FORCES THAT CREATE WEATHER • THUNDER AND LIGHTNING • LOCALIZED WINDS • FIELD FORECASTING IN THE MOUNTAINS • CREATING CUSTOM WEATHER BRIEFINGS • APPLYING THE INFORMATION

CHAPTER 28

MOUNTAIN WEATHER

It is no accident that many of the world's grandest monuments and temples—the pyramids of Egypt and Mexico, for example—mimic mountains. Mountains exude massive strength and permanence, their summits frequently assailed by storms that the ancients believed were signals of divine presence and power. Approaching the summit of such a peak was an act thought to risk the disfavor of the gods.

Today most climbers believe that a disastrous encounter with severe weather is the result of insufficient respect for the elements or bad luck, rather than the work of an angry god. There is no question that a trip into the mountains can expose people to more dangerous weather than most other environments on earth. Refuge can be harder to find, and major peaks can manufacture their own weather. Despite improvements in weather forecasting, knowledge of exactly how the atmosphere works, particularly in mountainous regions, is still incomplete. The wise climber not only carefully checks weather forecasts and reports before a trip but also develops an ability to assess the weather in the field.

FORCES THAT CREATE WEATHER

Understanding weather forecasts and reports requires a basic grasp of the forces that create weather. Such knowledge will not only help mountaineers better digest such information before leaving home, it will also help climbers detect important changes on the trail or climbing route as the weather changes over time.

THE SUN

The sun does far more than simply illuminate Planet Earth. It is the engine that drives the earth’s atmosphere, providing the heat that, along with other factors, creates the temperature variations that are ultimately responsible for wind, rain, snow, thunder, and lightning—everything known as weather.

The key to the sun’s impact is that the intensity of the sun’s radiation varies across the earth’s surface. Closer to the equator, the sun’s heat is more intense. The extremes in temperature between the equator and the poles come as little surprise; however, those differences in air temperature also lead to air movement, which moderates those temperature extremes.

AIR MOVEMENT

The horizontal movement of air (what is called *wind*) is all too familiar to anyone who has pitched a tent in the mountains. However, air also rises and descends. When air cools, it becomes denser and sinks; the air pressure increases. But when air warms, it becomes less dense and rises; the air pressure decreases. These pressure differences, the result of temperature differences, produce moving air. Air generally moves from an area of high pressure to one of low pressure (fig. 28-1). Remember, wind direction is defined as the direction the wind is coming from, not the direction it is moving toward.

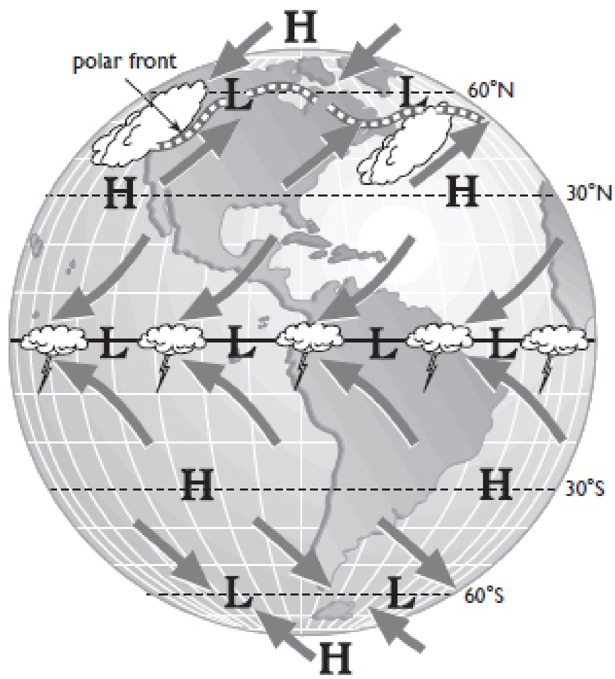

Fig. 28-1. The earth's air circulation patterns: movement from areas of high pressure at the poles toward areas of low pressure at the equator, deflected in the middle latitudes by the earth's rotation.

