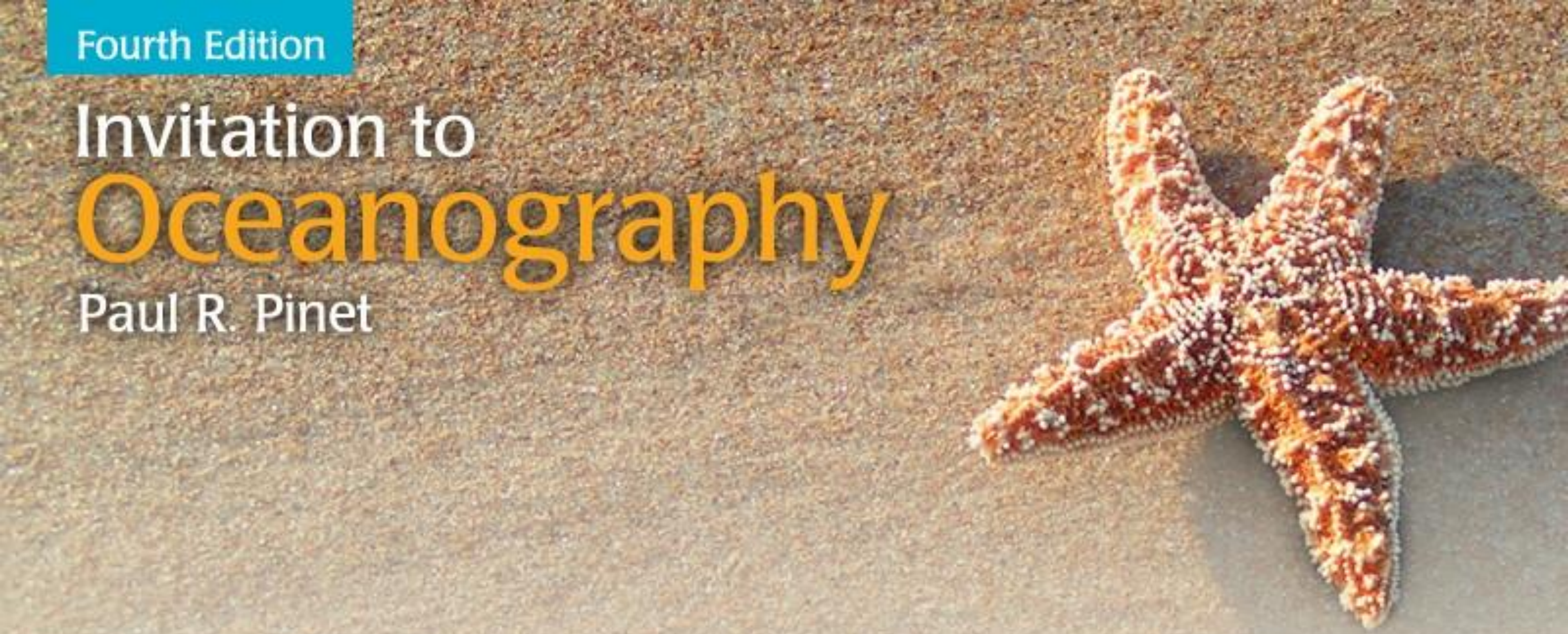


Chapter 6

Wind and Ocean Circulation

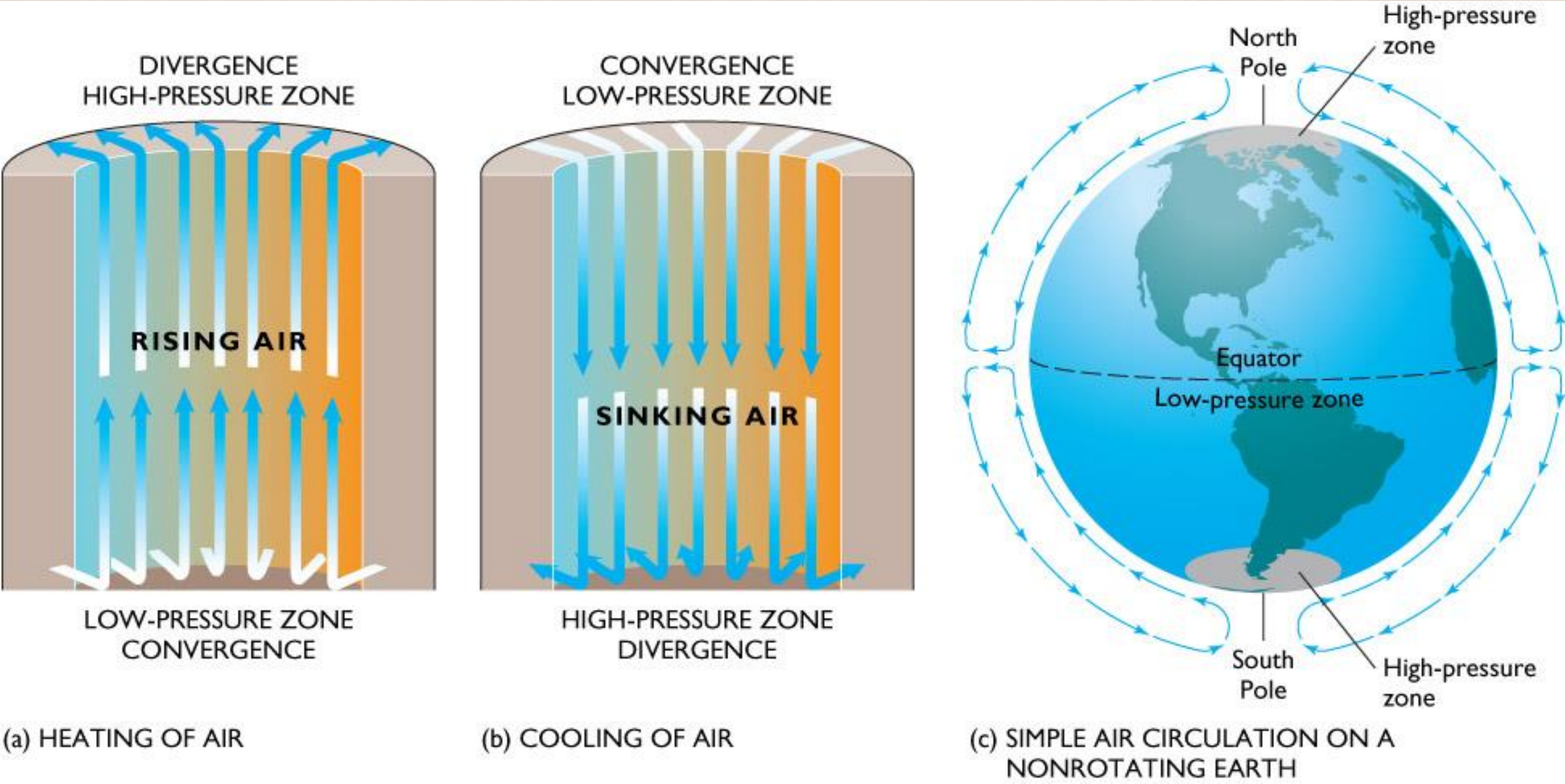


Figure 6-1 Air Pressure

6-1 Atmospheric Processes

Rotation of the Earth strongly influences winds.

Coriolis deflection is the apparent deviation of objects moving across Earth’s surface.

- Objects are deflected to the **right** of direction of travel in the **northern hemisphere**,
- Objects are deflected to the **left** of direction of travel in the **southern hemisphere**.

