

PRIVATE PILOT GROUND SCHOOL

MODULE 3-3 — WEATHER THEORY

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FACTS TO REMEMBER

KNOW THESE COLD

- Air pressure is how often and how hard air molecules strike a surface.
Source: NWS JetStream; AWH TC
- Warm air is less dense than cool air: in the open atmosphere, heated molecules move faster and spread farther apart.
Source: NWS JetStream TC
- Air density is determined by pressure, temperature, and humidity.
Source: NWS TC
- Humid air is less dense than dry air — a water molecule weighs less than the nitrogen or oxygen molecule it displaces.
Source: NWS; Dalton/Avogadro TC
- Any one of high, hot, or humid raises density altitude — all three are not required.
Source: TC (misconception #3)
- The atmosphere is about 78 percent nitrogen, 21 percent oxygen, and 1 percent other gases including water vapor.
Source: AWH ch. 2 TC
- Nearly all weather happens in the troposphere, the lowest layer.
Source: AWH TC
- Temperature normally falls with altitude at an average of about 2°C per 1,000 feet — the standard (environmental) lapse rate.
Source: AWH ch. 6 TC
- Rising air cools by expansion with no heat exchange — the adiabatic process that builds every cloud.
Source: NWS "How Clouds Form"; AWH TC
- Sinking air warms by compression, which is why descending air dries out.
Source: NWS; AWH TC
- Dry adiabatic lapse rate: about 3°C per 1,000 feet for unsaturated rising air.
Source: AWH ch. 6 TC
- Saturated rising air cools more slowly (roughly 1.2–3°C per 1,000 feet) because condensation releases latent heat.
Source: AWH TC
- The environmental lapse rate is the measured temperature profile of the actual air — a different quantity from the adiabatic rates a parcel follows.
Source: AWH ch. 13; TC (misconception #2)
- Dewpoint is the temperature air must cool to for saturation — the real moisture number.
Source: NWS La Crosse; AWH TC
- The temperature–dewpoint spread predicts fog, cloud bases, and structural ice before they appear.
Source: AWH ch. 6/12 TC

- In a rising convective parcel the spread closes about 2.5°C per 1,000 feet, so cumulus bases sit near $(\text{spread} \div 2.5) \times 1,000$ feet.

Source: AWH ch. 6/12 TC

- Relative humidity changes with temperature even when moisture does not — dewpoint, not RH, is the measure to plan with.

Source: NWS La Crosse TC (misconception #7)

- Warmer air can contain more water vapor.

Source: NWS TC

- Cloud droplets form when vapor condenses onto condensation nuclei in cooling air.

Source: NWS TC

- Condensation releases latent heat, and that release is the fuel of thunderstorms.

Source: AWH TC

- Freezing rain at your altitude means a warmer-than-freezing layer is above you.

Source: AWH TC

- Frost forms by deposition: on clear, cold nights the surface cools below both freezing and the dewpoint.

Source: AWH ch. 20 TC

- All frost, ice, and snow must be removed from lift surfaces before flight.

Source: AWH ch. 20 TC

- Stability is the atmosphere's resistance to vertical motion — it either enhances or suppresses rising air.

Source: AWH 13.1 TC

- The parcel test: a lifted parcel that stays warmer than its surroundings keeps rising; one that turns cooler sinks back.

Source: NWS Parcel Theory; AWH 13.2 TC

- An inversion — temperature rising with height — marks strongly stable air.

Source: AWH 5.8.3 TC

- Inversions trap haze, smoke, and pollutants; expect smooth air but poor visibility beneath them.

Source: AWH TC

- Stable air signature: smooth, stratiform clouds, steady precipitation, poor visibility.

Source: AWH TC

- Unstable air signature: turbulence, cumuliform clouds, showery precipitation, good visibility.

Source: AWH TC

- A stagnant high-pressure system can mean bad VFR — the inversion under a high traps haze for days.

Source: TC (misconception #6)

- Uneven heating of the Earth's surface is the root driver of all weather.

Source: AWH TC

- Land heats and cools faster than water.

Source: AWH TC

- Sea breeze: daytime flow from the cool water toward the heated land.

Source: AWH TC

- Land breeze: nighttime flow from the cooled land toward the warmer water.

Source: AWH TC

- Clear, calm nights radiate surface heat away, setting up surface inversions and radiation fog.

Source: AWH TC

- Wind is air sliding from high pressure toward low pressure.

Source: NWS Origin of Wind TC

- Coriolis force turns moving air to the right in the Northern Hemisphere.

Source: NWS TC

- Above the friction layer, wind blows roughly parallel to the isobars.

