Hail is possible with any thunderstorm and can exist as part of the main rain shaft. Hail can also occur many miles from the main rain shaft, especially under the thunderstorm anvil. Pea-sized hail usually will not damage a glider, but hail with a severe storm (3/4 inch diameter or larger) can dent metal gliders or damage the gelcoat on composite gliders, whether on the ground or in the air.

Icing is generally only a problem within a cloud, especially at levels where the outside temperature is around –10°C. Under these conditions, super-cooled water droplets (that is, water droplets existing in a liquid state at below 0°C) can rapidly freeze onto wings and other surfaces. At the beginning of the mature stage, early precipitation below cloud base may be difficult to see. At times, precipitation can even be falling through an updraft feeding the cloud. Snow, graupel, or ice pellets falling from the forming storm above can stick to the leading edge of the wing, causing degradation in performance. Rain on the wings can be a problem since some airfoils can be adversely affected by water.

Poor visibility due to precipitation and possible low ceilings as the air below the thunderstorm is cooled is yet another concern. Even light or moderate precipitation can reduce visibility dramatically. Often, under a precipitating Cb, there is no distinction between precipitation and actual cloud.

Lightning in a thunderstorm occurs in-cloud, cloud-to-cloud (in the case of other nearby storms, such as a multicell storm), or cloud-to-ground. Lightning strikes are completely unpredictable, and cloud-to-ground strikes are not limited to areas below the cloud. Some strikes emanate from the side of the Cb and travel horizontally for miles before turning abruptly towards the ground. In-flight damage to gliders has included burnt control cables and blown off canopies. In some cases, strikes have caused little more than mild shock and cosmetic damage. On the other extreme, a composite training glider in Great Britain suffered a strike that caused complete destruction of one wing; fortunately, both pilots parachuted to safety. In that case, the glider was two or three miles from the thunderstorm. Finally, ground launching, especially with a metal cable, anywhere near a thunderstorm should be avoided.

Severe thunderstorms can sometimes spawn tornadoes, which are rapidly spinning vortices, generally a few hundred to a few thousand feet across. Winds can exceed 200 mph. Tornadoes that do not reach the ground are called funnel clouds. By definition, tornadoes form from severe thunderstorms. Obviously, they should be avoided on the ground or in the air.

WEATHER FOR SLOPE SOARING

Slope or ridge soaring refers to using updrafts produced by the mechanical lifting of air as it encounters the upwind slope of a hill, ridge, or mountain. Slope soaring requires two ingredients: elevated terrain and wind.

Slope lift is the easiest lift source to visualize. When it encounters topography, wind is deflected either horizontally, vertically, or in some combination of the two. Not all topography produces good slope lift. Individual or isolated hills do not produce slope lift because the wind tends to deflect around the hill, rather than over it. A somewhat broader hill with a windward face at least a mile or so long, might produce some slope lift, but the lift will be confined to a small area. The best ridges for slope soaring are at least a few miles long.

Slope lift can extend to a maximum of two or three times the ridge height. However, the pilot may only be able to climb to ridge height. As a general rule, the higher the ridge above the adjacent valley, the higher the glider pilot can climb. Ridges only one or two hundred feet high can produce slope lift. The problem with very low ridges is maintaining safe maneuvering altitude, as well as sufficient altitude to land safely in the adjacent valley. Practically speaking, 500 to 1,000 feet above the adjacent valley is a minimum ridge height. [Figure 9-22]

In addition to a ridge being long and high enough, the windward slope needs to be steep enough as well. An ideal slope is on the order of 1 to 4. Shallower slopes do not create a vertical wind component strong enough to compensate for the glider's sink rate. Very steep, almost vertical slopes, on the other hand, may not be

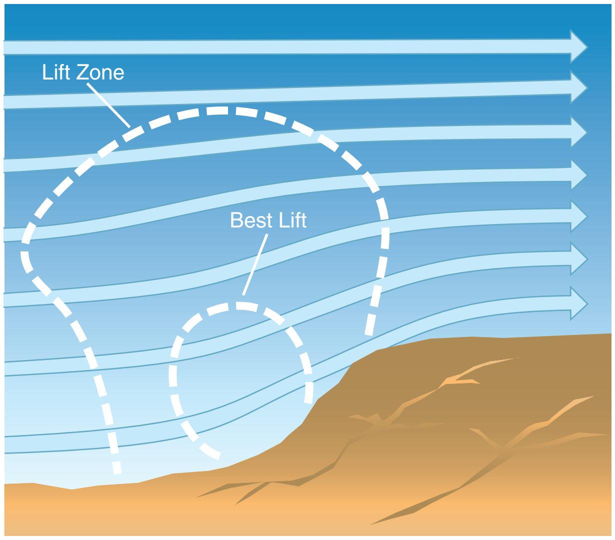

Figure 9-22. Slope soaring.

ideal either. Such slopes create slope lift, but can produce turbulent eddies along the lower slope or anywhere close to the ridge itself. In such cases, only the upper part of the slope may produce updrafts, although steeper slopes do allow a quick escape to the adjacent valley. [Figure 9-23]

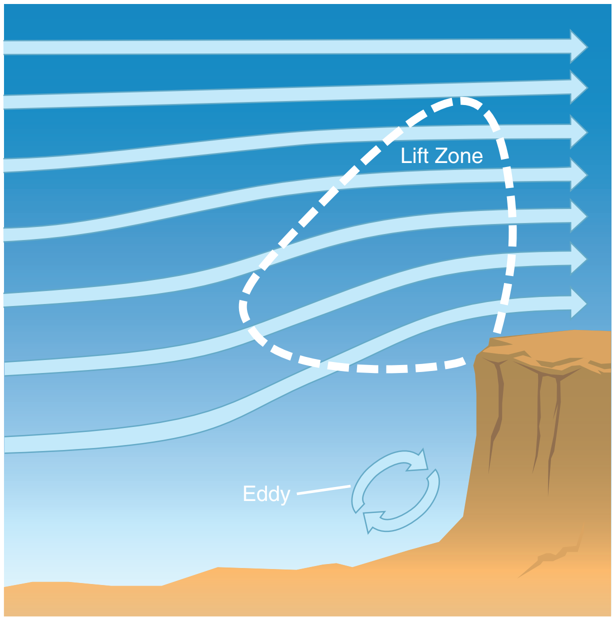

Figure 9-23. Slope lift and eddy with near-vertical slope.

A ridge upstream can block the wind flow, so that no low-level flow occurs upwind of an otherwise promising ridge, and hence no updraft. Additionally, if lee waves are produced by an upstream ridge or mountain, slope lift can be enhanced or destroyed, depending on the wavelength of the lee waves. Locally, the downdraft from a thermal just upwind of the ridge can cancel the slope lift for a short distance. The bottom line: never assume slope lift is present. Always have an alternative.

Just as the flow is deflected upward on the windward side of a ridge, it is deflected downward on the lee side of a ridge.[Figure 9-24] This downdraft can be alarmingly strong—up to 2,000 fpm or more near a steep ridge with strong winds (A). Even in moderate winds, the downdraft near a ridge can be strong enough to make penetration of the upwind side of the ridge impossible. Flat-topped ridges also offer little refuge, since sink and turbulence can combine to make an upwind penetration impossible (B). Finally, an uneven upwind slope, with ledges or "steps," require extra caution since small-scale eddies along with turbulence and sink can form there (C).

Three-dimensional effects are important as well. For instance, a ridge with cusps or bowls may produce better lift in upwind-facing bowls if the wind is at an angle from the ridge. However, sink may be encountered on the lee side of the bowl. If crossing ridges in windy conditions, always plan for heavy sink on the lee side and make sure an alternative is available. [Figure 9-25]

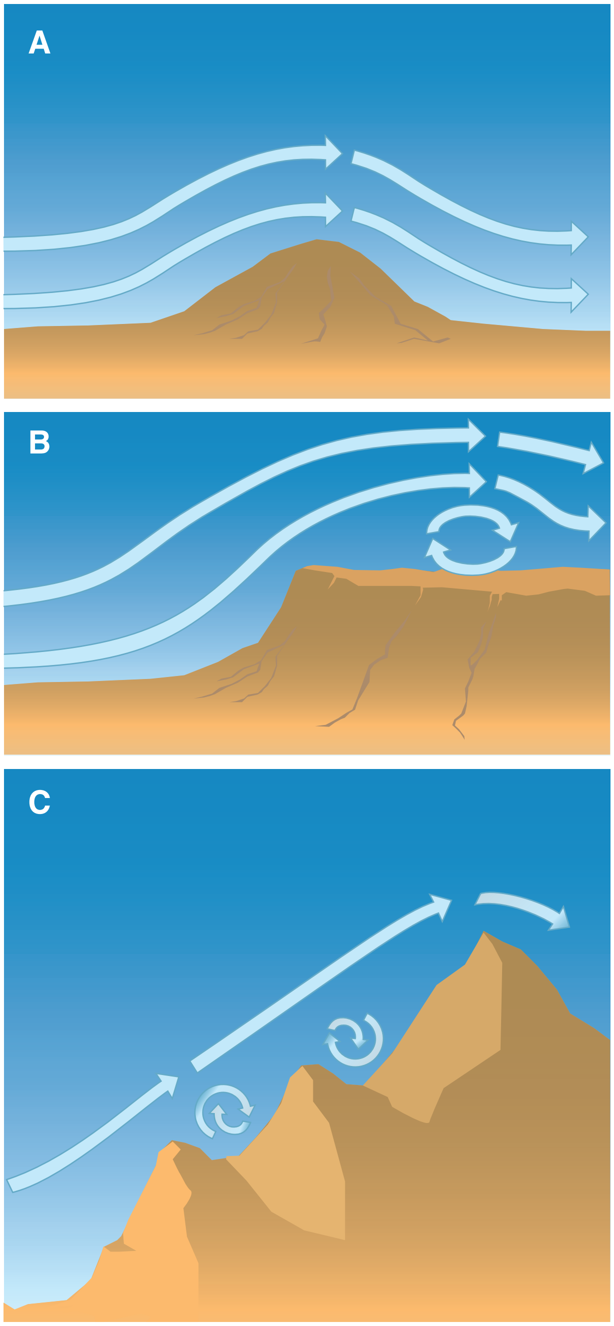

Figure 9-24. Airflow along different ridges.

Depending on the slope, wind speed should be 10-15 knots and blowing nearly perpendicular to the ridge. Wind directions up to 30° or 40° from perpendicular may still produce slope lift. Vertical wind shear is also a consideration. High ridges may have little or no wind along the lower slopes, but the upper parts of the ridge may be in winds strong enough to produce slope lift there.

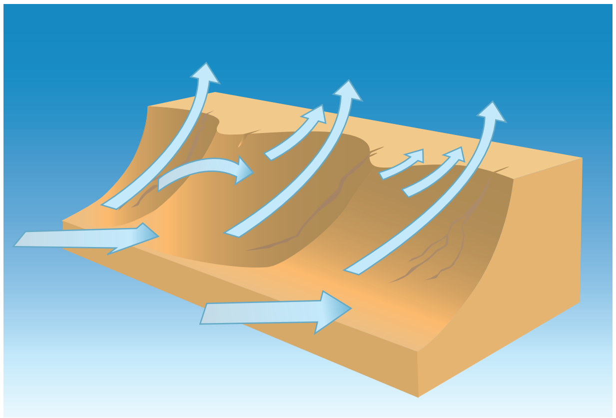

Figure 9-25. Three-dimensional effects of oblique winds and bowls.

The area of best lift varies with height. Below the ridge crest, the best slope lift is found within a few hundred feet next to the ridge, again depending on the slope and wind strength. As mentioned, very steep ridges require extra speed and caution, since eddies and turbulence can form even on the upwind side. Above the ridge crest, the best lift usually is found further upwind from the ridge the higher one climbs. [Figure 9-22]

When the air is very stable, and the winds are sufficient but not too strong, slope lift can be very smooth, enabling safe soaring close to the terrain. If the air is not stable, thermals may flow up the slope. Depending on thermal strength and wind speed, the thermal may rise well above the ridge top, or it may drift into the lee downdraft and break apart. Downdrafts on the sides of thermals can easily cancel the slope lift; hence, extra speed and caution is required when the air is unstable, especially below the ridge crest near the terrain. The combination of unstable air and strong winds can make slope soaring unpleasant or even dangerous for the beginning glider pilot.

