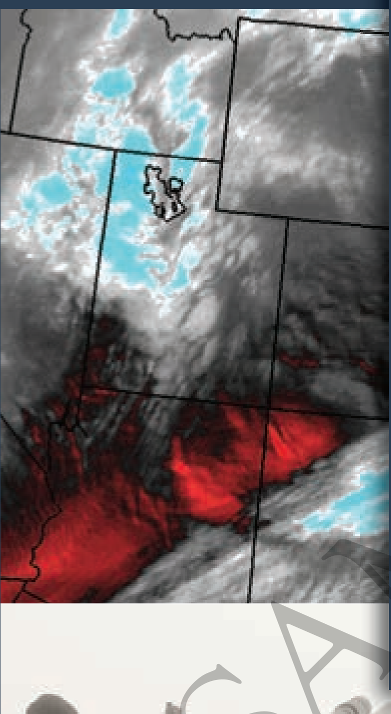

SECRETS OF THE GREATEST SNOW ON EARTH

WEATHER, CLIMATE CHANGE, AND FINDING DEEP POWDER IN UTAH'S WASATCH MOUNTAINS AND AROUND THE WORLD

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INTRODUCTION

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Is it true? Does Utah really have the Greatest Snow on Earth? What about claims that Utah's snow is lighter and drier than elsewhere, that magic snowflakes are created because the western deserts dry out snow, or that moisture from the Great Salt Lake fuels storms?

The first meteorologist to ponder these questions was S. D. Green in the 1930s. Green was an avid skier who worked for the US Weather Bureau (now the National Weather Service). Lake Placid had just hosted the 1932 Olympics and was a favorite winter-sports destination for easterners. The West, however, was largely unknown to skiers. In an article published in the *Salt Lake Tribune* in 1935, Green argued that the "natural advantages" of Lake Placid were inferior to those of Utah and that upper Big and Little Cottonwood Canyons offered the best skiing in the Wasatch Mountains (Kelner 1980, 155).

In the late 1930s lifts were installed in the Cottonwood Canyons and Alta quickly become a mecca for skiers who wanted to avoid the packed slopes of the Alps or the eastern United States. In the 1940s and 1950s, Fred Speyer, Dick Durrance, Sverre Engen, Alf Engen, and Dolores LaChapelle pioneered techniques for deep-powder skiing at Alta. Their new approaches to skiing could have been developed only at a ski area with abundant, high-quality natural snowfall. Enthusiastically taken up by European ski professionals, these techniques, as noted by Lou Dawson, "spread around the world like pollen in strong wind" (Dawson 1997, 166).

If Utah were to become a powder paradise, however, techniques to minimize avalanche hazard following major storms needed to be developed; in the 1940s, these techniques didn't exist. Shortly after World War II, the US Forest Service appointed Monty Atwater as Alta's snow ranger. Recognizing that adventurers flocked to Alta to ski powder, not to be hemmed in by ropes and closed-area signs, Atwater and fellow avalanche hunter Ed LaChapelle pioneered the use of explosives and artillery to intentionally trigger avalanches before they became life-threatening menaces. Alta became the place for training in snow science and avalanche-control techniques.

With a snow reputation firmly established, skiing blossomed at Wasatch Mountain ski areas now known as Brighton, Solitude, Snowbird, Alta, Park City, Deer Valley, Canyons, Snowbasin, and Powder Mountain. Today, winter recreation represents a $1 billion industry for the State of Utah. More and more skiers and snowboarders are venturing into the Wasatch backcountry. The slogan Greatest Snow on Earth is one of the most successful in outdoor recreation. For many who come to Utah, powder is more than snow. It is a way of life.

Having grown up in upstate New York, my first western ski experience was in January 1986. The trip was a high school graduation gift from my father. We skied on long, skinny racing skis, slept in a Motel 6 in the Salt Lake Valley, and hit five ski areas, including Alta, where we had an epic bluebird powder day. Lift tickets at Solitude were $5. As a budding young meteorologist who had just had his first taste of the Greatest Snow on Earth, I, like S. D. Green before me, began to wonder about the "natural advantages" of Big and Little Cottonwood Canyons.

Figure 0.1. The author on the cover of the September 2008 issue of the *Bulletin of the American Meteorological Society*. Photo by Tyler Cruickshank. © American Meteorological Society. Used with permission.

Over the next ten years I aligned my ski and science passions, eventually earning a PhD in atmospheric sciences from the University of Washington with a specialty in mountain meteorology. Incredibly, I was offered a position at the University of Utah right after graduation. It was 1995 and Salt Lake City had just scored the 2002 Olympic Winter Games. I seized the opportunity and have since spent much of my career studying winter storms over the Intermountain West, Wasatch Mountains, and Great Salt Lake (figure 0.1). I've spent most of my free time skiing in the Wasatch Mountains.

I've written this book to set the record straight: to dig into Wasatch weather lore, expose the myths, explain the reality, and tell people the real reasons why Utah's powder skiing and snowboarding are so incredible. *Secrets of the Greatest Snow on Earth* is a meteorological guide not only to the weather and climate of the Wasatch Mountains but also to mountain weather and snow around the world. It is written for skiers, snowboarders, weather weenies, and anyone else who can't sleep when the flakes start to fly. I hope it will help you find deep powder and bluebird skies.

1 THE SECRETS

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Home
The Salt Lake Tribune
TEENS • TV • RECORDS
The Greatest Snow on Earth, — Complete TV Logs for the Week,

The Greatest Snow On Earth

Figure 1.1. Earliest known published use of the phrase "Greatest Snow on Earth." *Home Magazine*, *Salt Lake Tribune*, December 4, 1960. Source: J. Willard Marriott Library, University of Utah.

On December 4, 1960, the legend was born. Inspired by a recent visit of the Ringling Bros. and Barnum & Bailey Circus, a young editor named Tom Korologos opened a special ski edition of the *Salt Lake Tribune*'s *Home Magazine* with the headline "The Greatest Snow on Earth" (figure 1.1). Tom exclaimed, "Intermountain folk will tell you that the winds blowing from the west leave the wet, sticky snows in the Sierras. When the storms reach the Intermountain ranges, only the most perfect dry powder is left. That's just a sprinkling of what you'll find in this vast, scenic country that is the Intermountain area. And what an area. It's some 600 miles long and 2½ miles high. That's the extent of the Intermountain's big top which supports this real, true Greatest Snow on Earth."

The State of Utah began using Greatest Snow on Earth as a slogan in 1962 and engraved it on license plates in 1985, winning a plate of the year award from the Automobile License Plate Collectors Association (figure 1.2). Utah's trademark on the slogan survived a court challenge from the Ringling Bros. and Barnum & Bailey Circus in the 1990s; the courts ruled that Greatest Snow on

Earth doesn't dilute the circus's slogan. But was Tom Korologos right? Is Utah's snow really the greatest on Earth?

No scientist can answer that question. The greatness of snow, like beauty, is in the eye of the beholder. There is no doubt, however, that skiers and snowboarders believe there is something special about Utah snow. Utah ski areas, especially those in Big and Little Cottonwood Canyons southeast of Salt Lake City (figure 1.3), are perennially ranked at or near the top for powder in North America. Alta and Snowbird in upper Little Cottonwood Canyon are frequently co-listed as number one.

Figure 1.2. Classic and modern Greatest Snow on Earth license plates. Source: Zul32, Wikipedia Commons, CC BY-SA 3.0.

What makes the snow in Utah so special? Many people believe, as suggested on the Alta Lodge website, that "it is a scientific fact that Utah's snow is lighter and drier." Others argue that the snow in Utah is superior because of the Great Salt Lake or the drying influence of upstream deserts. However, these are not the secrets of the Greatest Snow on Earth. It turns out that Utah snow isn't even the lightest and driest in the United States.

SNOW WATER CONTENT

The density of snow depends on its **water content**, the percentage of the snow that is frozen or liquid water. Light, dry snow has a low water content, is fluffy and easy to shovel, and is a breeze to ski through (figure 1.4). Heavy, wet snow has a high water content, is dense and difficult to shovel, and is often more challenging to ski. Meteorologists classify new snow as light when it has a water content of less than 7 percent, average when it has a water content of 7 to 11 percent, and heavy when it has a water content of greater than 11 percent. Man-made snow has a water content of 24 to 28 percent, which is why it is

