

## Chapter 9

# Soaring Weather

### Introduction

Glider pilots face a multitude of decisions, starting with the decision to take to the air. Pilots must determine if weather conditions are safe, and if current conditions support a soaring flight. Gliders, being powered by gravity, are always sinking through the air. Therefore, glider pilots must seek air that rises faster than the sink rate of the glider to enable prolonged flight. Glider pilots refer to rising air as lift, not to be confused with the lift created by the wing.



## The Atmosphere

The atmosphere is a mixture of gases surrounding the earth. Without it, there would be no weather (wind, clouds, precipitation) or protection from the sun's rays. Though this protective envelope is essential to life, it is extraordinarily thin. When compared to the radius of the earth, 3,438 nautical miles (NM), the vertical limit of the atmosphere represents a very small distance. Although there is no specific upper limit to the atmosphere—it simply thins to a point where it fades away into space—the layers up to approximately 164,000 feet (about 27 NM) contain 99.9 percent of atmospheric mass. At that altitude, the atmospheric density is approximately one-thousandth the density of that at sea level. [Figure 9-1]

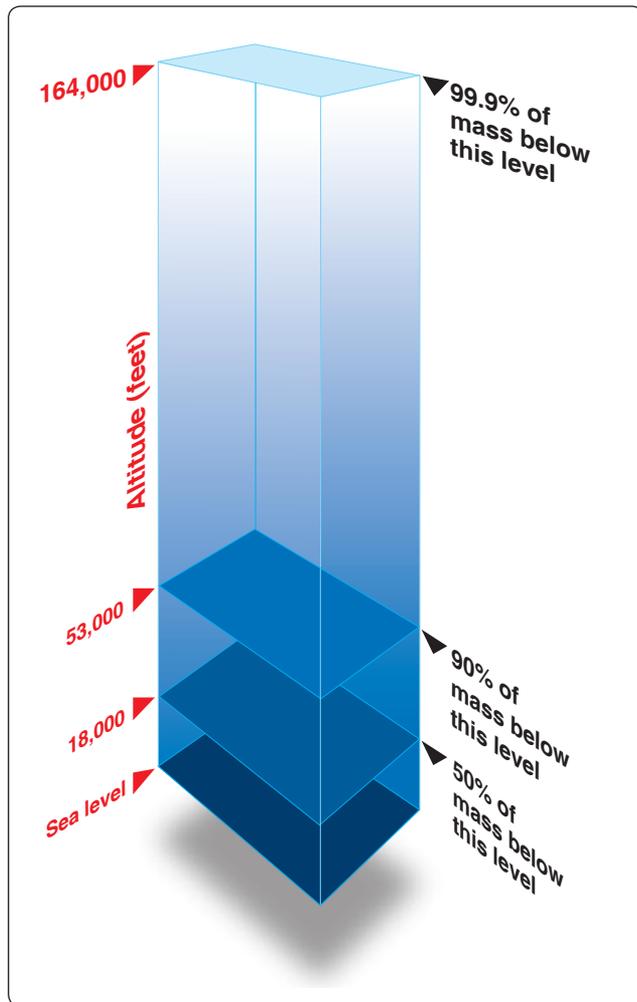


Figure 9-1. Atmospheric mass by altitude.

### Composition

The earth's atmosphere is composed of a mixture of gases, with small amounts of water, ice, and other particles. Two gases, nitrogen ( $N_2$ ) and oxygen ( $O_2$ ), comprise approximately 99 percent of the gaseous content of the atmosphere; the other one percent is composed of various trace gases. Nitrogen and oxygen are both considered permanent gases, meaning

their proportions remain the same to approximately 260,000 feet. Water vapor ( $H_2O$ ), on the other hand, is considered a variable gas. Therefore, the amount of water in the atmosphere depends on the location and the source of the air. For example, the water vapor content over tropical areas and oceans accounts for as much as 4 percent of the gases displacing nitrogen and oxygen. Conversely, the atmosphere over deserts and at high altitudes exhibits less than 1 percent of the water vapor content. [Figure 9-2]

Although water vapor exists in the atmosphere in small amounts as compared to nitrogen and oxygen, it has a significant impact on the production of weather. This is because it exists in two other physical states: liquid (water) and solid (ice). These two states of water contribute to the formation of clouds, precipitation, fog, and icing, all of which are important to aviation weather.

### Properties

The state of the atmosphere is defined by fundamental variables, namely temperature, density, and pressure. These variables change over time and, combined with vertical and horizontal differences, lead to daily weather conditions.

### Temperature

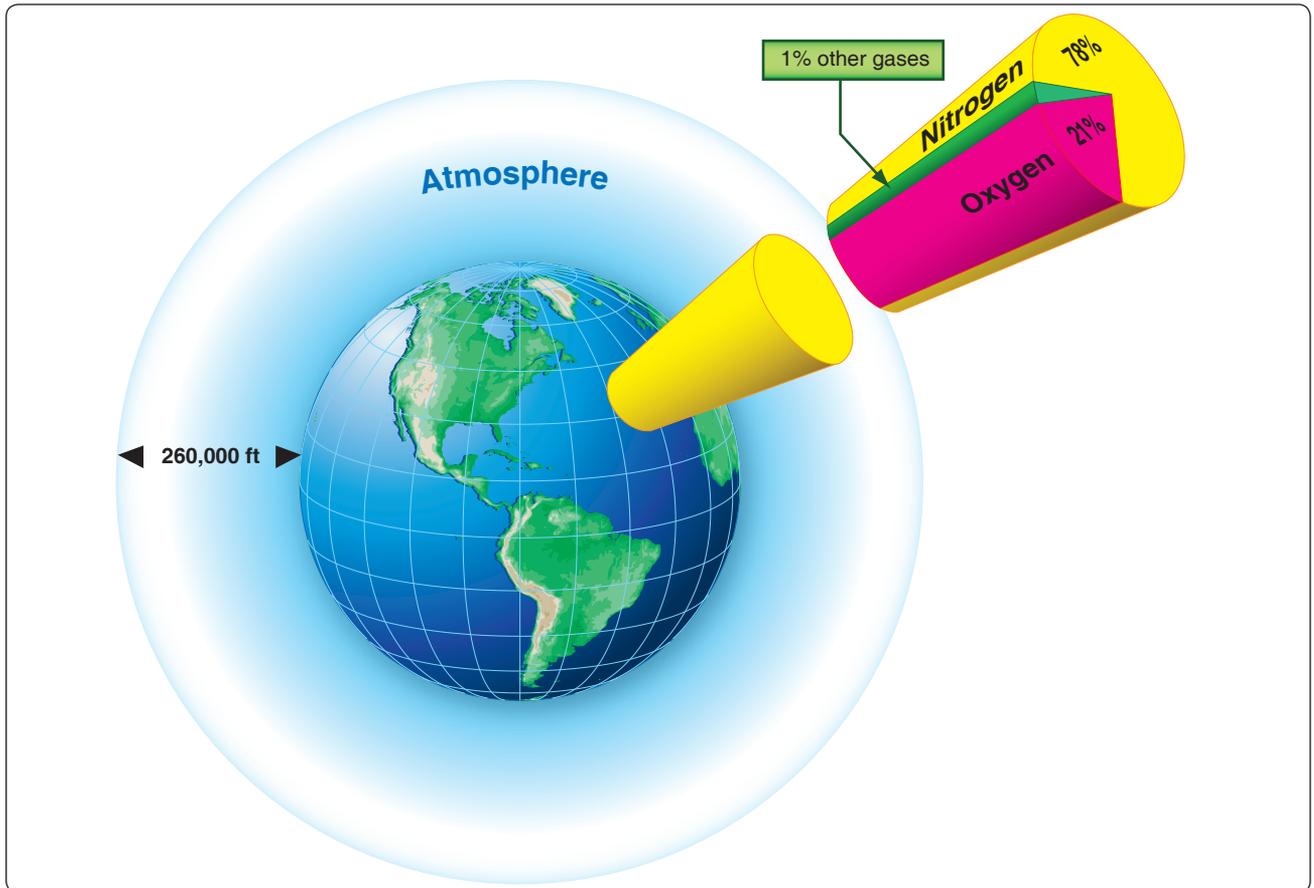
The temperature of a gas is the measure of the average kinetic energy of the molecules of that gas. Fast-moving molecules are indicative of high kinetic energy and warmer temperatures. Conversely, slow-moving molecules reflect lower kinetic energy and lower temperatures. Air temperature is commonly thought of in terms of whether it feels hot or cold. For quantitative measurements, the Celsius ( $^{\circ}C$ ) scale is used in aviation, although the Fahrenheit ( $^{\circ}F$ ) scale is still used in some applications.

### Density

The density of any given gas is the total mass of molecules in a specified volume, expressed in units of mass per volume. Low air density means a smaller number of air molecules in a specified volume while high air density means a greater number of air molecules in the same volume. Air density affects aircraft performance, as noted in Chapter 5, Glider Performance.

### Pressure

Molecules in a given volume of air not only possess a certain kinetic energy and density, but they also exert force. The force per unit area defines pressure. At the earth's surface, the pressure exerted by the atmosphere is due to its weight. Therefore, pressure is measured in terms of weight per area. For example, atmospheric pressure is measured in pounds per square inch ( $lb/in^2$ ). From the outer atmosphere to sea level, a typical value of atmospheric pressure is  $14.7 lb/in^2$ .



**Figure 9-2.** *The composition of the atmosphere.*

In aviation weather reports, the units of pressure are inches of mercury ("Hg) and millibars (mb) and 29.92 "Hg equals 1013.2 mb. This force or pressure is created by the moving molecules act equally in all directions when measured at a given point.

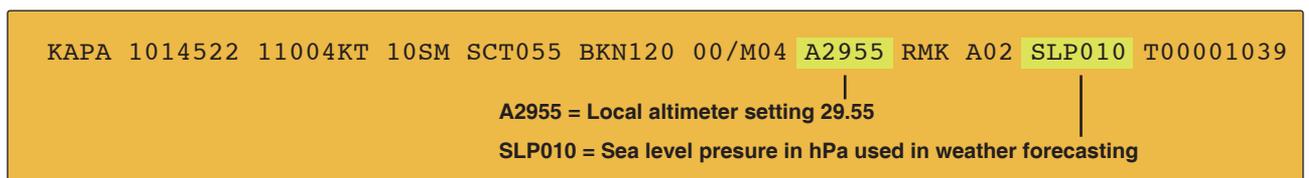
In the METAR report, see *Figure 9-3*, the local altimeter setting "A2955", read as 29.55, is the pressure "Hg. In the remarks (RMK) section of this report, sea level pressure expressed as "SLP010", the value expressed in millibars (hPa), is used in weather forecasting.

Dry air behaves almost like an ideal gas, meaning it obeys the gas law given by  $P/DT = R$ , where P is pressure, D is density, T is temperature, and R is a constant. This law states that the ratio of pressure to the product of density and temperature must always be the same. For instance, at a given pressure

if the temperature is much higher than standard, then the density must be much lower. Air pressure and temperature are usually measured, and using the gas law, density of the air can be calculated and used to determine aircraft performance under those conditions.

### Standard Atmosphere

Using a representative vertical distribution of these variables, the standard atmosphere has been defined and is used for pressure altimeter calibrations. Since changes in the static pressure can affect pitot-static instrument operation, it is necessary to understand basic principles of the atmosphere. To provide a common reference for temperature and pressure, a definition for standard atmosphere, also called International Standard Atmosphere (ISA), has been established. In addition to affecting certain flight instruments, these standard conditions are the basis for most aircraft performance data.



**Figure 9-3.** *Example of how pressure is used in an aviation weather report.*

At sea level, the standard atmosphere consists of a barometric pressure of 29.92 "Hg, or 1,013.2 mb, and a temperature of 15 °C or 59 °F. Under standard conditions (ISA), a column of air at sea level weighs 14.7 lb/in<sup>2</sup>.

Since temperature normally decreases with altitude, a standard lapse rate can be used to calculate temperature at various altitudes. Below 36,000 feet, the standard temperature lapse rate is 2 °C (3.5 °F) per 1,000 feet of altitude change. Pressure does not decrease linearly with altitude, but for the first 10,000 feet, 1 "Hg for each 1,000 feet approximates the rate of pressure change. It is important to note that the standard lapse rates should be used only for flight planning purposes with the understanding that large variations from standard conditions can exist in the atmosphere. [Figure 9-4]

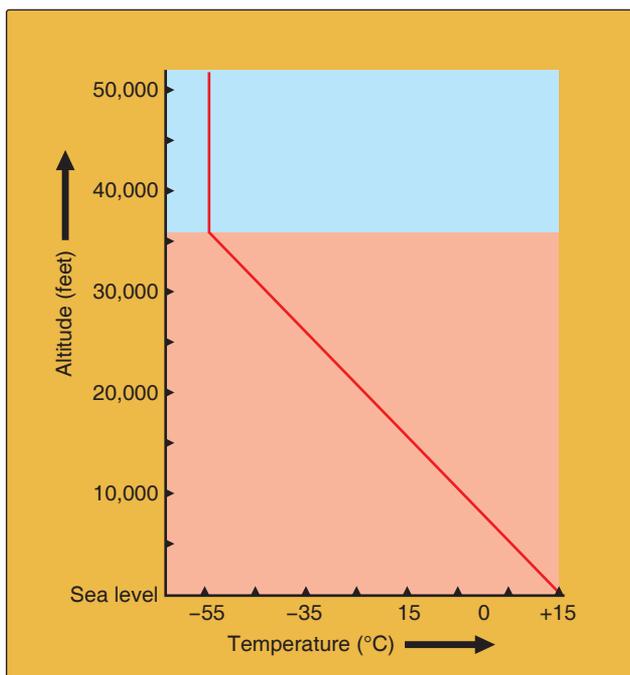


Figure 9-4. Standard atmosphere.