Air moving from high to low pressure carries moisture with it. As that air moves into the zone of lower pressure, then rises and then cools, the moisture may condense into clouds or fog. The reason is that, as the air cools, its capacity to hold water vapor is reduced. This is why you can "see" your breath when the air temperature becomes cold: the water vapor in your mouth condenses into liquid water droplets as you breathe out. The process of cooling and condensation operates on a large scale in the earth's atmosphere as air moves from high-pressure systems into low-pressure systems, where it rises.

Because Arctic and Antarctic polar air is colder and therefore denser than air closer to the equator, it sinks. The zone where it sinks and piles up is a region of high pressure. As the air sinks and its pressure increases, its temperature warms a bit. The effect is similar to what happens to football or rugby players caught at the bottom of a pile: they get squeezed the most, and their temperature (and possibly temperament) heats up. In the atmosphere, this warming within a high-pressure area tends to evaporate some of the moisture present. That is why the Arctic receives very little precipitation. Although this sinking motion heats the air enough to evaporate much of the moisture in it, the air does not heat up enough to transform the poles into the tropics!

THE EARTH'S ROTATION

If the earth did not rotate, the cold polar air would just continue to slide toward the equator. However, the air sinking and moving from the poles toward the equator and the air rising from the equator do not form a simple loop moving from north to south (or from south to north) and back again. The rotation of the earth around its axis deflects this air. Some of the air rising from the equator descends over the subtropics, creating a region of high pressure. In turn, part of the air moving from these subtropical highs moves north into the air moving south from the north pole (or moves south into the air moving north from the south pole). The boundary between these two very different air masses is called the *polar front* (see Figure 28-1). When this boundary does not move, it is called a *stationary front*. It often serves as a nursery for the development of storms.

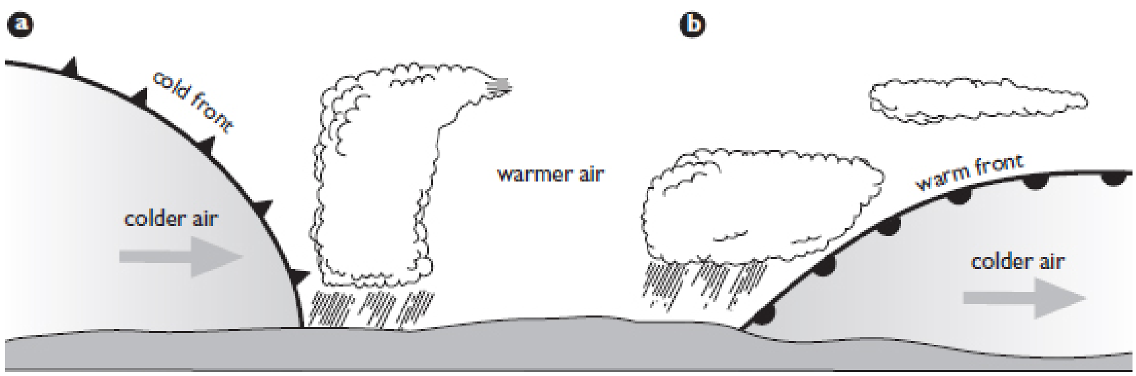

Fig. 28-2. Fronts: a, cold front displaces warmer air; b, warm front displaces colder air.

COLD FRONTS AND WARM FRONTS

Because of the great contrast in temperatures across the polar front, together with imbalances caused by the rotation of the earth and differing influences of land, sea, ice, and mountains, some of the cold, dry air from the north slides south (or, in the southern hemisphere, air from the south slides north). That forces some of the warm air to rise. The zone where cold air is replacing warm air is referred to as a *cold front* (fig. 28-2a), and the zone where warm air is gradually replacing cooler air is referred to as a *warm front* (fig. 28-2b); both types of fronts appear as a “wave” or bend on the stationary front. An *occluded front* combines characteristics of warm and cold fronts and is typically found near the center of a mature low-pressure system.

Both cold and warm fronts are marked by unique clouds, which help the mountaineer distinguish one type of front from the other. Clouds seen ahead of, along, or just behind a cold front include cumulus (fig. 28-3a), altocumulus (fig.

