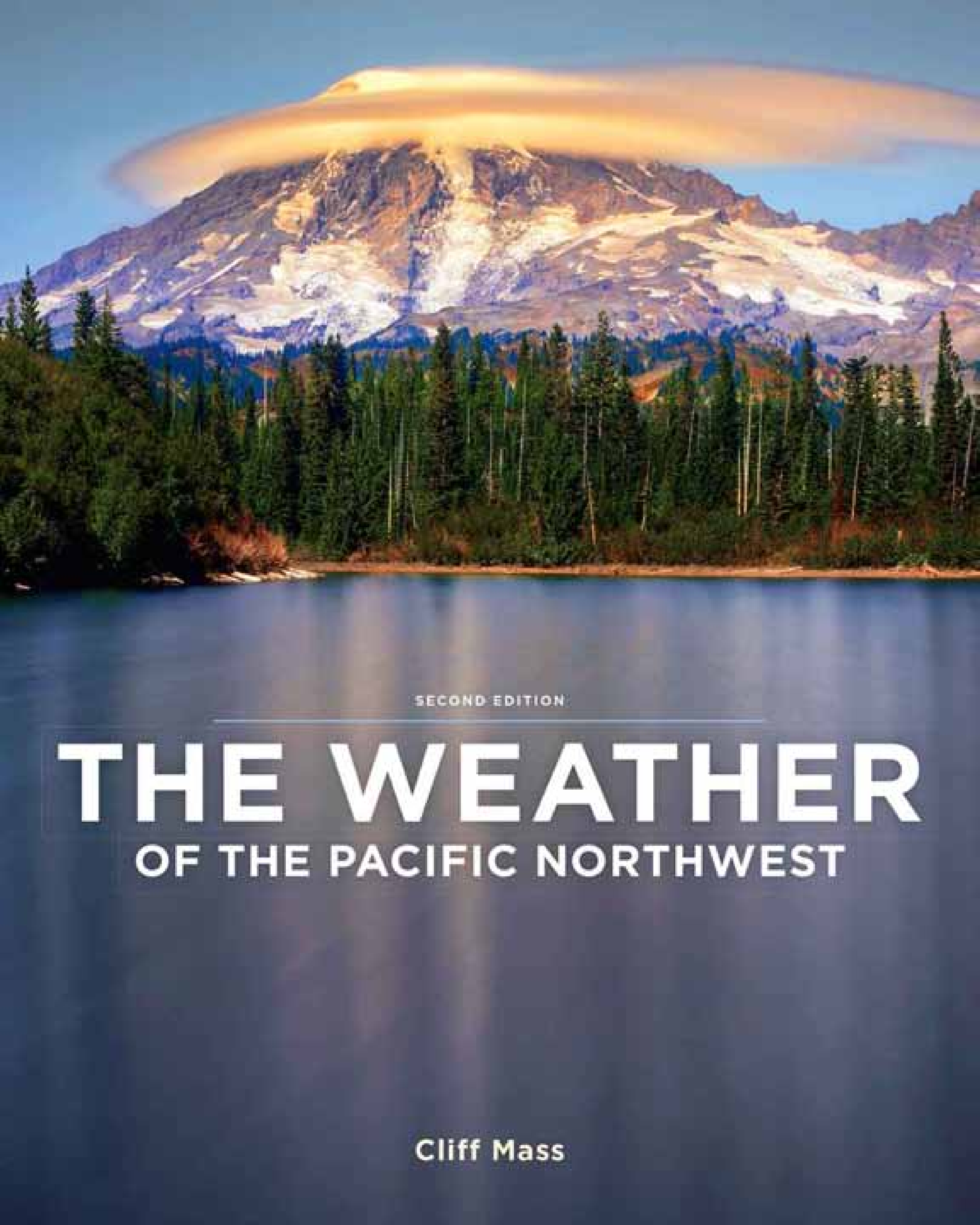


SECOND EDITION

THE WEATHER OF THE PACIFIC NORTHWEST

Cliff Mass

THE WEATHER OF THE PACIFIC NORTHWEST

THE WEATHER
OF THE PACIFIC NORTHWEST

SECOND EDITION

Cliff Mass

UNIVERSITY OF WASHINGTON PRESS
SEATTLE

The Weather of the Pacific Northwest **was made possible in part by a grant from the Samuel and Althea Stroum Endowed Book Fund.**

Design by Laura Shaw Design, Inc.
Composed in Harriet, typeface designed by Jackson Showalter-Cavanaugh, Okay Type; and Gotham, typeface designed by Hoefler & Co.
Illustrations and photographs are by the author unless otherwise noted.

25 24 23 22 21 5 4 3 2 1

Printed in South Korea

UNIVERSITY OF WASHINGTON PRESS
uwapress.uw.edu

LIBRARY OF CONGRESS CATALOGING-IN-PUBLICATION DATA
Names: Mass, Cliff, author.
Title: The weather of the Pacific Northwest / Cliff Mass.
Description: Second edition. | Seattle : University of Washington Press, [2021]
Includes bibliographical references and index.
Identifiers: LCCN 2020058646 (print) | LCCN 2020058647 (ebook) | ISBN 9780295748436 (hardcover)
ISBN 9780295748443 (paperback) | ISBN 9780295748450 (ebook)
Subjects: LCSH: Northwest, Pacific—Climate. | Weather forecasting—Northwest, Pacific.
Classification: LCC QC984.N97 M37 2021 (print) | LCC QC984.N97 (ebook) | DDC 551.69795—dc23
LC record available at https://lccn.loc.gov/2020058646
LC ebook record available at https://lccn.loc.gov/2020058647

The paper used in this publication is acid free and meets the minimum requirements of American National Standard for Information Sciences—Permanence of Paper for Printed Library Materials, ANSI Z39.48–1984.∞

ADDITIONAL PHOTOGRAPHY CREDITS
Page ii: Crater Lake National Park at sunrise. © iStock.com/freebilly.
Page v: Forest in the mist at Mount Rainier National Park. © iStock.com/KingWu.
Page vi: Puget Sound before a thunderstorm. © iStock.com/philotera.
Page viii: Afternoon light filters through fog and clouds at a ski area in Washington. © iStock.com/Vince Barnes.
Page 2: Autumn landscape at Columbia River Gorge National Reserve Area. © iStock.com/vitpho.
Page 292: Olympic National Park, at Rialto Beach during sunset. © iStock.com/Sean Pavone.
Page 300–301: Mount Rainier wildflowers. © iStock.com/Aaron_Huang.

TO MY PARENTS, WHO ENCOURAGED AND SUPPORTED MY PASSION FOR WEATHER

CONTENTS

ACKNOWLEDGMENTS

A NUMBER OF INDIVIDUALS have greatly contributed to the preparation of the second edition of *The Weather of the Pacific Northwest*. First and foremost is Beth Tully, who played a crucial role in drafting many of the graphics and diagrams. Her dedication to quality and clear communication made this book possible. Professor Richard Reed and Mark Albright, past state climatologist, taught me much about the intricacies of Northwest weather. I have also learned a great deal about Northwest meteorology working with University of Washington graduate students over the years, including Justin Sharp, Garth Ferber, Fang Chien, Matt Garvert, Jim Steenburgh, Brian Colle, Bri Dotson, Eric Grimit, Tony Eckel, Mathew Brewer, Mike Warner, Joseph Zagrodnik, and Robert Conrick. Ben Slivka reviewed the final proofs, providing many valuable corrections and suggestions.

Several past and present research meteorologists in the atmospheric sciences department—David Ovens, Richard Steed, Jeff Baars, and Ken Westrick—have been my constant colleagues in dissecting the inner workings of regional weather features. Art Rangno provided many of the excellent cloud photographs found throughout these pages. I gratefully acknowledge the financial support of the Northwest Modeling Consortium, the National Science Foundation, and the National Oceanographic and Atmospheric Administration, which made possible much of the modeling and research that provide the foundation for this book.

Finally, the University of Washington Press has been an extraordinary partner in preparing both editions of *The Weather of the Pacific Northwest*. Special appreciation goes to senior acquisitions editor Andrew Berzanskis, who suggested a second edition and provided valuable suggestions that greatly improved the final draft. The attractive book design was created by Laura Shaw, and the text was substantially enhanced by copyeditor Amy Smith Bell. The continued interest in Northwest weather by readers of my blog was an inspiration for the new edition, which attempts to answer the many questions they have sent me over the years.

THE WEATHER OF THE PACIFIC NORTHWEST

1

THE EXTRAORDINARY WEATHER OF THE PACIFIC NORTHWEST

On Columbus Day in 1962 the most powerful nontropical cyclone to strike the continental United States during the past one hundred years pummeled the West Coast from northern California to southern British Columbia. With winds exceeding 150 miles per hour over the coastal headlands and 100 miles per hour across Puget Sound and the northern Willamette Valley, the cyclone left devastating damage in its wake (figure 1.1). Power outages extended over most of the region, more than fifty thousand buildings were damaged, and forty-six people lost their lives. How could such a storm strike a region known for its benign weather and the velvet softness of its clouds, fog, and incessant light rain? Pacific Northwest weather is often surprising, both in its intensity and the startling contrasts between nearby locations.

