2

The Physical Environment

- *Case Study*: Climatic Variation and Salmon
- Climate
- Atmospheric and Oceanic Circulation
- Global Climatic Patterns
- Regional Climatic Influences

- Climatic Variation over Time
- The Chemical Environment
- *Case Study Revisited*
- *Connections in Nature*: Climatic Variation and Ecology

Case Study: Climatic Variation and Salmon

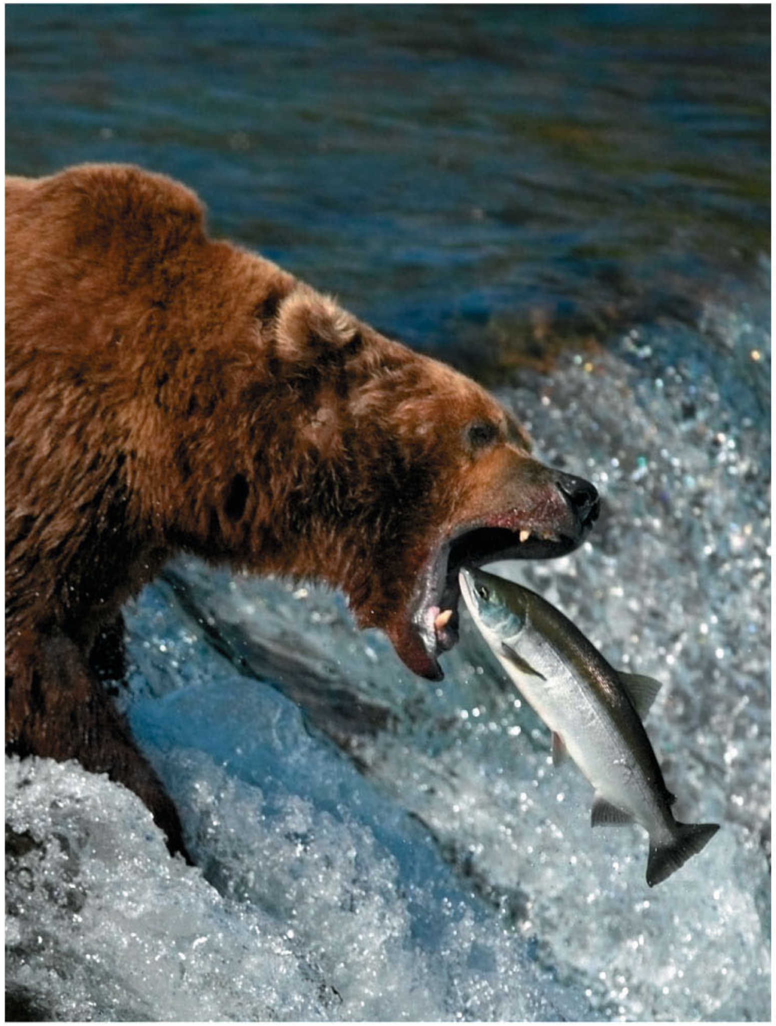


Figure 2.1 A Seasonal Opportunity

Grizzly bears feed on spawning salmon.

Salmon are **anadromous**: They return to streams from the ocean to spawn.

Case Study: Climatic Variation and Salmon

Salmon are also an important food source, and a central part of the culture of Native Americans.

Salmon are also fished commercially.

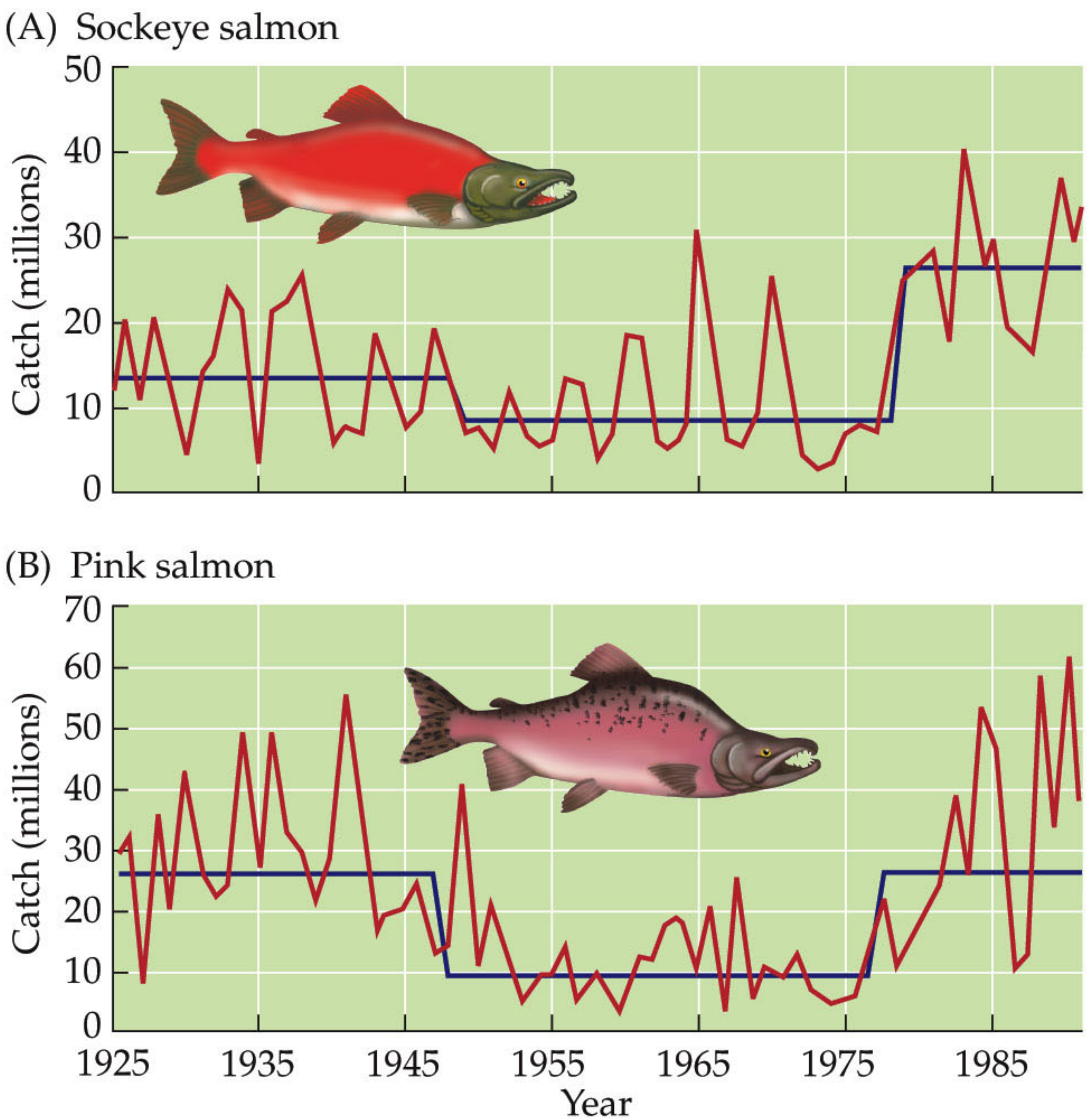
Many threats to streams, such as damming, pollution, and overfishing, have decreased the spawning and reproductive success of salmon.

Case Study: Climatic Variation and Salmon

Hare and Francis (1994) showed that climatic variation in the Pacific Ocean also influenced the abundance of salmon.

Mantua et al. (1997) found a relationship between salmon production and sea surface temperatures.

Figure 2.2 Changes in Salmon Harvests over Time



ECOLOGY, Figure 2.2

Introduction

The physical environment ultimately determines where organisms can live, and the resources that are available to them.

Thus, understanding the physical environment is key to understanding all ecological phenomena.

Concept 2.1: Climate is the most fundamental characteristic of the physical environment.

Weather: Current conditions—temperature, precipitation, humidity, cloud cover.

Climate: Long-term description of weather, based on averages and variation measured over decades.

Climate

Climatic variation includes daily and seasonal cycles, and large-scale cycles that occur over years or decades.

Long-term climate change can be a result of changes in the intensity and distribution of solar radiation.

Climate

Climate determines the geographic distribution of organisms.

Climate is characterized by average conditions, but extreme conditions are also important to organisms as they contribute to mortality.

Figure 2.3 Widespread Mortality in Piñon Pines

(A)

(B)

Climate

The physical environment must be characterized by its variability over time, as well as average conditions.

The timing of variation is also important, such as seasonality of rainfall.

Climate

In a Mediterranean type climate, most precipitation is in winter, summers are dry. Dry summers promote fire.

Grasslands may receive the same amount of annual precipitation, but it is spread evenly throughout the year.

Climate

Climate affects abiotic processes, such as the rate of rock weathering, which releases nutrients.

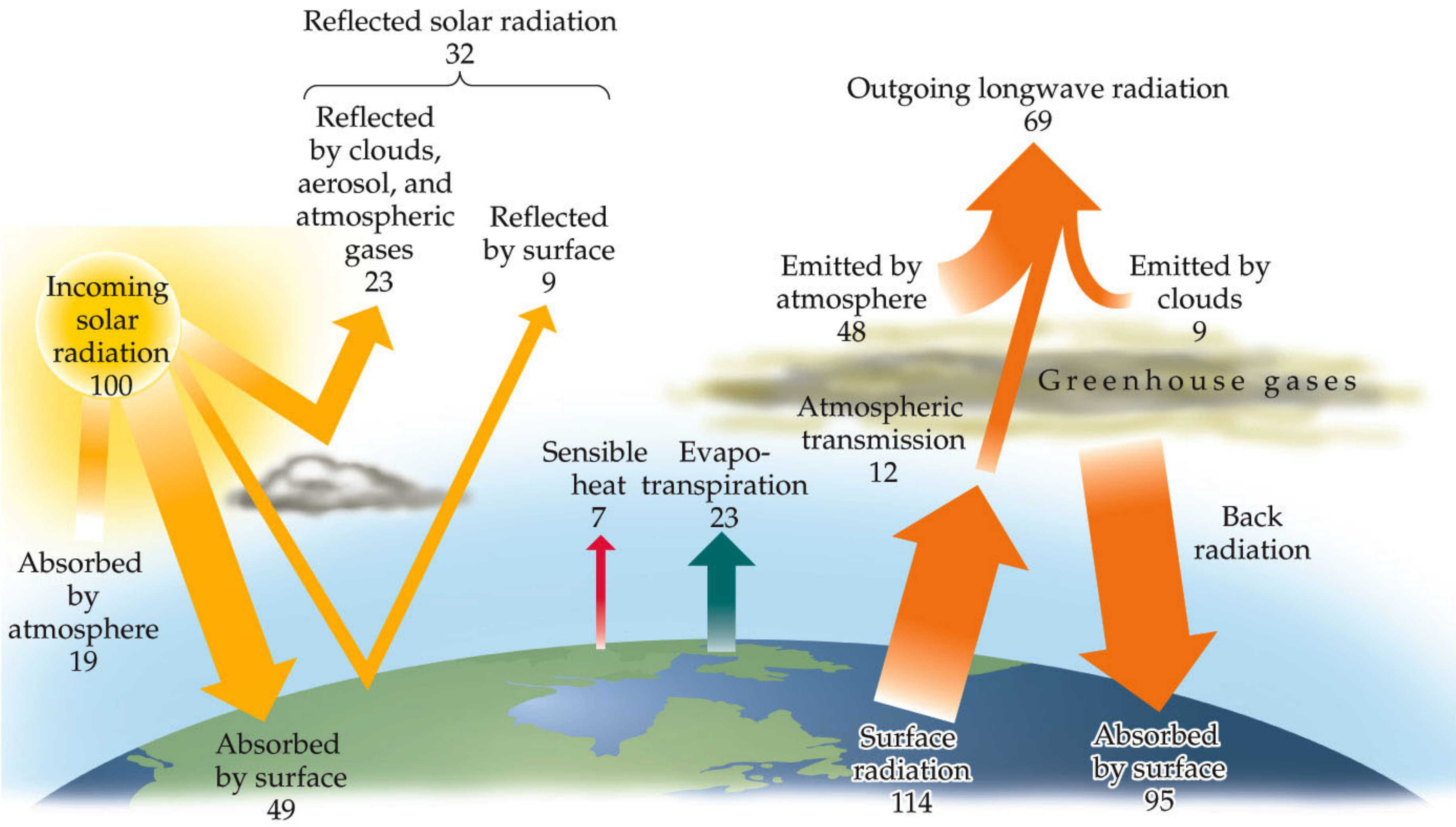
Periodic disturbances such as fires, rockslides, and avalanches kill organisms and disrupt biological communities, but also create opportunities for the growth of new organisms and communities.

Climate

The sun is the ultimate source of energy that drives the global climate.

Energy gains from solar radiation must be offset by energy losses if Earth’s temperature is to remain the same.

Figure 2.4 Earth's Radiation Balance



ECOLOGY, Figure 2.4

Much of the solar radiation absorbed by Earth’s surface is emitted to the atmosphere as infrared radiation.

When water at the surface evaporates it absorbs energy—**latent heat flux**.

Conduction: Kinetic energy is transferred by molecules in direct contact with one another.

Convection: Energy transfer by movements of air (wind) and water currents.

Energy transfer from the warm air immediately above the surface to the cooler atmosphere by convection and conduction—**sensible heat flux**.

The atmosphere contains radiatively active (greenhouse) gases that absorb and reradiate the infrared radiation emitted by Earth.

These gases include water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

Climate

Without greenhouse gases, Earth's climate would be about 33°C cooler.

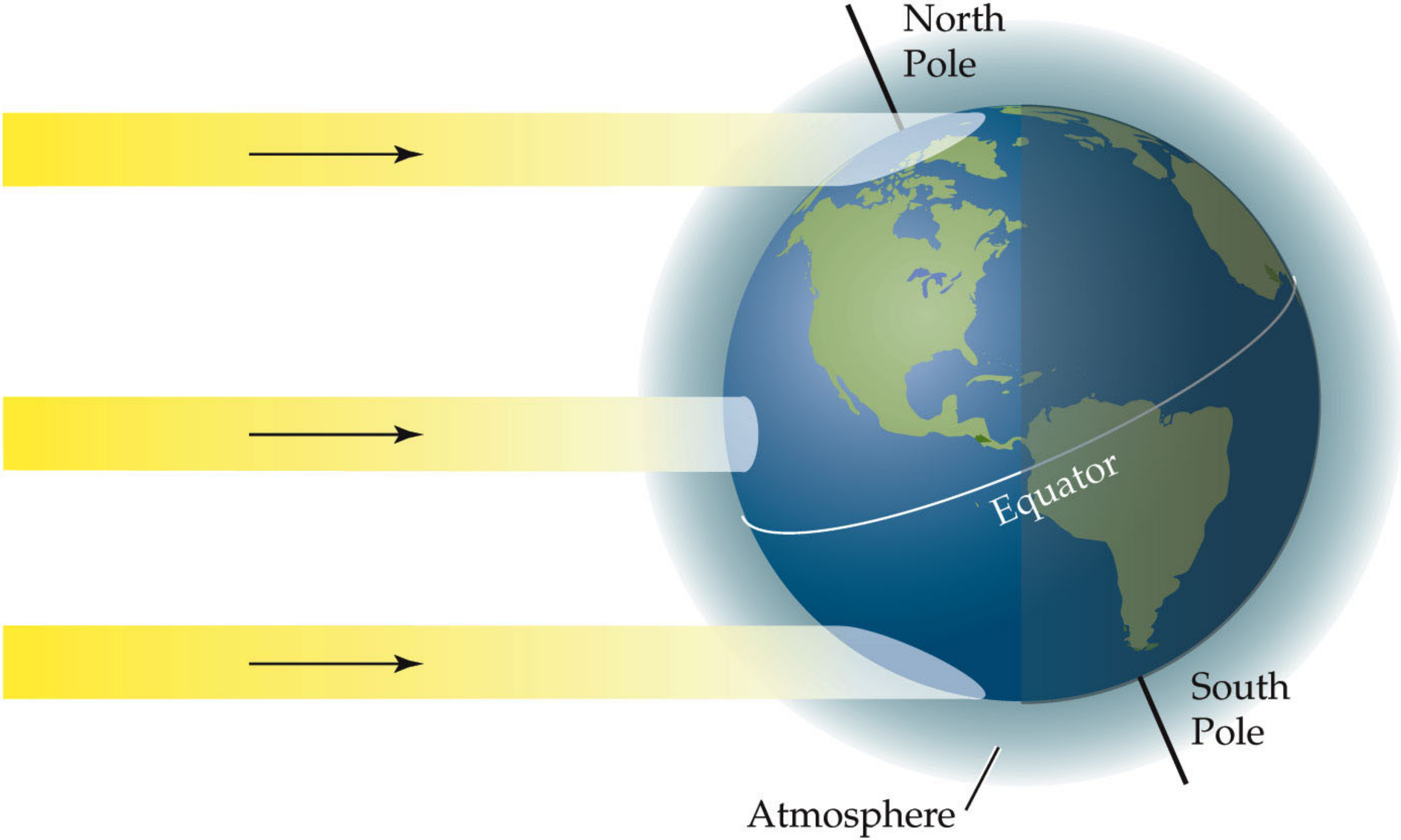
Increases in concentrations of greenhouse gases due to human activities are altering Earth's energy balance, changing the climate system, and causing global warming.

Concept 2.2: Winds and ocean currents result from differences in solar radiation across the surface of Earth.

Near the equator, the sun’s rays strike Earth’s surface perpendicularly.

Toward the poles, the sun’s rays are spread over a larger area and take a longer path through the atmosphere.

