9

REGIONAL WEATHER SURVEY, PART III
Himalaya, Karakoram, Andes, and Alps

Chapter Highlights:

- ✓ Season-by-season description of weather in the Himalaya and Karakorum
- ✓ The Monsoon revealed.
- ✓ Weather and Climate south of the border- The Andes
- ✓ Mountain Meteorology, where it all started- The Alps

In this chapter we will explore the weather and climate of the worlds highest mountains. The primary hindrance to such an endeavor is the fact that there is not very much weather data from these regions; past or present. Despite these limitations you will find this overview helpful in not only understanding the weather and climate of these regions, but in planning trips as well.

Himalaya and Karakoram

The Himalaya ('abode of snow') and the Karakoram ('black gravel') mountain ranges are adjacent to each other, frequently however the weather is radically different from one range to the other. On the large-scale (synoptic) the primary control on weather in these mountains are latitude and distance from the Indian Ocean. On the local-scale, weather is controlled by elevation and the height of the surrounding terrain. The most important topographic feature in all of Asia is the Tibetan Plateau. Without this enormous high elevation land mass, the weather and climate of Indian Subcontinent, Central Asia, and even Southeast Asia would be radically different than it currently is.

The Himalaya stretch from northern Burma (Myammar) and Arunachal Pardesh, across the northern fringes of the Indian plain, finally terminating in northeast Pakistan (Figure 9.1). This arc of mountains is about 2400 km (1,500 mi) in length and forms the southern edge of the Tibetan Plateau. The Karakoram lie in northern Pakistan, and form a transition zone between the Indian Subcontinent to the south and Central Asia to the north. Along with the Pamir Mountains which lies due north, the Karakoram form the western edge of the Tibetan Plateau.

The 'dividing line' that separates the Karakoram from the Himalaya is quite nebulous. The general consensus is that the mountains which lie to the south of the Indus River are in the Himalaya, while those located to the north of the river are in the Karakoram. This makes Nanga Parbat (8120 m or 26,620 ft) which lies about 15 km (9 mi) south of the Indus River a part of the Himalaya, while the mountains 100-200 km (60-120 mi) due east are considered part of the Karakoram.

Both of these ranges are of course further divided into smaller sub-ranges. The Himalaya for example, are often broken down into five ranges based on height and proximity to the Indian Plain. We won't be using this classification very much, nevertheless you should be aware that it exists. Note that the Karakoram lie further north (34-38°) than the eastern Himalaya (27°). K2 for example lies about 8° of latitude further north than Mt. Everest, with a straight-line distance of 1300 km (800 mi) separating the two mountains. In addition, the eastern Himalaya lie within 700 km (430 mi) of the Bay of Bengal, which means that they are considerably closer to a large source of moisture than the Karakoram. This results in the eastern Himalaya being considerably wetter than the Karakoram. It is an interesting fact however, that the glaciers in the Karakoram and extreme northern Himalaya, are much bigger than anything found in the eastern Himalaya. Obviously temperatures play as major a role in glacier meteorology as does snowfall.

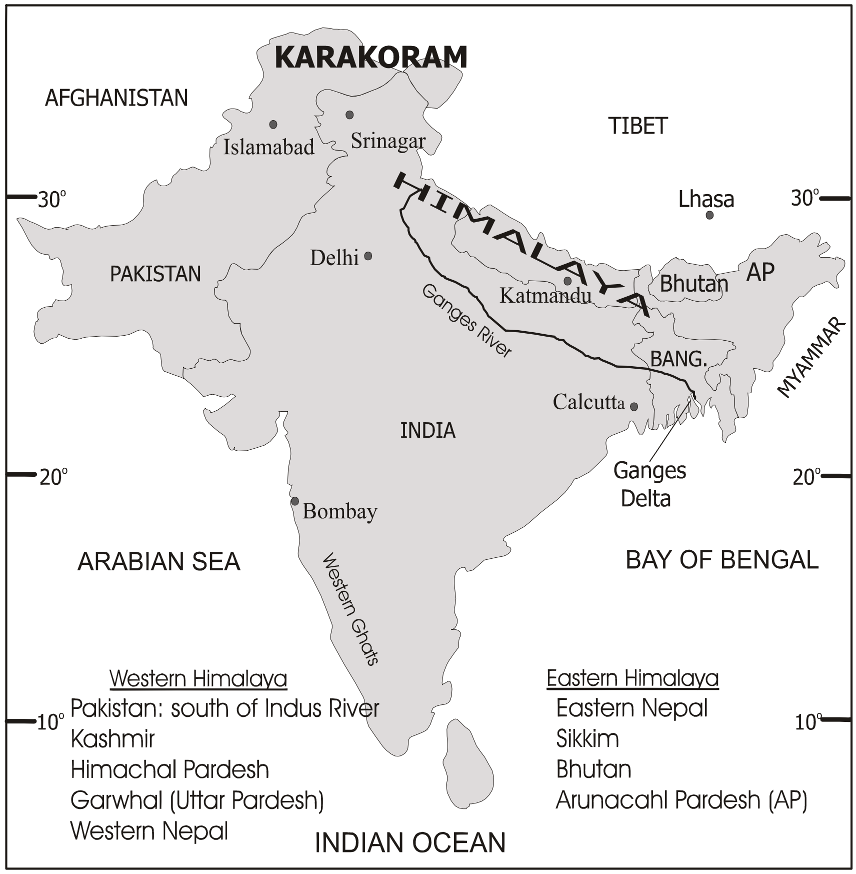
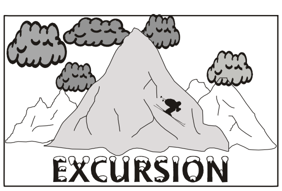


Figure 9.1- Geography of the Indian Subcontinent.

The weather over the entire Indian Subcontinent, of which the Himalaya and Karakoram form the northern border, can be broken down into two basic regimes: the winter and summer monsoons. During the winter monsoon the low-level winds are out of the north, while in summer they are out of the south-to-southwest. Travelers from outside the region know that the "best time" to trek or climb in this part of the world is May or October, and they vaguely know that it has something to do with the summer monsoon. In this chapter the discussion will focus on: how the summer monsoon works, precipitation patterns across the region, location of the predominate storm tracks, and why May and October are the optimum months to travel in the Himalaya, and why summer is the best time to travel in the Karakoram.



Monsoons

The term 'monsoon' is derived from an Arabic word which means- season. In the 10th-13th centuries, Arab traders and merchants sailed up and down the east coast of Africa and around the Arabian Peninsula. They quickly learned that the winds in the western Indian Ocean tend to blow predominately from one direction for about six months, after which they would reverse direction for the remaining six months. They termed this seasonal shift in winds as the 'monsoon'. The importance was that if you wanted to sail to India and conduct business, you had to do it during the southwest monsoon (summer). When it came time to return to Africa you had to wait for the northeast monsoon (winter).

During the 19th century, as the science of meteorology began to emerge, a number of meteorologists in India noticed the connection between the monsoon winds and precipitation. Since those early days, considerable research has been aimed at not only gaining a better understanding of how the monsoon works, but being able to predict the amount of rain it produces as well. There are other regions of the world that experience monsoonal weather, chiefly Southeast Asia. As noted in Chapter 8, Arizona, New Mexico, and Colorado experience a weak (in comparison to India) monsoon during the second-half of the summer as well.

Winter

During the winter months high pressure forms over Siberia due to that region's extreme continentality and high latitude. With high pressure over Siberia and low pressure over the Indian Ocean, low-level air (0-3 km above ground level) tends to flow from north-to-south over Central Asia and the Indian Subcontinent. In the middle and upper troposphere the winds blow out of the west, as both the polar and sub-tropical jet streams are very strong. There are times when both of these jets merge over Central Asia, and there are other times when they are distinct. In this part of the world the sub-tropical jet (STJ) is typically found between 20-35°N, that is it lies over the southern edge of the Tibetan Plateau, never far from the Himalaya. During the winter months the 4500 m (14,700 ft) high Tibetan Plateau is extremely cold; in fact due to longwave radiational cooling, it is considerably colder than the air in the free atmosphere at the same elevation. This cold source creates a large temperature contrast (gradient) between the air over Tibet and the air over the Indian Ocean. This helps intensify the STJ during the winter. The core of strongest winds in the STJ is typically around 200 mb (12 km winter and 13.5 km summer), in which the average wind speed is about 35-40 m/s (75-90 mph), however winds in excess of 80 m/s (175 mph) are not uncommon (Figure 9.2). Below the jet core, wind speeds decrease considerably. At an elevation of 8-9 km (5-5.6 mi), the average free atmospheric wind speed is roughly 50% of that found in the jet core. This means that if your climbing at 7000 m (23,000 ft) in the Himalaya and a 60 m/s (130 mph) STJ lies over head, you should expect wind speeds (ignoring topographic affects) on the order of 25-30 m/s (55-60 mph).

The polar jet stream almost always remains north of 30-35° N, so it generally only affects the western Himalaya, however it does have a significant impact on the weather in the Karakoram, Pamirs, and Tien Shan ranges. Troughs and lows that developed along the polar jet transport moisture into this region from the Mediterranean and Arabian Seas. These disturbances often produce light to moderate widespread precipitation across the Karakoram and western Himalaya, but generally have little influence over the eastern Himalaya. As these disturbances move through the region they typically produce cooler temperatures aloft, as cold air from Iran and Afghanistan is transported southeastward. Troughs and lows also form along the sub-tropical jet stream. These disturbances produce widespread snow in both the western and eastern Himalaya.

