Flightline STUDIOS

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Thunderstorms & Weather Radar.

How a thunderstorm actually forms, what's happening inside it at each stage, how to read reflectivity on a radar screen, and why the picture on your display is older than it looks.

Written by pilots, for people learning to fly.
Flightline Studios

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CHAPTER 01

Why Thunderstorms Matter More to Pilots

A thunderstorm packs more hazard into one contained volume of air than almost any other weather phenomenon a pilot will encounter: severe turbulence, hail, lightning, sudden wind shear, and icing, all inside the same few miles of sky.

None of those hazards individually is unique to thunderstorms. Turbulence exists without them, icing exists without them, strong wind exists without them. What makes a thunderstorm different is concentration. All of it shows up at once, in a small area, and it can develop faster than a pilot's planning cycle accounts for. A cell that didn't exist on the briefing you got two hours before departure can be fully mature by the time you're airborne.

> **KEY IDEA**
>
> Respecting a thunderstorm isn't about fearing rain or a bumpy ride. It's about recognizing that the storm concentrates several independently dangerous hazards into one place, and that the most violent of them, the internal wind shear, often isn't visible from outside the cloud at all.

Why general aviation carries more of the risk

A jet with onboard weather radar, predictive wind shear detection, and a service ceiling well above 40,000 feet has real tools for dealing with convective weather, and altitude options a piston single simply doesn't have. Most general aviation aircraft carry none of that hardware, rely on datalink imagery that's inherently several minutes old, and can't outclimb a cell that's still building. The same storm that a transport-category crew treats as a routine deviation can be a genuine emergency for a piston GA aircraft caught underneath it.

This guide walks through how a thunderstorm forms and evolves, what's actually happening inside it stage by stage, how to read it on radar, and where radar itself falls short.

CHAPTER 02

How a Thunderstorm Actually Forms

Every thunderstorm needs the same three ingredients, and removing any one of them prevents the storm from forming or sustains it from continuing.

- **Moisture.** Water vapor in the lower atmosphere, the fuel that condenses into cloud and eventually falls as precipitation.
- **Instability.** Air that, once it starts rising, keeps accelerating upward on its own because it stays warmer than the surrounding air at each altitude. Unstable air is what turns an ordinary cloud into a towering one.
- **Lift.** Something to start the air rising in the first place: surface heating, a front, a mountain range, or converging winds.

> **KEY IDEA**
>
> All three ingredients need to be present at the same time in the same place. A hot, humid afternoon with no lifting mechanism just produces haze. Strong lift with dry air produces wind, not storms. It's the combination that matters, not any one ingredient in isolation.

Three ways the lift shows up

The moisture and instability tend to be regional, tied to the air mass sitting over an area on a given day. What varies most from storm to storm is where the lift comes from, and that difference is usually enough to sort thunderstorms into three broad categories.

TYPE	SOURCE OF LIFT	TYPICAL BEHAVIOR
Air mass	Daytime surface heating alone	Isolated, short-lived, weakens after sunset as the heating that drove it disappears
Frontal	A cold front wedging under warmer air	Organized into lines, can be widespread and severe, moves with the front
Orographic	Terrain forcing air upward over rising ground	Tied to mountains and high terrain, often repeats in the same locations afternoon after afternoon

> **TIP**
>
> Air mass storms are the ones most likely to catch a pilot off guard precisely because they don't need a front or a mountain range to form, just a hot afternoon and enough moisture. A clear morning briefing can still turn into a building cumulus field by mid-afternoon.

Once those three conditions align, the storm develops through three distinct stages, each with its own internal wind pattern and its own set of hazards. The next three chapters cover them in order.

CHAPTER 03

Stage One: Cumulus

The cumulus, or developing, stage is defined by one thing: a strong, continuous updraft, with no precipitation reaching the ground yet.

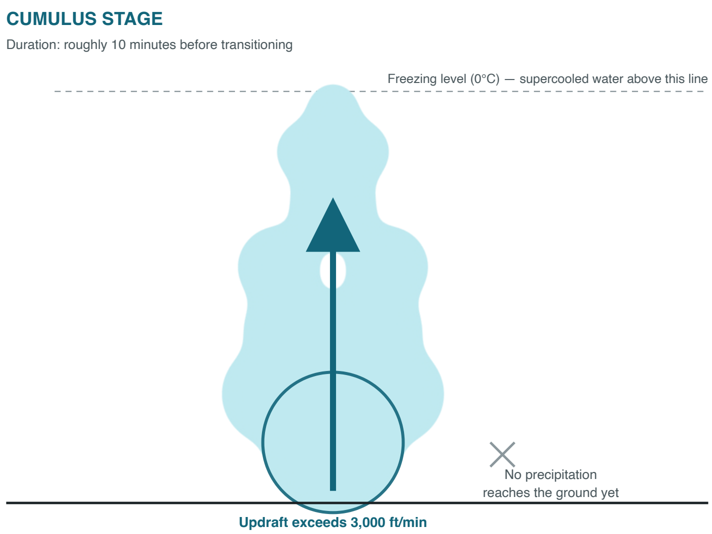

Figure 3.1: The cumulus stage in cross-section. A single continuous updraft builds the tower upward through the freezing level, where supercooled water starts feeding the ice process that eventually produces hail.

