CHAPTER 6: ENERGY, TEMPERATURE, AND HEAT

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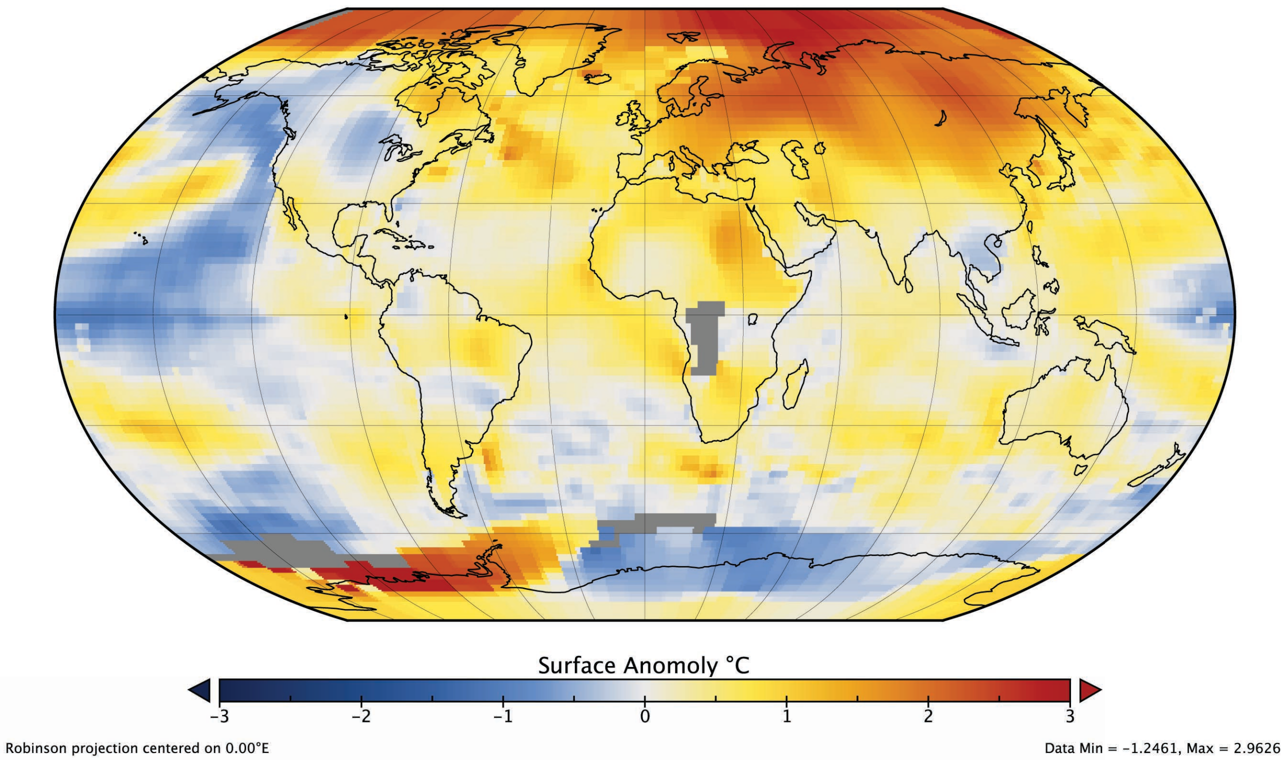

2008 Surface Air Temperature Anomaly. Map of the global surface air temperature anomaly for the year 2008 relative to the 1961-1990 average. This map shows that Eurasia, the Arctic and the Antarctic Peninsula were exceptionally warm (above the average) during this year. We can also see that large portions of the Pacific Ocean were cooler (below the average) than the 1961-1990 normal period. These negative anomalies were due to a strong **La Niña** that persisted in the first half of the year. *(Source: NASA - Goddard Institute for Space Studies)*

STUDENT LEARNING OUTCOMES

After reading this chapter you should be able to:

- Define the concept of surface air temperature.
- Explain how surface air temperature is measured in a standardized way at more than 15,000 weather stations.
- Outline how temperature means, ranges, normals, and extremes are calculated.
- Describe how latitude, altitude, mountain barriers, cloud cover, ocean currents, and the maritime and continental effects influence air temperature.
- Discuss the relationship of daily and annual cycles of surface air temperature to changes in insolation and net radiation.
- Illustrate with maps the annual and seasonal global patterns of surface air temperature and ocean surface temperature.
- Explain the relationship between the physical environment and the partitioning of heat energy to sensible heat, latent heat, and ground storage.

RADIATION TRANSFER AND TEMPERATURE

Heat can be produced in an object by the absorption of energy in the form of **radiation**. The quantity of radiation absorbed determines how hot the object will get. Greater absorption results in greater warmth. Objects cool off when they emit radiation to their surrounding environment. An object's temperature can fluctuate over time because of relative changes in radiation **absorption** and **emission** (**Figure 6.1**). If absorption exceeds radiation loss from emission, the object will heat up. An object cools down when radiation absorption is less than emission. When these two processes of radiation transfer are in balance, the temperature of the object will remain unchanged.

The heating of the ground surface, water bodies, and atmosphere on our planet is controlled mainly by the processes just described. The main power source for this heating is of course the Sun, which supplies an initial input of shortwave radiation. However, **insolation** is not the only type of radiation used in generating heat energy. Our planet also receives considerable quantities of **longwave radiation** much of which comes from the **greenhouse effect**. The best measure of how much energy is available for the heating process is net radiation. **Net radiation** is determined by subtracting an object's emissions (outputs) of all types of radiation from the quantity of all wavelength radiation that is absorbed (inputs). In Chapter 5, we examined the patterns of net radiation available for the Earth's combined surface and atmosphere annually and for the months of January and July (see **Figures 5.30** and **5.31**). We will see in this chapter that these patterns are closely correlated to spatial variations in surface air temperature.

The most common measurement of heat energy on our planet that is recorded on a regular basis is surface air temperature. Surface air temperature readings are recorded at approximately 15,000 weather stations all over the world. These readings are then transmitted via radio or television and used to construct weather maps and forecasts. The routine measurement of surface air temperature is very important for a variety of human activities.

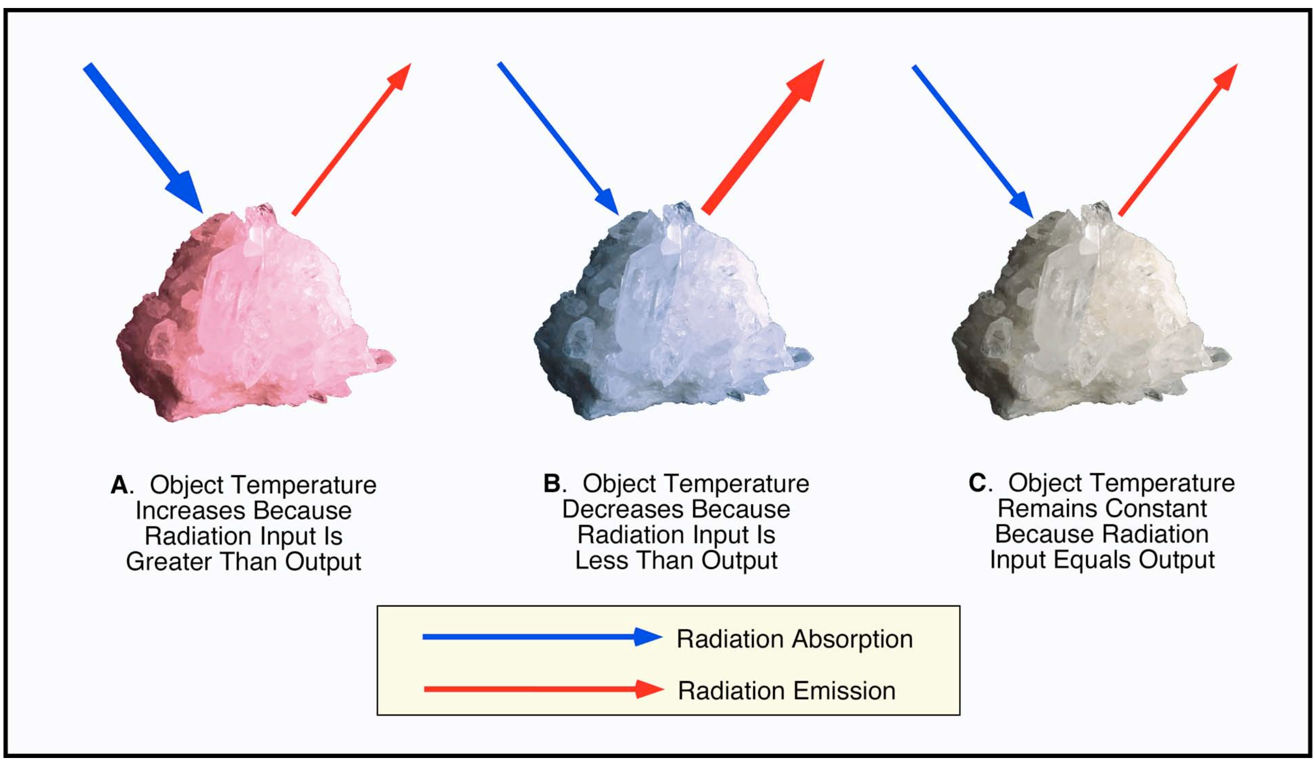

FIGURE 6.1 Relationship between radiation absorption and emission and the heating and cooling of an object. The heating of an object can occur when the absorption of radiation exceeds radiation loss from emission. Cooling of an object can take place when radiation emission exceeds radiation absorption. If absorption and emission are in balance the temperature of an object will remain constant. *(Image Copyright: Michael Pidwirny)*

MEASUREMENT OF SURFACE AIR TEMPERATURE

INSTRUMENTS FOR MEASURING TEMPERATURE

Any instrument that is used to measure the temperature of a substance is called a **thermometer**. The most common type is the **liquid-in-glass thermometer**. Liquid-in-glass thermometers consist of a sealed glass tube with a small uniform bore and a bulb at one end filled partially with a suitable liquid. The liquid used in these devices physically responds to the addition or loss of **heat energy** from the outside environment by changing its volume. When heat is added, the liquid inside the bulb expands and moves up the thermometer's tube. Cooling causes the liquid to contract. The length of a liquid-in-glass thermometer's tube is graduated with quantities that are calibrated to values on standard temperature scales. The two most common temperature scales used worldwide are Celsius and Fahrenheit (**Figure 6.2**). By international agreement most countries utilize the **Celsius scale** for meteorological measurements. The United States is the only major country that routinely still uses the **Fahrenheit scale**.

The measurement of the daily fluctuations in surface air temperature usually employs the use of two different

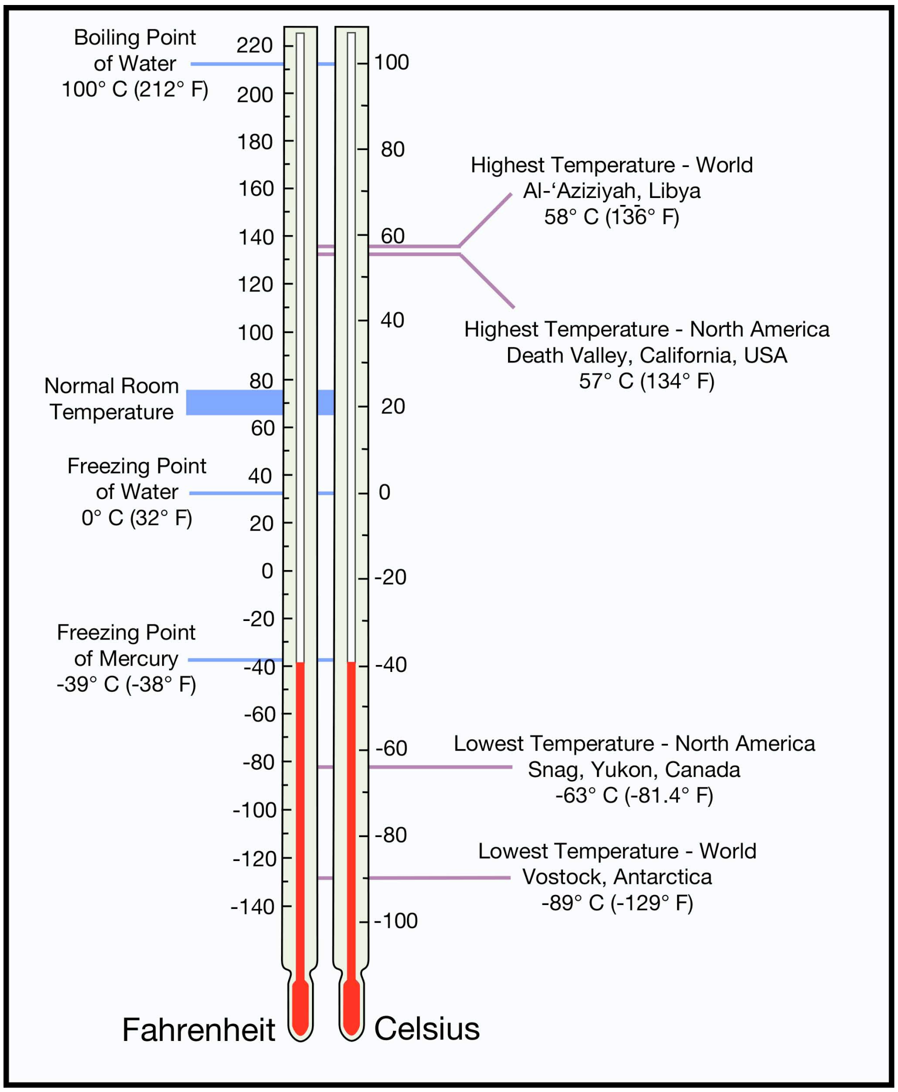

FIGURE 6.2 Fahrenheit and Celsius temperature scales. The Celsius (° C) and Fahrenheit (° F) scales are the most common systems used to measure temperature. *(Image Copyright: Michael Pidwirny)*

