CHAPTER 9
Soaring Weather

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 whether the conditions will support 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, 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 nautical miles) 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]

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 four percent of the gases displacing nitrogen and oxygen. Conversely, the atmosphere over deserts and at high altitudes exhibits less than one 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. In addition, by absorbing the **radiant energy** from the Earth's surface, water vapor reduces surface cooling, causing surface temperatures to be warmer.

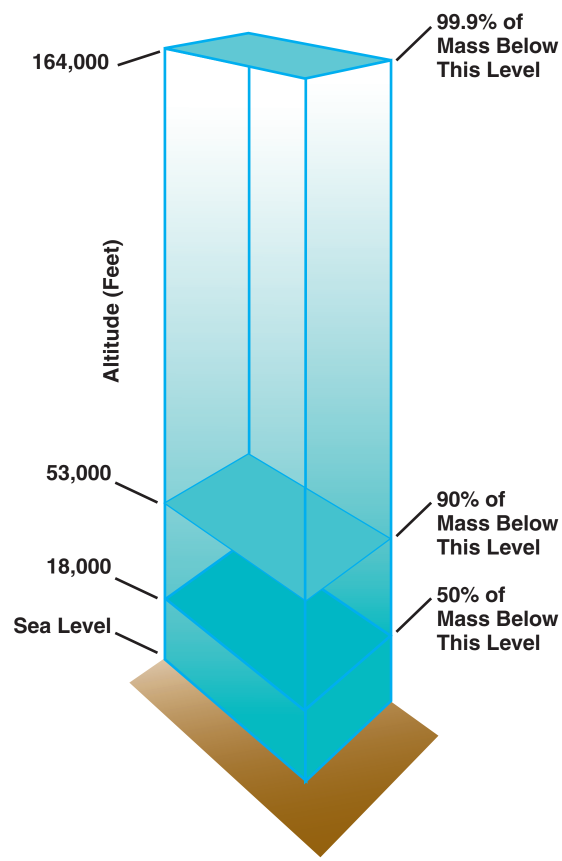


Figure 9-1. Atmospheric mass by altitude.

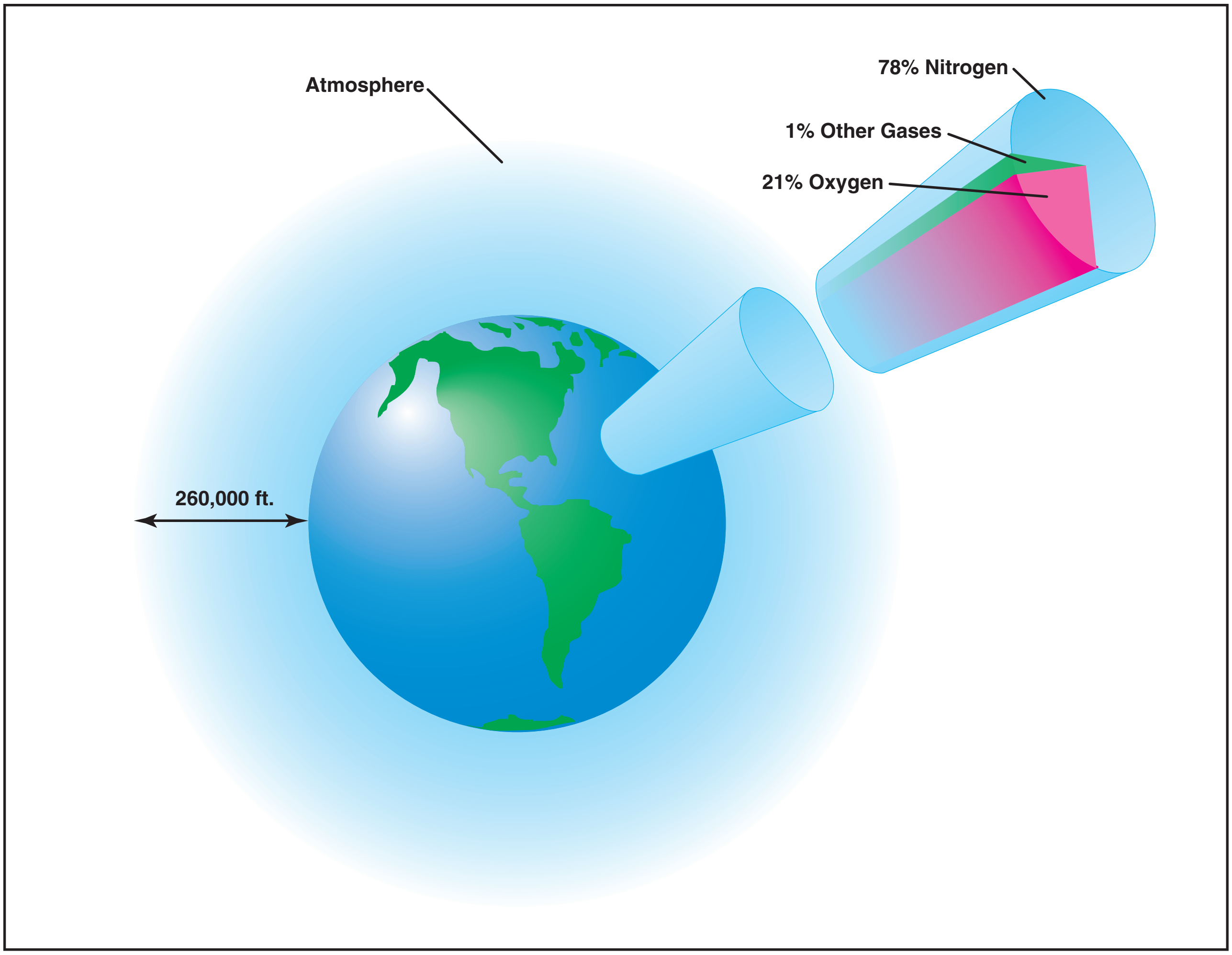


Figure 9-2. The composition of the atmosphere.

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 scale is used in aviation, although the Fahrenheit 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 fewer 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 posses 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} This force measured at sea level is commonly reported as 29.92 inches of mercury (in. Hg.) (from the level of mercury at standard sea-level pressure in a mercurial barometer). In aviation weather reports, the common reporting unit is millibars. When 29.92 in. Hg. is converted, it becomes 1013.2 millibars. The force created by the moving molecules act equally in all directions when measured at a given point.

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 the 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. At sea level, the standard atmosphere consists of a barometric pressure of 29.92 in. Hg., (1013.2 millibars) and a temperature of 15°C (59°F). This means that under the standard conditions, a column of air at sea level weighs 14.7 lb./in.^{2}.

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 in.Hg. for each 1,000 feet approximates the rate of pressure change. It is important to note that the standard lapse rates should only be used for flight planning purposes with the understanding that large variations from standard conditions can exist in the atmosphere. [Figure 9-3]

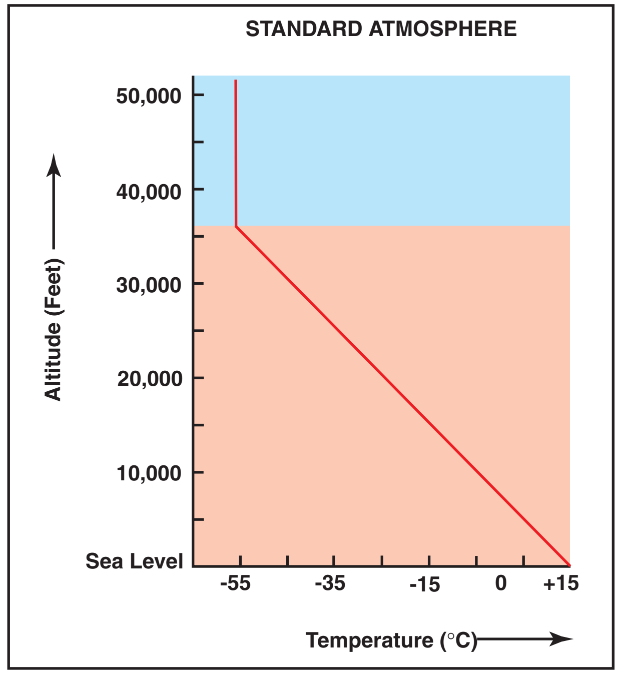


Figure 9-3. Standard Atmosphere.

LAYERS OF THE ATMOSPHERE

The Earth's atmosphere is divided into four strata or layers: troposphere, stratosphere, mesosphere, and thermosphere. 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 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 atmospheres) and density is decreased to about 25 percent of its sea-level value. Temperature reaches its minimum value at the tropopause, approximately -55° Celsius (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° Celsius (32°F) reaching its maximum value at about 160,000 feet MSL. Unlike the troposphere where 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, the mesosphere and thermosphere, 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 life span of the phenomena in each scale is roughly proportional, so that larger size scales coincide with longer lifetimes. The term microscale refers to features with spatial dimensions of 1/10th to 1 nautical mile and lasting for seconds to minutes. An example is an individual **thermal**. Mesoscale refers to horizontal dimensions of 1 to 1,000 nautical miles 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. Macroscale refers to horizontal dimensions greater than 1,000 nautical miles and lasting for weeks to months. These include the long waves in the general global circulation and the jetstreams imbedded within those waves. [Figure 9-4]

Smaller-scale features are imbedded 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 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 is more predictable, with forecast skill decreasing as scale diminishes. For instance, forecasts 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 lies in the smaller mesoscale and microscale range, prediction of soaring weather is a challenge.

Soaring forecasts should begin with the macroscale, that is, identifying 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 airmass 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.

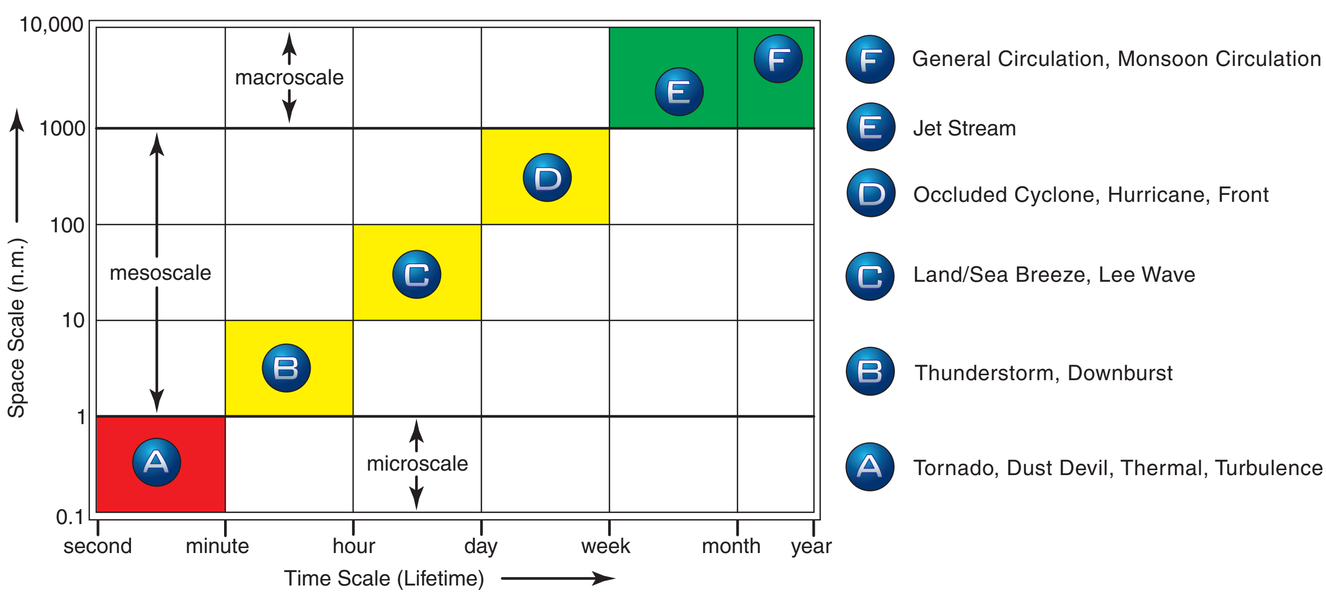


Figure 9-4. Scale of circulation—horizontal dimensions and life spans of associated weather events.

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 sometimes are careless with the use of the word "convection" and use it 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.

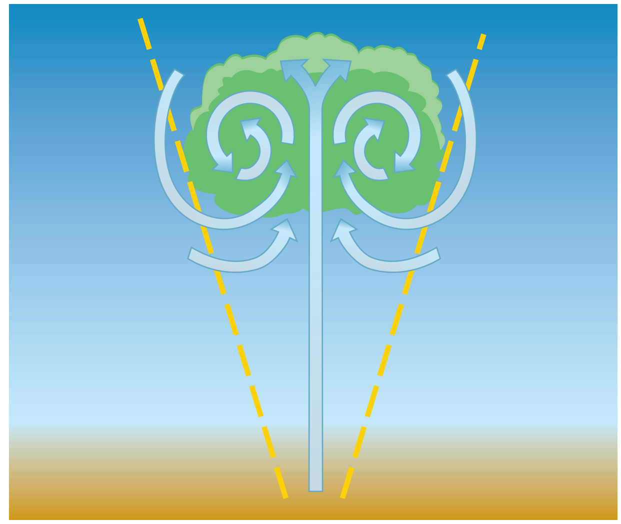


Figure 9-5. The bubble or vortex ring model of a thermal.

THERMAL SHAPE AND STRUCTURE

Two primary conceptual models exist for the structure of thermals, the bubble model and the 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. It must be kept in mind, these models attempt to simplify a complex and often turbulent phenomenon, so that 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 that 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 9-5]

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 a 1,000 feet or more. This suggests the column or plume model of thermals is more common. [Figure 9-6]

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

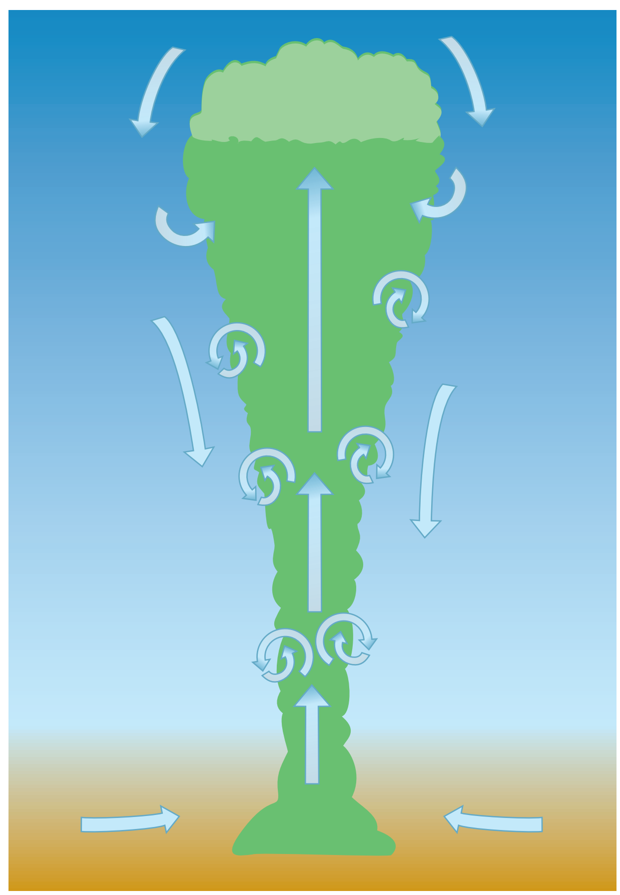


Figure 9-6. The column or plume model of a thermal.

Whether the thermal is 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 bulls-eye pattern. Real thermals usually are not perfectly concentric; techniques for best using thermals are discussed in the next chapter. [Figure 9-7]

Figure 9-7. Cross-section through a thermal. Darker green is stronger lift, red is sink.

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 9-8.

ATMOSPHERIC STABILITY

Stability in the atmosphere tends to hinder vertical motion, while instability tends to promote vertical motion. A certain amount of instability is desirable for glider pilots, since without it, thermals would not develop. If the air is moist enough, and the atmospheric instability 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, for instance, in the evolution of large-scale cyclones, are not covered here.

Generally, a stable dynamic system is one in which a displaced element will return to its original position. An unstable dynamic system is one in which a displaced element will accelerate further 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)**. As discussed below, on a thermodynamic chart, parcels cooling at the DALR are said to follow a **dry adiabat**. 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°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 only 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°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°C. In both scenarios, a parcel of air that started at 20°C at the surface has cooled to 11°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 will sink. The parcel in the second scenario would need to be forced to 3,000 feet AGL by a mechanism other than convection,

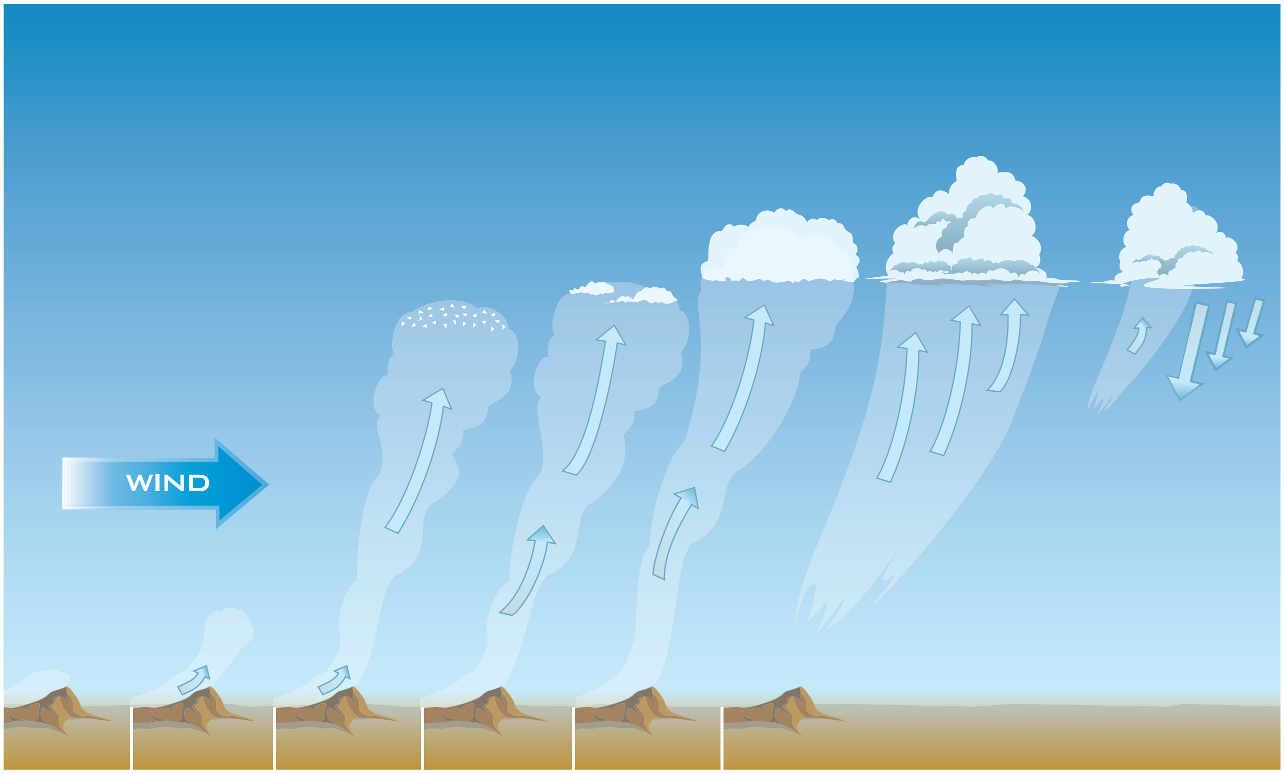


Figure 9-8. Life cycle of a typical thermal with cumulus cloud.

being lifted up a mountainside or a front for instance. [Figure 9-9]

Figure 9-9 also illustrates factors leading to instability. A stable atmosphere can turn unstable in one of two ways. First, if the surface parcel warmed by more than 2°C (greater than 22°C), the layer to 3,000 feet would then become 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 temperature 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 layer in which the temperature 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, they also effectively provide 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 **dew point**, 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 slower 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

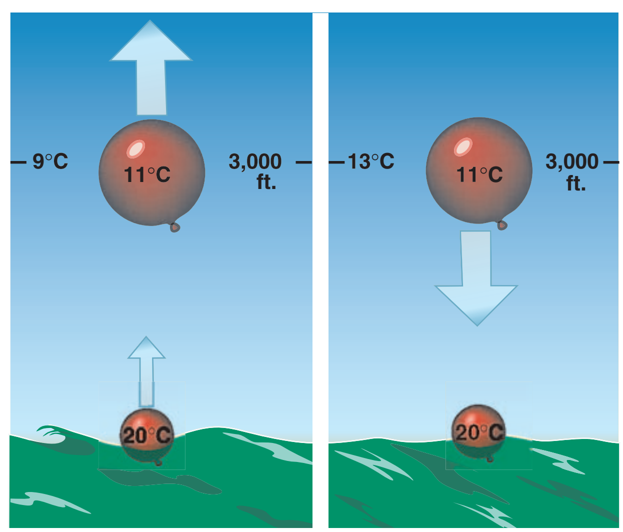


Figure 9-9. Stable and unstable parcels of air.

of 1.2°C per 1,000 feet, whereas in mid levels it increases to 2.2°C per 1,000 feet. Very high up, above about 30,000 feet, little water vapor exists to condense, and the SALR approaches the DALR.