The weather of the Pacific Northwest is exceptional in many ways. While much of the eastern two-thirds of the United States endures warm, humid summers and cold, often snowy winters, the western side of the Northwest enjoys mild, dry summers and temperate, wet winters. In large portions of the country, weather varies gradually from one location to another; in contrast, localized weather features are the norm in the Northwest, where radically different weather conditions are often only separated by a few miles. While summer thunderstorms are major weather features over much of the United States, in the Northwest they are infrequent events, with strong thunderstorms, tornadoes, and hail a rarity. Although hurricanes can strike the Atlantic and Gulf coasts of the United States and greatly influence the weather far inland, the Northwest is never affected by such tropical storms.

Not only is the weather different in the Northwest, but so is its prediction. While weather forecasts for the central and eastern portions of the country are enhanced by the dense observing network over North America, Pacific Northwest predictions are challenged by a sparsity of upstream surface observations, since most West Coast weather systems originate over the relatively data-poor North Pacific. Weather satellites now

provide essential weather information over the vast Pacific, and during the past several decades they have facilitated a rapid improvement in Northwest weather forecast skill.

Although Northwest weather is usually gentle and benign, some of the continent's most severe weather occurs here. Intense Pacific low-pressure systems, like the Columbus Day Storm, packing hurricane-force winds and extending over considerably larger areas than tropical storms, can bring destruction to wide swaths of the region. Localized windstorms, often associated with gaps in Northwest mountains or downslope flow on major terrain features, have produced severe small-scale winds reaching 100 miles per hour or more. One such event destroyed the Hood Canal Bridge in 1979 at a cost of more than $140 million, and other windstorms have peeled off roofs in the Cascade foothills town of Enumclaw. While snow is infrequent and generally light over the Northwest lowlands, the heaviest measured snowfall on the continent strikes the Cascade Mountains, resulting in buried roads and avalanches. During the last week of December 1996, such heavy snow closed all Cascades passes in Washington and resulted in widespread building collapses on both sides of the state.

Even though rainfall amounts are usually light to moderate during Northwest winters, so-called Pineapple Express rainstorms, associated with rivers of atmospheric moisture originating near Hawaii, can bring several feet of rain to Northwest communities over a few days, resulting in catastrophic flooding and mudslides. Such conditions hit the region with full force in November 2006, with Mount Rainier National Park experiencing the most severe damage since its inception (figure 1.2) and losses from flooding in Oregon and Washington totaling hundreds of millions of dollars. Billion-dollar storms have occurred several times

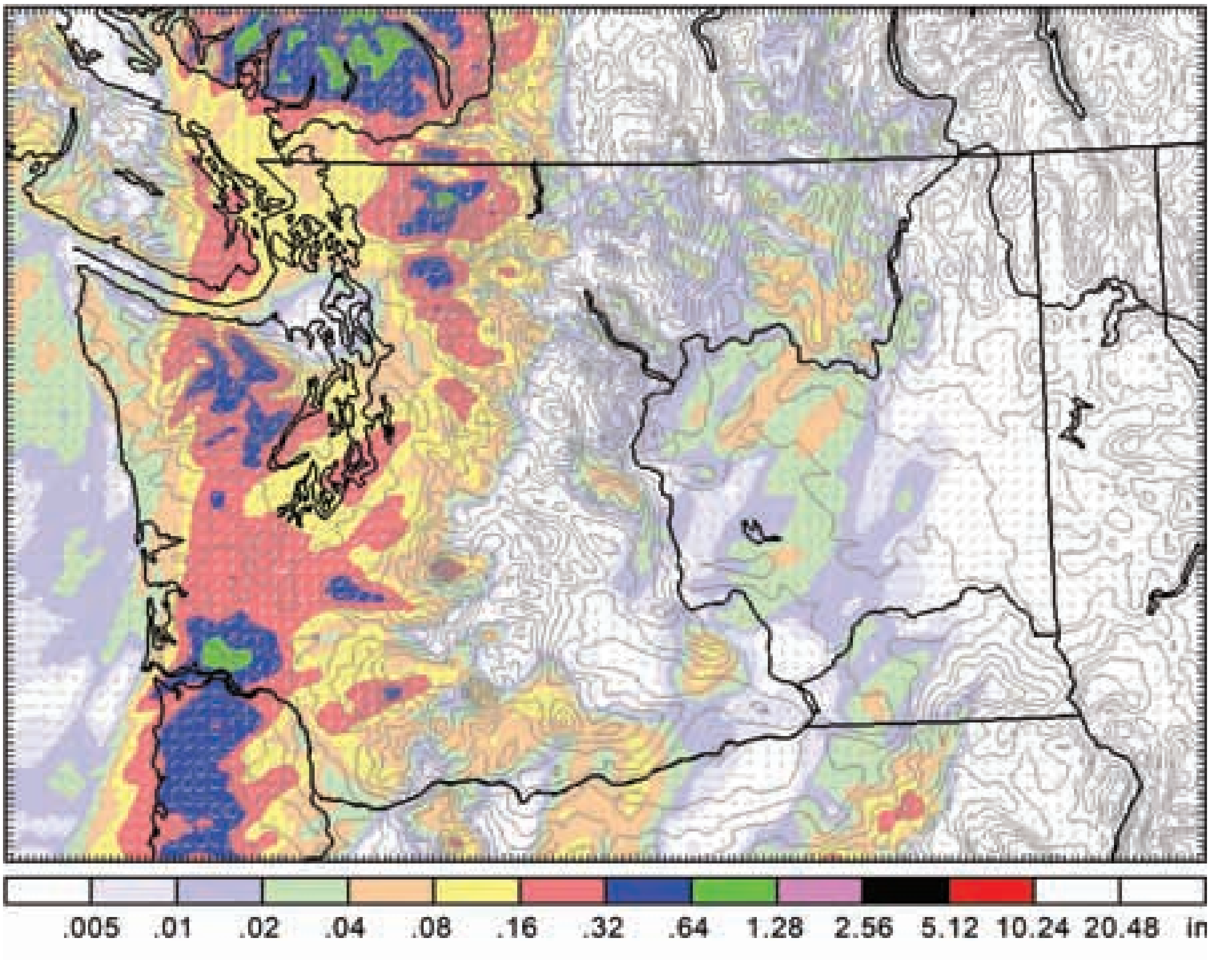
1.1 • (*opposite*) The bronze statue *The Circuit Rider*, on the grounds of the Oregon State Capitol in Salem, was toppled by hurricane-force winds during the 1962 Columbus Day Storm. Photo by Hugh Stryker and provided courtesy of the Salem Public Library Historic Photograph Collections.

1.2 • (*right*) Record-breaking rains on November 6, 2006, caused catastrophic slope and road failures across Mount Rainier National Park, resulting in the closure of much of the park for months. This picture shows damage to Nisqually Road at Sunshine Point in the southwestern portion of the park. Photo courtesy of the National Park Service.

in the Northwest since 1980, and all of them have been associated with severe flooding.

Startling contrasts over small distances are some of the most singular aspects of Pacific Northwest weather. The region's high terrain often separates radically different climate and weather regimes, with transitions occurring over a matter of miles. The Olympic Mountains are a prime example: rainforest conditions and annual precipitation approaching 200 inches a year are found over its western slopes, such as within the Hoh River valley, while a few dozen miles away on the mountains' northeastern side, Sequim typically receives about 15 inches a year. It is easy to see why this town is a magnet for retirees in search of California-like conditions in the Northwest. Similarly large contrasts occur over the Columbia Gorge, with the change from the wet, lush forest environment near Cascade Locks to arid, barren conditions just east of Hood River occurring in a little over 40 miles and less than an hour's drive on Interstate 84. On December 18, 1990, an unexpected foot of snow crippled the city of Seattle during rush hour, while 20 miles to the north and south the ground remained bare. Northwest winds can also vary greatly over short distances. An extreme case occurred on the night of December 24, 1983, during a severe cold spell west of the Cascades. Air rushed westward through a gap in the Cascades and descended toward Enumclaw and vicinity, bringing wind gusts of over 120 miles per hour that tore off roofs and crumpled high-tension power-line towers. In contrast, 25 miles to the northwest in Seattle the winds were dead calm. No wonder local TV stations love to describe Northwest weather as "weird" or "wacky."

The Pacific Northwest is also home to notable weather anomalies. When air descends the steep terrain that bestrides the Oregon-California border (the Siskiyou/Klamath Mountains), the southern Oregon coast can be 10–20 °F warmer than the rest of the Northwest, with high temperatures soaring into the 80s °F even in midwinter. Not surprisingly, the local chamber of commerce advertises this area as a "banana belt" providing near-tropical warmth. Other Northwest locations are famous for their extreme cold. Mazama and Winthrop, Washington, located in a deep valley protruding into the northern Cascades, are often the coldest locations in the state, both setting the all-time record low for Washington of –48 °F on December 30, 1968. Even colder temperatures can occur within the frigid valleys of the uplands of eastern Oregon, where Ukiah and Seneca cooled to –54 °F during the winter of 1933. The all-time record for annual snowfall in the



1.3 • High-resolution computer predictions of Pacific Northwest weather have greatly improved weather forecasts. This figure shows a twenty-four-hour prediction of precipitation over Washington State using a state-of-the-art computer forecasting model. The values shown are for the three hours ending at 5:00 PM (Pacific Daylight Time) on October 16, 2019, given in hundredths of an inch, with blue and green indicating the heaviest precipitation. Precipitation was very light in the rain shadow to the northeast of the Olympic Peninsula. Terrain contours (gray lines) and near-surface winds are also presented.

United States occurred at Mount Baker ski area, where 1,140 inches fell during the 1998–99 winter season, breaking the previous record (1,122 inches) at Mount Rainier. The snow was so plentiful that year that skiing had to be suspended until the ski lifts were dug out.

