SC-407 and MC-226
Introduction to Environmental Studies

Lecture 4

Yash Vasavada
DA-IICT
1st April 2024

Some Fun Facts about Earth's Environment

A Visual Depiction of Effect of Earth's Tilt

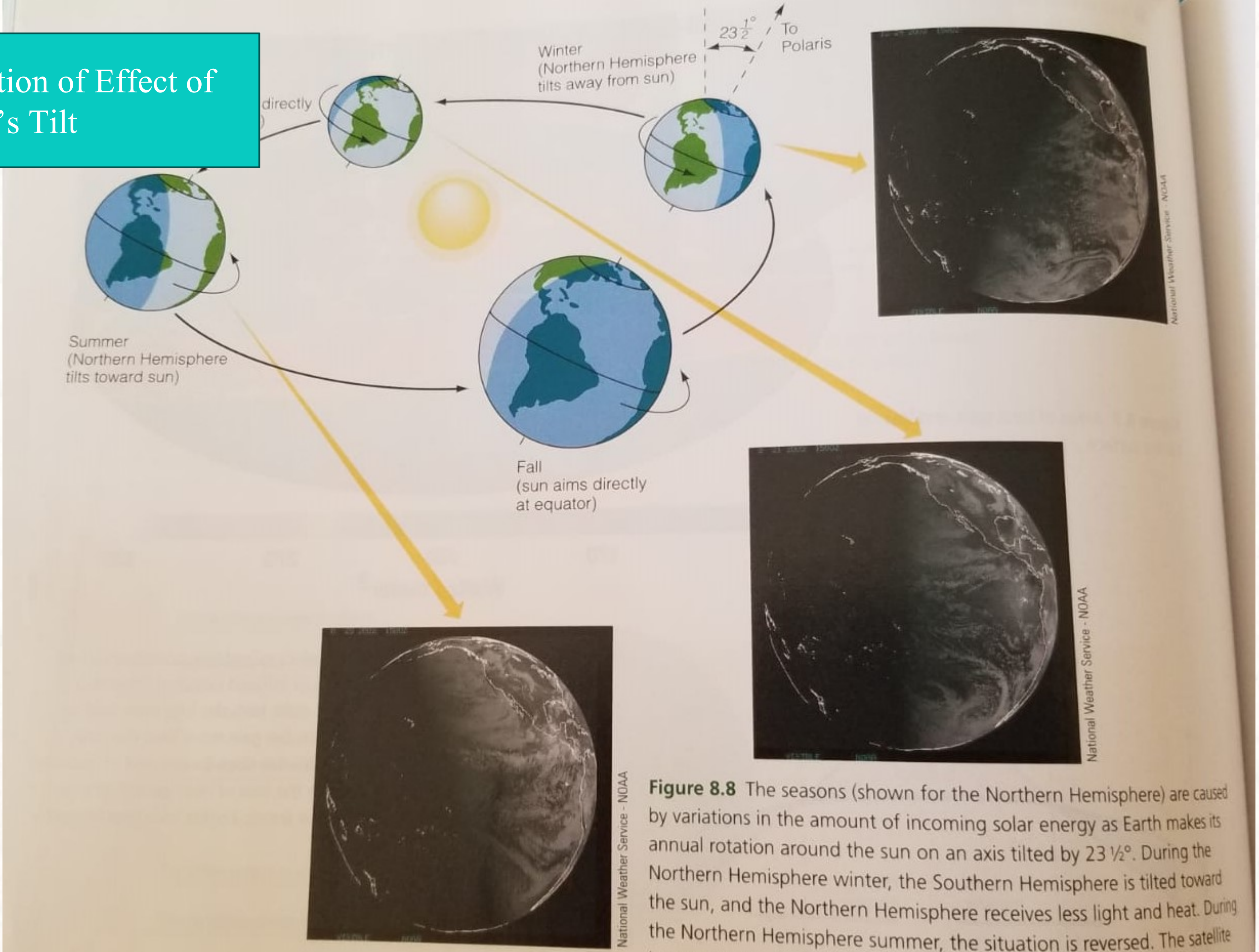


Figure 8.8 The seasons (shown for the Northern Hemisphere) are caused by variations in the amount of incoming solar energy as Earth makes its annual rotation around the sun on an axis tilted by 23 ½°. During the Northern Hemisphere winter, the Southern Hemisphere is tilted toward the sun, and the Northern Hemisphere receives less light and heat. During the Northern Hemisphere summer, the situation is reversed. The satellite images clearly show the significant difference in illumination angles in December, September, and June.

Troposphere: First about 8 to 15 km above the Earth

- The lowest layer of the Earth's atmosphere, extending from the Earth's surface up to an average altitude of about 8 to 15 kilometers (5 to 9 miles) above sea level.
  - Closer to the equator and the tropics, the troposphere may extend up to around 20 kilometers (12 miles)
  - At higher latitudes or in colder conditions, it may be lower, closer to 8 kilometers (5 miles).
- The temperature decreases with altitude in the troposphere. This is known as the environmental lapse rate – approximately 6.5°C per kilometer (or 3.5°F per 1000 feet) on average
  - As you move away from the Earth's surface, there is less heat being absorbed directly from the sun.
  - As you move upward in the troposphere, you're moving into regions where the air is cooler because it's further away from the warm surface.
  - As air rises in the atmosphere, it expands due to the decrease in pressure with altitude. When air expands, it cools down. This process - known as adiabatic cooling - contributes to the decrease in temperature with altitude
  - The troposphere is primarily heated from below. The Earth's surface absorbs sunlight and warms the air directly above it. Warm air is less dense and rises, while cooler air sinks. This creates vertical air movements known as convection currents
- The majority of the mass of the entire atmosphere is contained in the troposphere—between approximately 75 and 80 percent.
  - Most of the water vapor in the atmosphere, including most of the clouds, along with dust and ash particles, are found in the troposphere

Stratosphere: Next ~35 km

- The stratosphere is the next layer up from Earth's surface – reaching from the top of the troposphere, which is called the tropopause, to an altitude of approximately 50 kilometers (30 miles).
- A high concentration of ozone, a molecule composed of three atoms of oxygen, makes up the ozone layer of the stratosphere.
  - This ozone absorbs some of the incoming solar radiation, shielding life on Earth from potentially harmful ultraviolet (UV) light
- Temperatures in the stratosphere increase with altitude
  - Ozone molecules absorb high-energy UV radiation from the sun, converting the UV energy into heat, warming the surrounding air. This heating effect is particularly strong in the lower stratosphere
  - Unlike the troposphere, where vertical air drafts due to convection occur, the stratosphere is much more stable. This stability prevents the mixing of air masses, leading to a stratified temperature profile where warmer air sits above cooler air.

Mesosphere, Thermosphere and Exosphere: the Outer Layers

- Mesosphere
  - The top of the stratosphere is called the stratopause. Above that is the mesosphere, which reaches as far as about 85 kilometers (53 miles) above Earth's surface.
  - Temperatures decrease in the mesosphere with altitude.
    - The coldest temperatures in the atmosphere are near the top of the mesosphere—about -90°C (-130°F).
  - The atmosphere is thin but still thick enough so that meteors will burn up as they pass through the mesosphere—creating what we see as "shooting stars."
- Thermosphere
  - Located above the mesopause and reaches out to around 600 kilometers (372 miles).
  - Not much is known about the thermosphere except that temperatures increase with altitude.
  - Solar radiation makes the upper regions of the thermosphere very hot, reaching temperatures as high as 2,000°C (3,600°F).
- Exosphere
  - This is where many artificial satellites orbit the Earth and the phenomena like the auroras occur
  - Extends to about 10000 km above the Earth's surface, as it gradually transitions into the vacuum of outer space.
  - Very few gas molecules. Thus, there's hardly anything to transfer heat between particles. So even though the temperature might be high based on particle motion, it wouldn't feel hot because there's nothing to conduct that heat

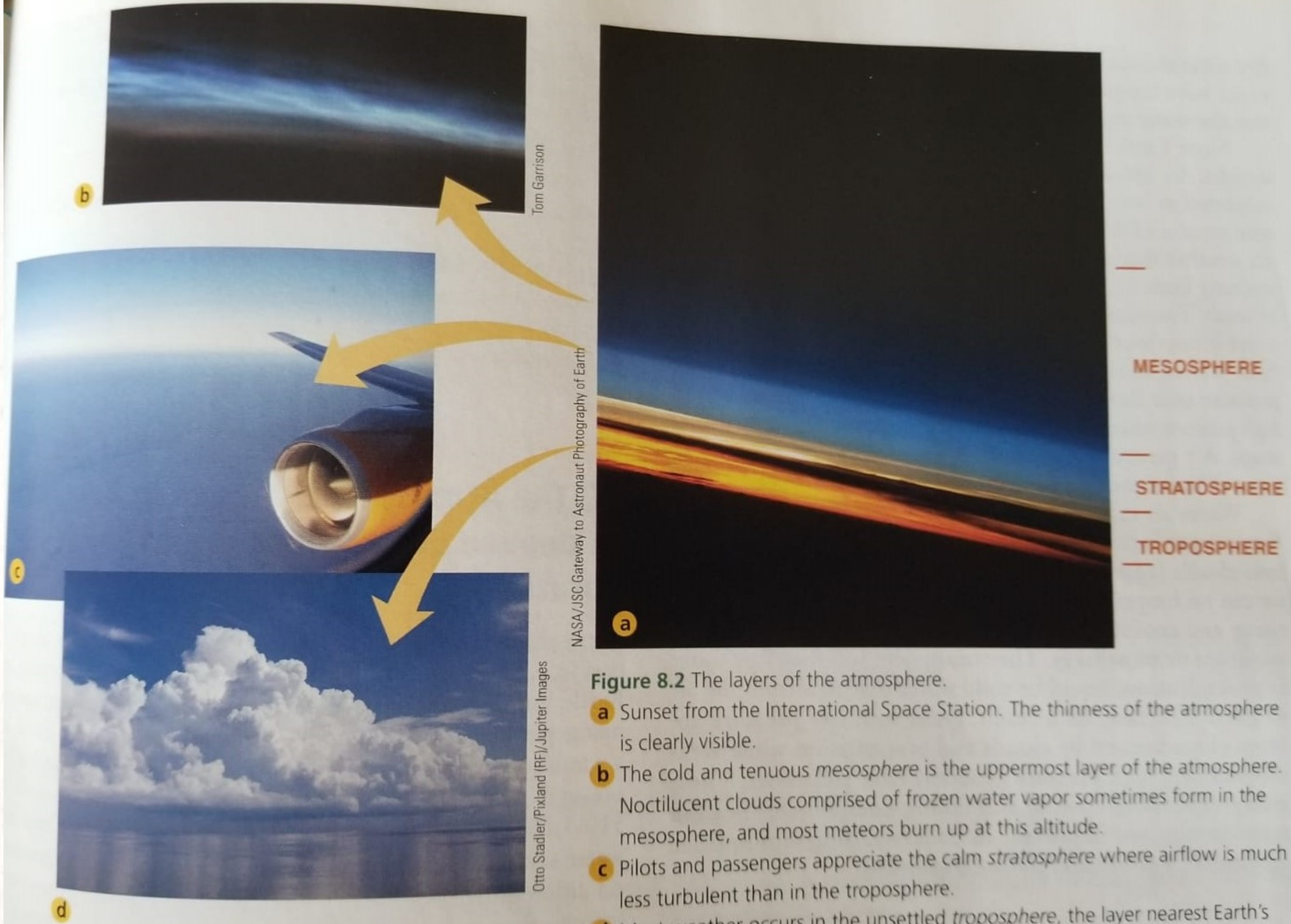


Figure 8.2 The layers of the atmosphere.

a Sunset from the International Space Station. The thinness of the atmosphere is clearly visible.

b The cold and tenuous *mesosphere* is the uppermost layer of the atmosphere. Noctilucent clouds comprised of frozen water vapor sometimes form in the mesosphere, and most meteors burn up at this altitude.

c Pilots and passengers appreciate the calm *stratosphere* where airflow is much less turbulent than in the troposphere.

d Most weather occurs in the unsettled *troposphere*, the layer nearest Earth's surface that contains most of the atmosphere's mass.

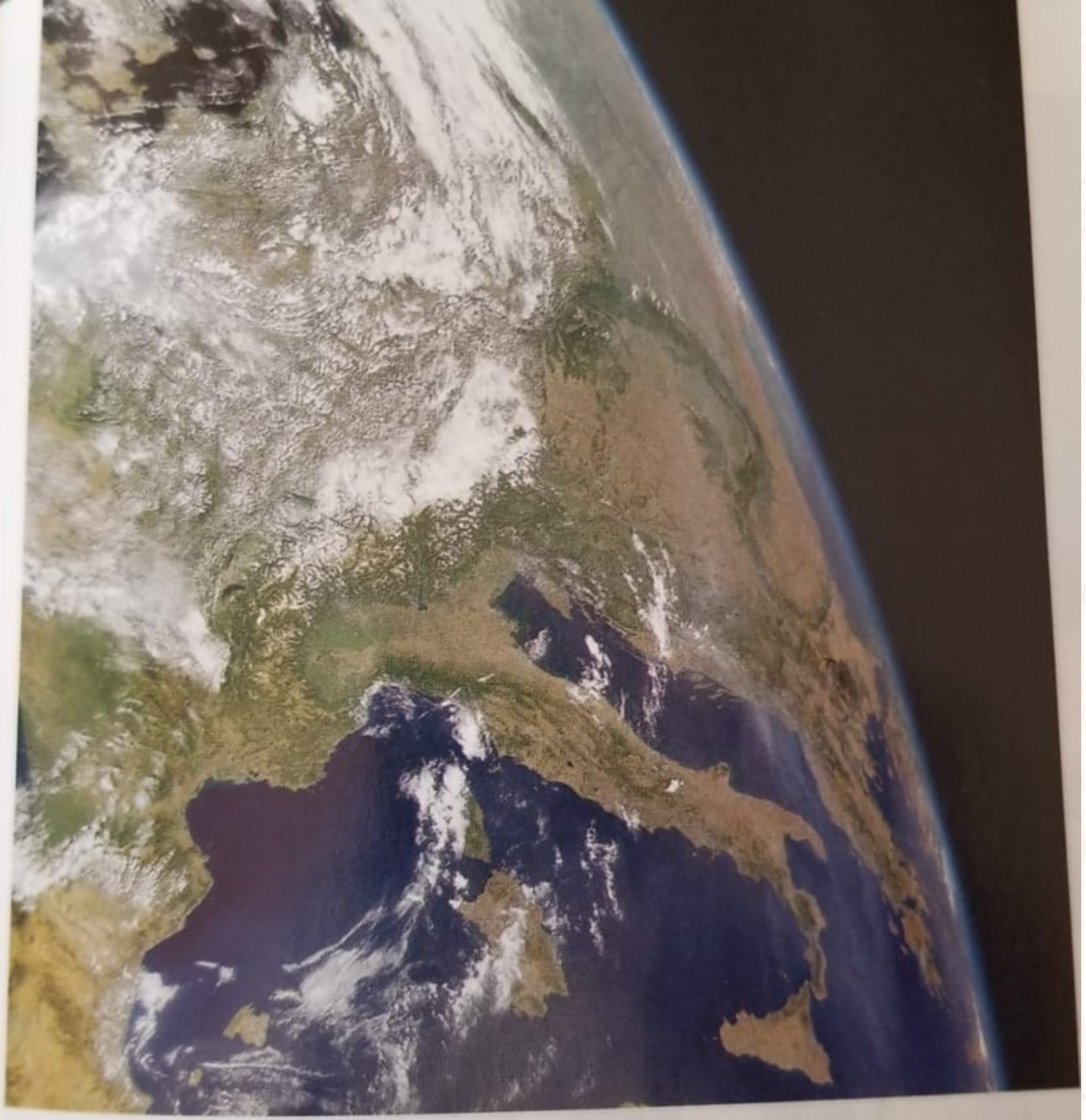


Figure 8.14 Earth's atmosphere viewed from space. Note how thin it is. If Earth were to shrink to the size of a large beach ball, its inhabitable atmosphere would be thinner than a piece of paper. Compare this image with Figures 8.10 and 8.15.

- National Geographic Page on Atmosphere
- Ten facts about Earth's atmosphere

Plate Tectonic Theory and Its Evidence

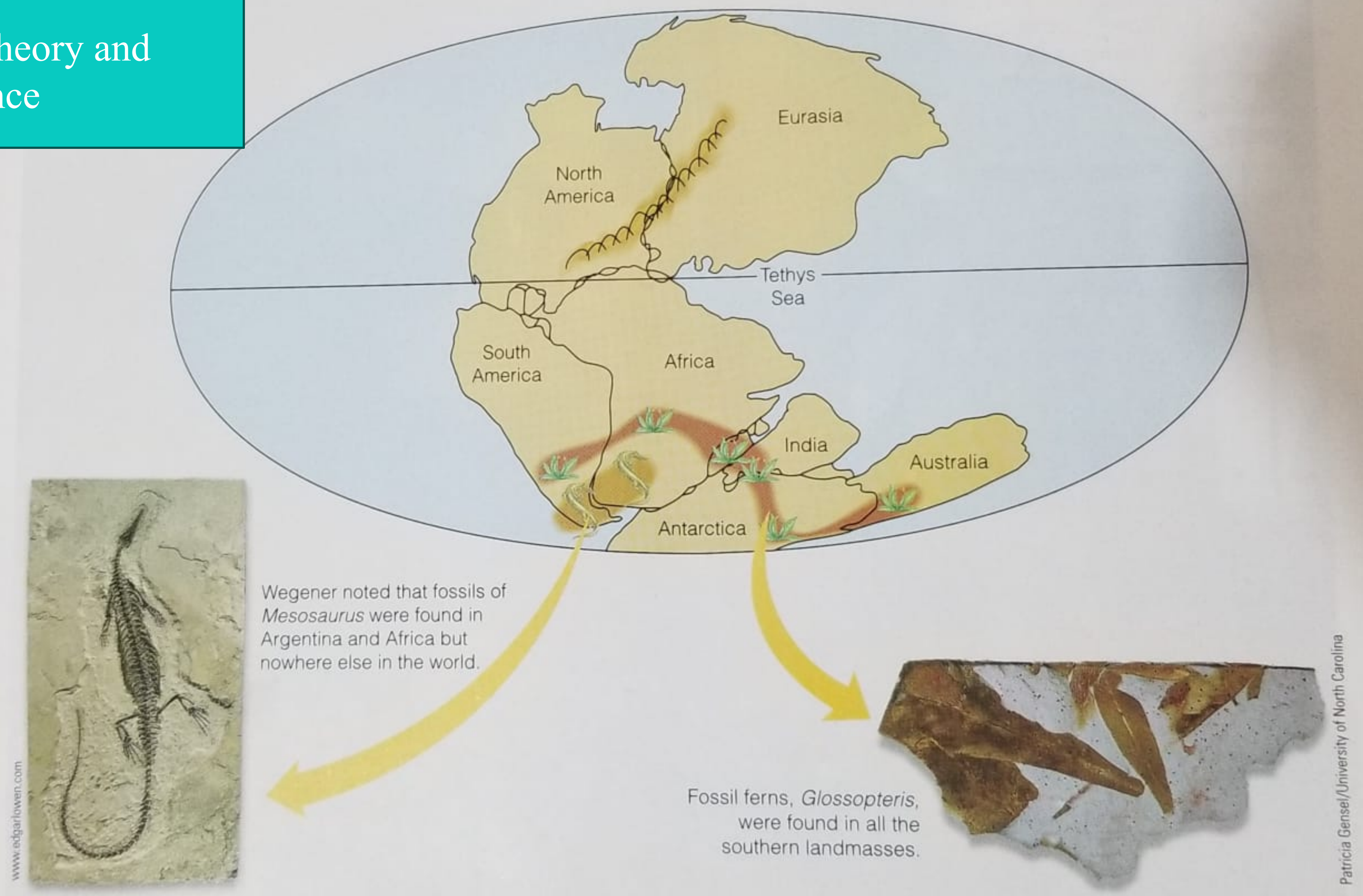


Figure 3.3 Mountain ranges in Scandinavia, Scotland, and North America are now separated by the Atlantic, but are remarkably similar in age and composition. Fossils of the reptile *Mesosaurus* were found in Argentina and Africa, but nowhere else. The seed fern *Glossopteris* was found in all the southern landmasses. *If* the continents were once joined, as shown here, these mountain ranges and fossil bands would have formed continuous chains.

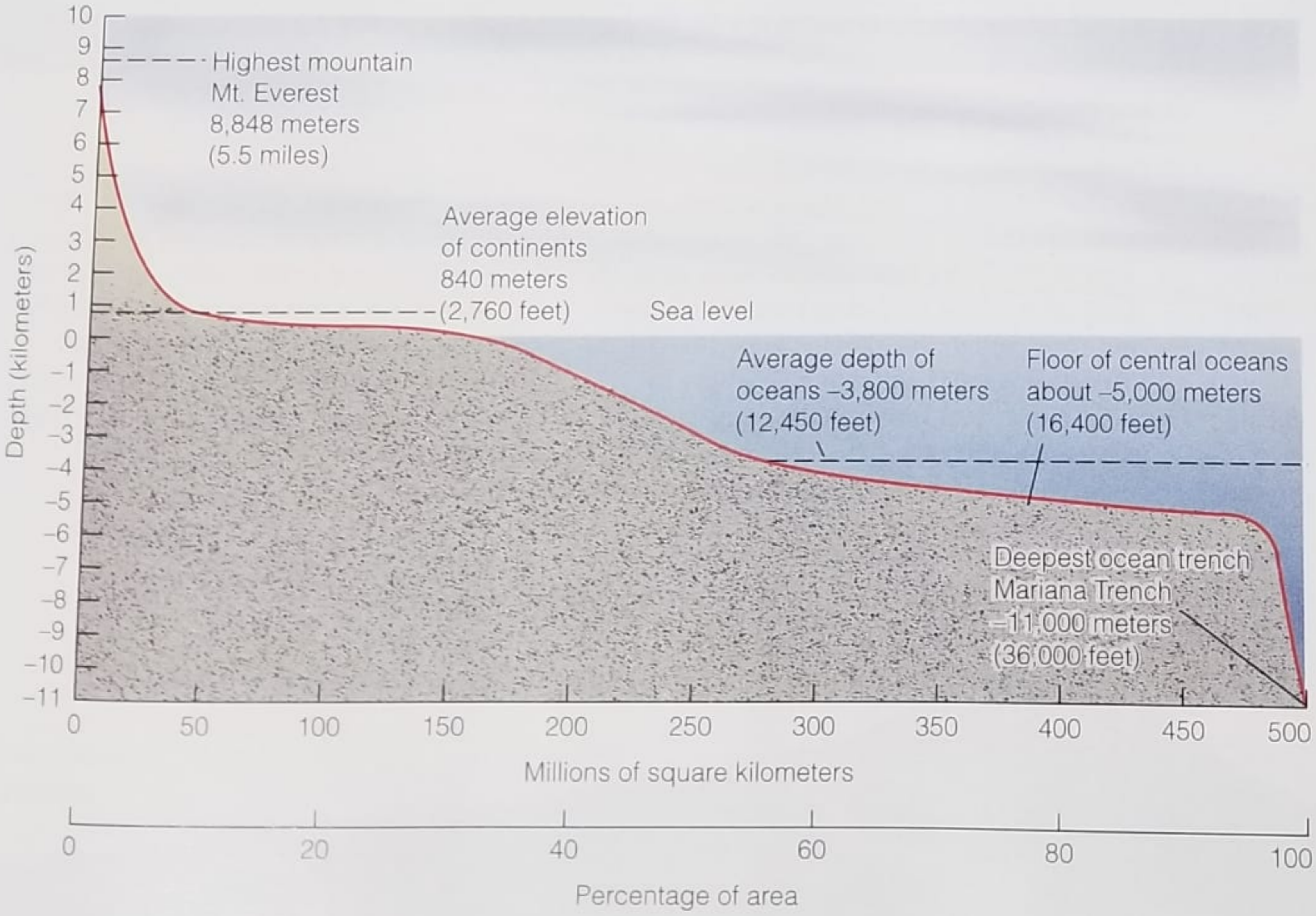
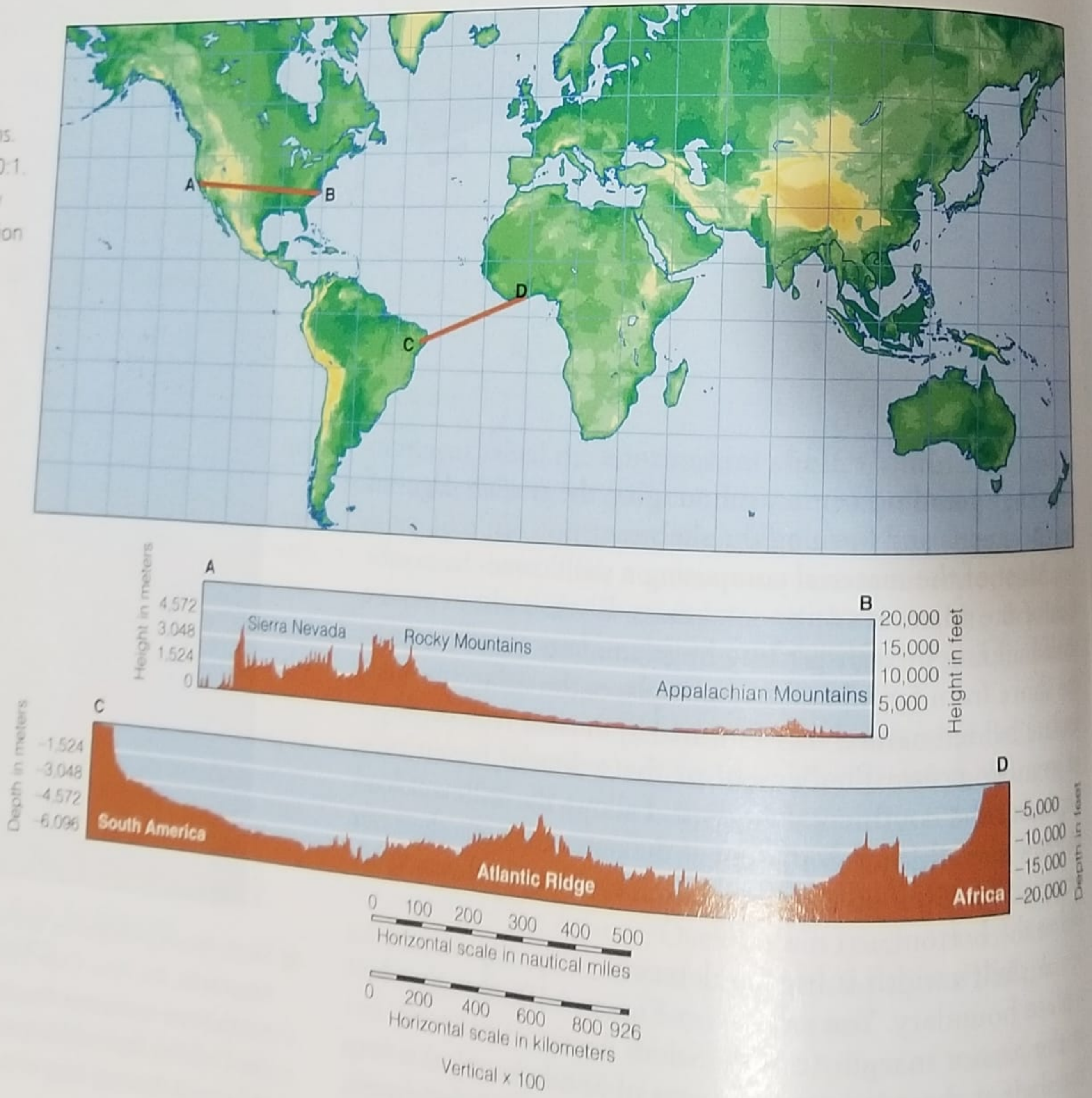


Figure 4.7 A graph showing the distribution of elevations and depths on Earth. This curve is not a land-to-sea profile of Earth, but rather a plot of the area of Earth's surface above any given elevation or depth below sea level. Note that more than half of Earth's solid surface is at least 3,000 meters (10,000 feet) below sea level. The average depth of the world ocean (3,796 meters or 12,451 feet) is much greater than the average height of the continents (840 meters or 2,760 feet)

Figure 4.6 Cross sections of the Atlantic Ocean basin and the continental United States, showing the range of elevations. The vertical exaggeration is 100:1. Although ocean depth is clearly greater than the average elevation of the continent, the general range of contours is similar.



