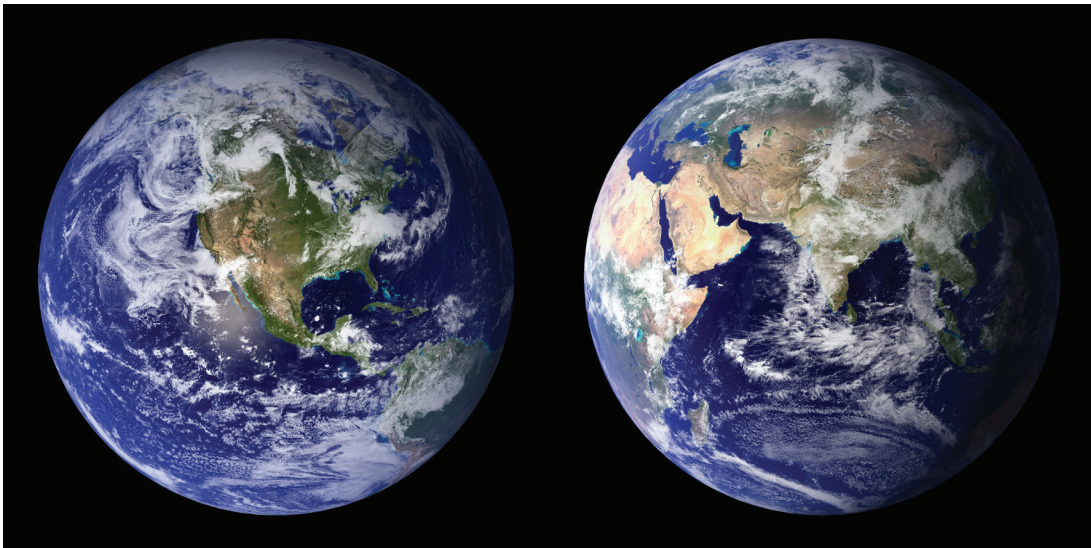


The  
**Teacher-Friendly**  
Guide™

to Climate Change



Edited by Ingrid H. H. Zabel, Don Duggan-Haas, & Robert M. Ross

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On the front cover: the "Blue Marble." Composite images produced by NASA in 2001-2002.

On the back cover: Atmospheric CO<sub>2</sub> concentration at Mauna Loa Observatory from 1958 to 2014 (NOAA).



# Chapter 6: US Regional Climates, Current and Future

## Describing Climates

The United States—which extends south to the tropics and north to the Arctic Circle, and which has over 12,000 miles of coastline as well as vast inland regions—has within its borders a wide variety of regional climates. Each of these regional climates—from the equatorial **wetlands** of Florida to the arid deserts of Arizona—is impacted by the changing global climate, but these impacts are and will not be uniform. Coastal communities are being affected by rising sea levels and increased **storm surges**, while desert communities may be facing longer and more frequent **droughts** and heat waves. Ski resorts in the Rocky Mountains may have to adapt to less snowfall and smaller **snowpacks**, while communities in the Northeast are experiencing more heavy rainfalls. In this section, we present an overview of the existing regional climates and the impact that climate change will have on these regional climates in the future.

A commonly used way to categorize climate is with the Köppen-Geiger map, developed by Wladimir Köppen in the late 19<sup>th</sup> century and early 20<sup>th</sup> century and refined by Rudolf Geiger (see *Box 6.1*). The US contains all five main climate groups of the Köppen-Geiger map (Equatorial, Arid, Warm Temperate, Continental, and Polar). For the purposes of discussion, in this chapter we divide the contiguous US into seven regions (Northeast, Southeast, Midwest, South Central, Northwest Central, Southwest, and West), and we consider Hawaii and Alaska separately. We will follow the sun as it rises in the east and moves westward, starting at the easternmost point in the US—West Quoddy Head, Maine—and ending at the westernmost point—Cape Wrangell, Alaska.

Another way of describing climate is through **climate normals**: averages of climate variables over 30-year periods. These can be useful for comparison purposes, as an indicator (though not the only one) of how climate has changed from one 30-year period to another. *Figure 6.1* shows averages over the period of 1981-2010 of annual minimum temperature, maximum temperature, and precipitation for the contiguous US.

This chapter presents projections of future climate that come from **climate models**: numerical simulations performed on a computer that incorporate scientists' best understanding of the interactions, **forcings**, and **feedbacks** within the Earth's climate system. A useful analogy for building and working with a climate model is that of trying to understand a complex sports car without looking under the hood (*Box 6.2*).

**wetland** • land region where the soil is covered or saturated with water, either for part or all of the year.

**storm surge** • a large volume of ocean water pushed onto land by offshore winds during a storm.

**drought** • a long period of unusually low rainfall, resulting in lack of water for plants, animals, and people.

**snowpacks** • snow accumulated over time, often in mountainous areas that have a long cold season. When snowpack melts it feeds streams and rivers.

**climate normal** • thirty-year averages of variables such as daily temperature, rainfall, snowfall, and frost and freeze dates that can be compared with thirty-year averages of these variables from other time periods.

## CHAPTER AUTHORS

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## Northeast

**climate model** • a computer-generated simulation of the Earth's climate system, projected through time.

**forcings** • a change that has a directional impact on what is being changed (e.g., a solar forcing on the Earth directly impacts the Earth's heat absorption).

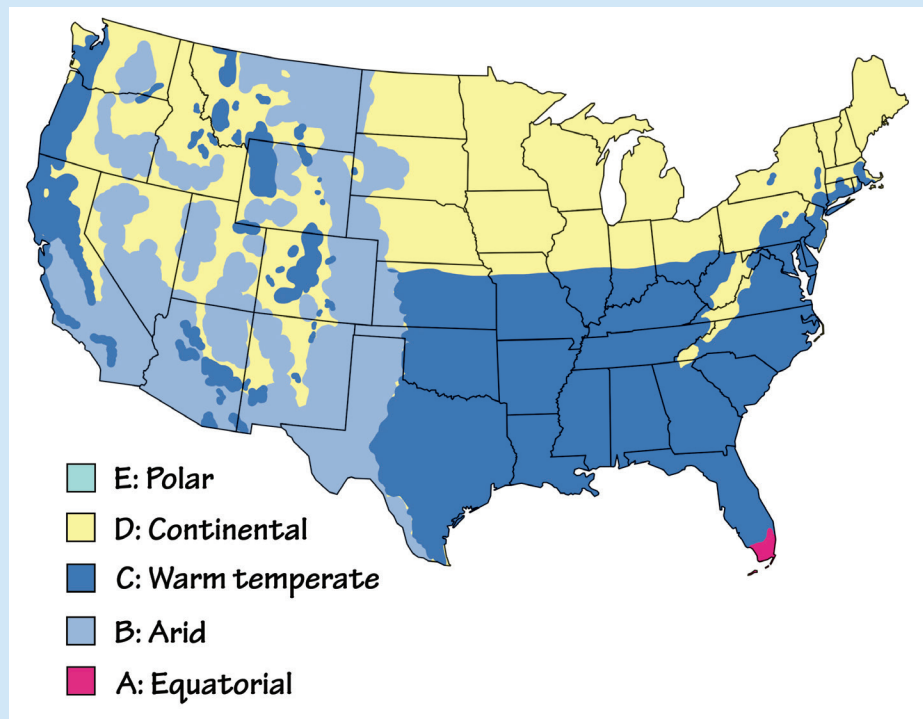
**feedback** • the response of a system to some change that either balances/opposes or reinforces/enhances the change that is applied to a system. Balancing feedback (sometimes called negative feedback) tends to push a system toward stability; reinforcing feedback (sometimes called positive feedback) tends to push a system towards extremes.

**Köppen system** • a commonly used system of climate categorization developed by Russian climatologist Wladimir Köppen. It is based on the kinds of vegetation that areas sustain, and defines 12 climate types: rainforest, monsoon, tropical savanna, humid subtropical, humid continental, oceanic, Mediterranean, steppe, subarctic, tundra, polar ice cap, and desert. Updated by Rudolf Geiger, it has been refined to five groups each with two to four subgroups.

# US Regional Climates

## Box 6.1: Köppen-Geiger maps

The Köppen-Geiger map is based on the kinds of vegetation areas can sustain. As originally conceived by Köppen, it defined 12 climate types, many of which are familiar: rainforest, **monsoon**, tropical **savanna**, humid subtropical, humid continental, oceanic, Mediterranean, **steppe**, subarctic, **tundra**, polar ice cap, and desert. The updated version has five main climate groups, each with two to four subgroups. In the following sections we refer to this map and the lettered climate categories (A, B, C, D, E) described in the figure legend.



*Köppen-Geiger map of the continental United States. (See Teacher-Friendly Guide website for a full color version.)*

## 1. Northeast

### 1.1 Description

The sun first rises in the United States in West Quoddy Head, Maine. Maine is one of the states in the Northeastern US, which also includes New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, Pennsylvania, New Jersey, Delaware, and Maryland. The Northeast shares a border with Canada, the Atlantic Ocean, and two of the Great Lakes: Lake Ontario and Lake Erie. Climate, of course, does not follow state boundaries, so as with all the regions in this chapter the climate characteristics of this region can overlap with those of neighboring regions.



# US Regional Climates



6

## Northeast

**monsoon** • a seasonal wind pattern in the Indian Ocean and South Asia which reverses direction between southwesterly and northeasterly, creating a wet season in summer and a dry season in winter.

**savanna** • a grassland in tropical or subtropical regions.

**steppe** • a large, flat, dry grassland area.

**tundra** • a region and climate zone with frozen ground (PERMAFROST) and no trees.

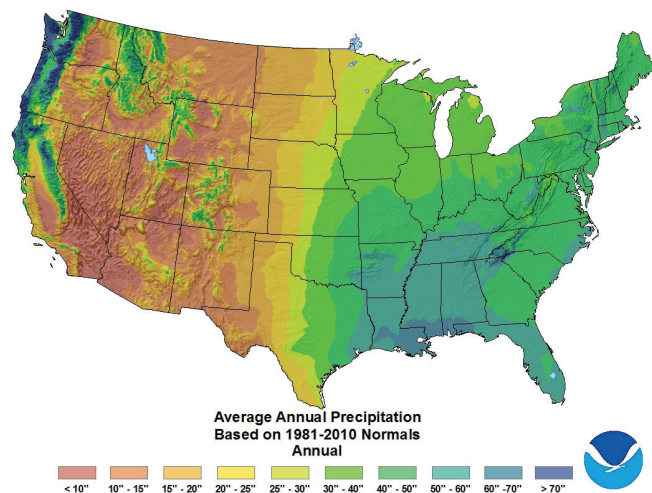
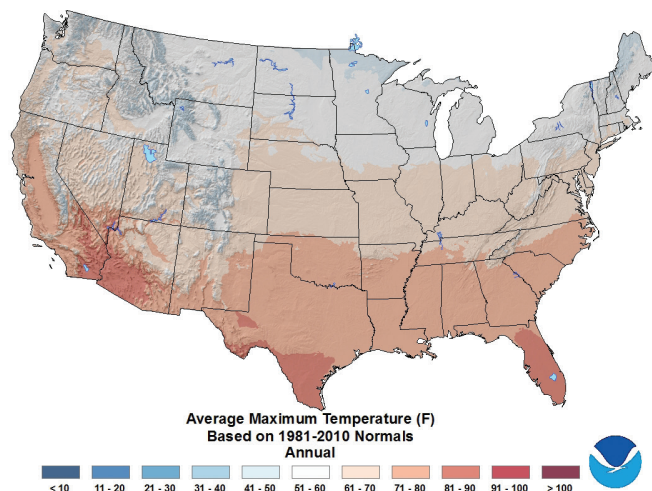
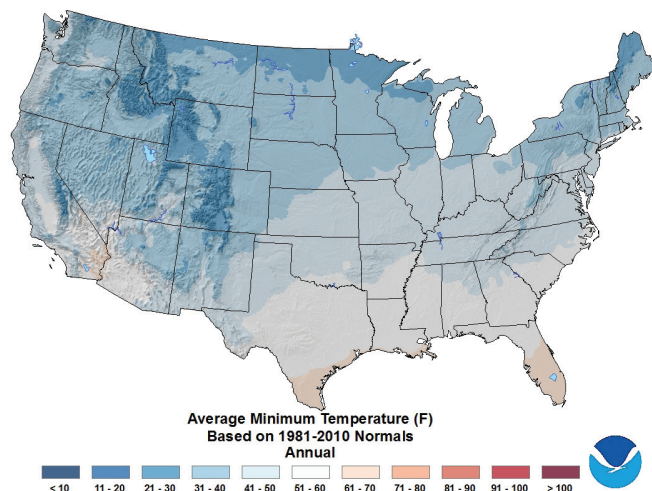


Figure 6.1: Maps of 1981-2010 climate normals (30-year averages for this time period) for the contiguous United States: A) annual minimum temperature (°F); B) annual maximum temperature (°F); and C) annual precipitation (inches). (See Teacher-Friendly Guide website for a full color version.)



## Northeast

**relative humidity** • the ratio of the water vapor density in the air to the maximum water vapor density possible in the air at a given temperature and pressure (the saturation water vapor density).

**solar radiation** • electromagnetic energy emitted by the Sun.

# US Regional Climates

## Box 6.2: The climate system as a fancy sports car<sup>1</sup>

Imagine the Earth's climate system as a fancy sports car owned by a playful friend. Your friend is happy to let you look and listen to the car and will on occasion give you a ride in it. But he's unwilling to let you look under the hood or study the user's manual. If you want to try and understand how the car works, and maybe even build your own, you are going to need to be clever and use all the tools at your disposal to figure out how this car works.

This is very much like how Earth scientists try to understand the real world. The real world, even more so than the fancy sports car, is very complex and intricate. We are unable to look under reality's hood or read reality's user's manual. What we are able to do is to make careful observations, come up with hypotheses as to how the real world works, test our hypotheses with experiments, and create models to test and explore our understanding.

When you start to build your own car, the first thing you are going to gather are the major parts: a frame, an engine, wheels, rods, doors, spark plugs, fuel and so on. For the Earth's climate, instead of parts we have variables: ocean temperature, **relative humidity**, **solar radiation**, carbon dioxide (CO<sub>2</sub>) concentrations, and many others.

However, you need a plan to put your parts together. You need an understanding of some of the interactions between the parts you have and the function of your car. You know that fuel needs to be injected into the engine in a particular way. You know that the wheels need to be connected both to the engine and to the brakes if you ever want to actually drive your car. Earth scientists know that sunlight heats the surface of the Earth, which in turn heats the atmosphere. They know that warm air holds more water than cold air. Any successful climate model needs to have these elementary parts.

To put these parts together you need a design framework. For our car, this is an engineering schematic of the parts and their functionality. We know when brakes are applied, the velocity of the car decreases. For Earth scientists, this is typically in the form of code and equations. We know that precipitation falls as rain if the temperature is above freezing and falls as snow if the temperature is below freezing.

During our first attempt, there are many things we don't know. We know that there is an interaction between the stick shift and the engine. We know that there is some interaction between the oceans and the atmosphere. But we don't know the exact details. To begin to understand these unknowns we must make careful observations of the thing we're trying to model and come up with tentative hypothesis and theories. We can listen to the revving of the engine or make observations of ocean and atmospheric temperatures.