UNDERSTANDING SOUNDINGS

The so-called Skew-T/Log-P (or simply Skew-T for short) is an example of the **thermodynamic diagram** most commonly used in the United States. The Skew-T part of the name comes from the fact that temperature lines on the chart are slanted, while the Log-P is a reminder that pressure does not decrease linearly in the atmosphere. A temperature and dewpoint sounding presented on a Skew-T shows a record of the current atmospheric stability, moisture content, and winds versus altitude. Given surface forecast temperatures, the potential for thermal soaring, including the likelihood of cumulus and/or overdevelopment can then be forecast. Using Skew-T diagrams to their fullest potential requires practice. [Figure 9-10]

There are five sets of lines on a standard Skew-T. Other types of thermodynamic charts, for instance the Tephigram often used in Great Britain, have the same lines, but with a somewhat different presentation. The colors and actual number of lines vary, but the main diagram components should always be present. The following discussion refers to the Skew-T in Figure 9-10.

Horizontal blue lines indicate pressure levels and are labeled every 100 millibars (mb) along the left side of the diagram. On this diagram, the approximate height (in feet) of each pressure level in the standard atmosphere is shown on the right. The actual height of each pressure level varies from day to day. Slanted (skewed) blue lines indicate temperature and are labeled every 10°C along the right side of the isotherm. Thin red lines slanted at an angle almost perpendicular to the temperature lines indicate dry adiabats. (An air parcel following a dry adiabat is changing temperature with height at the DALR.) Thin green lines curving in the same direction as, but at a different angle to, the dry adiabats represent saturated adiabats. (An air parcel that is saturated follows a saturated adiabat is changing temperature with height at the SALR.) The thin orange lines slanting in the same

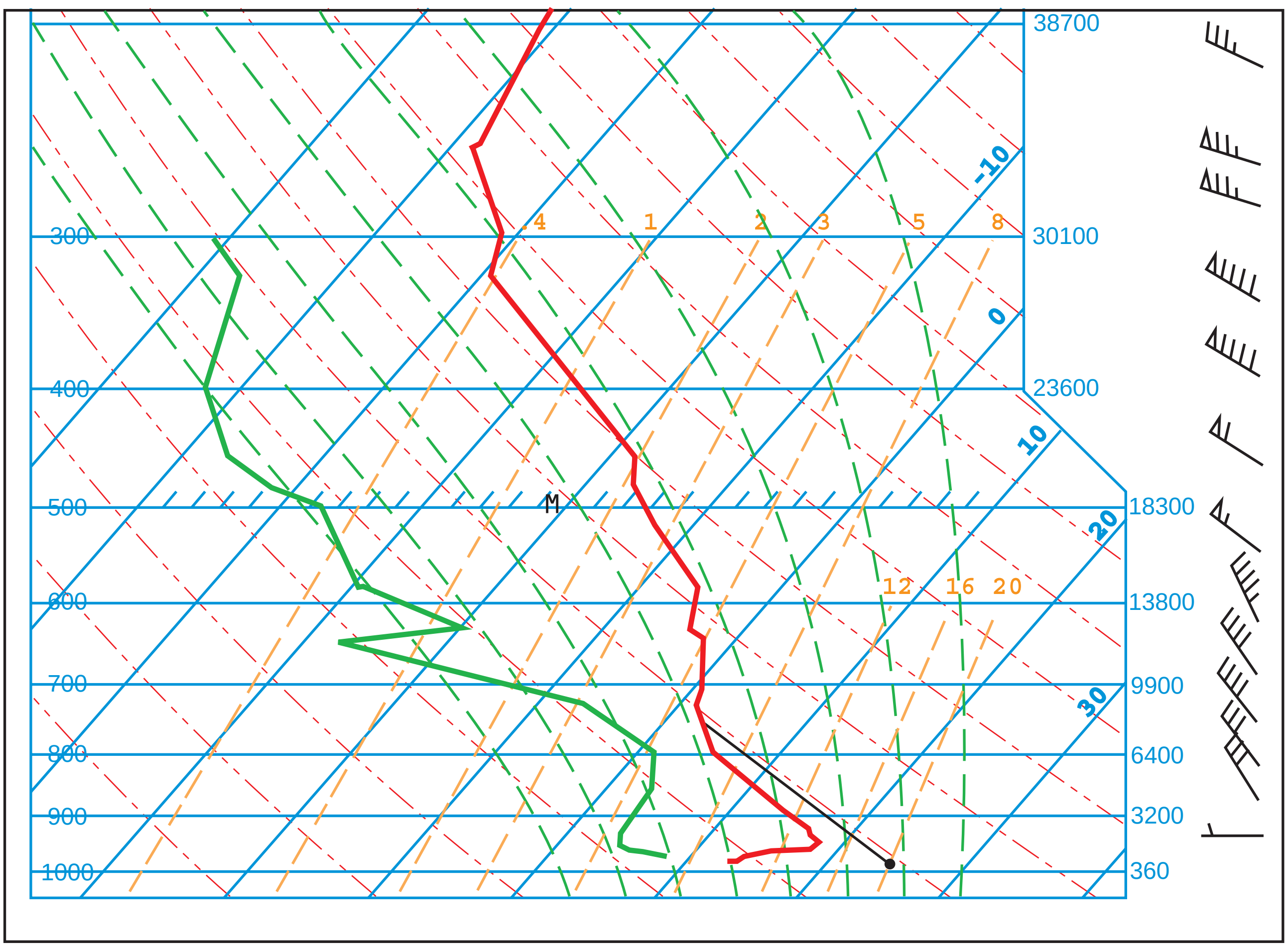


Figure 9-10. Skew-T from an actual sounding.

direction, but at an angle to the temperature lines represent the ratio of water vapor to dry air, called the **mixing ratio**. Lines of constant mixing ratio are labeled in grams of water vapor per kilogram of dry air, abbreviated g/kg.

Over the continental United States, several dozen sounding balloons are launched twice daily, at 00 and 12 Universal Coordinated Time (UTC). These sounding balloons record temperature, humidity, and winds at several mandatory levels, as well as "significant" levels, where notable changes with height occur. In Figure 9-10, the actual temperature sounding (shown in bold red), the actual dew-point temperature (shown in bold green), and the winds aloft (shown in wind barbs on the right side) for this day are shown.

The basic analysis for forecasting the potential for dry thermals based on a sounding is achieved by answering the question, "At what levels is a parcel of air rising from the surface warmer than the ambient air?" Assume on this day, the surface temperature is forecast to reach 23°C. This point is marked on the Skew-T; the parcel of air at 23°C is warmer than the surrounding air and starts to rise at the DALR. When the parcel has risen along a dry adiabat (parallel to the slanted red line) to 900 mb (3,200 feet), it has cooled to 17.2°C, which is warmer than the surrounding air at 15°C. Continuing upward along the dry adiabat, at about 780 mb (7,100 feet) the air parcel and surrounding air are at the same temperature, and the air no longer rises due to its buoyancy. The **Thermal Index (TI)** at each level is defined as the temperature of the air parcel having risen at the DALR subtracted from the ambient temperature. Experience has shown that a TI should be -2 for thermals to form and be sufficiently strong for soaring flight. Larger negative numbers favor stronger conditions, while values of 0 to –2 may produce few or no thermals. On this day, with a surface temperature of 23°C, the TI is found to be 15–17.2 or -2.2 at 900 mb, sufficient for at least weak thermals to this level. At 780 mb, the TI is 0, and as mentioned, the expectation is that this would be the approximate top of thermals.

Thermal strength is difficult to quantify based on the TI alone since many factors contribute to thermal strength. For instance, in the above example, the TI at 800 mb (6,400 feet) was –1. The thermal may or may not weaken at this level depending on the thermal size and the amount of vertical wind shear. These factors tend to mix in ambient air and can decrease the thermal strength.

It is important to remember that the TI calculated as above is based on a forecast temperature at the surface. If the forecast temperature is incorrect, the analysis above produces poor results. As a further example, assume that on this day the temperature only reached 20°C. From a point on the surface at 20°C and following a dry adiabat upwards, the TI reaches 0 only 1,000 feet AGL, making the prospects for workable thermals poor. On the other hand, if temperatures reached 25°C on this day, thermals would reach about 730 mb (8,800 feet), be stronger, and have more negative TI values.

The previous analysis of the morning sounding calculated the TI and maximum thermal height based upon a maximum afternoon temperature. In reality, the sounding evolves during the day. It is not untypical for a morning sounding to have an inversion as shown in Figure 9-10. A weaker inversion on another day is shown in Figure 9-11. This sounding was taken at 12 UTC, which is 05 local time (LT) at that location. The surface temperature was 13°C at the time of the sounding. A shallow inversion is seen near the surface with a nearly isothermal (no temperature change) layer above. Two hours after the sounding was taken (07 LT), the surface temperature had risen to only 14°C. By 09 LT, the temperature had risen to 17°C. The line labeled "09" shows how the sounding should look at this time. It was drawn by taking the surface temperature at that time, and following the DALR until TI is 0, which is the same as intercepting the ambient temperature. Lines at other times are drawn in a similar fashion. At 10 LT, the TI becomes 0 at about 2,200 feet AGL, so the first thermals may be starting. By 12 LT, at 25°C, thermals should extend to 4,000 feet AGL. Because of the isothermal layer, thermal heights increased steadily until about 16 LT, when temperatures reached 31°C, at which time they reached about 8,000 feet AGL. Understanding this evolution of the convective layer can help predict when thermals will first form, as well as if and when they might reach a height satisfactory for an extended or cross-country flight. [Figure 9-11, on next page]

The analysis presented thus far has neglected the possibility of cumulus clouds, for which the orange slanted mixing ratio lines on the Skew-T need to be considered. The assumption that a rising parcel conserves its mixing ratio is also needed. For instance, if an air parcel has a mixing ratio of 8 g/kg at the surface, it will maintain that value as it rises in a thermal. Typically, this is true, though factors, such as mixing with much drier air aloft can cause errors.

Refer to the sounding in Figure 9-12. The temperature on this day reached 26°C during the afternoon. In order to determine if cumulus clouds would be present, draw a line from 26°C at the surface parallel to a red dry adiabat as before. Draw a second line from the surface

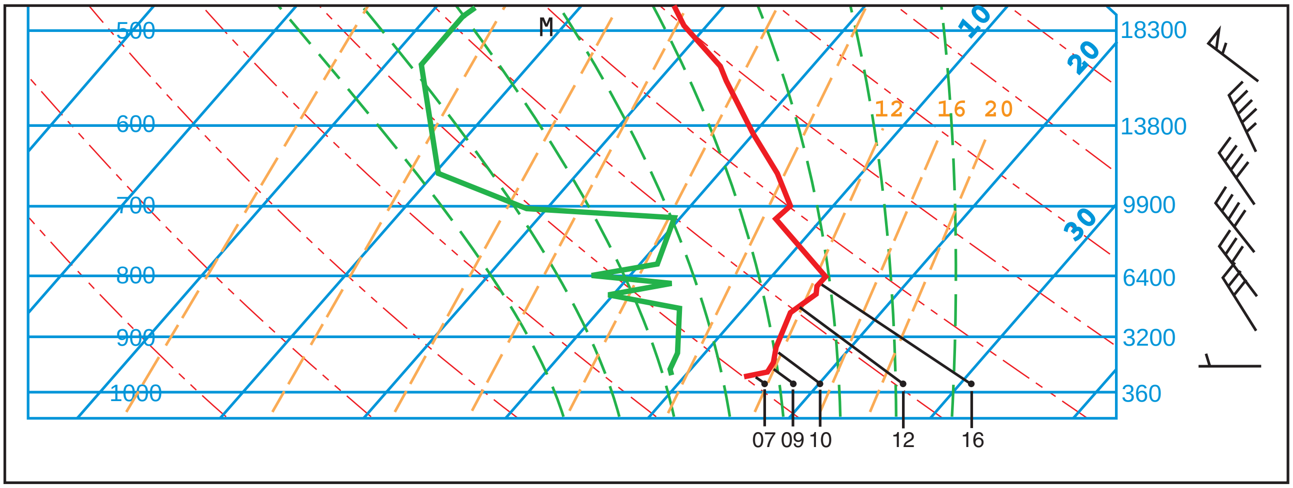


Figure 9-11. Skew-T from an actual sounding.

dew point temperature parallel to the orange mixing ratio lines. The two lines intersect at a point before the parcel has a zero TI. This is the base of the cumulus, called the **convective condensation level (CCL)**. In this case, cloudbase occurs at about 750 mb (8,100 feet). Since the parcel is saturated above this level, it no longer cools at the DALR, but at the SALR. Next, from the CCL, draw a line parallel to a saturated adiabat until it intersects the original sounding temperature curve. This shows the maximum cumulus height, at about 670 mb (11,000 feet). [Figure 9-12]

The above analysis leads to a rule of thumb for estimating the CCL. The temperature and dew point converge at about 4.4°F per 1,000 feet of altitude gain. This is the same as saying for every degree of surface temperature and dew point spread in Fahrenheit, multiply by 225 feet to obtain the base of the convective cloud (if any). Since aviation surface reports are reported in degrees Centigrade, convert the data by multiplying every degree of surface temperature and dew point spread in degrees Centigrade by 400 feet. For example, if the reported temperature is 28ºC and the reported dew point is 15°C, we would estimate cloud base as (28 – 15) x 400 = 5200 feet AGL.

Notice that in Figure 9-12, the dew point curve shows a rapid decrease with height from the surface value. As thermals form and mixing begins, it is likely that the drier air just above the surface will be mixed in with the moister surface air. A more accurate estimate of the CCL is found by using an average dew point value in the first 50 mb rather than the actual surface value. This refinement can change the analyzed CCL by as much as 1,000 feet.

The second example, Figure 9-11, would only produce dry thermals, even at this day's maximum temperature of 32°C. Following a line parallel to a mixing ratio line from the surface dew point, the height of any cumulus would be almost 12,000 feet AGL, while at 32°C, thermals should only reach 9,000 feet AGL. The elevated inversion at 9,000 to 10,000 feet AGL effectively caps thermal activity there.

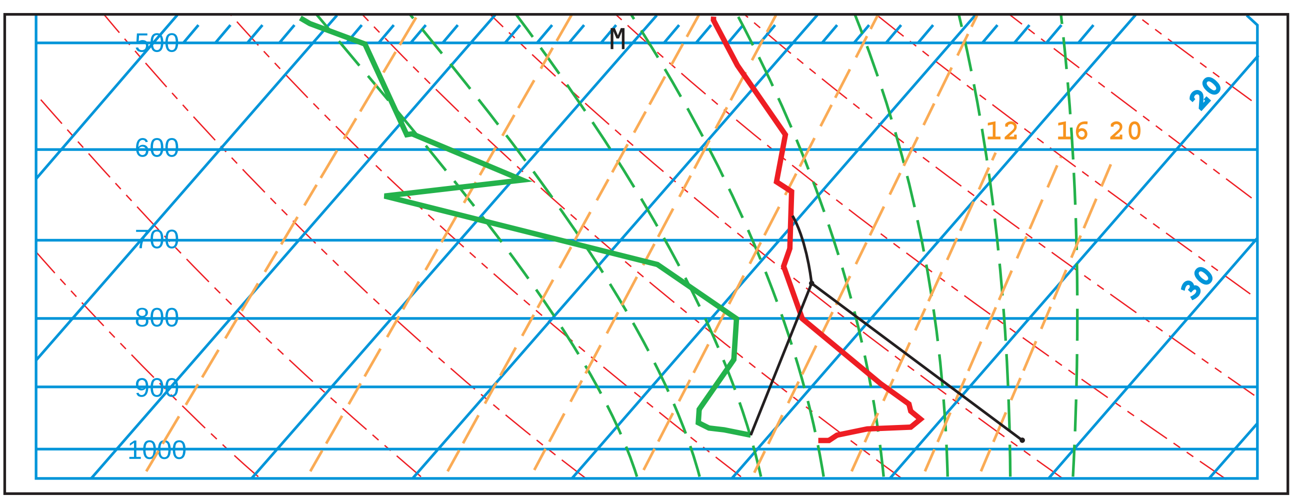


Figure 9-12. Skew-T from an actual sounding.

It is also important to recognize the limitations of a sounding analysis. The sounding is a single snapshot of the atmosphere, taken at one time in one location. (This is not absolutely true since the sounding balloon rises at about 1,000 feet per minute (fpm), so it takes about 30 minutes to reach 30,000 feet, during which time it has also drifted with the winds aloft from the launch point). The analysis is limited by how well the sounding is representative of the greater area. This may or may not be a factor depending on the larger-scale weather situation, and in any case, tends to be less valid in regions of mountainous terrain. In addition, the upper air patterns can change during the day due to passing fronts or smaller-scale, upper-air features. For example, local circulation patterns near mountains can alter the air aloft over nearby valleys during the day. A temperature change aloft of only a few degrees also can make a large difference. Despite these limitations, the sounding analysis is still an excellent tool for soaring pilots.

In recent years, with the advent of the Internet, soundings from numerical weather model forecasts have become available in graphical form, like the Skew-T. Thus, forecast soundings are available for a variety of locations (far more numerous than the observational sounding network) and at many intervals over the forecast cycle. The advantage of using model forecast soundings is a dramatic increase in both space and time resolution. For instance, maps of the predicted thermal tops can be made over a large (e.g., multi-state) area from model data spaced every 10 miles or closer. Great detail in the forecast distribution of thermals is available. In addition, model output can be produced far more frequently than every 12 hours. For instance, hourly model soundings can be produced for a location. This is a tremendous potential aide to planning both local and cross-country flights. The disadvantage is that these forecasts are not real data. They are a model forecast of what the real atmosphere *should* do. Model forecasts of critical items, such as temperatures at the surface and aloft, are often inaccurate. Thus, the model-forecast soundings are only as good as the model forecast. Fortunately, models show continual improvement, so this new tool should become more useful in the future.

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 too dry so 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 rain showers 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 post-frontal 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 will spread 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.

