2
Atmospheric Properties

Atmospheric properties directly affect the weather. These include temperature, pressure, moisture, and stability. Advection transfers properties horizontally; vertical motion moves a property from one level to another. Vertical motion is a key player in the weather machine. (Abundant moisture, an upward vertical motion producer, and unstable air are the three ingredients required for thunderstorms.) Throughout the chapter we'll put together these concepts and draw practical relationships.

Temperature, pressure, moisture, and elevation determine density. Density plays a significant part in most weather phenomena and affects aircraft performance. Density is weight per unit volume often expressed as "pounds per cubic foot" (lb/ft3) or "grams per cubic meter" (g/m3). We're not really interested in these units, but the fact that atmospheric density varies both horizontally and vertically is vitally important.

Before we continue let's discuss the term "average." Average is a single value (a mean) that represents the middle point of a set of unequal values. In aviation it's often used as a base or standard for calculating aircraft performance—where the "standard value" rarely occurs in nature. In the atmosphere, on average temperature and pressure decreases with height, wind speed increases with height.

The International Standard Atmosphere (ISA) is a hypothetical vertical distribution of atmospheric properties. Figure 2-1 shows temperature on the horizontal axis in degrees Celsius (C), height in feet (black) on the right vertical axis, and pressure in millibars (blue) on the left vertical axis. Temperature decreases to a value of -57°C at approximately 36,000 ft. Above 36,000 ft, in the standard atmosphere, temperature remains constant to about 66,000 ft. The standard lapse rate—decrease of temperature with height—is approximately 2°C per thousand ft. The red line in Fig. 2-1 represents "standard" temperature and pressure with height.

In the International Standard Atmosphere moisture is NOT considered.

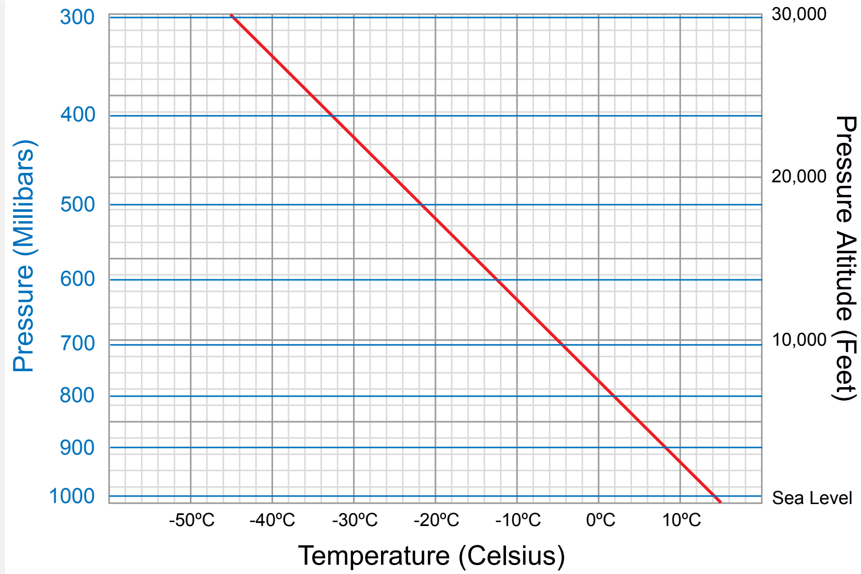


Fig. 2-1. *Since standard conditions rarely exist in nature, the ISA was developed to provide a common reference for atmospheric properties.*

Standard conditions rarely exist in the "real world" and aircraft performance charts are based on standard conditions. Accommodation must be made for a nonstandard environment. Manufacturers sometimes provide an ISA conversion with performance charts for high, standard, and low values of temperatures or simply note performance data based on standard conditions. The aircraft doesn't understand any of this; its performance—or lack there of—is based on the prevailing flight environment. (More on the effects of a nonstandard environment and the application of performance charts in chapter 19, Aircraft Performance.)

Temperature

Both dry air and water vapor are transparent to visible light. The Earth's surface absorbs most of the Sun's energy—not the atmosphere. Radiant energy raises the temperature of land and water surfaces.

During the day the Earth's surface absorbs solar radiation and in turn heats the air near the surface by *conduction*—a process of heat transfer by contact from one medium to another. At night the Earth radiates heat back into space—*radiational cooling*. This process, in turn, cools the air in contact with the surface.

The amount of energy absorbed by the Earth depends on several factors. Due to Sun angle, more energy is absorbed at the equator than the poles; more during the warm season than the cool season; more midday than early morning or late afternoon.

Different surfaces absorb and reflect different amounts of solar radiation. Dense clouds significantly reduce the amount of energy reaching the surface. Snow covered terrain reflects most incoming solar radiation. Land absorbs radiation to a greater degree than water. Different land surfaces absorb different amounts of radiation. Plowed fields absorb more radiation than green pastures, green pastures more than rivers or lakes. These properties have a significant effect on weather and aviation operations.

albedo—The amount of energy reflected by a particuar surface. A surface's albedo is important in the interpretation of visual satellite imagery.

