Oceanography, An Invitation to Marine Science | 9e
Tom Garrison

8

Circulation of the Atmosphere

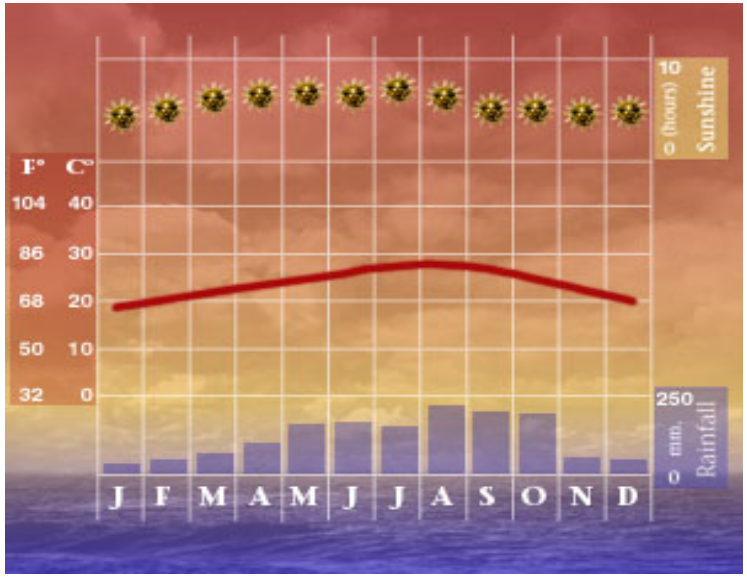
Key Concepts

- Earth's ocean and atmosphere are unevenly heated by the sun—more solar energy is absorbed near the equator than near the poles
  - The atmosphere circulates in response to this difference in heating
- The atmosphere circulates in six large circuits (three in each hemisphere)
- Storms can form between two air masses (frontal storms) or within one air mass (tropical cyclones)

The Atmosphere and Ocean Interact with Each Other

- The interactions of the atmosphere and ocean influence our weather and climate.
- Wind – mass movement of air
- Atmosphere – gases that envelop Earth

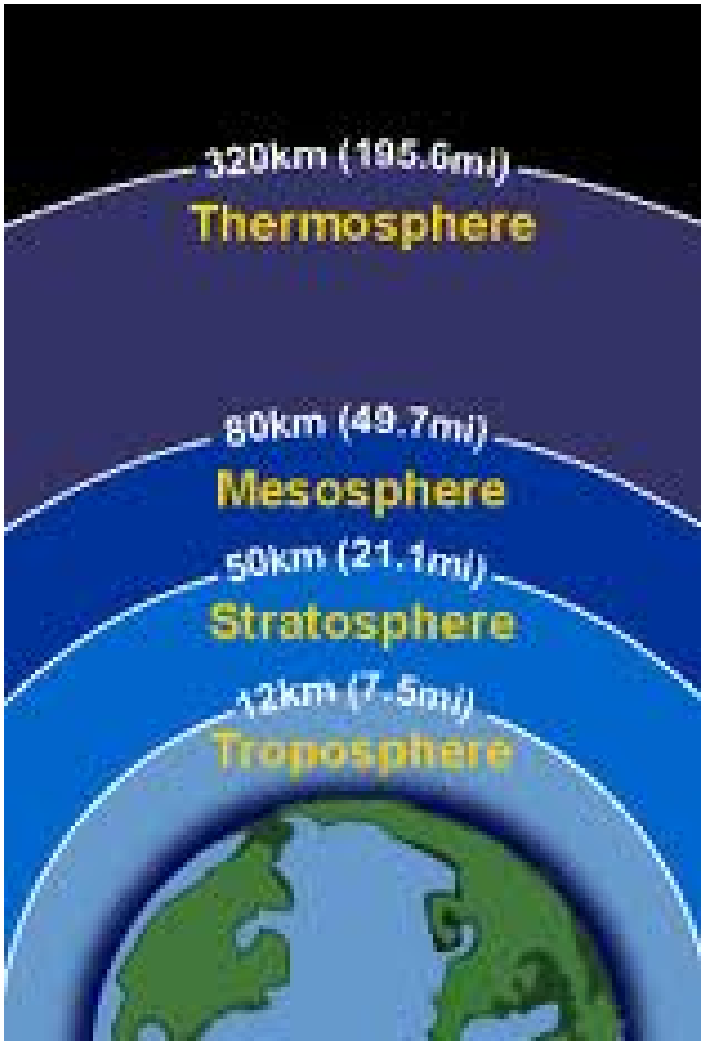
Weather: state of the atmosphere at a specific time and place



Climate: the long-term statistical view of weather

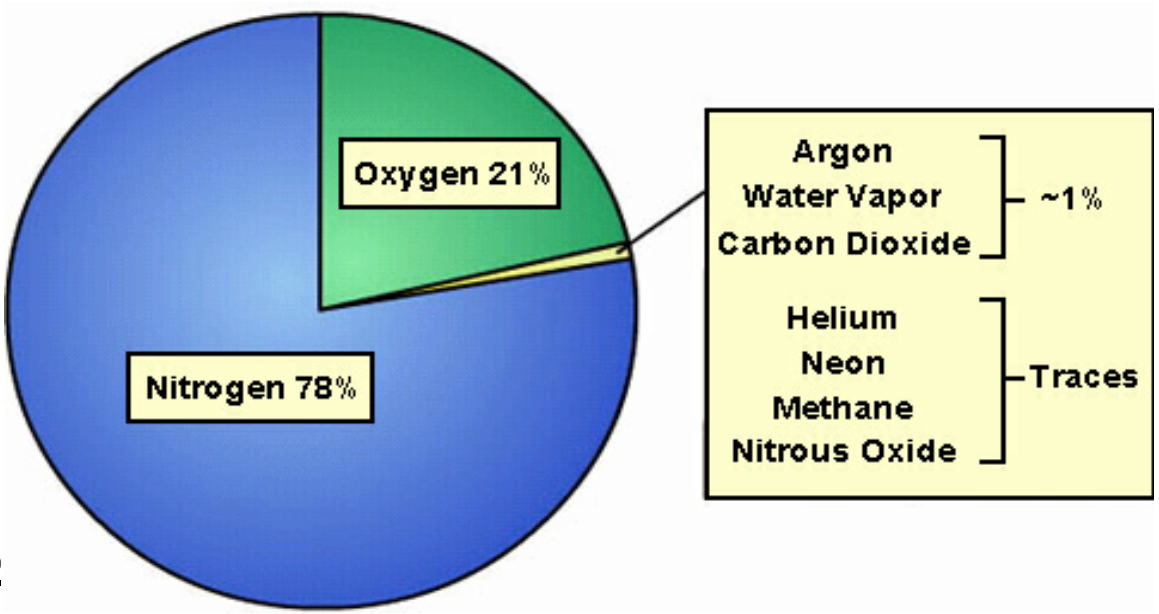
- Average temperature
- Average precipitation

- **Atmosphere**: volume of gases, water vapor, and particles surrounding the Earth
- 4 layers
  - Troposphere: the layer of the atmosphere closest to the Earth
    - Weather occurs here
  - Stratosphere: the second layer of the atmosphere
    - The Ozone (O_3) layer exists here
  - Mesosphere: the 3rd layer
  - Thermosphere: the 4th layer



Troposphere Is Composed Mainly of Nitrogen, Oxygen, and Water Vapor

- **The lower atmosphere is a fairly homogeneous mixture of gases.**



  - **Nitrogen = 78%**
  - **Oxygen = 21%**
  - **Other compounds = less than 1 %**

Atmosphere Is Composed Mainly of Nitrogen, Oxygen, and Water Vapor

- *Water vapor* can occupy up to 4% volume of air
  - Enters air through evaporation
  - If evaporation is high, percentage of water vapor will be higher.
- Temperature and water content influence air density
- Warm air can hold more water vapor than cold air
- Precipitation results from air rising and cooling

Expansion and Compression of Air

Density = mass/volume

Warm air is less dense than cold air

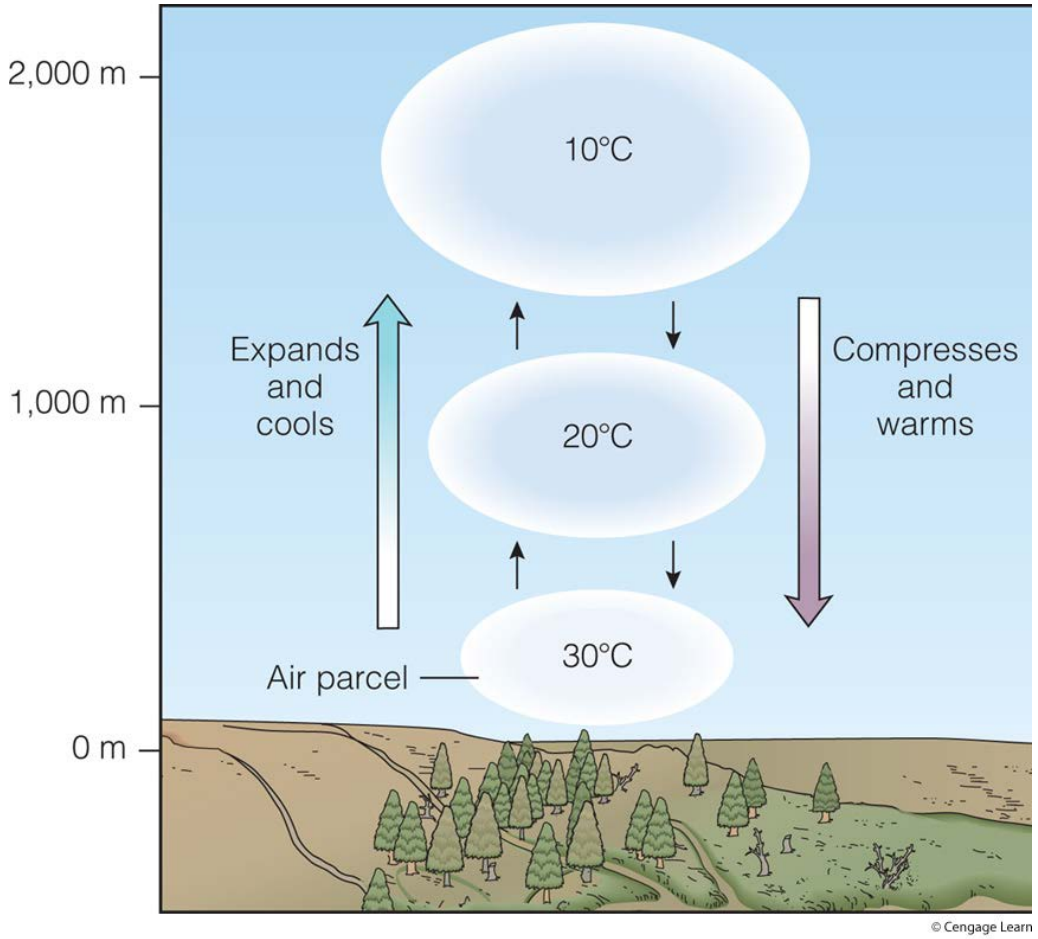
Humid air is less dense than dry air at the same temperature