Moisture must be considered. If air rising in the slope lift is moist and cools sufficiently, a so-called cap cloud may form. The cloud may form above the ridge, and if the air moistens more with time, the cloud will slowly lower onto the ridge and down the upwind slope, limiting the usable height of the slope lift. Since the updraft forms the cloud, it is very easy to climb into the cap cloud—obviously a dangerous situation. Under certain conditions, a morning cap cloud may rise as the day warms, then slowly lower again as the day cools.

WAVE SOARING WEATHER

Where there is wind and stable air, there is the likelihood of waves in the atmosphere. Most of the waves that occur throughout the atmosphere are of no use to the glider pilot. However, often mountains or ridges produce waves downstream, the most powerful of which have lifted gliders to 49,000 feet. Indirect measurements show waves extending to heights around 100,000 feet. If the winds aloft are strong and widespread enough, mountain lee waves can extend the length of the mountain range. Pilots have achieved flights in mountain wave using three turn points of over 2,000 km. Another type of wave useful to soaring pilots is generated by thermals, which were discussed in the previous section.

A common analogy to help visualize waves created by mountains or ridges uses water flowing in a stream or small river. A submerged rock will cause ripples (waves) in the water downstream, which slowly dampen out. This analogy is useful, but it is important to realize that the atmosphere is far more complex, with vertical shear of the wind and vertical variations in the stability profile. Wind blowing over a mountain will not always produce downstream waves.

Mountain wave lift is fundamentally different from slope lift. Slope soaring occurs on the upwind side of a ridge or mountain, while mountain wave soaring occurs on the downwind side. (Mountain wave lift sometimes tilts upwind with height. Therefore, at times near the top of the wave, the glider pilot may be almost directly over the mountain or ridge that has produced the wave). The entire mountain wave system is also more complex than the comparatively simple slope soaring scenario.

MECHANISM FOR WAVE FORMATION

Waves form in stable air when a parcel is vertically displaced and then oscillates up and down as it tries to return to its original level, illustrated in Figure 9-26. In the first frame, the dry parcel is at rest at its equilibrium level. In the second frame, the parcel is displaced upward along a DALR, at which point it is cooler than the surrounding air. The parcel accelerates downward toward its equilibrium level, but due to momentum, it overshoots the level and keeps going down. The third frame shows that the parcel is now warmer than the surrounding air, and thus starts upward again. The process continues with the motion damping out. The number of oscillations depends on the initial parcel displacement and the stability of the air. In the lower part of the figure, wind has been added, illustrating the wave pattern that the parcel makes as it oscillates vertically. If there were no wind, a vertically displaced parcel would just oscillate up and down, while slowly damping, at one spot over the ground, much like a spring. [Figure 9-26]

The lower part of Figure 9-26 also illustrates two important features of any wave. The **wavelength** is the horizontal distance between two adjacent wave crests. Typical mountain wavelengths vary considerably, between 2 and 20 miles. The **amplitude** is half the vertical distance between the trough and crest of the wave. Amplitude varies with altitude and is smallest

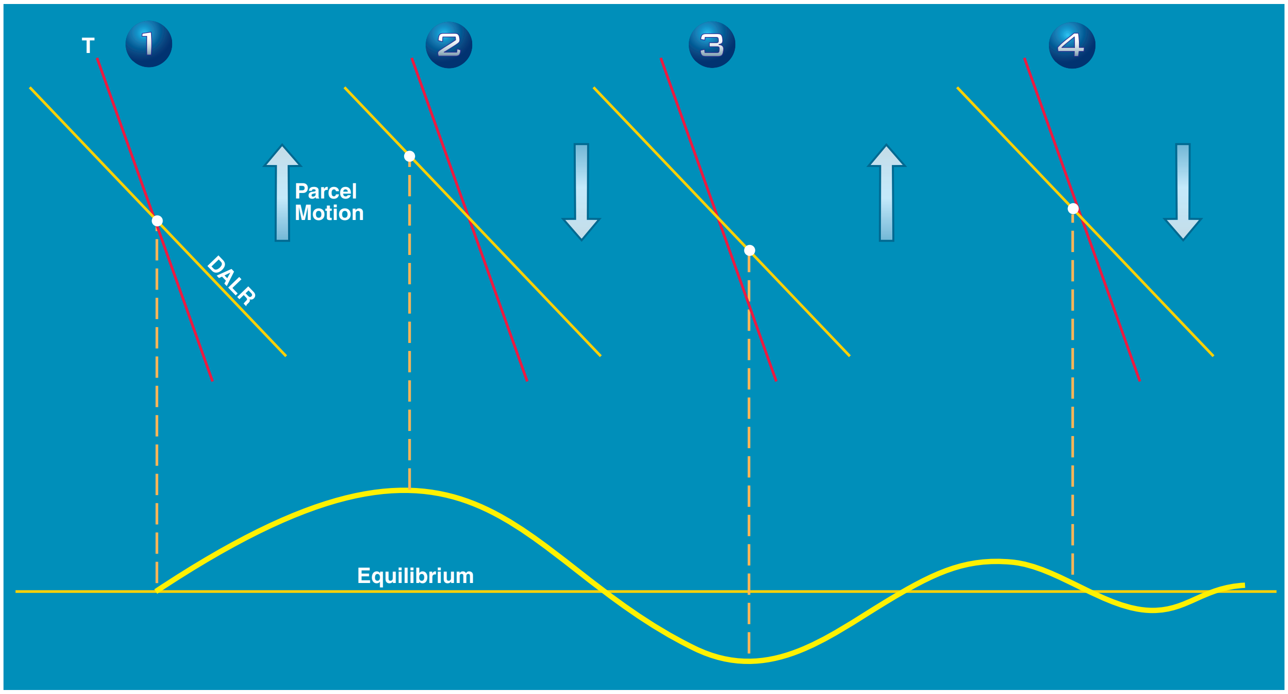

Figure 9-26. Parcel displaced vertically and oscillating around its equilibrium level.

near the surface and at upper levels. As a note, mountain lee waves are sometimes simply referred to as mountain waves, lee waves, and sometimes, standing waves.

In the case of mountain waves, it is the airflow over the mountain that displaces a parcel from its equilibrium level. This leads to a two-dimensional conceptual model, which is derived from the experience of many glider pilots along with post-flight analysis of the weather conditions. Figure 9-27 illustrates a mountain with wind and temperature profiles. Note the increase in wind speed (blowing from left to right) with altitude and a stable layer near mountaintop with less stable air above and below. As the air flows over the mountain, it descends the lee slope (below its equilibrium level if the air is stable) and sets up a series of oscillations downstream. The wave flow itself is usually incredibly smooth. Beneath the smooth wave flow is what is known as a low-level turbulent zone, with an imbedded rotor circulation under each crest. Turbulence, especially within the individual rotors is usually moderate to severe, and on occasion can become extreme. [Figure 9-27]

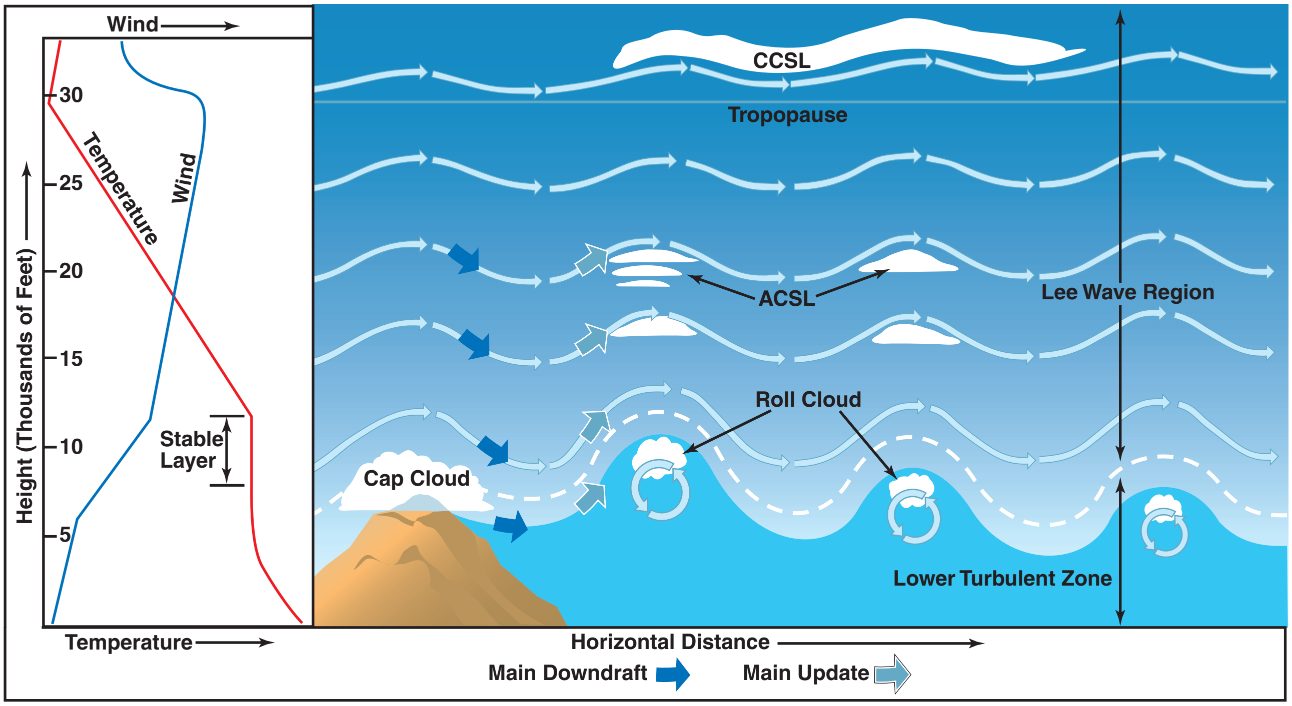

Figure 9-27. Mountain lee wave system.

This conceptual model is often quite useful and representative of real mountain waves, but many exceptions exist. For instance, variations to the conceptual model occur when the topography has many complex, three-dimensional features, such as individual higher peak, large ridges or spurs at right angles to the main range. Variations can occur when a north-south range curving to become oriented northeast-southwest. In addition, numerous variations of the wind and stability profiles are possible.

Turbulence associated with lee waves deserves respect. Low-level turbulence can range from unpleasant too dangerous. Glider pilots refer to any turbulence under the smooth wave flow above as **“rotor”**. The nature of rotor turbulence varies from location to location as well as with different weather regimes. At times, rotor turbulence is widespread and fairly uniform, that is, it is equally rough everywhere below the smooth wave flow. At other times, uniformly moderate turbulence is found, with severe turbulence under wave crests. On occasion, no discernable turbulence is noted except for moderate or severe turbulence within a small-scale rotor under the wave crest. Typically, the worst turbulence is found on the leading edge of the primary rotor. Unfortunately, the type and intensity of rotor turbulence is difficult to predict. However, the general rule of thumb is that higher amplitude lee waves tend to have stronger rotor turbulence.

Clouds associated with the mountain wave system are also indicated in Figure 9-27. A **cap cloud** flowing over the mountain tends to dissipate as the air forced down the mountain slope warms and dries. The first (or primary) wave crest features a roll or rotor cloud with one or more **lenticulars** (or lennies using glider terminology) above. Wave harmonics further downstream (secondary, tertiary, etc.) may also have lennies and/or rotor clouds. If the wave reaches high enough altitudes, lennies may form at cirrus levels as well. It is important to note that the presence of clouds depends on the amount of moisture at various levels. The entire mountain wave system can form in completely dry conditions with no clouds at all. If only lower level moisture exists, only a cap cloud and rotor clouds may be seen with no lennies above as in Figure 9-28(A). On other days, only mid-level or upper-level lennies are seen with no rotor clouds beneath them. When low and mid levels are very moist, a deep rotor cloud may form, with lennies right on top of the rotor cloud, with no clear air between the two cloud forms. In wet climates, the somewhat more moist air can advect in, such that the gap between the cap cloud and primary rotor closes completely, stranding the glider on top of the clouds (B). Caution is required when soaring above clouds in very moist conditions.