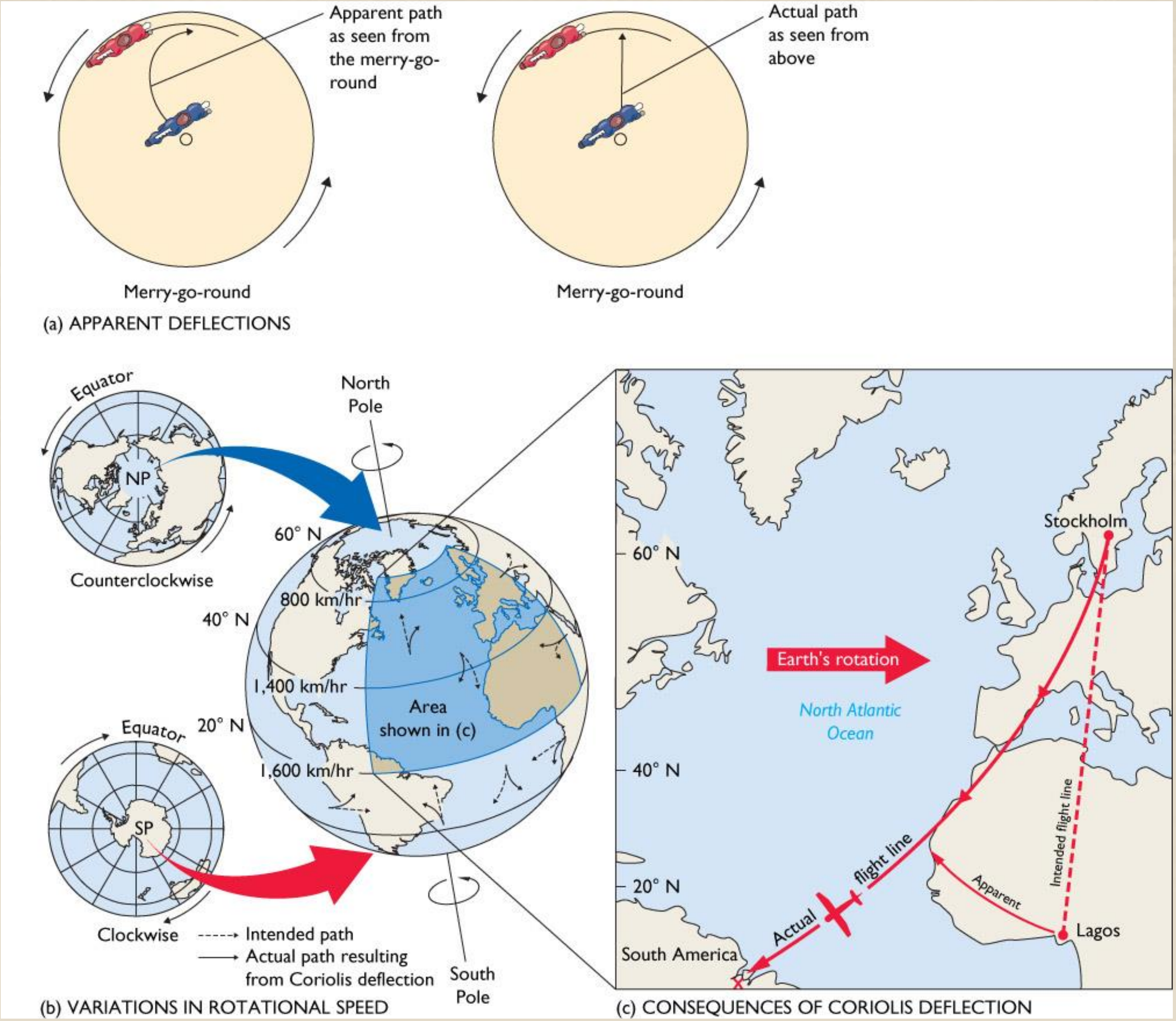


Figure 6-2 Coriolis Deflection

6-1 Atmospheric Processes

Global Wind Circulation

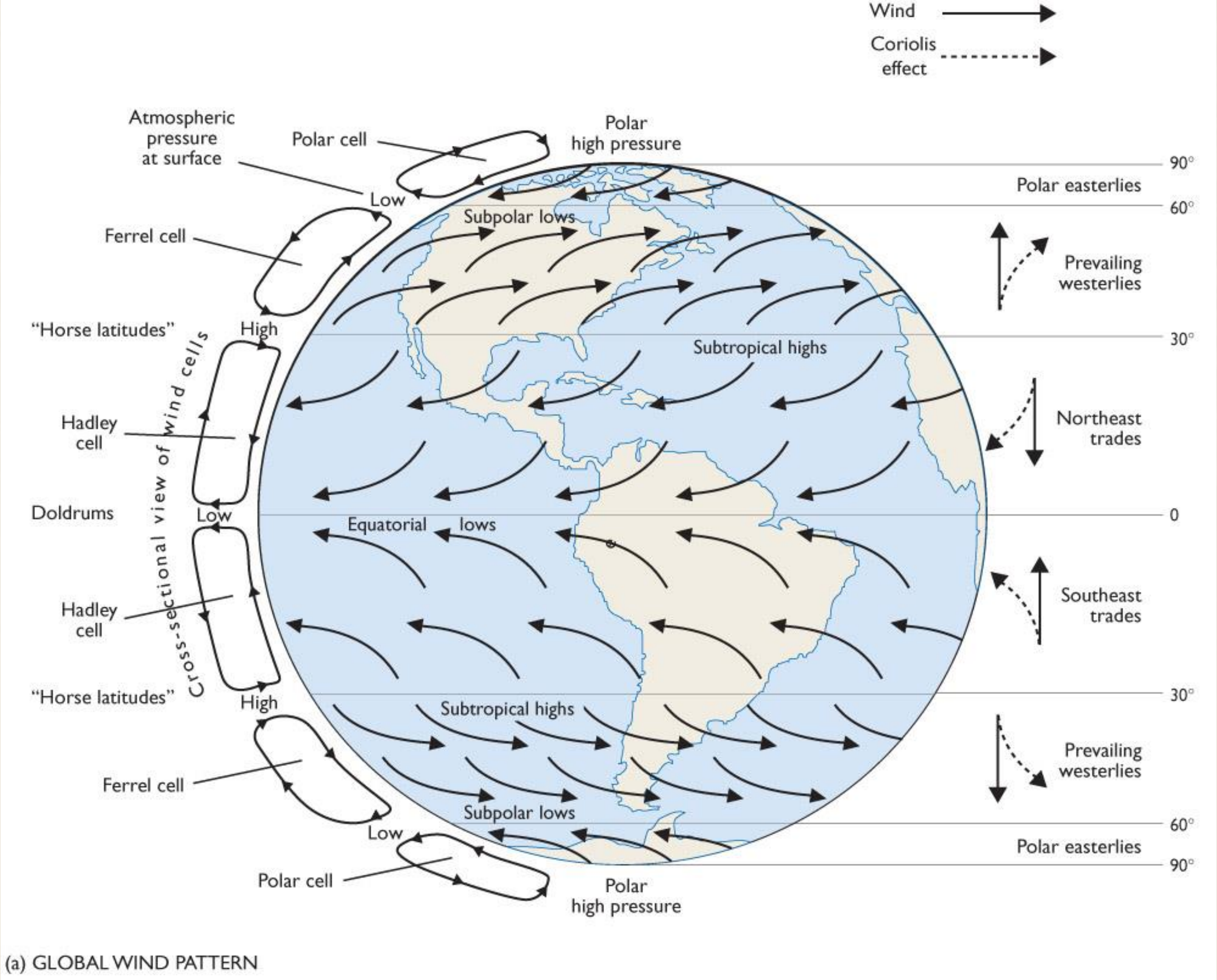


Figure 6-3a Global Wind Pattern

6-1 Atmospheric Processes

Global Wind Circulation

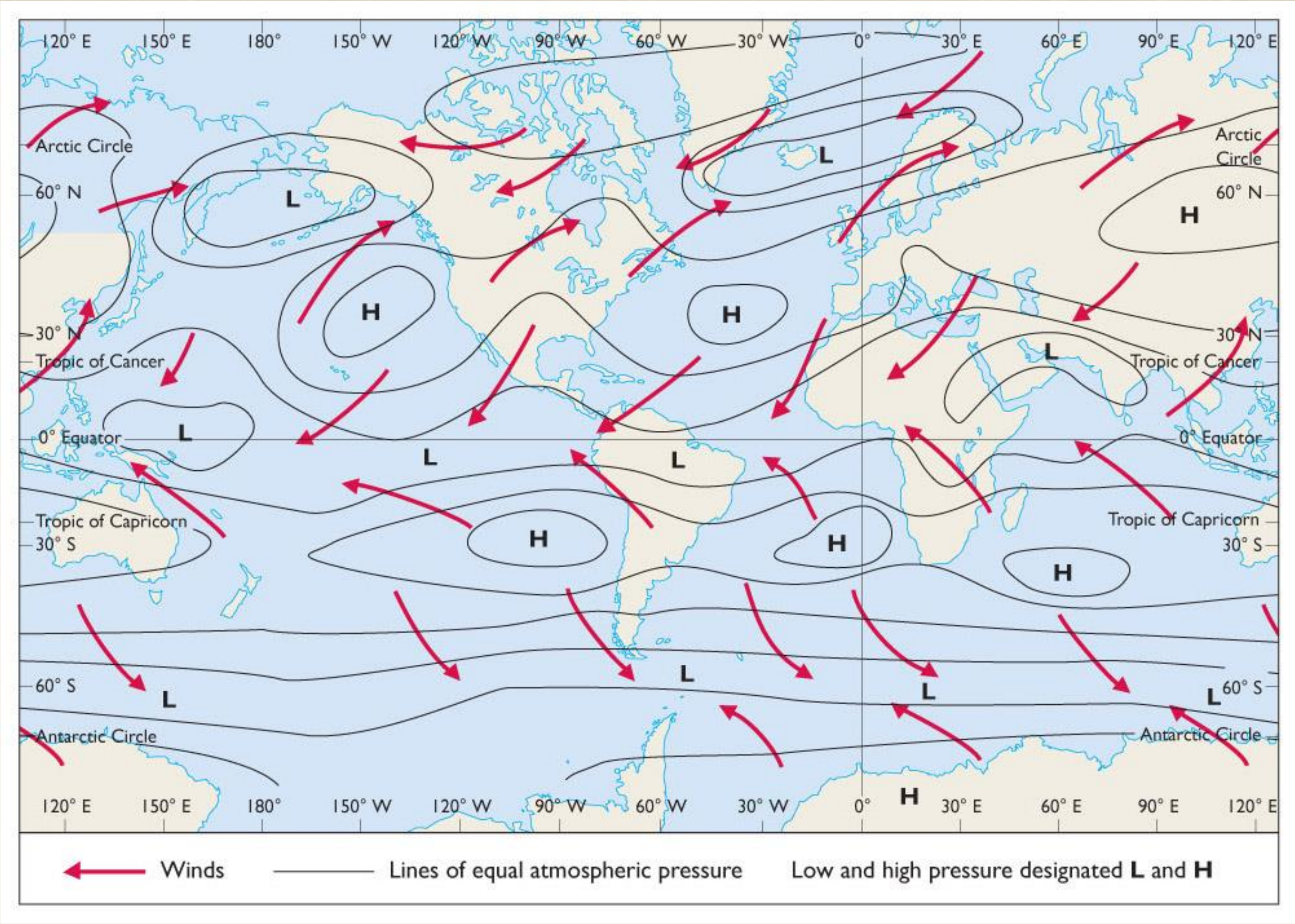


Figure 6-3b Air Pressure and Prevailing Winds

6-1 Atmospheric Processes

- **Zonal wind flow** is wind moving nearly parallel to latitude.
  - This is a result of Coriolis deflection.

- A **gyre** is a circular current caused by:
  - Westerly-driven ocean currents in the trade winds
  - easterly-driven ocean currents in the Westerlies
  - deflection of the ocean currents by the continents

Surface Ocean Currents

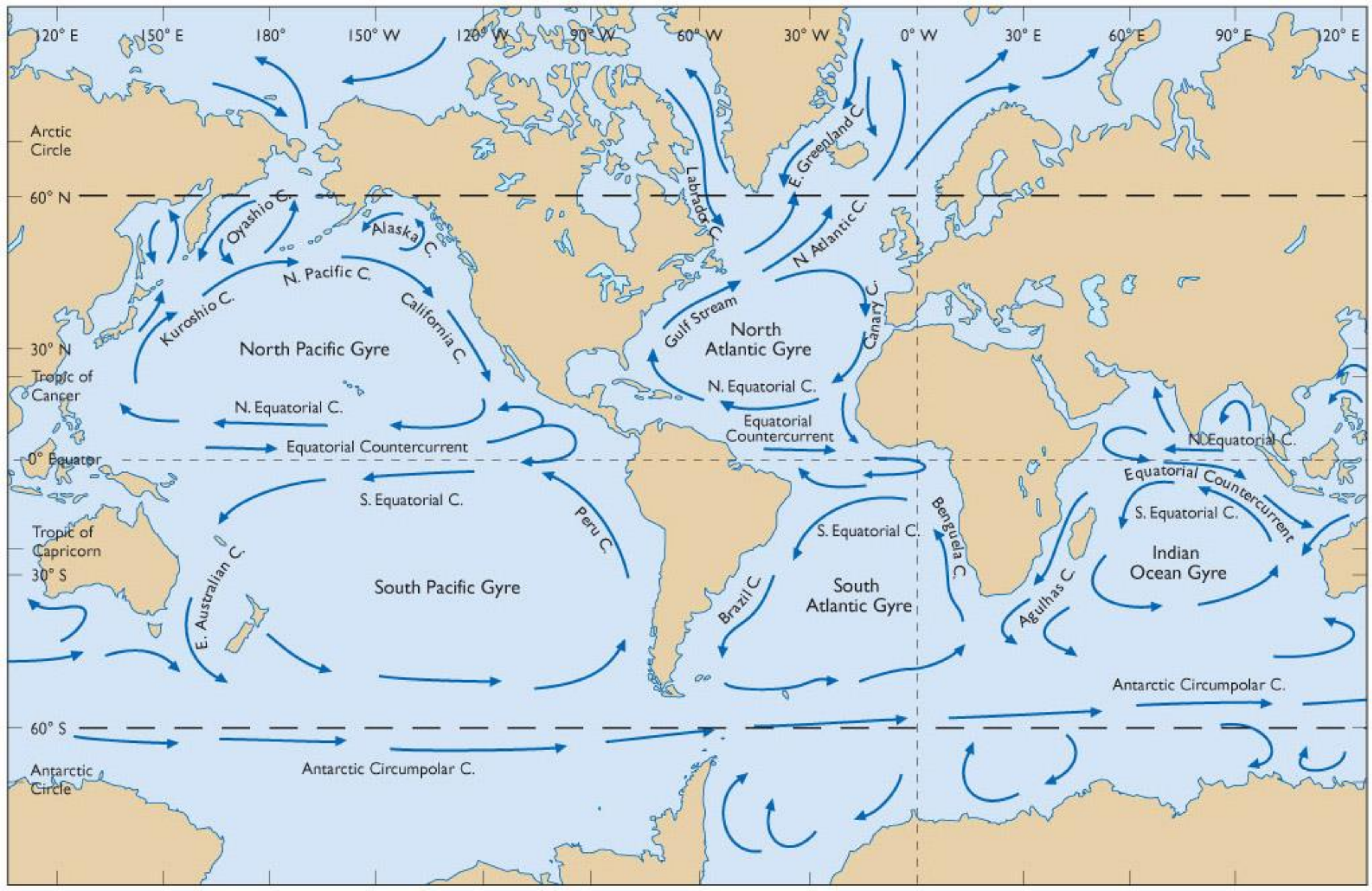


Figure 6-4 Surface Ocean Currents

6-2 Surface Ocean Currents

Ocean currents

- Moving seawater
- Surface ocean currents
  - Transfer heat from warmer to cooler areas
  - Similar to pattern of major wind belts
  - Affect coastal climates
- Deep ocean currents
  - Provide oxygen to deep sea
- Affect marine life

Types of ocean currents

- Surface currents
  - Wind-driven
  - Primarily horizontal motion
- Deep currents
  - Driven by differences in density caused by differences in temperature and salinity
  - Vertical and horizontal motions

Surface currents

- Frictional drag between wind and ocean
- Wind plus other factors such as
  - Distribution of continents
  - Gravity
  - Friction
  - Coriolis effect cause
- Gyres or large circular loops of moving water

- With time, wind-driven surface water motion extends downward into the water column.
  - speed decreases
  - direction changes because of Coriolis deflection

- Ekman Spiral is the pattern caused by changes in water direction and speed with depth.

Ekman spiral

- Surface currents move at angle to wind
- Ekman spiral describes speed and direction of seawater flow at different depths
- Each successive layer moves increasingly to right (N hemisphere)

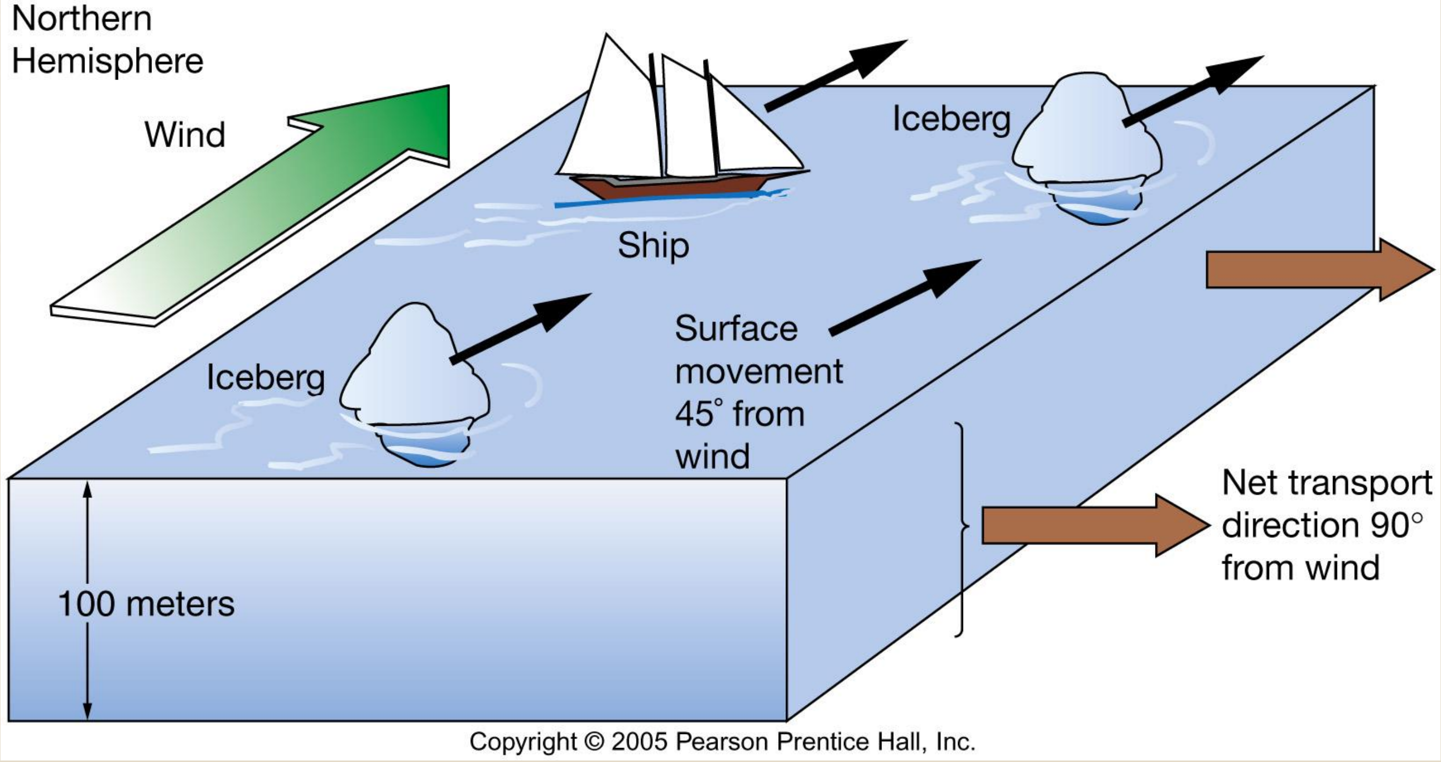


Fig. 7.5

- Eckman transport is the net transport of water by wind-induced motion.
    - Net transport of the water in an Eckman spiral has a Coriolis deflection of **90º** to the direction of the wind.