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. Wind speed 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

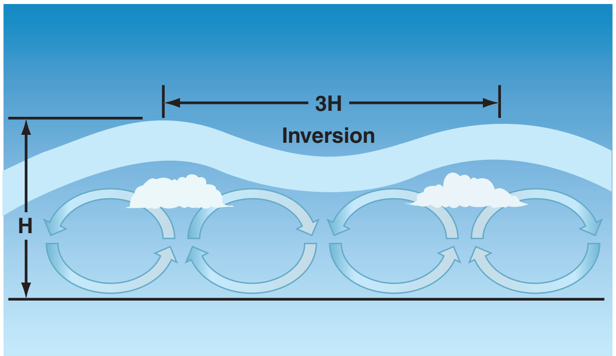


Figure 9-13. Circulation across a cloud street.

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 wave-like form for the inversion capping the cumulus clouds. If the winds above the inversion are perpendicular to the cloud streets and increasing at 10 kts per 5,000 feet or more, waves called cloud-street waves can form in the stable air above. Though usually relatively weak, thermal waves can produce lift of a 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.

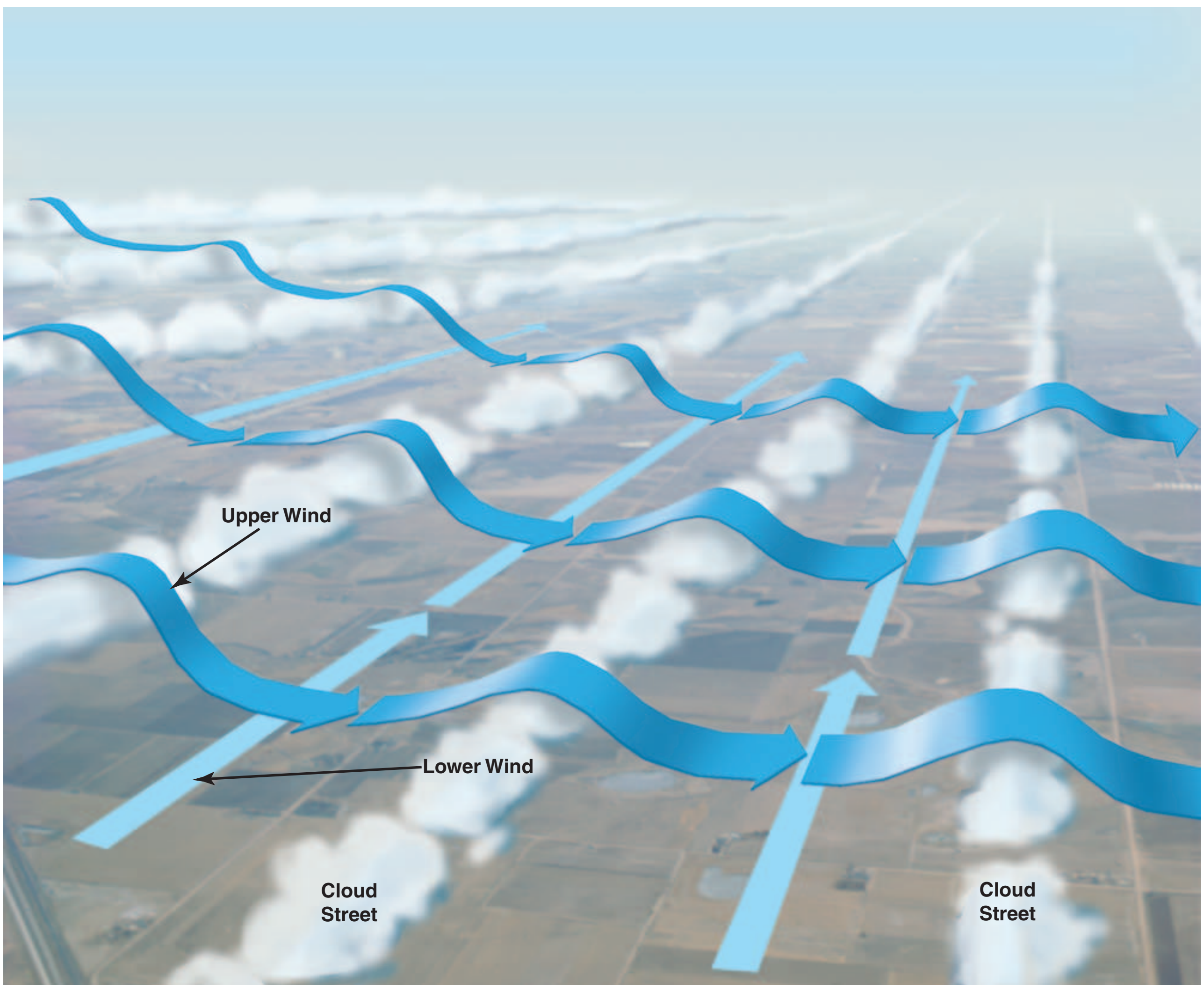


Figure 9-14. Cloud street wave.

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. Thunderstorms are local storms produced by Cb and are accompanied by lightning, thunder, rain, **graupel** or hail, strong winds, turbulence, and even tornadoes. 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 on average 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 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. We will use the term "ordinary" to describe this 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

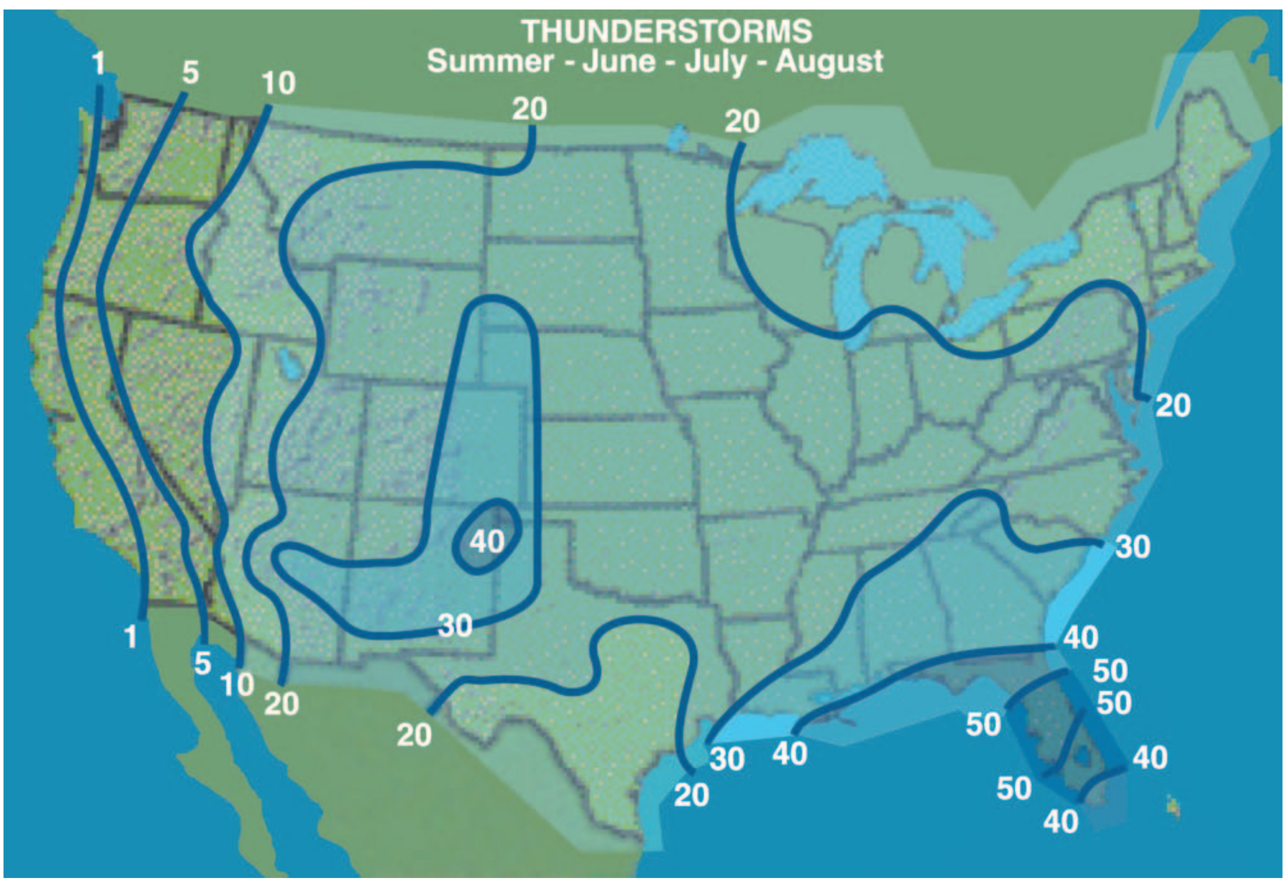


Figure 9-15. Thunderstorm frequency in the summertime.

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. Lightning and thunder form along with precipitation (rain, graupel, or hail) below cloud base, which has now increased to several miles in diameter. It may become difficult to discern cloud from precipitation after this stage. The cloud top reaches to the tropopause, or nearly so, and sometimes strong cells even extend into the stratosphere. The cloud top forms a cirrus anvil indicating the mature stage. The direction in which the anvil streams provides an estimate of the direction of thunderstorm movement. Often organized circulations form within the Cb and the longevity of the thunderstorm partly depends on the nature of those circulations. The greatest storm intensity and hazards (discussed below) are attained during the mature stage.

The precipitation and downdrafts in an ordinary thunderstorm are eventually responsible for its demise, as the supply of heat and moisture is cut off, leading to the dissipating stage. As the Cb dissipates, the mid-level cloud becomes more stratiform (spread out). Remnant cloud can linger for some time after the storm begins to dissipate, especially the upper-level cirrus anvil, which consists mostly of ice. In hazy conditions, or with Cb imbedded in widespread cloudiness, judging the stage of the Cb lifecycle can be difficult.

Thunderstorms frequently last longer than an hour. As an ordinary thunderstorm reaches its mature stage, cool and sometimes quite strong surface outflows are created by Cb downdrafts reaching the ground and spreading out. The outflows can act as a focus for lifting warm, moist air that may still be ahead of the advancing storm. New cells form in the direction of storm movement, for instance, a Cb moving eastward will generate new storms on the east side. The new cell undergoes a mature and dissipating stage as it progresses towards the back of what has become a cluster of Cb. This is an example of a **multi-cell thunderstorm**, which, depending on the vertical shear of the wind, will continue to regenerate new cells as long as unstable air exists ahead of the moving storm. Multi-cell thunderstorms can last for several hours and travel 100 miles or more. As usual when dealing with weather phenomena, there is no clear distinction between an ordinary and multi-cell thunderstorm. For instance, a thunderstorm may last one to two hours after having undergone regeneration two or three times. Pilots need to closely watch apparently dissipating thunderstorms 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. [Figure 9-17]

Another type of thunderstorm is the **supercell**. These huge and long-lasting storms are usually associated with severe weather: strong surface winds exceeding 50 knots, hail at least $^{3}/_{4}$ inch in diameter, and/or tornadoes. Supercells can occur anywhere in the United States, but are most common in the southern Great Plains. They differ from ordinary thunderstorms in two ways. First supercells are much larger in size. Second, they form in an unstable environment with

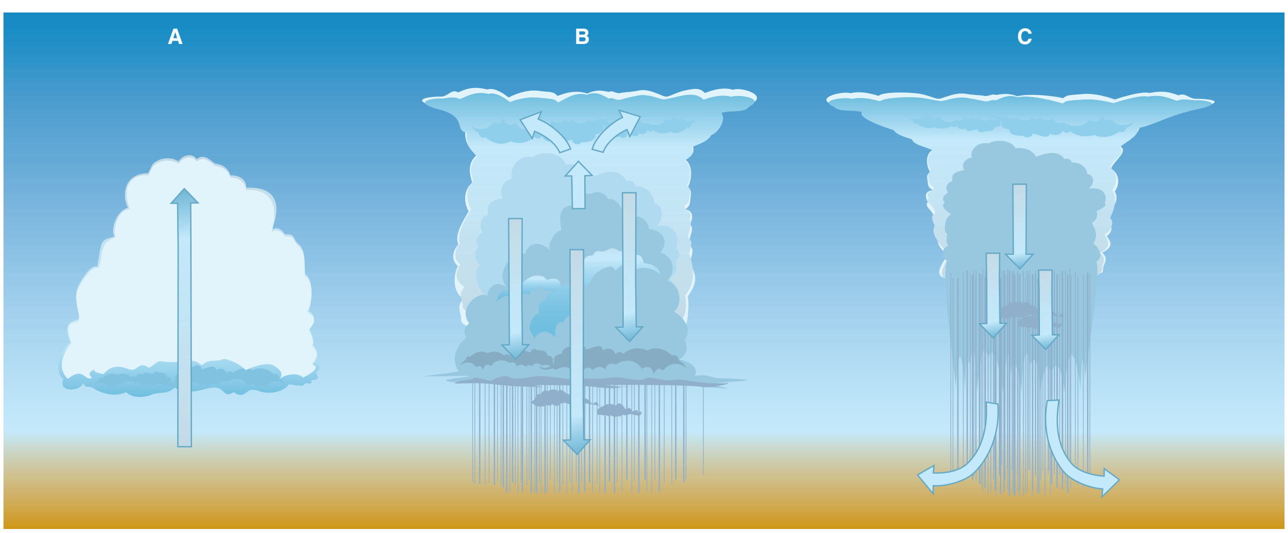


Figure 9-16. Lifecycle of an ordinary thunderstorm (A) cumulus stage, (B) mature stage, (C) dissipating stage.

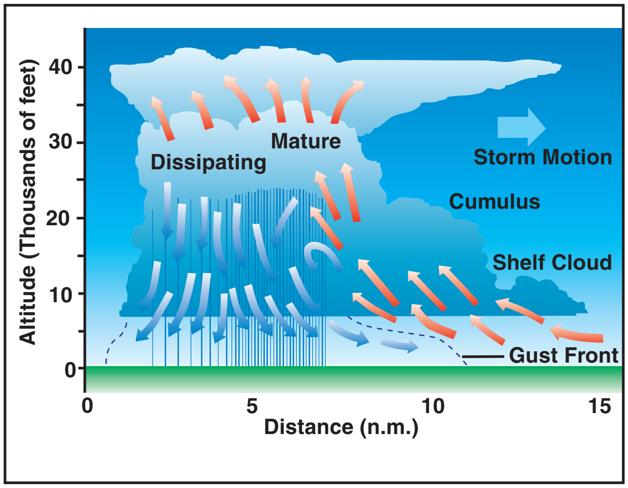


Figure 9-17. Multi-cell thunderstorm.

large vertical direction and speed shear, which causes the updraft to be tilted or even twisted so that is located away from the main downdraft. This leads to an organized circulation within the storm, hence the longevity of a supercell. These dangerous storms should be avoided. [Figure 9-18]

Thunderstorms sometimes exist in clusters, known to meteorologists as **Mesoscale Convective Systems (MCS)**. Most commonly, MCSs form east of the Rocky Mountains in the spring and summer months. **Squall lines** are MCSs that are organized in a line or arc, sometimes hundreds of miles long. A cold front or upper-level trough advancing on unstable air can be the forcing mechanism for squall-line development. Strong lift can be found ahead of advancing squall line and some extended cross-country flights have been made using them. Unfortunately, they come with all the dangers of severe thunderstorms, so their use is not recommended. Another type of MCS has a similar name, the Mesoscale Convective Complex (MCC), which form as a cluster of storms not along any distinct line or arc. When viewed from satellite, MCCs reveal a circular or elliptical shape to the cirrus anvil, which can be a few hundred miles across. Severe thunderstorms are often embedded within the MCC. Fortunately, the huge cirrus shield tends to suppress thermals away from the thunderstorm, so soaring pilots should not have the opportunity to approach an MCS. However, since they can contain severe weather, the forecast of a possible MCS or other severe thunderstorm may inspire the glider pilot to avoid leaving a glider outside overnight if other options are available, e.g., an enclosed trailer. Securing the trailer extra well would also be advisable.

Using the Skew-T and a morning sounding, the possibility of thunderstorms can be predicted. Figure 9-19 illustrates a late-spring morning sounding from the southeast United States. The temperature and dew point are within about a degree below a shallow surface inversion, indicating the likelihood of haze and the possibility of fog. In addition, a shallow layer

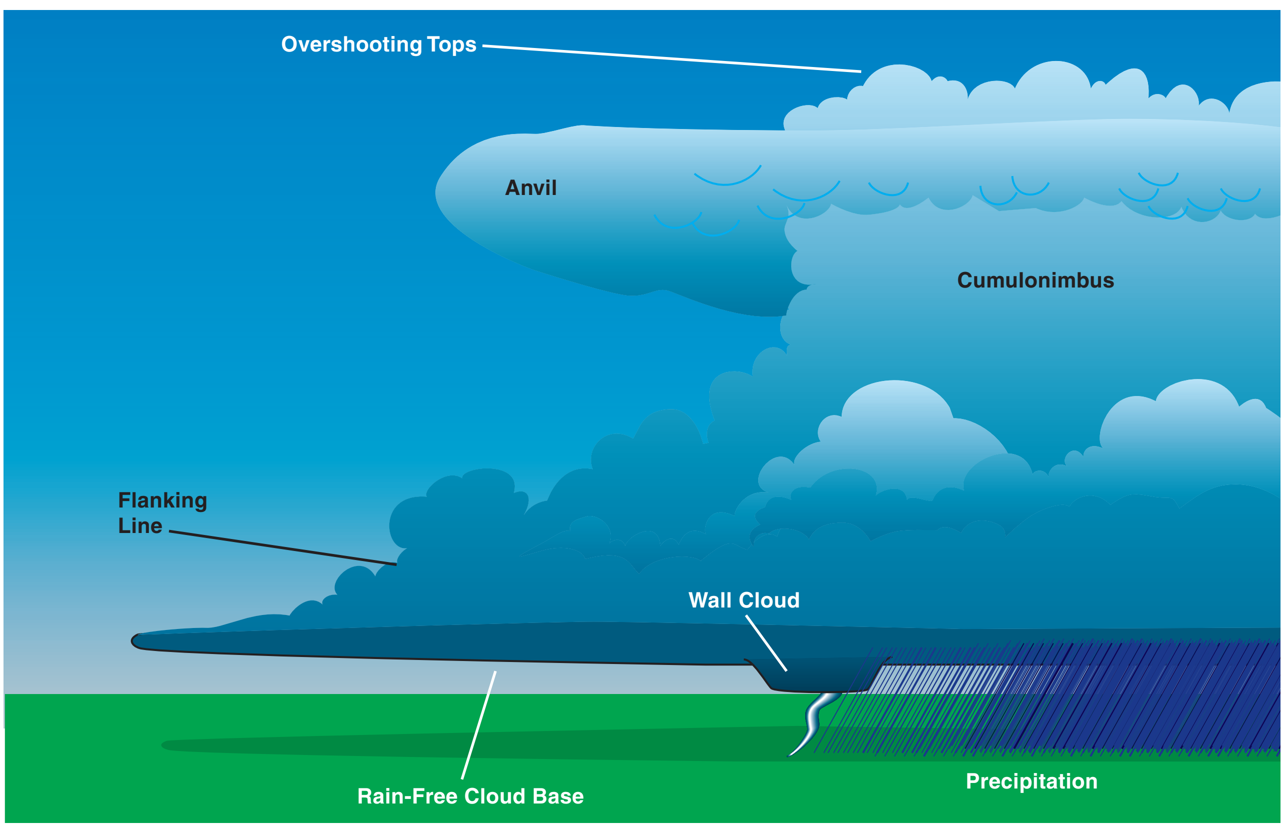


Figure 9-18. Supercell thunderstorm. Air enters on left into the bottom of the storm and exits at top towards the reader.

where temperature and dew point coincide are also located at about 12,000 feet, indicating a thin, mid-level cloud.