28-3b), cumulonimbus (fig. 28-3c), and stratocumulus (fig. 28-3d). These clouds are puffy, resembling cotton candy. The name *cumulus* refers to their “pile” or “heap” shape. Stratocumulus clouds are sheetlike layers of cumulus clouds; the name *stratus* refers to the “sheetlike” or “layered” characteristics of these clouds.

Clouds seen ahead of or along a warm front include a halo (fig. 28-3e), lenticular (fig. 28-3f), stratus (fig. 28-3g), cirrocumulus (fig. 28-3h), cirrostratus (fig. 28-3i), altostratus (fig. 28-3j), and nimbostratus (fig. 28-3k). Overall, lowering and thickening clouds signal the approach of precipitation and lowered visibility.

The “wave” or bend that develops along what started out as a stationary front may develop into a low-pressure system, with air circulating counterclockwise around the low (the opposite direction of air moving around a high)—again, a consequence of the earth’s rotation and friction.

THUNDER AND LIGHTNING

Thunderstorms can be set off by the collision of different air masses when fronts move through or by the rapid heating of air when it comes in contact with sun-warmed mountain slopes. Once this air is warmed, it becomes buoyant and tends to rise. If the atmosphere above is cold enough, the air tends to keep rising, producing what are called *air-mass thunderstorms*. A single lightning bolt can heat the surrounding air up to 50,000 degrees Fahrenheit (approximately 25,000 degrees Celsius). That heating causes the air to expand explosively, generating earsplitting thunder.

Thunderstorms in the mountains can and do kill (fig. 28-4)—and not just from lightning strikes, although lightning is the biggest killer, claiming an average of 200 lives in the United States alone each year. Lightning can also spark dangerous wildfires, and even a moderate thunderstorm may release up to 125 million gallons (473 million liters) of rainwater. The resulting flash floods can quickly inundate streambeds and small valleys, sweeping away entire camp-grounds. The growing popularity of canyoneering, particularly rappelling in deep slot canyons, increases climbers’ exposure to flash floods and drowning. Thunderstorms can also produce winds of lethal intensity, capable of leveling entire stretches of forest.

TABLE 28-1. CLOUD-COVER CLUES

IF	THEN	CHECK FOR
High cirrus clouds, halo around sun or moon	Precipitation possible within 24–48 hours	Lowering, thickening clouds
High cirrus clouds forming tight ring or corona around sun or moon	Precipitation possible within 24 hours	Lowering, thickening clouds
“Cap” or lenticular clouds forming over peaks	Precipitation possible within 24 to more than 48 hours; strong winds possible near summits or leeward slopes	Lowering, thickening clouds
Thickening, lowering, layered flat clouds	Warm or occluded front likely within 12–24 hours	Shifting wind; dropping pressure
Breaks in cloud cover closing up	Cold front likely within 12 hours	Shifting wind; dropping pressure