Water vapor has less mass than nitrogen and oxygen

Water vapor rises, expands, and cools

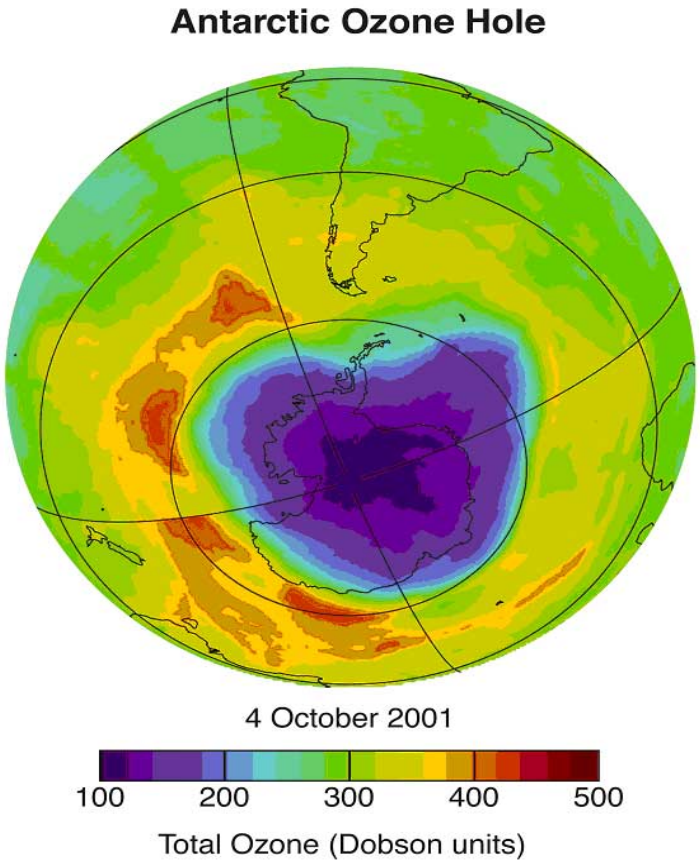
Cold air holds less water

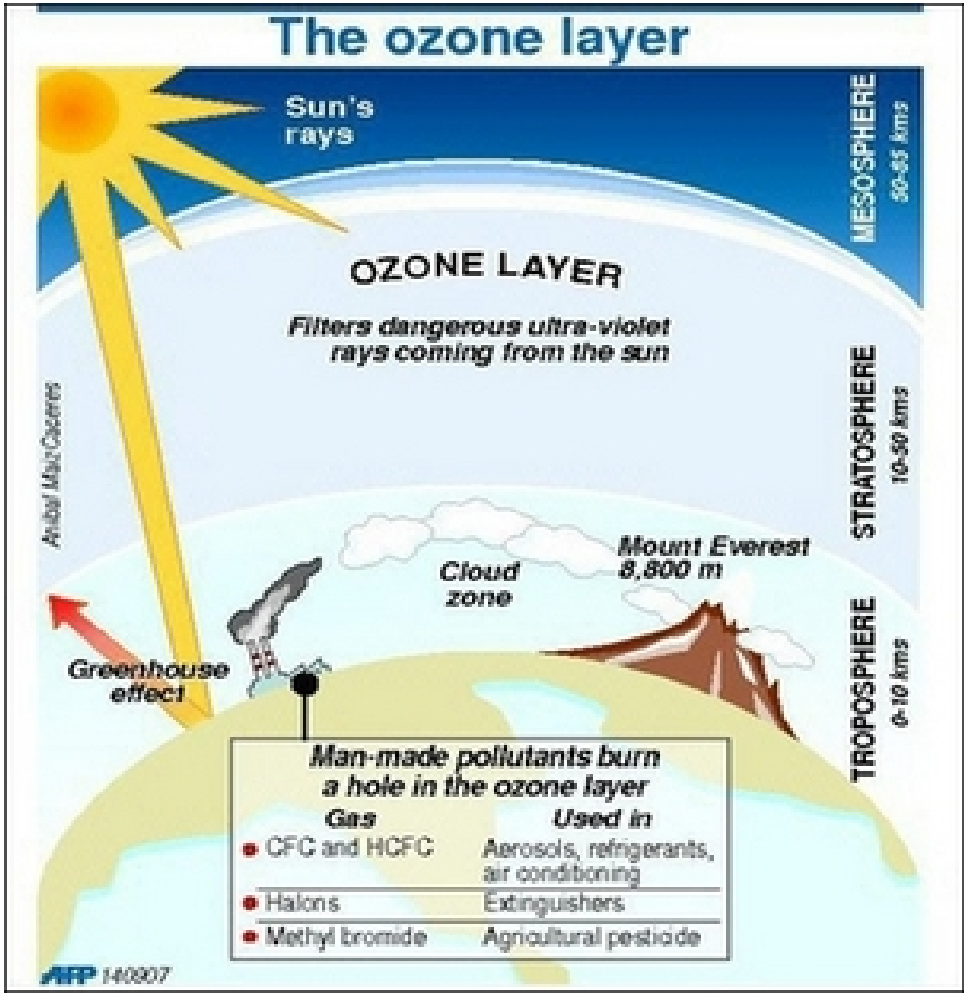
It condenses and comes down as precipitation



The Stratosphere and the Ozone Layer

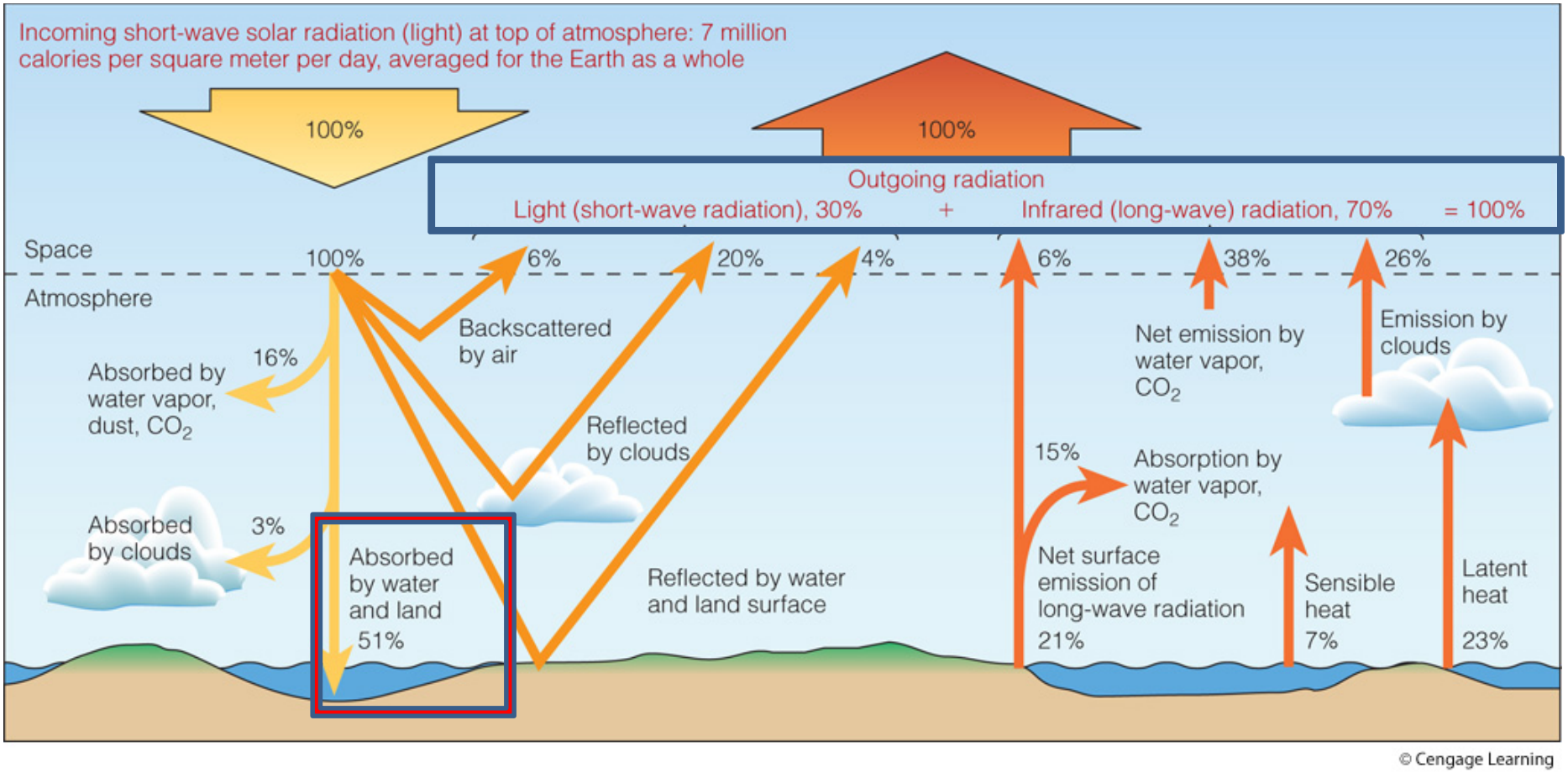
- Ozone Layer: Blocks UV rays from hitting the Earth
  - Ozone = O_3
  - Hole (“thinning”) in the Ozone Layer over the poles
  - Allows more UV rays to reach the Earth





