Water and Climate

TOPIC 8

How Scientists Study Climate

Where would be the worst place to live if you didn't like the hottest temperatures?

You might guess the equator, because the equator gets the most incoming solar radiation at the top of the atmosphere. Therefore, you might think that it has the hottest air temperatures all the time. But the equator has a lot of thunderstorm (cumulonimbus) cloud cover that reflects the radiation back into space. Also much of the insolation that does arrive at the surface at the equator does not heat the surface, because it is converted to latent heat in the evaporation of water and in the conversion of solar energy into food in the process of photosynthesis thanks to the vast plant life of the tropical rain forests.

However, at 25° to 30° of latitude, the falling air molecules compress the atmosphere so there isn't as much cloud cover. Therefore, at those latitudes you would experience the hottest surface air temperatures most of the time, especially in the summer season.

TOPIC 8

Water and Climate

Vocabulary

capillarity	porosity	unsorted
climate	prevailing winds	urbanization
ground water	runoff	water cycle
hydrologic cycle	seep	water retention
infiltrate	sorted	water table
permeability	stream discharge	

Topic Overview

While weather is the study of the short-term events of our atmosphere, climate is the study of the conditions of the atmosphere over long periods of time—tens, hundreds, thousands of years.

Climate greatly affects the kind of natural vegetation, the type of landscape features, and the crops and animals that are native to a region. Water is one of Earth's most important natural resources—one that people need to sustain their lives, help grow crops, and provide transportation. Water also has an effect on weather and climate and erodes Earth's surface. Since liquid water covers about 70 percent of Earth's surface, it creates environments for a large percentage of the life forms on our planet in streams, ponds, lakes, seas, and oceans.

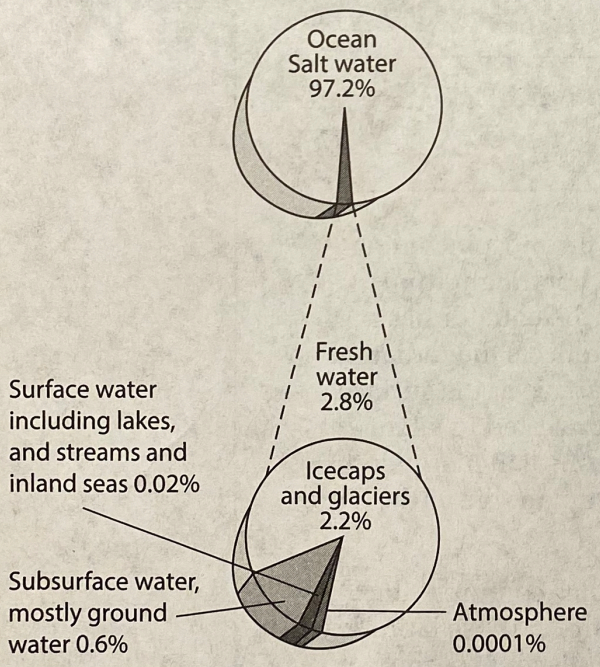


Figure 8-1. Graph of distribution of Earth's water by volume: Most of Earth's water is located in the ocean and is too salty for most human uses. Most fresh water is in the ice of glaciers or frozen on top of the oceans. Ground water is the biggest readily available supply of the natural resource fresh water.

The Water Cycle

Earth has been recycling its water supply for approximately 4 billion years—ever since the outgassing of water vapor (from Earth's solid surface) and its cooling to form liquid water. Many scientists believe that most of Earth's water supply was created when Earth formed and that large amounts have not been gained or lost since. Figure 8-1 illustrates the locations of Earth's water. This figure shows that the oceans contain most of the water, while the majority of the water people can drink—fresh water—is in glacier ice and floating on ocean tops in cold regions.

One model used to illustrate the movement and the phase changes of water at and near Earth's surface is the **water cycle**—also called the **hydrologic cycle.** (See Figure 8-2.) The water cycle is "fueled" by solar energy—insolation—which changes liquid or solid water to water vapor, and by gravity pulling water down in the

atmosphere, hydrosphere, and upper parts of the lithosphere. The ultimate source of most water on land is the evaporation of the oceans' water. The moisture gets to the land from the oceans by way of the atmosphere. When precipitation falls on the land, four things can happen to it.

- Precipitation can be stored or retained on the land surface as ice or snow—**water retention.** Water can also be retained on the leaves of trees and other plants.
- Precipitation can **infiltrate,** or **seep** (sink) into the upper parts of Earth's lithosphere under the influence of gravity. All the water beneath Earth's surface is called subsurface water.
- Precipitation can flow over Earth's surface as **runoff.** About one third of the precipitation falling on land is returned to the water cycle through runoff.
- The combination of evaporation and transpiration is evapotranspiration. It usually includes the sublimation of ice and snow directly into water vapor. Approximately two thirds of the precipitation that falls on land is evaporated or transpired back into the atmosphere.

MemoryJogger

Recall that evaporation is the change in phase from liquid to a gas, such as liquid water into water vapor. Remember too that transpiration is the process by which a plant releases water vapor into the atmosphere as part of its life function.

Factors Affecting Infiltration

Most infiltration occurs in the loose material (including soil) that directly covers much of Earth's solid surface or is beneath a thin vegetation zone. Some infiltration can also occur into rock exposed at or near Earth's solid surface. The amount of water that can infiltrate when precipitation occurs depends on several variables.

Slope of the Land The steeper the slope (gradient) of Earth's solid surface, the less the infiltration or seepage.

Degree of Saturation The more saturated the materials at Earth's surface, the less the infiltration. Figure 8-2 shows that Earth's surface is divided into the zone of saturation, where the pores between particles are filled with water and the zone of aeration, where the pores are filled with air and water. Surface water infiltrates down, under the influence of gravity, until it meets the **water table** interface between the zone of saturation and zone of aeration. The subsurface water below the water table is called **ground water**. The depth of the water table varies with amounts of infiltration; the greater the infiltration the higher the water table and the closer it is to Earth's surface. It is ground water—through wells and springs—that supplies a large portion of human water requirements. Withdrawing water from wells faster than it can be replenished lowers the water table.

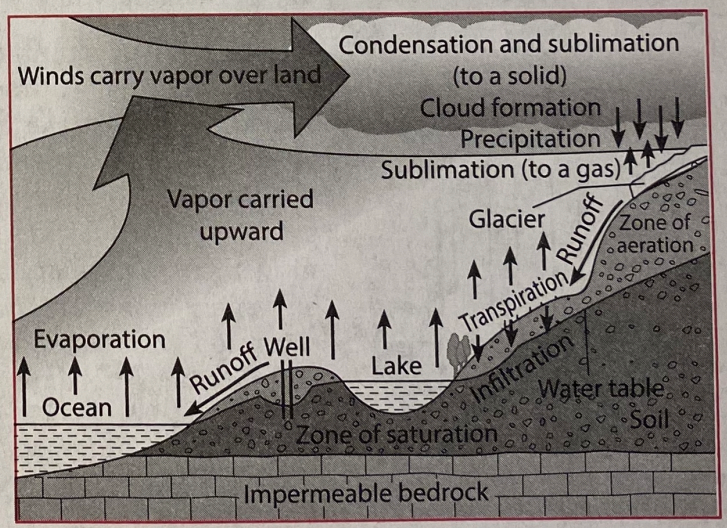


Figure 8-2. The water cycle—a model of the movement and phase changes of water at and near Earth's surface: The water table is an interface of changing position between the zone of saturation, where the pores of Earth's loose materials are filled with water (ground water), and the zone of aeration, where the pores are only partly filled with water (capillary water). Withdrawal of water from wells causes the water table to be lower.

Porosity The percentage of open space (pores and cracks) in a material compared to its total volume is its **porosity.** Generally, the greater the porosity of the loose materials at Earth's surface and the rocks, the greater the amount of infiltration that

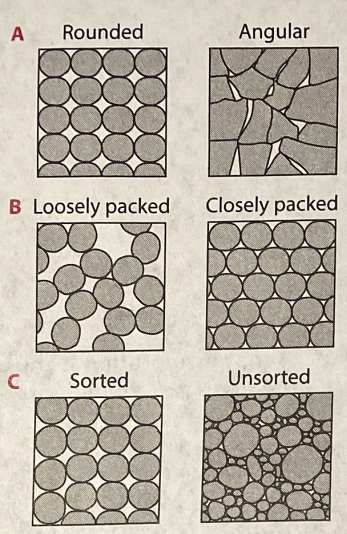


Figure 8-3. Effect of particle or sediment shape, packing, and sorting on the porosity of loose materials on Earth's surface: White regions are areas of porosity. (A) Well-rounded particles have more porosity than particles with angular shapes. (B) Loosely packed particles have more porosity than closely packed particles. (C) Sorted particles have more porosity than unsorted particles.

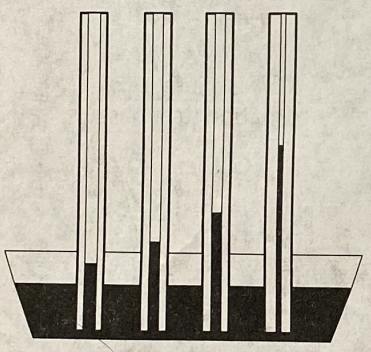


Figure 8-4. Capillary action, or migration, as a result of pore size: Capillarity causes water to move up against gravity in these glass tubes in the same way it moves up in Earth's loose materials and rocks by capillary action. The smaller the grain or sediment sizes are, the smaller the pores. The smaller the pores are, the higher the capillary action.

can occur. The shape, packing, and sorting of the particles composing a material determine its porosity. (See Figure 8-3.)

Shape Well-rounded particles have greater porosity than angular or plate-shaped particles because round shapes do not fit together as tightly as the other shapes do.

Packing The more closely packed the particles, the lower the porosity. The constant passage of people, animals, or vehicles in the same place or path will pack the soil, lowering the rate of infiltration.

Sorting If all the particles in a material are about the same size, they are said to be **sorted;** if the particles are of mixed sizes, they are said to be **unsorted.** The more unsorted the particles, the lower the porosity because the small particles can fit into the spaces between the larger particles. It should be noted that particle size by itself does not affect porosity. For example, a material with large particles may have about the same porosity as one with smaller particles if the shape, packing, and sorting of both particle sizes are about equal. If there were two rooms of equal size, one filled with marbles and the other filled with basketballs, the total volume of pore space would be about the same for both rooms.

Permeability The ability of a material to allow fluids such as water to pass through it is **permeability.** The permeability rate is the speed at which fluids will flow through a material. A material can be porous and yet impermeable—not permeable. It is often how well connected the pores or openings in rock and loose materials are that will determine the degree of permeability, not just the volume of openings. Impermeability may be due to tight packing or cementing of particles, which seals off the pores from one another so that water cannot enter them. In the winter the cementing is often due to ice. Ground water can deposit some of its dissolved minerals, adding cement to loose materials and rocks, and thus reducing porosity and permeability. In loose particles, the larger the particle size, the faster the permeability rate and infiltration because the size of the pores increases.

