7

REGIONAL WEATHER SURVEY, PART I
Mountains of Alaska, Cascades and Sierra Nevada

Chapter Highlights:

✓ Detailed information on the weather and climate of the Alaska Range, St. Elias Mountains, Coast Range, Cascades, and Sierra's.

Alaska

Weather in Alaska is a direct result of two interrelated phenomena: the position and strength of both the polar jet stream and Aleutian low pressure system. In Chapter 4 you learned that over the course of a year the polar jet migrates through a very broad range of latitude. Along the 150^o W meridian (Pacific Ocean) for example, the polar jet can be found anywhere between the Alaska Range (64^o N) and the North Pacific (30^o N). For reasons which are not germane to our present discussion, there are times when the polar jet stream is very strong and other times when it is weak. Occasionally the polar jet stream splits into two parts, one section at high latitudes and the other in the mid-latitudes. During most of the year the polar jet is positioned just to the south of the Aleutian Islands and the Gulf of Alaska. However, when the jet moves north over the state, widespread clouds and precipitation can be expected. This is a very simplified view of the movement polar jet since it is rarely parallel to latitude circles; more often than not the jet contains curves and bends which redirect the flow of air north and south as well. For example, when the polar jet is over the North Pacific it is common for it to cover as much as 30^o of latitude.

The Aleutian low is a seasonal (October-April) center of low pressure that resides near the Aleutian Islands, and is a region of frequent storm generation. The majority of large storms that move into Alaska as well as the west coast of North America, originate in the Aleutian Low. Subsequently, the primary direction from which synoptic-scale storms move into Alaska is from west to south, as illustrated in Figure 7.1. These are the storms that transport large amounts of moisture from the either the Bering Sea or Gulf of Alaska. Storms that originate from the east are much drier, less frequent and less energetic than their western counterparts.

The parameters which influence weather in any specific region of Alaska are latitude, the distance from an ocean, and elevation. Latitude influences weather and climate by regulating temperatures, which in turn restricts the amount of moisture that an air mass can hold. Generally, at higher latitudes the annual temperature is cooler and therefore the annual precipitation is reduced, when compared to mid-latitude sites. This does not mean that daily or monthly averages of temperature and precipitation cannot be higher than locations further to the south. For example, the area around Fairbanks (this includes all of the interior of Alaska) is much warmer in June-August, than it is in Anchorage 450 km (280 mi) to the south. In fact it is considerably warmer in the summer in Fairbanks than it is in any major city on the West Coast. However, since winters are so much colder north of the Alaska Range, the annual temperature for towns like Fairbanks is well below those of Anchorage or Seattle.

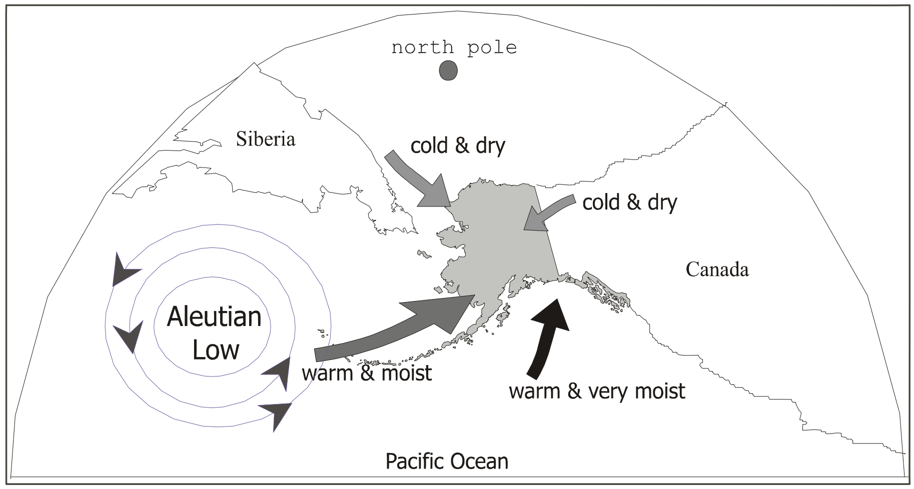


Figure 7.1- Winter storm track for Alaska.

An additional influencing factor is the distance that a particular region is from either the Gulf of Alaska or the Bering Sea. The term that is used by meteorologists to describe this effect is: continentality**.** Since the ocean contains a large volume of water that heats-up and cools-down very slowly, towns located near the ocean, like Anchorage or Valdez, have modest seasonal temperature ranges. In winter for example, the Interior (the area north of the Alaska Range and south of the Brooks Range) is considerably colder (15^o to 25^o C or 27^o to 45^o F) than the area along the Gulf of Alaska because of the warming influence of the ocean in the latter region. In the summer, the Interior is warmer and the coastal areas are cooler. Due to the almost year round cover of sea ice, the thermal influence of the Arctic Ocean on the area north of the Brooks Range is limited. In addition, since the storm track is rarely from the north, the Arctic Ocean is not a very big supplier of moisture. Incidently, most of the moisture that reaches the Brooks Range is transported from the Bering Sea or Gulf of Alaska.

Elevation influences weather because in general: both temperature and moisture decrease with increasing elevation. In Chapter 5 it was pointed out that precipitation does not continue to increase with increasing elevation for most large mountains. In the Alaska Range for example, there are very few precipitation gages higher than 1000 m (3,280 ft), therefore our knowledge of precipitation (snow and rain) at higher elevations is based in large part on an educated guess. The following list is an estimate of annual precipitation in Alaska's mountain ranges:

Brooks Range: 0.5-0.8 m (20-31 in)	St. Elias: 3.0 to 6.0 m (110-220 in)
Alaska Range: 0.5 to 2.0 m (19-78 in)	Alaska Coast Range: 2.0 to 5.0 m (78-196 in)

The wide range in annual precipitation in a particular mountain range occurs not only because of the variation in elevation, but also due to the fact that windward slopes intercept the bulk of the precipitation. As a consequence, two sites with the same elevation can have dramatically different precipitation regimes if one site is located on the windward side of the range and the other is on the leeward side. One of the wetter regions in the state is around Mt. Fairweather, where on the windward slopes annual precipitation is estimated to be 7.6 m (300 in). Also keep in mind that precipitation gradients tend to be much steeper on the leeward side of these ranges. For example, on the St. Elias

Mountains the annual precipitation ranges from 6.0 m (235 in) on the windward slopes to around 0.5 m (19 in) at the base of the range in the Yukon Territory. This occurs over a horizontal distance of about 150 km (92 mi). As a consequence the western half of the Yukon Territory is in the rain shadow of the St. Elias Range.

Alaska Range--Denali National Park

The Alaska Range is a 1040 km (650 mi) arc of mountains that divides the Interior from Southcentral Alaska. The western section of the Alaska Range is primarily composed of volcanic mountains, while the northern section is of a fault-block origin. The average height varies between 2700-3500 m (8,800-11,500 ft), with a handful of peaks higher than 4000 m (13,100 ft). Most of the Alaska Range can be considered to lie in a continental climate regime, the exception being the southwest corner near Cook Inlet, which is semi-maritime (Figure 7.2, data for April-August). The Alaska Range as does most of Alaska, receives the majority of its precipitation from mid-August through October**.** Winters are cold with a considerably more cloud-free to partly cloudy days than overcast days. This pattern is broken by the occasional multi-day snowstorm. The northern side of the range is colder than the southern slopes. Climatologically, the months of April, May, and June are the driest, with only about 20% of the annual precipitation occurring during this period. This should not be understood to mean that it rarely rains or snows in the Alaska Range in April through June. In fact most precipitation that does occur in April and May is associated with synoptic-scale disturbances that move over the area. Climate data from towns such as Talkeetna, Healy, and McKinley Park, show a pronounced increase in

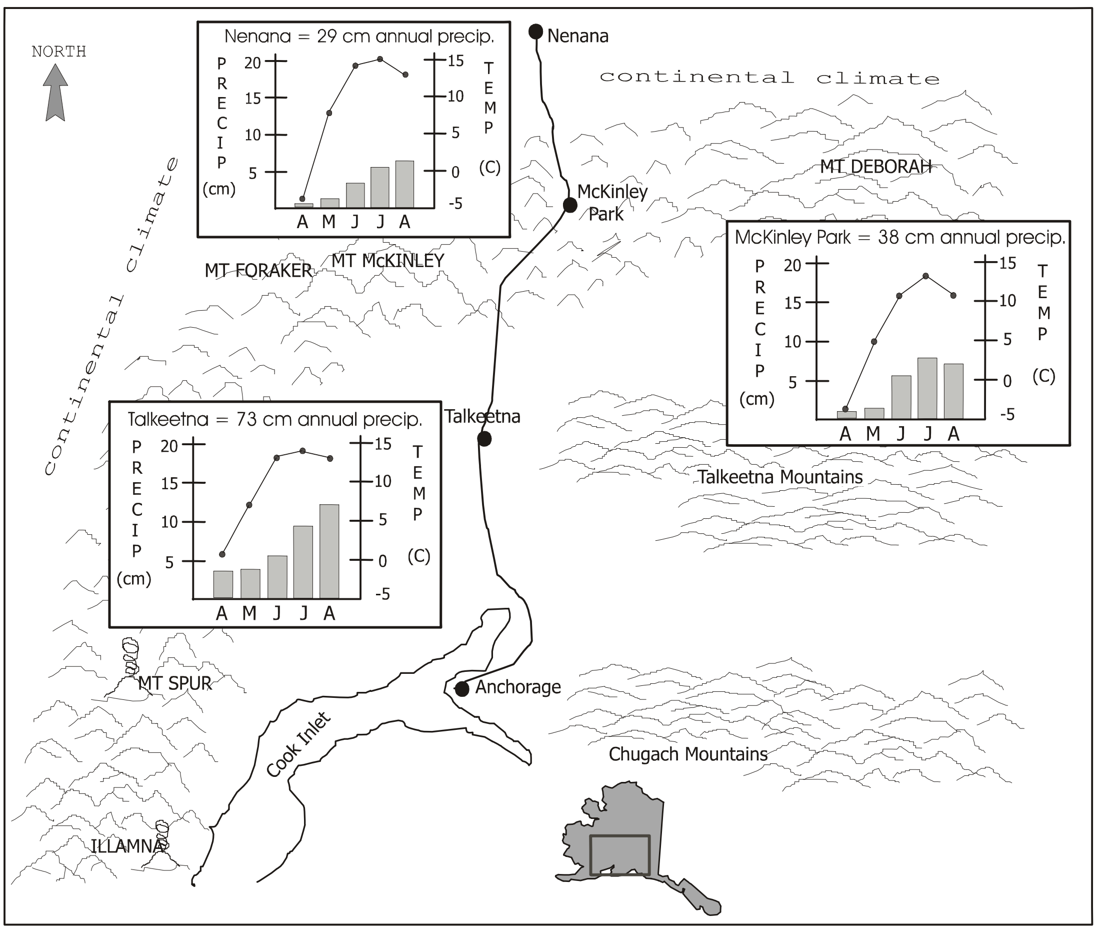


Figure 7.2- Topography and climate of the Alaska Range. In climate boxes, temperatures are shown as a line with the scale on the right axis. Precipitation is represented by the bars with the scale on the left axis.

precipitation in June when compared with the previous two months. However, this has to be taken in perspective since most of the summertime precipitation falls in the afternoon and evening from convective rain showers. These showers can produce several centimeters (1 in) of rain at lower elevations, and 10-20 cm (4-8 in) of snow at higher elevations in the Alaska Range.

Since the majority of climbers in the Alaska Range are attracted to Denali National Park, most of the remaining material in this section will focus on Mt. McKinley weather. With 4000+ m (13,100 ft) of relief, Mt McKinley and Mt. Foraker are major orographic barriers to air moving through the region. What makes these mountains unique when compared to other mountains around the planet (for completeness we should also include Mt. Logan and Mt. St. Elias), is their position at high latitudes (63° N). This translates into cooler temperatures at a given elevation compared to the same elevation on a mid-latitude mountain. However, their true uniqueness is due to the proximity in which the summits of these mountains lie in relation to the polar and arctic jet streams. Since the polar jet stream is constantly migrating between the Pacific Ocean and Alaska, there are times when it is positioned directly over Denali National Park (Figure 7.3). When this occurs, the summits of McKinley and Foraker are quite close to the level of maximum jet stream winds.