- Along coastal areas, Eckman transport can induce:
  - downwelling by driving water towards the coast, **or**
  - upwelling by driving water away from the coast

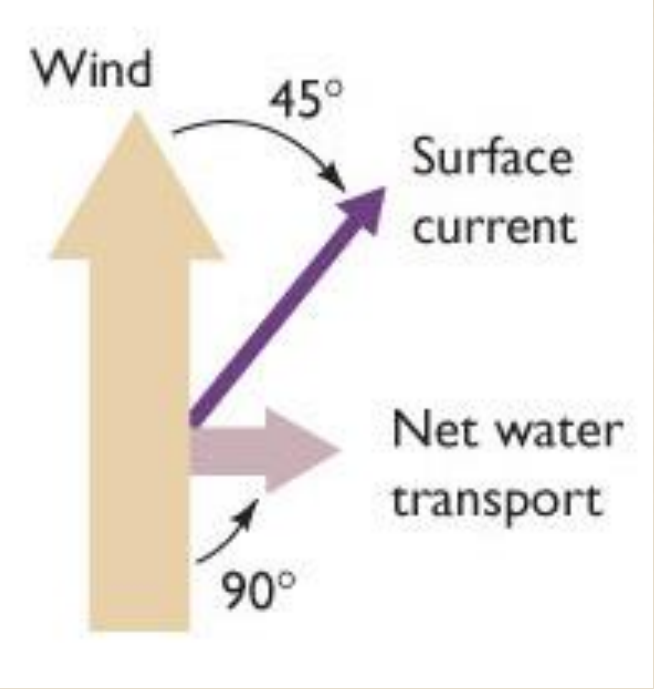


Figure 6-6b Map View

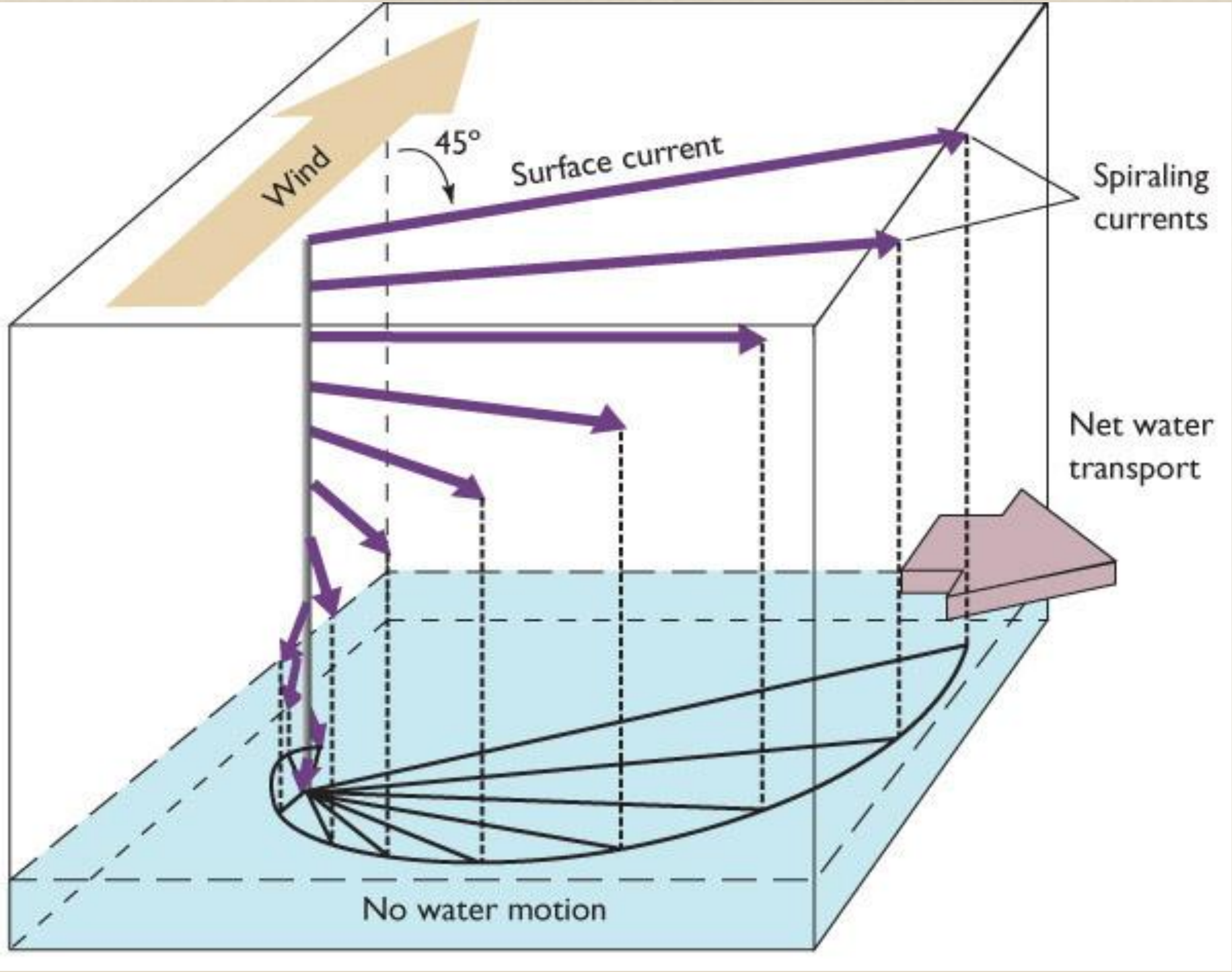


Figure 6-6a Ekman Spiral in the Northern Hemisphere

6-2 Surface Ocean Currents

Convergence & Divergence of Water Currents in the Northern Hemisphere

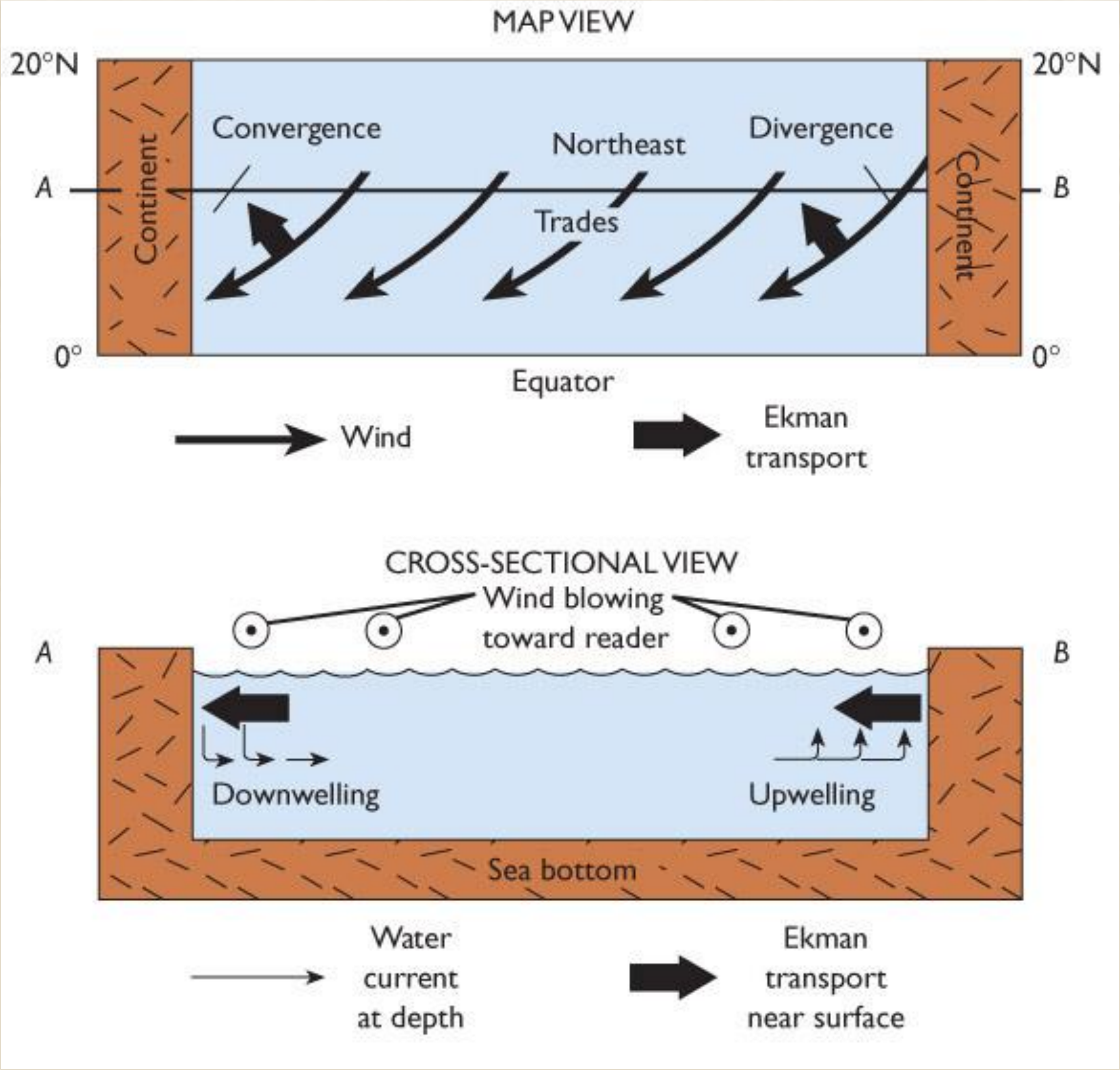


Figure 6-7a Coastal Divergence & Convergence

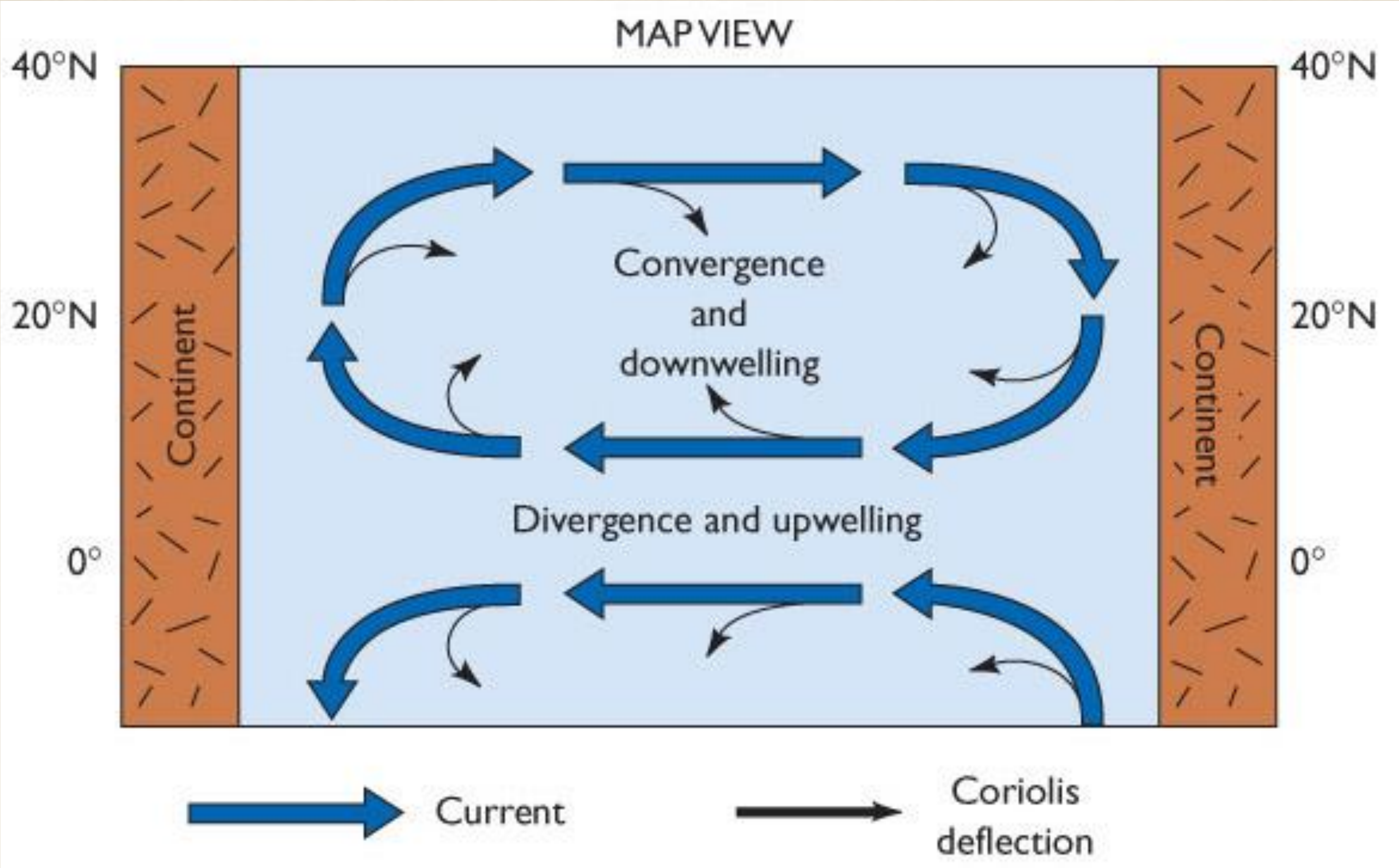


Figure 6-7b Ocean Divergence & Convergence

6-2 Surface Ocean Currents

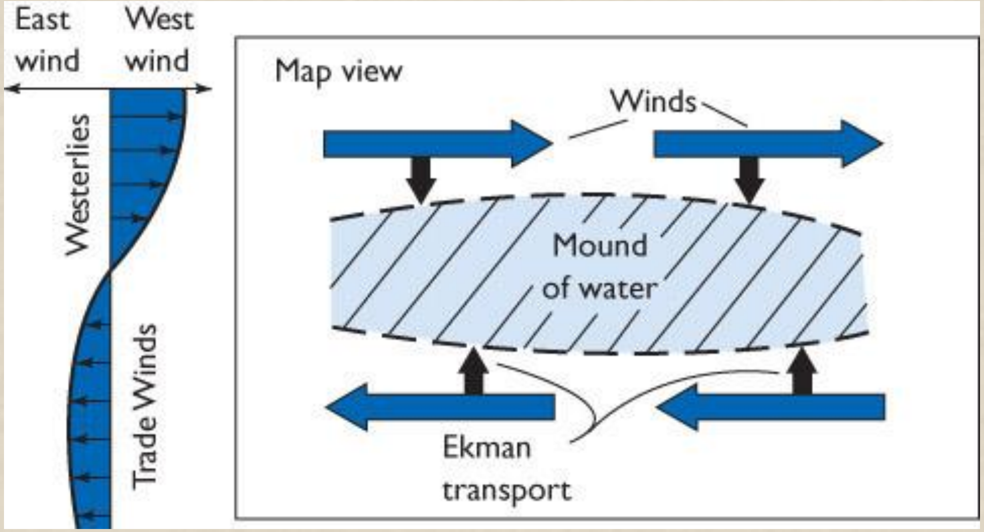
Geostrophic flow allows currents to flow long distances with no apparent Coriolis deflection.