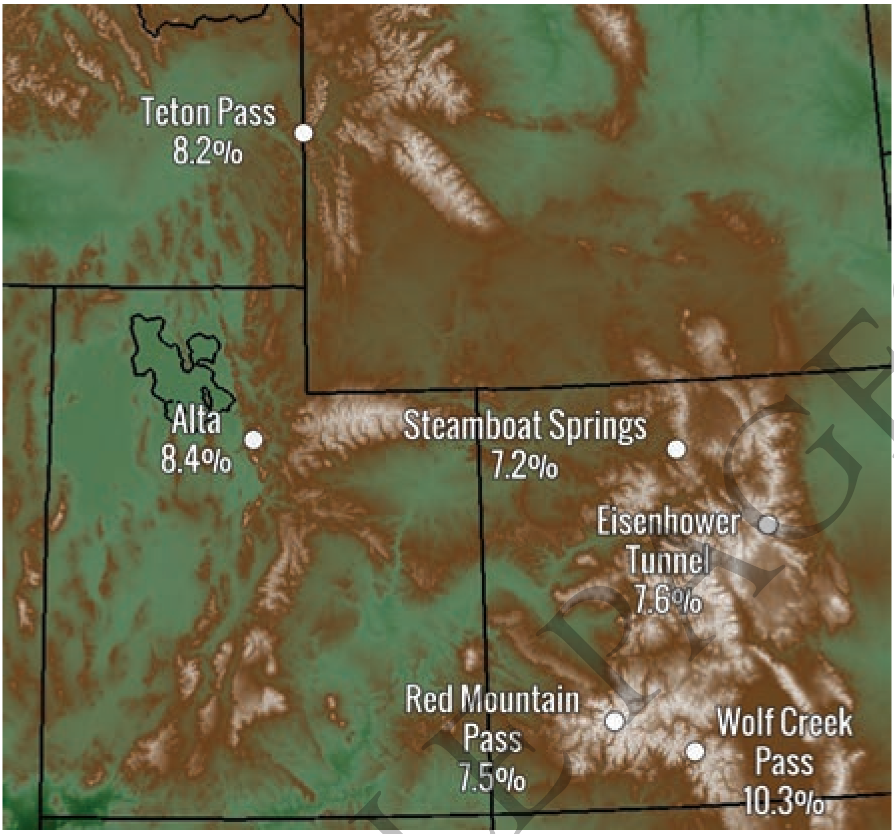


Figure 1.8. Average water content of freshly fallen snow at selected sites in the western United States. Sources: Judson and Doesken 2000; Steenburgh and Alcott 2008.

the 10.3 percent observed at Wolf Creek Pass in southwest Colorado, where warm, southwesterly flow impinging on the San Juan Mountains frequently produces higher water content snow.

Although there is some uncertainty in these numbers, given the difficulties of measuring snow depth and water content, they clearly debunk the myth that Utah snow is the lightest and driest. However, it is also a myth that dry snow produces the best deep-powder skiing.

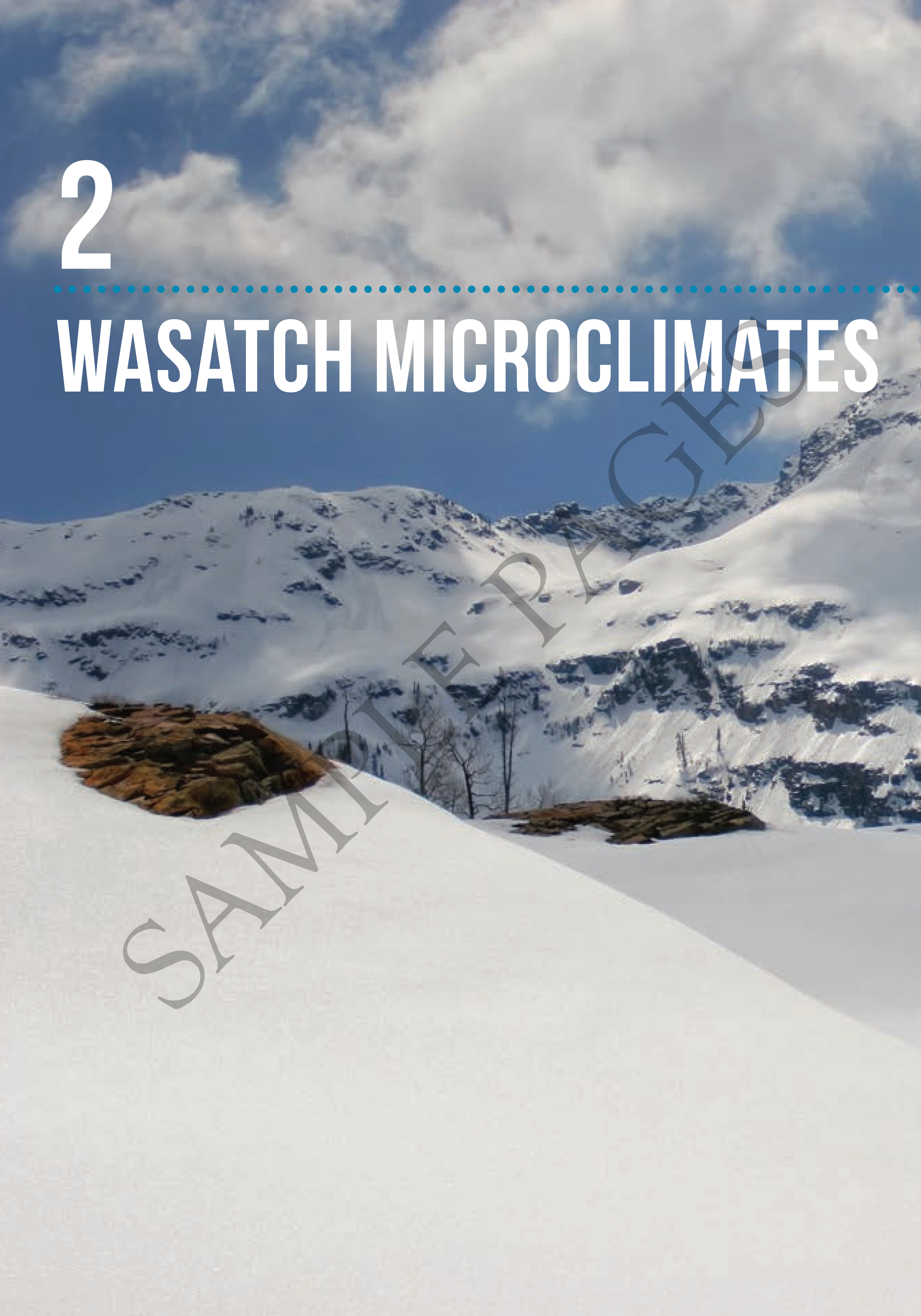
THE SECRETS OF GREAT POWDER SKIING

Legendary avalanche researcher and powder skier Ed LaChapelle knew more about snow than anyone. While an avalanche hunter at Alta, Ed recognized that "the best deep-powder skiing is not found in the lightest snow, but rather in snow with enough ‘body’ to provide good flotation for the running ski” (Lachapelle 1962). In other words, there’s more to great powder skiing than light, dry snow.

There are actually three ingredients necessary for great powder skiing. The first is the amount of new snow. This is obvious, but how much is needed? For real powder skiing, the skis or snowboard must float in the new snow. The powder must be **bottomless** so that your skis or snowboard do not ride on the underlying surface. Taos ski instructor Lito Tejada-Flores suggests in his 2006 book *Breakthrough on the New Skis* that real powder skiing requires at least a foot of new snow. This is a pretty good estimate, but for our discussion, I’ll use ten inches as the minimum snowfall required to qualify as a deep-powder day at a ski area. This lower threshold reflects the proliferation of fat skis and snowboards, which float more easily than the narrow skis of yesteryear. However, there is also an upper limit, known as “too much of a good thing.” Huge storms create dangerous avalanche conditions, forcing the closure of steep terrain at ski areas, and the deep snow makes it difficult to maintain momentum when skiing or snowboarding lower-angle slopes or to break trail in the **backcountry** (figure 1.9a). The best powder skiing comes in **Goldilocks storms:** those that aren’t too small or too big, but just right (figure 1.9b).

The second ingredient is a soft underlying surface. Deep-powder skiing is possible with less than ten inches of snow if it falls on settled powder from a previous storm. Such conditions are rare, however, at ski areas, which are usually tracked out each day, but can be found outside the area boundaries in the backcountry. In contrast, ten inches of new snow might not be enough for bottomless skiing if the snow is bone dry and falls on a hard packed or icy snow surface. When such **dust-on-crust** conditions exist (figure 1.9c), the skiing looks great, but your skis and snowboards sink right through the dry powder and ride on the underlying hardpack.

The third ingredient is a **right-side-up snowfall**, which means that lighter snow sits on top of heavier snow. This **vertical profile of snow water content** is critical for great powder skiing because it helps skis and snowboards float. Right-side-up snow is often called **hero snow** because the skis or snowboard float easily, turns can be made with little or no effort, and skiers and snowboarders feel invincible. On the other hand, in an **upside-down snowfall**, heavy snow sits on top of lighter snow. Skis tend to dive and remain submerged. Fat skis and snowboards help in these conditions, but turning is more difficult and requires a more refined technique.



2

WASATCH MICROCLIMATES

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Figure 2.1. Mount Millicent and Brighton Basin in Big Cottonwood Canyon as photographed by meteorologist S. D. Green on November 26, 1931. Courtesy Special Collections Department, J. Willard Marriott Library, University of Utah.

Utah's powder reputation is built primarily on the snow climate found in the Cottonwood Canyons, a fact that was apparent to the earliest Wasatch skiers. In 1935, meteorologist and backcountry skier S. D. Green predicted that "skiers will eventually find that the Brighton Basin, or the heads of the [Cottonwood] canyons within a short radius of this winter paradise, offer the best skiing to be found in the Wasatch Mountains" (Kelner 1980, 155) (figure 2.1). Green was right. The Cottonwood Canyons are the climatological sweet spot of the Wasatch Mountains, with their own **microclimate** that produces more snow than falls in the surrounding area. On any given day, understanding the microclimates of the Wasatch Mountains can help you find the deep powder, sunshine, or spring snow that your heart craves.