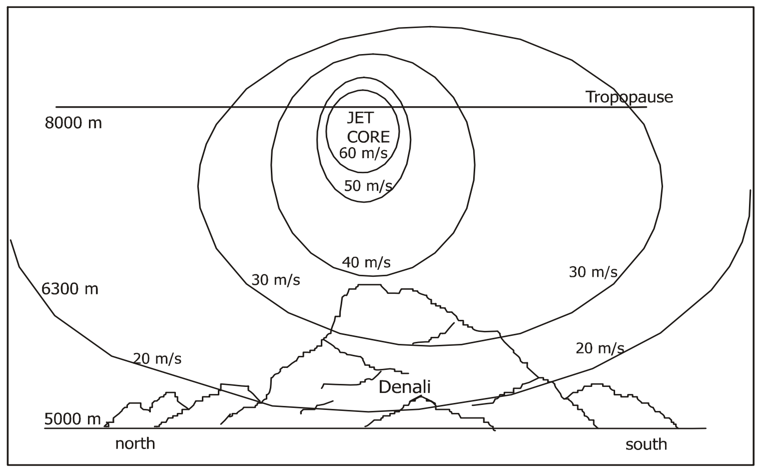


Figure 7.3- Idealization of jet stream winds over the Alaska Range. Due to a lower tropopause at high latitudes, strong winds extend down toward the summit in this example.

From a statistical perspective the Aleutian low is much stronger and persistent in the winter than in the summer. However, occasionally during the April-June period, powerful lows do develop in the central and southern Bering Sea (Figure 7.4a). These storms have a tendency to transport large amounts of moisture into the Alaska Range from the southwest. Most of these storms produce high winds and fresh snow for a period of 36-48 hours, however on occasion they can linger for much longer. With a low positioned in the eastern Gulf of Alaska (Figure 7.4b) generally two scenarios are plausible: if the storm is fairly weak, climbing weather on McKinley will remain good. If the storm is powerful then expect moderate to strong easterly winds with considerable amounts of new snow.
This particular pattern tends to generate widespread convection, hence snow is intermittent (showers) rather than continuous.

Westerly flow often brings moderate moisture to the slopes of McKinley from the Bering Sea (Figure 7.4c,d). When the state of Alaska is under the influence of a ridge of high pressure (Figure 7.4e), a broad range of weather can result: if the pressure gradient (or height gradient) is weak and the jet stream winds are weak or well to the south of McKinley, the climbing weather should be good. If the jet stream is over the mountain and moderate to strong and the flow is from the northwest, expect substantial wind speeds high on the mountain, although there is a good chance that precipitation will be light or not a factor at all. If however the ridge moves east, and the winds become southwesterly, expect poor climbing weather. In fact many of the most significant storms that occur during April-June are associated with a high amplitude ridge positioned over the eastern Gulf of

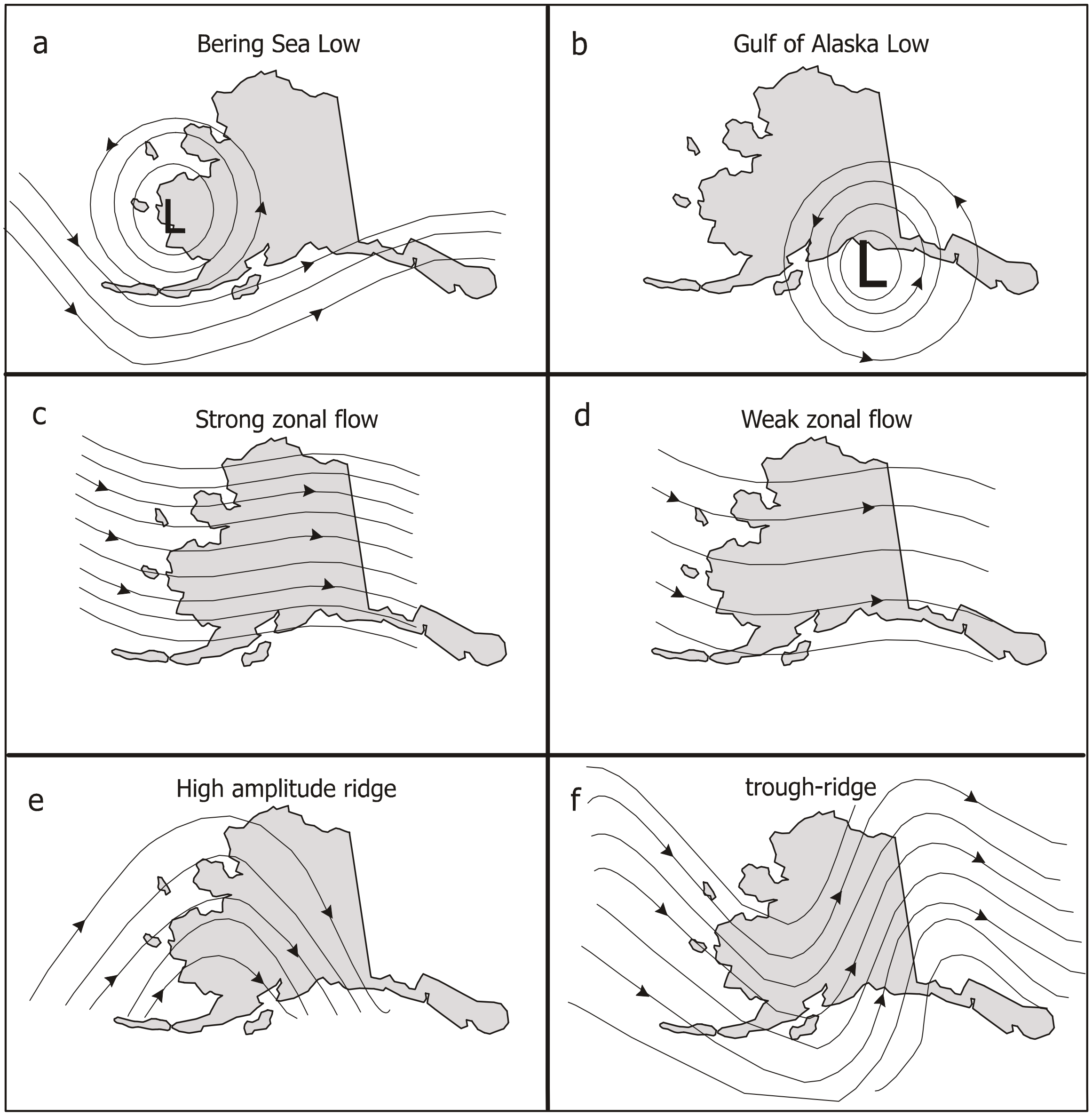


Figure 7.4- Synoptic-scale weather patterns over Alaska as depicted by 500 mb heights.

Alaska, with a trough to the west (Figure 7.4f). These storms are the most dangerous for climbers who are on Mt. McKinley and Mt. Foraker because the ridge is semi-stationary, often producing high inds and fresh snow for many consecutive days.

At lower elevations around Denali (and the Alaska range in general), the annual temperature range is extremely large. During the winter, when Alaska is under the influence of a ridge of high pressure, the coldest temperatures occur at lower elevations where very strong inversions develop due to intense radiational cooling. Temperatures in the -35^o C to -50^o C (-31^o to -58^o F) can be expected during these periods, which often last for one to two weeks. ‘Normal’ winter temperatures at low elevations (below 2000 m) range from -15^o C to -25^o C (5^o to -13^o F) . At higher elevations winter temperatures (based on 500 mb free atmosphere values) are typically around -30^o to -40^o C (-22^o to -40^o F). In the winter when synoptic storms move over the region, temperatures warm considerably at all elevations. Some of the largest increases in temperature however, occur at lower elevations. As a warmer air mass moves into the Alaska Range, cold surface air which was trapped by an inversion, is replaced by the warm air. When this occurs surface temperatures can increase by 20° C (36° F) in a 24 hour period.

During the summer at elevations below 1500 m (4,900 ft), temperatures range from lows around +5° C to highs near +25° C (40° to 77° F). At the Kahiltna Base Camp (2135 m) mid-April through June temperatures typically range from -10° C to +5° C (14° to 40° F) , with a gradual warming from late April to June. At the rangers camp (4270 m) during the summer temperatures range from to -10° C to -25° C (+14° to -13° F) , while near the summit -25° C to -35°C (-13° to -31° F) . These numbers represent 'typical' values, temperatures can of course deviate substantially from these. The seasonal temperature trend at 700 mb and 500 mb in the free atmosphere is illustrated in Figure 7.5. The data used to construct this plot represents a 30 year average of each day from April 15 to June 30. The steady increase in temperatures is evident at both levels. On a daily basis the coldest summer temperatures occur when a low or trough moves into the region (opposite of winter case). Also note that even though it is summer time and the sun is above the horizon for 17-21 hours, there is a pronounced diurnal temperature cycle in the Alaska Range in general.

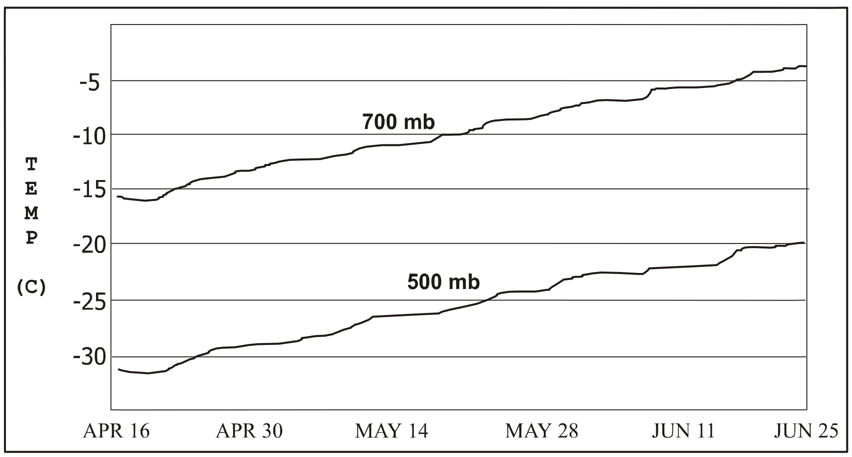


figure 7.5- Thirty-year average of free atmosphere air temperatures over Mt. McKinley. 700 mb corresponds to an elevation of about 3300 m (10,800 ft), and 500 mb is roughly 5400 m (17,700 ft).

The most important weather element that climbers on Mt. McKinley should be prepared for are high winds. This is based on the following considerations: 1) periods of high winds on the upper half of the mountain are frequent during the climbing season, 2) high winds often have a rapid onset, and; 3) A typical wind storm on Mt. McKinley lasts for 2 to 3 days, on occasion however they have been known to last for a week. Wind storms occur in association with many different weather patterns, low pressure systems (and troughs) may or may not produce high winds (figure 7.4a). In fact, many of the classic wind events that have taken place on the mountain, occurred when a ridge of high pressure was positioned over the eastern Gulf of Alaska (Figure 7.4f). Closer analysis of these wind events shows that they all occur when the upper level polar jet stream was positioned over or in close proximity to Denali National Park. The strongest winds occur between 300 mb and
200 mb (8.5-11.5 km), in response to large temperature changes in the lower stratosphere and upper troposphere.   The second half of May 1992 for example, was a period when the upper half of McKinley and Foraker experienced very strong winds. During this interval however, there were periods of 12-24 hours, when wind speeds decreased and climbers were able to move around without getting blown off the mountain. Wind storms can occur in association with snowstorms or under cloud free conditions. Most multi-day wind storms tend to produce considerable amounts of fresh snow as well. In such cases as you might imagine, white-out conditions are the rule.