Atmosphere Moves in Response to Uneven Solar Heating and Earth's Rotation

- Earth's heat budget

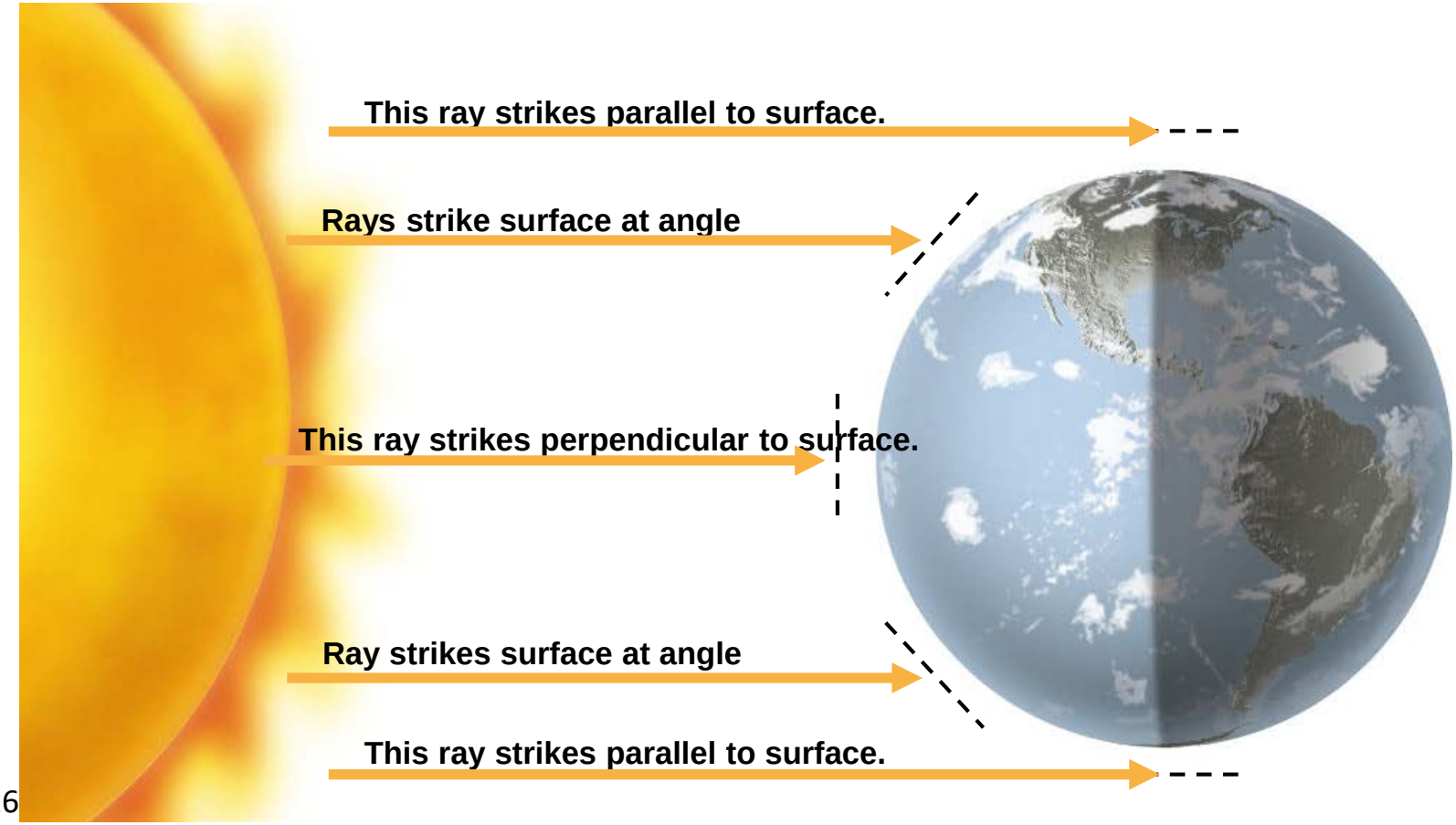


How Solar Energy Input Varies with Latitude

Sun's rays hit the Earth at varying angles – more direct at the equator.

Equal amounts of sunlight are spread over a greater surface area near the poles than in the tropics.

Ice near the poles reflects much of the energy that reaches the surface.

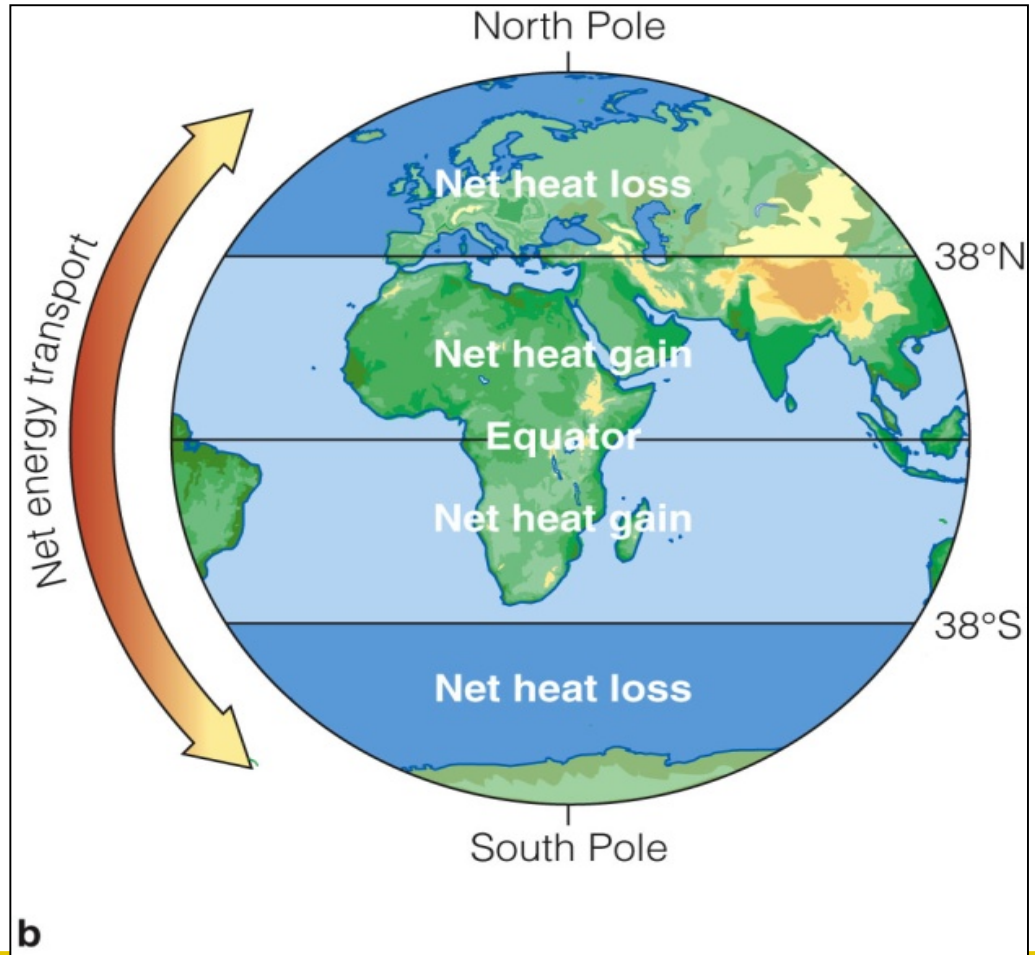


The Solar Heating of Earth Varies with Latitude

Earth as a whole is in thermal equilibrium, but different latitudes are not.

Polar latitudes lose more heat to space than they gain

Tropical latitudes gain more heat than they lose



Only at about 38° N and 38° S latitudes does the amount of radiation received equal the amount lost.

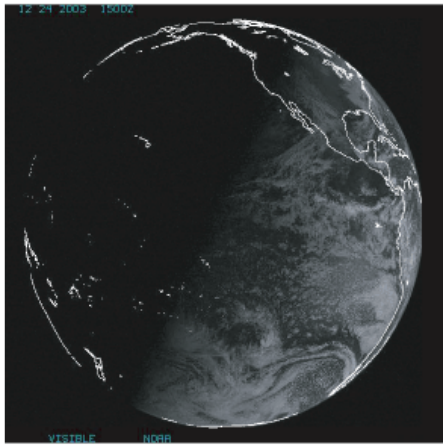
Since the area of heat gained equals the area of heat lost, Earth's total heat budget is balanced.

Spring (sun aims directly at equator)

Winter (Northern Hemisphere tilts away from sun)

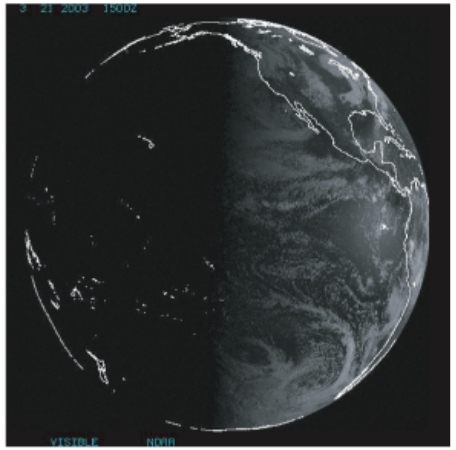
23½°

To Polaris

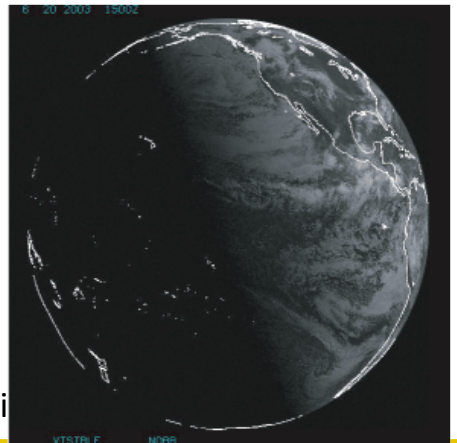


Summer (Northern Hemisphere tilts toward sun)

Fall (sun aims directly at equator)