What's happening inside

Warm, moist air keeps rising and condensing, building the cloud upward as a towering cumulus. Updraft speeds inside a developing cell can exceed 3,000 feet per minute, strong enough on its own to overwhelm the climb performance of almost any piston aircraft that wanders into it.

> **COMMON MISTAKE**
>
> Assuming a tall, building cumulus cloud with no visible rain underneath is harmless because "nothing's falling yet." The absence of precipitation doesn't mean the absence of a violent updraft. The cumulus stage is quiet from the outside and dangerous on the inside.

This stage typically lasts around ten minutes before transitioning to the mature stage, once precipitation inside the cloud grows heavy enough to fall.

CHAPTER 04

Stage Two: Mature

The mature stage begins the moment precipitation reaches the ground, and it is, without qualification, the most dangerous point in a thunderstorm's life.

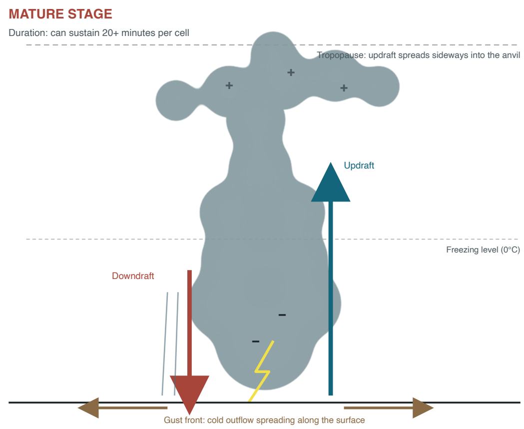

Figure 4.1: The mature stage in cross-section. Updraft and downdraft run side by side in the same cell; charge separation between the cloud's upper and lower halves drives the lightning; the downdraft's outflow spreads out as a gust front once it hits the surface.

Two opposing winds, in the same cell

As precipitation falls, it drags the surrounding air down with it through friction, creating a downdraft that now exists alongside the updraft that's still feeding the storm from below. Having both a strong updraft and a strong downdraft active in close proximity, sometimes within the same few thousand feet of each other, is what generates the storm's most violent turbulence.

This is the stage most associated with the storm's headline hazards: large hail, damaging straight-line winds, flash flooding, frequent lightning, and, in the most severe cells, tornadoes. It's also usually the stage that shows the tallest cloud tops and the heaviest rainfall rates.

> **KEY IDEA**
>
> The mature stage isn't a single moment, it's a sustained condition that can last twenty minutes or more per cell, and multicell storms can regenerate new mature-stage cells one after another, extending the hazard well past what a single cell's life cycle would suggest.

The tallest point of the cloud

As the mature stage peaks, the updraft can push cloud tops well above the tropopause, the boundary where the atmosphere stops cooling with height. When that happens, the rising air spreads out sideways instead of continuing to climb, flattening into the anvil shape that gives a mature thunderstorm its recognizable outline. Occasionally the updraft is strong enough to punch a dome through the top of that anvil, called an overshooting top, a visible sign of an especially intense updraft underneath.

Where the lightning comes from

Inside the mature stage, collisions between ice crystals and soft hail carried up and down by the opposing updraft and downdraft separate electrical charge, negative charge collecting lower in the cloud and positive charge higher up. Once that separation builds enough voltage, it discharges as lightning, either within the cloud, between clouds, or to the ground. Frequent lightning is one of the more reliable outward signs that a cell has entered, or is deep into, its mature stage.

CHAPTER 05

Stage Three: Dissipating

Eventually the downdraft, still fed by falling precipitation, spreads out and cuts off the updraft that was supplying the storm's warm moist air. Without that supply, the storm loses its energy source and begins to weaken.

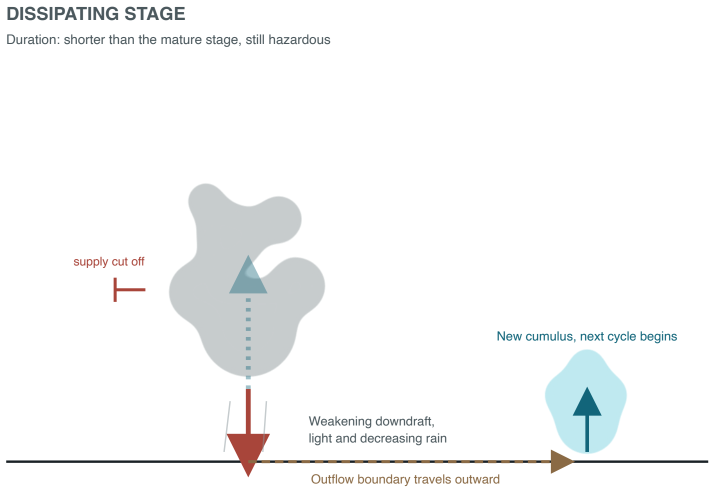

Figure 5.1: The dissipating stage in cross-section. The spreading downdraft has choked off its own updraft supply, but that same outflow boundary is often what triggers the next cell's cumulus stage nearby.