Figure 2.5 Latitudinal Differences in Solar Radiation at Earth's Surface

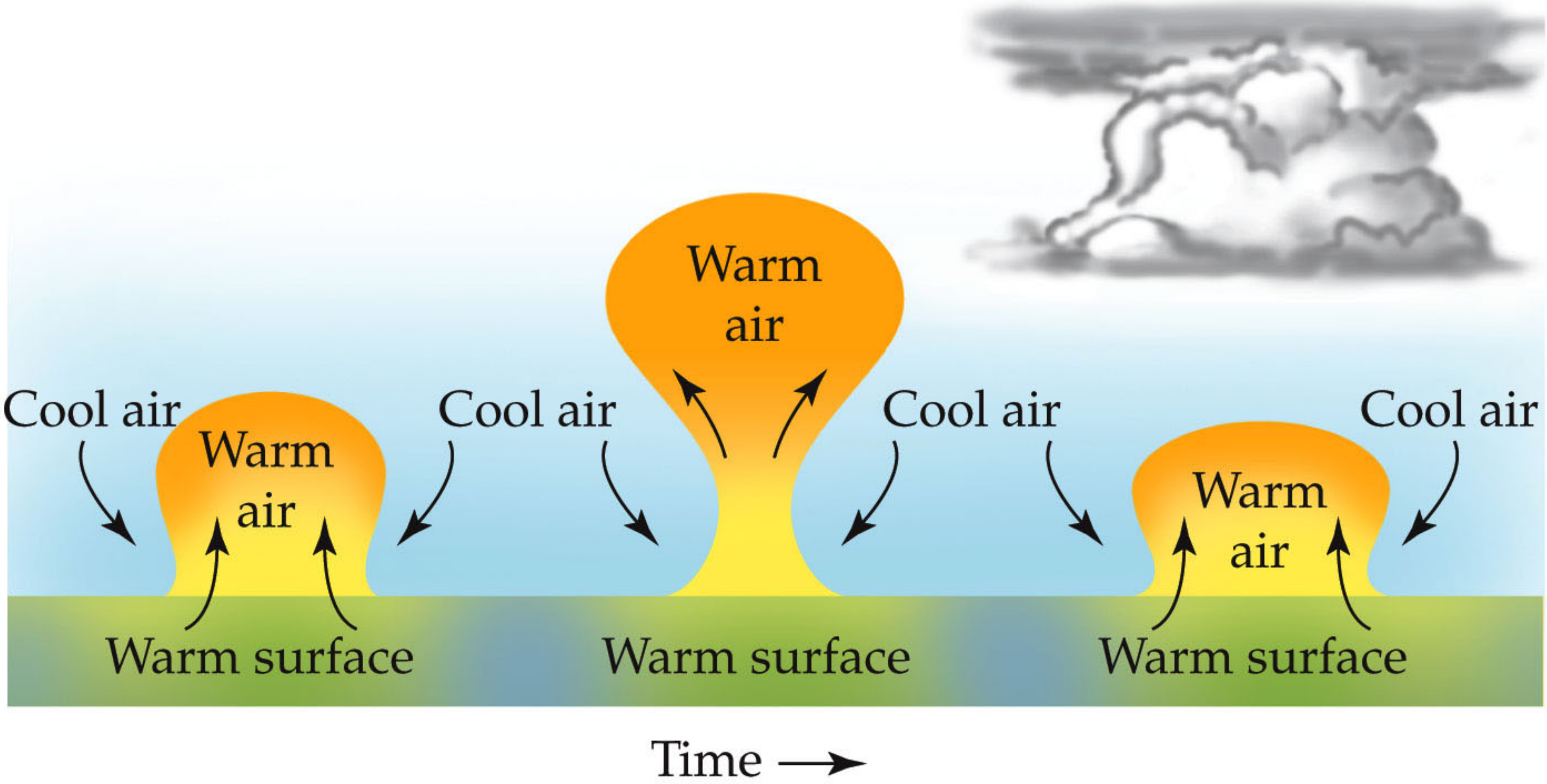


When solar radiation heats Earth's surface, the surface warms and emits infrared radiation to the atmosphere, warming the air above it.

Warm air is less dense than cool air, and it rises—**uplift**.

Air pressure decreases with altitude, so the rising air expands, and cools.

Figure 2.6 Surface Heating and Uplift of Air



Cool air holds less water vapor than warm air.

The rising air expands and cools, and water vapor condenses to form clouds.

The condensation is a warming process, which may act to keep the pocket of air warmer than the surrounding atmosphere and enhance its uplift.

In summer, cumulus clouds form thunderstorms when there is heating at Earth’s surface, and progressively cooler atmosphere above.

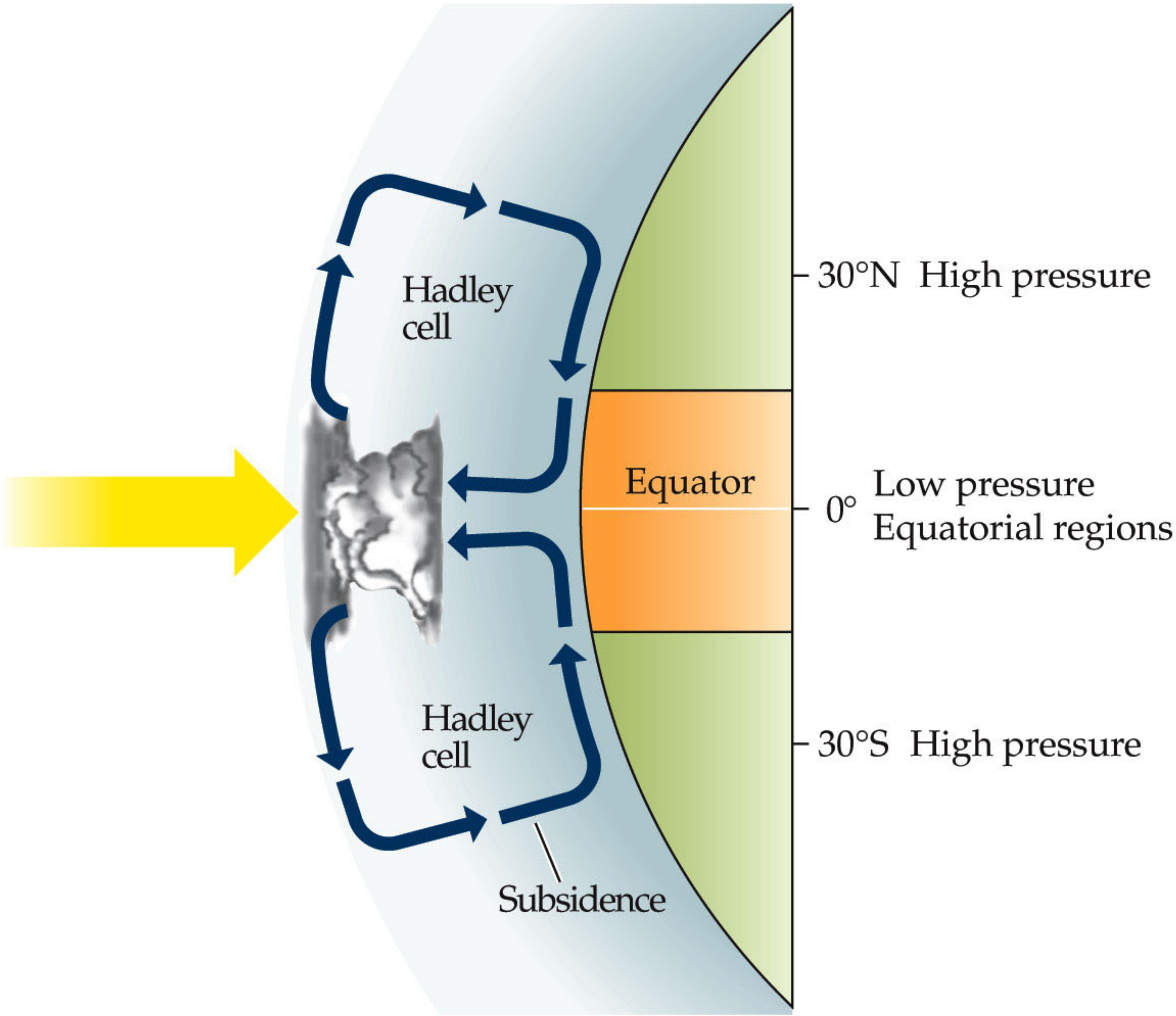
Thunderclouds reach to the boundary between the troposphere and stratosphere—where temperatures are warmer.

Tropical regions receive the most solar radiation, and thus have the most precipitation.

Uplift of air in the tropics results in a low atmospheric pressure zone.

When air masses reach the boundary between the troposphere and stratosphere, air flows towards the poles.

Figure 2.7 Equatorial Heating and Atmospheric Circulation Cells



ECOLOGY, Figure 2.7

Subsidence—the air descends when it cools and forms a high pressure zone at about 30° N and S.

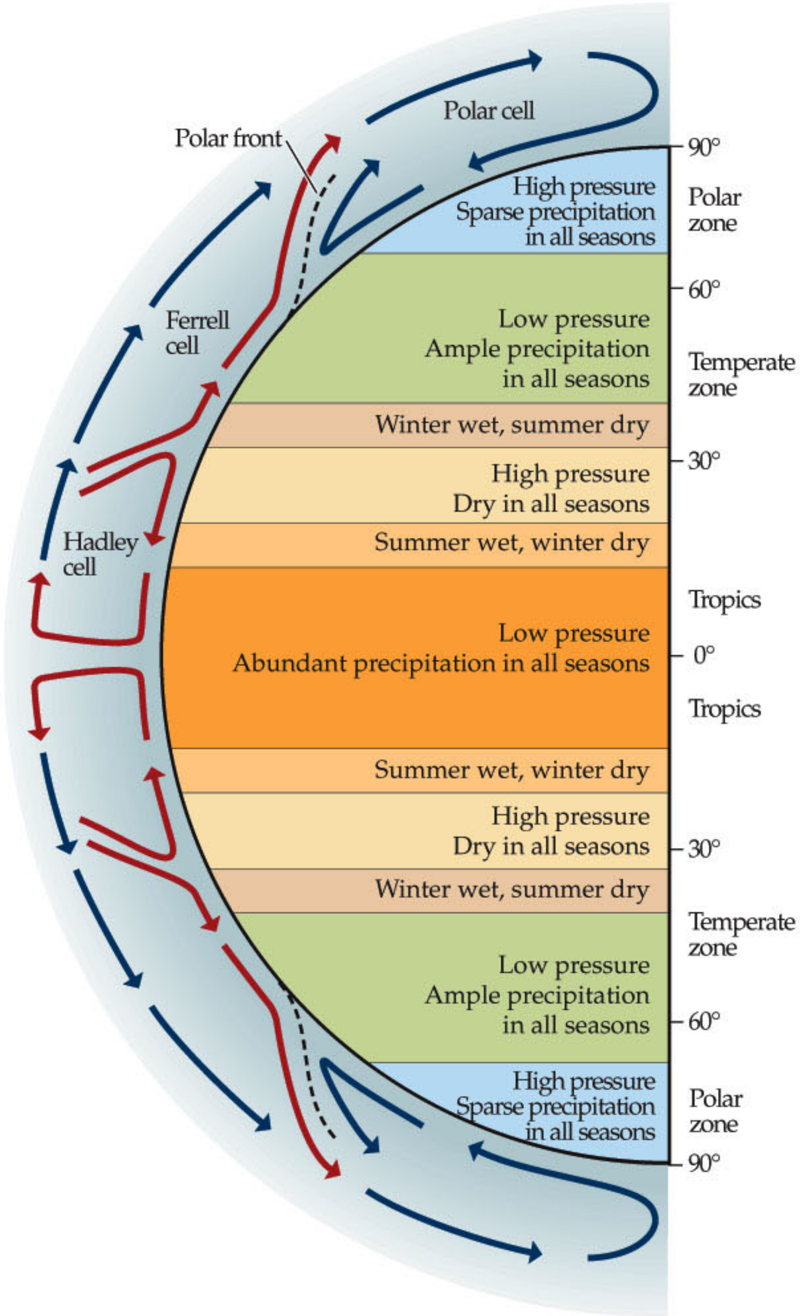
Major deserts of the world are at these latitudes.

Equatorial uplift creates a large-scale, three-dimensional pattern of atmospheric circulation known as a **Hadley cell**.

The **polar cell** occurs at the North and South Poles—high pressure zones with little precipitation—“polar deserts.”

Ferrell cells exist at mid-latitudes.

Figure 2.8 Global Atmospheric Circulation Cells and Climatic Zones



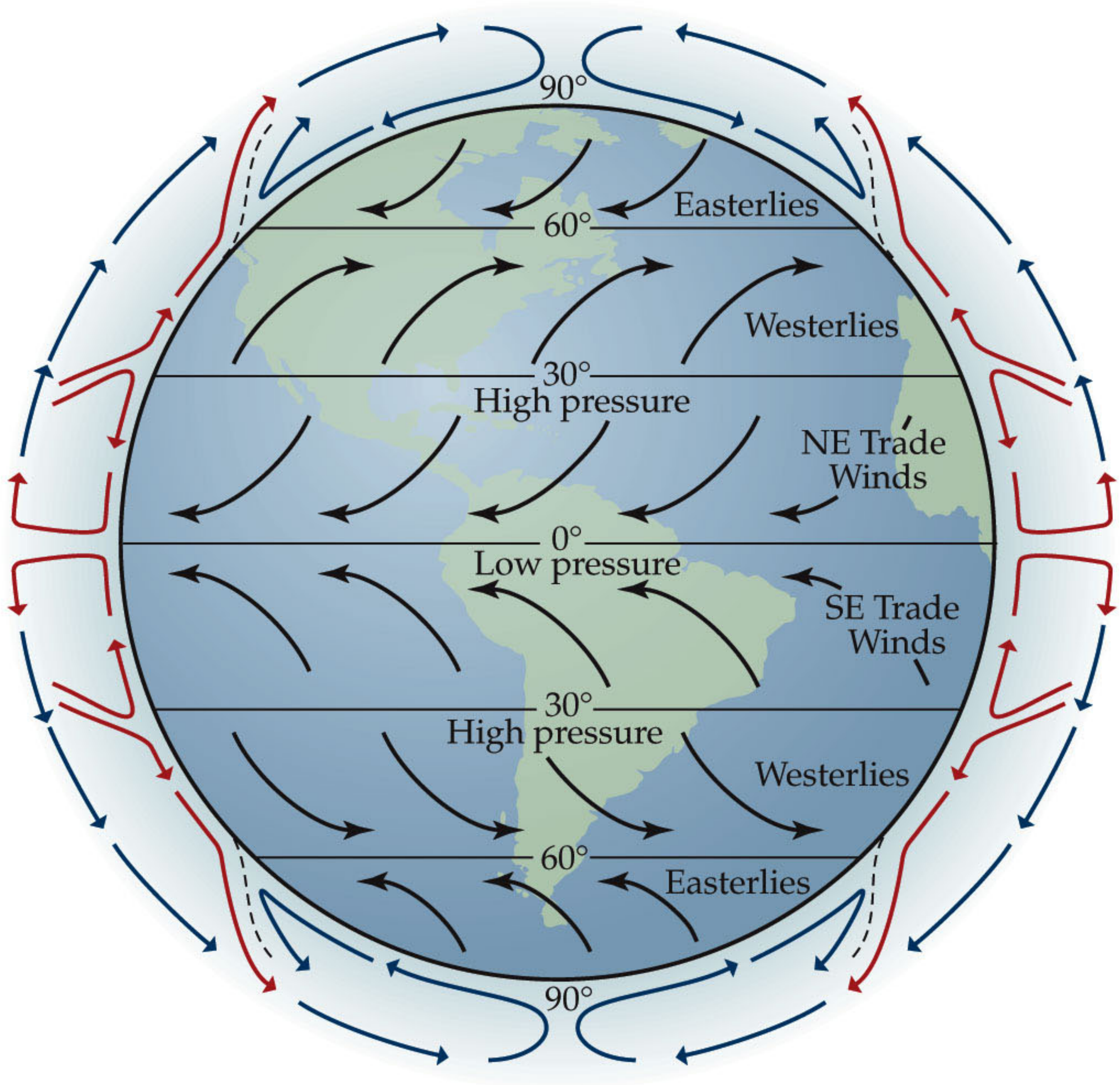
ECOLOGY, Figure 2.8

The three cells result in the three major climatic zones in each hemisphere: **Tropical**, **temperate**, and **polar zones**.

Areas of high and low pressure created by the circulation cells result in air movements called **prevailing winds**.

The winds are deflected to the right (clockwise) in the Northern Hemisphere and to the left (counterclockwise) in the Southern Hemisphere—the **Coriolis effect**.

Figure 2.9 Influences on Global Wind Patterns



ECOLOGY, **Figure 2.9**

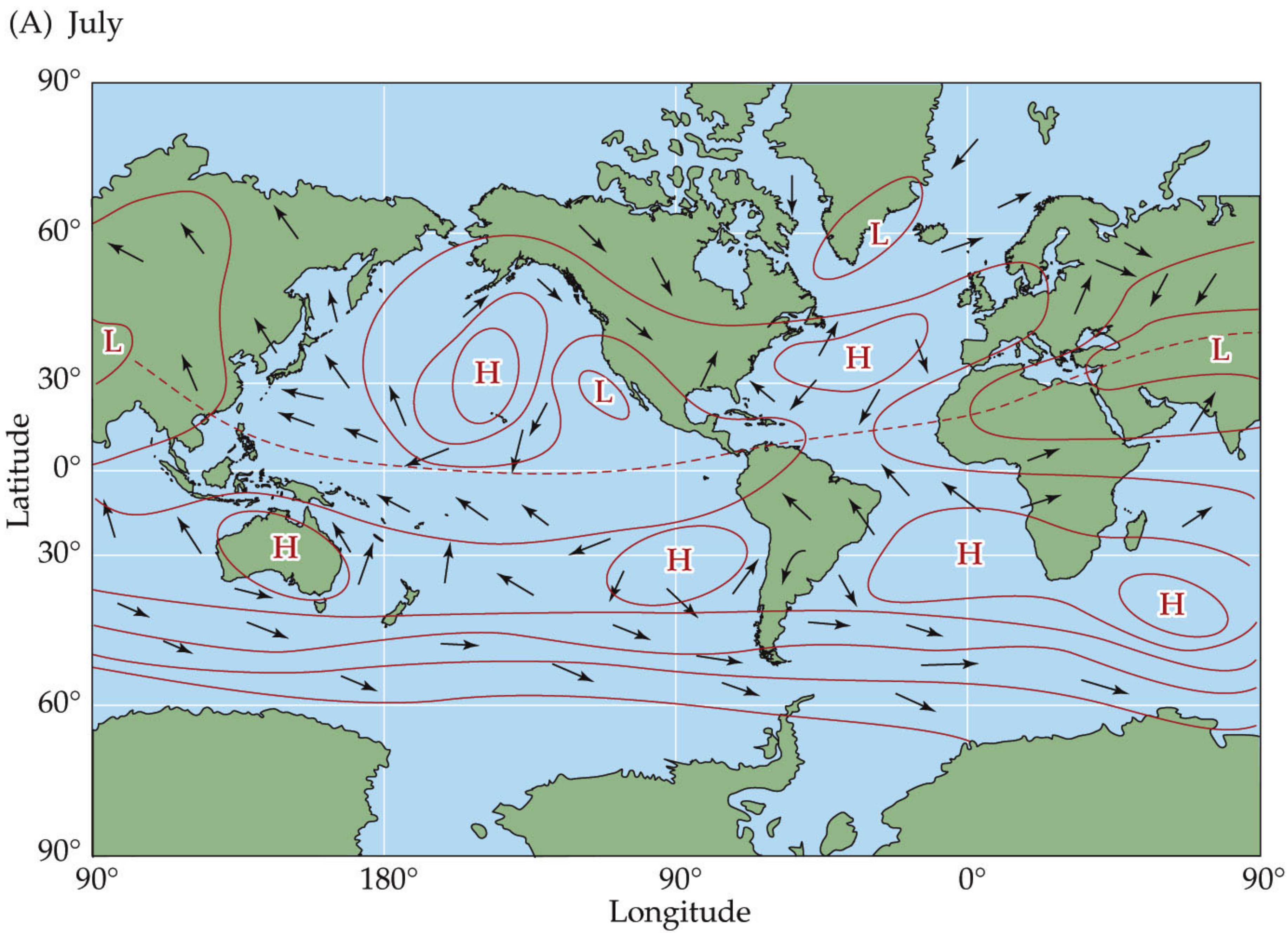
Atmospheric and Oceanic Circulation

Water has a higher **heat capacity** than land—it can absorb and store more energy without changing temperature.