Capillarity During infiltration, some water is stopped from moving downward by the attractive force between water molecules and the surrounding Earth materials. This attractive force is **capillarity.** The water that is stored in small openings in the zone of aeration is capillary water. Capillarity also causes water to move up from the water table, against gravity, toward Earth's surface in the zone of aeration. This upward movement is capillary migration (capillary action). Capillary migration is extremely important in supplying water to plants when the soil is not saturated with water, which is the usual situation. When the particle size of loose particles become smaller, the capillarity and capillary migration become greater. (See Figure 8-4.) When the size of the particles increases the size of pores increases, and the effects of capillarity are reduced.

Vegetation The amount and type of vegetation in an area influences the amount of water that infiltrates the ground. Grasses, trees, and other plant types intercept falling precipitation, reducing its velocity and temporarily storing some of the water above Earth's surface. The reduced speed of the precipitation gives the ground more time to absorb the water. Plant litter—dead and partly decayed vegetation—serves the same function. Some of the water stored on vegetation and plant litter falls to the ground after

precipitation has stopped, and this can increase infiltration and reduce runoff. Ground without vegetation usually has high runoff and low infiltration rates.

Land Use How land is used by people can greatly influence the amount of water seeping into the ground. Roads, parking lots, and buildings cover otherwise permeable ground and create impermeable surfaces. These impermeable surfaces often channel runoff directly to streams or drainage pipes, reducing the chances of water seeping into the ground. Farming, cutting down trees, and the grazing of domesticated animals often either reduce the amount of plant life in an area or compact the soil, making it less permeable.

Digging Deeper

Ground water is retained, or kept, in soil or sediment because of the capillary attraction of water to soil or sediment particles. The smaller the particles of soil or sediment the greater the amount of water retained after ground water has drained or has been withdrawn such as by infiltration or seepage.

Factors Affecting Runoff and Stream Discharge

Surface runoff can occur when

- the rate of precipitation exceeds the permeability rate (or infiltration rate) of Earth's solid surface
- the pore space of loose material or rock is saturated with water
- the slope of the surface is too great to allow infiltration to occur
- the water on the surface has not evaporated or sublimated to a gas

Most runoff gets to streams, which often carry the water back to the oceans—completing a major part of the water cycle. The greater the runoff, the greater the amount of stream discharge in local streams. There is a time lag between times of highest precipitation and greatest stream runoff due to the time it takes the water to get to the streams. **Stream discharge** is the volume of water flowing past a certain spot in a stream in a specific amount of time, and is expressed in units such as cubic meters/second or liters/minute.

Digging Deeper

Clay's small size (less than 0.0004 cm) affects its permeability. The combined adhesive properties of water and clay keep water from easily passing through clay sediments. Thus, even though it is porous, clay is impermeable to water movement because the pores are so small.

Flooding Flooding occurs when a stream overflows its normal channel. Flooding also happens when precipitation exceeds the ability of the ground to infiltrate the water, and evapotranspiration is not rapid enough, and when water is not able to move to the streams quickly enough. Flooding can also be the result of a hurricane's storm surge, coastal storms, the rising of sea level, sinking land, or tides moving water onto the land.

The first rule of safety in dealing with a flood, or the possibility of a flood, is to move to higher ground. Accurate predictions and measurements of snow or rain might give people sufficient time to evacuate an area before the flooding. Many communities have planned escape routes determined through the study of topographic maps and other elevation models.

Review Questions

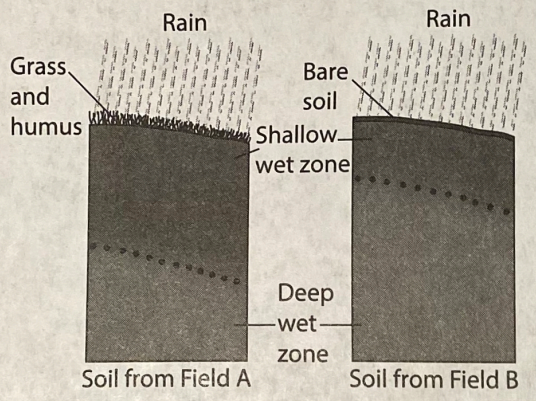
1. On Earth as a whole, what happens to most of the precipitation?

(1) It recharges the soil moisture deficit.
(2) It becomes runoff and moves to the oceans.
(3) It is stored in the soil as capillary water.
(4) It is returned to the atmosphere through evaporation and transpiration.

2. The primary source of moisture for the local water supplies is

(1) potential evaporation and transpiration
(2) actual evaporation and transpiration
(3) ground water storage
(4) precipitation

Base your answers to questions 3 through 5 on the following diagrams. The diagrams show two soil cross sections from adjacent fields in New York State. Both soils are the same except that human activities have removed the vegetation from the surface of field B. Each field has been receiving rain for several hours.



3. The soils in field B would have a higher rate of permeability if the soils
   (1) had lower porosity
   (2) had steeper surface slope
   (3) were composed of larger rock particles
   (4) were compacted by machinery traveling over the field

4. How would water infiltration be affected by replanting vegetation in field B?

5. If the skies remain clear for the week following this rain, the water in the shallow wet zone in field B will
   (1) mostly become surface runoff
   (2) partially evaporate into the air
   (3) all remain as stored water along the surface
   (4) mostly transpire into the ground

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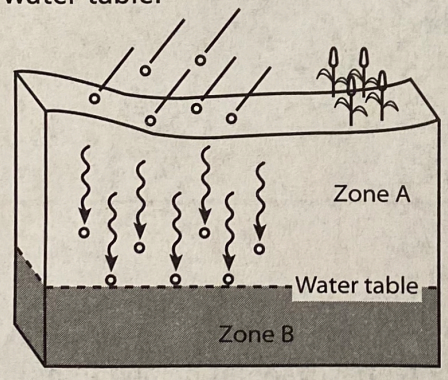
6. The following diagram is a cross-sectional view of rain falling on a farm field and then moving to the water table.

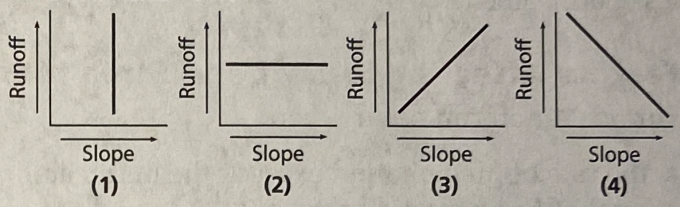


Which word best describes the movement of the rainwater through zone A?
(1) runoff (3) infiltration
(2) saturation (4) precipitation

7. Which event is a direct result of evaporation and transpiration?
   (1) The atmosphere warms.
   (2) Cloud cover decreases.
   (3) Moisture enters the atmosphere.
   (4) Moisture leaves the atmosphere.

8. What is the largest source of the moisture for the atmosphere?

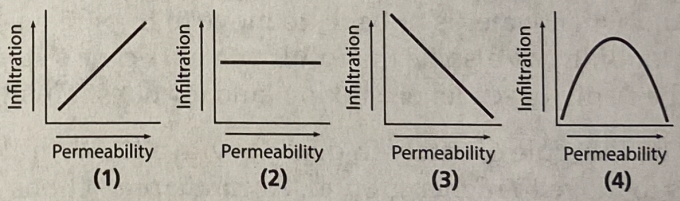
9. Which graph best illustrates the relationship between the slope of the land and the amount of surface runoff?



10. A rock with a high porosity will probably
    (1) be resistant to weathering
    (2) be composed of large grains
    (3) have a large percentage of space between particles
    (4) have a small percentage of rounded particles

11. Soil with the greatest porosity has particles that are
    (1) poorly sorted and densely packed
    (2) poorly sorted and loosely packed
    (3) well-sorted and densely packed
    (4) well-sorted and loosely packed

12. Which graph best represents the relationship between soil permeability rate and infiltration when all other conditions are the same?

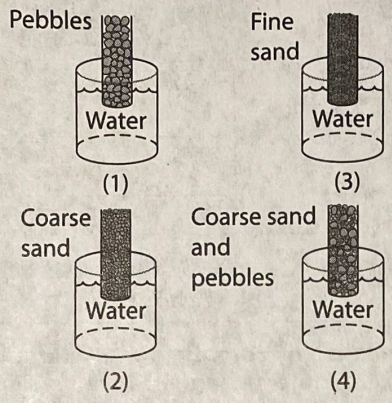


13. Which Earth material covering the surface of a landfill would permit the least rainwater to infiltrate the surface?
    (1) silt (2) clay (3) sand (4) pebbles

14. As the temperature of soil decreases from 10°C to −5°C, what will most likely happen to the infiltration rate of water through it?

15. Water moves upward through the soil because of
    (1) capillary action (3) porosity
    (2) permeability (4) infiltration

16. In which tube will capillary action be the greatest?

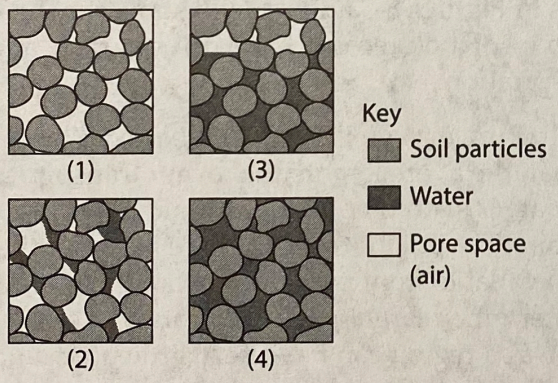


17. The rate of flow of water through rock is determined by the

(1) types of minerals that make up the rock
(2) total amount of space between mineral grains
(3) number of connected pore spaces and their sizes
(4) position of the rock with respect to the water table

18. As the amount of precipitation on the land increases, what happens to the distance from the surface of Earth to the water table?

19. Which diagram best illustrates the condition of the soil below the water table?



20. Surface runoff of precipitation occurs when

(1) porosity is exceeded by permeability
(2) the infiltration rate is greater than the precipitation rate
(3) the precipitation rate is greater than the infiltration rate
(4) the evaporation rate is increased

21. Surface runoff will be greatest when the

(1) rainfall is light and the ground is permeable
(2) infiltration rate is greater than the rainfall rate
(3) slope of the land is too great to permit infiltration
(4) ground is permeable and unsaturated

22. Why do most streams in New York State have a greater stream discharge runoff in spring than in summer?

(1) Potential evaporation and transpiration is greater in spring than in summer.
(2) More transpiration occurs in spring than in summer.
(3) Most areas of New York State get their maximum solar energy in spring.
(4) Melting snow increases runoff in spring.