<sup>1</sup>This analogy is adapted from a blog post by Ben Brown-Steiner, "The Climate System as a Foreign Sports Car," originally published in the Climate Change 101 Blog, October 27, 2014. <http://climatechange101.blogspot.com/>



## Box 6.2: Continued

You then put together a scheme that you think might work like the real thing. You design some system (or write some code) that combines what you know with the things you have hypothesized. Because you know that you are uncertain about particular interactions, you make those parts easy to observe and easy to modify or swap out with another part. This is what often is described as a parameterization or a scheme in a climate model. It's a variable or equation that you know you'll have to tweak or change out later on.

For instance, after you run the car you notice that your car moves backwards when you think it should be moving forwards or your climate snows when it should be raining. You look carefully at your variables and design and equations and parameters and try to find the error. You may have had your wires mismatched or you may have had inaccurately represented the relationship between moisture and temperature.

The next step takes this newfound understanding and incorporates it into your next model. You fix your mistakes and you tune your parameterizations. Then you test it again and repeat the whole process over and over until your understanding grows. Fundamentally, this is the way that science functions. It is an interactive process. It's never ending. You test and tune and observe and reformulate and repeat. Eventually, if you are clever and lucky, your model gets better and you gain a deeper understanding.

Unfortunately, since we are not able to look at the actual fancy sports car (because our friend is too secretive) and since we will never see the inner workings of the real world, we are never going to have a perfect model. Models by definition are simplifications of the real thing. You strive to have a really good simplification that provides insight and understanding. And you keep trying. This is science.

## 1.2 Present Climate

The Northeast has two broad climate regions, described in the **Köppen system** (see Box 6.1) with prefixes D (moist, continental, mid-latitude) in the north and C (moist, subtropical, mid-latitude) in the south. "D" climates tend to have cold winters, while "C" climates experience hot, humid summers. Average temperatures can vary from summer to winter by as much as 22°C (72°F) in Maine and 16°C (61°F) in Maryland. The Northeast can get hot—Pennsylvania experienced a record high of 44°C (111°F) in 1936—but in general, the Northeast's climate is cool enough that even the states in its southern portion have average low temperatures below freezing during the winter.

Average annual precipitation typically ranges from about 90 to 125 centimeters (35 to 50 inches) in the Northeast, though a few spots receive over 150 centimeters (60 inches) of rain annually due to their location on the windward side of a mountain range. Coastal areas tend to get more rain than do inland areas, and flooding is common in the Northeast due to extreme rainfall events, as well as from snowmelt and ice jams.



## Northeast

**hurricane** • a rapidly rotating storm system with heavy winds, a low-pressure center, and a spiral arrangement of thunderstorms. These storm systems tend to form over the tropical ocean, and are classified as hurricanes, typhoons, or cyclones (depending on their location in the world) once winds have reached 199 kilometers per hour (74 miles per hour). See also TROPICAL CYCLONE.

**Nor'easter** • a storm, often severe, along the U.S. East coast which forms when warm air from the Atlantic Ocean meets cold air from the north and west.

**lake-effect snow** • snowfall caused by the movement of cold weather systems over a lake, in which an air mass picks up water from the lake and deposits it in the form of snow across an adjacent land mass.

**heat waves** • a prolonged period of extremely high air temperatures.

# US Regional Climates

The Atlantic Ocean and the Great Lakes influence the Northeast's climate heavily. The Atlantic Ocean has a moderating effect on the temperatures of coastal regions because of air masses that pass from the ocean over the coast, warming in winter and cooling in summer. It is also the source of **hurricanes** that originate close to the equator over the Atlantic. In addition, a **Nor'easter**—a severe winter storm that regularly batters the Northeast—can form when cold polar air mixes with warm moist air from the Atlantic Ocean. The Great Lakes and Lake Champlain produce **lake-effect snow**, a wintertime phenomenon that occurs when cold, Arctic air moves south and east across the lakes, warms and picks up moisture, and deposits it as snow over land to the east. The town of Montague, New York lies east of Lake Ontario and once received 195 centimeters (77 inches) of snow during a 24-hour period in 1997, an astonishing amount for a non-mountainous area. Parts of the Buffalo, NY area received as much as 224 centimeters (88 inches) of snow during a late November storm in 2014.

In addition to adjoining large bodies of water, the Northeast contains the northern part of the Appalachian Mountain chain, which influences the climates in its subregions. In the southern part of the Northeast, the Appalachians partially protect the east coast from the prevailing winds coming from the west and the interior of North America. They also limit moist, Atlantic air from traveling to the western subregions. Several times a year the mountainous topography, coupled with a high-pressure air mass, produces a phenomenon called cold air damming. Cold air from the Northeast that would normally flow around the high-pressure region is blocked by the mountains; so instead, it flows south along the eastern side of the mountain chain, rapidly channeling cold air to the Southeast.

The Northeast is the most densely populated region of the United States, with almost all the counties along the east coast from New Hampshire to Maryland having 300 or more people per square mile. New York City—the largest city in the US, with over 8 million people living within the city limits—and other coastal cities are vulnerable to extreme weather hazards, such as public health risks brought on by **heat waves** (see Box 6.3,) water supply contamination during flooding, and transportation disruptions and power outages from ice and snow storms. The Northeast experiences its share of these weather hazards, as well as drought and fog. In 2012, Hurricane Sandy devastated communities on the mid-Atlantic coast, and rainfall from Hurricane Irene in 2011 led to severe flooding inland as well as major damage along the coast. An ice storm in 1998 caused hundreds of thousands of Northeast residents to lose power for weeks.

## 1.3 Future Climate

Studies show that the Northeast's climate is changing right now, and that change has accelerated in the latter part of the 20th century. These changes include the following:

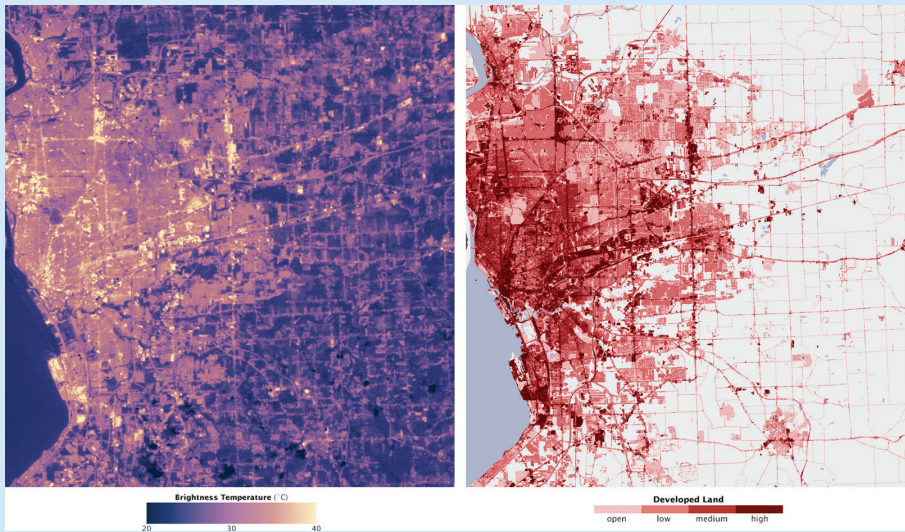
- Temperatures have increased almost 1°C (2°F) between 1895 and 2011.
- Average winter temperatures are 2°C (4°F) higher than in 1970.
- In New York State, average annual rainfall is up more than eight centimeters (three inches) since 1950, and precipitation across the Northeast has both increased and become more variable year to year.
- As of 2005, flowering bushes and fruit trees were blooming four to nine days earlier than they did in the 1960s.
- Sea level on the coast rose three centimeters (1.2 inches) per decade on average in the 20th century.
- Sea level is rising three to four times faster on the East Coast than it is worldwide.





## Box 6.3: Urban heat islands

During the summer, cities and metropolitan areas can be as much as 9°C (16°F) hotter than nearby rural areas as a result of absorption and re-radiation of heat by pavement and buildings. This phenomenon is called the urban heat island effect. In addition, the density of cars, air conditioning systems, and other machinery found in cities adds additional heat to their environments. Heat waves, already a public health threat, can be more deadly in cities because of this effect. The heat island effect can be reduced somewhat by planting trees and other vegetation, painting roofs white to reflect away sunlight, building green roofs (roofs with a layer of plants growing on them), or using pavement that reflects sunlight and increases water evaporation.



Satellite images of surface heat (A) and developed land (B) in the Buffalo, NY metropolitan area. (See Teacher-Friendly Guide website for a full color version.)

See Chapter 7: Climate Change Mitigation for more on the cooling effect of trees.

## Northeast

**climate model** • a computer-generated simulation of the Earth's climate system, projected through time.

**Climate models** (see Box 6.2) predict that the Northeast's average annual temperature will rise 2.5°C to 5.5°C (4.5°F to 10°F) by the 2080s if carbon emissions remain high, and 1.7°C to 3.3°C (3°F to 6°F) by the 2080s if carbon emissions are reduced dramatically.<sup>2</sup> By the latter part of 21st century, rising temperatures and increased humidity mean that summers in New Hampshire are likely to feel more like summers today in Virginia, North Carolina, or Georgia. More intense heat waves are a concern for the populations of large cities, dairy farmers, and anglers. In the last few decades, winters have been warming more rapidly than summers have, but models suggest that whether this trend continues will depend on future greenhouse gas emissions.

Winter precipitation is projected to increase by about 5% to 20% across the Northeast by the end of the 21st century. Because of warming temperatures,

<sup>2</sup> These projections for the Northeast and for other parts of the country can be found in the Third National Climate Assessment (US Global Change Research Program, 2014, <http://nca2014.global-change.gov/>). National Climate Assessments have been published in 2000, 2009, and 2014, with interim assessments in between. Additional assessments are expected approximately every four years.






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 Northeast
 

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# US Regional Climates

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Observed Change in Very Heavy Precipitation

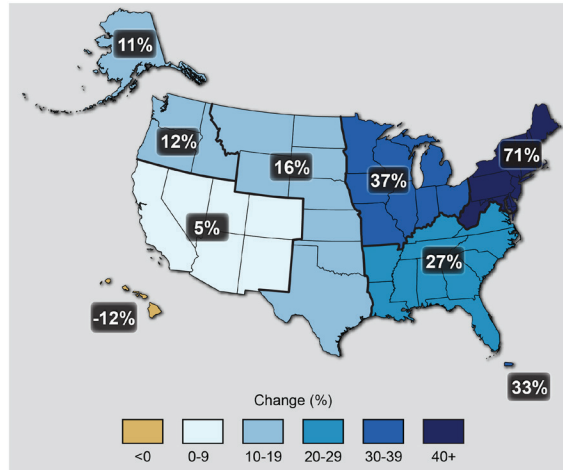


Figure 6.2: The map shows percent increases in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012 for each region of the continental United States. These trends are larger than natural variations for the Northeast, Midwest, Puerto Rico, Southeast, Great Plains, and Alaska. The trends are not larger than natural variations for the Southwest, Hawaii, and the Northwest. The changes shown in this figure are calculated from the beginning and end points of the trends for 1958 to 2012. (See Teacher-Friendly Guide website for a full color version.)

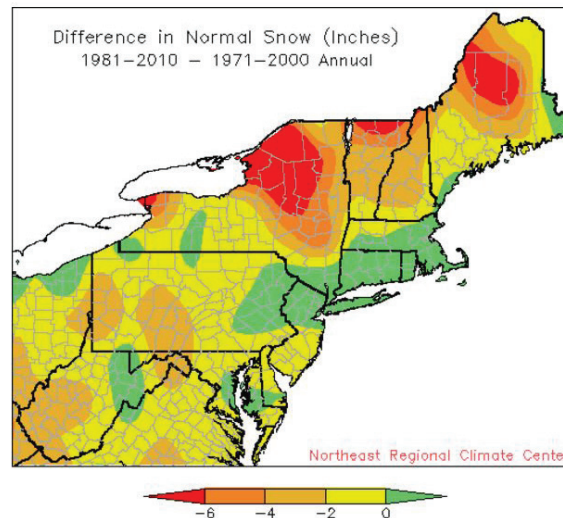


Figure 6.3: Difference between 30-year averages of snow depth for the Northeast. The comparison shows a decline in snow depth over much of the Northeast when comparing the years 1981-2010 and 1971-2000. (See Teacher-Friendly Guide website for a full color version.)

a bigger fraction of winter precipitation will fall as rain rather than snow. Heavy downpours have been increasing in frequency, a trend that is expected to continue. Increases in extreme rain have been greater in the Northeast than in any other region of the US (Figure 6.2).

Snow cover, a common winter feature across much of the Northeast, has been decreasing and will likely continue to do so. Changes in snowmelt and rainfall will change the flow of water in streams, affecting fish and other wildlife as well as human communities subject to flooding. Short-term droughts—lasting one to three months—brought on by warmer temperatures and less and earlier snow melt are likely to become more common, especially in the Adirondack and Catskill Mountains and in New England (Figure 6.3).

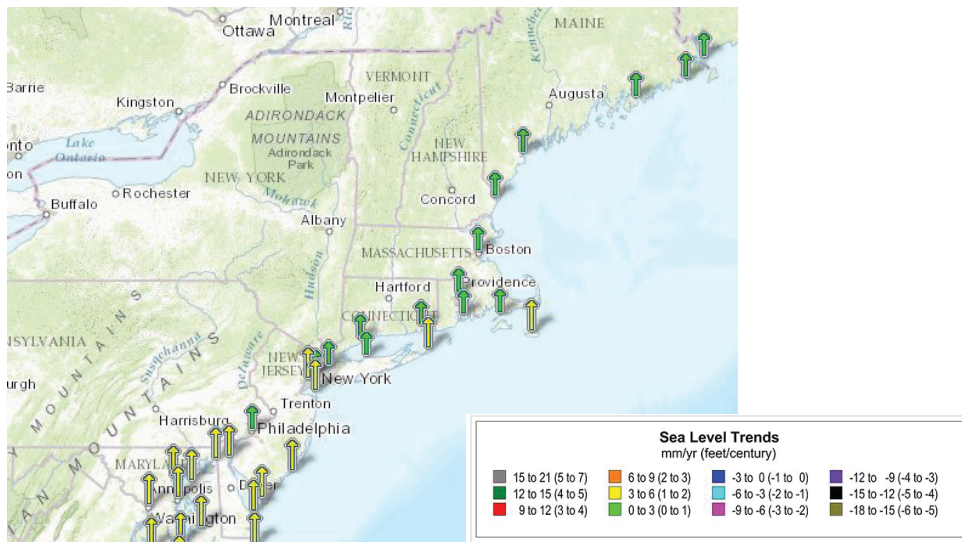


Figure 6.4: Sea level trends along the Northeast US coast. Arrows represent the direction and magnitude of the change. (See Teacher-Friendly Guide website for a full color version.)