Source: AWH TC

- Surface friction slows the wind and angles it across the isobars toward low pressure.

Source: AWH TC

- Northern Hemisphere circulation: clockwise and outward around highs, counterclockwise and inward around lows.

Source: NWS TC

- Air sinks in highs and dries out; air rises in lows and clouds up.

Source: NWS TC

- Closely spaced isobars mean a steep pressure gradient and strong wind.

Source: AWH TC

- Mountain waves form when strong wind crosses a ridge into stable air on the far side.

Source: AWH 16.2 TC

- Wind shear can occur at any altitude and in any direction — it is not only a thunderstorm product.

Source: AWH ch. 19 TC

- Frontal passage, thunderstorms, inversions, and terrain all produce low-level shear.

Source: AWH TC

- A shear that removes headwind on final costs airspeed and lift at the worst possible time.

Source: AWH TC

- An air mass takes on the temperature and moisture of the region it forms over.

Source: AWH 11 TC

- A front is the boundary zone between two air masses — a zone with depth, not a wall.

Source: AWH 11.3; TC (misconception #10)

- Frontal passage signs: wind shift, temperature change, and a pressure fall then rise.

Source: AWH 11.3 TC

- Cold front: steep and fast — a narrow band of showery, sometimes violent weather, then rapid clearing.

Source: AWH 11.3.2 TC

- Squall lines — solid lines of severe storms — can form ahead of fast cold fronts.

Source: AWH 11.3.2 TC

- Warm front: shallow and slow — widespread layered cloud and steady precipitation arriving far ahead of the surface front.

Source: AWH 11.3 TC

- Ahead of a warm front the clouds lower and thicken in sequence as the front approaches.

Source: PHAK cloud families TC (attribution caveat)

- Winter warm fronts are the freezing-rain factory: rain falls from the warm layer aloft into freezing air below.

Source: AWH TC

- Stationary front: little movement, prolonged weather along the boundary.

Source: AWH 11.3 TC

- Occluded front: a faster cold front overtakes a warm front and lifts it, mixing both fronts' weather.

Source: AWH 11.3.4 TC

- "Nimbo" in a cloud name means it is producing precipitation.

Source: AWH ch. 12 TC

- Cumulus forms read as instability; stratus forms read as stability.

Source: AWH TC

- Towering cumulus signals strong convective turbulence and possible storm development.

Source: AWH TC

- Turbulence has four causes: convective, mechanical, frontal, and wind shear.

Source: AWH ch. 19 TC

- Turbulence intensities are defined terms: light, moderate, severe, extreme.

Source: AWH 19.1 TC

- A thunderstorm needs three ingredients: moisture, instability, and a lifting action.

Source: NWS; AWH 22 TC

- Life cycle: cumulus stage (updrafts), mature stage (precipitation begins, updrafts and downdrafts together), dissipating stage (downdrafts).

Source: AWH 22.3 TC

- The mature stage is the most violent, and surface precipitation marks its start.

Source: AWH 22.3 TC

- Avoid severe storms by at least 20 miles, and do not fly between echoes less than 40 miles apart.

Source: AWH 22.8.2 TC

- Never fly under a thunderstorm or under its anvil.

Source: AWH 22.8.2 TC

- Never fly into a cloud mass containing embedded thunderstorms without airborne radar.

Source: AWH 22.8.2 TC

- A microburst is a small, intense downdraft — descent rates to 6,000 feet per minute.

Source: AWH TC

- Flying through a microburst swings you from headwind to tailwind — a 30-to-90-knot airspeed loss.

Source: AWH TC

- Structural icing needs two things: visible moisture and aircraft surface temperature at or below freezing.

Source: AC 91-74B TC

- Clear ice: large supercooled drops (freezing rain) spread before freezing — heavy, hard, hard to see.

Source: AC 91-74B; AWH TC

- Rime ice: small drops freeze on impact — rough, milky, builds on leading edges.

Source: AC 91-74B; AWH TC

- Freezing rain produces the fastest ice accumulation of any condition.

Source: AWH TC

- Carburetor ice is a warm-day hazard: most likely below about 70°F in humid air, possible up to 100°F — not a freezing-weather problem.

Source: PHAK ch. 7 TC (misconception #8)

- Fog is a cloud at the surface: visibility below 5/8 statute mile.

Source: AWH ch. 18 TC

- Fog rarely forms until the temperature–dewpoint spread closes to about 2°C or less.

Source: AWH TC

- Radiation fog: clear night, light wind, moist air — forms in low spots, burns off after sunrise.