### Layers of the Atmosphere

The earth's atmosphere is divided into five strata, or layers: troposphere, stratosphere, mesosphere, thermosphere, and exosphere. [Figure 9-5] These layers are defined by the temperature change with increasing altitude. The lowest layer, called the troposphere, exhibits an average decrease in temperature from the earth's surface to about 36,000 feet above mean sea level (MSL). The troposphere is deeper in the tropics and shallower in the polar regions. It also varies seasonally, being higher in the summer and lower in the winter months.

Almost all of the earth's weather occurs in the troposphere as most of the water vapor and clouds are found in this layer. The lower part of the troposphere interacts with the land and sea surface, providing thermals, mountain waves, and sea-

breeze fronts. Although temperatures decrease as altitude increases in the troposphere, local areas of temperature increase (inversions) are common.

The top of the troposphere is called the tropopause. The pressure at this level is only about ten percent of MSL (0.1 atmosphere) and density is decreased to about 25 percent of its sea level value. Temperature reaches its minimum value at the tropopause, approximately -55 °C (-67 °F). For pilots, this is an important part of the atmosphere because it is associated with a variety of weather phenomena, such as thunderstorm tops, clear air turbulence, and jet streams. The vertical limit altitude of the tropopause varies with season and with latitude. The tropopause is lower in the winter and at the poles; it is higher in the summer and at the equator.

The tropopause separates the troposphere from the stratosphere. In the stratosphere, the temperature tends to first change very slowly with increasing height. However, as altitude increases the temperature increases to approximately 0 °C (32 °F) reaching its maximum value at about 160,000 feet MSL. Unlike the troposphere in which the air moves freely both vertically and horizontally, the air within the stratosphere moves mostly horizontally.

Gliders have reached into the lower stratosphere using mountain waves. At these altitudes, pressurization becomes an issue, as well as the more obvious breathing oxygen requirements. Layers above the stratosphere have some interesting features that are normally not of importance to glider pilots. However, interested pilots might refer to any general text on weather or meteorology.

### Scale of Weather Events

When preparing forecasts, meteorologists consider atmospheric circulation on many scales. To aid the forecasting of short- and long-term weather, various weather events have been organized into three broad categories called the scales of circulations. The size and lifespan of the phenomena in each scale are roughly proportional, so that larger size scales coincide with longer lifetimes. The term "microscale" refers to features with spatial dimensions of .10 to 1 NM and lasting for seconds to minutes. An example is an individual thermal. The term "mesoscale" refers to the horizontal dimensions of 1 to 1,000 NM and lasting for many minutes to weeks. Examples include mountain waves, sea breeze fronts, thunderstorms, and fronts. Research scientists break down the mesoscale into further subdivisions to better classify various phenomena. The term "macroscale" refers to the horizontal dimensions greater than 1,000 NM and lasting for weeks to months. These include the long waves in the general global circulation and the jet streams embedded within those waves. [Figure 9-6]

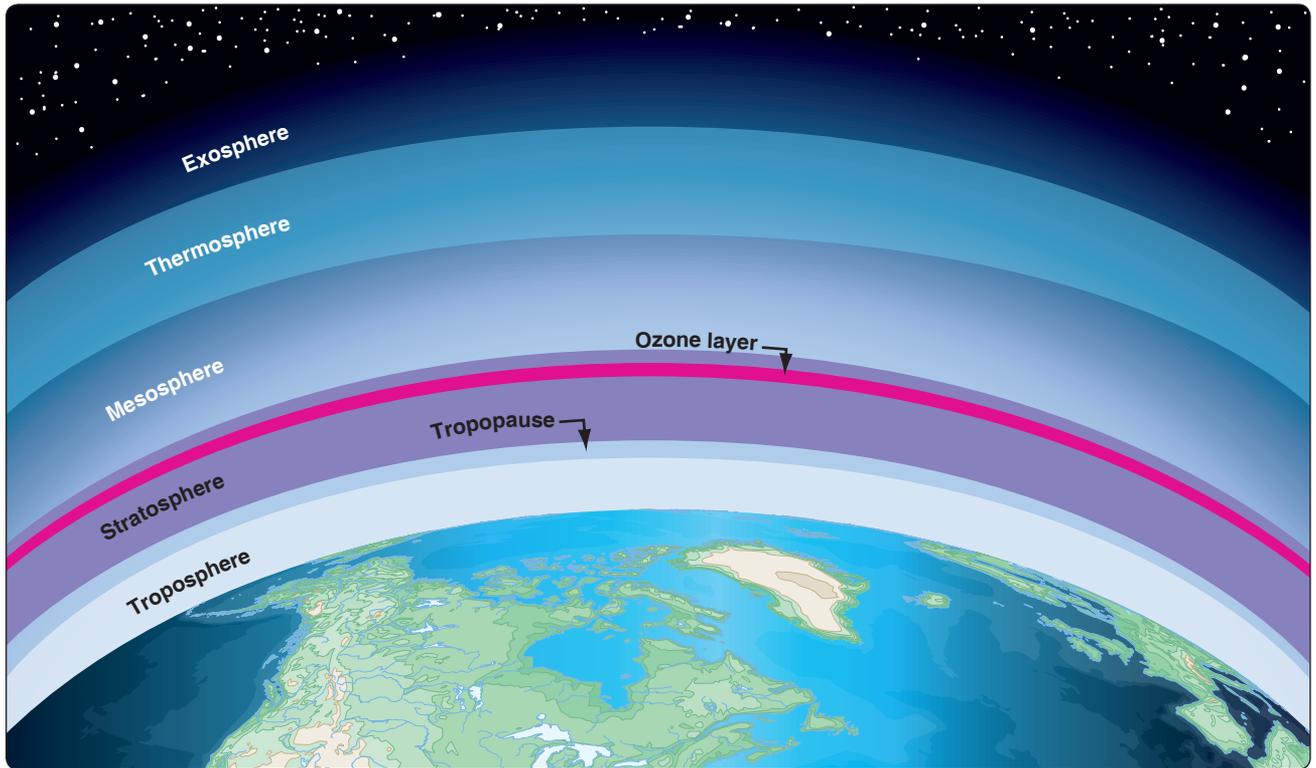


Figure 9-5. Layers of the atmosphere.

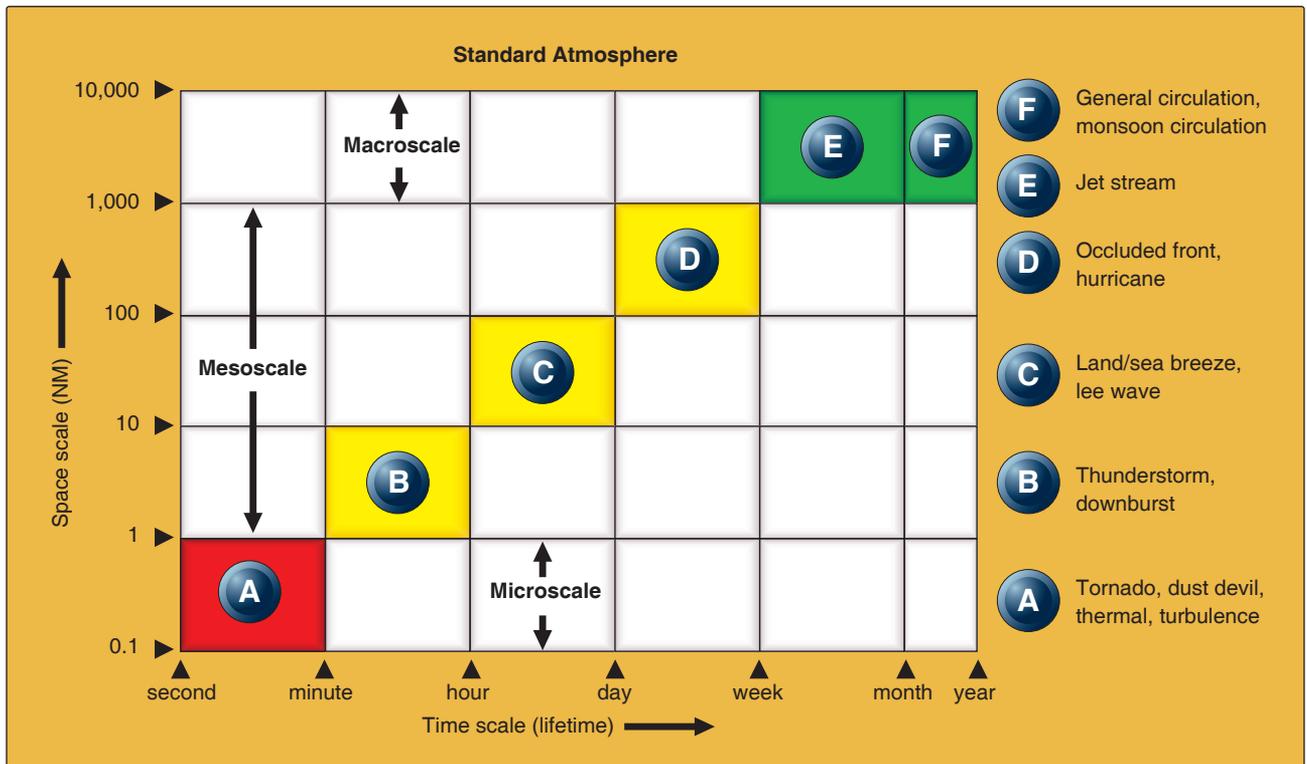


Figure 9-6. Scale of circulation—horizontal dimensions and life spans of associated weather events.

Smaller scale features are embedded in larger scale features. For instance, a microscale thermal may be just one of many in a mesoscale convergence line, like a sea breeze front.

The sea breeze front may occur only under certain synoptic (i.e., simultaneous) conditions, which is controlled by the macroscale circulations. The scales interact, with feedback

from smaller to larger scales and vice versa, in ways that are not yet fully understood by atmospheric scientists. Generally, the behavior and evolution of macroscale features are more predictable, with forecast skill decreasing as scale diminishes. For instance, forecasts of up to a few days for major events, such as a trough with an associated cold front, have become increasingly accurate. However, nobody would attempt to forecast the exact time and location of an individual thermal an hour ahead of time. Since most of the features of interest to soaring pilots lie in the smaller mesoscale and microscale range, prediction of soaring weather is a challenge.

Soaring forecasts should begin with the macroscale, which identifies large-scale patterns that produce good soaring conditions. This varies from site to site and depends, for instance, on whether the goal is thermal, ridge, or wave soaring. Then, mesoscale features should be considered. This may include items such as the cloudiness and temperature structure of the air mass behind a cold front, as well as the amount of rain produced by the front. Understanding lift types, and environments in which they form, is the first step to understanding how to forecast soaring weather.

## Thermal Soaring Weather

A thermal is a rising mass of buoyant air. Thermals are the most common updraft used to sustain soaring flight. In the next sections, several topics related to thermal soaring weather are explored, including thermal structure, atmospheric stability, the use of atmospheric soundings, and air masses conducive to thermal soaring.

Convection refers to an energy transfer involving mass motions. Thermals are convective currents and are one means by which the atmosphere transfers heat energy vertically. Advection is the term meteorologists use to describe horizontal transfer; for instance, cold air advection after the passage of a cold front. As a note of caution, meteorologists use the word “convection” to mean deep convection, that is, thunderstorms. Unfortunately, there is often a fine meteorological line between a warm, sunny day with plenty of thermals, and a warm, sunny day that is stable and produces no thermals. To the earthbound general public, it matters little—either is a nice day. Glider pilots, however, need a better understanding of these conditions and must often rely on their own forecasting skills.

## Thermal Shape and Structure

Two primary conceptual models exist for the structure of thermals: bubble model and column or plume model. Which model best represents thermals encountered by glider pilots is a topic of ongoing debate among atmospheric scientists. In reality, thermals fitting both conceptual models likely exist. A blend of the models, such as individual strong bubbles rising

within one plume, may be what occurs in many situations. These models attempt to simplify a complex and often turbulent phenomenon, so many exceptions and variations are to be expected while actually flying in thermals. Many books, articles, and Internet resources are available for further reading on this subject.

The bubble model describes an individual thermal resembling a vortex ring, with rising air in the middle and descending air on the sides. The air in the middle of the vortex ring rises faster than the entire thermal bubble. The model fits occasional reports from glider pilots. At times, one glider may find no lift, when only 200 feet below another glider climbs away. At other times, one glider may be at the top of the bubble climbing only slowly, while a lower glider climbs rapidly in the stronger part of the bubble below. [Figure 9-7] More often, a glider flying below another glider circling in a thermal is able to contact the same thermal and climb, even if the gliders are displaced vertically by 1,000 feet or more. This suggests the column or plume model of thermals is more common. [Figure 9-8]

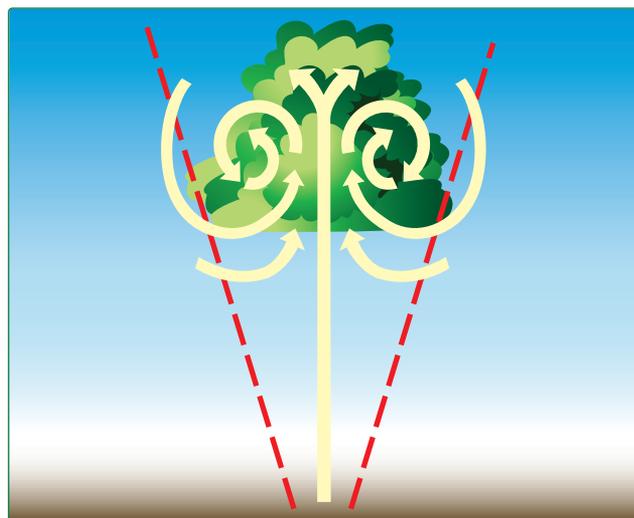
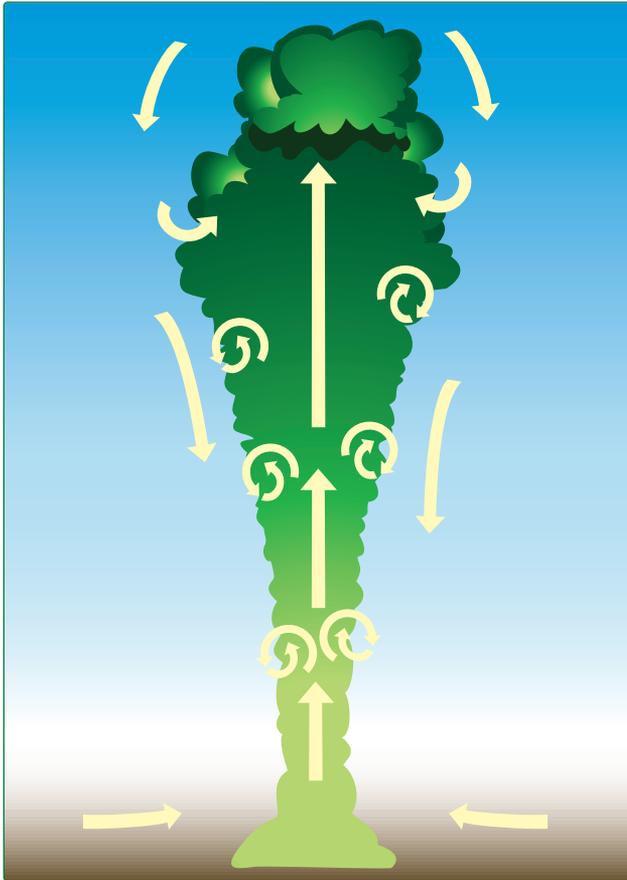


Figure 9-7. The bubble or vortex ring model of a thermal.

