Plan IFR Around Thunderstorms

Find them through forecasting skills so you don't have to stare them down in person. Predictions science gets better every year—that's the good news.

by Scott C. Dennstaedt

The bad news is that forecasting the time and location of thunderstorm initiation is incredibly difficult if not fundamentally impossible. Most of what you might have learned about thunderstorm forecasting is probably worthless, not to mention all the useless banter you hear from your local television weather personality. It's often littered with bloody misconceptions and in some cases, outright poppycock.

The good news is that I got your attention. It's obvious that the FAA requires an instrument-rated pilot to have a rudimentary knowledge base when thunderstorms are a flight risk. Being able to regurgitate the three stages of a thunderstorm, for example, is as useful as the Washington ADIZ is to pilots.

The FAA has good intentions and wants you to know that bad things can happen in and around thunderstorms. Any pilot that has taken a long cross-country flight in the spring, summer, or fall knows that the preflight planning process requires the pilot become a bit more weather savvy.

Atmospheric Motion

When someone mentions atmospheric motion, the first thing that pops out of our weather bag of knowledge is the wind. But reach into that bag a little deeper, and the general west-to-east movement of air, better known as the jet stream, might also emerge.

You can easily measure or approximate this horizontal motion at the surface and aloft using anemometers and weather balloons (rawinsondes), respectively. More importantly, meteorologists have been able to model this kind of large-scale motion to generate a fairly accurate forecast.

On the other hand, pilots rarely concern themselves with atmospheric motion that occurs in the vertical component. While vertical motion of the atmosphere can be associated with a large-scale synoptic feature such as an area of low pressure, most of the adverse weather faced in the form of thunderstorms is due to a much smaller scale vertical motion enabled by buoyancy and sustained through convection.

Clouds, precipitation and thunderstorms are all important manifestations of the vertical component of the atmosphere. The trouble is that you can't easily measure it; instead, vertical motion must be inferred by using the science of numerical weather prediction with the help of super-computers (see the July 2003 *Trust This Model Of Imperfection*). Even with all the computing power in the world, modeling individual updrafts to forecast the time and location of thunderstorm initiation is at the moment not possible.

> *"Most of what you might have learned about thunderstorm forecasting is probably worthless."*

A Few Definitions

Convection is a term that meteorologists tend to throw around a lot in reference to thunderstorms. Convection alone does not equate to a thunderstorm; it describes the transport of heat in the vertical and is largely responsible for the continued growth of thunderstorms.

Closely associated with convection, buoyancy can be thought of as the force that enables movement of air in the vertical. Updrafts in thunderstorm clouds are due to positive buoyancy, and more buoyant air equates to stronger updrafts. Downdrafts in a thunderstorm are characterized by negative buoyancy and contribute to most of the wind shear experienced at the surface.

An air mass is a large body of air that has homogenous characteristics of both temperature and moisture. Air masses are named according to the source region of their birth. For example, an air mass that originates in Canada will be referred to as a continental-polar air mass (dry and cold).

A frontal boundary is the separation of two air masses. A frontal boundary is also a convergence zone usually characterized by a large thermal gradient, as well as a change in pressure, humidity and always includes a wind shift.

Advection is the horizontal transport of heat and/or moisture by the wind and is *not* associated with buoyancy. Normally, meteorologists speak about cold-air, warm-air, or moisture advection. Advection can also occur in the vertical component, but I'll limit this discussion to horizontal advection.

Meteorologically speaking, there are three golden rules to remember: The atmosphere is always attempting to become and remain stabilized; solar heating creates atmospheric instability; and vertical motion is a process that attempts to alleviate the instability produced by the sun.

Keeping in mind these three golden rules, there are three basic ingredients before a thunderstorm can develop: Instability, moisture, and a lifting source. If any one of these three ingredients is missing, the probability of convective activity developing is much smaller.

Instability

When you worked on getting that private certificate, it was burned into your brain forever that the average atmospheric lapse rate (change of temperature with altitude) is 2 degrees Celsius for every 1000 feet gain in altitude.

Since warm air rises and cold air falls, it would appear that the atmosphere is always in a naturally unstable state with cold air existing over warm air. Even given this seemingly unstable situation, the atmosphere is normally hydrostatically balanced due to the weight (pressure) of the air above.