Summer: Air over oceans is cooler and denser, so air subsides and high pressures develop over the oceans.

Winter: Air over continents is cooler and denser, high pressure develops over continents.

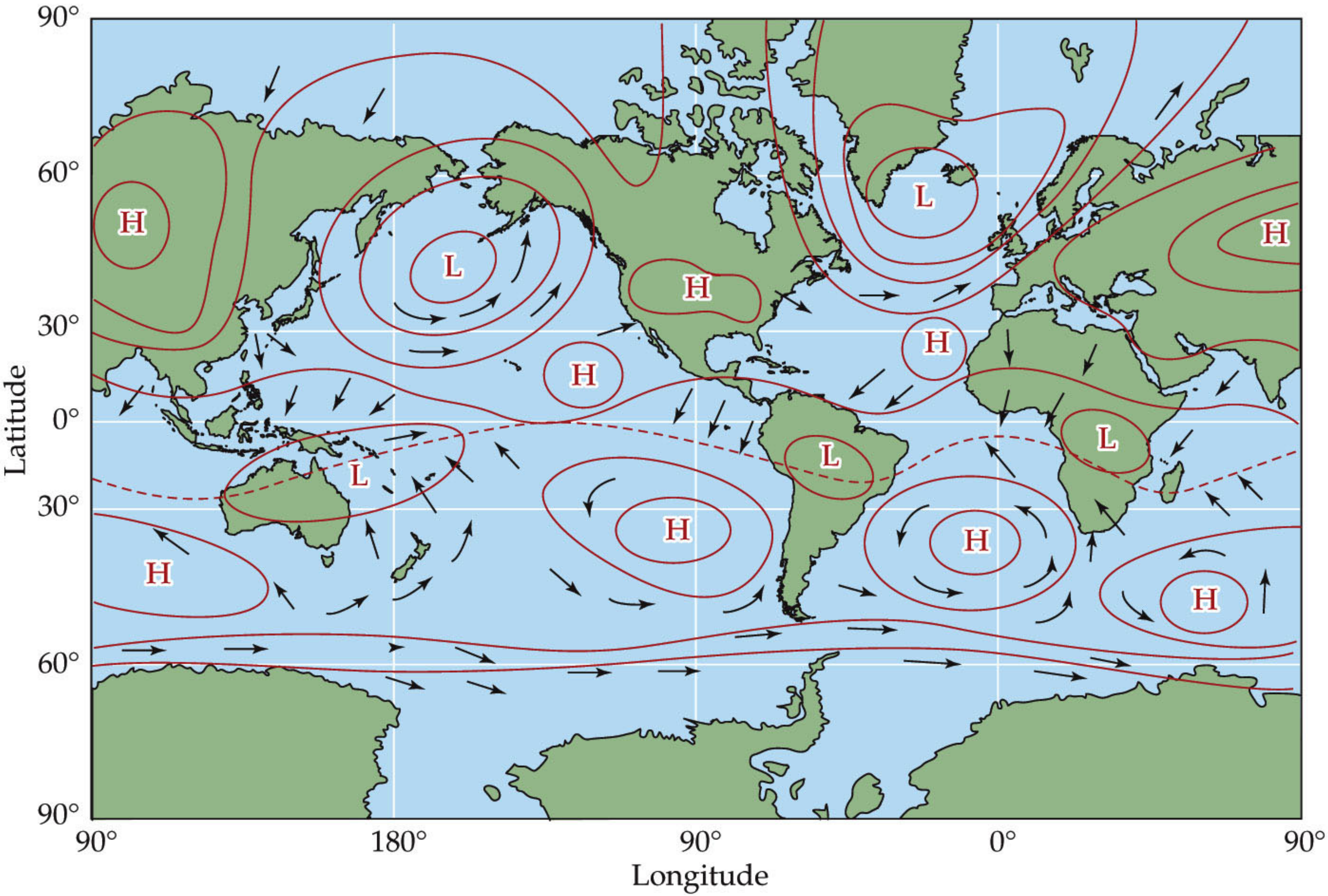
Figure 2.10 Prevailing Wind Patterns (Part 1)



ECOLOGY, Figure 2.10 (Part 1)

Figure 2.10 Prevailing Wind Patterns (Part 2)

(B) January



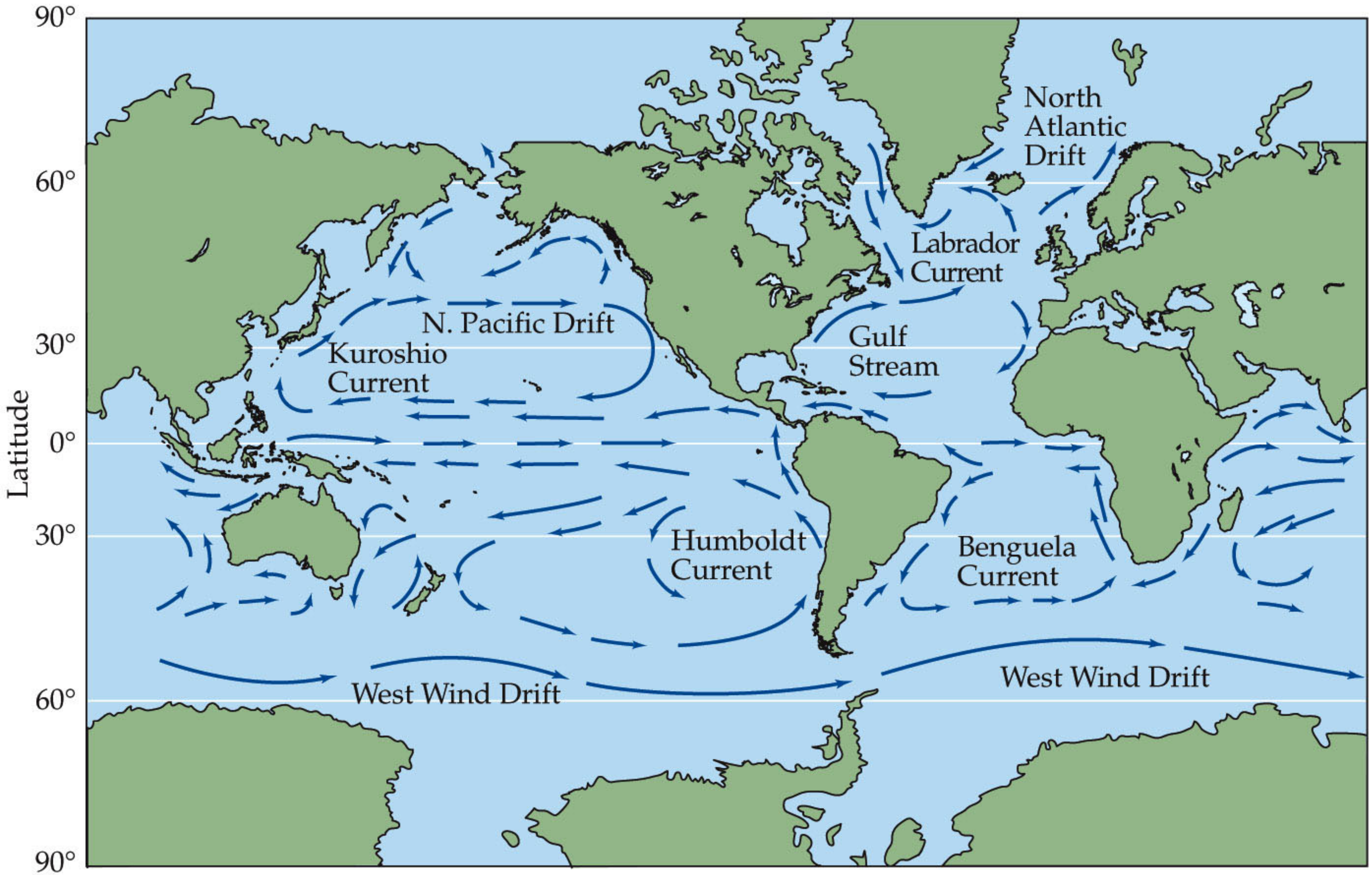
ECOLOGY, Figure 2.10 (Part 2)

Atmospheric and Oceanic Circulation

Major ocean surface currents are driven by surface winds, modified by the Coriolis effect.

Speed of ocean currents is about 2%–3% of the wind speed.

Figure 2.11 Global Ocean Currents



Ocean surface waters are warmer and less saline than deep waters, and thus less dense. The layers don’t mix.

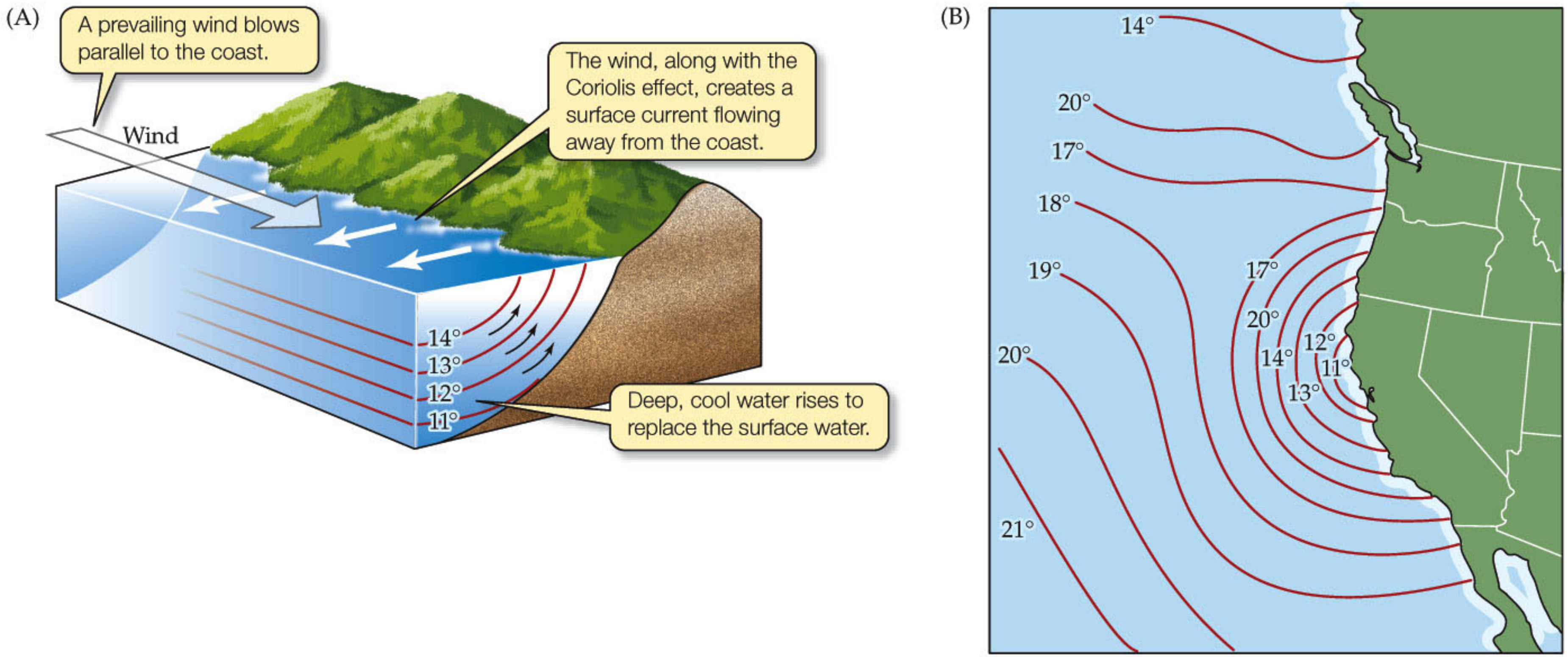
Where warm tropical currents reach polar areas, the water cools, ice forms, and the water becomes more saline and more dense. The water mass sinks in these regions, and moves back toward the equator.

Upwelling is where deep ocean water rises to the surface.

Occurs where prevailing winds blow parallel to a coastline. The force of the wind, (with the Coriolis effect), causes surface waters to flow away from the coast and deeper, colder ocean waters rise to replace them.

Upwellings influence coastal climates.

Figure 2.12 Upwelling of Coastal Waters



Upwellings also bring nutrients from the deep sediments to the **photic zone**—where light penetrates and phytoplankton proliferate.

This provides food for zooplankton and their consumers. These areas are the most productive in the open oceans.

Ocean currents affect climate.

The warm Gulf Stream affects the climate of Great Britain and Scandinavia.

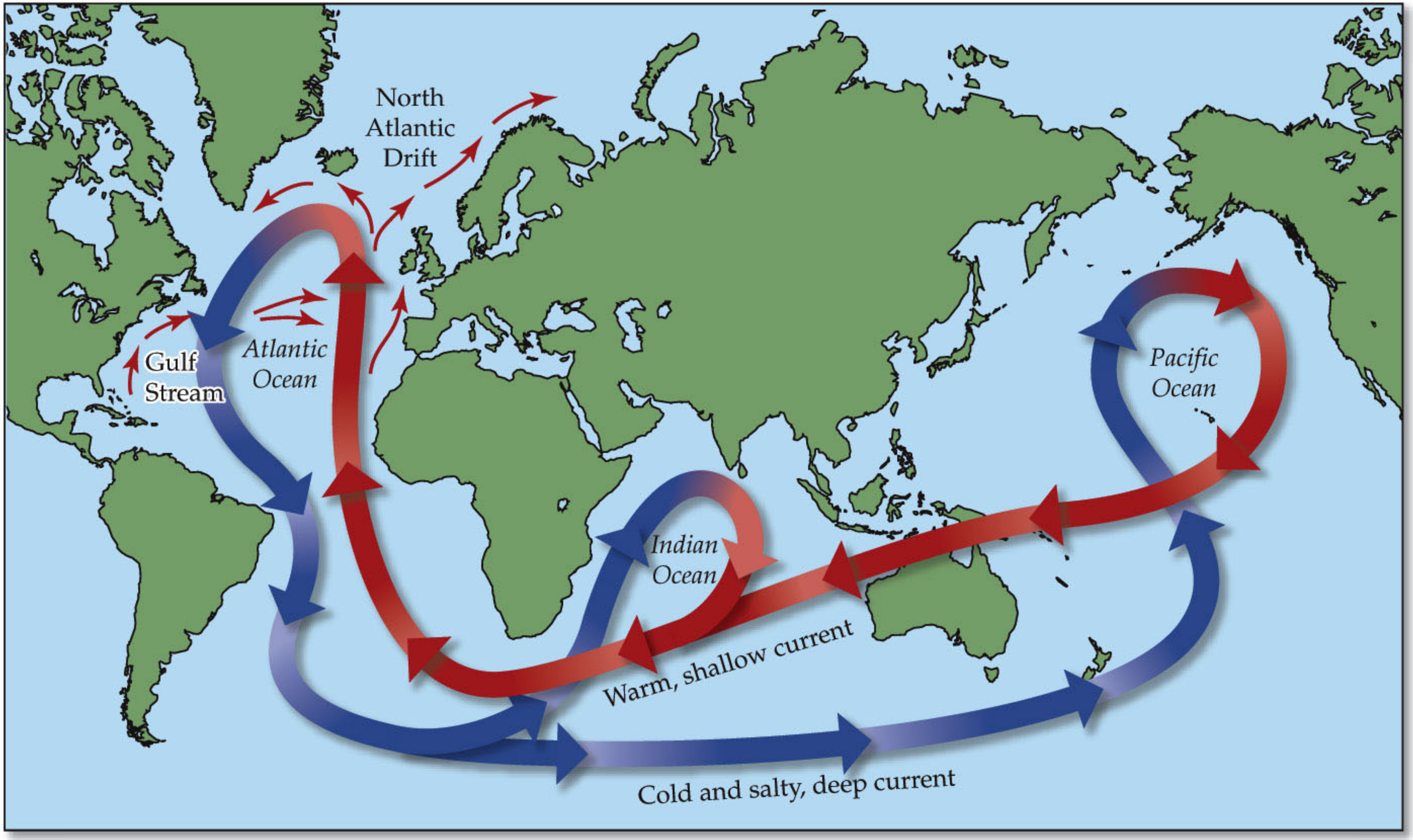
At the same latitude, Labrador is much cooler because of the cold Labrador Current.

Labrador has boreal forest, Great Britain has deciduous woodland and agriculture.

Ocean currents act as “heat pumps” or “thermal conveyers,” transferring heat from the tropics to the poles.

The “great ocean conveyer belt” is an interconnected system of ocean currents that link the Pacific, Indian, and Atlantic oceans.

Figure 2.13 The Great Ocean Conveyor Belt



Concept 2.3: Large-scale atmospheric and oceanic circulation patterns establish global patterns of temperature and precipitation.

Average annual temperatures become progressively cooler away from the equator toward the poles, but the patterns are influenced by ocean currents and relative distribution of land masses.