The Pacific Northwest is also well-known for weather curiosities. Air streaming over the Northwest mountains can sometimes create lens-shaped clouds that resemble flying saucers; in fact, such an apparition set off the UFO craze in 1947. Large changes in air temperature above Puget Sound can cause optical effects in which ferry boats and other marine vessels appear to be flying above the water, and shorelines seem thrust high into the sky. More ominously, the combination of strong winds and arid conditions east of the Cascades often produces terrible dust storms that decrease visibility to near zero and cause multicar accidents. The eruption of Mount Saint Helens in 1980 covered vast areas of the Northwest with darkness, with the ash cloud acting as an insulator that kept temperatures virtually constant for more than twelve hours across much of eastern Washington. And the foggiest location in the continental United States is found near the outlet of the Columbia River at Cape Disappointment, where the typical year brings 106 days of dense fog, with a visibility of a quarter mile or less.

Serious misconceptions about Pacific Northwest weather abound and many are put to rest in these pages. Probably the most repeated unsubstantiated claim is that Seattle receives more rain than virtually anywhere else in the continental United States. Not true. With an average annual precipitation of roughly 37 inches, Seattle is handily beaten by New York City (47 inches), Miami (56 inches), and many other locations across the eastern, central, and southern portions of the country. Another canard is that the Northwest is wet year-round. The truth is that more than half of the annual precipitation in the Northwest is concentrated over a relatively few months, from November through February, with summers among the driest in the nation—even considering the desert Southwest. Finally, some assert that Northwest terrain makes weather prediction difficult; but the mountains have the opposite effect, improving forecast skill and giving local forecasters advantages over their eastern colleagues.

Northwest meteorologists are often the brunt of local humor, and it is not unusual to hear people muse that dice would be a more reliable forecast guide. But the truth is that regional forecasts *are* getting better—in fact, *much* better. Making use of technologies such as weather radar, satellite imagery, and high-resolution computer weather simulation, meteorologists have unraveled many of the details of Northwest weather, with forecasting skill increasing substantially (figure 1.3). Although historical storms like the Columbus Day Storm of 1962 were poorly predicted, many of the recent great blows, such as the Inauguration Day Storm of 1993 or the Hanukkah Eve Storm of 2006, were forecast accurately days in advance. Something has changed, and this book describes the advances that have made improved predictions possible.

The implications of global warming on Pacific Northwest weather and climate is a subject of increasing concern. With its dependence on melting snow as a source of water and hydroelectric power during the summer and early fall, the Northwest is vulnerable to the effects of global warming. Recent increases in the extent of regional wildfires and summer smoke have stoked fears that a warming climate may permanently degrade the stunning weather of typical Northwest summers. Although the mountains and complex land-water contrasts of the Pacific Northwest make prediction of its future climate challenging, recent scientific advances are slowly revealing the region's climate future. Some of these revelations may be surprising, including increases in annual precipitation and springtime clouds west of the Cascades. The effects of global warming will vary greatly across the region, with warming weaker near the coast and enhanced on mountain slopes and east of the Cascade crest.

The complex meteorology of the Pacific Northwest has been the subject of intense scrutiny by local weather scientists since the late 1970s. Making use of these insights and rapid advances in observing technologies and computer simulation, this book describes the weather of the region stretching from British Columbia to the California border and from the western slopes of the Rockies to the Pacific Ocean. The goal is to provide a scientifically accurate description of Northwest weather that is accessible to a layperson.

2

THE BASICS OF PACIFIC NORTHWEST WEATHER

If one could use a single phrase to describe Pacific Northwest weather, "wet and mild" would be a start but not a particularly exact one. Although the region west of the Cascade crest is considered "wet" by many, it enjoys some of the driest summers in the nation and receives less annual precipitation than much of the eastern United States. East of the Cascades, where arid conditions dominate, "wet" is certainly not an apt description, and east-side temperature extremes, ranging from –48 °F to 119 °F, makes "mild" a misnomer at times. Northwest weather and climate are dominated by two main elements: (1) the vast Pacific Ocean to the west and (2) the region's mountain ranges that block and deflect the air currents approaching the region. Together, these geographical features explain many of the key aspects of Pacific Northwest weather. The ocean moderates the air temperatures year-round and serves as a source of moisture, while the mountains profoundly impact the distribution of clouds and precipitation and prevent the entrance of cold air from the continental interior during the winter.

Why Does Northwest Weather Generally Come from the West?

The Pacific Northwest is located in the midlatitudes, a zone stretching from approximately 30° to 60° north, where winds generally blow from west to east. This eastward movement of air is not uniform in the midlatitudes but is typically strongest in a relatively long, narrow current a few hundred miles across and a few miles deep, known as the *jet stream*. Usually centered 5–8 miles above the surface, jet-stream winds can reach 100–200 miles per hour during the winter. Weather systems, such as the low-pressure areas that bring rain and wind, tend to follow the jet stream, and thus the jet stream acts as an atmospheric "highway" for storms and precipitation. The jet stream undulates north and south like a sinuous snake and is not continuous around the globe. The Pacific Northwest is no stranger to the jet stream and accompanying storms. Typically, the eastern Pacific jet stream weakens during the summer, when it heads northward into Alaska. But during September and

October, the jet stream over the eastern Pacific strengthens and begins a southward journey, reaching the Pacific Northwest in November and bringing wind and rain. There it stays through February, after which the jet stream weakens and starts its slow northward return to northern latitudes. Too slow for most.

Why are winds from the west in the midlatitudes, and why is there a jet stream? The explanation begins with the difference in temperature between the warm tropics/subtropics and the cold Arctic latitudes to the north. This difference in temperature produces horizontal variations in pressure, with higher pressure to the south and lower pressure to the north. As described later in this book, on a rotating planet, such a north-south pressure variation produces westerly (from the west) winds. Since the temperature changes are usually found in a relatively narrow zone in the midlatitudes, the pressure differences and resulting winds are concentrated in a narrow current, the jet stream. Because north-south temperature changes are the "fuel" that drives midlatitude storms, the jet stream is associated with the low-pressure systems that bring rain and wind. And these storms tend to follow the jet stream, moving from west to east.

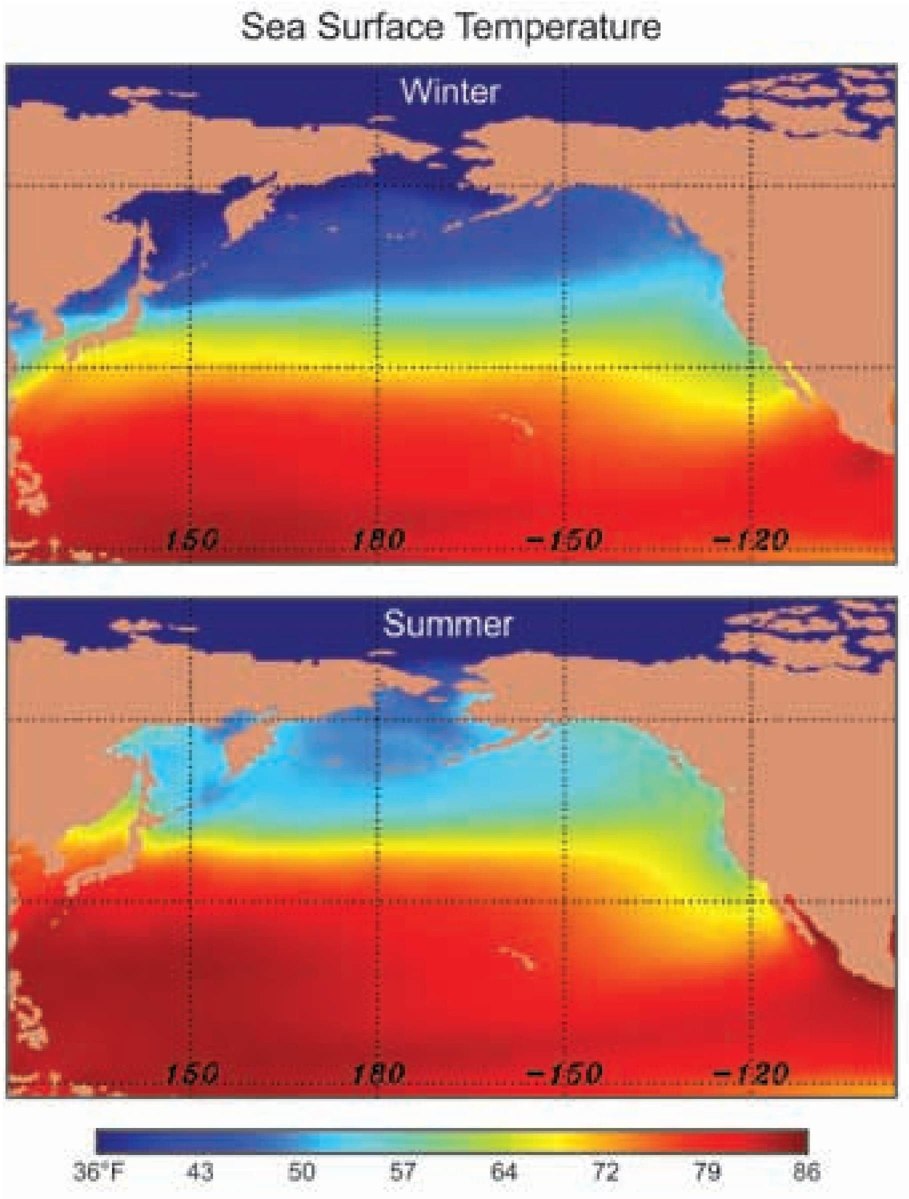
Why Are Pacific Northwest Temperatures Generally Mild?