As the day warms to 28°C, cumulus should form at about 2,500 feet AGL, using the same analysis as before. By the time surface the temperature reaches 31°C, the CCL should be around 4,000 feet AGL. Recall that once condensation occurs, the parcel follows the SALR. Following parallel to the nearest saturated adiabat from the CCL, the parcel does not intersect the ambient temperature line again until almost 40,000 feet. Thunderstorms are possible if the surface temperature reaches 31°C. [Figure 9-19]

Two common indices are routinely reported using this type of analysis, the Lifted Index (LI) and the K-Index (KI). The LI is determined by subtracting the temperature of a parcel that has been lifted (as in Figure 9-19) to 500 mb from the temperature of the ambient air. This index does not give the likelihood of occurrence; rather it gives an indication of thunderstorm severity *if* they occur. In the example above, LI would be given by –9 – (-4) = -5. Looking at Figure 9-20, a LI of –5 indicates moderately severe thunderstorms if they develop. [Figure 9-20]

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 dew point, and 500, 700, or 850 indicate the level in mb. All values are obtained from a morning sounding. In the above example, using values from the sounding KI = (16 –[-9]) + 12 – (6 –0) = 31. This indicates about a

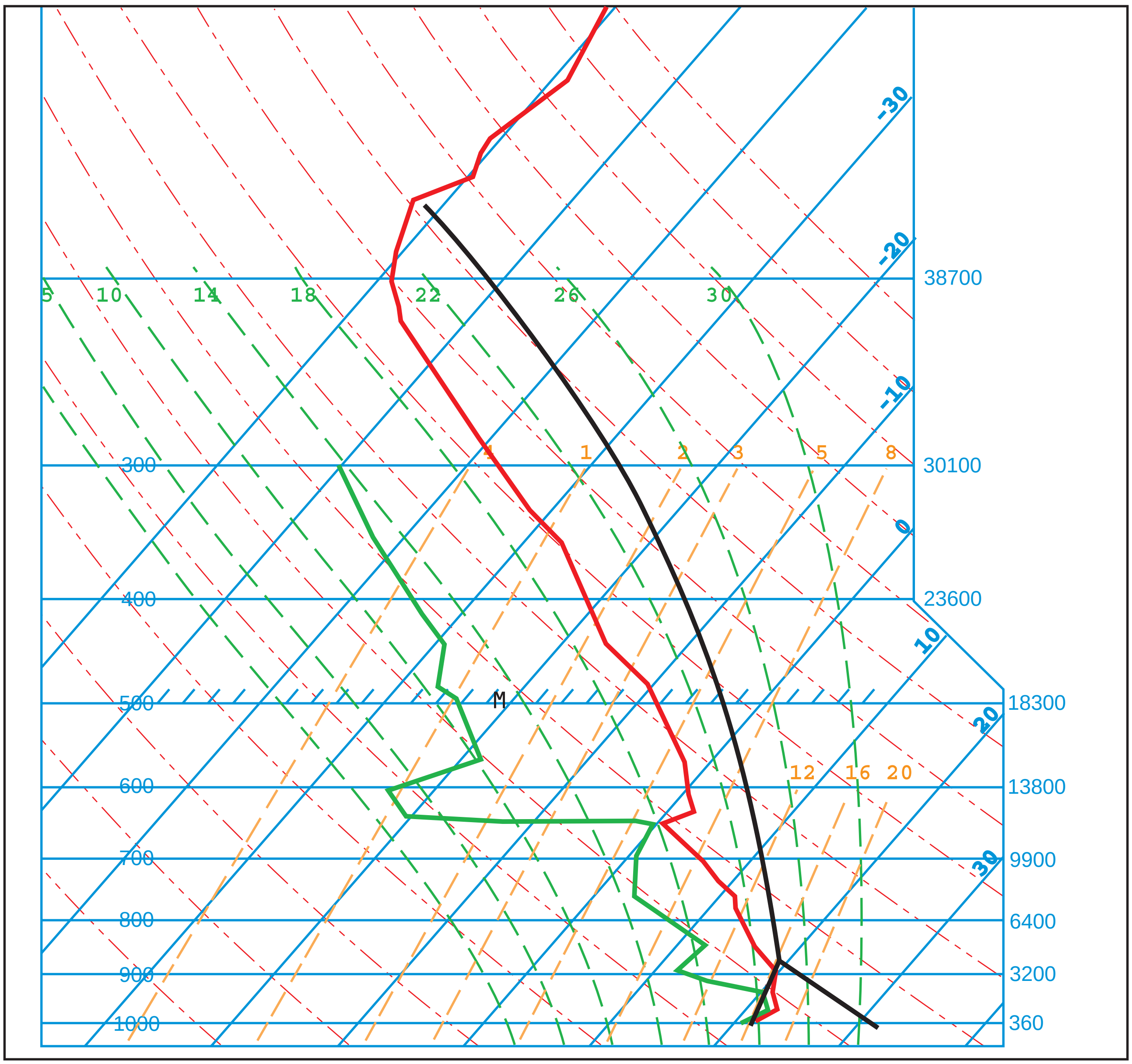


Figure 9-19. Skew-T from an actual sounding for a thunderstorm day.

Lifted Index	Chance of Severe Thunderstorm
0 to -2	Weak
-3 to -5	Moderate
< = -6	Strong

Figure 9-20. Lifted Index (LI) vs. thunderstorm severity.

60 percent probability that thunderstorms will occur. [Figure 9-21] As discussed below, charts showing both the LI and KI for all the sounding sites in the continental United States are produced daily.

Thunderstorms have several hazards, including turbulence, strong up and down drafts, 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.

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 9-21. K-Index (KI) vs. probability of thunderstorm occurrence.

Large and strong up 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 more 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 three-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 strong surface winds, that is, thunderstorm outflow referred to earlier. 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 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 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

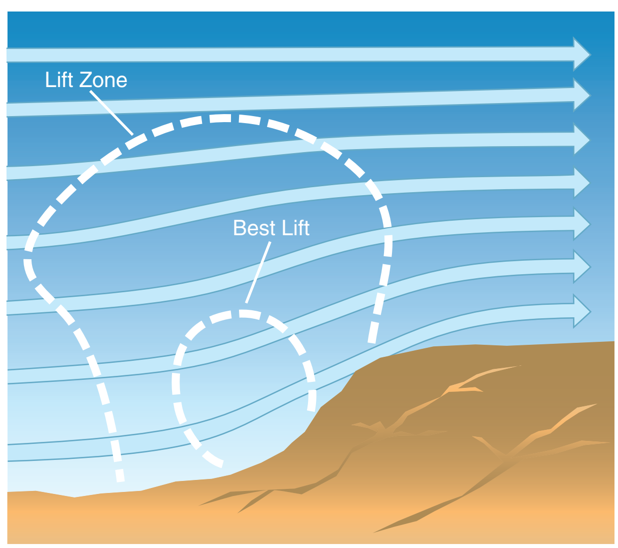


Figure 9-22. Slope soaring.

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]

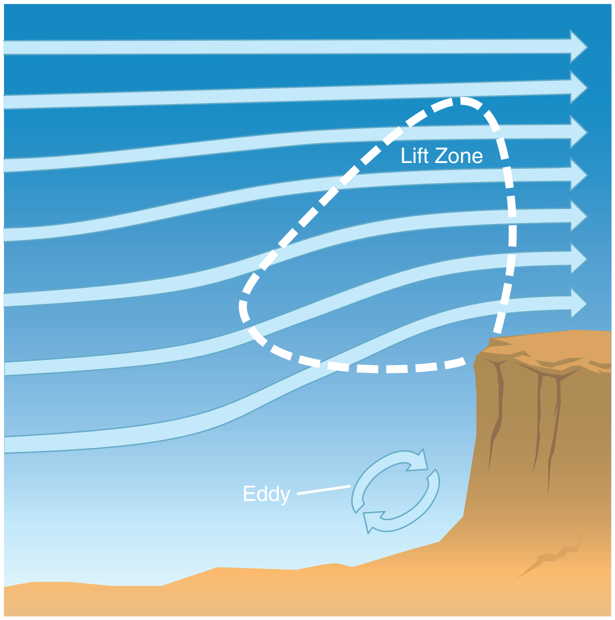


Figure 9-23. Slope lift and eddy with near-vertical slope.

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]

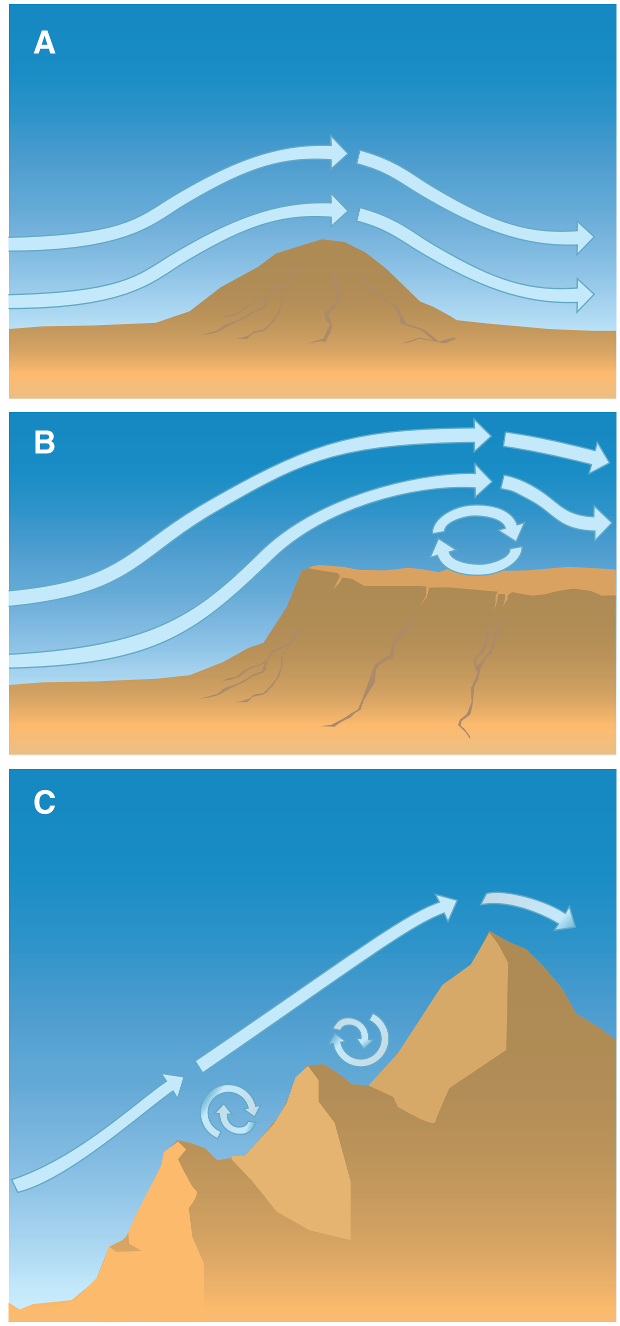


Figure 9-24. Airflow along different ridges.

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.

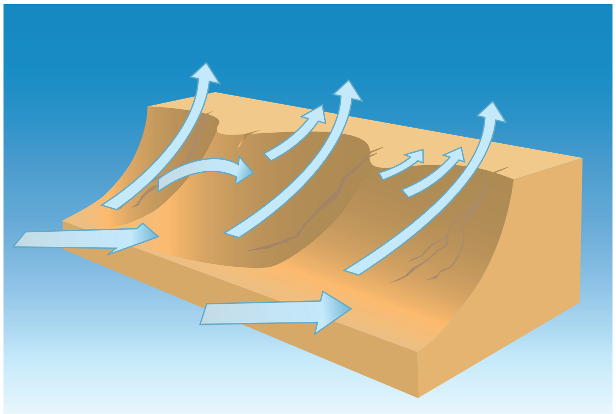


Figure 9-25. Three-dimensional effects of oblique winds and bowls.

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

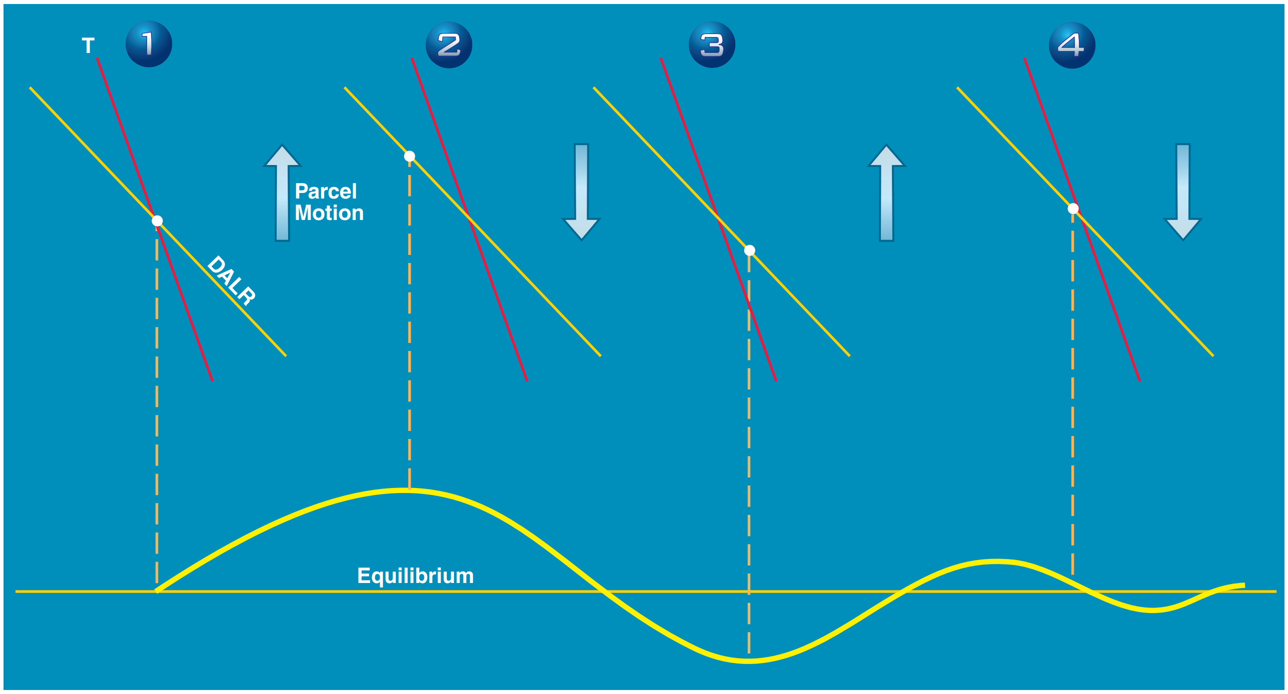


Figure 9-26. Parcel displaced vertically and oscillating around its equilibrium level.

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]

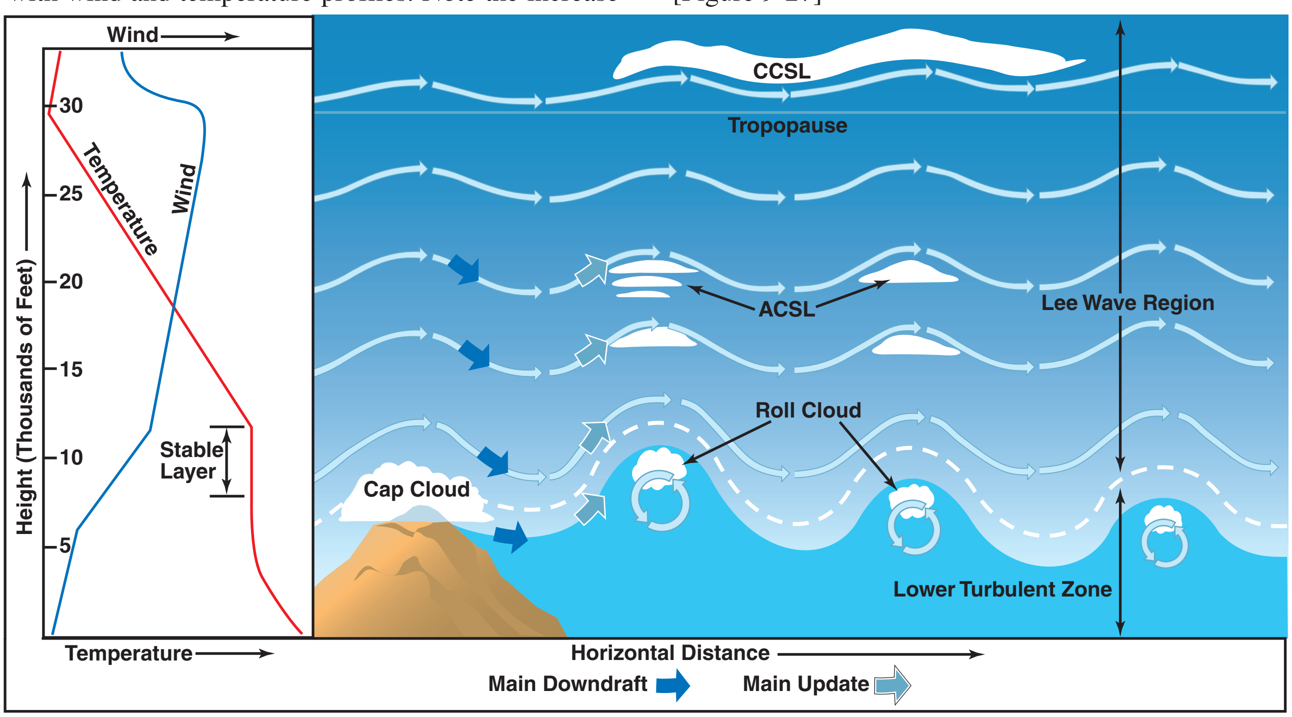


Figure 9-27. Mountain lee wave system.

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.

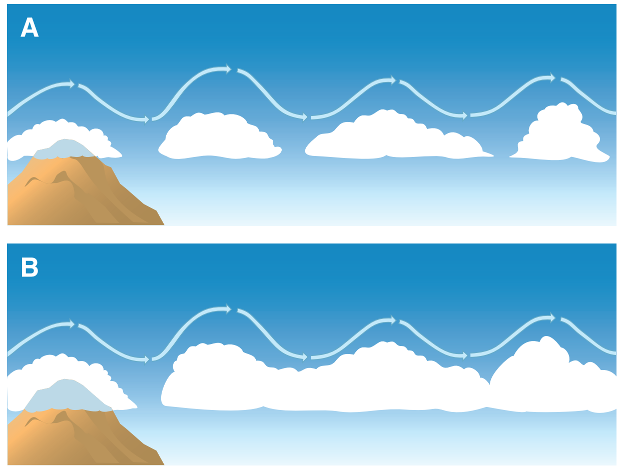


Figure 9-28. Small Foehn Gap under most conditions.

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,

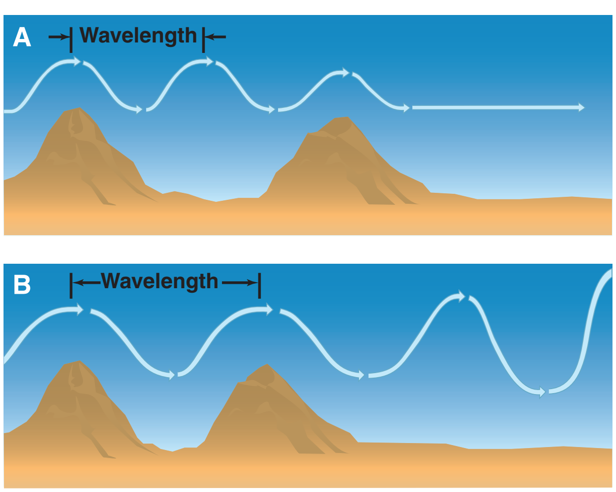


Figure 9-29. Constructive and destructive interference.

though the wave lift will be confined to a relatively small area in these cases.