In order to determine the frequency and duration of wind storms on Mt. McKinley, 40 years of mid-tropospheric wind data was analyzed, restricting the time frame from mid-April to the end of June.

The results are displayed in Tables 7.1 and 7.2. The data in Table 7.1 shows the frequency of free atmospheric winds above a given threshold. For example, 500 mb wind speeds are on average greater-than or equal-to 15 m/s (33 mph) about 19% of the time. What it does not indicate is how many days in a row the wind was above this threshold. The frequencies in Table 7.1 should be considered as minimum values since they were constructed using an average which tends to smooth the data. More importantly these values do not include local wind acceleration. Many climbers would like to know what is a typical critical wind speed above which movement on the upper slopes of the mountain is restricted. There is no deterministic value that works for everyone. There are a number factors that must be considered: the ability of the climbers and their fitness, the route, visibility restrictions, too name a few. As a rough estimate, I would speculate that 20 m/s (44 mph) is a threshold above which most climbers would be advised not attempt to move higher up the mountain.

TABLE 7.1- Wind frequency during climbing season

700 mb winds (approx. 3100 m)				
	≥ 10 m/s	≥ 15 m/s	≥ 20 m/s	≥ 25 m/s
Mean	21%	4.5%	1%	----
500 mb winds (approx. 5300 m)				
Mean	47%	19%	8%	2%

In Table 7.2 we have categorized wind storms based on both speed and duration. There will be times when a rapidly moving weather system such as a shortwave trough or low, brings high winds and snow to the mountain, but the storm is short lived (less than 48 hours). These are an inconvenience but are not that disruptive to climbers. From time-to-time however, a weather pattern is created which produces very high winds over the mountain for a sustained period of time. These are the storms that can create havoc and loss of life. Fortunately, these types of storms can be forecasted, we strongly suggest that if you have access to the Denali weather forecast, to make use of it (see paragraph below).

TABLE 7.2- Number of wind events per category between 1958-1997 at 500 mb

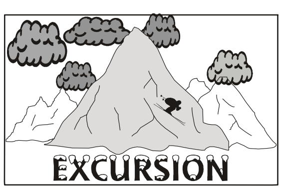
	≥ 20 m/s 24-48 hours	≥ 20 m/s 48-72 hours	≥ 20 m/s > 72 hours
April*	10	5	9
May	13	4	4
June	5	2	2
* from April 15-30			

Several conclusions can be reached from the data displayed in Table 7.2. From April to June there is a definite downward trend in the frequency of wind storms, keep in mind that the data for April only includes the second-half of the month. The frequency of the really large wind storms that pin climbers down for days on end are: once per every 3 seasons for April, once every 5 seasons for May, and once every 10 seasons for June. The sharp decrease in the number of high wind events between May and June is due to the weakening of the polar jet stream as the temperature gradient across East Asia and the North Pacific weakens in early summer.

There are several additional factors regarding winds on Mt. McKinley that should be taken into consideration: 1) Winds at the higher thresholds are usually very gusty. Make sure you factor this into your decision to climb on exposed routes during periods of high winds. 2) There are locations on the mountain where funneling of the wind through gaps and passes is common. Two locations on the West Buttress route where this commonly occurs are Windy Corner and Denali Pass. The amount of amplification through these gaps is unknown, but based on written accounts it must be substantial. In addtion, I highly recommend that you spend the time reading some of the accounts of major storms on Denali, this would include: *Minus 148* (Davidson), *Kingdom of the Mountain Gods* (Synder 1970), *White Winds* (Wilcox 1973), and *Facing the Extreme* (Koncor 1998). If nothing else these accounts will give you some appreciation of what extreme conditions on the mountain are like.

The Fairbanks office of the National Weather Service issues a daily weather forecast for Denali National Park (http://pafg.arh.noaa.gov). This forecast includes estimates of wind speeds, wind direction, cloud coverage and possible precipitation; for base, middle and summit elevations. These forecasts are available at both base and ranger camps on the West Buttress route. The detailed portion of the forecast is valid for 48 hours, while a general weather description extends the forecast for an additional three days. Keep in mind that the forecasted wind values are for the free atmosphere. It is very likely, due to mountain amplification and funneling, that actual wind speeds will be much higher at times.

Many readers are probably wondering if there are any periods during the climbing season when the weather is better for a summit attempt than at other times? In our opinion there is no magical period between mid-April and the end of June, when the weather is statistically better than at other times. In light of this however, there is certainly a decrease in the frequency of strong winds and a gradual warming as the season progresses. But this comes at a cost: in June there is an increase in cloud cover (mainly convective), softer snow, greater chances of avalanching and weaker snow bridges on the lower half of the mountain. The bottom line for weather considerations on Mt McKinley is: be prepared for extreme conditions. Along the same line of thought, while your on the upper half of the mountain keep a close watch on significant changes in wind speed and direction, cloud cover and visibility.



6000 meters- Alaska Range versus Himalaya

On a number of occasions we have heard the following statement “climbing at 6000 meters on Mt. McKinley is equivalent to climbing at 7000 meters in the Himalaya.” True or false? Let’s examine this statement in more detail. What are the main differences in weather and climate between the two ranges? The first consideration are temperatures. It will certainly be colder in the Alaska Range; how much colder depends on the current weather affecting each region at any given time. Fortunately we do know

the average free atmosphere temperatures at 30° N and 60° N (close enough to each region for this argument), at various times of the year. This data set was collected over many years by the U.S. Air Force and is called the Standard Atmosphere. On July 1 the middle troposphere (between 3-8 km or 9,800-26,200 ft) is on average 12° C (22° F) colder over the Alaska Range. On January 1 for comparison, the temperature difference increases to about
21° C (38° F).

The second factor we must consider are the winds. This really depends on the position of the arctic and polar jet stream over the Alaska Range and the subtropical jet stream over the Himalaya. In general, during the summer monsoon in the Himalaya (June-September), the sub-tropical jet disappears, however in the pre-monsoon and post-monsoon seasons, upper-level winds are generally quite strong. In addition, winds on a given mountain in the Himalaya are highly dependent on the type of terrain in the surrounding area. If you are at 6000 m in an area with many peaks above 7000 m, than it is possible that the higher peaks act as a barrier to the winds to some degree. In all fairness, this type of wind comparison is highly questionable since actual wind speeds vary on a daily basis. So we will assume that no meaningful wind comparison can be made between the two ranges.

Thirdly what about the amount of available oxygen at each site? For reasons discussed in Chapter 2, oxygen decreases vertically due to a decrease in air density. The amount of oxygen available at 500 mb remains constant. However the height of the 500 mb level (we could use any level) above the ground changes from day-to-day. This means that for a climber who is at a fixed elevation, the amount of available oxygen depends on the pressure at that elevation. In July for example, the difference in the geopotential height field at 6000 m (19,700 ft) over the Alaska Range and the Himalaya is about 270 m (890 ft). This translates into a pressure difference of about 18 mb, or a difference in the oxygen content of about 4%. Therefore during the summer, a climber at 6000 m on Mt. McKinley for example, has about 4% less oxygen to work with than a climber at the same altitude on any peak in the Himalaya. In January, a climber would have about 7% less oxygen on Mt. McKinley due to considerably colder conditions at higher latitudes.

In summary, on average, climbing at 6000 m in the Alaska or St Elias Ranges is roughly equivalent to climbing at an elevation of about 6500-7000 m in the Himalaya as per temperatures and available oxygen.

Wrangell Mountains and St. Elias Range

The Wrangell Mountains located in the Copper River Basin, form a link between the Alaska Range to the northwest and the St. Elias Range to the southeast. Due to their closer proximity to the Gulf of Alaska, the Wrangell Mountains tend to receive a higher amount of annual precipitation when compared to the eastern half of the Alaska Range, but considerably less than the St. Elias Range. In other respects this range has a similar climate regime as the Alaska Range. Most synoptic storms that move into the region do so from the southwest or south. In addition, from May-August the whole area experiences vigorous convection.

Anyone who has ever flown over or even just looked at the St. Elias Range on a map, quickly notices the sheer volume of glacial ice that can be found in this region, a testament to the large amounts of precipitation this range receives each year. A major factor is that the southern half of the St. Elias Range is considered the highest coastal range on earth. The St. Elias Range has a stepped structure that gradually rises to the highest peaks which are located some 40-100 km (25-61 mi) from the coastline. This means that large amounts of moisture are transported into the higher mountains. Most of the synoptic-scale storms which produce so much precipitation, move in from the southwest to south. With a large amount of terrain above 3000 m (9,800 ft), the St. Elias Range produces considerable upstream blocking and therefore enhanced precipitation due to very moist Pacific air being forced up the windward side of the barrier.

The St. Elias Range is virtually uninhabited, and as a consequence there is very little meteorological data. The nearest long-term weather station is at Yakutat, although situated on the coast, does provide some estimate of the regional weather (Figure 7.6). Yakutat's annual precipitation is about 3.85 m (151 in). The driest period is June and July, when only about 10% of the annual precipitation occurs. The wettest two month period is September and October when some

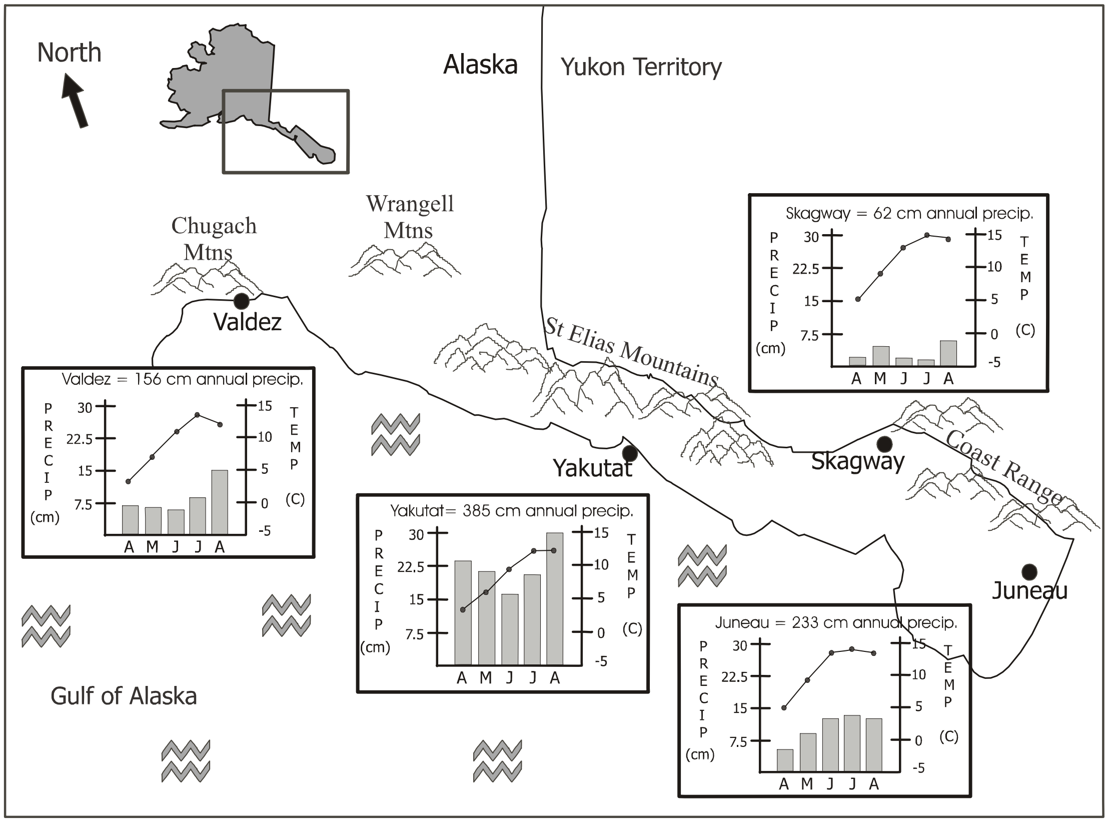


Figure 7.6- Summer precipitation and temperature for selected sea-level stations along the Gulf of Alaska. Notice how these stations have similar temperature trends, but differ widely in precipitation.

