system.
Ocean Circulation
Ocean Circulation

[Diagram showing ocean circulation patterns with arrows indicating flow of warm salty surface water and blue waters representing lower NADW (North Atlantic Deep Water) and AABW (Antarctic Bottom Water).]
Ocean Circulation
Ocean Waves

- **Surface waves receive their energy from wind**
  - The **size of a wave** is determined by wind speed, duration, and fetch (distance)
  - Important **wave dimensions** are the **height** (from crest to trough) and **wavelength** (from crest to crest or crest to trough)
  - As waves move, **each parcel of water revolves in a loop**, returning nearly to its former position once the wave has passed
  - At a **depth of half the wavelength**, water motion is negligible, this is the **wave base**
Ocean Waves

- Wavelength, L
- Height, H
- Amplitude, A
- Direction of wave propagation

![Diagram of ocean waves with labeled parts including wavelength, height, and amplitude.](image-url)
Ocean Waves

• Toward land, as water depth becomes less than L/2, the circular motion of the deepest water parcels is restricted by the shallow seafloor, flattening the loop.

• As depth decreases, the wave’s shape is distorted; height increases, wavelength shortens, and the wave front grows steeper, eventually collapsing (breaking).
  – This is turbulent surf.
Ocean Waves

- Wave becomes higher and steeper
- Breaking wave
- Swash
- Surf
- Beach
- Strong erosion

- Deep water
- Shallow water
- Slight erosion
- Wave first "feels bottom" here
- Looplike motion

- Wave base = \( L/2 \)
- Turbulent water
- Loops deformed by friction at seafloor
Ocean Waves

• Approaching shore, waves become refracted to parallel the bottom contours
• The path of an incoming wave can be resolved in two directional components
  – Parallel to the shore: longshore current
  – Perpendicular to the shore: surf
Ocean Waves

Waves reach shore at a more gentle angle due to refraction.

Longshore current

Wavecrests approaching shore at a sharp angle.
• **Tsunami**
  – Technically a *seismic sea wave*
  – Generated by *sudden movements on the seafloor*
    • Earthquake
    • Submarine or coastal landslide
    • Large volcanic eruption
  – Sudden *seafloor displacement causes displacement in overlying water*, when this water falls back down it splits into two oppositely moving components
• Tsunami
  – Travel at speeds up to 950 km/h
  – Have \textit{wavelengths} measured in kilometers
  – Wave \textit{height} is only 1-2 meters
    • Typically not seen or felt in the open ocean
  – \textit{Periodicity} can be from 20 min to 1 hr
  – As the crest moves on shore, water can \textit{pile up rapidly} to heights of 30 meters and travel great distances inland, as the trough moves on shore, it causes drawdown
The Asian Tsunami
December 26, 2004
Tsunami Damage
Receding waters,
Kalutora Beach,
Sri Lanka
Banda Aceh
Shore, Indonesia
Gleebruk Village, Indonesia
Gleebruk Village, Indonesia
Meulaboh, Indonesia
Meulaboh, Indonesia
Meulaboh, Indonesia
What caused the Asian tsunami
Earthquakes happen when the plates that make up the Earth’s surface suddenly move against each other.

On 26 December 2004 the biggest earthquake for 40 years occurred between the Australian and Eurasian plates in the Indian Ocean. The quake triggered a tsunami - a series of large waves - that spread thousands of kilometres over several hours.

The earthquake caused the sea floor to rupture along the fault line, causing a giant wave which carved a path of destruction across the 4,500 km-wide Indian Ocean over a period of seven hours.
Relationship between water depth and wavelength

\[ L = T(gd)^{1/2} \]
Relationship between water depth and wave velocity

\[ V = (gd)^{1/2} \]
Tsunamis are caused by

• Earthquakes that lead to seafloor displacements (December 26, 2004)
• Volcanic eruptions (Krakatoa, 1883)
• Underwater landslides (LaPalma, Canary Islands)
Tsunami Response

• Detect potential tsunami-causing event

• Detect wave using both surface buoys and seafloor measurements of pressure variations

• Issue tsunami alert

• Evacuate at-risk areas. This is not always possible

• Tsunami mitigation – structures that may reduce damage, for example barrier islands and coastal forests
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Ocean Tides

• Rhythmic, twice-daily rise and fall of ocean water along coastlines
• Caused by gravitational attraction between the Earth and Moon, and to a lesser extent, the Sun
• Generates tidal bulges due to gravitational pull and inertial force
  – Highest and lowest tides when sun and moon are aligned
  – Least tidal range when sun and moon are not
Fig. 17.11a  The fundamental standing wave in a closed basin has a central node where no vertical motion of the free surface occurs. Maximum water-level change occurs at the antinodes. The basin's length ($l$) is $\frac{1}{2}$ of the wavelength.

Fig. 17.11b  The fundamental standing wave in an open-ended basin has a node at the basin's mouth. Maximum change in water level occurs at the antinode. The basin's length ($l$) is $\frac{1}{4}$ of the wavelength.