Figure 2.14 Global Average Annual Temperatures (Part 1)

(A)

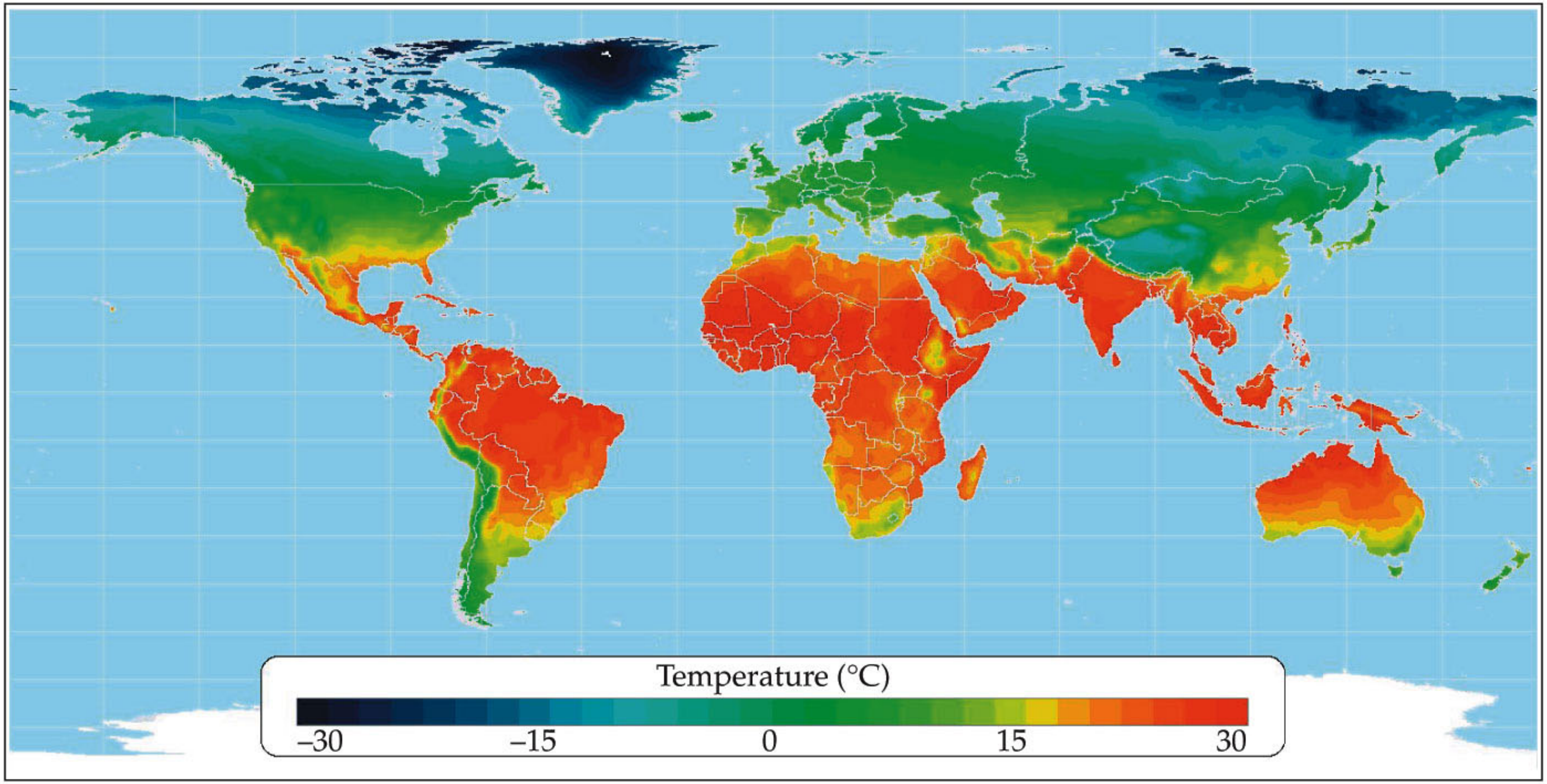
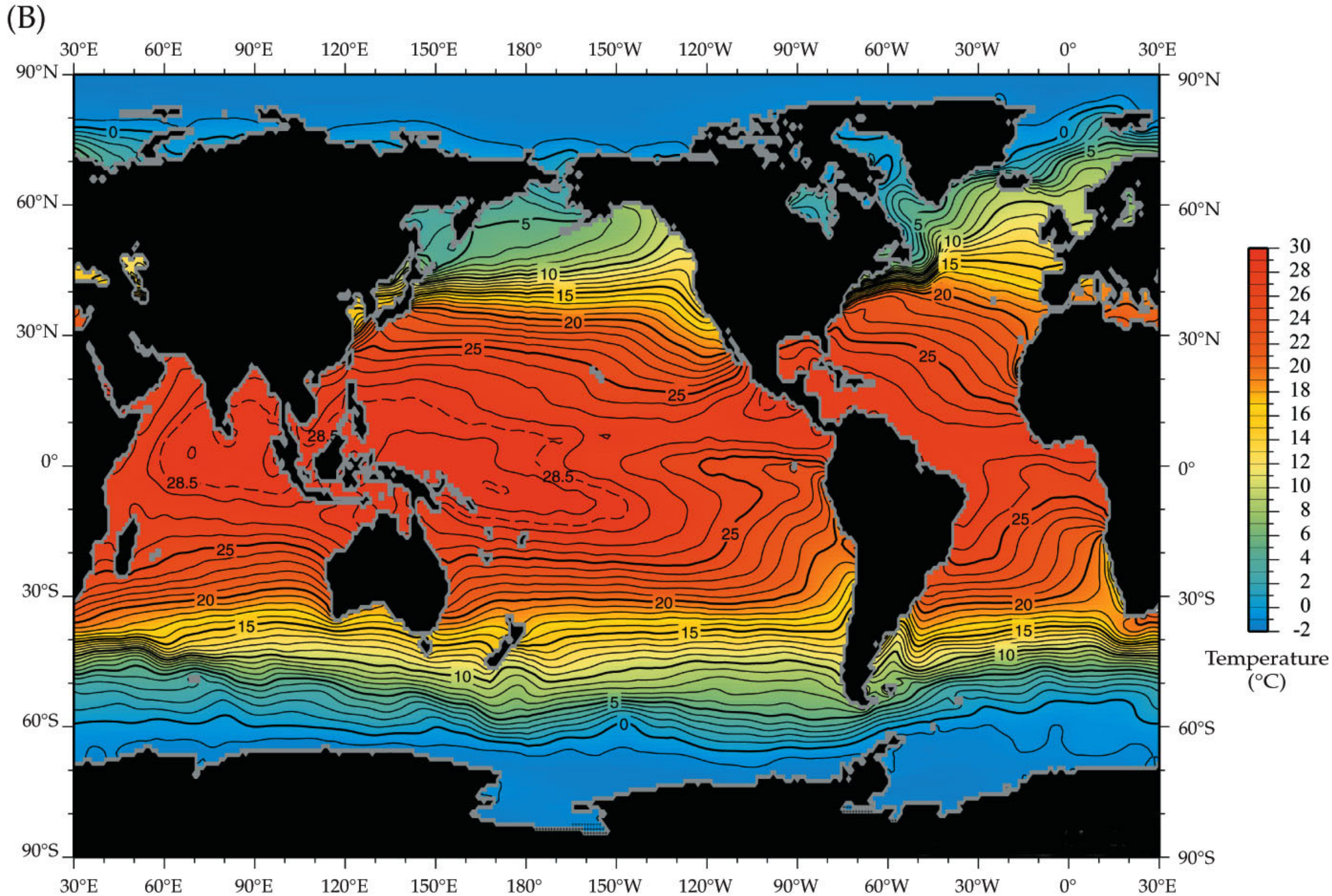


Figure 2.14 Global Average Annual Temperatures (Part 2)

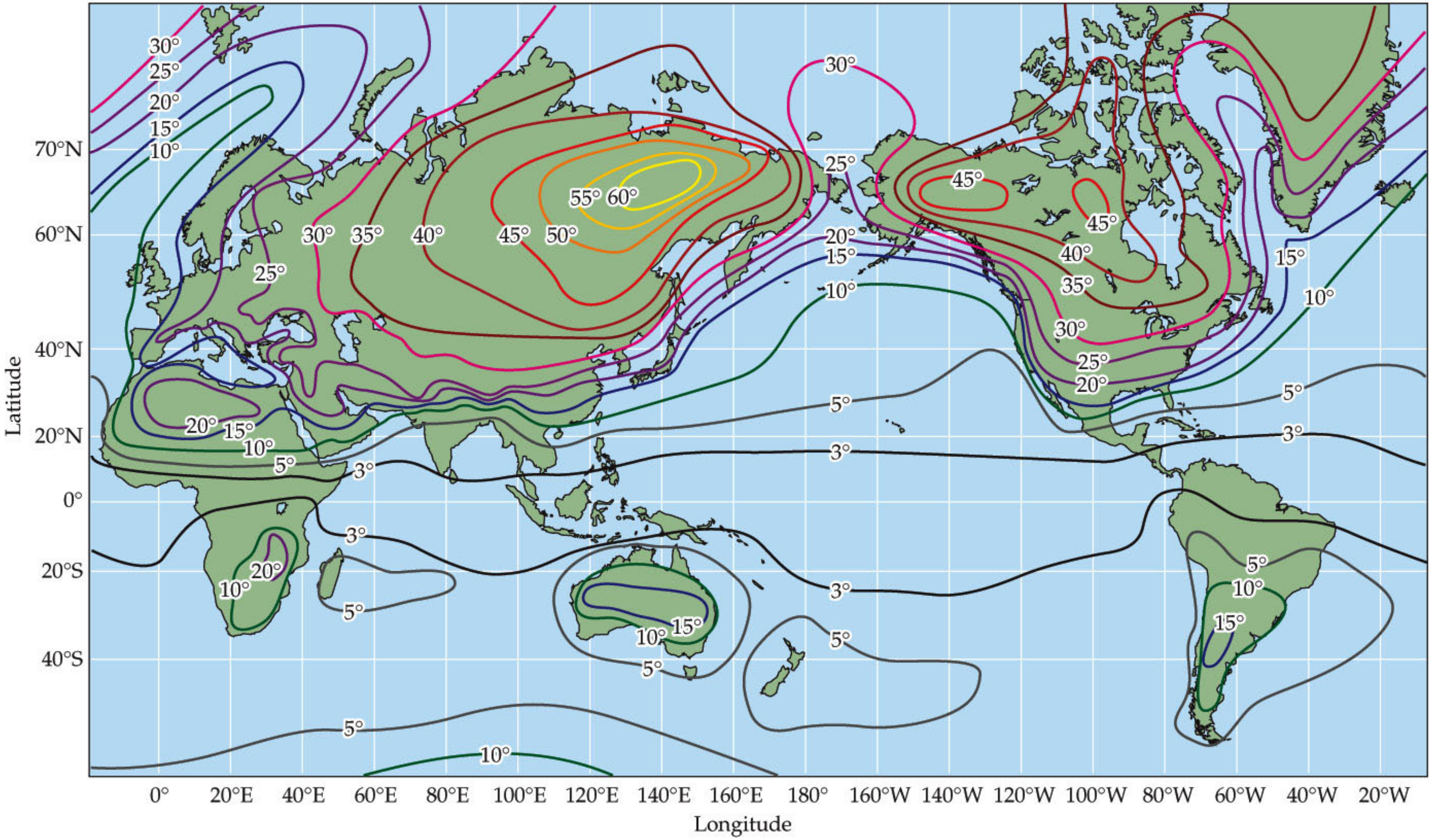


Global Climatic Patterns

Air temperatures on land show greater seasonal variation than those over the oceans.

Elevation also influences temperature. Colder climates at higher elevations result from lower air pressure and density with increasing elevation. As a result, the heat capacity of the air also decreases.

Figure 2.15 Annual Seasonal Temperature Variation



ECOLOGY, Figure 2.15

Highlands exchange air more effectively with cooler air in the surrounding atmosphere.

Lapse rate: The temperature of the atmosphere decreases with increasing height above the ground.

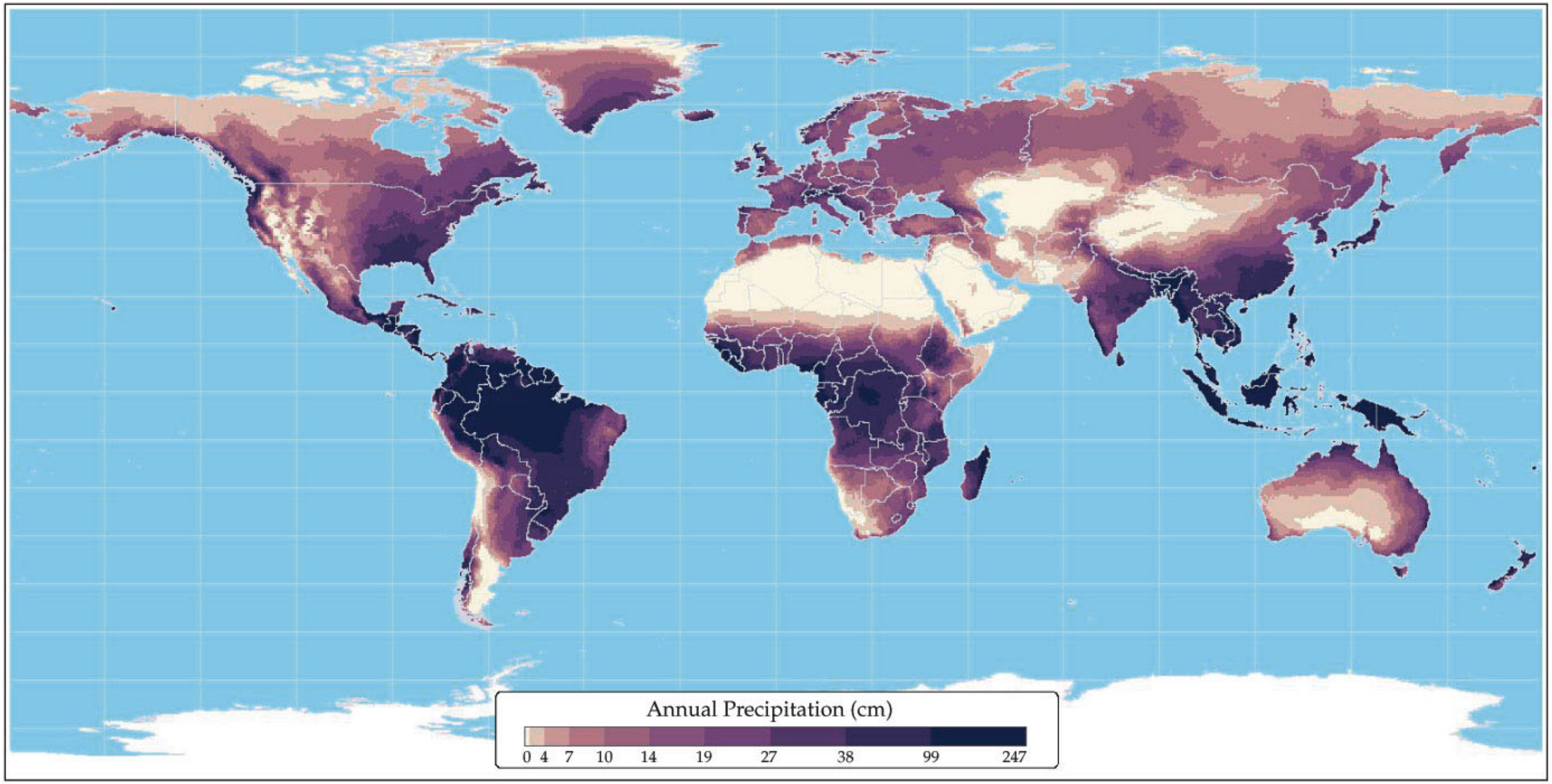
Wind velocity increases with increasing elevation due to less friction with the ground surface.

Global Climatic Patterns

The Hadley, Ferrell, and polar circulation cells suggest that precipitation should be highest in the tropical latitudes and in a band at about 60° N and S; and lowest in zones around 30° N and S.

Deviations from these patterns are associated with the semipermanent high and low pressure zones.

Figure 2.16 Average Annual Terrestrial Precipitation



Regional Climatic Influences

Concept 2.4: Regional climates reflect the influence of the distribution of oceans and continents, elevation, and vegetation.

Proximity to oceans, mountain ranges, and regional topography influence regional climate, which influences vegetation.

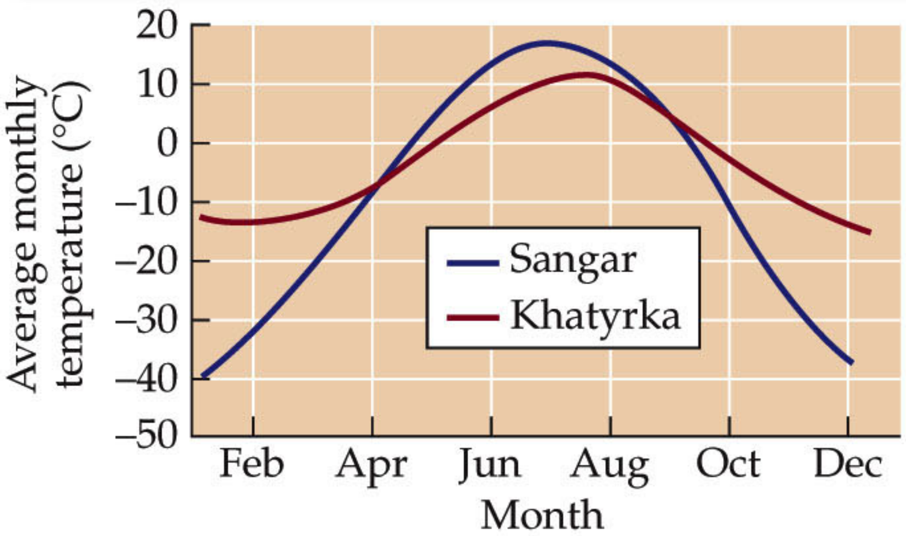
Vegetation in turn affects regional climate.

Regional Climatic Influences

Coastal areas have a **maritime climate**: Little daily and seasonal variation in temperature, and high humidity.

Areas in the center of large continents have **continental climate**: Much greater variation in daily and seasonal temperatures.

Figure 2.17 Monthly Mean Temperatures in a Continental and a Maritime Climate



ECOLOGY, Figure 2.17

Regional Climatic Influences

Abrupt shifts in vegetation on mountain slopes reflect the rapid changes in climate as temperatures decrease, precipitation increases, and wind speed increases with elevation.

When an air mass meets a mountain range, it is forced upwards, cooling and releasing precipitation.

Regional Climatic Influences

Slope aspect (direction the slope faces) can influence regional climate.

North-south trending mountain ranges create a **rain shadow**: The slope facing the prevailing winds (windward) receives high precipitation, while the leeward slope gets little precipitation.

The rain shadow effect influences vegetation.