23. Water will infiltrate surface material that is

(1) impermeable and unsaturated
(2) impermeable and saturated
(3) permeable and unsaturated
(4) permeable and saturated

24. In which area will surface runoff most likely be greater during a heavy rainfall?

(1) sandy desert
(2) wooded forest
(3) level grassy field
(4) paved city street

25. When rain falls on a soil surface, flooding at that location would most likely occur if the

(1) soil surface is permeable
(2) soil surface is covered with vegetation
(3) soil pore spaces are filled to capacity
(4) infiltration rate exceeds the precipitation rate

Climate

The overall view of a region's weather conditions over a long period of time—tens to thousands of years—is its **climate.** Climate is not just average weather; it includes extremes like the number of hurricanes and the number of days of damaging hail. The two major aspects of climate are temperature and moisture or water conditions.

Temperature and Moisture

In terms of climate, two characteristics of the temperatures of a region are most important: (1) the average temperature over the year, and (2) the range of average monthly temperatures—often called annual

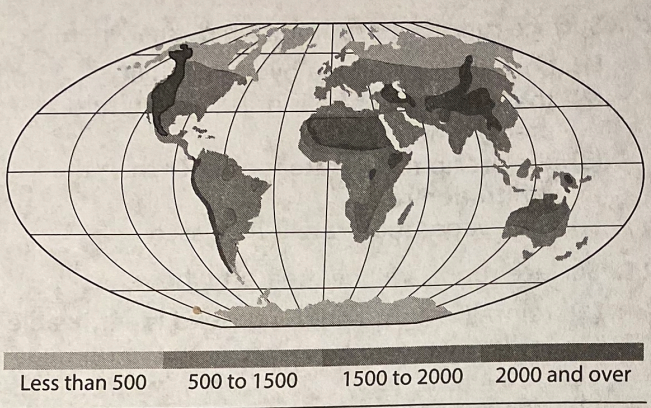


Figure 8-5. World map of insolation at Earth's surface in thousands of calories/cm²/year: Note how yearly insolation generally increases with decreasing latitude. Due to many factors, however, especially differences in cloud coverage, it is not a perfect correlation. (Darkest areas have very high elevation.)

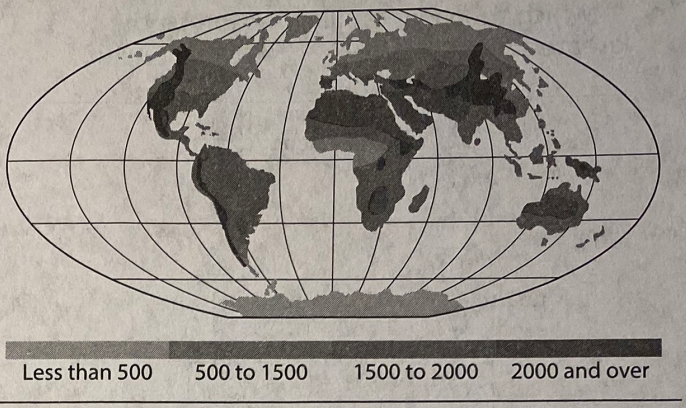


Figure 8-6. World map of potential for evaporation and transpiration in centimeters per year: Note the similarities to the yearly insolation map above. It is not a perfect correlation, because local heat values are affected by many other factors such as surface ocean currents and tropospheric convection currents.

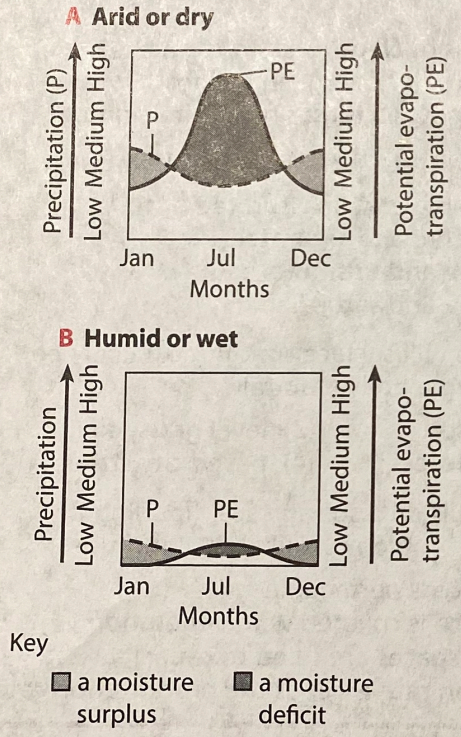


Figure 8-7. Examples of an arid and a humid climate: Graph A shows the relationship between precipitation (P) and potential evapotranspiration (PE) for a region of moderate amounts of rainfall but high potential evapotranspiration. Since the yearly totals of P are less than the yearly PE values for the year—there is a yearly moisture deficit—the region has an arid climate. Graph B represents a climate with low yearly amounts of P, but even smaller yearly amounts of PE. Since there is more P than PE for the year—there is a yearly moisture surplus—the climate is humid, or wet.

temperature range. This is the average difference between the average temperature of the hottest month and the coldest month, calculated using data from many years.

An area's climate is called arid, or dry, if the average total precipitation during the year is less than the average yearly potential evapotranspiration. Potential evapotranspiration is the amount of water vapor that would evapotranspirate from an area if the water were available. Potential evapotranspiration is largely determined by an area's amount of energy available for evapotranspiration thus temperature. An area's average temperature is often determined by the solar energy or insolation it receives. An analysis of Figures 8-5 and 8-6 will show the direct relationship between insolation received at Earth's surface and potential evapotranspiration.

An area's climate is humid, or wet, if the average precipitation for the year is greater than the average potential evapotranspiration. Thus, whether a climate is said to be arid or humid depends not on the amount of precipitation, but on the difference between the amount of moisture available from precipitation and the potential need for water as determined largely by temperature. As illustrated in Figure 8-7, a region can have very little precipitation and still have a humid climate. Regions where the potential evapotranspiration is much greater than what an area receives as precipitation are called deserts. If an area has somewhat equal amounts of precipitation and potential evapotranspiration, the term semi-arid or sub-humid can be used to describe the climate.

Factors Affecting Climate

The factors that determine climate include

- latitude
- planetary wind and pressure belts
- oceans and other large bodies of water
- ocean currents

- mountains
- elevation
- amount of cloud cover
- vegetation

Descriptions of these factors that determine the type of climate of an area follow. Often, many factors interact to determine an area's type of climate.

Latitude and Temperature Latitude is a major factor in determining climates because of its influence on both temperature and moisture conditions. Temperature characteristics vary with latitude because of the relationships between angle, intensity, and duration of insolation and latitude. At low latitudes, where the maximum angle of insolation is always high, average temperatures are high throughout the year. Because the duration of insolation is fairly constant at about 12 hours per day, there is little temperature variation during the year. At high latitudes, where the maximum angle of insolation is never large and in some months remains zero, average temperatures are low. Since the duration of insolation varies from zero to 24 hours a day, and is longest at the times of greatest angle of insolation, temperatures vary over a wide range from winter lows to summer highs. Figure 8-8 is an example of how Earth can be divided into temperature zones largely based on latitude.

Latitude and Moisture Moisture conditions vary with latitude because of the location of the planetary wind and pressure belts. Where there is low pressure at Earth's surface, such as near the equator and in mid-latitudes, the air rises. The cooling of the rising air results in many clouds, much precipitation, and humid climates. When air falls toward Earth's surface, it creates high pressure, warming of the air, and often arid or desert climates. These conditions result in the belts of arid climates around 30° latitude and around the geographic poles.

MemoryJogger

Recall that insolation (**IN**coming **SO**Lar radi**ATION**) is the part of the sun's radiation that is received by Earth.