Before reaching the Pacific Northwest, eastward-moving air traverses thousands of miles of the Pacific Ocean. Crossing the ocean over a period of several days, the air near the surface is greatly modified, moistening and taking on the temperature of the underlying ocean surface. The surface temperature of the midlatitude northern Pacific Ocean is relatively temperate even during the winter, typically ranging from 45 °F to 50 °F between Japan and the Northwest coast (figure 2.1). Thus low-level air reaching the Pacific Northwest during the winter is generally mild and moist, with typical winter daytime air temperatures west of the Cascades rising into the mid-40s °F.

The vast Pacific Ocean, like a huge liquid flywheel, warms slowly during the summer. Thus sea-surface temperatures off the Northwest coast vary little during the year and rarely rise above the mid-50s °F. As the jet stream and associated storms weaken and retreat northward during the warm season, high pressure builds northward over the northeastern Pacific in their wake (see figure 2.11, later in this chapter). With higher pressure offshore, cool air over the ocean is pushed inland, ensuring that summer temperatures west of the Cascades remain moderate, rarely exceeding 85 °F along the coast or over the Puget Sound lowlands. Only when the wind direction reverses and air moves westward from the warm continental interior can temperatures reach the upper 80s °F and higher to the west of the Cascade crest.

The other major element of Pacific Northwest weather is the terrain, ranging from the formidable Rocky and Cascade Mountains, which crest at approximately 5,000 to 14,000 feet, to the lower coastal mountains, which reach only 3,000 or 4,000 feet (figure 2.2). East of the Cascades, a topographical "bowl" encompasses the lower Columbia valley from the Tri-Cities, Washington, to Pendleton, Oregon, and is known as the Columbia Basin. Eastern Oregon is an elevated plateau, with higher peaks and several major valleys. Gaps in the region's terrain, such as the Columbia River gorge and the Fraser River valley, play a critical role as conduits for air through regional terrain.

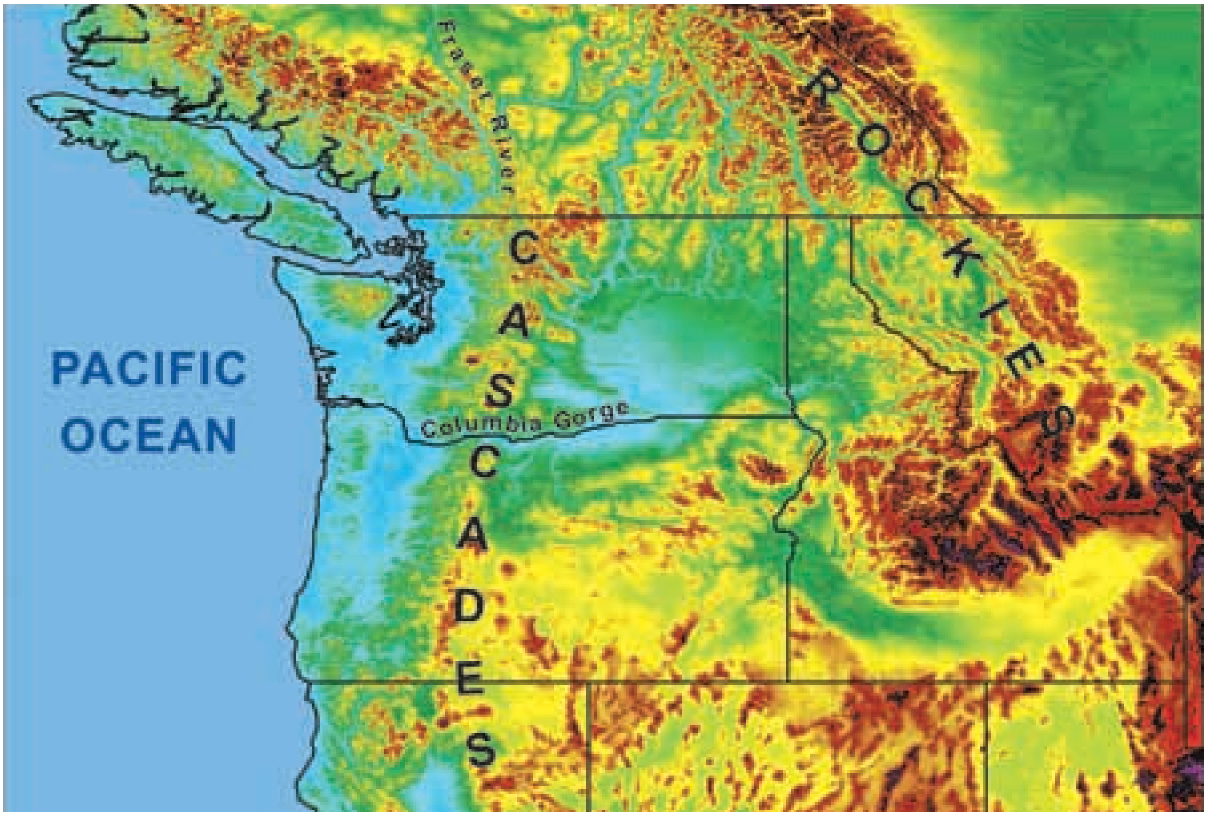
In the winter, the Rockies and Cascades form a double barrier to the cold air of the continental interior (figure 2.3). The Rockies act as the Northwest's first line of defense, blocking the cold air that develops over the snowfields of the Canadian Arctic and which subsequently moves southward into the interior of the continent. If the cold air becomes deep enough, some of it pushes westward over the Rockies. Since air warms as it descends

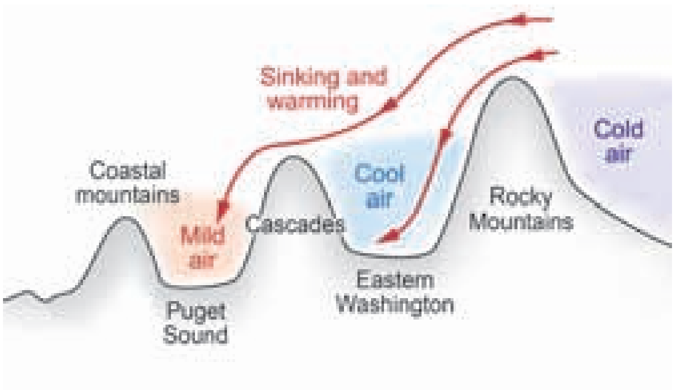


2.1 • Climatological sea-surface temperatures (°F) during late December and late July. The sea-surface temperatures of the northeastern Pacific west of the Northwest remain in the mid-40s °F to the mid-50s °F year-round. Image courtesy of the U.S. Navy's Fleet Numerical Meteorology and Oceanography Center, Monterey, California.

toward higher pressure at lower levels, the air moving down the western slopes of the Rockies reaches eastern Washington and Oregon considerably warmer than air at similar elevations east of the continental divide. Why does descending air warm? Because sinking air is compressed by the higher pressure at lower elevations. As observed when you touch a tire pump after it has inflated a tire, compressing air causes it to warm.

The next barrier protecting western Oregon and Washington is the Cascade Range, which blocks the westward movement of most of the cold air that reaches eastern Washington and Oregon at lower levels. During periods when the cold air over eastern Washington and Oregon becomes deep enough to push westward across the Cascades, it is warmed further as it descends the western slopes of the barrier. In short, because of the blocking effects of the Rockies and the Cascades, eastern Montana is colder than eastern Washington and Oregon, which in turn are colder than western Washington and Oregon. Even the most successful football coach





2.2 • (*above*) Color-enhanced topographic map of the Pacific Northwest.

2.3 • (*left*) The major mountain ranges of the Northwest protect the region from the frigid air of the interior of North America. At low levels the coldest air is found east of the Rockies, within the continental interior. Air that makes it across the Rockies warms as it descends into eastern Washington and Oregon. Any air that crosses the Cascades is further warmed by compression as it descends the western slopes of that barrier. Illustration by Beth Tully/Tully Graphics.

would be impressed by the Northwest's multilayer defense against the cold-air opponents.

Although the Rockies and the Cascades prevent most of the frigid, Arctic air from entering western Oregon and Washington, two major gaps or weaknesses in the Cascades permit the entrance of limited amounts of cold air at lower elevations. The first gap, the Fraser River valley, follows the Fraser River from the interior of British Columbia to its terminus northeast of Bellingham, Washington (see figure 2.2). The second is the narrow Columbia River gorge, which provides a near sea-level westward passage for cold air originating in the Columbia Basin of eastern Washington.

Cold air moves southwestward down the Fraser River valley when cold, Arctic air over the Yukon and northern British Columbia deepens sufficiently to push into the interior of British Columbia. The cold, dense air in the British Columbia interior is associated with higher atmospheric pressure at low levels in comparison to the lower pressure over the relatively warm western Washington interior. As a result of this pressure difference, the cold air in the British Columbia interior accelerates southwestward through the Fraser River valley, the lowest conduit across the Canadian Coast Mountains (the northward extension of the Cascades in British Columbia). Similarly, cold air moves westward through the Columbia Gorge when higher pressure and cold air become entrenched over eastern Washington. Strong winds, sometimes exceeding 50 miles per hour, and occasionally approaching 100 miles per hour, can develop over the western portions of the Fraser River valley and the Columbia Gorge during such cold-air outbreaks as air accelerates between the high pressure east of the Cascades/Coast Mountains and lower pressure to the west. Cold air from the Fraser Gap is often associated with western Washington snowstorms (see chapter 4), while cold air in the Columbia Gorge can produce snow and ice storms over the Portland metropolitan region.