- Coriolis effect deflects water into the center of the gyres, forming a low mound of water.

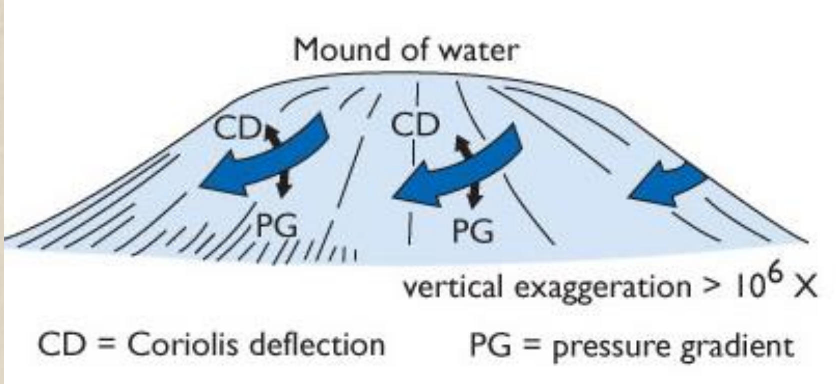
- As height of the mound increases, the pressure gradient steepens pushing the water outward to level the mound.

- When the pressure gradient equals Coriolis deflection, the current flows **parallel to the wind** around the mound.
  - This is called geostrophic flow.

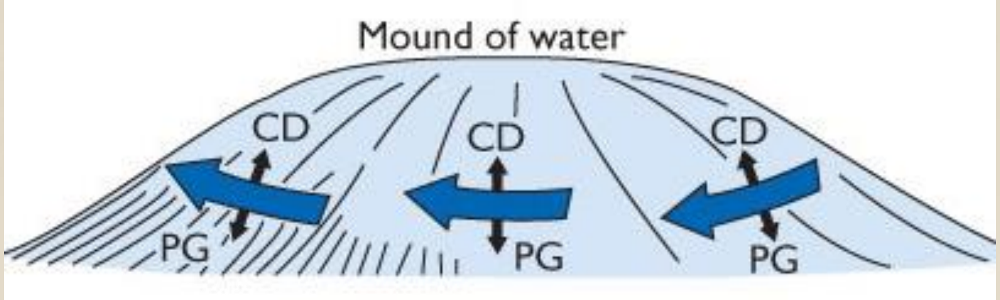
Geostrophic Currents



(a) Stacking of water in center of ocean



(b) Effect of pressure gradient



(c) Geostrophic currents

Figure 6-9

6-2 Surface Ocean Currents

Geostrophic flow

- Ekman transport piles up water within subtropical gyres
- Surface water flows downhill (gravity) and
- Also to the right (Coriolis effect)
- Balance of downhill and to the right causes geostrophic flow around the "hill"

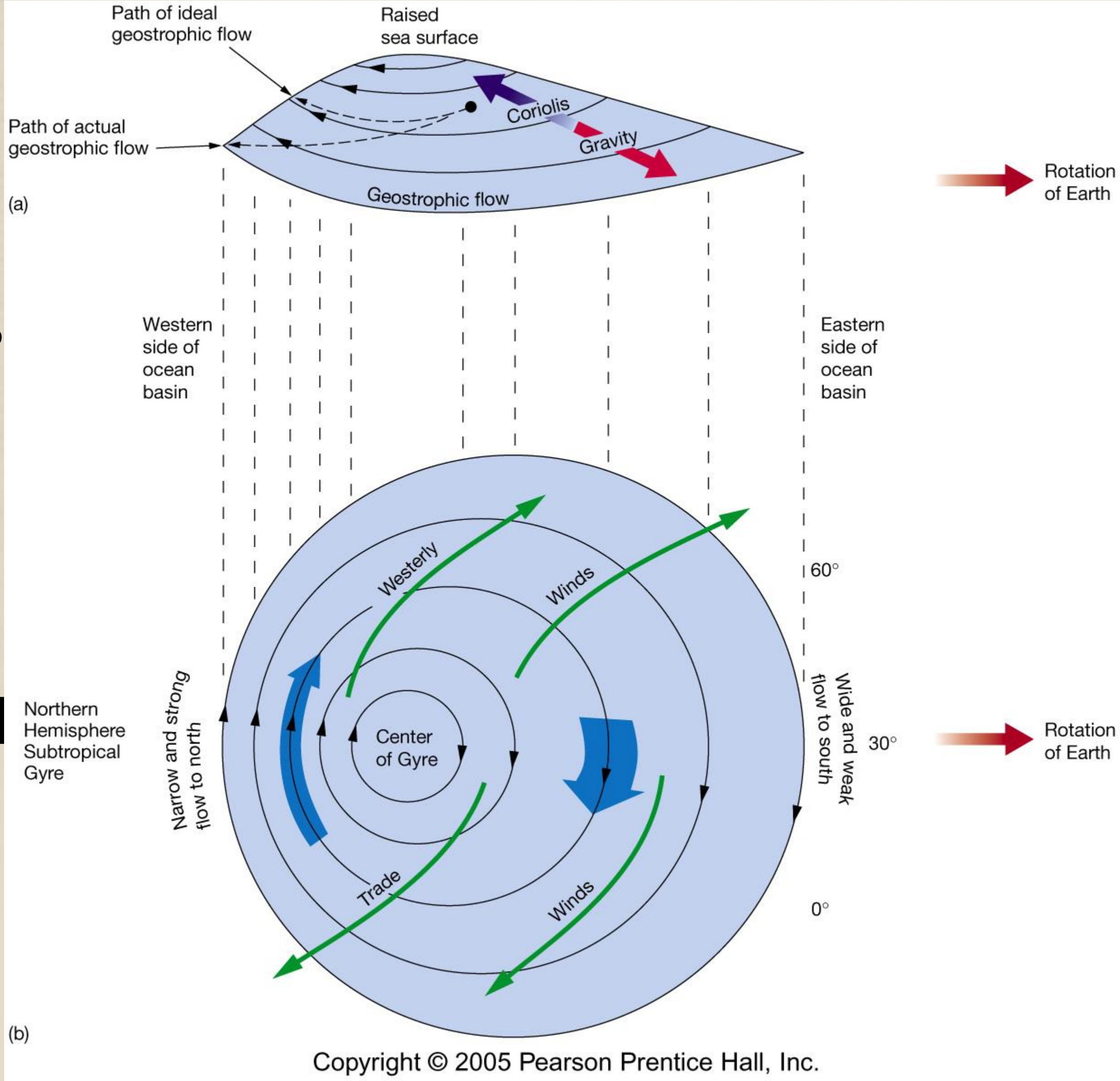
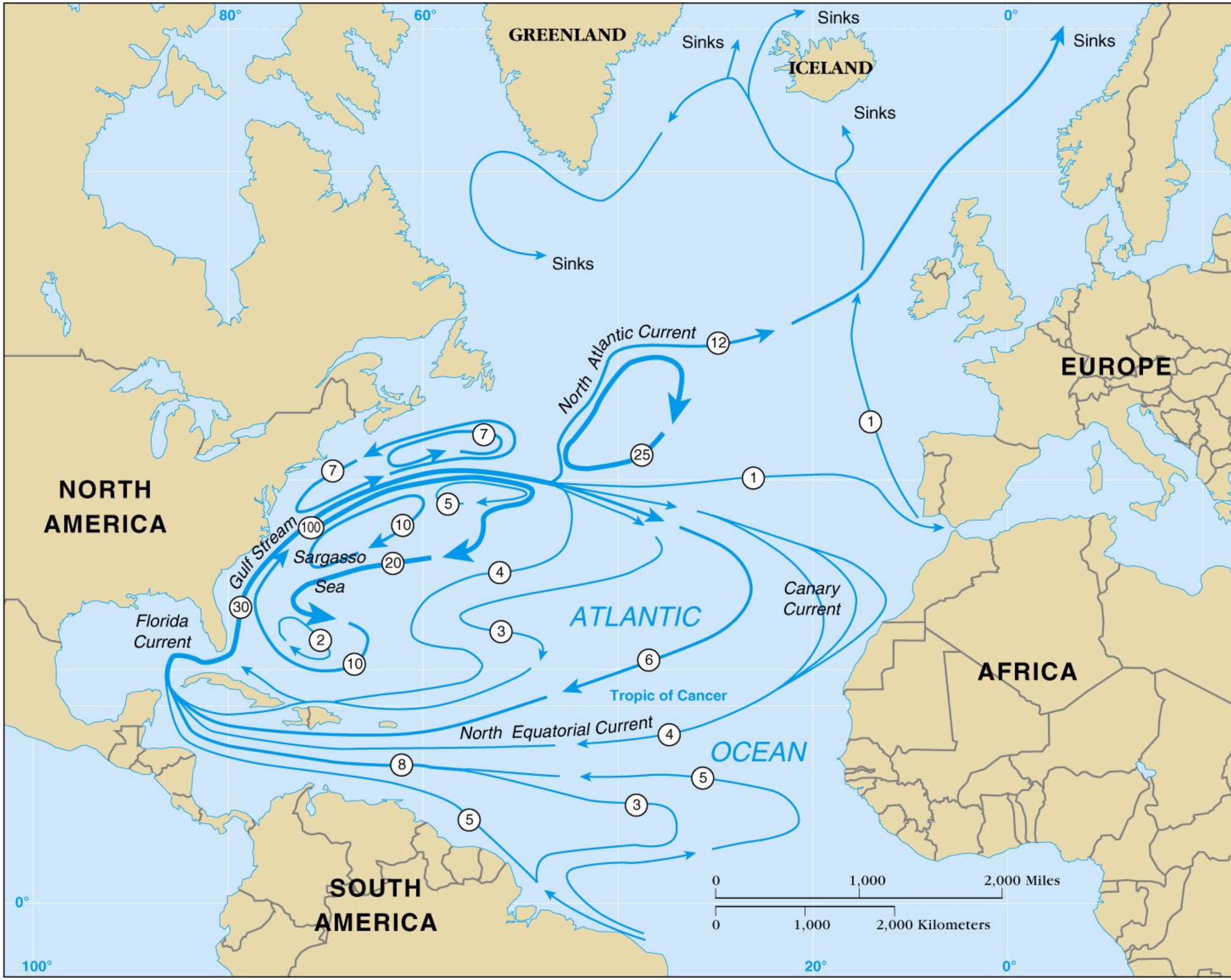


Fig. 7.7

Atlantic Ocean circulation

- North Atlantic Subtropical Gyre
- North Equatorial Current
- Gulf Stream
- North Atlantic Current
- Canary Current
- South Equatorial Current
- Atlantic Equatorial Counter Current



80°
60°
0°
GREENLAND
ICELAND
Sinks
Sinks
Sinks
Sinks
Sinks
North Atlantic Current
12
25
7
7
5
10
100
20
Gulf Stream
Sargasso
Sea
30
2
10
4
3
Florida
Current
NORTH
AMERICA
EUROPE
1
1
ATLANTIC
6
Canary
Current
AFRICA
Tropic of Cancer
North Equatorial Current
4
OCEAN
8
5
3
5
SOUTH
AMERICA
0°
100°
20°
0°
0
1,000
2,000 Miles
0
1,000
2,000 Kilometers

Fig. 7.15

- The current flow pattern in gyres is asymmetrical:
  - narrow, deep and swift currents along the basin’s western edge
  - broad, shallow slower currents along the basin’s eastern edge