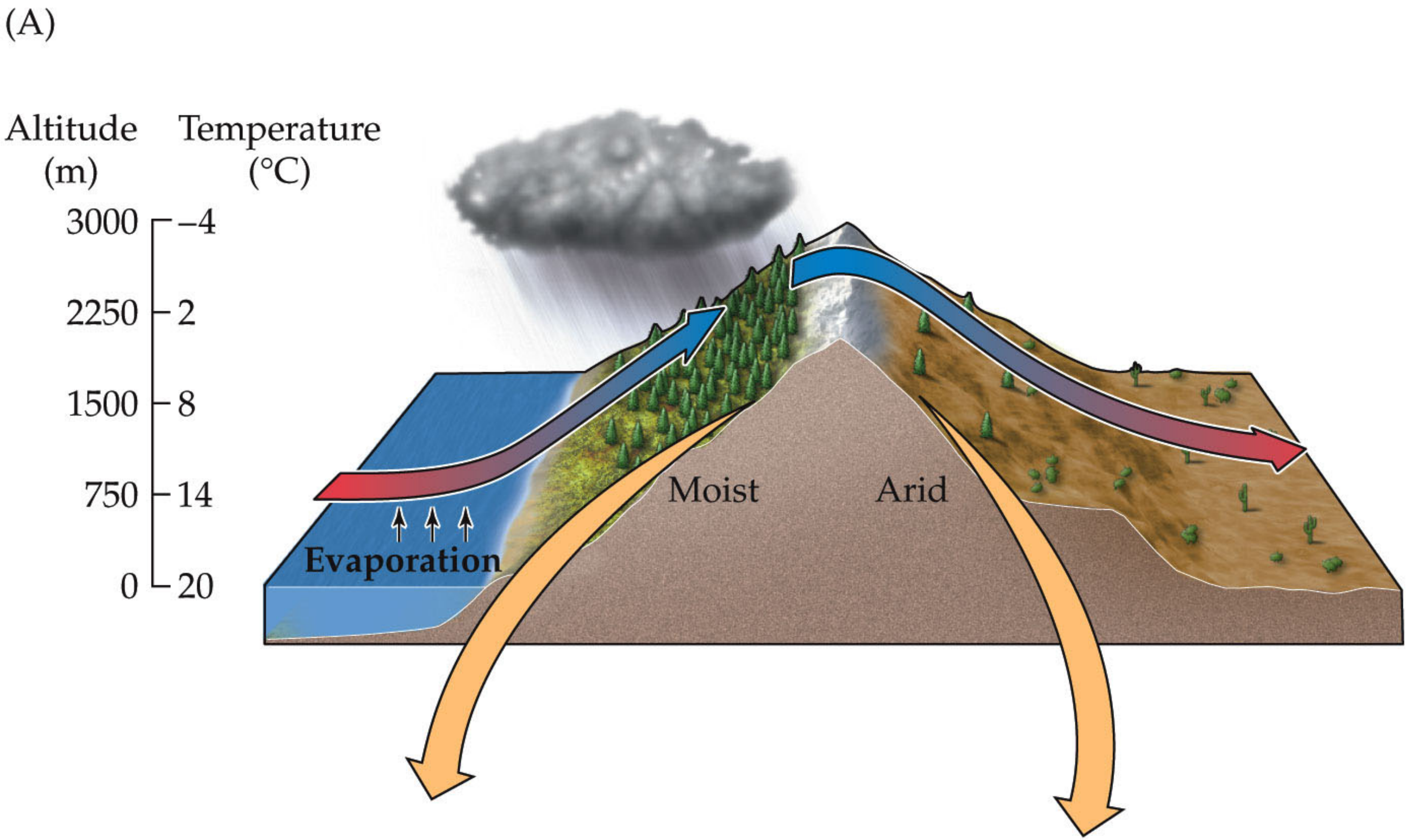
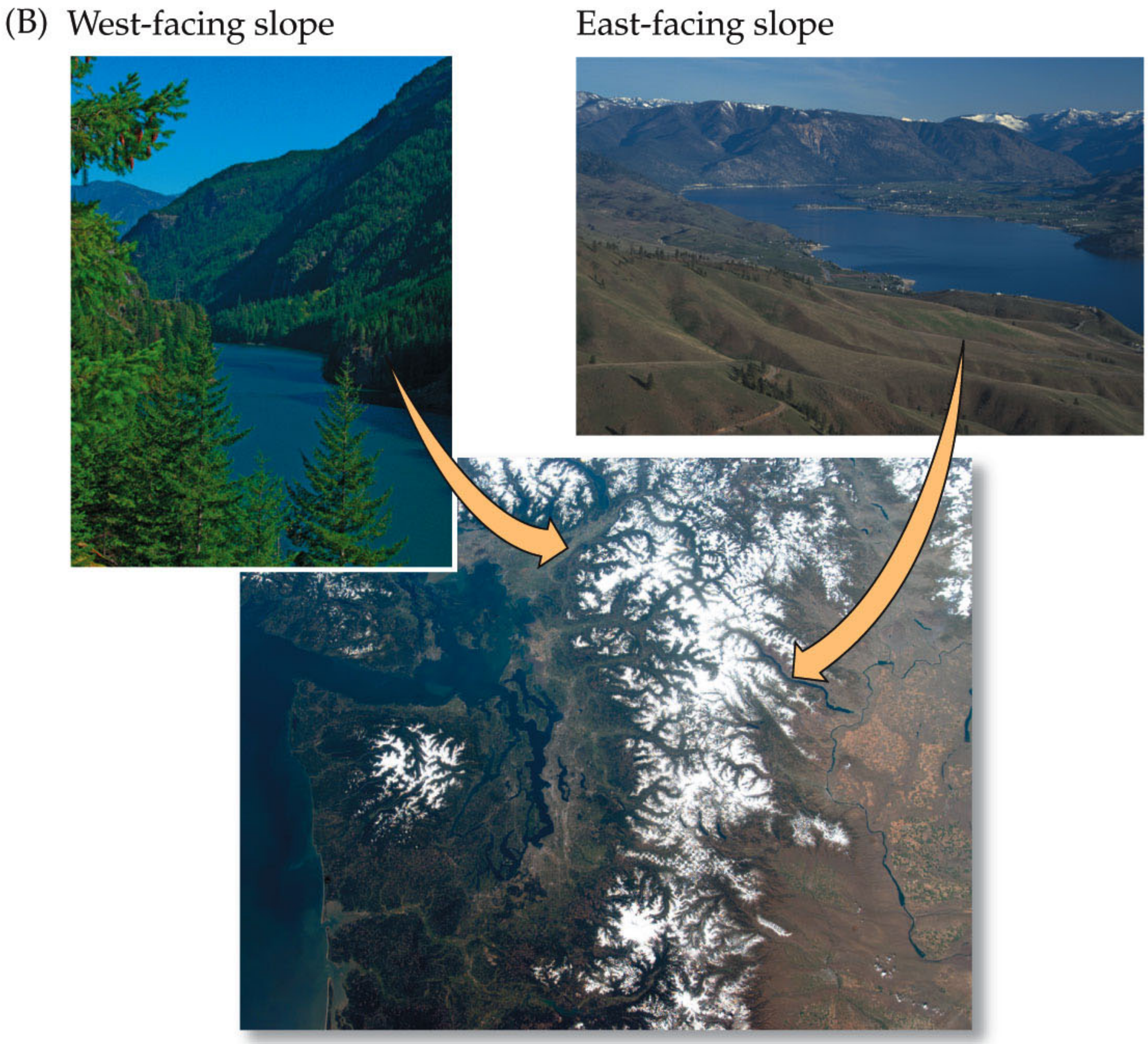

(A)
Altitude (m)
Temperature (°C)
3000
–4
2250
2
1500
8
750
14
0
20
Evaporation
Moist
Arid

Figure 2.18 The Rain-Shadow Effect (Part 2)



ECOLOGY, **Figure 2.18 (Part 2)**

Regional Climatic Influences

East-facing slopes receive more solar radiation and become warmer than the surrounding slopes and lowlands.

This differential heating creates localized upslope winds.

Clouds may form and produce thunderstorms that can move into the surrounding lowlands.

Regional Climatic Influences

At night, cooling is greater at higher elevations, and the cold, dense air flows downslope and pools in low-lying areas.

As a result, valley bottoms are the coldest sites in mountainous areas during clear, calm nights.

Regional Climatic Influences

Cordilleras—large mountain chains—can channel movement of air masses.

For example, the Rocky Mountains steer cold Canadian air through central North America and inhibit its movement through the intermountain basins to the west.

Vegetation can also influence climate.

Albedo—the capacity of a land surface to reflect solar radiation—is influenced by vegetation type, soils, and topography.

For example, a coniferous forest has a darker color and lower albedo than bare soil or a dormant grassland.

Evapotranspiration is the sum of water loss through transpiration by plants and evaporation from the soil.

Evapotranspiration transfers energy (as latent heat) and water into the atmosphere, thereby affecting air temperature and moisture.

Regional Climatic Influences

Loss or alteration of vegetation can affect climate.

Deforestation increases the albedo of the land surface, lowering the absorption of solar radiation and resulting in less heating.

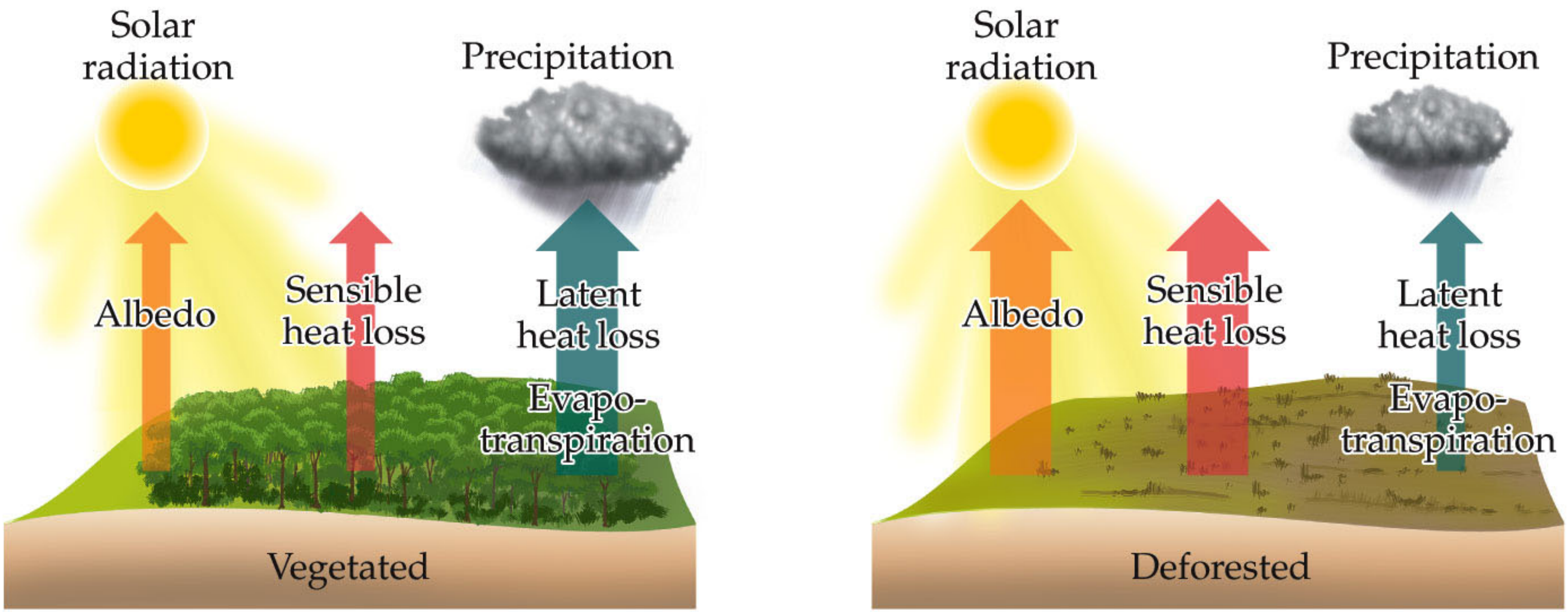
The lower heat gain is offset by less cooling by evapotranspiration, due to loss of leaf area.

Regional Climatic Influences

Decreased evapotranspiration results in less moisture in the atmosphere and less precipitation.

Deforestation in the tropics can lead to warmer, dryer regional climate.

Figure 2.19 The Effects of Deforestation Illustrate the Influence of Vegetation on Climate



ECOLOGY, **Figure 2.19**

Concept 2.5: Seasonal and long-term climatic variation are associated with changes in Earth's position relative to the sun.

Climate has varied over hundreds and thousands of years.

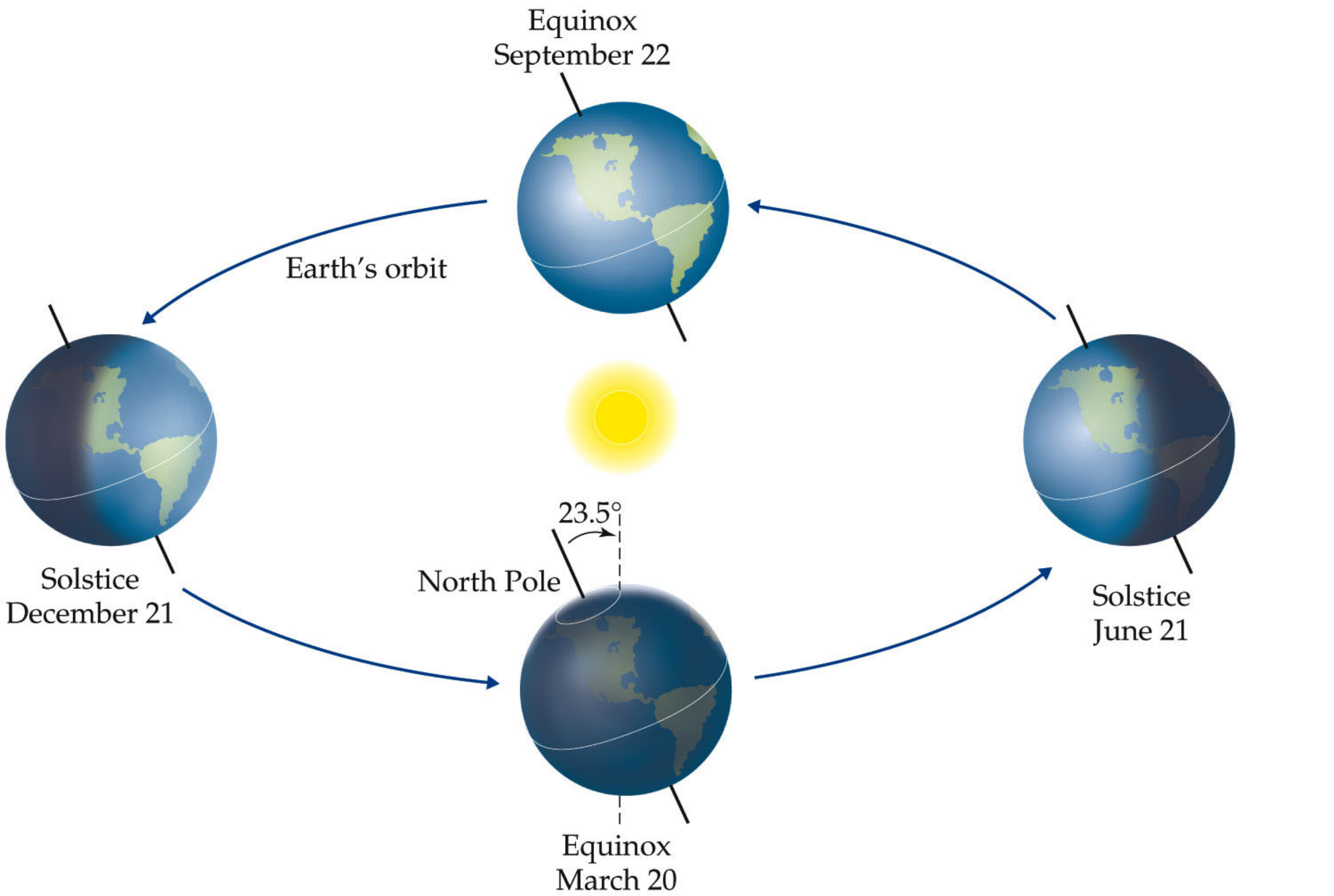
These variations have influenced the evolutionary history of organisms and the development of ecosystems.

Climatic Variation over Time

Earth is tilted at an angle of 23.5° relative to the sun’s direct rays.

The angle and intensity of the sun’s rays striking any point on Earth vary as Earth orbits the sun, resulting in seasonal variation in climate.

Figure 2.20 Seasonal Changes in Climate



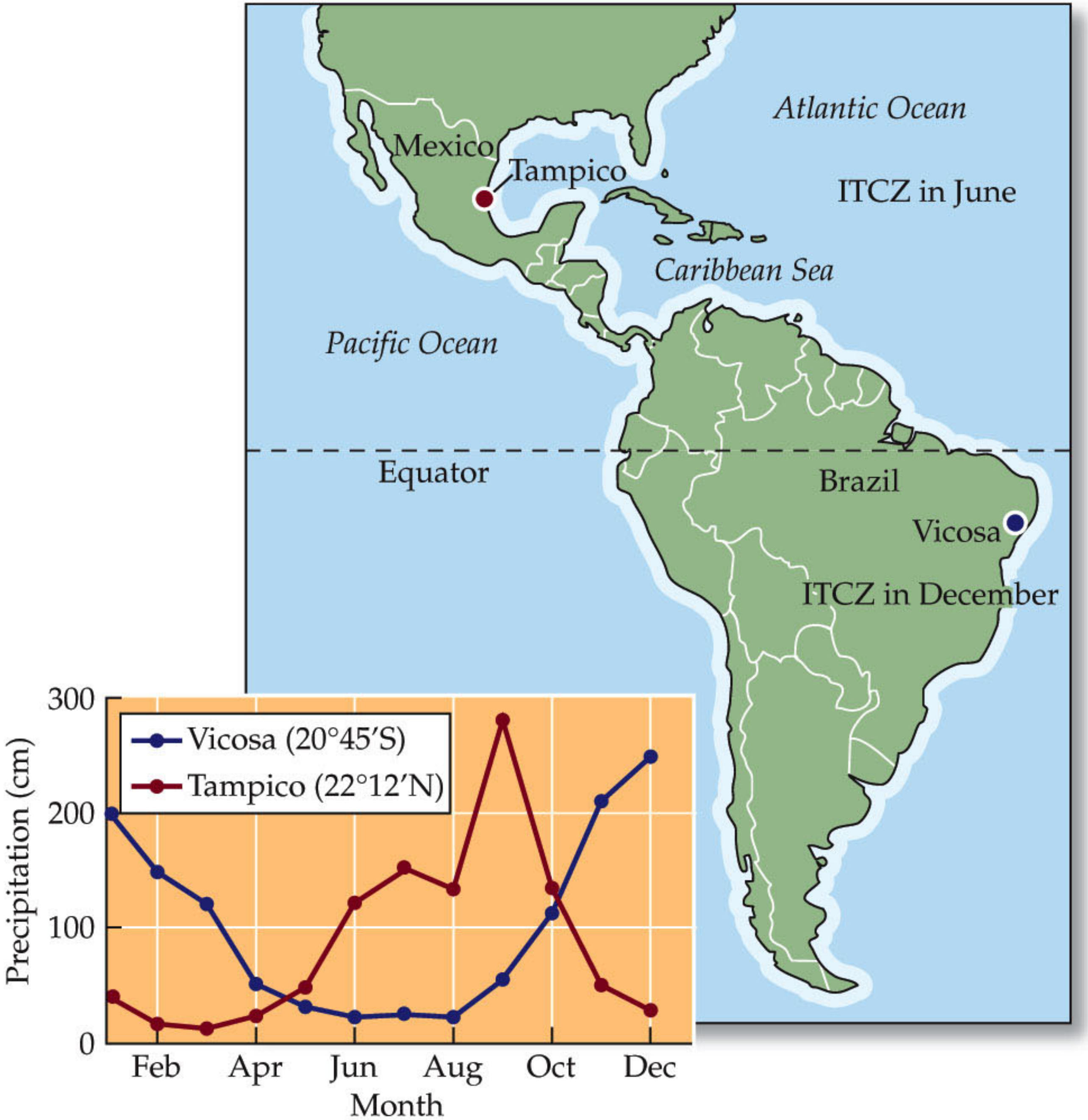
ECOLOGY, Figure 2.20

Climatic Variation over Time

In the tropics, seasons are marked by changes in precipitation.