Sea level rise is a great concern in the Northeast, with its extensive coastline and many vulnerable low-lying areas, especially in big cities. A rising sea leads to loss of wetlands, coastal erosion and property damage, larger and more damaging storm surges, inundation of populated areas, and stresses on municipal water and sewer systems. Sea level has risen steadily in the 20th century (Figure 6.4) and is projected to continue rising as the world's glaciers and ice sheets melt and a warmer ocean undergoes thermal expansion. By the year 2100, sea level may rise by 46 to 191 centimeters (18 to 75 inches) along New York's coast.<sup>3</sup>

## 2. Southeast

### 2.1 Description

The sun rises in Virginia Beach, Virginia—part of the Southeastern US—approximately twenty minutes after it rises in West Quoddy Head, Maine. The Southeast consists of West Virginia, Virginia, Kentucky, Tennessee, North Carolina, South Carolina, Georgia, Florida, Alabama, and Mississippi. The Southeast has a longer coast on the Atlantic Ocean than any other region, but also borders the Northeast, the Midwest, and the South Central US.

### 2.2 Present Climate

The location of the Southeast and its direct relationship to the Gulf of Mexico and Atlantic Ocean strongly influence the area's weather. Since it encompasses locations along the coast as well as areas farther inland, the Southeast experiences nearly every variety of extreme weather. Heat and cold waves, droughts, floods, blizzards, tornados, and hurricanes are all considerations for residents of the Southeast.

<sup>3</sup> Sea level rise projections vary locally based on factors such as vertical land motion and ocean currents that move water toward or away from the coast. These projections for New York's coast can be found on the NY State Department of Environmental Conservation's website at <http://www.dec.ny.gov/energy/45202.html>.



## Southeast

**Köppen system** • a commonly used system of climate categorization developed by Russian climatologist Wladimir Köppen. It is based on the kinds of vegetation that areas sustain, and defines 12 climate types: rainforest, monsoon, tropical savanna, humid subtropical, humid continental, oceanic, Mediterranean, steppe, subarctic, tundra, polar ice cap, and desert. Updated by Rudolf Geiger, it has been refined to five groups each with two to four subgroups.

**tropical cyclone (hurricane)** • a rapidly rotating storm system with heavy winds, a low-pressure center, and a spiral arrangement of thunderstorms. These storm systems tend to form over the tropical ocean, and are classified as HURRICANES, typhoons, or cyclones (depending on their location in the world) once winds have reached 199 kilometers per hour (74 miles per hour).

**tornado** • a vertical funnel-shaped storm with a visible horizontal rotation.

# US Regional Climates

Although much of the Southeast falls within the category of a “warm temperate zone” (represented by “C” in the **Köppen system**; see Box 6.1), using a single label to describe the Southeast’s climate doesn’t really represent the range of the region’s climate. In the wintertime, southern Florida is frequently warm and humid while the rest of the Southeast (and the rest of the United States) is cold and dry. The main features that influence the Southeast’s climate are latitude, the presence of the Atlantic Ocean and the Gulf of Mexico, and regional topography. For example, the Florida peninsula has a distinct summer rainy season, while other inland areas receive uniform precipitation all year round, and the highest elevations in North Carolina and Tennessee can receive as much snow as parts of New England. The warmest temperatures are found in Florida, Georgia, and Mississippi, while the coolest are found in West Virginia and Virginia. The Southeast’s overall average high temperature of 22°C (72°F) and average low of 9°C (48°F) are indicative, on the whole, of a warmer and more uniform climate than that found in most other parts of the United States.

Another factor besides latitude that influences temperature in the Southeast is proximity to the ocean, which has a moderating influence. Air masses that have passed over the Gulf of Mexico rarely get either extremely hot or extremely cold, and the Gulf Stream current that travels northward past the Atlantic seaboard carries warm tropical water with it, influencing temperatures on land. Thus the most extreme temperatures in the Southeast are found toward the center of the continent: The region’s record high and low temperatures are both held by Kentucky, which has experienced a high of 46°C (114°F) and a low of -38°C (-37°F). Of course, major temperature fluctuations can occur in every state. In July, average daily maximum temperatures range from 35°C (95°F) in southern Georgia and Florida to 24°C (75°F) in mountainous parts of West Virginia. Wintertime has a broader range of temperatures, with average daily minimums in January varying from around -7°C (20°F) in northern Kentucky to 16°C (60°F) in South Florida. Although the Southeast’s climate is subtropical, it can get cold, and sub-freezing temperatures are sometimes a concern for Florida orange growers.

The Southeast gets higher levels of annual precipitation than the rest of the US: the Southeast generally receives 100-125 centimeters (40-50 inches), and sometimes over 150 centimeters (60 inches), while the rest of the United States averages only 85 centimeters (34 inches). Some pockets of high precipitation also occur in the Appalachian Mountains (along the Eastern Continental Divide, a topographical high point where air is forced upward from both sides of the mountain range), and along the Atlantic coast. In the summer and fall **tropical cyclones (hurricanes)** often bring heavy rains to the Gulf and Atlantic coasts. Some of these cyclones, such as Hurricane Andrew in 1992, are extremely powerful and have devastated communities in the Southeast. Thousand-year weather events, referring to the 1-in-1000 chance of intense events happening in a given year, have increased in frequency in recent years, and climate models (see Box 6.2) predict a continuation of that increase. One such event occurred in the fall of 2015 when heavy rains associated with Hurricane Joaquin (but not actually part of the hurricane) brought over 50 centimeters (20 inches) of rain to parts of South Carolina, causing over one billion dollars in damage.

Snow is not unusual during winter in the northern and higher elevation parts of the Southeast, but in some of the southern regions snowfall and ice is rare enough that the communities do not invest in snow removal equipment like communities farther north do. As a result, when snow and ice do form in parts of the Southeast, the impact and damage tends to be more severe.

Severe thunderstorms and **tornados** are an additional threat—the geography and climate of the Southeast are nearly ideal for their formation, especially in



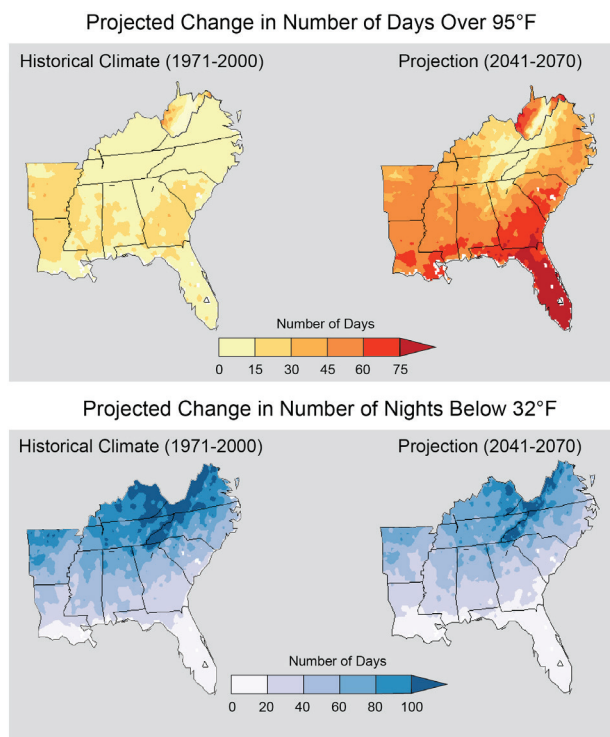
the summer. Only Kansas has more tornados per square mile than Florida, and several other Southeastern states rank in the top ten for tornado frequency.

## 2.3 Future Climate

The Southeast's average annual temperature fluctuated between warming and cooling periods during the 20<sup>th</sup> century, and has most recently risen since 1970 by about 1°C (2°F) on average. **Climate models** (see Box 6.2) predict that the Southeast's climate will continue to warm, and that the average annual temperature in most of the area will rise about 2° to 4.4°C (4° to 8°F) by the end of the 21st century.<sup>4</sup> Winter temperatures have risen the most—today, most of the Southeast experiences four to seven fewer freezing days than it did in the 1970s. By the middle of the 21st century one can expect 20 to 30 more days of freeze-free weather each year (*Figure 6.5*). Currently, the northern part of the Southeast typically has ten days a year with temperatures below -12°C (10°F). By the middle of the 21st century we can expect zero days with temperatures that low. These increased temperatures lead to a whole host of other effects, including drier soils from more evaporation, and the increased likelihood of drought and fires.

Precipitation has become more variable from year to year, and heavy downpours have increased since the late fifties (see *Figure 6.2*). Models for future precipitation do not predict large changes, but they predict generally less

**climate model** • a computer-generated simulation of the Earth's climate system, projected through time.



*Figure 6.5: Projected changes in number of days over 35°C (95°F) and number of nights below 0°C (32°F) for the Southeast over the next several decades. (See Teacher-Friendly Guide website for a full color version.)*

<sup>4</sup> These projections for the Southeast and for other parts of the country can be found in the Third National Climate Assessment (US Global Change Research Program, 2014, <http://nca2014.global-change.gov/>). National Climate Assessments have been published in 2000, 2009, and 2014, with interim assessments in between. Additional assessments are expected approximately every four years.





## Southeast

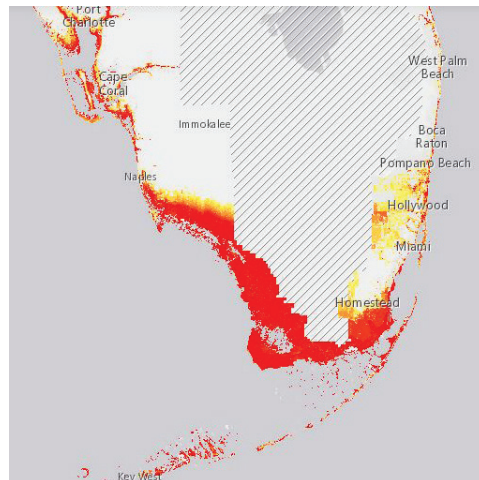
**thermal expansion** • the increase in size or extent of a material as it warms.

# US Regional Climates

rain in the far southwest part of the Southeast, and generally more rain in the far northeast part of the region. Water supply is an important issue in the Southeast, and communities will need to adapt to changes in precipitation, snowmelt, and runoff as the climate changes. Drier days and higher temperatures will amplify evaporation, increasing the desertification of already arid areas and affecting natural ecosystems as well as increasing pressure on the water supply for agriculture and cities. In low-lying areas, especially Florida, important aquifers are at extreme risk of being contaminated by saltwater thanks to rising sea levels.

Sea level rise from **thermal expansion** of a warmer ocean and from melting ice sheets is a major concern in the Southeast, with its extensive coastline and many low-lying areas, including coastal cities such as Miami, Tampa, Charleston, and Norfolk. A rising sea leads to retreating tidal forests, coastal erosion, larger and more damaging storm surges, inundation of populated areas, and stresses on municipal water and sewer systems. Increased inland flooding will impair stormwater drainage systems that empty into the ocean and destroy tidal wetlands, reducing environmental protection against storm surge and damaging important fishery habitat. Oil and gas production infrastructure located in areas protected by barrier islands will be at greater risk to storm surge. Regional studies project that by 2030, climate change could cause \$4.6 billion in damages to coastal property and assets on the Gulf Coast alone. By the end of the 21st century, the projected sea level rise around the Southeast is as much as a meter (3 feet), and could be higher with continued high carbon emissions.

Florida is especially susceptible to the risks of sea level rise. Nearly 10% of the state is within 1.5 meters (5 feet) of the mean sea level, and 40% of Florida's beaches are at risk of erosion and coastal flooding. *Figure 6.6* shows flood exposure for south Florida under different levels of rising seas. A one foot rise in sea level could threaten large portions of relatively flat coastal land up to 30 to 60 meters (approximately 100 to 200 feet) inland from the coasts.<sup>5</sup>



*Figure 6.6: Flood exposure in south Florida for sea level rise scenarios of 0 to 6 feet, which represent a rise in water above the average of the highest high tides (called mean higher high water, or MHHW) for hydrologically connected areas. Areas that are lower in elevation will be exposed to flooding from sea level rise first and are represented by the darkest red. Areas in yellow will be exposed to flooding at the highest sea level rise (6 feet). (See Teacher-Friendly Guide website for a full color version.)*

<sup>5</sup>“Saving Florida’s Vanishing Shores” (US Environmental Protection Agency, 2002, [www3.epa.gov/climatechange/Downloads/impacts-adaptation/saving\\_FL.pdf](http://www3.epa.gov/climatechange/Downloads/impacts-adaptation/saving_FL.pdf)) provides an overview of threats to Florida’s beaches and what communities and individuals can do to help protect Florida’s coasts.





## Midwest

### 3. Midwest

#### 3.1 Description

The sun rises in Columbus, Ohio—on the eastern side of the Midwestern US—approximately one hour after it rises in West Quoddy Head, Maine and about forty minutes after it rises in Virginia Beach, Virginia. The Midwestern US consists of Ohio, Michigan, Indiana, Illinois, Wisconsin, Iowa, and Minnesota and shares a border with all of the Great Lakes except for Lake Ontario. The Midwest also shares a border with Canada, the Northeast, the Southeast, as well as the South Central and Northwest Central regions. The Midwest, therefore, shares many of the regional climate features of a number of surrounding regions.

#### 3.2 Present Climate

Nearly all of the Midwest has a humid continental climate, with temperatures that vary greatly from summer to winter, and appreciable precipitation year-round. This is represented in the **Köppen system** with the prefix “D” (see Box 6.1). At an average temperature of 10°C (50°F), it seems similar to that of England, which has an average of 8°C (47°F). The Midwest, however, has a much more extreme range than England.

England—which is located only a few degrees latitude farther north than the Midwest—has a substantially smaller range of temperatures due to the buffering effect of the Atlantic Ocean. Average daily temperatures in England range from a low of 2°C (35°F) up to a high of 21°C (70°F). The Midwest, which has no nearby ocean to buffer its temperatures, has nearly twice as large of a temperature range, with average daily temperatures as low as -9°C (15°F) and as high as 29°C (85°F). The difference is even more apparent when we look at record temperature extremes. England has record low temperatures of -26.1°C (-14.9°F) and record high temperatures of 38.5°C (101.3°F)—a range of nearly 65°C (116°F)—while the Midwest has record low temperatures of -34°C (-30°F) and record highs of 43°C (110°F)—a range of 77°C (140°F)!

The Midwest is one of the most productive agricultural areas in the world, and the economies of its states depend on farmland. Its excellent soil, relatively flat geography, and bodies of water make it uniquely suited to cropland. Yet without a humid climate with warm summers, agriculture here would be completely different. It is one of the few places on earth where huge amounts of corn and soybeans can be grown with little or no irrigation.

In part because of its climate’s extreme temperature variation and humidity, the Midwest experiences nearly every variety of **severe weather**. Because the states are so far from the coasts, they rarely experience hurricanes, but heat and cold waves, droughts, floods, blizzards, and tornados are all fairly regular events.

The nearly flat geography and variable climate of the Midwest create ideal conditions for the formation of **thunderstorms**. Storms occur when there is strong convection in the atmosphere. Warm and moist air flowing north from the tropics clashes with cold and dry air flowing south from the Arctic. When these air masses collide, the strong **gradients** in both temperature and pressure create **turbulence**, strong **convection**, and large amounts of condensation and precipitation. Usually a thunderstorm loses energy once the warm air

**Köppen system** • a commonly used system of climate categorization developed by Russian climatologist Wladimir Köppen. It is based on the kinds of vegetation that areas sustain, and defines 12 climate types: rainforest, monsoon, tropical savanna, humid subtropical, humid continental, oceanic, Mediterranean, steppe, subarctic, tundra, polar ice cap, and desert. Updated by Rudolf Geiger, it has been refined to five groups each with two to four subgroups.