28% of the annual precipitation can be expected. Since Yakutat lies some 60 km (37 mi) upstream of the higher mountains, its precipitation is considerably less than what occurs at higher elevations. It has already been noted that the mountains around Mt. Fairweather probably receive the largest amounts of precipitation of any location in Alaska. It is not hard to figure out why; the Fairweather Range rises from sea-level to over 4000 m (13,100 ft) in about 40 km (25 mi).

In order to provide you with at least rough estimates of freezing levels in the St. Elias range during the climbing season, 13 years worth (1985-1997) of sounding data from Yakutat was analyzed. A typical freezing level above Yakutat in May is about 1200 m (3,900 ft), however on any given day it ranges from 500 to over 3000 m (1,600-9,800 ft), depending on the weather pattern. In June the mean rises to about 1900 m (6,200 ft) with a range of 1000 to 3500 m (3,200-11,400 ft). The highest freezing levels occur when a ridge of high pressure is located over Southeast Alaska (i.e.-the panhandle) or western Canada.

Alaska Coast Range

The coast range starts in the vicinity of Skagway where the St. Elias Range terminates, and extends down the eastern third of Southeast Alaska. The highest mountains are around 2150 m (7,050 ft), but the area is really known for its large icefields, especially the Juneau Icefield. Like the rest of the mountains lying adjacent to the Gulf of Alaska, the Coast Range has some large precipitation gradients in which the role of steep terrain cannot be over emphasized. The predominate moisture producing storm track for this region is from the south and southwest. During many of these storms, the low-level winds are often from the southeast as air moves from British Columbia into a low positioned in the eastern Gulf of Alaska. At the same time there is considerable funneling of these low-level winds in the fjord topography (also known as channels, passages, canals,) of Southeast Alaska.

Juneau's annual precipitation is on the order of 1.4 m (56 in) at the airport, to about 2.3 m (90 in) in town. Precipitation between May and July amounts to about 17% of the annual precipitation, while the August-October period receives about 37% of the annual precipitation. In both the St. Elias and Coast Ranges, due to large amounts of snowfall throughout the September through May period, avalanches are a real concern during the warmer months of the year. Freezing levels above Juneau in May are on average about 1500 m (4,900 ft) and in June 2000 m (6,500 ft), but vary considerably from week-to-week.

Alaska Weather Summary

* Driest period- April through June
* Wettest period- August through October
* Primary storm track direction- Southwest or south.
* Upper level winds- Strongest from the west-through-south, can occur anytime of the year. Beware of periods of very strong winds when jet stream(s) is over Alaska.
* Convective activity occurs in the Alaska Range, Wrangell Mountains, north side (interior) of St. Elias and Coast Ranges. Cloud-to-ground lightning possible from late May through August, but generally not a major concern.
* Gorge winds: Frequent in all mountain ranges in Alaska in the winter, including the islands of southeast Alaska.
* Barrier jets: north side of Brooks Range, all mountains bordering Gulf of Alaska.
* Downslope windstorms: all mountain ranges primarily during the cooler months of the year. Main areas affected: Western side of Chugach Mountains, north side of Alaska Range, and west side of Coast Range.

WEB: National Weather Service

Fairbanks **http://pafg.arh.noaa.gov**

Anchorage **http://pafc.arh.noaa.gov**

Juneau **http://pajk.arh.noaa.gov**

Mt. McKinley weather observations (~19,200 ft) **www.denali.gi.alaska.edu**

Cascades

The Cascade Range extends some 1000 km (600 mi) from Mt. Girabaldi in southern British

Columbia to Mt. Lassen in northern California. The average height of the Cascades is about 1700 m (5,500 ft), with the occasional stratovolcanoe rising above 3000 m (9,800 ft). You cannot begin to understand the weather and climate of the Cascades without consideration of the influence of the Coast Ranges as well. With an average height of about 1000 m (3,280 ft), and lying on average about 100 km (61 mi) upstream of the Cascades (with respect to the primary wind direction), the Coast and Olympic Ranges heavily influence the distribution of precipitation in northern California , western Oregon and western Washington. In fact there are sections of the Coast Ranges that receive as much annual precipitation as any location in the Cascades. In Washington for example, the relatively compact Olympic Range, is one of the wettest regions in the continental USA. The Coast Ranges of Oregon and northern California, although not as wet as the Olympics, do substantially block the inflow of low-level moisture as well.

There is a marked increase in annual precipitation between the southern and northern halves of the Cascades. Schermerhorn (1967) estimated the latitude dependency of annual precipitation at 8% per degree of latitude. Therefore, the mountains in the vicinity of the Oregon-California border receive about half the annual precipitation as the mountains near the Washington-British Columbia border. This particular distribution of precipitation is a result of the seasonal position of the storm track (Figure 7.7). During the winter in the Pacific Northwest, the jet stream and associated storm track, are frequently found between 45^o N and 55^o N, resulting in higher storm frequency in the northern half of the Cascades. From July through September the polar jet stream weakens and migrates northward. This shift typically produces extended periods of warm, dry weather in both the northern and southern parts of the range.

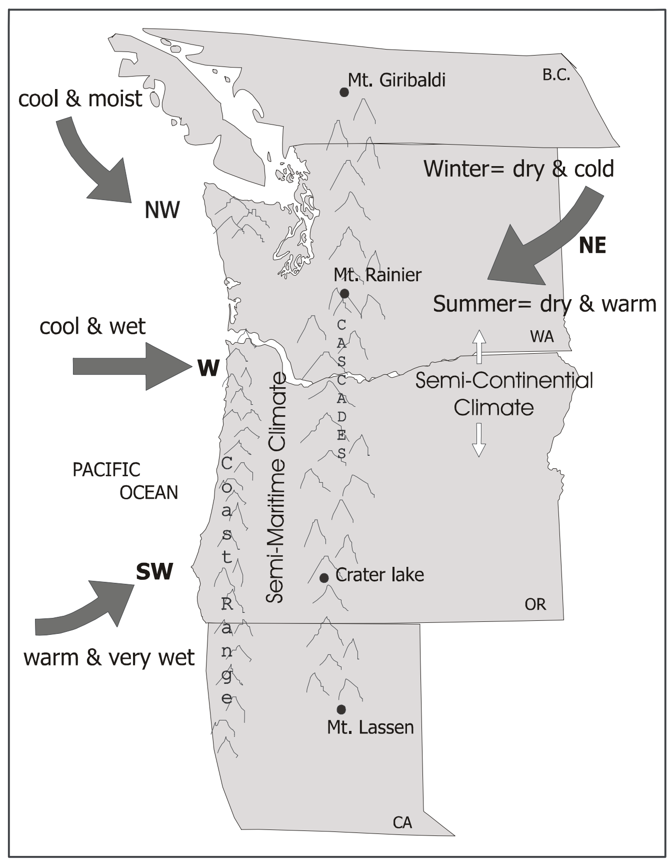


Figure 7.7- Storm tracks of the Pacific Northwest.

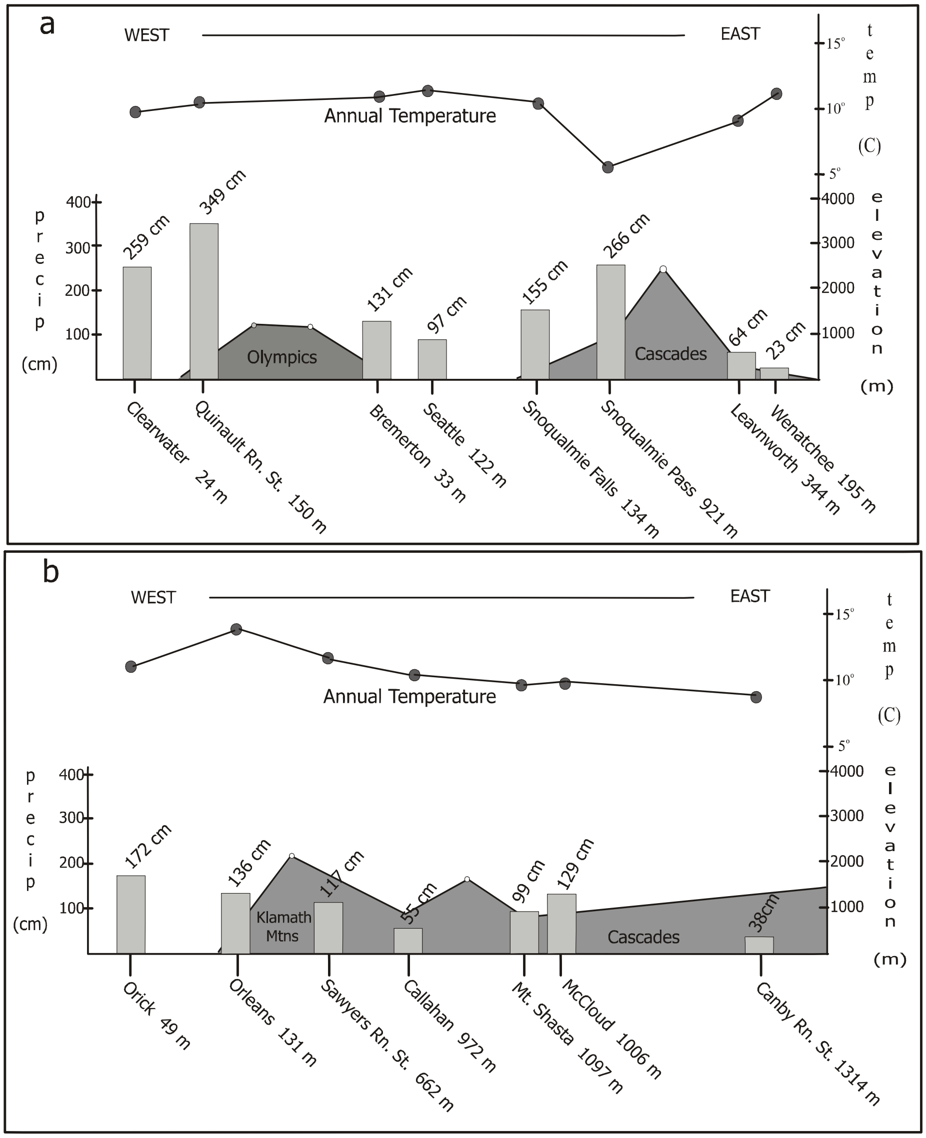


Figure 7.8- Two west-to-east transects across the Coast and Cascade Ranges. Vertical bars show annual precipitation in centimeters. Shading is a rough representation of the topography (m). (a) is through central Washington, and (b) is through northern California.

Since the Cascade Range is oriented north-to-south and due to the fact that the winds predominately blow from west-to-east, there is considerably more variation in temperature and precipitation across the width of the range, than there is over a comparable north-to-south distance. Due to the relatively low height of the Cascades, considerably more moisture is transported to the eastern slopes, when compared to the Sierras for example. In order to understand the west-to-east distribution of snow and rain, two precipitation transects, one from central Washington and other from northern California are displayed in Figure 7.8. In the upper panel notice the pronounced drying to the lee of the Olympics and then a sharp increase in precipitation over the windward slopes (western) of the Cascades. This is followed by a rain shadow on the eastern slopes of the range. In northern California, precipitation reaches a maximum along the coast and western slopes of the Klamath Mountains, with a secondary maximum in the vicinity of Mt. Shasta.