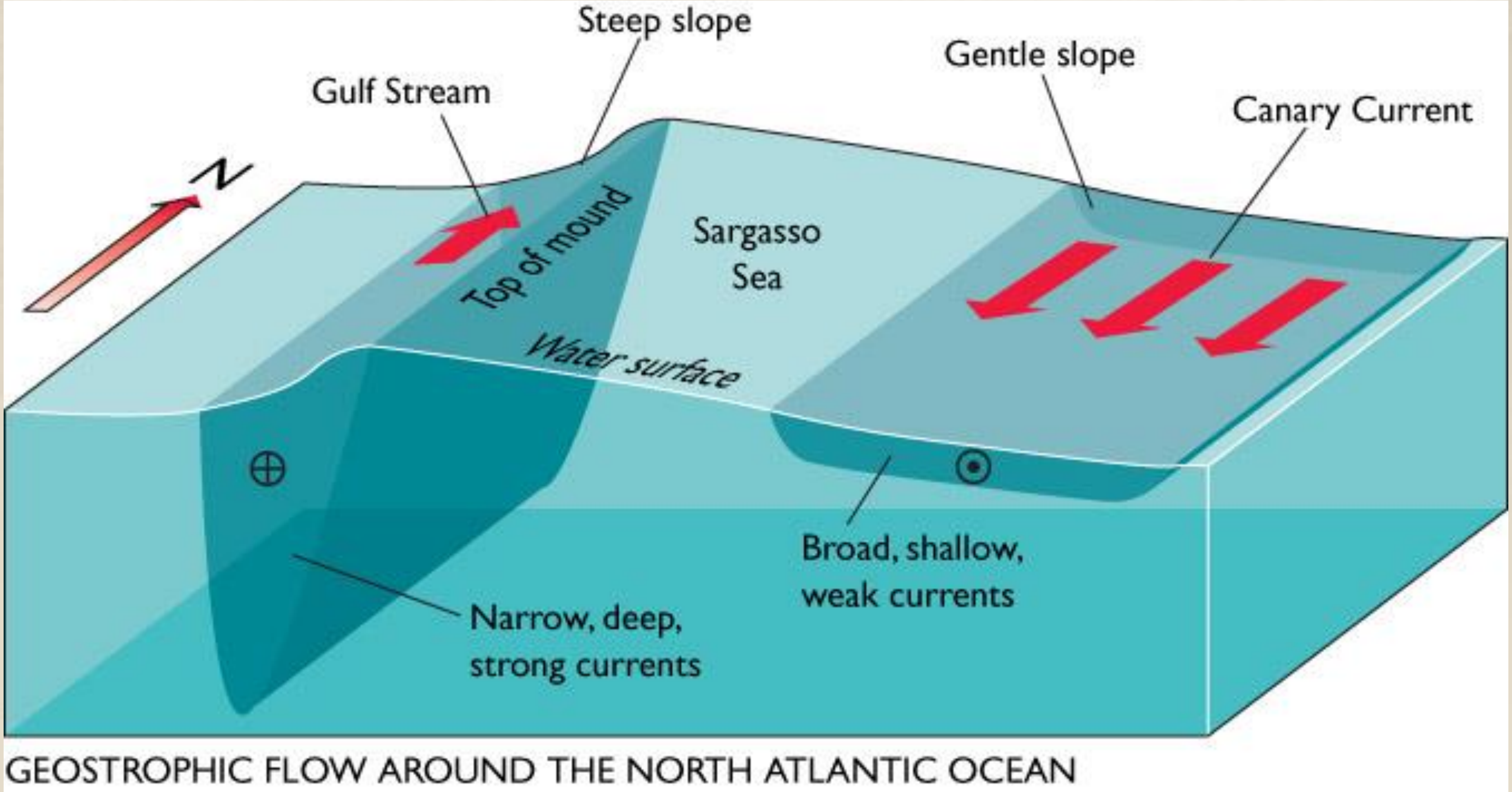


Figure 6-10 Flow Asymmetry Around Circulation Gyres

Western intensification

- Top of hill of water displaced toward west due to Earth's rotation
- Western boundary currents intensified
  - Faster
  - Narrower
  - Deeper

- The geostrophic mound is deflected to the western part of the ocean basin because of the eastward rotation of the Earth on its axis.

- The Sargasso Sea is a large lens of warm water:
  - encircled by the North Atlantic gyre
  - separated from cold waters below and laterally by a strong thermocline

(a) SARGASSUM SEAWEED

(b) THE SARGASSUM

- Western boundary currents, such as the Gulf Stream, form a **meandering** boundary.
- These boundaries separate coastal waters from warmer waters in the gyre’s center.
- Meanders can be cut off to form **warm-core** and **cold-core** rings.

Gulf Stream Meanders and Rings

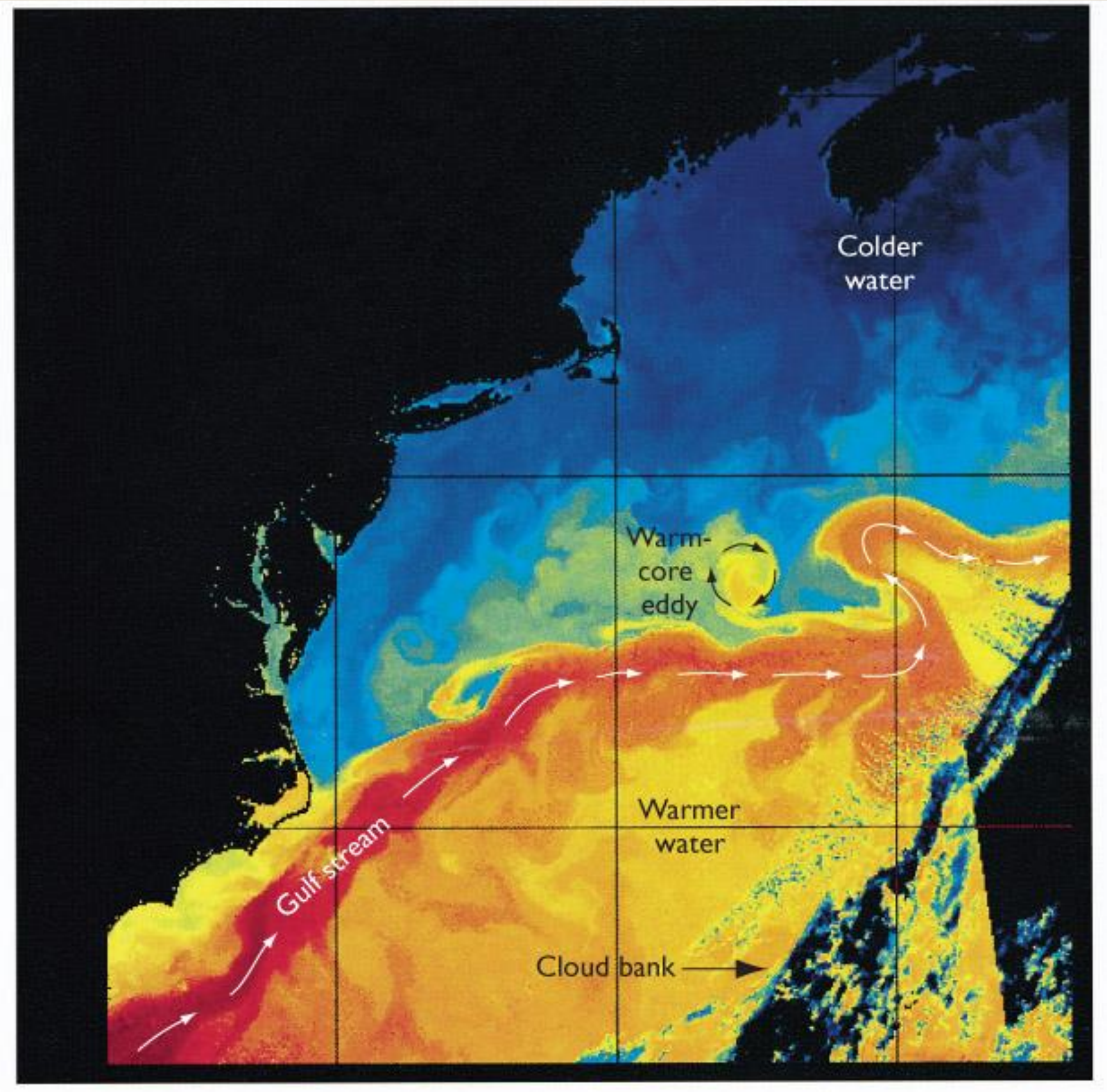


Figure 6-12a Heat Photo of Gulf Stream

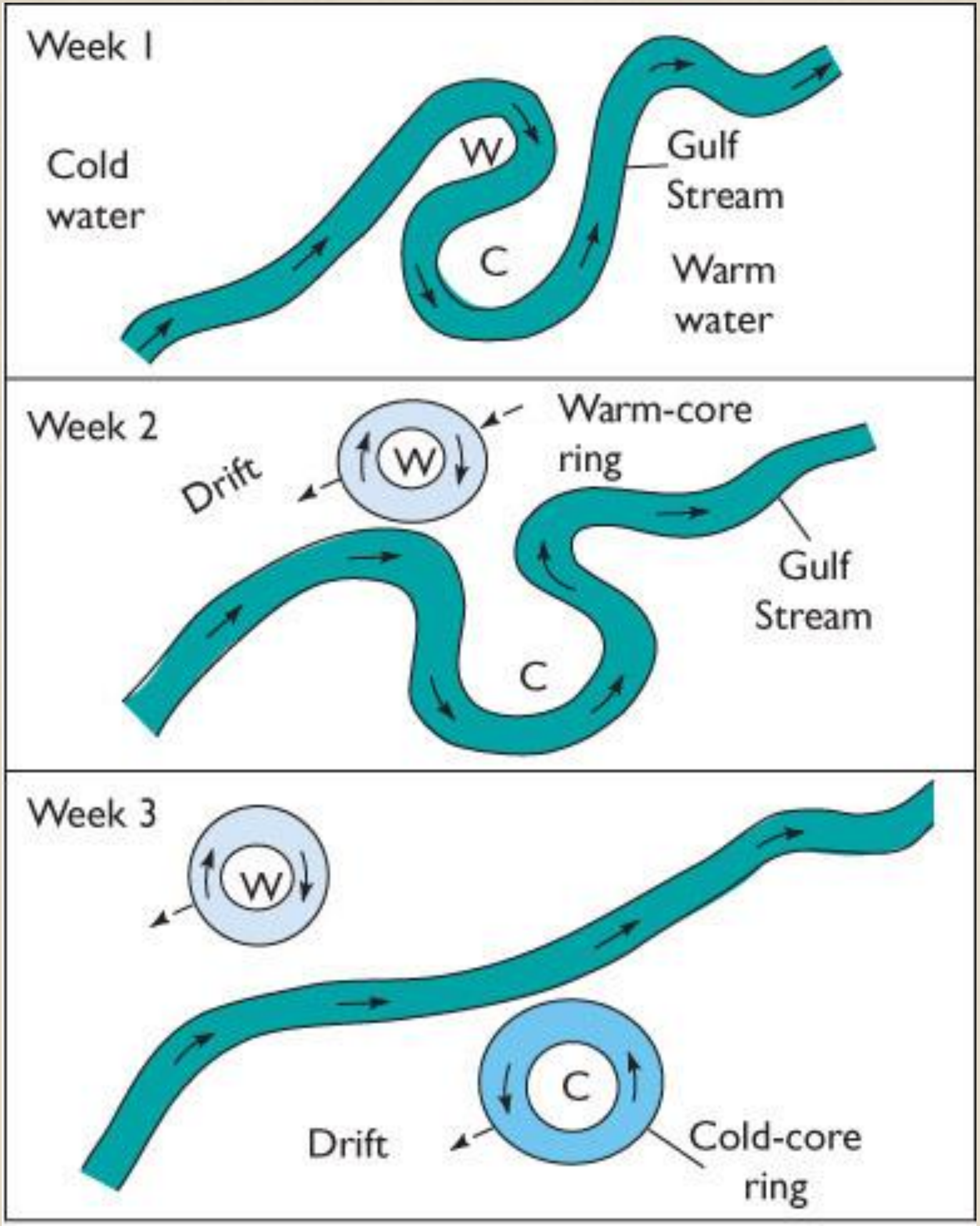


Figure 6-12b Formation of Rings

6-2 Surface Ocean Currents

Pacific Ocean circulation

- North Pacific subtropical gyre
- Kuroshio
- North Pacific Current
- California Current
- North Equatorial Current
- Alaskan Current

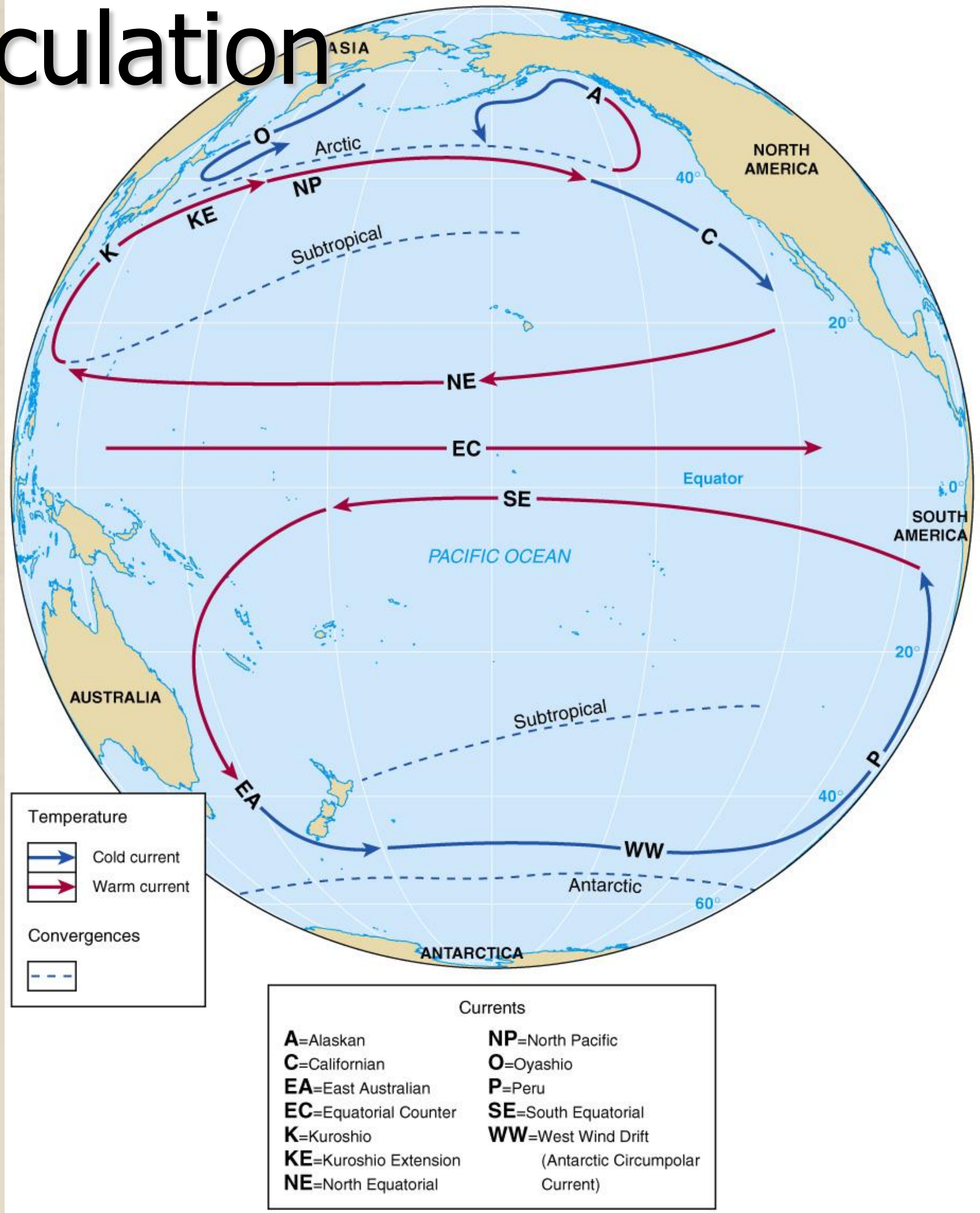


Fig. 7.17

Pacific Ocean circulation

- South Pacific subtropical gyre
- East Australian Current
- Antarctic Circumpolar Current
- Peru Current
- South Equatorial Current
- Equatorial Counter Current