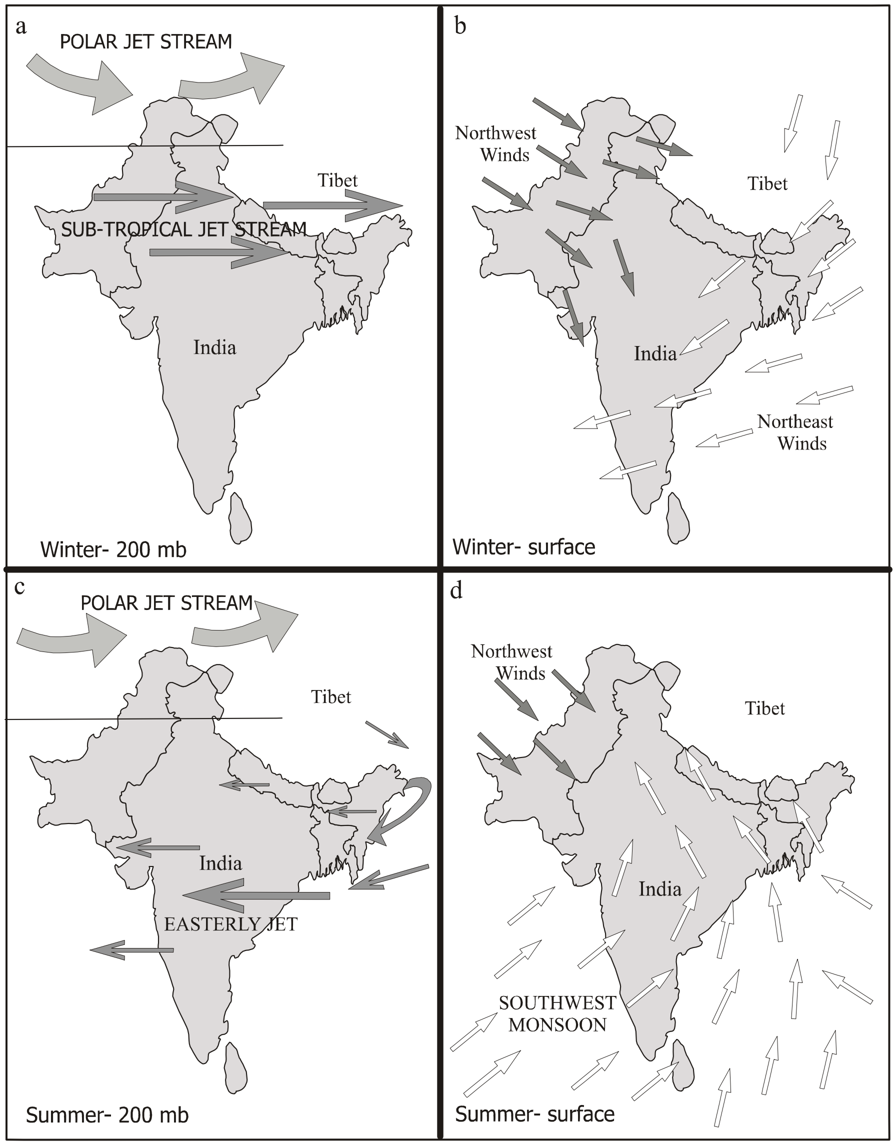


Figure 9.2- Winter and summer wind flow patterns over the Indian Subcontinent, at 200 mb and the surface.

Climbing and trekking is not out of the question during early winter in the eastern Himalaya. The primary factors to consider are cold temperatures and strong winds at higher elevations. The amount of snow that falls varies considerably from year-to-year. In years with large amounts of winter snow, many of the higher passes will be closed due to a deep snowpack. Climbing in the Indian Himalaya and Karakoram is pretty much a non-option in the winter due to moderate to heavy snow in the mid-elevation ranges as well as very cold temperatures. Trekking at lower elevations in the Karakoram is an option, however you should be prepared for cool temperatures, and considerable amounts of snow above 3500 m (11,500 ft).

Spring

Starting sometime in late March, in response to the increase in solar radiation and the subsequent development of low pressure over the Bay of Bengal, there is a dramatic increase in precipitation over the eastern Himalaya. This increase in precipitation is only a precursor to the heavy rains that accompany the summer monsoon. In addition, convective activity and thunderstorm frequency over the northern Indian plain increases between March and May. Several studies have shown that frequency of thunderstorms is at its highest when the STJ lies directly over the plains of northern India.

One aspect of the March and April weather that climbers in particular should note, and as seen in Figure 9.3, is that the STJ tends to weaken considerably during these months. This means that there will be days when the winds at higher elevations will be light-to-moderate, followed by days when the winds re-intensify. It is important not to remember that just because the upper-level winds have been light for several days, does not mean that they might not strengthen as a jet streak moves over the region. The data used to construct Figure 9.3 is from the Lhasa upper air data set. It is the closest long-term record available near the eastern Himalaya. Each data point is a weekly average, which means that the wind speeds experienced by climbers on any given day can be considerably higher or lower. The most obvious information that this figure conveys is the seasonal trend and the fact that wind speeds increase considerably with increasing elevation.

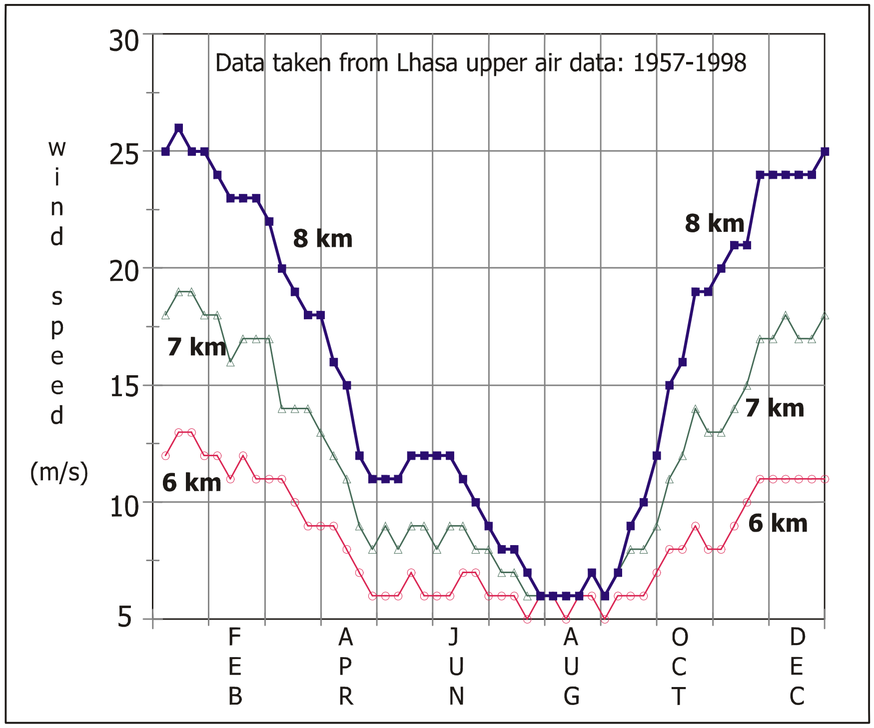


Figure 9.3- Weekly-averaged wind speeds for eastern Himalaya.

By the end of April or early May, as a direct result of the weakening of the Hadley Cell circulation system, the STJ virtually disappears for the summer. This marks the beginning of the pre-monsoon season in the Himalaya. In Table 9.1 May wind speeds observed at the 8 km (26,200 ft) level, are sub-divided into speed classes (taken from Lhasa upper air data). Climbers take note that speeds greater than or equal to 15 m/s (33 mph) have a frequency of occurrence of about 22%.

Table 9.1 Frequency of wind speeds during the month of May in the eastern Himalaya at 8 km.

speed (ms^{-1})	Frequency (%)
0-5	8.6
6-10	30.9
11-15	38.4
16-20	16.5
21-25	4.6
>25	1.0

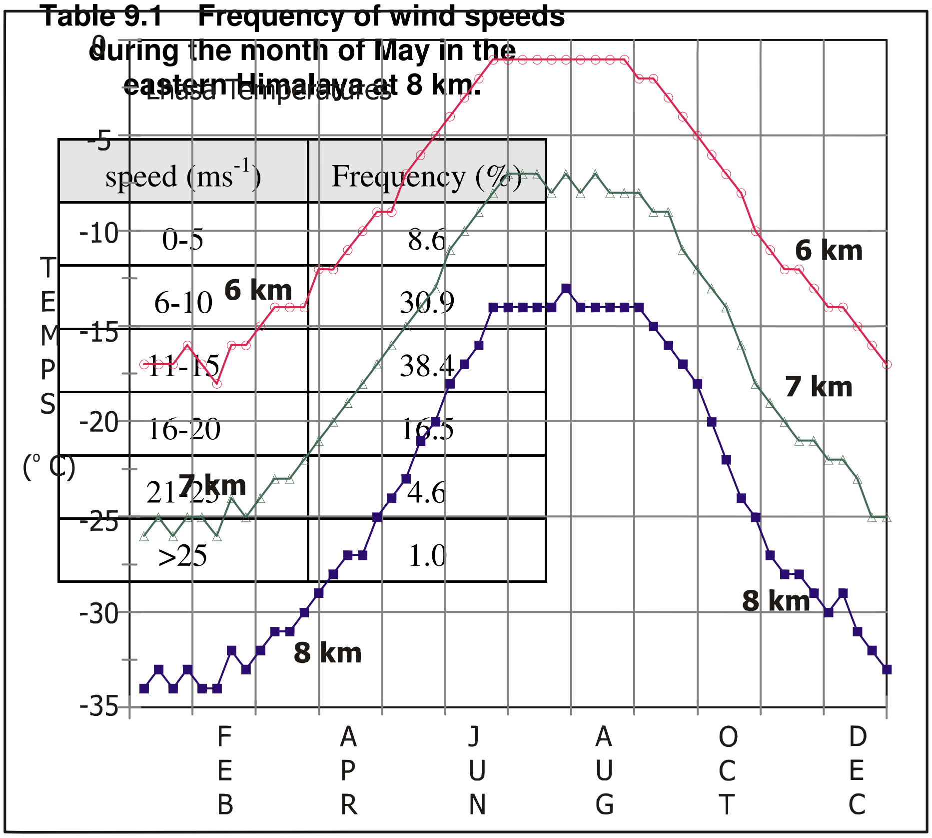


Figure 9.4- Weekly-average air temperatures over the eastern Himalaya.

The pre-monsoon season is more of a transition period between a relatively dry winter and a very wet summer. This means there can be a string of cloud free days, followed by several days that are mostly cloud with precipitation a possibility. By way of example, one of the authors and his wife spent 10 days in mid-May one year, hiking in the Garhwal Himalaya of northern India (the very northern part of the state of Uttar Pardesh). We experienced several days of rainy weather, followed by 3 or 4 days with clear blue skies, which was subsequently followed by another period of cooler rainy weather. These storms were more than afternoon thunderstorms, they were disturbances in the upper level westerlies that had a considerable amount of embedded convection.