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]

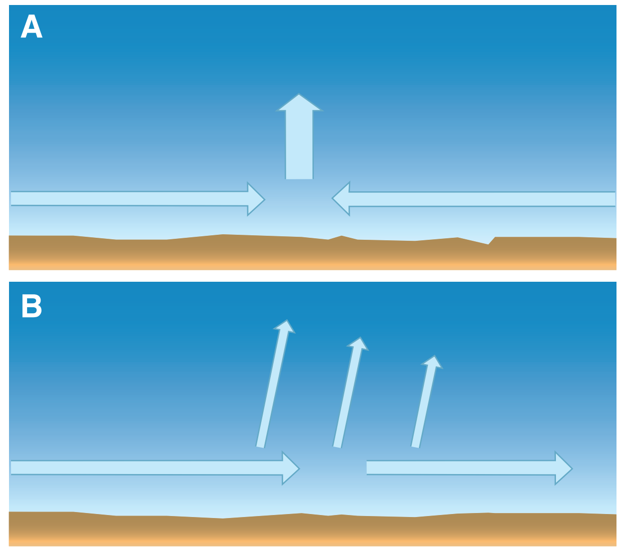


Figure 9-30. Convergence examples. (A) Wind from different directions. (B) Wind slows and "piles up."

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]

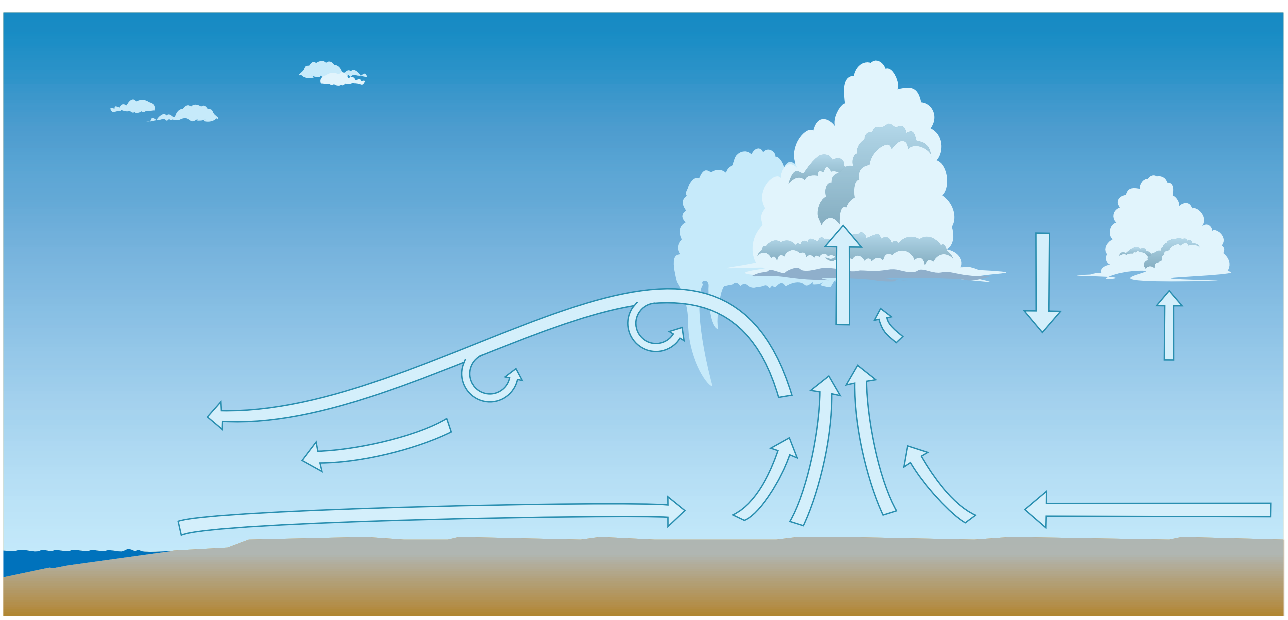


Figure 9-31. Sea-breeze front.

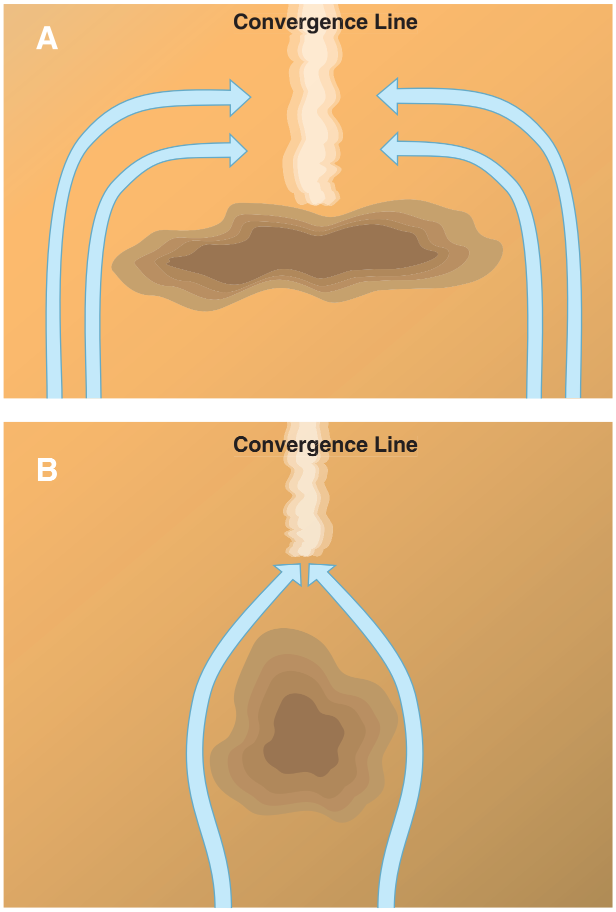


Figure 9-32. Convergence induced by flow around topography.

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,

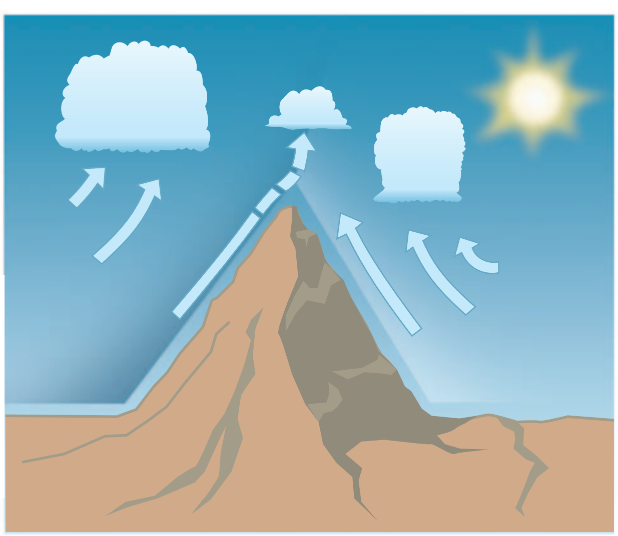


Figure 9-33. Mountain-top convergence.

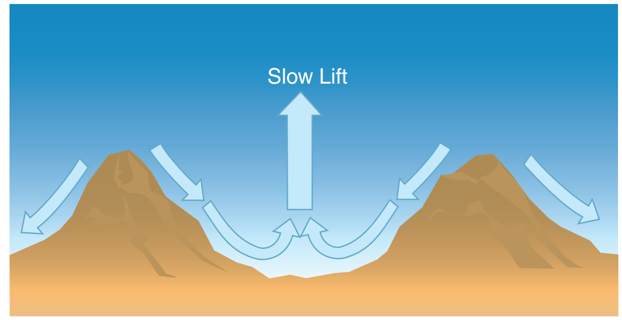


Figure 9-34. Convergence induced by flow around topography.

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.

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.

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 three types of briefings standard, abbreviated, or outlook.

A standard briefing is the most complete weather briefing and should be requested when a preliminary briefing has not been obtained or when the proposed flight is a cross-country. When a standard briefing is requested the following information will be provided by the briefer.

ADVERSE CONDITIONS—This includes the type of information that might influence the go, no-go decision.

VFR FLIGHT RECOMMENDATION—If the weather specialist indicates that VFR flight is not recommended, it means that, in the briefer's judgment, it is doubtful that the flight can be conducted under VFR conditions. Although, the final go, no-go decision, does rest with the pilot.

SYNOPSIS—This is a broad overview of the major weather systems or airmasses that will affect the flight.

CURRENT CONDITIONS—This information is a rundown of existing conditions including pertinent hourly, pilot, and radar weather reports. It is normally omitted when the departure time is more than 2 hours in the future.

ENROUTE FORECAST—This information summarizes the forecast conditions along the route of flight for cross-country flights and is omitted for local flights.

DESTINATION FORECAST—For cross-country flights, the briefer will provide the forecast for the destination airport for 1 hour before and after the estimated time of arrival (ETA).

WINDS AND TEMPERATURES ALOFT—This can be of particular interest to soaring pilots. This is summary of the winds along a route of flight. At the pilots request, the weather briefer can interpolate wind direction and speed between levels and reporting stations for various altitudes. Temperature is also provided only on request.

NOTICES TO AIRMEN—The briefer will supply notices to airman (NOTAM) information pertinent to the proposed flight. However, information, which has already been published in the NOTAM publication, is only provided on request.

AIR TRAFFIC CONROL DELAYS—This information advises of any known Air Traffic Control (ATC) delays. Soaring pilots don't normally need this information, unless they are flying a self-launch glider and the flight will terminate at an airport with a control tower.

OTHER INFORMATION—Upon request the briefer can provide other information, such as density altitude data, military operations areas (MOA), military training routes (MTR) within 100 nautical miles of the fight plan area.

An abbreviated briefing is used to update weather information from a previous briefing or when requesting specific information. This allows the briefer to limit the search for weather data to that information that has changed or can have a significant impact on the proposed flight. The briefer will automatically include adverse weather conditions, both present or forecast.

For a flight with a departure time of 6 or more hours away, an outlook briefing should be requested. This briefing provides forecast information appropriate to the proposed flight in order to help make a go no-go decision. An outlook briefing is designed for planning purposes only and a standard briefing should be requested just before the departure time to acquire current conditions and the latest forecasts.

DIRECT USER ACCESS TERMINAL SYSTEM

The FAA-funded direct user access terminal system (DUATS), allows pilots with a current medical certificate to receive weather briefings and file flight plans directly via personal computer and modem. The information on DUATS sites is presented in textual format, which requires some skill and practice to interpret. Information for the current DUATS providers can be found in the *Aeronautical Information Manual (AIM).*

ON THE INTERNET

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 import 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. One source of accurate weather information is the National Weather Service site located at: www.nws.noaa.gov.

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 will be 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, weather depiction chart, radar summary chart, and composite moisture stability chart.

SURFACE ANALYSIS CHART

A surface analysis chart is a computer-generated graphic that covers the 48 contiguous states and adjacent areas, for the valid time shown on the chart. The chart is prepared and disseminated every 3 hours by human observers.

A review of this chart provides a picture of the atmospheric pressure patterns at the earth's surface. [Figure 9-35] In addition, the chart depicts the amount of sky cover, the velocity and direction of the wind, the temperature, humidity, dewpoint, and other important weather data at specific locations. The observations from these locations are plotted on the chart to aid in analyzing and interpreting the surface weather features. [Figure 9-36, on next page.]

WEATHER DEPICTION CHART

The weather depiction chart provides an overview of favorable and adverse weather conditions for the chart time and is an excellent resource to help determine general weather conditions during flight planning. Information plotted on this chart is derived from aviation routine weather reports (METARs). Like the surface chart, the weather depiction chart is prepared and transmitted by computer every 3 hours and is valid at the time the data is plotted.

On this chart, a simplified station model is used to depict the type of weather, amount of sky cover, the height of the cloud base or ceiling, obstructions to vision, and visibility. Unlike the station model on a surface analysis chart, a bracket symbol is placed to the right of the circle to indicate an observation made by

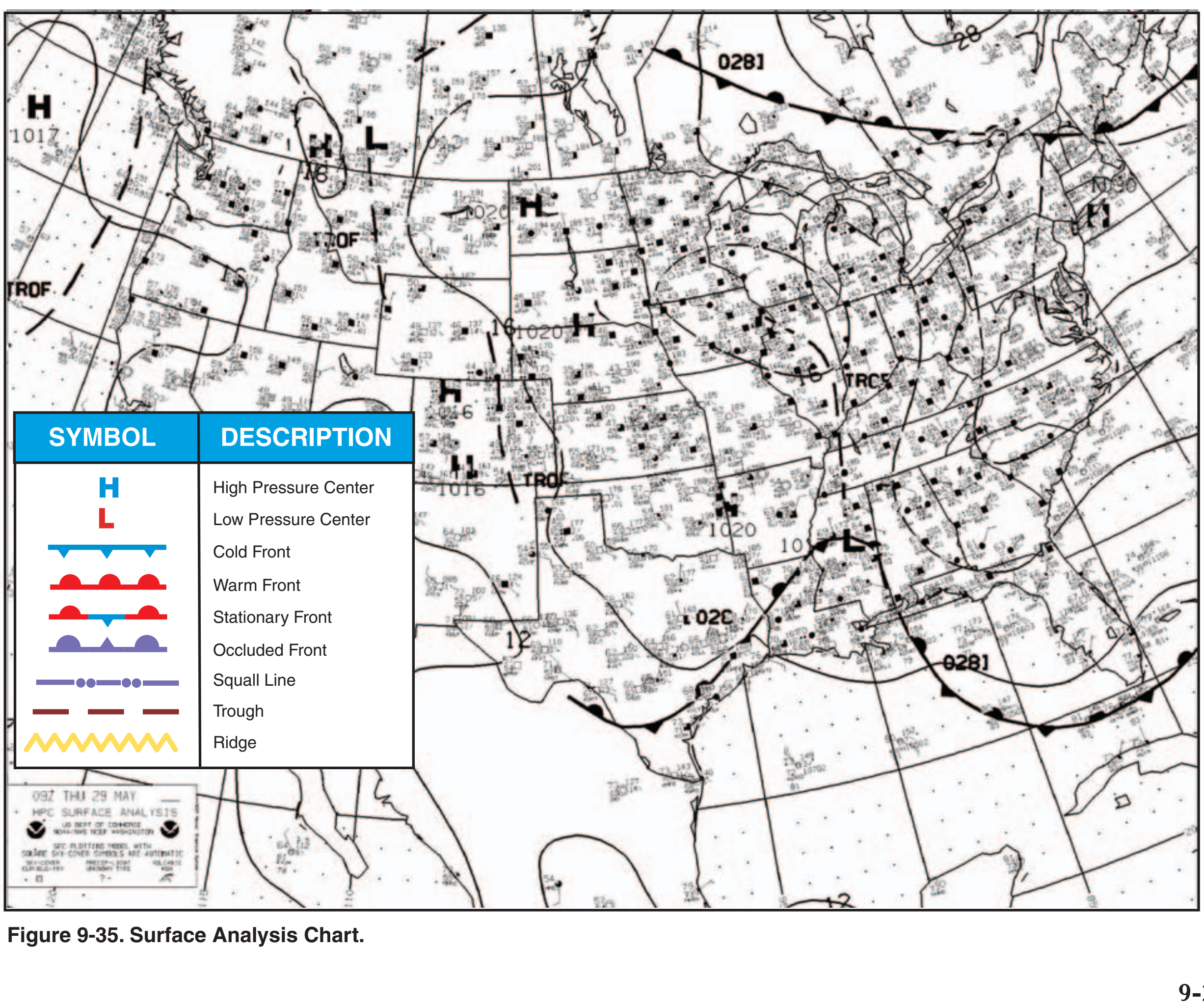


Figure 9-35. Surface Analysis Chart.

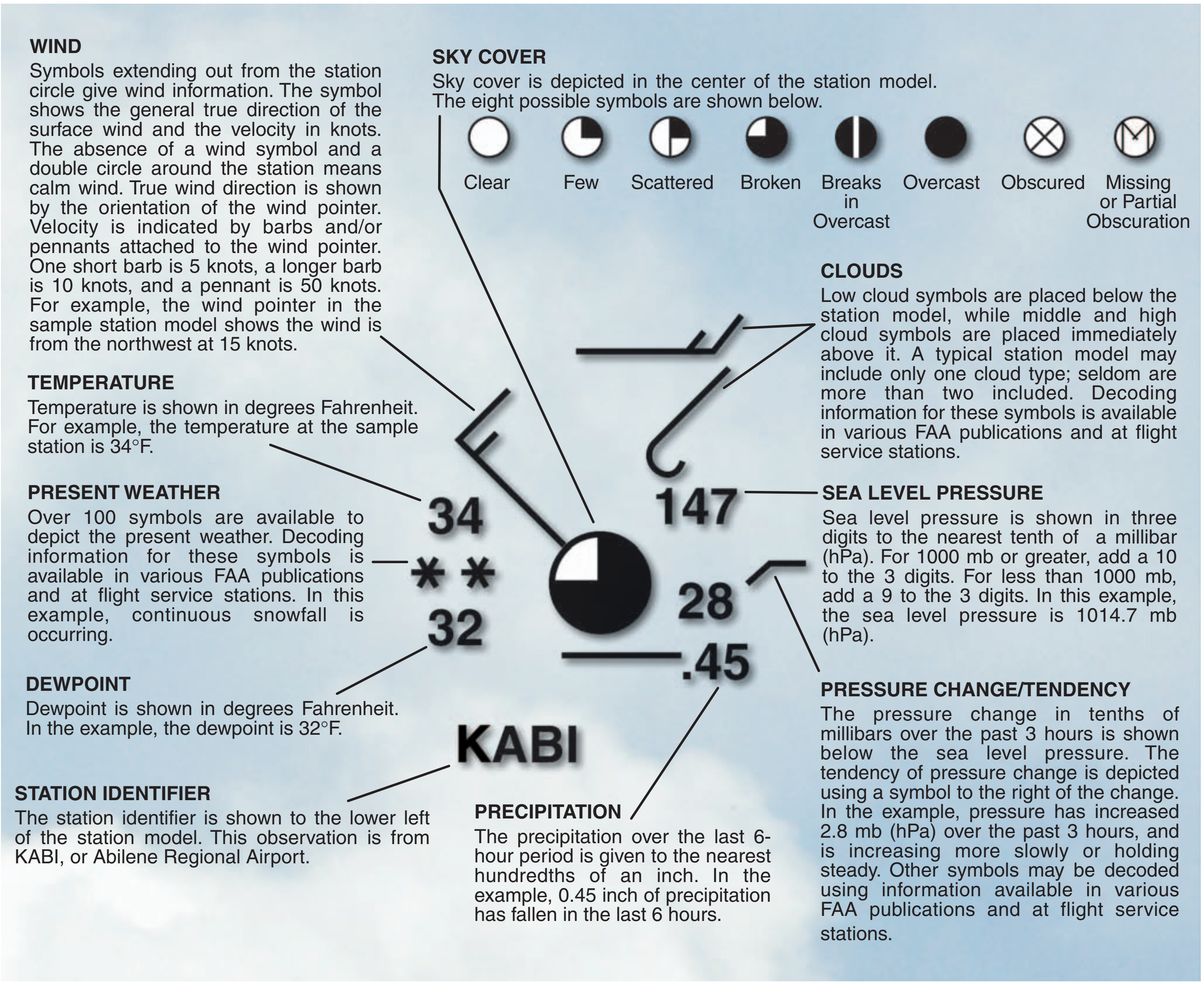


Figure 9-36. Station Model and Explanation.

an automated system only. [Figure 9-37] The observed ceiling and visibility for a general area is shown for IFR, MVFR, and VFR.