Indian Ocean circulation

- Indian Ocean subtropical gyre
- Agulhas Current
- North and South Equatorial Currents
- Antarctic Circumpolar Current
- West Australian Current
- Equatorial Countercurrent
- Leeuwin Current
- Monsoon (seasonal) winds
- Winds shift from winter to summer
- Southwest Monsoon Current replaces North Equatorial Current
- Somali Current

Indian Ocean circulation

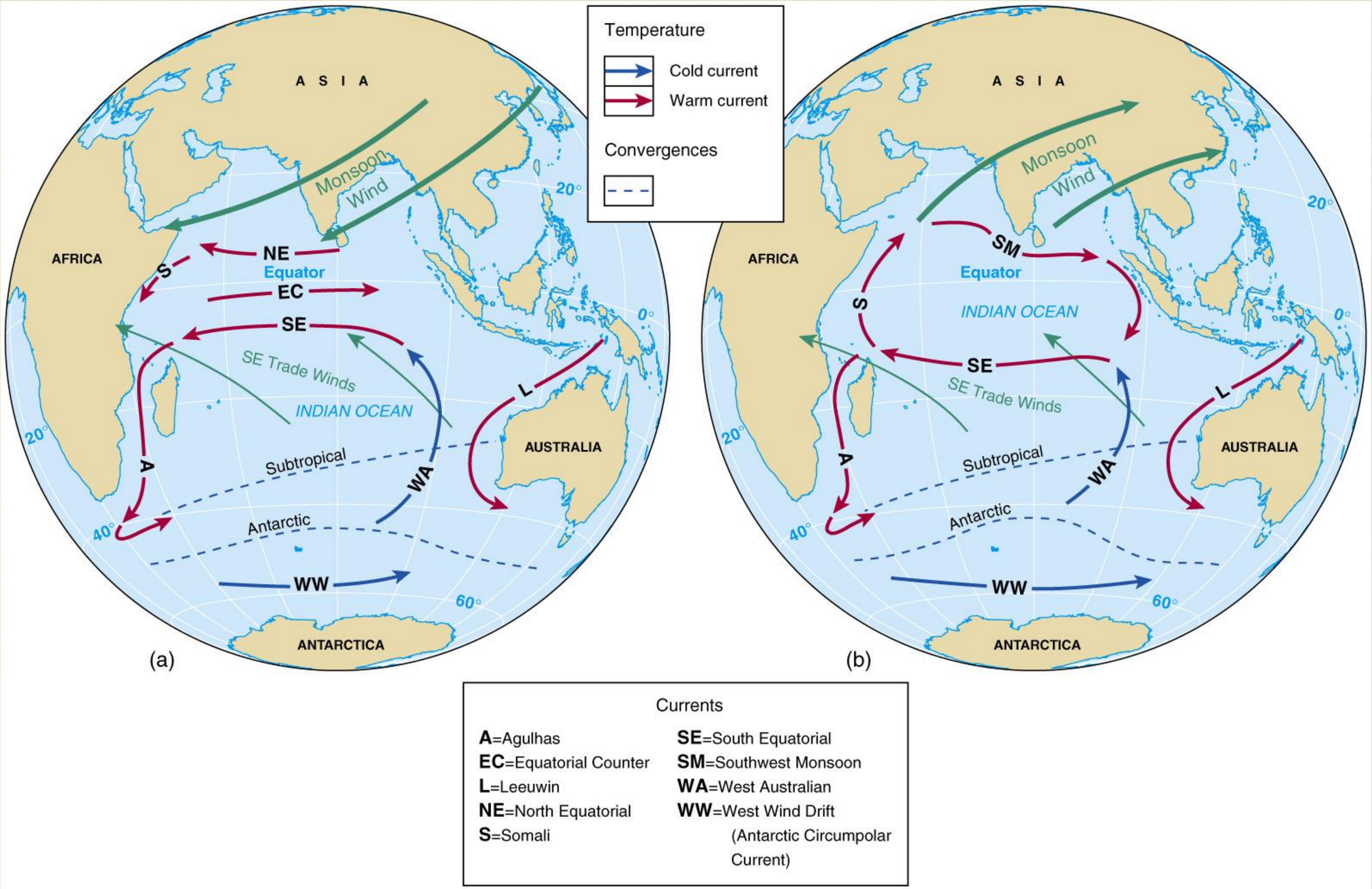
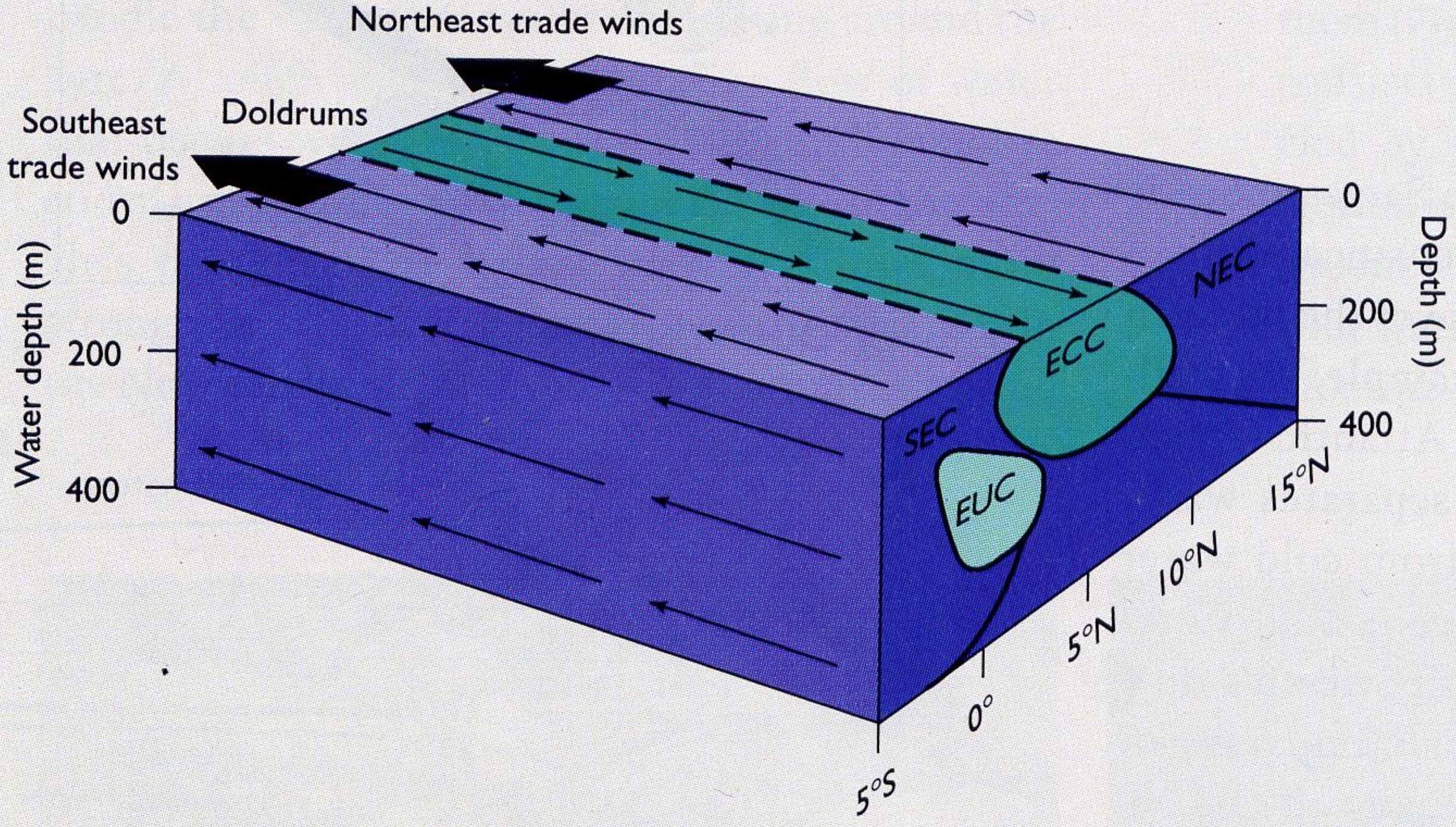
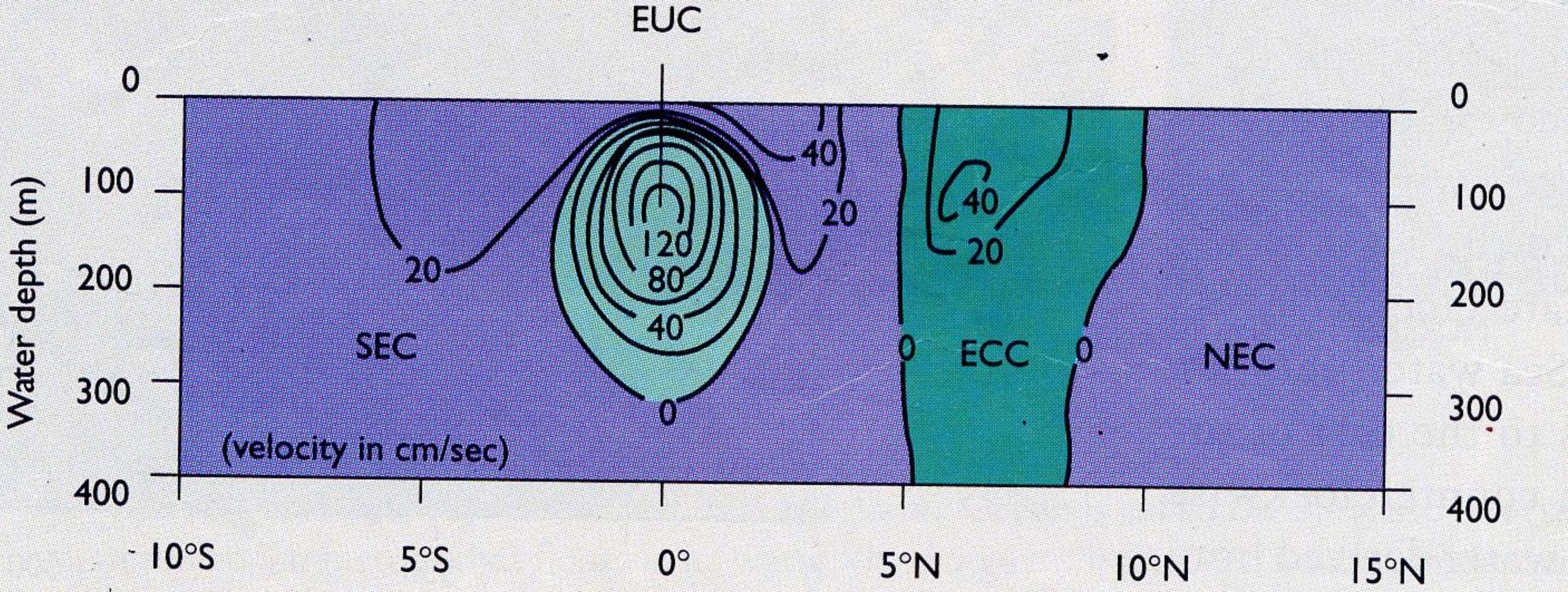