Therefore, the first goal in thunderstorm forecasting is to predict when there is enough *force* in the atmosphere to overcome this basic hydrostatic balancing act. The second and more difficult feat is to determine when and where this will likely happen and how long it will last.

As heating or warm-air advection takes place at the surface, this warmer air near the surface may gain enough positive buoyancy to begin to ascend. As this warm (and unsaturated) air rises it will *always* expand and cool. Unsaturated rising air cools at a constant lapse rate of 3 degrees C per 1000 feet. This is known as the dry adiabatic lapse rate and only applies to *unsaturated* air.

Note that the dry adiabatic lapse rate is *greater* than the standard lapse rate. As a result, rising unsaturated air generally finds itself in a warmer and more stable environment. That's why it takes some lifting source such as a cold or warm front for air to continue to rise and develop into a thunderstorm.

Moisture

Moisture is another key element for thunderstorm initiation and persistence. Assuming this unsaturated air continues to rise, it will eventually reach saturation. At the point of saturation (temperature and dew point are equal), the air rises at a lapse rate that is not constant like the dry adiabatic lapse rate, but varies with temperature. This is known as the moist adiabatic lapse rate. Since the moist adiabatic lapse rate varies with temperature, a lapse rate of 1.5 to 2.0 degrees C per 1000 feet is commonly used.

Ah, now the lapse rate of rising saturated air is less than the standard atmospheric rate making for an unstable scenario. Rising air will likely find itself in a cooler, and therefore, unstable environment. This point of saturation is known as the lifted condensation level (LCL). The bases of the towering cumulus or thunderstorms are likely to be found just above the LCL.

The added release of latent heat in a saturated updraft slows down the rate of cooling from the dry adiabatic lapse rate to the moist adiabatic lapse rate. Latent heat is the heat that was stored when evaporation took place near the surface. This release of heat adds more buoyancy and continued growth of the thunderstorm's updrafts.

Even several days prior to your flight, you can assess just how unstable the atmosphere is by looking at various model-forecasted instability indices such as the lifted index, Showalter index, K-index and convective available potential energy (CAPE). While these indices won't tell you the exact location and time of thunderstorm initiation, they will give you an indication of the magnitude of the instability that may exist along your planned route of flight.

Lifting Source

Frontal systems are typically the most notable lifting source. Any frontal system that includes cold, occluded, warm, and stationary components can provide the necessary vertical forcing. Additionally, orographic lifting due to air rising up and over mountains can also provide the necessary vertical motion to enable convection. Often you can see the birth of mountain-triggered thunderstorms on the visible satellite image.

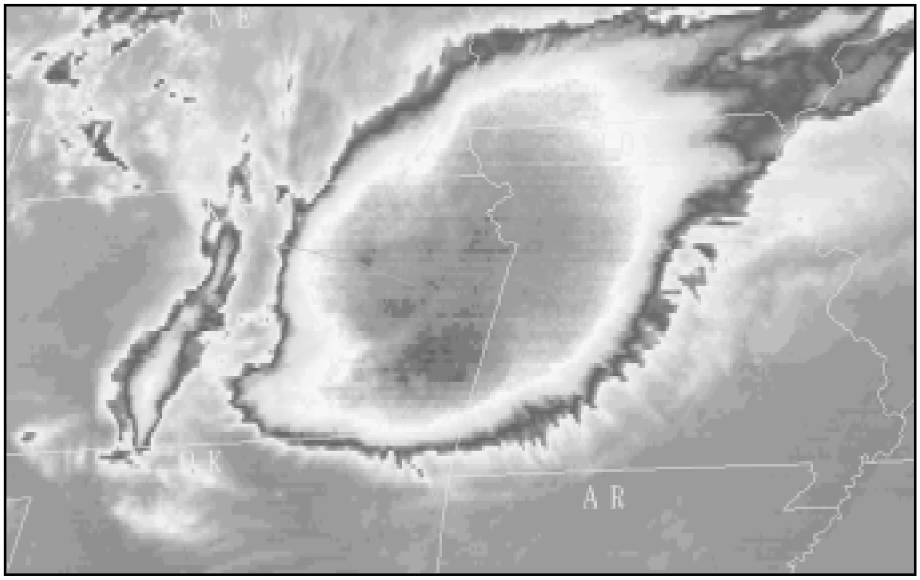
Outflow boundaries, sea breeze fronts, and upper air dynamics can also provide enough lifting to initiate thunderstorm development in an unstable atmosphere.