Water is a Unique Chemical Element

Excerpts from a book
Tom Garrison and Robert Ellis, Oceanography, An Invitation to Marine Science, Cengage, Tenth Edition, 2022

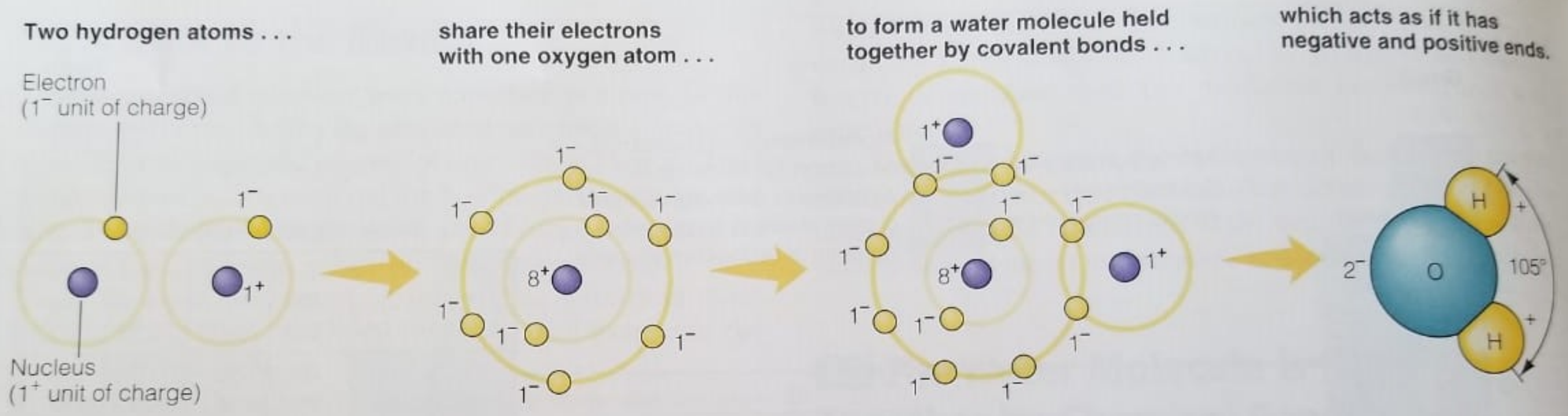
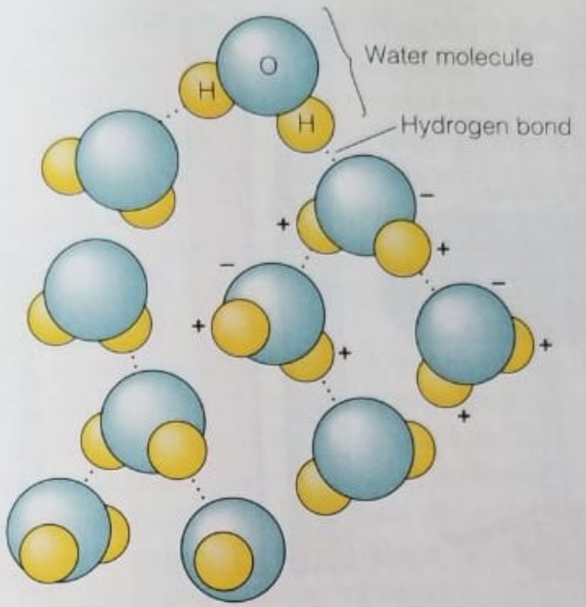


Figure 6.3 The formation of a water molecule. Atoms are most stable when they have a full outer shell of electrons. Hydrogen is most stable when it has two electrons in its outer shell and the larger oxygen atom (like many of the atoms relevant to our discussion of oceanography), is typically most stable with a total of 8 electrons in its outer shell. Since oxygen only has six electrons in its outer shell (because the first two of its eight electrons must fill the inner shell), oxygen bonds to two different hydrogen atoms by sharing hydrogen's electrons so that each atom has a full outer shell.



a Hydrogen bonds in liquid water. The attractions between adjacent polar water molecules form a webwork of hydrogen bonds. These bonds are responsible for cohesion and adhesion, the properties of water that cause surface tension and wetting. Hydrogen bonds among water molecules also make it difficult for individual molecules to escape from the surface.

Prokuronov Andrey/Shutterstock.com

b Surface tension allows small bugs to be able to walk on water.

Figure 6.4 Hydrogen bonds and surface tension.

Water – a Polar Molecule

- Many of the properties of the water are due to the hydrogen bonds
  - About 5% to 10% as strong as the covalent bond within the water molecule
- Gives to the water the properties of
  - Cohesion
    - Results in surface tension (the clean water glass can be filled slightly above its brim)
  - Adhesion
    - Water adheres to the other materials, i.e., makes them wet
- These two properties together result in the capillary action of the water, which allows
  - The water to spread to the other parts of the towel when only one corner is in the water bucket
  - Upflow of the water – against the gravity - from the ground to the leaves of the tree
  - Many cell level processes occur due to the capillary action
- Polar nature of the water molecule is also the reason why many compounds dissolve in water

By contrast, oil doesn't dissolve in water even if t
are thoroughly shaken together. When oil is dispe
water, it forms a mixture because molecules of oil a
polar in character. This means that oil has no pos

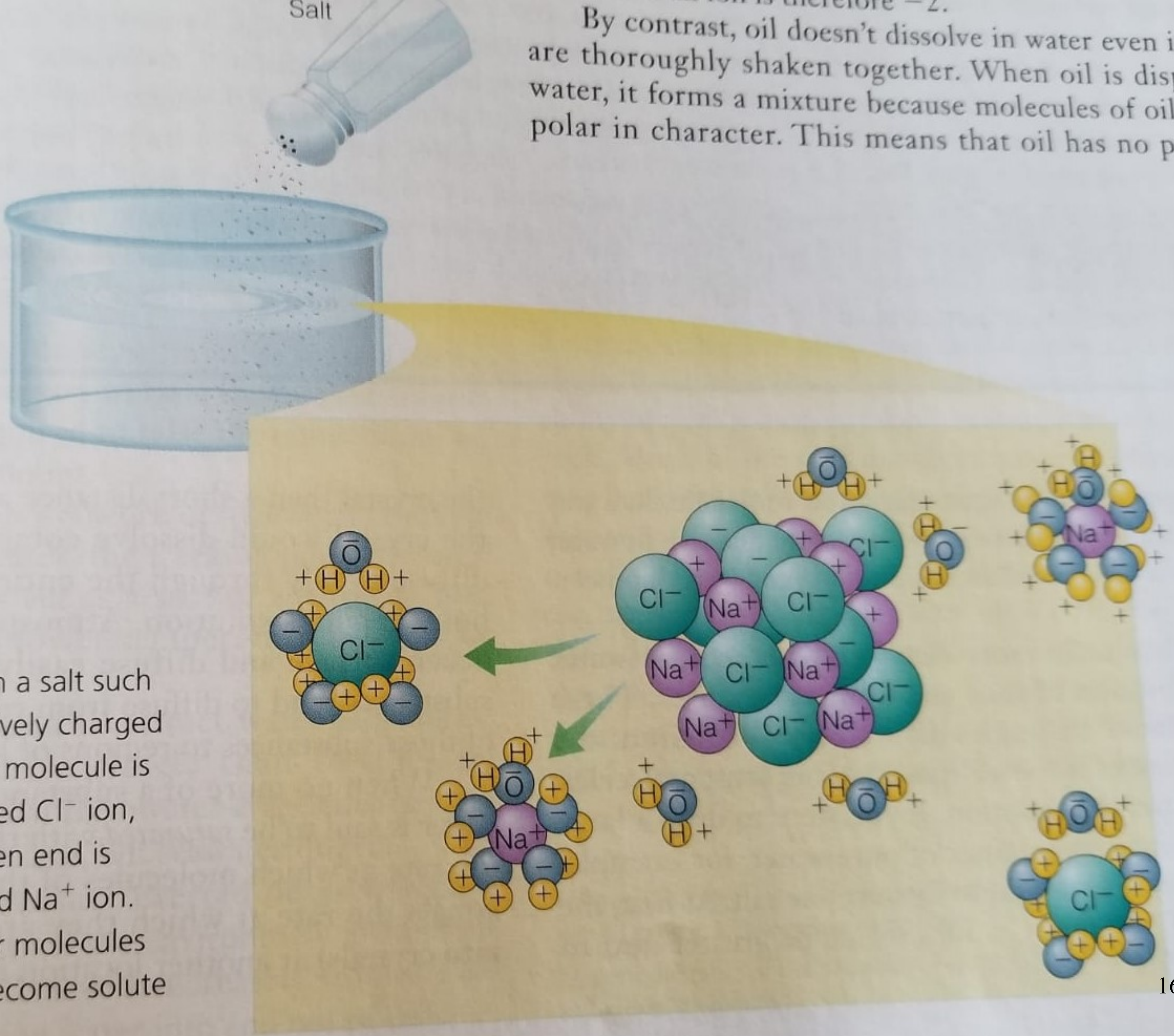


Figure 7.3 Salt in solution. When a salt such as NaCl is put in water, the positively charged hydrogen end of the polar water molecule is attracted to the negatively charged Cl^- ion, and the negatively charged oxygen end is attracted to the positively charged Na^+ ion. The ions are surrounded by water molecules that are attracted to them and become solute ions in the solvent.

- During the formation of the ice, the bond angle between the oxygen and hydrogen atoms increases to about 109^o from 105^o
- The space taken by 27 molecules of liquid water is occupied by 24 molecules of ice
- Results in a small gap between the atoms that was not there in the liquid state
- This results in the ice being less dense than the liquid water

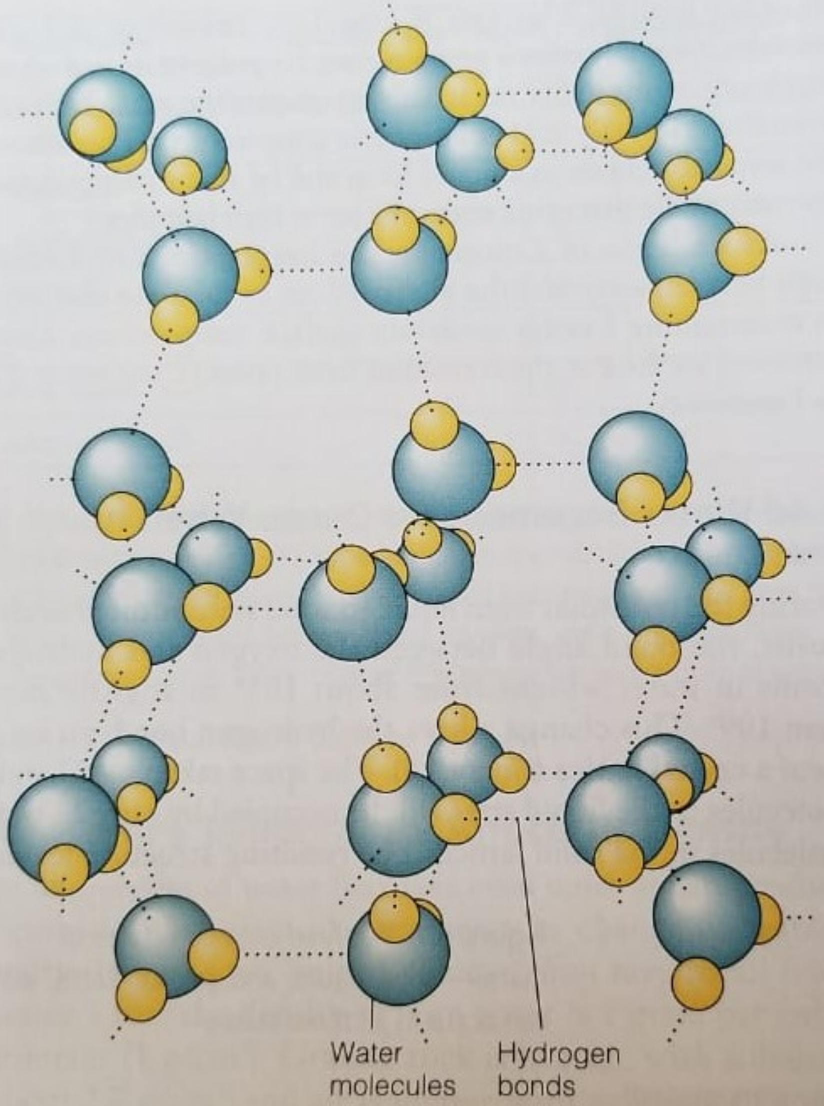


Figure 6.8 The lattice structure of an ice crystal, showing its hexagonal arrangement at the molecular level. Since fewer water molecules in a solid lattice take up the same amount of space than more water molecules in its liquid state, water will naturally expand as ice crystals form. This arrangement during the freezing process results in ice being less dense than liquid water causing it to float.

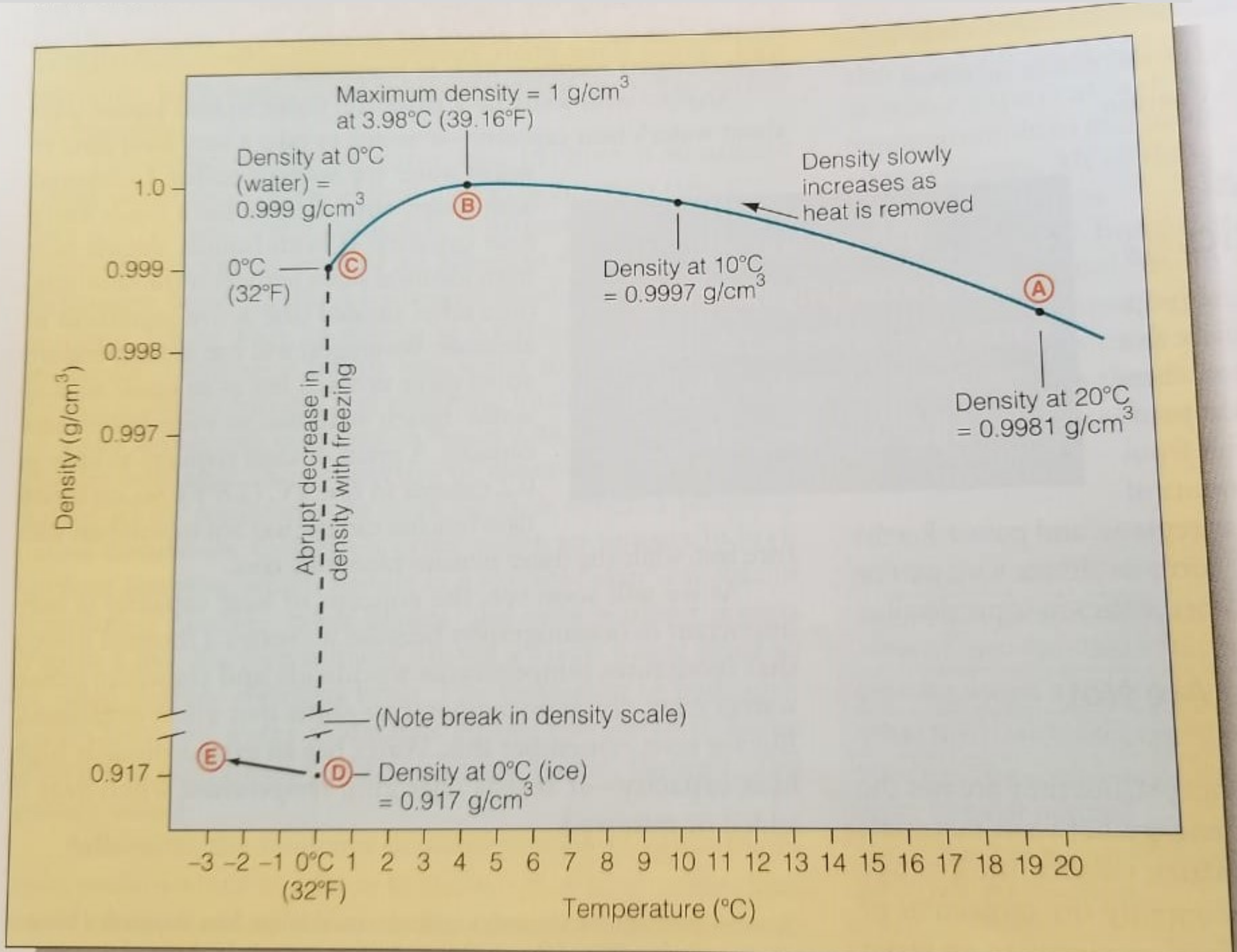


Figure 6.6 The relationship of density and temperature for pure water. Note that points C and D both represent 0°C (32°F) but show different densities, and thus different states of water. Ice floats because the density of ice is lower than the density of liquid water.

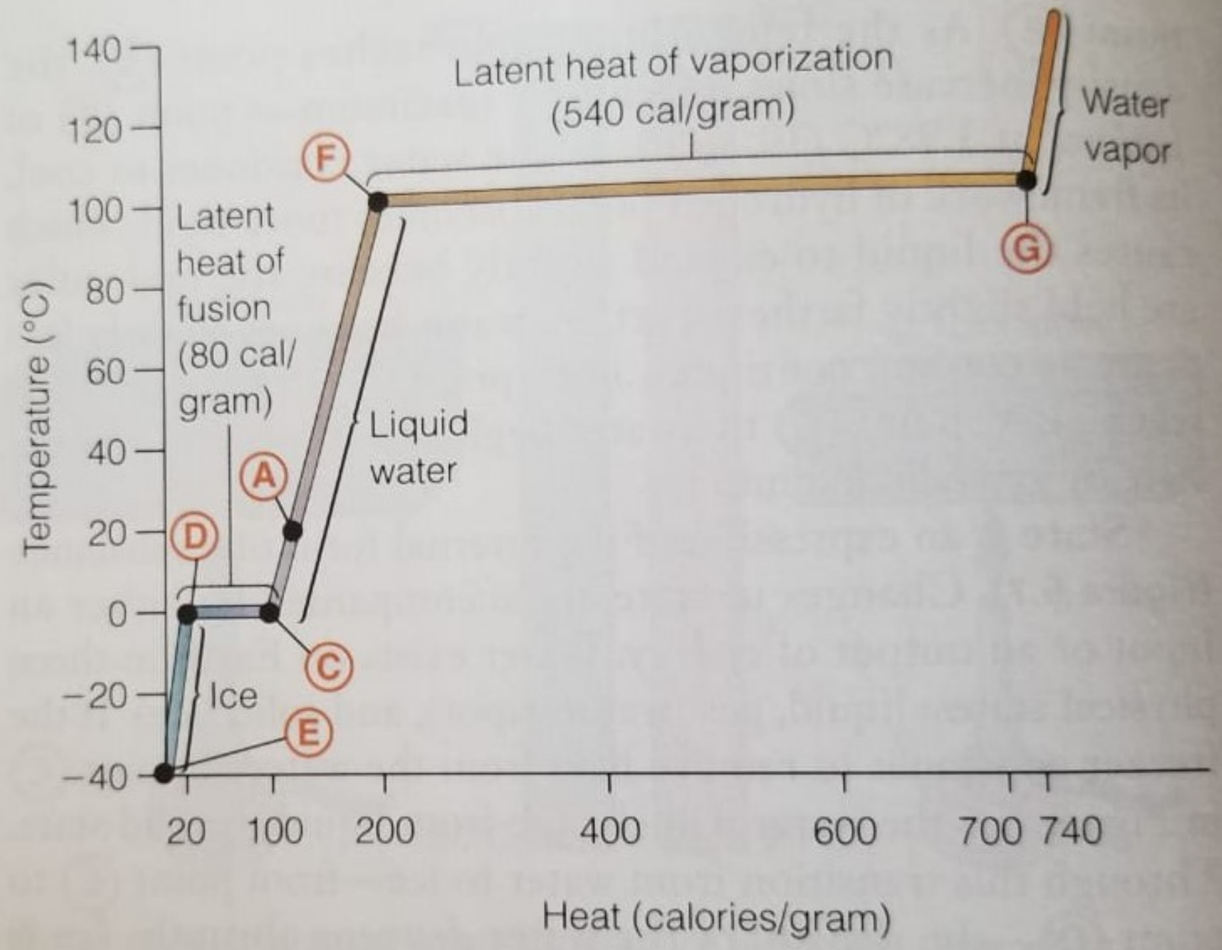


Figure 6.9 A graph of temperature versus heat as water freezes, melts, and vaporizes. The horizontal line between points Ⓒ and Ⓓ represents the latent heat of fusion, when heat is being added or removed but the temperature is not changing. The horizontal line between points Ⓖ and Ⓕ represents the latent heat of vaporization, when heat is being added or removed but the temperature is not changing. (Note that points Ⓐ-Ⓔ on this graph are the same as those in Figure 6.6.)

Why the latent heat of fusion is smaller than the latent heat of vaporization?

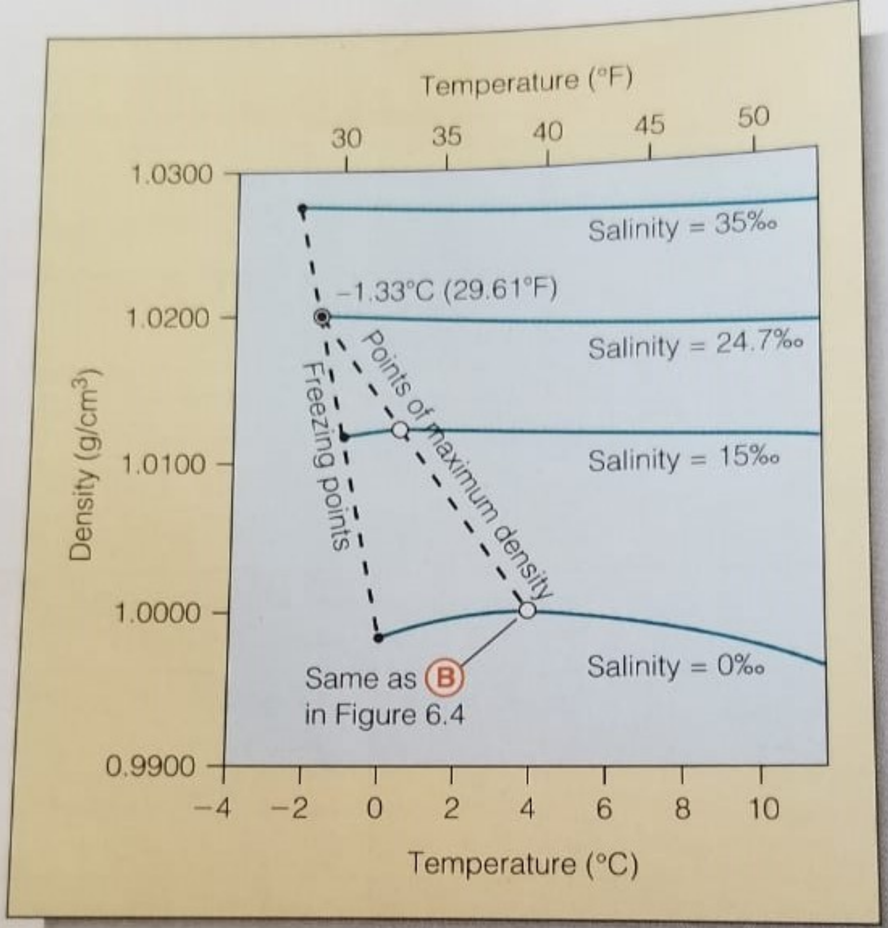


Figure 6.12 The dependence of freezing temperature and temperature of maximum density upon salinity (salt content). As we saw in Figure 6.6, pure water is densest at 3.98°C (39.2°F) (point B), and its freezing point is 0°C (32°F). Seawater with 15‰ salinity is densest at 0.73°C (33.31°F), and its freezing point is −0.80°C (30.56°F). The temperature of maximum density and the freezing point coincide at −1.33°C (29.61°F) in seawater with a salinity of 24.7‰. At salinities greater than 24.7‰ the density of water always decreases as temperature increases. Note that the symbol ‰ represents parts per thousand, so 2.47%; 24.7‰.