By April temperatures over the Himalaya start to warm-up dramatically. By mid-May the freezing level in the free atmosphere over the eastern Himalaya can rise to 4000-5000 m (13,100-16,400 ft) at times (Figure 9.4). May is considered the hottest month in the northern Subcontinent because of the increase in surface heating as the sun moves higher in the sky, and because compared to June-September, cloud cover is limited. This period corresponds to significant snow melt in the Himalaya, which causes the rivers and streams to rise substantially. In addition, the increase in shortwave radiation and warmer temperatures causes an increase in the number of avalanches. During the late spring, a considerable amount of dust and dirt is carried into the lower troposphere as a result of increased surface winds. These winds are produced by strong up-drafts and down-drafts that develop as a result of vigorous convection. As a consequence, the air quality and visibility over much of the Himalaya in late spring is not as good as at other times of the year.

Springtime weather in the Karakoram is not that much different than winter weather, the main difference being the gradual increase in air temperatures. By the middle of May, air temperatures in the 2500-4000 m (8,200-13,100 ft) elevation range are ideal for trekking. Unfortunately there are very few precipitation gages in the Karakoram, so it is hard to get a clear picture of the amount of precipitation that occurs during this time period. However, the number of synoptic-scale storms moving through the region decreases dramatically in May.

Summer

By late May the Tibetan Plateau and northern Indian plain heat-up to such a large extent that low pressure forms over the region. This in turn results in the northward shift of the thermal equator (region of warmest temperatures), which causes winds over the central and northern Indian Ocean to blow from the south. These winds are in essence very large-scale thermally generated winds that result in large part from the temperature contrast between the Indian Ocean and the Asian continent. When the low-level winds become southerlies and the sub-tropical jet stream disappears, the stage is set for the development of the summer monsoon. This also marks the end of the spring/early summer Himalayan climbing season. Rain produced by the summer monsoon is responsible for about 80% of the Indian Subcontinent's annual precipitation. The areas that receive the largest amounts of rain are the windward slopes of the Western Ghats (mountains located in southwest India) and the area around the Ganges Delta, including the eastern Himalaya and the hills of Assam.

During the summer monsoon surface winds over southern India are predominantly from the southwest, while the winds over central and northern India tend to be from the south or southeast (Figure 9.2). The bulk of the moisture carried inland from the Indian Ocean is found in the surface layer, which is about 1.0-1.5 km (0.5-1.0 mi) deep. Once the sub-tropical jet disappears in May, it is replaced in the upper troposphere by a large area of high pressure, called an anticyclone. This anticyclone produces easterly winds which extend from just above the monsoon layer into the lower stratosphere. A easterly wind 'jet' does form over central India (15^{o} N), but overall it has little influence on the Himalaya. In fact, over the Tibetan Plateau and the Himalaya, mid-tropospheric wind speeds are typically less than 10 m/s (22 mph), as seen in Figure 9.3.

It is important to understand that the start of the monsoon rains <u>do not</u> occur at the same time all over India. In a normal year heavy rain begins sometime around the first week of June in both the Western Ghats and in the Ganges Delta, eastern Nepal, Sikkim, and Bhutan. Over the next 3 to 4 weeks the leading edge of the monsoon rain slowly works its way up the Ganges River from the Bay of Bengal. As a result, monsoonal rains do not begin in the western Himalaya until late June.

There is considerable day-to-day variation in the amount of rain received across northern India and the Himalaya during the monsoon season. Periods of very heavy rain are generated by troughs that travel with the easterly jet, which have a tendency to move from the Bay of Bengal up the Ganges River, similar to what happens at the onset of the summer monsoon. Sometimes these troughs recurve back toward the northeast as they encounter the polar jet stream. There are some years when the summer monsoon never fully develops, rainfall is greatly reduced and a large part of the Indian Subcontinent experiences a drought.

The region of the Himalaya that receives the heaviest rains stretches from central Nepal eastward across Bhutan into Arunachal Pardesh. The number of sites where precipitation is collected is pretty sparse in this part of the world, however the Terai (jungle) and foothills of Himalaya receive the bulk of the precipitation. Within the higher peaks the distribution of precipitation is complex, as illustrated by the work of Higuchi *et al* (1982) in the Khumbu Himal of eastern Nepal. Along a transect up the Dudh Kosi River valley, June-October accumulated precipitation decreased with elevation (spanning a elevation range of 2800-4500 m). <u>On the mountains surrounding the Dudh Kosi River valley</u> however*,* precipitation was observed to be 4 to 5 times larger than what fell <u>in</u> the valley. On the ridges and summits, the heaviest precipitation occurred during the day, probably as a result of strong upslope and valley winds. In the valley itself, precipitation was most frequently observed between 6 pm and midnight, in response to convergent mountain and drainage winds.

As a rule of thumb, the further north one travels within the Himalaya during the summer monsoon, that is the closer you are to Tibet, the drier the conditions. For example, on the north side of the Annapurna Range, summer precipitation is a fraction of what falls in the vicinity of Pokhara to the south. If you are planning to trek during the summer monsoon, count on very wet conditions, this includes high water in rivers and streams, muddy trails, and mudslides to name a few. The good news about travel during this time of year is that the winds are for the most part very light. Typically the winds at the 500 mb level (5500 m) over the eastern Himalaya are from the east at 5-10 m/s (10-20 mph). Even at 300 mb (9500 m) the winds are not much stronger. In Himachal Pardesh and Kashmir the upper level winds are from the west and tend to be considerably stronger than what occurs over the eastern Himalaya. Freezing levels (free atmosphere) during the summer are typically around the 5000 m (16,200 ft) level. Above this elevation you should expect considerable quantities of fresh snow.

Since monsoon rains move northwest from the Bay of Bengal up the Ganges River, a legitimate question to ask is: how far north do they usually extend? Unfortunately it is not possible to draw a line of a map and say with any certainty that the monsoon rains stop here. In general, Kashmir is considered the northern most extent of the monsoon, however there is considerable variation from year to year. In some years abnormally large amounts of summer precipitation occur in the Karakoram and throughout central Pakistan. For example, one of the authors spent a significant amount of the summer of 1986 hiking around in the Karakoram, and overall it was abnormally cloudy and wet. Typically there were three or four days of rainy weather (at lower elevations) followed by the same number of days of clear or partly cloudy skies. Was the higher than normal amount of clouds and precipitation due to the monsoon? Most likely it was. This was also the summer when there were a large number of deaths on K2 (see Chapter 1).

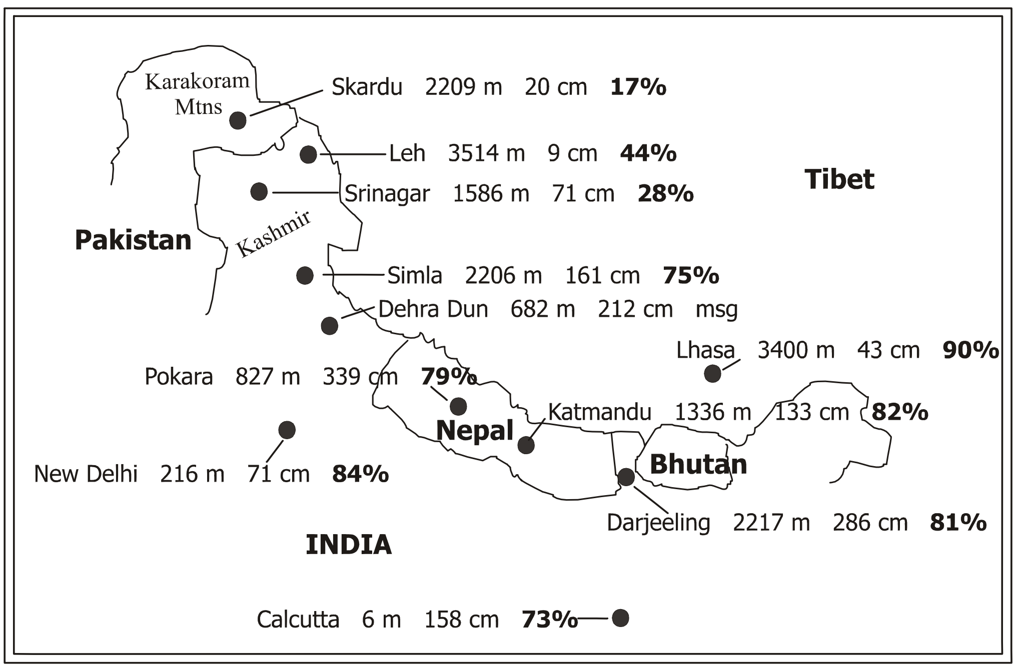


Figure 9.5- Annual precipitation for select stations in the Himalaya and northern India. Order of data is: station, elevation (m), annual precipitation (cm), and percent of annual precipitation which occurs from June-September. Missing data= msg.

Figure 9.5 shows annual precipitation and the percentage of annual precipitation that occurs during the summer monsoon (June-September). You should note that there is a dramatic increase in precipitation south of Kashmir, due to the monsoon. As noted earlier, as one travels closer to Tibet

the more arid the landscape becomes. Mean annual precipitation in Namche Bazar (3353 m) for example is on the order of 94 cm (37 in), while a little further to the north on the lower Khumbu Glacier (4900 m) it is estimated to be around 50 cm
(20 in).

Summer weather in the Karakoram is dominated by the polar jet stream. When the polar jet lies over the range, at a minimum you can expect strong winds at higher elevations and modest amount of cloud development. If a low or trough moves into the region, widespread precipitation should be expected as well. The polar jet of course is not a fixed feature over the region during the summer, it migrates between 30^{o}-60^{o} N. This means that the Pamirs and Tien Shan as well as the Karakoram can get hit with some very powerful storms during the summer months. Overall the upper level winds in the Karakoram are considerably stronger than they are in the eastern Himalaya during the summer. Table 9.2 displays the mean monthly precipitation and temperature data (1961-1990 normals) for Skardu (2209 m). Although these values are not representative of higher elevations, it does show the seasonal trends. It is evident that the bulk of the annual precipitation occurs from January-to-May. At higher elevations precipitation occurs anytime of the year there is moderate amounts of moisture in the middle troposphere. At elevations below 3000 m (9,800 ft), during the summer expect hot dusty conditions by day, with mild temperatures at night.