COMMON MISTAKE

Treating a visibly weakening, less towering cell as safe to fly through because "the worst has passed." The downdraft embedded in the remaining precipitation is still capable of producing real turbulence, wind shear, and icing, even as the cell shrinks and the radar return fades.

The dissipating stage is typically shorter than the mature stage and is characterized by decreasing rainfall intensity and a gradual loss of the tall, well-defined cloud structure. But "dissipating" describes the storm's trajectory, not its current safety, and it should be treated with the same respect as the mature stage until it has genuinely broken apart.

A single cell rarely acts alone

In many thunderstorm environments, a dissipating cell's own outflow becomes the trigger for the next one. The gust front spreading out from a weakening cell, covered in more detail in Chapter 8, can lift nearby warm, moist air just enough to start a fresh cumulus stage a few miles away. That's part of why thunderstorm activity in an unstable air mass tends to arrive in waves rather than as a single, isolated event that clears out once it passes.

TIP

Watching a cell dissipate on radar doesn't mean the broader weather situation is improving. Check whether new returns are developing nearby before deciding the area is clear.

CHAPTER 06

Downdrafts, Microbursts, and Wind Shear

A microburst is a small, intensely concentrated downdraft, and it's the single hazard most responsible for thunderstorm-related accidents at low altitude, particularly during takeoff and landing.

Why it's so dangerous close to the ground

When a strong downdraft reaches the surface, it has nowhere to go but outward, spreading horizontally in every direction from the point of impact. An aircraft flying through that outflow experiences a rapidly changing wind: a headwind increasing on the way in, followed by a sudden shift to a tailwind and a downdraft as the aircraft passes through the core. That combination, a sudden loss of headwind and airspeed paired with a downdraft, can exceed the climb or go-around performance of even a large transport aircraft at low altitude.

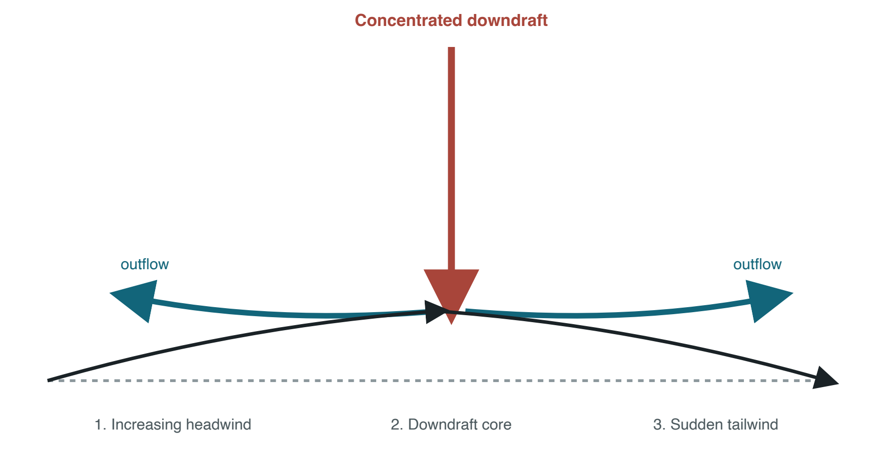

Figure 6.1: An aircraft flying through a microburst sees increasing headwind, then a downdraft and a sudden reversal to tailwind, all within a few seconds.

KEY IDEA

A microburst can occur under a thunderstorm that produces very little visible rain at the surface, sometimes called a "dry microburst," which makes it one of the harder hazards to anticipate visually.

Wind shear more broadly

Not every wind shear encounter near a thunderstorm is a full microburst. Gust fronts, outflow boundaries, and the general turbulent boundary around a storm all produce shear, a rapid change in wind speed or direction over a short distance, that can upset an aircraft's stability without reaching microburst intensity.

TIP

Modern airliners and many corporate jets carry predictive wind shear detection systems, but the vast majority of general aviation aircraft do not. For GA pilots, the real defense against microbursts is distance: staying well clear of any cell capable of producing one, not attempting to fly through or under it.

CHAPTER 07

Hail

Hail forms inside the same updraft that defines a storm's mature stage, and understanding that connection explains both why the strongest storms produce the largest hail and why hail can appear to come from a clear patch of sky.

The updraft is the whole mechanism

A small ice pellet caught in a strong updraft gets carried up through supercooled water droplets, accumulating layer after layer of ice, then eventually falls, gets caught in another updraft surge, and rises again, adding more layers each cycle. The stronger and more sustained the updraft, the more cycles a hailstone survives before it finally becomes heavy enough to fall all the way to the ground. Supercell updrafts, which can exceed 100 miles per hour, are capable of producing the largest hail, sometimes several inches in diameter.

COMMON MISTAKE

Assuming hail only falls directly beneath the darkest part of a cell. Strong upper-level winds can carry hail well outside the visible precipitation core before it falls, sometimes into apparently clear air several miles from the storm itself.

How hail size is reported

Rather than quoting a measurement in inches, hail size is almost always reported and briefed using a familiar object for comparison. The National Weather Service uses a standard reference scale, and the one-inch, quarter-size threshold is the specific point where hail is officially classified as severe.