A Survey of Pacific Northwest Temperatures

Temperatures across the Pacific Northwest are controlled by season, proximity to water, elevation, amount of clouds, and snow cover, among other factors. Figure 2.4 displays the typical surface air temperatures over the region during summer (July) and winter (January).[1] During January, nighttime low temperatures west of the Cascade crest typically drop into the lower 30s °F, except for the coastal zone and areas near Puget Sound, where

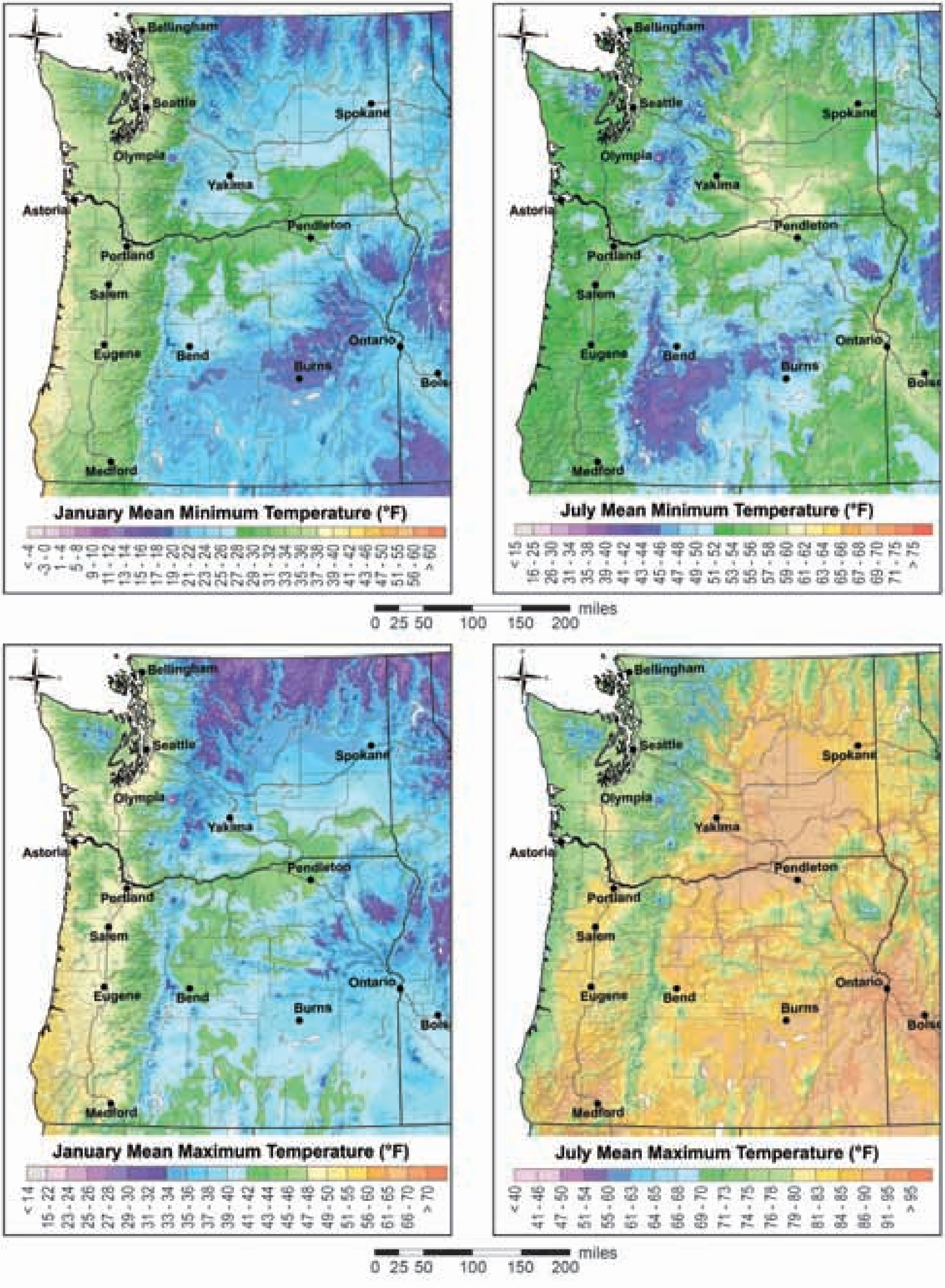
1 Surface air temperatures are generally measured in the shade at 2 meters, or roughly 6.5 feet above the ground.

2.4 • (*opposite*) **Climatological (1971–2000) maximum and minimum temperatures for January and July. Courtesy of Chris Daly and Mike Halbleib of the Oregon State University PRISM group.**

cooling is tempered by proximity to relatively warm water. Somewhat cooler minimum temperatures (upper 20s °F) extend eastward from the Columbia Gorge toward Pendleton and the Tri-Cities. East of the Cascades, temperatures drop as elevation increases, with the coldest temperatures over the high terrain of northeastern Washington and the plateau region of central Oregon, where nighttime temperatures typically plummet into the midteens.

January maximum temperatures follow a similar, but warmer, pattern. Over the western Washington and Oregon lowlands, January high temperatures rise into the mid-40s °F and lower 50s °F during the day, with the warmest temperatures over the southern Oregon coast. In contrast, over the higher terrain of the Cascades, northeastern Washington, and the central highlands of eastern Oregon, January high temperatures generally remain well below freezing.

Proximity to the relatively warm Pacific Ocean is a major reason why western Washington and Oregon are warmer during winter than the region east of the Cascade crest. Furthermore, differences in cloud cover also contribute to the winter temperature distributions. West of the Cascades, incessant winter clouds reduce maximum temperatures and increase daily lows. During the day, clouds reflect some of the incoming solar radiation, which is why clouds appear bright in visible weather-satellite imagery. Reflecting the sun's rays back into space means less heating at low levels. In contrast, clouds can warm the surface at night, since they intercept infrared radiation from below and emit radiation back down to the surface, reducing low-level cooling and acting like atmospheric blankets. Thus cloudy nights are generally warmer than clear ones, and low temperatures in cloudy western Washington rarely drop much below freezing during winter.


Bellingham
Seattle
Spokane
Olympia
Yakima
Astoria
Pendleton
Portland
Salem
Ontario
Eugene
Bend
Burns
Medford
January Mean Minimum Temperature (°F)
< -4
-3 - 0
1 - 4
5 - 8
9 - 10
11 - 12
13 - 14
15 - 16
17 - 18
19 - 20
21 - 22
23 - 24
25 - 26
27 - 28
29 - 30
31 - 32
33 - 34
35 - 36
37 - 38
39 - 40
41 - 42
43 - 46
47 - 50
51 - 55
56 - 60
> 60
July Mean Minimum Temperature (°F)
< 15
16 - 25
26 - 30
31 - 34
35 - 38
39 - 40
41 - 42
43 - 44
45 - 46
47 - 48
49 - 50
51 - 52
53 - 54
55 - 56
57 - 58
59 - 60
61 - 62
63 - 64
65 - 66
67 - 68
69 - 70
71 - 75
> 75
miles
0 25 50 100 150 200
January Mean Maximum Temperature (°F)
< 14
15 - 22
23 - 24
25 - 26
27 - 28
29 - 30
31 - 32
33 - 34
35 - 36
37 - 38
39 - 40
41 - 42
43 - 44
45 - 46
47 - 48
49 - 50
51 - 55
56 - 60
61 - 65
66 - 70
> 70
July Mean Maximum Temperature (°F)
< 40
41 - 46
47 - 50
51 - 54
55 - 60
61 - 63
64 - 65
66 - 68
69 - 70
71 - 73
74 - 75
76 - 78
79 - 80
81 - 83
84 - 85
86 - 90
91 - 95
> 95
miles
0 25 50 100 150 200

Interestingly, clouds also explain why winter low temperatures are often relatively moderate in the low-elevation bowl of eastern Washington, because the persistent winter low clouds of this area reduce nighttime cooling.