Which of the two models best describes thermals depends on the source or reservoir of warm air near the surface. If the heated area is rather small, one single bubble may rise and take with it all the warmed surface air. On the other hand, if a large area is heated and one spot acts as the initial trigger, surrounding warm air flows into the relative void left by the initial thermal. The in-rushing warm air follows the same path, creating a thermal column or plume. Since all the warmed air near the surface is not likely to have the exact same temperature, it is easy to envision a column with a few or several imbedded bubbles. Individual bubbles within a thermal plume may merge, while at other times, two adjacent and distinct bubbles seem to exist side by side.



**Figure 9-8.** *The column or plume model of a thermal.*

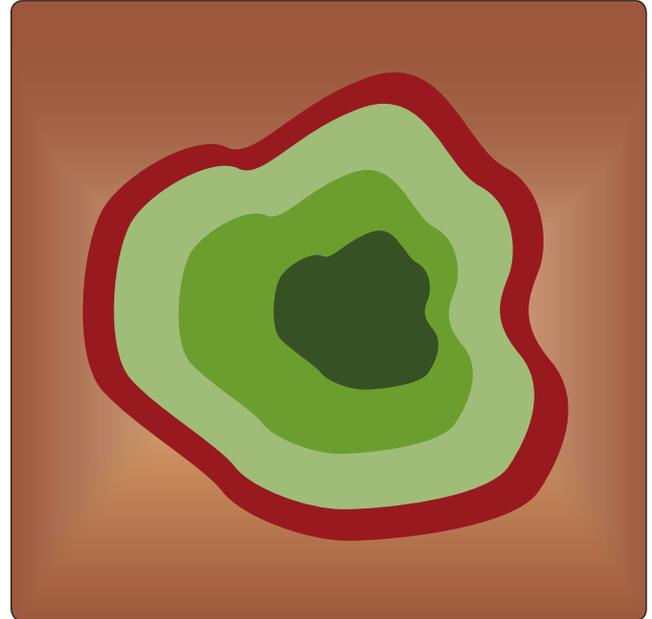
No two thermals are exactly alike since the thermal sources are not the same.

Whether considered a bubble or column, the air in the middle of the thermal rises faster than the air near the sides of the thermal. A horizontal slice through an idealized thermal provides a bull's-eye pattern. Real thermals usually are not perfectly concentric; techniques for best using thermals are discussed in the next chapter. [Figure 9-9]

The diameter of a typical thermal cross-section is on the order of 500–1,000 feet, though the size varies considerably. Typically, due to mixing with the surrounding air, thermals expand as they rise. Thus, the thermal column may actually resemble a cone, with the narrowest part near the ground. Thermal plumes also tilt in a steady wind and can become quite distorted in the presence of vertical shear. If vertical shear is strong enough, thermals can become very turbulent or become completely broken apart. A schematic of a thermal lifecycle in wind shear is shown in Figure 9-10.

### Atmospheric Stability

Stability in the atmosphere tends to hinder vertical motion, while instability tends to promote vertical motion. A certain

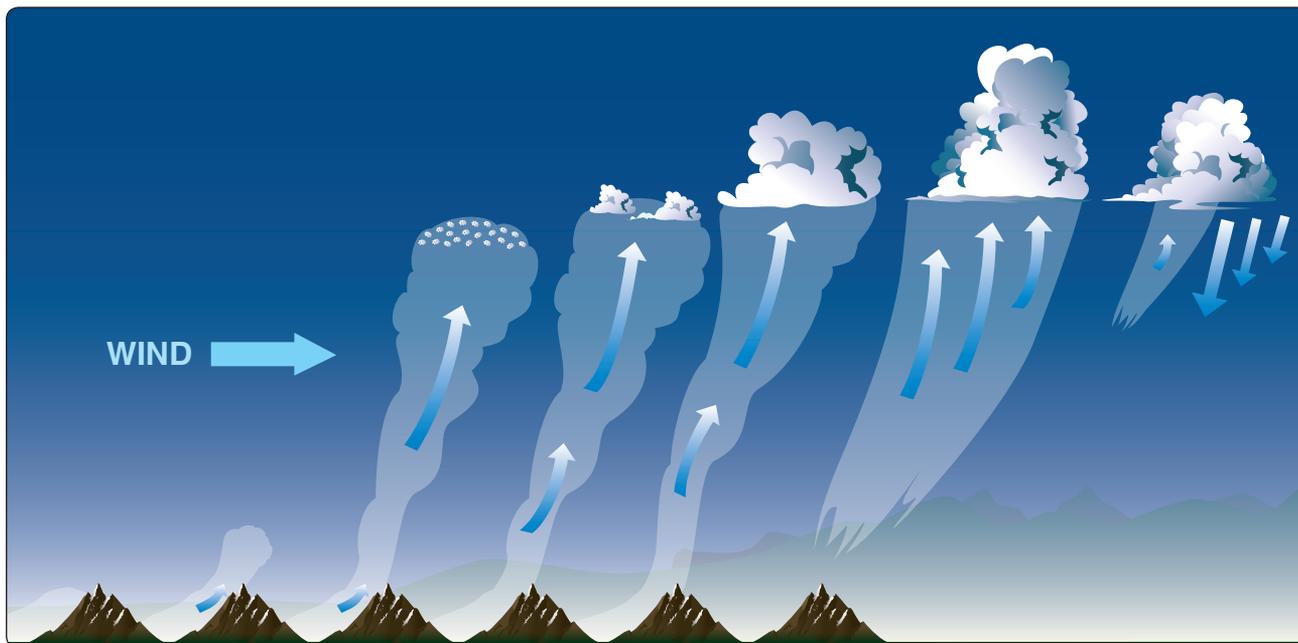


**Figure 9-9.** *Cross-section through a thermal. Darker green is stronger lift; red is sink.*

amount of instability is desirable for glider pilots; without it, thermals would not develop. If the air is moist enough and the atmospheric instability is deep enough, thunderstorms and associated hazards can form. Thus, an understanding of atmospheric stability and its determination from available weather data is important for soaring flight and safety. As a note, the following discussion is concerned with vertical stability of the atmosphere. Other horizontal atmospheric instabilities, such as the evolution of large-scale cyclones, are not covered here.

Generally, a stable dynamic system is one in which a displaced element returns to its original position. An unstable dynamic system is one in which a displaced element accelerates away from its original position. In a neutrally stable system, the displaced element neither returns to nor accelerates from its original position. In the atmosphere, it is easiest to use a parcel of air as the displaced element. The behavior of a stable or unstable system is analogous to aircraft stability discussed in Chapter 3, Aerodynamics of Flight.

For simplicity, assume first that the air is completely dry. Effects of moisture in atmospheric stability are considered later. A parcel of dry air that is forced to rise expands due to decreasing pressure and cools in the process. By contrast, a parcel of dry air that is forced to descend is compressed due to increasing pressure and warms. If there is no transfer of heat between the surrounding, ambient air and the displaced parcel, the process is called adiabatic. Assuming adiabatic motion, a rising parcel cools at a lapse rate of 3 °C (5.4 °F) per 1,000 feet, known as the dry adiabatic lapse rate (DALR).



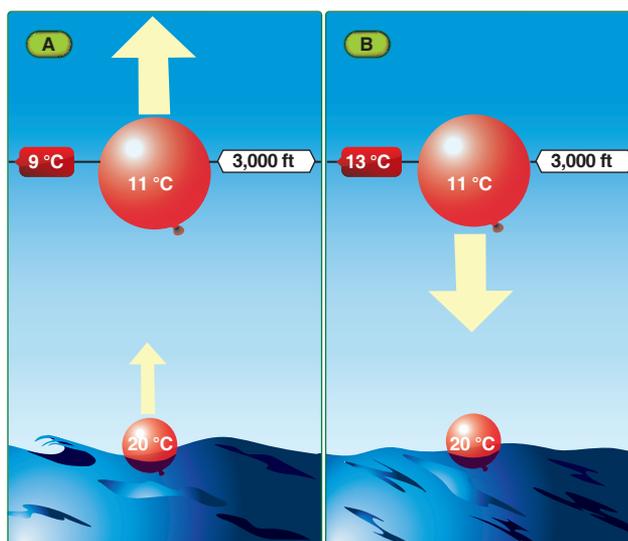
**Figure 9-10.** Lifecycle of a typical thermal with cumulus cloud.

The DALR is the rate at which the temperature of unsaturated air changes as a parcel ascends or descends through the atmosphere which is approximately  $9.8\text{ }^{\circ}\text{C}$  per 1 kilometer. On a thermodynamic chart, parcels cooling at the DALR are said to follow a dry adiabatic. A parcel warms at the DALR as it descends. In reality, heat transfer often occurs. For instance, as a thermal rises, the circulation in the thermal itself (recall the bubble model) mixes in surrounding air. Nonetheless, the DALR is a good approximation.

The DALR represents the lapse rate of the atmosphere when it is neutrally stable. If the ambient lapse rate in some layer of air is less than the DALR (for instance,  $1\text{ }^{\circ}\text{C}$  per 1,000 feet), then that layer is stable. If the lapse rate is greater than the DALR, it is unstable. An unstable lapse rate usually occurs within a few hundred feet of the heated ground. When an unstable layer develops aloft, the air quickly mixes and reduces the lapse rate back to DALR. It is important to note that the DALR is not the same as the standard atmospheric lapse rate of  $2\text{ }^{\circ}\text{C}$  per 1,000 feet. The standard atmosphere is a stable one.

Another way to understand stability is to imagine two scenarios, each with a different temperature at 3,000 feet above ground level (AGL), but the same temperature at the surface, nominally  $20\text{ }^{\circ}\text{C}$ . In both scenarios, a parcel of air that started at  $20\text{ }^{\circ}\text{C}$  at the surface has cooled to  $11\text{ }^{\circ}\text{C}$  by the time it has risen to 3,000 feet at the DALR. In the first scenario, the parcel is still warmer than the surrounding air, so it is unstable and the parcel keeps rising—a good thermal day. In the second scenario, the parcel is cooler than the surrounding air, so it is stable and sinks. The parcel in the second scenario would need to be forced to 3,000 feet AGL

by a mechanism other than convection, such as being lifted up a mountainside or a front. [Figure 9-11]



**Figure 9-11.** Unstable (A) and stable (B) parcels of air.

Figure 9-11 also illustrates factors leading to instability. A stable atmosphere can turn unstable in one of two ways. First, if the surface parcel warms by more than  $2\text{ }^{\circ}\text{C}$  (to greater than  $22\text{ }^{\circ}\text{C}$ ), the layer to 3,000 feet then becomes unstable in the second scenario. Thus, if the temperature of the air aloft remains the same, warming the lower layers causes instability and better thermal soaring. Second, if the air at 3,000 feet is cooler, as in the first scenario, the layer becomes unstable. Thus, if the temperature on the ground remains the same, cooling aloft causes instability and better thermal soaring. If the temperatures aloft and at the surface warm or cool

by the same amount, then the stability of the layer remains unchanged. Finally, if the air aloft remains the same, but the surface air cools (for instance, due to a very shallow front), then the layer becomes even more stable.

An inversion is a condition in which a layer warms as altitude increases. Inversions can occur at any altitude and vary in strength. In strong inversions, the temperature can rise as much as 10 °C over just a few hundred feet of altitude gain. The most notable effect of an inversion is to cap any unstable layer below. Along with trapping haze or pollution below, it also effectively provides a cap to any thermal activity.

So far, only completely dry air parcels have been considered. However, moisture in the form of water vapor is always present in the atmosphere. As a moist parcel of air rises, it cools at the DALR until it reaches its dewpoint, at which time the air in the parcel begins to condense. During the process of condensation, heat (referred to as latent heat) is released to the surrounding air. Once saturated, the parcel continues to cool, but since heat is now added, it cools at a rate lower than the DALR. The rate at which saturated air cools with height is known as the saturated adiabatic lapse rate (SALR). Unlike the DALR, the SALR varies substantially with altitude. At lower altitudes, it is on the order of 1.2 °C per 1,000 feet, whereas at middle altitudes it increases to 2.2 °C per 1,000 feet. Very high up, above approximately 30,000 feet, little water vapor exists to condense, and the SALR approaches the DALR.