REPORTED SIZE	DIAMETER
Pea	1/4 inch
Marble	1/2 inch
Penny	3/4 inch
Quarter (severe threshold)	1 inch
Golf ball	1 3/4 inches
Tennis ball	2 1/2 inches
Baseball	2 3/4 inches
Softball	4 inches

On radar, hail is one of the reasons very high reflectivity values, discussed in Chapter 10, are treated as a serious warning rather than just "heavier rain."

CHAPTER 08

Gust Fronts and Outflow Boundaries

A gust front is the leading edge, at ground level, of the cool air spreading out from a thunderstorm's downdraft, and it can arrive well before the storm's visible rain shaft does.

Ahead of the storm, not under it

As rain-cooled air reaches the surface and spreads outward, it pushes the warmer surrounding air up and ahead of it, acting like a small, fast-moving cold front. Pilots on the ground can experience a sudden windshift, a temperature drop, and gusty conditions minutes before the storm itself arrives overhead, and pilots airborne nearby can encounter real turbulence at the boundary even while still in otherwise clear air.

An outflow boundary is the same phenomenon described on a larger scale or after the parent storm has weakened. The boundary can persist and travel well beyond the storm that generated it, and it's also a common trigger for new thunderstorm development where it collides with another boundary or a source of lift.

A visible warning sign

Where humidity is high enough, the lifting along a gust front condenses into a low, horizontal, shelf-shaped cloud, called a shelf cloud, marking the boundary itself. Seeing one approach is a reliable visual cue that a wind shift and a burst of turbulence are only minutes away, well before the parent storm's heavier precipitation arrives.

> **TIP**
>
> A sudden, unexplained windshift or gust on the ramp, with no rain yet visible nearby, is worth treating as a gust front warning rather than a random gust. It often means a storm's outflow has already arrived even though the storm itself is still miles away.

CHAPTER 09

Squall Lines and Supercells

Not every thunderstorm stays a single, isolated cell. Two organized forms in particular change how a pilot has to think about avoidance: the squall line and the supercell.

Squall lines

A squall line is a group of storms arranged in a continuous or near-continuous line, sometimes hundreds of miles long but usually only ten to twenty miles wide. Because the individual cells share a single, continuous gust front, a squall line behaves less like a series of separate obstacles to route around and more like a wall, which is exactly why deviating around the end of a squall line is generally treated as safer than trying to thread a gap between cells within it.

Supercells

A supercell is a long-lived, highly organized storm, often lasting over an hour, built around a rotating, tilted updraft. The tilt is what sets a supercell apart: because the updraft and downdraft are offset from each other rather than stacked in the same column, the storm doesn't choke itself off the way an ordinary cell does, and it can sustain itself far longer. Supercells are responsible for the most extreme thunderstorm hazards: the largest hail, the strongest tornadoes, and the most violent internal turbulence.

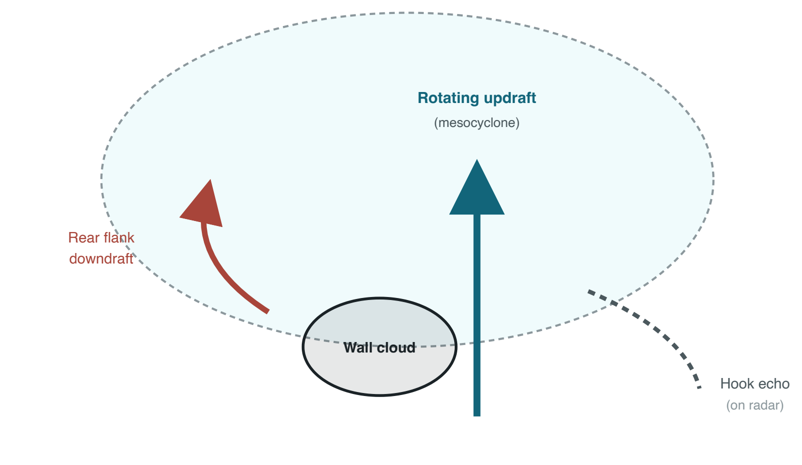

Figure 9.1: A supercell's rotating updraft, or mesocyclone, draws in a rear flank downdraft that wraps precipitation into the hook echo seen on radar.

Reading the structure

The mesocyclone is the rotating updraft itself, detected on Doppler radar as a tight rotational signature even before any precipitation shows it visually. As dry air wraps around the back of that rotation, called the rear flank downdraft, it drags rain and hail with it into a distinctive curl on the reflectivity display, the hook echo, one of the most recognizable and consequential shapes a pilot or forecaster can see on a radar screen. A wall cloud, a lowered, rotating cloud base beneath the updraft, is often the visible, ground-level signature of the same rotation.

> **KEY IDEA**
>
> Both squall lines and supercells are, in effect, upgrades on every hazard already covered in this guide, not new categories of danger. The individual mechanisms, updrafts, downdrafts, hail, gust fronts, are identical. What changes is scale and duration.

CHAPTER 10

Reading Weather Radar

Weather radar measures reflectivity, how much of the radar's transmitted energy bounces back off precipitation, expressed in a logarithmic unit called dBZ. Bigger, denser precipitation particles reflect more energy, which is what turns raw reflectivity into a genuinely useful proxy for storm intensity.