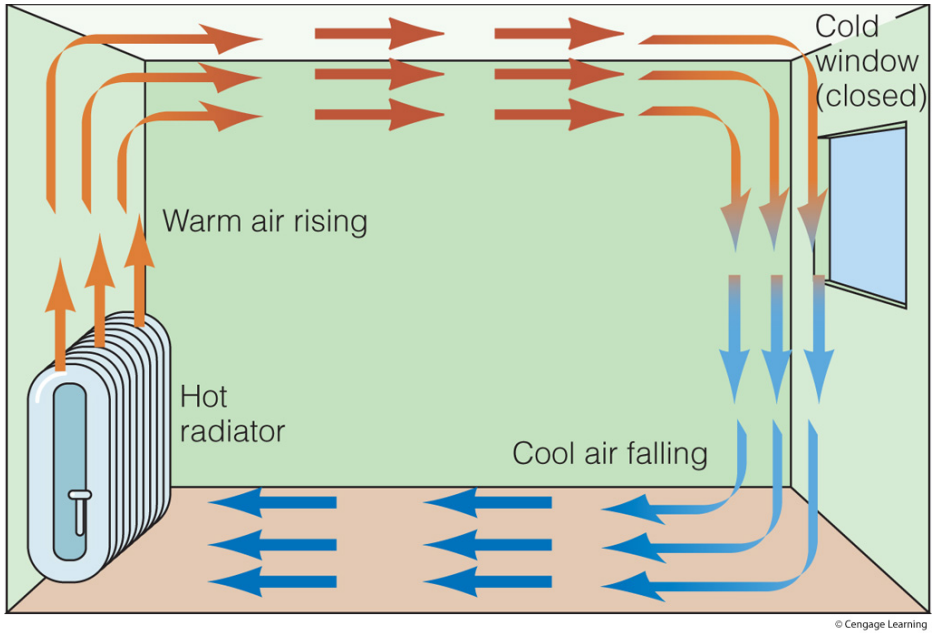
Seasons of the Northern Hemisphere



Stepped Art

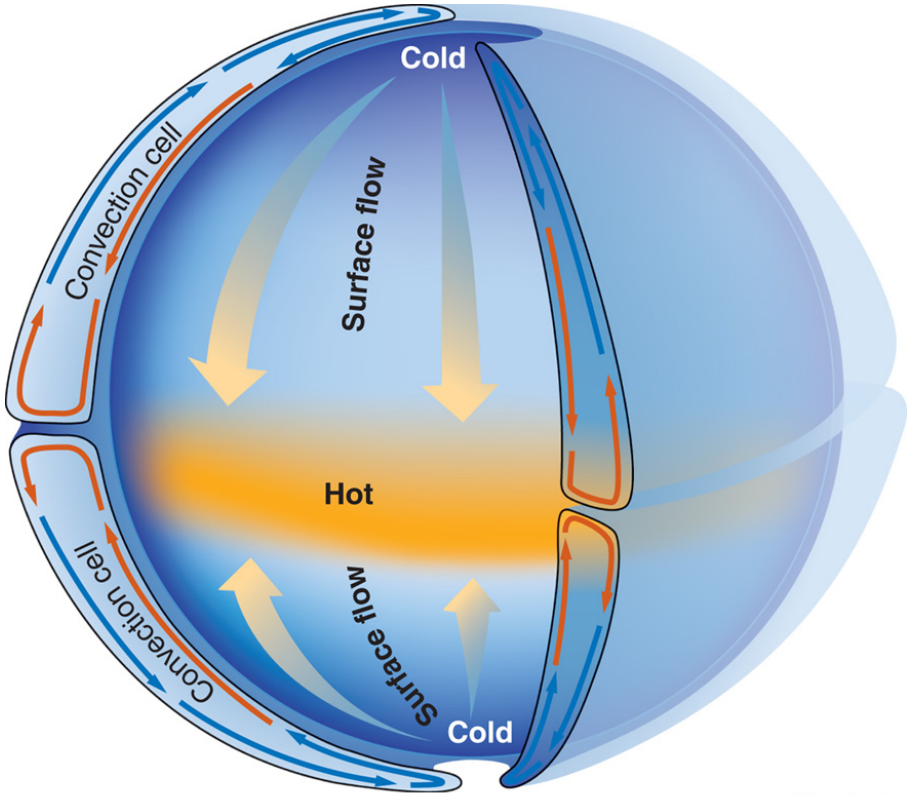
Figure 8-8 p233

Convection Currents



Warms air, expands, becomes less dense, and rises.

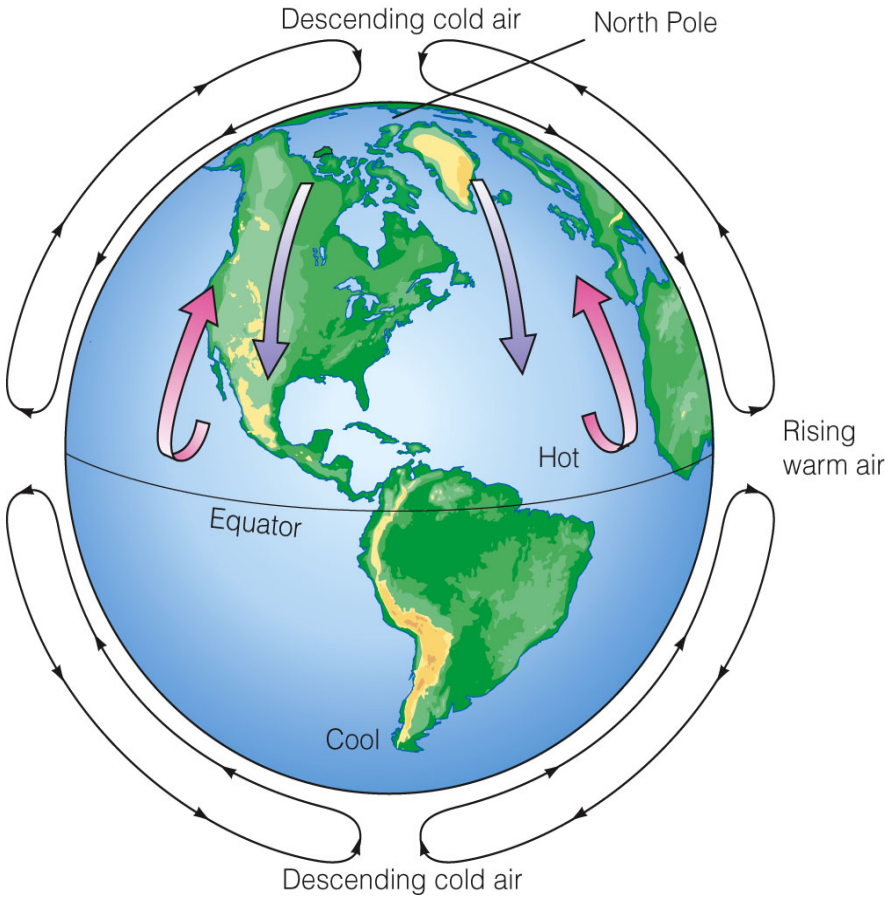
Cool air, contracts, becomes more dense, and falls.



Convection currents: circular current of air (or water) caused by difference in air density resulting from the difference in temperature

Earth's Uneven Solar Heating Results in Large-Scale Atmospheric Circulation

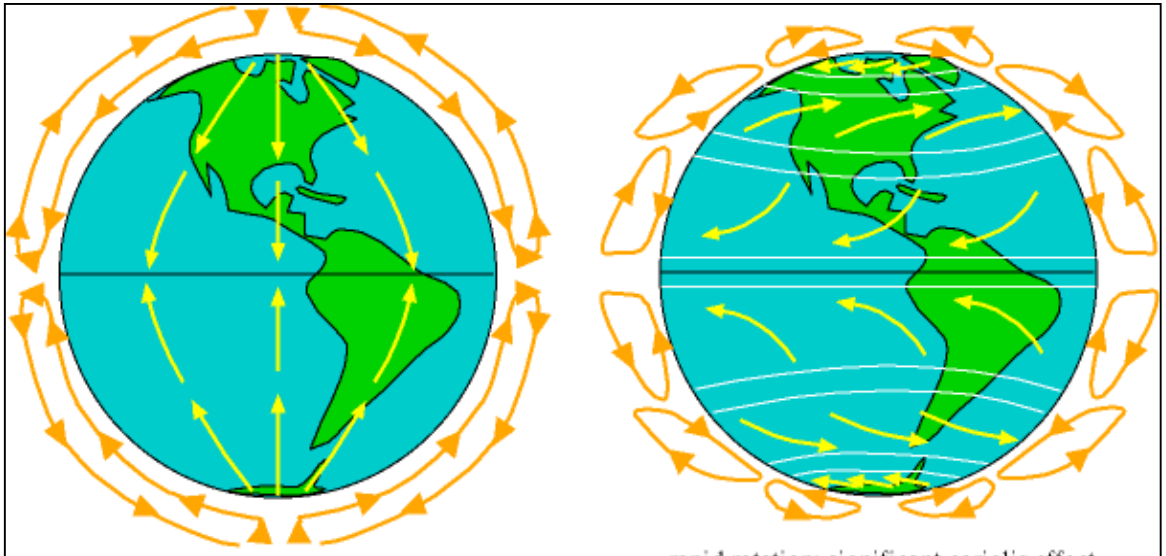
- If uneven solar heating were the only factor to be considered…
  - At the equator, air would warm, expand, and rise.
  - It would move toward the poles, where it would cool, become more dense and fall.
- However, we must consider… the Earth's rotation.



Earth's Uneven Solar Heating Results in Large-Scale Atmospheric Circulation

- Global circulation of air is controlled by 2 forces:
  1. Uneven solar heating
  2. Earth's rotation
  - The **Coriolis effect** is the observed deflection of a moving object is caused by the moving frame of reference on the spinning Earth.

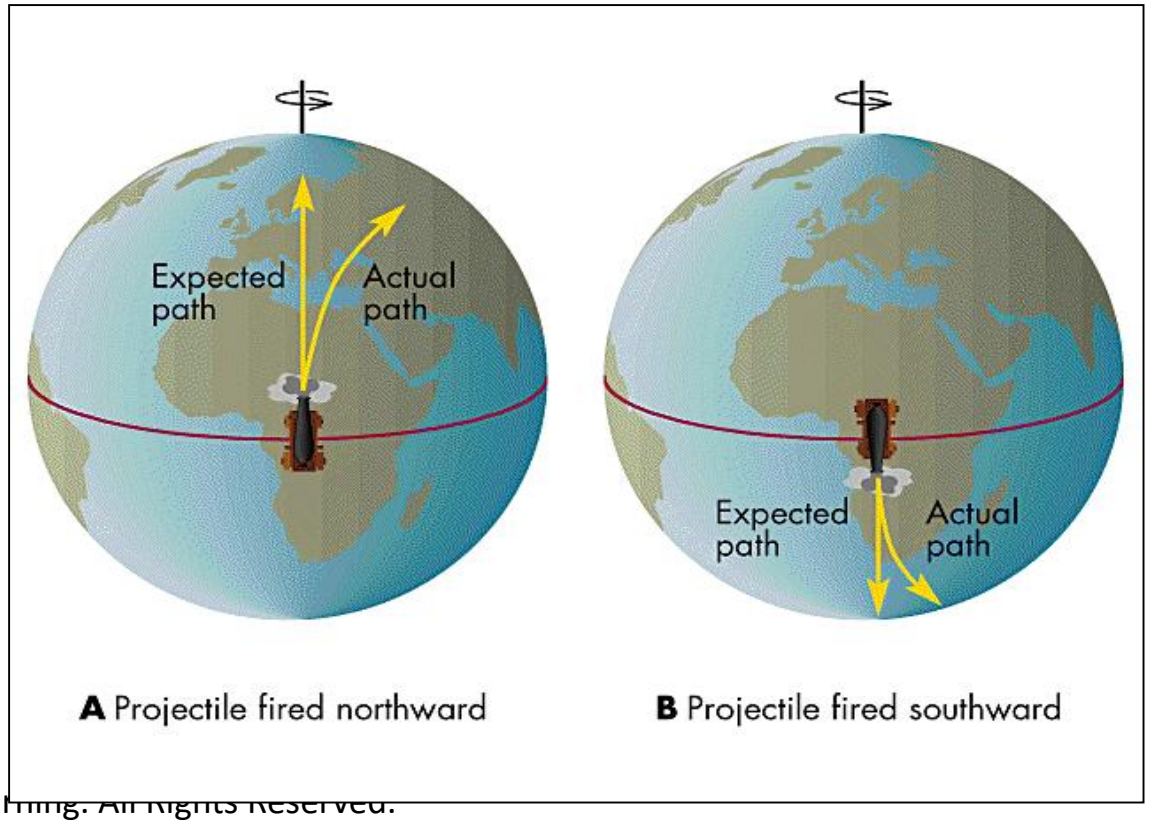
Corriolis effect



On a planet with little or no rotation, the global air circulation pattern is very simple. On a planet with rapid rotation, the coriolis effect creates large-scale eddies with belts of wind and belts of calm.