## Air Masses Conducive to Thermal Soaring

Generally, the best air masses for thermals are those with cool air aloft, with conditions dry enough to allow the sun's heating at the surface, but not dry enough that cumulus form. Along the West Coast of the continental United States, these conditions are usually found after passage of a Pacific cold front. Similar conditions are found in the eastern and mid-west United States, except the source air for the cold front is from polar continental regions, such as the interior of Canada. In both cases, high pressure building into the region is favorable, since it is usually associated with an inversion aloft, which keeps cumulus from growing into rainshowers or thundershowers. However, as the high pressure builds after the second or third day, the inversion has often lowered to the point that thermal soaring is poor or no longer possible. This can lead to warm and sunny, but very stable conditions, as the soaring pilot awaits the next cold front to destabilize the atmosphere. Fronts that arrive too close together can also cause poor postfrontal soaring, as high clouds from the next front keep the surface from warming enough. Very shallow cold fronts from the northeast (with cold air only one or two thousand feet deep) often have a stabilizing effect along the plains directly east of the Rocky Mountains. This is due to

cool low-level air undercutting warmer air aloft advecting from the west.

In the desert southwest, the Great Basin, and intermountain west, good summertime thermal soaring conditions are often produced by intense heating from below, even in the absence of cooling aloft. This dry air mass with continental origins produces cumulus bases 10,000 feet AGL or higher. At times, this air spreads into eastern New Mexico and western Texas as well. Later in the summer, however, some of these regions come under the influence of the North American Monsoon, which can lead to widespread and daily late morning or early afternoon thundershowers. [Figure 9-12]

## Cloud Streets

Cumulus clouds are often randomly distributed across the sky, especially over relatively flat terrain. Under the right conditions, however, cumulus can become aligned in long bands, called cloud streets. These are more or less regularly spaced bands of cumulus clouds. Individual streets can extend 50 miles or more while an entire field of cumulus streets can extend hundreds of miles. The spacing between streets is typically three times the height of the clouds. Cloud streets are aligned parallel to the wind direction; thus, they are ideal for a downwind cross-country flight. Glider pilots can often fly many miles with little or no circling, sometimes achieving glide ratios far exceeding the still-air value.

Cloud streets usually occur over land with cold air outbreaks, for instance, following a cold front. Brisk surface winds and a wind direction remaining nearly constant up to cloud base are favorable cloud street conditions. Windspeed should increase by 10 to 20 knots between the surface and cloud base, with a maximum somewhere in the middle of or near the top of the convective layer. Thermals should be capped by a notable inversion or stable layer.

A vertical slice through an idealized cloud street illustrates a distinct circulation, with updrafts under the clouds and downdrafts in between. Due to the circulation, sink between streets may be stronger than typically found away from cumulus. [Figure 9-13]

Thermal streets, with a circulation like *Figure 9-13*, may exist without cumulus clouds. Without clouds as markers, use of such streets is more difficult. A glider pilot flying upwind or downwind in consistent sink should alter course crosswind to avoid inadvertently flying along a line of sink between thermal streets.

## Thermal Waves

*Figure 9-14* shows a wavelike form for the inversion capping the cumulus clouds. If the winds above the inversion are

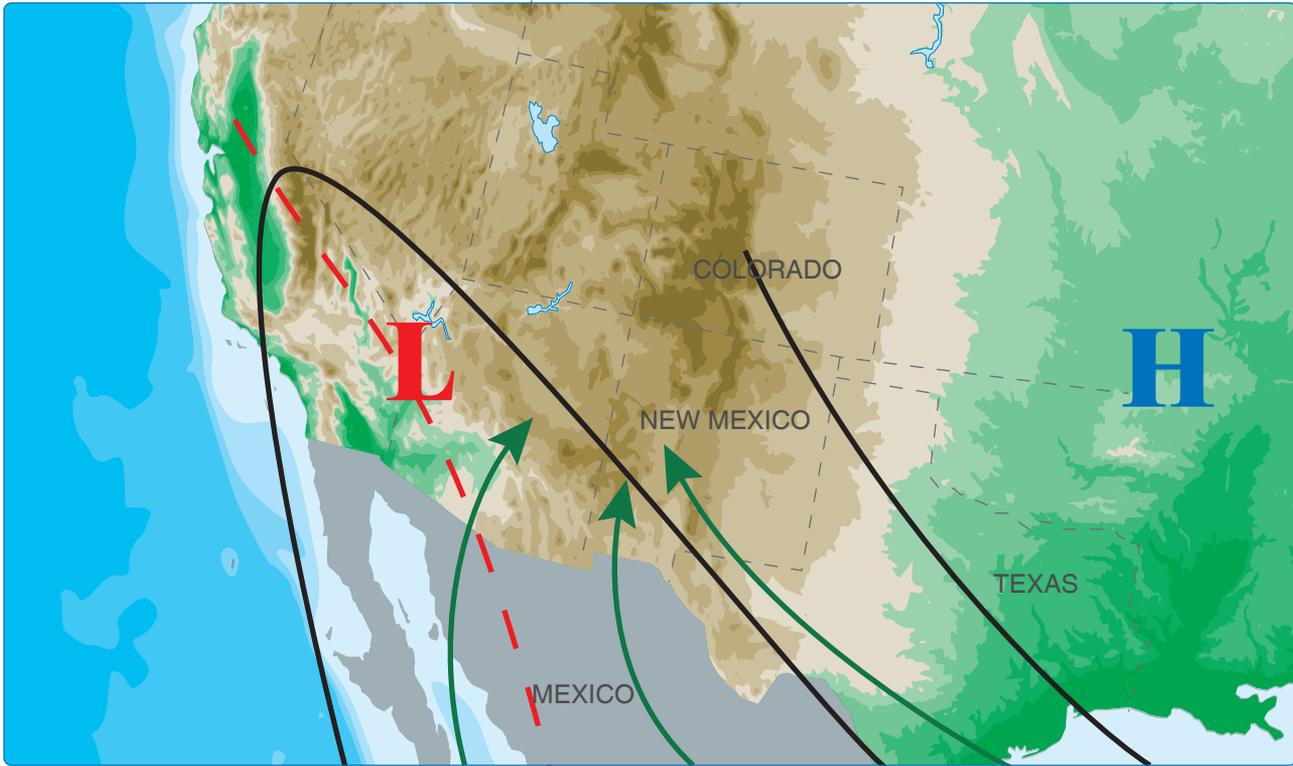


Figure 9-12. Typical North American monsoon flow.

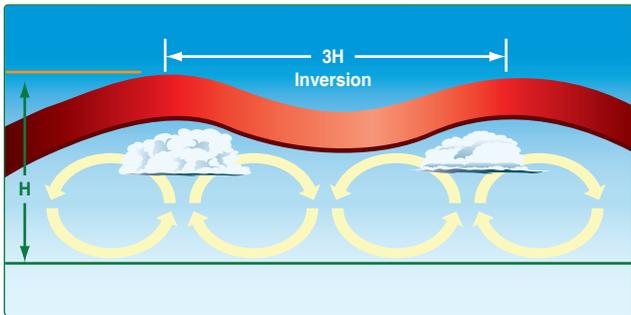


Figure 9-13. Circulation across a cloud street.

perpendicular to the cloud streets and increasing at 10 knots per 5,000 feet or more, cloud street waves can form in the stable air above. Though usually relatively weak, thermal waves can produce lift of 100 to 500 fpm and allow smooth flight along streets above the cloud base. [Figure 9-14]

So-called cumulus waves also exist. These are similar to cloud street waves, except the cumulus clouds are not organized in streets. Cumulus waves require a capping inversion or stable layer and increasing wind above cumulus clouds. However, directional shear is not necessary. Cumulus waves may also be short lived, and difficult to work for any length of time. An exception is when the cumulus is anchored to some feature, such as a ridge line or short mountain range.

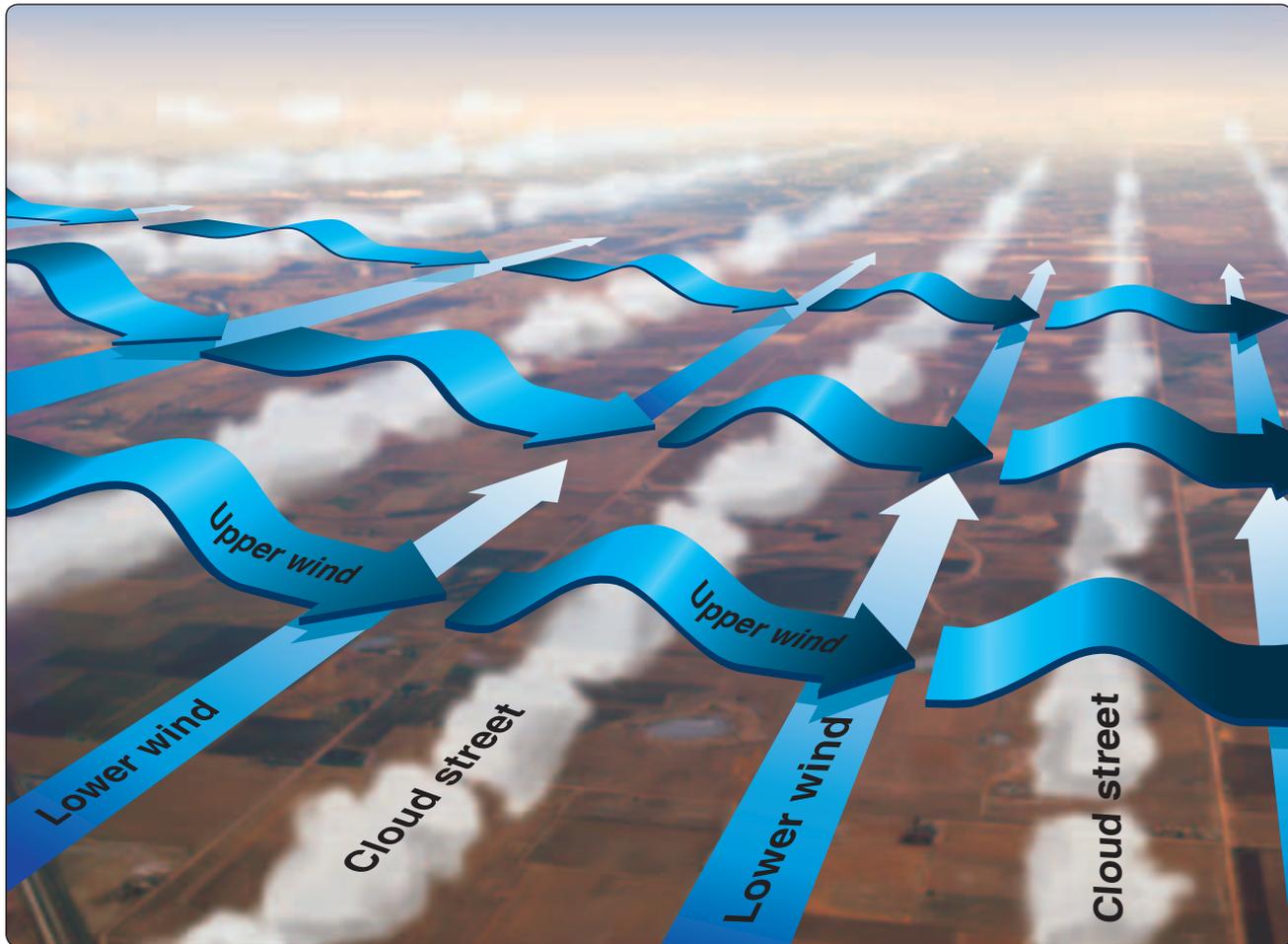
In these cases, the possible influence of the ridge or mountain in creating the wave lift becomes uncertain. Further discussion

of atmospheric waves appears later in this chapter. As a final note, thermal waves can also form without clouds present.

### Thunderstorms

An unstable atmosphere can provide great conditions for thermal soaring. If the atmosphere is too moist and unstable, however, cumulonimbus (Cb) or thunderclouds can form. Cb clouds are the recognized standard marker of thunderstorms. When Cb builds sufficiently, it changes from rainstorm to thunderstorm status. Well developed Cb clouds are thunderstorms. Not all precipitating, large cumulo-form clouds are accompanied by lightning and thunder, although their presence is usually an indication that conditions are ripe for full-blown thunderstorms. Forecasters sometimes use the term “deep convection” to refer to convection that rises to high levels, which usually means thunderstorms. The tremendous amount of energy associated with Cb stems from the release of latent heat as condensation occurs with the growing cloud.

Thunderstorms can occur any time of year, though they are more common during the spring and summer seasons. They can occur anywhere in the continental United States but are not common along the immediate West Coast, where an average of only about one per year occurs. During the summer months, the desert southwest, extending northeastward into the Rocky Mountains and adjacent Great Plains, experiences an average of 30 to 40 thunderstorms



**Figure 9-14.** *Cloud street wave.*

annually. Additionally, in the southeastern United States, especially Florida, between 30 and 50 thunderstorms occur in an average year. Thunderstorms in the cool seasons usually occur in conjunction with some forcing mechanism, such as a fast moving cold front or a strong upper-level trough. [Figure 9-15]

The lifecycle of an air-mass or ordinary thunderstorm consists of three main stages: cumulus, mature, and dissipating. The term “ordinary” describes the type of thunderstorm consisting of a single Cb, since other types of thunderstorms (described below) can occur in a uniform large scale air mass. The entire lifecycle takes on the order of an hour, though remnant cloud from the dissipated Cb can last substantially longer.