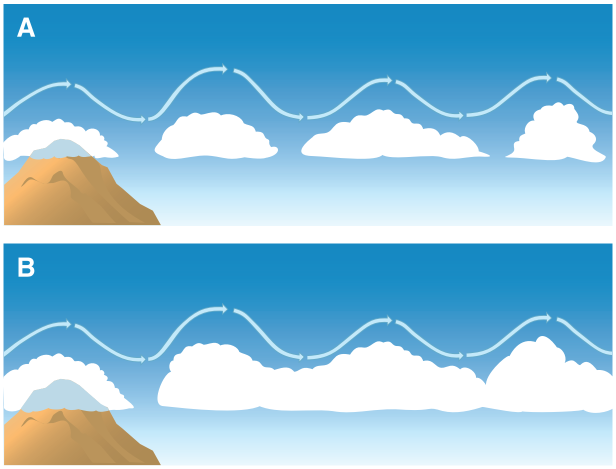

Figure 9-28. Small Foehn Gap under most conditions.

Suitable terrain is required for mountain wave soaring. Even relatively low ridges of 1,000 feet or less vertical relief can produce lee waves. Wave amplitude depends partly on topography shape and size. The shape of the lee slope, rather than the upwind slope is important. Very shallow lee slopes are not conducive to producing waves of sufficient amplitude to support a glider. A resonance exists between the topography width and lee wavelength that is difficult to predict. One particular mountain height, width, and lee slope is not optimum under all weather conditions. Different wind and stability profiles favor different topography profiles. Hence, there is no substitute for experience at a particular soaring site when predicting wave-soaring conditions. Uniform height of the mountaintops along the range is also conducive to better-organized waves.

The weather requirements for wave soaring include sufficient wind and a proper stability profile. Wind speed should be at least 15 to 20 knots at mountaintop level with increasing winds above. The wind direction should be within about 30° of perpendicular to the ridge or mountain range. The requirement of a stable layer near mountaintop level is more qualitative. A sounding showing a DALR, or nearly so, near the mountaintop would not likely produce lee waves even with adequate winds. A well-defined inversion at or near the mountaintop with less stable air above is best.

Weaker lee waves can form without much increase in wind speed with height, but an actual decrease in wind speed with height usually caps the wave at that level. When winds decrease dramatically with height, for instance, from 30 to 10 knots over two or three thousand feet, turbulence is common at the top of the wave. On some occasions, the flow at mountain level may be sufficient for wave, but then begins to decrease with altitude just above the mountain, leading to a phenomenon called “**rotor streaming**.” In this case, the air downstream of the mountain breaks up and becomes turbulent, similar to rotor, with no lee waves above.

Lee waves experience **diurnal effects**, especially in the spring, summer, and fall. Height of the topography also influences diurnal effects. For smaller topography, as morning leads to afternoon, and the air becomes unstable to heights exceeding the wave-producing topography, lee waves tend to disappear. On occasion, the lee wave still exists but more height is needed to reach the smooth wave lift. Toward evening as thermals again die down and the air stabilizes, lee waves may again form. During the cooler season, when the air remains stable all day, lee waves are often present all day, as long as the winds aloft continue. The daytime dissipation of lee waves is not as notable for large mountains. For instance, during the 1950s Sierra Wave Project, it was found that the wave amplitude reached a maximum in mid- to late afternoon, when convective heating was a maximum. Rotor turbulence also increased dramatically at that time.

Topography upwind of the wave-producing range can also create problems, as illustrated in Figure 9-29. In the first case (A), referred to as destructive interference, the wavelength of the wave from the first range is out of phase with the distance between the ranges. Lee waves do not form downwind of the second range despite winds and stability aloft being favorable. In the second case (B), referred to as constructive interference, the ranges are in phase, and the lee wave from the second range has a larger amplitude than it might otherwise.

Isolated small hills or conical mountains do not form "classic" lee waves. In some cases, they do form waves emanating at angle to the wind flow similar to water waves created by the wake of a ship. A single peak may only require a mile or two in the dimension perpendicular to the wind for high-amplitude lee waves to form, though the wave lift will be confined to a relatively small area in these cases.

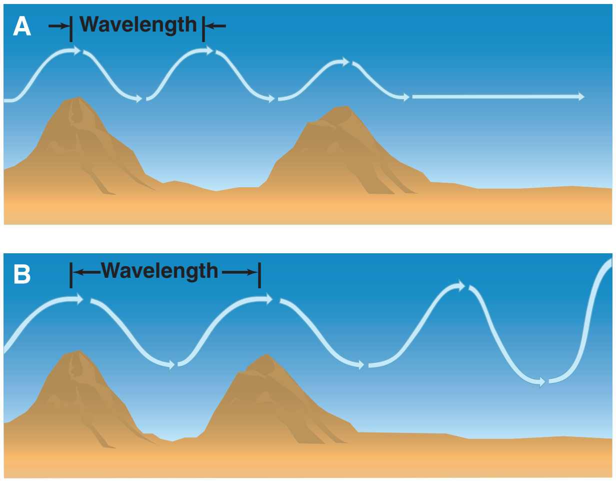

Figure 9-29. Constructive and destructive interference.

LIFT DUE TO CONVERGENCE

Convergence lift is most easily imagined as easterly and westerly winds meet. When the air advected by the two opposing winds meet, it must go up. Air does not need to meet "head on" to go up, however. Wherever air piles up, it leads to convergence and rising air. [Figure 9-30]

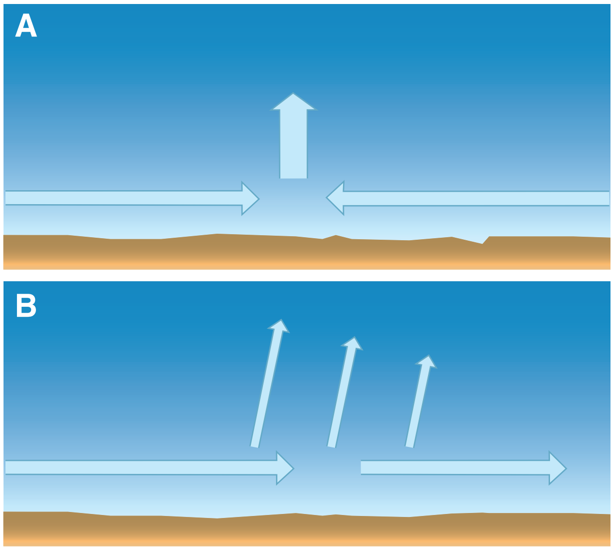

Figure 9-30. Convergence examples. (A) Wind from different directions. (B) Wind slows and "piles up."

Examples of converging air leading to rising air have already been discussed though not specifically referred to as convergence. In Figure 9-17, convergence along the outflow leads to air rising into the multi-cell thunderstorm. In Figure 9-13, the circulation associated with cloud streets leads to convergence under the cumulus. A synoptic-scale example of convergence is found along cold fronts. Convergence can occur along distinct, narrow lines (convergence or shear lines), as in Figure 9-30 (A), or can cause lifting over an area several miles across (**convergence zones**), as in Figure 9-30 (B). At times convergence lines produce steady lift along a line many miles long, while at other times they simply act as a focus for better and more frequent thermals.

One type of convergence line commonly found near coastal areas is the so-called sea-breeze front. Inland areas heat during the day, while the adjacent sea maintains about the same temperature. Inland heating leads to lower pressure, drawing in cooler sea air. As the cooler air moves inland, it behaves like a miniature shallow cold front, and lift forms along a convergence line. Sometimes consistent lift can be found along the sea-breeze front while at other times it acts as a trigger for a line of thermals. If the inland air is quite unstable, the sea-breeze front can act as a focus for a line of thunderstorms. Additionally, since the air on the coast side of the sea-breeze front is rather cool, passage of the front can spell the end of thermal soaring for the day.

Sea air often has a higher dew point than drier inland air. As shown in Figure 9-31, a "curtain" cloud sometimes forms, marking the area of strongest lift. Due to the mixing of different air along the sea-breeze front, at times the lift can be quite turbulent. At other times, weak and fairly smooth lift is found.

Several factors influence the sea-breeze front character (e.g., turbulence, strength, and speed of inland penetration, including the degree of inland heating and the land/sea temperature difference). For instance, if the land/sea temperature difference at sunrise is small and overcast cirrus clouds prevent much heating; only a weak sea-breeze front, if any, will form. Another factor is the synoptic wind flow. A weak synoptic onshore flow may cause quicker inland penetration of the sea-breeze front, while a strong onshore flow may prevent the sea-breeze front from developing at all. On the other hand, moderate offshore flow will generally prevent any inland penetration of the sea-breeze front.

Other sources of convergence include thunderstorm outflow boundaries already mentioned. Since this type of convergence occurs in an overall unstable environment, it can quickly lead to new thunderstorms. More subtle convergence areas form the day after ordinary thunderstorms have formed. If an area has recently been subject to spotty heavy rains, wet areas will warm more slowly than adjacent dry areas. The temperature contrast can give rise to a local convergence line, which acts similar to a sea-breeze front, and may be marked by a line of cumulus.

Convergence can also occur along and around mountains or ridges. In Figure 9-32(A), flow is deflected around a ridgeline and meets as a convergence line on the lee side of the ridge. The line may be marked by cumulus or a boundary with a sharp visibility contrast. The latter occurs if the air coming around one end of the ridge flows past a polluted urban area such as in the Lake Elsinore soaring area in southern California. In very complex terrain, with ridges or ranges oriented at different angles to one another, or with passes between high peaks, small-scale convergence zones can be found in adjacent valleys depending on wind strength and direction. Figure 9-32(B) illustrates a smaller-scale convergence line flowing around a single hill or peak and forming a line of lift stretching downwind from the peak.

Convergence also can form along the top of a ridgeline or mountain range. In Figure 9-33, drier synoptic-scale winds flow up the left side of the mountain, while a more moist valley breeze flows up the right side of the slope. The two flows meet at the mountain top and form lift along the entire range. If cloud is present, the air from the moist side condenses first often forming one cloud with a well-defined "step," marking the convergence zone.

As a final example, toward evening in mountainous terrain as heating daytime abates, a cool **katabatic** or drainage wind flows down the slopes. The flow down the slope converges with air in the adjacent valley to form an area of weak lift. Sometimes the convergence is not strong enough for general lifting, but acts as a trigger for the last thermal of the day. In narrow valleys, flow down the slope from both sides of the valley can converge and cause weak lift. [Figure 9-34]

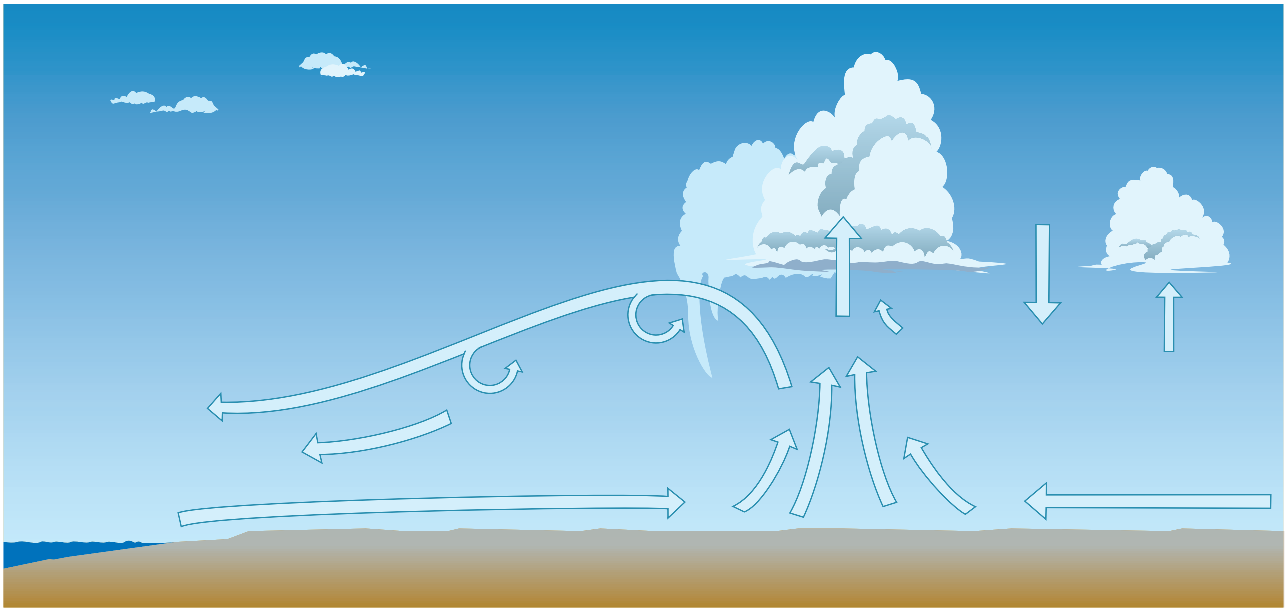

Figure 9-31. Sea-breeze front.