FIGURE 6.3 Standard minimum (top) and maximum (bottom) thermometers used to measure surface air temperature. *(Image Copyright: Michael Pidwirny)*

types of liquid-in-glass thermometers (**Figure 6.3**). To record the lowest daily temperature a minimum thermometer is used. **Minimum thermometers** are filled with alcohol that is dyed red to make the liquid more visible. Alcohol is appropriate for measuring the daily minimum temperature because of its low freezing point (-112°C or -170°F). Temperature readings are made from a minimum thermometer by noting the position of the black index slider in the instrument's tube (**Figure 6.4**). The index slider has the ability to freely move up and down the part of the tube that is filled with alcohol. To stop gravity

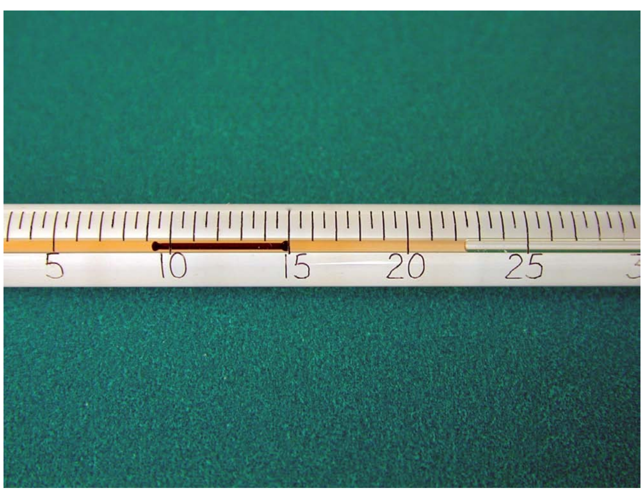

FIGURE 6.4 The minimum thermometer measures the lowest temperature over a specific time period with a metal slider located inside the bore of the thermometer. The surface tension that exists at the top of the alcohol column moves the slider as the temperature drops. When temperature increases the slider does not move with the expanding alcohol. In this example, the recorded minimum temperature is 15° C. Note that the current temperature is about 22.5° C. *(Image Copyright: Michael Pidwirny)*

from transporting the index slider to the bottom of the tube, the thermometer is mounted horizontally. In this position, the slider can only be moved by surface tension that exists where the top of the alcohol column meets the void in the tube. The index slider is pushed down the thermometer tube as the alcohol contracts, recording the lowest temperature achieved. When the temperature rises, the expanding alcohol does not influence the position of the slider. The thermometer is reset by tilting the bulb upward, causing the index slider to be positioned just below the top surface of the alcohol column once again.

The other type of thermometer used to record daily temperature fluctuations is called the **maximum thermometer**. This liquid-in-glass instrument is used specifically to record the highest temperature for a set time period. Maximum thermometers differ from minimum thermometers in that they are filled with mercury. Mercury thermometers are not used to measure low temperatures because this metallic liquid freezes at -39°C or -38°F. The construction of the maximum thermometer is quite similar to medical thermometers used to measure human body temperature. At the bottom of the thermometer is a reservoir bulb connected to a tube that extends up the shaft of the instrument. Between the bulb and the tube is a very narrow constriction that regulates the flow of the mercury from the bulb into the tube. When temperature increases, the constriction permits the mercury column to move up the tube by thermal expansion. However, the constriction is too narrow to allow the mercury in the tube to flow back into the bulb when cooling occurs. As a result, the maximum temperature is recorded. Shaking it vigorously resets the thermometer as this motion causes the mercury in the tube to be forced past the constriction and back into the reservoir bulb.

Instrument Shelters

By international agreement, the nations of the world have decided to measure **surface air temperature** in a similar fashion. This standardization is important for the accurate generation and comparison of weather maps and forecasts, both of which depend on having data determined in a uniform way. One requirement of this standardization is that surface air temperature measurements must be recorded in the shade of an instrument shelter. This requirement ensures that we are only measuring the temperature of the heat energy found in the air around the thermometer. A thermometer exposed to direct sunlight will gain additional heat energy from the absorption of solar radiation, thereby giving false readings.

The *World Meteorological Organization* (WMO) recommends the use of a specific type of instrument shelter known as a **Stevenson Screen** for housing maximum and minimum thermometers (**Figure 6.5**). The basic design of the Stevenson Screen consists of a wooden box, with a hinged door opening at the front. The outside surface of the box is painted white to minimize the absorption of solar radiation. The box is also mounted on a steel or wood stand elevating it to a height of about 1.5 m or 4.5 ft (varies from country to country between 1.2 to 1.8 m or 3.9 to 5.9 ft). Ventilation is made available to the interior of the box through openings in the double roof, the box bottom, and the louvered sides. This ventilation ensures that the thermometers mounted inside the box are always receiving a fresh supply of air. Some Stevenson Screens have a fan connected to the box that supplements ventilation during periods of still air or low winds. Finally, the WMO recommends that Stevenson Screens should be located on a grassed surface, once again to maintain consistency in measurement.

Some weather stations also take temperature readings continuously. To obtain continuous readings a special type of instrumentation is required. This type of instrumentation is sometimes called a **Maximum Minimum Temperature System** or MMTS (**Figure 6.6**). The instrument housing of a MMTS is much smaller than a Stevenson Screen and resembles a vented beehive. Inside this instrument shelter is a mounted **thermister** (thermal resistor) for measuring temperature. A thermistor is a type of thermometer that measures temperature electronically.

FIGURE 6.5 Stevenson Screen meteorological instrument shelters. These shelters are typically made of wood, painted white, and have louvered sides. They also are elevated to height of about 1.5 meters (about 4.5 feet) by a wooden or metal base. Some instrument shelters have an electric fan attached to them for better air circulation in the instrument box during light wind conditions. *(Image Copyright: Michael Pidwirny)*

FIGURE 6.5 The following meteorological instrument is called an Electronic Maximum and Minimum Temperature System (MMTS). These systems consist of three main parts: a white ventilated instrument shelter, an internal electrical thermistor, and a computerized data storage device (data logger). Thermistors are a type of thermometer that measures temperature based on the fact that electrical resistance of a conductor varies with temperature. Thermistors can provide a continuous digital record of temperature change. From this record, maximum, minimum, and mean temperatures can be determined daily. The U.S. National Weather Service is replacing the older liquid-in-glass thermometers with the Electronic Maximum and Minimum Temperature Systems at many of their primary and cooperative observing stations. *(Image Copyright: Michael Pidwirny)*

Temperature Means, Ranges, Normals, and Extremes

Measurements of surface air temperature are normally expressed in relation to some period or instant in time. Generally, the shortest period of time in which surface air temperature is expressed is one day or 24-hours (midnight to just before midnight on the next day). As previously stated, we record the maximum and minimum temperatures for each day of the year at over 15,000 weather stations. By dividing the sum of the maximum and minimum daily values at a station by two we can calculate a quantity known as the **daily mean temperature** (**Figure 6.7**). **Daily temperature range** is computed by determining the difference between the daily maximum and minimum. The **monthly mean temperature** is found by summing all of the daily means for a particular month, and then dividing this sum by the number of days in that month. **Annual**

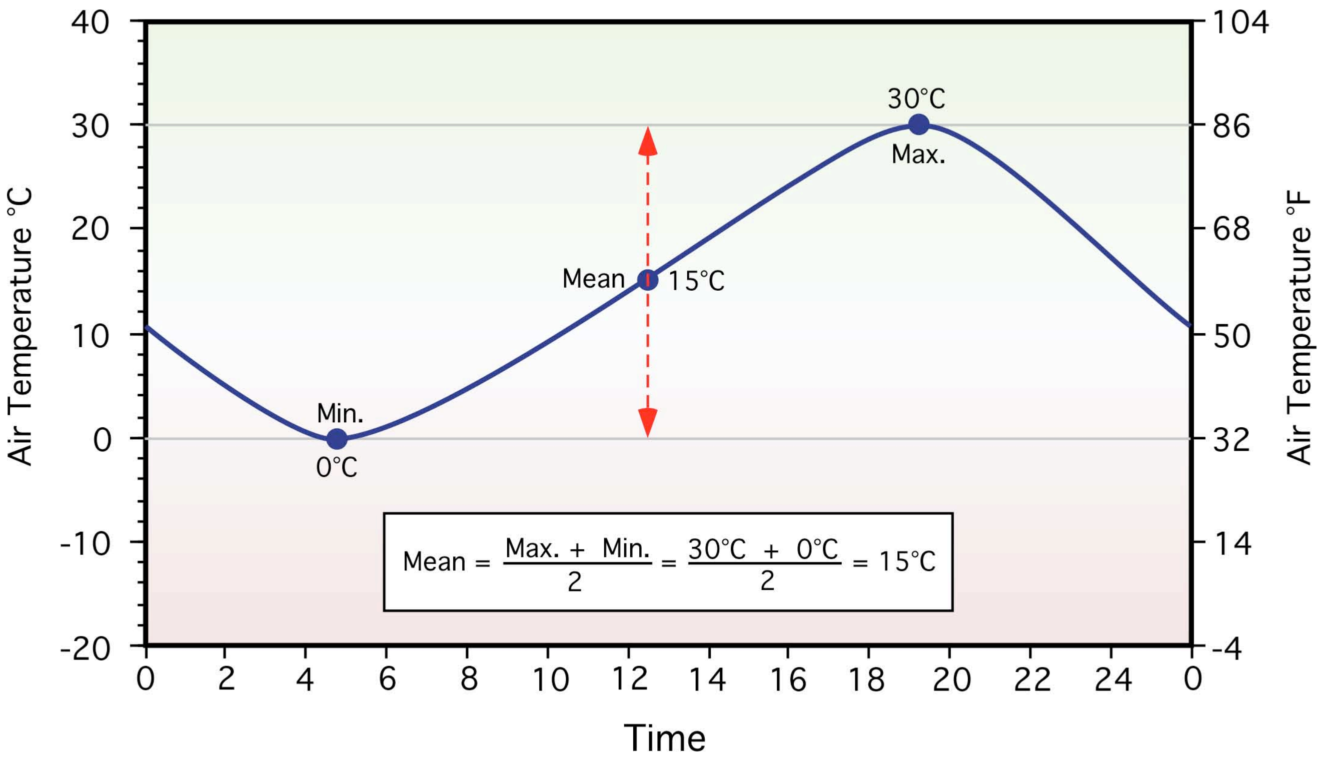

FIGURE 6.7 Calculation of daily mean surface air temperature. Daily mean surface air temperature is a measure derived by taking the average of the sum of the daily minimum and maximum temperature. *(Image Copyright: Michael Pidwirny)*

mean temperature is calculated by averaging all twelve monthly mean values that occur in a particular year of interest. To determine the **annual temperature range**, we would find the difference between the warmest and coldest monthly mean temperatures.

Temperatures vary with time. These variations can occur annually, daily, or even hourly. The magnitude of these variations can only be evaluated by looking at records of past measurements for similar time periods or occasions. Scientists often analyze these data sets to determine meteorological normals and extremes. A **meteorological normal** is computed by finding the average of a measured meteorological element, like surface air temperature, over a period of years. A **meteorological extreme** is the highest or the lowest value for a meteorological element in a specified time period. Data covering a continuous period of at least 30 years are usually needed to compute these values. **Figure 6.8** describes the meteorological normals and extremes for the monthly mean temperature data for Kelowna, British Columbia, Canada based on 88 years of record. Normals and extremes provide a useful yardstick to assess the relative significance of new observations. For example, is the new measurement similar to the normal or is it closer to the extreme values or has it set a new extreme benchmark? Normals and extremes can also be used in planning future activities that rely on specific temperature regimes.

Table 6.1 lists both high and low extremes of temperature for various regions of the world. Because of the variable nature of the Earth's climate system we can never be quite sure when these records will be broken in the future. Without a doubt some of these records will fall in our lifetime! It also is important to note that our records of past temperature fluctuations for most places are less than 100 years in length.

FACTORS INFLUENCING AIR TEMPERATURE

LATITUDE

The most important factor controlling surface air temperature is the input of radiation. On the Earth's surface, the amount of radiation input is largely controlled by the intensity and duration of insolation. As the result of

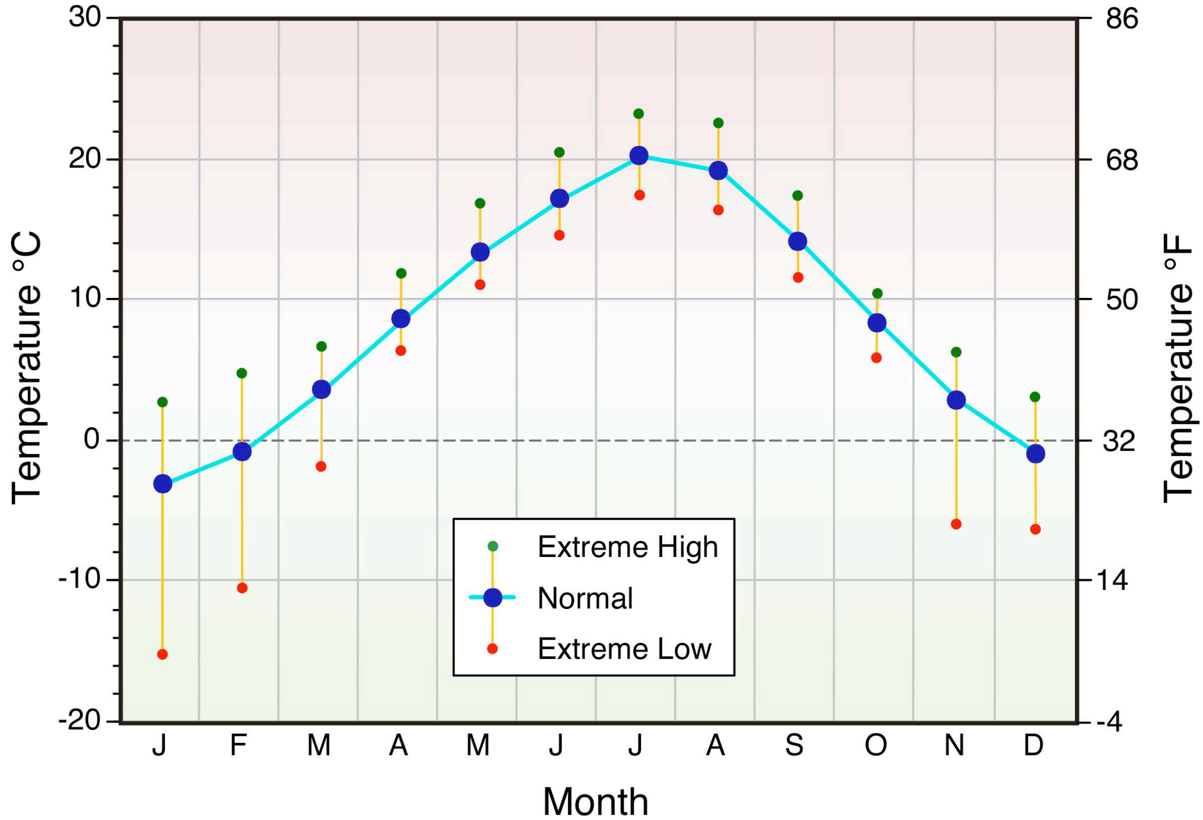

FIGURE 6.8 Mean monthly temperature normals and extremes for Kelowna, Canada for the period 1903 to 1991. *(Image Copyright: Michael Pidwirny)*

these two factors, the quantity of incoming solar radiation available at the surface varies annually with latitude (see **Figure 4.28**). From the equator to the North and South Pole, seasonal variations in day length and angle of incidence become greater with increasing latitude. Because of these variations, seasonal deviations in surface air temperature also become more extreme as we approach the poles (**Figure 6.9**). Highest temperatures tend to correspond roughly to the summer season when day lengths are the longest and Sun angles are at their maximum. When day lengths are at their shortest and Sun angles are at their minimum (winter), the lowest temperatures occur. Locations near the equator have only small variations in solar input annually because seasonal changes in day length and angle of incidence are slight. Consequently, variations in surface air temperature over the period of one calendar year also are minor (see **Figure 6.15**).