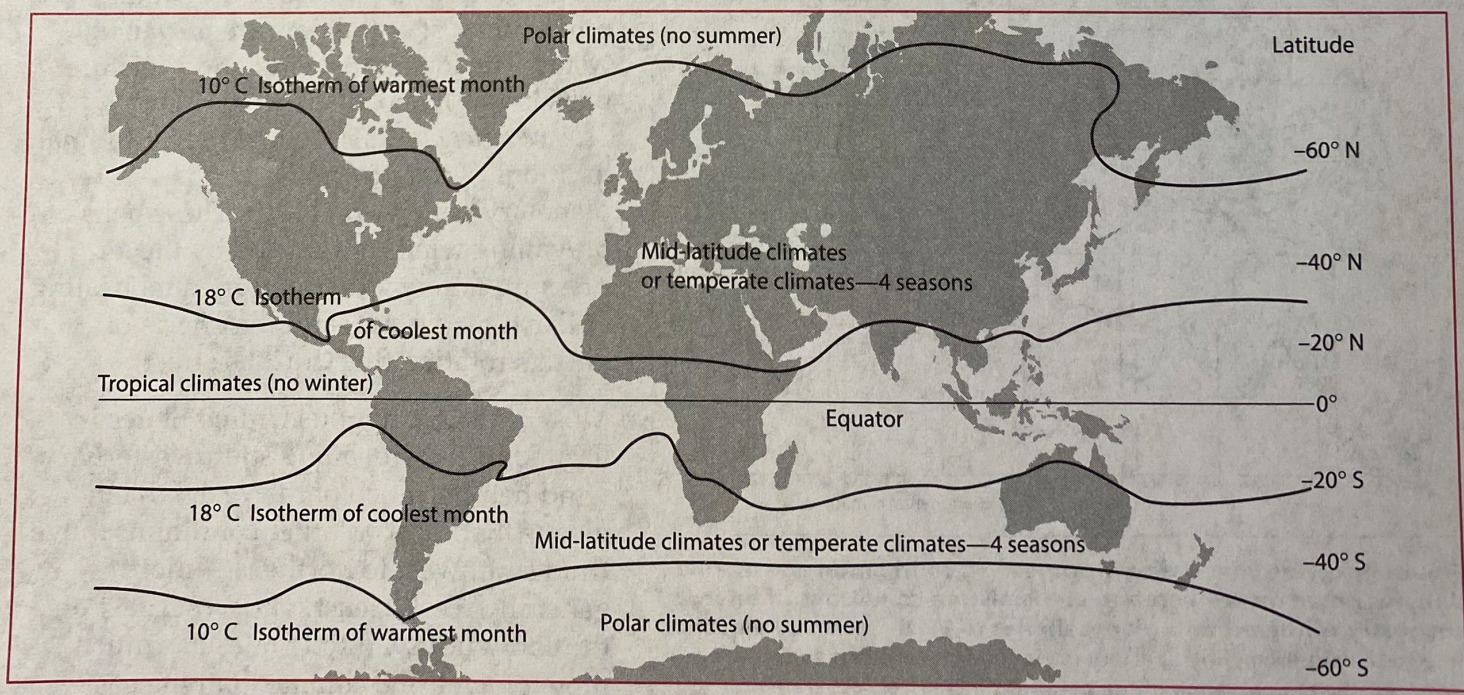


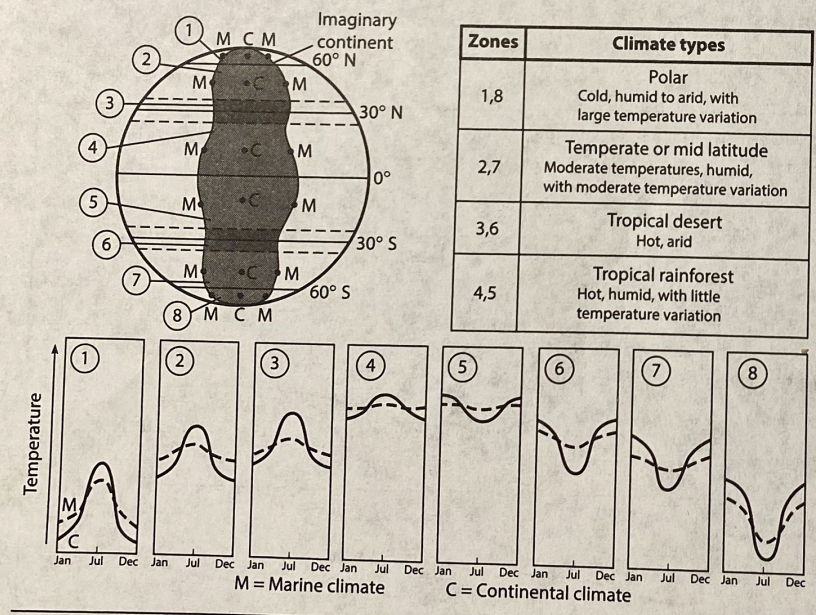
Figure 8-8. Earth's latitudinal climate zones based on temperature: The lines on the map are isotherms—isolines of equal temperature. This is a very basic climate classification based entirely on temperature. In the tropical climate zone, the average monthly temperatures at sea level never drop below 18°C. In the polar climate zones, the average monthly temperatures never rise above 10°C. Effects of altitude have been omitted.

The map Planetary Wind and Moisture Belts in the Troposphere in the *Earth Science Reference Tables* shows the locations of these dry belts and the wet belts.

Latitudinal Climatic Patterns The combination of the temperature and the moisture effects of latitude results in a basic distribution of climate types around the world—latitudinal climate patterns—shown in Figure 8-9. Note that with increasing distance from the equator (increasing latitude) the annual temperature range increases. This is largely because higher latitudes have a greater amount of change in duration of insolation during the year than areas of lower latitude nearer the equator.

Large Bodies of Water Large bodies of water—oceans, seas, and large lakes—serve to modify the latitudinal climate patterns. If a land mass is near a large body of water, its temperatures will be moderated by the slow heating up and cooling off of the water body. This is especially true if the prevailing winds blow toward the landmass much of the year.

An area with temperatures moderated by proximity to a body of water is said to have a marine climate. Marine climates have cooler summers and warmer winters than inland areas, and thus a small annual range of temperatures compared to inland areas at the same latitude. Inland areas away from the effects of large bodies of water have cooler winters and warmer summers and a wider annual range of temperatures. Such areas are said to have a continental climate. The larger a landmass is, and the farther it is from the effects of large bodies of water, the wider the annual temperature range. This is why central Eurasia has a more pronounced continental climate than North America. Figure 8-9 illustrates the differences in the temperatures of regions with continental versus marine climates.



Zones	Climate types
1,8	Polar Cold, humid to arid, with large temperature variation
2,7	Temperate or mid latitude Moderate temperatures, humid, with moderate temperature variation
3,6	Tropical desert Hot, arid
4,5	Tropical rainforest Hot, humid, with little temperature variation

Figure 8-9. Latitudinal climatic zones and continental and marine climates based on temperature and moisture conditions of an imaginary continent on a planet similar to Earth: Compare the zones here to the more simplified pattern in Figure 8-8. Note that as the latitude increases, the annual range of temperatures increases. Also note that marine climates—with ocean influences—have a much narrower annual temperature range than continental regions at similar latitudes. Notice the opposite temperature patterns in northern and southern hemispheres, which are the result of opposite seasons in the two hemispheres.

Prevailing Winds Movements of air over Earth's surface that blow in the same direction most of the time are **prevailing winds.** The Planetary Wind and Moisture Belts in the Troposphere in the *Earth Science Reference Tables* show the latitudinal locations of the prevailing winds—planetary winds—on Earth. These belts of prevailing winds are caused by the air pressure differences (from unequal heating of Earth by the sun) and the effects of Earth's rotation (the Coriolis effect).

Most of the contiguous United States is located in the prevailing southwesterly wind belt for much of the year, which means that most weather conditions move from southwest to northeast—more generally west to east. The west coast of the contiguous United States has much more of a marine climate than the east coast because the west coast's prevailing winds are from the ocean. Since the east coast has its prevailing winds blow from

the center of the North American continent, it has continental climates almost to the shore of the Atlantic Ocean. Long Island, New York, has some marine moderation of climate compared to the rest of the state, as do some western parts of New York State downwind of Lake Erie and Lake Ontario.

The prevailing southwesterly winds also have an important large climatic effect by moving the air masses and frontal low pressure storms across the contiguous United States generally from west to east. The paths of these air masses and storm movements are often called "tracks," as shown in Figure 8-10. Much of the precipitation in the mid-latitudes is the result of these tracks and associated weather. Western New York State is noted for the lake effect snows caused by winds and storms blowing over the Great Lakes, picking up moisture, and then dropping the moisture as deep snows.

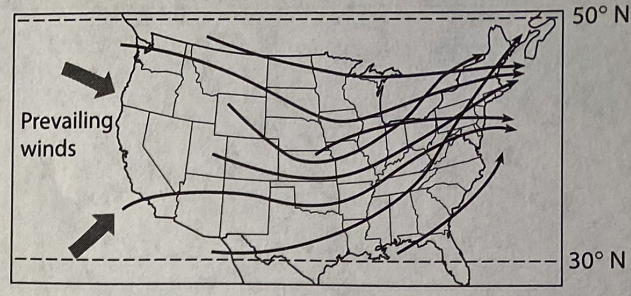


Figure 8-10. Tracks or paths of air masses and low-pressure storms across the contiguous United States: The weather systems are pushed across the United States by the prevailing southwest winds. These air masses and storms tend to follow similar tracks. Certain tracks are associated with specific parts of the year or seasonal shifting winds and pressure belts.

Monsoons are the weather changes caused by the seasonal shifts in the direction of prevailing winds. Though monsoons are usually associated with the wet summers and dry winters of southeast Asia—especially India—other areas experience a monsoon effect. Portions of southern Europe, northern Australia, and even the southeastern United States experience shifting prevailing winds and changing seasonal precipitation associated with the north and south seasonal movements of the vertical rays of the sun.

Besides the prevailing southwesterly wind belt, other wind belts also cause similar climatic effects in their associated latitudinal zones. The effects of the prevailing winds and their shiftings compared to the simple latitudinal climatic pattern of Figure 8-9 result in the more realistic climate zones illustrated in Figure 8-11.

Surface Ocean Currents Coastal climates are often modified by surface ocean currents. Currents flowing away from the equator carry warm water to higher latitudes, while currents flowing toward the equator carry cool water to lower latitudes. A cool ocean current will cause a coastal area to have cooler temperatures and less precipitation. One reason there is less precipitation is that cool water results in cool air, which cannot hold much water vapor. A warm ocean current will cause a coastal area's climate to be warmer and have more precipitation. The greater amounts of precipitation are due to the fact that warmer air can hold more water vapor and that warmer air—because it is less dense—will tend to rise and then cool, so that condensation can produce the clouds that bring precipitation. One of the best examples of an ocean current's climatic effects is illustrated in the warm, humid climates of Iceland, England, and Ireland, which result from the effects of the Gulf Stream and North Atlantic warm surface ocean currents. The locations of

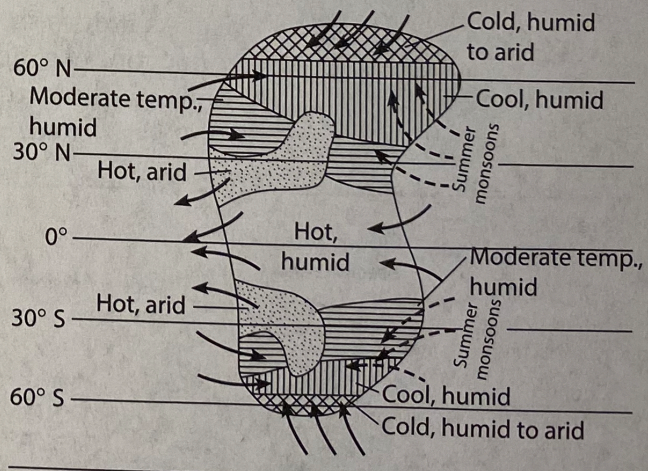


Figure 8-11. Climate zone of an imaginary continent modified from Figure 8-9 by addition of prevailing winds and their shifting latitudes during the year: Seasonal winds and their associated weather are often called monsoons. The summer winds shown on the diagram would bring humid weather with much precipitation into areas that would be much drier without the monsoons.

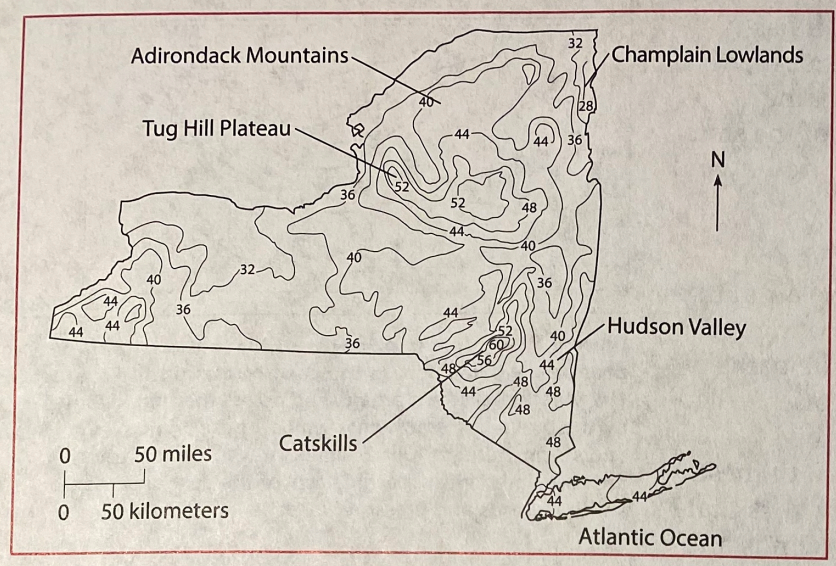


Figure 8-12. Isolines of average annual precipitation in New York State: Even though southeastern New York is on the ocean, this region doesn't have the highest amount of precipitation, because the prevailing southwest winds blow towards the ocean, not away from it. The prevailing winds cause air masses to deposit the most precipitation in the three highest regions of the state—the Catskills, Tug Hill Plateau, and the Adirondack Mountains. Areas downwind from these high elevation regions—such as the Hudson Valley and Champlain Lowlands—receive lower amounts of precipitation.

the warm and cool ocean currents are shown on the Surface Ocean Currents map in the *Earth Science Reference Tables*. (R)

Elevation The elevation of an area above sea level modifies the latitudinal climate pattern because as air rises, it expands and cools. Thus, the higher the altitude at any given latitude, the cooler the climate. Another reason higher elevations are cooler is the lower amounts of the greenhouse gases (carbon dioxide, water, and methane) at higher altitudes, and this means less absorption of long-wave radiation from the sun and Earth's surface.