The unusual properties of water

Table 6.1 Properties of Water

Property	Remarks	Importance to the Ocean Environment
Physical state	Only substance occurring naturally in all three phases as solid, liquid, and gas (vapor) on Earth's surface	Transfer of heat between ocean and atmosphere by phase change
Dissolving ability	Dissolves more substances in greater quantities than any other common liquid	Important in chemical, physical, and biological processes
Density: mass per unit volume	Density determined by (1) temperature, (2) salinity, and (3) pressure, in that order of importance. The temperature of maximum density for pure water is 4°C. For seawater, the freezing point decreases with increasing salinity.	Controls oceanic vertical circulation, aids in heat distribution, and allows seasonal stratification
Surface tension	Highest of all common liquids	Controls drop formation in rain and clouds; important in cell physiology
Conduction of heat	Highest of all common liquids	Important on the small scale, especially on cellular level
Heat capacity: quantity of heat required to raise the temperature of a substance by 1°C	Highest of all common solids and liquids	Prevents extreme range in Earth's temperatures; great heat moderator
Latent heat of fusion: quantity of heat gained or lost per unit mass by a substance changing from a solid to a liquid or a liquid to a solid phase without an accompanying rise in temperature	Highest of all common liquids and most solids (80 cal/g)	Thermostatic heat-regulating effect due to the release of heat on freezing and absorption on melting
Latent heat of vaporization: quantity of heat gained or lost per unit mass by a substance changing from a liquid to a gas or a gas to a liquid phase without an increase in temperature	Highest of all common substances (540 cal/g)	Immense importance: a major factor in the transfer of heat in and between ocean and atmosphere, driving weather and climate
Refractive index	Increases with increasing salinity and decreases with increasing temperature	Objects appear closer than in air
Transparency	Relatively great for visible light; absorption high for infrared and ultraviolet	Important in photosynthesis
Sound transmission	Good compared with other fluids	Allows sonar and precision depth recorders to rapidly determine water depth and detect subsurface features and animals; sounds can be heard for great distances underwater
Compressibility	Only slight	Density changes only slightly with pressure/depth
Boiling and melting points	Unusually high	Allows water to exist as a liquid on most of Earth

Sources: Sverdrup et al., 1942; Ingmanson and Wallace, 1995.

Cools the surrounding

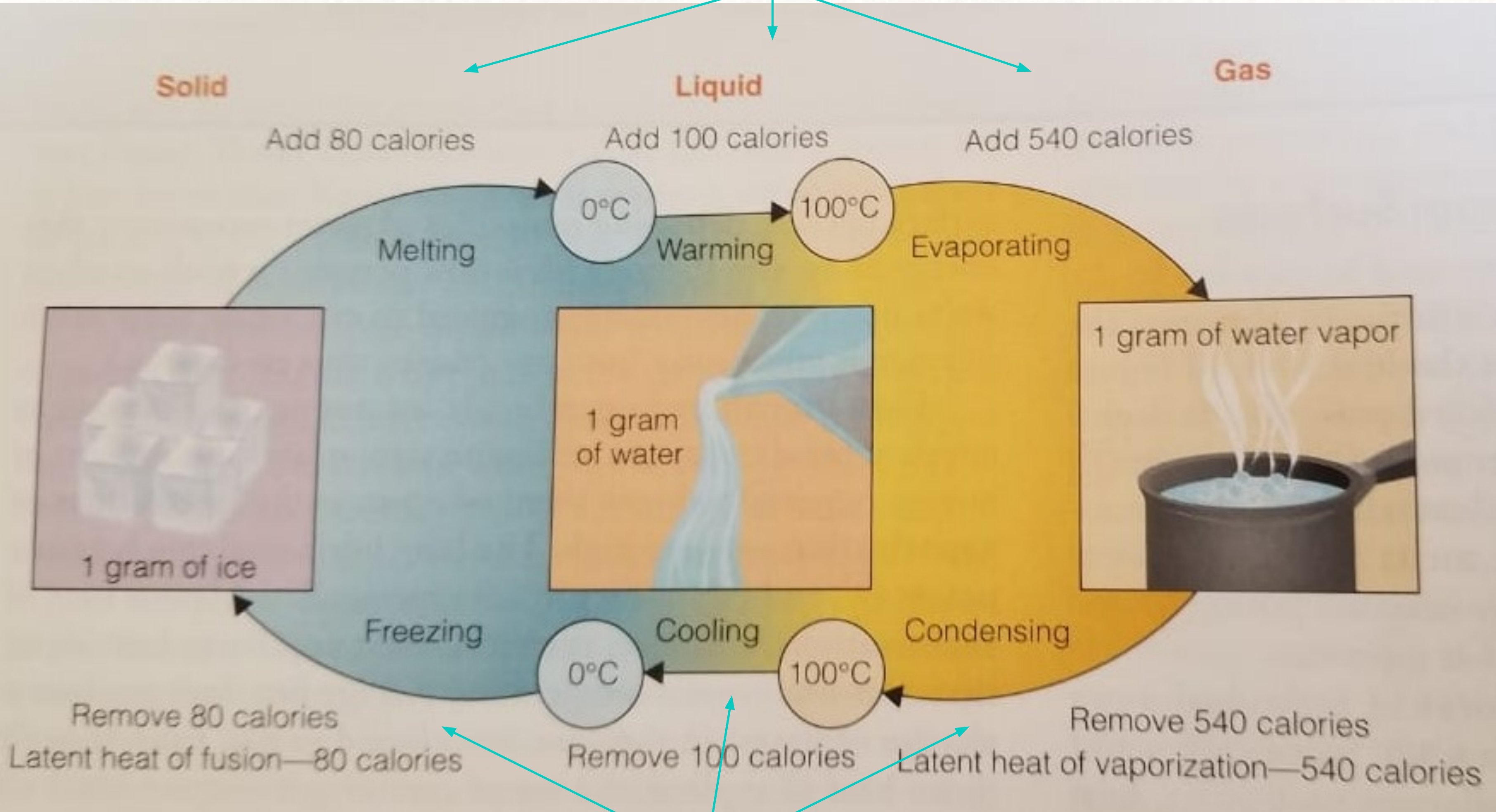


Figure 6.11 We must add 80 calories of heat energy to change a gram of ice to liquid water. After the ice is melted, about 1 calorie of heat is needed to raise each gram of water by 1°C. But 540 calories must be added to each gram of water to vaporize it—to boil it away. The process is reversed for condensation and freezing.

THINKING BEYOND THE FIGURE

How does the condensation of water vapor on the outside of a soda can warm the contents inside?

Warms the surrounding

Figure 6.10 Water vapor is invisible, but as it evaporates from the sea surface and rises into cool air, it can condense into tiny droplets that form clouds and fog. The low-lying fog bank often seen obscuring the Golden Gate Bridge at the entrance to San Francisco Bay forms when warm, moist air passes over the cold waters of the California Current. The air is cooled to the saturation point, and some of its water vapor condenses into fog droplets.

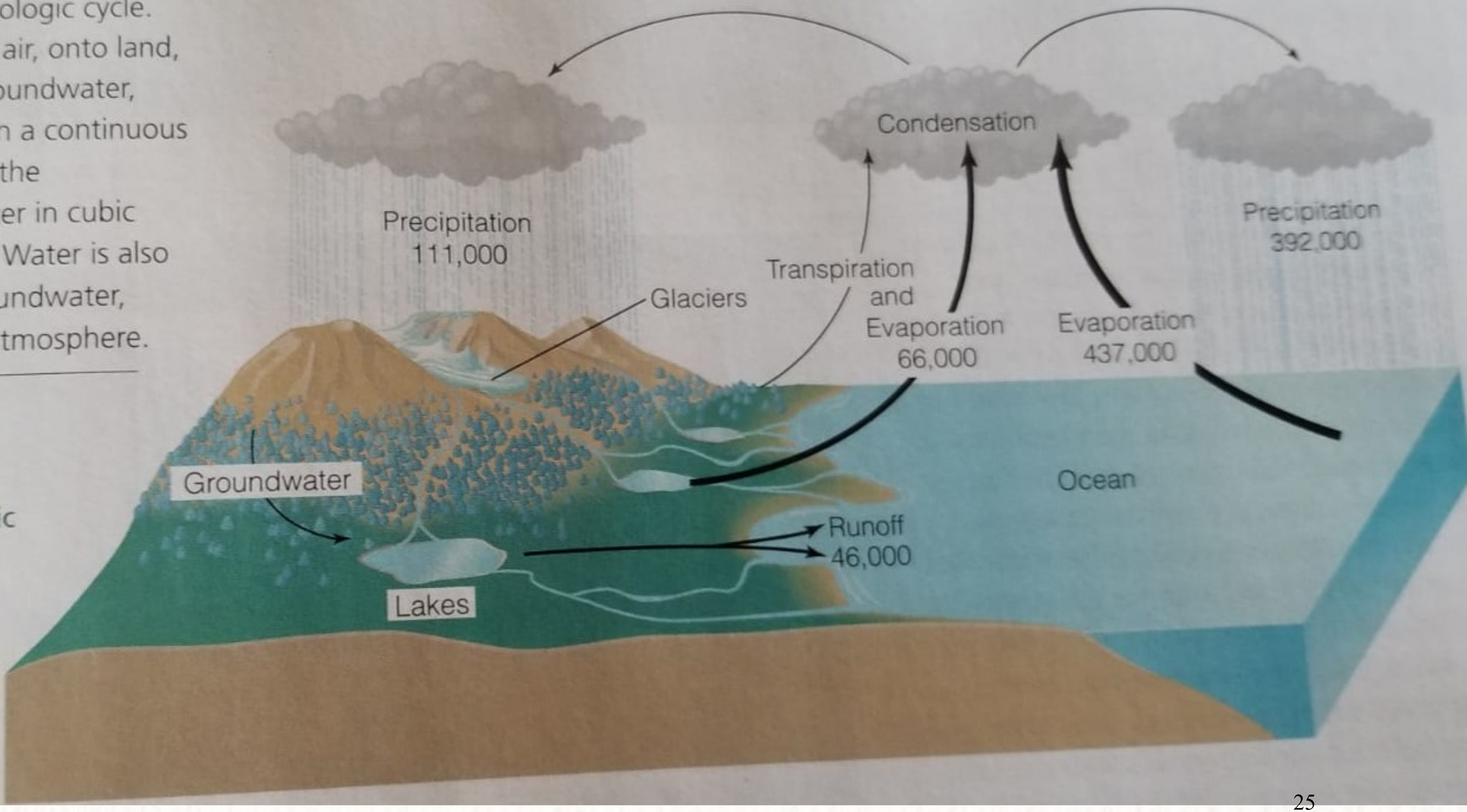
Evaporation and Condensation

- About 1 meter (3.3 feet) of water evaporates each year from the surface of the ocean
  - About 334000 km-cubed of water
- Evaporation is powered by the solar energy
- This energy (540 calories per gram of water vapor) is released when the water vapor condenses back to the liquid water
- Solar heat is, thus, the energy that empowers the rains, the monsoons and the thunderstorms

Figure 7.2 A simplified hydrologic cycle. Water moves from ocean to air, onto land, to lakes and streams and groundwater, back to the sky and ocean, in a continuous cycle. The numbers indicate the approximate volumes of water in cubic kilometers per year (km^3/yr). Water is also stored in the ocean, ice, groundwater, lakes and streams, and the atmosphere.

THINKING BEYOND THE FIGURE

What parts of the hydrologic cycle take millions of years to complete?



Water has a High Specific Heat Capacity

- The high specific heat capacity of the water acts as a thermostat for the Earth
  - Provides the Earth's climate a thermal inertia
- The sand and the asphalt road get extremely hot during the summer afternoon but the swimming pool of water remains relatively cold
- The variation of the temperature during the year on the land area of the Earth is very large
  - Exceeds 50^o C in the North African Desert and falls below -90^o C in the Antarctic continent
- In contrast, this variation over the ocean surface is less
  - Max of 32^o C to min of -2^o C

Ocean water provides the moderating thermostatic effect

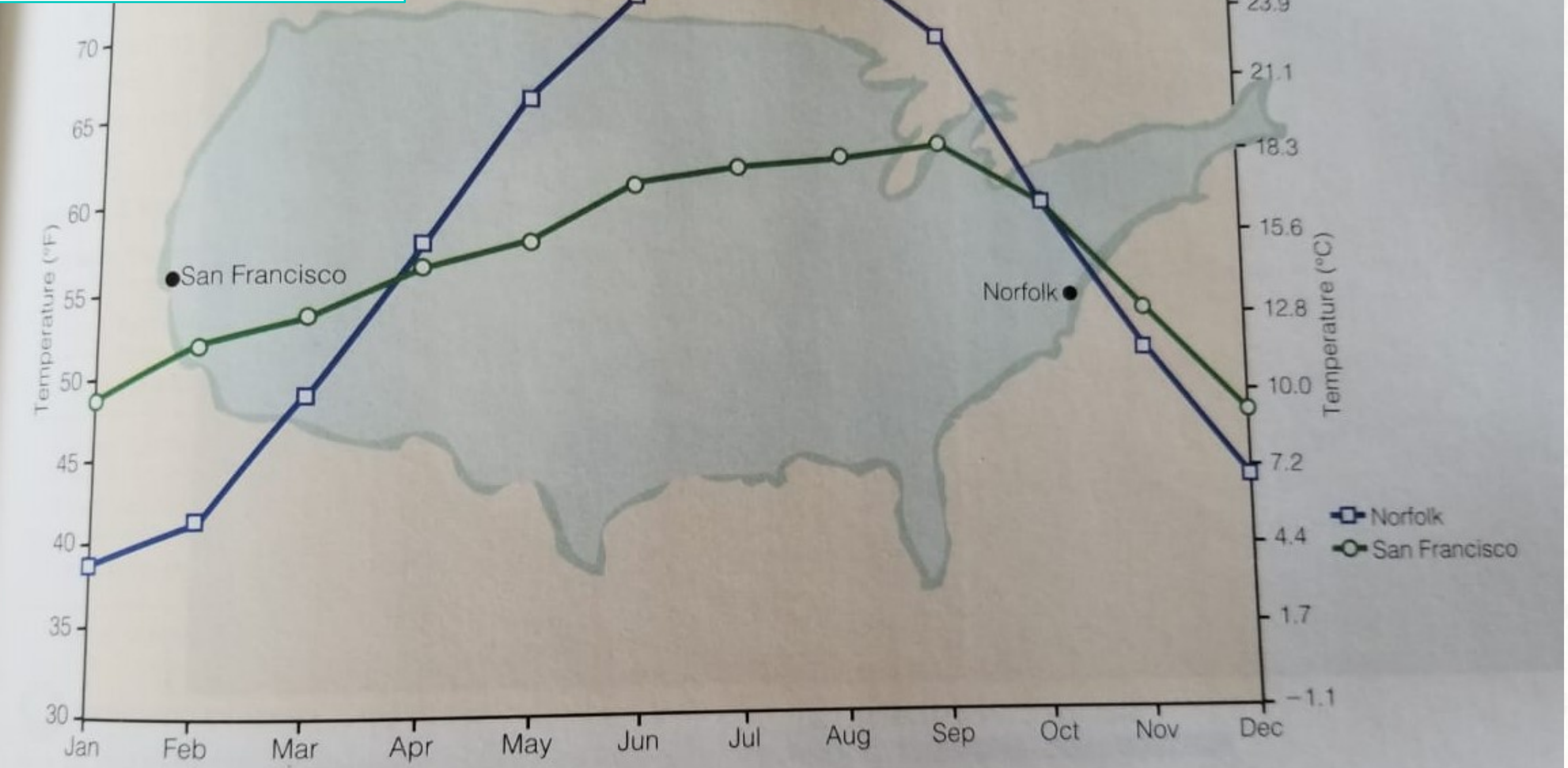


Figure 6.13 San Francisco, California, and Norfolk, Virginia, are on the same line of latitude, yet San Francisco is warmer in the winter and cooler in the summer than Norfolk. Part of the reason is that wind tends to flow from west to east at this latitude. Thus, air in San Francisco has moved over the ocean whereas air in Norfolk has approached over land. Water does not warm as much as land in the summer, nor cool as much in winter—a demonstration of thermal inertia.

Ice also provides the moderating thermostatic effect

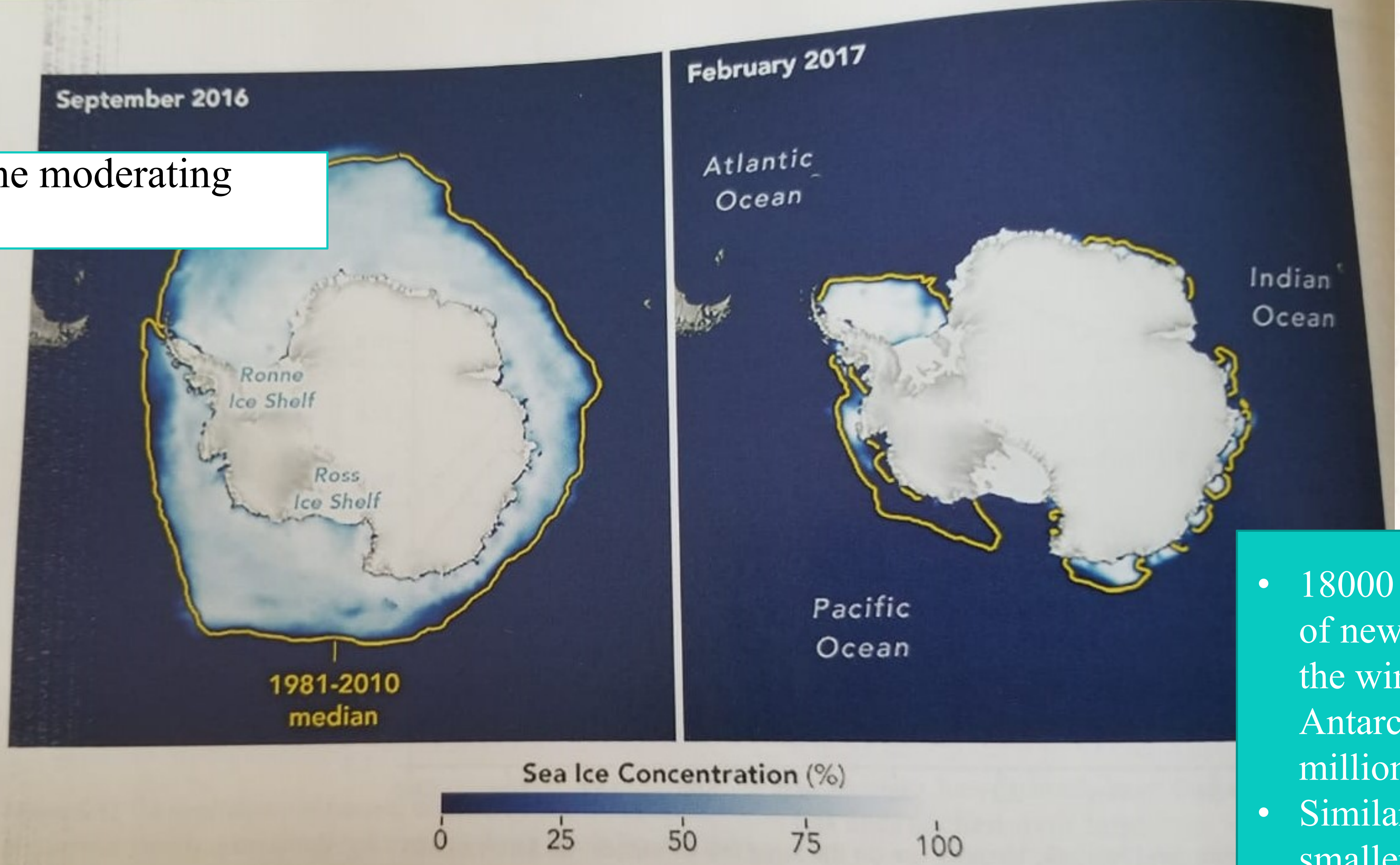


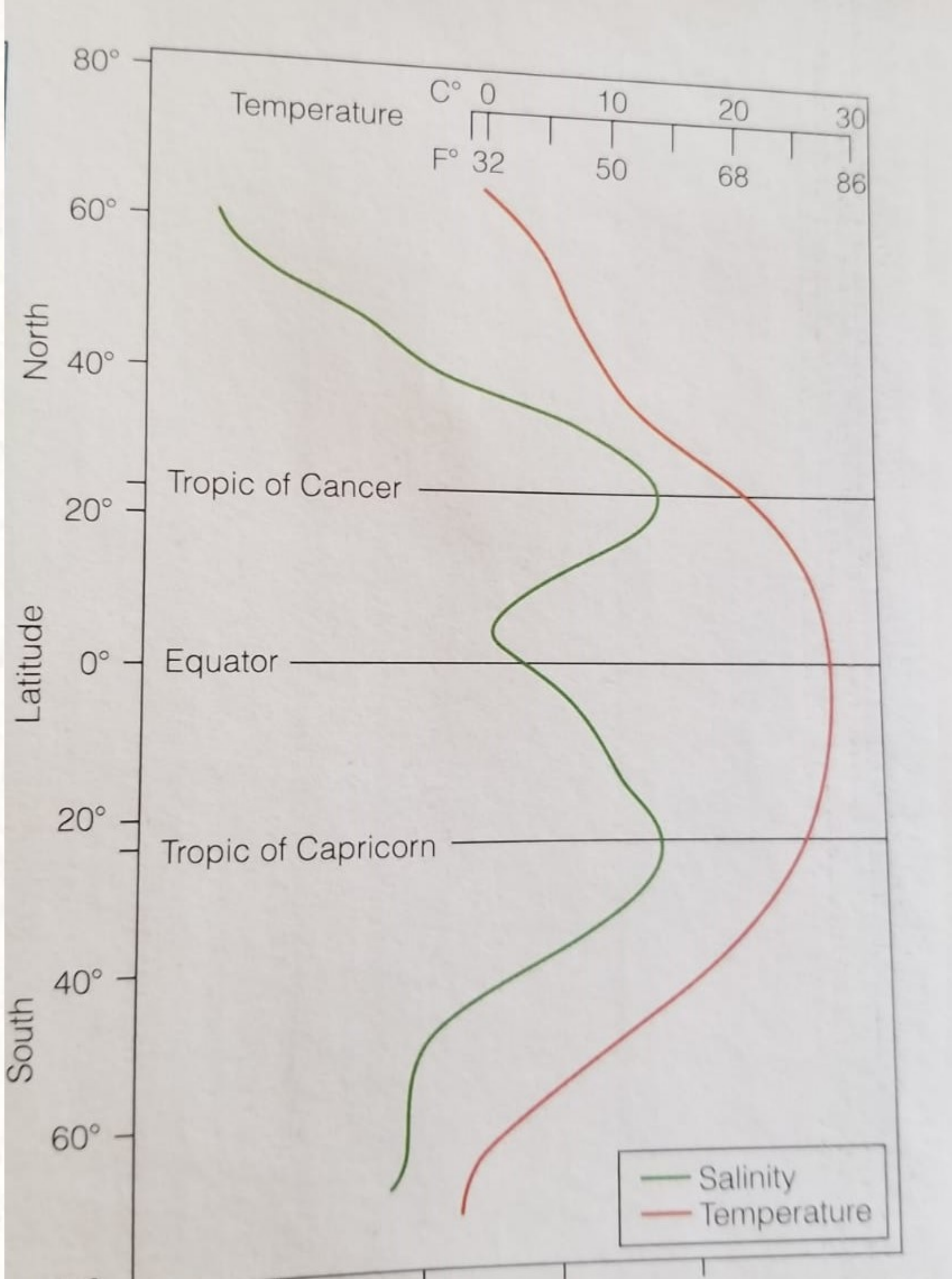
Figure 6.14 About 20 million square kilometers (7.7 million square miles) of ocean surface thaws and refreezes in the Southern Hemisphere each year—an area of ocean larger than South America! The autumn cooling of the atmosphere is delayed because heat energy is released as masses of water turn to ice. Heat is absorbed during ice melt in the spring. Seasonal extremes are moderated by the absorption and release of heat energy as ice thaws and refreezes. (Remember, the seasons are reversed in the Southern Hemisphere.) The scale shows the percentage of ocean surface completely covered by ice.

- 18000 cubic kilometers of new ice forms during the winter in the Antarctic, about 20 million square km
- Similar effect, but on a smaller scale (about 5 million square km), occurs at the North pole as well

Table 6.2 **Some Characteristics of the World Ocean Surface, by Latitude**

Characteristic	Tropical Oceanic Waters	Temperate Oceanic Waters	Polar Oceanic Waters
Winter temperature	20–25°C (68–77°F)	5–20°C (41–68°F)	About –2°C (28°F)
Annual variation of temperature	Less than 5°C (9°F)	About 10°C (18°F)	Less than 5°C (9°F)
Average salinity	35‰–37‰	About 35‰	28‰–32‰
Annual variation of air temperature	Less than 5°C (9°F)	About 10°C (18°F)	Up to 40°C (72°F)
Precipitation–evaporation balance	P exceeds E	E exceeds P	P exceeds E

Source: H. Charnock, 1971. Table created by Tom Garrison.