As a result, land becomes warmer during the day, while the temperature of water surfaces remain relatively constant. At night the land radiates heat, while water areas remain relatively unchanged. Large bodies of water tend to retain heat much longer than land areas. This results in moderate temperatures along coastal areas and why deep lakes do not freeze in the cool season.

Water vapor is transparent to incoming solar radiation, but opaque—appears solid—to outgoing terrestrial radiation. In dry, desert areas terrestrial radiation cools the land rapidly after sunset, while humid areas remain relatively warm.

During the day clouds reflect incoming solar radiation. At night clouds absorb nearly all terrestrial radiation and reflect it back to the surface. As a result, temperatures remain relatively cool on cloudy days and relatively warm on cloudy nights.

Diurnal temperature range is the Earth's daily range in temperature. The Earth receives its greatest amount of solar radiation at noon (Sun time) and the least heating at sunset and sunrise. Why doesn't maximum temperature occur at noon? Surface air temperature is also affected by the amount of reflected energy. At noon, the Earth is receiving its greatest heat, but it still is not warm enough to radiate as much energy as it's receiving. Surface air temperature continues to warm. Shortly after noon the Earth gets still warmer but begins to receive less solar radiation. Finally, incoming solar radiation exactly balances outgoing terrestrial radiation—the time of maximum temperature—typically just before midafternoon.

Radiation fog often forms and is most dense just after sunrise.

At night the surface receives no solar radiation but continues to cool. Just after sunrise, solar radiation begins again, but at a very low rate due to low Sun angle. Very little

The international standard for temperature is Celsius; named for its inventor, Swedish astronomer Anders Celsius (1701-1744). He established the centigrade (now Celsius) system; where 100 degrees was the freezing point of water and 0 its boiling point. Famed scientist Carl von Linné (Linnaeus) switched the order several years later. The Fahrenheit scale, with 32 degrees as the freezing point and 212 the boiling point, was developed by German physicist Daniel Gabriel Fahrenheit (1686-1736).

How much does the Earth's atmosphere weigh? It is estimated to weigh about five million billion tons!

The pressure unit of a "bar" was first introduced by Vilhelm Bjerknes—who developed the polar front theory—in 1910. He knew average sea level pressure is close to one bar. One standard atmosphere is not 1 bar, but rather 1.0132 bars (1013.2 mb). One newton/meter^2 is the same as one pascal; thus millibars and hectopascals are interchangeable.

heating occurs while the surface continues to cool. Not long after sunrise, solar radiation balances terrestrial radiation and begins to warm—the time of minimum temperature.

Note

> Winds and temperatures aloft forecasts have always used the Celsius temperature scale. Since July 1, 1996, with the adoption of the METAR (Aviation Routine Weather Report) international weather code, surface temperatures for aviation in the United States, as well as the rest of the world, are reported in Celsius.

From Fig. 2-1, standard temperature at sea level is 15°C (Celsius). This is nothing more than an average. Actual temperature for any location is rarely standard; its purpose is to provide a common reference.

Pressure

Pressure is force per unit area. For example, tires are inflated to a specified pressure. Units are typically described as pounds per square inch (lb/in2). The atmosphere exerts pressure. At sea level atmospheric pressure is approximate 14.7 lb/in2. (We don't directly experience this because our bodies exert an opposite and equal force. However, we do experience pressure changes in our ears, sinus cavities, and digestive track.)

Atmospheric pressure is the sum of all the air molecules above a specific point. This can be illustrated by an imaginary column of bricks. There are ten bricks in the column, each weigh one pound. If we weigh the bottom of the stack the scale reads 10 pounds. However, if we weigh the stack at the fifth brick, the scale reads five pounds; at the first brick, one pound. The atmosphere behaves in much the same way.

We commonly relate atmospheric pressure to inches of mercury (in Hg) or pressure in millibars (mb). However, inches of mercury are not a direct expression of force per unit area. The international unit of atmospheric pressure is the hectopascal (hPa), which is equivalent to the millibar. (So, what's a bar? It's a unit of pressure—100,000 newtons/square meter—you'll hear no more reference to a "bar" from this point on.)

Like temperature, pressure has a standard. At sea level it's 29.92 in Hg, or 1013.2 mb (1013.2 hPa). Guess what? For every level in the atmosphere there is a standard temperature and pressure in the—you know what's coming—standard atmosphere.

In meteorology we often refer to a *constant pressure surface*. Again, refer to Fig. 2-1. Notice that as we go higher in the atmosphere pressure decreases, but not at a uniform rate—illustrated by the "Pressure (Millibars)" scale.

The change in pressure with height is uniform below 700 mb (about 10,000 ft), but higher in the atmosphere pressure decreases at a greater rate with height. This is shown in Fig. 2-1 by an increase in the distance between the constant pressure levels. Why? The atmosphere, a gas, is compressible. That is, the weight of air molecules above compresses—push together—the molecules below. In Fig. 2-1 the pressure at sea level is approximately 1000 mb. Pressure decreases with height, but not at a uniform rate. In fact, half the atmosphere by weight exists below 18,000 ft—the 500 mb level.