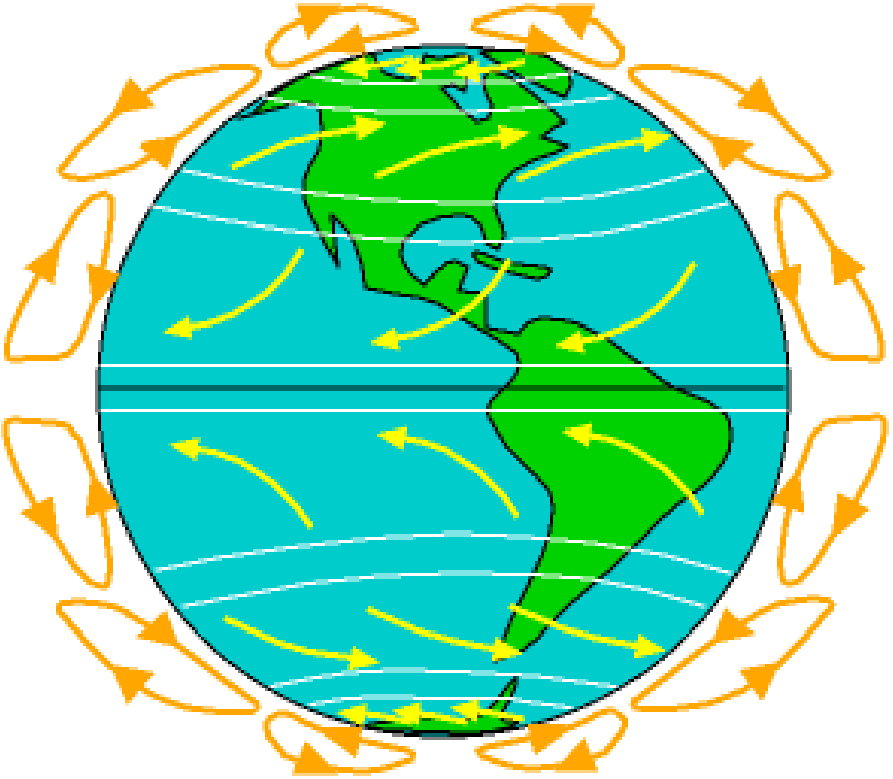
Earth's Uneven Solar Heating Results in Large-Scale Atmospheric Circulation

- **Coriolis effect**: Because the Earth is rotating, instead of objects traveling in a straight path, the air is deflected.
  - In the Northern Hemisphere air turns to the right (clockwise).
  - In the Southern Hemisphere air turns to the left (counterclockwise).



Uneven Solar Heating Results in Large-Scale Atmospheric Circulation

no rotation: no coriolis effect



rapid rotation: significant coriolis effect

On a planet with little or no rotation, the global air circulation pattern is very simple. On a planet with rapid rotation, the coriolis effect creates large-scale eddies with belts of wind and belts of calm.

Global Air Circulation in the Six-Cell Circulation Model

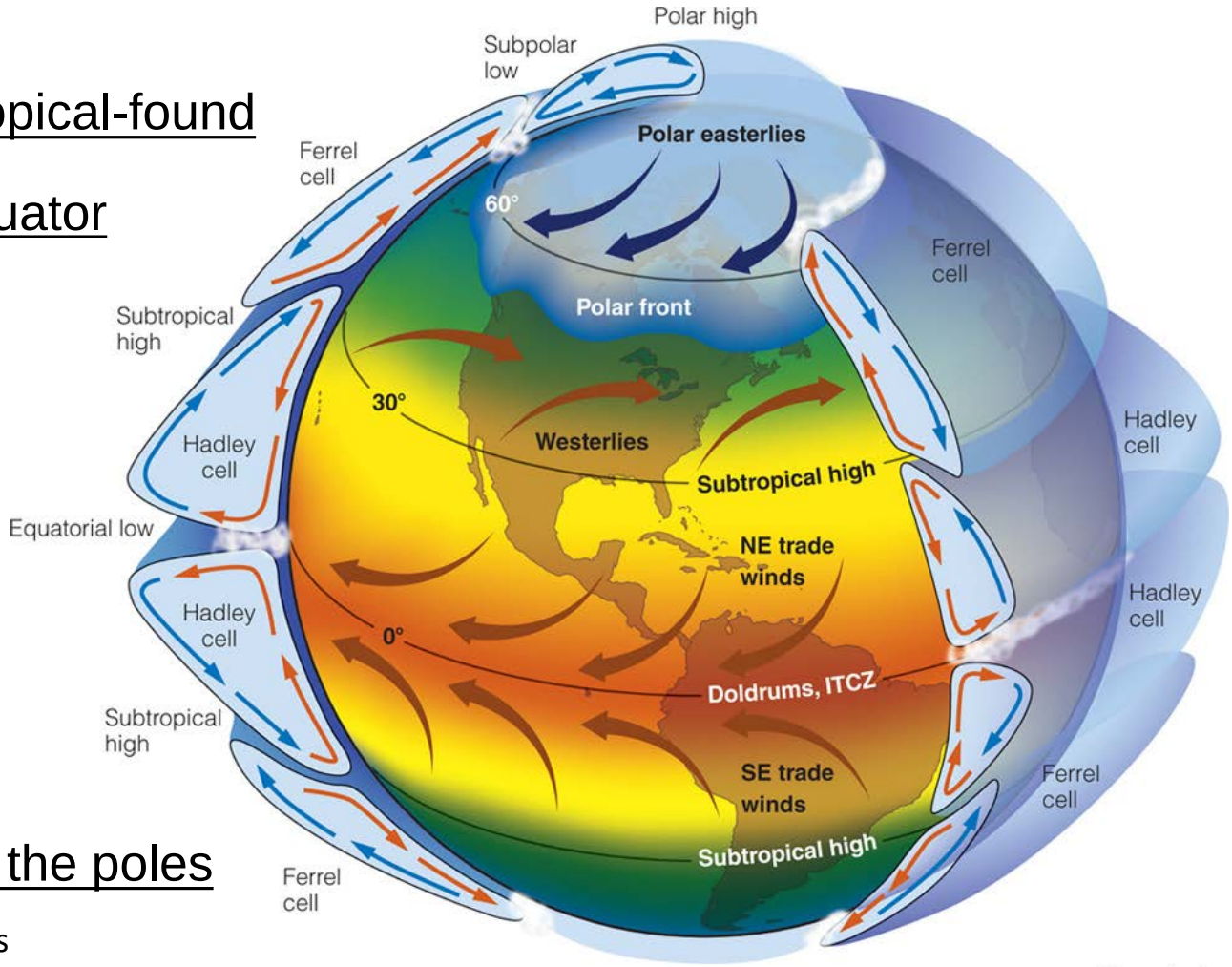
Three air cells circulate in each hemisphere

Air rises at the equator and falls at the poles, but instead of one great circuit in each hemisphere from equator to pole, there are three in each hemisphere.