Figure 7.9 displays annual values of precipitation, temperature, and snowfall for selected stations in the Cascades, with some stations along the coast added for comparison. Large-scale precipitation, as was noted earlier, is controlled by latitude (position of storm track), elevation, and distance from coastline. On the local-scale however, the actual amount of precipitation that a station receives is a function of the topography surrounding the site. For example, a station located in a valley will usually receive considerably less precipitation than the higher ground surrounding the valley. It should be point out that most of the climate stations in the Cascades are at relatively low elevations. You should also note from Figure 7.9 that along the coast, there is a definite increase in the number of rainy days from central Oregon northward. The coastal stations of northwest California, for example, typically have only about half (55%) the number of rainy days as stations to the north. However, when it does rain along the coast of southern Oregon and northern California, it has a higher intensity (higher rainfall rate) when compared to coastal stations in Washington and northern Oregon.

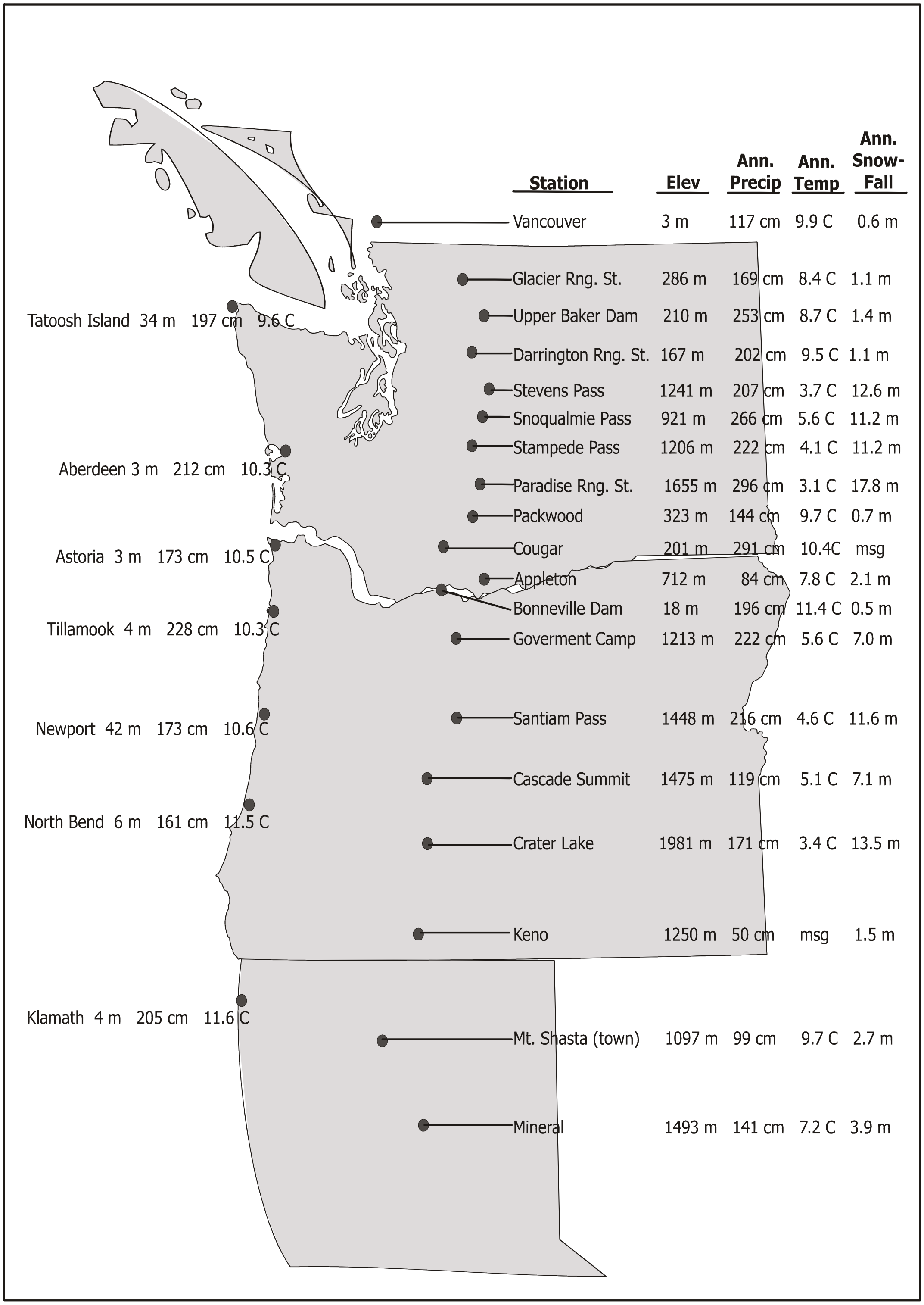


Figure 7.9- Climate data of the Pacific Northwest.

Another useful climate statistic is the number of days in which snow and rain occur over a given region. In Table 7.3 a precipitation frequency chart has been constructed that starts on the Washington coast and runs east through Mt. Rainier National Park (MRNP) to Yakima.

Table 7.3- Number of days with precipitation for west-to-east transect across

central Washington.

STATION NAME	Number of days per year with > 0.2 mm (light)	Number of days per year with > 13 mm (moderate)	Number of days per year with > 25 mm (heavy)	Annual precipitation (cm)
Aberdeen	191	58	23	212
Olympia	164	33	9	129
La Grande	183	21	3	98
Longmire	184	59	22	213
Paradise	194	81	37	296
Ohanapecosh	169	51	21	196
Tieton Dam	113	15	5	68
Yakima	70	2	2	21

Notice the sharp decrease in the number of days with greater than 0.2 millimeters (.01 inch or what we call a "light" precipitation) to the east of the Cascades. What is of real interest is the frequency of days with moderate and heavy precipitation (greater than 25 millimeters). There is a pronounced decrease from the coast into the southern Puget Sound area, with a large increase for stations in the Cascades, followed by the dramatic decrease to the lee of the Cascades. The higher frequency of days with moderate and heavy precipitation in the Cascades can be attributed to two causes: the first is the stalling or blocking of fronts as they pass over the mountains. This produces precipitation events that have a longer duration. Secondly; the higher terrain of the Cascades creates very strong updrafts, which in turn produces areas of significant moisture convergence that subsequently produce heavy precipitation. What is also apparent from last column Table 7.3 is the increase in annual precipitation between southern Puget Sound (La Grande) and the Cascades, this clearly shows how elevated terrain enhances precipitation.

In general the Cascades of northern California receive about half as many rainy days as the Washington Cascades. However, the percentage of days with heavy precipitation is relatively unchanged from north-to-south. Unlike other mountainous regions of the western USA, convective activity in the Cascades is relatively mild. Summer hailstorms and thunderstorms are not much of a concern to backcountry travelers. The reason for the subdued nature of convection in the Cascades is primarily due to the presence of warm stable air in the middle-troposphere.

Mt. Rainier National Park

Since more than 10,000 people per year attempt to reach the summit of Mt. Rainier, not to mention the tens of thousands of hikers and skiers that congregate in the park at various times of year, a detailed look at the weather and climate of this area is presented. Figure 7.10 is a map of the park with distances between key geographic points given in kilometers. There are four locations within the park where year-round climate data is either presently collected or has been in the past. These stations and their elevations are displayed on the first line of Figure 7.10, while annual precipitation (cm) and annual temperature (^oC) are displayed on the lines below.

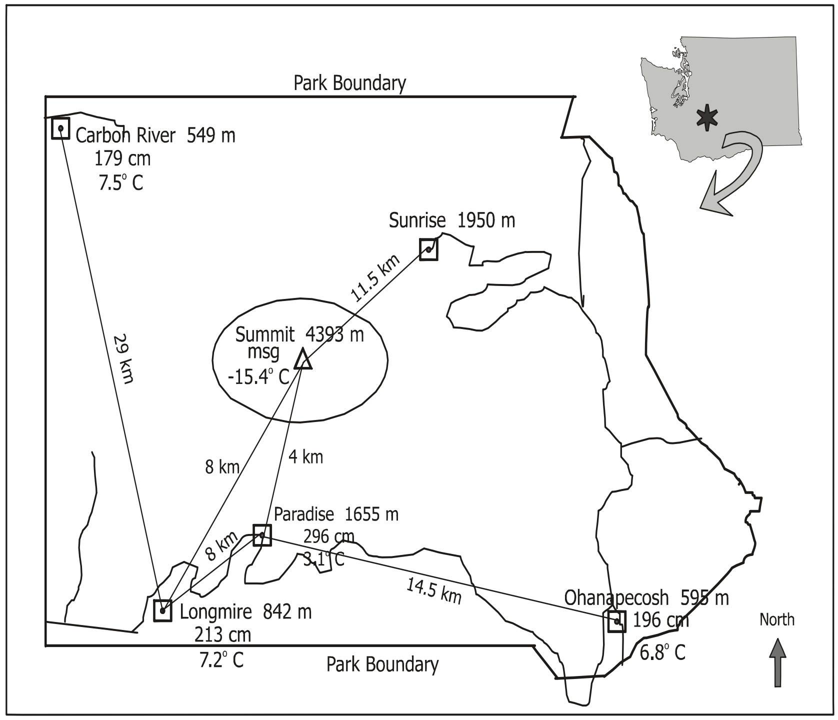


Figure 7.10- Mt. Rainier National Park with elevation (m), annual precipitation (cm) and annual temperature (c) displayed below station name. Dot-dashed lines represent distance (km) between key geographical locations. Dashed lines are roads.

During the period of June 1989 through August 1990, the National Park Service installed a temperature sensor on a small tower which was located near the summit (4393 m or 14,410 ft) of Mt. Rainier. Monthly average temperatures for the 14 months of data that was collected is displayed in Figure 7.11 Keep in mind this is only a rough approximation of the true long-term average. Notice how July through September temperatures are fairly constant. This period is followed by rapid cooling, with the coldest temperatures occurring in the January and February period, followed by a large spring warming trend.

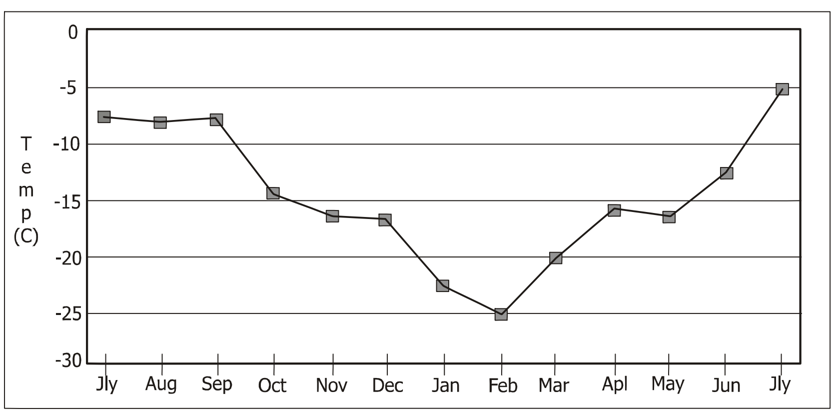


Figure 7.11- Mean monthly summit temperature (C) measure between June 1989 and August 1990.

Examination of the entire temperature record shows that the lowest temperature measured was -37° C (-34° F) which occurred on several occasions in January and February. The highest temperature was +2° C (34° F) which occurred in July. Since temperatures were recorded every 3 hours, it is instructive to analyze the diurnal cycle. The typical diurnal temperature range during the summer is on the order of 5° C (9° F) . The largest change in temperature (±10° C or 18° F) occurs when there is a exchange of air masses over the Pacific Northwest. In order to provide the reader with some idea what temperatures they can expect at various elevations, Figure 7.12 was constructed. If you are planning a summit climb in mid-June for example, you can expect temperatures to range between -1° C to -11° C (12° to 30° F) at the elevation of Camp Muir (3050 m or 10,000 ft), and between -7° C and -16° C (3° to 19° F) on the summit. Note that these ranges do not include extreme values.