LITTLE COTTONWOOD CANYON

Little Cottonwood Canyon, home to Alta, Snowbird, and extensive backcountry terrain, penetrates eastward into the Wasatch Mountains from the

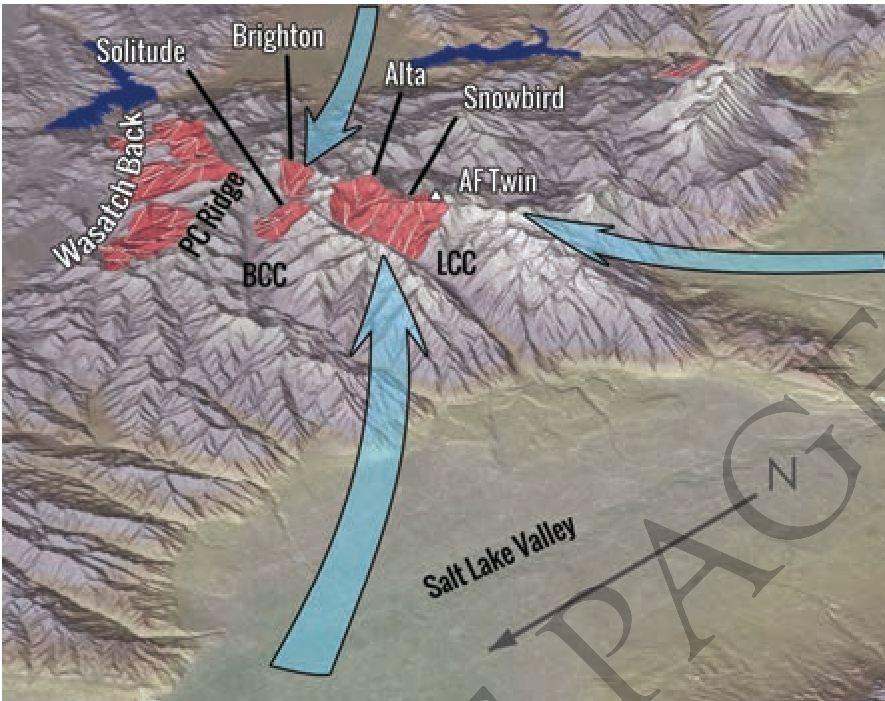

Figure 2.2. Little and Big Cottonwood Canyons (LCC and BCC, respectively) from the northwest. Exposure to flow from several directions (blue arrows) leads to precipitation enhancement in a wide variety of storms. Park City Ridgeline (PC Ridge) and American Fork Twin (AF Twin) are identified with abbreviations.

Salt Lake Valley (figure 2.2). It is a steep glacier-carved canyon surrounded by mountains that reach to over 11,000 feet, including the 11,498-foot American Fork Twin, the highest peak in the central Wasatch Mountains. Although Mount Timpanogos and Mount Nebo in the southern Wasatch Mountains are slightly higher, the high terrain surrounding Little Cottonwood Canyon is the most extensive in the Wasatch Mountains.

As Alta meteorologist Mike Kok once told me, “It doesn’t need a reason to snow in Little Cottonwood Canyon; it needs a reason to stop.” Storms don’t come to Little Cottonwood to die. They come to be reinvigorated and rage on. After a storm ends in downtown Salt Lake City, often one can look southeastward and see it dumping in Little Cottonwood Canyon fewer than twenty-five miles away.

The snowfall contrasts in Little Cottonwood are among the most dramatic in the world (figure 2.3). At the canyon entrance, the average annual snowfall is about 100 inches. Above 8,500 feet, which includes most of the terrain

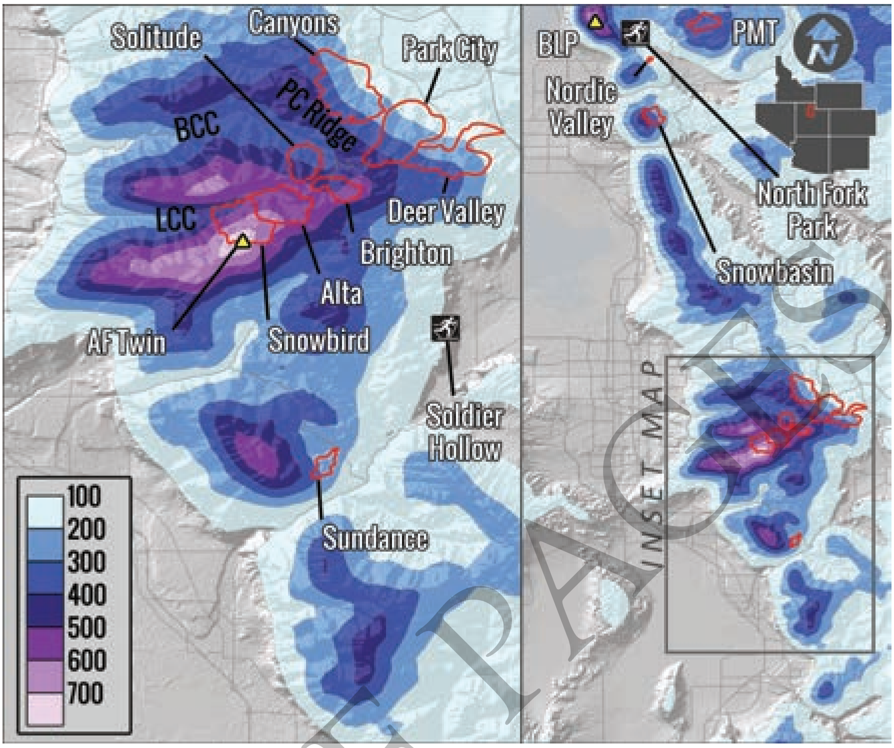

Figure 2.3. Estimated average annual snowfall in the Wasatch Mountains (in inches). Little Cottonwood Canyon (LCC), Big Cottonwood Canyon (BCC), Park City Ridgeline (PC Ridge), Ben Lomond Peak (BLP), and Powder Mountain (PMT) are identified with abbreviations. Red contours indicate ski area boundaries. Data sets used in generating this analysis include those provided by the PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu.

encompassed by Alta and Snowbird, the average annual snowfall exceeds 500 inches. Above 10,500 feet, the average annual snowfall likely exceeds 600 inches, but nobody knows for sure because there are no brave souls taking regular measurements at such altitudes. Throughout Little Cottonwood, the average annual snowfall increases about 100 inches per 1,000 feet of elevation gain.

BIG COTTONWOOD CANYON

Big Cottonwood Canyon lies immediately to the north of Little Cottonwood Canyon (figure 2.2). The high ridge between the two canyons rises to over 11,000 feet, but the terrain to the north of Big Cottonwood Canyon, including the Park City Ridgeline, is somewhat lower, with peaks near 10,000 feet. At

3

BEYOND UTAH

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Figure 3.1. The coastal ranges of northwest North America.

The Wasatch Mountains have an extraordinary climate for deep-powder skiing, especially in the Cottonwood Canyons, but what about the rest of the world? Each of the world's major ski regions features a unique snow climate and fascinating microclimates. Let's have a look.

COASTAL RANGES OF NORTHWEST NORTH AMERICA

The coastal ranges of northwest North America are among the snowiest in the world and include the Cascade Mountains of northern California, Oregon, and Washington; the Coast Mountains of British Columbia and southeast Alaska; and the Chugach and Wrangell–St. Elias Mountains of southern Alaska (figure 3.1). Mt. Baker ski area, located near the Canadian border in the Cascade Mountains of Washington, averages about 650 inches and observed a world-record 1,140 inches of snow during the 1998–1999 season (July to June [figure 3.2]). A whopping 304 inches fell in February 1999, forcing the area to close for two days just to dig out the lifts. The previous world record of 1,122 inches was also set in the Cascade Mountains, at Paradise Ranger Station on Mount Rainier

in 1971–1972. The single-storm world record is 189 inches, set at Mt. Shasta Ski Bowl in the Cascade Mountains of northern California February 13–19, 1959.

Due to the strong influence of the Pacific Ocean, the coastal ranges of northwest North America feature a maritime snow climate with mild temperatures, frequent low-elevation rain, and heavy upper-elevation snowfall. Snowfall increases rapidly with elevation, a consequence of both precipitation enhancement and a greater fraction of precipitation falling as snow at higher altitudes. Many regions and ski areas in the coastal ranges average more than 400 inches of snow annually—some much more. Nevertheless, snow conditions are quite variable and, during warm periods, rain can fall even at upper elevations.

Snow consistency and quality does improve somewhat as one moves northward. Although vulnerable to the occasional rainstorm, the Chugach Mountains of southern Alaska observe drier snow on average than the coastal ranges further to the south.