In aviation we most often refer to the 850, 700, 500, 300, and 200 mb constant pressure levels. From Fig. 2-1 we see that these constant pressure levels occur at approximately 5000, 10,000, 18,000, 30,000, and 39,000 ft respectively.

The slope of pressure surfaces, caused by horizontal temperature differences, determines approximate wind speed. The stepper the slope the stronger the wind. Slope tends to increase with height, the typical case in the troposphere. Recall the discussion of the jet stream. Typically, the highest winds occur within the jet, the area of greatest temperature difference.

Winds tend to be light or calm in areas of little or no horizontal temperature difference. And, in some cases, winds can decrease with height in the troposphere. This tends to occur within large high pressure areas.

As we fly higher density decreases. The higher we go the fewer molecules above—the air is less dense. When temperature and moisture remain constant: If pressure is higher than standard, density is higher; conversely, when pressure is lower than standard, density is lower.

Why do we measure pressure in inches of mercury? In 1643 Evangelista Torricelli (1608-1647), an Italian, invented an instrument for measuring atmospheric pressure—the mercurial barometer. Mercury was used because it was the heaviest material available that remains liquid at normal temperatures. (If water were used, the column would be 30 feet high!) Sea level pressure balances a column of mercury approximately 30 inches high. Hectopascal is named for Blaise Pascal (1623-1662) a French philosopher and mathematician.

Moisture

If we think of heat as the energy that drives the weather, then moisture—in the form of water vapor—supplies the fuel. Without moisture there would be no clouds or precipitation; no weather as we know it.

moisture ± vertical motion ± stability = weather

Atmosphere moisture—the first factor in the weather equation—occurs in the form of water vapor (a gas), water (a liquid), or ice crystals (a solid). Water vapor is invisible, suspended in the air. The effects of water vapor are an important factor in meteorology and aviation weather. Liquid water or ice crystals make up clouds and precipitation. (Precipitation is any form of water (solid or liquid) that falls to the Earth's surface.)

A parcel of air is a small volume that retains its composition; it does not mix with the surrounding air. (When I first heard the term, it made absolutely no sense whatsoever. But, by the end of the chapter you'll have a good understanding of the concept.)

A parcel can only accommodate a finite amount of moisture in the form of water vapor. When this amount is reached the air is saturated. Saturation may result in water vapor condensing into a liquid or solid, or deposition—where water changes directly from vapor into a solid (frost). This is referred to as *Change of Phase*. (More about Change of Phase later in the section.)

Air does not technically HOLD WATER VAPOR. This analogy helps describe the atmosphere in common (nonacademic) terms.

Temperature is one factor in determining the amount of water vapor the air can hold. Warm air can hold more water vapor than cool air. Any event that cools the air or adds moisture decreases its capacity to hold water vapor. Conversely, any event that warms the air or removes moisture increases its capacity to hold water vapor.

The amount of water vapor the air can hold is affected through the processes of conduction, expansion or compression, and evaporation or condensation. Air can be cooled by contact with a cooler surface or warmed by contact with a warmer surface. As air rises it cools due to expansion; when air descends it warms by compression. Evaporation adds water vapor as air moves over a moist surface or precipitation falls from a higher layer. Moisture is removed from the air through the process of condensation.

The amount of water vapor in the atmosphere is measured in several ways, usually relative humidity and dewpoint.

Relative humidity is the ratio, expressed as a percentage, of the water vapor present in the air compared to the maximum amount of water vapor the air could hold at its present temperature. *Dewpoint* is the temperature to which air must be cooled, water vapor remaining constant, to become saturated.

In the International Standard Atmosphere relative humidity is 0%.

Refer to Fig. 2-2. Each parcel contains the same amount of moisture. However, the warmer samples have the capacity to hold additional moisture in the form of water vapor. Because of this the relative humidity of the warmer samples are lower than the cooler samples. All have a dewpoint of 5 degrees. Therefore, the first sample would have to be cooled by 20 degrees and the second by 10 degrees to reach saturation.

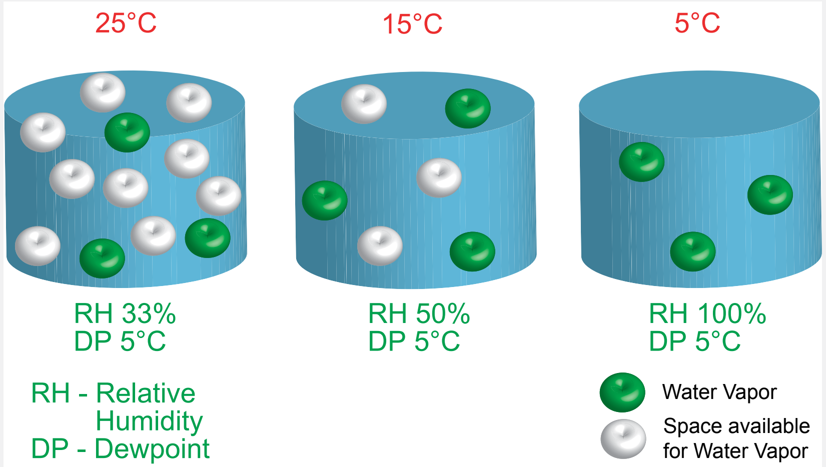


Fig. 2-2. *The warmer the air the greater its capacity to hold moisture in the form of water vapor.*

When the air can no longer hold additional water vapor relative humidity is 100 percent, temperature and dewpoint are equal—the air is saturated. Should any more water vapor be added or the air cooled to a lower temperature, condensation will normally occur in the form of visible moisture.