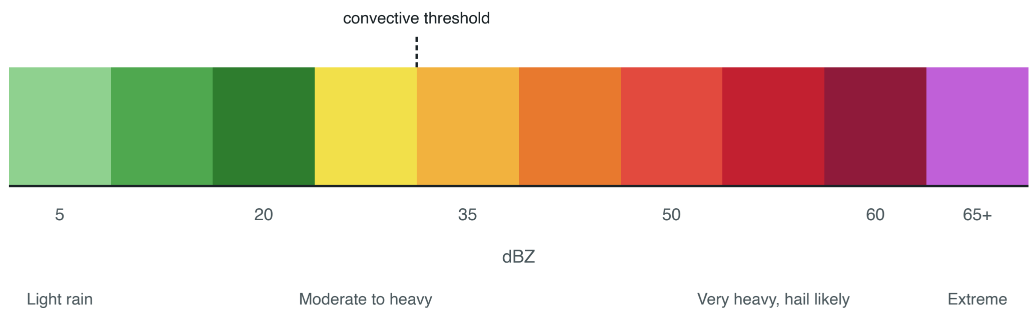

Figure 10.1: The reflectivity color scale most cockpit and ground displays use, from light rain in green to extreme returns in purple.

COLOR	APPROX. DBZ	WHAT IT TYPICALLY MEANS
Light to dark green	5 to 30	Light to moderate rain
Yellow to orange	30 to 50	Moderate to heavy rain, building convection
Red	50 to 60+	Very heavy rain, hail becomes increasingly likely

KEY IDEA

The scale is logarithmic, not linear: 50 dBZ represents roughly a thousand times more reflected energy than 20 dBZ. A jump from yellow to red is a far bigger jump in intensity than the color change alone suggests. Above roughly 40 dBZ is generally treated as the threshold where a cell has become genuinely convective.

What a real cell actually looks like on screen

On an actual display, reflectivity rarely forms a clean shape: an irregular blob banded from a soft green and yellow fringe down to a harder-edged red or purple core where the storm is most intense.

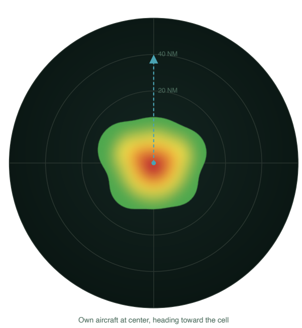

Figure 10.2: A mature cell on a radar scope, banded from a soft green edge down to a hard red-purple core, sitting directly on the aircraft's projected track. Range rings at 20 and 40 NM.

CHAPTER 11

What Radar Can't Tell You

Radar is a genuinely powerful tool, and it's also a tool with real, specific blind spots that every pilot relying on it needs to understand.

Attenuation

As a radar beam passes through heavy precipitation, some of its energy is absorbed and scattered before it ever reaches what's behind that precipitation. The practical result is that a cell sitting directly behind a very heavy, close-in storm can be underrepresented or entirely invisible on the display, a phenomenon sometimes called a "radar shadow." The most dangerous cell on your route can be the one radar is showing you the least about, simply because it's hidden behind a less dangerous one.

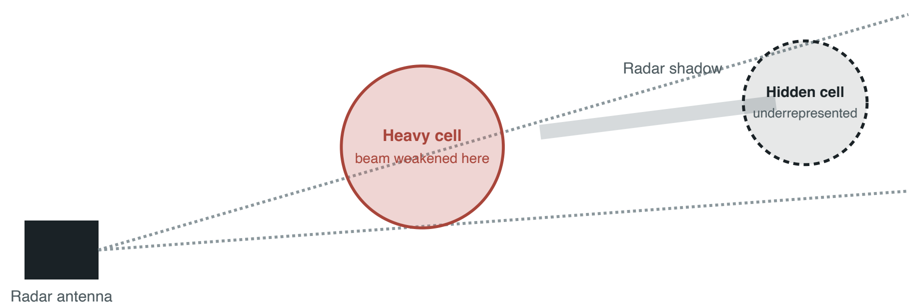

Figure 11.1: A heavy cell can weaken the beam enough that a second cell directly behind it is underrepresented or invisible on the display.

Beam height

Ground-based radar beams don't stay parallel to the earth's curved surface; they spread and rise with distance from the antenna. Far from the radar site, the beam can be scanning well above the altitude where the actual hazard, like low-level wind shear, is occurring, or entirely missing a shallow storm close to the ground.

What it never measures directly

Radar reflectivity is a measurement of precipitation, not of turbulence, lightning, or wind. All three are inferred from reflectivity patterns and historical correlation, not measured directly by a standard reflectivity display.

> **COMMON MISTAKE**
>
> Treating a "clean" gap between two red returns on a display as guaranteed smooth air. Turbulence and wind shear extend beyond the boundary of visible precipitation, often for several miles, in every direction from a strong cell.

CHAPTER 12

Datalink Weather Latency

The single most important thing to understand about cockpit datalink weather, delivered through services like FIS-B, is that the picture on your screen is never showing you the present moment.

How old is old

By the time a NEXRAD mosaic image is processed, assembled, and transmitted to your cockpit display, it is already at least five minutes old, and can be considerably older, up to fifteen or twenty minutes, depending on the specific data path and update cycle involved. The age indicator most datalink displays show is the age of the mosaic image itself, not necessarily a full accounting of every delay in the chain that produced it.