ALTITUDE

Surface air temperatures tend to cool gradually with increasing elevation. This phenomenon is well known to anyone living in a mountainous region. Temperatures in the valley bottoms are generally warmer than temperatures on mountainsides and peaks. When observing mountains from a distance, we can determine the elevation that roughly represents a surface temperature of 0°C (32°F) by finding the **snow line**. Above this boundary temperatures are cold enough to maintain snow and ice in a frozen state. Below the snow line average temperatures are above freezing.

Figure 6.10 describes the monthly mean temperatures for four locations in equatorial Columbia with similar latitudes but different elevations. Girardot has the lowest elevation (286 m, 938 ft) and a mean annual temperature of about 28°C (82°F). Just above Girardot, is Chinchina (1310 m, 4298 ft) and Tibacuy (1525 m, 5003 ft) with mean annual temperatures of 21°C (66°F) and 19°C (70°F), respectively. Bogota has the highest elevation (2556 m, 8386 ft) and an average annual temperature of about 14°C (57°F). We can calculate the rate of temperature drop between these places to be about 6.1°C per 1000 m (3.3°F per 1000 ft). This drop in temperature is related to the fact that the atmosphere becomes less dense with altitude.

TABLE 6.1 Surface air temperature extremes for various regions of the world.

Extreme High Temperatures

Region	Temperature ° C (° F)	Location	Elevation Meters (Feet)	Date
Africa	57.8 (136)	El Azizia, Libya	112 (367)	September 13, 1922
North America	56.7 (134)	Death Valley, California	-54 (-178)	July 10, 1913
Asia	53.9 (129)	Tirat Tsvi, Israel	-220 (-722)	June 21, 1942
Australia	50.7 (123.3)	Oodnadatta, South Australia	113 (370)	January 2, 1960
Europe	50.5 (122)	Seville, Spain	8 (26)	August 4, 1881
South America	49.1 (120)	Rivadavia, Argentina	206 (676)	December 11, 1905
Oceania	42.2 (108)	Tuguegarao, Philippines	22 (72)	April 29, 1912
Antarctica	15.0 (59)	Vanda Station, Scott Coast	15 (49)	January 5, 1974

Extreme Low Temperatures

Region	Temperature ° C (° F)	Location	Elevation Meters (Feet)	Date
Antarctica	-89.2 (-129)	Vostok	3420 (11,220)	July 21, 1983
Asia	-67.8 (-90)	Oimekon, Russia	800 (2625)	February 6, 1933
Asia	-67.8 (-90)	Verkhoyansk, Russia	107 (350)	February 7, 1892
Greenland	-66 (-87)	Northice	2342 (7687)	January 9, 1954
North America	-63 (-81.4)	Snag, Canada	646 (2120)	February 3, 1947
Europe	-58.1 (-72.6)	Ust'Shchugor, Russia	85 (279)	December 31, 1978
South America	-32.8 (-27)	Sarmiento, Argentina	268 (879)	June 1, 1907
Africa	-24 (-11)	Ifrane, Morocco	1635 (5364)	February 11, 1935
Australia	-23 (-9.4)	Charlotte Pass	1755 (5758)	June 29, 1994

The density of air influences both the heating and cooling of the atmosphere near the Earth's surface. At high elevations less of the incoming shortwave radiation is absorbed and reflected by particles found in the atmosphere lying overhead. This results in more incoming radiation available for conversion into heat energy. The most obvious outcome of having more heat energy available is a relatively rapid rise in daytime air temperature in high elevation locations. A thin atmosphere also causes less of the outgoing longwave radiation to be re-radiated back to the Earth's surface where it can be converted into heat energy again. This **greenhouse effect** is dependent on the availability of water and other **greenhouse gases**. When the air becomes thinner, the quantity of these atmospheric substances declines. The net effect of a weaker greenhouse effect is a rapid and intense nighttime cooling. The magnitude of this nighttime cooling is usually greater than the additional heat produced by more intense solar radiation. Consequently, daily mean, monthly mean, and annual temperatures generally decrease as altitude increases.

Cloud Cover

The presence of cloud cover has a definite effect on air temperature. During the daytime, cloud cover tends to block the transmission of sunlight to the Earth's surface. Less solar radiation leads to reduced heat generation and

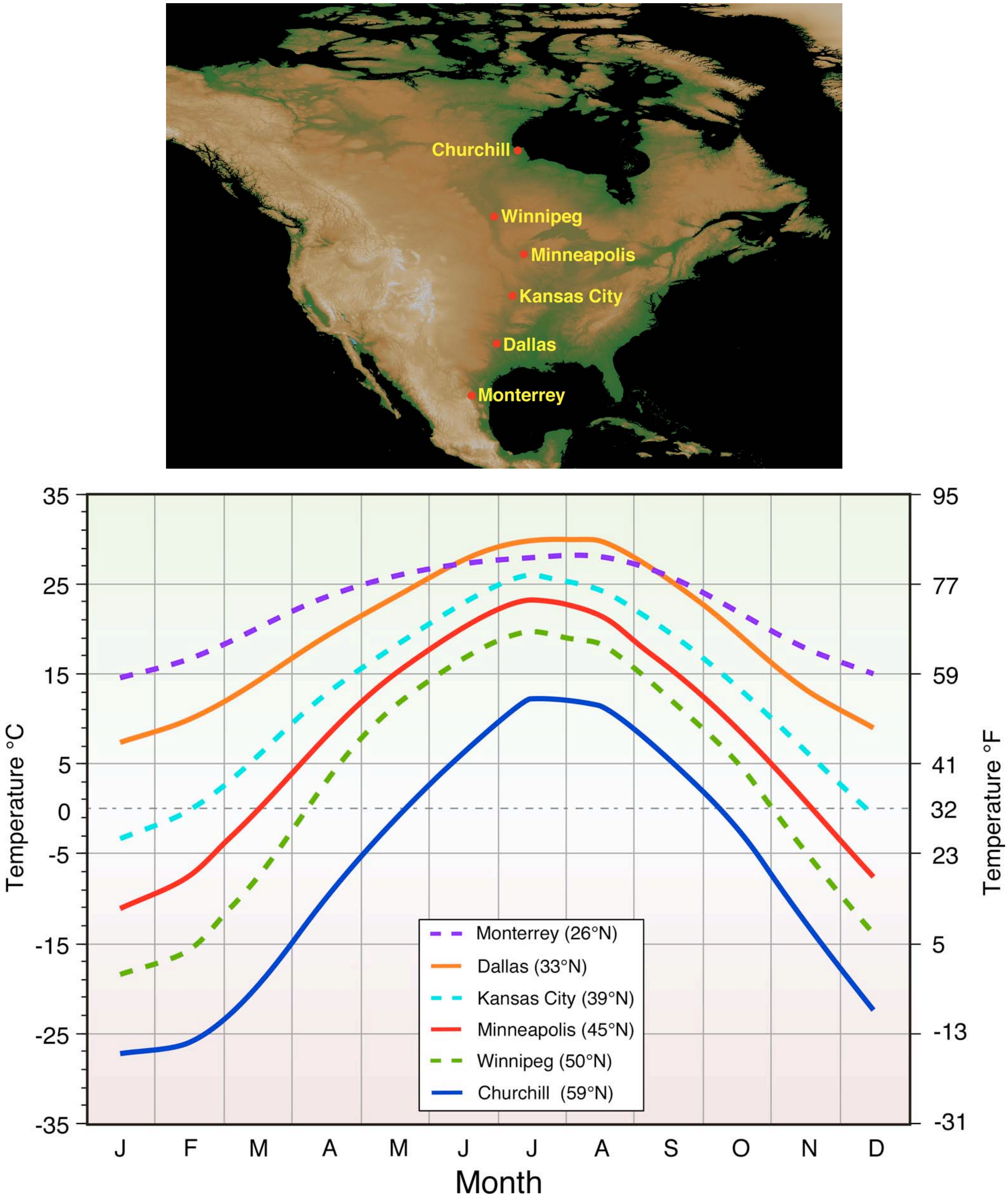

FIGURE 6.9 Latitude influence on mean monthly temperature. Mean monthly temperatures of five Northern Hemisphere locations with different latitudes. The graph suggests that monthly temperatures generally become higher as one moves toward the equator. Also, note that seasonal temperature variations between summer (June, July, and August) and winter (December, January, and February) become more extreme as latitude increases. *(Image Copyright: Michael Pidwirny)*

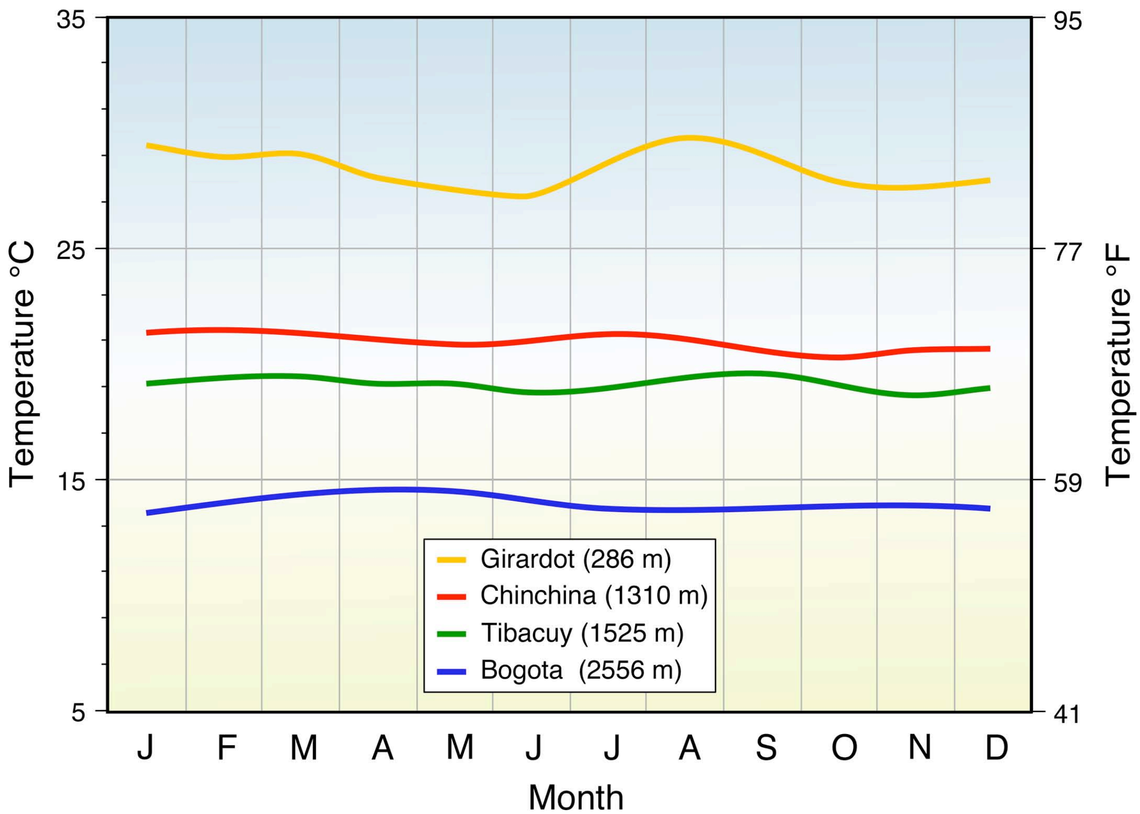

FIGURE 6.10 Elevation influence on mean monthly temperature. Comparison of mean monthly temperature patterns for four locations in Columbia with different elevations: Girardot (286 m, 938 ft), Chinchina (1310 m, 4298 ft), Tibacuy (1525 m, 5003 ft), and Bogota (2556 m, 8386 ft). These locations are found within 200 kilometers (125 miles) of each other at a latitude of about 5° North of the equator. *(Image Copyright: Michael Pidwirny)*

lower surface air temperatures. This process explains why daytime temperatures are cooler along the equator and hotter at the sub-tropical deserts. At the equator, **cumulus** and **cumulonimbus** (**thunderstorm**) clouds develop almost daily reducing the amount of incoming solar radiation absorbed at the Earth's surface. In the sub-tropical deserts, skies are almost always clear, maximizing the flow of solar radiation through the atmosphere to the surface. Thus, high heat generation at the surface makes desert temperatures very hot during the day.