80°
Temperature
C° 0
10
20
30
F° 32
50
68
86
60°
North
40°
Tropic of Cancer
20°
Latitude
0°
Equator
20°
Tropic of Capricorn
40°
South
60°
Salinity
Temperature

a *Terra* satellite data for the month of July, 2000, show areas on Earth where solar heat input exceeds the radiation of heat back into space (red, orange) and areas where the radiation of heat into space exceeds heat input from the sun (blue). The ocean does not boil away near the equator or freeze solid near the poles because heat is transferred by winds and ocean currents from equatorial areas to the polar regions.

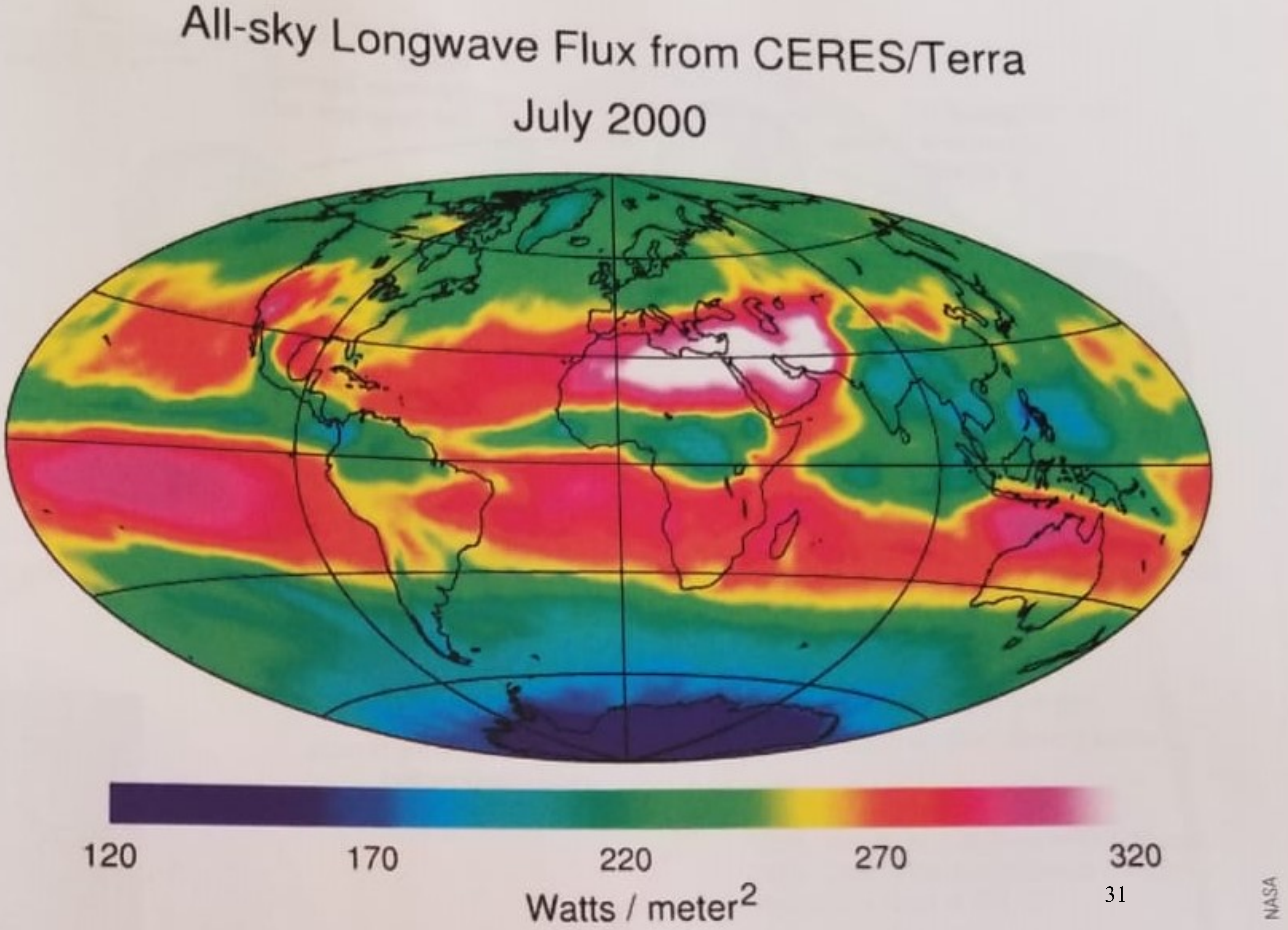
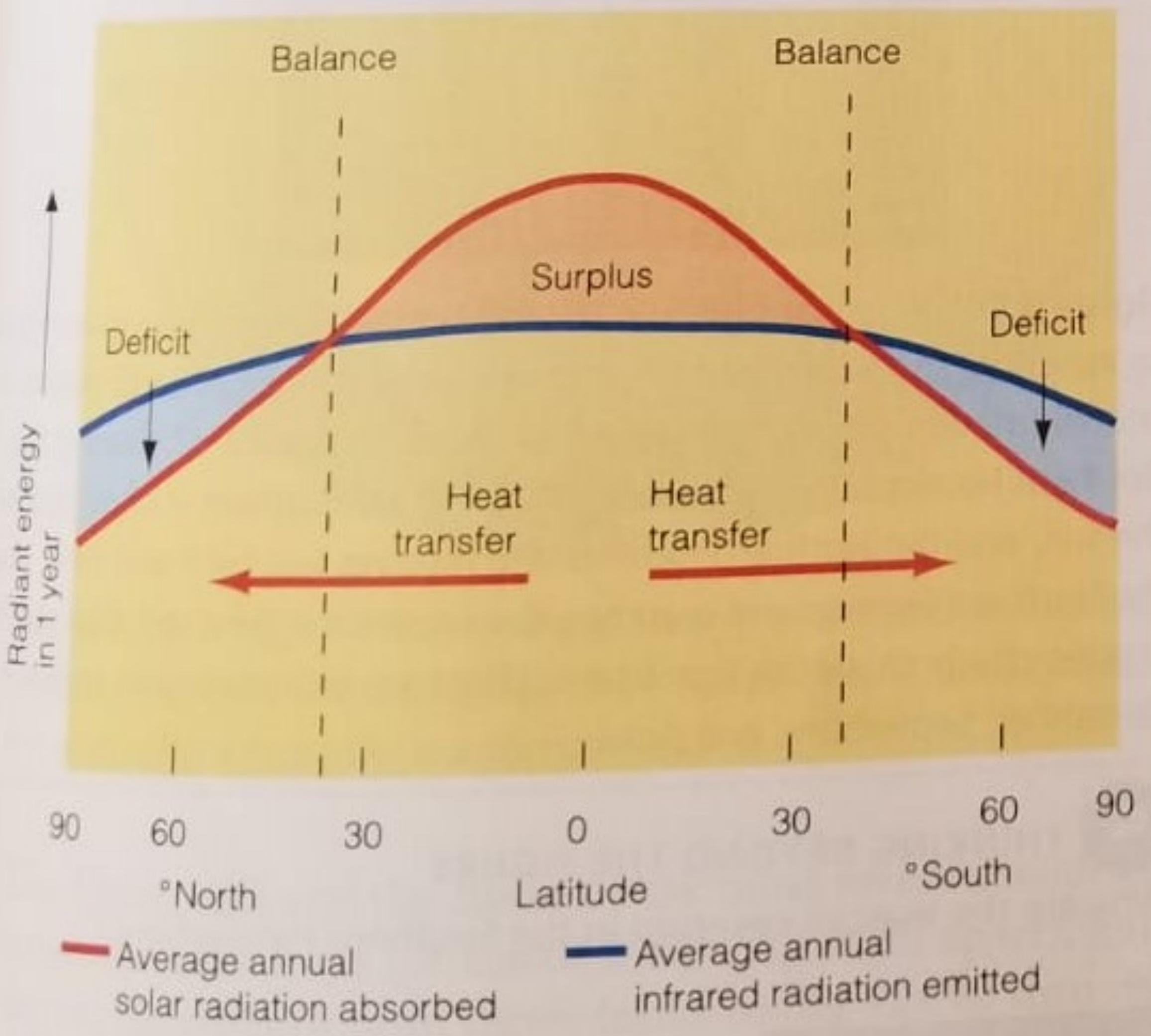
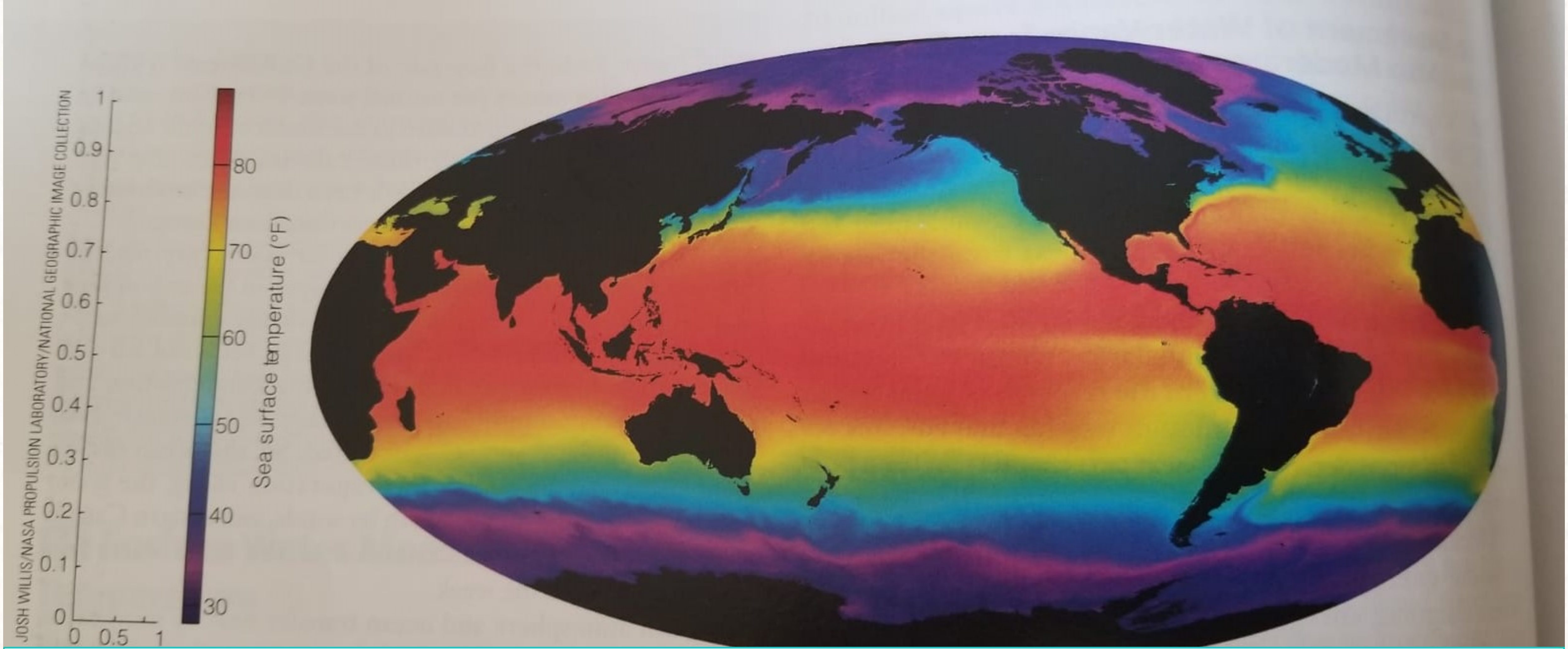


Figure 8.7 Areas of heat gain and loss on Earth's surface.



b The average annual incoming solar radiation (red line) *absorbed* by Earth is shown along with the average annual infrared radiation (blue line) *emitted* by Earth. As in **(a)**, note that polar latitudes lose more heat to space than they gain, and 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 (orange area) equals the area of heat lost (blue areas), Earth's total heat budget is balanced over time.



- The oceanic water transport ~550 trillion calories per second (see the calculation below)!
  - Northward ocean current is about 10^{o} C warmer than the inbound water
  - Therefore, each cubic meter of the ocean current water transports ~10 million calories of heat energy. Why?
  - The rate of the oceanic water flow is around 55 million cubic meter of water per second.
- Although the humankind has learnt to harness the natural energy, our efforts pale in comparison to the energy transfer naturally occurring in the environment

Transport of the Heat Energy by Vaporization

- Even more impressive is the transport of the heat energy by water vapor
- Let’s say, today some part of the ocean surface near Cuba (equator) – due to the solar energy that it absorbs – evaporates.
  - The stored heat in the water near Cuban sea gets transferred to the clouds that form.
- The ocean near Cuba is cooled by evaporation
- All the energy is carried by the clouds - in the form of water vapor - toward Canada
- The Eastern Canada is warmed by the condensation of the same water in the form of the water in the next week
- A high latent heat of vaporization of water implies that the water vapor transfers about twice as much heat per unit of mass of water as the liquid water

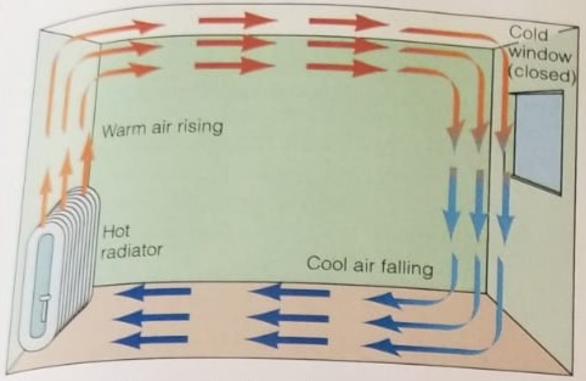


Figure 8.9 A convection current forms in a room when air flows from a hot radiator to a cold closed window and back. (For a practical oceanic application of this principle, look ahead to Figure 8.20.)

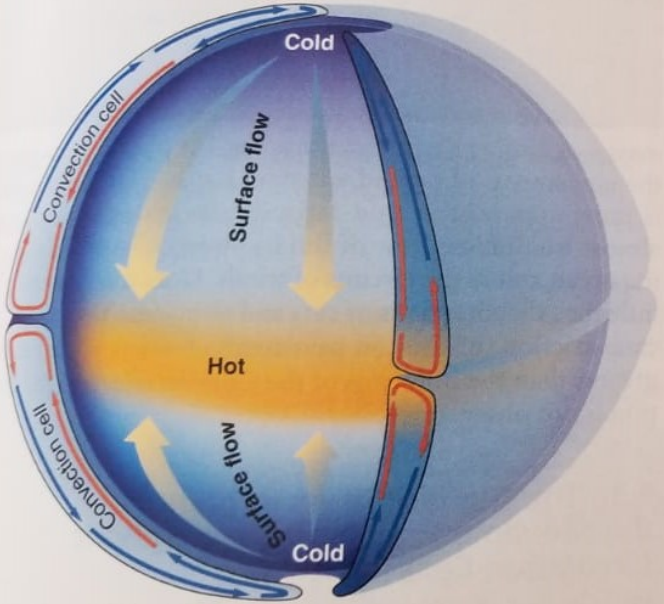


Figure 8.10 A hypothetical model of Earth's air circulation if uneven solar heating were the only factor to be considered. (The thickness of the atmosphere is greatly exaggerated.)

The Quito disk and the Buffalo disk must turn through 15° of ongitude each hour (or Earth would rip itself apart), but the ty on the equator must move faster to the east to turn its 15° ch hour because its "slice of the pie" is larger. Buffalo must

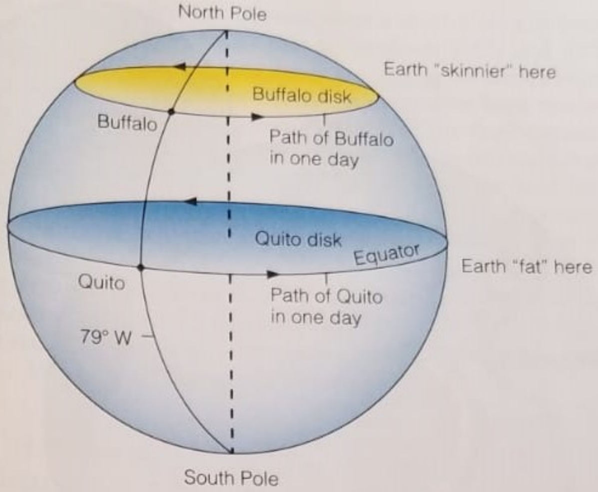


Figure 8.11 A sketch of the thought experiment in the text, showing that Buffalo travels a *shorter* path on the rotating Earth than Quito does.

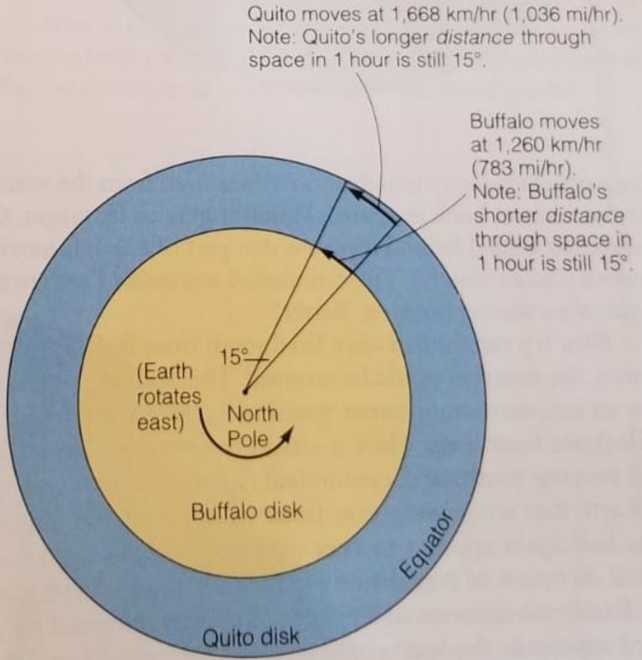


Figure 8.12 A continuation of the thought experiment. A look at Earth from above the North Pole shows that Buffalo and Quito move at differ-

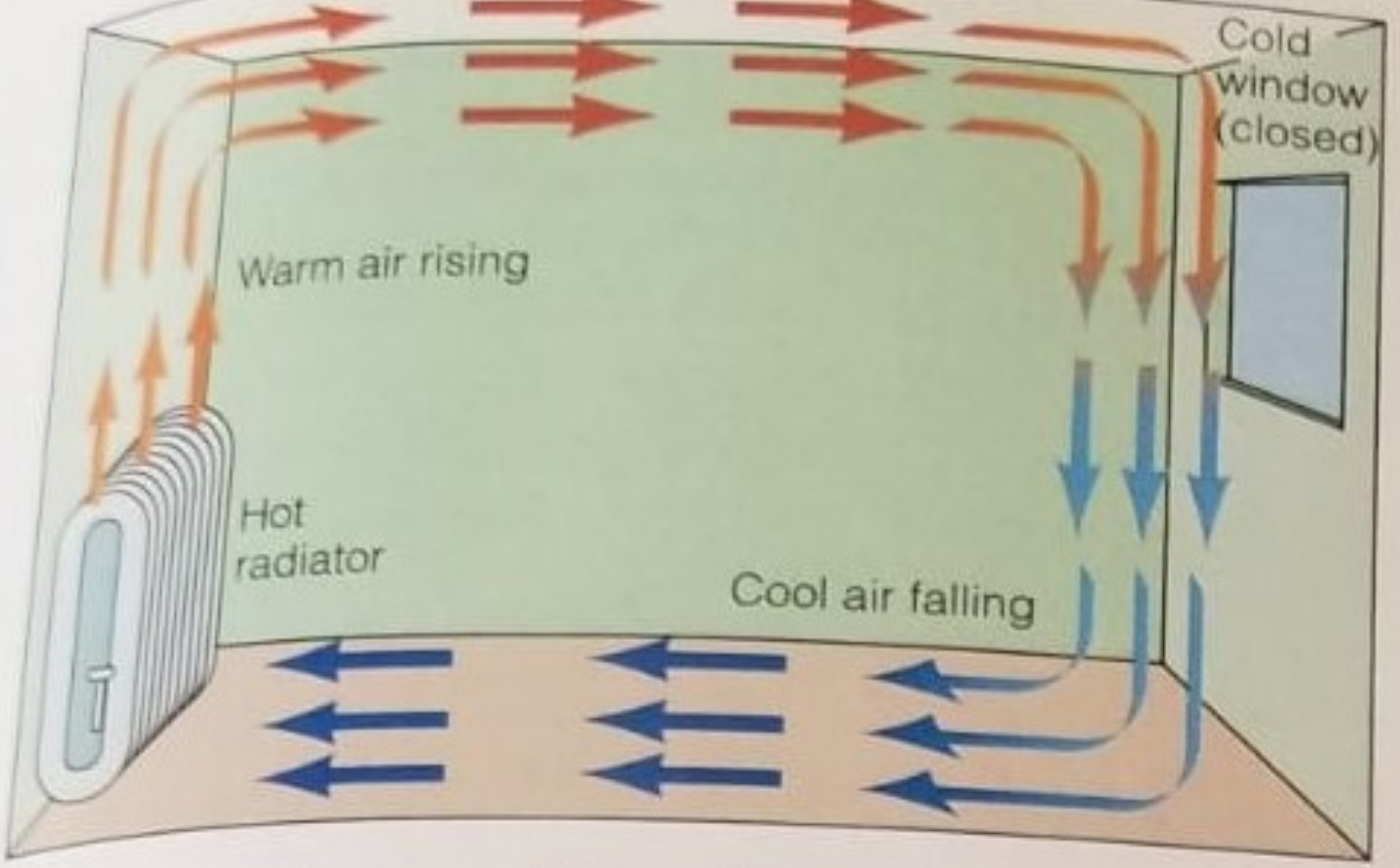
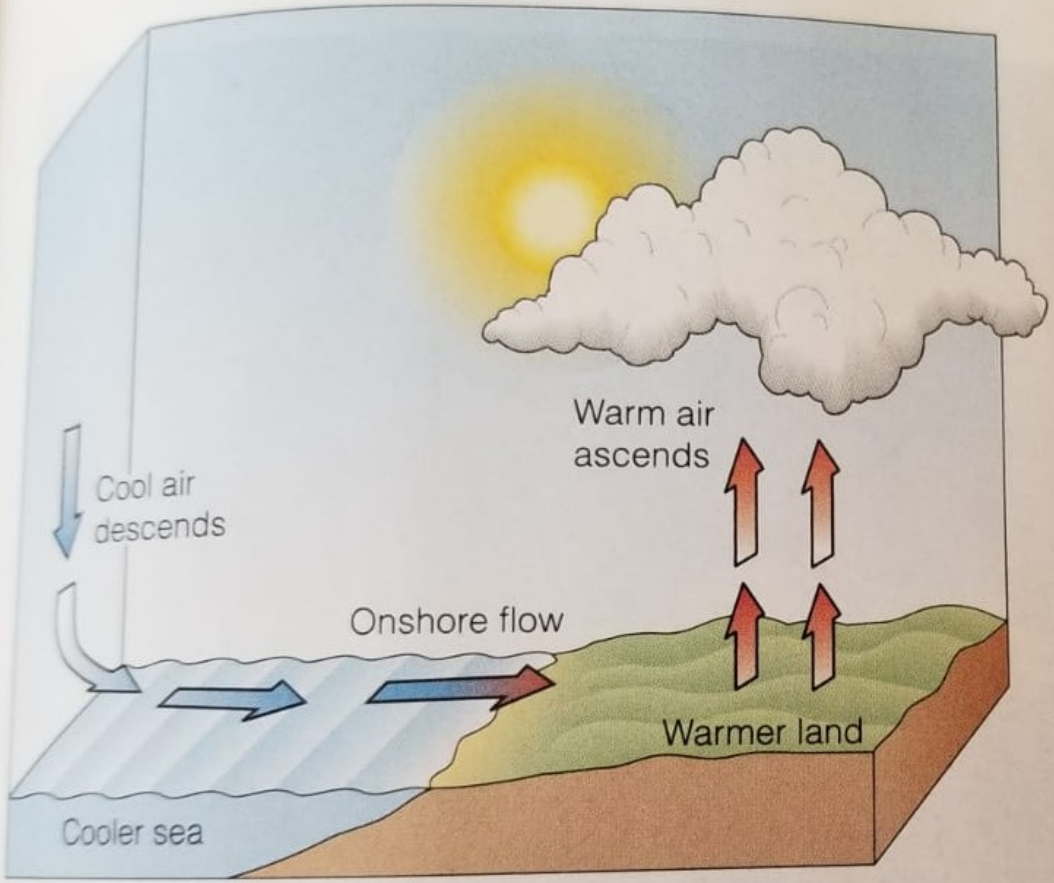
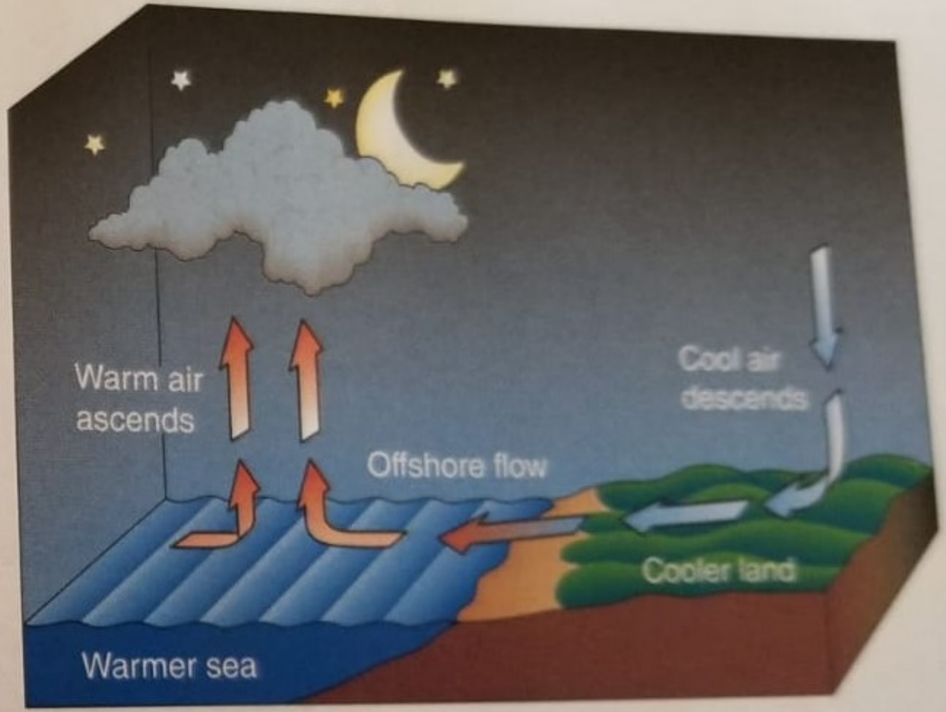


Figure 8.9 A convection current forms in a room when air flows from a hot radiator to a cold closed window and back. (For a practical oceanic application of this principle, look ahead to Figure 8.20.)