> **KEY IDEA**
>
> A storm cell moving at a typical 30 knots will have physically shifted five to ten miles during an eight-to-twenty-minute latency window. The red return on your screen may already be sitting somewhere your aircraft has no business being, even though the display looks current.

Two different mosaics, two different ages

FIS-B actually delivers two separate NEXRAD products, and they age differently. The regional mosaic, covering the area immediately around the aircraft, updates roughly every five minutes and is rebroadcast about every two and a half minutes. The CONUS mosaic, the wide, coarser view of the entire continental United States, only updates about every fifteen minutes. Zooming out to the CONUS view for a big-picture look at weather ahead can mean looking at a picture three times older than the regional view sitting right next to it.

Strategic tool, not tactical one

The practical implication is that datalink weather is excellent for strategic decisions made well in advance, choosing a general route, picking a direction to deviate, deciding whether to divert, and unsuitable for tactical, close-in maneuvering around individual cells. For that kind of close-range decision, only what you can see out the window, or a real-time onboard weather radar where equipped, is current enough to trust.

> **TIP**
>
> Treat the age shown on a datalink display as a floor, not a precise number. If it says five minutes, assume it could functionally be closer to fifteen once every stage of the pipeline is accounted for, and plan your clearance margin accordingly.

CHAPTER 13

METAR and TAF Thunderstorm Indicators

Thunderstorm activity shows up in a handful of specific codes in both METARs and TAFs, and the distance implied by each one is more precise than it might first appear.

CODE	MEANING
TS	Thunderstorm, reported in the body when lightning is observed within 5 NM of the station
VCTS	Thunderstorm in the vicinity, lightning observed 5 to 10 NM from the station
CB	Cumulonimbus cloud, appended directly to a cloud layer, for example BKN030CB
-TSRA	Thunderstorm with light rain (the intensity symbol modifies the precipitation, not the storm itself)
GR	Hail, often followed by a size note in remarks, for example GR 1 1/4
FC	Funnel cloud; coded +FC once it becomes a tornado or waterspout

Lightning observed 10 to 30 nautical miles from the station is typically noted only in the remarks section, not the main body of the report, which means a station report with no TS or VCTS in the body can still have real thunderstorm activity nearby, just outside the threshold for the headline code.

> **TIP**
>
> Always read the remarks section, not just the body. A clean-looking METAR body can still be sitting a few miles from real storm activity that only shows up as a distant lightning note in the remarks.

A worked example

A METAR body reading **KXYZ 161953Z 21018G27KT 3SM –TSRA BKN025CB OVC040** breaks down piece by piece: wind from 210 degrees at 18 knots, gusting to 27; visibility 3 statute miles; light thunderstorms with rain in progress; a broken cloud layer at 2,500 feet containing cumulonimbus; and an overcast layer at 4,000 feet above that. Three separate details, the gust spread, the reduced visibility, and the CB tag, are all pointing at the same active cell, not three unrelated facts.

CHAPTER 14

Avoidance Strategy

The FAA's Aeronautical Information Manual recommends staying at least 20 nautical miles clear of any thunderstorm showing intense or extreme radar echoes. That number isn't arbitrary caution, it's sized to account for hazards that extend well beyond the visible edge of the storm itself.

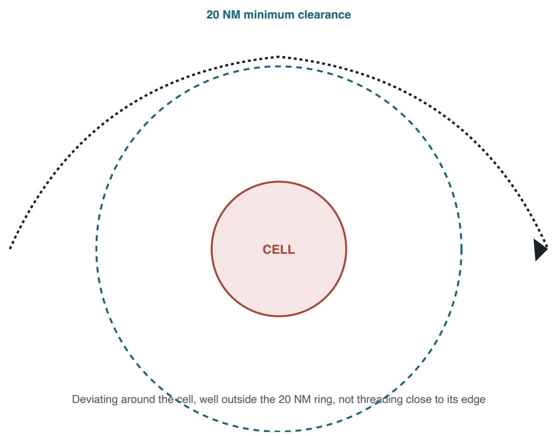

Figure 14.1: A 20 NM avoidance ring around a single cell, and a deviation path that respects it rather than skimming the boundary.

Around, not over, and never under

For a piston GA aircraft, going over a mature thunderstorm is rarely a realistic option; cell tops routinely reach altitudes far beyond normal piston service ceilings. Deviating around a cell, with real lateral margin rather than skimming its edge, is the standard strategy. Flying underneath a storm to stay visual is the option to avoid entirely, since that's exactly where microbursts and the most severe low-altitude wind shear are concentrated.

COMMON MISTAKE

Threading a gap between two cells that looks clear on radar or datalink. Given the latency covered in Chapter 12 and the invisible turbulence that extends beyond the visible precipitation covered in Chapter 11, a gap that looks adequate on a screen may already be closing, or may never have been as clear as it looked.

When in doubt, land and wait

A thunderstorm cell's life cycle is measured in tens of minutes, not hours. Landing short and waiting for a cell to move through or dissipate is very often the fastest way through a widespread convective area, not the slowest, once the time cost of a long, uncertain deviation is weighed honestly.