Energy, in the form of heat, is required to change water from a solid (ice) to liquid and from liquid to a gas (water vapor) and vice versa. The amount of heat exchanged (absorbed or released) is called *latent heat*. This process is illustrated in Fig. 2-3.

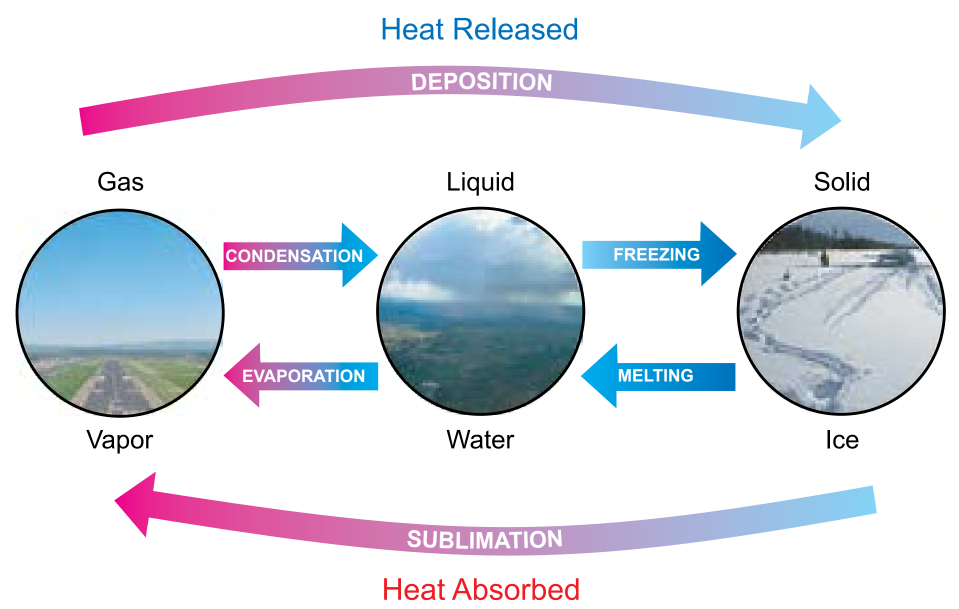


Fig. 2-3. *Water vapor normally condenses into a liquid, but it can deposit directly into a solid.*

We care because? When water vapor condenses (changes from a gas to a liquid or solid) heat is transferred, or released, to the environment. This is a primary source of energy in the weather machine—the latent heat of condensation. This process has a direct effect on atmospheric stability.

Can water vapor change to ice without going through the liquid stage? Yes. And ice can evaporate, bypassing the liquid stage, through the process of deposition and sublimation (Fig. 2-3). In the process of frost formation, water vapor in the atmosphere transforms (deposition) directly into a solid—ice. An aircraft with structural ice will lose ice once out of the icing environment (sublimation), even though the temperature remains below freezing.

Melting, freezing, evaporation, condensation, and deposition and sublimation are important factors in the weather machine. We'll continue to refer to this process in subsequent chapters.

In aviation we often see the term “freezing level.” This is a misnomer. Ice melts at 0°C, but liquid water can exist at temperatures below freezing! Structural icing results from *supercooled* liquid cloud and water droplets.

Another important concept is the heat capacity of water vapor. We have already mentioned that water vapor is transparent to solar radiation, but largely opaque to terrestrial radiation. That is, water vapor in the air absorbs terrestrial radiation and converts it to heat, raising the temperature of the air. Water vapor absorbs outgoing terrestrial radiation much as heat is trapped in a greenhouse—the *greenhouse effect*.

Moisture is a factor in air density. The higher the moisture content of the air the lower its density. Why? Water molecules weigh less than air molecules. This is not a major factor, however. What we need to remember is when its humid, air density is less than when conditions are dry.

"Click" *Moisture* to view animation.

Vertical Motion

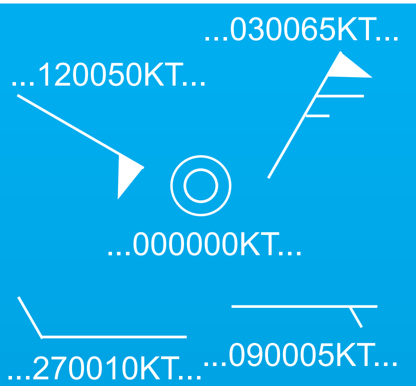
Vertical motion is the second factor in the weather equation. Clouds, weather, and aviation weather hazards are closely related to vertical motion. Vertical motion can be produced, enhanced, or diminished by one or all the processes in Table 2-1.