**severe weather** • dangerous weather events that can cause harm to life and property.

**thunderstorm** • a storm characterized by thunder and lightning, and also typically with heavy rain and high winds.

**gradient** • a change, either increasing or decreasing, in the magnitude of a quantity over space or time.

**turbulence** • irregular or chaotic movement of a fluid such as air or water.

**convection** • movement of a fluid, such as air or water, resulting from gravitational force on the fluid. Warmer, less dense matter rises and cooler, more dense matter sinks, producing heat transfer.



## Midwest

**tornado** • a vertical funnel-shaped storm with a visible horizontal rotation.

**lake-effect snow** • snowfall caused by the movement of cold weather systems over a lake, in which an air mass picks up water from the lake and deposits it in the form of snow across an adjacent land mass.

# US Regional Climates

and the cool air mix. In the Midwest, however, currents of air from the south can continue to mix with currents of air flowing from the north and west. This tends to add additional energy to the storm and can create storms of unusual magnitude that can persist for long periods of time. These conditions are also the reason for the Midwest's unusually high incidence of powerful **tornados**.

Tornado Alley is a nickname for an area extending from Texas to Minnesota (including the western Midwest) that experiences a high number of exceptionally strong tornados. During the period from 1991 to 2010, Illinois and Iowa had 54 and 51 tornados annually on average, respectively. The United States has more tornados per year (over 1,000) than any other country, followed by Canada with around 100 per year. Tornados tend to form in mid-latitude regions where cold air from the north meets warm, moist air from the subtropics, generating thunderstorms. The reasons why some rotating storms spawn tornados and some don't are not entirely understood, but scientists think that tornados develop when there are temperature changes across specific air boundaries within a type of rotating storm called a mesocyclone.

Large bodies of water can retain heat better than land surfaces, and during the wintertime this can create **lake-effect snow** in many regions in the Midwest—especially those regions on the eastern shores of the Great Lakes. Lake-effect snow occurs when the warmer and moister air over the Great Lakes mixes with colder and drier air that blows across the lakes from the north and west. The moisture picked up and dropped as snow creates strong bands of snow that can form quickly and which can quickly overwhelm communities. The Upper Peninsula of Michigan usually receives over five meters (200 inches) of snow per year, second only in the US to Tug Hill Plateau in New York, east of Lake Ontario, which also gets lake-effect snow.

## 3.3 Future Climate

The Midwest's climate has changed in the last century, with average annual temperature rising 1.5°F from 1895 to 2012 (*Figure 6.7*).<sup>6</sup>

The average temperature in the Midwest is predicted to continue to increase for the foreseeable future, likely by 3.1°C to 4.7°C (5.6°F to 8.5°F) at the end of the century (2081-2100), depending on the rate at which carbon emissions from burning fossil fuels continues. These average changes are not evenly distributed and can vary from location to location and from year to year. For example, since 1980, the average annual temperature for northern Illinois has increased from around 7°C (45°F) to 9°C (49°F), a change of 2°C (4°F), yet the average *winter* temperature has increased by 4°C (8°F). Higher temperatures and higher carbon dioxide levels are, up to a point, expected to extend the growing season and increase crop yields. In the longer term, however, higher temperatures are expected to reduce crop yields, and crops may face increased freeze damage when the early springs brought on by climate change are followed by damaging frosts. The US Government's Global Change Research Program expects the plant hardiness zones (see Box 6.4) for the Midwest to become warmer by up to one zone every 30 years, rapidly changing what kinds of plants and crops can survive. Translating this change to the Köppen climate classification, much of the Midwest will be redesignated as humid subtropical and feel more like states within the Southeast. Coupled with less precipitation

<sup>6</sup> These projections for the Midwest and for other parts of the country can be found in the Third National Climate Assessment (US Global Change Research Program, 2014, <http://nca2014.global-change.gov/>). National Climate Assessments have been published in 2000, 2009, and 2014, with interim assessments in between. Additional assessments are expected approximately every four years.



## Midwest

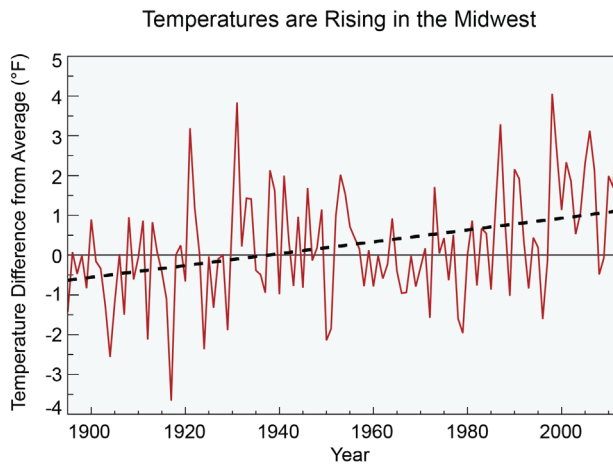
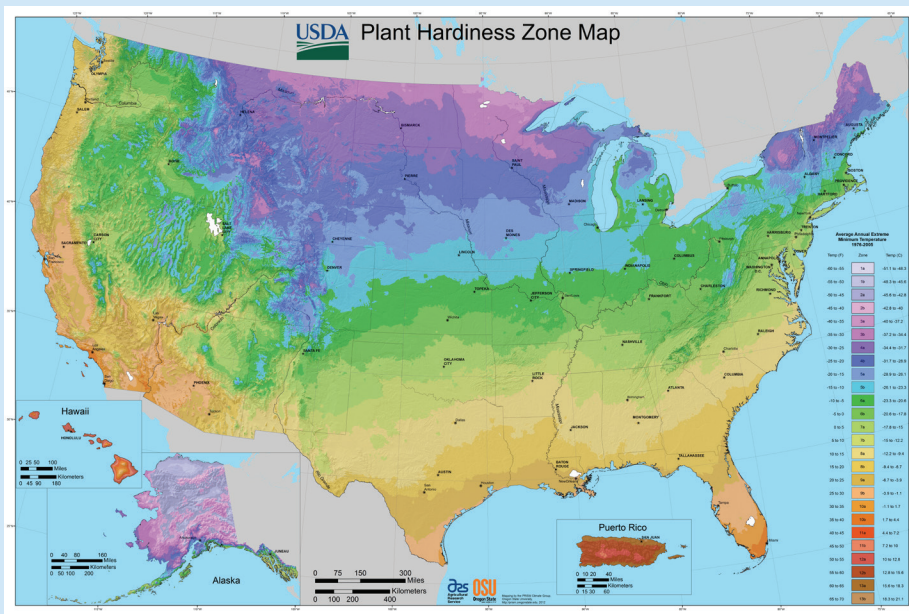


Figure 6.7: Annual average temperatures (red line) across the Midwest show a trend towards increasing temperature. The trend (heavy black line) calculated over the period 1895-2012 is equal to an increase of 1.5°F. (See Teacher-Friendly Guide website for a full color version.)

### Box 6.4: Plant hardiness zones

The US Department of Agriculture defines plant hardiness zones for gardeners and growers, to help them choose plants that will grow well in their regions. Plant hardiness zones are determined by the average annual minimum winter temperature. As of 2016, the USDA last updated its Plant Hardiness Zone Map in 2012. An interactive version of this map can be found online at <http://planthardiness.ars.usda.gov/phzmweb/interactivemap.aspx>.



2012 USDA Plant Hardiness Zone map. (See Teacher-Friendly Guide website for a full color version.)



# US Regional Climates

overall, a garden you planted in Michigan as a child will look like one from Arkansas by the time you are an adult, and then like one from Texas after 30 more years.

The Midwest can also expect more incidences of extreme weather, including heat waves and heavy rainfall. While individual weather events depend on a combination of large-scale and small-scale factors—which are difficult for global-scale climate models (Box 6.2) to predict—the large-scale climate changes that will impact the Midwest are very likely to increase extreme weather events in the region (see Box 6.5). For instance, since higher temperatures mean greater evaporation and the ability of the air to hold more water, precipitation will occur in greater amounts at a time, but less frequently. During the cooler spring this will lead to flooding, while in hot summers, droughts will become more frequent. Finally, higher atmospheric moisture content has also been correlated with an increased incidence of tornados, which is of particular concern for communities in the Midwest.

## Box 6.5: Climate change and extreme weather

What is the relationship between a warming Earth and the frequency and intensity of extreme weather events? This is nicely described in an article by Richard Alley, the Evan Pugh Professor of Geosciences at Pennsylvania State University:<sup>7</sup>

*There's very high scientific confidence that our fossil-fuel burning and other activities, which add carbon dioxide to the air, are turning up the planet's thermostat. In a warmer world, we expect more record highs and heat waves but fewer record lows, just as we're observing. Warmer air can carry more water vapor, so a warmer rainstorm can deliver more inches per hour. Hair dryers have a "hot" setting for good reasons, and warmer air between rainstorms can dry out the ground faster.*

*Thus, we expect rising CO<sub>2</sub> to bring more floods in some places and more droughts in others, with some places getting more of both. That might seem contradictory, but it's not. And with more energy to drive hurricanes, the peak winds may increase, even if the number of storms drops.*

*But couldn't nature have caused the ongoing changes without our help? Imagine playing dice with a shady character. Suppose, after you lose, you discover that some of the corners are filed off and there are carefully positioned weights inside. In court, your lawyer could say, 'The dice were loaded, double-sixes came up three times in a row, so the defendant owes restitution.'*

*His lawyer, however, might counter, 'My client doesn't recall where he got the dice, the modifications are really quite small, dice games are inherently variable, anomalous events do happen, so my client is innocent and should get to keep all the money plus the plaintiff's wallet.'*

*Out in the climate, the dice are being loaded to favor some unusual events. We can't prove that global warming caused any single new record, just as we can't prove that the weighted dice caused a run of double-sixes. But for many extreme weather events such as record heat, it is much harder to prove that our CO<sub>2</sub> is innocent, just as it is very hard to prove that loaded dice didn't affect the game.*

<sup>7</sup>For Alley's full article, see "Why the extreme weather?" USA Today 19 April 2012. <http://usatoday30.usatoday.com/news/opinion/forum/story/2012-04-18/global-warming-climate-change-tornadoes-heat/54394742/1>.





## South Central

## South Central

### 4.1 Description

The sun rises in New Orleans, Louisiana—part of the South Central US—approximately one hour after it rises in West Quoddy Head, Maine and only a few minutes after it rises in Columbus, Ohio. The South Central US consists of Louisiana, Arkansas, Missouri, Nebraska, Oklahoma, and Texas, and shares a border with Mexico, the Gulf of Mexico, as well as the Southeast, Midwest, Northwest Central, and Southwest regions of the US. The South Central US contains both coastal and desert regional climates.

### 4.2 Present Climate

The location of the South Central and its direct relationship to the Gulf of Mexico strongly influences the region's weather. And with locations along the coast, as well as the presence of areas farther inland, the South Central experiences nearly every variety of extreme weather—heat and cold waves, droughts, floods, blizzards, tornadoes, and hurricanes are all considerations for the residents of the South Central region.

Today, the South Central lies at the intersection of several distinct climate zones, with much of the region characterized as warm temperate (represented by “C” in the **Köppen system**; see Box 6.1). Northern Missouri and northern Kansas are characterized as continental (represented by “D”), and the eastern parts of Kansas and Texas are arid (represented by “B”).

Average temperatures in the South Central are highest over land away from the coasts in the southernmost states and coolest in the northernmost states. The average high temperature of the whole region is 20°C (68°F) and the average low is 9°C (49°F). This is indicative, on the whole, of a more uniform climate than that found in most other regions of the United States (see Section 3: Midwest). The record high daily temperature in the South Central region is 49°C (121°F) and the record low is -40°C (-40°F).

States in the South Central region are generally wetter than the average US state; while the average US state gets only 85.6 centimeters (33.7 inches) of rain each year, states in the South Central receive rainfall amounts ranging from a minimum in Kansas of 74.4 centimeters (29.3 inches) to a maximum in Louisiana of 146.3 centimeters (57.6 inches). This is due to the additional moisture that comes from the adjacent Gulf of Mexico. Louisiana is south of the path of many winter storm centers, but the northern parts of the state are susceptible. For this reason, the precipitation pattern of the winter is the reverse of that of the summer, with the heaviest precipitation found in the north (43 centimeters [17 inches]) and the lightest in the south (33 centimeters [13 inches]).

Like those of Louisiana, the winters of Arkansas are short. With its long growing season, coupled with the heaviest precipitation coming in the summer months, agriculture is the state's largest industry. In the winters, snow does fall, but it is primarily restricted to the northwest section of the state.

Farther inland, Oklahoma, Missouri, and Kansas enjoy a continental type of climate. In Oklahoma, summers are long and warm, and winters are shorter than

**Köppen system** • a commonly used system of climate categorization developed by Russian climatologist Wladimir Köppen. It is based on the kinds of vegetation that areas sustain, and defines 12 climate types: rainforest, monsoon, tropical savanna, humid subtropical, humid continental, oceanic, Mediterranean, steppe, subarctic, tundra, polar ice cap, and desert. Updated by Rudolf Geiger, it has been refined to five groups each with two to four subgroups.





## South Central

**tornado** • a vertical funnel-shaped storm with a visible horizontal rotation.

**climate model** • a computer-generated simulation of the Earth's climate system, projected through time.

# US Regional Climates

in other states of the Great Plains. Because of the moist warm air moving northward from the Gulf, rainfall decreases dramatically from east to west, with an average of 43 centimeters (17 inches) in the west and 142 centimeters (56 inches) in the far southeast. In the winter, the snowfall follows the reverse pattern, with more snow in the west than in the east. A similar pattern is found in Kansas, which, due to its flat topography, is home to a large number of **tornados** and dust storms. The warm moist air of the Gulf similarly influences the precipitation of Missouri in the summers, while the dry cold air from the north affects the winters.

Covering nearly 700,000 square kilometers (270,000 square miles), Texas is the second largest state. In the far west, annual precipitation is driven more by elevation than location. The remaining part of the state possesses significantly less complicated topography, with the terrain descending from northwest to southeast. Precipitation ranges from near-desert conditions in the west to annual accumulations close to 152 centimeters (60 inches) along the coast, where monthly average precipitation ranges from less than 1.3 centimeters (half an inch) to over 10 centimeters (4 inches). In the winter, significant snowfall is typically confined to the mountainous areas of the far west.