Hadley cells- tropical-found on each side of the equator

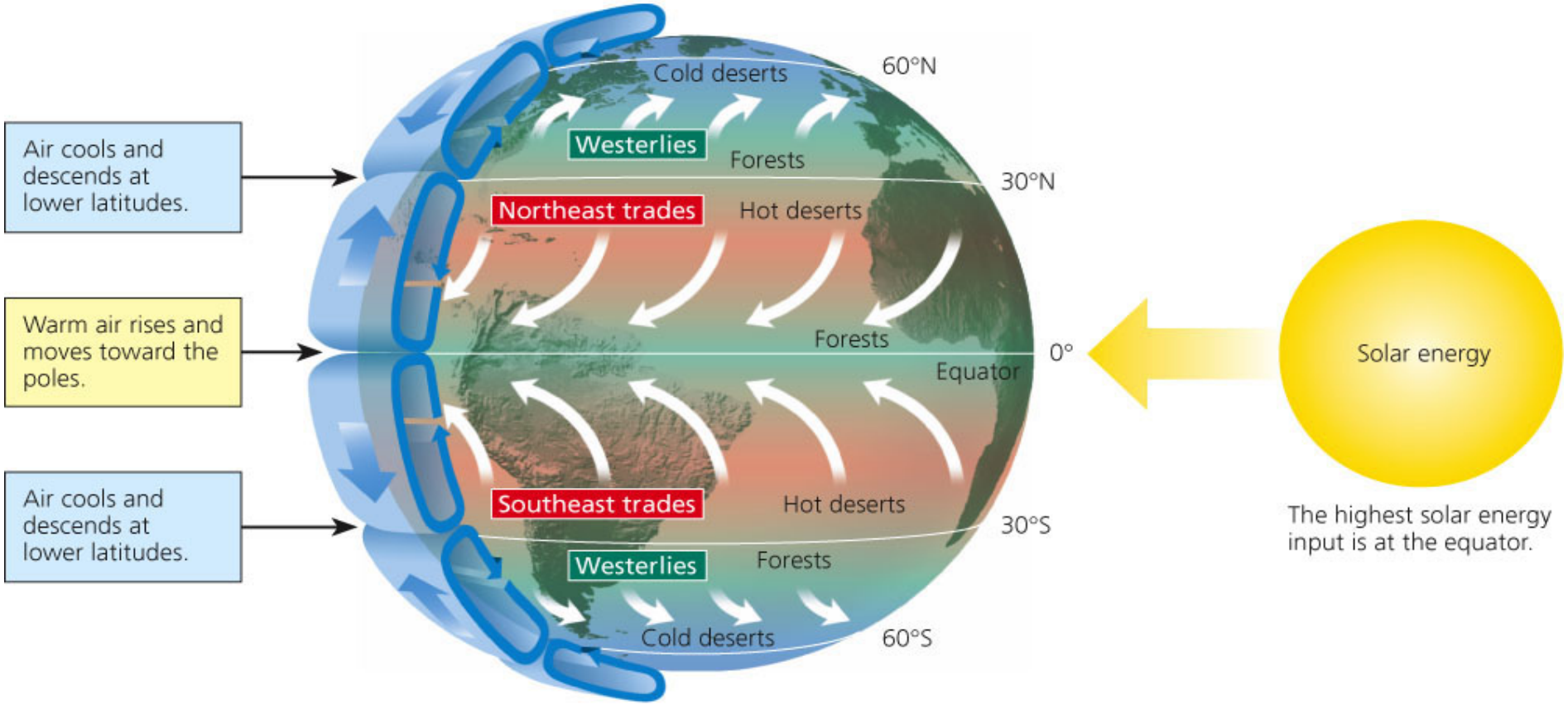
Ferrel cells- mid-latitudes

Polar cells- near the poles



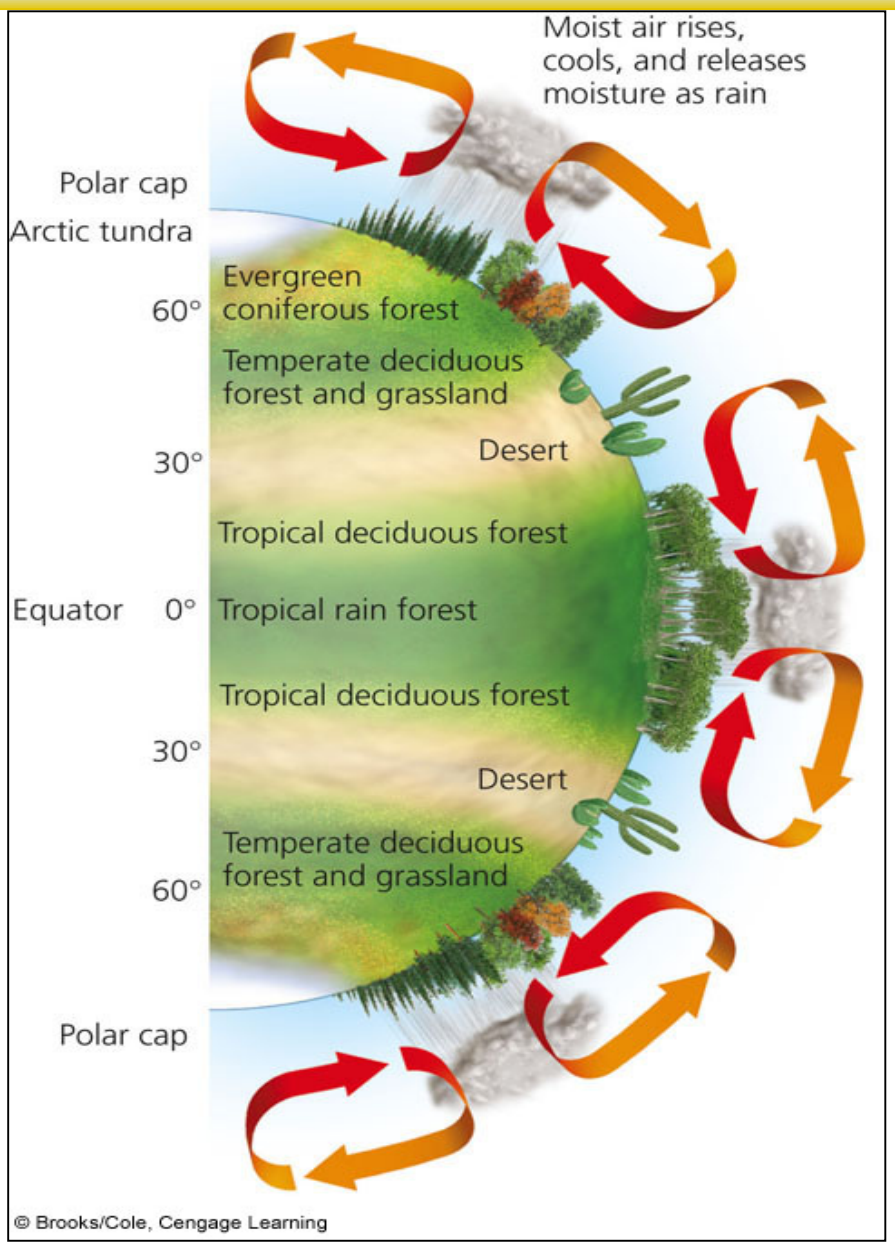
The Coriolis Effect Influences the Movement of Air in Atmospheric Circulation Cells

- **Wind patterns found WITHIN cells:**
  - **Trade winds** are surface winds of Hadley cells.
  - **Westerlies** are surface winds of Ferrel cells.
  - **Polar Easterlies** are surface winds of Polar cells.



The Coriolis Effect Influences the Movement of Air in Atmospheric Circulation Cells

- **Wind patterns found BETWEEN cells:**
  - **Horse latitudes** are areas of high atmospheric pressure between Hadley and Ferrel cells-subtropical high.
    - Sinking, arid air causes the deserts of the world to be located at 30 degrees N and S
    - Evaporation exceeds precipitation so ocean salinity is high.



Seasonal Changes in the Position of the Intertropical Convergence Zone (ITCZ)

Cell circulation centers on meteorological equator

- Thermal equator
  - Changes position throughout the year

Doldrums – equatorial low

- ITCZ (intertropical convergence zone)

Monsoons Are Wind Patterns That Change with the Seasons

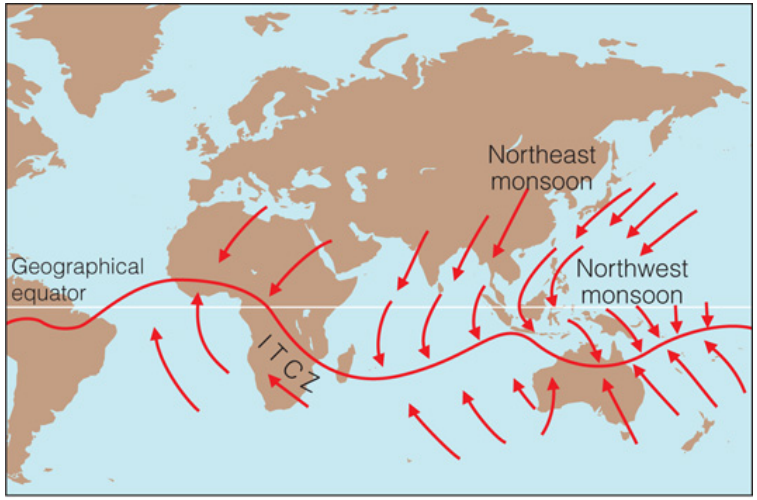
- **Monsoons**: local seasonal wind pattern caused by heating or cooling of the continents

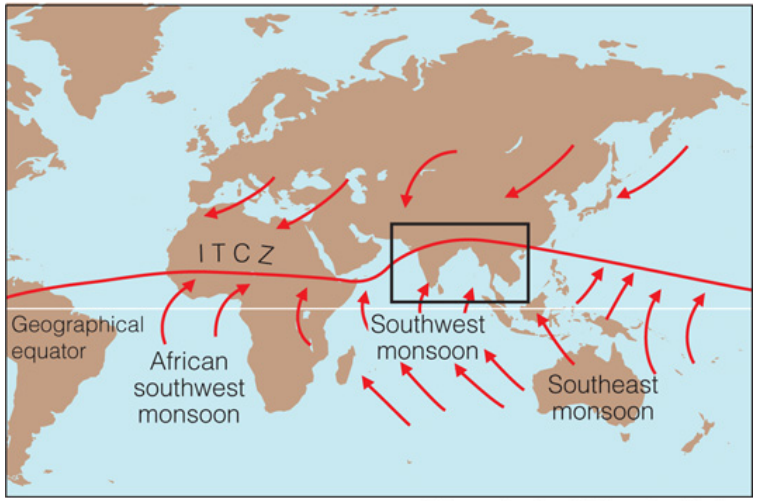
•Results in summers with significant rainfall and winters with very little.

•Caused by different specific heats of land and water.

Example: In spring, land heats more rapidly than ocean leading to summers with heavy rain.

Common on W. coast of India and southeast Asia.





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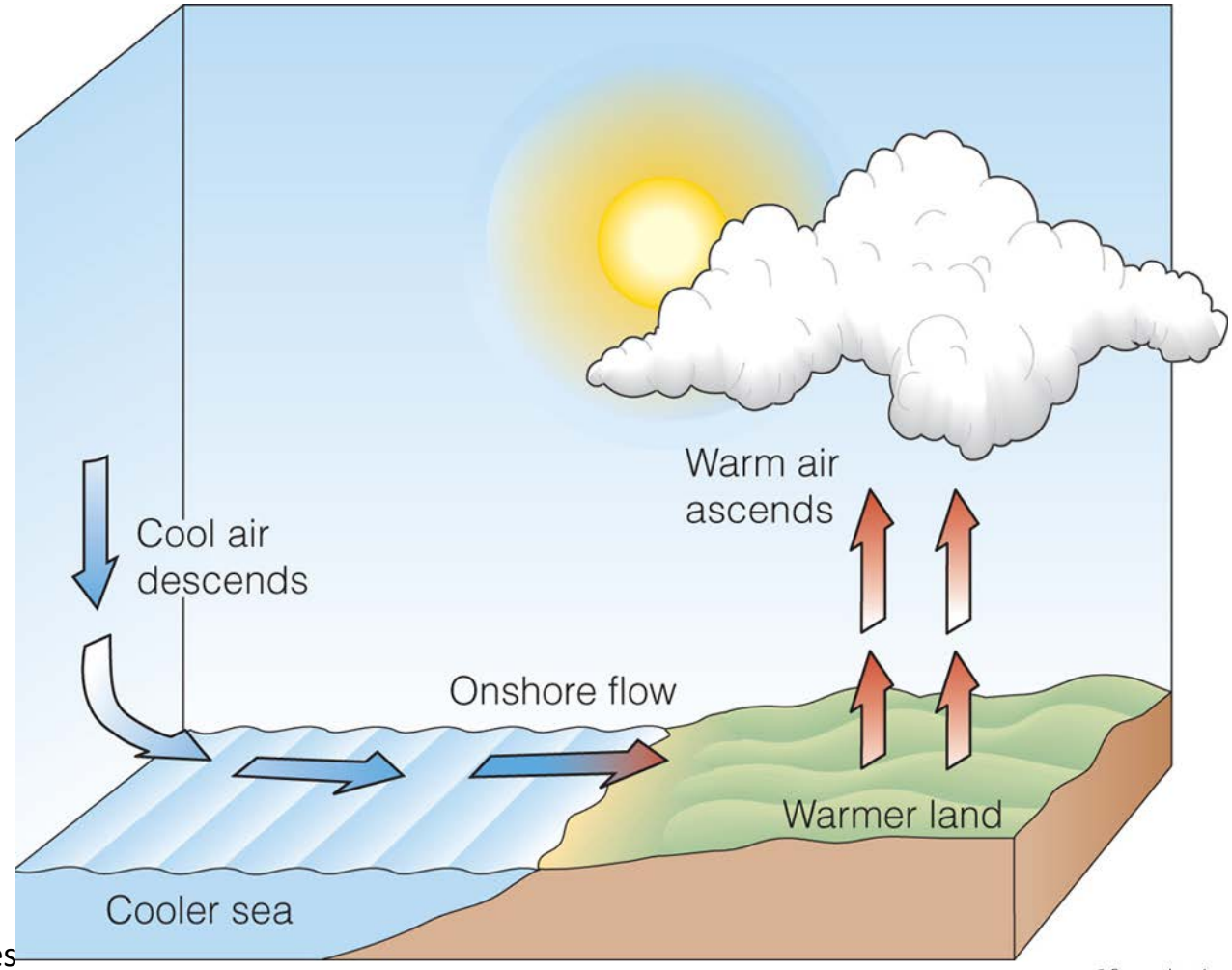
The Flow of Air in Coastal Regions During Stable Weather Conditions

- **Sea breeze** is cool air from over the water moving toward land.