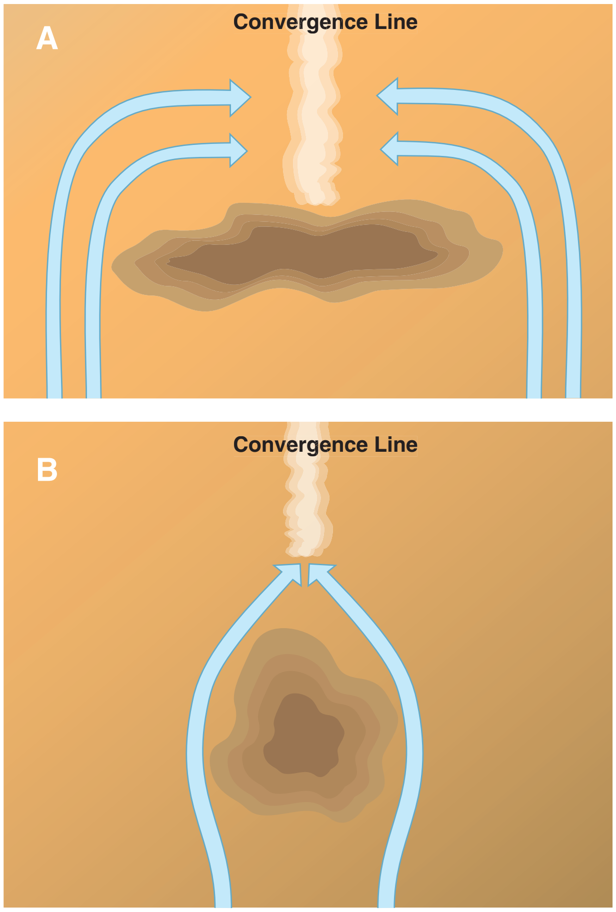

Figure 9-32. Convergence induced by flow around topography.

Many local sites in either flat or mountainous terrain have lines or zones of lift that are likely caused or enhanced by convergence. Chapter 10–Soaring Techniques covers locating and using convergence.

OBTAINING WEATHER INFORMATION

One of the most important aspects of flight planning is obtaining reliable weather information. Fortunately, pilots have several outlets to receive reliable weather reports and forecasts to help them determine if a proposed flight can be completed safely. For VFR flights, federal regulations only require pilots to gather weather reports and forecasts if they plan to depart the airport vicinity. Nevertheless, it is always a good idea to be familiar with the current and expected weather anytime a flight is planned. Preflight weather information sources include Automated Flight Service Stations (AFSS) and National Weather Service (NWS) telephone briefers, the Direct User Access Terminal System (DUATS), and the Internet. In addition, a multitude of commercial venders provide custom services.

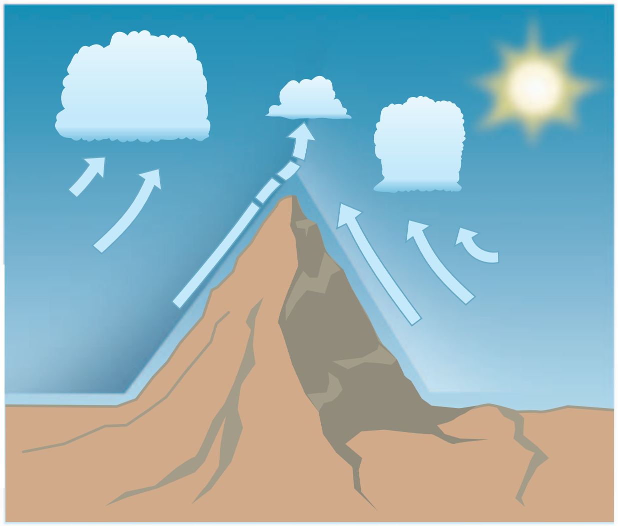

Figure 9-33. Mountain-top convergence.

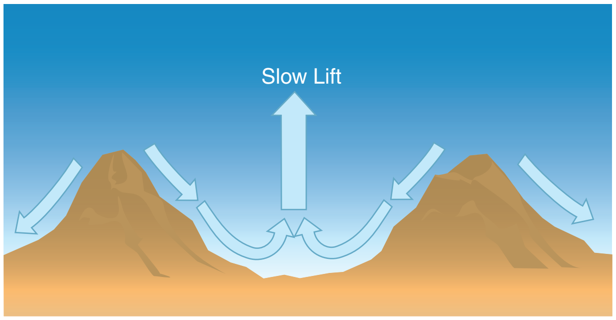

Figure 9-34. Convergence induced by flow around topography.

The following pages give a comprehensive synopsis of available weather services and products. For complete details, refer to the current version of AC 00-45, *Aviation Weather Services*.

AUTOMATED FLIGHT SERVICE STATIONS

Automated flight service stations (AFSS) are a primary source of preflight weather information. A briefing can be obtained from an AFSS, 24 hours a day by calling the toll free number, 1-800-WX BRIEF. The National Weather Service may also provide pilot weather briefings. Telephone numbers for NWS facilities and additional numbers for AFSSs can be found in the *Airport/Facility Directory* (A/FD) or the U.S. Government section of the telephone directory under Department of Transportation, Federal Aviation Administration, or Department of Commerce, National Weather Service.

PREFLIGHT WEATHER BRIEFING

To obtain a briefing, certain background information must be supplied to the weather specialist: type of flight planned (VFR or IFR), aircraft number or pilot's name, aircraft type, departure airport, route of flight, destination, flight altitude(s), estimated time of departure (ETD), and estimated time enroute (ETE). At many gliderports the operator or dispatcher will obtain the weather reports and forecasts from the AFSS or NWS at various times throughout the day and post them on a bulletin board for easy reference.

time. Just as the mechanics of simply flying the glider become second nature with practice, so do thermalling techniques. Expect to land early because anticipated lift was not there on occasion—it is part of the learning curve.

If **thermal waves** are suspected, climb in the thermal near cloud base, then head toward the upwind side of the Cu. Often, only very weak lift, barely enough to climb at all, is found in smooth air upwind of the cloud. Once above cloud base and upwind of the Cu, climb rates of a few hundred fpm can be found. Climbs can be made by flying back and forth upwind of an individual Cu, or by flying along cloud streets if they exist. If no clouds are present, but waves are suspected, climb to the top of the thermal and penetrate upwind in search of smooth, weak lift. Without visual clues, thermal waves are more difficult to work. Thermal waves are most often stumbled upon as a pleasant surprise when their presence is furthest from the pilot's mind.

RIDGE AND SLOPE SOARING

Efficient slope soaring (also called ridge soaring) is fairly easy; simply fly in the updraft along the upwind side of the ridge (see Figure 9-20). The horizontal distance from the ridge will vary with height above the ridge, since the best lift zone tilts upwind with height above the ridge. Even though the idea is simple, traps exist for both new and expert glider pilots. Obtain instruction when first learning to slope soar.

Avoid approaching from the upwind side perpendicularly to the ridge. Instead, approach the ridge at a shallower angle, so that a quick egress away from the ridge is possible should lift not be contacted. While flying along the ridge, a crab angle is necessary to avoid drifting too close to the ridge or, if gliding above the ridge, to avoid drifting over the top into the lee-side downdraft. For the new glider pilot, crabbing along the ridge may be a strange sensation, and it is easy to become uncoordinated while trying to point the nose along the ridge. This is both inefficient and dangerous, since it leads to a skid toward the ridge. [Figure 10-14]

In theory, to obtain the best climb, it is best to slope soar at minimum sink speed. However, flying that slowly may be unwise for two reasons. First, minimum sink speed is relatively close to stall speed, and flying close to stall speed near terrain has obvious dangers. Second, maneuverability at minimum sink speed may be inadequate for proper control near terrain, especially if the wind is gusty and/or thermals are present. When gliding at or below ridge top height, fly faster than minimum sink speed—how much faster depends on the glider, terrain, and turbulence. When the glider is at least several hundred feet above the ridge and shifting upwind away from it in the best lift zone, reduce speed. If in doubt, fly faster!

Slope soaring comes with several procedures to enable safe flying and to allow many gliders on the same ridge. The rules are:

1. make all turns away from the ridge;
2. do not fly directly above or below another glider;
3. pass another glider on the ridge side, anticipating that the other pilot will make a turn away from the ridge; and
4. the glider with its right side to the ridge has the right of way. [Figure 10-15]

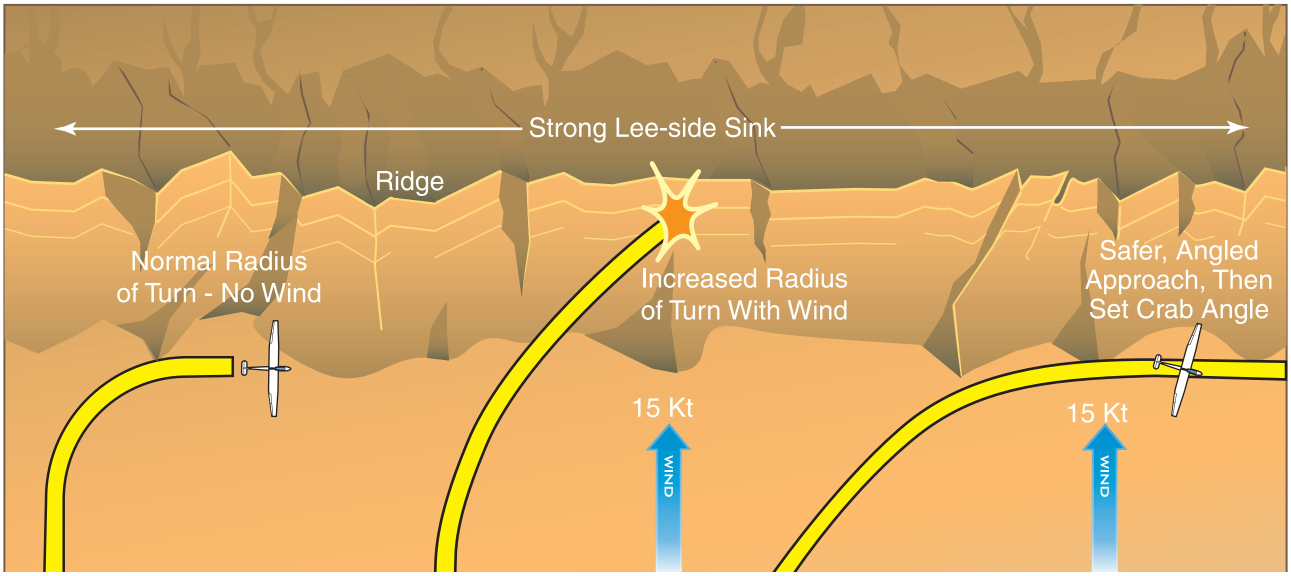

Figure 10-14. Flying with a wind increases the turn radius over the ground, so approach the ridge at a shallow angle.