Table 9.2 Skardu Climate Data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Ann**
mean precip (cm)	2.1	2.4	4.0	2.6	2.6	0.9	0.9	1.1	0.7	1.0	0.6	1.4	**20.3**
mean max temp. (C)	3.1	5.5	11.9	18.4	22.7	28.4	31.4	31.2	27.0	20.0	12.5	5.8	**18.2**
mean low temp. (C)	-7.8	-4.7	1.5	6.7	9.7	13.7	16.7	16.4	12.0	4.8	-1.8	-5.9	**5.1**

* Data provided by Pakistan Meteorological Office

Autumn

Autumn (late September through early November) weather in the Himalaya is prime time for trekking and climbing, because precipitation is generally light and skies can be cloud free.

The main concern for climbers is the re-establishment of the subtropical jet stream during the month of October. Look back at Figure 9.3 and carefully note how by mid-September wind speeds dramatically increase. There is no set week when the STJ re-appears, but when it does, the onset of strong upper level winds is often pretty rapid. The silver lining is that the strength of the upper-level winds tend to fluctuate from day-to-day.

Strong STJ winds occur in association with either storms or clear skies. Occasionally a trough or low will move over the Himalaya during this period, but they are much less frequent than at other times throughout the year. The frequency of October winds over Lhasa are displayed in Table 9.3. These winds should be a good indicator of what climbers can expect in the eastern Himalaya. It is obvious that the winds intensify significantly throughout the month.

Table 9.3 Frequency of wind speeds during the month of October in the eastern Himalaya at 8 km.

speed (ms^{-1})	Oct. 1-15 Frequency (%)	Oct. 16-31 Frequency (%)
0-5	0.6	1.0
6-10	9.2	5.4
11-15	32.0	16.7
16-20	37.9	31.2
21-25	15.7	25.6
>25	4.6	20.1

During this time of year temperatures start to cool as a result of the lower sun angle but also as a result of the rapid heat loss of the Tibetan Plateau due to a lack of moisture in the atmosphere. Figure 9.4 gives some indication of temperatures that you might expect at a given elevation. Notice how temperatures plummet starting in mid-September.

The eastern Himalaya are unique in that it is one of the few mountainous regions of the world that are influenced to some degree by hurricanes (known in the Eastern Hemisphere as typhoons). Typhoons develop in the Bay of Bengal and produce large amounts of heavy rain in Bangladesh or along the east coast of India. There are two typhoon seasons: April-May and October-November, which of course correspond to the pre-monsoon and post-monsoon periods. We have not seen any kind of study that documents the influence of these storms on the eastern Himalaya, but we would speculate that on occasions considerable amounts of residual moisture works its way into eastern Nepal, Sikkim, Bhutan, and Arunachal Pardesh. When this occurs it could certainly inconvenience trekkers and climbers, however keep in mind that these storms frequently kill tens of thousands of people in Bangladesh and India, so whatever inconvenience you experience is trivial in comparison.

Many travelers to the Himalaya have seen and photographed banner clouds, especially in the Khumbu region of Nepal. Hindman (1995) reports that banner clouds on Everest and Cho Oyu develop and dissipate on a diurnal cycle, reaching their maximum extent in the afternoon. The bulk of the moisture for these clouds is derived from the moist valley winds and convective thermals that pump moisture into the strong westerly winds. It should be noted that a reduction in the size or the dissipation of a banner cloud at night does not necessarily indicate that the strong westerly winds have diminished. The disappearance of the banner cloud in large part is due to the absence of the low-level moisture source.

Autumn in the Karakoram can bring some periods of very good trekking weather. At high elevations its too cold and windy to climb, but below 3500 m (11,500 ft) temperatures are moderating from summertime highs. Be prepared for the occasional synoptic-scale storm that moves over the region and produces wide spread precipitation.

Himalaya Weather Summary

* Wettest period: June-September
* Driest period: October-November
* Sub-tropical jet stream produces high winds at summit-level from mid-October through mid-April. It is important to remember that strong winds can develop anytime the STJ is over the Himalaya.
* Eastern Himalaya is overall considerably wetter than the western Himalaya.
* Western Himalaya is more subject to winter storms with heavier snowfall at mid-elevations when compared to the eastern Himalaya.
* Weakest winds (easterly at mid and upper elevations) occur during the summer monsoon season.
* Due to the transport of low-level moisture into the eastern Himalaya from the Bay of Bengal, prolific cloud formation during the warmer months of the year often occurs at lower and mid-elevations before it occurs at higher elevations.

WEB: Indian Institute of Tropical Meteorology
www.imdmumbai.gov.in/imd.htm

Karakoram Weather Summary

* Wetter period: November-April
* Drier period: normally May-October but depends on northern extent of summer monsoon.
* The polar and occasionally the subtropical jet stream dominate the weather. When the polar jet is located over the range, expect at a minimum strong summit level winds, although precipitation usually accompanies the better developed troughs and lows.
* Unlike the Himalaya, there is no extended period when the polar jet is absent from the region.
* Since the Karakoram are located some considerable distance from an ocean, the bulk of the the moisture is transported from the west and southwest in the middle troposphere. As a result, the bulk of precipitation in the Karakoram falls out at higher elevations (>4000 m).

WEB: Pakistan Meteorological Office
http://met.gov.pk

The Andes

Although certainly not the highest mountain range, the Andes are without question the longest continuous chain of mountains to be found on earth. This range stretches roughly 8000 km (5000 mi) from northwest Venezuela (10^o N) through Colombia, Ecuador, Peru, Bolivia, Argentina, finally terminating in southern Chile (54^o S). Due to the 64^o latitudinal range, the Andes and adjacent regions contain every conceivable climate regime; from some of the wettest regions (Patagonian region of southern Chile) on earth to some of the driest (Atacama Desert in northern Chile). Weather stations are few and far between in the Andes, therefore it is difficult to make a detailed weather assessment. Nevertheless the material in this section provides a basic overview of principal regional weather patterns as well as relevant climate data.

Since the Andes are oriented north-to-south and since the predominate wind direction is either east (in the tropics) or west (mid-latitudes), precipitation and temperatures vary more from east-to-west across the range, than over the same north-to-south distance. The Andes can be classified into many sub-ranges, however one of the standard classifications is to differentiate between the Cordillera Occidental ("western mountains") and the Cordillera Oriental ("eastern mountains"). In the central Andes there is a relatively broad plateau between the C. Oriental and the C. Occidental, that ranges in elevation from 3500 m to 4300 m (11,500-14,000 ft). This plateau is referred to as the Altiplano ("high plateau") or the Puna, and it reaches its greatest dimensions in southern Peru (12° S), Bolivia, and northern Argentina (26° S).

Elevation is one of the primary controls of weather in the Andes of course, but the influence that the Pacific Ocean and the Amazon Basin have on the range cannot be overstated. One of the important climate elements in the Pacific Ocean is the Peru Current, which flows from south-to-north (Figure 9.6). This current transports cold water which originates in the sub-polar regions as far north as Ecuador. The presence of cold water directly adjacent to the coast has a large influence on the weather of the coastal regions of Ecuador and Peru as well as northern Chile. Since evaporation from a cold body of water is significantly less than from a warm body of water, the air over the coastal zone tends to be drier than what would normally be expected for these latitudes. Equally important to the control of weather in western South American is the presence of a semi-permeant cell of high pressure located over the eastern Pacific. This sub-tropical high, produces a strong trade-wind inversion at a height of about 500-1000 m (1600-3200 ft) above the surface of the ocean. This high migrates north and south parallel to the coast over the course of a year; it is furthest north (20° S) in June and furthest south in December (35° S). As a consequence of both the cold Peruvian Current and the trade-wind inversion, the coastal zones of Peru and northern Chile (to about 26° S) are extremely arid. There are places in the Atacama Desert of northern Chile for example, where measurable rain occurs roughly once every 10 years. In one of those 'freaks of nature' it should be noted however that this same arid coastal zone is frequently blanketed by marine stratus clouds. Due to the low height of the trade-wind inversion, these clouds are shallow and therefore are not capable of forming rain droplets.

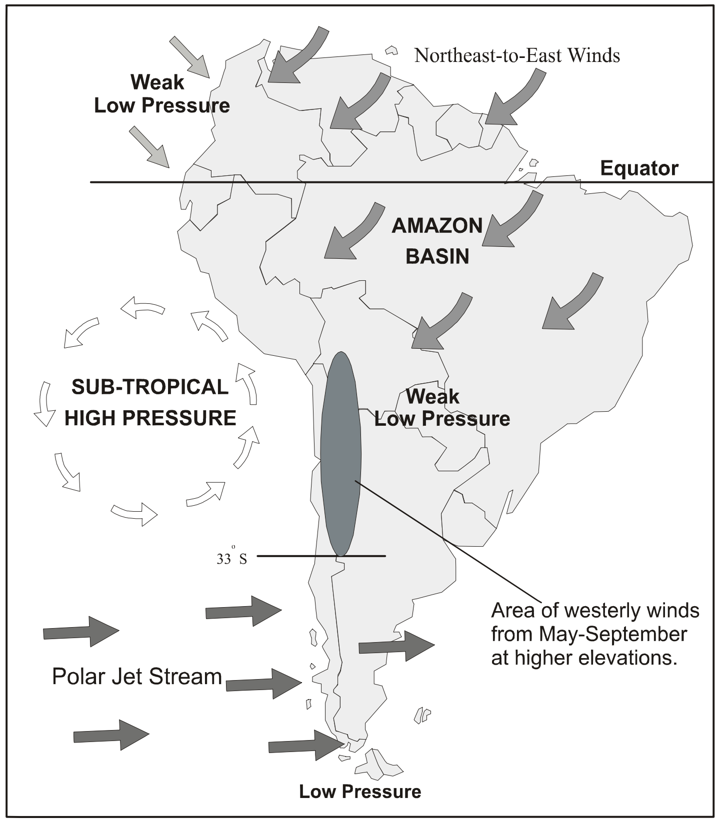


Figure 9.6- Prominent meteorological features over South America during May-September (Southern Hemisphere winter).