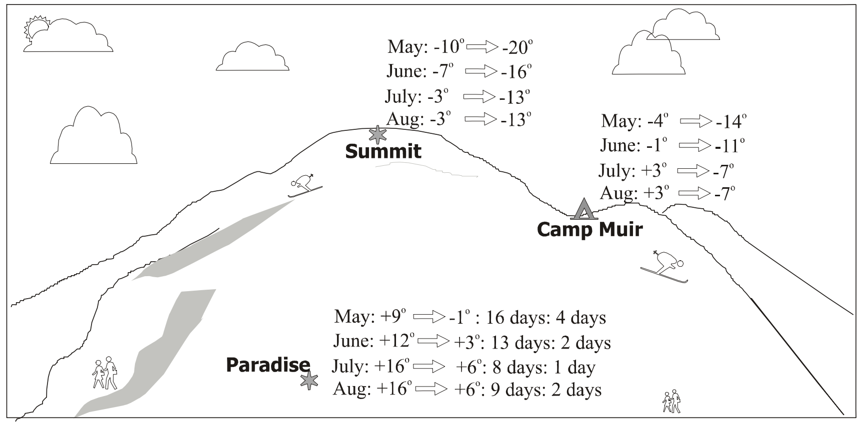


Figure 7.12- Summary of May-August temperature ranges. Paradise data also lists the average number of days per months with at least a trace of precipitation (third value), followed by the number of days per month with heavy precipitation (fourth value).

In Table 7.4 monthly statistics for precipitation, temperature and snowfall for the four climate stations in MRNP are given. Annual values are given on the bottom row. The wettest months are December and January , followed by February and November. There is an approximate 28% increase in annual precipitation at Paradise compared to Longmire. This increase in precipitation occurs over a distance of 8 km (5 mi) and a 800 m (2,600 ft) elevation difference.

Table 7.4- Climate data for Mt. Rainier National Park

	Mean Monthly Precip. (cm)				Mean Monthly Temp. (C)				Mean Monthly Snowfall (m)			
	Carb	Long	Para	Ohn	Carb	Long	Para	Ohn	Carb	Long	Para	Ohn
Jan	21.4	31.9	45.1	33.5	0.0	-1.0	-3.3	-1.0	0.37	1.33	3.31	1.27
Feb	20.3	22.6	34.6	22.7	2.3	1.0	-2.3	1/0	0.26	0.94	2.56	0.73
Mar	18.4	22.5	31.0	17.9	2.4	2.3	-1.7	2.4	0.25	0.84	2.72	0.48
Apr	12.5	13.3	21.5	12.3	6.3	5.3	0.5	5.1	0.05	0.27	1.68	0.11
May	11.0	10.2	12.7	7.4	10.2	9.3	4.2	10.7	0.0	0.03	0.57	0.0
Jun	12.0	9.1	10.2	6.1	12.7	12.6	7.3	Msg	0.0	0.0	0.13	0.0
Jly	5.0	3.5	5.1	2.6	15.1	16.1	11.1	16.8	0.0	0.0	0.0	0.0
Aug	6.2	5.5	6.9	3.9	14.9	15.8	11.4	16.8	0.0	0.0	0.0	0.0
Sep	9.8	10.4	13.1	7.7	12.3	13.2	8.9	11.8	0.0	0.0	0.07	0.0
Oct	17.2	20.0	24.6	17.1	7.7	8.5	4.4	9.3	0.0	0.04	0.73	0.0
Nov	21.4	28.9	44.0	30.5	4.2	3.1	-1.0	2.4	0.03	0.35	2.33	0.26

Dec	24.2	34.8	47.2	34.0	1.9	0.5	-2.8	0.0	0.30	0.98	3.07	1.00
ANN	**179.4**	**212.7**	**296.0**	**195.7**	**7.5**	**7.2**	**3.1**	**6.8**	**1.3**	**4.8**	**17.2**	**3.9**

(Carbon River Ranger Station= Carb; Longmire Ranger Station= Long; Paradise Ranger Station= Para; Ohanapecosh Ranger Station= Ohn, Msg=missing data)

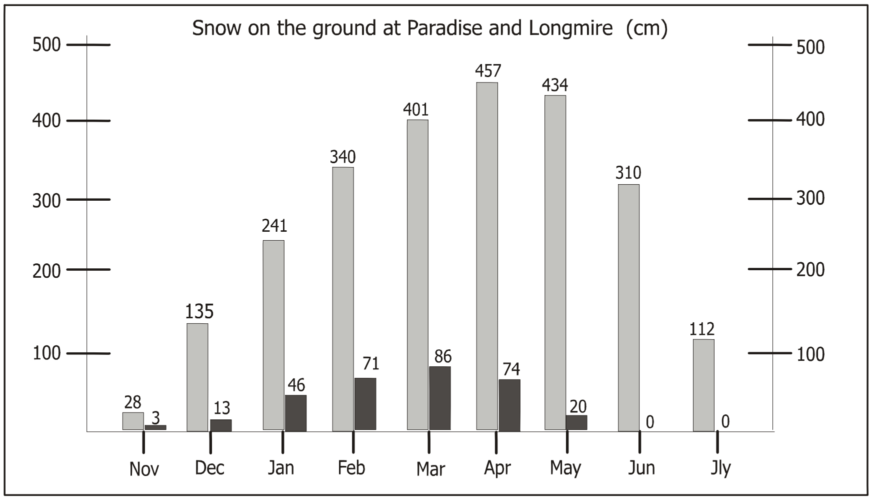


Figure 7.13- Comparison of snow on the ground (cm) at the beginning of selected months for Paradise (light shading) and Longmire (dark shading). Numbers on top of bars are the actual values. This graph is based on 30+ years of data.

The annual precipitation measured at Paradise varies considerably from year-to-year. The long term average is 296 cm (116 in), the wettest year on record was 1975 with 386 cm (152 in) of precipitation, and the driest year was 1969 with 179 cm (70 in). In terms of snowfall, the seasonal mean for September through August, at Paradise is 17.8 m (58 ft) and 4.9 m (16 ft) at Longmire. The biggest snowfall season at Paradise was the winter of 1971-72 when 28.6 m (93 ft) of the white stuff fell. The lowest seasonal total at Paradise was 1976-77 with 10.5 m (34 ft). The single largest observed monthly snowfall was January 1972 when they received 7.1 m (23 ft).

Seasonal snow-on-the-ground at both Paradise and Longmire is shown in Figure 7.13. On average the deepest snowpack at Paradise (4.57 m or 15 ft) occurs during the first two weeks of April. At Longmire the peak is during the first two weeks of March with a typical depth on the order of 0.9 m (35 in). The long-term snow-on-the-ground records indicate that on average, snow disappears from Paradise during mid-August and from Longmire during the second week in May. There can of course be considerable variation from year-to-year.

<u>Olympic National Park</u>

The west side of the Olympic Peninsula in general and Mt. Olympus specifically, is the wettest region in the 48 contiguous states. Unfortunately little meteorological data has been collected at higher elevations within the Park. What climate data that does exists comes from a handful of low elevation sites on the edge of the Park, which are listed in Table 7.5. The wettest area is the southwest and western slopes. Not all of the stations listed in Table 7.5 are still recording data, nevertheless their period of record was long enough to establish climate statistics. The barrier aspect refers to what side of the Olympic Range the station is located on with respect to the storm track.

Notice the dramatic decrease in the number of days with heavy precipitation on the east and north side of the range. Table 7.5 illustrates two apparent precipitation anomalies: the relatively dry area between Port Angeles and Port Townsend, and the relatively wet zone on the east side of the Olympic Mountains centered around Quilcene. The dry area on the northeast corner of the Olympic

Peninsula lies to the lee of the mountains for moist flow from the west and southwest. Northwest flow does bring rain to the area, but flow from the northwest is considerably less frequent and drier then flow from the west and southwest. The relatively wet region on the east side is probably due to the fact that the Olympics lie on the western edge of the Puget Sound Convergence Zone. We will not describe this meteorological feature in any detail, just summarize by saying that it forms when winds flowing around the north and south side of the Olympics, converge over Puget Sound, forming an area of enhanced rising motion and precipitation.

Table 7.5- Climate data for Olympic Peninsula

Station	Elev (m)	Barrier Aspect	Annual Precip (cm)	Number of days with precipitation		Annual Temp. (C)
				>0.2 mm	>25 mm	
Sappho	232	NW	242	146	29	9.4
Forks	107	W	301	212	38	9.8
Spruce	122	W	318	188	41	msg
Quinault Rn. St.	67	SW	349	163	46	10.4
Cushman Dam	232	SE	255	168	35	10.4
Quilcene	37	E	140	162	15	10.1
Port Angeles	30	NE	65	141	3	9.6
Elwha Rn. St.	92	N	142	148	15	9.2

On the west and southwest side of the Olympic Range from November through March, on average about 20-23 days out of the month will have measurable precipitation, with 4-8 of those days receiving in excess of 2.5 cm (1 in) of rain per day. From June through September, measurable rainfall occurs on 4-8 days out of the month, with 0-2 days receiving heavy precipitation.

During the August 1957-July 1958 period, a meteorological station was temporarily established at the base of Mt Olympus. During this period that station recorded 378 cm (149 in) of precipitation (snow and rain). During the same period the stations at Forks and Spruce, which had below normal precipitation, measured 240 cm (94 in) and 296 cm (117 in), respectfully. This would make the area around Mt Olympus the wettest in the region with an estimated annual precipitation on the order of 410-430 cm (160-170 in).

Crater Lake National Park

Crater Lake is unique because it represents one of the highest stations in the Cascades that has a long term record of observations (60+ years). The climate station is located at an elevation of 1981 m (6500 ft) and receives an annual average of 171 cm (67 in) of precipitation. This is considerably less precipitation than what is observed at Paradise on Mt. Rainier, but a larger percentage falls as snow rather than rain. As is true for most of the Cascades, the wettest months are December and January followed by November and February. However, the month that receives the most snow is January with 2.7 m (106 in) followed by December with 2.4 m (94 in). The average annual snowfall is 13.5 m (44 ft), the largest snowfall in a season was 1950-51 with 21.2 m (69 ft). The lowest was 1976-77 with 6.5 m (21 ft). The deepest snowpack occurs in late March and early April with an average depth of about 3 m (9.8 ft). Snow on the ground typically disappears somewhere around the first of July.

Mount's Shasta and Lassen

As noted previously in this chapter, the Cascades of northern California receive considerably less precipitation than the rest of the range. As seen in Figure 7.9, the town of Mt. Shasta located just off of Interstate 5, at the relative low elevation of 1097 m (3,600 ft) receives on the order of 99 cm (39 in) of annual precipitation. There are no long term climate observations higher on Mt. Shasta, however there is a snow course located at 2410 m (7,900 ft) on the west side of the mountain. Long term records from the snow course show that the average snow depth as of April 1 is about 3.23 m (128 in). The same data set also suggest that the annual precipitation at the snow course is on the order of 1.6 m (63 in), a 60% increase over what is measured in the town of Mt. Shasta.

Mt. Lassen which lies approximately 120 km (75 mi) to the southeast of Mt. Shasta is in an area that receives significantly more precipitation than Mt. Shasta This is due to the fact that when storms move into the region from the west to southwest, there is considerably less mountainous terrain upstream of Mt. Lassen. The Lower Lassen Peak snow course, located at 2515 m (8,200 ft) has a long term average April 1 snow depth of 4.44 m (175 in). The amount of water equivalent in the average April 1 snowpack suggests that this site receives about 77% more precipitation than is observed at the nearest climate station at Mineral, some 16 km (10 mi) to the southwest.

Winter snowstorms occur less frequently here than in any other part of the Cascades, nevertheless, when these storms do occur, snowfall can be on the order of a meter (3+ ft). The predominate snow producing pattern is when a 500 mb low or trough is positioned off the coast of Oregon. This produces strong and moist west-to-southwest flow into northern California. However, since the polar jet is frequently well to the north of this region, sunny winter days are common here. Convection during the summer is in turn more substantial here than in the rest of the Cascades due to the drier conditions. Therefore cloud-to-ground lightning is a bigger threat here than in the rest of the range.