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



b 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 flow (a land breeze).

Figure 8.20 The flow of air in coastal regions during stable weather conditions.

THINKING BEYOND THE FIGURE

How does the daily shift in winds influence waves and surfers?

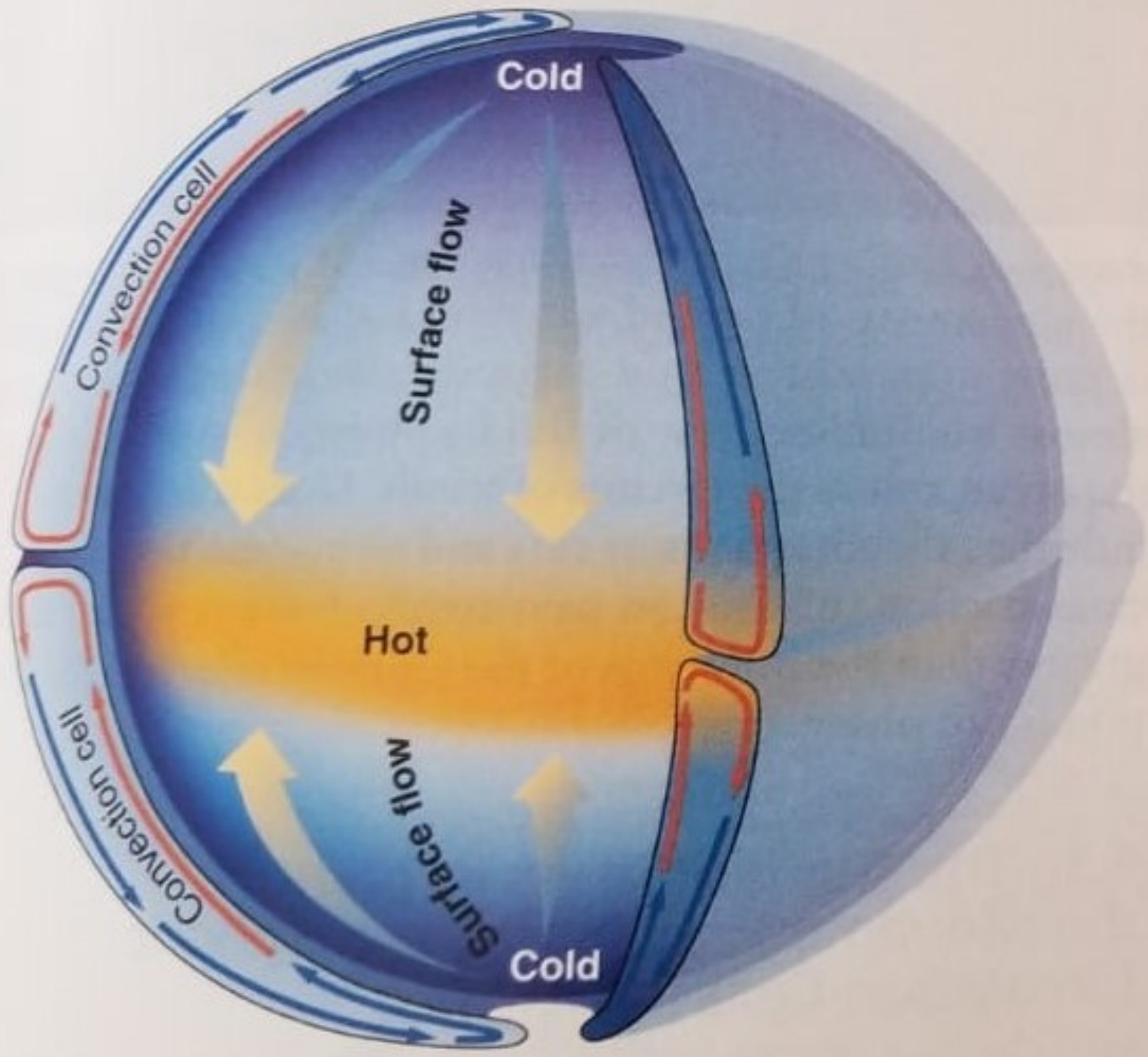


Figure 8.10 A hypothetical model of Earth's air circulation if uneven solar heating were the only factor to be considered. (The thickness of the atmosphere is greatly exaggerated.)

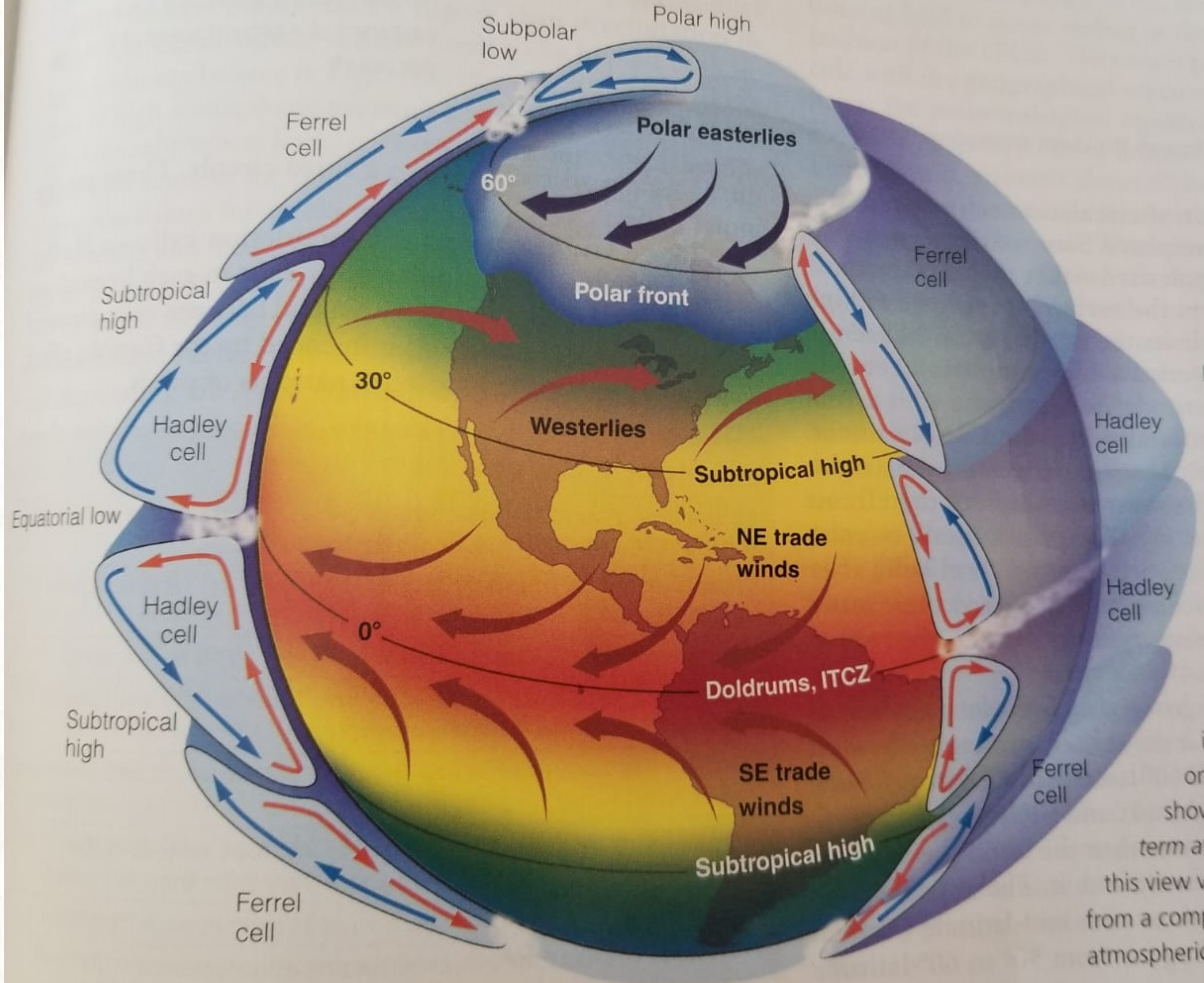


Figure 8.15 Global air circulation as described in the six-cell circulation model. As shown in Figure 8.10, air rises at the equator and falls at the poles. But instead of one great circuit in each hemisphere from equator to pole, there are *three in each hemisphere*. Note the influence of the Coriolis effect on wind direction. The circulation shown here is ideal—that is, a *long-term average* of wind flow. (Contrast this view with Figure 8.18, an excerpt from a computer simulation of true atmospheric flow.)

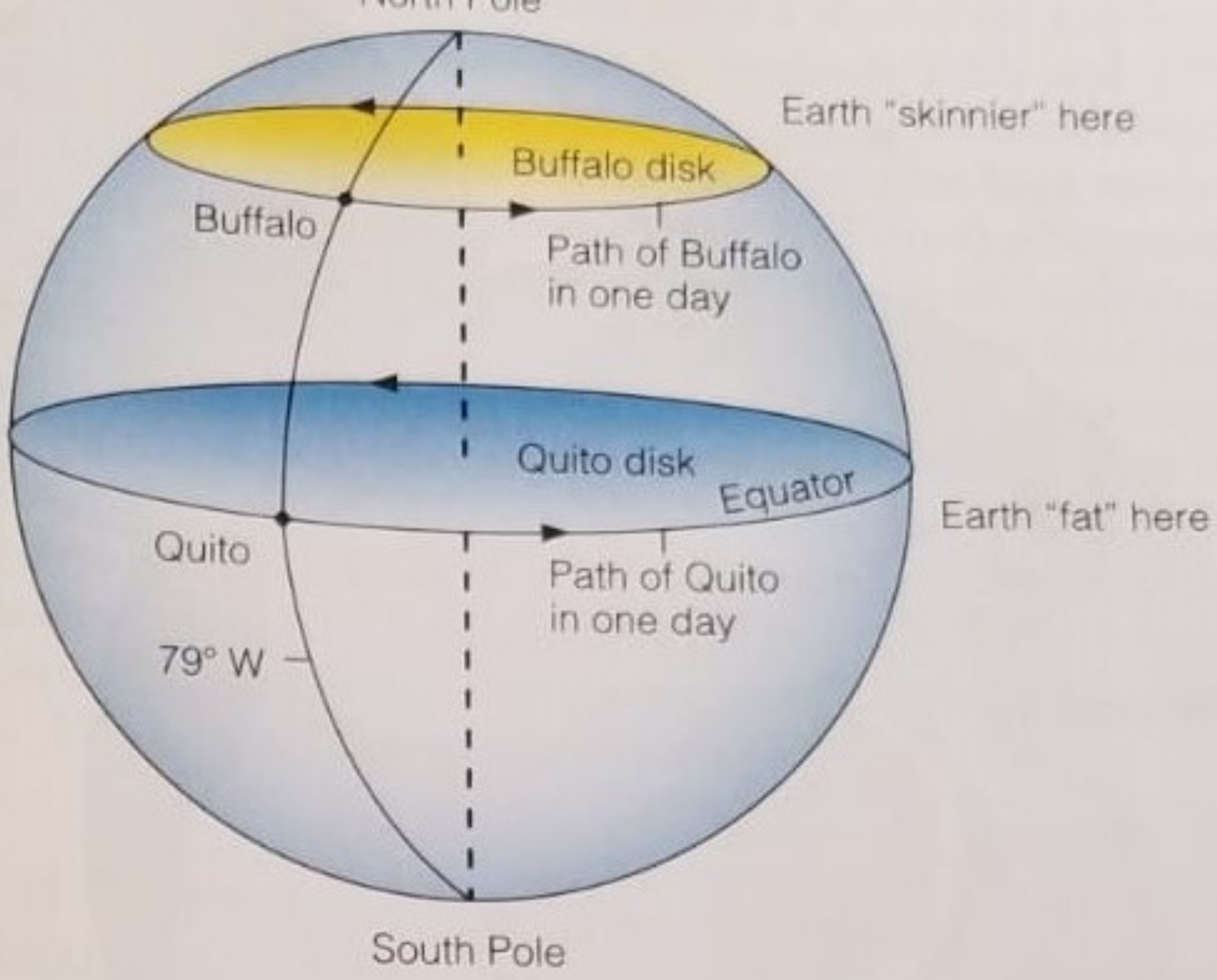


Figure 8.11 A sketch of the thought experiment in the text, showing that Buffalo travels a *shorter* path on the rotating Earth than Quito does.

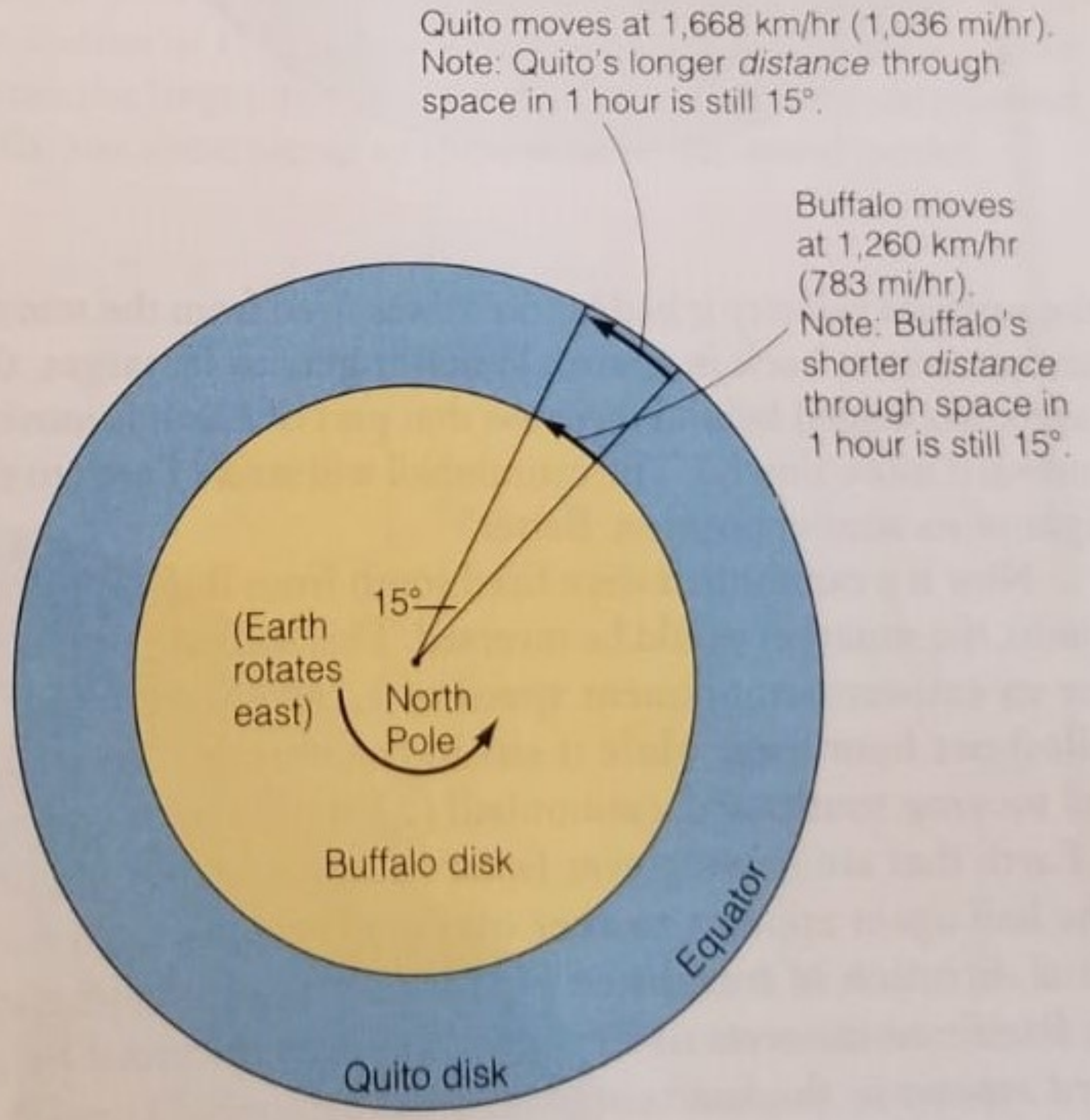
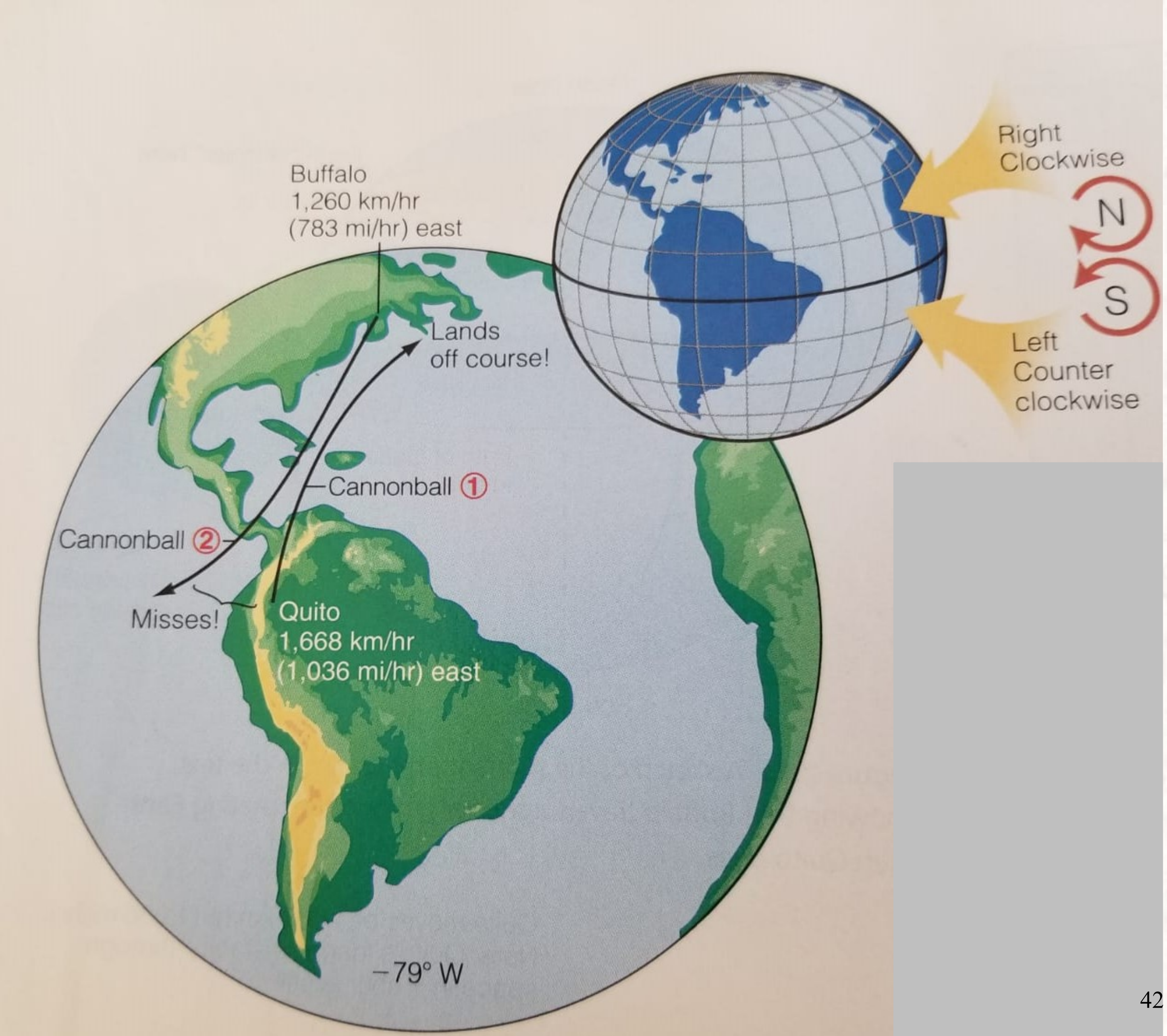


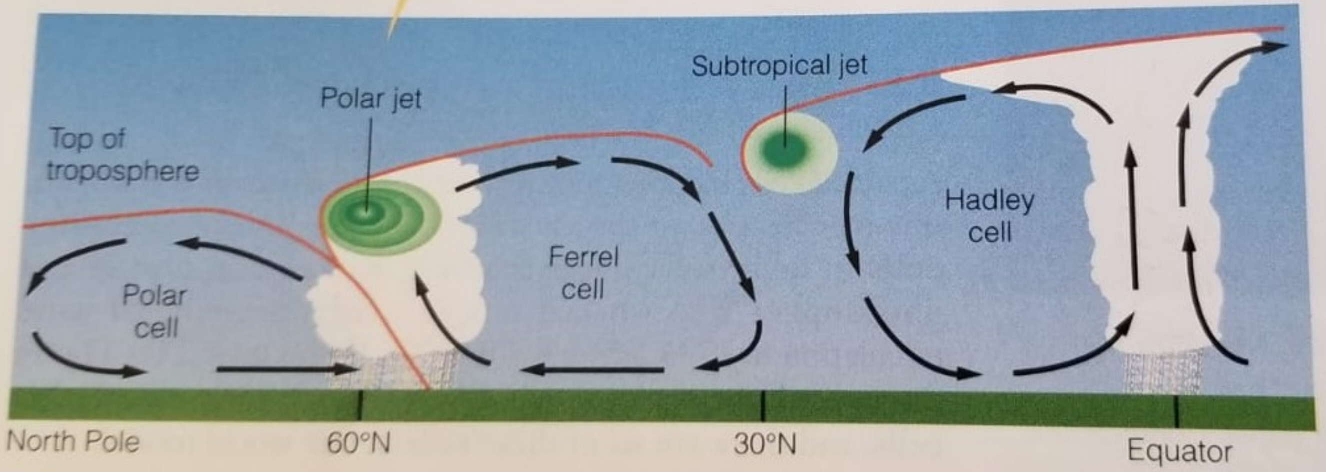
Figure 8.12 A continuation of the thought experiment. A look at Earth from above the North Pole shows that Buffalo and Quito move at differ-

A hypothetical example of the Coriolis Effect



https://www.nationalgeographic.org/encyclopedia/coriolis-effect/12th-grade/

b A polar jet stream flowing across the north Pacific. Polar jets form at around 7 to 12 kilometers (23,000 – 52,000 feet) and are of great importance to commercial aviation.



a The polar, Ferrel, and Hadley Cells shown in detail. Note that the troposphere is higher in the tropics than in the polar regions. Jet streams—rivers of fast-moving air—form at cell junctions.

c Airliners can save fuel by riding in (or avoiding) jet streams. This 747 has added the 225-mile-per-hour speed of a well-placed northern Pacific jet stream to its normal cruising speed and is traveling eastward at a ground speed of 810 miles per hour!

Figure 8.16 A cross section through the lower atmosphere from the North Pole to the Equator.

Table 8.1 **Major Wind and Pressure Systems and Related to Weather**

Region	Name	Pressure	Surface Winds	Weather
Equator (0°)	Doldrums (ITCZ) (equatorial low)	Low	Light, variable winds	Cloudiness, abundant precipitation in all seaso breeding ground for hurricanes. Relatively low sea-surface salinity because of rainfall (see Figures 6.16 and 6.17)
0°–30°N and S	Trade winds (easterlies)	—	Northeast in Northern Hemisphere, southeast in Southern Hemisphere	Summer wet, winter dry; pathway for tropica disturbances
30°N and S	Horse latitudes (subtropical high)	High	Light, variable winds	Little cloudiness; dry in all seasons. Relatively sea-surface salinity because of evaporation
30°–60°N and S	Prevailing westerlies	—	Southwest in Northern Hemisphere, northwest in Southern Hemisphere	Winter wet, summer dry; pathway for subtr high and low pressure
60°N and S	Polar front	Low	Variable	Stormy, cloudy weather zone; ample precip in all seasons
60°–90°N and S	Polar easterlies	—	Northeast in Northern Hemisphere, southeast in Southern Hemisphere	Cold polar air with very low temperatures
90°N and S	Poles	High	Southerly in Northern Hemisphere, northerly in Southern Hemisphere	Cold, dry air; sparse precipitation in all se

Note: Compare to Figure 8.13. (From *Earth in Crisis: An Introduction to the Earth Sciences*, 2/e, Thomas L. Burrus, Herbert J. Spiegel, 1980. C. V. Mosby Co. Reprinted by permissic authors.)