At night, the presence of clouds is associated with less dramatic nighttime cooling. Nighttime cooling is the result of heat energy in the lower atmosphere being converted into outgoing longwave radiation. In a clear atmosphere, most of this emission leaves the Earth and only a small amount of this outgoing energy is re-emitted as counter-radiation to partially offset radiative cooling at the Earth's surface and lower atmosphere. The presence of clouds greatly enhances the greenhouse process. When cloud cover is extensive and thick, most of the outgoing longwave is redirected back to the surface where it once again creates heat energy. Therefore, cloudy nights tend to be warmer than cloudless nights.

Maritime and Continental Effects

The two dominant surface types found on the Earth are land and water. These surface types influence the heating and cooling of the air directly above them in different ways. Simply stated, the heating and cooling of air over land is more intense and rapid creating more extreme temporal variations in surface air temperature. The causes of this phenomenon are related to the following factors:

- Because of its solid form and low **thermal conductivity**, only a small portion of the heat energy created by absorption of solar radiation at the surface of land flows into this substance.

- Most of the heat created by absorption flows almost immediately into the atmosphere by **conduction** and **convection**. This transfer of energy is high when insolation input is great. Likewise, when insolation input is small the amount of heat entering the atmosphere is low. This fact explains why extreme diurnal (daily) and annual variations of air temperature occur over land.

Water stores a lot of heat energy because of its fluid nature and high specific heat. Fluid mixing redistributes the heat generated from solar radiation absorption throughout the vertical expanse of the water body. Thus, deep bodies of water like our planet's oceans contain heat energy from thousands of years of insolation absorption. Some of this heat is available for conductive and convective transfer into the atmosphere. The amount of heat transferred from the surface of the ocean to the lower atmosphere is strongly controlled by the heat stored in the oceans. Annual variations in availability of solar radiation have minimal effect on the quantity of this heat flow. Consequently, the amount of heat energy flowing into the atmosphere is relatively high even when insolation input is low.

Figure 6.11 illustrates the **maritime effect** of oceans on surface air temperature. The graphs in this figure describe the annual variations in monthly mean, maximum, and minimum air temperature for four terrestrial locations with similar latitudes but differing proximity to the Pacific and Atlantic Oceans. Vancouver and St. Johns are located along the west and east coast of North America, respectively. Minot and Winnipeg are found at the center of North America and their climates are strongly influenced by the **continental effect** (also called **continentality**). Comparing the monthly temperatures of these places reveals that annual variations are almost twice as great for the continental locations. Minot and Winnipeg also have greater differences between monthly maximum and minimum temperatures for most months indicating greater diurnal variations. Of the maritime climates, Vancouver is slightly milder than St. Johns and experiences less annual variation in temperature. The moderating influence of the oceans is greater for Vancouver because weather in the mid-latitudes generally travels from west to east.

The maritime and continental effects also influence surface air temperature variations on a global scale. The latitudinal distribution of land and water on the Earth's surface is not even. From 30° North to 70° North more land than water covers the Earth's surface, while from 30° South to 70° South ocean surface dominates. The climatic effects of this difference can be seen in **Table 6.2**. For the regions of interest, the data in this table indicate that seasonal temperature fluctuations in the Southern Hemisphere are considerably less than in the Northern Hemisphere.

Ocean Currents

Ocean waters on our planet are constantly in motion. These motions occur in the horizontal and in the vertical. Horizontal motions of ocean waters produce surface and sub-surface flows known as **ocean currents**. Currents that occur at the ocean's surface are driven by the winds associated with the large-scale **global circulation** of the atmosphere. Frictional drag caused by wind blowing over the ocean surface is the primary factor determining the course that these currents will take. The presence of land masses can also influences the direction of ocean currents. These barriers redirect the flow of east or west flowing currents in a north or south direction. We will examine the characteristics of our planet's surface ocean currents in greater depth in Chapter 14.

Surface ocean currents can influence the climate of locations because the ocean water that they transport can have a contrasting temperature. In general, currents that flow from the tropics to higher latitudes have relatively warm flows. Cold flows of ocean water are produced when the currents move from the high latitudes to the tropics. The moderating effect of warm ocean currents on land temperatures is well known. The *Gulf Stream* warms temperatures along the eastern seaboard of the United States from Florida to North Carolina (**Figure 6.12**). Also, an extension of this flow, known as the *North Atlantic*

TABLE 6.2 Difference between mean (1994-2006) January and July near surface air temperatures by latitude zone and hemisphere, °C (°F). Original analyzed data from NASA's International Satellite Cloud Climatology Project.

Latitude Zone	Northern Hemisphere	Southern Hemisphere
0-10°	0.4 (0.7)	0.9 (1.6)
10-20°	4.1 (7.4)	3.0 (5.5)
20-30°	10.6 (19.1)	6.4 (11.5)
30-40°	17.1 (30.8)	6.3 (11.3)
40-50°	22.1 (39.7)	4.9 (8.9)
50-60°	24.7 (44.5)	4.8 (8.6)
60-70°	29.9 (53.8)	11.1 (19.9)
70-80°	26.6 (47.9)	14.1 (25.4)
80-90°	28.8 (51.9)	13.2 (23.7)

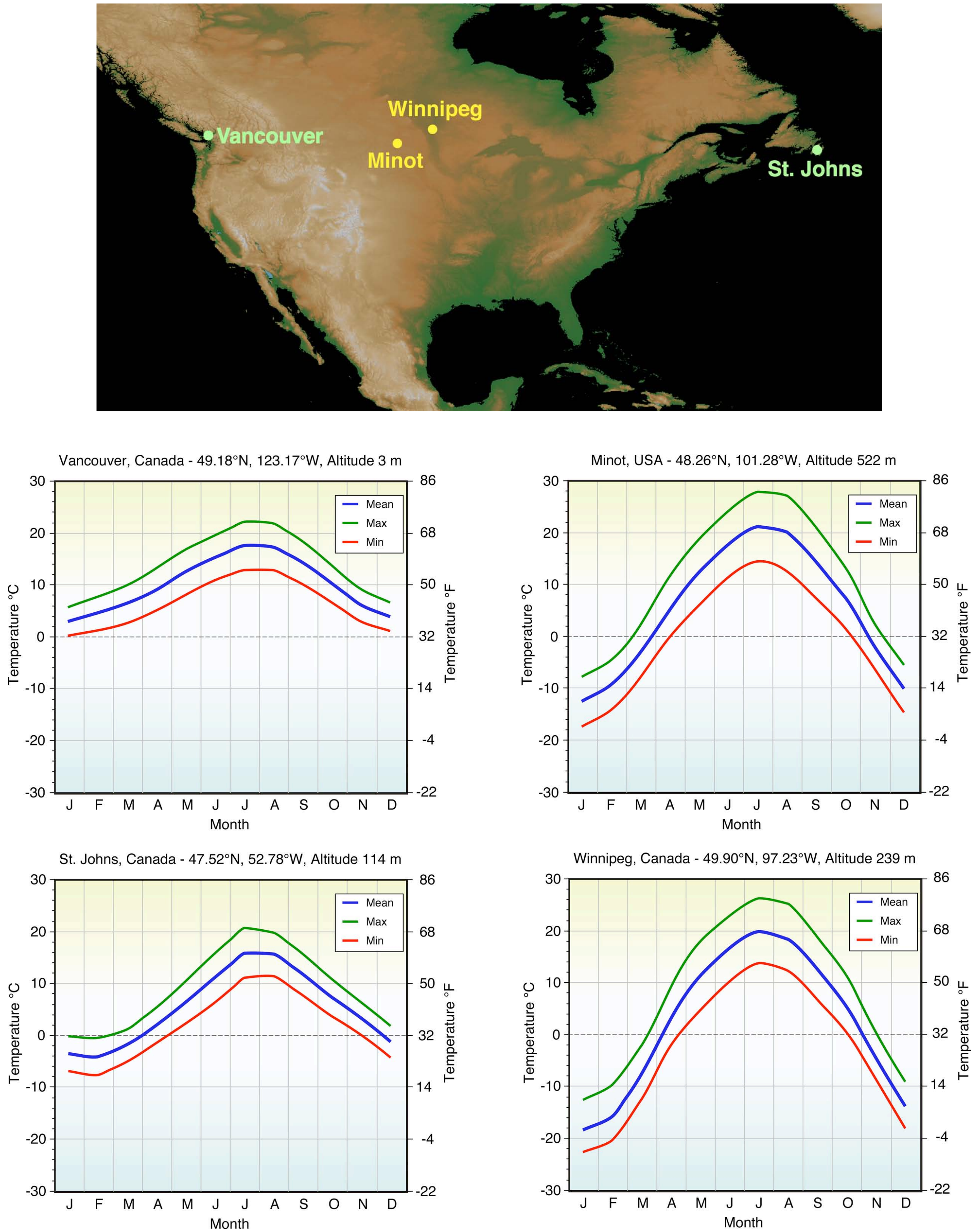

FIGURE 6.11 Maritime versus continental effects on monthly temperatures. Comparison of monthly mean, maximum, and minimum temperatures of two maritime (Vancouver and St. Johns) and two continental (Minot and Winnipeg) Northern Hemisphere locations with similar latitudes. *(Image Copyright: Michael Pidwirny)*

Drift, travels across the Atlantic Ocean warming air temperatures in Britain and Western Europe. This warming is most pronounced in the winter. For example, during this season average January mean temperature in Coimbra, Portugal is 10.1°C (18.1°F) warmer than Philadelphia despite the fact that these two locations are at roughly the same latitude (40°N).

Cold surface ocean currents originate in polar and temperate latitudes and generally flow towards the equator. Like the warm surface currents, they are driven largely by atmospheric circulation. The climatic effects of cold currents are most obvious in the summer season. For example, the cold *California Current* off the west coast of the United States moderates air temperatures from the state of Washington to California (**Figure 6.12**). The magnitude of this cooling can be seen by comparing the summer temperature records for cities on the east and west coast of the United States with similar latitudes. For example, the average July mean temperature in Santa Cruz, California is 8.9°C (16.0°F) cooler than Norfolk, Virginia. Yet, both locations are located at about 37°N latitude.

CYCLES OF AIR TEMPERATURE

DAILY CYCLES

At the Earth's surface, quantities of **insolation** and **net radiation** undergo daily cycles of change because the planet rotates on its polar axis once every 24-hours. Variations in net radiation are primarily responsible for the particular patterns of rising and falling surface air temperature over a 24-hour period. Insolation is usually the main positive component making up net radiation.

Figure 6.13 shows hypothetical average curves of insolation, net radiation, and air temperature for a typical land-based location in the Northern Hemisphere at 45° of latitude on the equinoxes and solstices. For all dates, peak reception of insolation occurs at solar noon when the Sun attains its greatest height above the horizon. The net radiation graph indicates that there is a surplus of radiation during most of the day and a deficit throughout the night. This deficit begins just before sunset when emitted longwave radiation from the Earth's surface exceeds

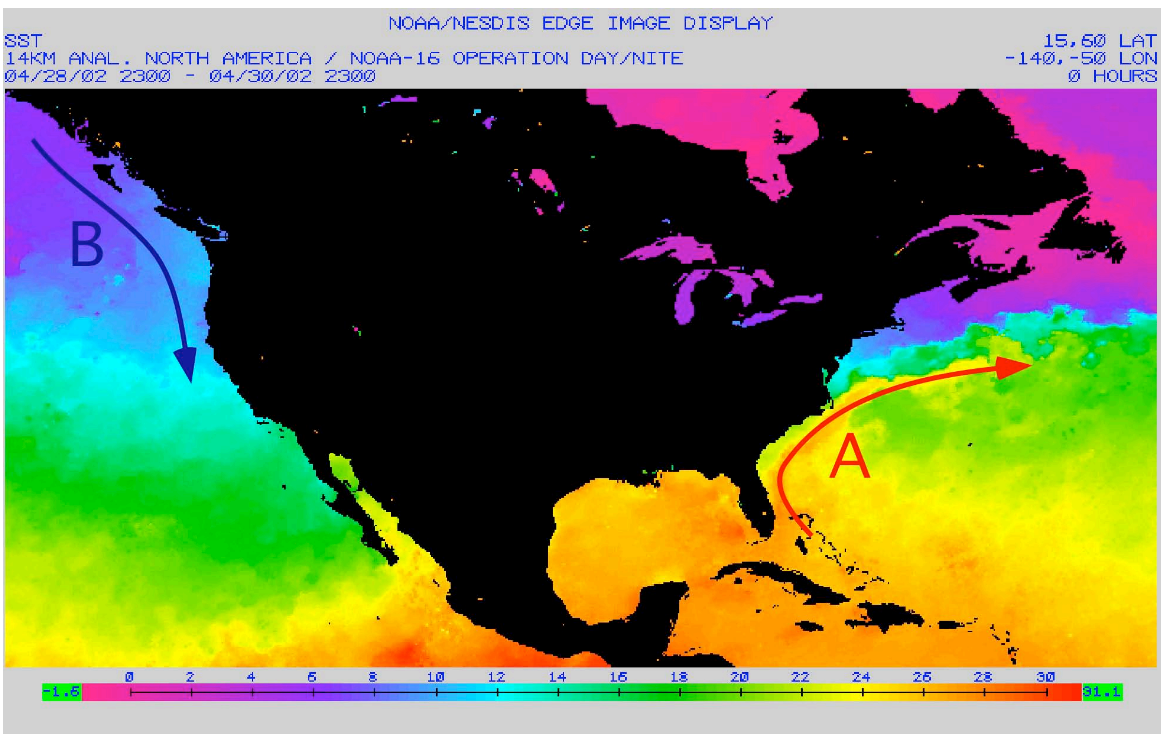

FIGURE 6.12 The Gulf Stream (A) moves a current of warm water from the tip of Florida northward along the coastline of Georgia, South Carolina, and North Carolina. Off the coast of Virginia, the Gulf Stream changes its direction and begins to move more eastward. The California Current (B) starts off the coast of British Columbia and moves cold water down the west coast of North America. The scale at the bottom matches ocean surface temperature in degrees Celsius with the colors found on the satellite image. *(Source: NOAA)*

insolation and re-radiated longwave radiation (greenhouse effect) from the atmosphere. The relative placement of the temperature profiles for the various dates is associated to the amount of net radiation available for daily surface absorption and heat generation. The more energy is available, the higher up the Y-axis the temperature profile is on the graph. The September equinox (September 21/22) is warmer than the March equinox (March 21/22) because of the heating that occurred in the previous summer months. This heat energy is stored in the atmosphere and in the ground.