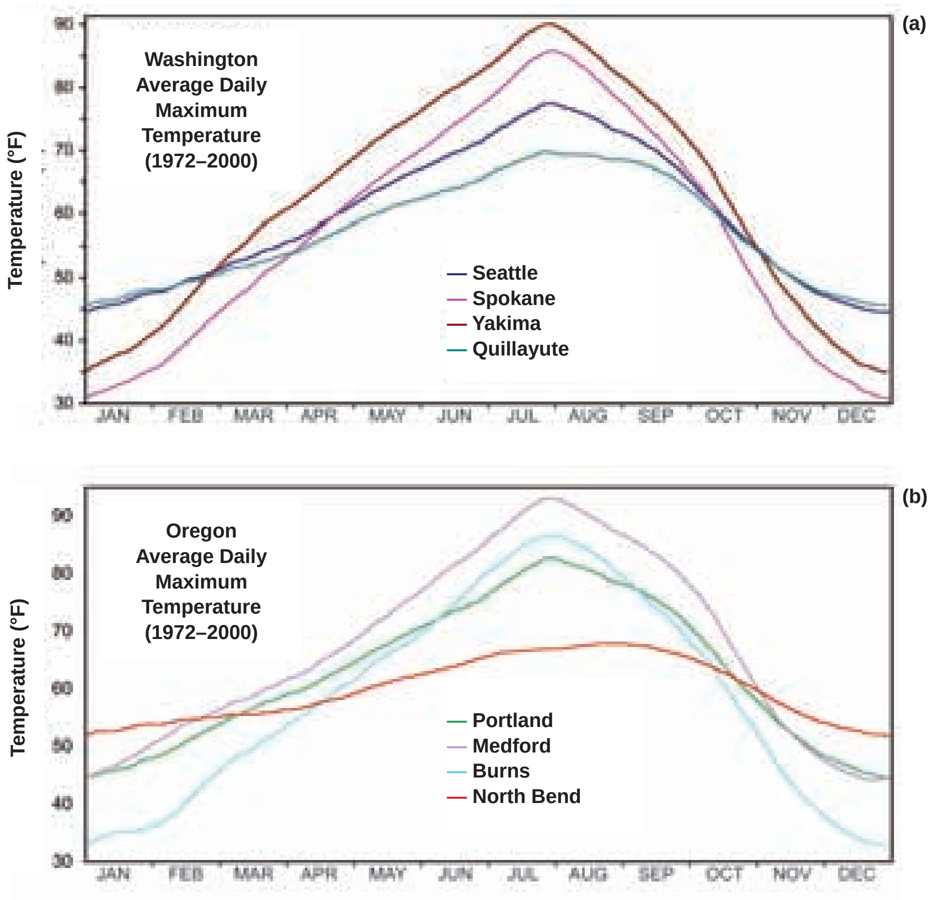
Summer brings much warmer temperatures and a very different pattern of temperature variation across the region. July minimum temperatures are relatively uniform west of the Cascades, with lows in the mid- to lower 50s °F. Warmer July minimum temperatures are found east of the Cascades in the lower elevations of the Columbia River basin, particularly in the topographic bowl encompassing the Tri-Cities and Pendleton, where temperatures only decline to about 60 °F. Over the higher elevations of the Cascades and the plateau of eastern Oregon, nighttime temperatures are chilly even in midsummer, with typical minimum temperatures dropping to the 40s °F.

For average summer maximum temperatures, there are significant variations west of the Cascades. Over the Willamette Valley, high temperatures range between the 90s °F over the southern portion to the 80s °F to the north, while over the western Washington lowlands, temperatures reach only the mid-70s °F. These temperature contrasts are caused by terrain and proximity to water. Western Washington lowlands are flooded with marine air from off the Pacific Ocean that subsequently moves over the relatively cool waters of the Straits of Juan de Fuca and Georgia, as well as Puget Sound. In contrast, the Willamette Valley is landlocked on three sides, limiting access to air tempered by a cool water surface. Thus, although air conditioning is rarely needed in most Puget Sound communities, it is often found in homes from Portland to Eugene. The Medford, Oregon, area, found in a topographic basin within the Siskiyou/Klamath Mountains, is cut off from marine air and typically warms into the 90s °F during summer afternoons. The region's warmest summer temperatures are generally found over the lower elevations east of the Cascades within the Columbia River basin, where temperatures frequently reach the mid-90s °F. The all-time temperature records for the Northwest have occurred in this heated bowl (see chapter 9). Maximum summer temperatures decrease with elevation over the Oregon plateau and the Cascade Mountains, with the lowest maxima (the upper 50s °F) over the highest terrain.

Examining the annual variation in temperature around the Northwest reveals some intriguing differences (figure 2.5). Perhaps most striking is that the range of annual temperatures is *far* larger east of the Cascade crest than over the more temperate western side. For example, average daily maximum temperatures can vary by 55 °F between January and July east of the Cascades at Yakima and Spokane, while on the western side, a 30-degree annual variation is typical. The eastern side of Washington has a far more *continental* climate, being isolated from the moderating marine influence that controls the climate on the state's western side.

But even on the same side of the state, there can be noticeable temperature differences. Seattle, in central Puget Sound, and Quillayute, on the Northwest coast, experience nearly identical maximum temperatures (mid-40s °F) during the winter because of persistent, strong onshore flow, but Seattle, more distant from the ocean, is about 10 °F warmer during midsummer. For both western Washington locations, the coldest temperatures occur during late December, followed by a slow warm-up to the annual peak around August 1. East of the Cascades, Spokane is decidedly cooler than Yakima throughout the year (by about 5 °F), with the warmest temperatures at both locations sharply peaking near August 1 and their lowest temperatures occurring around New Year's.

Oregon locations away from the coast also tend to have their highest temperatures around August 1, in contrast to North Bend along the central Oregon coast, where the warmest temperatures occur

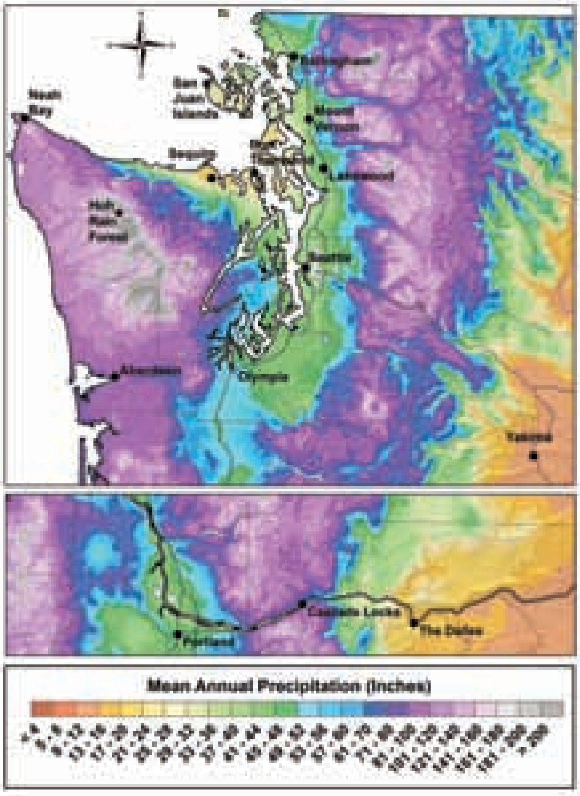


2.5 • Average daily maximum temperatures for some observing locations in (a) Washington and (b) Oregon. Most stations in these states achieve their highest temperatures near August 1 and their lowest around January 1. Based on NOAA data.

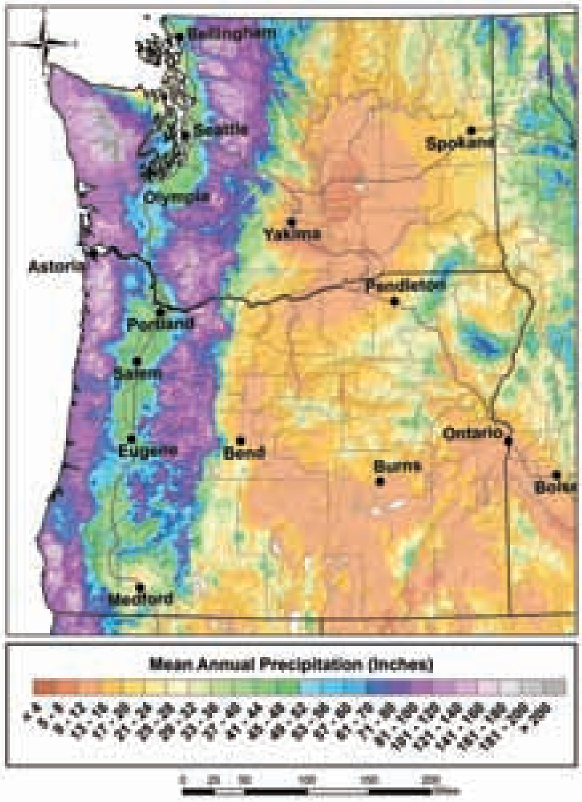
about a month later. North Bend is not the place to go for temperature extremes, with highs ranging from the low 50s °F in winter to the mid-60s °F during August and September. The reason, of course, is the nearby Pacific Ocean, whose temperature only cools by about 5 °F to approximately 50 °F during the winter. In contrast, Burns, located in the state's eastern highlands, has a far greater temperature range, with highs ranging from near freezing in late December and January to the mid-80s °F during midsummer. Although similar to Portland during the fall and early winter, Medford, isolated from a marine influence, gets far warmer in the summer, with average highs in the mid-90s °F and thus perfect for a wet run down the nearby Rogue River.

Rainforest and Desert: Why Precipitation Varies So Much across the Pacific Northwest

Nowhere in North America are precipitation contrasts greater than in the Pacific Northwest. Driving east on Interstate 84 through the Columbia River gorge, one transitions from rain-forest conditions near Cascade Locks on the western side of the Cascades (typically 80 inches of rainfall per year) to the arid environment at The Dalles (13 inches annually), only 45 miles to the east (figure 2.6). On the southwest side of the Olympics there is the sodden Hoh rain forest, which receives about 140 to 160 inches a year, while 40 miles to the northeast, the town of Sequim in the Olympic rain shadow



2.6 • Annual total precipitation (1971–2000) over northwestern Washington and the Columbia River gorge of Oregon. Courtesy of Chris Daly and Mike Halbleib of the Oregon State University PRISM group.