Elevation also affects precipitation. As the elevation increases, the temperature and water vapor capacity decrease; the air thus approaches the dew point, condensation forms clouds, and precipitation often occurs. Therefore, areas at higher altitudes generally have more precipitation than lower areas. In New York State, the Catskills and the Adirondack Mountains are generally cooler and have more precipitation than most surrounding areas. (See Figure 8-12 and Landscape Regions of New York State and Their Characteristics in the Appendix.)

Mountains Mountains that intersect prevailing winds, such as those associated with the planetary wind belts, can modify the latitudinal climate pattern. Figure 8-13 shows a cross section of a mountain against which the prevailing winds blow from the left. This side is the windward side. As the wind strikes the windward side of the mountain, the air is forced to rise. As it does so, it expands and cools. When rising air cools to the dew point, condensation releases stored heat energy, which lowers the rate of cooling with increasing elevation. At elevations above the place the dew point is reached, condensation results in clouds and then precipitation on the windward side. On the opposite side of the mountain—the leeward side—the air begins to descend. As the air descends, it is compressed and warmed. The warming of the air raises the temperature above the dew point, and condensation and precipitation stop. As a result, the leeward side is warmer than the windward side at any given altitude. The leeward side also has much less precipitation because the air has lost much of its moisture, and its water vapor capacity rises as its temperature increases. A good example of this mountain effect is the fact that the Champlain Lowlands get the least amount of precipitation in New York State. The Champlain Lowlands are on the leeward side of the Adirondack Mountains.

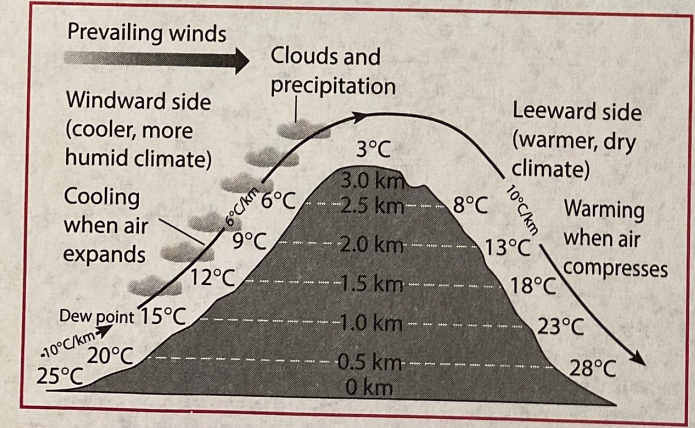


Figure 8-13. Climate effect when mountains intersect prevailing moist winds: The windward side of mountains has much precipitation while the leeward side is dry.

Another way that mountains modify climate is by acting as barriers to moving air masses, preventing cold air or warm air from crossing the mountain to the other side. As a result, opposite sides of a mountain can have different temperature patterns. In southeastern New York, the Hudson Highlands often keep warmer air south and colder air north. Therefore, sometimes during winter when it rains in New York City, there is either snow or no precipitation in the Hudson Valley north of the Hudson Highlands.

Vegetation An area's natural vegetation amounts and types are largely determined by the climate. Thus, an arid area has desert vegetation and a hot, humid climate has tropical rainforest vegetation. On the other hand, the vegetation of an area can help determine the climate of an area. When rainforests are cut down and converted into farms or grazing land, the climate often becomes hotter and less humid. Part of the reason for this is that there is more runoff and less transpiration to add humidity. Also, without all the trees to absorb solar energy and convert it into potential food energy, the solar energy heats the land instead, which then heats the atmosphere it touches. Have you ever noticed how much cooler it is under just one shade tree than it is when you are out in the open? Cutting down or deforestation of whole sections of forest would just multiply the effect of moving out from under a tree. Building cities—**urbanization**—also causes a decrease in forests and grasslands and causes changes in climate and weather.

Cloud Cover If an area has a high percentage of cloudy days, this will have a major climatic effect. Without clouds, the atmosphere is much more transparent to insolation, and more of the sun's energy can reach and heat Earth's surface. The high angle of incidence and thus high intensity of the sun's rays near the equator would make you think that areas at or near the equator would be the hottest on Earth, but this is not true. Thunderstorm clouds often cover the area around the equator, and these clouds absorb a large percentage of the insolation or reflect it back into space. On the other hand, the desert regions that exist around or at 30 degrees of latitude seldom have clouds. These dry latitudes without much cloud cover are often hotter than regions closer to the equator. See the dry and wet latitude belts on the Planetary Wind and Moisture Belts in the Troposphere in the *Earth Science Reference Tables*.

Climatic Change

A study of Figure 8-14 will indicate that Earth has gone through many times of overall increasing or decreasing temperatures. During the times of cooling, glaciers have advanced from the polar regions into the mid-latitudes and maybe even into the regions that are now considered warm or tropical. These times of advancing glaciers into the mid-latitudes were the ice ages. Global warming, El Niño, the greenhouse effect, the ozone "hole" problem, the effects of volcanic ash and other aspects of climatic change cause changes in Earth's climates over time.

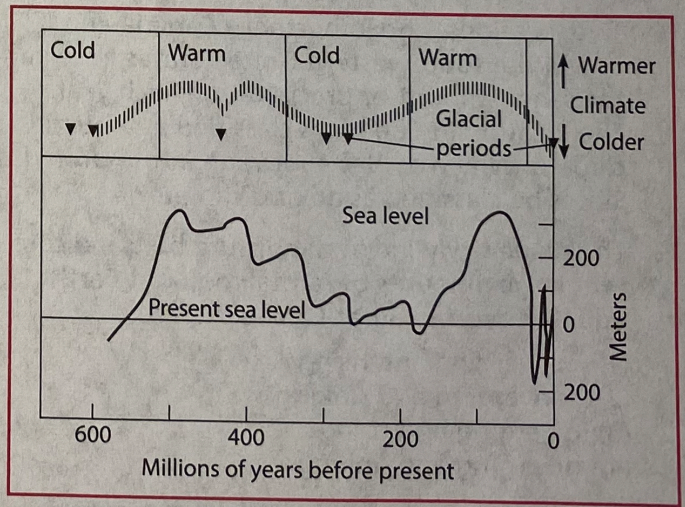


Figure 8-14. Graph of climatic changes on Earth: The graph shows a comparison of the generalized sea levels and climatic conditions over the past 600 million years. Periods of warmer climate generally correspond with times of higher sea levels and periods of colder climates, with ice ages, generally correspond to the times of lower sea levels.

Review Questions

26. Which would cause the potential evaporation and transpiration to increase in a given month?

(1) below-normal precipitation
(2) a major flood
(3) a month-long cold spell
(4) higher amount of solar energy

27. Although New York City is at approximately the same latitude as Omaha, Nebraska, New York City's winter months are warmer and summer months are cooler. Which statement best explains why this is so?

(1) The sun's rays shine more directly on New York City in the winter.
(2) Nebraska is nearer to the Rocky Mountains.
(3) The water around New York City has a moderating effect on the temperature
(4) The prevailing westerlies have a greater effect on Omaha than on New York City.

28. Which would cause the potential evaporation and transpiration to decrease in a given month?

(1) below-normal precipitation
(2) drilling of a large well
(3) a month-long cold spell
(4) a high rainfall

29. Which generally has the greatest effect in determining the climate of an area?

(1) degrees of longitude
(2) extent of vegetation
(3) distance from equator
(4) month of the year

30. Two locations, one in northern Canada and one in the southwestern United States, receive the same amount of precipitation each year. The location in Canada is classified as a humid climate. Why would the location in the United States be classified as an arid climate?

31. The planetary wind and moisture belts indicate that large amounts of rainfall occur at Earth's equator because air at Earth's surface is

(1) converging and rising
(2) converging and sinking
(3) diverging and rising
(4) diverging and sinking

32. Describe the temperature differences between a coastal city and an interior city, at the same latitude, during summer and winter.

33. Which climate conditions are typical of regions near the North Pole and the South Pole?

(1) low temperature and low precipitation
(2) low temperature and high precipitation
(3) high temperature and low precipitation
(4) high temperature and high precipitation

34. As the degrees of latitude from the equator increases, what generally happens to the yearly average temperature?

35. On one of the Hawaiian Islands, the annual rainfall is 200 inches per year on one side of the island and less than 20 inches per year on the opposite side of the same island. This difference is most likely caused by

(1) jet streams
(2) hurricanes or typhoons
(3) monsoons
(4) prevailing winds and mountains

36. Which two climate factors are most directly responsible for the amount of snowfall normally received in Buffalo, New York?

(1) ocean currents and storm tracks
(2) mountain barriers and average temperatures
(3) elevation and potential evaporation and transpiration
(4) prevailing wind direction and proximity to a large body of water

37. Which planetary wind pattern is present in many areas of little rainfall?

(1) Air sinks and winds converge.
(2) Air rises and winds converge.
(3) Air sinks and winds diverge.
(4) Air rises and winds diverge.

38. Which area of New York State would probably have the lowest annual temperature range?

(1) Long Island
(2) the Catskills
(3) the Adirondack peaks
(4) the Mohawk Valley

39. Bodies of water have a moderating effect on climate primarily because

(1) Water gains heat more rapidly than land does.
(2) Water surfaces are flatter than land surfaces.
(3) Water temperatures are always lower than land temperatures.
(4) Water temperatures change more slowly than land temperatures do.

40. Which is a characteristic of water that helps the oceans to moderate the climates of Earth?

(1) Water is a fluid with a high specific heat.
(2) Water can exist as a high-density solid.
(3) Water can dissolve and transport minerals.
(4) Water can flow into loose sediments to deposit mineral cements.