For all dates, minimum temperature occurs shortly after sunrise. Temperature drops throughout the night because of two processes. First, the Earth's radiation balance at the surface becomes negative after sunset. Thus, the surface of the Earth stops heating as solar radiation is not being absorbed. Secondly, conduction and convection transport heat energy into the atmosphere and the warm air that was at the surface is replaced by cooler air from above by atmospheric mixing. Temperature begins rising as soon as the net radiation budget of the surface becomes positive. Temperature continues to rise from sunrise until sometime after solar noon. After this time, the air near the Earth's surface has gained enough heat to initiate strong convective updrafts. These updrafts move warm air from near the surface to higher altitudes. This process also causes surface air temperatures to begin dropping because the rising warm air is replaced by the downward flow of cooler air from higher altitudes.

Annual Cycles

As the Earth revolves around the Sun, locations on the surface undergo seasonal changes in air surface temperature. Monthly temperature variations generally follow temporal changes in the availability of net radiation. Net radiation represents energy available to do work. When received at the Earth's surface, much of this energy is used to create sensible heat that we perceive as surface air temperature. Variations in net radiation are primarily controlled by changes in the intensity and duration of received insolation that are in turn controlled mainly by latitude (see **Figures 5.24** and **5.30**).

The discussion that follows examines how changes in the quantity of net radiation influences mean monthly temperatures for seven locations with different latitudes (**Figure 6.14**). **Table 6.3** lists these locations and describes the annual net radiation, annual mean temperature, and annual temperature range for each. This table also illustrates the effect increasing latitude has on each of these climatic variables.

At Singapore (latitude 1°N), values of monthly net radiation averages 132 W m-2. Monthly variation in net radiation is very small because there is little seasonal change in insolation input (**Figure 6.15**). Because of the consistent nature of net radiation, average mean monthly air temperature only varies annually by 1.5°C (2.7°F). Yearly receipts of net radiation are highest in February, March, and April. This time is associated with a seasonal dry period that produces less cloud cover and higher inputs of solar radiation. Highest temperatures occur in May and June (27.5°C or 81.5°F) one month after the annual net radiation peaks. Periods of maximum net radiation are not always synchronized with peaks in average mean monthly temperature. For most locations there is a time lag of one to two months. The delayed transfer of stored heat energy in the ground by conduction, convection, and longwave radiation emission into the lower atmosphere is responsible for this lag effect. This same process can also postpone the timing of the lowest mean monthly temperature.

Singapore's monsoon rainy season occurs from November to January. Clouds associated with the monsoons are responsible for a seasonal dip in net radiation and average mean monthly temperature. Net radiation reaches its lowest value in November, which is the beginning of the rainy season. Associated with the rainy season is greater cloud cover that reduces the amount of insolation being absorbed at the ground surface. The lowest average mean monthly temperature (26.0°C or 78.8°F) occurs in January at the end of the monsoon season.

Net radiation at the dry tropical location Aden Khormaksar (latitude 13°N) has two peaks over the one-year period shown in **Figure 6.16**. The two net radiation maximums occur in April and August. These dates coincide to the time when the Sun is directly overhead at solar noon and the intensity of insolation is at its greatest. All locations between the Tropic of Cancer (23.5°N) and the Tropic of Capricorn (23.5°S) have two days when the Sun is directly overhead at solar noon. Consequently, Aden Khormaksar also experiences two peaks in average mean monthly temperature. The first occurs in June (32.2°C or 90.0°F), two months after the April net radiation maximum. The second peak takes place in September (31.2°C or 88.2°F) only one month after the secondary net radiation maximum in August. The coolest month is January with an average mean temperature of 25.1°C (77.2°F). Once again, a lag exists between the timing of the coolest mean monthly temperature and the lowest monthly value of net radiation. The lowest annual value of net radiation occurs in

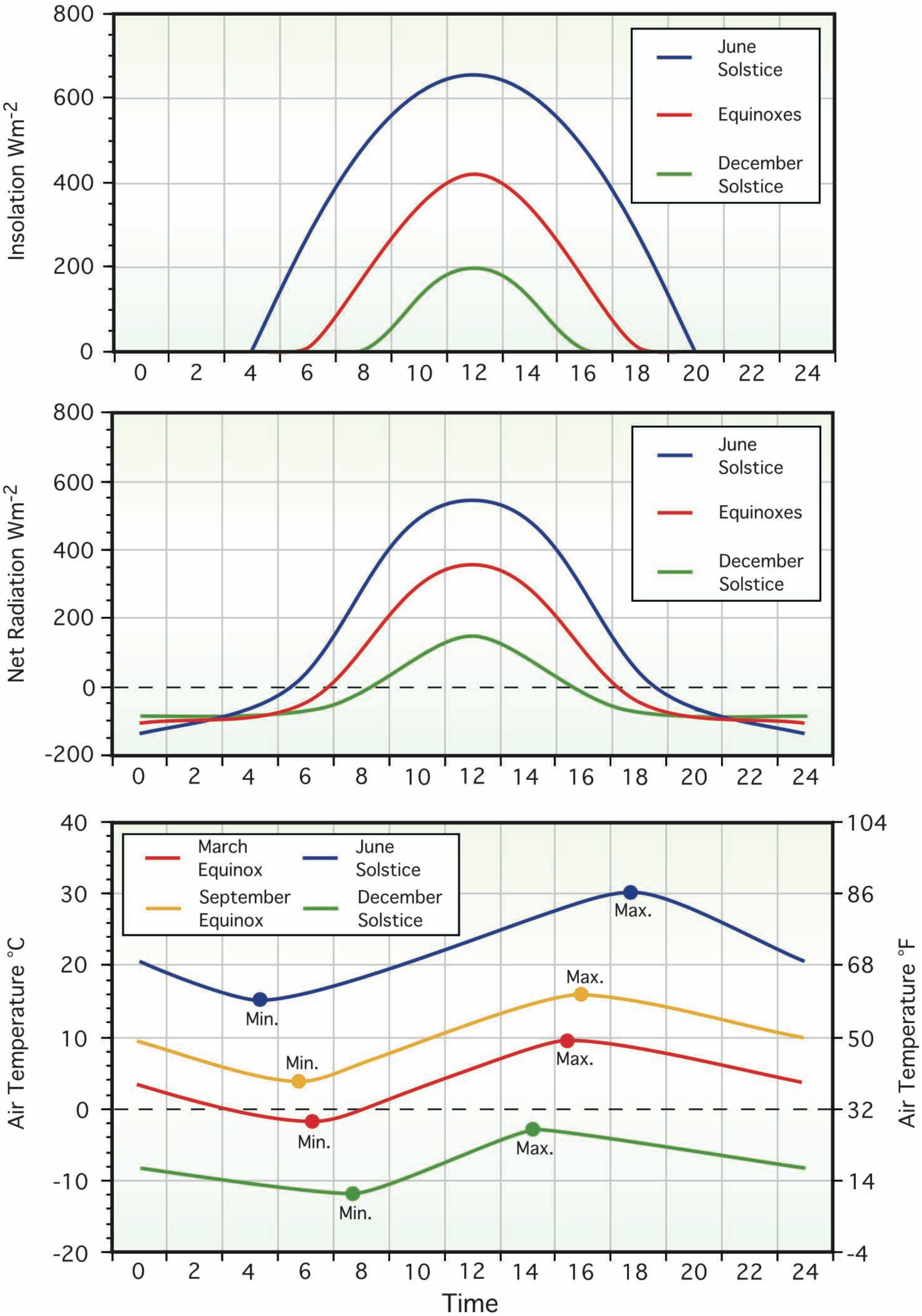

FIGURE 6.13 Hypothetical hourly variations in insolation, net radiation, and surface air temperature for a location at 45° North latitude for the two equinoxes, June solstice, and December solstice. *(Image Copyright: Michael Pidwirny)*

FIGURE 6.14 Locations for net radiation/temperature comparisons. *(Image Copyright: Michael Pidwirny)*

December when the Sun reaches its lowest altitude above the horizon (53.5° at solar noon) and day length is at a minimum (about 11 hours and 22 minutes).

The last of low latitude locations is Maputo, Mozambique (latitude 26°S). Of the three low latitude locations examined, Maputo's annual patterns of net radiation and average mean monthly surface air temperature are the most variable. This variability has also become monotonic in form: only one high and one low annually for both measures. This pattern will be a common feature in the remaining four locations examined. For Maputo, maximum net radiation and the highest average mean monthly temperature (25.8°C or 78.4°F) happen together in the month of January (**Figure 6.17**). The timing of this peak roughly coincides with summer in the Southern Hemisphere when day lengths are long and solar heights are at a maximum. This is the opposite of what occurs in the Northern Hemisphere. Lowest monthly temperatures

TABLE 6.3 Variation in annual net radiation, annual mean temperature, and annual temperature range for seven locations with different latitudes.

Location	Latitude	Annual Net Radiation W m^{-2}	Annual Mean Temperature °C (°F)	Annual Temperature Range °C (°F)
Singapore	1°N	132	26.9 (80.4)	1.5 (2.7)
Aden Khormaksar, Yemen	13°N	116	28.6 (83.5)	7.1 (12.8)
Maputo, Mozambique	26°S	72	22.4 (72.3)	7.4 (13.3)
Buenos Aires, Argentina	35°S	105	16.6 (61.9)	13.5 (24.3)
Lethbridge, Canada	50°N	45	5.5 (41.9)	27.0 (48.6)
Whitehorse, Canada	61°N	31	-0.9 (30.4)	32.4 (58.3)
Resolute, Canada	75°N	13	-16.4 (2.5)	37.5 (67.5)

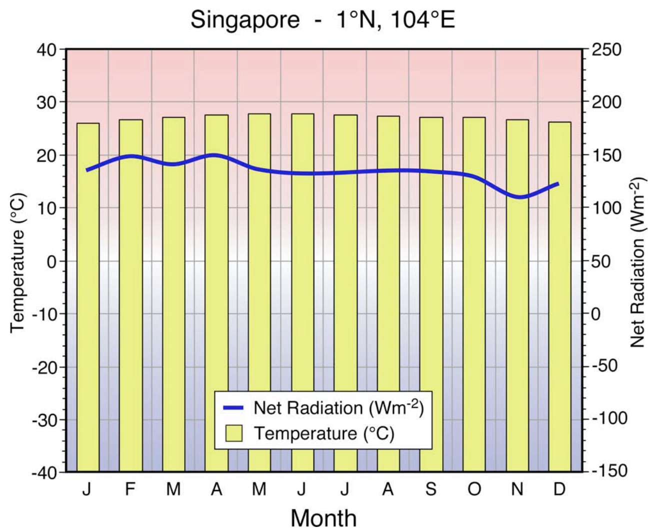

FIGURE 6.15 Relationship between mean monthly net radiation and surface air temperature for Singapore. Averages of mean monthly surface air temperatures were calculated for the period 1877 to 1988. Average mean monthly net radiation data from the Global Energy Balance Archive (GEBA). *(Image Copyright: Michael Pidwirny)*

occur in July (18.4°C or 65.1°F) one month after net radiation reaches its annual low.

Buenos Aires, Argentina (latitude 35°S) and Lethbridge, Canada (latitude 50°N) represent typical middle latitude locations. For both locations, variations in net radiation and monthly temperature are closely synchronized. Highest and lowest monthly temperatures for Buenoes Aires occur in December (23.5°C or 74.3°F) and July (10.0°C or 50.0°F), respectively (**Figure 6.18**). Accordingly, the annual range in surface air temperature is 13.5°C (24.3°F). Lethbridge experiences greater variations in net radiation and monthly temperature (**Figure 6.19**). This greater variation can be explained by the effect increasing latitude has on day length and angle of incidence. At 50°N, day length varies annually from 16 hrs and 18 minutes (June Solstice) to 7 hrs and 42 minutes (December Solstice), and maximum Sun angles range from 63.5° (June Solstice) to 16.5° (December Solstice) above the horizon. The highest monthly temperatures in Lethbridge occur in July (18.6°C or 65.5°F), while the lowest temperatures occur in January (-8.4°C or 16.9°F). Thus, Lethbridge's annual range in monthly temperature is 27°C (48.6°F), which is twice as great as Buenos Aires'. It is also important to note that four of the months have negative net radiation values. Most terrestrial locations

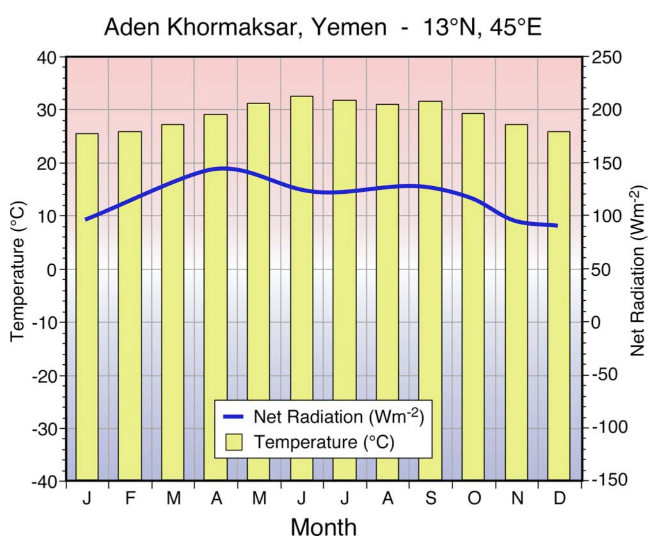

FIGURE 6.16 Relationship between mean monthly net radiation and surface air temperature for Aden Khormaksar, Yemen. Averages of mean monthly surface air temperatures were calculated for the period 1881 to 1990. Average mean monthly net radiation data from the Global Energy Balance Archive (GEBA). *(Image Copyright: Michael Pidwirny)*