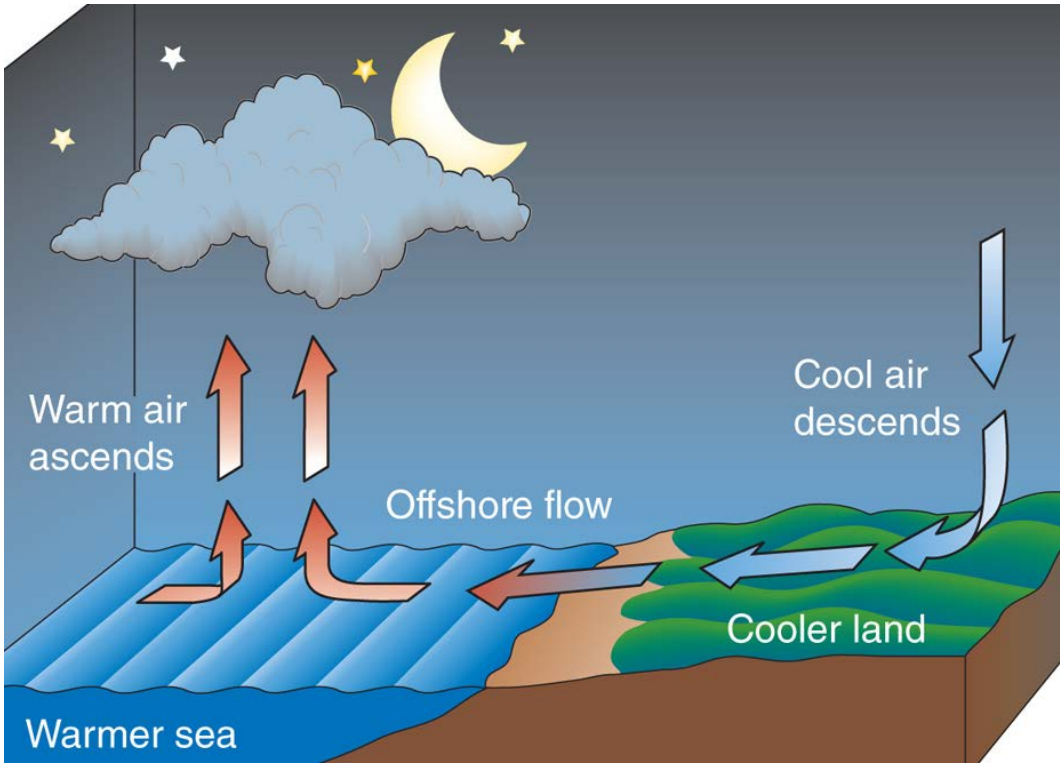
In the afternoon, the land is warmer than the ocean surface, and the warm air rising from the land is replaced by an onshore **sea breeze.**



The Flow of Air in Coastal Regions During Stable Weather Conditions

- **Land breezes** occur after sunset when air warmed by land blows toward the water.

At night, as the land cools, the air over the ocean is now warmer than the air over the land. The ocean air rises. Air flows offshore to replace it, generating an **offshore land breeze**.



Storms Are Variations in Large-Scale Atmospheric Circulation

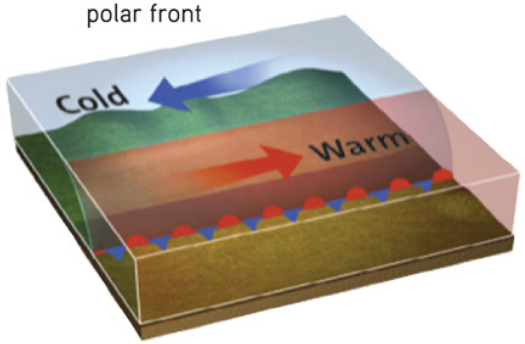
- Storms – regional disturbances
- Air mass – uniform temperature, humidity, and density
- Front – boundary between air masses

1. **Tropical cyclones** occur in tropical regions.
2. **Extratropical cyclones** occur at the polar front, between Ferrel and Polar cells, and are winter weather disturbances.

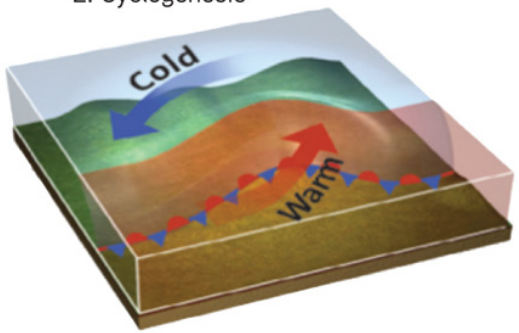
- Both types of storms are **cyclones,** or rotating masses of low-pressure air.

Formation of a Mid-Latitude Cyclone

1. Stationary polar front



2. Cyclogenesis



Mid-latitude cyclones are found between 35° and 70° of latitude in the zone of the westerly winds. Most are occluded fronts. (1) Characterized by intense, heavy precipitation, cold polar air—with a boundary known as a front—meets warm tropical air. (2) A wave develops along the frontal boundary as the opposing air masses interact. Cyclogenesis (the birth of a cyclone) begins. (3) The faster-moving cold air forces the warm air

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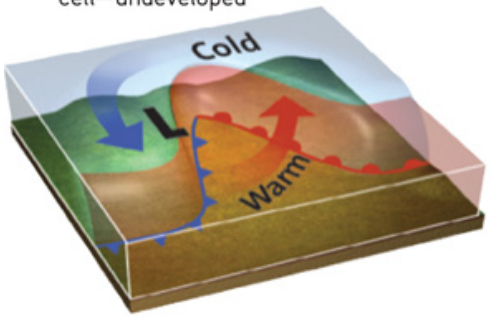
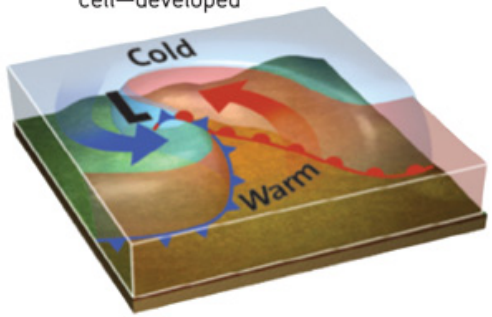
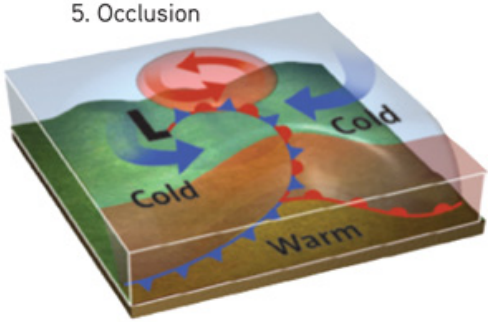
3. Low pressure cell—undeveloped



4. Low pressure cell—developed



5. Occlusion



to lift above the cold. (4) Full rotation develops, counter-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. (5) Complete occlusion occurs as the warm air, fully caught-up by the cold air, has been lifted away from the surface. Because the warm air is completely separated from the surface, the characteristics of the cold air are felt on the ground in the form of unsteady, windy, and wet weather.

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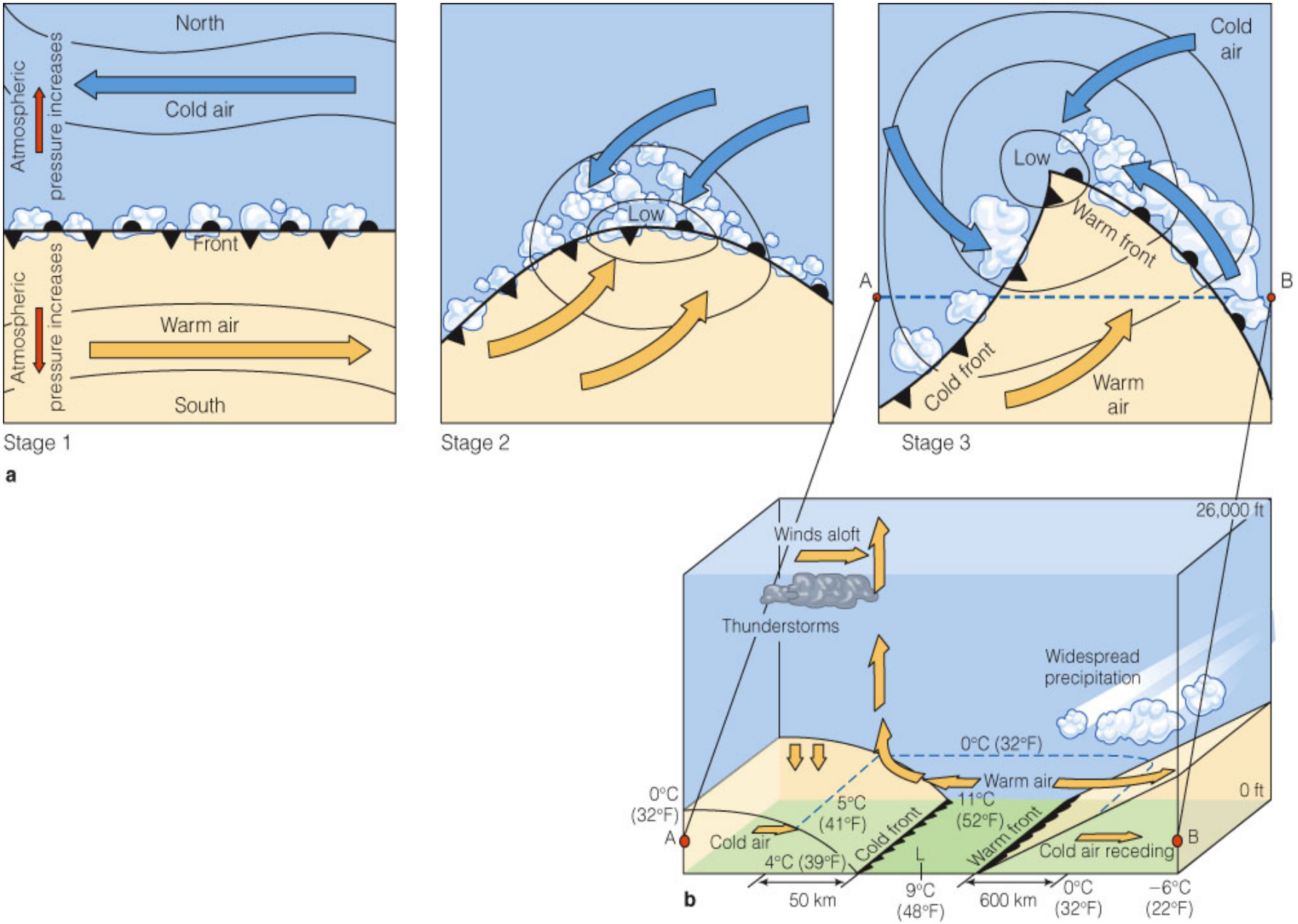
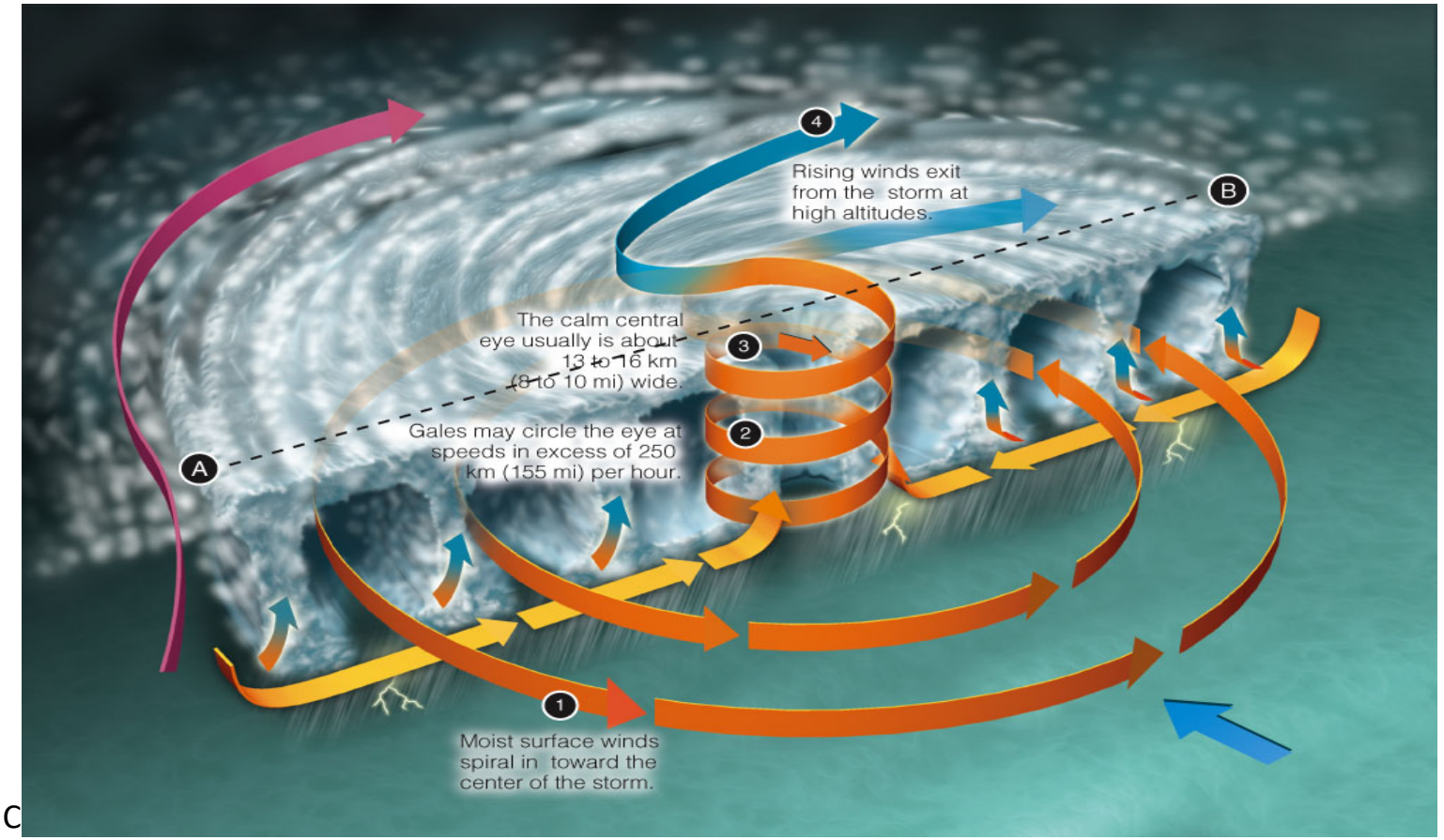
Extra-tropical Cyclones Form between Two Air Masses