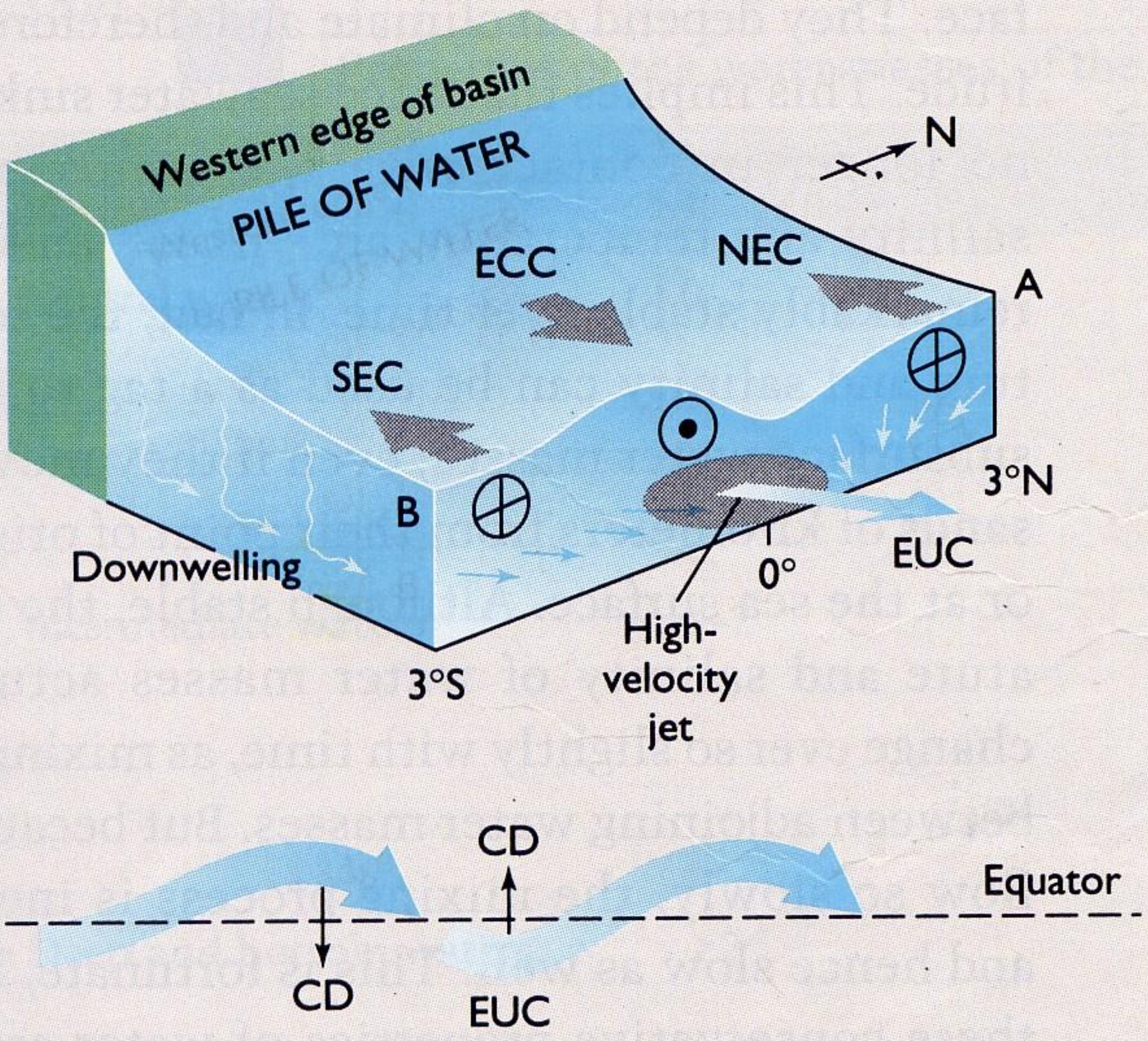
Fig. 7.23



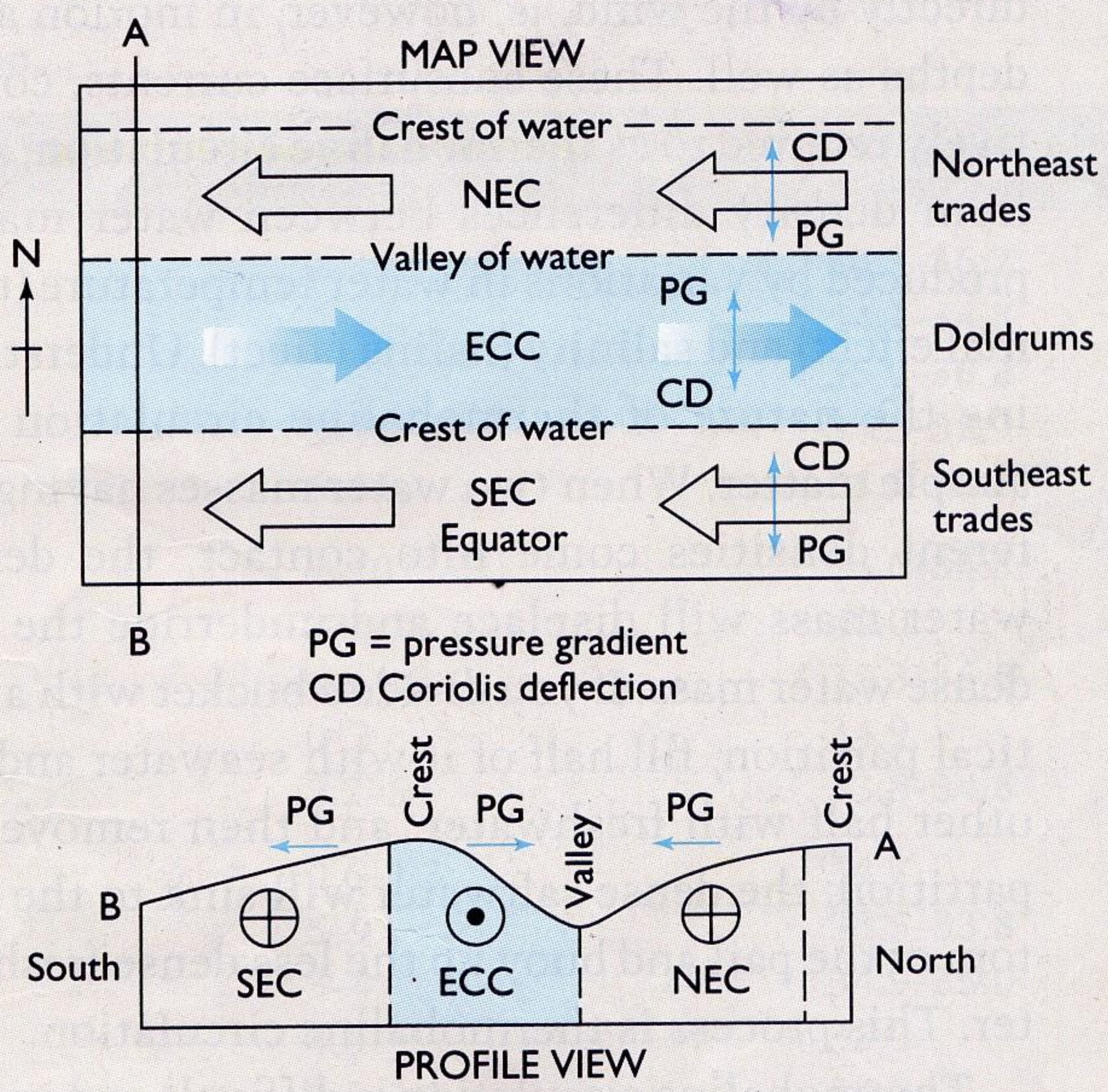
(a) GENERALIZED SCHEME OF EQUATORIAL PACIFIC CURRENTS



(b) VELOCITY PROFILE ACROSS EQUATORIAL PACIFIC



(a) ORIGIN OF EQUATORIAL UNDERCURRENT (EUC).



(b) ORIGIN OF EQUATORIAL COUNTERCURRENT (ECC)

- **Thermohaline circulation** is:
  - a density driven flow of water
  - generated by differences in salinity or temperature
- Water at the surface is exposed to changes in:
  - Salinity, through evaporation or precipitation
  - Temperature, through cooling or heating

Thermohaline circulation

- Below the pycnocline
- 90% of all ocean water
- Slow velocity
- Movement caused by differences in density (temperature and salinity)
  - Cooler seawater denser
  - Saltier seawater denser

- Salinity and temperature vary little once water sinks and becomes isolated from the atmosphere.

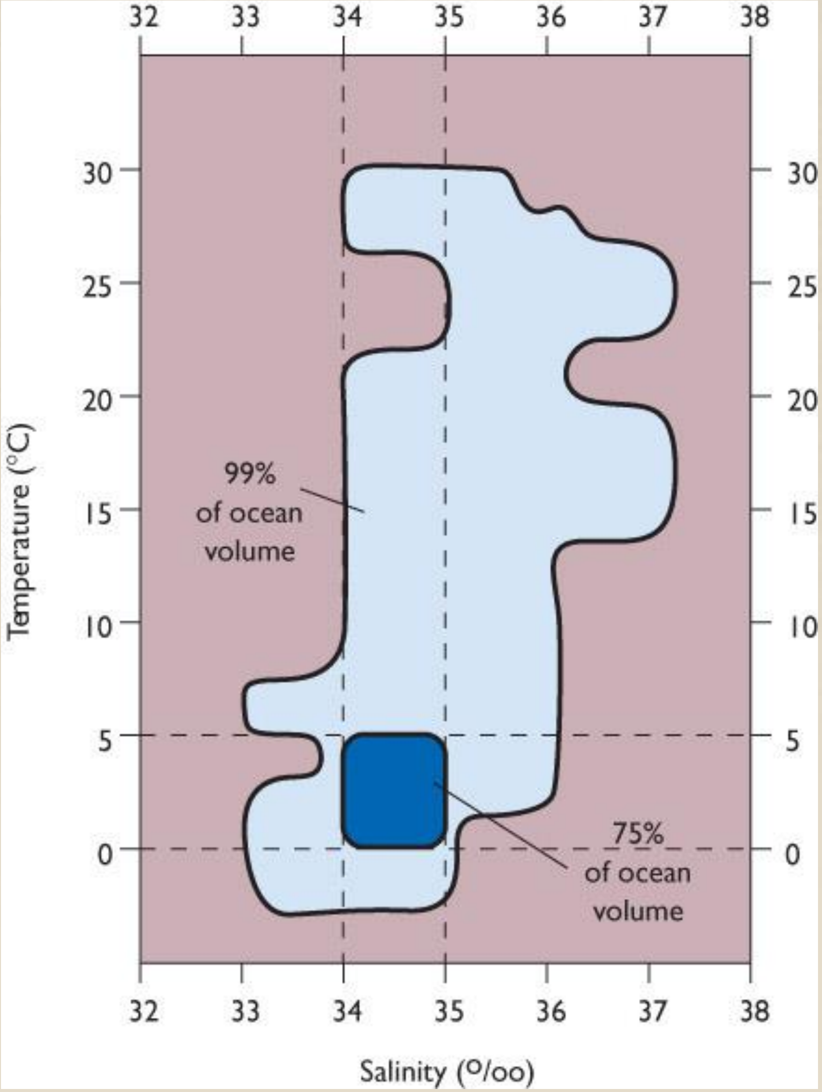


Figure 6-13 temperature and salinity range of seawater

6-3 Deep-Ocean Circulation

- Based upon depth, surface water masses can be broadly classified as:
  - Central waters (from 0 to 1 km)
  - Intermediate waters (from 1 to 2 km)
  - Deep and bottom waters (greater than 2 km)

TABLE **6-2**

Properties of the water masses of the global ocean

Water-Mass Types	Approximate Depth Range (km)	Water Mass*	Temperature (°C)**	Salinity (‰)
Central waters	0–1	SPCW	9–20	34.3–36.2
		NPCW	7–20	34.1–34.8
		NACW	4–20	35.0–36.8
		SACW	5–18	34.3–35.9
		SICW	6–16	34.5–35.6
Intermediate waters	1–2	NPIW	4–10	34.0–34.5
		RSIW	23	40.0
		MIW	6–11.9	35.3–36.5
		AIW	0–2	34.9
		AAIW	2.2–5	33.8–34.6
Deep and bottom waters	>2	CoW	0.6–1.3	34.7
		PSW	5–9	33.5–33.8
		NADW	3–4	34.9–35.0
		AADW	4.0	35.0
		NABW	2.5–3.1	34.9
		AABW	−0.4	34.6

*See Figure 6–15 for explanations of these abbreviations.
**See Appendix II for Fahrenheit equivalents.
Source: Adapted from M. U. Sverdrup, M. W. Johnson, and R. M. Fleming, *The Oceans: Their Physics, Chemistry, and General Biology* (Englewood Cliffs, N.J.: Prentice-Hall, 1942; A. Defant, *Physical Oceanography*, vol. 1 (Oxford: Pergamon Press, 1961); and O. I. Mamaev, *Temperature-Salinity Analysis of World Ocean Waters* (Amsterdam: Elsevier, 1975).

- Most deep and bottom water originate at the surface where cooling and increased salinity raise their density until they sink.

- Ocean basins interconnect and exchange water with each other and with the surface.

- Inter-ocean basin circulation and exchange between surface and deep water are driven mostly by waters of the North Atlantic.

- The major thermohaline currents appear to flow mainly equatorward. This is because :
  - they originate in the polar regions
  - their outward flow is confined between the continents

- Warmer water (>10^{o}C) is confined between 45^{o} north and south latitude.

- Poleward of 45^{o}, density of water increases because of:
  - declining temperature
  - increased salinity caused by evaporation or ice formation