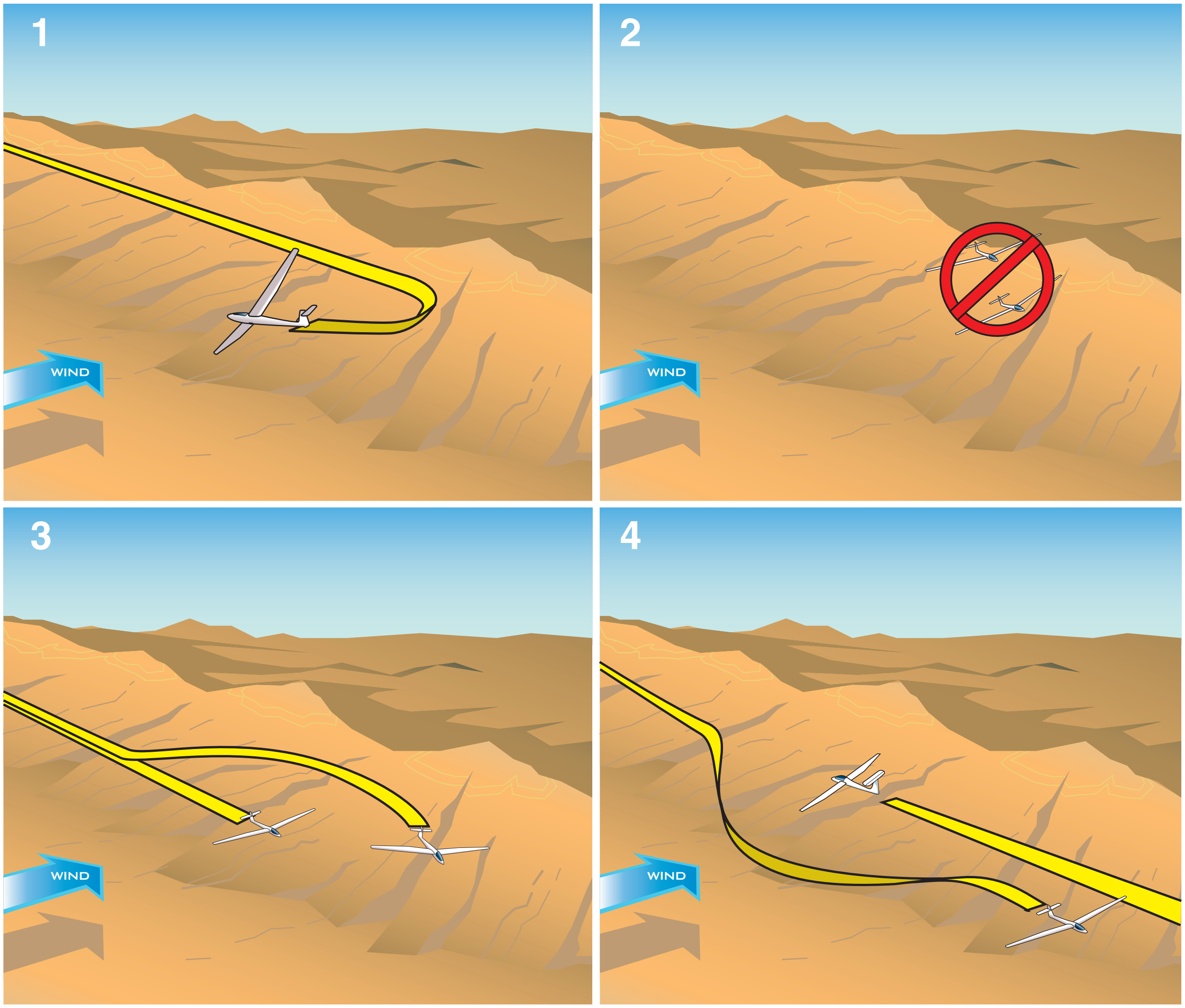

Figure 10-15. Ridge rules.

These procedures deserve some comment.

Procedure #1: A turn toward the ridge is dangerous, even if gliding seemingly well away from the ridge. The ground speed on the downwind portion of the turn will be difficult to judge properly, and striking the ridge is a serious threat. Even if above the ridge, it will be easy to finish the turn downwind of the ridge in heavy sink.

Procedure #2: Gliders spaced closely together in the vertical are in each other's blind spots. A slight change in climb-rate between the gliders can lead to a collision.

Procedure #3: Sometimes the glider to be passed is so close to the ridge that there is inadequate space to pass between the glider and the ridge. In that case, either turn back in the other direction (away from the ridge) if traffic permits, or fly upwind away from the ridge and rejoin the slope lift as traffic allows. When soaring outside of the United States, be aware that this rule may differ.

Procedure #4: Federal Aviation Regulations call for aircraft approaching head-on to both give way to the right. A glider with the ridge to the right may not have room to move in that direction. The glider with its left side to the ridge should give way. When piloting the glider with its right side to the ridge, make sure the approaching glider sees you and is giving way in plenty of time. In general, gliders approaching head-on are difficult to see; therefore, extra vigilance is needed to avoid collisions while slope soaring.

If the wind is at an angle to the ridge, bowls or spurs extending from the main ridge can create better lift on the upwind side and sink on the downwind side. If at or near the height of the ridge, it may be necessary to detour around the spur to avoid the sink, then drift back into the bowl to take advantage of the better lift. After passing such a spur, do not make abrupt turns toward the ridge (Rule #1), and as always, consider what the general flow of traffic is doing. If soaring hundreds of feet above a spur, it may be possible to fly over it and increase speed in any sink. This requires caution, since a thermal in the upwind bowl, or even an imperceptible increase in the wind, can cause greater than anticipated sink on the downwind side. Always have an escape route or, if in any doubt, detour around. [Figure 10-16]

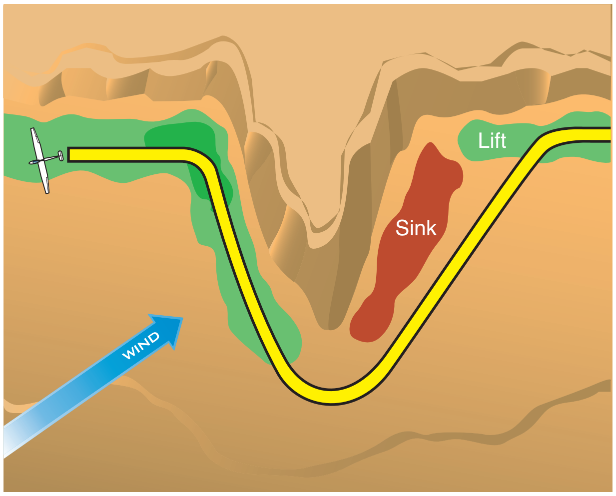

Figure 10-16. Avoid sink on the downwind side of spurs by detouring around them.

It is not uncommon for thermals to exist with slope lift. Indeed, slope soaring can often be used as a "save" when thermals have temporarily shut down. Working thermals from slope lift requires special techniques. When a thermal is encountered along the ridge, a series of S-turns can be made into the wind. Drift back to the thermal after each turn if needed and, of course, never continue the turn to the point that the glider is turning toward the ridge. Speed is also important, since it is easy to encounter strong sink on the sides of the thermal. It is very likely that staying in thermal lift through the entire S-turn is not possible. The maneuver takes practice, but when done properly, a rapid climb in the thermal can be made well above the ridge crest, where thermalling turns can begin. Even when well above the ridge, caution is needed to ensure the climb is not too slow as to drift into the lee-side sink. Before trying S-turns make sure it will not interfere with other traffic along the ridge. [Figure 10-17]

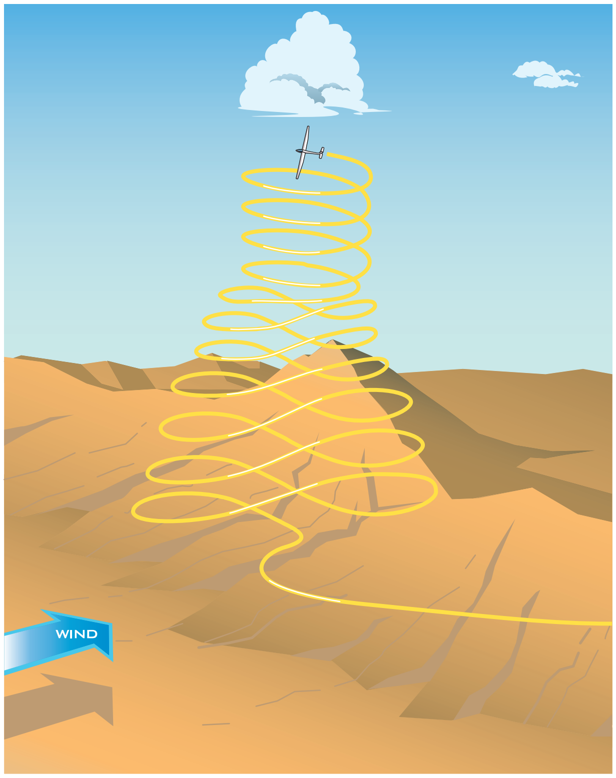

Figure 10-17. One technique for catching a thermal from ridge lift.

A second technique for catching thermals when slope soaring is to head upwind away from the ridge. This works best when Cu mark potential thermals and aide timing. If no thermal is found, the pilot should cut the search short while still high enough to dash back downwind to the safety of the slope lift. [Figure 10-18]

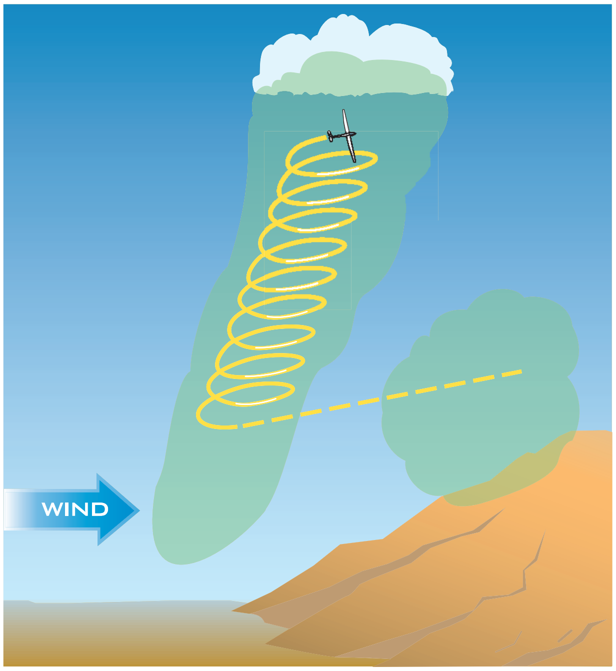

Figure 10-18. Catching a thermal by flying upwind away from the slope lift.

As a final note, caution is also needed to avoid obstructions when slope soaring. These primarily include wires, cables, and power lines, all of which are very difficult to see. Aeronautical charts show high-tension towers that, of course, have many wires between them. Soaring pilots familiar with the area should be able to provide useful information on any problems with the local ridge.

WAVE SOARING

Almost all high-altitude flights are made using mountain lee waves. As covered in Chapter 9—Soaring Weather, lee wave systems can contain tremendous turbulence in the rotor, while the wave flow itself is usually unbelievably smooth. In more recent years, the use of lee waves for cross-country soaring has lead to flights exceeding 1,500 miles, with average speeds over 100 mph. [Figure 10-19]

PREFLIGHT PREPARATION

The amount of preflight preparation depends on the height potential of the wave itself. Let us assume that the pilot is planning a flight above 18,000 feet MSL during the winter. (Pilots planning wave flights to much lower altitudes can reduce the list of preparation items accordingly.)