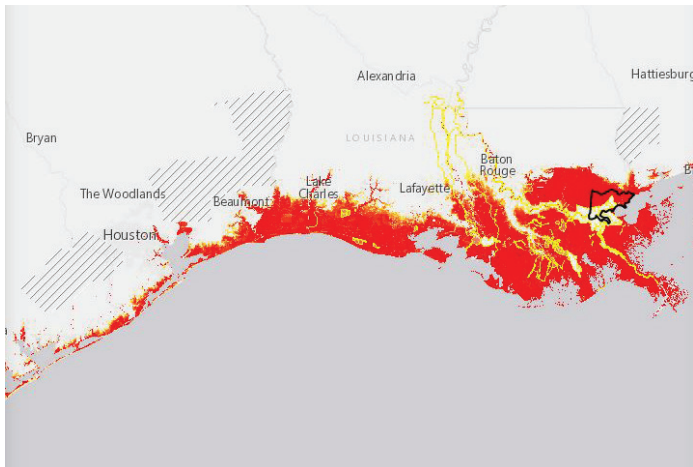
Tornado Alley is a nickname for an area extending from Texas to Minnesota that experiences a high number of exceptionally strong tornadoes. Most of the South Central resides within Tornado Alley, leading to more tornadoes in this region of the United States than in any other. From 1991 to 2010, for example, an annual average of 115, 62, and 96 tornadoes occurred in Texas, Oklahoma, and Kansas, respectively. To the east of Tornado Alley, far fewer tornado strikes occur, with an annual average of 37, 39, and 45 striking Louisiana, Arkansas, and Missouri, respectively.

## 4.3 Future Climate

Studies show that the South Central's climate has already experienced notable changes and that these changes have accelerated in the latter part of the 20th century. These changes include the following:

- The number of days with temperatures above 35°C (95°F) has been steadily increasing for the last 25 years
- The city of St. Louis experiences about four heat waves each summer—a number which has doubled over the last 60 years.
- Locations along the Gulf of Mexico have experienced over 8 inches of sea level rise in the last 50 years.
- Altered flowering patterns due to more frost-free days have increased the South Central's pollen season for ragweed, a potent allergen, by 16 days since 1995.

**Climate models** (see *Box 6.2*) predict that the South Central will continue to warm, and that the average annual temperature will continue to increase for the foreseeable future—likely a 3°C (5°F) increase by 2100. Summer temperatures in Oklahoma, for example, are expected to increase by 3 to 6°C (6 to 10°F) by 2100. These increased temperatures lead to a whole host of other effects, including drier soils from more evaporation, and the increased likelihood of drought and fires. Texas, which contains the largest acreage of crop-, pasture-,



*Figure 6.8: Map of areas flooded from sea level rise scenarios of 0 to 6 feet, which represent a rise in water above the average of the highest high tides (called mean higher high water, or MHHW) for hydrologically connected areas. Areas that are lower in elevation will be exposed to flooding from sea level rise first and are represented by the darkest red. Areas in yellow will be exposed to flooding at the highest sea level rise (6 feet). (See Teacher-Friendly Guide website for a full color version.)*

and rangeland in the United States, could be severely impacted by these changes.

Sea level rise from thermal expansion of a warmer ocean and melting ice sheets will be a concern for populated coastal areas, including major cities such as New Orleans and Houston. The coastal zones of the South Central region are one of the US's areas most vulnerable to sea level rise. *Figure 6.8* shows areas subject to flooding along the Texas and Louisiana coasts under different sea level rise scenarios. Regional studies project that by 2030, climate change could cause \$4.6 billion in damages to coastal property and assets on the Gulf Coast alone.

## Northwest Central

### 5.1 Description

The sun rises in Omaha, Nebraska—part of the Northwest Central US—approximately two hours after it rises in West Quoddy Head, Maine and about one hour after it rises in New Orleans, Louisiana. The Northwest Central consists of Nebraska, North and South Dakota, Montana, Idaho, and Wyoming. It shares a border with Canada, as well as the Midwest, South Central, Southwest, and Western US\_regions. The Northwest Central region is inland, and does not border any ocean or any of the Great Lakes.

### 5.2 Present Climate

Due to their diverse topographical features, the Northwest Central states encompass a broad range of climates, including subarid steppe in the Great Plains, warm temperate highlands in the Cordilleran, and humid continental plains in the eastern Central Lowland. Even individual states can have tremendous diversity—all of the Northwest Central states (see *Box 6.1*) have two or three climate types, including everything but polar and equatorial. The



## Northwest Central

**rain shadow** • an area on one side of a mountain that experiences little rainfall.

**Continental Divide** • a ridge of high land on a continent, which separates regions where water flows to oceans or seas on different sides of the continent.

# US Regional Climates

main drivers of climate in the Northwest Central US are exposure to Arctic air from Canada in the winter, the lack of large bodies of water nearby (except for Idaho, whose climate is influenced by the Pacific Ocean), and the presence of the Rocky Mountain chain in the west. These mountains block moist Pacific Ocean air from the interior of the continent and create a cold, high altitude zone.

Temperatures in the Northwest Central are cool on average relative to the average temperature of the contiguous US, and characterized by seasonal extremes. South Dakota's temperature, for example, varies between an average low of  $-14^{\circ}\text{C}$  ( $6^{\circ}\text{F}$ ) in January and an average high of  $86^{\circ}\text{F}$  ( $30^{\circ}\text{C}$ ) in July. Record lows and highs are astonishing:  $-57^{\circ}\text{C}$  ( $-70^{\circ}\text{F}$ ) in Montana in 1954 and  $49^{\circ}\text{C}$  ( $121^{\circ}\text{F}$ ) in North Dakota in 1936. Average temperatures in the Northwest Central tend to decrease northward, which is in part the influence of latitude: lower latitudes receive more heat from the sun over the course of a year. The overall warmest temperatures are found in Nebraska, and the coolest found in North Dakota and parts of Wyoming.

The Northwest Central US is dry compared with many other parts of the United States, so dry that all the states within it except Nebraska rank within the top 10 driest states based on annual precipitation. Precipitation generally tends to decrease to the west across the Rocky Mountains, with an average annual precipitation of 65–90 centimeters (25–35 inches) in the Central Lowland region of the eastern Dakotas and Nebraska, about 25–50 centimeters (10–20 inches) in the Great Plains, and less than 25 centimeters (10 inches) in parts of Wyoming and Idaho (*Figure 6.9*). By comparison, the average annual amount of precipitation for the United States is 85.6 centimeters (33.7 inches). The decrease in precipitation is due in large part to **rain shadow** effects from mountain ranges located west of as well as within the Northwest Central. Rain shadows occur when moist air moves eastward with the prevailing winds, and is pushed upward and cools when it encounters a mountain chain. Water vapor condenses from this cool air and falls as rain or snow on the western side of the mountain. The air that continues to move east over the mountains is now much drier, and as it moves down the eastern side of the mountain range it warms, promoting evaporation (*Figure 6.10*). The mountainous **Continental Divide**, which runs through western Montana, creates a rain shadow effect that contributes to the aridity of the plains and badlands in the eastern part of the state. Nebraska's semi-arid west and fairly uniform average temperatures are moderated by dry, warm rain shadow winds blowing eastward from the Rocky Mountains.

Exceptions to the westward drying trend are found in the mountainous parts of northwestern Wyoming and Montana, and in northern Idaho, where average annual precipitation is typically 40 to 50 inches, demonstrating the impact of moisture carried inland from the Pacific Ocean. Idaho's climate is strongly moderated by the Pacific Ocean, even though the state lies nearly 560 kilometers (350 miles) from the coast. In the winter, humidity from the ocean creates heavy cloud cover and precipitation that helps to moderate temperature.

Harsh winter storms are a fact of life in the Northwest Central US, carried in by the polar jet stream which typically falls near or over the area, especially in the winter. Blizzards with high winds, large amounts of snowfall, and low visibility are common and are brought on by cold air masses known as the Alberta Low from the north and the Colorado Low from the south. Since the Rocky Mountain region is dry, some residents use fences to capture snow for later use as a water source. Spring storms are also common, and heavy downpours can lead to flash flooding. Rain coupled with rapid snowmelt in the spring is another common source of flooding in the Rocky Mountain region's river basins.

# US Regional Climates



6

## Northwest Central

### ANNUAL PRECIPITATION

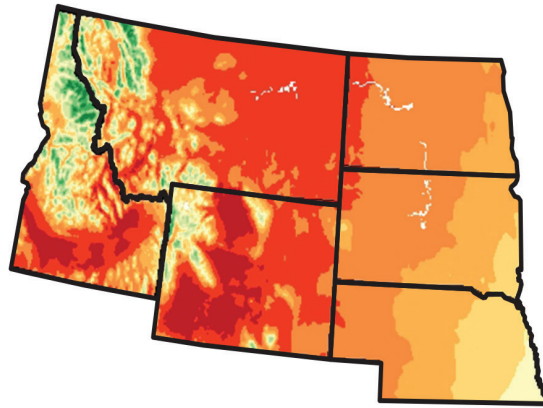
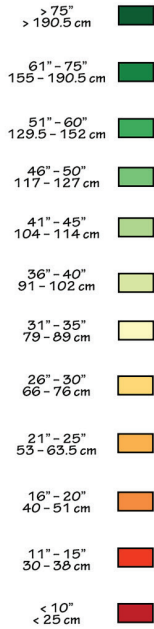


Figure 6.9: Mean annual precipitation for the Northwest Central States. (See Teacher-Friendly Guide website for a full color version.)

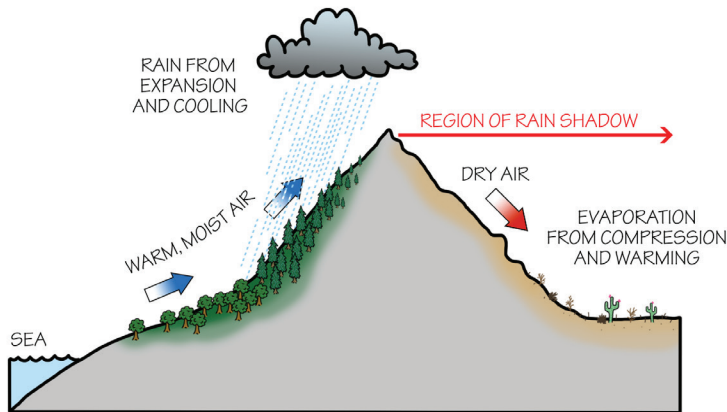


Figure 6.10: The key characteristics of a rain shadow. (See Teacher-Friendly Guide website for a full color version.)

The Northwest Central US is sparsely populated, with less than seven million people. Weather hazards are a concern for communities and for agriculture. When the area experiences severe drought as Wyoming did from 1999 to 2004, residents experience costly losses in food and water supply, grazing land for livestock, soil erosion, wildfire damage, and air quality. The Red River in North Dakota is highly susceptible to flooding, and since it runs through Fargo and Grand Forks, the populations and infrastructure of those cities are put at risk during floods. In the winter, cold waves brought on by Arctic air masses entering the area can damage livestock and crops. Nebraska, located in a corridor known as Tornado Alley, commonly experiences violent thunderstorms and tornados in spring and summer.





## Northwest Central

**climate model** • a computer-generated simulation of the Earth's climate system, projected through time.

# US Regional Climates

## 5.3 Future Climate

Studies show that the Northwest Central region's climate is changing right now, and that change has accelerated in the latter part of the 20<sup>th</sup> century. North Dakota's average temperature increased 3.4° F (1.9° C) during the last 130 years, the fastest increase in the US. Soils in Nebraska are becoming warm enough to plant corn one to three weeks earlier in the 2000s compared with the 1990s. Springtime snowmelts in Wyoming in 1990 were flowing 4 days earlier than in 1950. In 1850, Montana's Glacier National Park contained an estimated 150 glaciers (*Figure 6.11*). Today, only 25 glaciers remain. Models predict that all of them will have disappeared by 2030.

**Climate models** (see *Box 6.2*) predict that the Northwest Central region's climate will continue to warm, and that the average annual temperature in most of the region will rise by 6° to over 10° F (3° to 6° C) by the end of the 21<sup>st</sup> century. Models also predict that much of the region's climate will become wetter, with more precipitation especially in winter and spring. In Idaho, it is likely that increasingly a higher proportion of precipitation will fall as rain rather than snow, and snow in the mountains will melt earlier in the spring. This could strain the water supply in the warm season. Whether climate change will change the frequency of extreme storms in the Northwest Central region is not clear.

Agriculture is a huge industry in the Northwest Central region, especially in the Great Plains and Central Lowland. To the advantage of soybean and corn growers in Nebraska, warmer temperatures and more soil moisture have brought on longer growing seasons. Warmer temperatures, however, also make it easier for insect pests to overwinter and produce more generations. The European corn borer, a devastating pest found in the central and eastern US, produces more generations in warmer parts of the country. As the Great Plains and Central Lowland warm, one can expect three or four generations of these pests annually in regions that previously had one or two (*Figure 6.12*).



*Figure 6.11: Sperry Glacier in 1981, in Glacier National Park, Montana. This glacier still exists today, but its mass is decreasing.*





## Southwest

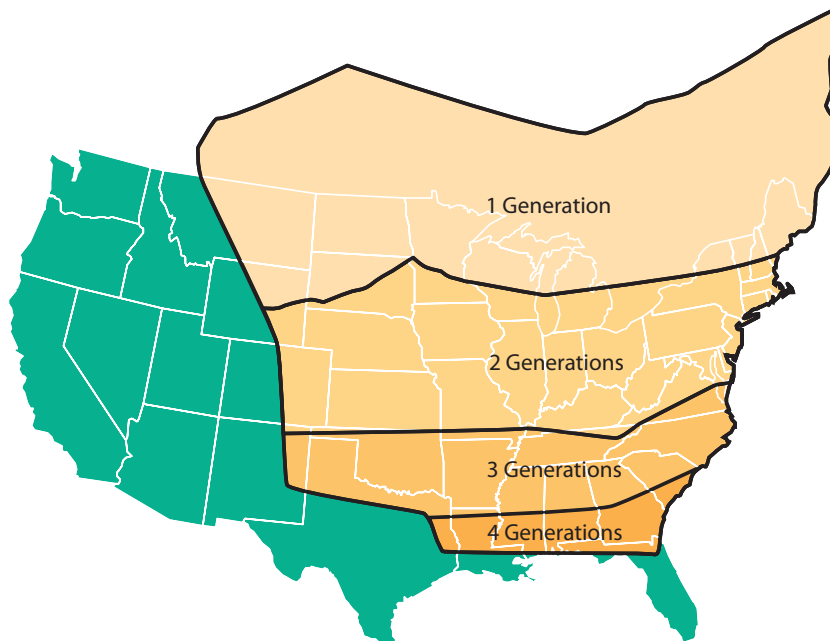


Figure 6.12: The European Corn Borer, an agricultural insect pest, currently produces one to four generations a year depending on its location in the US. As the climate warms further north, they are expected to produce more generations in the Great Plains and Central Lowland, causing more crop damage. (See Teacher-Friendly Guide website for a full color version.)

**Köppen system** • a commonly used system of climate categorization developed by Russian climatologist Wladimir Köppen. It is based on the kinds of vegetation that areas sustain, and defines 12 climate types: rainforest, monsoon, tropical savanna, humid subtropical, humid continental, oceanic, Mediterranean, steppe, subarctic, tundra, polar ice cap, and desert. Updated by Rudolf Geiger, it has been refined to five groups each with two to four subgroups.

## 6. Southwest

### 6.1 Description

The sun rises in Denver, Colorado—part of the Southwest—approximately two and a half hours after it rises in West Quoddy Head, Maine and about thirty minutes after it rises in Omaha, Nebraska. The Southwestern US consists of Colorado, Arizona, New Mexico, and Utah. It shares a border with Mexico, as well as the South Central US, the Northwest Central US, and the Western US.