Thunderstorms in the mid-latitudes can be organized in one of three basic ways: Linear, complexes or banding. There is also a fourth case where thunderstorm initiation may be contained entirely within an air mass and therefore organization may or may not be as apparent. More about this later.

Linear

The most common form of thunderstorms we experience consists of a line of thunderstorm cells. Normally, a line of thunderstorms occurs along

Above: *Stay visual in a convective environment. Compare what you see outside the cockpit with on-board weather systems such as a Stormscope.*



Above: *The Mesoscale Convective Complex's (MCC) signature circular cloud shield is easily identified on this enhanced infrared satellite image.*

a strong thermal and moisture gradient between two air masses. When one air mass moves into another, a line of thunderstorms may develop, grow, and persist. Lines are most closely tied to cold or occluded fronts and dry lines, but may exist along a warm or stationary front as well.

The term squall line or instability line has also been associated with a line of intense thunderstorms ahead of a cold front. A squall line thunderstorm is not particularly different than any other thunderstorm except that it has a characteristic strong gusty wind (at least 16 knots) that is sustained for at least two minutes. Another criterion to be met is that the squally winds need to occur at two or more locations along the line.

Squall lines develop along outflow boundaries typically a couple hundred miles ahead of an intense cold front. These boundaries are an effective surface-based lifting mechanism for thunderstorm initiation. As the line of convection continues or dies away, it may lay out the outflow boundary for the next day's round of thunderstorms.

The next grouping of thunderstorms has been given the name mesoscale convective system (MCS), or its big brother, the mesoscale convective complex (MCC). Meteorologists only recently described this category of thunderstorm organization in the early 1980s, so don't feel bad if you haven't heard of them.

It's easy to distinguish an MCS from a typical line of thunderstorms by looking at a satellite image. They have a characteristic signature that can be seen on the enhanced infrared satellite imagery as a large and near-circular cloud-top shield that can grow to be the size of the state of Wyoming.

An MCS normally begins as a number of isolated thunderstorm cells forms in the late afternoon. By late evening, the thunderstorm's anvil cloud-tops merge creating the signature circular cloud shield you see on the enhanced infrared satellite imagery. This cloud shield masks what can be seen as an arced line of returns on radar imagery.

MCSs are nocturnal and normally persist into the early morning hours and sometimes can persist for as long as 24 hours. Complexes are typically not fast moving and can become nearly stationary. They can produce torrential rains, flash flooding, and hail with little or no movement. They rarely produce tornadoes; however, mature MCSs can produce severe windstorms called derechos. Crescent-shaped radar echoes are often observed with a derecho. These convective complexes can occur just about anywhere in the US, but tend to form more frequently in the lee of the Rocky Mountains. An MCC was thought to be the cause of the Great Johnstown Flood in Pennsylvania in 1889.

Banding

Thunderstorms that occur with tropical storms and hurricanes are not associated with a separation of air masses. Instead, these thunderstorms are organized in bands around the tropical system's eye wall and move outward from the eye wall. Besides the heavy rains, these storms also can produce small tornadoes.

Unorganized

You may have heard the terms air-mass thunderstorm, popcorn thunderstorm, or pop-up thunderstorm. As the terms suggest, do these thunderstorms develop in some random fashion? Not exactly.

According to research meteorologist Dr. Charles Doswell, thunderstorms develop at a particular time and place for a reason, even though it's often difficult to the point of being impossible to diagnose those reasons with enough accuracy to be able to forecast thunderstorm initiation time and location. There's a tendency to label a thunderstorm as either air mass or frontal (i.e., those that form along a strong thermal gradient).

As explained above, fronts provide an adequate lifting mechanism to develop convection, whereas other thunderstorms develop within broad areas of more or less homogeneous characteristics (air masses). It also is often taken to imply that the thunderstorms develop more or less randomly in the air mass, as opposed to the organization provided by the front.

Dr. Doswell believes that many thunderstorms develop outside of surface frontal zones (i.e., synoptic-scale fronts). Moreover, he believes the development of thunderstorms is *never* random; they develop in particular places at particular times for reasons that we may not be able to observe and/or understand, but it is absurd to think that thunderstorms develop, in effect, for no reason.