For flights above 14,000 feet MSL, the CFRs state that required crewmembers must use supplemental oxygen. Pilots must be aware of their own physiology; however, it may be wise to use oxygen at altitudes well below 14,000 feet MSL. In addition, signs of hypoxia should be known. The U.S. Air Force in cooperation with the FAA provides a one-day, high-altitude orientation and chamber ride for civilian pilots. The experience is invaluable for any pilot contemplating high altitude soaring and is even required by many clubs and operations as a prerequisite. Before any wave flight, it is important to be thoroughly familiar with the specific oxygen system that will be used, as well as its adequacy for potential heights. The dangers of oxygen deprivation should not be taken lightly. At around 20,000 feet MSL pilots might have only 10 minutes of "useful consciousness." By 30,000 feet MSL, the timeframe for "useful consciousness" decreases to one minute or less! For planned flights above 25,000 feet MSL, an emergency oxygen back-up or **bailout bottle** should be carried.

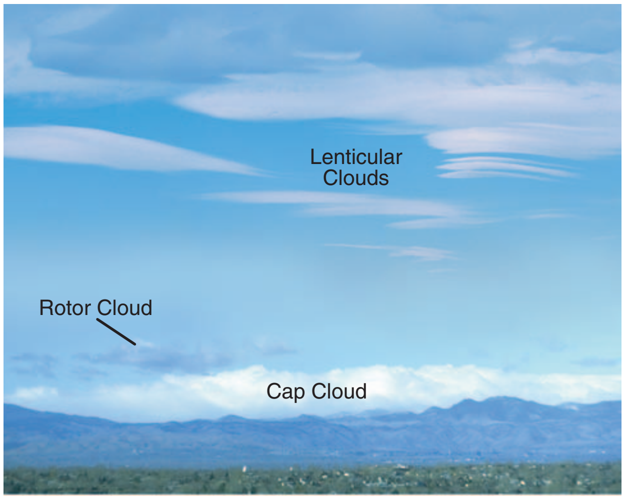

Figure 10-19. Rotor and cap clouds with lenticulars above.

Proper clothing is a must since temperatures of –30° to –60°C may be encountered at altitude. Proper preparation for the cold is especially difficult since temperatures on the ground are often pleasant on wave soaring days. Sunshine through the canopy keeps the upper body amazingly warm for a time, but shaded legs and feet quickly become cold. Frostbite is a very real threat. After an hour or two at such temperatures, even the upper body can become quite cold. Layered, loose -fitting clothing aides in insulating body heat. Either wool gloves or light fitting gloves with mittens over them work best for the hands. Mittens make tasks such as turning radio knobs difficult. For the feet, two or three pair of socks (inner silk, outer wool) with an insulated boot is recommended.

Within the continental United States, Class A airspace lies between 18,000 and 60,000 feet MSL (FL 180 to FL 600). Generally, flights in Class A must be conducted under Instrument Flight Rules (IFR). However, several clubs and glider operations have established so-called **"Wave Windows"**. These are special areas, arranged in agreement with Air Traffic Control (ATC), in which gliders are allowed to operate above 18,000 feet MSL under VFR operations. Wave windows have very specific boundaries. Thus, to maintain this privilege, it is imperative to stay within the designated window. On any given day, the wave window may be opened to a specific altitude during times specified by ATC. Each wave window has its own set of procedures agreed upon with ATC. All glider pilots should become familiar with the procedures and required radio frequencies.

True Airspeed (TAS) becomes a consideration at higher altitudes. To avoid the possibility of flutter, some gliders require a reduced indicated never-exceed speed as a function of altitude. For instance, at sea level the POH for one common two-seat glider, the V_{NE}, is 135 knots. However, at 19,000 feet MSL it is only 109 knots. Study the glider's POH carefully for any limitations on indicated airspeeds.

There is always the possibility of not contacting the wave. Sink on the downside of a lee wave can be high—2,000 fpm or more. In addition, missing the wave often means a trip back through the turbulent rotor. The workload and stress levels in either case can be high. To reduce the workload, it is a good idea to have minimum return altitudes from several locations calculated ahead of time. In addition, plan for some worse case scenarios. For instance, consider what off-field landing options are available if the planned minimum return altitude proves inadequate.

A normal preflight of the glider should be performed. In addition, check the lubricant that has been used on control fittings. Some lubricants can become very stiff when cold. Also, check for water from melting snow or a recent rain in the spoilers or dive brakes. Freezing water in the spoilers or drive brakes at altitude can make them difficult to open. Checking the spoilers or dive brakes occasionally during a high climb helps avoid this problem. A freshly charged battery is recommended, since cold temperatures can reduce battery effectiveness. Check the radio and accessory equipment, such as a microphone in the oxygen mask even if it is not generally used. As mentioned, the oxygen system is vital. Other specific items to check depend on the system being used. A checklist such as PRICE is often helpful. The acronym PRICE stands for:

- Pressure—Check pressure in the oxygen bottle.
- Regulator—Check at all settings.
- Indicator—Check flow meters or flow-indicator blinkers.
- Connections—Check for solid connections, possible leaks, cracks in hoses, etc.
- Emergency—Check that the system is full and properly connected.

A briefing with the towpilot is even more important before a wave tow. Routes, minimum altitudes, rotor avoidance (if possible), anticipated tow altitude, and eventualities should the rotor become too severe, are among topics that are best discussed on the ground prior to flight.

After all preparations are complete, it is time to get in the glider. Some pilots may be using a parachute for the first time on wave flights, so make sure you are familiar with its proper fitting and use. The parachute fits on top of clothing that is much bulkier than for normal soaring, so the cockpit can suddenly seem quite cramped. It will take several minutes to get settled and organized. Make sure radio and oxygen are easily accessible. If possible, the oxygen mask should be in place, since the climb in the wave can be very rapid. At the very least, the mask should be set up so that it is ready for use in a few seconds. All other gear (e.g., mittens, microphone, maps, barograph, etc.) should be securely stowed in anticipation of the rotor. Check for full, free rudder movement, since footwear is likely larger than what you normally use. In addition, given the bulky cold-weather clothing, check to make sure the canopy clearance is adequate. The pilot's head has broken canopies in rotor turbulence so seat and shoulder belts should be tightly secured. This may be difficult to achieve with the extra clothing and accessories, but take the time to make sure everything is secure. There will not be time to attend to such matters once the rotor is encountered.

GETTING INTO THE WAVE

There are two possibilities for getting into the wave: soaring into it or being towed directly into it. Three main wave entries while soaring are: thermalling into the wave, climbing the rotor, and transitioning into the wave from slope soaring.

At times, an unstable layer at levels below the mountaintop is capped by a strong, stable layer. If other conditions are favorable, the overlying stable layer may support lee waves. On these days, it is sometimes possible to largely avoid the rotor and thermal into the wave. Whether lee waves are suspected or not, near the thermal top the air may become turbulent. At this point, attempt a penetration upwind into smooth wave lift. A line of cumulus downwind of and aligned parallel to the ridge or mountain range is a clue that waves may be present. [Figure 10-20]

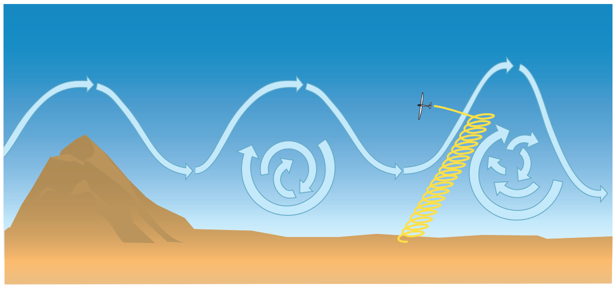

Figure 10-20. Thermalling into wave.

Another possibility is to tow into the upside of the rotor, then climb the rotor into the wave. This can be rough, difficult, and prone to failure. The technique is to find a part of the rotor that is going up and try to stay in it. The rotor lift is usually stationary over the ground. Either "figure-8" in the rotor lift to avoid drifting downwind, fly several circles with an occasional straight leg, or fly straight into the wind for several seconds until lift diminishes. Then circle to reposition in the lift. Which choice works depends on the size of the lift and the wind strength. Since rotors have rapidly changing regions of very turbulent lift and sink, simple airspeed and bank angle control can become difficult. This wave-entry technique is not for new pilots.

Depending on the topography near the soaring site, it may be possible to transition from slope lift into a lee wave that is created by upwind topography as shown in Figure 9-27. In this case, climb as high as possible in slope lift, then penetrate upwind into the lee wave. When the lee waves are in phase with the topography, it is often possible to climb from slope to wave lift without the rotor. At times, the glider pilot may not realize wave has been encountered until they find lift steadily increasing as they climb from the ridge. Climbing in slope lift and then turning downwind to encounter possible lee waves produced downwind of the ridge is generally not recommended. Even with a tailwind, the lee-side sink can put the glider on the ground before the wave is contacted.

Towing into the wave can be accomplished by either towing ahead of the rotor or through the rotor. Avoiding the rotor completely will generally increase the towpilot's willingness to perform future wave tows. If possible, tow around the rotor and then directly into the wave lift. This may be feasible if the soaring site is located near one end of the wave-producing ridge or mountain range. A detour around the rotor may require more time on tow, but it's well worth the diversion. [Figure 10-21]

Often, a detour around the rotor is not possible and a tow directly through the rotor is the only route to the wave. The rotor turbulence is, on rare occasion, only light. However, moderate to severe turbulence is usually encountered. The nature of rotor turbulence differs from turbulent thermal days, with sharp, chaotic horizontal and vertical gusts along with rapid accelerations and decelerations. At times, the rotor can become so rough that even experienced pilots may elect to remain on the ground. Any pilot inexperienced in flying through rotors should obtain instruction before attempting a tow through rotor.

When towing through a rotor, being out of position is normal. Glider pilots must maintain position horizontally and vertical as best they can. Pilots should also be aware that an immediate release may be necessary at any time if turbulence becomes too violent. Slack-producing situations are common, due to a rapid deceleration of the towplane. The glider pilot must react quickly to slack if it occurs and recognize that slack is about to occur and correct accordingly. The vertical position should be the normal high-tow. Any tow position that is lower than normal runs the risk of the slack line coming back over the glider. On the other hand, care should be taken to tow absolutely no higher than normal to avoid a forced release should the towplane suddenly drop. Gusts may also cause an excessive bank of the glider, and it may take a moment to roll back to level. Full aileron and rudder deflection, held for a few seconds, is sometimes needed.

Progress through the rotor is often indicated by noting the trend of the variometer. General down swings are replaced by general upswings, usually along with increasing turbulence. The penetration into the smooth wave lift can be quick, in a matter of few seconds, while at other times it can be more gradual. Note any lenticulars above—a position upwind of the clouds helps confirm contact with the wave. If in doubt, tow a few moments longer to be sure. Once confident about having contacted the wave lift, make the release. If heading more or less crosswind, the glider should release and fly straight or with a crab angle. If flying directly into the wind, the glider should turn a few