41. If Lake Michigan were to vanish, the winters in Chicago would probably

(1) remain the same in temperature and humidity
(2) remain the same in temperature but become drier
(3) become colder and drier
(4) become warmer and drier

42. Which locality has the greatest annual range of temperature?

(1) Seattle, Washington
(2) Bismarck, North Dakota
(3) New York City
(4) Miami, Florida

43. Compared to an inland location of the same elevation and latitude, a coastal location is likely to have

(1) warmer summers and cooler winters
(2) warmer summers and warmer winters
(3) cooler summers and cooler winters
(4) cooler summers and warmer winters

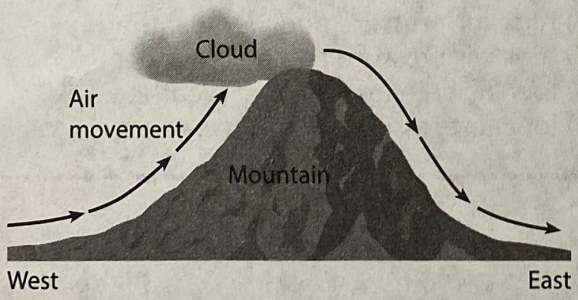
44. A low-pressure storm center located over New York State will most likely move toward the

(1) southeast
(2) southwest
(3) east
(4) northwest

45. As a parcel of air rises, its temperature will

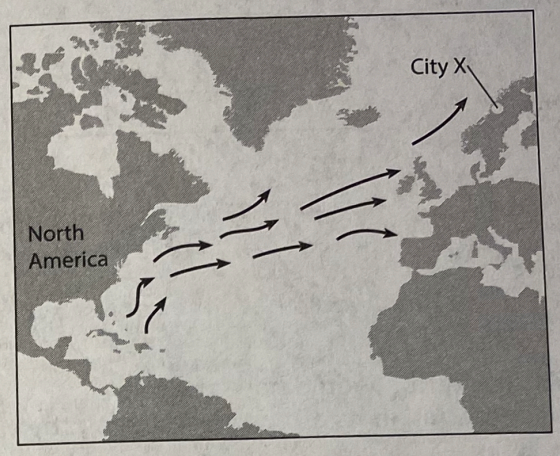
(1) decrease due to expansion
(2) decrease due to compression
(3) increase due to expansion
(4) increase due to compression

46. Which statement best explains why a cloud is forming in the following diagram?



(1) Water vapor is condensing.
(2) Moisture is evaporating.
(3) Cold air rises and compresses.
(4) Warm air sinks and expands.

47. Arrows on the map represent ocean currents.



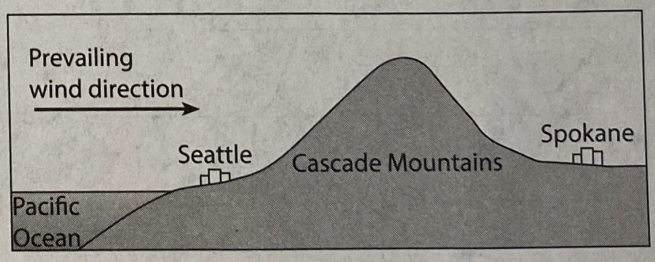
These ocean currents affect the climate pattern of city X by

(1) decreasing the average annual cloud cover
(2) decreasing the average annual evaporation and transpiration
(3) increasing the average annual temperature
(4) increasing the average annual air pressure

48. Two coastal cities have the same latitude and elevation, but are located near different oceans. Which statement best explains why the two cities have different climates?

(1) They have different longitudes.
(2) They are near different ocean currents.
(3) They have different angles of insolation.
(4) They have different numbers of daylight hours.

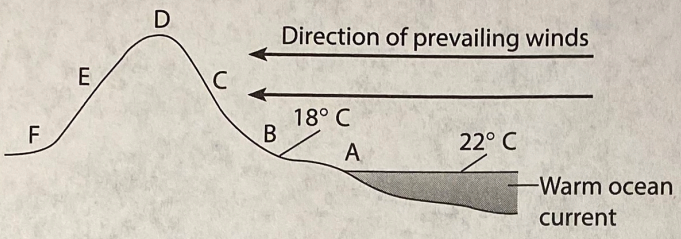
49. The following diagram shows the locations of the cities of Seattle and Spokane, Washington. Both cities are located at approximately 48°N latitude, and the Cascade Mountains separate them.



How does the climate of Seattle compare with the climate of Spokane?

(1) Seattle—hot, dry; Spokane—cool, humid
(2) Seattle—hot, humid; Spokane—cool, dry
(3) Seattle—cool, humid; Spokane—warm, dry
(4) Seattle—cool, dry; Spokane—warm, humid

Refer to the following diagram to answer questions 50 through 53.



50. Which location would have the coolest average temperature?

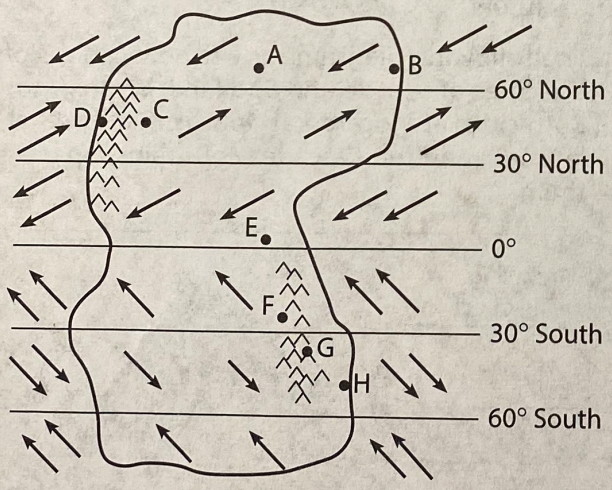
51. Which location would have the most condensation in its atmosphere during the year?

(1) B (3) E
(2) C (4) F

52. Which location would most likely be driest?

53. How is the potential evaporation and transpiration of area A-B affected by the ocean current?

Base your answers to questions 54 through 57 on your knowledge of earth science and on the following diagram. The diagram represents an imaginary continent on Earth surrounded by water. The arrows indicate the direction of the prevailing winds. Two large mountain regions are also indicated. Points A, B, E, and H are located at sea level; C, D, and F are in the foothills of the mountains; G is high in the mountains.



54. Which physical characteristic would cause location G to have a colder yearly climate than any other location?

(1) the nearness of location G to a large ocean
(2) the location of G with respect to the prevailing winds
(3) the elevation of location G above sea level
(4) the distance of location G from the equator

55. Which location probably has the greatest annual rainfall?

(1) A (2) F (3) C (4) D

56. Which location probably has the widest range in temperature during the year?

(1) A (2) B (3) H (4) D

57. Which location will probably record its highest potential evaporation and transpiration values for the year during January?

(1) A (2) F (3) C (4) D

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58. Which New York State location is most likely to experience the heaviest winter snowfall when the surface winds are blowing from the west or north-west?

(1) New York City (3) Oswego
(2) Binghamton (4) Plattsburgh

59. Which ocean current transports warm water away from Earth's equatorial region?

(1) Brazil Current
(2) West Australia Current
(3) Falkland Current
(4) California Current

60. Once the surface of Lake Erie completely freezes over with ice, the amount of snow from each snowstorm is usually reduced. Explain why a covering of ice on Lake Erie may cause the amount of snow from snowstorms to be reduced.

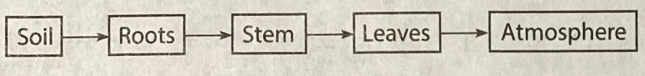
61. Earth's entire equatorial climate zone is generally a belt around Earth that has

(1) high air pressure and wet weather
(2) high air pressure and dry weather
(3) low air pressure and wet weather
(4) low air pressure and dry weather

Directions
Review the Test-Taking Strategies section of this book. Then answer the following questions. Read each question carefully and answer with a correct choice or response.

Part A

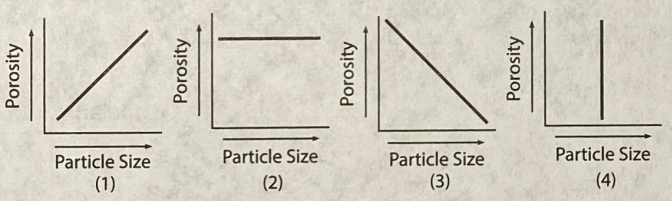
1 The following flowchart shows one process by which moisture enters the atmosphere.



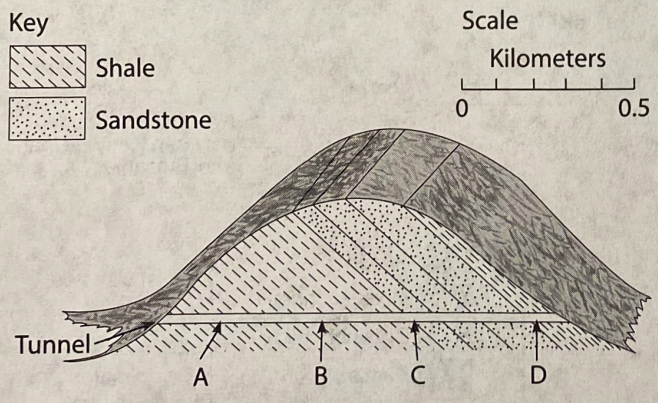
The last step of this process is known as
(1) condensation (3) radiation
(2) convection (4) transpiration

2 Replanting forests usually results in an increase in
(1) floods (3) run-off
(2) ground water (4) soil erosion

3 Which graph best represents the relationship between porosity and particle size for soil samples of uniform size, shape, and packing?



4 The following diagram represents a cross-sectional view of a tunnel cut through a mountain. The area where the mountain is located receives heavy rainfall. If the shale layers are impermeable, at which point would the most water seep through the roof of the tunnel?

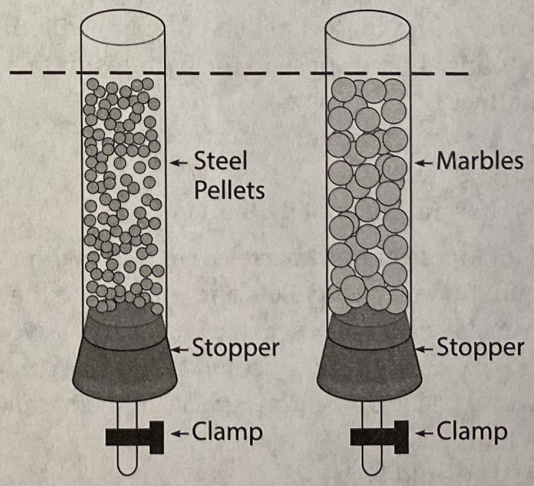


(1) A (2) B (3) C (4) D

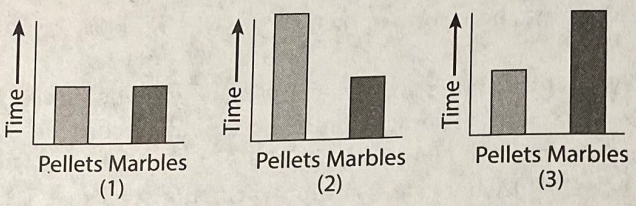
5 Which statement best explains why Plattsburgh has a low average annual precipitation compared to most of New York State?
(1) Ocean currents bring warm, moist air to Plattsburgh.
(2) A planetary low-pressure belt is located over Plattsburgh.
(3) High latitudes cause a warm, dry climate near Plattsburgh.
(4) Prevailing winds travel over the Adirondack Mountains before they reach Plattsburgh.