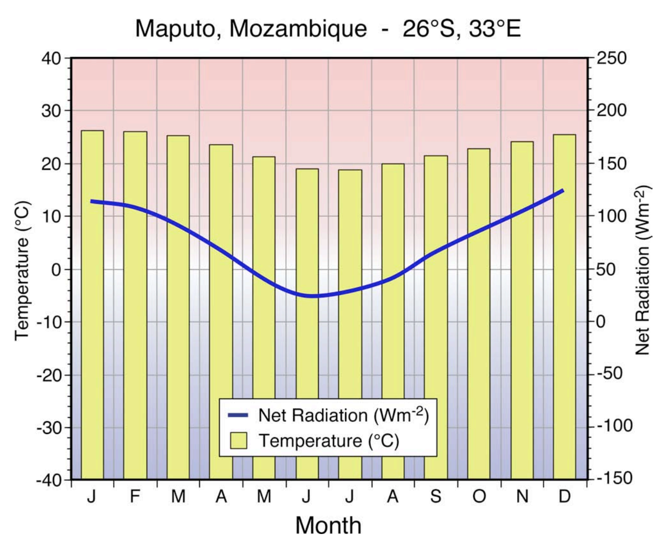

FIGURE 6.17 Relationship between mean monthly net radiation and surface air temperature for Maputo, Mozambique. Averages of mean monthly surface air temperatures were calculated for the period 1892 to 1990. Mean monthly net radiation data from the Global Energy Balance Archive (GEBA). *(Image Copyright: Michael Pidwirny)*

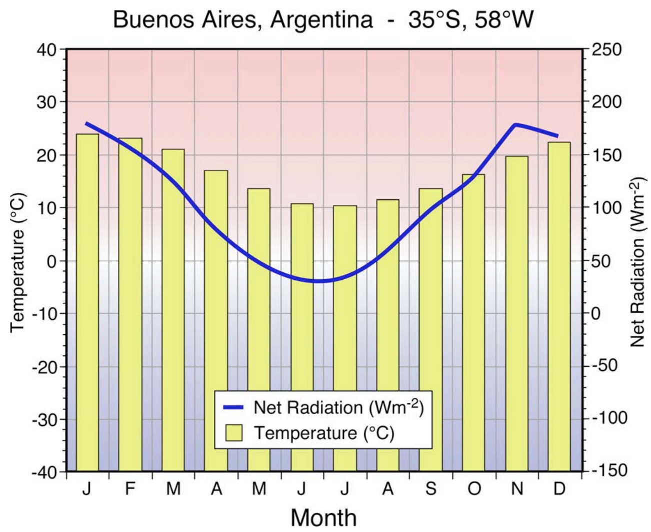

FIGURE 6.18 Relationship between mean monthly net radiation and surface air temperature for Buenos Aires, Argentina. Averages of mean monthly surface air temperatures were calculated for the period 1856 to 1989. Average mean monthly net radiation data from the Global Energy Balance Archive (GEBA). *(Image Copyright: Michael Pidwirny)*

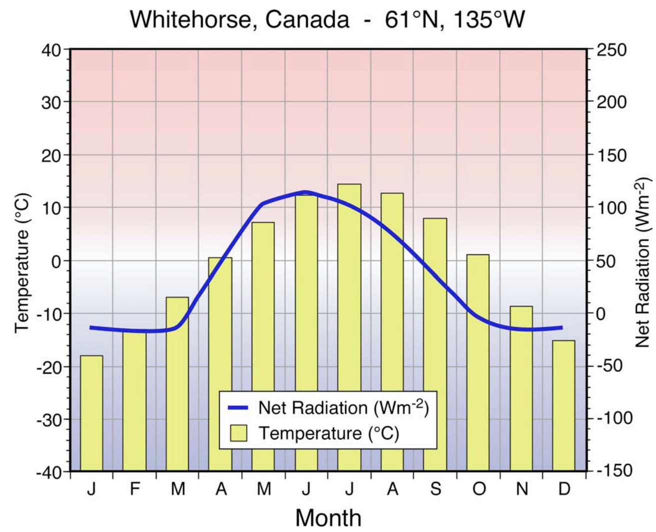

FIGURE 6.20 Relationship between mean monthly net radiation and surface air temperature for Whitehorse, Canada. Averages of mean monthly surface air temperatures were calculated for the period 1942 to 1990. Average mean monthly net radiation data from the Global Energy Balance Archive (GEBA). *(Image Copyright: Michael Pidwirny)*

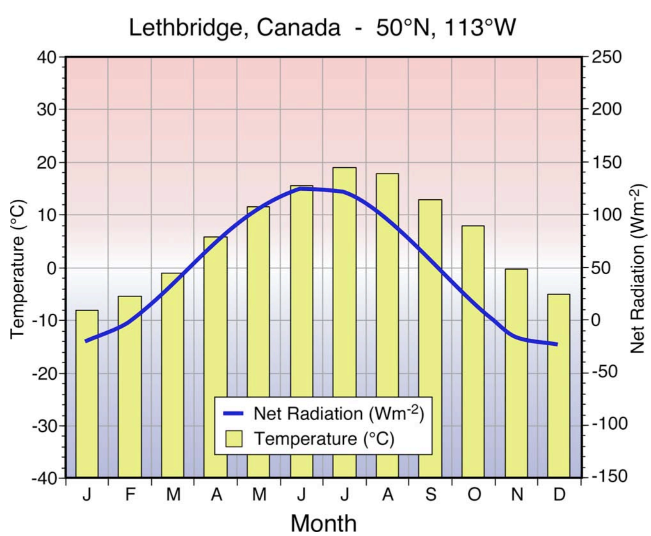

FIGURE 6.19 Relationship between mean monthly net radiation and surface air temperature for Lethbridge, Canada. Averages of mean monthly surface air temperatures were calculated for the period 1936 to 1990. Average mean monthly net radiation data from the Global Energy Balance Archive (GEBA). *(Image Copyright: Michael Pidwirny)*

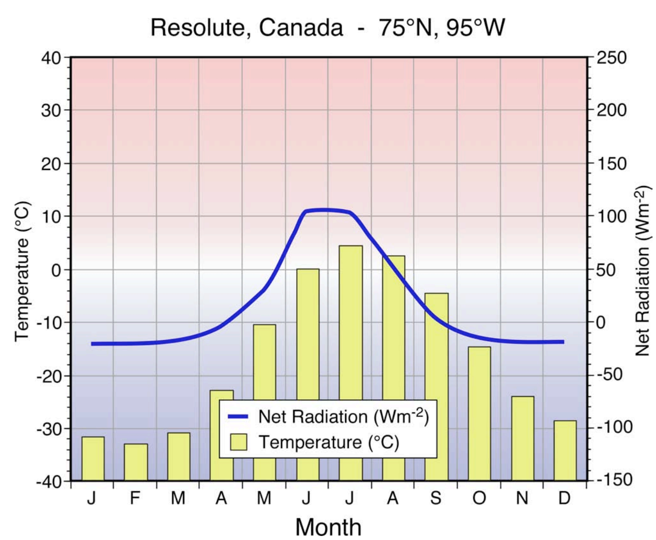

FIGURE 6.21 Relationship between mean monthly net radiation and surface air temperature for Resolute, Canada. Averages of mean monthly surface air temperatures were calculated for the period 1948 to 1990. Average mean monthly net radiation data from the Global Energy Balance Archive (GEBA). *(Image Copyright: Michael Pidwirny)*

poleward of 35°N and S have a period during the year when net radiation is negative. The length of this period generally becomes longer as latitude increases. Periods of negative net radiation arise when outgoing longwave radiation exceeds incoming radiation.

The final two locations examined are found in the high latitudes: Whitehorse, Canada (latitude 61°N) and Resolute, Canada (latitude 75°N). Whitehorse has a six-month period when net radiation is less than zero (**Figures 6.20** and **6.21**). The highest and lowest monthly temperatures for Whitehorse take place in July (14.0°C or 57.2°F) and January (-18.4°C or -1.1°F) respectively, and the annual range in temperature is 32.4°C (58.3 °F). Resolute experiences an additional month of negative net radiation because of its higher latitude and only two months have average temperatures above freezing (Figure 6.21). This location's coldest month is February with a temperature of -33.3°C (-27.9°F). Similar to the other locations examined, the warmest month occurs in July with a temperature of only 4.2°C (39.6°F). Annual temperature range is an extreme 37.5°C (67.5°F)!

GLOBAL TEMPERATURE PATTERNS

AVERAGE MEAN ANNUAL SURFACE AIR TEMPERATURES

Figure 6.22 describes average mean annual temperature data for the Earth for the period 1959-1997. The patterns of temperature distribution on this figure are strongly controlled by latitude's influence on solar radiation input. Highest surface air temperatures are found just outside the equator over the tropical deserts where skies are frequently clear and sunlight is intense. Poleward of these zones temperature gradually drops until we reach global minimums over the North and South Pole. The latitudinal banding of surface air temperature is partially upset by the fact that water bodies react differently than land surfaces in terms of heating and cooling. The figure also shows the effect of altitude (e.g., Himalayas and Andes mountains) and albedo (Greenland and Antarctica) on surface air temperature. As discussed earlier in this chapter, temperatures tend to drop with altitude because of greater loss of outgoing longwave radiation. Surfaces with a high

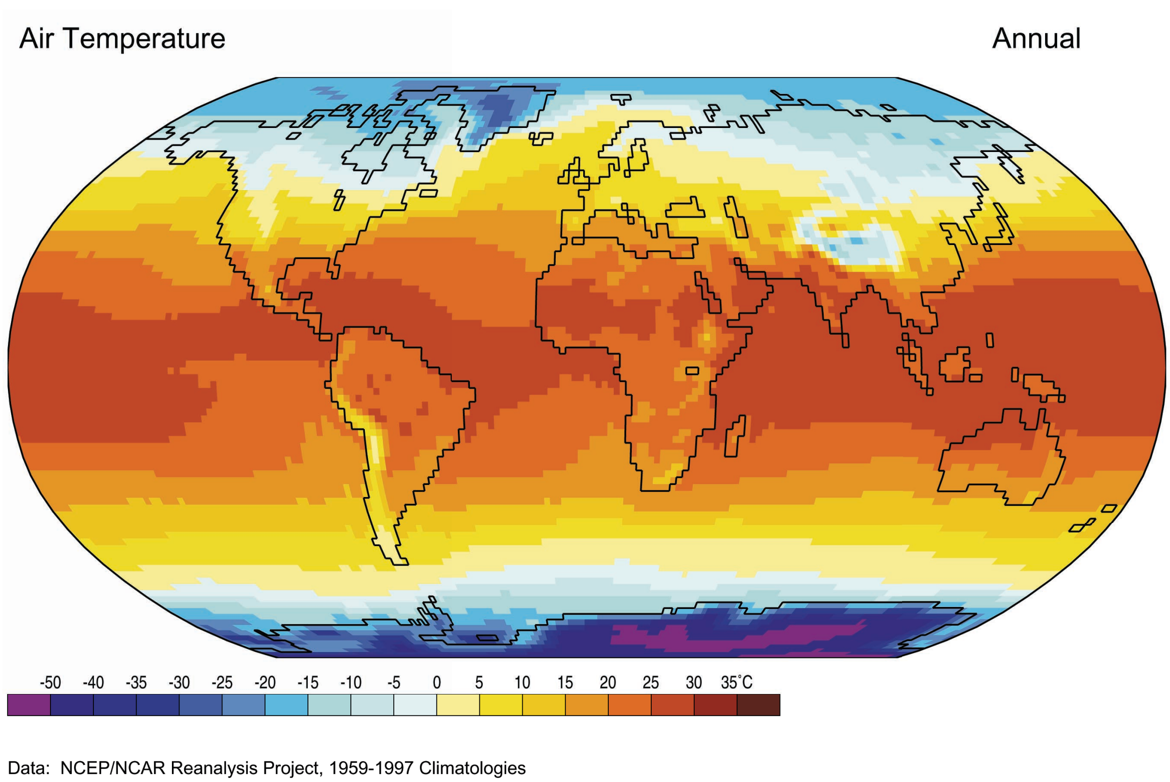

FIGURE 6.22 Average global mean annual surface air temperature, 1959-1997. Note the effect off latitude on the pattern of surface temperature. Warmest temperatures are near the equator, while coldest temperatures are near the poles. *(Figure courtesy of J.J. Shinker, Department of Geography, University of Oregon)*

albedo have limited absorption of incoming shortwave radiation, which is required for the generation of heat energy.

January Average Surface Temperatures

Figure 6.23 illustrates the Earth's temperature distribution patterns for an average January based on 39 years of data. Note that the spatial variations of temperature on this figure are mostly latitudinal. However, the horizontal banding of zones of similar temperature are somewhat upset by the fact that water heats up more slowly in the summer and cools down more slowly in the winter when compared to land surfaces. During January, much of the terrestrial areas of the Northern Hemisphere are below freezing. Some notable Northern Hemisphere cold-spots include the area around Baffin Island Canada, Greenland, Siberia, and the Plateau of Tibet. At the same latitude, temperatures over oceans tend to be warmer because of the water's ability to hold heat energy.

In the Southern Hemisphere, temperatures over the major land masses are generally greater than 20°C (68°F) with localized hotspots in west-central Australia, the Kalahari Desert in Africa, and the plains of Bolivia, Paraguay, and Argentina. The sub-tropical oceans are often warmer than land mass areas near the equator. At this latitude, land areas receive less incoming solar radiation because of the daily convective development of cumulus and cumulonimbus clouds. In the mid-latitudes, oceans are often cooler than land mass areas at similar latitudes. Terrestrial areas are warmer because of the rapid heating of land surfaces under frequently clear skies. Antarctica remains cold and below 0°C (32°F) due to the presence of permanent glacial ice, which reflects much of the solar radiation received back to space.

July Average Surface Air Temperatures

In July, the Northern Hemisphere is experiencing its summer season because the North Pole is now tilted towards the Sun. Some conspicuous Northern Hemisphere hotspots include the south-central United States, Arizona and northwest Mexico, northern Africa, the Middle East, India, Pakistan, and Afghanistan (**Figure 6.24**).