IFR—Ceilings less than 1,00 feet and/or visibility less than 3 miles are depicted in the hatched area outlined by a smooth line.

MVFR (Marginal VFR)—Ceiling 1,000 to 3,000 feet and/or visibility 3 to 5 miles is depicted in a non-hatched area outlined by a smooth line.

VFR—No ceiling or ceiling greater than 3,000 feet and visibility greater than 5 miles are not outlined.

RADAR SUMMARY CHART

The computer-generated radar summary chart is produced 35 minutes past each hour and depicts a collection of radar weather reports (SDs). This chart displays areas and type of precipitation, intensity, coverage, echo top, and cell movement. In addition, an area of severe weather is plotted if they are in effect when the chart is valid. [Figure 9-38]

U.S. LOW-LEVEL SIGNIFICANT WEATHER PROGNOSTICATION CHART

The low-level significant weather prognostic chart is divided into two forecast periods. The two panels on the left show the weather prognosis for a 12-hour period and those on the right for a 24-hour period. The valid times and titles for each panel are shown in the lower left corner of the respective panel.

The two upper panels depict cloud cover, altitudes of the freezing level, and areas where turbulence can be expected. The two lower panels depict the forecasters best estimate of the location of frontal and pressure systems, as well as the areas and types of precipitation. It

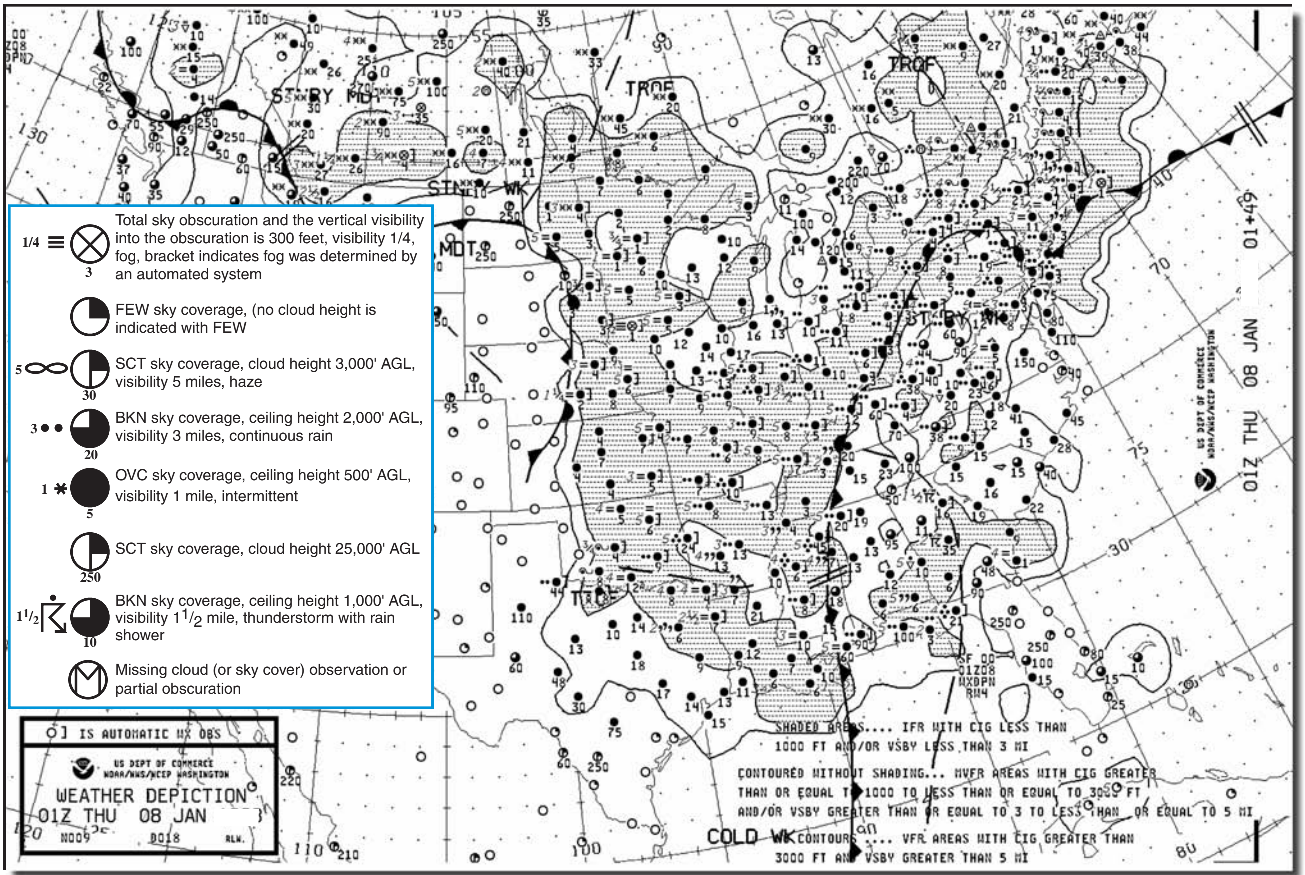
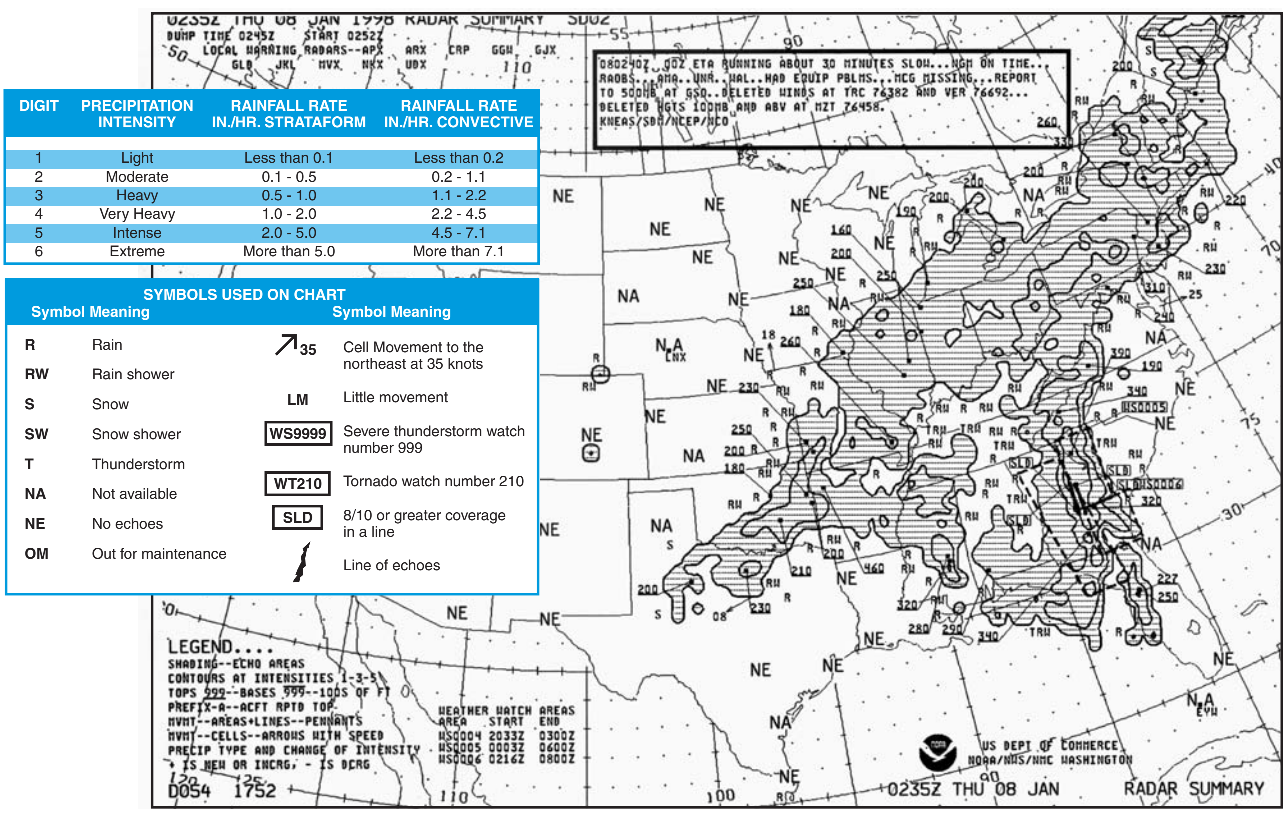


Figure 9-37. Weather Depiction Chart.



DIGIT	PRECIPITATION INTENSITY	RAINFALL RATE IN./HR. STRATAFORM	RAINFALL RATE IN./HR. CONVECTIVE
1	Light	Less than 0.1	Less than 0.2
2	Moderate	0.1 - 0.5	0.2 - 1.1
3	Heavy	0.5 - 1.0	1.1 - 2.2
4	Very Heavy	1.0 - 2.0	2.2 - 4.5
5	Intense	2.0 - 5.0	4.5 - 7.1
6	Extreme	More than 5.0	More than 7.1

Figure 9-38. Radar Summary Chart.

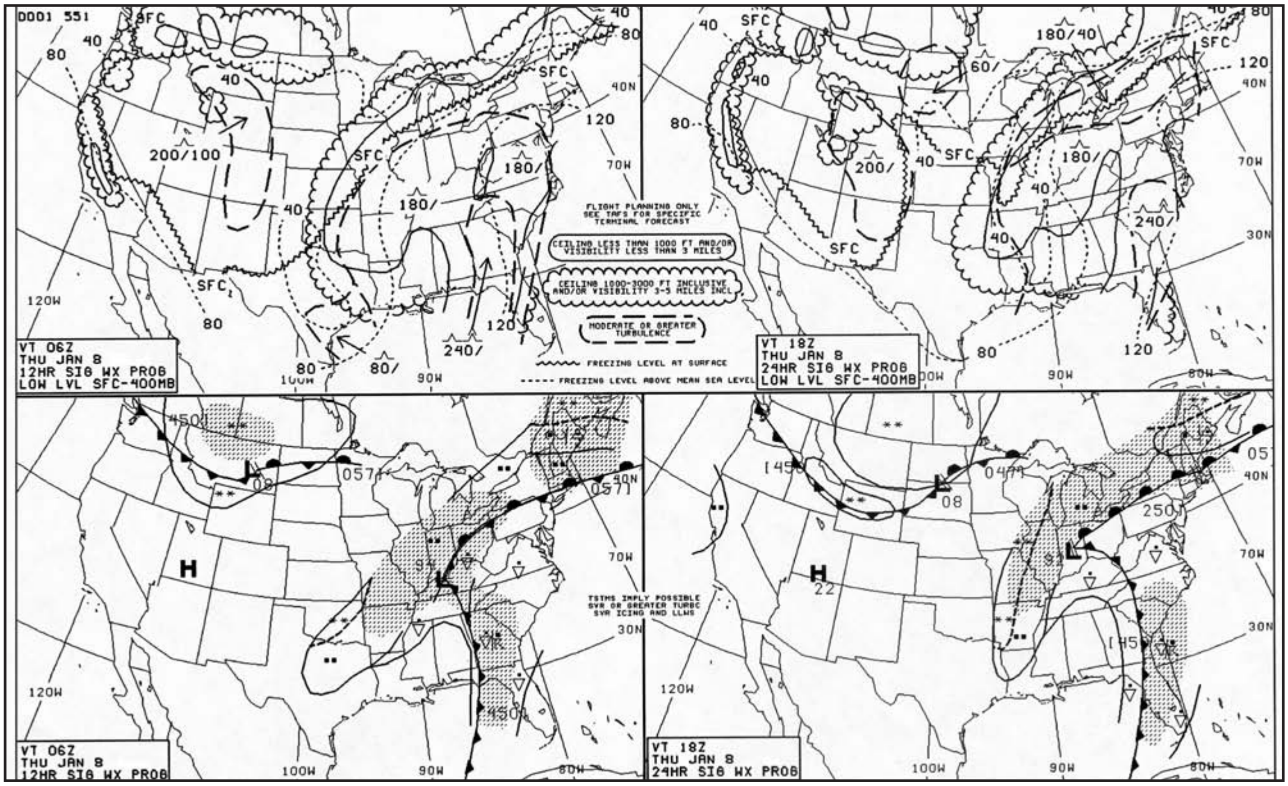


Figure 9-39. U.S. Low-Level Significant Weather Prognostic Chart.

is important to remember that a prognostic chart is a forecast and actual conditions may vary due to a number of factors. [Figure 9-39]

An area that is expected to have continuous of intermittent precipitation is enclosed by a solid line. If only showers are expected, the area is enclosed with a dot-dash pattern. Areas where precipitation is expected to cover one-half or more of the area is shaded. On the prognostic chart, special symbology is used to indicate various types of precipitation and how it will occur. [Figure 9-40]

WINDS AND TEMPERATURES ALOFT CHART

The winds and temperatures aloft chart (FD) is a 12-hour chart that is issued at 0000Z and 1200Z daily. It is primarily used to determine expected wind direction and velocity, and temperatures for the altitude of a planned cross-country flight. The chart contains eight panels that correspond to forecast levels 6,000; 9,000; 12,000; 18,000; 24,000; 30,000; 34,000; and 39,000 feet MSL. Soaring pilots planning to attempt a proficiency award for altitude should be aware that the levels below 18,000 feet are in true altitude, and levels 18,000 feet and above are reported in pressure altitude.

The predicted winds are depicted using an arrow from the station circle pointing in the direction of the wind. The second digit of the wind direction is given near the outer end of the arrow. Pennants and barbs are used to depict wind speed in much the same manner as the surface analysis chart. When calm winds are expected the arrow is eliminated and 99 is entered below the station circle. Forecast temperatures are shown as whole degrees Celsius near the station circle. In the example, the temperature is 3° Celsius and the wind is 160° at 25 knots. [Figure 9-41]

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 hazards to aviation hazards, such as thunderstorms and icing. [Figure 9-42]

The stability panel located in the upper left corner of the chart outlines areas of stable and unstable air. [Figure 9-43] The numbers on this panel resemble fractions, the top number is the lifted index (LI), and the lower number is the K index (KI). The lifted index is the difference between the temperature of a parcel of air being lifted from the surface to the 500-millibar level (approximately 18,000 feet MSL) and the actual temperature at the 500-millibar 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

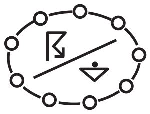
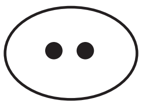
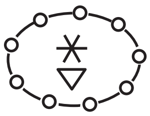
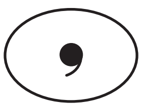
SYMBOL	MEANING	SYMBOL	MEANING	SYMBOL	MEANING
	Showery precipitation (thunderstorms/rain-showers) covering half or more of the area.		Rain Shower		Severe Turbulence
					Moderate Icing
	Continuous precipitation (rain) covering half or more of the area.		Snow Shower		Severe Icing
			Thunderstorms		Rain
	Showery precipitation (snow showers) covering less than half of the area.		Freezing Rain		Snow
			Tropical Storm		
	Intermittent precipitation (drizzle) covering less than half of the area.		Hurricane (Typhoon)		Drizzle
			Moderate Turbulence		

Figure 9-40. Prognostic Chart Symbology.

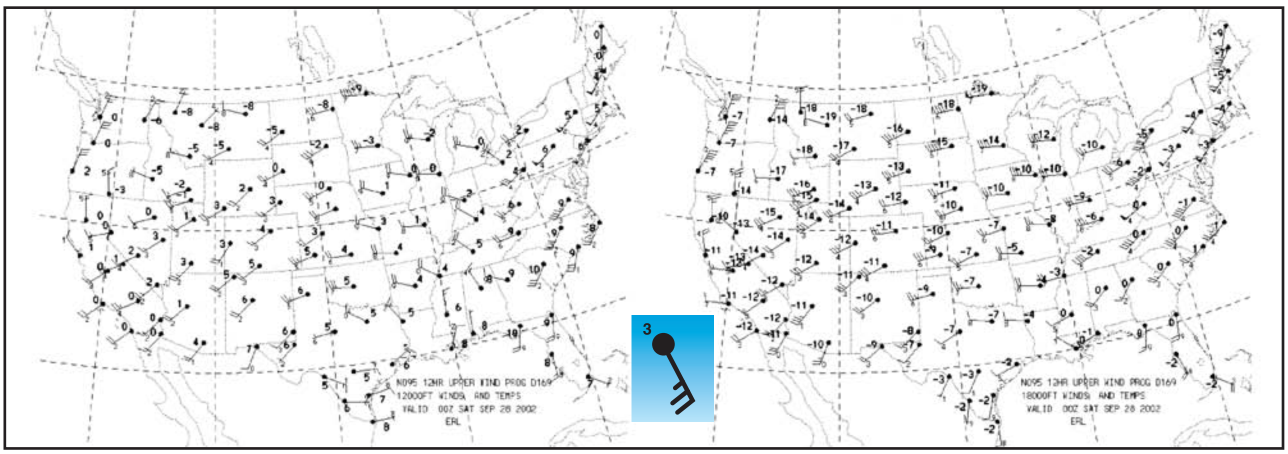


Figure 9-41. Winds and Temperatures Aloft (FD) chart.

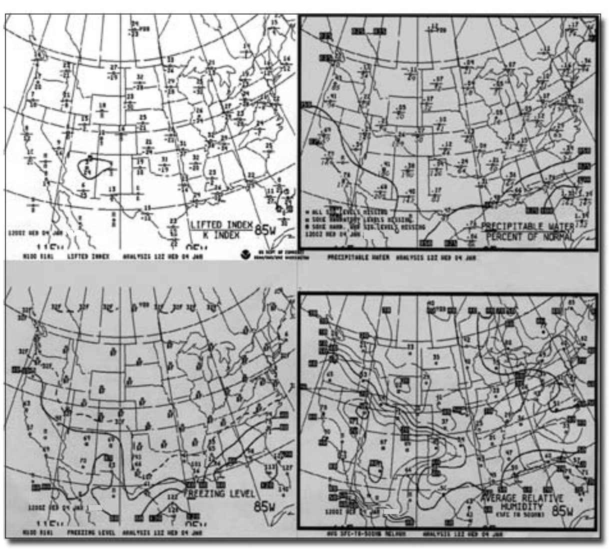


Figure 9-42. Composite Moisture Stability Chart.

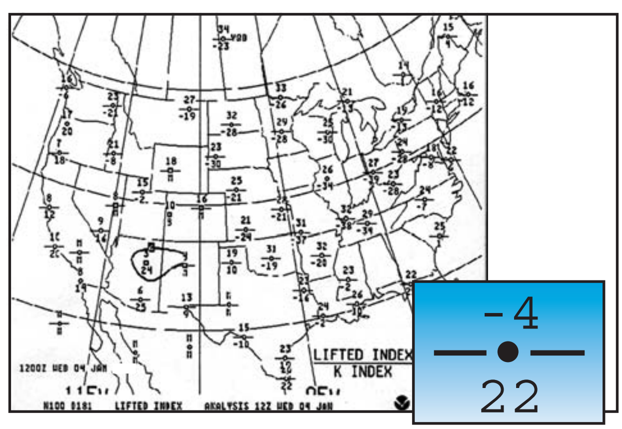


Figure 9-43. Stability Panel.

THUNDERSTORM POTENTIAL			
LIFTED INDEX (LI)	**SEVERE POTENTIAL**	**K INDEX**	**AIRMASS THUNDERSTORM PROBABILITY**
		<15	near 0%
0 to -2	Weak	15-19	20%
		20-25	21-40%
-3 to -5	Moderate	26-30	41-60%
		31-35	61-80%
≤ -6	Strong	36-40	81-90%
		>40	near 100%

Figure 9-44. Thunderstorm Potential.