The only major ski area in Alaska's Chugach Mountains is Alyeska. Alyeska has a base elevation of only 250 feet, with lifts to 2,750 feet, although those willing to earn their turns can climb to the Mount Alyeska summit at 3,939 feet. The average annual snowfall in the Alyeska area increases dramatically from about 210 inches at 250 feet near the base to just over 500 inches at 1,400 feet. Snowfall is even greater on the upper mountain. This remarkable contrast reflects not only the increase of precipitation with altitude but also a greater fraction of precipitation falling as snow instead of rain.

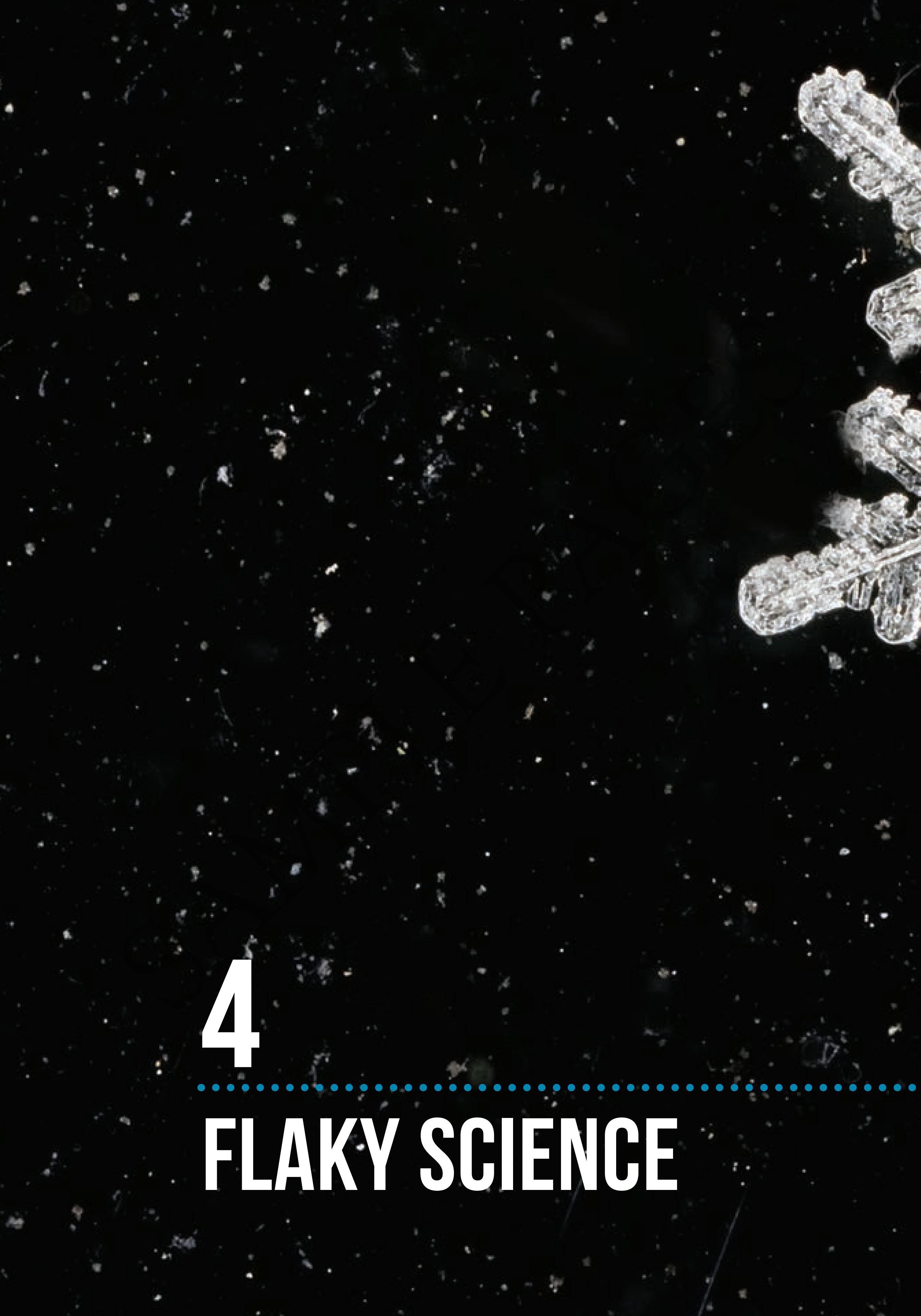
Similarly, prolific snow falls in the heli-skiing region around Valdez, Alaska. The world-record two-day snowfall record of 120.6 inches was set at Thompson Pass just east of Valdez December 29–30, 1955. During that storm, the three-, four-, and five-day accumulations were 147, 163, and 175.4 inches, respectively.

Although the snow is drier on average than in the coastal ranges to the south, the challenge in the Chugach is the short day length during the high-latitude winter and the dramatic and frequently rapid variability in weather and snow conditions arising from the battle between maritime air masses from over the Pacific Ocean and continental air masses from Alaska's interior. You could have the greatest skiing of your life one day, and your worst the next. Bring your snorkel, but be prepared for anything.

CALIFORNIA'S SIERRA NEVADA

The Sierra Nevada occupy most of eastern California, with Lake Tahoe roughly marking the transition between the lower northern Sierra and the

Figure 3.2. A towering snowbank at Mt. Baker ski area during the world-record 1998–1999 season. Courtesy Mt. Baker ski area.



4

FLAKY SCIENCE

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A million billion snowflakes fall every second for your skiing pleasure. The shape, size, and composition of these snowflakes determine if you are skiing hero snow, crud, or concrete. If you want blower pow, you're looking for **stellar dendrites**, which have six treelike arms, a lot of cavities and pores, and a low water content (figure 4.1). On the other hand, maybe you are partial to **graupel**, which looks and feels like a Styrofoam ball and has a high water content, but behaves like ball bearings and provides a unique, creamy ski experience. There are ten snowflake types in the simplest classification system used by meteorologists and eighty in one of the more complex. How does Mother Nature manufacture so many varieties?

MOTHER NATURE'S FIVE-STEP PLAN FOR A SNOWSTORM

Many people believe that snowflakes form when raindrops freeze, but this process produces a pellet of ice known as **sleet**. Instead, Mother Nature employs a five-step plan to squeeze water vapor out of the atmosphere and dump it out as snowflakes on your favorite ski hill. These five steps are condensation, glaciation, vapor deposition, riming, and aggregation.

Condensation

The first step to produce a snowstorm is to create a cloud. Clouds are produced by **condensation**, which occurs when there is a net flow of water from vapor to liquid. For example, dew forms when atmospheric water vapor condenses into water droplets on a cold surface, such as grass or your windshield. The temperature at which this occurs is known as the **dewpoint**. When the temperature and the dewpoint are the same, the relative humidity is 100 percent and the atmosphere is at **saturation**. The atmosphere is **supersaturated** if the relative humidity is greater than 100 percent.

Clouds form when the atmosphere becomes saturated or supersaturated and condensation occurs. This leads to the creation of **cloud droplets**, which form on small microscopic particles known as **cloud condensation nuclei**, or **CCN** (figure 4.2). CCN are vanishingly small and are composed of dust, clay, smoke, pollution, sea salt, or other small particles. There are literally hundreds or, more commonly, thousands of CCN per cubic inch of air, and as a result, hundreds or thousands of microscopic cloud droplets form per cubic inch.

You create your own cloud when you step outside on a cold morning and can see your breath. As you exhale, the water vapor in your breath (as well as a small amount from the atmosphere) condenses into thousands of tiny cloud