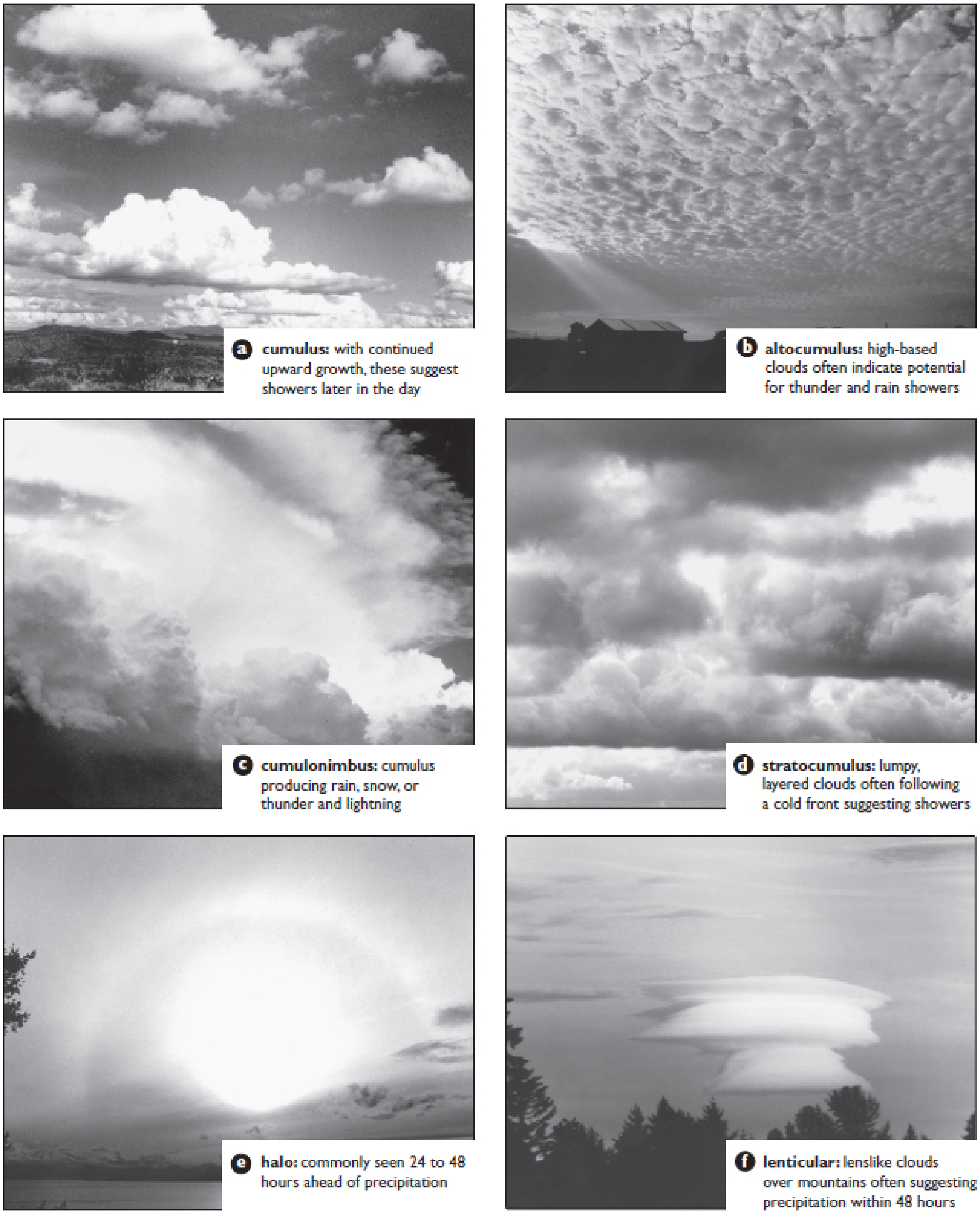

Fig. 28-3. Identifying cloud types: a, b, c, and d, cloud types seen ahead of, along, or just behind a cold front; *(continued on next page)*

g **stratus:** layerlike clouds associated with widespread precipitation or ocean air

h **cirrocumulus:** very high clouds, typically made of ice crystals, a warning of approaching storms

i **cirrostratus:** high, very thin clouds composed of ice crystals

j **altostratus:** when part of an approaching warm front, these clouds follow cirrostratus

k **nimbostratus:** stratus clouds producing widespread precipitation and low stability

Fig. 28-3. (continued from preceding page) e, f, g, h, i, j, and k, cloud types seen ahead of or along a warm front.