Back In The Cockpit

Circumnavigating thunderstorms is not a wise choice without some kind of weather-avoidance equipment such as WxWorx or Anywhere Weather. While some aircraft are equipped to fly over these beasts, many are stuck with flying around or between them. If you do have some kind of reliable weather-avoidance equipment such as on-board radar, Stormscope, or Nexrad, the best strategy is to fly high and stay visual (this is especially difficult to do after the sun goes down). The reason to fly high is to be able to remain above the haze layer that *frequently* exists in an inversion-capped atmosphere. If you are flying below this layer, you may not be able to see the full extent of the cumulus field that may be starting to penetrate the capped atmosphere.

What altitude is high enough? The higher the better is always the best answer. It's always better to be looking down at the cumulus field than trying to fight your way through it. The beginning of the haze layer varies but typically occurs below 10,000 feet AGL. If you become familiar with forecast temperature soundings, you can usually estimate where this haze layer might be lurking. Of course, you'll establish its exact location once you become airborne.

As you compare what you see visually with the graphical products that are at your fingertips (which can be 10 minutes or more old), you can plot to remain separated with these boomers. A solid line on the other hand either means a huge diversion or a land-and-wait-it-out situation. And remember, diversions suck fuel out of the tank, so plan accordingly.

Blocking patterns (see September 2003 for more) in the summer tend to produce an environment where isolated or scattered thunderstorms develop and circumnavigation is highly possible. Don't be fooled. An active Stormscope will certainly keep you out of the truly ugly parts of a thunderstorm.

Keep in mind that it doesn't take lightning to represent a metal-bending (or composite-straining for those Cirrus or Lancair pilots) threat. You can have a huge and dangerous growing cell without one strike on your Stormscope. That's why on-board radar or ground-based radar such as Nexrad is so critical. Stay out of the reds and yellows—and God forbid purple—and you'll remain clear of most of the rough stuff. Most.

Unlike icing conditions that can shut down entire sections of the country for long periods of time for us non-certified-into-known-icing folks, thunderstorms are a little more forgiving. Planning your flying activity in the early morning hours is still one of the absolute best practices. From a daily perspective, thunderstorms are more likely to be active between the hours of 2 pm and 9 pm local due to the daytime heating that supplies the instability in the atmosphere.

This is not to say that thunderstorms (even severe ones) won't happen outside of this convective window. You still must be cognizant of the synoptic picture and the forecast. A persistent MCS or strong cold front can produce a thunderstorm at 8 AM in the dead of winter.

So, even though you're operating IFR in thunderstorm season, a little awareness of how these monsters live will make for more go than no-go. And that's always good news.

Scott Dennstaedt is a meteorologist, IFR *contributing editor, and Cirrus Standardized Instructor. Contact him at: scott@chesavtraining.com.*

Forecast Guidance

There are a plethora of weather products at your fingertips just prior to your departure. Products such as Nexrad, convective SIGMETs, severe weather watches, area forecasts, terminal forecasts and Center weather advisories are extremely helpful in making that final go/no-go decision.

However, what products should you use if you are a day or two away from your planned departure? After all, if you have a flexible schedule, wouldn't it make sense to fly on a different day if a threat of significant thunderstorms is present on your planned day of departure?

The convective outlook from the Storm Prediction Center (SPC) is a good starting point. One of the drawbacks is that the convective outlook is valid for a 24-hour period and provides a broad-brush forecast. The text that goes along with them may drop some hints as to when thunderstorm outbreaks are likely.

One of my favorite charts is the 850-500 mb average relative humidity and lifted index chart. This chart is output by forecasting models four times a day out to 3.5 days for the Eta (Greek letter) computer forecasting model. Any area that has a negative lifted index and is in an area of 70 percent or greater relative humidity is an area to watch carefully. Moreover, a lifted index of -4 or less (more negative) is consistent with severe thunderstorms.

In addition to the lifted-index chart, the convective available potential energy (CAPE) chart will tell you about how much potential energy is available for updraft strength. Values above 1000 J/kg in the presence of a lifting source indicate the potential for thunderstorm development. CAPE values above 2500 J/kg are indicative of severe thunderstorms. ***—SD***