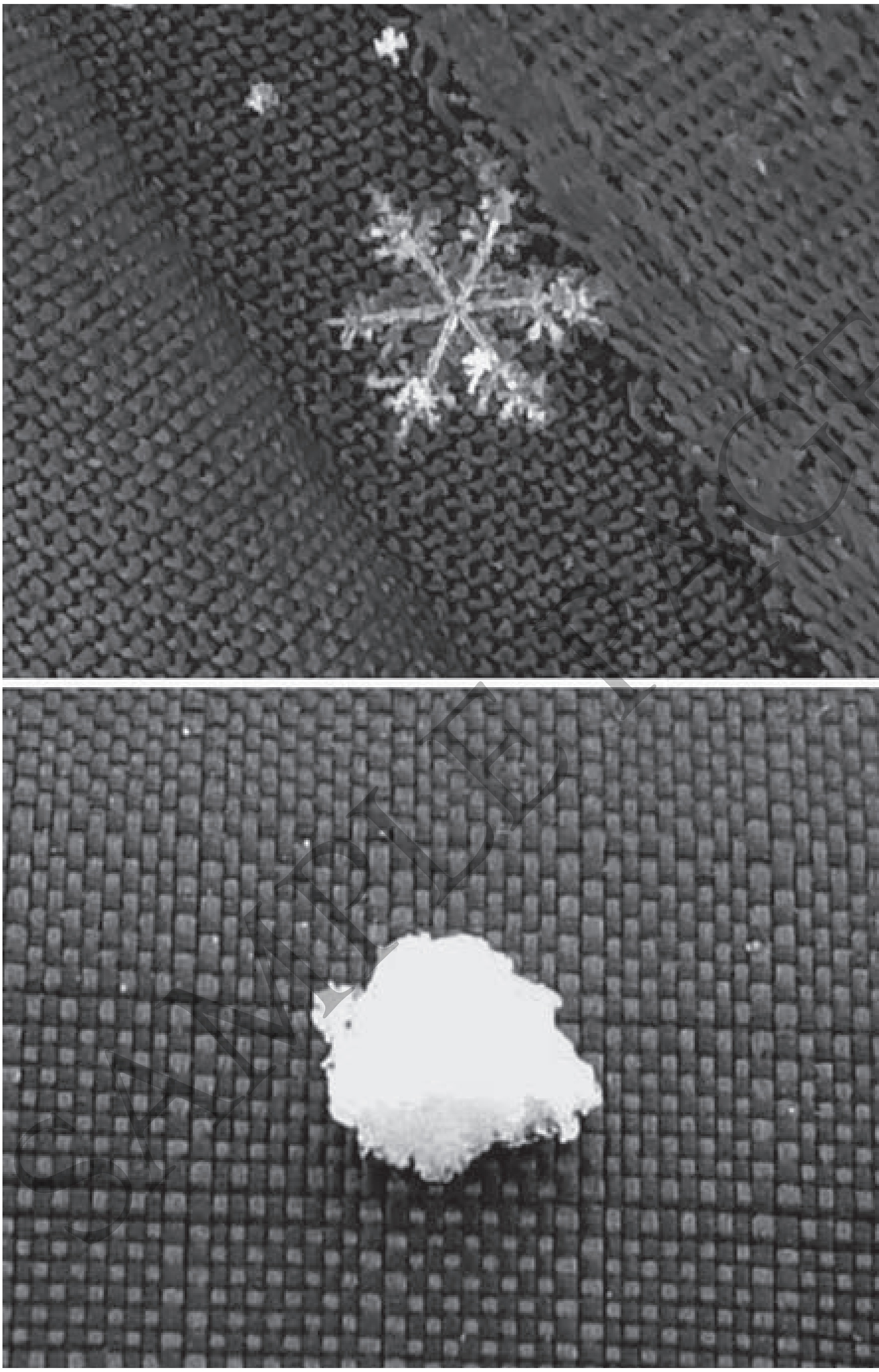

Figure 4.1. Stellar dendrites (top) come in many forms, but all have six treelike arms radiating away from the center. Graupel (bottom) can be lump (as pictured), cone, or hexagonal shaped.

5

LAKE EFFECT

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Conventional wisdom and marketing hype suggest that the Great Salt Lake effect is the holy grail of Utah powder skiing. For example, skisaltlake.com claims that "storms suck up moisture as they pass over the nearby Great Salt Lake and [drop it] on Salt Lake's Mountains just miles away. The light powder snow, thanks to the lake's salinity, falls en masse upon Alta, Brighton, Snowbird, and Solitude, creating some of the best powder skiing and snowboarding in the world."

On the other hand, meteorologists have a love-hate relationship with the Great Salt Lake effect. Many Utah meteorologists are skiers and love a powder day as much as anyone, but forecasting the Great Salt Lake effect is incredibly difficult. So much so that meteorologists call it the **dreaded lake effect**, although we use saltier language in private.

What is the Great Salt Lake effect and why is it so hard to forecast? To answer these questions, we first need to know a bit more about the Great Salt Lake, one of the most unusual bodies of water in the world.

THE GREAT SALT LAKE

The Great Salt Lake is the largest body of water in the western United States and the fourth-largest **terminal lake** in the world (figure 5.1). A terminal lake has no outlet, so the only escape for water that flows into the Great Salt Lake is evaporation. As a result, the depth, elevation, and area of the Great Salt Lake vary significantly, increasing during snowy years that produce a lot of spring runoff and decreasing during droughts (figure 5.2). Geological records suggest that over the past 10,000 years, the Great Salt Lake has never gone completely dry and has crested twice near or above 4,217 feet. At that level, water begins to flow through a low divide to the Great Salt Lake Desert.

Since the mid-1800s, the elevation of the Great Salt Lake has averaged 4,200 feet, with a minimum of 4,191 feet in 1963 and a maximum of 4,212 feet in 1986 and again in 1987. Because much of the land around the Great Salt Lake is very flat, these changes in surface elevation produce large changes in lake area, which averages 1,700 square miles but was as low as 950 square miles in 1963 and as high as 3,300 square miles in 1986. Nevertheless, even at its largest, the Great Salt Lake is much smaller than Lake Ontario, which at 7,340 square miles is the smallest of the Great Lakes of the eastern United States and Canada. Fortunately, the Great Salt Lake is longest (75 miles) along an axis that runs from northwest to southeast, which means that cold northwesterly flow remains over the lake as long as possible before moving over the Cottonwood Canyons.

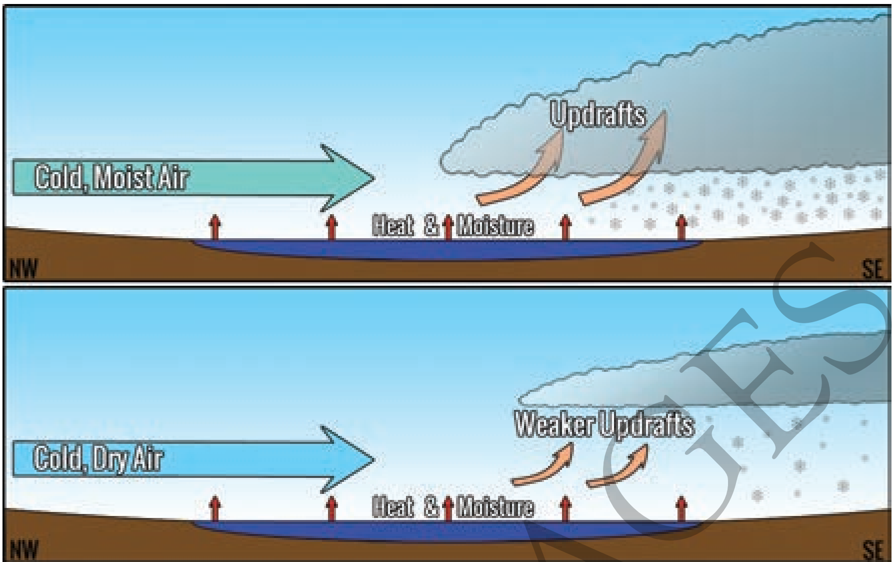

Figure 5.4. The development and intensity of lake-effect precipitation is influenced by the characteristics of the upstream air mass. A moist upstream air mass (top) produces a stronger, more intense lake-effect system than a dry upstream air mass (bottom).

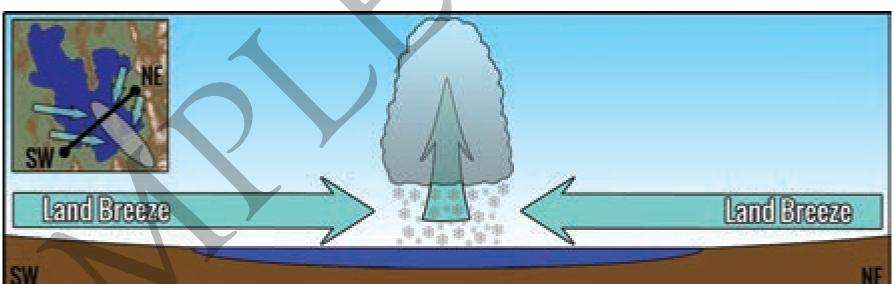

Figure 5.5. Triggering of a lake-effect storm by land-breeze convergence.

But cold, moist air is still not enough. Lake effect needs a trigger. The lake-effect trigger is something meteorologists call **convergence**. When airstreams converge over the Great Salt Lake, the air has nowhere to go but up, and the resulting lift triggers and helps organize lake-effect storms.

The Great Salt Lake can generate its own trigger. After sunset, the air surrounding the lake cools faster than the air over the warm lake surface. This produces **land breezes**, currents of air that blow from the surrounding land and converge over the Great Salt Lake (figure 5.5). This **land-breeze convergence** often serves as the trigger for lake-effect storms, including intense, isolated