Between 33°-45° S, the climate along the Chilean coast and the western slopes of the Andes is similar to the climate of western Oregon and Washington. The primary control of weather in these

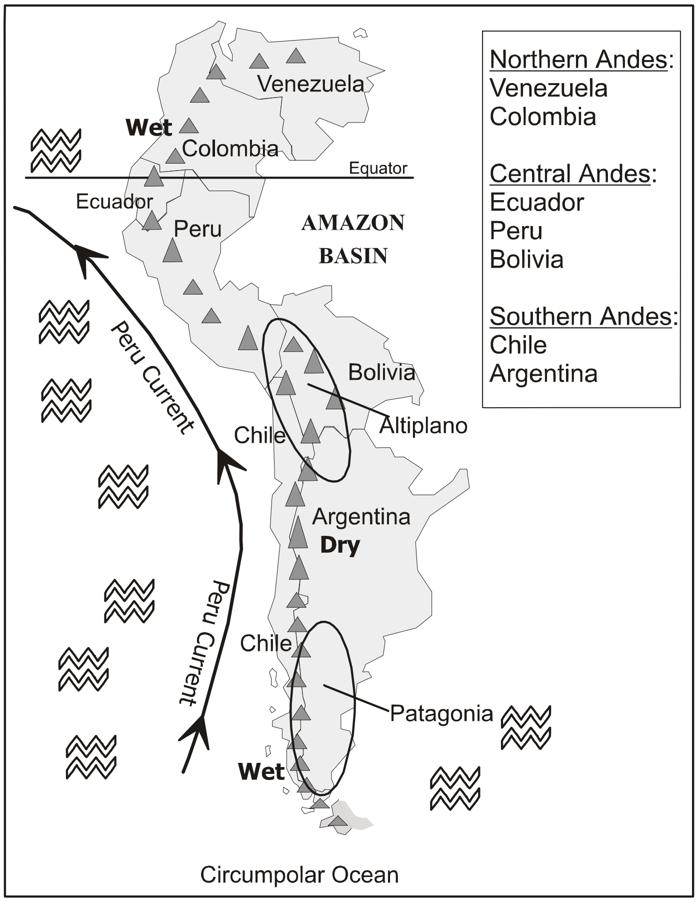


Figure 9.7- Geography of the Andes.

mid-latitudes is the polar jet stream (Southern Hemisphere equivalent to the polar jet stream which produces high winds and stormy weather over North America). The southern tip of Chile (45^o S) has a very wet and windy climate because it is surrounded by water. The Circumpolar Ocean which encircles Antarctica, is a breeding ground for storms due to the temperature contrast between the relatively warm water and the very cold air over the Antarctic icecap.

The Amazon Basin forms the eastern border of the northern and central Andes. The low and mid-level winds over the Amazon are primarily from the east. These easterly winds transport large amounts of moisture from the Amazon to the eastern slopes of the Andes. Because of the extreme aridity in the coastal zone, the C. Oriental of Ecuador, Peru and Bolivia tend to be much wetter than the C. Occidental (Figure 9.7). Since rain and snowfall data is very scarce in the high Andes, it is very difficult to establish accurate precipitation maps. We do know however that there are a number of very wet regions. The eastern slopes of the Ecuadorian Andes are very wet as will be described below. Another wet area is the western slopes of the Andes in southern Chile, south of 45^o S, where annual precipitation is on the order of 5-8 m (16-26 ft) in some places. Keep in mind that due to the transport of low-level moisture, the 500-2000 m (1,600-6,400 ft) elevation zone on either side of the Andes receives the bulk of the precipitation.

The primary climbing season in the central Andes (Ecuador south to northern Chile and Argentina) is May-September, which corresponds to the Southern Hemisphere winter. This is one of the few mountainous regions in the world where the best climbing weather occurs in the winter. The reason for this is due to the low-latitude position of the central Andes. During the summer months of Nov-April, the central Andes receive some 60-90% of its annual precipitation. From May-September, the moisture laden easterly winds diminish, producing a significant ‘dry period’. There are a number of exceptions to the aforementioned rule of thumb as will be noted in the following sections.

Note: *In the Southern Hemisphere, air flows in the opposite direction around HIGHS and LOWS when compared to the Northern Hemisphere. Therefore, air moves counterclockwise around HIGHS and clockwise around LOWS. Likewise the Coriolis deflection is to the <u>left in the Southern Hemisphere</u>. Figure 9.8 displays a generic 500 mb height field which would be valid from May through September (winter).*

<u>Ecuador</u>

For a small country Ecuador has a very complex climate, in part due to its position on the equator, and secondly because it is a narrow wedge (350 km) of elevated terrain sandwiched between the Pacific Ocean and the Amazon Basin. One of the easiest ways to identify climate zones is by noting the types of vegetation that grow in an area, as well as the overall appearance of the landscape. Variations in climate zones are apparent as one travels south along the Pan American Highway from Otavalo through Quito, to Ambato (this whole region is referred to as the <u>highlands</u>). In the vicinity of Otavalo the landscape is quite dry, the native vegetation consist of xerophytic plants and scrubs. Quito is considerably greener than the region to the north, with an annual rainfall on the order of 1.2 m (47 in), most of which occurs between October and May. Just south of Quito is a fertile valley which contains extensive farms and ranches. Another 75-100 km (45-60 mi) further south however the hills turn brown and the landscape is semi-arid. In this region annual rainfall is only about 0.45 m (18 in). Continuing further south the landscape becomes even more arid.

Climate data for Quito is given in Table 9.4. It is apparent that there is little seasonal change in air temperature at Quito, and for that matter across the entire highlands. The decrease in rainfall and the number of days per month with thunderstorms between June and September is evidence of the reduction in moisture transport from the Amazon Basin. In this region the majority of the rain occurs in the afternoon and early evening hours, in response to convective processes. A secondary dry period is evident from December through early February.

Table 9.4- Monthly climate data for Quito, Ecuador (2820 m)

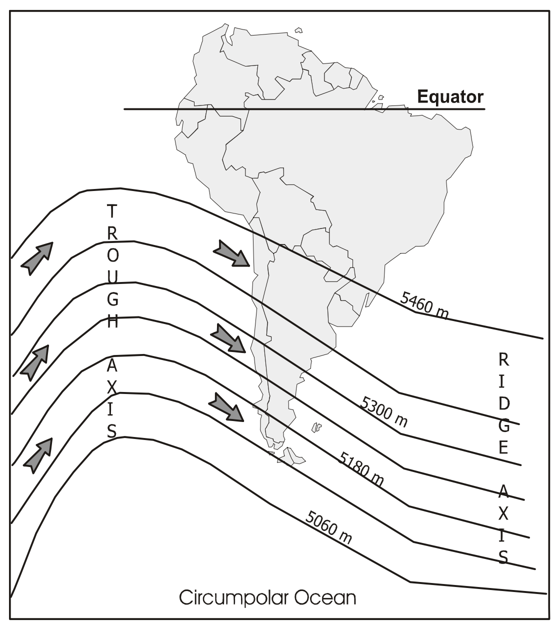


Figure 9.8- A typical 500 mb pattern over South America during the winter (May-September). Notice the difference in the orientation of troughs and ridges with respect to the Northern Hemisphere.

	Temperature (^oC)		Precipitation	Thunderstorm
	Mean Max.	Mean Min.	(cm)	Days
Jan	22	8	9	7
Feb	21	8	13.5	7
March	21	8	14.8	12
April	21	9	16.5	16
May	22	8	11.0	13
June	21	8	4.9	8
July	22	7	2.9	4
Aug	23	7	3.5	5
Sept	23	7	8.4	7
Oct	22	8	13.5	13
Nov	21	8	9.9	10
Dec	21	8	9.4	7

The wettest regions of Ecuador are the lower elevation zones (500-2000 m or 1,640-6,500 ft) on the windward slopes of the C. Oriental and C. Occidental. For example, the eastern slopes below Cotopaxi and above the jungle town of Tena (500 m), are extremely wet. Tena averages about 620 cm (243 in) of rain per year, however in 1969 it received an astronomical 890 cm (350 in). These large rainfall rates are no doubt related to the fact that Tena is located at the base of a

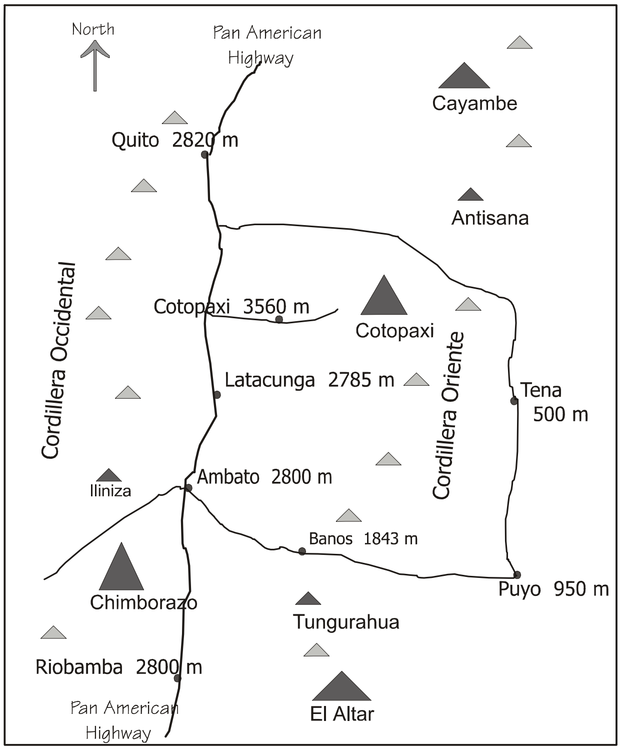


Figure 9.9- Geography of Ecuadorian Highlands.