### 6.2 Present Climate

The Southwest regional climate is strongly influenced by the topographical extremes across this area. Generally, the Southwest's climate is mostly dry and hot, with much of the region characterized as arid (represented by "B" in the **Köppen system**; see Box 6.1). Cold continental conditions (represented by "D") dominate the higher altitudes, especially within the Rocky Mountains. Scattered pockets of drier, Mediterranean temperatures (represented by "C") can also be found.

The Southwest is known for its topography, but also its dryness. The driest desert regions, such as southwestern Arizona, receive the least annual precipitation of any other region—as low as 8 centimeters (3 inches)—and some of the highest day-night temperature swings. A day that has a daytime maximum of 32°C (90°F) can fall below freezing during the night! At higher altitudes in the Southwest such as the Rocky Mountains of Colorado, annual snowfall can exceed 8 meters (25 feet). This snowpack melts in the warmer



# US Regional Climates

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months and flows into rivers that provide a welcome relief to the otherwise dry desert conditions.

Average temperatures found in the Southwest tend to decrease northward, following the increasing latitude and increasing elevations. Lower latitudes receive more heat from the sun over the course of a year: for each degree increase in latitude, there is about a 1°C (2°F) decrease in temperature. Higher elevations (such as those found in the Rockies and on the Colorado Plateau) are also cooler, with about a 1.5°C (3°F) decrease in mean annual temperature for each 300-meter (1000-foot) increase in elevation.

An additional factor that influences temperatures in the Southwest is the region's aridity. The lack of moisture in the air allows heat trapped during daylight hours to rapidly radiate away, leading to cool evenings. Thus, each Southwestern state experiences both extreme highs and lows. In New Mexico, for example, the average difference between the daily high and low temperatures ranges from 14 to 19°C (25 to 35°F). Record high temperatures for the Southwest range from 53°C (128°F) in Arizona to 47°C (117°F) in Utah, while record low temperatures range from -56°C (-69°F) in Utah to -40°C (-40°F) in Arizona. The average amount of precipitation for the United States is 85.6 centimeters (33.7 inches). In the Southwest, average precipitation ranges from only 34 centimeters (13.4 inches) in Utah to 39.9 centimeters (15.7 inches) in Colorado, which is indicative of the area's general aridity. Elevation does, however, play a key role in precipitation received throughout the Southwest. In New Mexico, for example, average annual precipitation ranges from less than 25 centimeters (10 inches) within the Great Plains and Basin and Range regions to more than 50 centimeters (20 inches) at the higher elevations to the northwest. Arizona's highest elevations receive an average of 65 to 76 centimeters (25 to 30 inches), with lower areas in the state's southwestern portion averaging less than 8 centimeters (3 inches). In Utah, areas below 1200 meters (4000 feet) receive less than 25 centimeters (10 inches) per year, while higher elevations in the Wasatch Mountains receive more than 100 centimeters (40 inches).

Across New Mexico, Arizona, and Utah, summer rains originate from moisture brought into the area from the Gulf of Mexico. Warm, moist air from the south occasionally but infrequently moves into Colorado during the summer. During the winter, moisture travels from the west, as storms from the Pacific Ocean move east. Pacific storms lose most of their moisture as they pass over the Rocky Mountains, so much of the Southwest's winter precipitation falls as snow within the area's mountainous regions.

## 6.3 Future Climate

The Southwest's climate is already changing, and these changes are expected to accelerate in the latter part of the 20th century. These changes include the following:

- The number of days with temperatures above 35°C (95°F) and nights above 24°C (75°F) has been steadily increasing since 1970, and the warming is projected to continue (*Figure 6.13*).
- The onset of stream flows from melting snow in Colorado has shifted two weeks earlier due to warming spring temperatures. Flows in late summer are correspondingly reduced, leading to extra pressure on the state's water supplies.



## Southwest

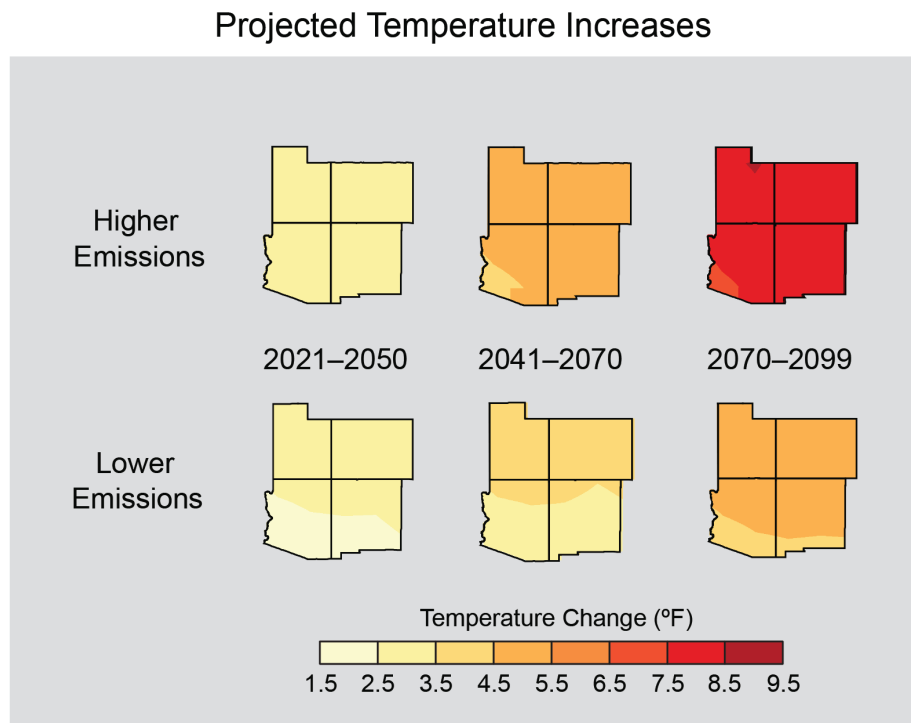


Figure 6.13: Projected temperature increases for the Southwestern states over the next century, as compared to the average for 1971–1999. The “higher emissions” scenario assumes emissions continue to rise, while the “lower emissions” scenario assumes a substantial reduction in emissions. In both cases, temperatures will continue to rise. (See Teacher-Friendly Guide website for a full color version.)

- Streamflow totals for the last decade in the Great Basin, Rio Grande, and Colorado River were between 5 and 37% lower than their 20th century averages.
- Increased heat in the Pacific Ocean has altered the weather patterns of Pacific storms, decreasing snowfall in the mountains of western Utah and Arizona.
- In the last decade, the Southwest’s frost-free season has increased by around 7% compared to the average season length for the 20th century.

Recent warming within the Southwest has been among the most rapid in the United States, and models predict that the area’s climate will continue to warm. The average annual temperature in most of the Southwest is predicted to rise 2.2 to 5.5°C (4 to 10°F) by 2100. Summer **heat waves** will become hotter and longer, while winter cold snaps will occur less often. These increased temperatures lead to a whole host of other effects, including a decrease in **snowpack**, declines in river flow, drier soils from more evaporation, and the increased likelihood of drought and fires. In winter, rising temperatures have increased the number of frost-free days—today, most of the Southwest experiences about 17 fewer freezing days than it did over the last century. By 2070, one can expect up to 38 more days of freeze-free weather each year (Figure 6.14). These warmer temperatures and increased precipitation have helped bring on longer growing seasons. While changes in the growing season can have a positive effect on some crops (such as melons and sweet potatoes), altered flowering patterns due to more frost-free days can lead to early bud bursts, damaging perennial crops such as nuts and stone fruits.

**heat wave** • a prolonged period of extremely high air temperatures.

**snowpack** • snow accumulated over time, often in mountainous areas that have a long cold season. When snowpack melts it feeds streams and rivers.



# US Regional Climates

## Projected Changes in Frost-Free Season Length

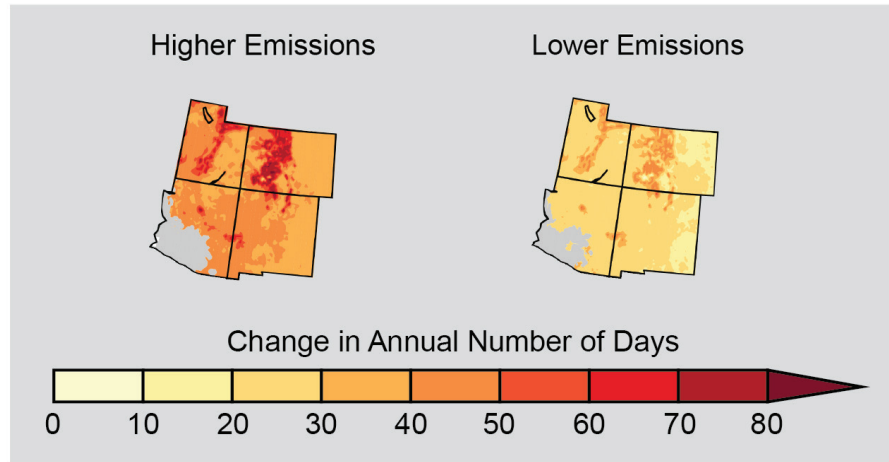


Figure 6.14: Projected changes in the number of frost-free days for the Southwestern states over the next century, as compared to the average for 1971–2000. The “higher emissions” scenario assumes emissions continue to rise, while the “lower emissions” scenario assumes a substantial reduction in emissions. Gray areas are projected to experience more than 10 frost-free years. (See Teacher-Friendly Guide website for a full color version.)

Water supply is an important issue in the Southwest, and communities will need to adapt to changes in precipitation, snowmelt, and runoff as the climate changes. Agriculture accounts for more than half of the Southwest’s water use, so any major reduction in the availability of water resources will create a serious strain on ecosystems and populations. Drier days and higher temperatures will amplify evaporation, increasing the desertification of already arid areas and affecting natural ecosystems as well as increasing pressure on the water supply for agriculture and cities (Figure 6.15). An increased frost-free season length also leads to increased water demands for agriculture and heat stress on plants. Cattle ranches throughout the Southwestern states rely on rain-fed grazing forage, making them extremely susceptible to climate change and drought. In addition, temperature increases and recent drought lead to earlier spring snowmelt and decreased snow cover on the lower slopes of high mountains, bringing about more rapid runoff and increased flooding. These changes to rain and snowpack are already stressing water sources and affecting agriculture.

Precipitation has become more variable from year to year, and heavy downpours across the US have increased in the last 20 years. Because higher temperatures mean greater evaporation and warmer air can hold more water, precipitation will occur in greater amounts at a time, but less frequently. Although there has so far been little regional change in the Southwest’s annual precipitation, the area’s average precipitation is expected to decrease in the south and remain stable or increase in the north. Most models predict a decrease in winter and spring precipitation by the middle of the century, and more frequent precipitation extremes during the last half of the century.



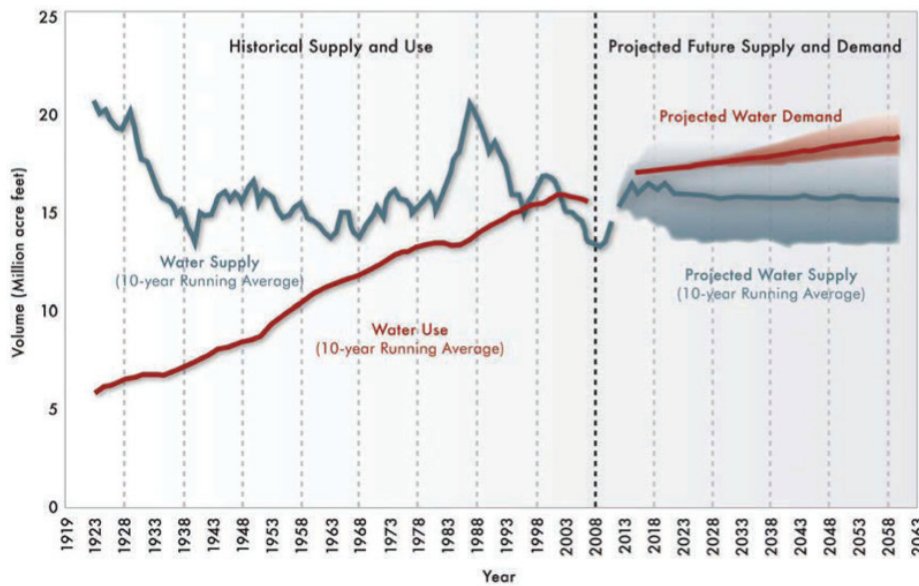


Figure 6.15: Projected 21st-century supply-demand imbalance for the use of water from the Colorado River. The Colorado drains roughly 15% of the continental United States, and is relied upon for municipal and agricultural use by over 35 million people in seven states. (See Teacher-Friendly Guide website for a full color version.)

## West

**Köppen system** • a commonly used system of climate categorization developed by Russian climatologist Wladimir Köppen. It is based on the kinds of vegetation that areas sustain, and defines 12 climate types: rainforest, monsoon, tropical savanna, humid subtropical, humid continental, oceanic, Mediterranean, steppe, subarctic, tundra, polar ice cap, and desert. Updated by Rudolf Geiger, it has been refined to five groups each with two to four subgroups.

## 7. West

### 7.1 Description

The sun rises in Las Vegas, Nevada—part of the Western US—approximately three hours after it rises in West Quoddy Head, Maine, and about thirty minutes after it rises in Denver, Colorado. The Western US consists of Washington, Oregon, California, and Nevada, and is the only region within the continental US that borders the Pacific Ocean. It also shares a border with both Canada and Mexico, as well as the Northwest Central and the Southwestern US.

### 7.2 Present Climate

Because of its wide latitudinal range, the proximity of the Pacific Ocean, and the presence of long, north-south mountain ranges, the Western States have an enormous variety of climatic areas. These include hot, dry deserts in the Basin and Range, a Mediterranean climate along the southern Pacific border, rainforests in the northern Pacific border and Alaska, and tundra in Alaska's far north. Even individual states can have tremendous diversity—depending on which of the many **Köppen system** maps you refer to, the state of Washington alone contains as many as eight different climate types.

With such diverse climate types, the West experiences a wide range of temperatures (Figure 6.16). Generally, temperatures tend to decrease northward and farther inland, with cooler temperatures at higher elevations and across the West's north-south mountain ranges. Temperatures in coastal areas are moderated by the Pacific Ocean and, in the northwest, by the Rocky Mountains, which prevent cold Arctic air from reaching the coast. Average lows and highs in Southern California range from 3° to 46°C (37° to 114°F) inland in Death Valley and 9° to 24°C (49° to 76°F) on the coast in San Diego. Statewide



## West

**jet stream** • a fast-flowing, narrow air current found in the ATMOSPHERE. The polar jet stream is found at an altitude of 7–12 kilometers (23,000–39,000 feet), and the air within can travel as fast as 160 kph (100 mph). Jet streams are created by a combination of the Earth's rotation and atmospheric heating.