6

ALTA GOES TO WAR

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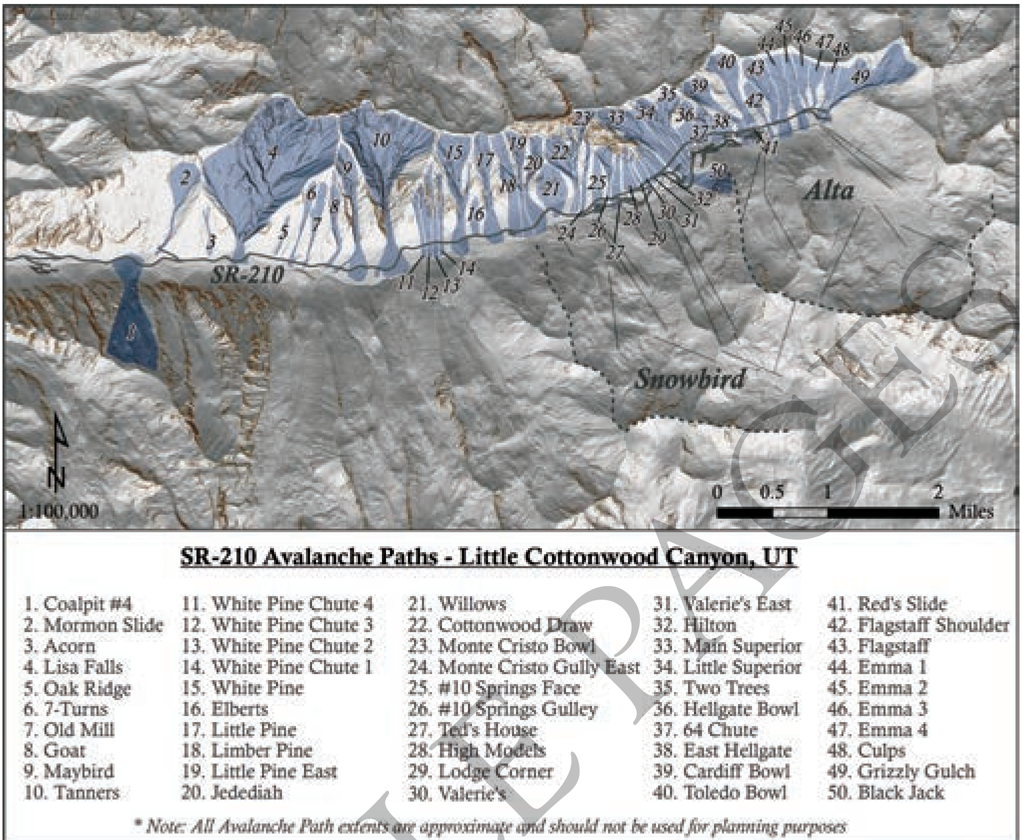

Figure 6.1. Avalanche paths that intersect SR-210 and other roads and parking lots in Little Cottonwood Canyon. Courtesy Utah Department of Transportation/Adam Naisbitt.

All major ski areas and most mountain highways in the Wasatch Mountains are susceptible to avalanches, but Little Cottonwood Canyon is an especially dangerous place. Roughly fifty **avalanche paths** threaten State Route 210 (SR-210) and other roads and parking lots in Little Cottonwood Canyon (figure 6.1), which are hit by an average of thirty-three avalanches per year (figure 6.2). The combination of frequent avalanches and heavy traffic leads to the highest avalanche hazard of any highway in the United States. Seven major avalanche paths lie above the town of Alta, while others cross parking lots and portions of Snowbird village. Add in thousands of acres of avalanche terrain within the ski area boundaries and it takes a Herculean effort by many snow-safety professionals just so you can get the goods after a storm. Those who came to Little Cottonwood Canyon in years past were not so lucky.

Figure 6.2. An avalanche triggered by artillery on Mount Superior above the Little Cottonwood Canyon highway. The highway was closed to vehicle traffic at the time. Courtesy Adam Naisbitt.

THE MINING ERA

It was not long after Mormon pioneers arrived in Utah in 1847 that development came to Little Cottonwood Canyon. First came logging and lumber mills, then mining. By 1873, several mining camps were operating in the canyon and Alta was a town with 180 buildings and a seasonal population of about 3,000. Mining is dangerous enough, but now add the natural hazards of working in a steeply sloped mountain canyon that receives more than 500 inches of snow a year. Further, while the south-facing slopes north of Alta are naturally treeless, logging for buildings and mining denuded the north-facing slopes above Alta, exposing more terrain to the threat of avalanches (figure 6.3). Avalanche disasters would strike and strike often.

The number of people killed in avalanches during Alta's mining days is unclear. In 1884, the *Salt Lake Tribune* reported, "Since mines at Alta were first opened 14 years ago, 143 people have been killed by snowslides in and around Alta" (Kalitowski 1988). According to the Alta Historical Society, documented fatalities total seventy-four. In any event, by 1887 the mining boom was over

7

BEYOND THE ROPES

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Greg and Loren woke up on an early January morning, dropped their three-year-old son off at day care, and drove to Canyons. Expert skiers, they probably took a few laps at the ski area, but were lured by the untracked powder in the easily accessed backcountry surrounding the Ninety-Nine 90 high-speed quad. They spoke with ski patrollers, who warned of high avalanche danger, but ultimately the desire to ski deep powder proved too great. They passed through a backcountry access gate and booted up a ridge to Square Top, a 9,800-foot peak with northeast-facing avalanche-prone slopes of more than thirty-five degrees.

That afternoon Greg and Loren did not pick up their son at day care. Friends and authorities began a search that evening. Where were they? Did they go skiing at Snowbird? Perhaps Park City? Eventually, a friend found their car in one of the parking lots at Canyons.

The next morning, someone spotted a boot track up Square Top and two short ski tracks from the summit that ended at a fracture line where a massive **slab avalanche** released from the slope. A search party of forty-five volunteers and ski patrollers located a ski and then, using long poles to probe the snow, two bodies beneath 1.5 to 3.5 feet of snow. Greg's hand was close to the surface.

US AVALANCHE FATALITIES

An average of about thirty people die each year in avalanches in the United States.[1] More than 90 percent of these deaths occur in the backcountry, which includes lift-accessible terrain outside of ski area boundaries, such as where Greg and Loren tragically perished. Most of the victims are outdoor recreationists (96 percent), nearly all of whom are experts at their sport. Snowmobilers comprise 42 percent of all victims, followed by skiers and snowboarders (39 percent), climbers (9 percent), and snowshoers (6 percent).

Among ski and snowboard victims, 59 percent are earn-your-turns types who access the backcountry without the assistance of a lift. Another 31 percent enter the backcountry after riding a lift, either through open backcountry avalanche gates or illegally through closed backcountry gates and roped area boundaries.

An average of slightly less than one avalanche fatality occurs per year in terrain that has been opened by the ski patrol at US ski areas. This represents only 6.5 percent of all skier and snowboarder avalanche fatalities, despite the fact that there are almost 60 million skier visits per year at US ski areas, about 8.5 million of which involve skiing on ungroomed slopes that are steep enough to avalanche. This puts the odds of being killed by an avalanche in open, inbounds terrain at about 1 per 10 million skier days. Although not quite zero, these odds are quite long.

Some skiers and snowboarders refer to backcountry that can be accessed from a ski lift as **sidecountry** (if turns can be made with no climbing) or **slackcountry** (if turns require some climbing, either by booting or using **climbing skins**).[2] Don't let these names suggest that you are skiing anything but the backcountry. Whether you call it backcountry, sidecountry, or slackcountry, the snowpack is not the same as it is in bounds, where it has been subjected to substantive avalanche-control efforts. The snowpack in bounds might seem to be absolutely bomber (meaning stable and safe), but as soon as you cross that rope line, you enter a new world where the avalanche hazard can be higher, sometimes much higher. Don't let a safe, euphoric day of in-bounds powder skiing seduce you into thinking otherwise and making a deadly trip into the backcountry.

UTAH AVALANCHE FATALITIES

Utah averages about four avalanche fatalities a year. Backcountry skiers and snowboarders represent 45 percent of the victims, followed by snowmobilers with 36 percent.[3] Of the backcountry skier and snowboard victims, *more than 50 percent entered the backcountry after riding a ski lift*. This compares to only 31 percent nationally, despite the fact that Utah has a large earn-your-turns backcountry ski and snowboard community. Utah skiers also comprise 26 percent of all US avalanche victims who entered the backcountry after riding a lift, despite the fact that Utah is home to only 9 percent of the ski areas in the western United States.

AVALANCHE ESSENTIALS

Avalanches are torrents of moving snow that may contain rocks, dirt, or ice and come in several varieties. The deadliest is the slab avalanche, in which an entire plate of snow fractures from the snowpack and breaks into blocks and pieces as it rushes down the mountain, typically at speeds of sixty to eighty miles per hour, far faster than you can ski. Don't assume you can outrun one.

Slab avalanches are responsible for most skier and snowboarder fatalities, as the slab frequently fractures from above and around the victim or victims after they have skied partway down the slope. This was the case with the avalanche that killed Greg and Loren. The fracture at the top of the slab is called

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POWDER PREDICTION

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Prediction is very difficult, especially about the future. Those words, famously quipped in one form or another by everyone from Nobel Prize–winning physicist Niels Bohr to Hall of Fame baseball catcher Yogi Berra, are figuratively tattooed on the shoulder of every professional or armchair meteorologist who has tried to forecast for the Wasatch Mountains. Our storms are chewed into pieces by the Sierra Nevada, Cascade Mountains, and other upstream mountain ranges; our topography is super steep and narrow; and we have this salty puddle of water known as the Great Salt Lake that sometimes teases us with lake effect following the passage of a cold front. All of these things make powder prediction in the Wasatch Mountains very difficult. Nevertheless, weather observations and forecasts are getting better ever day and can help you anticipate when to call in sick to work or where to find the deepest powder.