4000 m (13,100 ft) high mountain barrier (Figure 9.9). Quito and the valley 50 km (30 mi) to its south are a wet spot in the midst of a other wise dry highland valley. It appears that this rainfall anomaly is due in large part to the fact that moisture from the east is able to move into the highlands between the “gap” formed by Cayambe (5790 m) and Antisana (5704 m) to the north and Cotopaxi (5897 m) to the south. Switching to the Pacific side of the highlands, the lower slopes of the C. Occidental directly to the west of Quito, typically receive about twice as much annual precipitation as the capital. Starting about another 150 km (92 mi) south however, the western slopes of the Andes (<2500 m) tend be dry, reaching desert-like conditions in northern Peru.

Table 9.5 shows a comparison of average monthly precipitation for five highland stations and the town of Puyo, which is located at the base of the C. Oriental. Note that the Cotopaxi station listed in this table is at the base of the mountain on the west side, not high on the mountain.

Ecuador Climbing Weather

The traditional climbing season in Ecuador is dictated by wet and dry seasons with seasonal temperature changes of little consequence. The driest months in the central highlands are July and August followed by a short dry period centered around January. This should not be taken to mean that skies are cloud free during these months and that perfect climbing weather is assured. Episodes of precipitation and high winds do occur during these periods. Keep in mind that the further east a peak is located, the higher the annual precipitation, which means that there is a greater chance of precipitation during the so called “dry periods”.

Table 9.5- Average Monthly Precipitation in Ecuador (cm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Ann**
Banos	7.2	7.4	9.8	13.1	15.0	19.3	17.8	15.8	13.0	9.1	6.6	6.5	**140**
Cotopaxi	8.9	10.5	14.4	13.3	12.4	8.1	4.6	4.0	8.4	10.6	10.3	8.7	**114**
Latacunga	2.8	5.4	5.4	6.5	3.8	3.2	1.7	1.6	2.8	5.5	5.5	4.1	**48**
Puyo	30.1	29.8	42.9	46.5	40.8	45.7	38.9	34.6	36.5	38.2	36.4	33.2	**454**
Quito	9.0	13.5	14.8	16.5	11.0	4.9	2.9	3.5	8.4	13.5	9.9	9.4	**117**

Riobamba	2.6	4.2	5.4	4.9	3.0	4.0	1.7	1.7	2.9	4.8	4.6	3.0	**43**

In addition, some of the heaviest rain in the jungle occurs from April through July. Even though precipitation in the jungle is on the decline during August-September, considerable amounts "spill over" into the eastern Andes. Cayambe, Antisana, Tungurahua, and El Altar can receive large amounts of precipitation anytime of the year. Rachowiecki and Wagenhauser (1994) report that the highest summit success rate for climbers on the higher peaks of the C. Oriental, occurs in December and January. Analysis of weather data indicates that between mid-December and late January, high pressure forms over northern Brazil. As a result winds over the eastern Ecuadorian Andes tend to be from the north and considerably drier than easterly winds which dominate for most of the rest of the year. This December and January drier period is clearly evident in Table 9.5 at the stations of Banos and Puyo.

Cotopaxi (the mountain) receives substantially less annual precipitation than either Cayambe or Antisana. This is due to the fact that the elevated terrain directly to the east of Cotopaxi intercepts the bulk of the low-level moisture than moves in from the Amazon. As a result of the complex interplay between precipitation and winds, there are two traditional climbing seasons: June through early September and mid-December through late January. March through May should generally be avoided for climbing because of abundant precipitation.

The snow line varies from storm to storm but generally lies between 4000-5000 m (13,100-16,400 ft) . Temperatures in the vicinity of 4700 m (15,400 ft-approximate hut level on Cotopaxi and Chimborazo), typically range from -5° to -10° C (23° to 14° F), with little seasonal variation. At 6000 m (19,680 ft) temperatures range from -15° to -20° C (5° to -4° F). Winds at higher elevations are predominately from the east (northeast-to-southeast) for most of the year.

Peru

Since the low-level westerly winds which originate over the Pacific at this latitude are very dry, virtually all of the rain and snow that falls in the mountains of Peru has to come from the Amazon Basin. As a result, the eastern ranges receive considerably more precipitation than the western ranges. Thunderstorms are a common occurrence during the wet season as well. In the C. Blanco and C. Huayhuash ranges of northern Peru, 70-80% of the annual precipitation occurs from October-April, with January-March being the wettest months (Table 9.6). Prime climbing and trekking weather occurs from May-September.

The mountain ranges around Cuzco (3320 m) the C. Vilcabamba and the C. Urubamba, form the northeastern edge of the Altiplano. About 80% of the annual precipitation that falls in this region occurs between November-April. Keep in mind however, that due to the proximity of these mountains to the Amazon, the weather during the May-September climbing season is not as dry and cloud-free as is it elsewhere in the Peruvian Andes. Also note that the cities and towns of Cuzco, Huaraz, and Huacnuco have considerable amounts of terrain to the east, which of course shields them from receiving large amounts of precipitation. The town of Tingo Maria on the other hand lies at 664 m (2,100 ft) on the eastern slopes, hence it receives the full impact of Amazonian moisture.

Table 9.6- Precipitation data (cm) for Peru.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Ann**
Cuzco	14.9	11.5	9.7	3.8	0.7	0.3	0.4	0.6	2.4	4.7	7.0	10.9	**67**
Huaraz	11.6	10.3	12.6	8.2	2.7	0.3	0.2	1.7	3.1	7.4	7.1	8.6	**74**
Huanuco	5.1	6.5	6.4	2.9	1.0	0.4	0.3	0.6	1.4	3.2	4.3	5.9	**38**
Tingo Maria	43.0	41.8	36.7	28.5	21.9	15.0	14.1	11.9	17.1	30.3	31.4	36.2	**328**

Bolivia

The primary destination of trekkers and climbers in Bolivia is the C. Real, which is located between Ancohuma (6427 m) in the north, and Illimani (6462 m) in the south. As elsewhere in the central Andes, May-September (winter) is the dry season, with 80% of the annual precipitation occurring between November-April (summer). During November-April cumulus clouds typically develop in the early afternoon, while most rain showers tend to occur between 5-10 pm. You should note that during the dry season, due to cloud free skies, lower sun angles and low relative humidities, the diurnal temperature range on the Altiplano is on the order of 20° C (36° F), and as large as 30° C (54° F) on occasions. This means the day time highs can be relatively warm, but night time lows are quite cold. In addition, thermally generated winds (valley, mountain, glacier) tend to be a little stronger during the dry season.

It does occasionally snow on the Altiplano during the winter, but generally never more than about ten centimeters (4 in). Short periods of stormy weather during the winter may delay or cancel some flights in and out of La Paz's El Alto airport from time-to-time. Table 9.7 displays monthly average temperature, precipitation, and surface wind direction at El Alto. During the winter, winds over the Altiplano are generally from the west. When these winds are strong, they frequently create large dust storms over the arid landscape. The town of Oruro (3700 m) has a reputation for being a windy dirty outpost of civilization during the winter months because of these storms.

Table 9.7- Climate data for El Alto Airport, Bolivia (4100 m)

	Temperature (°C) Mean Max.	Mean Min.	Precip. (cm)	Prevailing wind direc.
Jan	13	3	13.0	east
Feb	13	3	11.0	east
March	14	3	7.2	east
April	14	2	4.7	east
May	13	0	1.3	west
June	13	-2	0.6	west
July	13	-2	0.9	west
Aug	14	-1	1.4	west
Sept	14	0	2.9	east

Oct	16	2	4.0	east
Nov	16	3	5.0	east
Dec	14	3	9.3	east

The arid C. Occidental forms the western edge of the Altiplano, and also serves as the border between Chile and Bolivia. What little precipitation that does fall in this region, occurs between October-April. Sajama (6542 m) is the highest peak in Bolivia and is the main attraction in the C. Occidental. An automated weather station was installed on Sajama's summit in October 1996, in order for researchers to get a better understanding of high altitude tropical meteorology (Hardly *et al* 1998). Although the data record is short, observations during 1997 show that minimum daily temperatures on the summit ranged between -13° C and -20° C (9° and -4° F) while maximum daily temperatures ranged from -5° C to -12° C (23° and 10° F). From May-September winds at the summit were primarily from the north or northwest. The strongest winds occurred at night and frequently exceeded 10 m/s (22 mph).

Travelers to the southern Altiplano will observe a very arid landscape. This region is lies directly to the east of the South American subtropical high. This means that there is almost no transport of moisture from the Pacific, and little transport from the southern region of the Amazon Basin as well. What precipitation that does occur (estimated to be 10-20 cm per year), falls between November and April. Due to the lack of available moisture, there are many 6000+ m peaks in this region that are devoid of permanent snow and ice. From May through September the winds are primarily from the west or northwest, and are frequently quite strong.

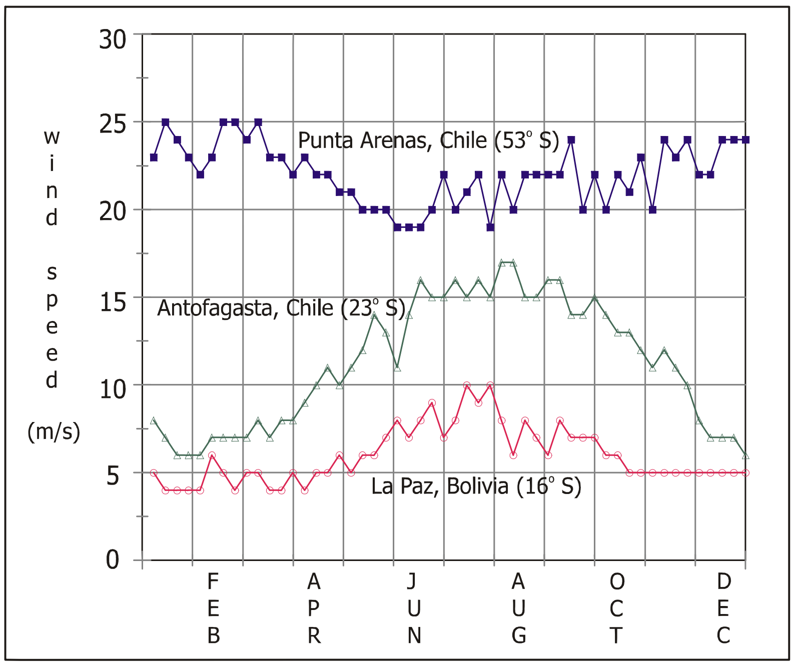


Figure 9.10- Weekly-averaged wind speeds for three South American upper air stations. Data is for 6 km (19,700 ft) above sea-level.