6 Under which condition would a climate be classified as humid?
(1) When the soil moisture is being used all year long.
(2) When the annual precipitation equals the annual potenital evapotranspiration.
(3) When the annual precipitation is much greater than the annual evapotranspiration.
(4) When the annual precipitation is much less than the annual potential evapotranspiration.

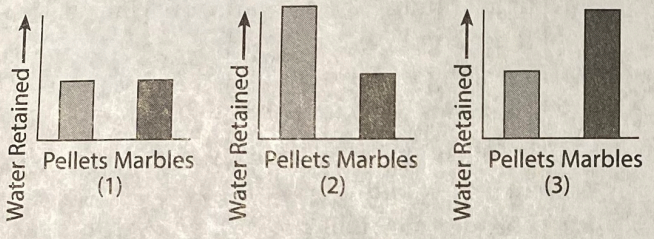
Base your answers to questions 7 through 11 on the following diagram. The diagram represents two identical barrels, each filled to the same level, one with steel pellets and the other with marbles.



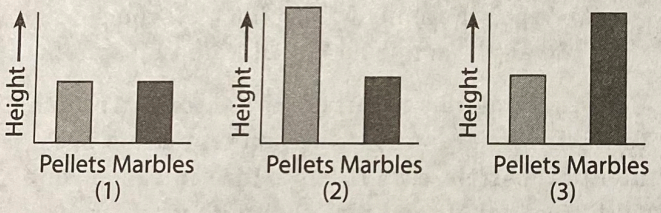
7 If water were added to each barrel to the height of the dashed line and then the clamps opened, which graph best illustrates how fast the water would run through each barrel?



8 After the water has been allowed to pass freely through the barrels, which graph best illustrates the amount of water retained by each barrel?



9 If the barrels and their contents were dried of all water and then arranged in such a way as to show capillary action, which graph best illustrates the height to which water would rise in each barrel?

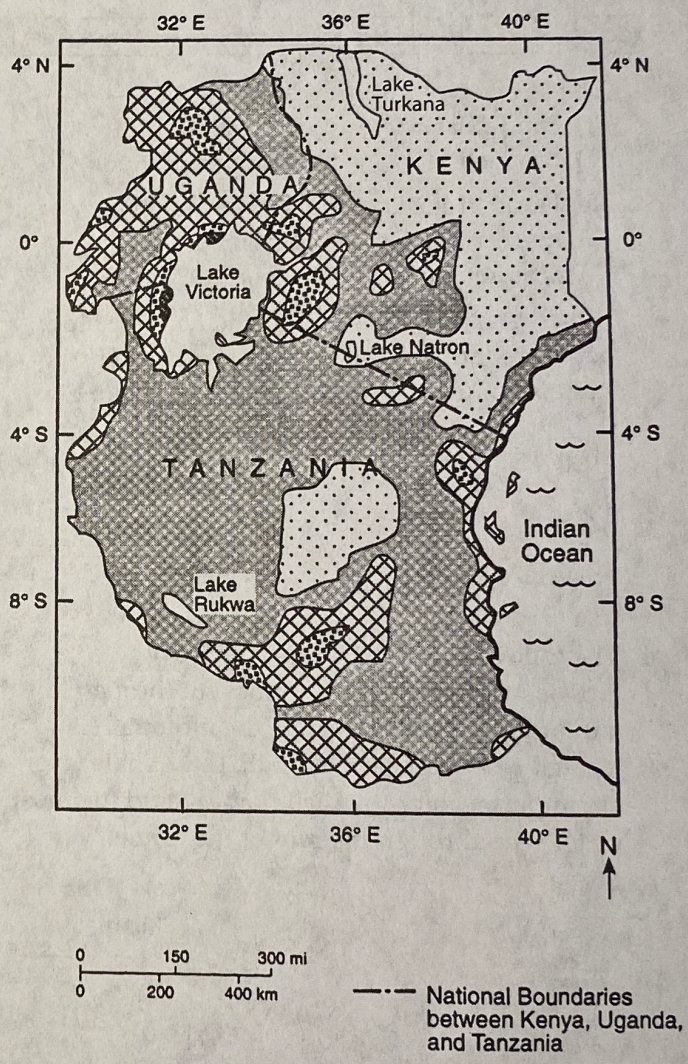


10 How does the total amount of pore space in the barrel with the steel pellets compare with the total amount of pore space in the barrel with the marbles?
(1) It is much more.
(2) It is much less.
(3) It is approximately the same.

11 If an identical third barrel were filled with a mixture of steel pellets and marbles to the same level as the other two barrels, how would the size of the pore spaces in this barrel compare with the size of the pore spaces in the barrel of marbles?
(1) It would be less.
(2) It would be greater.
(3) It would be the same.

12 As the heat and pressure applied to buried sediments is increased, the porosity of the sediments will probably
(1) decrease
(2) increase
(3) remain the same

Base your answers to questions 13 through 15 on the following map. The map shows the climate classifications of some countries in eastern Africa.



13 Which inference best explains the cause of the climate of the northeastern section of Kenya?

(1) The air reaching this section comes from a dry landmass region.

(2) Warm ocean currents bring moisture to this coastal section.

(3) Mountains force air to rise over this section.

(4) Cloud cover reflects most insolation in this section.

14 Which body of water appears to produce the greatest increase in the climate humidity of the adjacent land area?

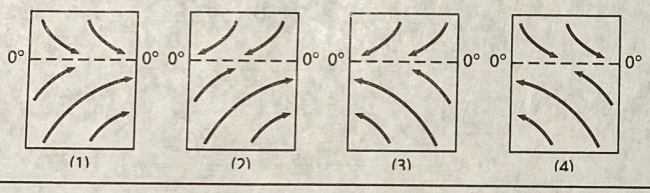
(1) Indian Ocean

(2) Lake Turkana

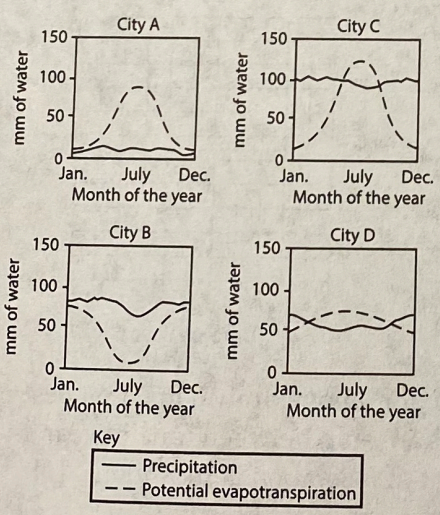
(3) Lake Rukwa

(4) Lake Victoria

15 Which pattern represents the general surface planetary winds during March in this region?



16 The following graphs show some climate data for four cities: A, B, C, and D.



Which city would have the driest climate?

(1) A

(2) B

(3) C

(4) D

17 What is the best explanation for the following two statements?

- Some mountains located near Earth's equator have snow-covered peaks.
- Ice exists at Earth's poles.

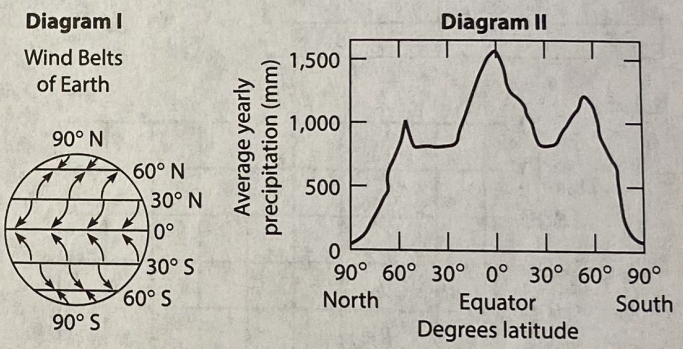
(1) High elevation and high latitude have a similar effect on climate.

(2) Both mountain and polar regions have arid climates.

(3) Mountain and polar regions receive more energy from the sun than other regions do.

(4) An increase in snowfall and an increase in temperature have a similar effect on climate.

18 Diagram I shows the planetary wind belts of Earth. Diagram II is a graph of the average yearly precipitation for locations between 90° N latitude and 90° S latitude.



Which statement about Earth's average annual yearly precipitation is best supported by the diagrams?

(1) Precipitation is lowest at latitudes where planetary winds converge (meet).

(2) Precipitation is highest at latitudes where planetary winds converge (meet).

(3) Precipitation is highest at latitudes where planetary winds diverge (move apart).

(4) Precipitation is unrelated to planetary wind belts.

19 There are greater extremes of temperature at the South Pole than at the North Pole because the

(1) continent of Antarctica is primarily a landmass

(2) Gulf Stream flows around the continent of Antarctica

(3) North Pole is inclined toward the sun

(4) South Pole is inclined toward the sun

Part B

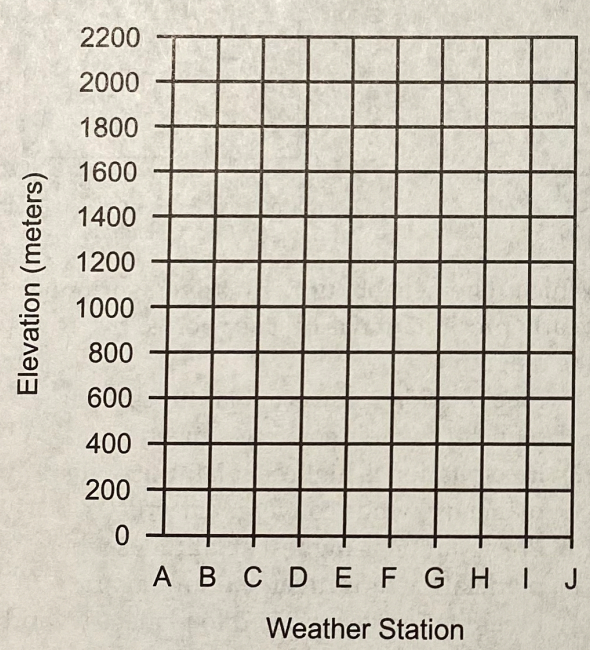
Base your answers to questions 20 through 22 on the data table below. The table shows the elevation and average annual precipitation at ten weather stations, A through J, located along a highway that passes over a mountain.