EASY-ACCESS WEATHER INFORMATION AND FORECASTS

For skiers and snowboarders who simply want reliable weather information and forecasts, I recommend the following websites. The first is utahavalanchecenter.org, which provides highly detailed avalanche and mountain weather advisories. These are prepared for backcountry travelers, but they are also extremely useful for getting a handle on weather at the ski areas, although the avalanche advisories and ratings apply only to backcountry areas, not within ski area boundaries where avalanche-control work is done. Next is the website for the Salt Lake City National Weather Service Forecast Office (www.wrh.noaa.gov/slc/). In addition to the usual weather observations, discussions, and forecasts, this source also produces a detailed forecast for the Cottonwood Canyons (www.wrh.noaa.gov/slc/snow/mtnwx/mtnForecast.php). There's also opensnow.com, run by Joel Gratz and University of Utah atmospheric sciences alumni Andrew Murray.

Another great site is wasatchsnowinfo.com, which specializes in ski weather and is the brainchild of Chris Larson, a University of Utah computer science alum with a self-described "PhD in powder skiing at Alta." It provides point-and-click, one-stop shopping for snow reports, avalanche and snowpack information, observations from mountain weather stations, forecasts, and webcams. Finally, utahskiweather.com is produced by atmospheric sciences students at the University of Utah who, in addition to being capable forecasters, are well known for their ski and snowboard adventures (I can always count on low class attendance on big powder days). The site includes resort-specific and backcountry weather forecasts, discussions of snow conditions, and a blog.

PRODUCING YOUR OWN WEATHER FORECASTS

The sites above are great for basic information, but surely you don't want your powder pursuits to depend on the whims of professional "weather guessers." Perhaps you can do better? I know some amateur weather forecasters who are quite good, largely because they have developed a great feel for the weather and climate where they like to ski or snowboard. They learned the basics of weather forecasting, started forecasting using products readily available on the Internet, and now have a heads-up on the competition when it comes to getting the goods.

Meteorologists use a technique known as the **forecast funnel** to predict the weather in mountainous regions (figure 8.1). The forecast funnel starts with what meteorologists call the large scale. Begin by getting a handle on the location and movement of high- and low-pressure systems, fronts, and troughs and ridges at jet-stream level. Then, funnel down to smaller scales and evaluate how the interaction of these systems with the regional and local topography will influence the weather at the ski or backcountry area of interest.

For example, suppose there is a moisture-laden cold front moving across Utah today and you want to ski powder at two different ski areas over the next two days. The **computer models** suggest that ahead of the front the flow will be southwesterly, whereas behind the front it will be northwesterly. That's the big picture—now funnel down and add in the topographic effects. During southwesterly flow storms, ski areas like Sundance and Snowbasin usually (but not always) see strong orographic precipitation enhancement (see chapter 2). Either of these might be a good option for your first day. On the other hand, tomorrow, when the front has passed, you might want to hit a ski area in the Cottonwood Canyons, which are favored in northwesterly flow.

That example makes it sound easy, but usually weather forecasting is more complicated. For example, the moisture might be confined to near the front, which is sagging slowly into Utah from the northwest. This could mean that Snowbasin, which is further north, will get more snow than Sundance. On the other

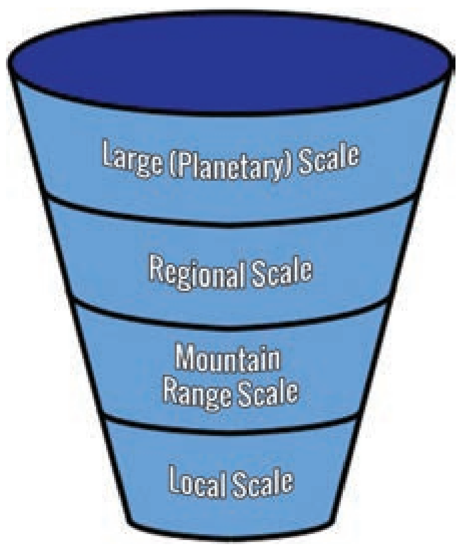

Figure 8.1. The forecast funnel. Adapted from Snellman 1982; Horel, Staley, and Barker 1988.

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GLOBAL WARMING

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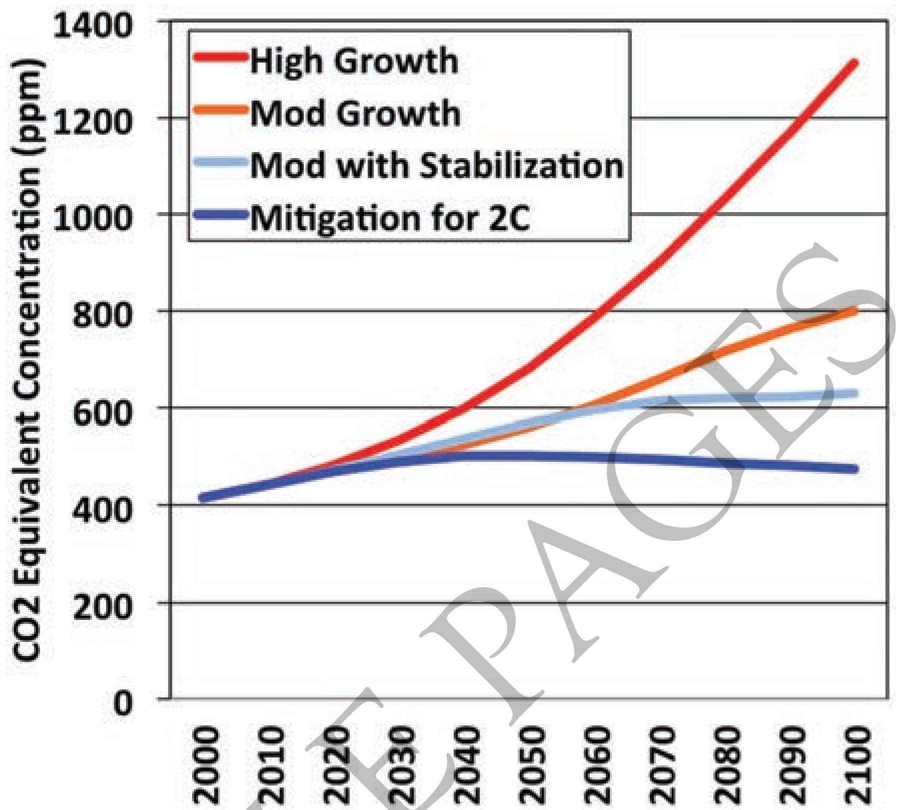

Figure 9.6. CO_2-equivalent concentration scenarios used in climate model projections for the twenty-first century. Data source: Integrated Assessment Modeling Consortium Representative Concentration Pathways (IAMC RCP) Database (http://www.iiasa.ac.at/web/home/research/researchPrograms/Energy/RCP.en.htmlQ1).

current difference in average annual temperature between Salt Lake City and Park City.

IMPACTS OF WARMING ON THE GREATEST SNOW ON EARTH

Based on the climate model projections discussed above and other research on global and regional climate, there is high confidence that Utah will warm during the twenty-first century, with the rate and size of the temperature rise depending on future greenhouse gas emissions and the sensitivity of the climate system. In the next decade or two, natural climate variability will likely dominate snowfall and snowpack trends in the Wasatch Mountains. Eventually,

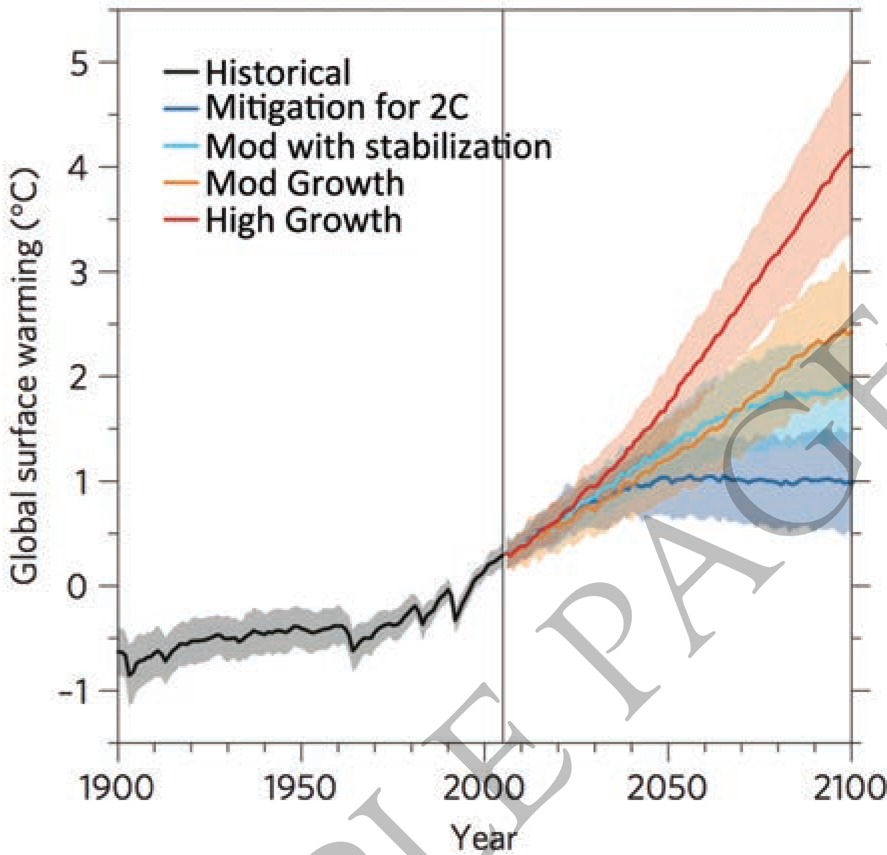

Figure 9.7. Global surface temperature (°C, relative to the average for 1985–2005) projections by climate models for the twenty-first century. Line and shading indicate the average and range within one standard deviation of projections for each scenario, respectively. Roughly 70 percent of the model projections fall within the one standard deviation range. Adapted by permission from Macmillan Publishers Ltd: *Nature Climate Change*, Robustness and uncertainties in the new CMIP5 climate model projections, **3**, 369–373, Reto Knutti and Jan Sedláček, © 2012.

however, global warming will exert a growing influence on the Greatest Snow on Earth.