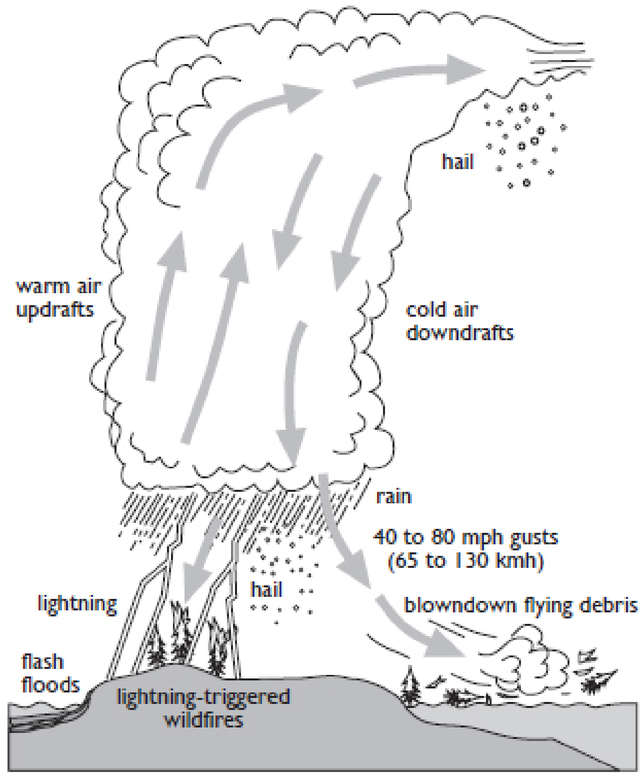

Fig. 28-4. Thunderstorm hazards include lightning, flash floods, and high winds.

By taking a few precautions, climbers can avoid most accidents caused by mountain thunderstorms (see the “Tips If Thunderstorms Are Forecast” sidebar). Begin by obtaining updated weather reports and forecasts before hitting the trail.

GAUGE THE MOVEMENT OF A THUNDERSTORM

How is it possible to gauge the movement of a thunderstorm? It is easy with a watch. Use the “flash to bang” principle: The moment lightning flashes, start counting the seconds. Stop timing once the bang of thunder is heard. Divide the number of seconds by five; the result is the thunderstorm’s distance away in miles. Continue to time lightning and thunder discharges to judge whether the thunderstorm is approaching, remaining in one place, or receding. If the time interval between the lightning and thunder is decreasing, the thunderstorm is approaching; if the interval is increasing, it is moving away.

TIPS IF THUNDERSTORMS ARE FORECAST

- Obtain updated weather reports and forecasts before hitting the trail.
- Do not camp or climb in a narrow valley or gully.

- Do not climb or hike in high, exposed areas.
- Climb high early and descend by the afternoon. Thunderstorms tend to develop with afternoon heating.
- Watch small cumulus clouds for strong, upward growth; this may signal a developing thunderstorm.
- Watch for cumulus clouds changing from white to dark gray or black.

This technique works because the light from the lightning moves much faster than the sound from the thunder. Although the thunder occurs at virtually the same instant as the lightning, its sound travels only about 1 mile (1.6 kilometers) every 5 seconds, whereas the lightning flash, traveling at 186,000 miles (300,000 kilometers) per second, arrives essentially instantaneously. That is why the lightning is seen before the thunder is heard, unless the thunderstorm is very close—too close.

IF A THUNDERSTORM APPROACHES

If climbers are caught out in the open during a thunderstorm, they should try to seek shelter. Tents are poor protection: metal tent poles may function as lightning rods; stay away from poles and wet items inside the tent. Take the following precautions to avoid being struck by lightning:

- **Get away from water** because it readily conducts electricity.
- **Seek low ground** if the party is in an open valley or meadow.
- **Move immediately** if your hair stands on end.
- **Avoid standing on ridgetops,** at lookout structures, or near or under lone tall trees, especially isolated or diseased trees, which are more likely to fall in thunderstorm winds.
- **Look for a stand of even-sized trees** if the party is in a wooded area.
- **Do not remain near or on rocky pinnacles or peaks.**
- **Do not remain near, touch, or wear metal or graphite equipment,** such as ice axes, crampons, climbing devices, and frame packs.