# US Regional Climates

## ANNUAL TEMPERATURE

76 – 80°F  
24.4 – 26.6°C



71 – 75°F  
21.6 – 24°C



66 – 70°F  
19 – 21°C



61 – 65°F  
16 – 18°C



56 – 60°F  
13.3 – 15.5°C



51 – 55°F  
10.5 – 13°C



46 – 50°F  
8 – 10°C



41 – 45°F  
5 – 7.2°C



36 – 40°F  
2.2 – 4.4°C



31 – 35°F  
0 – 2°C



21 – 30°F  
-6 – -1°C

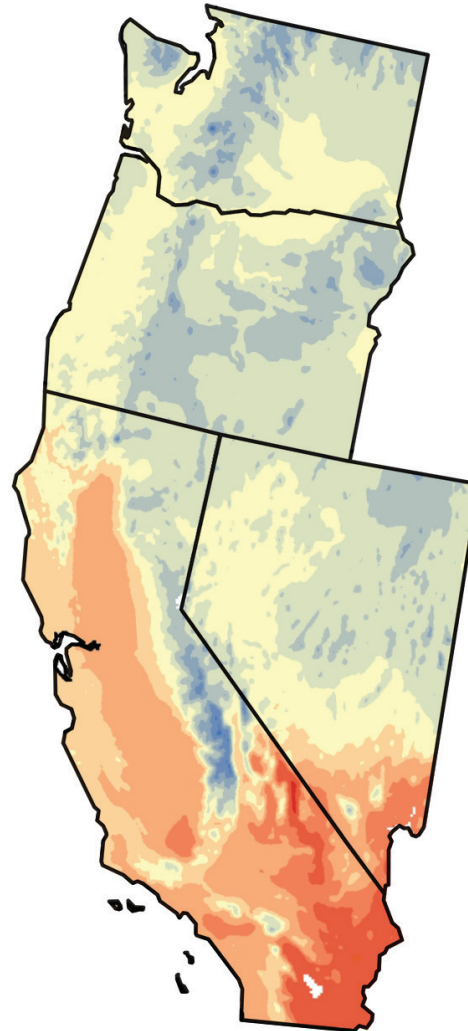


Figure 6.16: Mean annual temperature for the contiguous Western states. (See Teacher-Friendly Guide website for a full color version.)

average lows and highs in Oregon run from  $-3^{\circ}$  to  $28^{\circ}\text{C}$  ( $26^{\circ}$  to  $82^{\circ}\text{F}$ ), while in Washington, temperature ranges from  $-1^{\circ}$  to  $32^{\circ}\text{C}$  ( $29^{\circ}$  to  $89^{\circ}\text{F}$ ). Nevada experiences temperatures spanning from  $4^{\circ}$  to  $40^{\circ}\text{C}$  ( $39^{\circ}$  to  $104^{\circ}\text{F}$ ).

The West's spectacular mountain ranges run from north to south. These ranges—the Coastal Range, the Cascades, and the Sierra Nevada—create a pronounced east-west precipitation gradient across the Western states. As moist air moves inland from the Pacific Ocean, the mountain ranges force this air upward, which causes its pressure and temperature to drop, creating precipitation. The overall effect is to produce very wet conditions on the western sides of the West's mountain ranges, and very dry rain shadows (see Figure 6.10) on the eastern sides. This effect is most pronounced from Northern California up through Washington, since the **jet stream** is often located over this area—especially in winter—and brings moist ocean air inland. As an example of how extreme this precipitation gradient can be, Olympic National Park in Washington receives over 190 centimeters (75 inches) of rain annually on average, whereas communities only 400 kilometers (250 miles) to the east



### ANNUAL PRECIPITATION

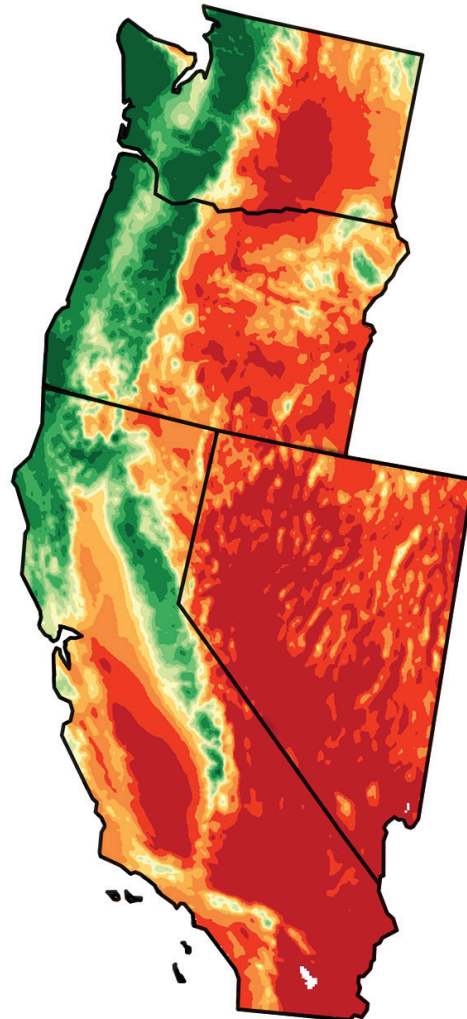
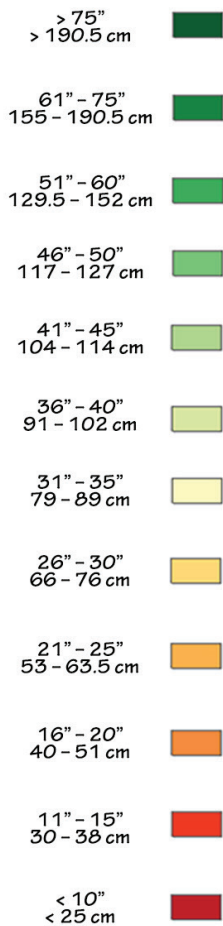


Figure 6.17: Mean annual precipitation for the West Coast. (See Teacher-Friendly Guide website for a full color version.)

in Washington receive only 18 to 20 centimeters (7 to 8 inches) annually. This is almost a full order-of-magnitude difference over a relatively short distance. Strong gradients like this are rarely found on our planet. As the most arid state in the US, Nevada receives only about 24 centimeters (9.5 inches) of rainfall a year (Figure 6.17).





## West

**climate model** • a computer-generated simulation of the Earth's climate system, projected through time.

# US Regional Climates

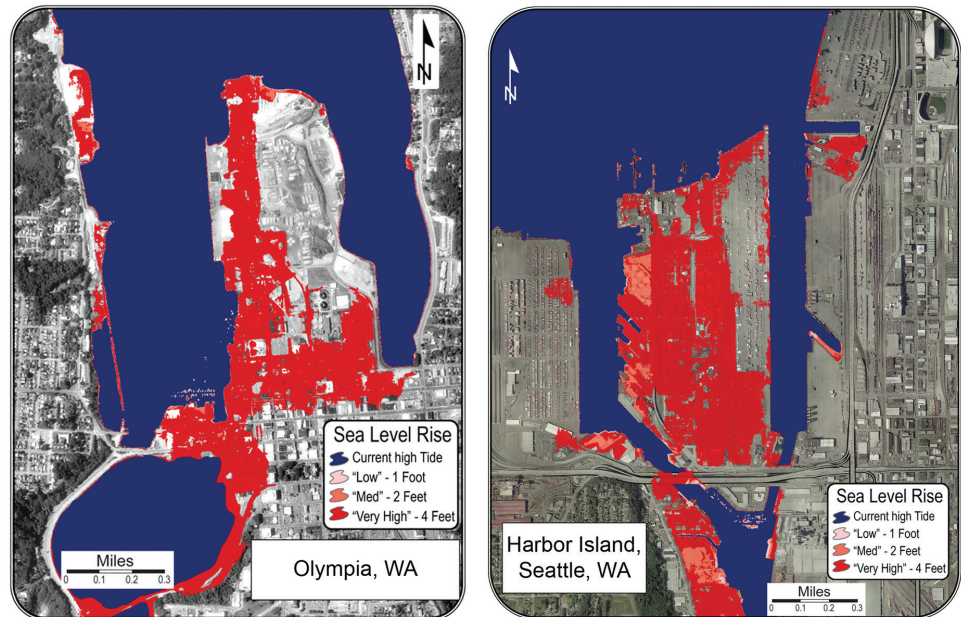


Figure 6.18: Maps showing portions of the cities of Olympia and Seattle, WA that will be inundated if sea level rises by one, two, or three feet. (See Teacher-Friendly Guide website for a full color version.)

## 7.3 Future Climate

Studies show that the West's climate is changing right now, and that change has accelerated in the latter part of the 20th century. These changes include the following:

- Temperatures in the West have increased in the last 25 years during all seasons.
- Nighttime temperatures in the southwestern part of the West have increased by almost 1.7°C (3°F) since 1900.
- The average annual number of wildfires of over 400 hectares (1000 acres) has doubled in California since the 1970s.
- The freeze-free season in the Northwest is on average 11 days longer for the period of 1991-2010, compared with 1961-1990.
- Heavy downpours have increased by 18% in the Northwest from 1948 to 2006.

**Climate models** (see Box 6.2) predict that the West's climate will continue to warm, and that the average annual temperature will rise by 2° to 6°C (3° to 10°F) by the end of the 21st century. The oceans are becoming warmer, and warm water expands and leads to sea level rise, a concern for West coast cities such as San Francisco, Seattle, and Olympia (Figure 6.18).

Water supply is a critical issue in the West, and communities will need to adapt to changes in precipitation, snowmelt, and runoff as the climate changes (Figure 6.19). Models predict that winter and spring storms in Nevada will shift northward, dropping less rain and snow in already arid areas. California will likely be faced with less water flowing in its rivers, declining high elevation forests, and expanding grasslands, along with increased pressure on the water supply for agriculture and cities.

The Northwest is expected to see less summer precipitation and more winter precipitation, and more of the winter precipitation falling as rain rather than





## Hawaii

*climate gradient • changes in climate across a distance.*



Figure 6.19: A dry riverbed in California, March 2009.

snow. Over the past 40 to 70 years, the Cascade Range has experienced a 25% decline in snowpack measured on April 1, a trend that is expected to continue. This means less water from snowmelt in the warm season. Spring runoff in Northwestern streams is expected to occur nearly 20 to 40 days earlier during the 21st century.

## 8. Hawaii

### 8.1 Description

The sun rises in Honolulu, Hawaii—the southernmost land mass in the US—approximately six hours after it rises in West Quoddy Head, Maine, and over two hours after it rises in Las Vegas, Nevada. Hawaii is far away from the rest of the United States—and from any other major land mass, for that matter. California is more than 2,000 miles away. Japan is nearly 4,000 miles away. Australia is nearly 5,000 miles away. The regional climate of Hawaii, therefore, is quite different from the rest of the US and closely tied to the behavior of the Pacific Ocean.

### 8.2 Present Climate

The eight main Hawaiian Islands stretch between 19° and 22° north latitude. This places them firmly within the tropics, and also within the belt of persistent northeast trade winds. This geography, combined with the high topography of many Hawaiian peaks, gives rise to large variations in climate across the islands—Hawai'i Island alone has some of the most extreme **climate gradients** of any place on Earth. Additionally, as half of the land area of Hawai'i lies within



## Hawaii

**trade winds** • persistent, large-scale winds in the tropical oceans which blow from the northeast in the Northern Hemisphere and from the southeast in the Southern hemisphere.

# US Regional Climates

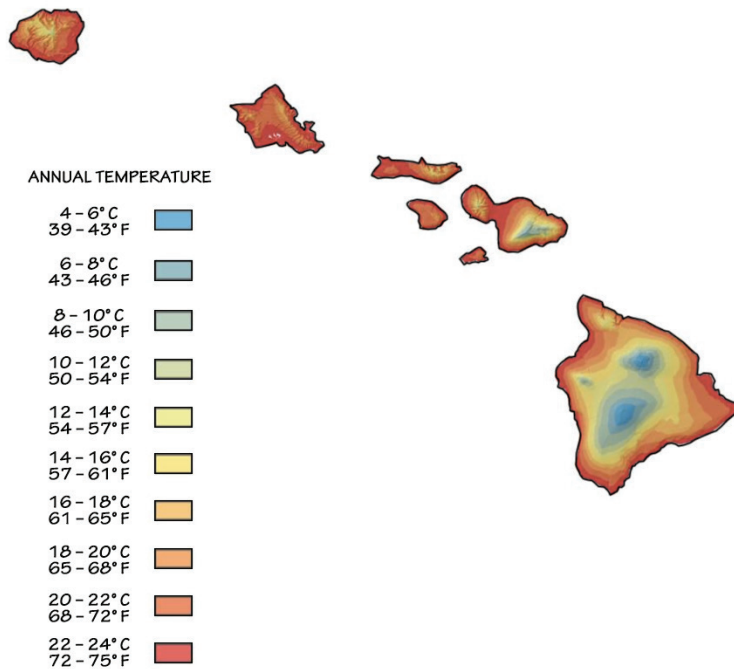


Figure 6.20: Mean annual air temperature in Hawai'i. Air temperature is inversely related to elevation, so the temperature variations are closely related to large-scale topographic features. (See Teacher-Friendly Guide website for a full color version.)

eight kilometers (five miles) of the ocean, and the farthest inland you can be on any of the islands is 65 kilometers (40 miles), the ocean is an important control on climate.

Hawai'i is a small archipelago in the center of the world's largest ocean. Water has a very high heat capacity (i.e., a lot of energy is required to raise the temperature of water). This means that the annual temperature variation of the ocean is small. Around the Hawaiian Islands the ocean surface temperature ranges between 24°C (75°F) in winter and 27°C (81°F) in summer. The seasonal variation in land surface temperature for coastal Hawai'i is similar, about 5°C (9°F) from winter to summer. This is very unlike many inland states, which can have large inter-seasonal variations in their temperature (see Section 3 in this chapter on the Midwest).

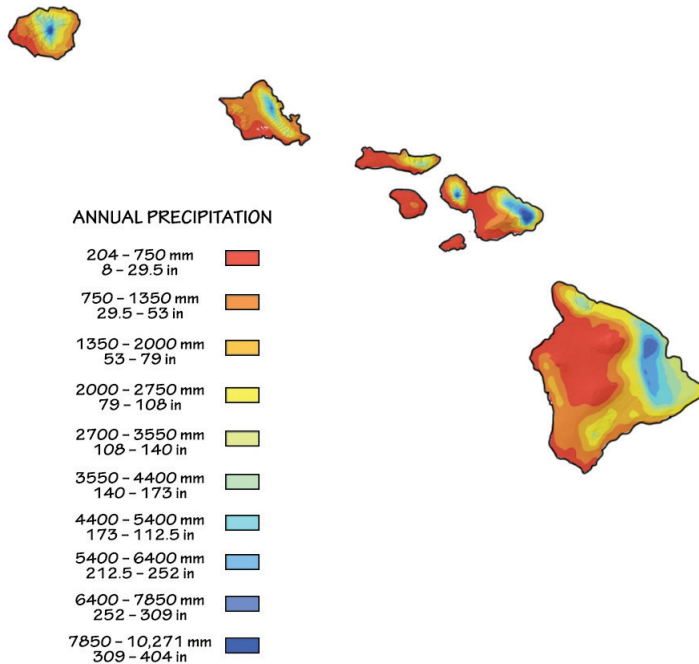
Another control on the climate of Hawai'i is the high topographic **relief** of the islands. The islands of Hawai'i, Maui, Kaua'i, Moloka'i and O'ahu all have summits that are above 1200 meters (4000 feet) in elevation. On Hawai'i Island the peaks of Mauna Kea and Mauna Loa are each above 4180 meters (13,700 feet). Without these summits, Hawai'i would be a warm and humid place with relatively low rainfall. However, the presence of these huge mountains changes the local climate dramatically, which, in turn, leads to the great diversity of climate zones found in Hawai'i (Figure 6.20).