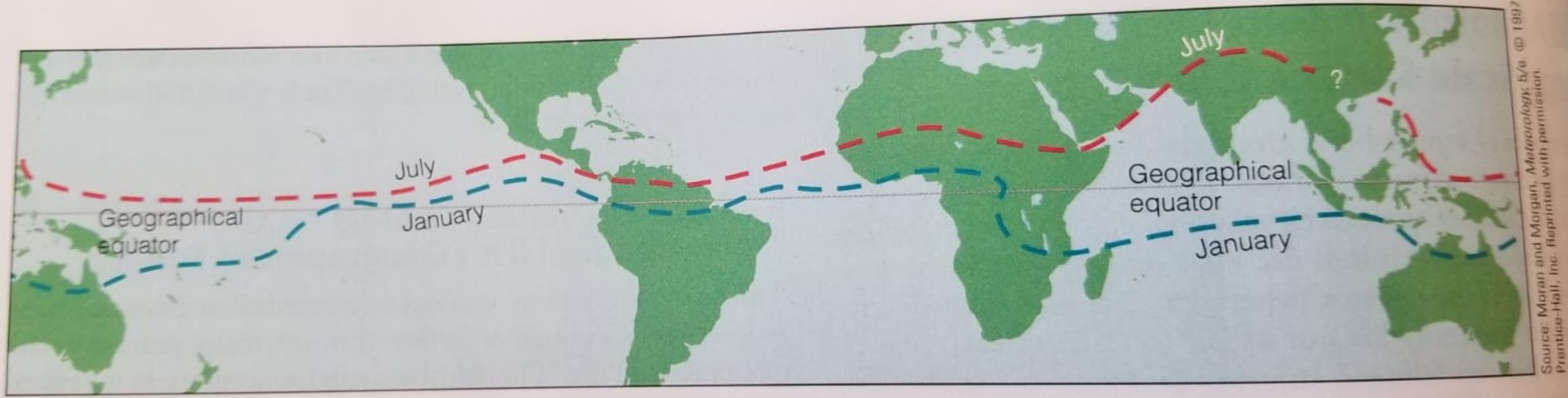
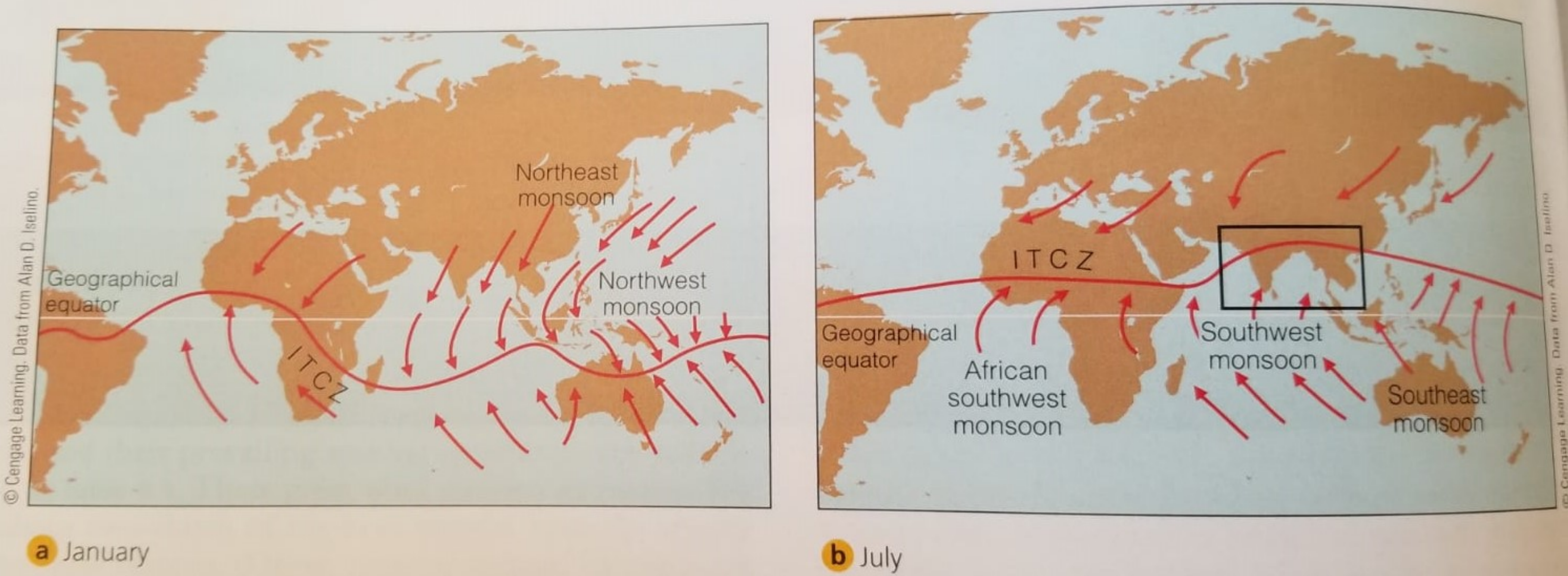


Figure 8.17 Seasonal changes in the position of the intertropical convergence zone (ITCZ). The zone reaches its most northerly location in July and its most southerly location in January. Because of the thermostatic effect of water, the seasonal north–south movement is generally less over the ocean than over land.

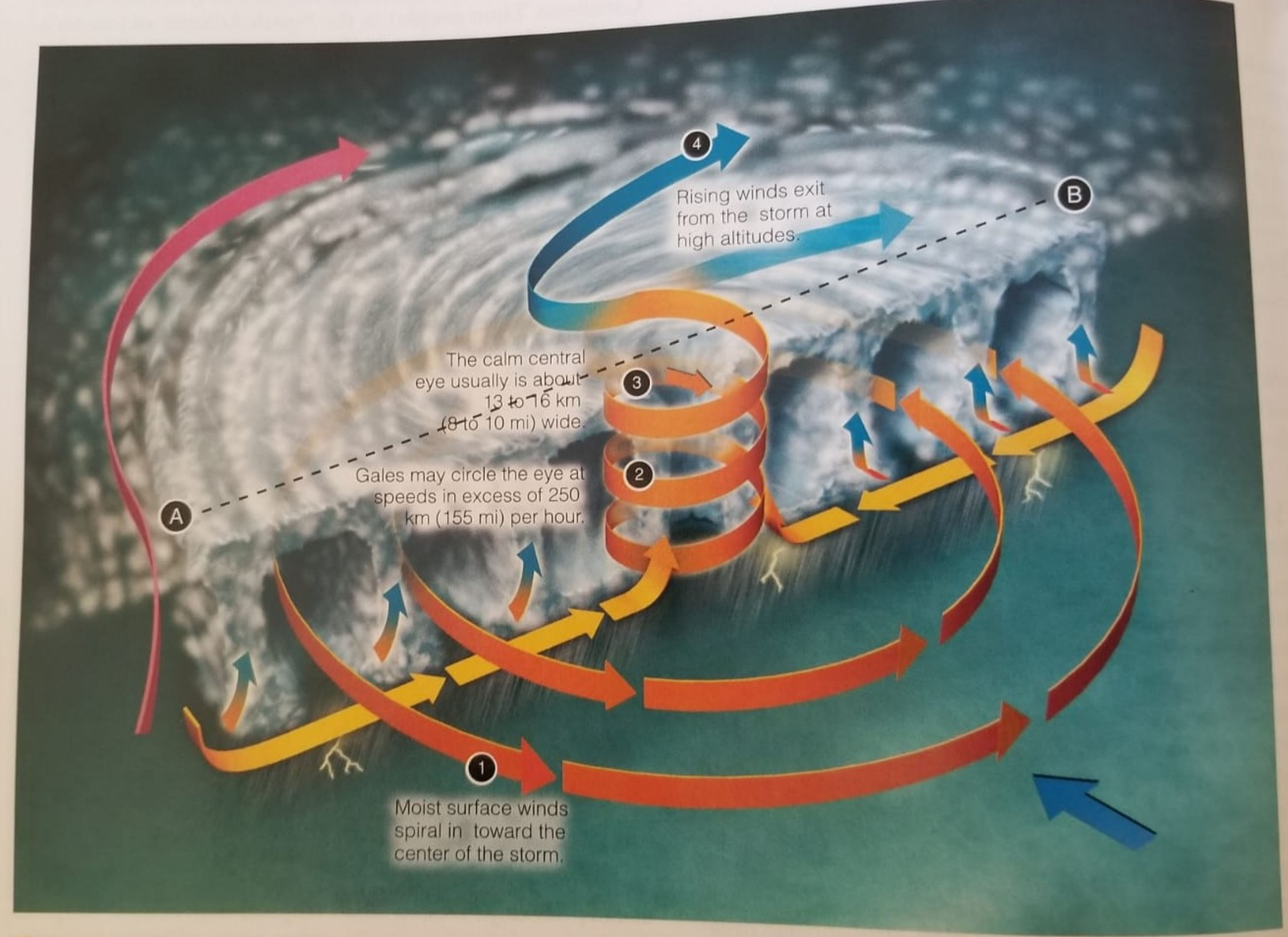
THINKING BEYOND THE FIGURE

Explain why the ITCZ changes in position seasonally.



During the monsoon circulations of January a and July b, surface winds are deflected to the right in the Northern Hemisphere and to t left in the Southern Hemisphere.

Few natural events underscore human insignificance like a great storm. When powered by stored sunlight, the combination of atmosphere and ocean can do fearful damage.

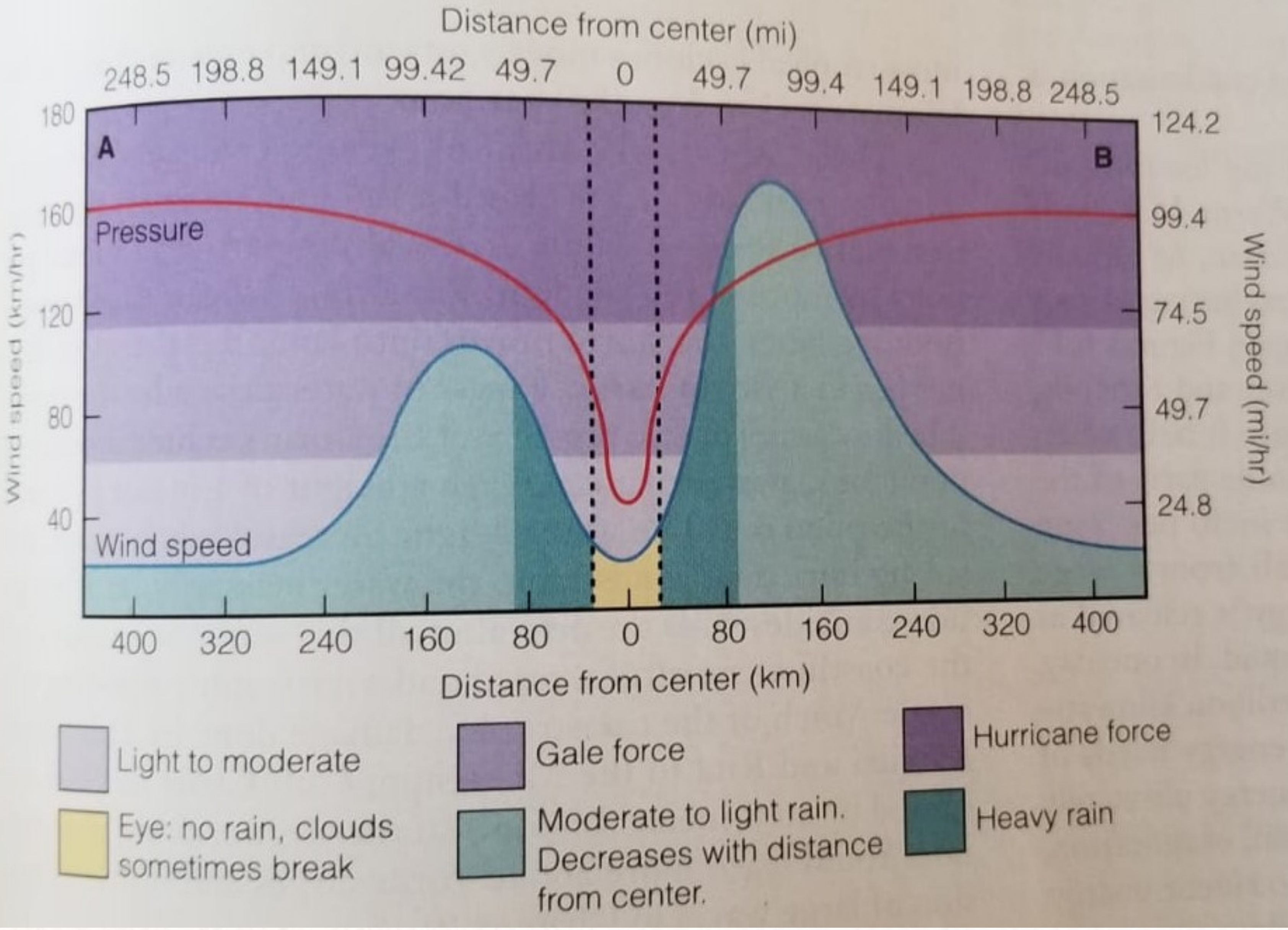


a The internal structure of a mature Northern Hemisphere tropical cyclone, or hurricane. In this diagram, the storm is moving to the northwest. (The vertical dimension is greatly exaggerated.)

Figure 8.24 Tropical cyclone structure.

Table 8.2 Classification of Tropical Cyclones

Storm	Description		Maximum Sustained Wind Speed	Potential Storm Surge	Damage
Tropical Depression	An organized system of clouds and thunderstorms with defined surface circulation but no eye. Lacks the spiral shape of more powerful storms. It is already becoming a low-pressure system, a "depression."		Less than 62 km/hr (38 mph)	None	None
Tropical Storm	An organized system of strong thunderstorms with a defined surface circulation and cyclonic shape, though usually lacking an eye. Government weather services assign first names to systems that reach this intensity (they become "named storms").		62–117 km/hr (39–73 mph)	Little or none	Little or none
Tropical Cyclone	Intense cyclonic winds exceeding 119 km/h (74 mph). Tropical cyclones consist of a tightly organized band of thunderstorms surrounding a central eye.	Category 1	119–153 km/hr (74–95 mph)	1.2–1.5 m (4–5 ft)	Damage to trees, shrubs, and unanchored mobile homes.
		Category 2	154–177 km/hr (96–110 mph)	1.8–2.4 m (6–8 ft)	Some trees blown down; major damage to exposed mobile homes; roof damage to permanent structures.
		Category 3	178–209 km/hr (111–130 mph)	2.7–3.7 m (9–12 ft)	Foliage removed from large trees; large trees blown down; mobile homes destroyed; some structural damage to permanent buildings.
		Category 4	210–249 km/hr (131–155 mph)	4.0–5.5 m (13–18 ft)	All signs blown down; complete roof structure failure on small residences; extensive damage to windows and doors. Major erosion of beach areas. Terrain may be flooded well inland.
		Category 5	250 km/hr (156 mph)	5.5 m (19+ ft)	Complete roof failure on many residences and industrial buildings. Some complete building failures with small buildings blown over or away. Flooding causes major damage to lower floors of all structures near the shore. Evacuation of residential areas usually required.



b A cross section of the storm showing wind speed and atmospheric pressure. Because the storm is moving northwestward *and* is rotating counterclockwise, the greatest destruction from wind and storm surge will occur to the east of its center.

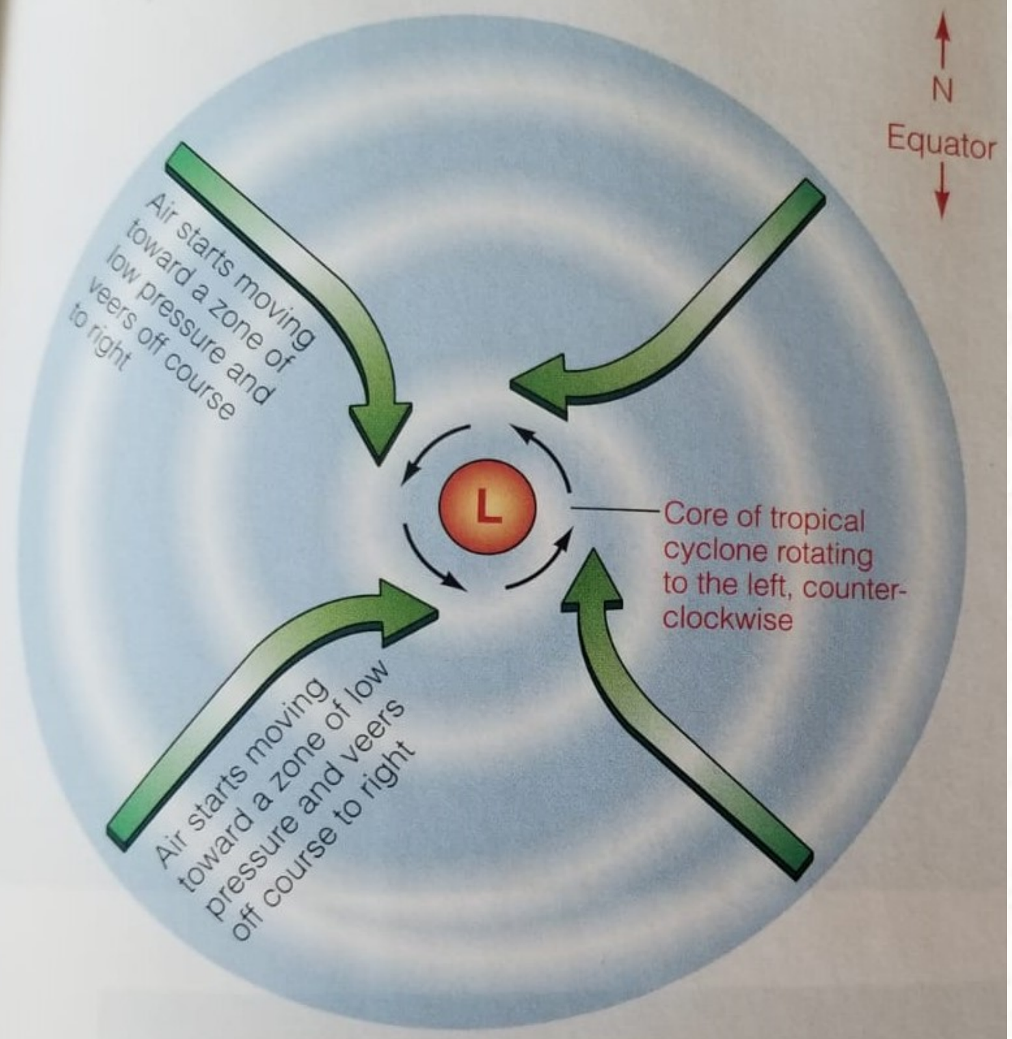
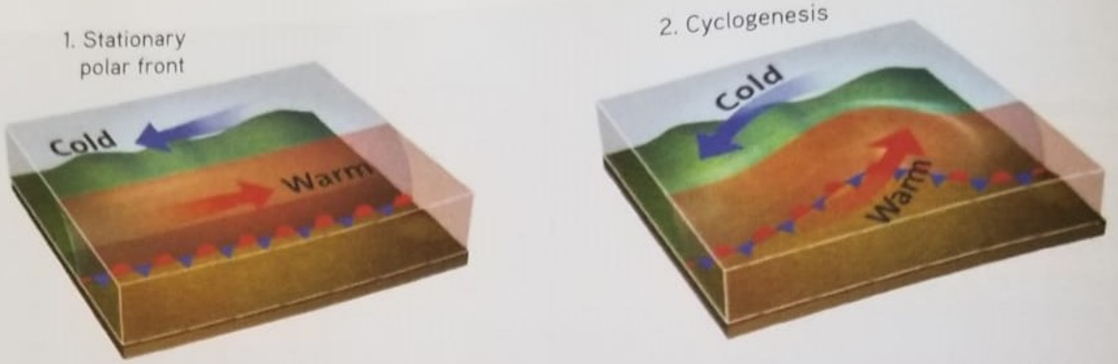
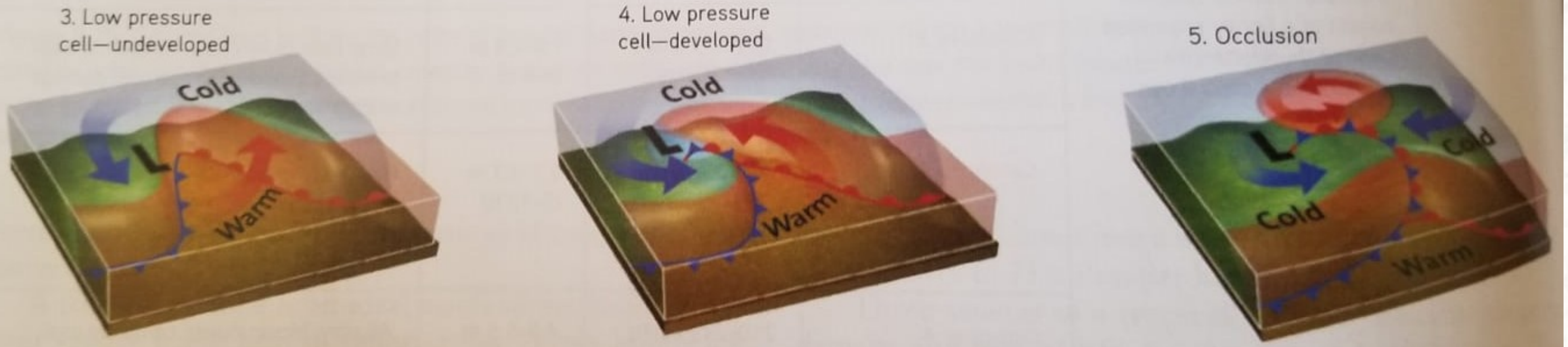


Figure 8.22 The dynamics of a tropical cyclone, showing the influence of the Coriolis effect. Note that the storm turns the "wrong" way (that is, counterclockwise) in the Northern Hemisphere, but for the "right" reasons. Extratropical cyclones are also areas of low pressure and rising air, which leads to winds moving toward the center and a similar rotational direction as seen in Figure 8.27.



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



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.

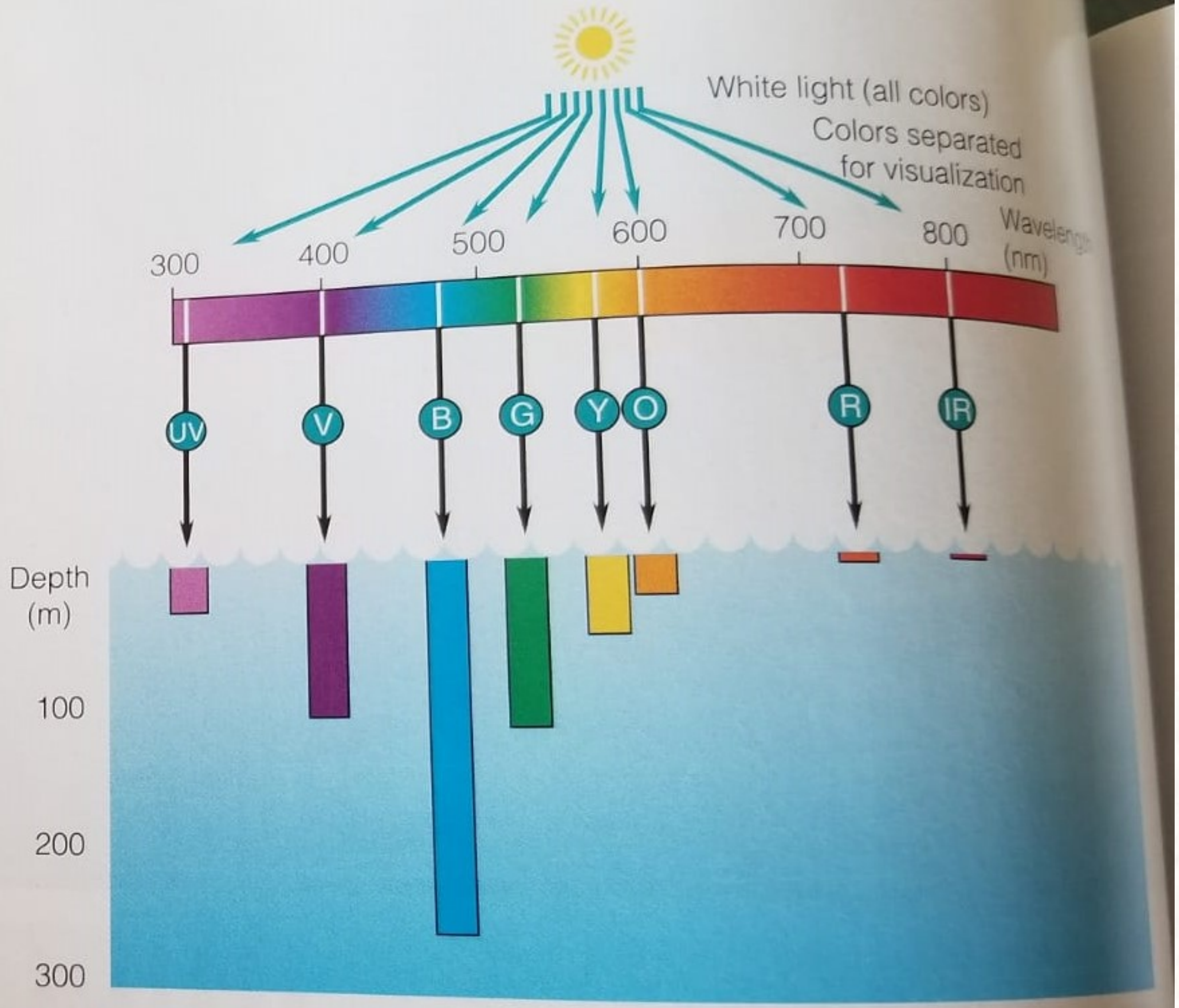
Figure 8.26 Formation of a mid-latitude cyclone. These cyclonic (spinning) storms form between air masses and are responsible for most of the weather in the temperate zones.