Chile and Argentina

Between 30°-45° S there is a pronounce increase in precipitation as one travels from north-to-south. This section of the Andes is a transition zone from the arid subtropical climate in the north, to the wet maritime climate in the south. This means that westerly winds dominate at all levels in the troposphere throughout the year, as seen in Figure 9.10. Take note that the further south you travel, the strong the winds.

Annual precipitation varies from about 1.5 m (59 in) in the north to 3-5 m (120-200 in) in the south. In addition, there is a very sharp decrease in precipitation on the leeward slopes of the Andes in Argentina. Unlike the central Andes, this region receives the majority of its precipitation between May and August. Table 9.8 displays climate data for Cristo Redentor, Argentina (3830 m), a semi-arid station in proximity to Aconcagua (6959 m). It is evident from Table 9.8 that October-April is the dry season, which corresponds to the southern-most position (35^{o} to 40^{o} S) of the South American sub-tropical high The traditional climbing season for Aconcagua is December-March (Biggar 1996), which as you can see from the wind speed data taken at 6 km over Antofagasta, Chile (Figure 9.10), is the period with the weakest winds of the entire year.

Table 9.8- Climate data for Cristo Redentor, Argentina (3830 m)

	Temp. (^{o}C) Mean	Precipitation (cm) Monthly Mean	# Days > trace
Jan	4.0	1	5
Feb	3.6	1	4
March	1.8	1	6
April	-0.6	2.2	6
May	-4.5	9.6	9
June	-5.9	4.4	10
July	-6.7	5.6	10
Aug	-6.5	6.4	11
Sept	-5.5	2.3	8
Oct	-3.5	1.9	9
Nov	-1.0	1	7
Dec	2.4	1	6

South of 45^{o} S the climate is very wet and windy, similar to southeast Alaska (panhandle). The heaviest precipitation occurs between 500-1500 m (1,600-4,800 ft), on the western slopes of the Andes. Precipitation is pretty evenly distributed throughout the year. There is a slight October-December decrease in precipitation in the climate record at Evagelistas, (elevation 55 m) Chile, but not by much. Estimated annual precipitation on the Patagonian Icefields is 300-500 cm (120-200 in). The permanent snowline is about 2000 m (6,500 ft) in the north of this region but closer to 1000 m (3,280 ft) in the south.

Westerly winds blow at all elevations throughout the entire year, as evident in Figure 9.10 at Punta Arenas. As was alluded to earlier in this section, the Circumpolar Ocean is a breeding ground for strong low-pressure systems. The southern Andes are the only elevated terrain for thousands of kilometers, as a consequence, as these storms move on-shore, large amounts of precipitation are generated. Travelers to Fitzroy and Torres Del Paine National Park in Argentina, take note; even though these parks lie to the lee of the crest of the Andes, they frequently get hammered by major storms. The driest season to visit southern Patagonia is January-to-March, when the storm track is closer to Antarctica than to Patagonia. This also corresponds to the period when the South American sub-tropical high reaches its southern most latitude. Climbers should allow plenty of extra time for possible weather delays.

Andes-Climbing and Trekking Seasons

Colombia: November to March
Ecuador: June to early September, mid-December to January
Peru: June to September
Bolivia: June to September

Chile/Argentina:
north of 27° S: June to September
between 27°-45° S: October to March. Aconcagua: December to March
south of 45° S: January to March, give or take a month.

WEB	Brazilian Meteorological Office	**www.inmet.gov.br**
	Chile Meteorological Office	**www.meteochile.cl**
	Peru Meteorological Office	**www.senamhi.gob.pe**
	Ecuador Meteorological Office	**www.inamhi.gov.ec**

The Alps

The study of weather in the Alps began almost two hundred years ago, with some of the earliest weather stations dating back to around 1820. By the middle of the 19th century national weather services were being organized throughout the Alpine countries. As a result there is an 150+ year continuous record of weather observations in many regions of the Alps, and in some cases there are sporadic records that date back much further.

Beginning in southeast France and extending across Switzerland, northern Italy, Austria, Slovenia and Croatia, the Alps form a 800 km (500 mi) arc across southern Europe . Like any other large mountain range, the Alps are divided into numerous sub-ranges. Several of the more important sub-ranges are the: Jura of northwest Switzerland, the Bravarian Alps of southern Germany, and the Dinaric Alps of Slovenia and Croatia. The Pyrenees Mountains which straddle the border between Spain and France, are not considered a part of the Alps.

Like most mountain ranges the Alps, act as a climate divide; in this case they separate the Mediterranean climate to the south, from the temperate mid-latitude (west) or semi-continental (east) climate to the north. The Alps themselves have three geographic climate zones: the northern slopes, the inner Alpine valleys, and the southern slopes. The northern slopes block cool northwest or northerly winds from reaching the Mediterranean, conversely the southern slopes limit the amount of warm Mediterranean air reaching continental Europe. As a result the northern slopes tend to be cooler and cloudier than the corresponding elevation on the southern slopes. The inner Alps, especially the valleys, tend to be considerably drier than any either the southern or northern slopes. Temperatures in the winter in these alpine valleys can be colder than any other place in the Alps at the same elevation, due to persistent temperature inversions. Overall, the southern slopes are sunnier and have fewer days with precipitation than the northern slopes. However, when precipitation does occur over the southern slopes, the intensity is frequently quite high.

The predominate 500 mb flow patterns are illustrated in Figure 9.11. The so-called split jet pattern which is shown in Fig.9.11a, is fairly common during the cooler months of the year, especially in the spring when high pressure forms over the eastern Atlantic Ocean. When this pattern occurs in the winter, expect sunny days with cold clear nights. When it occurs in the summer expect sunny days with little precipitation, although some convective showers are always possible. On the southern slopes expect some wide spread precipitation if the southern jet works its way into the northern Mediterranean Basin. If the jet remains over the southern Mediterranean, expect dry and sunny conditions over the Alps. When a trough or low is positioned to the west of Portugal, air flows into the Alps from the southwest (Fig.9.11b). This pattern is a major precipitation producer in southeast France, northern Italy and the Dinaric Alps. This pattern occurs more often in the spring and autumn than at other times of the year. When the flow is westerly as shown in Fig.9.11c, weather in the Alps is variable. If the westerly winds are strong, some moisture will be transported into the western Alps. If on the other hand the westerlies are weak, little stratiform precipitation can be expected. This is one of those weather patterns where you also have to look at a surface weather map to see the position of any fronts. Remember that precipitation occurs when several hundred kilometers on either side of fronts.

When a well developed cut-off low is positioned over eastern Europe in the winter (Figure 9.11d), you can expect cold temperatures in the northern Alps, particularly in Austria and Germany. This pattern does not occur very often in the summer, but when it does expect cooler than normal temperatures for that time of year. Since the middle atmosphere becomes cooler with this flow pattern, convection can be enhanced as long as the supply of moisture is not completely shut-off. In Fig.9.11e notice that the ridge axis is west of the Alps, this produces northerly to northwesterly

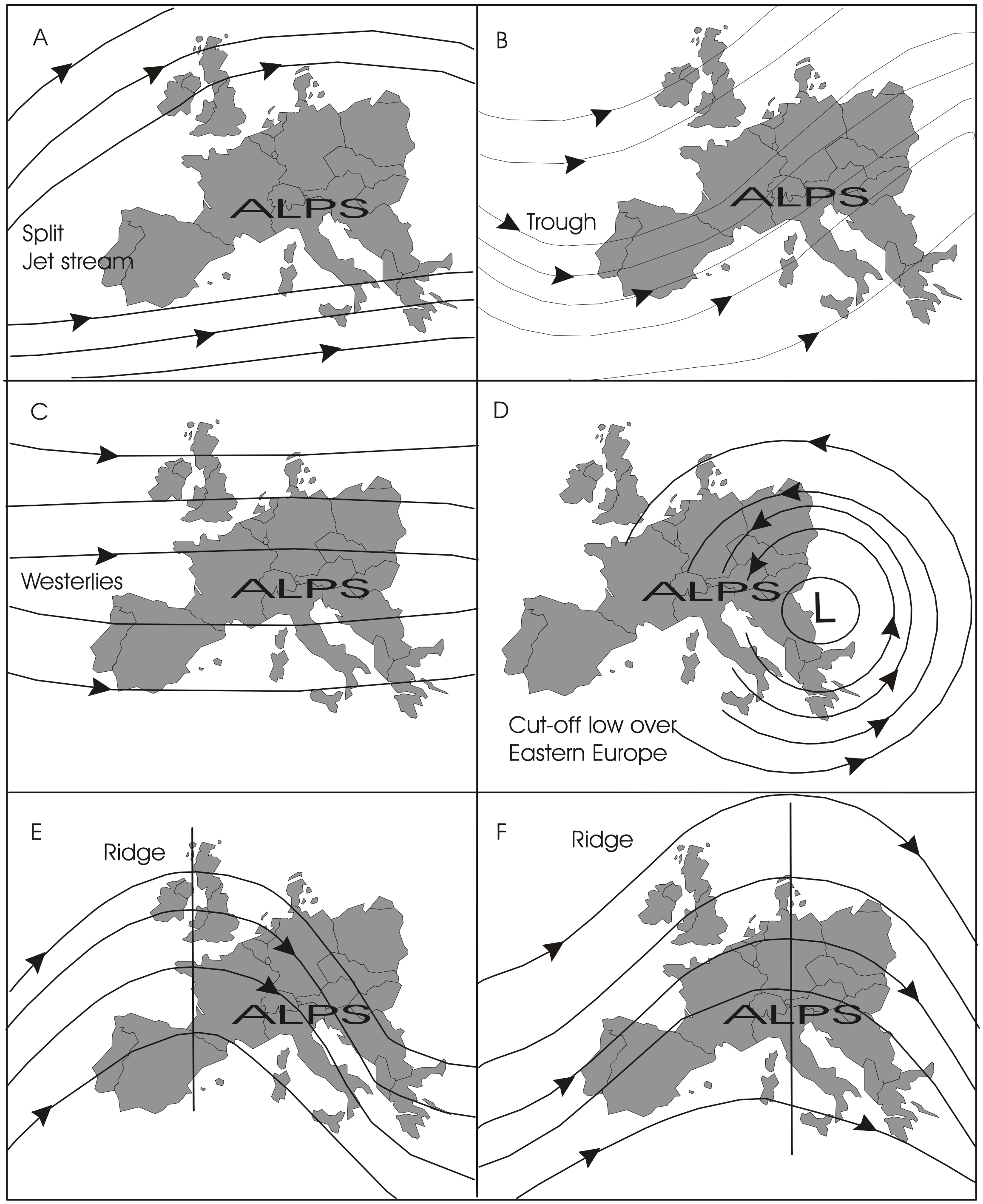


Figure 9.11- Depiction of six common 500 mb flow patterns over Europe.

winds over the mountains. Some precipitation could be expected on the northern slopes as moisture is transported from the North Atlantic and North Sea. If the ridge continues to move eastward, the trough that was originally in the eastern Atlantic moves into Europe, resulting in a pattern similar to Fig.9.11b.