–6 or less is considered very unstable, and severe thunderstorms are likely to occur. A zero index is neutrally stable. [Figure 9-44]

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.

The chart 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 which 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

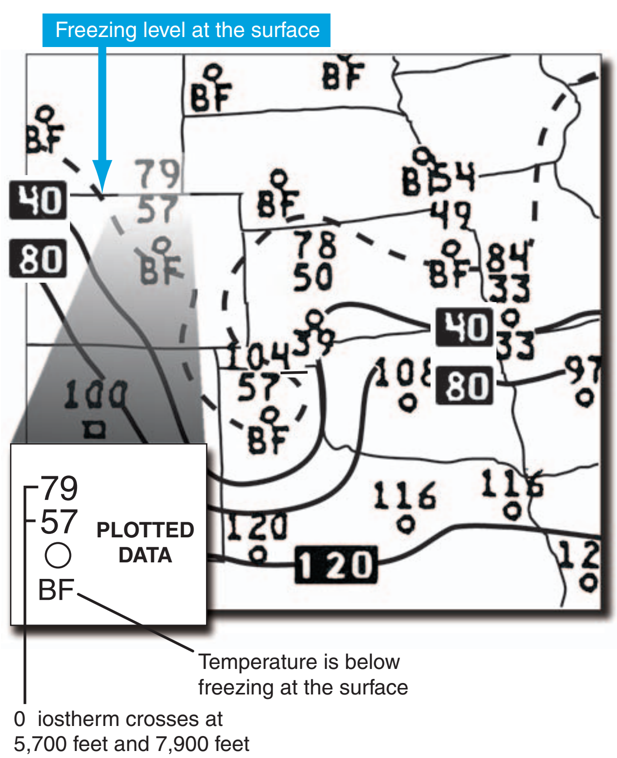


Figure 9-45. Freezing Level Panel.

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 lower left panel of the chart is the freezing level panel. [Figure 9-45] This panel plots the observed freezing level data gathered from upper air observations. When the freezing level (0° Celsius **isotherm**) is at the surface, it is shown as a dashed contour line. The abbreviation "BF" is used to indicate a station that is reporting a temperature below freezing. As the freezing level increases in height, it is depicted on the chart as a solid line. These isotherms, lines of equal temperature, are given in 4,000-foot intervals but are labeled in hundreds of feet MSL. For example, an isotherm labeled 40 indicates that the freezing level is at 4,000 feet MSL. Since the freezing level panel plots an overall view of the isotherms, it is easy to determine at which altitude structural icing is probable. An inversion, with warm air above the freezing level is indicated by multiple crossings of 0° Celsius isotherms.

The precipitable water panel, located in the upper right corner of the composite moisture stability chart, graphically depicts the atmospheric water vapor available for condensation. The coverage for this panel is from the surface to the 500-millibars level. The top number in the station model represents the amount of precipitable water in hundredths of an inch. The lower number is the percent of normal value for the month. For example, when the value is .68/205, there is 68 hundredths of an inch of precipitable water, which is 205 percent of the normal (above average) for any day during the month. When a station symbol is darkened, the precipitable water value at the station is 1 inch or more. **Isopleths** are also plotted on the chart for every $^{1}/_{4}$-inch. To differentiate the isopleths, a heavier line is used to indicate 1/2-inch of precipitable water. [Figure 9-46]

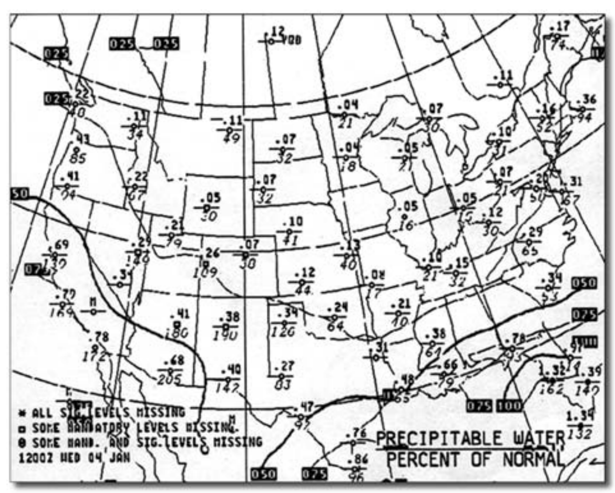


Figure 9-46. Precipitable Water Panel.

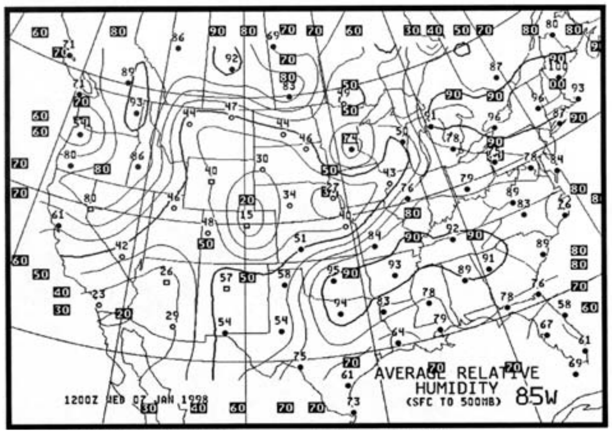


Figure 9-47. Average Relative Humidity Panel.

This panel is used primarily by meteorologists who are concerned with predicting localized flooding. However, when used with reference to the other panels it adds credibility to the prediction and probability of severe weather.

In the lower right corner of the composite moisture stability chart is the average relative humidity panel. The values for each station are plotted as a percentage and are valid from the surface to the 500-millibar level. For quick reference **isohumes** are drawn and labeled for every 10 percent, with heavier isohumes drawn for 10, 50, and 90 percent. When the stations is reporting humidity higher than 50 percent, the station symbol is darkened. If relative humidity data is missing, an "M" is placed above the station symbol. [Figure 9-47]

For flight planning, this chart is useful for determining average air saturation at altitudes from the surface to 18,000 feet MSL. Average relative humidity of 50 percent or higher is frequently associated with areas of clouds and possible precipitation. However, an area with high humidity may or may not be indicative of high water vapor content (precipitable water). For example, Kansas City may have the same relative humidity as New Orleans, but if the precipitable water value were .13 inches in Kansas City and .66 inches in New Orleans, greater precipitation would be expected in New Orleans.

While each panel of the composite moisture stability chart provides important information for predicting weather over a wide area of the United States, it is more important to reference all four panels to develop the best weather picture.

PRINTED REPORTS AND FORECASTS

Weather reports and forecasts are beneficial in numerous ways. For example, predictions of warm temperatures signal the beginning of thermal soaring in the northern climates, if it were only that simple. Printed reports and forecasts provide much more information to help pilots decide if a flight can be conducted safely. To that end, wide varieties of weather products are available to assist pilots in that decision-making process.

PRINTED WEATHER REPORTS

In the simplest of terms, a weather report is a record of observed weather conditions at a particular location and time. Weather information gathered by trained observers, radar systems, and pilots is disseminated in a variety of reports. The types of reports pilots are likely to encounter include aviation routine weather reports, radar weather reports, and pilot reports.

AVIATION ROUTINE WEATHER REPORT

An aviation routine weather report (METAR) is a weather observer's interpretation of weather conditions at the time of the observation. This report is used by the aviation community and the National Weather Service to determine the flying category of the airport where the observation is made. Based on the observed weather conditions, this determination dictates whether the pilots will operate under visual flight rules (VFR), marginal visual flight rules (MVFR), or instrument flight rules (IFR) in the vicinity of the airport. Additionally, the METAR is used to produce an aviation terminal forecast (TAF).

Although, the code that makes-up a METAR is used worldwide, some variations of the code used in the United States exist in other countries. In the United States, temperature and dewpoint are reported in degrees Celsius, using current units of measure for the remainder of the report.

A METAR consists of a sequence of observed weather conditions or elements, if an element is not occurring or cannot be observed at the time of the observation, the element is omitted from the report. The elements of the report are separated by a space except temperature and dewpoint, which are separated by a slash (/). A non-routine METAR report, referred to as a SPECI report, is issued any time the observed weather meets the SPECI criteria. The SPECI criteria includes initial volcanic eruptions and the beginning or ending of thunderstorms as well as other hazardous weather conditions.

The METAR for Los Angles in Figure 9-48 was given on the 14^{th} day of the month, at 0651 UTC. When a METAR is derived from a totally automated weather observation station, the modifier AUTO follows the date/time element. The wind was reported to be 140° at 21 knots with gusts to 29 knots. The reported surface visibility is 1 statute mile. Runway visual range (RVR) is based on the visual distance measured by a machine looking down the runway. In the example above, the runway visual range for runway 36 left is 4,500 feet variable to 6,000 feet. The weather phenomena is rain

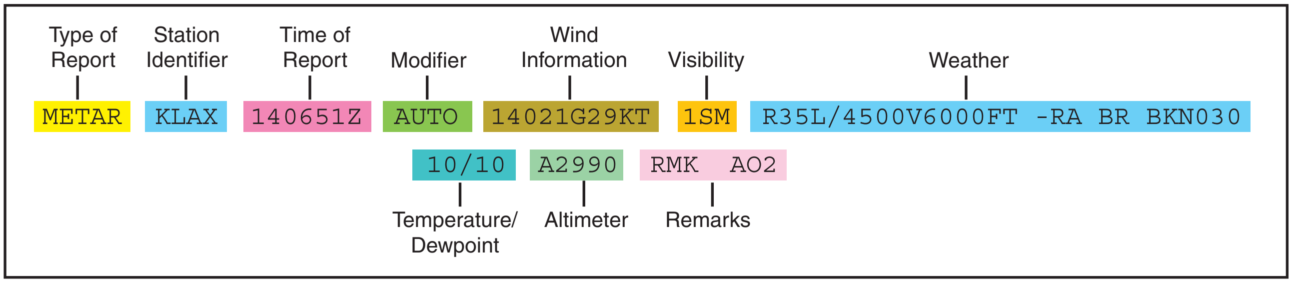


Figure 9-48. Typical Aviation Routine Weather Report (METAR) as generated in the United States.

(RA) and mist (BR), note the minus sign preceding the RA indicates light rain is falling. The sky condition element indicates there are broken clouds at 3,000 feet above the ground. Temperature and dewpoint are reported in a two-digit format in whole degrees Celsius separated by a slash. In the example, the temperature is 10°C and the dewpoint is 10°C. The altimeter setting is reported in inches and hundredths of inches of mercury using a four-digit format prefaced by an A and is reported as 29.90 in. Hg. The Remarks element is included in a METAR or SPECI when it is appropriate. If the reporting station is automated, AO1 or AO2 will be noted. Certain remarks are included to enhance or explain weather conditions that are considered significant to flight operations. The types of information that may be included are wind data, variable visibility, beginning and ending times of a particular weather phenomenon, pressure information, and precise temperature/dewpoint readings. Refer to Appendix A at the end of this chapter for further explanation of TAF and METAR codes and references.

PIREP FORM	
Pilot Weather Report	→ = Space Symbol
3-Letter SA Identifier — — →	1. UA → ____ Routine Report UUA → ____ Urgent Report
2. /OV →	Location: In relation to a NAVAID
3. /TM →	Time: Coordinated Universal Time
4. /FL →	Altitude/Flight Level: Essential for turbulence and icing reports
5. /TP →	Aircraft Type: Essential for turbulence and icing reports
Items 1 through 5 are mandatory for all PIREPs	
6. /SK →	Sky Cover: Cloud height and coverage (scattered, broken, or overcast)
7. /WX →	Flight Visibility and Weather: Flight visibility, precipitation, restrictions to visibility, etc.
8. /TA →	Temperature (Celsius): Essential for icing reports
9. /WV →	Wind: Direction in degrees and speed in knots
10. /TB →	Turbulence: Turbulence intensity, whether the turbulence occurred in or near clouds, and duration of turbulence
11. /IC →	Icing: Intensity and Type
12. /RM →	Remarks: For reporting elements not included or to clarify previously reported items

Figure 9-49. PIREP Form.

PILOT REPORTS

Of all of the weather reports available to pilots, PIREPs provide the most timely weather information for a particular route of flight. The advantage for pilots is significant because unforecast adverse weather conditions, such as low in-flight visibility, icing conditions, wind shear, and turbulence can be avoided along a route of flight. When significant conditions are reported or forecast, ATC facilities are required to solicit PIREPs. When unexpected weather conditions are encountered, pilots should not wait for ATC to request a PIREP of conditions, but offer them to aid other pilots. [Figure 9-49]

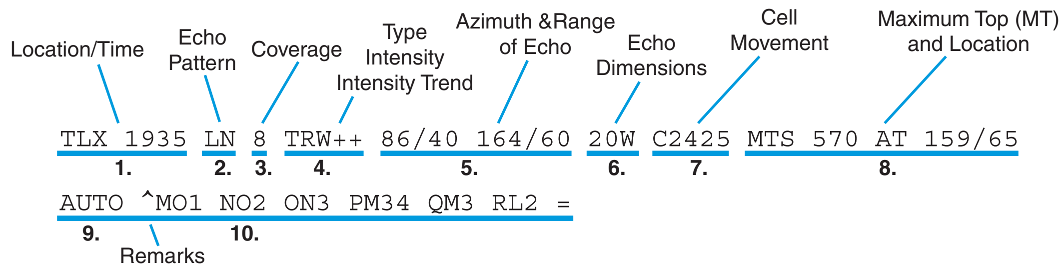
Another type of PIREP is an AIREP (ARP) or air report. These reports are disseminated electronically and are used almost exclusively by commercial airlines. However, pilots may see AIREPs when accessing weather information on the Internet.

RADAR WEATHER REPORTS

Radar weather reports (SDs), derived from selected radar locations are an excellent source of information about precipitation and thunderstorms. [Figure 9-50] The report describes the type, intensity, intensity trend, and height of the echo top of precipitation. [Figure 9-51] If the base of the precipitation is considered significant, it is also included in the report. All heights are reported in hundreds of feet MSL.

PRINTED FORECASTS

Everyday, National Weather Service Offices prepare a variety of forecasts using past weather observations and computer modeling. Weather specialists develop printed forecasts for more than 2,000 forecasts for airports, over 900 route forecasts, which are intended for flight planning purposes. The printed forecasts pilots need to become familiar with include the aviation terminal forecast, aviation area forecast, and the winds and temperatures aloft forecast.



Above SD report decoded as follows:

1. Location identifier and time of radar observation (Oklahoma City SD at 1935 UTC).

2. Echo pattern (LN in this example). The echo pattern or configuration may be one of the following:
   a. Line (LN) is a line of convective echoes with precipitation intensi ties that are heavy or greater, at least 30 miles long, at least 4 times as long as it is wide, and at least 25% coverage within the line.
   b. Area (AREA) is a group of echoes of similar type and not classified as a line.
   c. Cell (CELL) is a single isolated convective echo such as a rain shower.

3. Coverage, in tenths, of precipitation in the defined area (8/10 in this example).

4. Type and intensity of weather (thunderstorm [T] with very heavy rainshowers [RW++]).

5. Azimuth, referenced to true north, and range, in nautical miles (NM) from the radar site, of points defining the echo pattern (86/40 164/60 in this echo). For lines and areas, there will be two azimuth and range sets that define the pattern. For cells, there will be only one azimuth and range set. (See the examples that follow for elaboration of echo patterns.)

6. Dimension of echo pattern (20 NM wide in this example). The dimension of an echo pattern is given when azimuth and range define only the center line of the pattern. (In this example, "20W" means the line has a total width of 20 NM, 10 miles either side of a center line drawn from the points given in item "e" above.)

7. Cell movement (cells within line moving from 240 degrees at 25 knots in this example). Movement is only coded for cells; it will not be coded for lines or areas.

8. Maximum top and location (57,000 feet MSL on radial 159 degrees at 65 NM in this example). Maximum tops may be coded with the symbols "MT" or "MTS." If it is coded with "MTS" it means that satellite data as well as radar information was used to measure the top of the precipitation.

9. The report is automated from WSR-88D weather radar data.

10. Digital section is used for preparing radar summary chart.

Figure 9-50. Sample Radar Weather Report.

TERMINAL AERODROME FORECAST

The terminal aerodrome forecast (TAF) is derived from weather data and observations at a specific airport. It is a concise statement of expected weather conditions within a five statute mile radius of the center of the airport's runway complex. Normally valid for a 24-hour period, TAFs are scheduled for dissemination four times a day at 0000Z, 0600Z, 1200Z, and 1800Z. Each TAF contains the International Civil Aviation Organization (ICAO) station identifier, time and date of issuance, valid period, and the body of the forecast. With a few exceptions, the coding used in a TAF is similar to that found in a METAR.

SYMBOL	INTENSITY
-	Light
(none)	Moderate
+	Heavy
++	Very Heavy
X	Intense
XX	Extreme

Figure 9-51. Intensity and intensity trend symbols.

The TAF for Pierre, South Dakota [Figure 9-52] was issued on the eleventh day of the month at 1140Z. This TAF is valid from 1200Z to 1200Z on the 11-day of the month. The first three digits of the surface wind forecast indicate direction and the following two indicate speed in knots (KT). In this case, the winds are 130° at 12 knots. P6SM indicates the visibility is forecast to be greater than 6 statute miles. BKN100 forecasts a broken layer of clouds at 10,000 feet AGL. The temporary (TEMPO) change group is used when fluctuations of

```
TAF
KPIR 111140Z 111212 13012KT P6SM BKN100 TEMPO 1214 5SM BR
   FM0000 14012KT P6SM BKN080 OVC150 PROB40 0004 3SM TSRA BKN030CB
   FM0400 14008KT P6SM SCT040
   BECMG 0810 32007KT=
```

Figure 9-52. Terminal Aerodrome Forecast.

wind, visibility, weather, or sky conditions are expected to last for less than one hour at a time, and expected to occur during less than half the time period. The four digits following the temporary code give the expected beginning and ending hours during which the conditions will prevail. In the example, reduced visibility due to mist is expected to prevail between 1200 hours and 1400 hours. The from (FM) change group is used to describe a rapid and significant change in the forecast weather that is expected to occur in less than an hour. When a gradual change in the forecast weather is expected over a period of about 2-hours, the becoming (BECMG) group is used. The probability-forecast group is used when there is less than a 50 percent chance of thunderstorms or precipitation. In the example, PROB40 indicates that between 0000Z and 0400Z there is a 40 to 50 percent chance of a moderate rain showers associated with a thunderstorm, 3 statute miles visibility, and broken cloud layer at 3,000 feet AGL. The CB following the sky condition stands for cumulonimbus clouds.