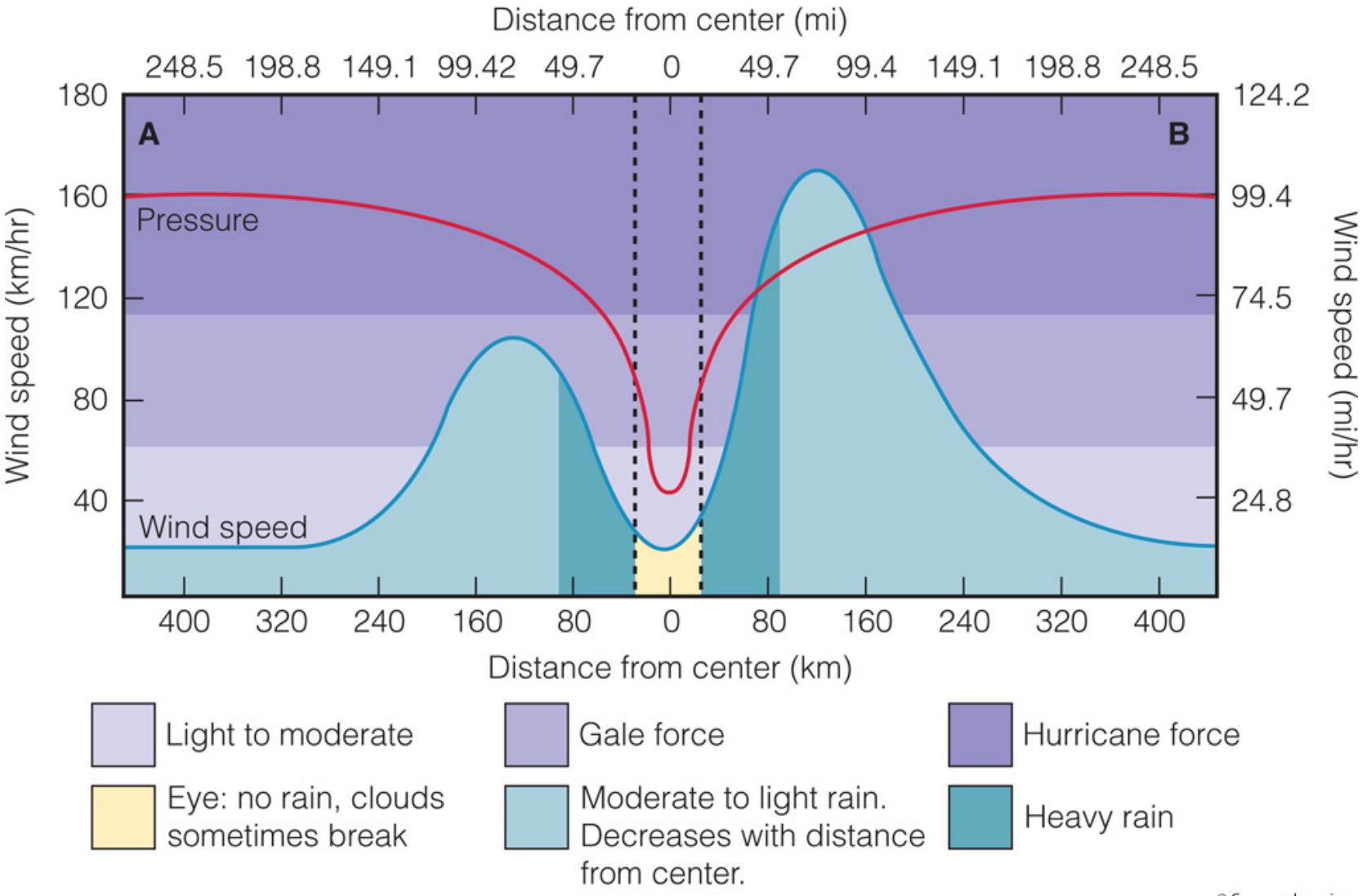
Tropical Cyclones Form Within One Warm, Humid Air Mass

- Form within the warm, humid Hadley Cells
- Multiple names depending on location:
  - Hurricanes = North Atlantic and eastern Pacific
  - Typhoons = western Pacific
  - Tropical cyclones = Indian Ocean



Tropical Cyclones Form in One Air Mass

The internal structure of a mature northern hemisphere tropical cyclone



The Dynamics of a Tropical Cyclone

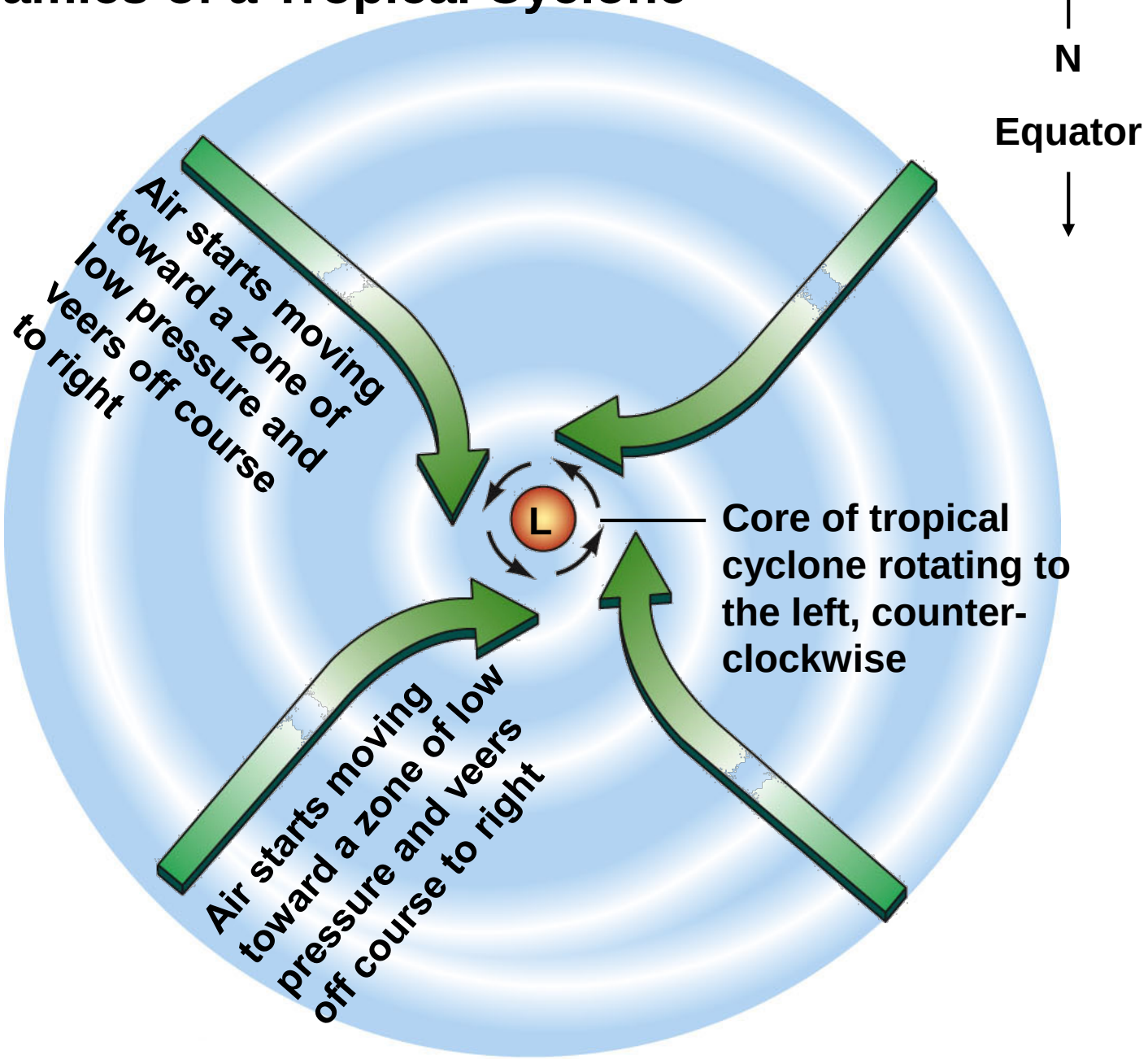


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Figure 8-28 p249