The cumulus stage is characterized by a cumulus growing to a towering cumulus (Tcu), or cumulus congestus. During this stage, most of the air within the cloud is going up. The size of the updraft increases, while the cloud base broadens to a few miles in diameter. Since the cloud has increased in size, the strong updraft in the middle of the cloud is not susceptible to entrainment of dryer air from the outside. Often, other

smaller cumulus in the vicinity of the Tcu are suppressed by general downward motion around the cloud. Towards the end of the cumulus stage, downdrafts and precipitation begin to form within the cloud. On some days, small cumulus can be around for hours, before Tcu form, while on other days, the air is so unstable that almost as soon as any cumulus form, they become Tcu. [Figure 9-16]

As the evolution of the thunderstorm continues, it reaches its mature stage. By this time, downdrafts reach the ground and spread out in what are known as downbursts or microbursts. These often lead to strong and sometimes damaging surface winds. Gliders should not be flown or exposed to microbursts and the associated windshears. While increased headwinds can momentarily improve performance, the distance from the landing area may be increased beyond the capabilities of the glider. Attempting to launch with possible windshears can result in fatal consequences.

Note: Launching of a glider either behind a towplane or ground launch is risky. Given the size of windshears, the towplane could be in a tailwind situation while the glider

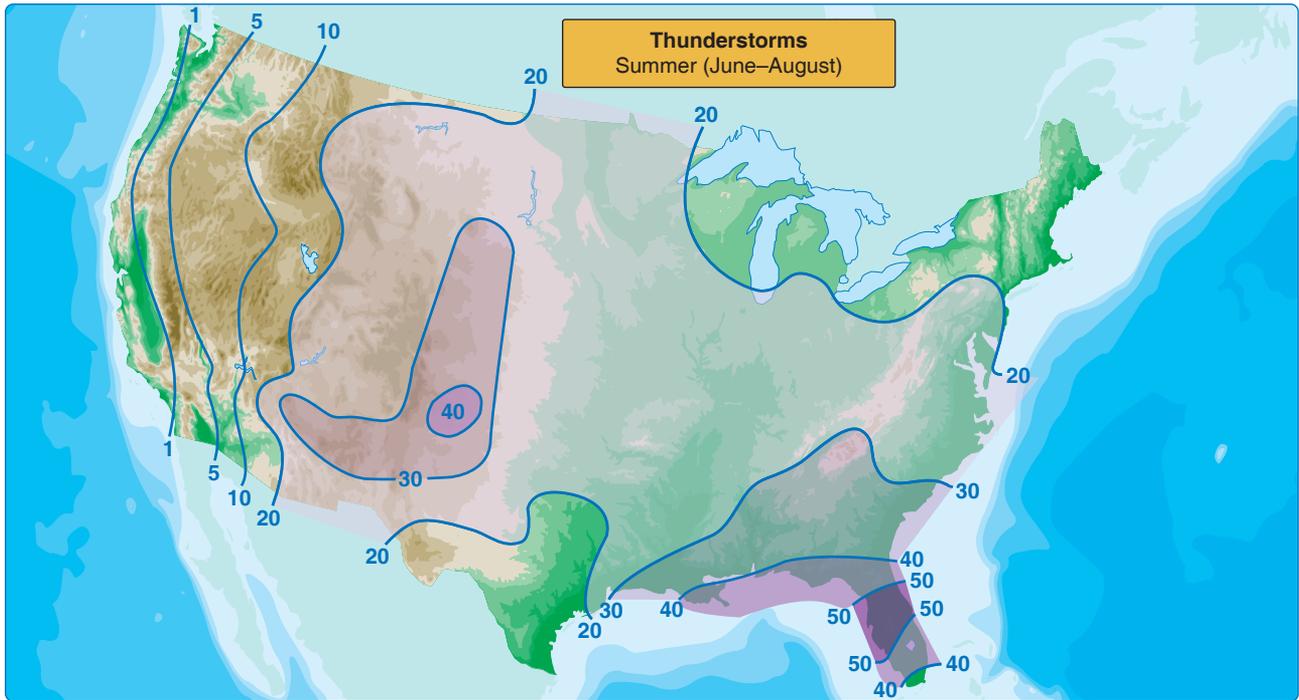


Figure 9-15. Thunderstorm frequency in the summertime.



Figure 9-16. A cumulus growing to a towering cumulus.

is in a headwind situation. With the likely outcome of that combination of factors, and the hazards of ground handling, operations in such conditions must be severely discouraged.

Pilots need to watch apparently dissipating thunderstorms closely for new dark, firm bases that indicate a new cell forming. In addition, outflow from one Cb may flow several miles before encountering an area where the air is primed for lifting given an extra boost. The relatively cool air in the

outflow can provide that boost, leading to new a Cb, which is nearby but not connected to the original Cb.

### Lifted Index

The LI is determined by subtracting the temperature of a parcel that has been lifted to 500 mb from the temperature of the ambient air. This index does not give the likelihood of thunderstorm occurrence; rather, it gives an indication of thunderstorm severity if one does occur. In Figure 9-17, an LI of  $-5$  indicates moderately severe thunderstorms if they develop.

Lifted Index	Chance of Severe Thunderstorm
0 to $-2$	Weak
$-3$ to $-5$	Moderate
$\leq -6$	Strong

Figure 9-17. Lifted index (LI) versus thunderstorm severity.

### K-Index

The KI is used to determine the probability of thunderstorm occurrence and uses information about temperature and moisture at three levels. It is given by the equation  $KI = (T850 - T500) + Td850 - (T700 - Td700)$ . Here, T stands for temperature, Td is the dewpoint, and 500, 700, or 850 indicates the level in mb. All values are obtained from a morning sounding. Using the following values from a morning sounding  $KI = (16 - [-9]) + 12 - (6 - 0) = 31$ . This indicates about a 60 percent probability that thunderstorms will occur. [Figure 9-18] As discussed below, charts showing both the LI and KI for all the sounding sites in the continental United States are produced daily.

K Index	Thunderstorm Probability (%)
< 15	near 0
15 to 20	20
21 to 25	20 to 40
26 to 30	40 to 60
31 to 35	60 to 80
36 to 40	80 to 90
> 40	near 100

**Figure 9-18.** *K-Index (KI) versus probability of thunderstorm occurrence.*

Thunderstorms have several hazards, including turbulence, strong updrafts and downdrafts, strong shifting surface winds, hail, icing, poor visibility and/or low ceilings, lightning, and even tornadoes. Once a cloud has grown to be a Cb, hazards are possible, whether or not there are obvious signs. Since thermal soaring weather can rapidly deteriorate into thunderstorm weather, recognition of each hazard is important. Knowledge of the many hazards may inspire the pilot to land and secure the glider when early signs of thunderstorm activity appear—the safest solution.

Moderate turbulence is common within several miles of a thunderstorm, and it should be expected. Severe or even extreme turbulence (leading to possible structural failure) can occur anywhere within the thunderstorm itself. The inside of a thunderstorm is no place for glider pilots of any experience level. Outside of the storm, severe turbulence is common. One region of expected turbulence is near the surface gust front as cool outflow spreads from the storm. Violent updrafts can be followed a second or two later by violent downdrafts, with occasional side gusts adding to the excitement—not a pleasant proposition while in the landing pattern. At somewhat higher altitudes, but below the base of the Cb, moderate to severe turbulence can also be found along the boundary between the cool outflow and warm air feeding the Cb. Unpredictable smaller scale turbulent gusts can occur anywhere near a thunderstorm, so recognizing and avoiding the gust front does not mean safety from severe turbulence.

Large and strong updrafts and downdrafts accompany thunderstorms in the mature stage. Updrafts under the Cb base feeding into the cloud can easily exceed 1,000 fpm. Near the cloud base, the distance to the edge of the cloud can be deceptive; trying to avoid being inhaled into the cloud by strong updrafts can be difficult. In the later cumulus and early mature stage, updrafts feeding the cloud can cover many square miles. As the storm enters its mature stage, strong downdrafts, called downbursts or microbursts, can be encountered, even without very heavy precipitation present. Downbursts can also cover many square miles with descending air of 2,000 fpm or more. A pilot unlucky enough to fly under a forming downburst, which may not be visible, could encounter sink of 2,000 or 3,000 fpm, possibly

greater in extreme cases. If such a downburst is encountered at pattern altitude, it can cut the normal time available to the pilot for planning the approach. For instance, a normal 3-minute pattern from 800 feet AGL to the ground happens in a mere 19 seconds in 2,500 fpm sink!

When a downburst or microburst hits the ground, the downdraft spreads out, leading to the strong surface winds, known as thunderstorm outflow. Typically, the winds strike quickly and give little warning of their approach. While soaring, pilots should keep a sharp lookout between the storm and the intended landing spot for signs of a wind shift. Blowing dust, smoke, or wind streaks on a lake indicating wind from the storm are clues that a gust front is rapidly approaching. Thunderstorm outflow winds are usually at speeds of 20 to 40 knots for a period of 5 to 10 minutes before diminishing. However, winds can easily exceed 60 knots, and in some cases, with a slow-moving thunderstorm, strong winds can last substantially longer. Although damaging outflow winds usually do not extend more than 5 or 10 miles from the Cb, winds of 20 or 30 knots can extend 50 miles or more from large thunderstorms.

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 does not damage a glider, but the large hail associated with a severe storm can dent metal gliders or damage the gelcoat on composite gliders, whether on the ground or in the air.

Icing is usually a problem only within a cloud, especially at levels where the outside temperature is approximately  $-10^{\circ}\text{C}$ . Under these conditions, supercooled water droplets (water existing in a liquid state  $0^{\circ}\text{C}$  and below) can rapidly freeze upon contact with 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. Inflight damage to gliders has included burned 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 and should obviously 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 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 is 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 be able to climb only to ridge height. As a general rule, the higher the ridge above the adjacent valley, the higher the glider pilot can climb. Ridges only 100 or 200 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 9-19]

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

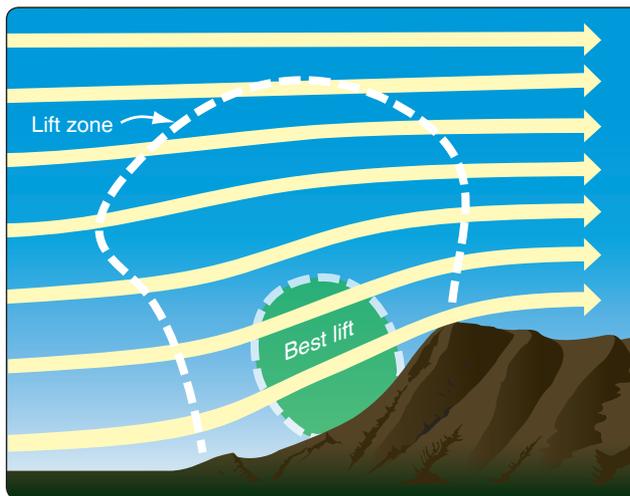


Figure 9-19. Slope soaring.

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 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 9-20]

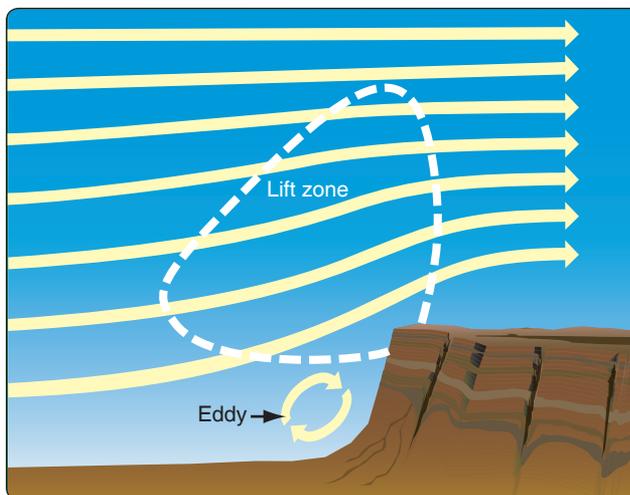
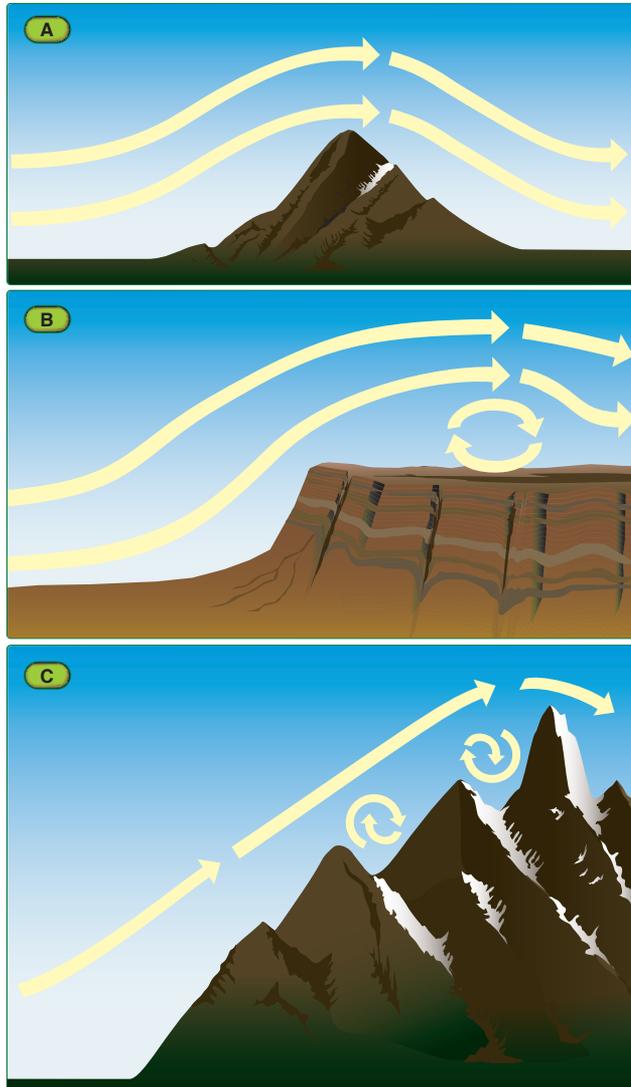


Figure 9-20. Slope lift and eddy with near-vertical slope.