2.7 • Annual precipitation (in inches) for Washington and Oregon. Heavier precipitation falls on the windward (typically western) slopes of the Cascades and coastal mountains, with arid conditions over the rain shadow regions of eastern Washington and Oregon. Courtesy of Chris Daly and Mike Halbleib of the Oregon State University PRISM group.

enjoys a relatively dry, sunny climate with about 15 inches annually. Sequim is so dry that cacti grow there and irrigation is required for most crops (see chapter 10).

The distribution of precipitation over the Pacific Northwest is greatly influenced by the region's mountain ranges (figure 2.7).[2] Clouds and precipitation are associated with rising air, while clearing occurs as air descends. Since air typically moves across the region from the southwest to the northeast during the wet winter season, precipitation generally increases on the southwestern or western slopes of Northwest mountains, where air is forced to rise. In contrast, precipitation typically decreases over the northeastern or eastern mountain slopes, where air descends. Meteorologists typically refer to the slope facing the wind as the *windward* side, while the downwind slope, where the air descends, is known as the *leeward* side.

Moist air moving eastward from off the Pacific Ocean is first forced to rise by the coastal mountains of Oregon, Washington, and Vancouver Island, producing substantial precipitation on their western slopes. Annual precipitation totals

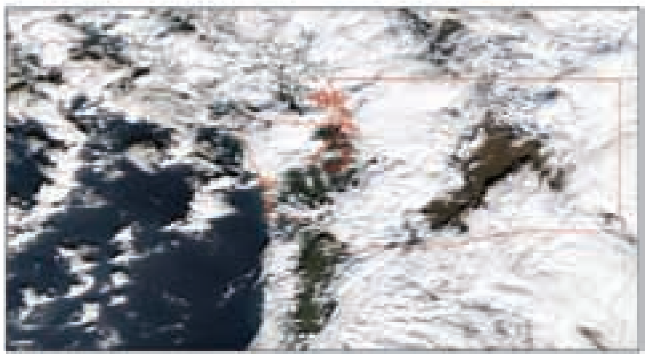
2 The term *precipitation* means the total of all types of precipitating water in liquid or solid forms (rain, snow, ice, hail, and others).

range from 60 to 80 inches on the lower elevations of the coastal mountains to 90 to 160 inches on the western slopes of the highest coastal terrain, the Olympics and the higher mountains of Vancouver Island. As the air crosses the coastal mountains and descends into the lowlands of western Washington and Oregon (Puget Sound through the Willamette Valley), the annual precipitation decreases to around 35 to 45 inches a year. Thus the lowland urban corridor stretching from Bellingham to Eugene is in the rain shadow of the coastal mountains and enjoys a far drier climate than the coastal zone. If Lewis and Clark had known this, perhaps they would have built their encampment in the relatively dry Willamette Valley rather than the extraordinarily wet coastal location they chose (near Astoria, Oregon).

In west-side locations downstream of the highest terrain, such as northeast of the Olympic Mountains, precipitation is further reduced. As noted earlier, the town of Sequim lies in the middle of the Olympic rain shadow and receives only about 16 inches of precipitation a year, a total more typical of southern California. Los Angeles precipitation in western Washington—no wonder so many people are interested in retiring there! Another arid west-side region is found in southwestern Oregon near Medford and Ashland, which are located in a bowl-like valley within the relatively high Siskiyou/Klamath Mountains, a terrain barrier that stretches from the coast to the southern Cascades. Medford typically receives only 18 inches of precipitation a year and is surrounded by rangeland, an environment more typical of the eastern side of the Cascades.

As air continues to move eastward, it is forced to rise by the Cascades, dropping about 60 to 120 inches of precipitation each year on the barrier's western slopes from southern Oregon into British Columbia. Although precipitation initially increases with elevation over the western side of the Cascades, it appears that precipitation begins to decline at the highest elevations, above approximately 7,000 feet. Why? At such heights there is less blocking terrain to push the air upward, and the normal decrease of water vapor with height results in less cloud and precipitation formation. After crossing the Cascade crest, air descends rapidly over the eastern slopes of the Cascades, producing a sharp decrease of clouds and precipitation. Air descending into the Columbia River basin of eastern Washington produces extreme aridity, with annual precipitation decreasing to less than 10 inches a year. In contrast, eastern Oregon is mainly high plateau, so air subsides less there than over the Columbia Basin. Thus eastern Oregon is dry, with annual totals of 10 to 20 inches, but less arid than eastern Washington. A weather satellite image illustrates the enhancement of clouds west of the Cascades crest, with rapid evaporation to the east (figure 2.8).

Less frequently, regional winds blow from the east. On such occasions, the distributions of clouds and precipitation are reduced, with the eastern slopes of the Cascades and Olympics becoming enshrouded in clouds and showers, while the usually wet western slopes turn warm and dry.



2.8 • NASA MODIS visible satellite image taken near noon on December 18, 2018. As cold, showery air approached from the west, there was enhancement of clouds on the western side of the Olympics and coastal mountains, with fewer clouds over Puget Sound and the Willamette Valley as air descended into the lowlands. Air ascended again on the western slopes of the Cascades, greatly enhancing the clouds and associated precipitation. On the eastern side of the Washington Cascades, sinking air produced clear skies over portions of the Columbia Basin.

TABLE 2.1

Long-term averages of precipitation and cloud cover for select U.S. cities, 1971–2001

LOCATION	ANNUAL AVERAGE PRECIPITATION (INCHES)	NUMBER OF DAYS WITH A TRACE OR MORE OF PRECIPITATION	NUMBER OF CLOUDY DAYS
Seattle, Washington	38.4	157	228
Portland, Oregon	37.4	151	229
Houston, Texas	46.9	101	166
New York, New York	43.1	120	133
Boston, Massachusetts	43.8	126	161
Atlanta, Georgia	49.8	116	146
Miami, Florida	57.1	128	117

SOURCE: NOAA

The mountain crests can remain shrouded in clouds regardless of the prevailing wind direction. That is why ski areas near the Cascade crest are often cloudy: they are engulfed in clouds whether the winds are from the east or the west. When winds are from the southeast, the southeastern portions of the Olympics and nearby areas can receive extraordinarily heavy precipitation as air is forced upward on the southeast side of the barrier, sometimes collecting from 5 to 10 inches of water per day. In such situations, if temperatures are cool enough, heavy snow (from 6 to 24 inches) can fall over the Kitsap Peninsula to the southeast of the Olympics. Heavy upslope precipitation on the southeastern side of the Olympics can cause Olympic Peninsula rivers such as the Skokomish to overflow their banks, flooding nearby communities.

Is the Pacific Northwest *Really* That Wet?

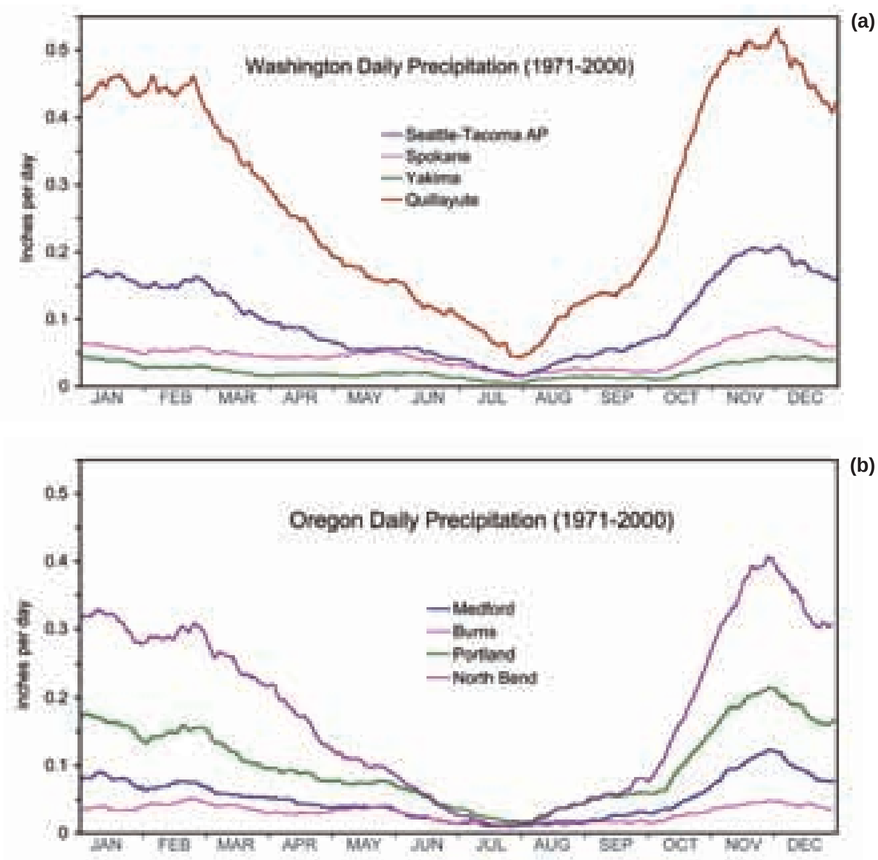
The Pacific Northwest has a reputation for being wet and moss-covered, but in reality, major Northwest cities receive less annual precipitation than many of their counterparts in the eastern and central United States. Seattle and Portland receive nearly 20 inches *less* per year than Miami, 10 inches *less* than Houston and Atlanta, and about 5 inches *less* than New York and Boston (table 2.1). With extended periods of drizzle and few thunderstorms, Northwest precipitation is typically lighter than the eastern U.S. variety, resulting in the number of days with at least a trace of precipitation being considerably greater over the Northwest than at locations back East (157 days in Seattle versus roughly 120 over the eastern states).[3] The Northwest's lead in the number of cloudy days is even more pronounced, with nearly 230 days per year in Seattle and Portland, compared to approximately 160 in Boston and Houston and 117 in Miami. Since Northwest winters are accompanied by many cloudy days and relatively short durations of (weak) daylight, it is no wonder that wintertime depression (known as seasonal affective disorder, or SAD) hits some residents of the region.