CHAPTER 15

Common Mistakes and Practical Tips

Most thunderstorm encounters that turn into real trouble share a small set of decision patterns, more than any single piece of missing knowledge.

- **Trusting a datalink picture as real-time.** It's strategic information, aged by minutes, not a live feed.
- **Treating a dissipating cell as finished.** The downdraft can outlast the visible storm structure.
- **Flying under a storm to stay visual.** That's exactly where the worst wind shear concentrates.
- **Threading a gap between cells.** Invisible turbulence and hail extend beyond the visible precipitation edge.
- **Reading only the METAR body, not the remarks.** Nearby lightning can be noted only in remarks.

> **TIP**
>
> The most useful habit isn't a single rule, it's building in decision points well before you're close enough to a cell that your options have narrowed. Deciding whether to deviate, divert, or wait it out is a much easier call fifty miles out than it is at ten.

The next section covers every term from this guide in one place, followed by practice questions covering all fifteen chapters.

Glossary

Air mass thunderstorm
A storm driven by daytime surface heating alone, typically isolated and short-lived.

Frontal thunderstorm
A storm driven by a cold front lifting warmer air, often organized into lines.

Orographic thunderstorm
A storm driven by terrain forcing air upward over rising ground.

Cumulus stage
The first stage of a thunderstorm's life, defined by a strong updraft and no precipitation reaching the ground.

Mature stage
The most dangerous stage, beginning when precipitation reaches the surface; updraft and downdraft coexist.

Dissipating stage
The final stage, as the downdraft cuts off the storm's updraft supply. Still hazardous, not yet safe.

Updraft
Rising air inside a storm, the mechanism that builds the cloud and suspends growing hail.

Downdraft
Sinking air, driven by falling precipitation dragging surrounding air downward.

Microburst
A small, intensely concentrated downdraft capable of producing severe wind shear at low altitude.

Wind shear
A rapid change in wind speed or direction over a short distance.

Gust front
The leading edge, at ground level, of a thunderstorm's rain-cooled outflow air.

Outflow boundary
The broader or longer-lasting boundary formed by a storm's spreading outflow air.

Squall line
A group of storms organized in a continuous line, sharing a single gust front.

Shelf cloud
A low, horizontal cloud marking the leading edge of a gust front, a visible warning sign of an approaching wind shift.

Anvil
The flat, spreading cloud top formed when a storm's updraft hits the tropopause, the boundary where the atmosphere stops cooling with height, and can no longer rise.

Supercell
A long-lived, highly organized storm built around a rotating, tilted updraft.

Mesocyclone
The rotating updraft at the core of a supercell, detectable on Doppler radar before precipitation shows it visually.

Rear flank downdraft
A surge of dry air wrapping around the back of a supercell's rotation, dragging precipitation into a hook echo.

Hook echo
A hook-shaped extension in radar reflectivity caused by the rear flank downdraft wrapping around a mesocyclone, often paired with a rotating wall cloud visible from the ground.

Reflectivity
The amount of radar energy reflected back by precipitation, measured in dBZ.

dBZ
The logarithmic unit used to measure radar reflectivity.

Attenuation
The weakening of a radar beam as it passes through heavy precipitation, hiding what's behind it in a radar shadow.

NEXRAD
The national network of ground-based Doppler weather radar sites the FAA and NWS use to produce reflectivity imagery.

FIS-B
Flight Information Services-Broadcast, the datalink service that delivers weather, including NEXRAD imagery, to the cockpit.

Regional and CONUS mosaics
The two NEXRAD images delivered via FIS-B: a nearer-range regional view updating roughly every five minutes, and a wider continental view updating only every fifteen.

TS
METAR/TAF code for thunderstorm, used when lightning is observed within 5 NM of the station.

VCTS
METAR/TAF code for thunderstorm in the vicinity, lightning observed 5 to 10 NM from the station.

CB
Cumulonimbus, the cloud type associated with thunderstorms, appended to a cloud layer in a METAR.

GR
METAR code for hail, often followed by a size note in the remarks section.

FC
METAR code for funnel cloud, upgraded to +FC once it becomes a tornado or waterspout.

Practice Questions

Seventeen questions covering everything in this guide. Answers and explanations follow on the next page.

1. The three ingredients required for a thunderstorm to form are:

A. Moisture, instability, and lift
B. Heat, humidity, and wind
C. Pressure, temperature, and altitude
D. Lightning, hail, and rain

2. The cumulus stage of a thunderstorm is characterized by:

A. A strong downdraft and heavy rain
B. A strong updraft with no precipitation reaching the ground yet
C. Hail only, no wind
D. A weakening, dissipating cloud

3. The mature stage begins when:

A. The cloud first becomes visible
B. Precipitation reaches the ground
C. The storm produces its first lightning strike
D. The updraft completely stops

4. The dissipating stage of a thunderstorm should be treated as:

A. Completely safe to fly through
B. Still hazardous, since the downdraft can outlast the visible structure
C. Only dangerous if hail was previously reported
D. Safe once cloud tops drop below 10,000 feet

5. A microburst is best described as:

A. A weak, wide area of sinking air
B. A small, intensely concentrated downdraft
C. A rotating updraft found only in supercells
D. A type of lightning strike