The zone of maximum solar radiation and atmospheric uplift—the Intertropical Convergence Zone (ITCZ), moves between 23.5°N and 23.5°S, bringing the wet season with it.

Figure 2.21 Wet and Dry Seasons and the ITCZ



ECOLOGY, Figure 2.21

Climatic Variation over Time

Temperate and polar zones have seasonal variation in solar radiation and temperatures.

The difference in solar radiation between summer and winter increases from the tropics toward the poles, and also results in varying day lengths.

Aquatic environments also experience seasonal changes in temperature.

Water is most dense at 4°C. Ice has a lower density, and forms on the surface.

Ice has higher albedo than open water.

Oceans and lakes can become **stratified**—warm surface water on top of colder, denser water results in layers that do not mix.

Stratification determines the movement of nutrients and oxygen; both are important to organisms.

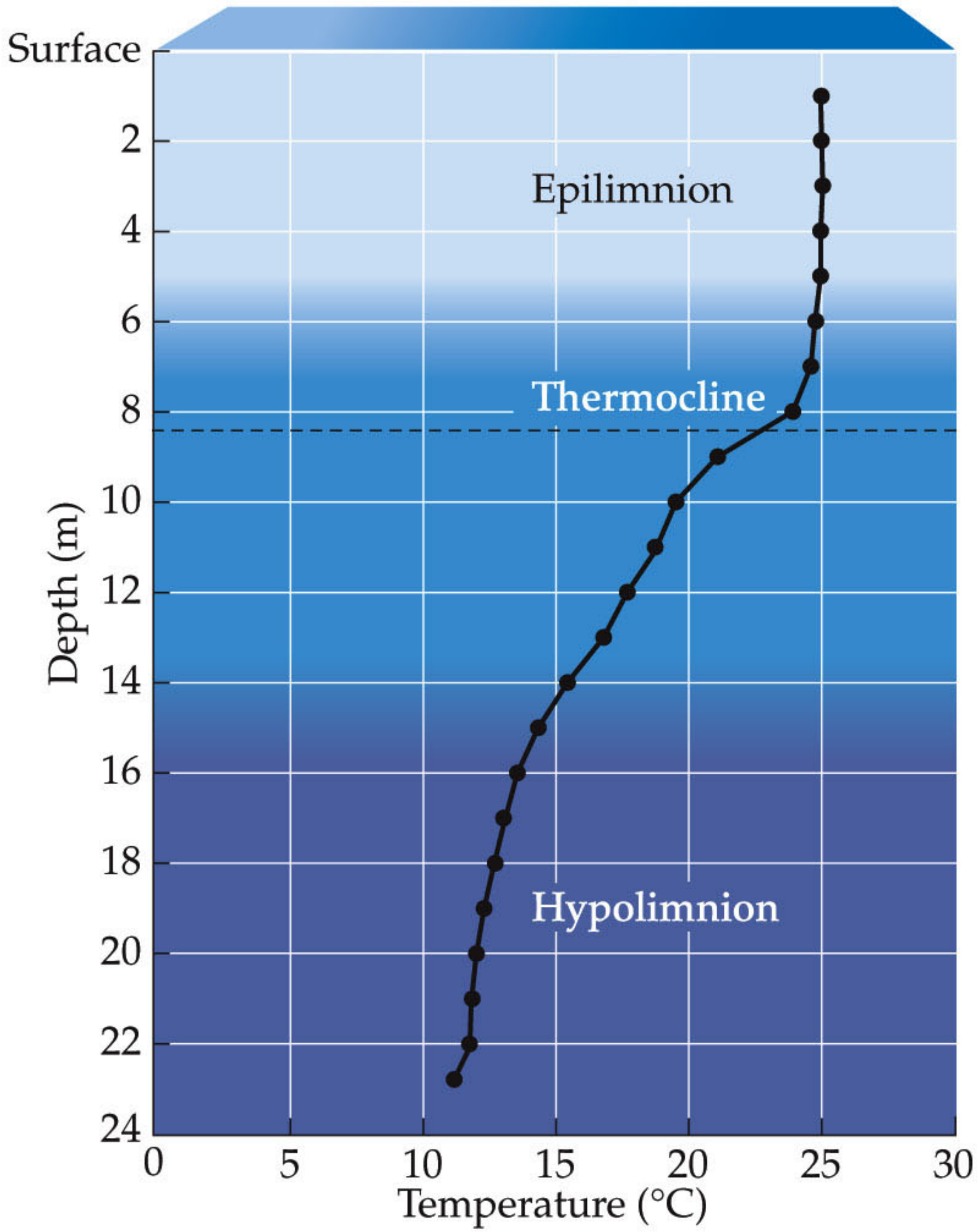
Climatic Variation over Time

In temperate-zone lakes, changes in stratification occur with the seasons.

In summer, stratification is most intense; the warm **epilimnion** lies over the colder **hypolimnion**. The **thermocline** is the zone of transition.

Complete mixing (**turnover**) occurs in spring and fall when water temperature and density become uniform with depth.

Figure 2.22 Lake Stratification



ECOLOGY, Figure 2.22

Climatic Variation over Time

El Niño events are longer-scale variations in climate associated with a switch (or oscillation) in the positions of high- and low-pressure systems over equatorial Pacific.

The **El Niño Southern Oscillation** (ENSO) has a frequency of 3 to 8 years, and lasts about 18 months.

The trade winds that normally push surface water toward Southeast Asia are weakened, or shift direction.

The upwelling of deep ocean water off the coast of South America ceases, resulting in much lower fish harvests.

Figure 2.23 El Niño Global Climatic Variation (Part 1)

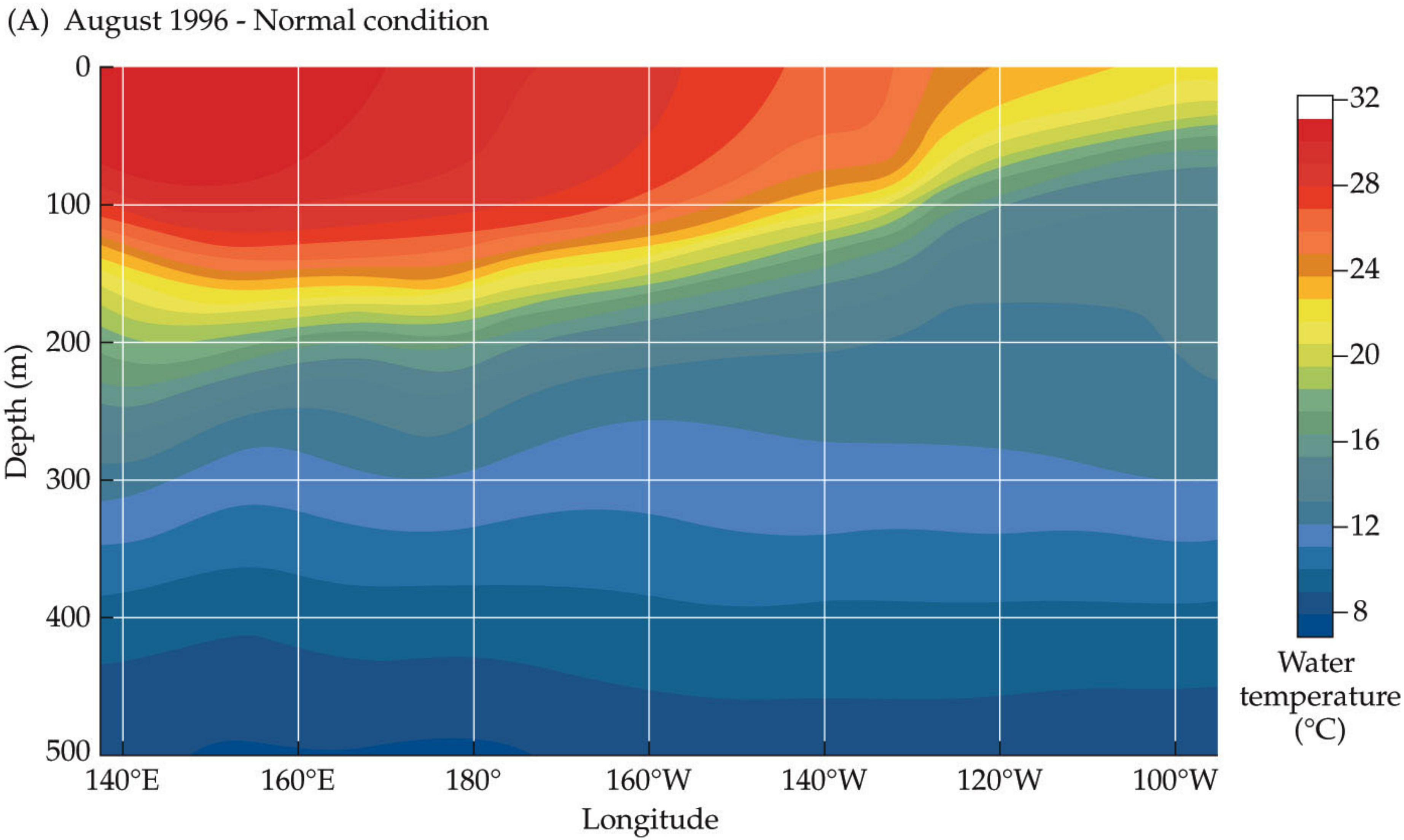
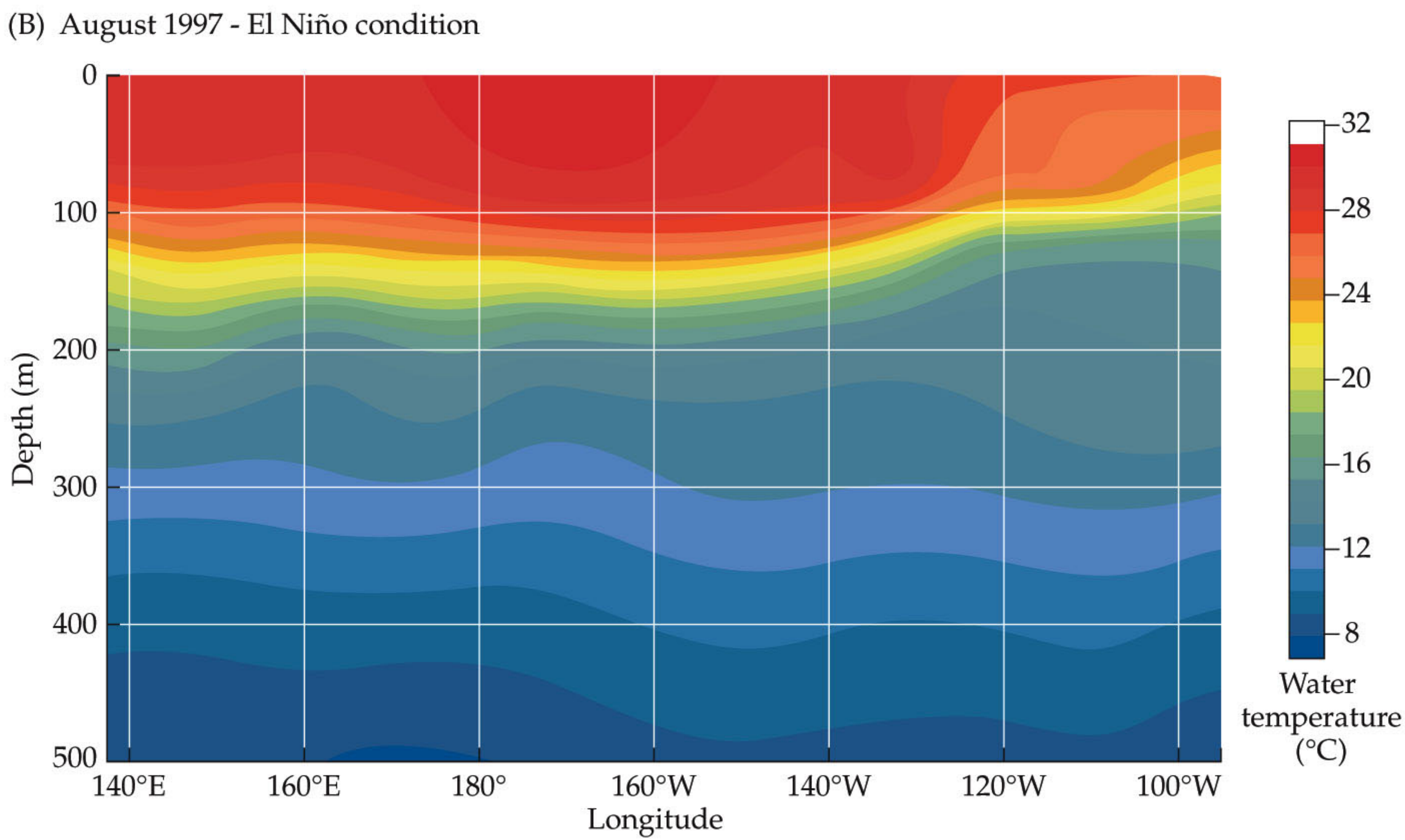


Figure 2.23 El Niño Global Climatic Variation (Part 2)

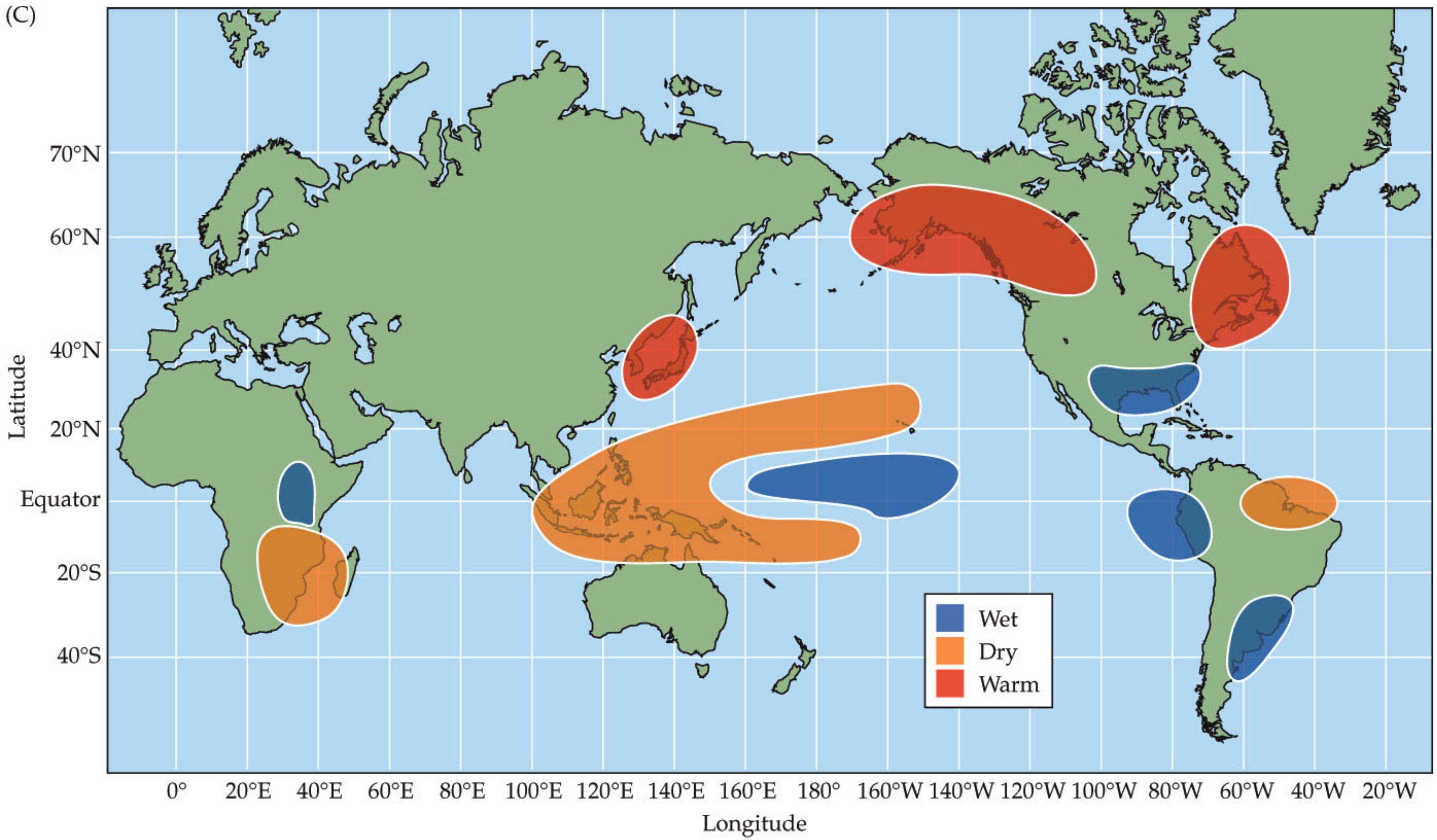


ENSO also includes **La Niña** events, stronger-than-average phases of the normal pattern, with high pressure off the coast of South America and low pressure in the western Pacific.

La Niña events usually follow El Niño, but tend to be less frequent.

ENSO is connected with unusual climate patterns in distant places.