The air above the ocean—the boundary layer—has a high relative humidity because it is in contact with the warm tropical ocean. Northeast **trade winds** carry this moisture-laden air to the Hawaiian Islands. The mountainous islands divert the airflow both around and over the topographic obstructions. Air that rises over the mountains expands and cools, and the moisture carried in

# US Regional Climates



6



## Hawaii

**windward** • the side of a mountain range or other high landmass which is facing toward the direction the wind is coming. For example, if a wind is coming from the West, the windward side of a mountain range is the western side.

**leeward** • the side of a mountain range or other high landmass which is facing away from the direction the wind is coming. For example, if a wind is coming from the West, the leeward side of a mountain range is the eastern side.

Figure 6.21: Mean annual rainfall in the Hawaiian Islands. Northeast trade winds combine with topography to create a strongly asymmetrical rainfall distribution. Leeward (west) areas receive little rainfall while windward (east) slopes are some of the wettest places on Earth. (See Teacher-Friendly Guide website for a full color version.)

from the ocean condenses and rains out. The **windward** sides of each island are therefore places with frequent and abundant precipitation (Figure 6.21). As the air continues down the **leeward** slopes it is at first compressed, and subsequently warms, and no additional moisture condenses; the leeward island shores are therefore very dry. On most of the Hawaiian Islands, the maximum rainfall occurs at 610–910 meters (2000–3000 feet) above sea level, although the two wettest spots in the islands are slightly higher in elevation. Wai'ale'ale on Kaua'i (1570 meters [5150 feet]) and Big Bog on Maui (1650 meters [5400 feet]) vie with each other for the title of wettest spot in the US, and indeed at about 1000 centimeters (about 400 inches) of annual rainfall they are two of the wettest spots on Earth. Because of the cold temperatures at the highest elevations of the mountains Mauna Kea, Mauna Loa, and Haleakalā, their summits are typically covered in snow in winter.

## 8.3 Future Climate

Hawai'i stands to be significantly impacted by climate change, with serious potential effects on both its ecosystems and economy. Air temperatures in Hawaii have been warming since 1900, at a rate of 0.06°C (0.11°F) per decade for the last four decades and this trend is expected to continue. These rising temperatures could disrupt the pattern of trade winds, changing rainfall patterns across the islands and creating periods of flooding or drought. Higher temperatures will also place more stress on native plants and animals, enabling the proliferation of invasive species that are better able to withstand temperature extremes.



## Alaska

**ocean acidification** • the increasing acidity, or lowered pH, of ocean waters, caused by absorption of atmospheric carbon dioxide.

# US Regional Climates

Hawai'i is unique among US states in that it is an island state isolated in the Pacific Ocean, and therefore any changes to the Pacific Ocean will impact Hawai'i as well. **Ocean acidification** occurs when excess carbon dioxide in the atmosphere dissolves in the ocean, forming carbonic acid. Both warmer water temperatures and ocean acidification can have devastating effects on coral reefs. Warmer water leads to increased coral bleaching, and more acidic water can damage the shells of marine organisms. Finally, sea level rise could inundate much of Hawai'i's coastline—the worst case scenario of a 2-meter (6-foot) sea level rise would bring Hawai'i's coast a mile inland in some places, submerging or eroding important economic locations like Waikiki Beach and parts of Honolulu.

## 9. Alaska

### 9.1 Description

The westernmost point you can reach in the United States is Cape Wrangell, Alaska. The sun rises here almost eight hours after it rises in West Quoddy Head, Maine and, because it is so far north, the sun rises later than it does in Honolulu, Hawaii in the winter months, but earlier than it does in the summer months. Alaska shares a border with Canada, has large coastlines on the Pacific and Arctic Oceans, and is only 55 miles away from Russia. Alaska is twice the size of the second largest state, Texas, and larger than the smallest 21 states combined. It contains both the westernmost point in the US—Cape Wrangell—and the northernmost point—Point Barrow—and the distance between these points is larger than the distance between Los Angeles, California and Houston, Texas or the distance between Denver, Colorado and Washington, D.C.

### 9.2 Present Climate

Alaska's climate, like that of other parts of the Western US, is influenced by its mountain ranges and its proximity to the ocean. Statewide averages range from a low of  $-17^{\circ}\text{C}$  ( $2^{\circ}\text{F}$ ) in January to a high of  $17^{\circ}\text{C}$  ( $63^{\circ}\text{F}$ ) in July (*Figure 6.22*). North of the Brooks Range, Alaska has a cold, dry, polar climate with frequent winter blizzards. Temperatures on the coast are moderated somewhat by the Arctic Ocean. Central Alaska has a dry continental climate, with a large variation between summer and winter temperatures. For example, the town of Takotna in Alaska's interior has an average low temperature of  $-27^{\circ}\text{C}$  ( $-17^{\circ}\text{F}$ ) in January and an average high of  $22^{\circ}\text{C}$  ( $72^{\circ}\text{F}$ ) in July.

A third climate region exists in the Alaskan southeast, south coast, and southwestern islands, and in west-central Alaska in the summer. These areas have moderate temperatures—an average annual temperature of about  $7^{\circ}\text{C}$  ( $45^{\circ}\text{F}$ )—and high precipitation. Some areas are home to lush rainforests and receive around 500 centimeters (200 inches) of rain a year (*Figure 6.23*). The climate in west-central Alaska is influenced by a phenomenon that is unique in the United States: the seasonal presence of sea ice. In the winter when sea ice covers the Bering Sea, this area loses the moderating effect of open water and has a continental climate. When the sea ice melts in summer, the climate returns to a warmer, more humid maritime state.



# US Regional Climates



6

## Alaska

### ANNUAL TEMPERATURE

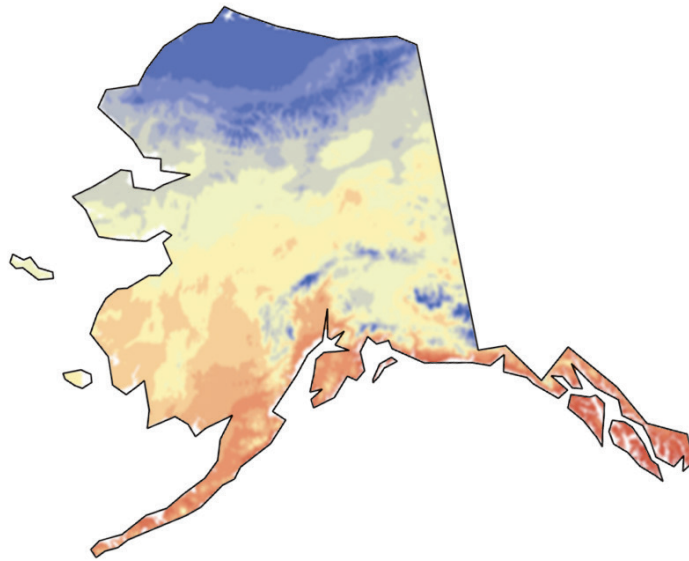
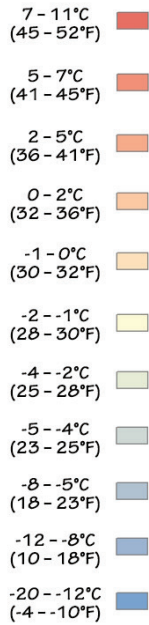


Figure 6.22: Mean annual temperature for Alaska. (See Teacher-Friendly Guide website for a full color version.)

### ANNUAL PRECIPITATION

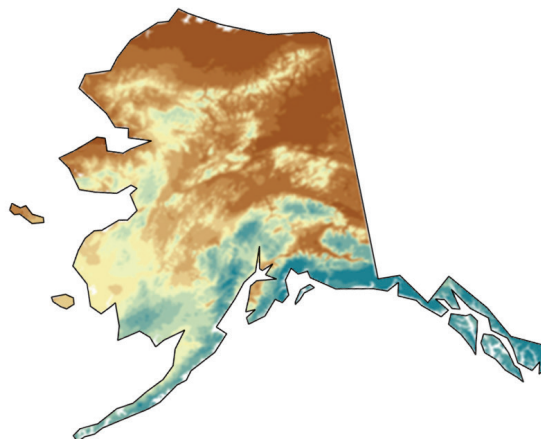
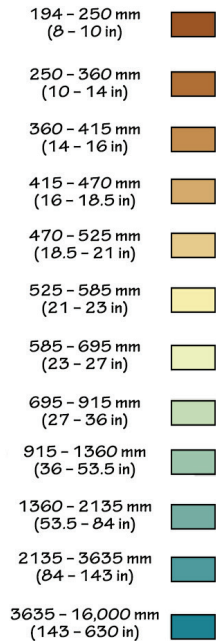


Figure 6.23: Mean annual precipitation for Alaska. (See Teacher-Friendly Guide website for a full color version.)



# US Regional Climates

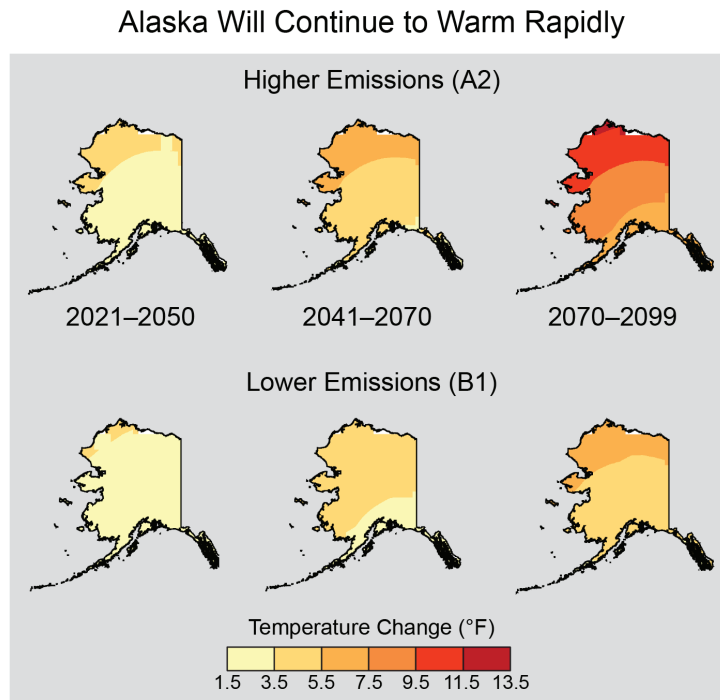


Figure 6.24: Northern latitudes are warming faster than more temperate regions, and Alaska has already warmed much faster than the rest of the country. Maps show changes in temperature, relative to 1971–1999, projected for Alaska in the early, middle, and late parts of this century, if heat-trapping gas (also known as greenhouse gas) emissions continue to increase (higher emissions, A2) or are substantially reduced (lower emissions, B1). (See Teacher-Friendly Guide website for a full color version.)

## 9.3 Future Climate

Nearly one-third of Alaska lies within the Arctic Circle, which is warming much faster than the global average temperature under climate change. In addition, nearly 80% of the land within Alaska lies above a layer of frozen permafrost, which under a warming climate is thawing. This, combined with rising sea levels and coastal erosion, has already resulted in buildings falling into the ocean and “drunken forests,” where trees growing in thawing permafrost are tilted sideways.<sup>8</sup> All of these trends are expected to accelerate in the future, and present an imminent threat to Alaska’s infrastructure (buildings, roads, and pipelines).

Statewide average temperatures in Alaska have already increased, with winter temperatures increasing the most: up 3.2°C (5.8°F) from 1949 to 2011. By the middle of the 21<sup>st</sup> century, temperatures in Alaska are expected to rise by 2° to 4°C (3.5° to 7°F) relative to the late 20<sup>th</sup> century (*Figure 6.24*). These increased temperatures lead to a whole host of effects, including drier soils from more evaporation, the increased likelihood of drought and fires, and more rain (rather than snow) in the winter.

**Climate models** (see Box 6.2) project that Alaska will receive more precipitation, but that soils will actually become drier due to increased evaporation from

<sup>8</sup> Learn more about “drunken forests” here: <http://news.nationalgeographic.com/news/2014/04/140417-drunken-trees-melting-permafrost-global-warming-science/>

# US Regional Climates

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warmer air temperatures. Summers are expected to support a longer growing season, and also to see more drought and wildfires. Invasive insects that damage Alaskan trees will be better able to survive warmer winters, and will therefore increase and spread. Sea ice will cover the ocean for shorter portions of the year, possibly changing the distribution of plankton blooms, a part of the marine food chain upon which Alaska's fisheries depend.

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Alaska

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# US Regional Climates

## Resources

### US Climate Data and Maps

Köppen-Geiger maps, including an animation showing how they evolve with predicted future climate: <http://koeppen-geiger.vu-wien.ac.at/>

Third National Climate Assessment (2014): <http://nca2014.globalchange.gov/>. National Climate Assessments have been published in 2000, 2009, and 2014, with interim assessments in between. Additional assessments are expected approximately every four years.

NOAA/NESDIS Technical Reports - Regional Climate Trends and Scenarios for the US National Climate Assessment. These reports contain historical and projected climate data for all regions of the United States. [http://www.nesdis.noaa.gov/technical\\_reports/142\\_Climate\\_Scenarios.html](http://www.nesdis.noaa.gov/technical_reports/142_Climate_Scenarios.html)

Temperature and precipitation data, graphs, and maps in your region and much more are available from your NOAA Regional Climate Center (<https://www.ncdc.noaa.gov/customer-support/partnerships/regional-climate-centers>). The length of the data records available varies by location, but some data go back to the late 19<sup>th</sup> century.

Historical climate data for the US, on NOAA's Climate at a Glance website: <http://www.ncdc.noaa.gov/cag/>. Here you can generate maps and time-series plots of temperature, precipitation, and drought data for a broad choice of regions and time periods. Data are also available for cities, from two reliable sources: either the Global Historical Climatology Network or the US Historical Climatology Network.

Summaries of Regional Climate Trends and Scenarios (prepared for the Third National Climate Assessment): <https://scenarios.globalchange.gov/node/1155>

Information about regional climate change and its impacts: <http://climatenexus.org/learn/regional-impacts>

Climate Explorer, an interactive map that shows assets and climate threats and interactive graphs of historical temperature and precipitation at weather stations across the US: <https://toolkit.climate.gov/tools/climate-explorer>

Information about climate change and its impacts in the US, including regional summaries: <https://www.epa.gov/climatechange>





## **US Climate Projections**

Future Climate chapter of the Third National Climate Assessment: <http://nca2014.globalchange.gov/highlights/report-findings/future-climate>. This chapter contains maps which show projected change in temperature, precipitation, soil moisture, and more in the US at the end of the 21<sup>st</sup> century for two different emissions scenarios.

1001 Blistering Future Summers: a tool to see what future temperatures of many cities could be: <http://www.climatecentral.org/news/summer-temperatures-co2-emissions-1001-cities-16583>

Climate Data US, a site to explore NASA temperature and precipitation projections on a map: <http://www.climatedata.us/>