3 A *trace* is defined as less than 0.01 inch of liquid precipitation. This amount of rain is roughly what it takes to make concrete uniformly wet.

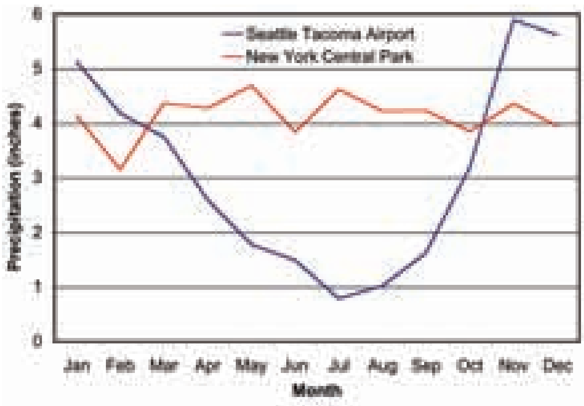
The Pacific Northwest's "Mediterranean" Precipitation Regimes

The Pacific Northwest experiences essentially three weather regimes during the year: a wet season from mid-November through mid-February, a dry midsummer period from early July through mid-September, and the transition times of spring and fall. These features and others are illustrated in figure 2.9, which shows the average (1971–2000) daily precipitation for a collection of Washington and Oregon locations.

Throughout Washington State there is a large decrease in daily precipitation as one progresses from the coast (Quillayute) and Puget Sound (Seattle) to the extraordinary dryness at Yakima, just east of the Cascades (figure 2.9a). Daily precipitation begins to rise again at Spokane as air ascends the western slopes of the Rockies. The large seasonal variations in precipitation are striking, particularly west of the Cascades. Typically, 50–60 percent of the precipitation over the western half of the region falls in November through February, with roughly 75 percent during the wet half of the year from October through March. In contrast, only about 8 percent of the annual precipitation falls in June through August. In fact, western Washington and Oregon enjoy some of the driest summers in the entire country, drier even than Arizona during midsummer. East of the Cascades, a similar annual variation occurs, except that the summer months (June through August) include a slightly higher percentage of the annual precipitation (roughly 15 percent) as a result of occasional



2.9 • Daily average precipitation (1971–2000) for four locations in (a) Washington and (b) Oregon. Pacific Northwest locations get much of their precipitation during the winter months, with summers being quite dry. Based on NOAA data.



2.10 • Monthly mean (1971–2000) precipitation at New York City (in Central Park) and Seattle (the Seattle-Tacoma Airport). For more than half the year Seattle is drier than New York. Based on NOAA data.

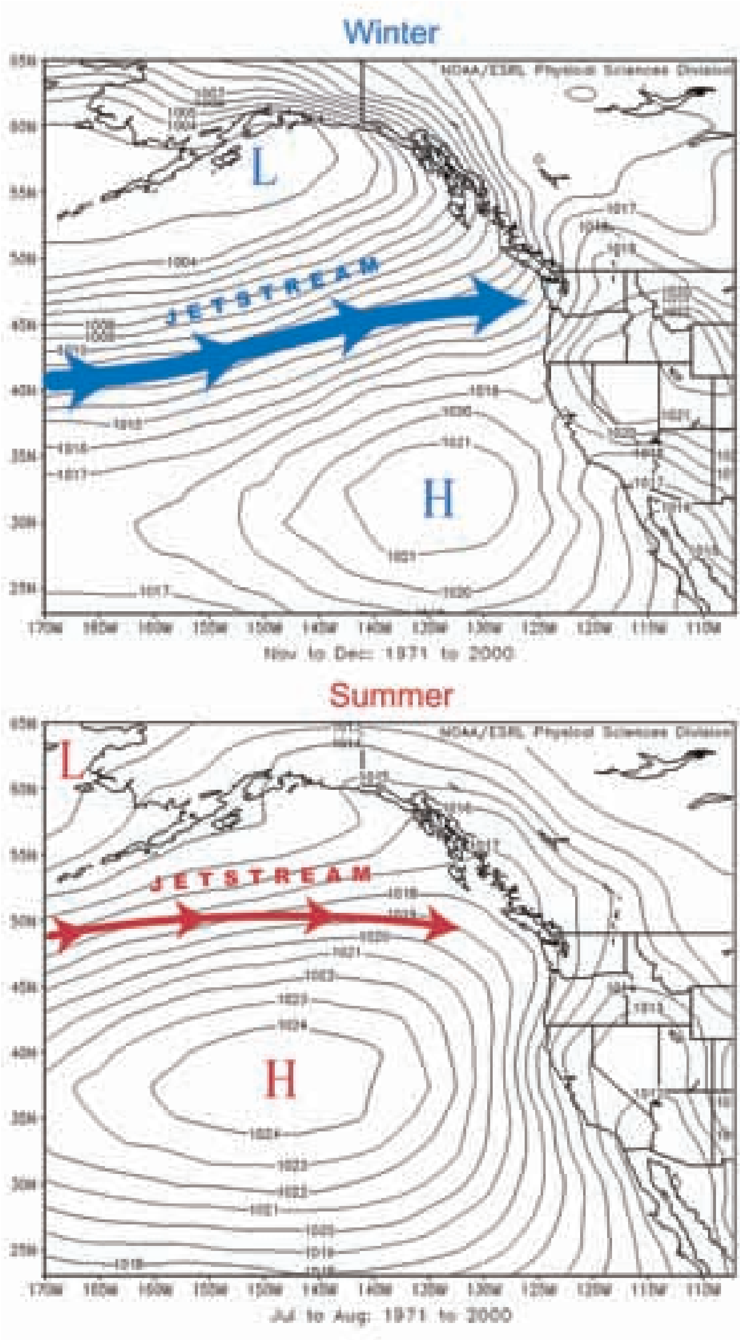
thunderstorms. This pattern of cloudy, wet winters and dry, sunny summers is known as a *Mediterranean climate*, since southern Europe experiences a similar variation.

A closer look at Washington's annual precipitation variation reveals interesting details. Although the period from November through February is generally quite wet, the greatest rainfall occurs during the last weeks of November, around Thanksgiving. There is actually a drying trend in December, followed by a secondary period of heavier precipitation in January and early February. March brings a steady downward trend in daily rainfall that ends in the extraordinary dry period of late July and early August—an ideal time to plan a wedding or any outdoor activity.[4] During any individual day during this magical two-week period, many locations of western Washington receive rain only once in ten years. The rapid summer descent into dry conditions typically begins right after the July Fourth weekend. Thus the humorous comment within weather circles that summer starts in the Northwest on July 12 is not without some basis. Rainfall increases slowly in September, followed by a steep jump in October. The transition in October is often jarring, going from the generally dry, warm days of September to the wet, cool, and windy clime of November, with much of the transition often occurring over a period of only a week or two. Few regions around the world experience such a rapid initiation of "winter."

Throughout Oregon, seasonal precipitation changes mimic those of Washington, but with a few differences (figure 2.9b). Like Washington, the coastal zone (North Bend) is far wetter than the western lowlands (Portland). An anomaly is Medford, which experiences far less precipitation than Portland or other west-side locations. Although Medford's more southern position makes a small contribution to its dryness, the key factor is the city's location in a topographic bowl within the Siskiyou/Klamath Mountains, with descending air resulting in drying. Burns, in the central portion of eastern Oregon, receives even less precipitation than Medford. For both Oregon and Washington the geographic variations in precipitation are greatest during the wet season, with only minor spatial differences in precipitation during the midsummer dry period.

The large variation in precipitation between summer and winter throughout the Pacific Northwest is quite different than observed over the eastern two-thirds of the United States, where precipitation doesn't vary greatly by season. For example, New York City receives about the same precipitation each month, roughly 4 inches (figure 2.10). In contrast, Seattle's precipitation over the year varies substantially, being far *less* than New

4 The author enjoys holding "dry sky" parties during the drought week at the end of July.



2.11 • The differences between winter (top) and summer (bottom) atmospheric weather patterns help explain the large seasonal variations in precipitation at most Pacific Northwest locations. The axis of the upper-level jet stream is indicated by the bold lines with arrows, while the black lines indicate lines of constant sea-level pressure in hPa (or millibars). The thickness of the arrows denotes the strength of the jet stream. In winter the jet stream and the storms associated with it are strong and pass directly over the Northwest, while during summer they weaken and move to the north. High pressure and associated fair weather are pushed far south during winter, but strengthen and extend northward during summer. Illustration by Beth Tully/Tully Graphics.

York's for about half of the year and only exceeding the Big Apple from November through February. It is not without some irony that Seattle's baseball stadium, T-Mobile Park (formerly Safeco Field), was built with a $100 million movable roof, while baseball parks back East, where summertime rain is far more prevalent, are open to the sky. Stranger yet, Seattle's football stadium (Century Link Field and soon to be named Lumen Field) does not have a roof, even though the football season coincides with Seattle's wettest period.

Why does the Pacific Northwest have such extreme wet and dry seasons? The answer is twofold: the seasonal shifts in the jet stream over