Cascade Weather Regimes

As you have already figured out, the weather on any given day for a specific region of the Cascade's depends on many factors. The number one concern, as in any mountainous region, is knowing the location of the polar jet stream. Figure 7.14 shows six of the major weather patterns that control Cascade weather. For example, a cut-off low pressure system is depicted in 7.14a. This type of storm typically produces plenty of precipitation for periods ranging from 2 to 4 days. When the center of the storm is located near Vancouver Island or off the Washington coast, expect heaviest precipitation in the northern half of the range. The Coast Range will of course get hit hard as well with this type of pattern. When the storm center is near the mouth of the Colombia River or the central Oregon coast, the southern half of the range receives the heaviest precipitation.

These storms are far more intense and common from October through April, than at other times of the year. You can expect strong westerly winds at pass level and above. During the cooler months of the year, these storms can also produce fair amounts of rime ice at higher elevations in the Cascades. The exact timing of precipitation depends on considerably on the passage of fronts. Note that with these types of events, precipitation at lower elevations is much less than what occurs at higher elevations. Therefore the amount of precipitation that may be currently falling in Seattle or Portland, is not much of an indicator what is occurring at 1,200 m (4,000 ft) for example. The good news is that these storms are pretty easy to forecast several days in advance. Their longevity however is a bit harder to predict.

The pattern displayed as 7.14b is called a shortwave trough and can occur in winter as well in summer. It is a weaker version of the pattern in 7.14a. The winds are usually not as strong and precipitation is not as great either. When this pattern occurs in summer expect a day, possibly two days of clouds and light precipitation. In a case like this you also need to look at what is occurring at the surface, if there is a fairly well developed surface low off the coast, then you should expect a more powerful storm (more precipitation and wind). If 7.14b occurs with no surface support, then you should expect mid-level and high clouds, with precipitation in the mountains being absent or light.

Figure 7.14c shows a high amplitude ridge (high pressure) over the Cascades. This pattern produces dry relatively cloud free conditions as long as the ridge axis remains to the west of the range. This occurs because the air in this part of the ridge is descending from higher elevations within the troposphere, hence it warms and dries in the process. Once the ridge axis moves to the east however,

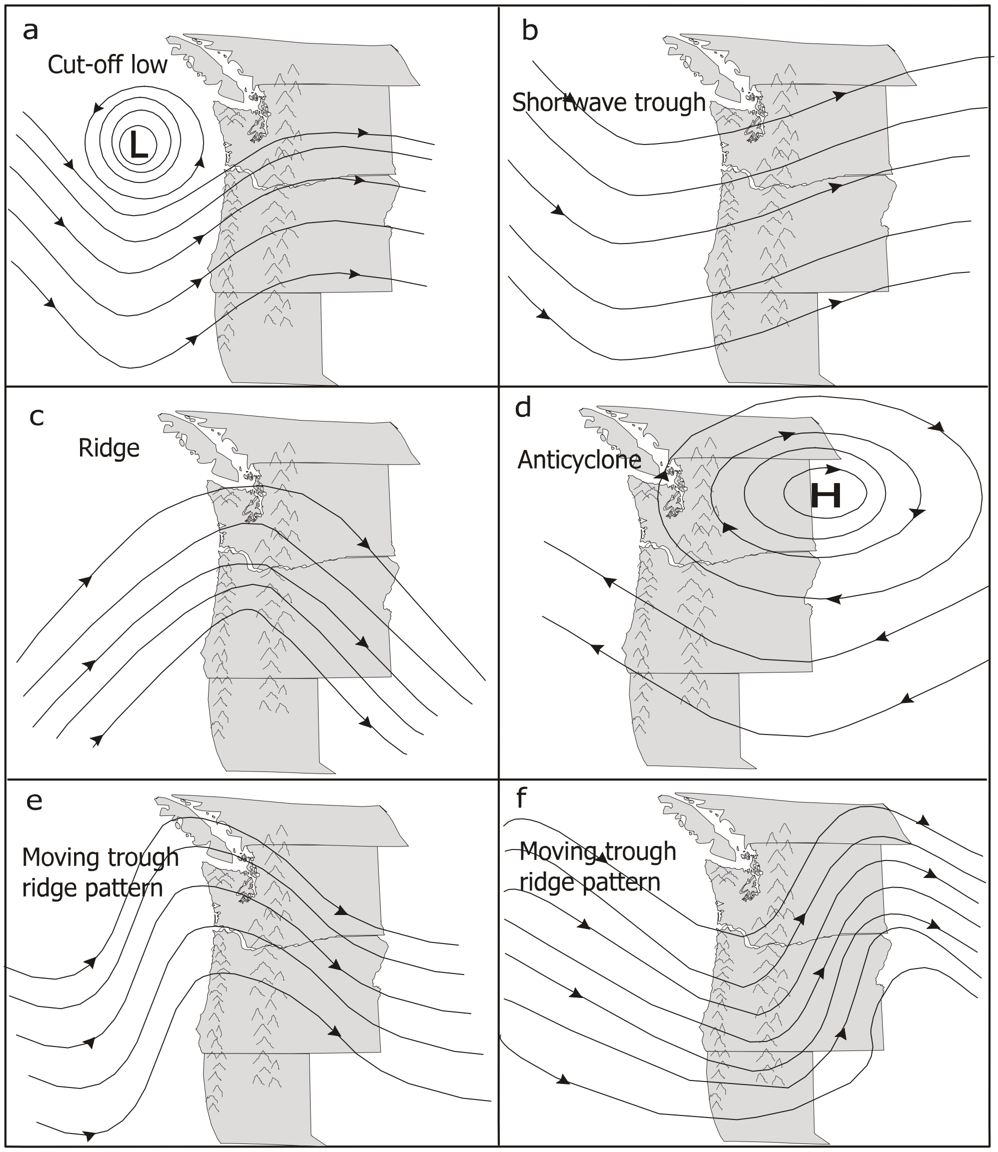


Figure 7.14- 500 mb flow patterns for the Pacific Northwest.

the flow into the Cascades is from the southwest, which in turn may produce rising motion. When this regime occurs during the summer you should expect some very high freezing levels (3500-4500 m or 12,000-15,000 ft). Note however, when the freezing level is mentioned in a weather forecast or discussion, it is for the free atmosphere only. At night, due to the ground emitting large amounts of longwave radiation, the air near the ground at high elevations can actually reach the freezing point. For example, if you are camped at 2130 m (7,000 ft) on an exposed ridge in mid-August, and if the free atmosphere freezing level is 3660 m (12,000 ft), its quite possible that your location could experience freezing temperatures by the early morning hours, due to the aforementioned cooling.

The pattern shown as 7.14d is called an anticyclone. In the winter this regime will produce some of the coldest temperatures of the year in the central and western regions of Washington and Oregon, especially if the anticyclone center is located north of the Canadian border. This pattern will produce moderate to strong easterly winds along the eastern slopes of the Cascades. After several days a pool of cold air often starts to accumulate and deepen in central and eastern Washington and Oregon. When this occurs very strong gap and gorge winds will occur in the western Cascades. On occasions these winds are strong enough to produce considerable property damage. If this pattern or something similar should occur during the summer then you should expect hot and very dry conditions (high fire danger as well), as air flows into the range from the Great Basin.

The flow patterns depicted in 7.14e,f are related. If you happen to look at the forecast models and see a pattern like what is shown, here is what you can expect: 7.14e is of course very much like what we already discussed in 7.14c, with one major difference, notice the trough out to the west. Expect several days of very nice weather as the ridge approaches and is over the Cascades. Increasing clouds and cooler temperatures will occur as the trough approaches (7.14f), the extent of cloud cover and precipitation of course depends on the strength of the trough. This pattern represents are eastward moving traveling wave which are more pronounced in winter than in summer.

The vast majority of precipitation that falls in the Cascades and Coast Ranges occurs in the October through April period. Needless to say, winters in the region are typically cloudy and wet. From the central Oregon area northward, May and June can be considered a ‘transitional’ weather period. What we mean is that the weather during these two months typically alternates from being relatively cloud free and warm, to cool and wet. The cycle roughly last a week or so, and is linked to the north-south migration of the polar jet. The dry season typically starts in early July and extends into late September, and in some years into late October.

Note that during the summer months, weak west-to-southwest flow often leads to the intrusion of marine air (low stratus clouds) into western Washington and western Oregon. This marine layer is a ‘fly in the ointment’ to hikers and climbers. The eastern extent of these clouds can vary considerably. The good news is that the top of the cloud layer is frequently located between 1500 m and 2100 m (5,000-7,000 ft). One of the best marine layer forecasting rules of thumb is to look at the pressure difference between North Bend (Oregon) and Seattle. When the geostrophic flow is from the southwest and the pressure at North Bend is 4 mb or more than at Seattle, marine stratus clouds will usually form. Also note that you should use visible satellite imagery instead of infrared when you want to look for low stratus and fog. This is the case because infrared images tend to ‘emphasize’ higher clouds rather than low clouds.

Cascade Weather Summary

* Wet Season: October through April
  Transition season: May and June
  Dry season: July through September
* Large snowfall accumulation above 1500 m (5000 ft)
* A significant decrease in frequency of rainy days from north-to-south
* Decrease in annual precipitation from north-to-south (not necessarily true for coastal stations)
* Storms move into region from northwest-to-southwest
* Summertime convective activity is limited, but more frequent in the southern part of the range.
* Gorge winds: Columbia Gorge, Snoqualmie Pass, Fraser Gap, Howe Sound
* Barrier jets: Coast Range, western slopes of Olympic Mountains

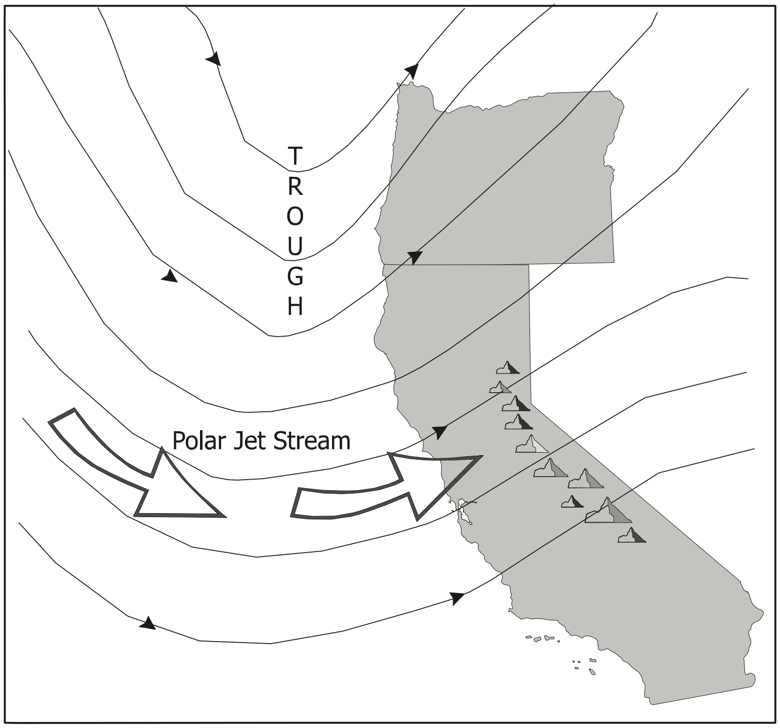


Figure 7.15- Typical 500 mb flow pattern for a major wintertime precipitation event in the Sierras.

* Glacier winds: very localized around glaciated mountains
* Downslope windstorms: more frequent on east side but occasionally occur on the west side during the cooler months of the year, when the geostrophic winds blow across the Cascades from east-to-west.