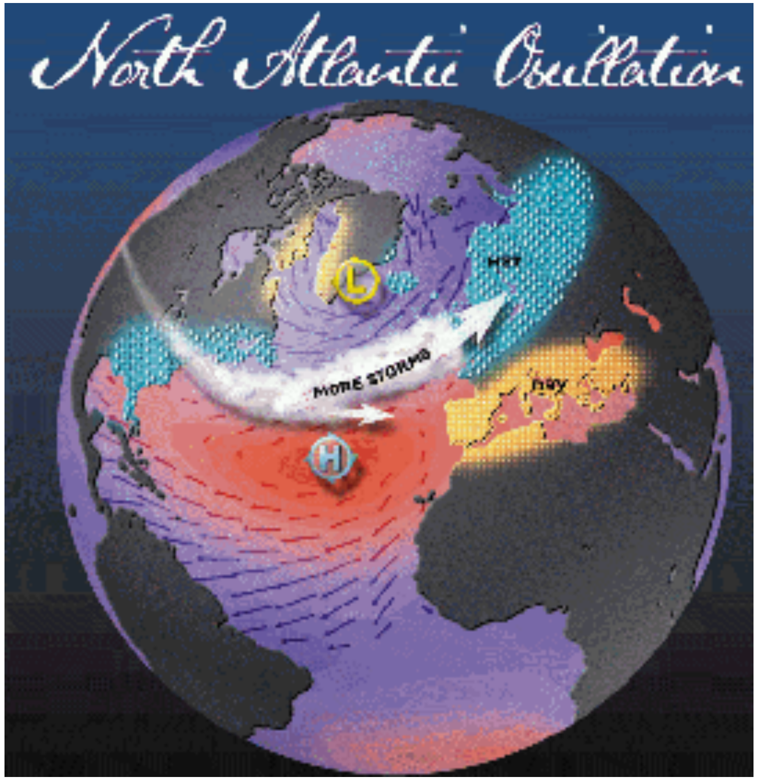
Figure 2.23 El Niño Global Climatic Variation (Part 3)

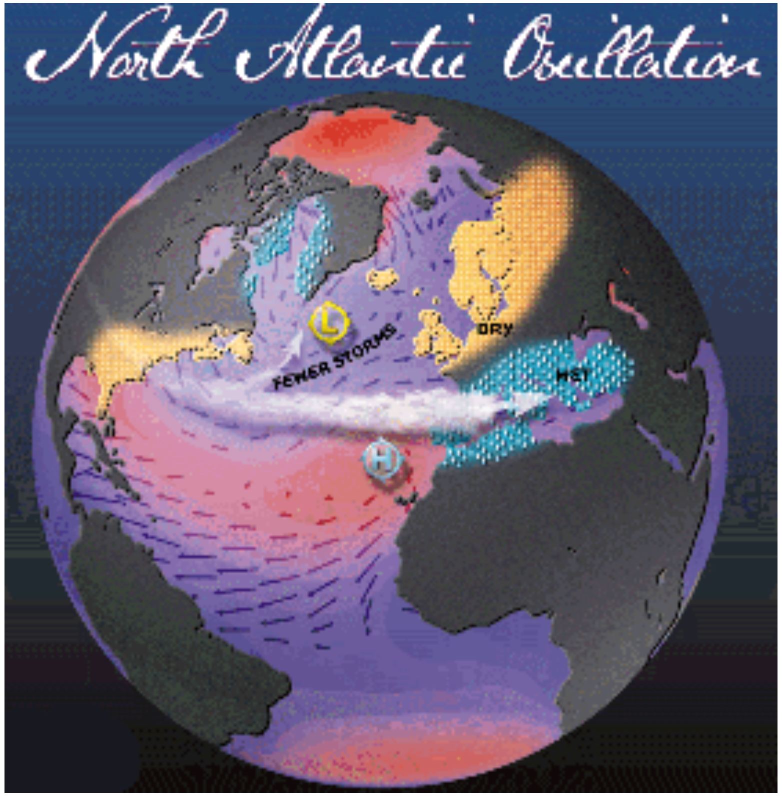


ECOLOGY, Figure 2.23 (Part 3)

The **North Atlantic Oscillation** (NAO) is a similar atmospheric pressure–ocean current oscillation that affects climate in Europe, northern Asia, and the eastern coast of North America.

The **Pacific Decadal Oscillation** (PDO) affects climate in the North Pacific.


North Atlantic Oscillation
L
MORE STORMS
H


North Atlantic Oscillation
L
FEWER STORMS
DRY
H

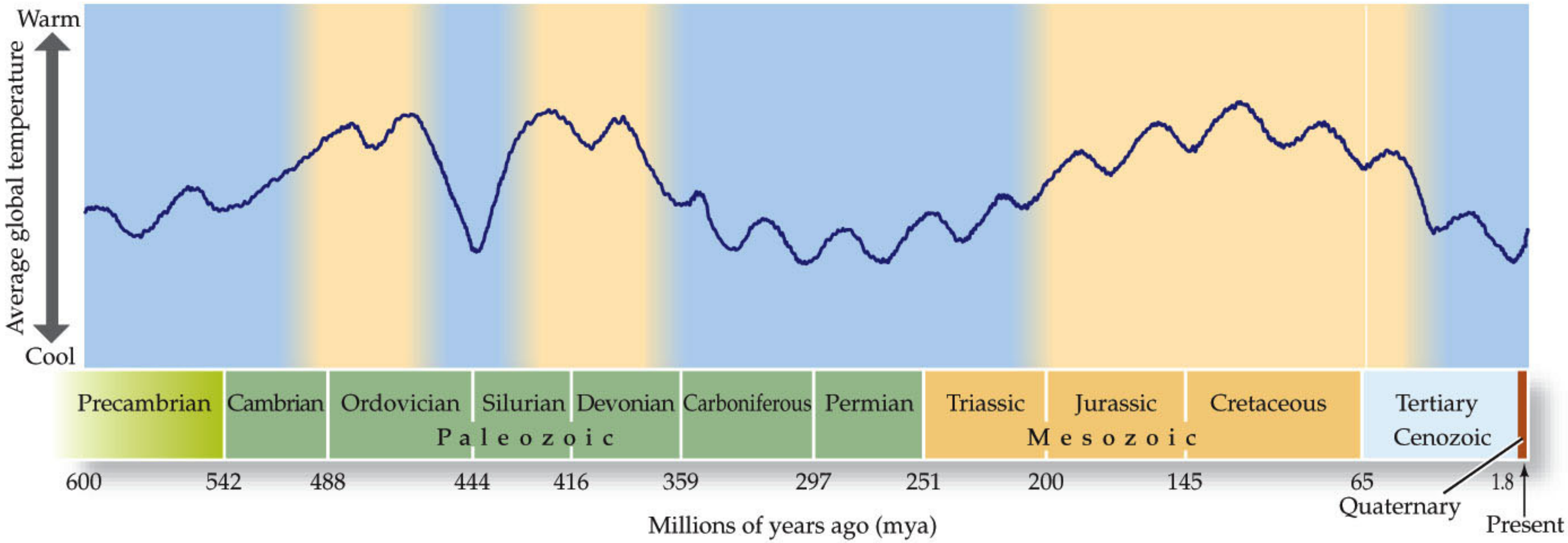
Climatic Variation over Time

Fossils of dinosaurs and trees in Antarctica indicate that climate there was once much warmer.

Over the past 500 million years, Earth's climate has fluctuated between warmer and cooler conditions several times.

Warmer periods are associated with higher concentrations of greenhouse gases.

Figure 2.24 Long-Term Record of Global Temperature



Climatic Variation over Time

Earth is currently in a cool phase characterized by formation and advance of glaciers (glacial maxima), followed by warm periods with glacial melting and decline (interglacial periods).

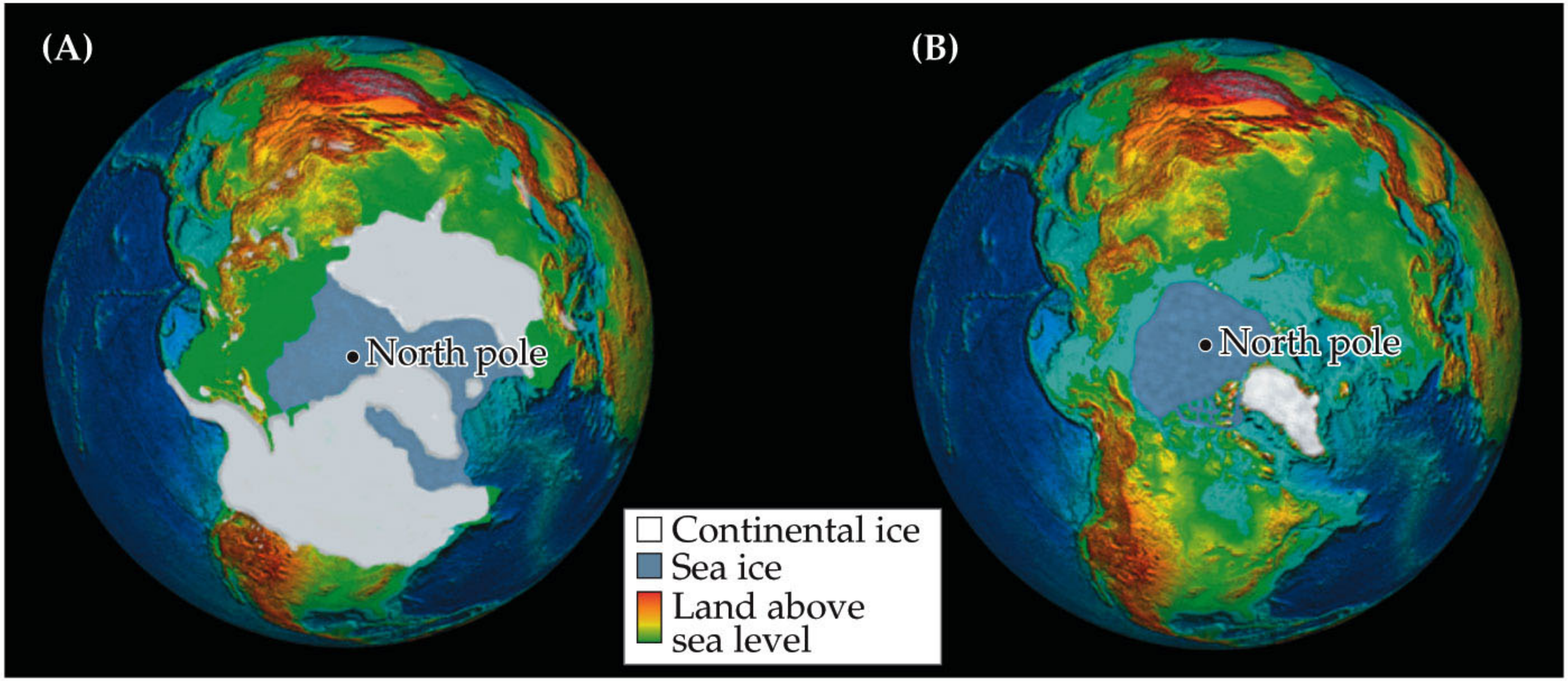
These glacial–interglacial cycles occur at frequencies of about 100,000 years.

Climatic Variation over Time

We are currently in an interglacial period; these have lasted approximately 23,000 years in the past.

The last glacial maximum was approximately 18,000 years ago.

Figure 2.25 The Most Recent Glaciation of the Northern Hemisphere



These long-term climate oscillations have been explained by regular changes in the shape of Earth’s orbit and the tilt of its axis—**Milankovitch cycles**.

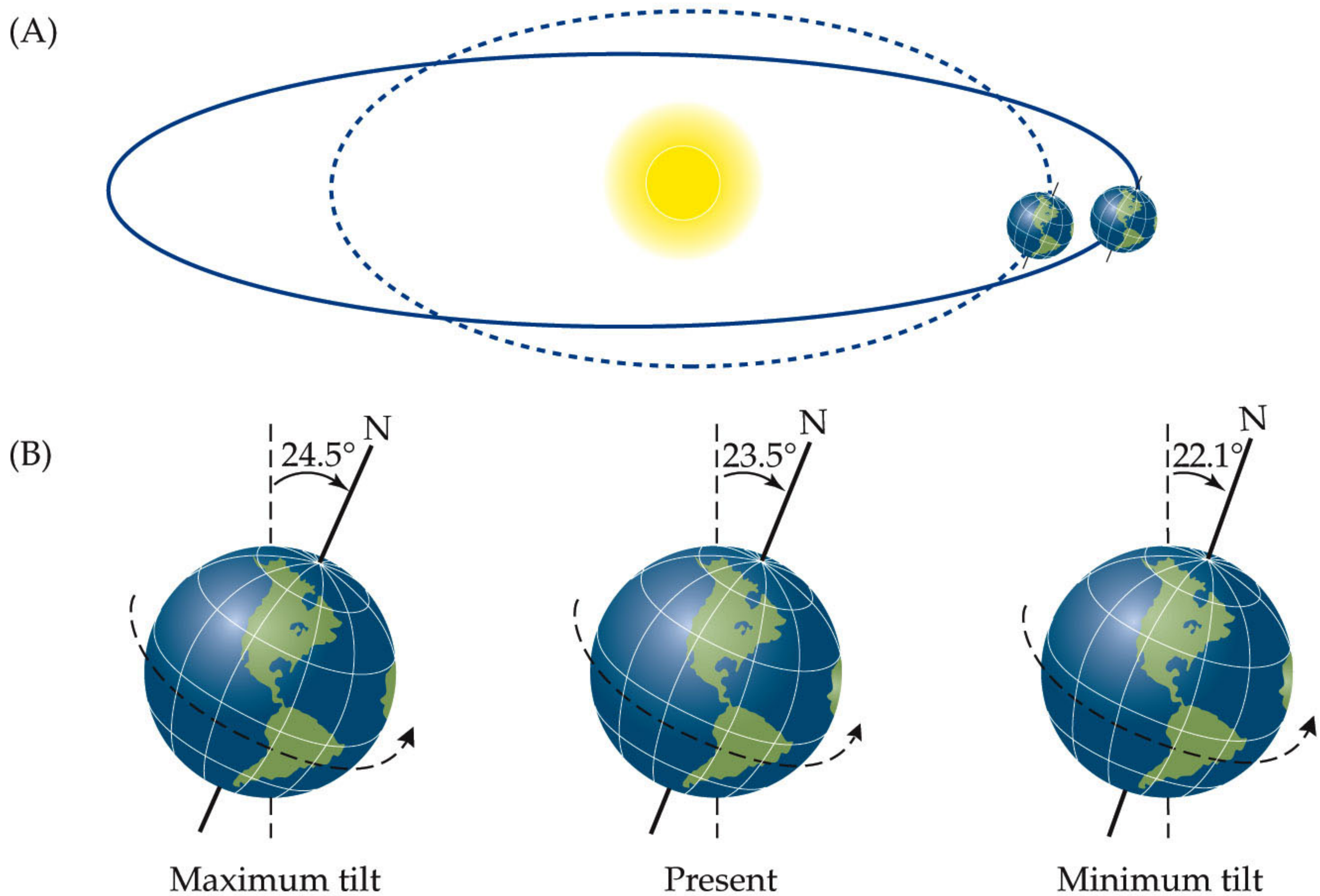
The intensity of solar radiation reaching Earth changes, resulting in climatic change.

Climatic Variation over Time

The shape of Earth's orbit varies from circular to more elliptic on a 100,000-year cycle.

The angle of tilt of Earth's axis changes in cycles of about 41,000 years.

Figure 2.26 Milankovitch Cycles and Long-Term Climatic Variation (Part 1)



ECOLOGY, Figure 2.26 (Part 1)

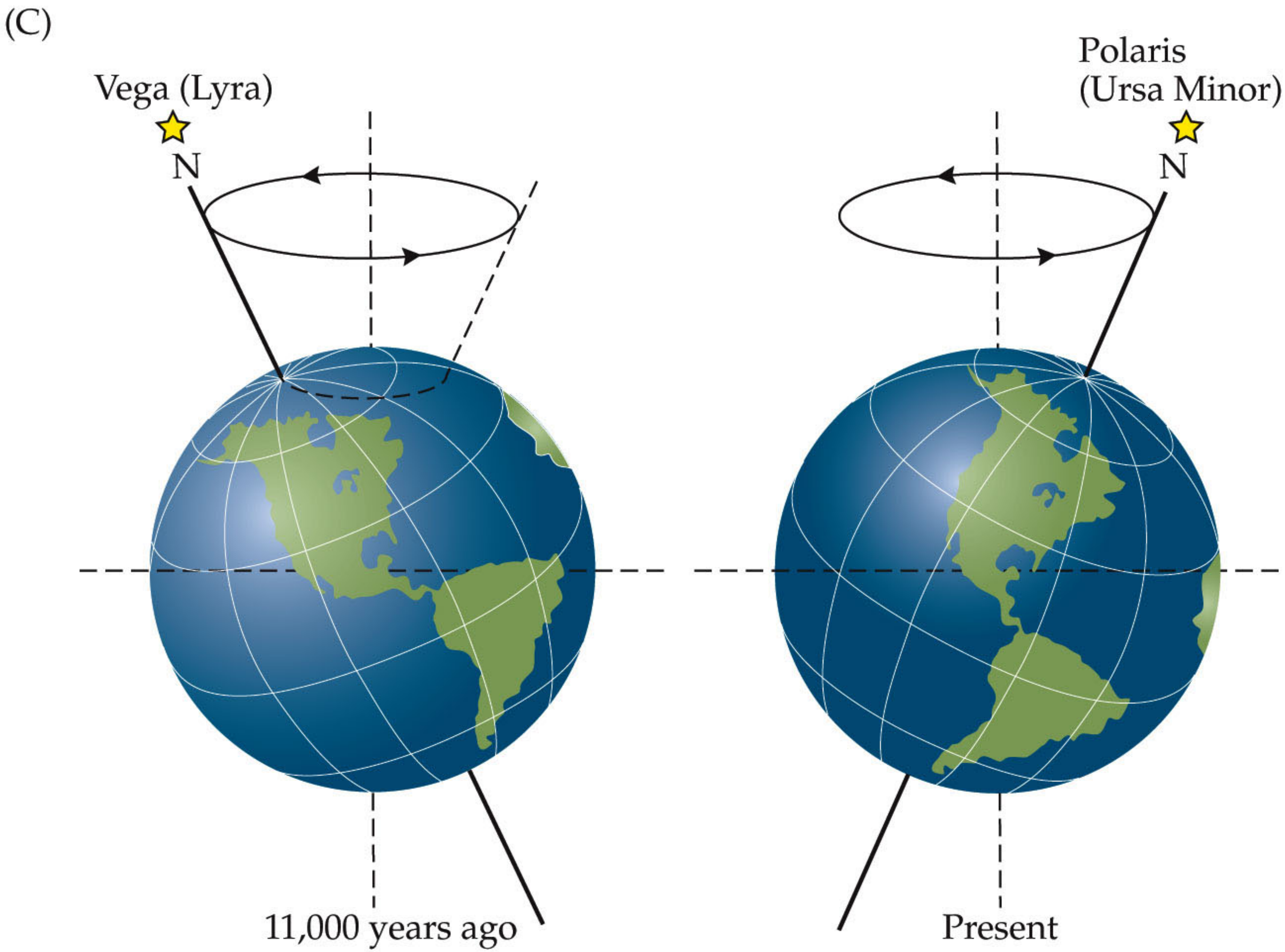
Climatic Variation over Time

Earth's orientation relative to other celestial bodies changes in regular cycles of about 22,000 years.

Today, the North Pole is oriented toward Polaris, the North Star, but that has not always been the case.

These changes influence the timing of the seasons.

Figure 2.26 Milankovitch Cycles and Long-Term Climatic Variation (Part 2)



ECOLOGY, Figure 2.26 (Part 2)

Concept 2.6: Salinity, acidity, and oxygen concentrations are major determinants of the chemical environment.

All organisms, both aquatic and terrestrial, are bathed in a matrix of chemicals.

Composition of the atmosphere is relatively constant, but small changes in chemical concentrations in water (including soil water) have important consequences for organisms.

The atmosphere:

- Nitrogen (78%).
- Oxygen (20%).
- Water vapor (1%).
- Argon (0.9%).
- Trace gases, including the greenhouse gases.
- Pollutants.

The Chemical Environment

Salinity: Concentration of dissolved salts in water.

Salts influence the properties of water, and affect ability of organisms to absorb water.

Salts can also be nutrients.