A ridge upstream can block the wind flow, so that no low-level flow occurs upwind of an otherwise promising ridge, and 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.

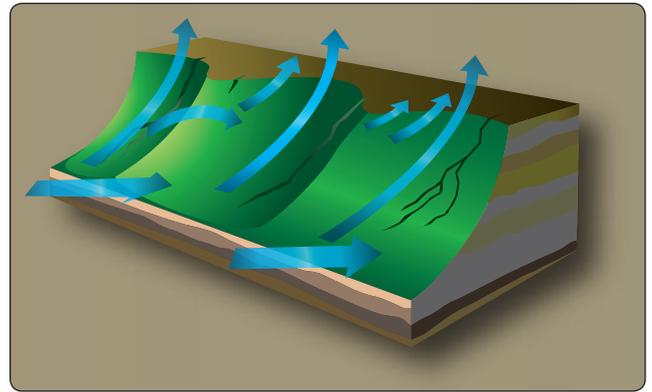
Just as the flow is deflected upward on the windward side of a ridge, it is deflected downward on the lee side of a ridge. [Figure 9-21] This downdraft can be alarmingly strong—up to 2,000 fpm or more near a steep ridge with strong winds (see depiction A). Even in moderate winds, the downdraft near a 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 (see depiction B). Finally, an uneven upwind slope with ledges or “steps” requires extra caution since small-scale eddies, turbulence, and sink can form there (see depiction C).



**Figure 9-21.** Airflow along different ridges.

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 9-22]



**Figure 9-22.** Three-dimensional effects of oblique winds and bowls.

Depending on the slope, windspeed 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.

The area of best lift varies with height. Below the ridge crest, the best slope lift is found within a few hundred feet of 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 9-19]

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 windspeed, 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; extra speed and caution are 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 slowly lowers 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 [Figure 9-23]—a dangerous situation.



**Figure 9-23.** *Cap cloud.*

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, mountains or ridges often 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 kilometers. 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 causes 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 does 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 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 9-24*. In the first frame, the dry parcel is at rest at its equilibrium level. In the second frame, the parcel is displaced upward along the DALR, where it is cooler than the surrounding air. The parcel accelerates downward toward its equilibrium level but it overshoots the level due to momentum and keeps going down. The third frame shows that the parcel is now warmer than the surrounding air, and 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 9-24*]

The lower part of *Figure 9-24* 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 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 plus postflight analysis of the weather conditions. *Figure 9-25* illustrates a mountain with wind and temperature profiles. Note the increase in windspeed (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 usually is incredibly smooth. Beneath the smooth wave flow is what is known as a low-level turbulent zone, with an embedded rotor circulation under each crest. Turbulence, especially within the individual rotors, is usually moderate to severe, and can occasionally become extreme. [*Figure 9-25*]

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

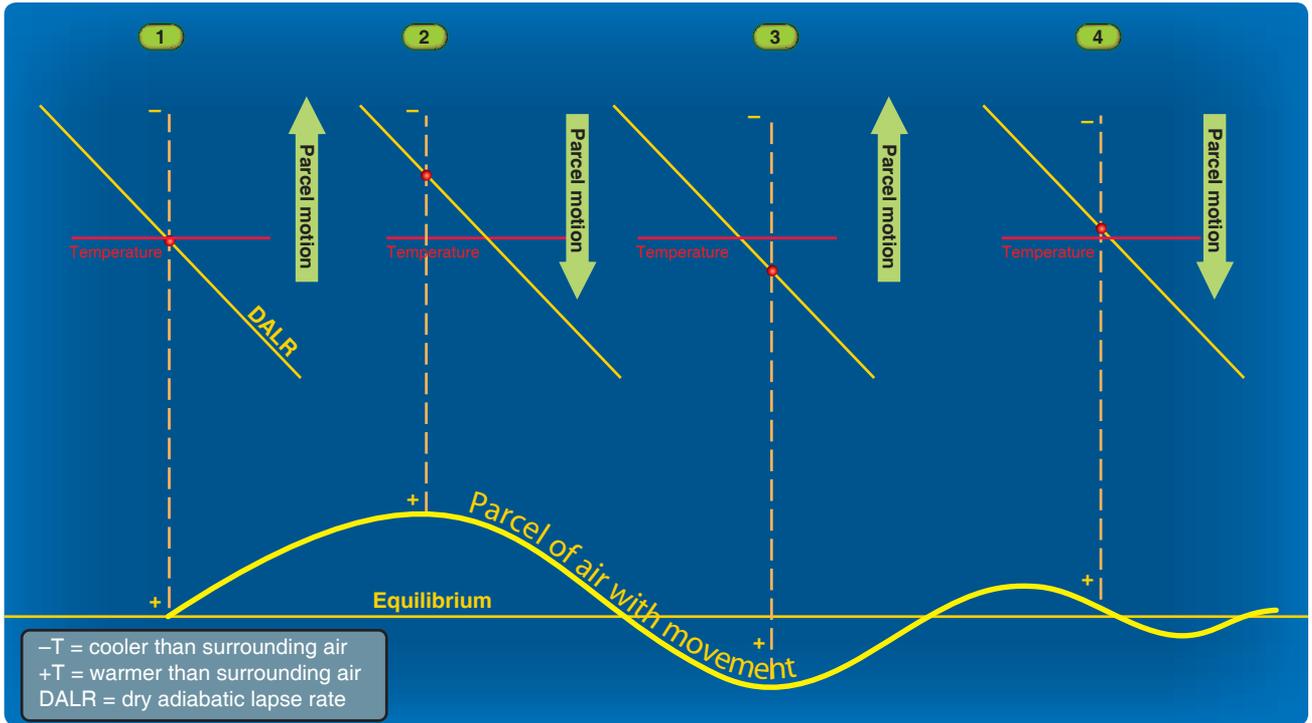


Figure 9-24. Parcel displaced vertically and oscillating around its equilibrium level.

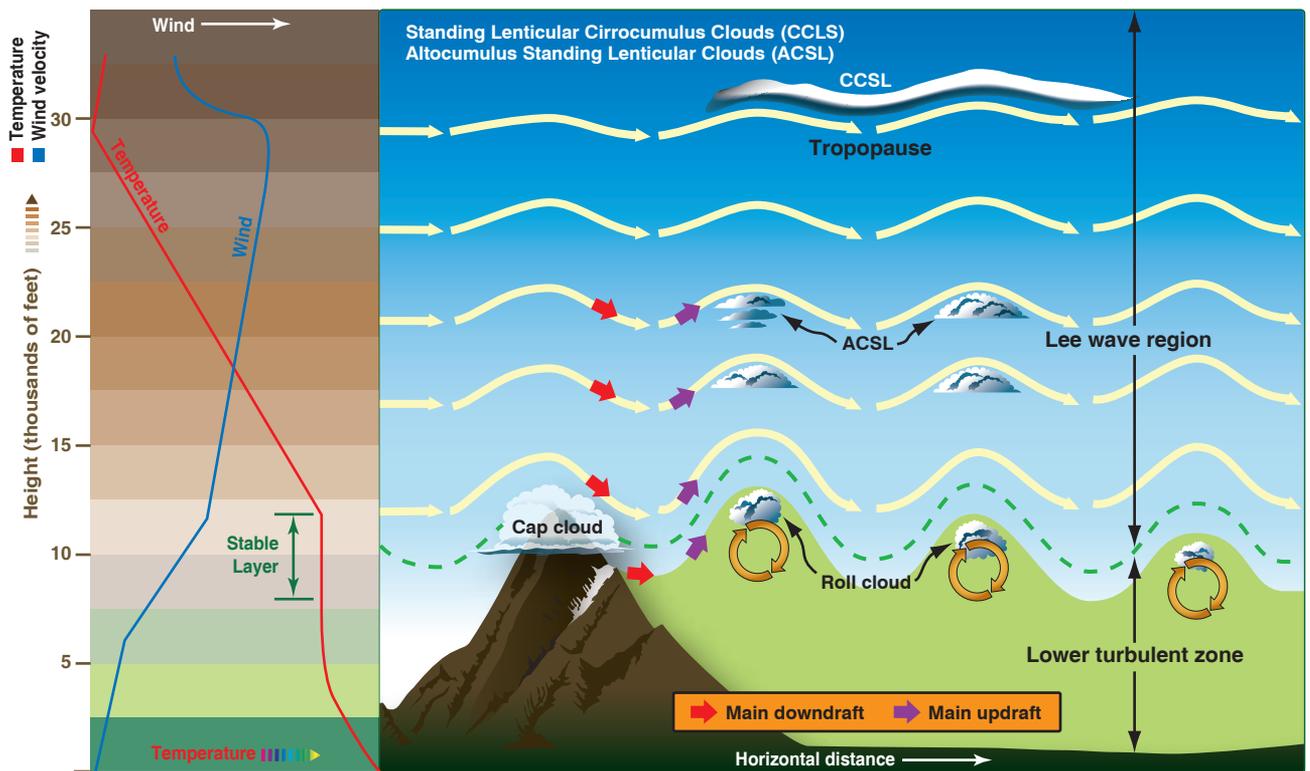


Figure 9-25. Mountain lee wave system.

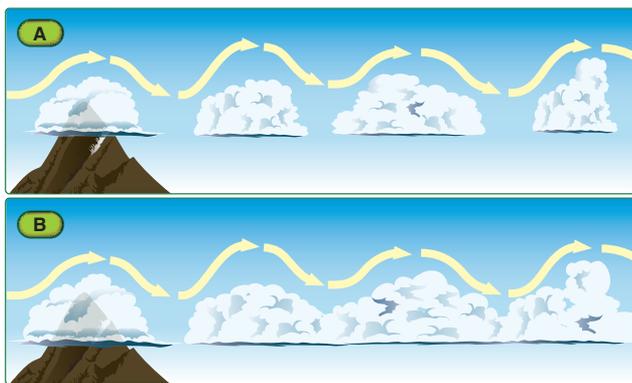
topography has many complex, three-dimensional features, such as individual higher peak, large ridges, or spurs at right angles to the main range. Variations can occur when a north-

south range curves 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 to 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 are 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 9-25*. 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 slang) above. Wave harmonics farther downstream (secondary, tertiary, etc.) may also have lenticulars and/or rotor clouds. If the wave reaches high enough altitudes, lenticulars 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 lenticulars above, as in *Figure 9-26A*. On other days, only mid-level or upper-level lenticulars are seen with no rotor clouds beneath them. When low and mid levels are very moist, a deep rotor cloud may form, with lenticulars right on top of the rotor cloud, with no clear air between the two cloud forms.



**Figure 9-26.** *Small Foehn Gap under most conditions.*

In wet climates, the somewhat more moist air can advect (meaning to convey horizontally by advection) in, such

that the gap between the cap cloud and primary rotor closes completely, stranding the glider on top of the clouds, as in *Figure 9-26B*. Caution is required when soaring above clouds in very moist 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.

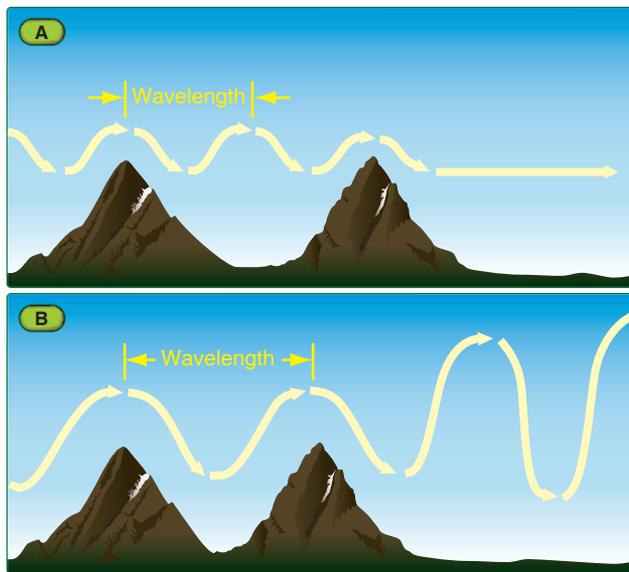
The weather requirements for wave soaring include sufficient wind and a proper stability profile. Windspeed should be at least 15 to 20 knots at mountaintop level with increasing winds above. The wind direction should be within about 30° perpendicular to the ridge or mountain range. The requirement of 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 windspeed with height, but an actual decrease in windspeed 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 (see [www.soaringmuseum.org](http://www.soaringmuseum.org)), 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 9-27*. In the first case [*Figure 9-27A*], 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 [*Figure 9-27B*], 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.



**Figure 9-27.** Constructive and destructive interference.

Wave flight is a unique soaring experience and requires planning, equipment and Federal Aviation Administration (FAA) notification for the flight. The Soaring Society of America (SSA) Awards and Badges offers soaring pilots Lennie Awards for completing and documenting a wave flight. [*Figure 9-28*]

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



While working out of the Bishop, California, airport in the late 1940s, mountain pilot and wave pilot pioneer Robert F. Symons created a new and unique system of awards for wave flying, which he called "lennie" pins. Pilots who soared to great heights in the Sierra Wave received a one-lennie pin for attaining an altitude of 25,000 to 35,000 feet, a two-lennie pin for reaching 35,000 to 40,000 feet, and a three-lennie pin for exceeding 40,000 feet.

Very early, Symons recognized the excellent soaring conditions in the Owens Valley and helped organize a soaring group in 1938. As a professional pilot engaged in cloud seeding, he learned first hand of the power generated in the Sierra Wave and became well known for his studies and lectures on mountain wave phenomena. Although his lists are incomplete, it is believed that he issued some 35 one-lennie, 16 two-lennie, and 10 three-lennie pins. The awarding of these pins ceased in 1958, when Symons lost his life in a glider accident.