Table 2-1. *Vertical Motion Producers*

Upward Vertical Motion	Downward Vertical Motion
convergence	divergence
lows	highs
troughs	ridges
fronts	
drylines	
positive vorticity	negative vorticity
upslope	downslope
convection	
(surface) warm-air advection	(surface) cold-air advection
(aloft) cold-air advection	(aloft) warm-air advection

Upward vertical motion is cumulative. A surface front supported by an upper level trough may produce severe weather; a front moving through an upper ridge may result in little, if any, weather.

Downward vertical motion tends to produce clear skies and smooth flying conditions. No absolutes! Exceptions occur when downward vertical motion traps fog, haze, and smoke near the surface. Widespread areas of IFR can develop within a few thousand feet of the surface. A turbulence hazards can develop in areas of strong pressure gradients and downslope winds.



As shown in Fig. 2-4, wind is plotted as the "true" direction "from" which the wind is blowing represented by the shaft (or arrow). Speed is shown using half-barbs (5 kts), barbs (10 kts), and flags (50 kts). A calm wind is indicated by a circle around the station.

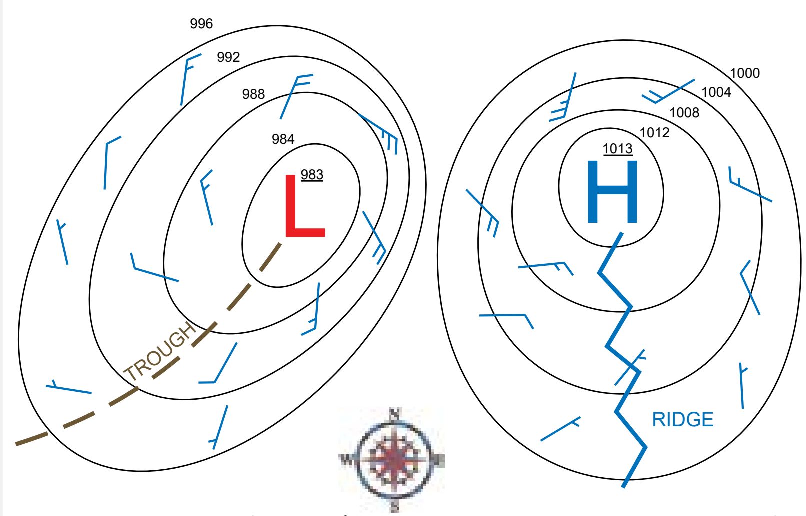


Fig. 2-4. *Near the surface convergence compresses the air; divergence causes an expansion of the air.*

Convergence refers to an in-flow or squeezing of the air. In Fig. 2-4 isobars narrow on the east side of the low. When air flow into an area is greater than the out-flow, convergence occurs. Since the ground prevents the air from going down, there is only one way for it to go—up. Near the surface convergence occurs at the center of low pressure areas and along low pressure troughs. (A trough is shown as a dashed brown line.) When moisture is adequate and convergence strong enough, condensation occurs.

On weather maps isobars are labeled in millibars at four millibar intervals. In Fig. 2-4 the LOW (L) has a central pressure of 983 mb; the HIGH (H) has a central pressure of 1013 mb.

Divergence is indicated by a widening of the isobars. In Fig. 2-4 divergence takes place on the southeast side of the high. When air flow out of an area is greater than the in-flow, the air diverges. Downward motion (subsidence) causes the air to spread out at the surface. Surface divergence occurs at the center of high pressure areas and along high pressure ridges. (A ridge is shown as a zigzag blue line. Ridges are rarely depicted on NWS charts.) Divergence is a drying, stabilizing process.

In the general circulation large areas have gradually ascending or descending air. Large bodies of cool air undercut less dense warm air; large areas of warm air may override retreating cooler air forcing the warm air aloft.

Air masses of different properties—temperature, humidity, and wind—don't tend to mix. These density differences may change rapidly over short distances. This zone of rapid change separating air masses is a *frontal zone*, more commonly referred to as a front. In these zones the less dense air is lifted, resulting in vertical motion. The type of weather is dependent on the moisture available and the stability of the atmosphere.

A *dryline*, or temperature-dewpoint front, marks the boundary between moist, warm air from the Gulf of Mexico and dry, hot air from the southwestern United States and northern Mexico. Drylines usually develop in New Mexico, Oklahoma, and Texas during the warm season. Since the moist air from the Gulf is less dense than the dry, hot desert air, it's forced aloft. If the air mass is unstable, thunderstorms develop along the boundary.

Anything that spins has *vorticity*, which includes the Earth. Vorticity is a mathematical term that refers to the tendency of the air to spin; the faster it spins, the greater its vorticity. A parcel of air that spins counterclockwise (cyclonic) has *positive vorticity*; a parcel that spins clockwise (anticyclonic) has *negative vorticity*. Cyclonic spin produces upward vertical motion, anticyclonic spin downward vertical motion.