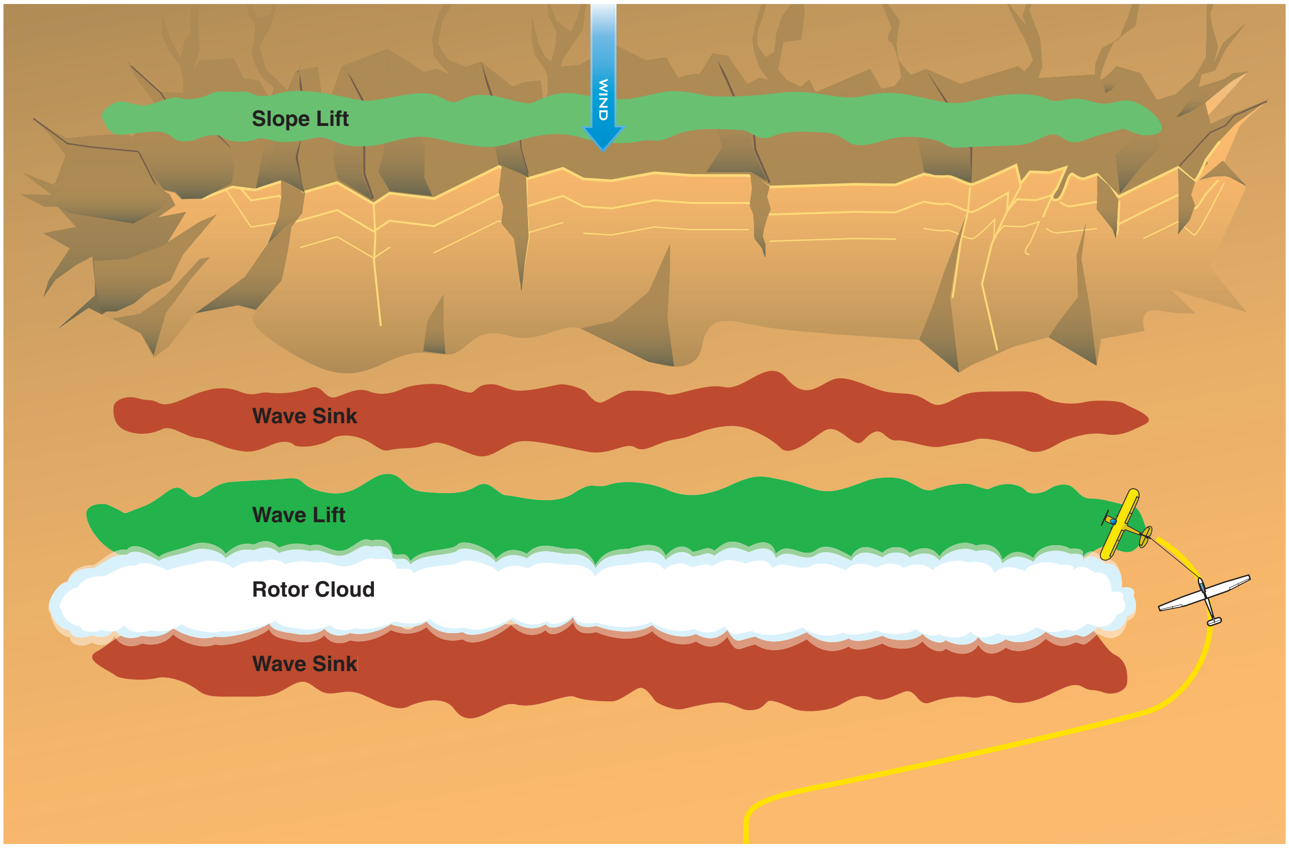

Figure 10-21. If possible, tow around the rotor directly into the wave.

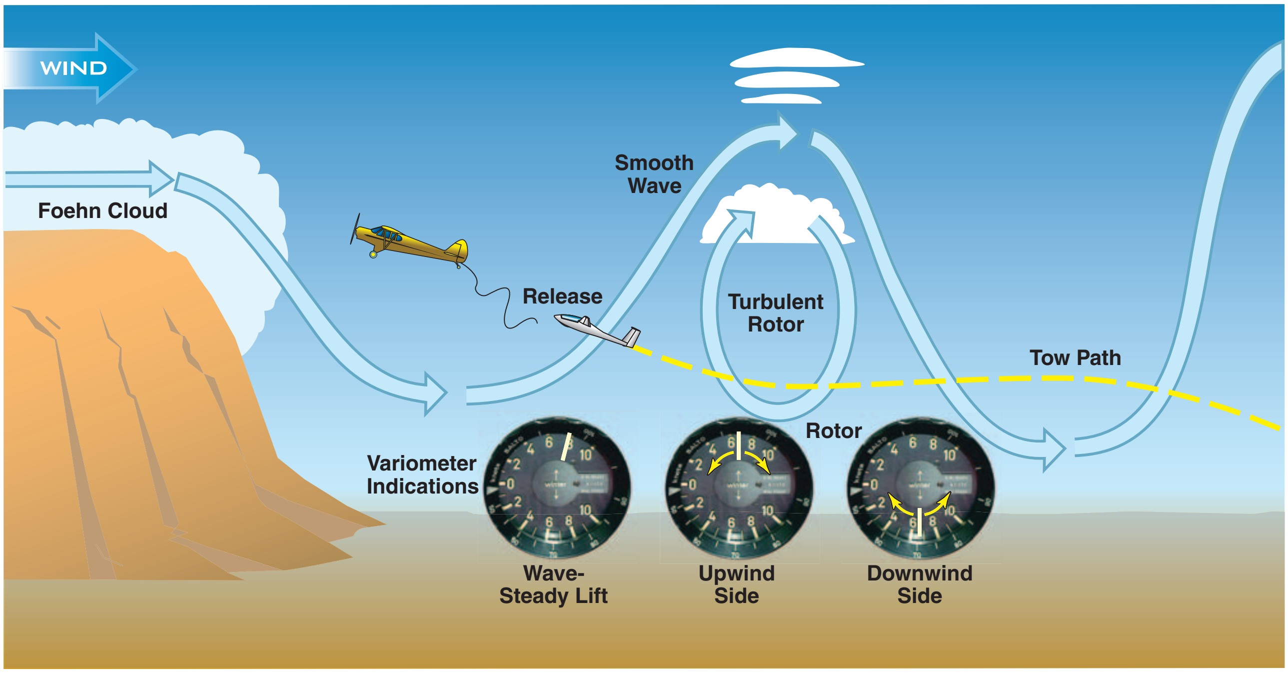

Figure 10-22. Variometer indications during the penetration into the wave.

degrees to establish a crosswind crab angle. The goal is to avoid drifting downwind and immediately lose the wave. After release, the towplane should descend and/or turn away to separate from the glider. Possible non-standard procedures need to be briefed with the towpilot before takeoff. [Figures 10-22 and 10-23]

FLYING IN THE WAVE

Once the wave has been contacted, the best techniques for utilizing the lift depends on the extent of the lift (especially in the direction along the ridge or mountain range producing the wave) and the strength of the wind. The lift may initially be weak. In such circumstances, be patient and stay with the initial slow climb. Patience is usually rewarded with better lift as the climb continues. At other times, the variometer may be pegged at 1,000 fpm directly after release from tow.

If the wind is strong enough (40 knots or more), find the strongest portion of the wave and point into the wind, and adjust speed so that the glider remains in the strong lift. The best lift will be found along the upwind side of the rotor cloud or just upwind of any lenticulars. In the best-case scenario, the required speed will be close to the glider's minimum sink speed. In quite strong winds, it may be necessary to fly faster than minimum sink to maintain position in the best lift. Under those conditions, flying slower will allow the glider to drift downwind (fly backwards over the ground!) and into the down side of the wave. This can be a costly mistake since it will be difficult to penetrate

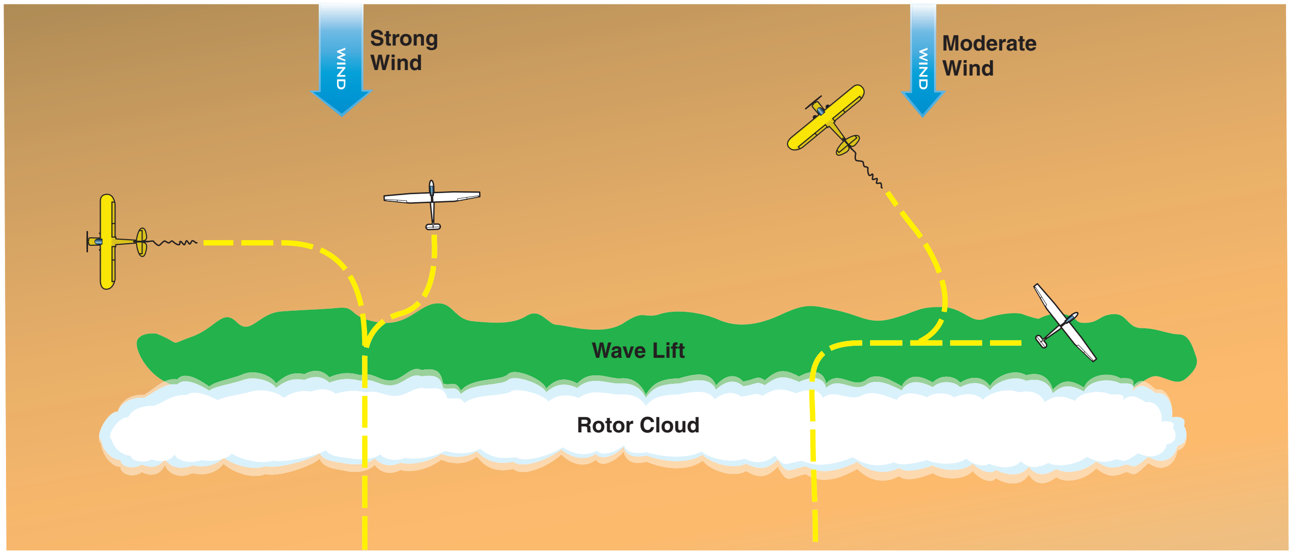

Figure 10-23. Possible release and separation on a wave tow.

back into the strong headwind. When the lift is strong, it is easy to drift downwind while climbing into stronger winds aloft, so it pays to be attentive to the position relative to rotor clouds or lenticulars. If no clouds exist, special attention is needed to judge wind drift by finding nearby ground references. It may be necessary to increase speed with altitude to maintain position in the best lift. Often the wind is strong, but not quite strong enough for the glider to remain stationary over the ground, so that the glider slowly moves upwind out of the best lift. If this occurs, turn slightly from a direct upwind heading, drift slowly downwind into better lift, and turn back into the wind before drifting too far. [Figure 10-24]

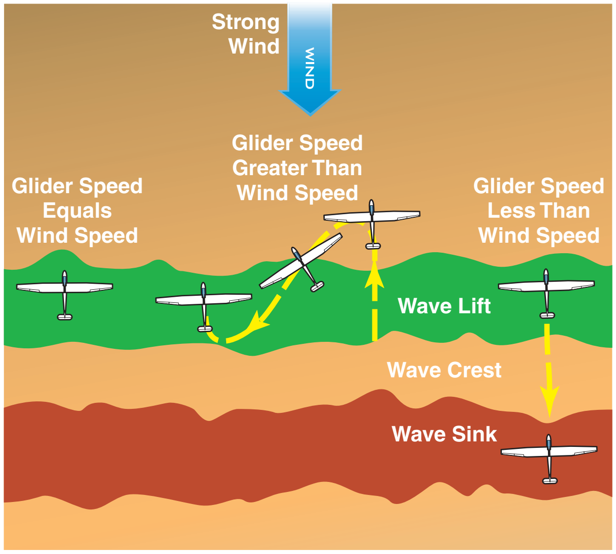

Figure 10-24. Catching a thermal by flying upwind away from the slope lift.

Oftentimes, the wave lift is not perfectly stationary over the ground since small changes in wind speed and/or stability can alter the wavelength of the lee wave within minutes. If lift begins to decrease while climbing in the wave, one of these things has occurred: the glider is nearing the top of the wave, the glider has moved out of the best lift, or the wavelength of the lee wave has changed. In any case, it is time to explore the area for better lift, and it is best to search upwind first. Searching upwind first allows the pilot to drift downwind back into the up part of the wave if he or she is wrong. Searching downwind first can make it difficult or impossible to contact the lift again if sink on the downside of the wave is encountered. In addition, caution is needed to avoid exceeding the glider's maneuvering speed or rough-air redline, since a penetration from the down side of the wave may put the glider back in the rotor. [Figure 10-25]

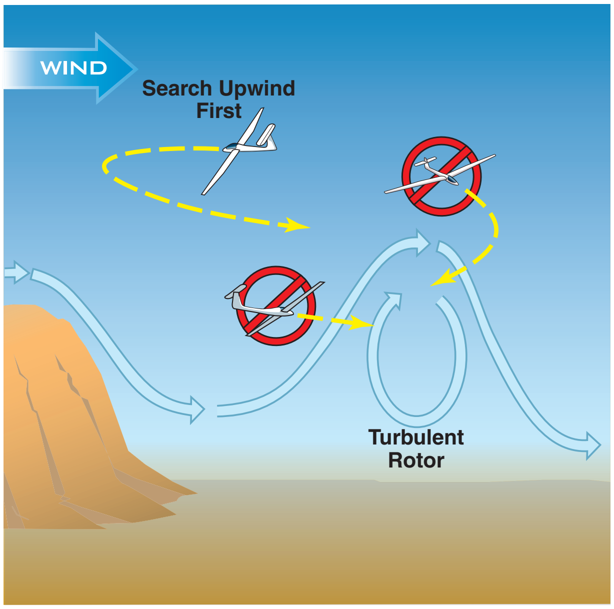

Figure 10-25. Search upwind first to avoid sink behind the wave crest or the rotor.