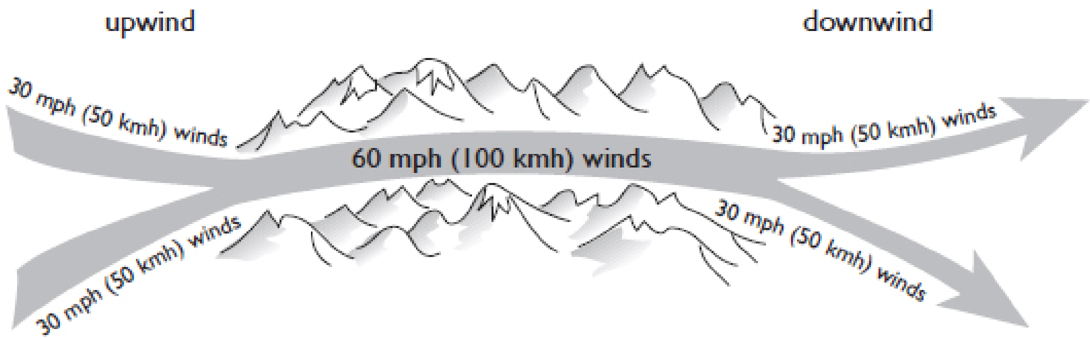

Fig. 28-5. Wind accelerates through gaps and passes.

- **Insulate yourself from the ground** if possible. Place a soft pack or foam pad beneath you to protect against step voltage transfer of the lightning strike through the ground—though ground currents may move through such insulation.
- **Crouch to minimize your profile,** and cover your head and ears.
- **Do not lie down**—lying down puts more of your body in contact with the ground, which can conduct more electrical current.

LOCALIZED WINDS

Understanding large-scale wind patterns, both at the earth's surface and in the upper atmosphere, is important for being able to gauge the weather. However, because mountains, by their very nature, alter wind considerably, understanding localized patterns is crucial to the mountaineer. It can mean the difference between successfully reaching the summit, being tent-bound, or getting blown off the mountain.

GAP WINDS

Winds are often channeled through gaps in the terrain such as major passes or even between two peaks. Wind speeds can easily double as they move through such gaps (fig. 28-5).

Climbers can use this knowledge to their advantage. If possible, gauge the surface wind speeds upwind of a gap or pass before traveling into the vicinity of these terrain features. Knowing the upwind velocities can prepare a climber for gap winds that may be twice as strong. Avoid camping near the downwind portion of the gap, and consider selecting climbing routes not exposed to such winds. A major peak can block or slow winds for a few miles downwind.

VALLEY AND GRAVITY WINDS

Sparsely vegetated ground is typically found closer to ridges. Because it heats more rapidly than forest-covered land near valley floors, and because heated air rises, wind is generated that moves up either side of a valley, spilling over adjoining ridgetops. Such uphill breezes, called valley winds, can reach 10 to 15 miles (16 to 24 kilometers) per hour, attaining peak speed during the early afternoon and dying out shortly before sunset.

TABLE 28-2. WIND DIRECTION AND SPEED CLUES (NORTHERN HEMISPHERE)

IF	AND IF	THEN
Winds shift to E or SE	Air pressure drops; low-pressure system approaching	Clouds lower, thicken; precipitation possible
Winds shift from SW to NW	Air pressure rises	Drying and clearing likely; showers on windward slopes, especially along US or Canadian west coast
Increasing winds from from E to SE	Continued air pressure drop; low-pressure system approaching	Winds likely to increase
Winds shift from SW to W	Air pressure rises; high-pressure system approaching	Showers possible along windward slopes, especially along US or Canadian west coast

At night the land cools, and the cool air flows downslope in what is called a gravity wind. Such downslope breezes reach their maximum after midnight, dying out just before sunrise. Camping at the base of a cliff may result in an uncomfortably breezy evening. The more open the slopes between a campsite and the ridge above, the faster the winds will be.

FOEHN WINDS (CHINOOKS)

When winds descend a slope, air temperatures may increase dramatically in what is called a *foehn wind* or, in the western United States, a *chinook*. The air heats as it sinks and compresses on the leeward side of the crest (fig. 28-6), sometimes warming 30 degrees Fahrenheit (17 degrees Celsius) in minutes, melting as much as a foot of snow in a few hours. These winds are significant because of their potential speed, the rapid rise in air temperature associated with them, and the potential they create for both rapid melting of snow and flooding. Such winds can increase the risk of avalanches, weaken snow bridges, and lead to sudden rises in stream levels.