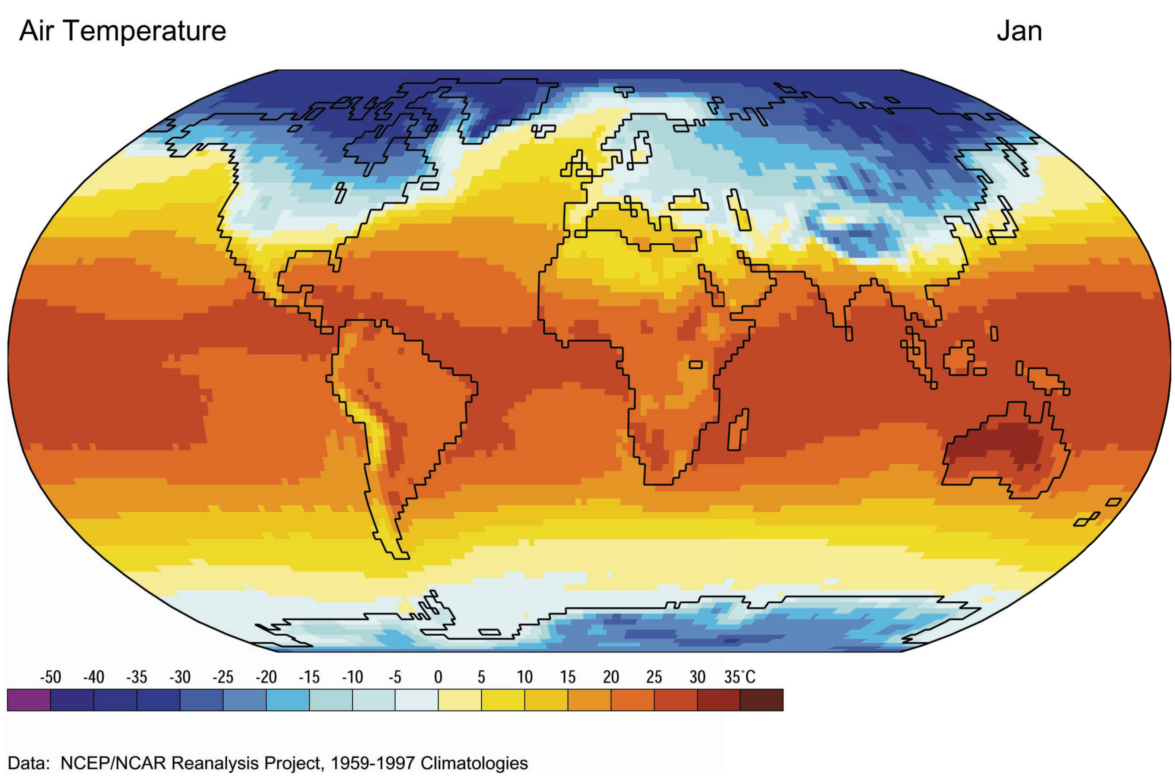

FIGURE 6.23 Average global mean January surface air temperature, 1959-1997. Note the expansion of cold temperatures in the Northern Hemisphere high latitudes and the warming of the Southern Hemisphere. *(Figure courtesy of J.J. Shinker, Department of Geography, University of Oregon)*

Temperatures over oceans tend to be relatively cooler because of the land's ability to heat quickly. Northern Hemisphere areas of cooler temperatures include Greenland, Canadian Rocky Mountains, and the Plateau of Tibet. In these regions, most of the incoming solar radiation is sent back to space because of the presence of reflective ice and snow.

In the Southern Hemisphere, temperatures over the major land masses are generally cooler than ocean surfaces at the same latitude. Antarctica is bitterly cold because it is experiencing total darkness. Also, note that Antarctica is much colder than the Arctic was during its winter season (compare **Figures 6.23** and **6.24**). The Arctic consists mainly of ocean. During the summer (July), this surface is able to absorb considerable quantities of sunlight, which is then converted into heat energy. The heat stored in the ocean is carried over into the winter season (January). Antarctica has a surface composed primarily of snow and ice. This surface absorbs only a small amount of the solar radiation during the summer. So it never really heats up and the amount of heat energy stored into the winter season is minimal.

Seasonal Temperature Variations

Figure 6.25 describes the annual range in global surface temperatures. The patterns seen on this map illustrate the idea that land and water have very different thermal characteristics. Near the equator, temperature ranges are very similar for the two surface types varying by about 5°C (9°F). This observation can be explained by the fact that in this region radiation input remains constant all year round. Outside this area, definite differences in temperature range become much greater over land masses because of the continental effect. Sub-polar regions in the center of North America and Asia experience temperature ranges greater than 40°C (72°F). In comparison, ocean surfaces at the same latitude only encounter an annual range of between 10° to 15°C (18° to 27°F) because they are moderated by the maritime effect.

Ocean Surface Temperatures

The Earth’s surface consists of about 30% land and 70% ocean. Measuring surface air temperature on land is relatively simple as weather stations are easy to set-up and

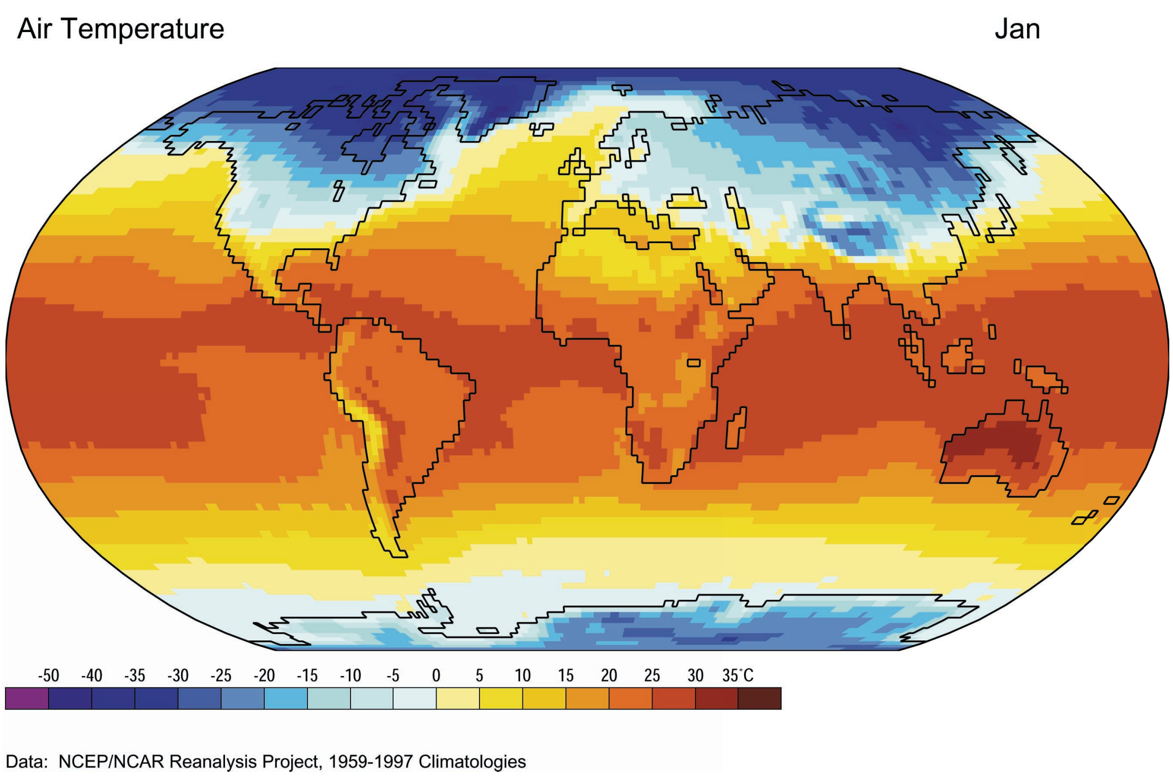

FIGURE 6.24 Average global mean July surface air temperature, 1959-1997. Note the expansion of cold temperatures in the Southern Hemisphere high latitudes and the warming of the Northern Hemisphere. *(Figure courtesy of J.J. Shinker, Department of Geography, University of Oregon)*

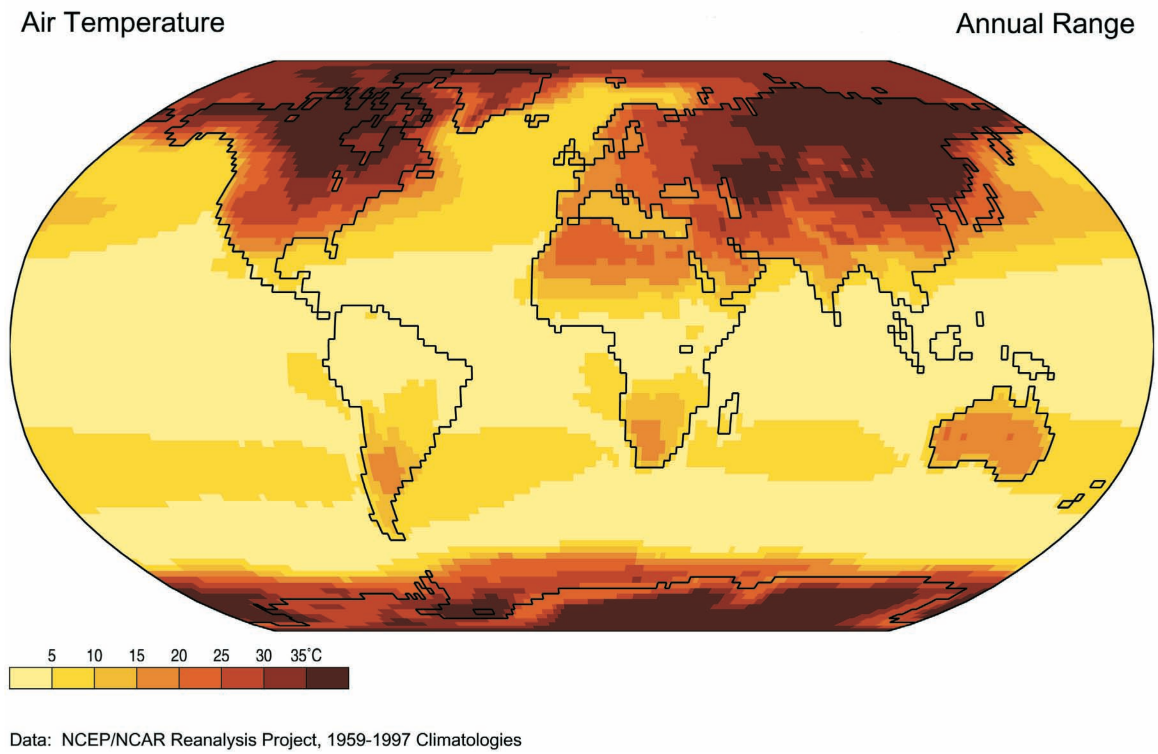

FIGURE 6.25 Global annual range in surface air temperature, 1959-1997. Calculated by determining the difference between the highest and lowest average monthly mean temperature for the period 1959-1997. *(Figure courtesy of J.J. Shinker, Department of Geography, University of Oregon)*

maintain. As a result, a network of over 15,000 land-based weather stations is currently operating providing daily climatic measurements. Measuring surface air temperature over our planet's oceans is a much more difficult task. Part of this difficulty is related to the fact that we do not have permanent stationary communities on the open ocean surface. Yet, we do have a large number of ships moving about the oceans at any moment in time. The *World Meteorological Organization* (WMO) uses some of these ships as roving weather stations. About 7000 ships take routine real-time measurements of ocean conditions that are transmitted to weather data processing centers. As one might guess, reports from these ships are concentrated along the major shipping routes, mainly in the North Atlantic and North Pacific Oceans. Data collection in the Southern Hemisphere oceans is sparse.

Several nations also have created a network of remote automated weather stations that are mounted on permanently anchored buoys. In the United States, the *National Data Buoy Center* (NDBC) manages the operation and maintenance of about 65 **weather station buoys** in coastal and offshore waters from the western Atlantic to the Pacific Ocean around Hawaii, and from the Bering Sea to the South Pacific. NDBC's weather station buoys come in four sizes: 3, 10, and 12 m (10, 33, and 39 ft) circular hulls, and a 6 m (20 ft) boat-shaped hull. The type of hull used typically depends on the intended location of deployment (**Figure 6.26**). Locations with frequent storms and big ocean swells require larger hulls or a boat shaped hull to reduce the chance of capsizing. NDBC's moored buoys measure barometric pressure, wind direction, wind speed, and air and sea temperature. The instrument used to measure surface air temperature is mounted on a tower between 4 to 10 m (13 to 33 ft) above the sea surface. Weather measurements made by the buoys are transmitted to one of National Oceanic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellites (GOES) once every hour. From the satellite, the data are then transmitted to a weather data processing center in Virginia, USA.

Scientists also measure the temperature of the ocean's surface (**Figure 6.27**). The development of weather in the lower atmosphere is often related to sea surface temperatures. For example, in the tropical Pacific Ocean occasional variations in the sea surface temperature known as **La Niña** and **El Niño** can occur. These temperature

FIGURE 6.26 Remote weather station buoy with a 6-meter boat shaped hull. *(Source: NOAA)*

variations have been linked to a number of changes in regional weather conditions around the world. Both ships and stationary buoys are used to collect sea surface temperature data. Yet, the value of these measurements is limited because significant portions of the Earth's ocean surface are not being monitored. Over the last two decades, scientists have used a variety of sensors aboard a number of space satellites to more effectively measure sea surface temperatures. Comparisons of the satellite sea surface temperature data with measurements taken by ships and remote weather station buoys have shown them to be very accurate.

THE GLOBAL HEAT BALANCE

Figure 6.28 describes the annual values of net shortwave and net longwave radiation from the South Pole to the North Pole. On closer examination of this graph one notes that the lines representing incoming and outgoing radiation do not have the same values. From 0 to about 35° latitude North and South incoming solar radiation exceeds outgoing terrestrial radiation and a surplus of energy exists. The reverse holds true from 35 to 90° latitude North and South and these regions have a deficit of energy. Surplus energy at low latitudes and a deficit at high latitudes results in energy transfer from the equator to the poles. It is this **meridional transport** of energy that causes atmospheric and oceanic circulation. If there were no energy transfer the poles would be 25°C (45°F) cooler, and the equator 14°C (25°F) warmer!