Source: National Geographic Collegiate Atlas p. 33

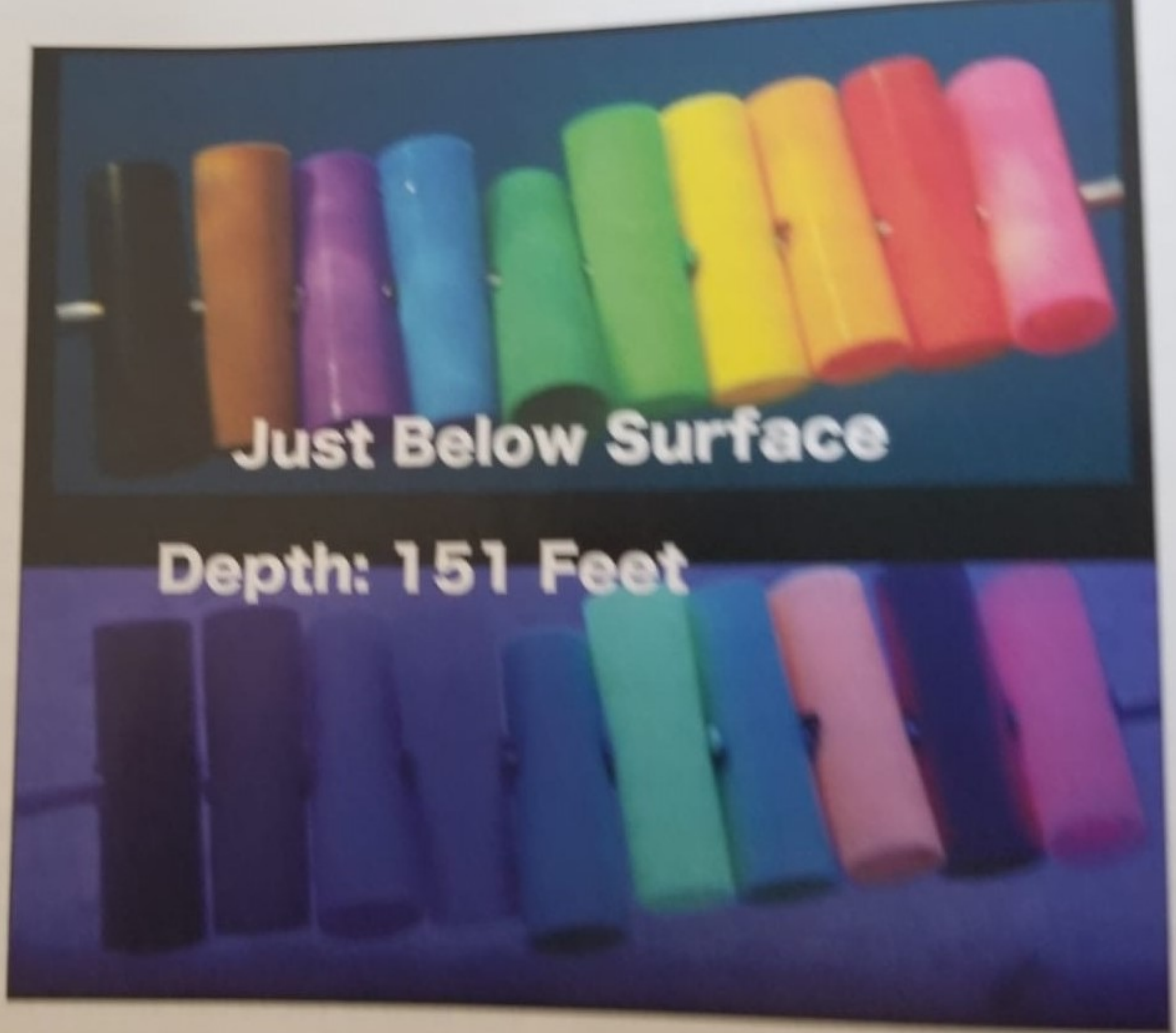
Absorption of Light in Different Wavelengths (Colors) by Seawater

Color	Wavelength (nm)	Percentage of Light Absorbed in 1 Meter of Water	Depth in Which 99% Is Absorbed (m)
Ultraviolet (UV)	310	14.0	31
Violet (V)	400	4.2	107
Blue (B)	475	1.8	254
Green (G)	525	4.0	113
Yellow (Y)	575	8.7	51
Orange (O)	600	16.7	25
Red (R)	725	71.0	4
Infrared (IR)	800	82.0	3

a The table shows the percentage of light absorbed in the uppermost meter of the ocean and the depths at which only 1% of the light of each wavelength remains.



b The bars show the depths of penetration of 1% of the light of each wavelength (as in the last column of the table).


Just Below Surface
Depth: 151 Feet

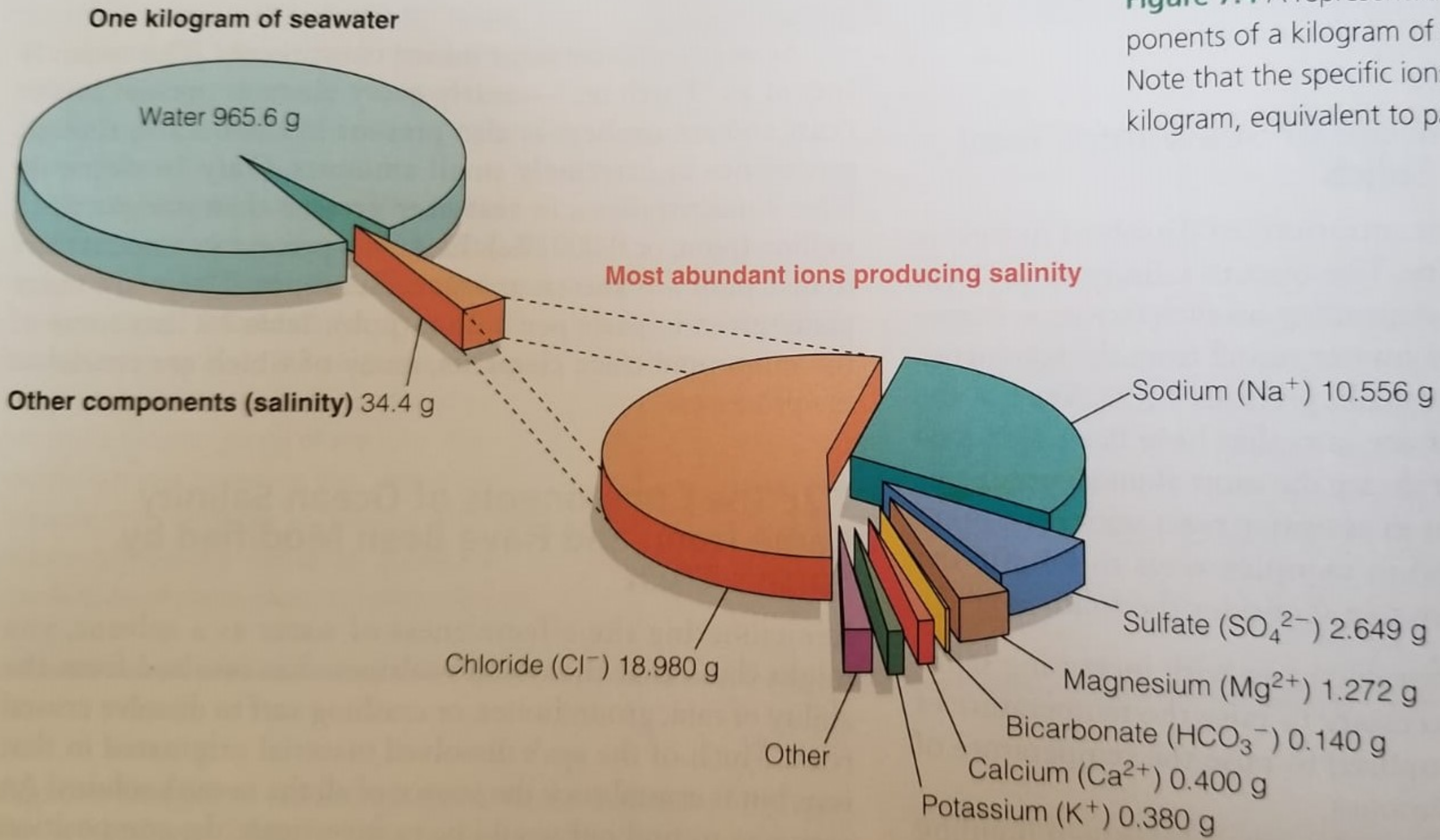
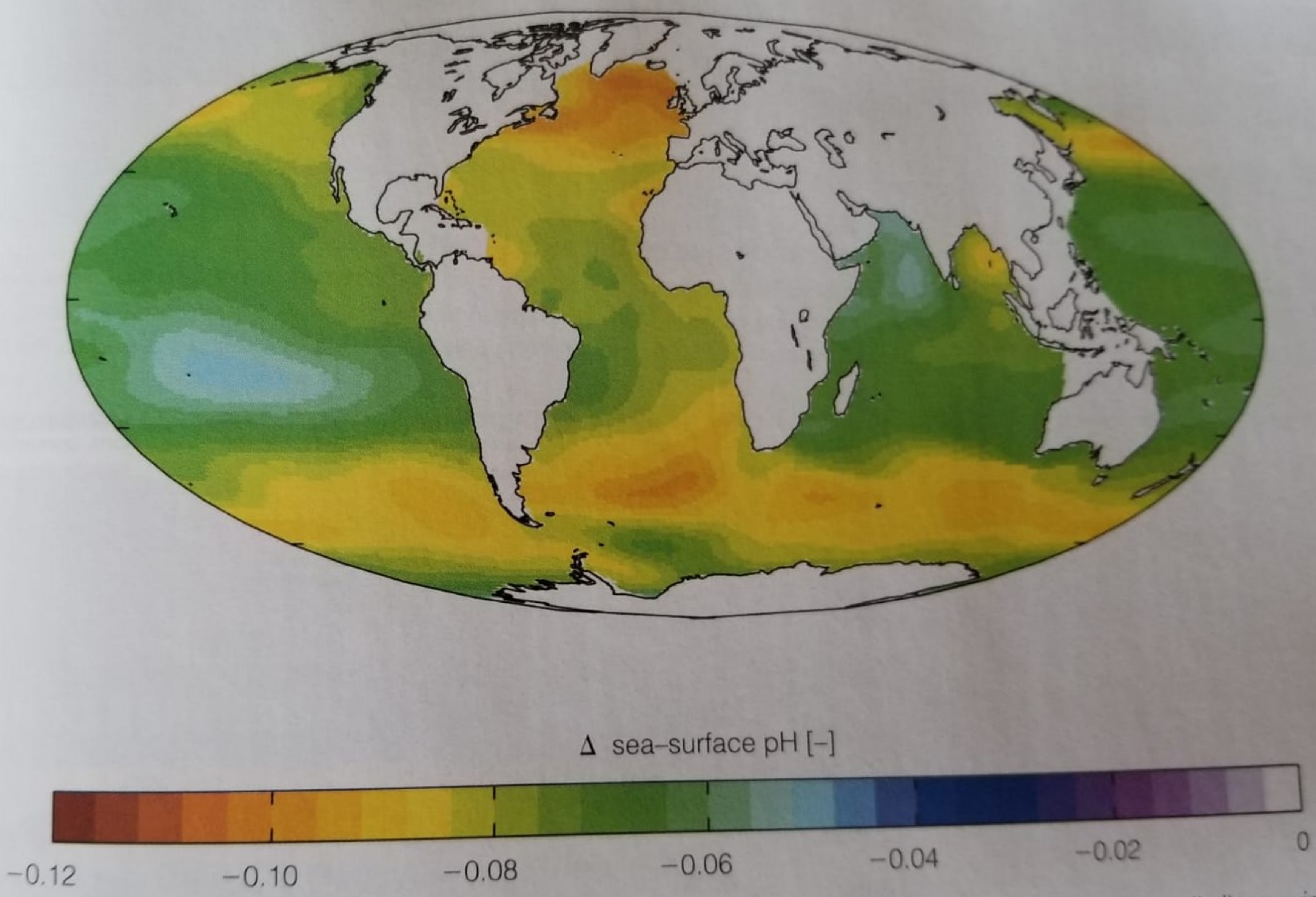
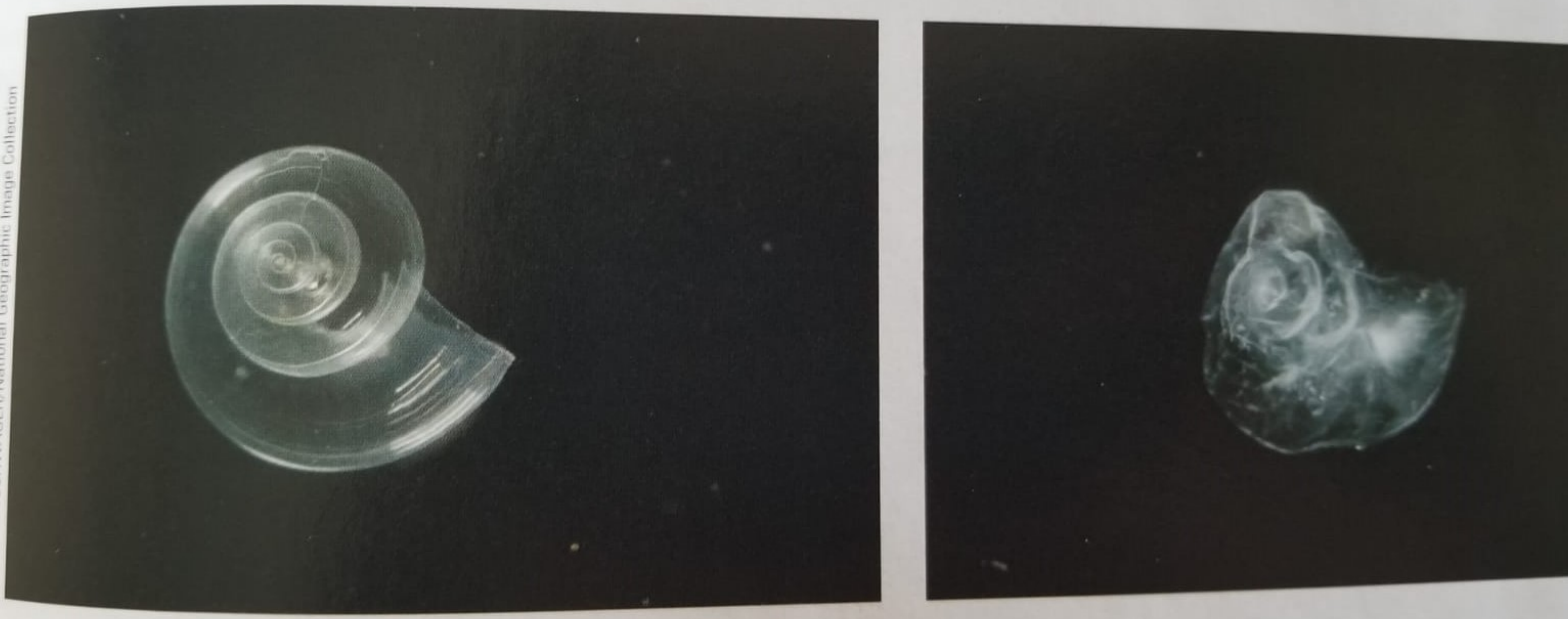


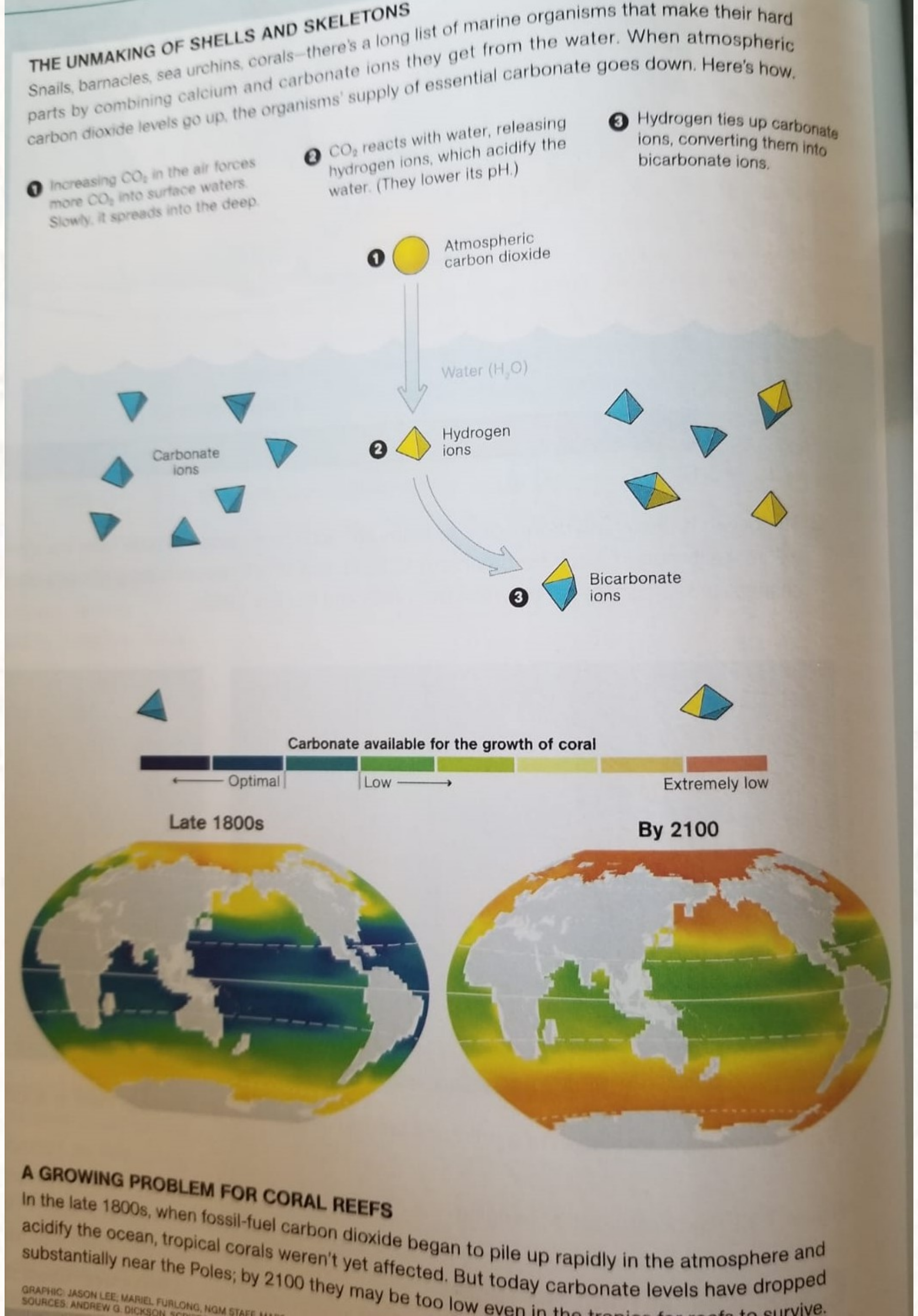
Figure 7.4 A representation of the most abundant components of a kilogram of seawater at 34.4‰ salinity. Note that the specific ions are represented in grams per kilogram, equivalent to parts per thousand (‰).



a The ocean is becoming more acidic as it absorbs additional carbon dioxide from the atmosphere. A less alkaline environm
will make it more difficult for organisms to build hard structures containing calcium (shells, coral, and so forth). The chart
changes in sea-surface pH between the 1700s and the late 1990s.



b, c Progressive dissolution of a pteropod (a small animal with a calcareous shell) in acidified seawater.



THE UNMAKING OF SHELLS AND SKELETONS

Snails, barnacles, sea urchins, corals—there's a long list of marine organisms that make their hard parts by combining calcium and carbonate ions they get from the water. When atmospheric carbon dioxide levels go up, the organisms' supply of essential carbonate goes down. Here's how.

1 Increasing CO_2 in the air forces more CO_2 into surface waters. Slowly, it spreads into the deep.

2 CO_2 reacts with water, releasing hydrogen ions, which acidify the water. (They lower its pH.)

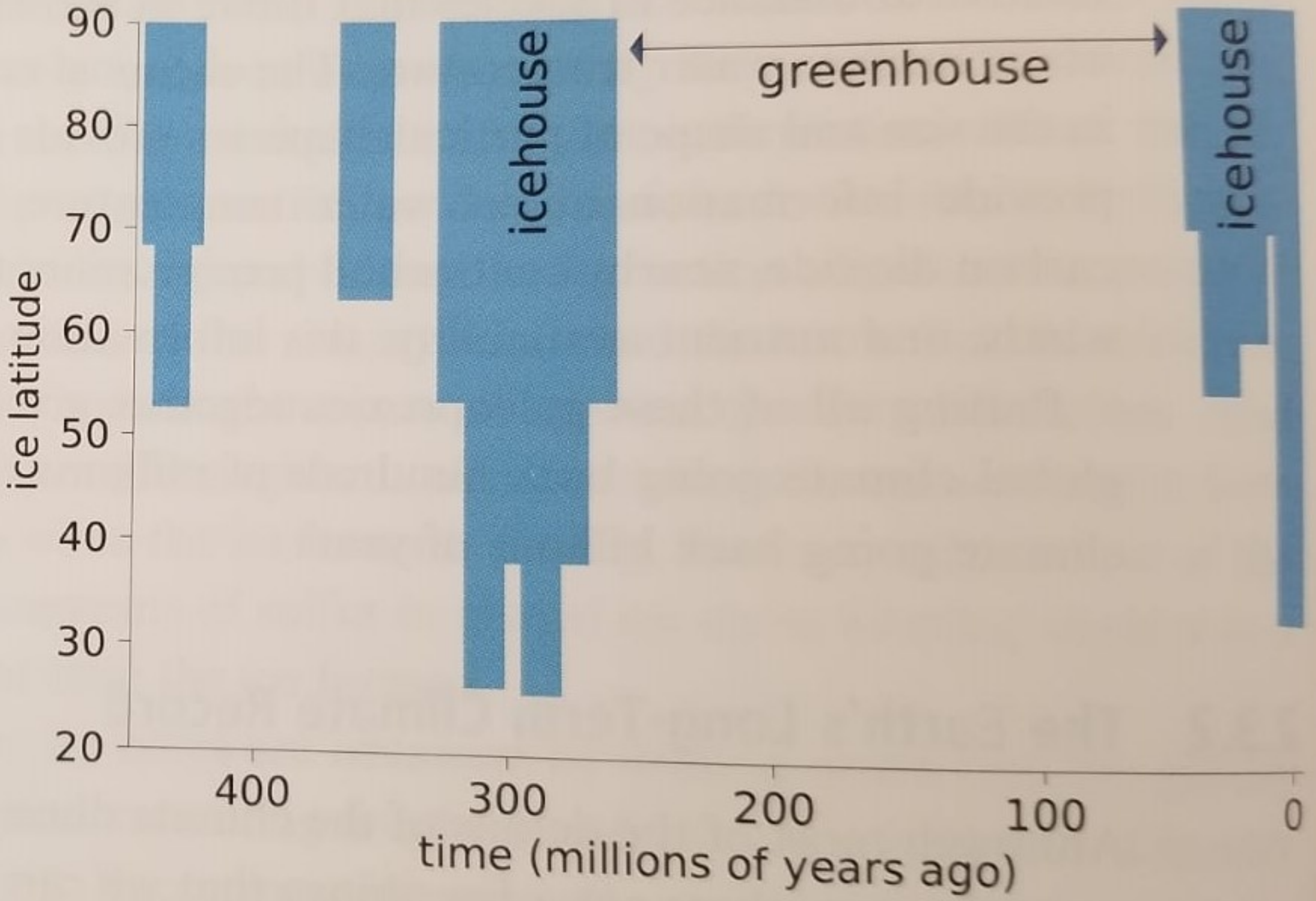
3 Hydrogen ties up carbonate ions, converting them into bicarbonate ions.

A GROWING PROBLEM FOR CORAL REEFS

In the late 1800s, when fossil-fuel carbon dioxide began to pile up rapidly in the atmosphere and acidify the ocean, tropical corals weren't yet affected. But today carbonate levels have dropped substantially near the Poles; by 2100 they may be too low even in the tropics for reefs to survive.

GRAPHIC: JASON LEE; MARIEL FURLONG, NGM STAFF
SOURCES: ANDREW G. DICKSON

Figure 2.10 Extent of continental ice deposits, showing icehouse–greenhouse cycles. The blue bars show the largest latitudinal extent of ice over time. Adapted from Figure 1 of Foster et al. (2017).