Downslope wind storms, which are know as foehn in the Alps, are quite common throughout many regions. They occur on either the northern or southern slopes, depending on the geostrohpic wind direction over the Alps. Foehn occur during the cooler months of the year, with April have the highest frequency. During winter and spring, cold air to the north of the Alps flows through the gaps in the mountains near Lake Geneva, producing a drainage flow know as the bise. When cold air drainage occurs around the western Alps in France, it goes by the name of mistral. In the eastern Alps, a bora is produced when cold air that forms over eastern Europe flows through the lower terrain that separates the Alps from the Dinaric Alps. When a bora occurs, temperatures along the eastern Adriatic coast cool significantly.

Due to numerous deep valleys that dissect the Alps, valley as well as mountain winds are well developed and are a major influence on the weather and climate of towns and villages located in these valleys. It is not uncommon for mountain winds to attain speeds of 10 m/s (22 mph) in the early morning hours, as cold air flows down valley, out of the mountains.

Precipitation and Temperatures

Along the northern slopes of the Alps average annual precipitation ranges from 100 to 150 cm (39-59 in), with several climate stations receiving well over 200 cm (88 in). There is a distinct summer precipitation maximum throughout this region except in the far west, where the precipitation is more evenly distributed throughout the year (Figure 9.12). Mountain travelers should remember that even though July-September are the wettest months, that the bulk of these summer rains consists of a short burst of convective showers which most often occur during the late afternoon and evening hours. In the winter, most of the precipitation is associated with large synoptic-scale storms that move over the region from the west or northwest. These storms produce wide-spread light snow (or rain at lower elevations) and typically have a duration of one to two days.

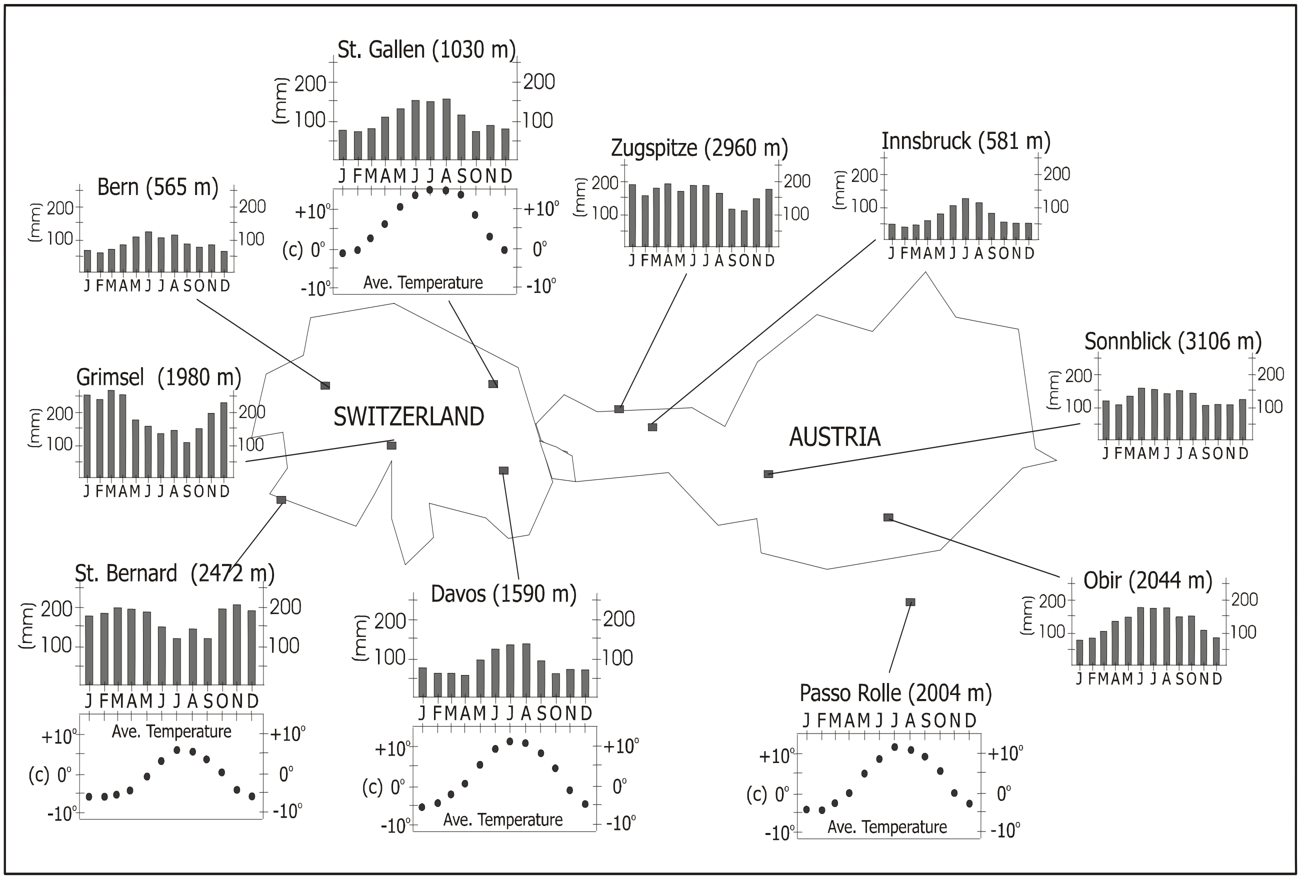


Figure 9.12- Monthly precipitation (mm) and air temperature (C) for select stations in the Alps.

Frei and Schar (1998) studied the distribution of annual precipitation along a north-to-south transect of the Alps, roughly from Munch to Trento. They found that areas 50-80 km (30-50 mi) upstream of the base of the Alps, had enhanced amounts of precipitation because of the far-reaching upstream influence of elevated terrain. Their study also indicated that precipitation appears to reach a maximum at an elevation of about 800 m (2,600 ft) on the northern slopes and at about 1200 m (3,900 ft) on the southern slopes. Above these elevations annual precipitation decreases noticeably.

It is worth mentioning that from September through April, a large number of low pressure systems are generated in and near northern Italy, just to the south of the Alps. Low pressure centers form over this region for two reasons: during the cooler months of the year, low-level cold air flows around either end of the Alps. This cold air adjacent to warm air already positioned over the Mediterranean Sea, produces a large temperature gradient, which facilitates the generation of a front. At the same time, as middle and upper level air flows over the Alps and descends over northern Italy, it tends to create an incipient low because the air has a considerable amount of counterclockwise rotation. As these incipient lows move into a region where there is large temperature contrast (gradient), they intensify and become mature systems. The high frequency of these lows during the cooler months of the year, is why parts of the southern slopes of the Alps are some of the wettest regions in continental Europe. The term used by meteorologist for this phenomena is lee-side cyclogenesis, and it also frequently occurs directly to the east of the Rocky Mountains as well.

In the mountains of the southern Alps, precipitation tends to be heaviest in the spring and autumn. Numerous flash floods as well as river floods occur in northern Italy in spring and autumn.

In spring, heavy rain can accelerate alpine snow melt, producing floods. In autumn, heavy rain in the mountains often leads to flash flooding. During the summer months expect the usual late-afternoon and evening rain showers with the occasional thunderstorm.

Table 9.9 shows monthly average temperature data from three Swiss stations that are located at different elevations in the Bernse Alps. This data gives a range of high and low temperatures for summer month, and is applicable all across the Alps. On any given day of course, temperatures in the western Alps can differ substantially from those 500 km to the east, however Table 9.9 gives an indication what you can expect in terms of average conditions.

Table 9.9- Alps temperature data

station	(°C)	May	June	July	August	Sept.
Jungfrau (3580 m)	lows	-12 to -6	-9 to -3	-6 to 0	-6 to 0	-8 to -2
	highs	-7 to -1	-2 to +2	-2 to +4	-2 to +4	-3 to +3
Gutsch (2287 m)	lows	-2 to +2	-1 to +4	+1 to +7	+1 to +7	-1 to +6
	highs	0 to +6	+5 to +11	+8 to +14	+8 to +14	+7 to +13
Interlaken (580 m)	lows	+3 to +9	+7 to +13	+9 to +14	+9 to +14	+6 to +12
	highs	+14 to +21	+17 to +24	+18 to +26	+17 to +25	+15 to +22

Alps Weather Summary

* Precipitation- heaviest along the northern and southern mountains. Due to the barrier effect, the central mountains are considerably drier.
* Summer-time convection occurs over the entire range. The highest frequency of heavy rain and thunderstorms is in late afternoon and evening.
* Gap winds are frequent in many regions during the winter. This winds are best developed when central Europe experiences an extensive cold spell.
* Foehn are common along at the base of the northern and southern mountains, depending on the direction of the large-scale winds. This downslope windstorms are best developed during the cooler months of the year.
* Due to the presence of large and deep valleys throughout much of the Alps, moderate and occasionally strong valley and mountain winds are frequent.

Web

Austrian weather/climate	**www.zamg.ac.at**
Swiss Meteorological Office	**www.westwind.ch**
German Meteorological Office	**www.wetterzentrale.de**
British Meteorological Office	**www.meto.govt.ul**