The redistribution of energy across the Earth's surface is accomplished primarily through three processes: sensible heat flux, latent heat flux, and surface heat flux in the oceans. **Sensible heat flux** is the process where heat energy is transferred from the Earth's surface to the atmosphere by conduction and convection. This energy is then moved from the tropics to the poles by advection, creating atmospheric circulation. As a result, atmospheric circulation moves warm tropical air to the polar regions and cold air from the poles to the equator. **Latent heat flux** moves energy globally when solid and liquid water is converted into vapor. This vapor is often moved by our planet's atmospheric circulation both vertically and horizontally to cooler locations where it is condensed as rain or is deposited as snow releasing the heat energy stored within it. Finally, large quantities of radiation energy are transferred into the Earth's tropical oceans by **surface heat flux**. The energy enters these water bodies at the surface when absorbed radiation is converted into heat energy. The warmed surface water is then transferred downward into the water column by conduction and convection. This heat energy is then horizontally transferred from low latitudes to high latitudes by ocean currents.

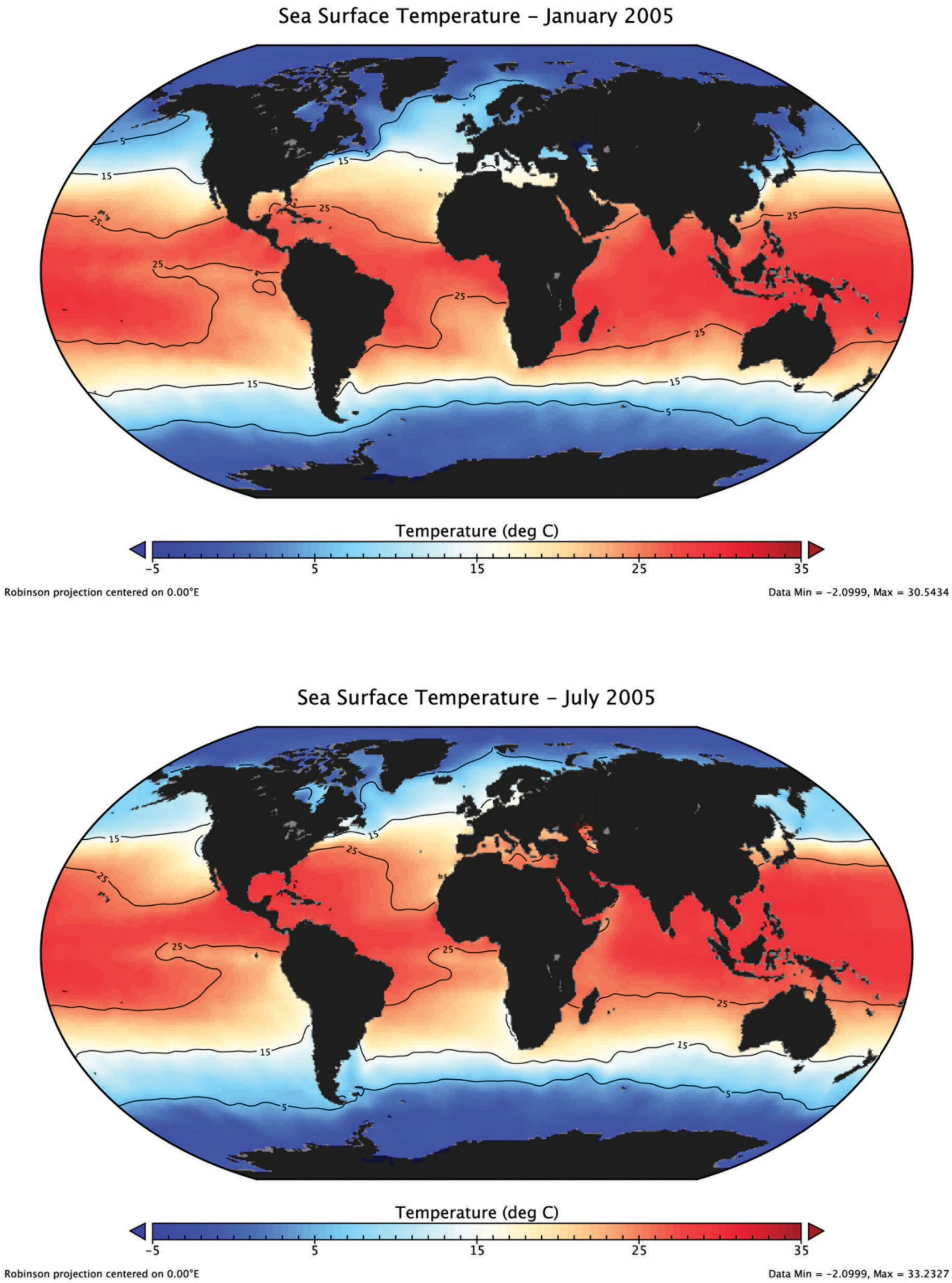

FIGURE 6.27 January and July mean monthly global sea surface temperatures for the the year 2005. *(Source: NOAA - National Oceanographic Data Center)*

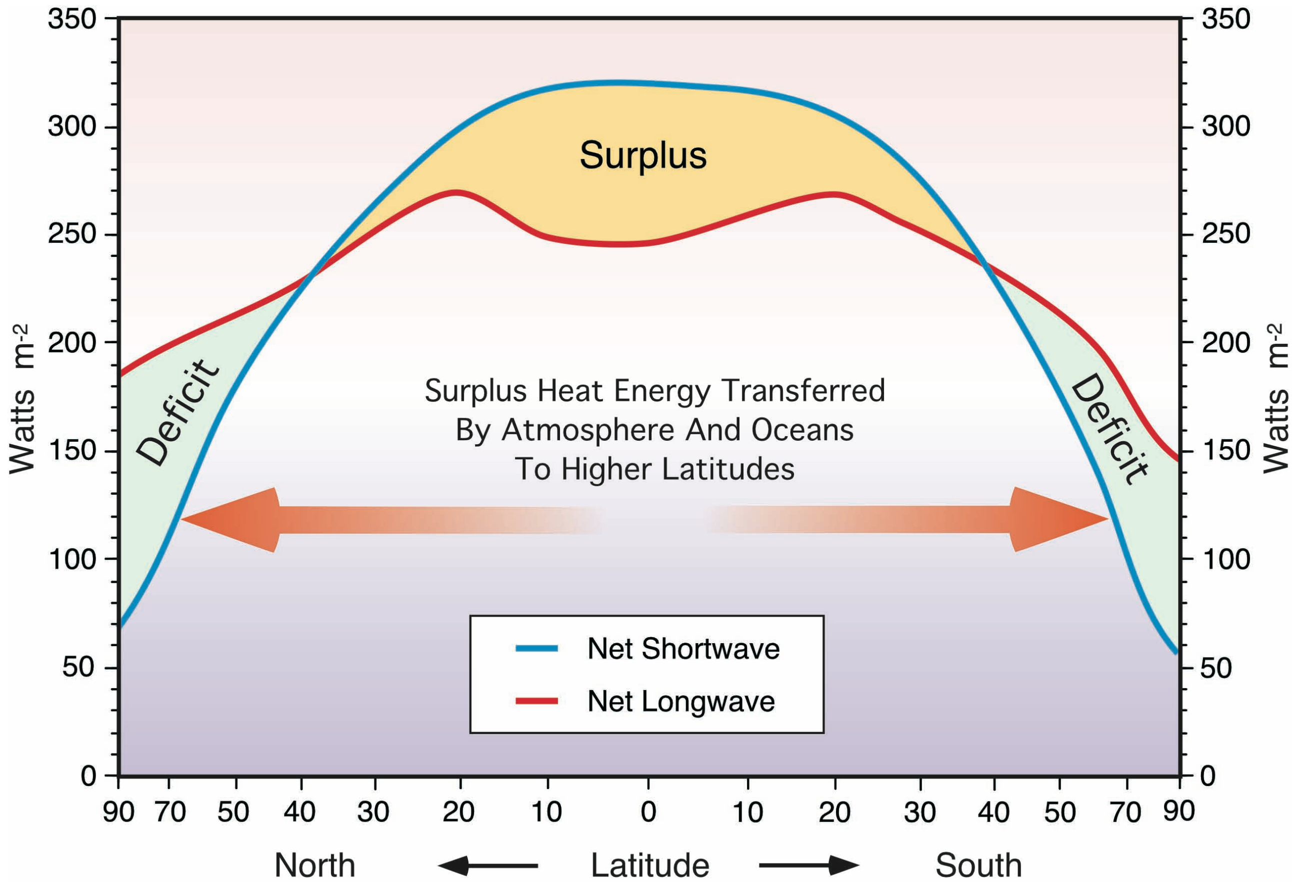

FIGURE 6.28 Global balance between net shortwave and net longwave radiation. Tropical and subtropical locations have a surplus of heat energy available, while locations in the middle and high latitudes have a deficit situation. *(Image Copyright: Michael Pidwirny)*

CHAPTER SUMMARY

- The reception of radiation at the Earth's surface causes the heating of the lower atmosphere. Because radiation input fluctuates on a variety of time scales so does temperature.
- We actively measure the fluctuations of surface air temperature because of their importance to our daily activities. These measurements are made with a number of specialized devices that are placed in instrument shelters known as Stevenson Screens.
- Daily measurements of surface air temperature are made at more than 15,000 locations distributed all over our planet. Standardized measurements of surface air temperature are often expressed to some distinct period of time like a day, month, or year.
- We also calculate from surface air temperature measurements a variety of values that determine means, ranges, normals, and extremes for these time periods.
- Latitude, altitude, cloud cover, ocean currents, and maritime and continental effects can all influence surface air temperature.
- Latitude influences air temperature by controlling the input of radiation, which generates heat energy at the ground surface.
- Locations near the equator tend to have relatively high surface air temperatures that vary little during the year.
- As we move away from the equator, surface air temperature becomes more seasonally variable because of annual changes in day length and the Sun's angle of incidence.
- Surface air temperatures have a tendency to drop with increasing altitude. This occurrence is due to the fact that elevated locations have greater losses of heat energy due to longwave emission.
- The presence of cloud cover tends to moderate air temperature through the greenhouse effect. Locations without significant cloud cover, like deserts, experience extreme fluctuations in daily temperatures.
- Ocean currents can transport cold or warm water across our planet modifying the climate of locations in the path of these flows.
- The type of surface found directly beneath near surface air also influences its temperature characteristics. Air located above land surfaces experiences more extreme heating and cooling over time. Water surfaces tend to moderate daily and annual fluctuations in air temperature.
- All places on the Earth show some degree of daily and annual variation in surface air temperature. These fluctuations are mainly due to temporal changes in net radiation: the balance between input and output of shortwave and longwave radiation.
- On a daily or annual cycle, temperatures tend to rise when net radiation is increasing. Decreasing temperatures are associated with declines in net radiation. The range of temperature change that occurs with a daily or annual cycle is of course controlled by the quantity of change that occurs in net radiation.
- Examining the exchanges of radiation input and output indicates that an imbalance exists across the Earth's surface. Places from the equator to 35°N and S have a surplus of energy, while areas outside of this zone have a deficit. Through the circulation of the atmosphere and the ocean this imbalance is corrected by the meridional transport of energy.
- Atmospheric and oceanic circulation moves this energy via three processes: sensible heat flux, latent heat flux, and surface heat flux. This transport of energy plays an important role in warming the higher latitudes and cooling off the tropics.

IMPORTANT TERMS

Absorption	**Continentality**	**El Niño**
Annual mean temperature	**Convection**	**Emission**
Annual temperature range	**Cumulus**	**Fahrenheit scale**
Celsius scale	**Cumulonimbus**	**Global circulation**
Conduction	**Daily mean temperature**	**Greenhouse effect**
Continental effect	**Daily temperature range**	**Greenhouse gas**

[Heat](#)
[Heat energy](#)
[La Niña](#)
[Latent heat flux](#)
[Liquid-in-glass thermometer](#)
[Longwave radiation](#)
[Maritime effect](#)
[Maximum Minimum Temperature System](#)
[Maximum thermometer](#)
[Meridional transport](#)
[Meteorological extreme](#)
[Meteorological normal](#)
[Minimum thermometer](#)
[Monthly mean temperature](#)
[Net radiation](#)
[Ocean current](#)
[Radiation](#)
[Sensible heat flux](#)
[Snowline](#)
[Stevenson Screen](#)
[Surface air temperature](#)
[Surface heat flux](#)
[Thermal conductivity](#)
[Thermister](#)
[Thermometer](#)
[Thunderstorm](#)
[Weather station buoy](#)

CHAPTER REVIEW QUESTIONS

1. Explain how maximum and minimum thermometers determine the highest and lowest temperatures during a day.
2. Why are Stevenson Screens used to house thermometers for recording surface air temperature? How is their unique construction related to the process of recording temperature?
3. Describe how mean daily, mean monthly, and annual temperatures are calculated.
4. Discuss how latitude influences the annual cycle of air temperature through net radiation for locations near the equator, the mid-latitudes, and the high latitudes.
5. Describe how the five factors of latitude, altitude, cloud cover, ocean currents, and maritime and continental effects influence surface air temperature on the Earth.
6. Discuss the relationship between insolation, net radiation, and daily changes in surface air temperature for a typical location at 45°N latitude. Consider this relationship for the following points in time: the December solstice, the March equinox, the June solstice, and the September equinox.
7. Explain how latitude influences the annual changes in air temperature through net radiation. Use Figures 6.15, 6.17, 6.19, and 6.21 as visual aids in this discussion.
8. How is surface air temperature measured over the world's oceans?
9. Considering the global map of annual surface air temperature in Figure 6.22, explain how spatial variations in insolation received and cloud cover, the maritime effect, and the continental effect produce the patterns observed.
10. Discuss the energy imbalance that exists between the input and output of radiation across the Earth's surface. How does atmospheric and oceanic circulation help to reduce this disparity and moderate temperatures on our planet?

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