Data Table

Weather Station	Elevation (m)	Average Annual Precipitation (cm)
A	1,350	20
B	1,400	24
C	1,500	50
D	1,740	90
E	2,200	170
F	1,500	140
G	800	122
H	420	60
I	300	40
J	0	65

Symbol Chart

Key for Average Annual Precipitation	
0–25 cm	
26–75 cm	
76–127 cm	
128–170 cm	



20 On the grid above, graph the data shown on the data table by following the directions below.

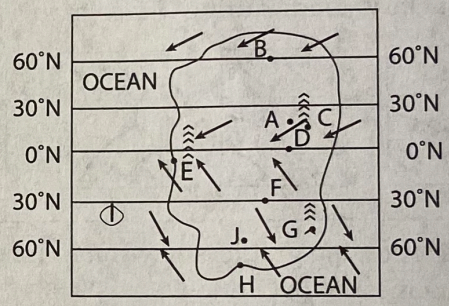
a Mark the grid with a point showing the elevation of *each* weather station. [1]

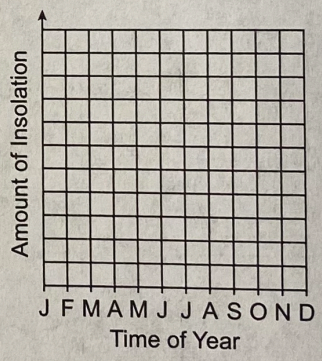
b Surround *each* point with the proper symbol from the symbol chart to show the amount of average annual precipitation for the weather station. [1]

21 State the relationship between the elevation of weather stations *A* through *E* and the average annual precipitation at these weather stations. [1]

22 Although stations *C* and *F* are at the same elevation, they have very different amounts of average annual precipitation. Explain how the prevailing wind direction might cause this difference. [1]

Base your answers to questions 23 through 34 on the map below. The map represents an imaginary continent and an island on Earth, which are surrounded by oceans. Locations E and H are on a coast at sea level, locations B, D, F, I, and J are about 500 meters in elevation, locations A and C are at the base of mountains at about 500 meters elevation, and Location G is at the top of a mountain at an elevation of 3000 meters. The arrows represent the direction of the prevailing winds. Some of these arrows have been omitted. Three mountain ranges with elevations over 1,000 meters are indicated.





23 On the grid above draw a line that best represents the relationship between time of year and the amount of insolation at location *F*. [1]

24 What is the main reason why location *B* is colder in January than in July? [1]

25 Which location, with an elevation below 600 meters, most likely has the lowest average yearly temperature? [1]

26 Which non-polar location has the most arid (dry) climate due to falling air from the upper troposphere? [1]

27 Why would location *F* have cooler winters and warmer summers than location *I*? [1]

28 On the map draw three arrows to indicate the prevailing wind direction between 35°N and 50°N. [1]

29 Draw a big **W** in the ocean just off the west coast of the imaginary continent where there is most likely the location of a cold water ocean current just off the coast. [1]

30 How would a warm water ocean current just off of location *C* affect the amount of precipitation at this location? [1]

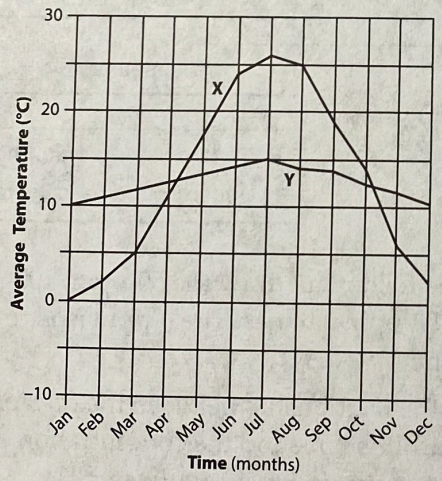
31 Which location on the map has the combination of highest yearly temperatures and high yearly amounts of precipitation? [1]

32 Why is location A much more arid (drier) than location *C*? [1]

33 What physical aspect of location *G* would cause it to be much colder than location *J*? [1]

34 Which location has higher than normal amounts of precipitation for its latitude because moist air is forced to rise, expand, cool, producing large volumes of clouds? [1]

Base your answers to questions 35 through 37 on the graph below, which shows the average monthly temperatures for a year for city *X* and city *Y*. Both cities are located at the same latitude.



35 What was the range in the average monthly temperatures for city *Y* during the year? [1]

36 Explain why city *X* has a greater difference between summer and winter temperatures than city *Y*. [1]

37 What evidence shown on the graph indicates that both cities, *X* and *Y*, are located in the Northern Hemisphere? [1]

Part C

38 Many astronomers believe that between 3 billion and 4 billion years ago, the sun radiated only 70 percent of the energy radiated today. This would suggest that at that time Earth would not have been hot enough to have liquid water at its surface. However, geologists cite evidence of sedimentary rocks and fossils that formed in liquid water during this time. Suggest a way in which Earth's surface could have been warm enough to have liquid water and life forms with much less energy coming from the sun. [1]

39 In a region of flat landscape, one family is obtaining drinking water from a well drilled 150 feet below the surface and 50 feet below the water table—all in sediment. Another family, in the same landscape area 2 miles away, has the same type of well drilled to the same depth, but this well produced almost no water. Describe a sediment condition that could account for the differences in water production from the two wells. [1]

40 You are at an ocean beach where it hasn't rained in weeks. You observe that for miles along the beach the sand is saturated with water about 5 feet inland and about 2 feet higher than any recent ocean levels. Describe a common condition that would account for the water-saturated sand above ocean levels. (Don't consider splashing of waves.) [1]

41 In the last few years drought in the southwestern United States has been associated with sinking land and development of cracks in Earth's surface. Some of the mile-long cracks are over 12 feet deep and over 20 feet in width. Soil scientists have suggested that the cracks and sinking land are due to the lowering of the water table and changes in the sediments between the new and old water-table levels. Describe how sediments above and below the water table have changed and how the changes could account for the sinking land and the formation of surface cracks. [2]

Base your answers to questions 42 through 47 on the article and diagram that follow.

New York Lake-Effect Snows

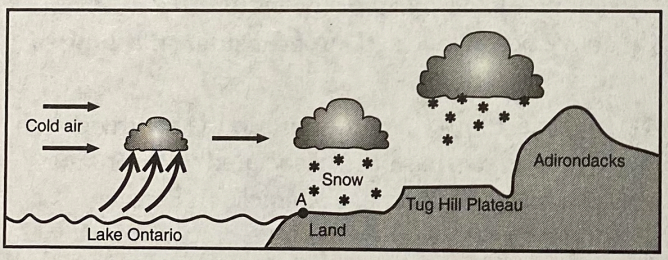
In much of western and central New York State winter snows called lake-effect snows are a major

part of daily life, often closing roads with drifting snows. These snows usually account for a large portion of the total yearly precipitation.

What creates this lake-effect snow that is so common in areas around Buffalo, Rochester, Syracuse, and Oswego among other locations in an area of New York State commonly called the "snow belt"? The diagram that follows will aid in answering this question.

In late fall and for most of an average winter, the water temperature of Lake Ontario (as well as Lake Erie) is warmer than the surrounding land in the USA and Canada. When the prevailing westerly winds blow over Lake Ontario, the air is warmed and this warmer air evaporates large amounts of water vapor from the lake. The greater the difference between the cooler air from the land and the warmer lake temperatures, the more water evaporates into the air as it moves over the lake. The amount of evaporation is aided by the long east–west orientation of Lake Ontario and Lake Erie combined with the westerly winds.

When the warmer moist air blows over the eastern end of the lakes and over the land, orographic lifting, the effect of the air being forced to rise, cools the air to the dewpoint. The resulting condensation creates the clouds and often heavy snows characteristic of this snow belt. The air continues to rise from the Erie-Ontario Lowlands to the Tug Hill and Allegheny Plateaus and even over the higher Adirondack Mountains.



42 State the relationship that must exist between water temperature and air temperature for lake-effect snow to develop. [1]

43 State why locations east and southeast of Lake Ontario are more likely to receive lake-effect snow than are locations west of the lake. [1]

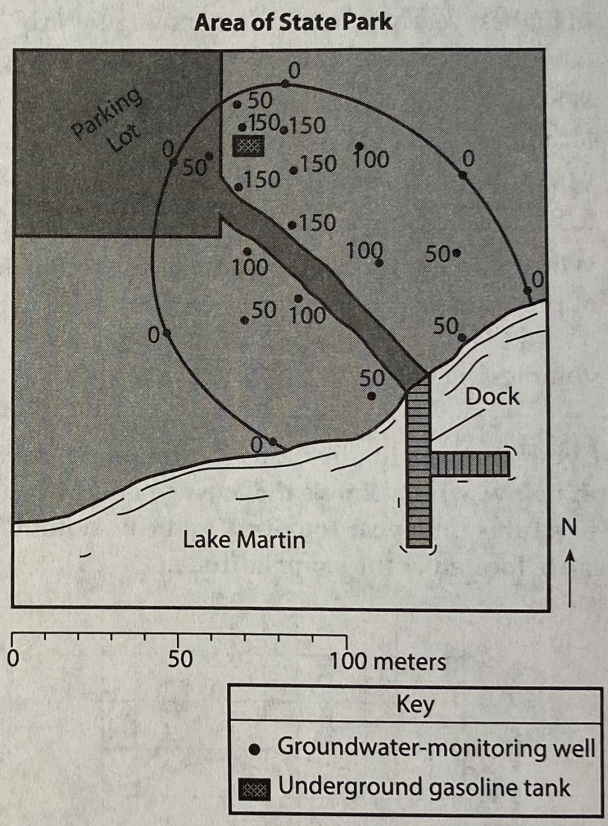
44 State where on the diagram above the annual precipitation would most likely be the lowest. [1]

45 State why very heavy snowfall occurs in the Tug Hill Plateau region. [1]

46 State where it would be the safest location to plant crops that would be killed by large extremes of temperature. [1]

47 State two reasons why the land around location *A* is cooler in the summers compared to areas fifty miles directly east of location *A*. [1]

Base your answers to questions 48 through 50 on the field map below, which shows an area of a state park where an underground gasoline tank leaked and contaminated the groundwater. Groundwater-monitoring wells were installed to determine the extent of the contamination. The concentration of contaminants in parts per million (ppm) in each of the wells is indicated on the map.



48 On the field map, draw the 50-ppm, 100-ppm, and 150-ppm isolines. The 0-ppm isoline has been drawn for you. [1]

49 State the relationship between the distance from the gasoline tank and the concentration of contaminants in the groundwater. [1]

50 Park officials do not want to see another incident of groundwater contamination from gasoline tanks. State *one* action that park officials could take to prevent gasoline from contaminating the groundwater in the future. [1]