In 1962 Carl Burson, Jr., saw one of these pins and upon learning of its history, became interested in reestablishing their issuance as a memorial to Bob Symons. In 1963, the program was reestablished under the official auspices of the SSA, with each new pin holder also receiving a handsome wall plaque. The pin itself is 7mm in diameter (the same as the FAI Gold Badge) and has one, two, or three white lenticular clouds against a blue background with a silver rim. Each pin is consecutively numbered.

**Figure 9-28.** Lennie Awards are given for completing and documenting a wave flight.

### Lift Due to Convergence

Convergence lift is most easily imagined when easterly and westerly winds meet. When two opposing air masses meet, air is pushed aloft by the two opposing winds. Air does not need to meet head on to go up, however. Wherever air piles up, it leads to convergence and rising air.

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 focus 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 dewpoint than drier inland air. As shown in *Figure 9-29*, 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, forms. 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 generally prevents any inland penetration of the sea-breeze front.

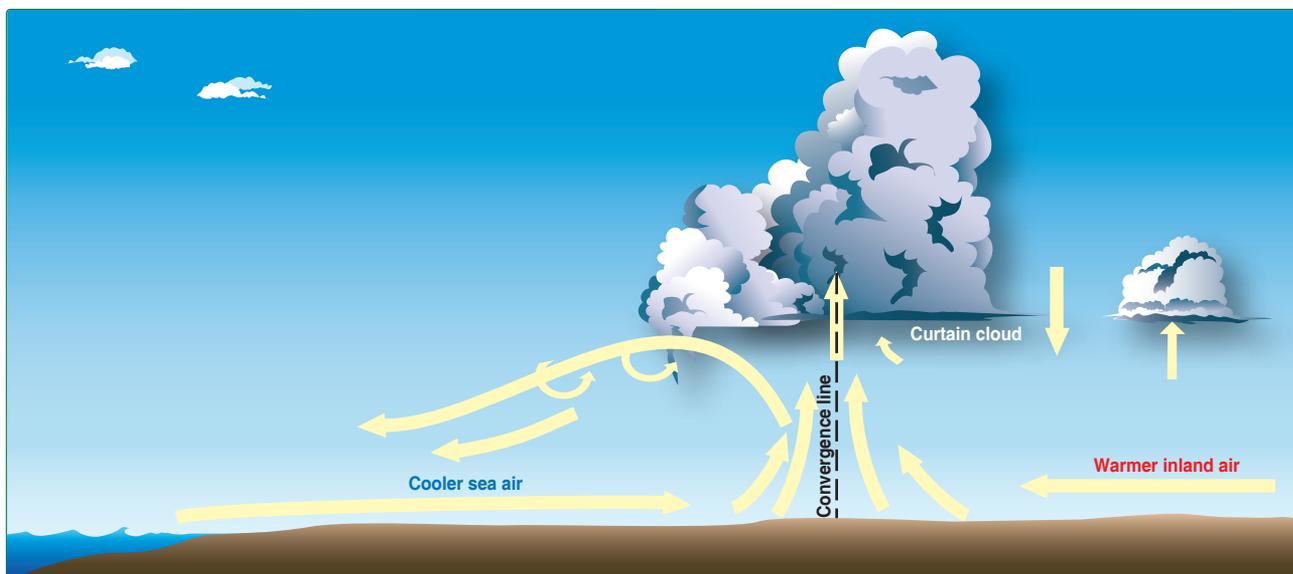
If the sea-breeze front is well defined and marked by a curtain cloud, the pilot can fly straight along the line in fairly steady lift. A weaker convergence line that is not well-defined often produces more lift than sink and the pilot must fly slower in lift and faster in sink. Soaring pilots must be aware that convergence zone lift can be turbulent especially if the colder and warmer air is mixing and be prepared that flying the thermals may be difficult at times.

Convergence can also occur along and around mountains or ridges. In *Figure 9-30A*, 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 9-30B* 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 can also form along the top of a ridgeline or mountain range. In *Figure 9-31*, drier synoptic-scale wind flows 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 clouds are present, the air from the moist side condenses first, often forming one cloud with a well-defined step, marking the convergence zone. For this scenario, the better lift conditions will be found on the west side where the air is dryer rather than the east side where clouds are more likely to form.

As a final example, toward evening in mountainous terrain and 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 9-32*] Many local sites in either flat or mountainous terrain have lines or zones of lift that are likely to be caused or enhanced by convergence. Chapter 10, Soaring Techniques, covers locating and using convergence.



**Figure 9-29.** Sea-breeze front.

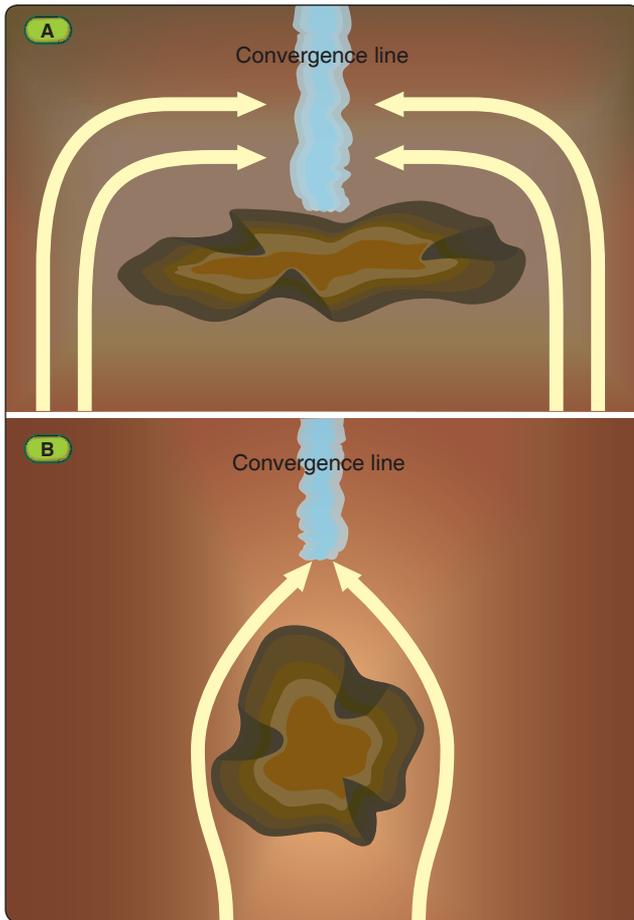


Figure 9-30. Convergence induced by flow around topography.

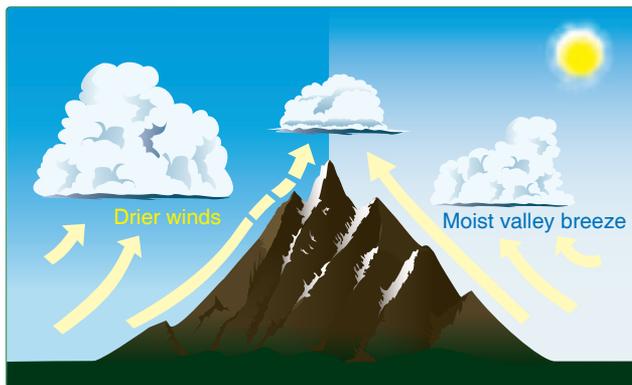


Figure 9-31. Mountain-top convergence.

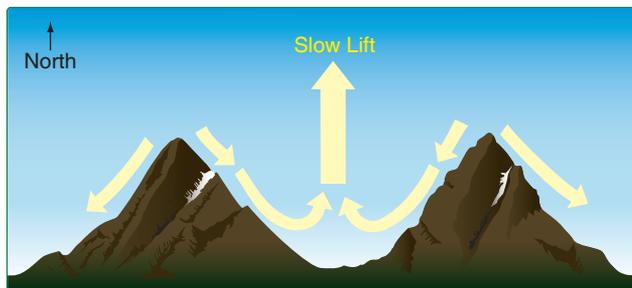


Figure 9-32. Convergence induced by flow around topography.

## 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 visual flight rules (VFR) flights, federal regulations require pilots to gather weather reports and forecasts only if they plan to depart the airport vicinity. Nevertheless, it is always a good idea to be familiar with the current and expect 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 vendors provide custom services.

For complete details regarding available weather services and products, refer to the current version of the FAA Advisory Circular (AC) 00-45, Aviation Weather Services, and in the Pilot's Handbook of Aeronautical Knowledge, Chapter 12, Aviation Weather Services.

## Preflight Weather Briefing

Often times in order to obtain a preflight weather briefing, certain background information must be given to the weather specialist: type of flight planned, whether flying VFR (Visual Flight Rules) or IFR (Instrument Flight Rules), aircraft registration or pilot's name, aircraft type, departure airport, route of flight, destination, flight altitude(s), estimated time of departure (ETD), and estimated time en route (ETE). Operators of airports, gliderports, or fixed-base operators (FBO) may obtain current reports and forecasts from the AFSS or NWS at various times throughout the day and post them on a bulletin board for easy reference.

Weather briefers do not actually predict the weather; they simply translate and interpret weather reports and forecasts within the vicinity of the airport, route of flight, or the destination airport if the flight is a cross-country. A pilot may request one of four types of briefings: standard, abbreviated, soaring [Figure 9-33], or outlook.

## Weather-Related Information

Weather-related information can be found on the Internet, including sites directed toward aviation. These sites can be found using a variety of Internet search engines. It is important to verify the timeliness and source of the weather information provided by the Internet sites to ensure the information is up to date and accurate. Pilots should exercise caution when accessing weather information on the Internet, especially if the information cannot be verified. Other sources of accurate weather information are the NWS website located at

## Soaring Forecast

National Weather Service Denver/Boulder, Colorado  
645 AM MDT Wednesday August 25, 2010

This forecast is for Wednesday August 25, 2010:

If the trigger temperature of 77.3 F/25.2 C is reached...then  
Thermal Soaring Index..... Excellent  
Maximum rate of lift..... 911 ft/min (4.6 m/s)  
Maximum height of thermals..... 16119 ft MSL (10834 ft AGL)

Forecast maximum temperature..... 89.0 F/32.1 C  
Time of trigger temperature..... 1100 MDT  
Time of overdevelopment..... None  
Middle/high clouds during soaring window..... None  
Surface winds during soaring window..... 20 mph or less  
Height of the -3 thermal index..... 10937 ft MSL (5652 ft AGL)  
Thermal soaring outlook for Thursday 08/26..... Excellent

Wave Soaring Index..... Poor  
Wave Soaring Index trend (to 1800 MDT)..... No change  
Height of stable layer (12-18K ft MSL)..... None  
Weak PVA/NVA (through 1800 MDT)..... Neither  
Potential height of wave..... 14392 ft MSL (9107 ft AGL)  
Wave soaring outlook for Thursday 08/26..... Poor

Remarks...

Sunrise/Sunset..... 06:20:55 / 19:42:44 MDT  
Total possible sunshine..... 13 hr 21 min 49 sec (801 min 49 sec)  
Altitude of sun at 13:01:25 MDT... 60.82 degrees

Upper air data from rawinsonde observation taken on 08/25/2010 at 0600 MDT

Freezing level..... 15581 ft MSL (10296 ft AGL)  
Additional freezing level..... 54494 ft MSL (49209 ft AGL)  
Convective condensation level... 13902 ft MSL (8617 ft AGL)  
Lifted condensation level..... 14927 ft MSL (9641 ft AGL)  
Lifted index..... -3.4  
K index..... +9.7

\*\*\*\*\* Numerical weather prediction model forecast data valid \*\*\*\*\*

08/25/2010 at 0900 MDT	08/25/2010 at 1200 MDT
K index... +4.0	K index... -0.7

This product is issued twice per day, once by approximately 0630 MST/0730 MDT (1330 UTC) and again by approximately 1830 MST/1930 MDT (0130 UTC). It is not continuously monitored nor updated after its initial issuance.

The information contained herein is based on rawinsonde observation and/or numerical weather prediction model data taken near the old Stapleton Airport site in Denver, Colorado at

North Latitude: 39 deg 46 min 5.016 sec  
West Longitude: 104 deg 52 min 9.984 sec  
Elevation: 5285 feet (1611 meters)

and may not be representative of other areas along the Front Range of the Colorado Rocky Mountains. Note that some elevations in numerical weather prediction models differ from actual station elevations, which can lead to data which appear to be below ground. Erroneous data such as these should not be used.

The content and format of this report as well as the issuance times are subject to change without prior notice. Comments and suggestions are welcome and

should be directed to one of the addresses or phone numbers shown at the bottom of this page. To expedite a response to comments, be sure to mention your interest in the soaring forecast.

DEFINITIONS:

Convective Condensation Level - The height to which an air parcel possessing the average saturation mixing ratio in the lowest 4000 feet of the airmass, if heated sufficiently from below, will rise dry adiabatically until it just becomes saturated. It estimates the base of cumulus clouds that are produced by surface heating only.

Convection Temperature (ConvectionT) - The surface temperature required to make the airmass dry adiabatic up to the given level. It can be considered a "trigger temperature" for that level.

Freezing Level - The height where the temperature is zero degrees Celsius.

Height of Stable Layer - The height (between 12,000 and 18,000 feet above mean sea level) where the smallest lapse rate exists. The location and existence of this feature is important in the generation of mountain waves.

K Index - A measure of stability which combines the temperature difference between approximately 5,000 and 18,000 feet above the surface, the amount of moisture at approximately 5,000 feet above the surface, and a measure of the dryness at approximately 10,000 feet above the surface. Larger positive numbers indicate more instability and a greater likelihood of thunderstorm development. One interpretation of K index values regarding soaring in the western United States is given in WMO Technical Note 158 and is reproduced in the following table:

below -10	no or weak thermals
-10 to 5	dry thermals or 1/8 cumulus with moderate thermals
5 to 15	good soaring conditions
15 to 20	good soaring conditions with occasional showers
20 to 30	excellent soaring conditions, but increasing probability of showers and thunderstorms
above 30	more than 60 percent probability of thunderstorms

Lapse Rate - The change with height of the temperature. Negative values indicate inversions.