6. A "dry microburst" is dangerous in part because:

A. It only occurs at night
B. It can occur with very little visible rain at the surface
C. It never produces wind shear
D. It only affects aircraft above 10,000 feet

7. Hail grows larger inside a storm primarily because of:

A. Repeated cycling through a strong updraft
B. Cold air at the surface
C. Lightning strikes freezing water droplets
D. Low humidity at cloud base

8. A gust front is:

A. The trailing edge of a storm's rain shaft
B. The leading edge of a storm's rain-cooled outflow at ground level
C. A synonym for a squall line
D. Only found ahead of supercells

9. What makes a supercell different from an ordinary thunderstorm cell?

A. It has a rotating, tilted updraft that keeps the updraft and downdraft separated
B. It never produces hail
C. It only forms over water
D. It has no downdraft at all

10. On a typical radar display, red returns generally correspond to approximately:

A. 5 to 30 dBZ
B. 30 to 50 dBZ
C. 50 to 60+ dBZ
D. Below 5 dBZ

11. The radar reflectivity scale is:

A. Linear, so 50 dBZ is roughly 2.5 times 20 dBZ
B. Logarithmic, so 50 dBZ is roughly 1,000 times 20 dBZ
C. Not comparable between different values
D. Measured in knots, not dBZ

12. Radar attenuation refers to:

A. The beam rising above the storm at long range
B. The weakening of the radar beam as it passes through heavy precipitation, hiding what's behind it
C. A failure of the radar antenna
D. The delay in transmitting radar data to the cockpit

13. A typical NEXRAD image delivered via datalink to the cockpit is:

A. Always perfectly real-time
B. At least several minutes old, sometimes up to fifteen or twenty
C. Delayed only during nighttime hours
D. Updated instantly with no meaningful lag

14. Given typical datalink latency, a storm cell moving at 30 knots may have shifted approximately how far from its displayed position?

A. Less than half a mile
B. 5 to 10 miles
C. 50 miles
D. It never shifts position on the display

15. In a METAR, "VCTS" indicates lightning observed:

A. Within 5 NM of the station
B. 5 to 10 NM from the station
C. Only at the station itself
D. More than 30 NM away

16. The FAA's Aeronautical Information Manual recommends staying clear of an intense thunderstorm echo by at least:

A. 5 nautical miles
B. 10 nautical miles
C. 20 nautical miles
D. 50 nautical miles

17. The safest strategy for a piston GA aircraft encountering a line of thunderstorms is generally to:

A. Climb above the tops
B. Fly beneath the storms to stay visual
C. Deviate well around the cells, or land and wait
D. Thread the narrowest visible gap between two cells

Answer Key

1. A, moisture, instability, and lift. All three must be present together; removing any one prevents storm formation.

2. B, a strong updraft with no precipitation reaching the ground yet. Updraft speeds can exceed 3,000 feet per minute even though the storm looks quiet from outside.

3. B, precipitation reaches the ground. That's the defined transition point into the storm's most dangerous stage.

4. B, still hazardous. The embedded downdraft can persist and remain dangerous even as the visible cloud structure weakens.

5. B, a small, intensely concentrated downdraft. Its concentration is exactly what makes it capable of producing severe wind shear.

6. B, it can occur with very little visible rain at the surface. That makes it one of the hardest hazards to anticipate visually.

7. A, repeated cycling through a strong updraft. Each pass through the updraft adds another layer of ice before the stone finally falls.

8. B, the leading edge of a storm's rain-cooled outflow at ground level. It can arrive well before the storm's visible rain shaft.

9. A, a rotating, tilted updraft that keeps the updraft and downdraft separated. That separation is what lets a supercell sustain itself far longer than an ordinary cell.

10. C, 50 to 60+ dBZ. Very heavy rain, with hail becoming increasingly likely.

11. B, logarithmic, roughly 1,000 times. Which is why a jump from yellow to red represents a much bigger intensity change than the color alone suggests.

12. B, the weakening of the beam through heavy precipitation, hiding what's behind it. Sometimes called a radar shadow.

13. B, at least several minutes old, sometimes up to fifteen or twenty. The displayed age indicator may not capture every stage of delay in the pipeline.

14. B, 5 to 10 miles. A meaningful shift, given how close pilots often try to fly to a cell's displayed edge.

15. B, 5 to 10 NM from the station. Lightning within 5 NM is coded as TS instead; 10 to 30 NM shows up only in the remarks.

16. C, 20 nautical miles. Sized to account for hazards, like invisible turbulence and displaced hail, that extend beyond the visible cell.

17. C, deviate well around the cells, or land and wait. Flying under a line concentrates exactly the low-altitude wind shear risk that's most dangerous, and threading gaps trusts a picture that may already be stale.

Respect the storm, not just the rain.

Every hazard in this guide, the updrafts, the downdrafts, the hail, the wind shear, comes from the same handful of underlying mechanisms. Understanding them is what turns a red blob on a screen into something you can actually reason about and plan around.

This is the third release in an ongoing series of free aviation study material from Flightline Studios. More topics are on the way.

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This guide is intended for educational and training purposes only. It is not a substitute for official FAA publications, an authorized ground school, or qualified flight instruction, and should not be used as a sole source for real-world flight planning, dispatch, or operational decisions.