Air moving through a ridge, spinning clockwise, gains anticyclonic relative vorticity. Air moving through a trough, spinning counterclockwise, gains cyclonic relative vorticity. This results in downward vertical motion in ridge-to-trough flow—indicated by the red and yellow shading in Fig. 2-5, and upward vertical motion in trough-to-ridge flow—indicated by the blue shading.

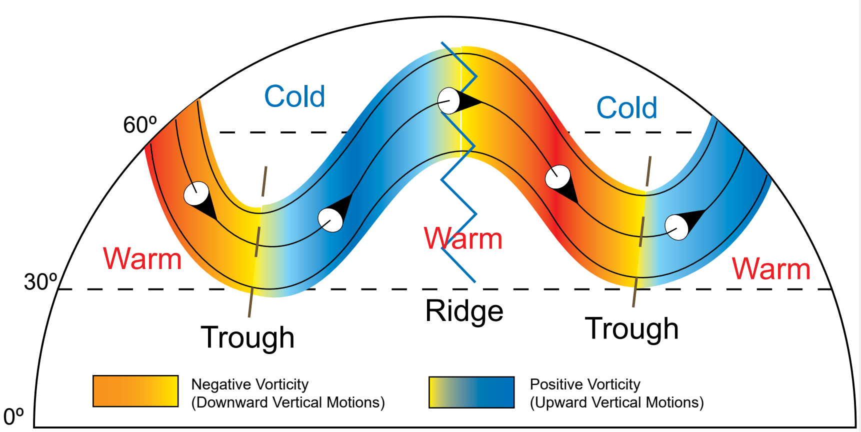


Fig. 2-5. *There tends to be downward vertical motion in ridge-to-trough flow and upward vertical motion in trough-to-ridge flow.*

Orographic describes the effects of terrain, especially mountains. An orographic effect can be upslope or downslope. As air moves upslope it expands due to the decrease in pressure and cools. Relative humidity increases and with sufficient moisture clouds form. As air moves downslope it's compressed and warms. Relative humidity decreases and any clouds tend to dissipate.

Convection transports atmospheric properties vertically. Near the surface convection results from surface heating—a major vertical motion producer.

From the surface to about 10,000 ft, *warm-air advection* produces upward vertical motion and *cold-air advection* downward vertical motion. As warmer, less dense air moves into an area it will tend to rise. Warm-air advection causes surface pressures to fall. This results in convergence and upward vertical motion. Warm-air advection destabilizes the lower atmosphere. When cooler, denser air moves into an area it tends to sink. Cold-air advection causes surface pressures to rise. This results in divergence and downward vertical motion. Cold-air advection tends to stabilize the weather at and near the surface.

Above the 500 mb level (aloft) the opposite occurs. Cold-air advection destabilizes conditions and warm-air advection stabilizes the atmosphere. Cold-air advection above the 500 mb level decreases the lapse rate. This enhances any convective activity that might develop. Conversely, warm-air advection aloft stabilizes the atmosphere by increasing the lapse rate, retarding any convection.

"Click" *Vertical Motion* to view animation.

Stability

Stability—or the lack thereof—significantly affects our flying activities. Stability is a major player in the weather machine and the third factor in the weather equation. As a parcel moves vertically it does not tend to mix with the surrounding air and behaves in accordance with universal gas laws. How the parcel reacts depends on its relative temperature to the surrounding air.

Stability is the capacity of the air to remain in equilibrium—its ability to resist displacement. If an external lifting mechanism moves a parcel of air (vertically—up or down), then stops one of several things that will occur depending on the temperature of the parcel and the surrounding air.

- absolute stability: The parcel tends to return to its original position.
- absolute instability: The parcel continues to rise without any additional lifting force.
- conditional instability: The parcel initially resists upward displacement, then spontaneously continues upward.
- neutral stability: The parcel remains at the level where the external force ceases.

Lapse rate is a change of temperature with height. The lapse rate of dry air is 3°C per 1000 ft. That is, the rate at which unsaturated air cools when forced upward—the *dry-adiabatic lapse rate*. Conversely, when unsaturated air descends it warms at 3°C per 1000 ft. What about saturated air? The moist, or *saturated-adiabatic lapse rate* varies from between one and two degrees Celsius per 1000 ft.

A parcel is *absolutely stable* when it resists vertical displacement whether saturated or unsaturated. If the existing lapse rate is warmer than the lifted parcel it is absolutely stable. When the parcel is forced upward it cools at the dry-adiabatic rate when unsaturated and then the saturated-adiabatic rate. Since the parcel is always cooler (denser) than the surrounding air, it wants to sink. Thus, unless it is the result of an external force, vertical motion is impossible.

Both isothermal layers and inversions strongly resist lifting and, in many cases, put a "cap" or "lid" on weather. The ultimate example is the tropopause, which restricts almost all weather to the troposphere.