Warning signs make it possible to anticipate a potentially dangerous foehn wind or chinook. Expect such a wind with temperatures warming as much as 6 degrees Fahrenheit per 1,000 feet (3 degrees Celsius per 300 meters) of descent, if these three conditions are met:

1. You are downwind of a major ridge or crest, primarily to the east of mountains.
2. Wind speeds across the crest or ridge exceed 30 miles (48 kilometers) per hour.
3. You observe precipitation above the crest.

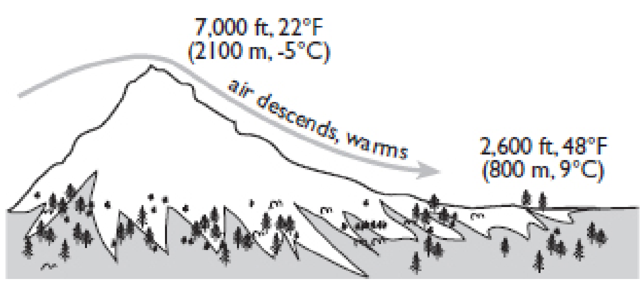

Fig. 28-6. Foehn winds (chinooks) descend and warm quickly.

MAJOR INDICATORS OF AN APPROACHING STORM

- Changes in cloud cover
- Changes in air pressure
- Changes in wind direction
- Changes in wind speed

BORA WINDS

The opposite of a chinook is a *bora* or, as it is called in Greenland, a *piteraq*. A bora is simply wind consisting of air so cold that its sinking, compressing motion as it flows downslope fails to warm it significantly. Such subzero winds are most common downslope of large glaciers. Their speeds can easily exceed 50 miles (80 kilometers) per hour. A bora can blow away tents, throw climbers off balance, lower the windchill to dangerous levels (see "Windchill Index" in Chapter 24, First Aid), and obscure visibility by blowing snow.

FIELD FORECASTING IN THE MOUNTAINS

The process of gathering and evaluating weather data should not end at the trailhead or at the beginning of the climbing route. Changes in weather—which can cause weather-related accidents in the mountains—rarely occur without warning. At times the clues can be subtle, and sometimes they are as broad as daylight (see the "Major Indicators of an Approaching Storm" sidebar).

No single one of the four factors shown in the sidebar will tell you all you need to know; examine each carefully. The rest of this section gives some guidelines for evaluating these elements, which can enhance the weather reports and forecasts climbers obtain before leaving home. Occasionally, such information can also be updated en route via smartphone, although that's subject to coverage and the reliability of the phone app or source. For changes in cloud cover, see Table 28-1; for changes in wind direction and speed, see Table 28-2.

TABLE 28-3. AIR PRESSURE AND/OR ALTIMETER CHANGE OVER 3 HOURS

PRESSURE DECREASE	ALTIMETER INCREASE	ADVISED ACTION
0.02–0.04 inch (0.6–1.2 millibars)	20–40 feet (6–12 meters)	None; continue to monitor
0.04–0.06 inch (1.2–1.8 millibars)	40–60 feet (12–18 meters)	If clouds lowering hourly or thickening,

		begin checking pressure changes hourly
0.06–0.08 inch (1.8-2.4 millibars)	60–80 feet (18–24 meters)	Winds ranging from 18 to 33 knots (21 to 38 miles per hour) likely—consider less-exposed locations, continue monitoring conditions
More than 0.08 inch (more than 2.4 millibars)	More than 80 feet (more than 24 meters)	Winds of 34 knots (40 miles per hour) or greater likely—move immediately to protected area

AIR PRESSURE CLUES

A barometer or barometric altimeter can give excellent warning of an approaching weather system. A barometer measures air pressure directly; a barometric altimeter measures air pressure and reports elevation. A decrease in air pressure shows on an altimeter as an increase in elevation even when the party has not changed its elevation; an increase in air pressure shows on an altimeter as a decrease in elevation, again, even when the party has not changed its elevation. (See "Altimeter" in Chapter 5, Navigation.)