Lifted Condensation Level - The height to which an air parcel possessing the average dewpoint in the lowest 4000 feet of the airmass and the forecast maximum temperature must be lifted dry adiabatically to attain saturation.

Lifted Index - The difference between the environmental temperature at a level approximately 18,000 feet above the surface and the temperature of an air parcel lifted dry adiabatically from the surface to its lifted condensation level and then pseudoadiabatically thereafter to this same level. The parcel's initial temperature is the forecast maximum temperature and its dewpoint is the average dewpoint in the lowest 4000 feet of the airmass. Negative values are indicative of instability with positive values showing stable conditions.

Lift Rate - An experimental estimate of the strength of thermals. It is computed the same way as the maximum rate of lift but uses the actual level rather than the maximum height of thermals in the calculation. Also, none of the empirical adjustments based on cloudiness and K-index are applied to these calculations.

Maximum Height of Thermals - The height where the dry adiabat through the forecast maximum temperature intersects the environmental temperature.

Figure 9-33. Soaring forecast.

**Maximum Rate of Lift** - An estimate of the maximum strength of thermals. It is computed from an empirical formula which combines the expected maximum height of thermals with the difference in the environmental temperatures between the maximum height of thermals and the temperature 4,000 feet above the ground. After this computation, further empirical adjustments are made based on the value of the K-index and the amount and opacity of middle and high level cloudiness expected between the time of trigger temperature and the time of overdevelopment.

**Middle/High Clouds** - The amount and opacity of middle (altostratus, altocumulus) or high (cirrus, cirrostratus, cirrocumulus) clouds. Broken means that between 60% and 90% of the sky is covered by the cloud, with overcast conditions occurring when more than 90% of the sky is covered by the cloud. Thin implies that the clouds are predominantly transparent, meaning that some sunlight is reaching the ground, in contrast to opaque which suggests that little sunlight is reaching the ground.

**Potential Height of Wave** - The minimum of the following two heights:  
 1. Level above the height of stable layer (or 14,000 feet if none exists) where the wind direction changes by 30 degrees or more  
 2. Level above the height of stable layer (or 14,000 feet if none exists) where the wind speed no longer increases with height

**PVA/NVA** - Positive vorticity advection (PVA)/negative vorticity advection (NVA) on the 500 millibar isobaric surface (approximately 18,000 feet above mean sea level). Weak PVA has been shown to assist in mountain wave soaring.

**Soaring Window** - The time between the time the trigger temperature is reached and the time of overdevelopment.

**Thermal Index** - The difference between the environmental temperature and the temperature at a particular level determined by following the dry adiabat through the forecast maximum temperature up to that level. Negative values are indicative of thermal lift.

**Thermal Soaring Index** - An adjective rating (for sailplanes) based on the computed maximum rate of lift, and the wind speed and middle and high cloud cover expected during the soaring window (the time of the trigger temperature and the time of overdevelopment) according to the following:

Maximum rate of lift	Adjective Rating
≥ 800 fpm	Excellent
≥ 400 and < 800 fpm	Good
≥ 200 and < 400 fpm	Fair
< 200 fpm	Poor

**Time of Overdevelopment** - The time one or more of the following phenomena, which essentially shut off thermal lift, is expected to occur:  
 1. formation of broken to overcast convective cloud cover  
 2. formation of scattered to numerous downbursts  
 3. initiation of widespread precipitation

**Time of Trigger Temperature** - The time the surface temperature is expected to reach the trigger temperature.

**Trigger Temperature** - The surface temperature required to make the first 4000 feet of the atmosphere dry adiabatic.

**Wave Soaring Index** - An empirical, adjective rating (for sailplanes) which attempts to combine a variety of phenomena important in mountain wave soaring into a single index number. Objective points are assigned to these phenomena: wind speed and direction at 14,000 ft MSL, the static stability in the 12,000-18,000 ft MSL layer, the wind speed gradient above the stable layer, jet stream location and frontal and upper trough movements.

www.nws.noaa.gov, the NOAA site at <http://aviationweather.gov/adds/metars/> and Dr. Jack's regional forecasts at <http://www.drjack.info/BLIP/RUC>.

## Interpreting Weather Charts, Reports, and Forecasts

Knowing how and where to gather weather information is important but the ability to interpret and understand the information requires additional knowledge and practice. Weather charts and reports are merely records of observed atmospheric conditions at certain locations at specific times. Trained observers using electronic instruments, computers, and personal observations produce the weather products necessary for pilots to determine if a flight can be conducted safely. This same information can be used by soaring pilots to determine where they can find lift and how long the lift is usable for soaring flight.

### Graphic Weather Charts

Reports of observed weather are graphically depicted in a number of weather products. Among them are the surface analysis chart, radar summary chart, weather depiction chart, winds and temperature aloft chart, and the composite moisture stability chart. For detailed information about the surface analysis chart, weather depiction charts, and radar summary chart, refer to the Pilot's Handbook of Aeronautical Knowledge and Advisory Circular 00-45G, "Aviation Weather Services."

### Winds and Temperatures Aloft Forecast

The winds and temperatures aloft forecast (FB) is a 12-hour product that is issued at 0000Z and 1200Z daily. [Figure 9-34] It is used primarily to determine expected wind direction and velocity, and temperatures for the altitude of a planned cross-country flight. The forecast contains nine columns that correspond to forecast levels 3,000; 6,000; 9,000; 12,000; 18,000; 24,000; 30,000; 34,000; and 39,000 feet MSL. Soaring pilots planning to attempt proficiency for altitude should be aware that the levels below 18,000 feet are based on local altimeter settings. Above 18,000 feet, flight levels are based on standard altimeter setting of 29.92 "Hg. For example 19,000 feet is FL190. Wind direction is from true north. No winds are forecast within 1,500 feet of station elevation. Also, no temperatures are forecast for the 3,000 foot level or for any level within 2,500 feet of station elevation. Temperature is in whole degrees Celsius and assumed to be negative above 24,000 feet. Figure 9-34 shows an example winds aloft message as well as how to decode it.

Figure 9-33. Soaring forecast (continued).

### Sample winds aloft

DATA BASED ON 010000Z  
 VALID 010600Z FOR USE 0500-0900Z. TEMPS NEG ABV 24000  
 FT 3000 6000 9000 12000 18000 24000 30000 34000 39000  
 MKC 2426 2726-09 2826-14 2930-21 2744-32 2751-41 275550 276050 276547

### Sample message decoded:

DATA BASED ON 010000Z

Forecast data is based on computer forecasts generated the first day of the month at 0000 UTC.

**VALID 010600Z FOR USE 0500-0900Z. TEMPS NEG ABV 24000**

The valid time of the forecast is the first day of the month at 0600 UTC. The forecast winds and temperature are to be used between 0500 and 0900 UTC. Temperatures are negative above 24,000 feet.

**FT 3000 6000 9000 12000 18000 24000 30000 34000 39000**

FT indicates the forecast location, the numbers indicate the forecast levels.

**MKC 2426 2726-09 2826-14 2930-21 2744-32 2751-41 275550 276050 276547**

This example shows data for MKC (Kansas City, MO). The 3,000 foot wind is forecast to be 240 degrees at 26 knots. The 6,000 foot wind is forecast to be 270 degrees at 26 knots and the air temperature is forecast to be -9 degrees Celsius. The 30,000 foot wind is forecast to be 270 degrees at 55 knots with the air temperature forecast to be -50 degrees Celsius.

If a coded direction is more than "36," then the wind speed is 100 knots or more. Therefore, if the direction number is between 51 and 86, the wind speed will be over 100 knots. For example, a forecast at 39,000 feet of "731960" shows a wind direction from 230 degrees (73-50=23) and the speed is 119 knots (100+19=119). The temperature is minus 60 degrees Celsius.

If the wind speed is forecast to be 200 knots or greater, the wind group is coded as 199 knots. For example, "77999" is decoded as 270 degrees at 199 knots or greater.

Wind direction is coded to the nearest 10 degrees. When the forecast speed is less than 5 knots, the coded group is "9900" and read, "LIGHT AND VARIABLE."

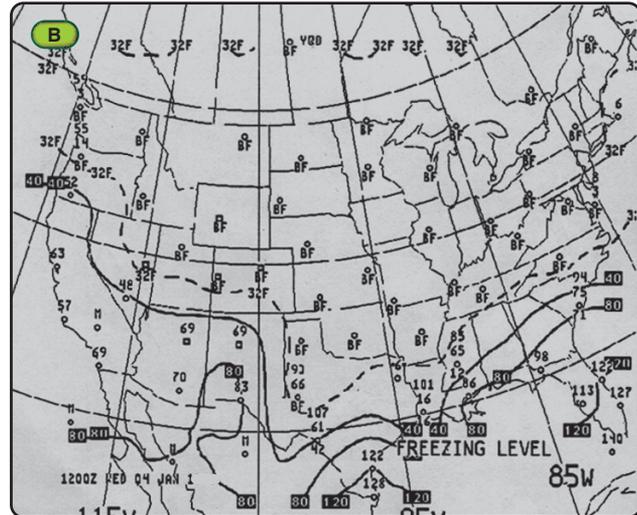
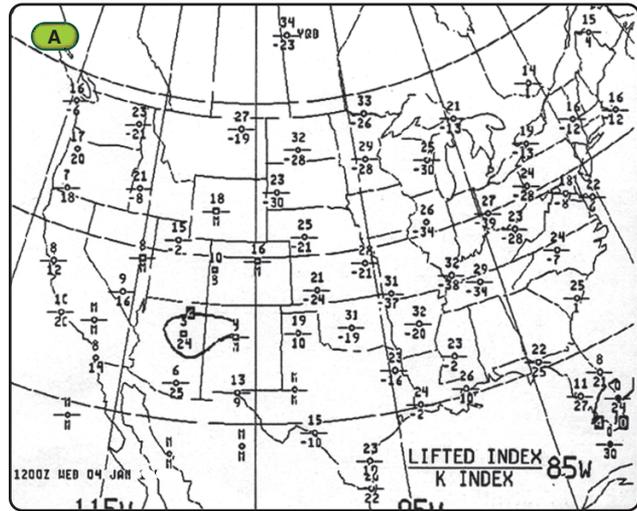


Figure 9-34. Types of briefings.

NOTE: The winds aloft forecasts were formally known as FD.

### Composite Moisture Stability Chart

The composite moisture stability chart is a four-panel chart, which depicts stability, precipitable water, freezing level, and average relative humidity. It is a computer-generated chart derived from upper-air observation data and is available twice daily with a valid time of 0000Z and 1200Z. This chart is useful for determining the characteristics of a particular weather system with regard to atmospheric stability, moisture content, and possible aviation hazards, such as thunderstorms and icing. [Figure 9-35]

Figure 9-35. Composite moisture stability chart.

For the purpose of soaring flight, the stability panel located in the upper left corner of the chart [Figure 9-35 Panel A] can be useful when obtaining weather as it outlines areas of stable and unstable air. The numbers on this panel resemble fractions; the top number is the lifted index (LI) and the lower number is the K index (KI). [Figure 9-36] The LI is

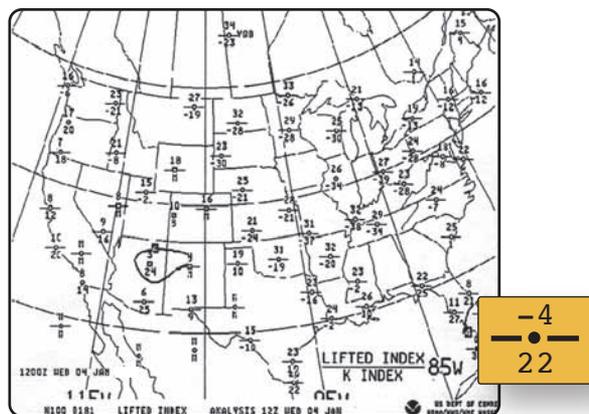


Figure 9-36. Stability panel.

the difference between the temperature of a parcel of air being lifted from the surface to the 500 mb level (approximately 18,000 feet MSL) and the actual temperature at the 500 mb level. If the number is positive, the air is considered stable. For example, a lifted index of +8 is very stable, and the likelihood of severe thunderstorms is weak. Conversely, an index of -6 or less is considered very unstable, and severe thunderstorms are likely to occur; however, the instability may give rise to favorable soaring conditions. A zero index is neutrally stable. [Figure 9-37]

Caution should be exercised if the K index is high, indicating moisture is sufficient for storm development. Although the lifting index may be very negative and good for soaring, too much moisture can make good soaring conditions very dangerous once the storms develop. A very negative LI with high KI may mean a better day to soar close to the gliderport, whereas very negative LI and low KI values make for clear soaring conditions in general.

THUNDERSTORM POTENTIAL	
Lifted index (LI)	Severe Potential
0 to -2	Weak
-3 to -5	Moderate
≤ -6	Strong

Figure 9-37. Airmass stability.

The chart in Figure 9-37 shows relative instability in two ways. First, the station circle is darkened when the lift index is zero or less. Second, solid lines are used to delineate areas that have an index of +4 or less at intervals of 4 (+4, 0, -4, -8). The stability panel is an important preflight planning tool because the relative stability of an airmass is indicative of the type of clouds that can be found in a given area. For example, if the airmass is stable, a pilot can expect smooth air and, given sufficient moisture, steady precipitation. On the other hand, if the airmass is unstable, convective turbulence and showery precipitation can be expected.

The K index indicates whether the conditions are favorable for airmass thunderstorms. The K index is based on temperature, low-level moisture, and saturation. A K index of 15 or less would be forecast as a 0 percent probability for airmass thunderstorms, and an index of 40 or more would be forecast as 100 percent probability. [Figure 9-38]

THUNDERSTORM POTENTIAL	
K index	Airmass Thunderstorm Probability
<15	near 0%
15-19	20%
20-25	21-40%
26-30	41-60%
31-35	61-80%
36-40	81-90%

Figure 9-38. Thunderstorm potential.