Air is *absolutely unstable* when vertical displacement of a parcel within the layer is spontaneous, whether saturated or unsaturated. The temperature of the lifted parcel is always warmer (less dense) than the surrounding air. The cooler denser air surrounding the parcel forces it upward.

Conditional instability refers to the structure of a column of air which will produce free convection—spontaneous upward motion—of a parcel upon saturation. The lifted parcel is stable to the point where saturation occurs. Below the *Lifted Condensation Level* (LCL) the parcel exhibits absolute stability. Upon saturation upward displacement becomes spontaneous. This is the *Level of Free Convection* (LFC) at which a stable parcel, lifted at the dry-adiabatic rate, becomes saturated. Now warmer than the surrounding air the parcel continues to rise in the unstable environment. The Level of Free Convection (LFC) is the defining feature of a conditionally unstable vertical column of air.

When a parcel is displaced and remains at rest—even when the lifting force ceases—the layer exhibits *neutral stability*. For a parcel of unsaturated air to be neutrally stable, its lapse rate must equal the dry-adiabatic rate; for a parcel of saturated air, its lapse rate must equal the saturated-adiabatic rate.

Dry air in low levels and high moisture content aloft favor stability. High moisture content in low levels and dry air aloft favor instability.

At this point the concepts of stability most likely are "clear as mud." They certainly were to me when I was first introduced to the subject. In the following discussion graphically describes the effects of stability, which should help "clear" things up.

To understand the adiabatic process, it's helpful to use the concept of a parcel of air. Recall, a parcel is a small volume that retains its composition; it doesn't tend to mix with the surrounding air. It responds to all meteorological processes; it can expand or be compressed; thus, temperature can change. Its moisture remains constant as long as the parcel remains unsaturated.

As a parcel is forced upward pressure decreases and the parcel expands—volume increases. Expansion requires energy to keep the molecules apart. The energy comes from the gas itself in the form of a loss, or decrease, in temperature. (Recall the discussion of Change of Phase Fig. 2-3.) If the parcel were returned to its starting point, the reverse occurs. As pressure increases, temperature increases and volume decreases—the adiabatic process. The mathematical computation of the process is complex and cumbersome. However, we can illustrate the process graphically using the adiabatic chart in Fig. 2-6.

Like the standard atmosphere (Fig. 2-1), the adiabatic chart shows temperature on the horizontal axis and pressure on the vertical (millibars on the left, pressure altitude on the right). The solid, red diagonal lines represent *dry adiabats*. Long dashed, green lines are *mixing ratio*—a measurement of water vapor content. Short dashed, blue lines signify *saturated adiabats*.

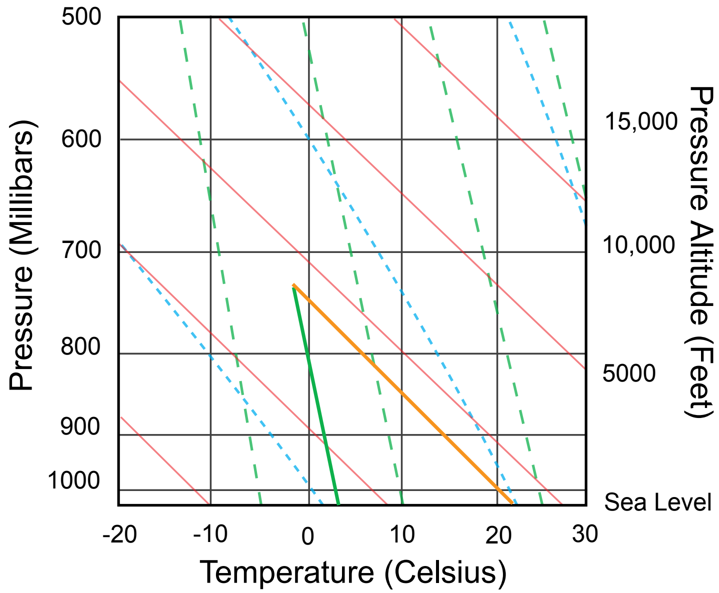


Fig. 2-6. *An unsaturated parcel cools at the rate of 3°C per 1000 ft, along the dry adiabats; its dewpoint decreases along the mixing ratio.*

Take a sea level parcel with a temperature of 22°C and a dewpoint of 3°C. If we lift the parcel it cools at three degrees per 1000 ft, along the dry adiabats (red) lines. (The solid orange line in Fig. 2-6.) As the parcel rises the dewpoint decreases along the mixing ratio (dashed green) lines. (The solid green line in Fig. 2-6.) When a parcel is lifted, the actual amount of water vapor does not change. However, its relative humidity increases, and the dewpoint temperature changes, but at a much slower rate than the decrease in temperature.

Why does its temperature-dewpoint spread decrease and humidity increase as unsaturated air rises? The temperature of a rising parcel decreases due to expansion. The dewpoint, however, remains approximately the same because water vapor remains constant. Since the temperature-dewpoint spread of rising air decreases, then the air's relative humidity must increase. Conversely, the temperature of descending air increases while the dewpoint remains approximately constant. Thus, the temperature-dewpoint *spread* of sinking air increases and relative humidity decreases.