Table 28-3 evaluates a developing low-pressure system, but rapidly building high pressure also can have its troublesome effects—principally, strong winds.

FREEZING LEVEL AND SNOW LEVEL

It can be useful to estimate the freezing level and snow level. Such estimates are subject to error because they are based on the average decrease in temperature as altitude increases: 3.5 degrees Fahrenheit per 1,000 feet (2 degrees Celsius per 304 meters) of elevation gain (see the "Estimating the Freezing Level" sidebar). Still, such estimates are usually better than the alternative: no estimate. Once the freezing level has been estimated, use the guidelines in Table 28-4 to estimate the snow level.

ESTIMATING THE FREEZING LEVEL

To estimate the elevation at which the temperature drops to 32 degrees Fahrenheit, climbers simply need to know their elevation and the temperature in degrees Fahrenheit:

$$\text{your elevation in feet} + \frac{(\text{Fahrenheit temperature} - 32) \times 1000}{3.5} = \text{estimated freezing level}$$

For example:

$$1000 \text{ feet elevation} + \frac{(39 \text{ degrees F} - 32) \times 1000}{3.5} = 1000 \text{ feet} + \frac{7000}{3.5} = 1000 \text{ feet} + 2000 = 3000 \text{ feet}$$

To estimate the elevation at which the temperature drops to 0 degrees Celsius, climbers simply need to know their elevation and the temperature in degrees Celsius:

$$\text{your elevation in meters} + \frac{(\text{camp temperature degrees Celsius}) \times 304}{2} = \text{estimated freezing level}$$

For example:

$$1000 \text{ meters elevation} + \frac{(3 \times 304)}{2} = 1000 \text{ meters} + \frac{912}{2} = 1000 \text{ meters} + 456 = 1456 \text{ meters } (\sim 1500 \text{ meters})$$

TABLE 28-4. ESTIMATING THE SNOW LEVEL

IF	AND IF	THEN
Stratus clouds or fog present	Steady, widespread precipitation	Expect to find the snow level 1,000 feet (304 meters) below the freezing level
Cumulus clouds present or a cold front approaching	Locally heavy precipitation	Expect to find the snow level as much as 2,000 feet (608 meters) below the freezing level; snow will stick 1,000 feet

(304 meters) below the
freezing level

CREATING CUSTOM WEATHER BRIEFINGS

Consider gathering weather information at least one day, and preferably two to three days, before a planned departure. That gives the party a chance to verify the forecasts by observing conditions. If the forecasts are pretty close to what the party actually sees, climbers can proceed with planning with more confidence than if the forecast and observed weather conditions are 180 degrees apart.

TWO TO THREE DAYS BEFORE THE TRIP

- **Check the overall weather pattern:** the positions of highs, lows, and fronts.
- **Check the projected weather forecast** for the next two days.

ONE DAY BEFORE THE TRIP

- **Check the current weather** to evaluate the accuracy of the previous day's forecasts.
- **Check the overall weather pattern again:** the positions of highs, lows, and fronts.
- **Check the projected weather** for the next two days.
- **Check for updates every six to eight hours** if the possibility of strong winds, thunderstorms, or significant snow or rain is mentioned. The lead time on such forecasts is short because of the rapid changes that sometimes occur.

ON THE DAY OF THE TRIP

- **Check the current weather** to evaluate the accuracy of the previous day's forecasts.
- **Check the projected weather** for the trip's duration.
- **Make decisions** based on current forecasts, the track record of earlier forecasts, personal experience, and the demands of the trip.

APPLYING THE INFORMATION

Mountaineers have a rich supply of weather forecast sources available to them before they depart on a trip. Such information gathered with a purpose is of great value. Begin with the vital step of obtaining current forecasts for the locale of the climb, followed by careful observation during the outing. Analyze changes in cloud cover, pressure, and wind speed and direction. Consider all such weather information thoroughly when selecting approach and climbing routes, camp locations, and start and turnaround times. Constant awareness of the environment and its impact on the party's plans will create a greater margin of safety during your pursuit of the freedom of the hills.