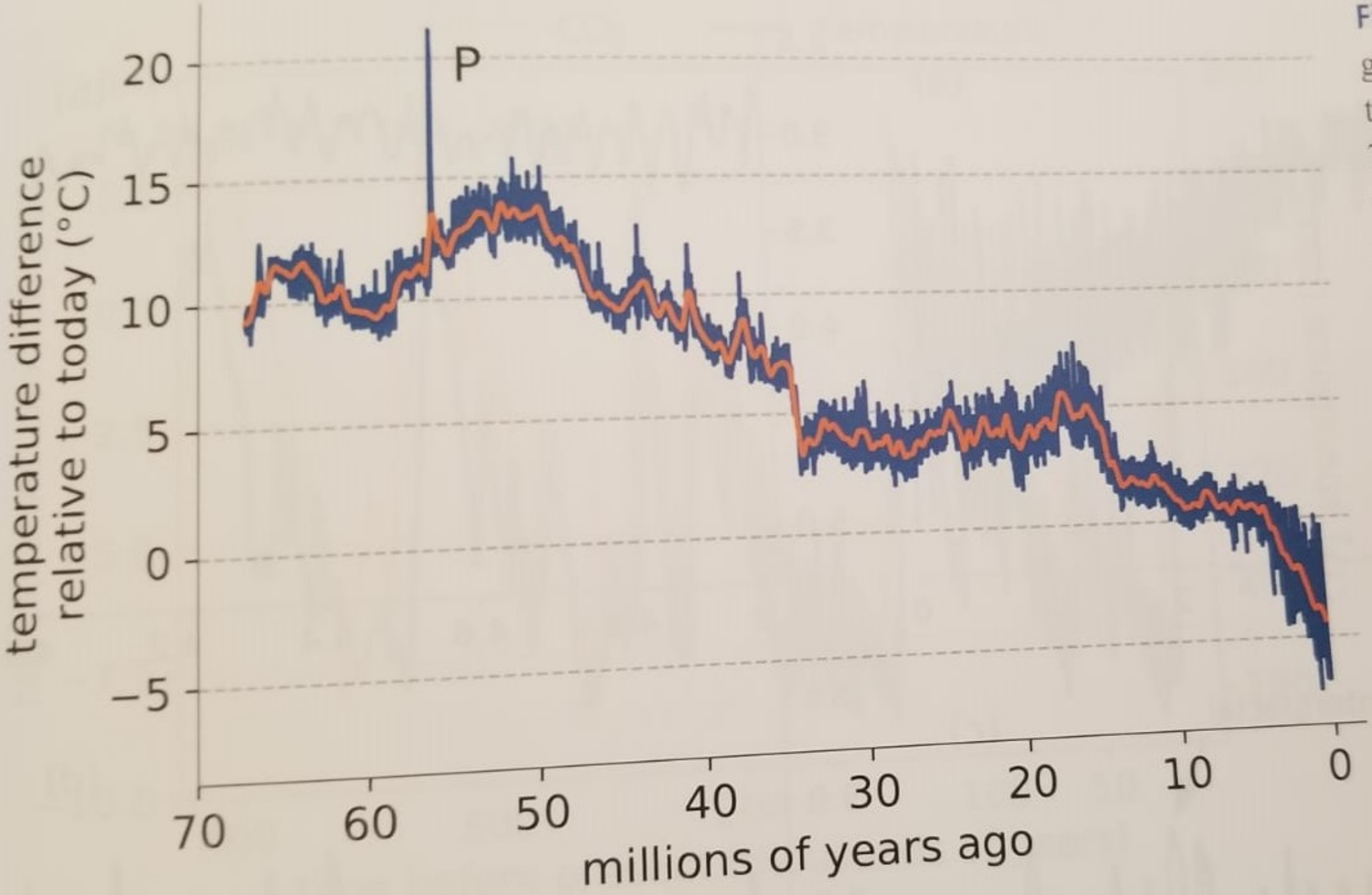


Figure 2.11 Reconstructed global average surface temperature over the past 70 million years, relative to today's temperature. The sharp temperature spike 55 million years ago (labeled "P") represents the Paleocene–Eocene Thermal Maximum (PETM). This plot is adapted from Figure 1 and Table S34 of Westerhold et al. (2020).

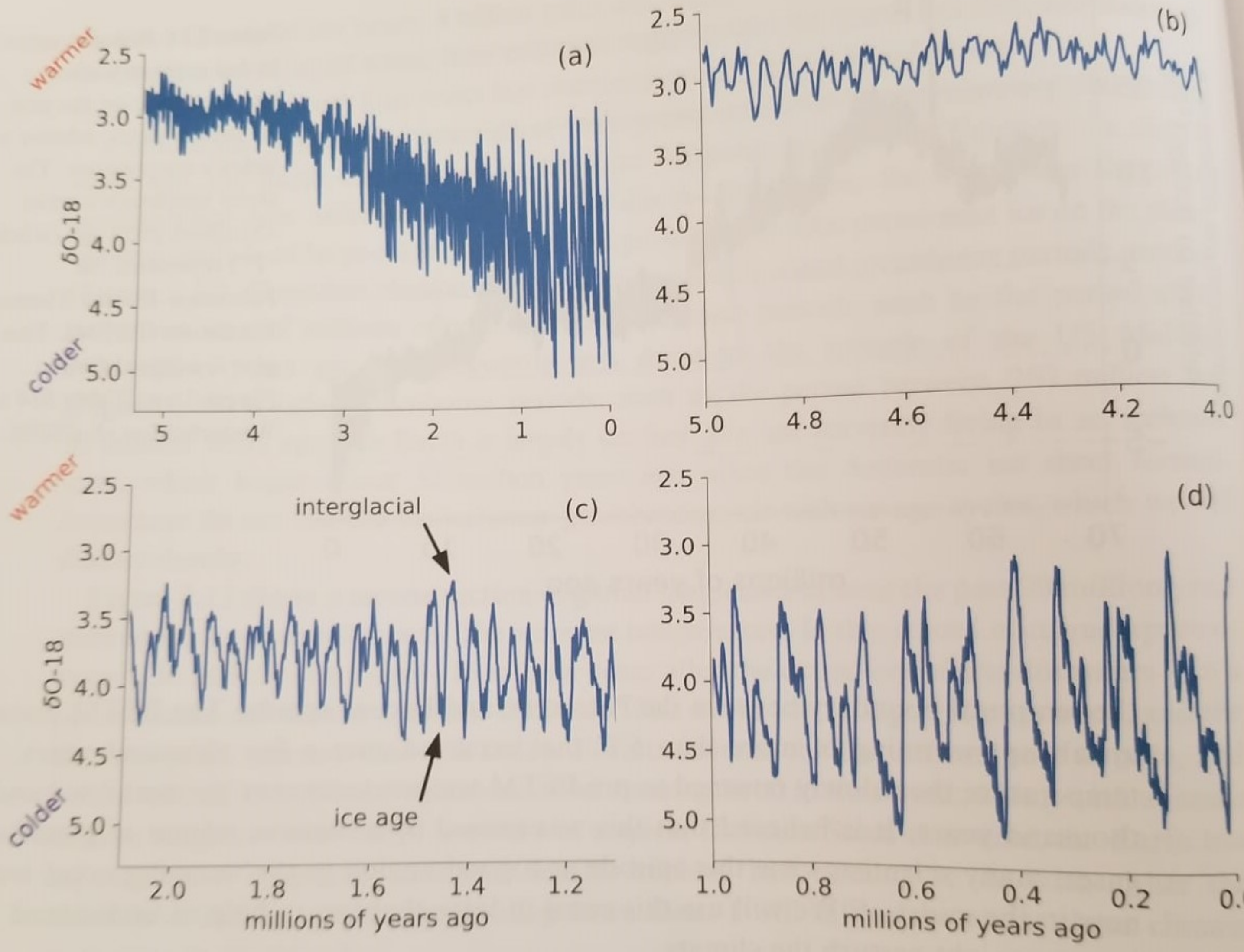


Figure 2.12 Measurement of deep ocean temperature and global ice volume over the past 5.3 million years. The vertical axis measures the relative abundance of oxygen-18, a heavy isotope of oxygen that is a proxy for temperature, in ocean sediment cores. The global average temperature difference between the top and bottom of the graph is roughly 10°C. Data are from Lisiecki and Raymo (2005) (downloaded from https://lorraine-lisiecki.com/stack.html, accessed May 29, 2020).

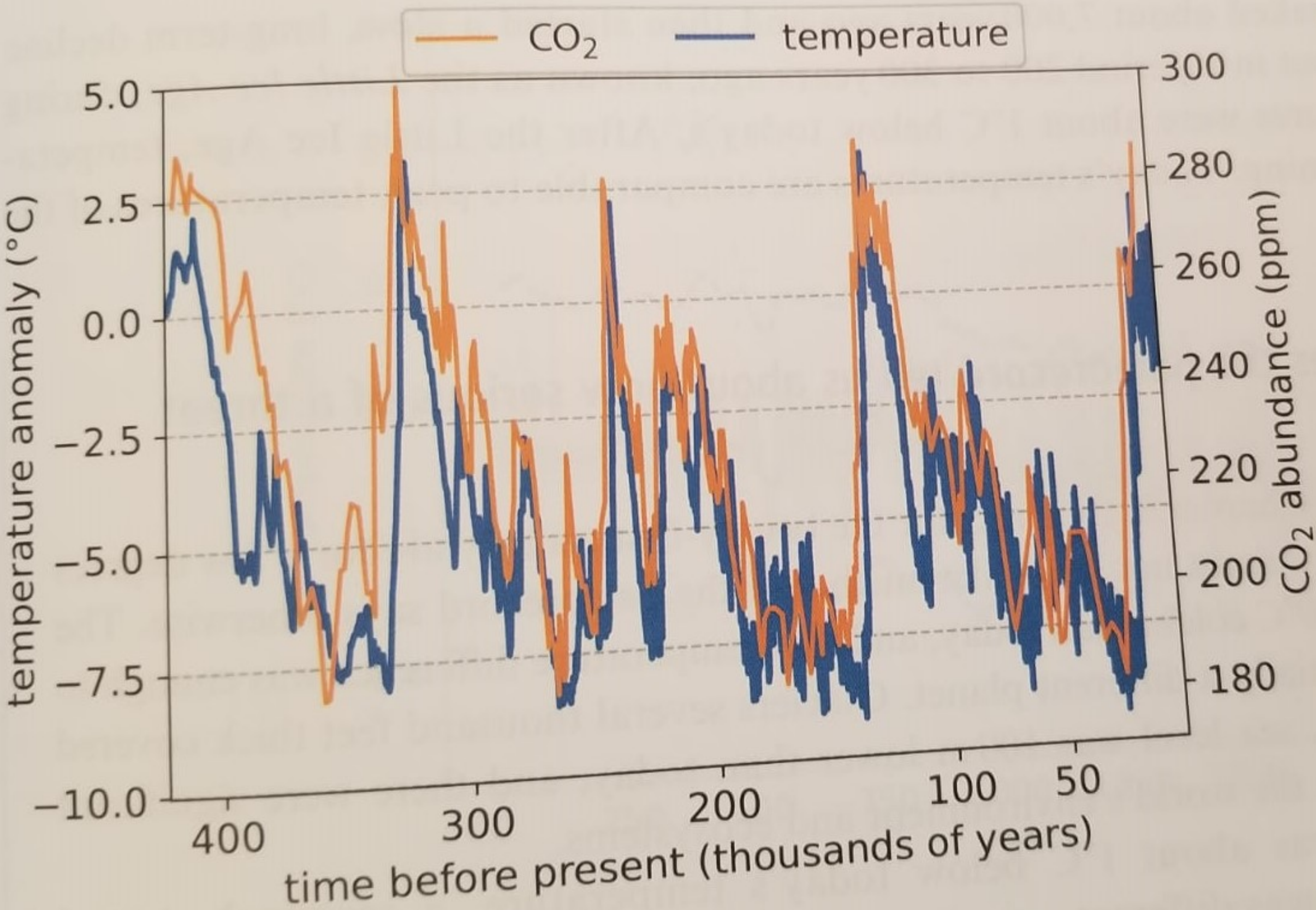


Figure 2.13 Temperature anomaly of the southern polar region (blue line) over the past 410,000 years, relative to today's temperature, constructed from an Antarctic ice core. Carbon dioxide (orange line) is from air bubbles trapped in the ice (data from Petit et al. (2000); downloaded from https://cdiac.ess-dive.lbl.gov/climate/paleo/paleo_table.html, accessed September 29, 2020).

Environmental Activism and Policy Making in the USA

- How the smog that blanketed the town of Donora, PA, lead to an early version of the clean-air act of 1963
  - https://www.smithsonianmag.com/history/deadly-donora-smog-1948-spurred-environmental-protection-have-we-forgotten-lesson-180970533/
- How a book “Silent Spring” Ignited the Environment Movement in the 1960s:
  - https://www.nytimes.com/2012/09/23/magazine/how-silent-spring-ignited-the-environmental-movement.html
    - By acquiescing in an act that causes such suffering to a living creature, who among us is not diminished as a human being?”
    - demanded personal action to right the wrongs of society.
    - No one,” says Carl Safina, an oceanographer and MacArthur fellow who has published several books on marine life, “had ever thought that humans could create something that could create harm all over the globe and come back and get in our bodies
- How a burning river helped usher in the clear-air act
    - https://www.alleghenyfront.org/how-a-burning-river-helped-create-the-clean-water-act/
- How groundwater pollution case (Love Canal) brought about RCRA
  - https://blogs.roosevelt.edu/mbryson/2013/12/01/love-canal-a-still-unfolding-legacy-of-a-toxic-waste-community-disaster/

Components of Environment

- Atmosphere: the sphere of air around the Earth
- Hydrosphere and the cryosphere: the part of the Earth that comprises water and snow/ice.
- Lithosphere: the part of the Earth that comprises the land, the soil, the rocks, etc.
- Biosphere: all the living organisms.
- Biotic and Abiotic components

2. Natural Resources

- Classification of Resources
- Forest resources:
  - Use and overexploitation, deforestation, Timber extraction, mining, dams and their effects on forests and tribal people
- Water resources:
  - Use and overutilization of surface and ground water, floods, drought, conflicts over water, dams, benefits and problems
- Mineral resources: Use and exploitation, environmental effects of extracting and using mineral resources
- Food resources:
  - World food problems, changes caused by agriculture and overgrazing, effects of modern agriculture, fertilizers, pesticide problems, water logging, salinity
- Energy resources: Growing energy needs, renewable and nonrenewable energy sources, use of alternate energy sources
- Land resources: Land as a resource, land degradation, man induced landslides, soil erosion and desertification.

3. Ecology and Ecosystems

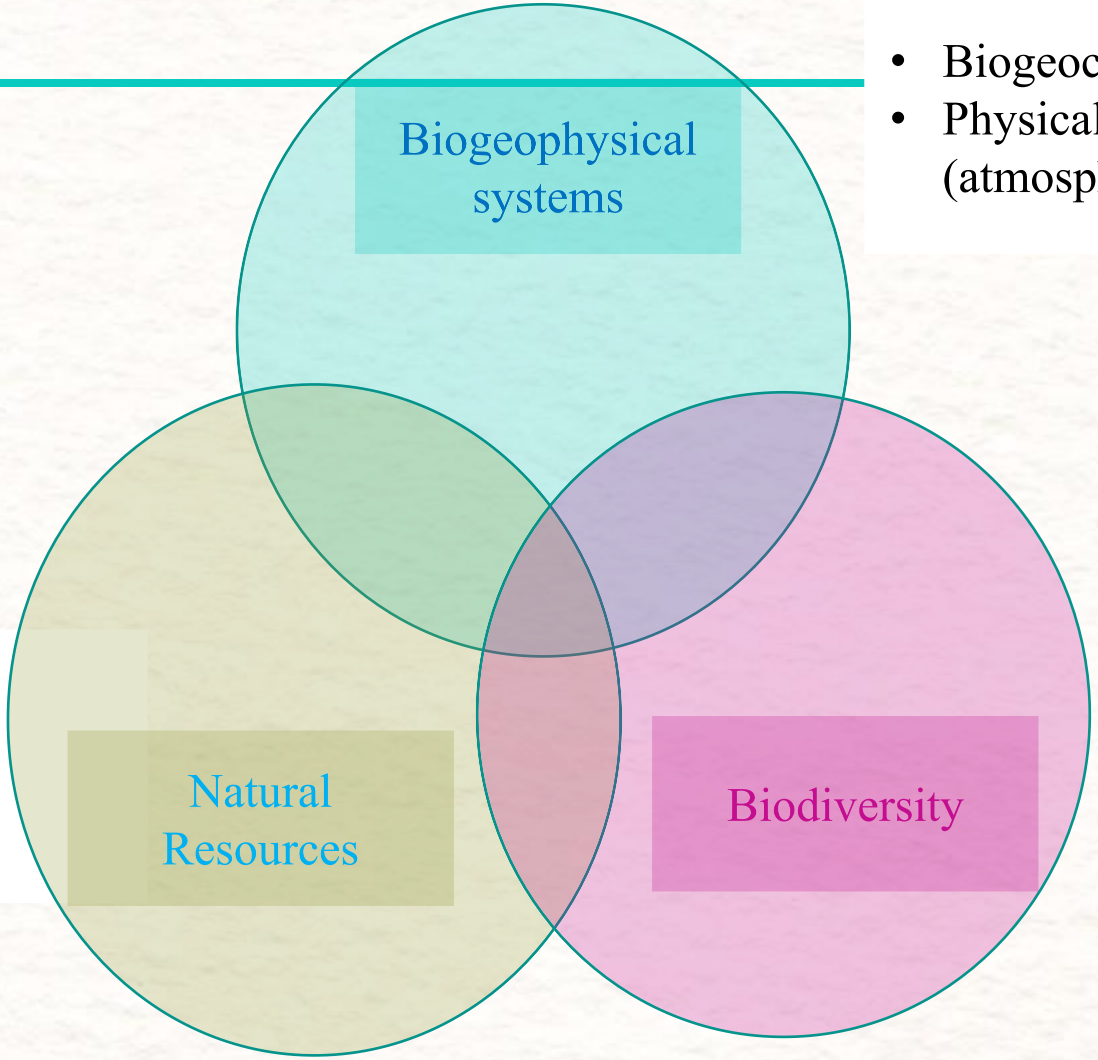
- Concept of an ecosystem:
  - all the living and nonliving things depend on each other and affect each other
  - Water, air, soil, plants, animals are all interlinked
- Structure and function of an ecosystem
- Producers, consumers and decomposers
- Energy flow in the ecosystem
- Ecological succession
- Food chains, food webs and ecological pyramids
- Types, characteristic features, structure and function of several ecosystems:
  - Forest ecosystem Grassland ecosystem Desert ecosystem Aquatic ecosystems (ponds, streams, lakes, rivers, oceans, estuaries)

4. Biodiversity and Its Conservation

- Introduction, definition: genetic, species and ecosystem diversity
- Bio-geographical classification of India
- Value of biodiversity: consumptive use, productive use, social, ethical, aesthetic and option values
- Biodiversity at global, National and local levels
- India as a mega-diversity nation
- Hotspots of biodiversity
- Threats to biodiversity: habitat loss, poaching of wildlife, man-wildlife conflicts
- Endangered and endemic species of India
- Conservation of biodiversity: insitu and exsitu conservation of biodiversity

$I = P \times A \times T$

- Biogeochemical cycles
- Physical systems (atmosphere, climate)



- Water
- Minerals
- Fossil Fuels

- Mass Extinction and loss of biodiversity

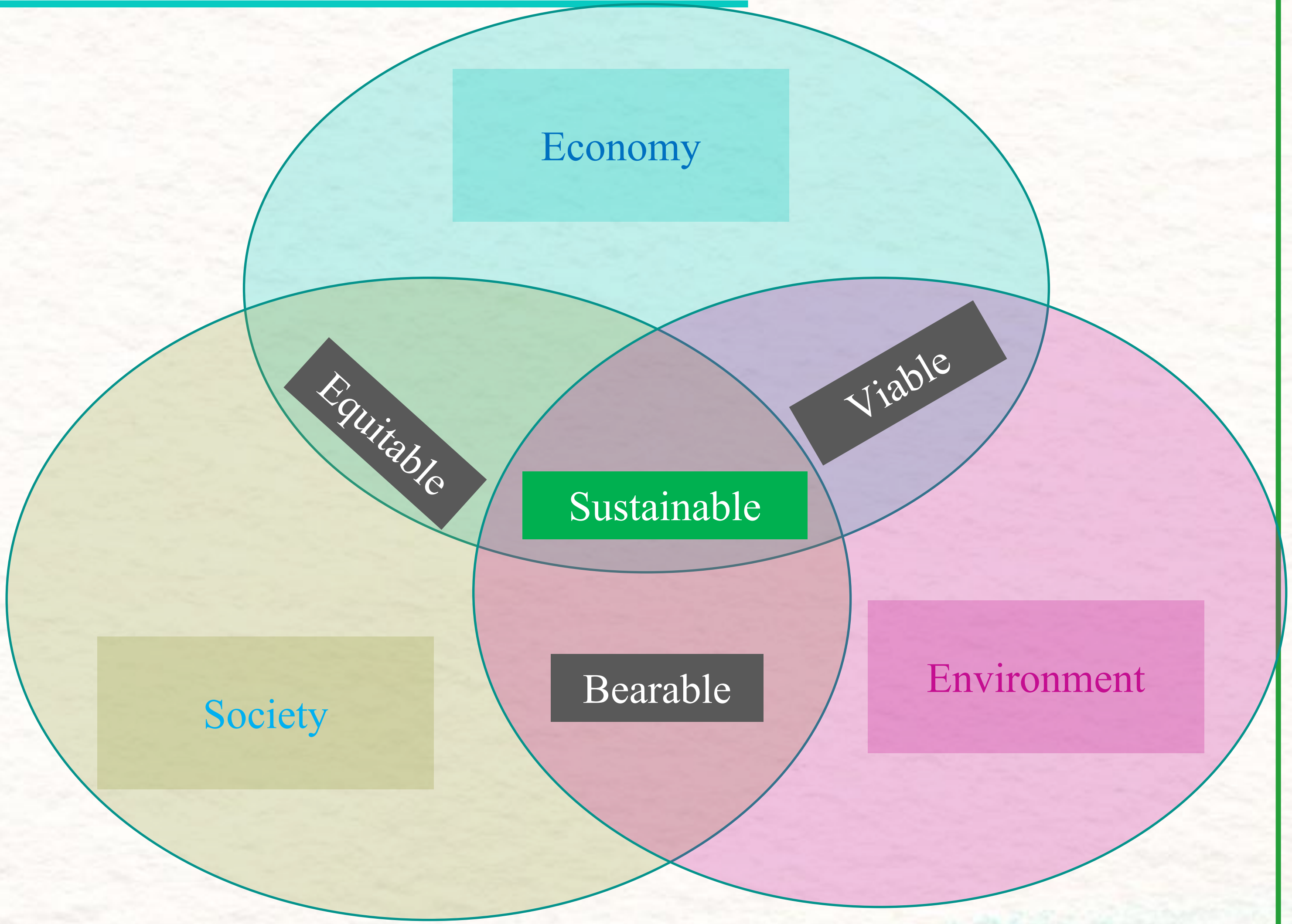
5. Environmental Pollution

- Air, water and soil pollution
  - Pollution of river such as Ganges, pH level goes haywire,
  - Water-borne diseases and lack of sanitation, majority of diseases in the developing world are due to lack of clean potable water
- Marine, Noise and Thermal pollution
- Nuclear hazards, solid waste management
- Causes, effects and control measures of urban and industrial wastes
- Role of an individual in prevention of pollution

6. Societal Issues and Environment

- From unsustainable to sustainable development
  - Earth Overshoot Day: https://en.wikipedia.org/wiki/Earth_Overshoot_Day
  - Ecological Footprint: https://en.wikipedia.org/wiki/Ecological_footprint
  - Ecological Footprint Calculator: https://www.wwf.org.au/get-involved/change-the-way-you-live/ecological-footprint-calculator
  - Carrying capacity of the Earth: https://www.researchgate.net/figure/Ecological-Footprint-versus-Earths-carrying-capacity-from-Meadows-et-al-2004_fig2_242385083
  - https://en.wikipedia.org/wiki/Carrying_capacity
  - Millennium Development Goals (MDGs): https://www.un.org/millenniumgoals/, and Sustainable Development Goals (SDGs): https://sdgs.un.org/goals
- Sustainable use of the water resource
  - Water conservation, rain water harvesting, watershed management
- Environmental ethics: Issues and possible solutions
- Wasteland reclamation
- Consumerism and waste products
- Environment Protection Act
  - Air (Prevention and Control of Pollution) Act
  - Water (Prevention and Control of Pollution) Act
  - Wildlife Protection Act
  - Forest Conservation Act
- Issues involved in enforcement of environmental legislation
- Public awareness.

- The economical growth may imply some people are getting richer
- However, as an effect of the economical growth, if the environment is affected, some other people may become sick or not well off



Demographics and Environment

- Human Population and the Environment
- Population growth, variation among nations
- Environment and human health

- https://en.wikipedia.org/wiki/Human_overpopulation

Climate Change

- Tragedy of Commons
  - an economic theory by Garrett Hardin: individuals acting independently and rationally according to each's self-interest behave contrary to the best interests of the whole group by either depleting some common resource or not contributing to the development of a common resource
  - The tale of Akbar and Birbal
  - Prisoner's Dilemma
- Greenhouse gases and global warming
  - Human activity induced greenhouse gases caused warming came to the attention first time in 1983 when USA's EPA and the National Academy of Sciences reported that the build up of CO2 and other greenhouse gases will likely lead to global warming
  - 1987: Montreal Protocol
  - 1992: Earth Summit in Rio De Janeiro, the nonbinding CO2 reduction goals are set
  - 1995: IPCC reports human influence on the climate change
  - 1997: The Kyoto Protocol mandates that the industrial nations reduce CO2 emissions by 6-8% relative to 1990 level by 2012
- Acid rain
- Ozone layer depletion

Environment and Economics

- Circular Economy versus Linear Economy

Some Questions to Ponder

- The AI can “learn” the music but its processors go into overload and get heated up. In contrast, why we enjoy the music?
- A related question: in today’s deep learning based systems, the machines have to be fed millions of training examples. In contrast, how is a baby able to pick up intricate rules of grammar and learn the complexities of language at a young age without nowhere near as much training?
- In contrast, why is it difficult for us to concentrate over a long time? Why is meditation difficult?
- Why there is something rather than nothing?
- Problem of evil

A Specific Objective

- Understand the impact of your decisions on the Environment, on the Nature
  - Develop an “eye” that discriminates between the sustainable versus non-sustainable actions
    - Sustainable use of a resource: one which ensures that the resource is not depleted or permanently damaged
    - Sustainable development/engineering: one that meets the needs of the present without compromising the ability of the future generations to meet their needs
    - A paradox in taking a non-sustainable action

Sustainable Engineering

- Main principle of sustainable engineering: the path that takes one from engaging in wrong actions to doing the right things comprises three steps:
  1. To be aware and accept that one is doing wrong &
  2. Feel the desire to stop doing the wrong and be willing to come out of the comfort zone and possibly sacrifice some valuable thing and suffer as a result &
  3. Solve the challenge in implementing the right/correct course of action
  - The three steps in short: Awareness and Acceptance Intention Problem Solution
- Implementation approaches: top-down versus bottoms-up
- Life-Cycle Thinking and Planning
- Systems Engineering