Where the dry adiabat and mixing ratio lines intersect the temperature and dewpoint are equal—the parcel has reached saturation. In Fig. 2-6 this occurs at 8000 ft. This intersection is the Lifted Condensation Level—relative humidity 100%.

Here's where we again apply the discussion of Change of Phase. Condensation is a warming process—heat is released. This adds heat to the air and partially offsets adiabatic cooling. If we continue to lift the parcel above saturation, it absorbs the heat and no longer cools at the dry—adiabatic rate. The parcel now cools at the slower

“Click” *Stability* to view animation.

saturated—adiabatic rate, along the saturated adiabat (short dashed, blue) lines. The solid blue line in Fig. 2-7. Lift the parcel to 15,000 ft and its temperature will decrease to -13°C. The temperature and dewpoint remain the same—relative humidity 100%.

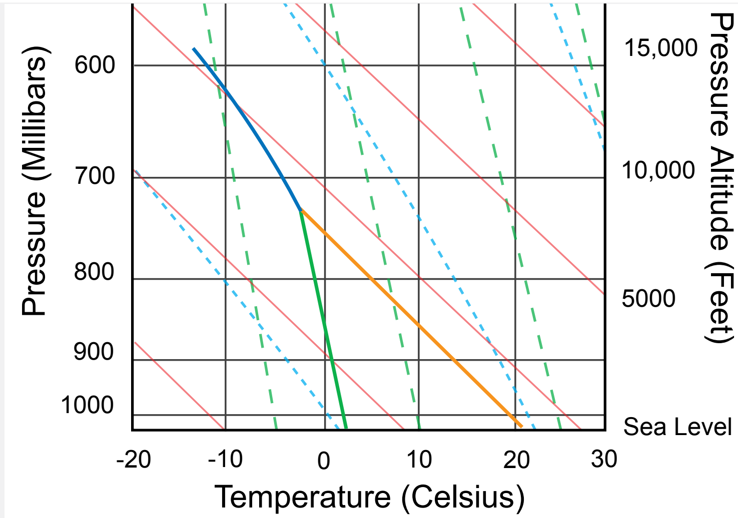


Fig. 2-7. *Upon saturation the parcel continues to rise at the saturated–adiabatic lapse rate.*

As saturated air rises its water vapor content decreases. This occurs because the lowering temperature reduces its capacity to hold water vapor. Where does the water vapor go? It condenses or deposits from a gas into either liquid or solid form, depending on the temperature of the air. Visible moisture condenses in the form of clouds and precipitation.

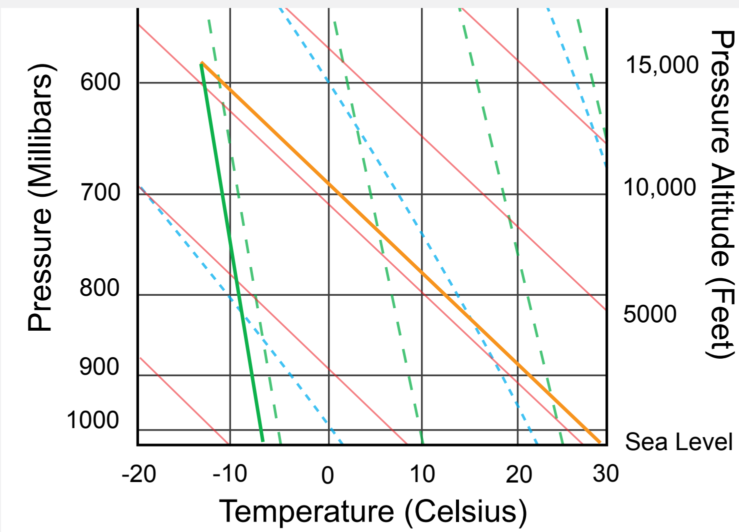


Fig. 2-8. *When air sinks, but contains no visible moisture, it warms at the dry adiabatic rate.*

When saturated air sinks, but contains no visible moisture, it warms at the dry adiabatic rate; illustrated in Fig. 2-8. We'll assume the parcel is saturated but contains no visible moisture. The air warms at 3°C per 1000 ft, the dry—adiabatic lapse rate; represented by the solid orange line in Fig. 2-8. At sea level its temperature will be 30°C. Moisture follows the mixing ratio (dashed green) lines; represented by the solid green line in Fig. 2-8. At sea level its dewpoint is -7°C. The air is hotand dry. This process explains the hot, dry Santa Ana winds of Southern California and the Chinook that develops along the eastern slopes of the Rockies.

Alistair B. Fraser, Professor of Meteorology, Pennsylvania State University has developed a web site called “Bad Clouds” (personal.ems.psu.edu/~fraser/Bad/BadClouds.html). The site provides a “scientific” explanation of many of the “oversimplifications” and “generalizations” used to describe aviation weather to the non-meteorologist.

“Be very, very careful what you put into that head, because you will never, ever get it out.”

Thomas Cardinal Wolsey
(1471-1530)