More Rain, Less Snow

One of the most likely future effects of global warming is a greater fraction of precipitation falling as rain instead of snow as winter storms become warmer. Local meteorologists Leigh Sturges (née Jones) and John Horel

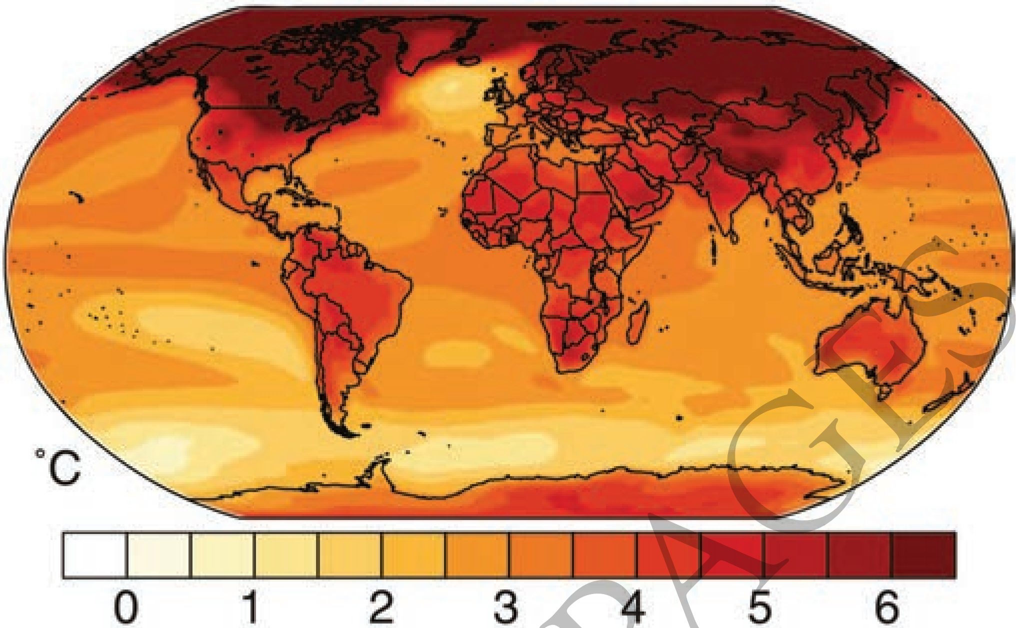

Figure 9.8. Average wintertime (December–February) surface air temperature change (°C) projected by climate models from 1986–2005 to 2080–2099 for the high-growth scenario. With kind permission from Springer Science+Business Media: *Climatic Change*, Climate change hotspots in the CMIP5 global climate model ensemble, 114, 2012, 813–822, Noah S. Diffenbaugh and Filippo Giorgi, Figure 2, © The Authors 2012.

recently estimated how much of the wintertime precipitation that currently falls as snow would instead fall as rain if winter storms were 1°, 2°, 3°, or 4°C warmer (figure 9.9). For a temperature rise of 1°C (about 1.8°F), about 10 percent of the precipitation that currently falls as snow would instead fall as rain at 7,000 feet (roughly the base elevation of Canyons, Park City, and Deer Valley). At 9,500 feet (midmountain at Snowbird and Alta and upper mountain at Canyons, Park City, and Deer Valley), however, it's only 3 percent. This reflects the fact that the upper elevations are well above the freezing level during most storms and thus have more "insurance" against global warming.

The numbers get worse, however, with greater warming. For a 4°C temperature increase (about 7.2°F), about 40 percent of the precipitation that currently falls as snow would instead fall as rain at 7,000 feet. At 9,500 feet, it's about 20 percent. Thus, while all elevations will see more wintertime precipitation falling as rain instead of snow due to warming during the twenty-first century, the change will be greatest in the lower elevations. Therefore, the

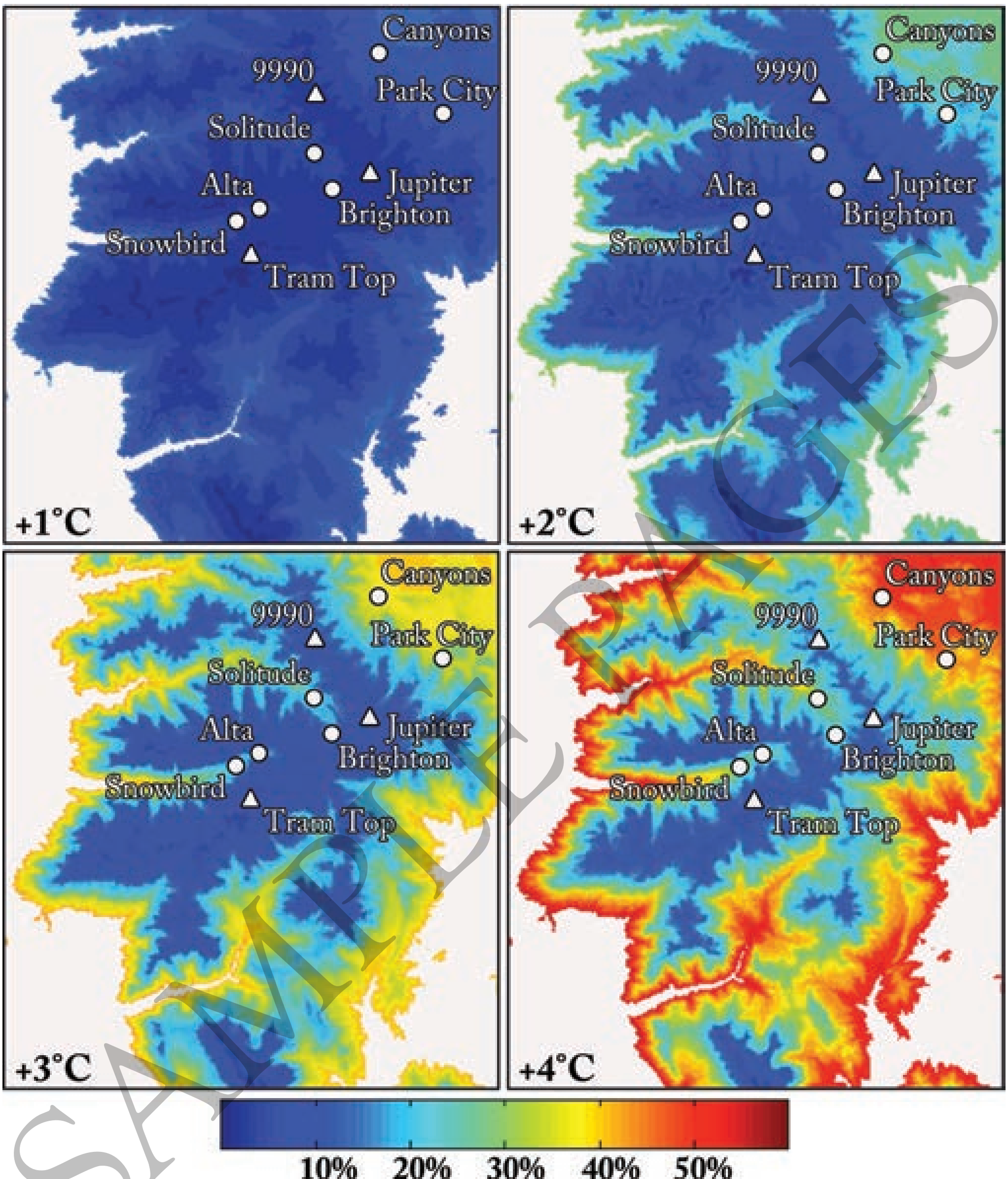

Figure 9.9. Percent of wintertime precipitation that currently falls as snow that would instead fall as rain for a temperature increase of 1°, 2°, 3°, and 4°C. Selected ski-area bases (circles) and summits (triangles) annotated. Adapted from Jones 2010.

contrast between the lower-elevation and upper-elevation snowfall (and snowpack) will likely increase over the next few decades, with upper-elevation ski terrain becoming an increasingly precious and valued commodity.

ABOUT THE AUTHOR

Dr. Jim Steenburgh is a professor of atmospheric sciences at the University of Utah, an avid backcountry and resort skier, and creator of the popular blog Wasatch Weather Weenies. An award-winning teacher and leading authority on the weather and climate of the Wasatch Mountains and western United States, his research on snow, winter storms, and forecasting has been featured by *The Weather Channel,* the *New York Times, USA Today,* and the *Salt Lake Tribune*.