AVIATION AREA FORECAST

An aviation area forecast (FA) covers general weather conditions over several states or a known geographical area and is a good source of information for enroute weather. It also helps determine the weather conditions at airports, which do not have Terminal Aerodrome Forecasts. FAs are issued three times a day in the 48

Heading Section

```
SLCC FA 141045
SYNOPSIS AND CLDS/WX
SYNOPSIS VALID UNTIL 150500
CLDS/WX VALID UNTIL 142300... OUTLK VALID 142300-150500
ID MT NV UT WY CO AZ NM
```

Precautionary Statements

```
SEE AIRMET SIERRA FOR IFR CONDS AND MTN OBSCN.
TSTMS IMPLY PSBL SVR OR GTR TURBC SVR ICG LLWS
AND IFR CONDS.

NON MSL HGTS ARE DENOTED BY AGL OR CIG.
```

Synopsis

```
SYNOPSIS...HIGH PRES OVER NERN MT CONTG EWD
GRDLY. LOW PRES OVR AZ NM AND WRN TX RMNG
GENLY STNRY. ALF...TROF EXTDS FROM WRN MT INTO
SRN AZ RMNG STNRY.
```

VFR Clouds and Weather

```
.
ID MT
FROM YXH TO SHR TO 30SE BZN TO 60SE PIH TO LKT TO
YXC TO YXH.
70-90 SCT-BKN 120-150. WDLY SCT RW-. TOPS SHWRS 180.
OTLK...VFR
RMNDR AREA...100-120. ISOLD RW- MNLY ERN PTNS AREA.
OTLK...VFR
.
UT NV NM AZ
80 SCT-BKN 150-200. WDLY SCT RW-/TRW-. CB TOPS 450.
OTLK...VFR
.
WY CO
FROM BZN TO GCC TO LBL TO DVC TO RKS TO BZN.
70-90 BKN-OVC 200. OCNL VSBY 3R-F. AFT 20Z WDLY SCT
TRW-. CB TOPS 450. OTLK...MVFR CIG RW.
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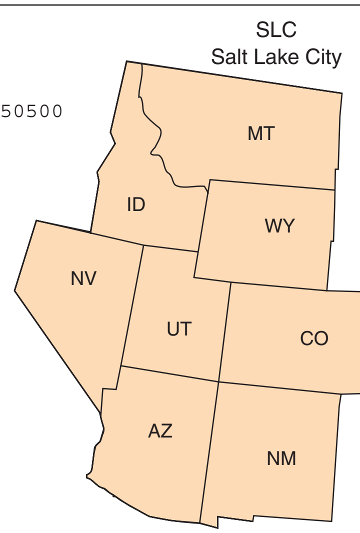

Figure 9-53. Aviation Area Forecast.

contiguous states, and amended as required. NWS offices issue FAs for Hawaii and Alaska; however, the Alaska FA uses a different format. An additional specialized FA may be issued for the Gulf of Mexico by the National Hurricane Center in Miami, Florida.

The FA consists of several sections: a communications and product header section, a precautionary statement section, and two weather sections (synopsis and VFR clouds and weather). Each area forecast covers an 18-hour period. [Figure 9-53]

COMMUNICATIONS AND PRODUCT HEADERS

Refer to figure 9-53 for the following discussion. In the heading SLCC FA 141045, the SLC identifies the Salt Lake City forecast area, C indicates the product contains clouds and weather forecast, FA means area forecast, and 141045 is the date time group and indicates that the forecast was issued on the 14th day of the month at 1045Z. Since these forecasts times are rounded to the nearest full hour, the valid time for the report begins at 1100Z. The synopsis is valid until 18 hours later, which is shown as the 15th 0500Z. The clouds and weather section forecast is valid for 12-hour period, until 2300Z on the 14th. The outlook portion is valid for six hours following the forecast, from 2300Z on the 14th to 0500Z on the 15th. The last line of the header lists the states that are included in the Salt Lake City forecast area.

Amendments to FAs are issued whenever the weather significantly improves or deteriorates based on the judgment of the forecaster. An amended FA is identified by the contraction AMD in the header along with the time of the amended forecast. When an FA is corrected, the contraction COR appears in the heading, along with the time of the correction.

PRECAUTIONARY STATEMENTS

Following the headers are three precautionary statements, which are part of all FAs. The first statement alerts the pilot to check the latest AIRMET Sierra, which describes areas of mountain obscuration which may be forecast for the area. The next statement is a reminder that thunderstorms imply possible severe or greater turbulence, severe icing, low-level wind shear, and instrument conditions. Therefore, when thunderstorms are forecast, these hazards are not included in the body of the FA. The third statement points out that heights, which are not MSL, are noted by the letters AGL (above ground level) or CIG (ceiling). All heights are expressed in hundreds of feet.

SYNOPSIS

The synopsis is a brief description of the location and movement of fronts, pressure systems, and circulation patterns in the FA area over an l8-hour period. When appropriate, forecasters may use terms describing ceilings and visibility, strong winds, or other phenomena. In the example, high pressure over northeastern Montana will continue moving gradually eastward. A low-pressure system over Arizona, New Mexico, and western Texas will remain generally stationary. Aloft (ALF), a trough of low pressure extending from western Montana into southern Arizona is expected to remain stationary.

VFR CLOUDS AND WEATHER

The VFR clouds and weather portion is usually several paragraphs long and broken down by states or geographical regions. It describes clouds end weather, which could affect VFR operations over an area of 3,000 square miles or more. The forecast is valid for 12 hours, and is followed by a 6-hour categorical outlook (18 hours in Alaska).

When the surface visibility is expected to be six statute miles or less, the visibility and obstructions to vision are included the forecast. When precipitation, thunderstorms, and sustained winds of 20 knots or are forecast, they will be included in this section. The term OCNL (occasional) is used when there is a 50 percent or greater probability, but for less than 1/2 of the forecast period, of cloud or visibility conditions which could affect VFR flight. The area covered by showers or thunderstorms is indicated by the terms ISOLD (isolated), meaning single cells. WDLY SCT (widely scattered, less then 25 percent of the area), SCT or AREAS (25 to 54 percent of the area), and NMRS or WDSPRD (numerous or widespread, 55 percent or more of the area).

The outlook follows the main body of the forecast, and gives a general description of the expected weather using the terms VFR, IFR, or MVFR (marginal VFR). A ceiling less than 1,000 feet and/or visibility less than 3 miles is considered IFR. Marginal VFR areas are those with ceilings from 1,000 to 3,000 feet and/or visibility between 3 and 5 miles. Abbreviations are used to describe causes of IFR or MVFR weather.

In the example shown above, the area of coverage in the specific forecast for Wyoming and Colorado is identified using three-letter designators. This area extends from Bozeman, Montana to Gillette, Wyoming to Liberal, Kansas to Dove Creek, Wyoming to Rocksprings, Wyoming, and back to Bozeman. As mentioned previously under the header, the valid time begins on the 14th day of the month at 1100Z for a 12-hour period. A broken to overcast cloud layer begins between 7,000 to 9,000 feet MSL, with tops extending to 20,000 feet. Since visibility and wind information is omitted, the visibility is expected to be greater than 6 statute miles and the wind less than 20 knots. However, the visibility (VSBY) is forecast to be occasionally 3 miles in light rain and fog (3R-F). After 2000Z, widely scattered thunderstorms with light rain showers are expected, with cumulonimbus (CB) cloud tops to 45,000 feet. The 6-hour categorical outlook covers the period from 2300Z on the 14th to 0500 on the 15th. The forecast is for marginal VFR weather due to ceilings (CIG) and rain showers (RW).

CONVECTIVE OUTLOOK CHART

The convective outlook chart (AC), is a two-panel chart that forecasts general thunderstorm activity for the valid period of the chart. ACs describe areas in which there is a risk of severe thunderstorms. Severe thunderstorm criteria include winds equal to or greater than 50 knots at the surface or hail equal to or greater than 3/4 inch in diameter, or tornadoes. Convective outlooks are useful for planning flights within the forecast period. Both panels of the convective outlook chart qualify the risk of thunderstorm activity at three levels, as well as areas of general thunderstorm activity.

Slight (SLGT)—implies well-organized severe thunderstorms are expected but in small numbers and/or low coverage.

Moderate (MDT)—implies a greater concentration of severe thunderstorms, and in most cases greater magnitude of severe weather.

High (HIGH)—means a major severe weather outbreak is expected, with a greater coverage of severe weather with a likelihood of violent tornadoes and/or damaging high winds.

General thunderstorm activity is identified on the chart by a solid line with an arrowhead at one end. This indicated that the area of general thunderstorm activity is expected to the right of the line from the direction of the arrowhead.

The left panel [Figure 9-54] describes specific areas of probable thunderstorm activity for day-1 of the outlook. The day-1 panel is issued five times daily, starting a 0600Z and is valid from 1200Z that day until

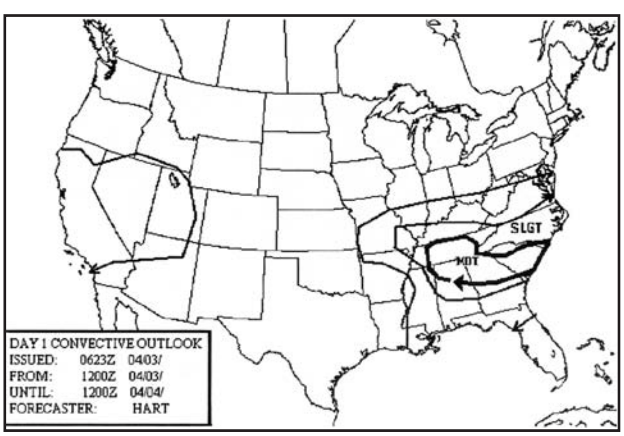

Figure 9-54. Day-1 panel of the Convective Outlook Chart.

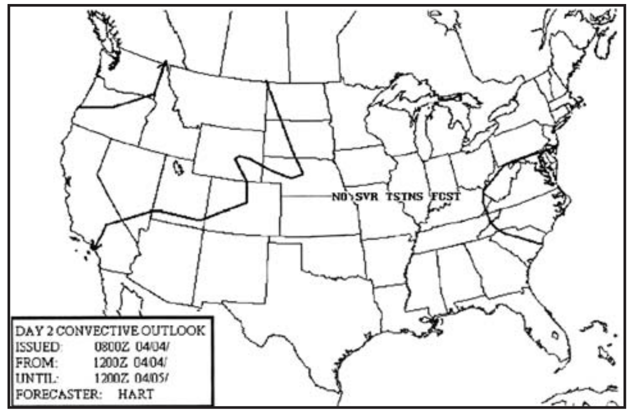

Figure 9-55. Day-2 panel of the Convective Outlook Chart.

1200Z the day after. The other issuance times are 1300Z, 1630Z, 2000Z, and 0100Z and are valid until 1200Z the day after the original issuance day.

The right panel [Figure 9-55] is the day-2 chart, it is issued twice daily. The initial issue is 0830Z standard time, 0730Z daylight time and is updated at 1730Z. The valid time of the chart is from 1200Z following the original issue of the day-1 chart until 1200Z of the next day. For example, if the day-1 chart is issued on Monday it is valid until 1200Z on Tuesday, subsequently the day-2 chart is valid from 1200Z Tuesday until 1200Z on Wednesday.

WINDS AND TEMPERATURES ALOFT FORECAST

A winds and temperatures aloft forecast (FD) provides an estimate of wind direction relation to true north, wind speed in knots and the temperature in degrees Celsius for selected altitudes. Depending on the station elevation, winds and temperatures are usually forecast for nine levels between 3,000 and 39,000 feet. Information for two additional levels (45,000 foot and 53,000 foot) may be requested from a FSS briefer or NWS meteorologist but is not included on an FD. [Figure 9-56]

The heading begins with the contraction FD, followed by the four-letter station identifier. The six digits are the day of the month and the time of the transmission. The next two lines indicate the time of the observation and the valid time for the forecast. In the example, the observation was taken on the 15th day of the month at 1200Z, is valid at 1800Z, and is intended to be used between 1700Z and 2100Z on the same day.

The first two numbers indicate the true direction from which the wind is blowing. For example, 1635-08 indicates the wind is from 160° at 35 knots and the temperature is –8°C. Determining the wind direction and speed and temperature requires interpolation between two levels. For instance, to determine the

FD KWBC 151640

BASED ON 151200Z DATA

VALID 151800Z FOR USE 1700-2100Z TEMPS NEG ABV 24000

FD	3000	6000	9000	12000	18000	24000	30000
ALA			2420	2635-08	2535-18	2444-30	245945
AMA		2714	2725+00	2625-04	2531-15	2542-27	265842
DEN			2321-04	2532-08	2434-19	2441-31	235347
HLC		1707-01	2113-03	2219-07	2330-17	2435-30	244145

Figure 9-56. Winds and Temperatures Aloft Forecast.

wind direction and speed for a flight at 7,500 feet over Hill City (HLC), a good estimate of the wind at 7,500 feet is 190° at 10 knots with a temperature of -2C.

Wind speed between 100 and 199 knots are encoded, so direction and speed can be represented by four digits. This is done by adding 50 to the two-digit wind direction; and subtracting 100 from the velocity. For example, a wind of 270° at 101 knots is coded as 7701 (27 + 50 = 77 for wind direction and 101 – 100 = 0l for wind speed). A code of 9900 indicates light and variable winds (less than five knots). However, wind speeds of 200 knots or more are encoded as 199.

It is important to note that temperatures are not forecast for the 3,000-foot level or for any level within 2,500 feet of the station elevation. Likewise, wind groups are omitted when the level is within 1,500 feet of the station elevation. For example, the station elevation at Denver (DEN) is over 5,000 feet, so the forecast for the lower two levels is omitted.

TRANSCRIBED WEATHER BROADCASTS

A transcribed weather broadcast (TWEB) contains recorded weather information concerning expected sky cover, cloud tops, visibility, weather, and obstructions to vision in a route format. This information is transmitted over selected navigation aids such as very high frequency omni-directional ranges (VORs) and non-directional radio beacons (NDBs). At some locations, the information is only broadcast locally and is limited to items, such as the hourly weather for the transmitting station and up to five adjacent stations, local NOTAM information, the local TAF, and potential hazardous conditions.

When a TWEB is available along a route of flight, it is particularly useful for timely in-flight weather information. At some locations, telephone access to the recording is also available (TEL-TWEB), providing an additional source of preflight information. The telephone numbers for this service are listed in the *A/FD*. A circled “T” inside the communication boxes of selected NDBs and VORs on National Aeronautical Charting Office (NACO) enroute and sectional charts identifies the TWEB availability. In the regions where there has been high utilization of TWEB, the FSS puts the TWEB on a recording called Telephone Information Briefing Service (TIBS). It can be accessed prior to flight by calling 1-800-WX-BRIEF, then choosing TIBS from the menu.

KEY to AERODROME FORECAST (TAF) and AVIATION ROUTINE WEATHER REPORT (METAR) (FRONT)

TAF KPIT 091730Z 091818 15005KT 5SM HZ FEW020 WS010/31022KT
FM 1930 30015G25KT 3SM SHRA OVC015 TEMPO 2022 1/2SM +TSRA OVC008CB
FM0100 27008KT 5SM SHRA BKN020 OVC040 PROB40 0407 1SM -RA BR
FM1015 18005KT 6SM -SHRA OVC020 BECMG 1315 P6SM NSW SKC

METAR KPIT 091955Z COR 22015G25KT 3/4SM R28L/2600FT TSRA OVC010CB 18/16 A2992 RMK SLP045 T01820159

FORECAST	EXPLANATION	REPORT
TAF	Message type : TAF-routine or TAF AMD-amended forecast, METAR-hourly, SPECI-special or TESTM-non-commissioned ASOS report	**METAR**
KPIT	ICAO location indicator	**KPIT**
091730Z	Issuance time: **ALL** times in UTC "Z", 2-digit date, 4-digit time	**091955z**
091818	Valid period: 2-digit date, 2-digit beginning, 2-digit ending times	
	In U.S. **METAR**: CORrected of; or AUTOmated ob for automated report with no human intervention; omitted when observer logs on	**COR**
15005KT	Wind: 3 digit true-north direction , nearest 10 degrees (or VaRiaBle); next 2-3 digits for speed and unit, KT (KMH or MPS); as needed, Gust and maximum speed; 00000KT for calm; for **METAR**, if direction varies 60 degrees or more, Variability appended, e.g. 180V260	**22015G25KT**
5SM	Prevailing visibility; in U.S., Statute Miles & fractions; above 6 miles in **TAF** Plus6SM. (Or, 4-digit minimum visibility in meters and as required, lowest value with direction)	**3/4SM**
	Runway Visual Range: R; 2-digit runway designator Left, Center, or Right as needed; "/", Minus or Plus in U.S., 4-digit value, FeeT in U.S., (usually meters elsewhere); 4-digit value Variability 4-digit value (and tendency Down, Up or No change)	**R28L/2600FT**
HZ	Significant present, forecast and recent weather: see table (on back)	**TSRA**
FEW020	Cloud amount, height and type: Sky Clear 0/8, FEW >0/8-2/8, SCaTtered 3/8-4/8, BroKeN 5/8-7/8, OVerCast 8/8; 3-digit height in hundreds of ft; Towering Cumulus or CumulonimBus in **METAR**; in **TAF**, only CB. Vertical Visibility for obscured sky and height "VV004". More than 1 layer may be reported or forecast. In automated **METAR** reports only, CLeaR for "clear below 12,000 feet"	**OVC 010CB**
	Temperature: degrees Celsius; first 2 digits, temperature "/" last 2 digits, dew-point temperature; Minus for below zero, e.g., M06	**18/16**
	Altimeter setting: indicator and 4 digits; in U.S., A-inches and hundredths; (Q-hectoPascals, e.g. Q1013)	**A2992**

KEY to AERODROME FORECAST (TAF) and AVIATION ROUTINE WEATHER REPORT (METAR) (BACK)

FORECAST	EXPLANATION	REPORT
WS010/31022KT	In U.S. **TAF**, non-convective low-level (≤ 2,000 ft) Wind Shear; 3-digit height (hundreds of ft); "/"; 3-digit wind direction and 2-3 digit wind speed above the indicated height, and unit, KT	
	In **METAR**, ReMarK indicator & remarks. For example: Sea-Level Pressure in hectoPascals & tenths, as shown: 1004.5 hPa; Temp/dew-point in tenths °C, as shown: temp. 18.2°C, dew-point 15.9°C	**RMK SLP045 T01820159**
FM1930	FroM and 2-digit hour and 2-digit minute **beginning** time: indicates significant change. Each FM starts on a new line, indented 5 spaces	
TEMPO 2022	TEMPOrary: changes expected for <1 hour and in total, < half of 2-digit hour **beginning** and 2-digit hour **ending** time period	
PROB40 0407	PROBability and 2-digit percent (30 or 40): probable condition during 2-digit hour **beginning** and 2-digit hour **ending** time period	
BECMG 1315	BECoMinG: change expected during 2-digit hour **beginning** and 2-digit hour **ending** time period	

Table of Significant Present, Forecast and Recent Weather- Grouped in categories and used in the order listed below; or as needed in TAF, No Significant Weather.

QUALIFIER
INTENSITY OR PROXIMITY
'-' Light "no sign" Moderate '+' Heavy
VC Vicinity: but not at aerodrome; in U.S. **METAR**, between 5 and 10SM of the point(s) of observation; in U.S. **TAF**, 5 to 10SM from center of runway complex (elsewhere within 8000m)

DESCRIPTOR

MI	Shallow	BC	Patches	PR	Partial	TS	Thunderstorm
BL	Blowing	SH	Showers	DR	Drifting	FZ	Freezing

WEATHER PHENOMENA

PRECIPITATION

DZ	Drizzle	RA	Rain	SN	Snow	SG	Snow grains
IC	Ice Crystals	PL	Ice Pellets	GR	Hail	GS	Small hail/snow pellets
UP	Unknown precipitation in automated observations						

OBSCURATION

BR	Mist (≥5/8SM)	FG	Fog (<5/8SM)	FU	Smoke	VA	Volcanic ash
SA	Sand	HZ	Haze	PY	Spray	DU	Widespread dust

OTHER

SQ	Squall	SS	Sandstorm	DU	Duststorm	PO	Well developed dust/sand whirls
FC	Funnel cloud	+FC	tornado/waterspout				

-Explanations in parentheses "( )" indicate different worldwide practices.
- Ceiling is not specified; defined as the lowest broken or overcast layer, or the vertical visibility.
- NWS **TAFs** exclude turbulence, icing & temperature forecasts; NWS **METARs** exclude trend forecasts

January 1999 **Department of Transportation**
Aviation Weather Directorate **FEDERAL AVIATION ADMINISTRATION**