Thermohaline circulation

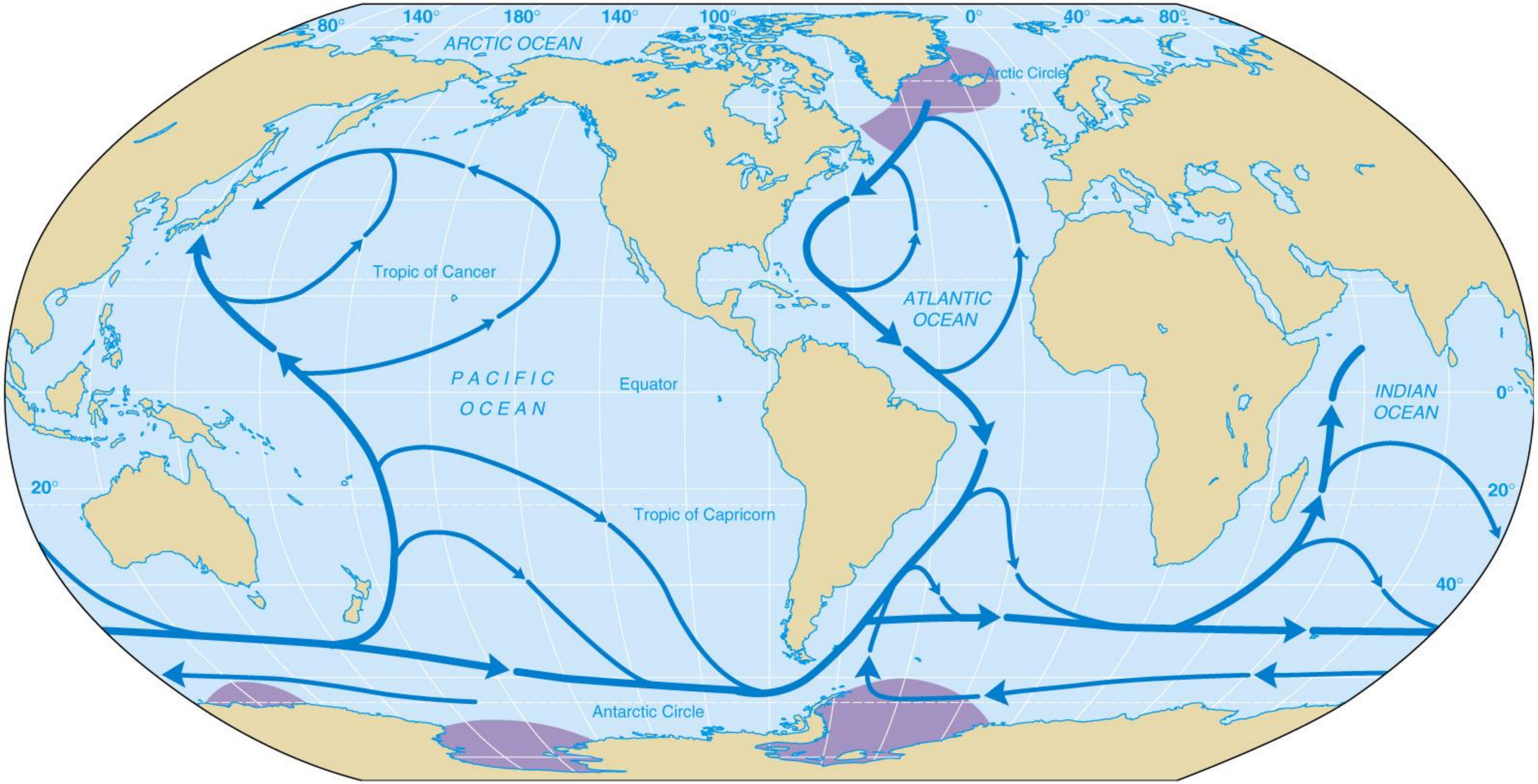
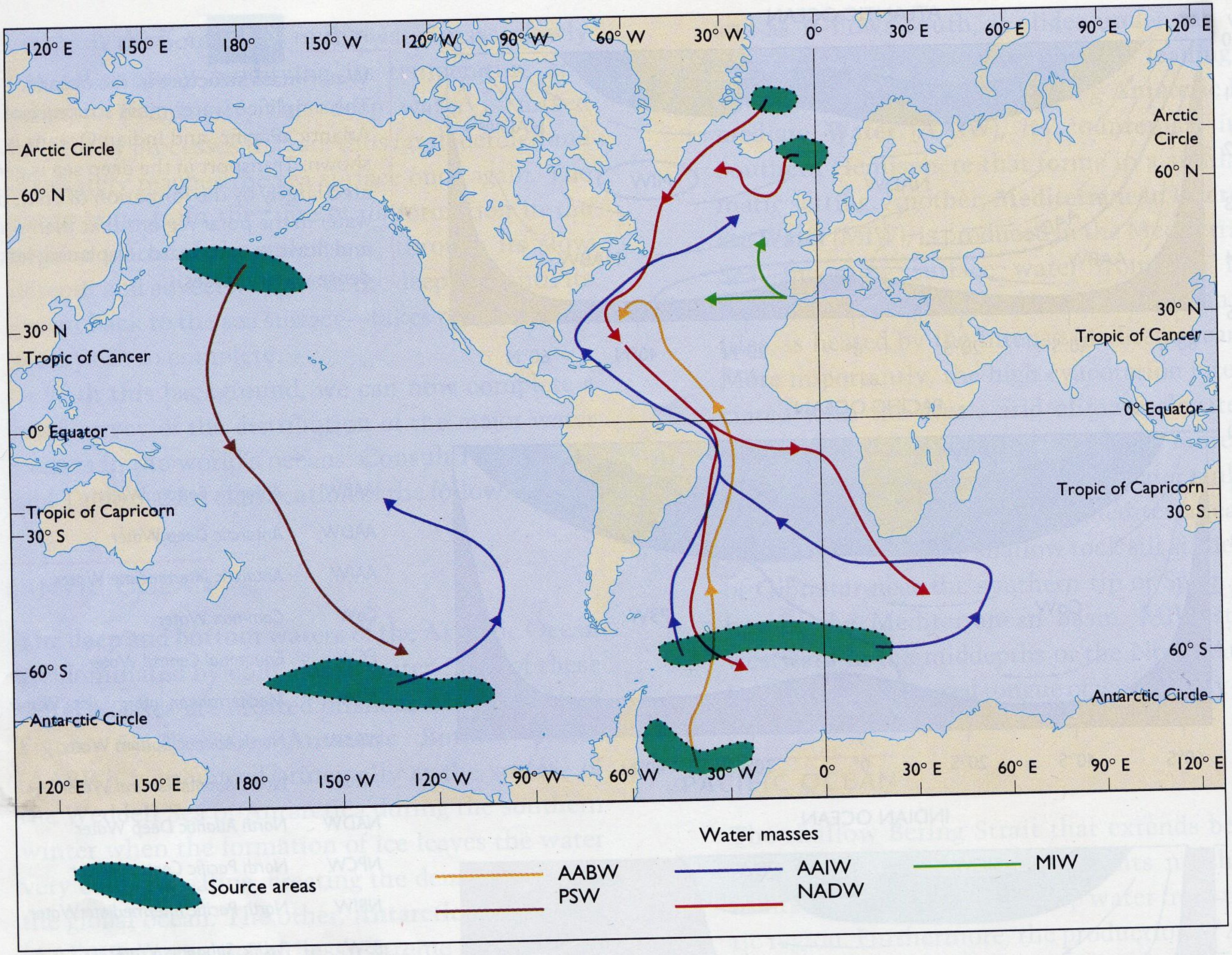


Fig. 7.26



(a) THERMOHALINE CIRCULATION

- The water sinks to a density-appropriate level and then slowly flows equatorward across the basin.
- Deep water gradually mixes with other water masses and eventually rises to the surface.

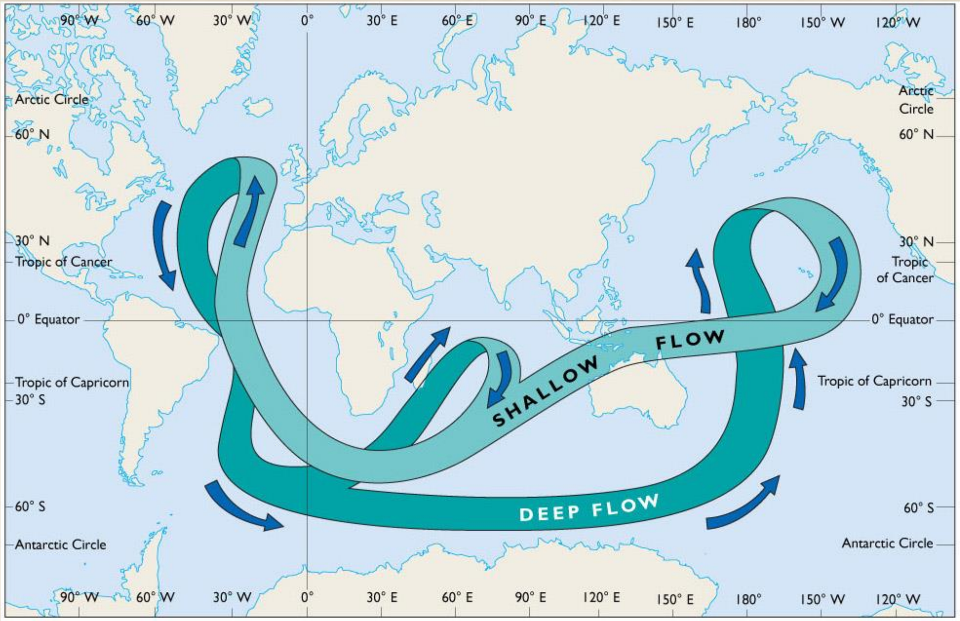


Figure 6-16b Surface and Deep Water Exchange

- The Atlantic Ocean has the most complex ocean stratification containing the following layers:
  - Antarctic Bottom Water
  - Antarctic Deep Water
  - North Atlantic Deep Water
  - Arctic Intermediate Water
  - Mediterranean Intermediate Water

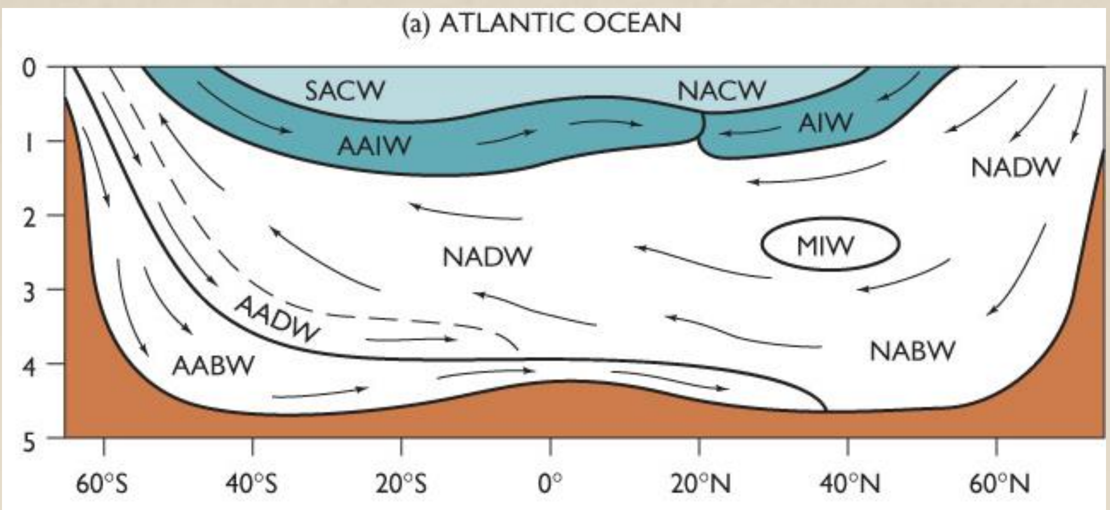
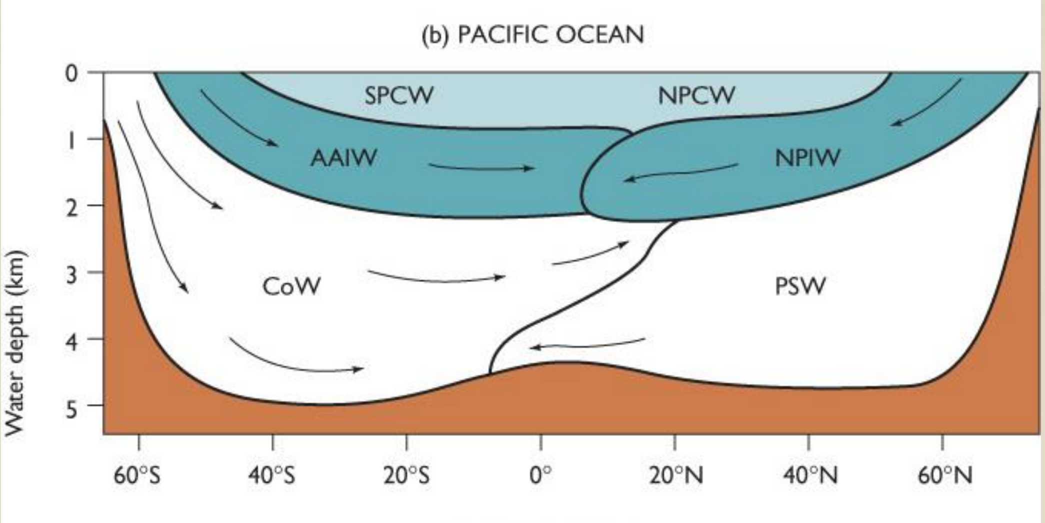
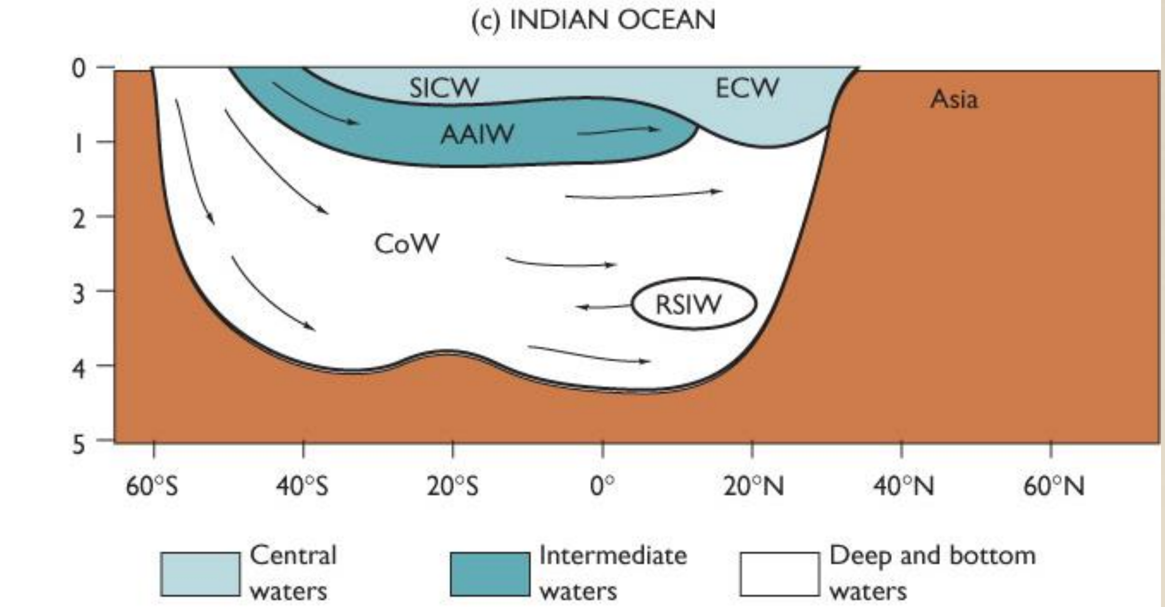


Figure 6-15a

- The Pacific Ocean:
  - has a less complex stratification than the North Atlantic
  - is weakly layered
  - displays sluggish circulation
  - is remarkably uniform below 2000m



- The Indian Ocean has the simplest stratification consisting of:
  - Common Water
  - Antarctic Intermediate Water
  - Red Sea Intermediate Water



There are two principle ways to measure currents:

- Eulerian method employs current meters fixed to the sea bottom.

- Langrangian method employs:
    - Drifters
    - Drogues
    - Floats.
  - These are set loose at the sea surface or at predetermined depths and tracked acoustically.