If the winds are moderate (20 to 40 knots), and the wave extends along the ridge or mountain range for a few miles, it is best to fly back and forth along the wave lift while crabbing into the wind. This technique is similar to slope soaring, using the rotor cloud or lenticular as a reference. All turns should be into the wind to avoid ending up on the down side of the wave or back into the rotor. Once again, it is easy to drift downwind into sink while climbing higher and searching for better lift should be done upwind first. When making an upwind turn to change course 180°, remember that the heading change will be less, depending on the strength of the wind. Note the crab angle needed to stay in lift on the first leg, and assume that same crab angle after completing the upwind turn. This will prevent the glider from drifting too far downwind upon completing the upwind turn. With no cloud, ground references are used to maintain the proper crab angle, and avoid drifting downwind out of the lift. While climbing higher into stronger winds, it may become possible to transition from crabbing back and forth to a stationary upwind heading. [Figure 10-26]

Weaker winds (15 to 20 knots) sometimes require different techniques. Lee waves from smaller ridges can form in relatively weak winds, on the order of only 15 knots. Wave lift from larger mountains will rapidly decrease when climbing to a height where winds aloft diminish. As long as the lift area is big enough, use a technique similar to that used in moderate winds. Near the wave top, there sometimes remains only a small area that still provides lift. In order to attain the maximum height; fly shorter "figure-8" patterns within the remaining lift. If the area of lift is so small that consistent climb is not possible, a series of circles can be flown with an occasional leg into the wind to avoid drifting too far downwind. Another possibility is an oval-shaped pattern—fly straight into the wind in lift, and as it diminishes, fly a quick 360° turn to reposi-

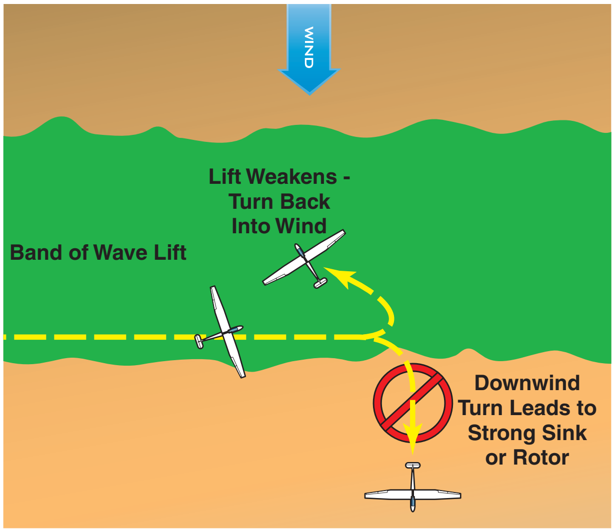

Figure 10-26. Proper crabbing to stay in lift and effects of upwind turn (correct) or downwind turn (incorrect).

tion. These last two techniques do not work as well in moderate winds, and not at all in strong winds since it is too easy to end up downwind of the lift and into heavy sink. [Figure 10-27]

In the discussion thus far, we have assumed a climb in the primary wave. It is also possible to climb in the secondary or tertiary lee wave (if they exist on a given day) and then penetrate into the next wave upwind. The success of this depends on wind strength, clouds, the intensity of sink downwind of wave crests, and the performance of the glider. Depending on the height attained in the secondary or tertiary lee wave, a trip through the rotor of the next wave upwind is a distinct possibility. Caution is needed if penetrating upwind at high speed. The transition into the downwind side of the rotor can be as abrupt as on the upwind side, so speed should be reduced at the first hint of turbulence. In any case, expect to lose surprising amounts of altitude while penetrating upwind through the sinking side of the next upwind wave. [Figure 10-28]

If a quick descent is needed or desired, the sink downwind of the wave crest can be used. Sink can easily be twice as strong as lift encountered upwind of the crest. Eventual descent into downwind rotor is also likely. Sometimes the space between a rotor cloud and overlying lenticulars is inadequate and a transition downwind cannot be accomplished safely. In this case, a crosswind detour may be possible if the wave is produced by a relatively short ridge or mountain range. If clouds negate a downwind or crosswind departure from the wave, a descent on the upwind side of the wave crest will be needed. Spoilers or dive brakes may be used to descend through the updraft, followed by a transition under the rotor cloud and through the rotor. A descent can be achieved by moving upwind of a very strong wave lift if spoilers or dive brakes alone do not allow a quick enough descent. A trip back through the rotor is at best unpleasant. At worst it can be dangerous if the transition back into the rotor is done with too much speed. In addition, strong wave lift and lift on the upwind side of the rotor may make it difficult to stay out of the rotor cloud. This wave descent requires

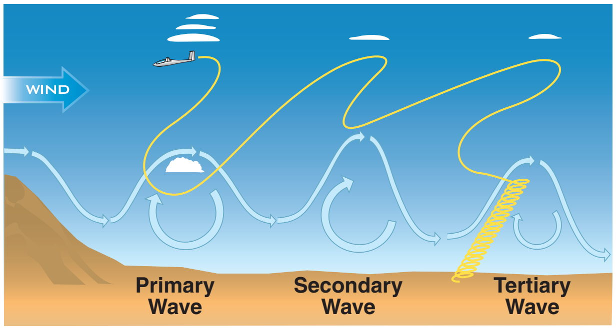

Figure 10-28. Possible flight path while transitioning from the tertiary into the secondary and then into the primary.

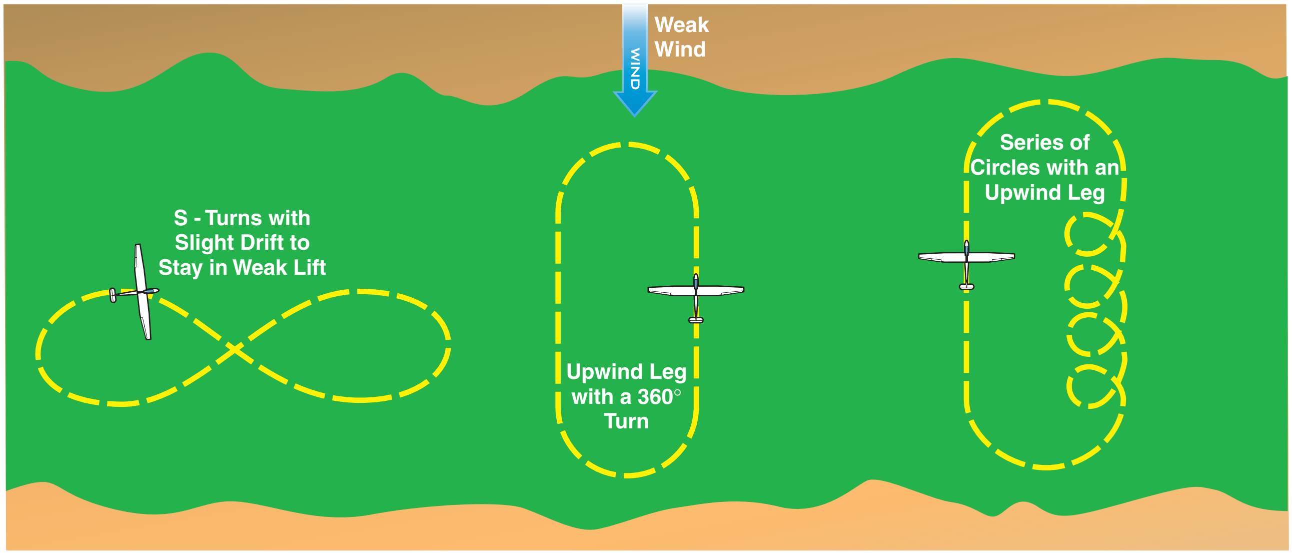

Figure 10-27. Techniques for working lift near the top of the wave in weak winds.

a good deal of caution and emphasizes the importance of an exit strategy before climbing too high in the wave, keeping in mind that conditions and clouds can rapidly evolve during the climb.

Some of the dangers and precautions associated with wave soaring have already been mentioned. Those and others are summarized below.

- If any signs of hypoxia appear, check the oxygen system and immediately begin a descent to lower altitudes below which oxygen is not needed. Do not delay!
- Eventually, regardless of how warmly you are dressed, it will become cold at altitude. Descend well before it becomes uncomfortably cold.
- Rotor turbulence can be severe or extreme. Caution is needed on tow and when transitioning from smooth wave flow (lift or sink) to rotor. Rotors near the landing area can cause strong shifting surface winds—20 or 30 knot. Wind shifts up to 180° sometimes occur in less than a minute at the surface under rotors.
- Warm, moist exhaled air can cause frost on the canopy, restricting vision. Opening air vents may alleviate the problem or prolong frost formation. Clear-vision panels may also be installed. If frosting cannot be controlled, descend before frost becomes a hazard.
- In "wet" waves, those associated with a great deal of cloud, beware of the gaps closing beneath the glider. If trapped above cloud, a benign spiral mode is an option, but only if this mode has been previously explored and found stable for your glider.
- Know the time of actual sunset. At legal sunset, bright sunshine is still found at 25,000 feet while the ground below is already quite dark. Even at an average 1,000 fpm descent it takes 20 minutes to lose 20,000 feet.

SOARING CONVERGENCE ZONES

Convergence zones are most easily spotted when cumulus clouds are present. They appear as a single straight or curved cloud street, sometimes well defined and sometimes not, for instance when a wind field as in Figure 9-30(B) causes the convergence. The edge of a field of cumulus can mark convergence between a mesoscale air mass that is relatively moist and/or unstable from one that is much drier and/or more stable. Often the cumulus along convergence lines have a base lower on one side than the other, similar to Figure 9-33.

With no cloud present, a convergence zone is sometimes marked by a difference in visibility across it, which may be subtle or distinct. When there are no clues in the sky itself, there may be some on the ground. If lakes are nearby, look for wind differences on lakes a few miles apart. A lake showing a wind direction different than the ambient flow for the day may be a clue. Wind direction shown by smoke can also be an important indicator. A few dust devils, or better, a short line of them, may indicate the presence of ordinary thermals vs. those triggered by convergence. Spotting the subtle clues takes practice and good observational skills, and is often the reason a few pilots are still soaring while others are already on the ground.

The best soaring technique for this type of lift depends on the nature of the convergence zone itself. For instance, a sea-breeze front may be well-defined and marked by "curtain" clouds, in which case the pilot can fly straight along the line in fairly steady lift. A weaker convergence line often produces more lift than sink, in which case the pilot must fly slower in lift and faster in sink. An even weaker convergence line may just act as focus for more-frequent thermals, in which case normal thermal techniques are used along the convergence line. Some combination of straight legs along the line with an occasional stop to thermal is often used.

Convergence zone lift can at times be somewhat turbulent, especially if air from different sources is mixing, such as along a sea-breeze front. The general roughness may be the only clue of being along some sort of convergence line. There can also be narrow and rough (but strong) thermals within the convergence line. Work these areas like any other difficult thermals—steeper bank angles and more speed for maneuverability.

COMBINED SOURCES OF UPDRAFTS

Finally, lift sources have been categorized into four types: thermal, slope, wave, and convergence. Often, more than one type of lift exists at the same time. For instance, thermals with slope lift, thermalling into a wave, convergence zones enhancing thermals, thermal waves, and wave soaring from slope lift were all considered. In mountainous terrain, it is possible for all four lift types to exist on a single day. The glider pilot needs to remain mentally nimble to take advantage of various pieces of rising air during the flight.

Nature does not know that it must only produce rising air based on these four lift categories. Sources of lift that do not fit one of the four lift types discussed probably exist. For instance, there have been a few reports of pilots soaring in travelling waves, the source of which was not known. At some soaring sites it is sometimes difficult to classify the type of lift. This should not be a problem—simply work the mystery lift as needed, then ponder its nature after the flight.