WEB- National Weather Service
Seattle
www.wrh.noaa.gov/seattle
Portland
www.wrh.noaa.gov/portland
Medford
www.wrh.noaa.gov/medford
Sacramento
www.wrh.noaa.gov/sacramento
Northwest Avalanche Center-
www.nwac.noaa.gov

Sierra Nevada

The Sierras begin south of Mt. Lassen and stretch some 600 km (375 mi) further to the south, terminating northeast of Bakersfield. The Sierras differ from the Cascades in a number of ways: the Sierras are primarily fault block mountains formed by the differential lifting/sinking of the earth's crust. As a result the Sierras form a continuous elevated barrier, especially the region from Yosemite to Sequoia National Park. This section of the Sierra crest, often referred to as the High Sierra, has an average height of 3500-4000 m (11,400-13,100 ft).

The predominate storm track for heavy precipitation events in the Sierras is depicted in Figure 7.15. This type of flow pattern forms when either a trough or low forms off of the coast of Oregon or even Washington. This produces strong southwesterly winds at virtually all levels within the troposphere over the Sierras, as the axis of the polar jet stream becomes positioned directly over central California. Since most of the Coast Range along the central California coast is not very high (less than 1000 m or 3,280 ft), considerable amounts of Pacific moisture is transported the 250 km (155 mi) into the Sierras. Heggli and Rauber (1988) note that powerful storms as shown in Figure 7.15 are responsible for the majority of floods which occur in the Sacremento and San Joaquin valleys. It should be pointed out that precipitation in the Sierras tends to be much more episodic in nature than precipitation in the Cascades. What do we mean by episodic precipitation? Basically there are fewer days with precipitation in the Sierras compared to the Cascades, however when precipitation does occur, it is usually of high intensity. For example, the average number of days with a trace or more of precipitation in the western Sierras is on the order of 75 days, less than half of the number of days that occur in the northern Cascades. What this should mean to you, the backcountry traveler, is that when a synoptic-scale storm moves into the Sierras, rainfall or snowfall totals can be quite impressive.

Climate statistics for select stations in the Sierras are displayed in Figure 7.16. Keep in mind that these climate stations are located at mid-elevations (between 1000-2000 m or 3,300 and 6,600 ft), so they may not be representative of higher elevations. What is readily apparent from this figure is the increase in precipitation in the Sierras relative to stations in the San Joaquin and Sacremento valleys. The amount of annual precipitation that a specific station receives, is of course, a function of the height of the terrain that is upstream of the station, as well as the height of the climate station itself. Notice for example that Blue Canyon along Interstate 80 receives double the annual precipitation as any of the stations in the vicinity of Lake Tahoe. This holds true because by the time parcels of air reach Lake Tahoe, much of the moisture has already been depleted over the western slopes of the Sierras.

In Figure 7.16 also notice how dry it is directly in the lee of the Sierras, as represented by Lee Vining (38 cm or 15 in) and Bishop (14 cm or 5.5 in). By comparison, the climate station at 3800 m (12,400 ft) in the White Mountains, to the east of Bishop, has an annual precipitation of 48 cm (19 in), more than three times the Bishop average. This shows that more moisture is flowing over the lee of the Sierras at crest level than one would expect by simply using the precipitation data from low elevation sites at the base of the eastern Sierras.

The distribution of annual precipitation in the Sierras can be summarized as follows: there is a pronounced winter wet season in the Sierras, and in the state of California in general. On the order of 75-80% of the annual precipitation falls from the first of November through the end of March. January is the wettest month without question. What is evident from the climate record is that there is a noticeable increase in the percentage of precipitation that is observed in the second half of winter, between the northern and southern Sierras. In other words, in the southern Sierras (south of Yosemite), more snow occurs during the months of February and March, than in November and December. The opposite is true in the northern Sierras.

In Table 7.6 we have listed average snow depths for a number of snow courses scattered throughout the Sierras. These sites are generally at higher elevations than the climate stations, and a number of them are in remote locations. The data is collected by different agencies that have some interest in snowmelt runoff, so the lengths of the records vary. Nevertheless this information provides the backcountry skier with some guide to what kind of snowdepths to expect in an <u>average year</u>.

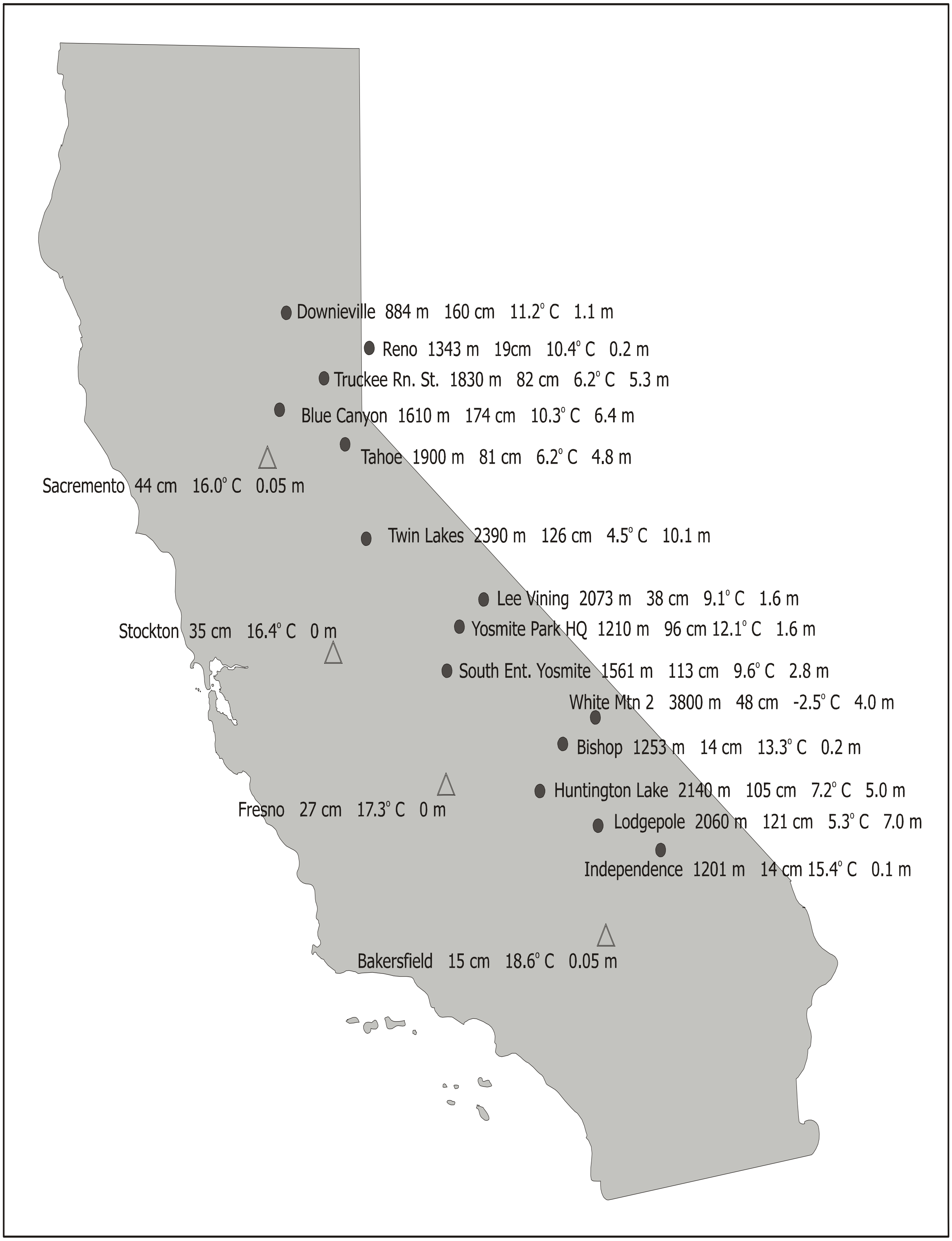
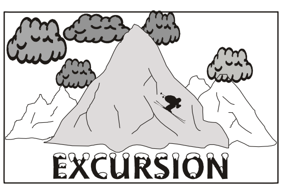


Figure 7.16- Climate data for the Sierra Nevada. Order of the data is: station name, elevation (m), annual precipitation (cm), annual temperature (C), annual snowfall (m). Note valley data for comparison.

Table 7.6- Sierra snowcourses and snowdepth

STATION	BASIN	elev (m)	FEB.	MAR.	APRIL	MAY
Upper Carson Pass	American	2590	155	201	208	147
Lake Lucille	Lake Tahoe	2500	---	358	378	---
Rubicon Peak 2	Lake Tahoe	2290	---	203	198	137
Ward Creek 3	Lake Tahoe	2060	165	211	234	188
Highland Meadow	Mokelumne	2682	201	267	287	256
Deadman Creek	Stanislaus	2820	---	---	221	196
Dana Meadows	Tuolumne	2990	155	198	218	150
Tioga Pass	Mono Lake	2990	142	162	193	---
Gem Pass	Mono Lake	3277	147	196	233	---
Mammoth Pass	Owens	2900	196	256	287	269
Bishop Lake	Owens	3445	104	147	173	155
Snow Flat	Merced	2650	191	246	264	229
Mono Pass	San Joaquin	3490	135	188	218	---
Bishop Pass	Kings	3415	150	216	234	218
Bighorn Plateau	Kern	3460	99	142	163	140



Sierra Corn Snow

The higher elevations of the Sierras are well known for their spring and early summer skiing. Corn snow is responsible for this worthy distinction. Corn snow is the name given to a type of large well-rounded snow particle that forms when the surface of the snow is subject to a consistent diurnal melt-freeze cycle. During the day, the direct solar radiation incident on the surface of the snow, as well as increasing daytime temperatures, produce a net positive energy balance within the upper layers of the snowpack that in turn produces ever increasing amounts of melt water. As snow particles near the surface melt, the water slowly percolates through the pore space of adjacent particles and into the layers below. In this water rich environment, larger snow particles tend to grow larger while smaller snow particles melt. By late afternoon, the upper layer of the snowpack is drained of most of its melt water. The water that does remain acts to bond the individual snow particles via surface tension. As the energy budget becomes negative (at night), the water-snow particle matrix freezes. In time (over a number of days) relatively large clusters of rounded snow particles form in the upper layers of the snowpack, these particles are what we call corn snow. Corn snow has a rounded shape because a sphere has the least surface area for any given volume of matter.

These rounded snow particles provide some very good skiing conditions. By the afternoon however, as melt water is produced within the snowpack, the upper layers of the snowpack become nearly saturated, and the snow becomes mushy and the skiing is over for the day. This also means that the avalanche danger increases throughout the day.

Why are the Sierras a great place for the development of corn snow? The Sierras have good corn snow development because of sunny days and cold clear nights which frequently occur at higher elevations in the spring and early summer. Sunny days provides abundant melt water for the ice-water mixture, and clear nights allows the longwave radiation given off by the upper layers of the snowpack to be admitted to space, driving the melt-freeze cycle.

The Sierras are a mountain range that does experience considerable amounts of summer convective activity. Backpackers and climbers should note that heavy rain, hail, and cloud-to-ground lightning are all common in the afternoon and early evening, from late June through early September. The area of greatest thunderstorm activity lies from the central part of the range to the crest of the Sierras. The reason that thunderstorms are much more frequent and vigorous in the Sierras than in the northern half of the Cascades is a result of a combination of factors. First, the middle and upper troposphere over the Sierras is a little drier, and secondly, there is considerably more elevated terrain in the Sierras's that acts as an elevated heat source once the ground becomes free of snow.

Sierra Nevada Weather Summary

* Wet season: November through March.
* Storm track is from the west or southwest at which time the polar jet will be located directly over central California.
* Summer convective activity (hail and lightning) is substantial, especially near the crest of the Sierra.
* Precipitation is infrequent compared to the Cascades or Coast Range, however, when it does occur, rainfall or snowfall are substantial.
* Barrier jets: well developed during winter when geostrophic flow is from west or southwest.
* Downslope windstorms: Common during winter east of Sierra crest. These events can produce very strong winds in the Owens Valley.

WEB: National Weather Service

Sacramento **www.wrh.noaa.gov/sacramento**

Hartford **www.wrh.noaa.gov/hartford**

Reno **www.wrh.noaa.gov/reno**

California Snow Cooperative

www.cdec.water.ca.gov/snow