Source: AWH ch. 18 TC

- Advection fog: moist air flowing over a cooler surface — needs wind, can persist for days and move onshore at night.

Source: AWH ch. 18 TC

- Upslope fog: moist air cooled adiabatically as terrain forces it up.

Source: AWH ch. 18 TC

- Precipitation-induced (frontal) fog forms when rain saturates the cold air beneath a front.

Source: AWH ch. 18 TC

- Smoke, dust, and blowing obscurations cut visibility fastest in stable air that holds them near the surface.

Source: AWH ch. 21 TC

- Never fly through volcanic ash — it destroys engines and abrades windscreens; avoid by wide margins.

Source: AWH TC

GOING DEEPER

- Humidity is the weakest of the three density levers: fully saturated warm air is only about 0.5 to 1 percent lighter than dry air.

Source: TC (physics-precision pass)

- The cloud-base estimator works for convective cumulus only — it fails for stratus and frontal decks.

Source: TC (accuracy caveat)

- Frost matters because it is sandpaper on the wing: up to about 30 percent lift loss and 40 percent drag rise.

Source: AWH TC

- Stability is judged by comparing the environmental lapse rate to the adiabatic rates — the answer almost no one gives by the numbers.

Source: AWH ch. 13; TC (DPE gouge)

- Moisture destabilizes: because saturated air cools slower as it rises, moist air turns unstable more easily.

Source: AWH 13.3 TC

- Conditional instability: air that is stable while dry becomes unstable once lifted to saturation.

Source: AWH 13.3.4 TC

- The level of free convection is the height above which a lifted parcel rises on its own — the key to elevated and embedded storms.

Source: AWH 13.6.3 TC

- Wind veers (shifts clockwise) and strengthens as you climb out of the friction layer.

Source: NWS mechanism TC

- The rotor zone under mountain wave crests carries potentially severe-to-extreme wind shear and turbulence.

Source: AWH 16.2.5 TC

- Lenticular and rotor clouds mark a wave, but a dry wave gives no visual warning at all.

Source: AWH 16.2 TC

- Low-level wind shear is defined as 10 knots or more per 100 feet in a layer more than 200 feet thick, within 2,000 feet of the surface.

Source: AWH 19.2.4.1 TC

- Warm-front occlusions are the embedded-thunderstorm factory: storms hide inside stratiform decks.

Source: AWH 11.3.4 TC

- Clouds are classified by height families; the AWH uses three levels while the PHAK keeps a fourth

vertical-development group — a real two-book difference.

Source: AWH ch. 12; PHAK TC

– "Severe" turbulence means large, abrupt changes and the aircraft momentarily out of control — report it with that word only when it was.

Source: AWH 19.1 TC

– Clear air turbulence rides near the jet stream and arrives with no cloud to warn you.

Source: AWH TC

– A single cell runs about 30 minutes, and its hazards peak at the end of the mature stage.

Source: AWH 22.3 TC

– Hail can fall in clear air beneath and beside the anvil.

Source: AWH 22 TC

– Storm tops at or above 35,000 feet are extremely hazardous.

Source: AWH 22.8.2 TC

– Circumnavigate any area with storms covering more than half the ground.

Source: AWH 22.8.2 TC

– Microbursts last 5 to 15 minutes; virga and blowing dust rings are the visible clues.

Source: AWH TC

– Most icing lives between 0 and -20°C; half of all reports fall between -8 and -12°C; icing is rare below -40°C.

Source: AWH TC

– Icing intensities are defined terms, and severe icing requires immediate exit by regulation.

Source: AC 91-74B TC

– Tailplane icing: extending flaps can trigger a tail stall — know the aircraft's guidance before configuring in ice.

Source: AC 91-74B TC

– Wind above about 15 knots lifts advection fog into a low stratus deck instead of clearing it.

Source: AWH ch. 18 TC

– Steam fog: cold air over warm water, with low-level turbulence and icing potential.

Source: AWH ch. 18 TC

– Mist (BR) is the same physics as fog with visibility 5/8 mile or more.

Source: AWH TC

– Haze creates the slant-visibility trap: looking down it seems clear; looking ahead into it, the horizon and traffic disappear.

Source: AWH ch. 21 TC

– A sounding (Skew-T) draws ideas 3 and 4 as two lines: where temperature and dewpoint pinch together is cloud; the temperature line's slope is the lapse rate.

Source: NWS JetStream (sounding pass) TC

– On a sounding, the temperature line crossing 0°C marks the freezing level; where it warms with height is an inversion.

Source: NWS JetStream TC