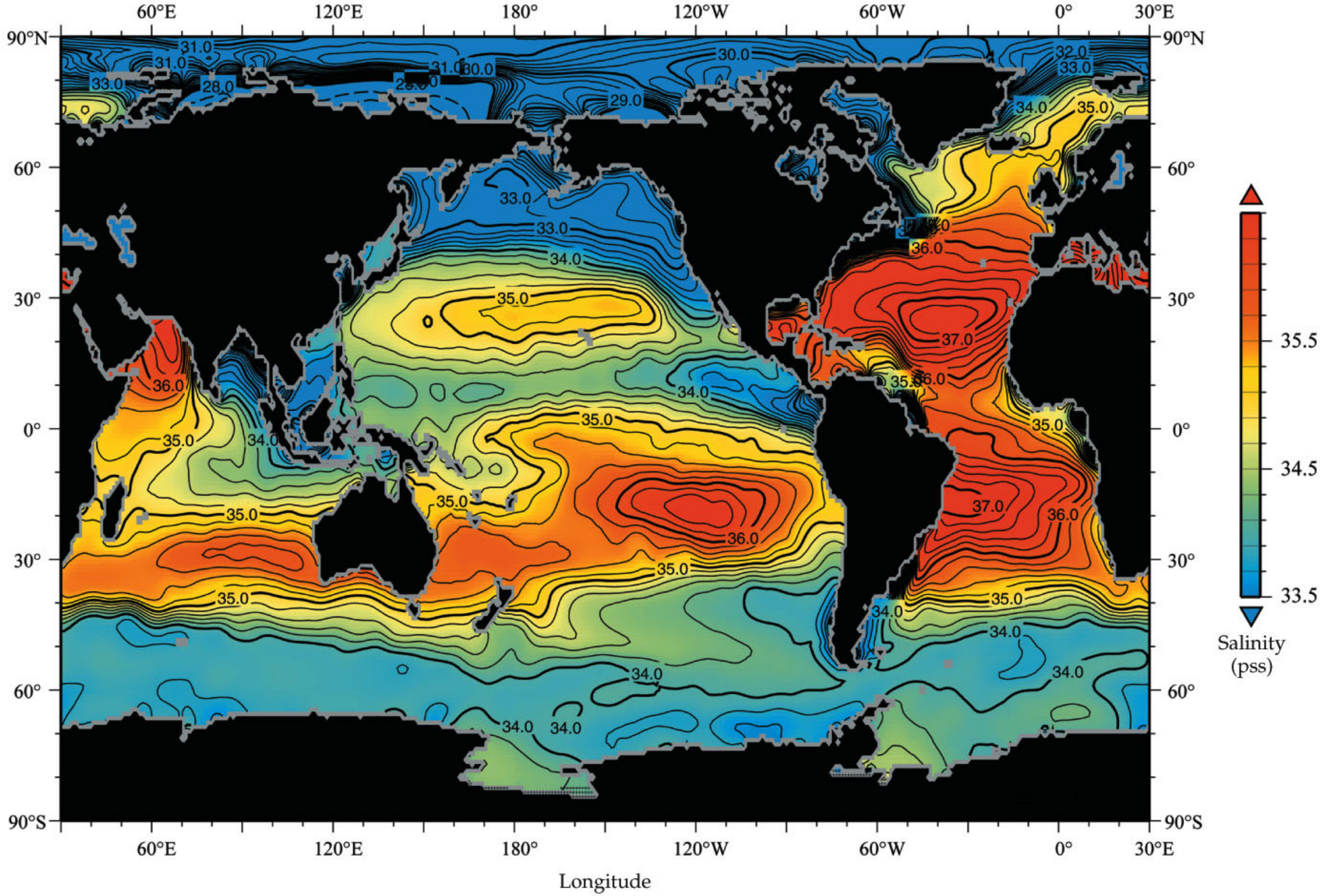
The Chemical Environment

Salinity of the oceans varies between 3.3% and 3.7%.

It varies as a result of evaporation, precipitation, and the melting of sea ice.

Salinity is highest near the equator, and decreases at high latitudes.

Figure 2.27 Global Variation in Salinity at the Ocean Surface



ECOLOGY, Figure 2.27

The Chemical Environment

Ocean salts consist mainly of sodium, chloride, magnesium, calcium, sulfate, bicarbonate, and potassium.

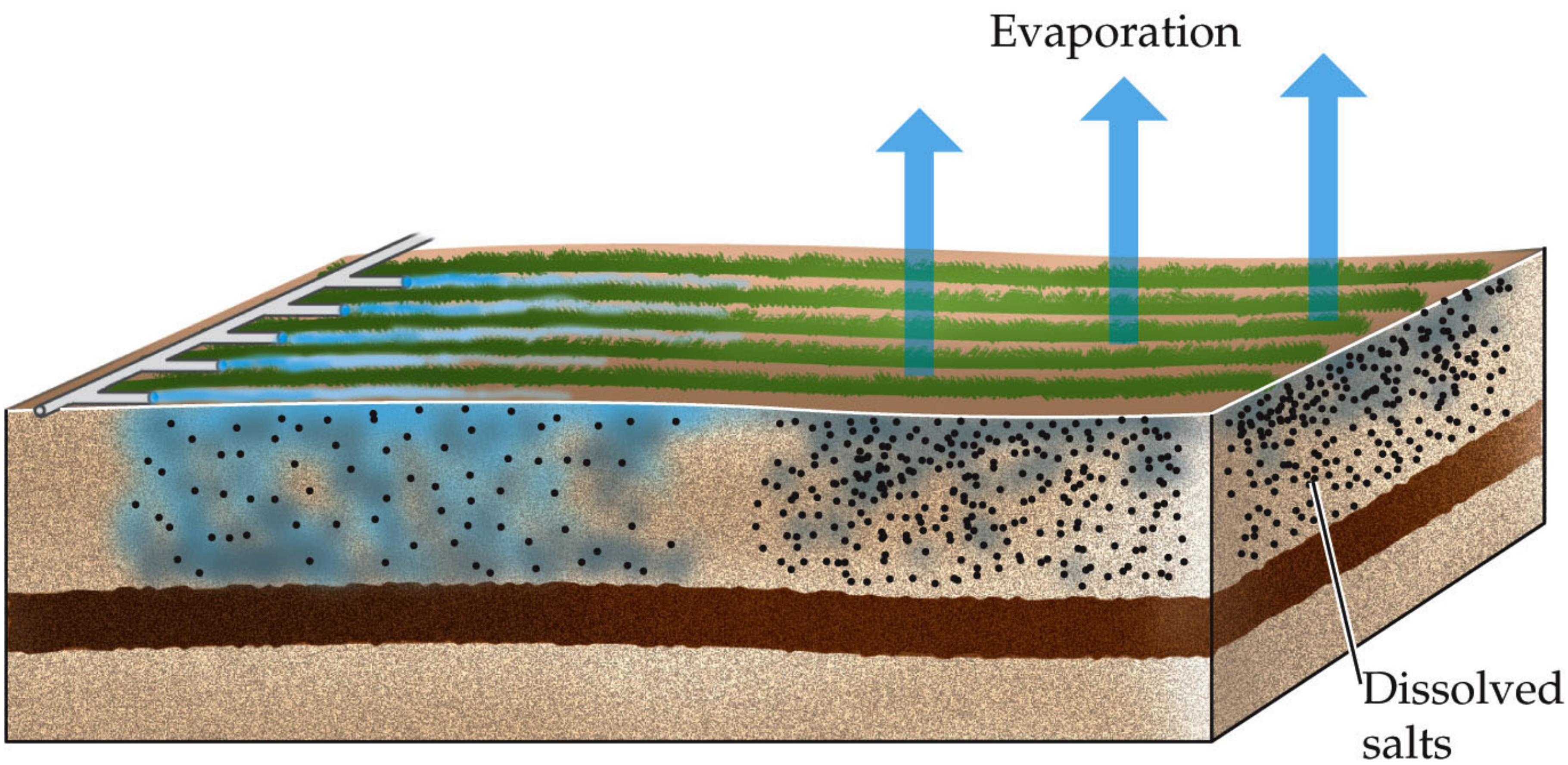
The salts come from gases emitted by volcanic eruptions early in Earth's history, and from the gradual breakdown of minerals in the rocks that make up the crust.

Some inland lakes become more saline over time, reflecting a balance between precipitation, evaporation, and inputs of salts.

Inland “seas” in arid regions can have higher salinity than the oceans—Dead Sea, Great Salt Lake.

Soils near oceans can have high salinity—in salt marshes, tidal estuaries.

Salinization: Soils in arid regions become saline when water is brought to the surface by plant roots or irrigation, and high rates of evapotranspiration result in salt build-up.



ECOLOGY, Figure 2.28

Acidity: Ability of a solution to act as an acid.

Alkalinity: Ability of a solution to act as a base.

Acids are compounds that give up protons (H^+) to the solution.

Bases take up H^+ or give up hydroxide ions (OH^-).

Acidity and alkalinity are measured as pH:

$-\log_{10}$ of the concentration of H^+.

pH of water influences metabolic funtions, and the chemistry and availability of nutrients.

Organisms have a limited range of pH tolerance.

The Chemical Environment

pH is more important in freshwaters and terrestrial ecosystems.

In the oceans, pH doesn’t vary much because the ocean water acts as a buffer.

But increasing CO_2 in the atmosphere may lead to increasing acidity of the oceans.

Water can become more acidic over time as soils develop.

Soils contain mineral particles from the breakdown of rocks. Some rock types, such as granites, generate acidic salts, while other rock types generate basic salts.

Basic minerals leach away more easily, and soils become acidic.

Soils also contain organic matter from the decomposition of dead plants and other organisms.

Plant organic matter also adds acids to soils.

Acidic pollutants can also increase the acidity of soils and surface waters.

The Chemical Environment

Except for some archaea, bacteria, and fungi, most organisms require oxygen for their metabolic processes.

Anoxic (low-oxygen) conditions can promote the formation of chemicals (e.g., hydrogen sulfide) that are toxic to many organisms.

Oxygen levels are important for chemical reactions that determine nutrient availability.

The Chemical Environment

Availability of atmospheric oxygen decreases with elevation above sea level, as the overall density of air decreases.

Oxygen concentration can vary greatly in soils and water.

The rate of diffusion of oxygen into water is slow. Waves and currents help mix oxygen from the atmosphere into water.

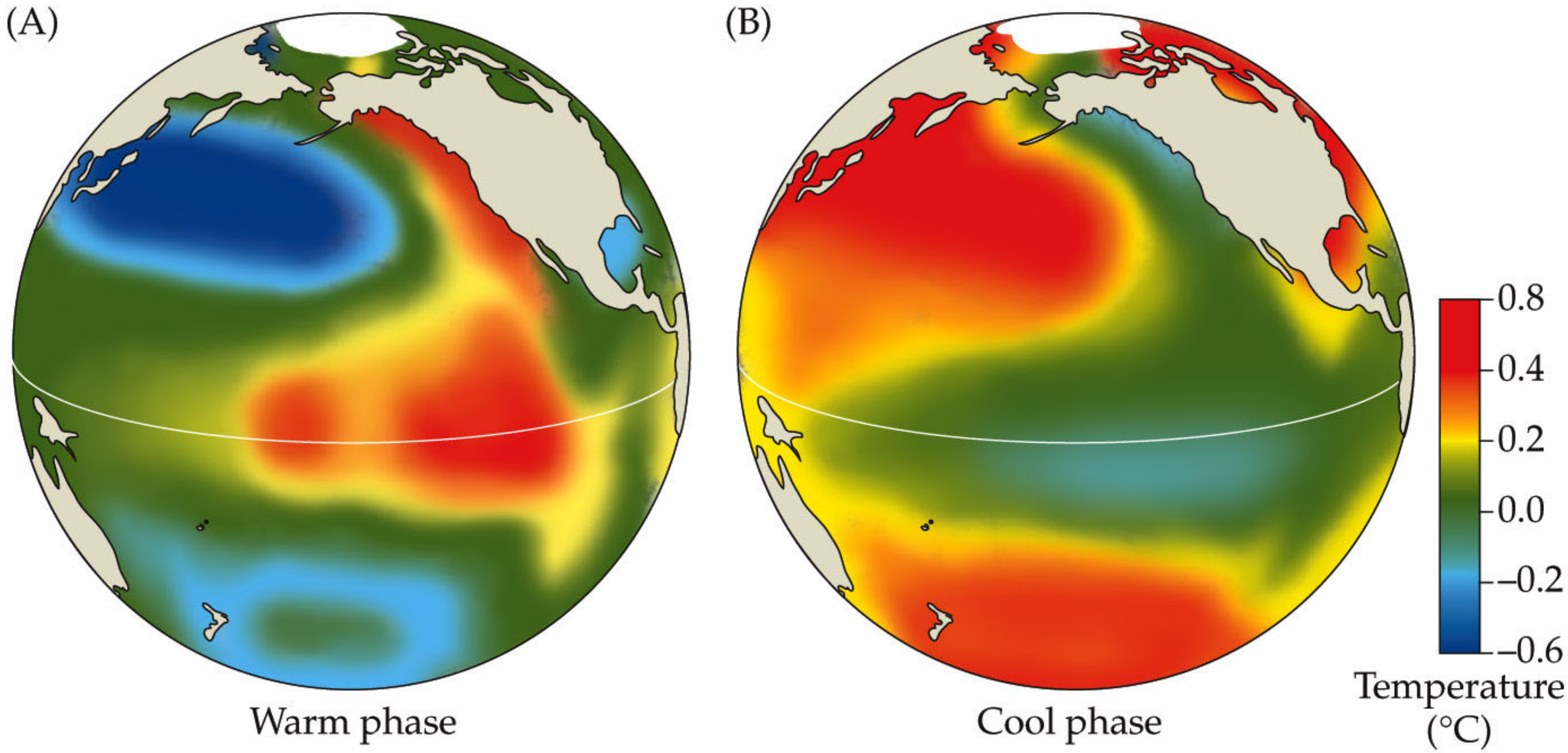
Case Study Revisited: Climatic Variation and Salmon

Research on salmon production led to the discovery of the Pacific Decadal Oscillation.

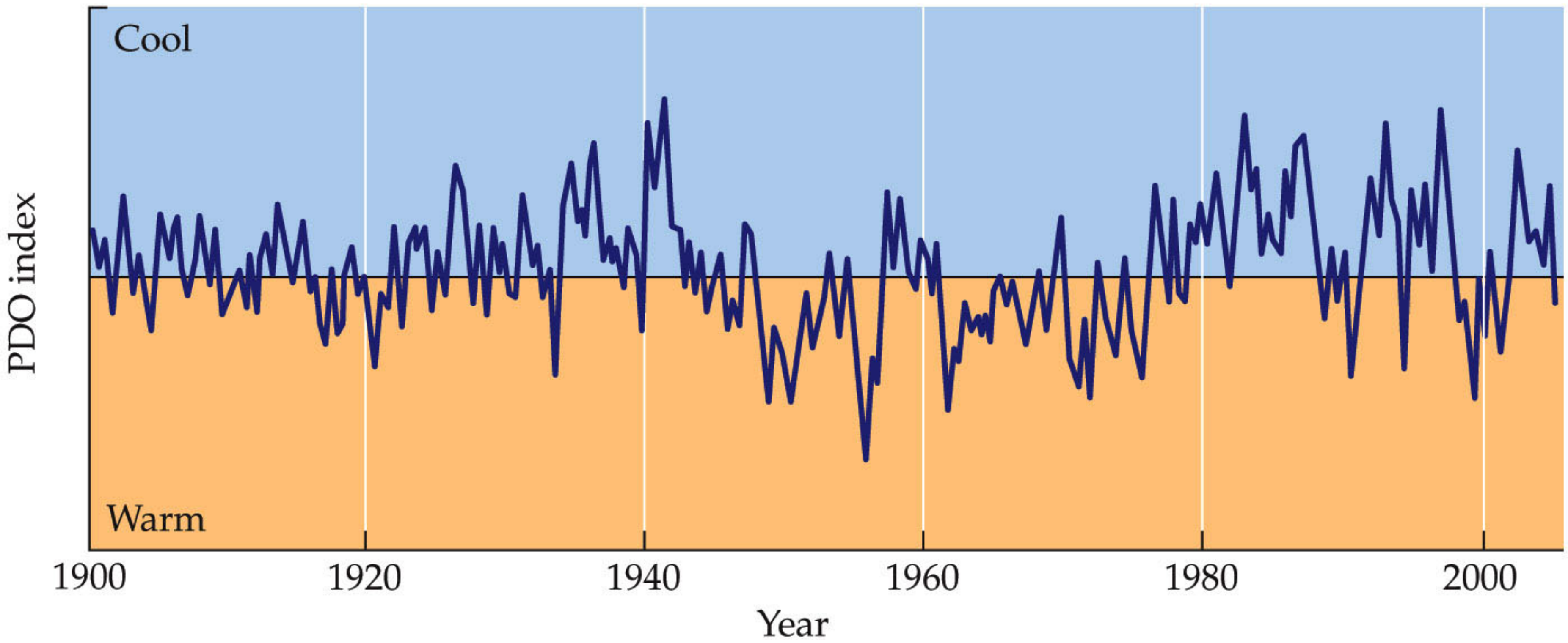
The PDO is associated with alternating 20–30-year periods of “warm” and “cool” temperatures in the North Pacific.

The warm and cool phases influence the marine ecosystems and thus salmon production.

Figure 2.29 The Pacific Decadal Oscillation and Ocean Temperatures (Part 1)



(C)



Case Study Revisited: Climatic Variation and Salmon

The PDO has been linked to changes in abundance and distribution of many marine organisms.

Through its climatic effects, it influences functioning of terrestrial ecosystems, primarily in western North America and eastern Asia, but also in Australia.

TABLE 2.1

Summary of Climatic Effects of the Pacific Decadal Oscillation (PDO)

Climatic effect	Warm phase PDO	Cool phase PDO
Ocean surface temperature in the northeastern and tropical Pacific	Above average	Below average
October–March northwestern North American air temperature	Above average	Below average
October–March southeastern U.S. air temperature	Below average	Above average
October–March southern U.S./northern Mexico precipitation	Above average	Below average
October–March northwestern North American and Great Lakes precipitation	Below average	Above average
Northwestern North American spring snowpack and water year (October–September) stream flow	Below average	Above average
Winter and spring flood risk in the Pacific Northwest	Below average	Above average

Source: Mantua 2001.

Two aspects of the PDO are particularly significant in the context of ecology:

1. The relationship between climate, the functioning of organisms and their growth and reproduction, and population and community processes.

2. The time scale of the PDO is long relative to the human life span.

The phases of the PDO may be longer than the life spans of most of the organisms affected by it, limiting their evolutionary responses to this cyclic climate change.

The PDO represents a disturbance, an event that detrimentally affects some species' populations.

Although the causes are uncertain, the PDO has been a part of the climate system for at least the last 400 years.

Understanding its effects will help us place other climatic phenomena in perspective.