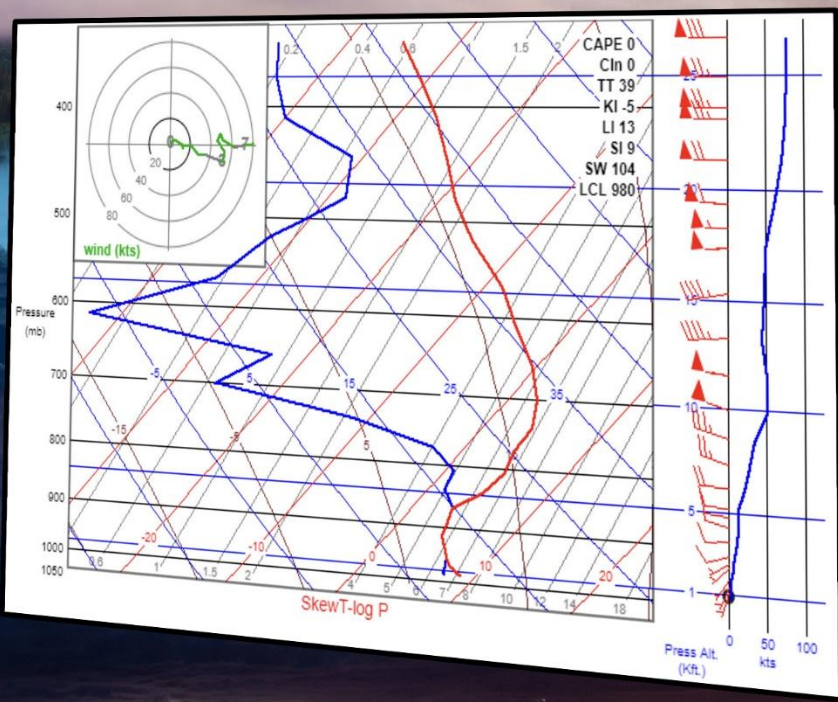
Weather Essentials for Pilots

The Skew-T Edition



AvWxWorkshops, INC

Scott Dennstaedt Ph.D.

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"The Skew-T log (p) diagram is the best kept secret in aviation if you know how to unlock its plentiful secrets. Learn the basic principles and concepts of weather by learning how to interpret the Skew-T diagram."

- Dr. Scott Dennstaedt

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The Skew-T Edition

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1-Why the Skew-T?

When flying any piston-powered airplane, is there a need to have advanced training about managing your engine? After all, the "handbook" gives the proper settings for throttle and mixture. Full stop, right? Not exactly. Any pilot that has gone through a detailed engine management course taught by an expert knows there are many reasons to dig deeper. There's not only a financial advantage to running your engine(s) properly, but there's a safety component as well that may have been absent during your primary training. The goal of such training is not to impart a massive amount of knowledge to become an airframe and powerplant (A&P) mechanic, but to extend your superficial knowledge of engine management topics so you make better decisions that have a lasting payoff in the end. So why should weather be any different?

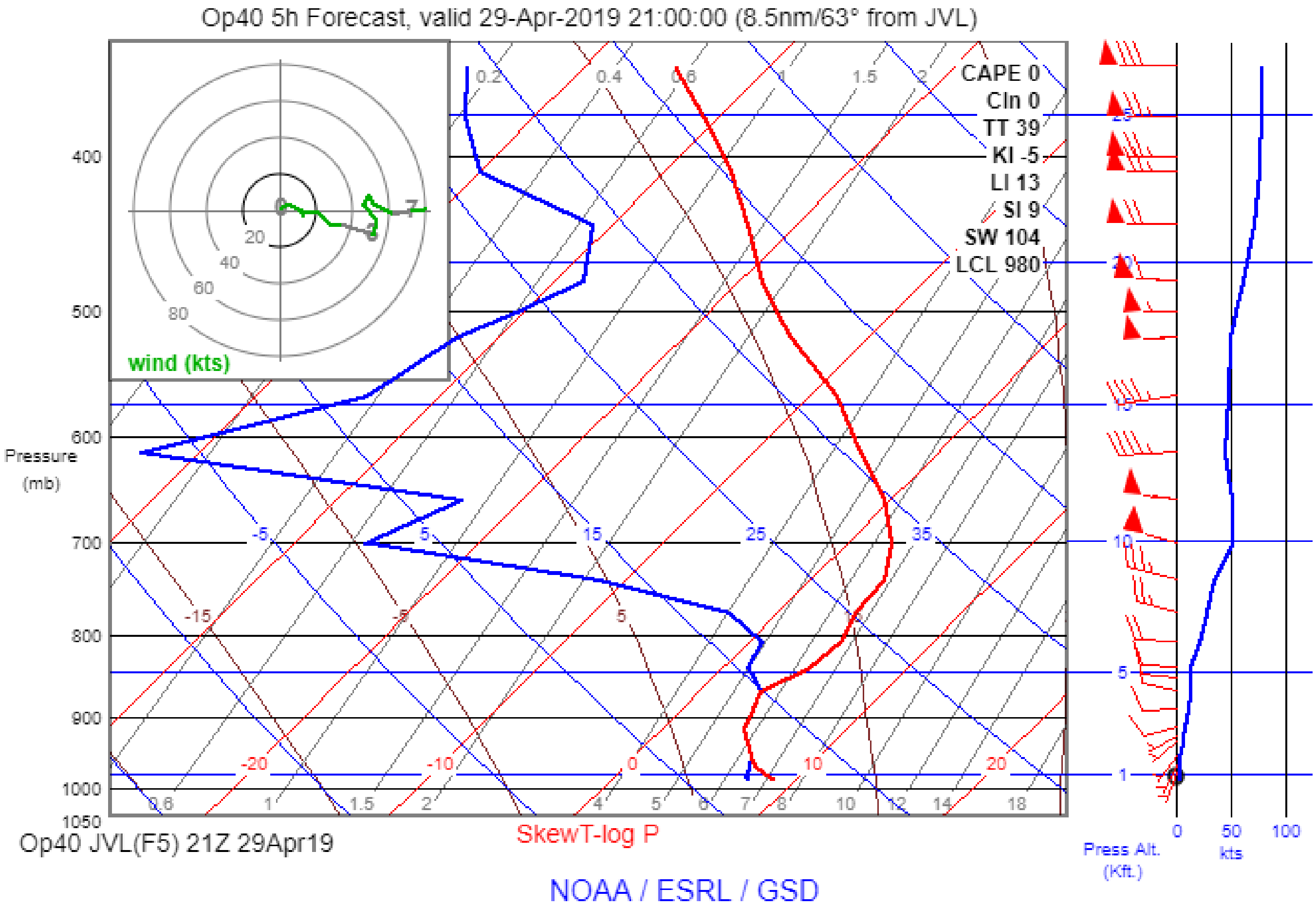

Fig. 1-1: *Temperature, dewpoint temperature and wind plotted as a function of pressure on a Skew-T log (p) diagram.*

There's no question that weather is the single biggest physical factor affecting your flying activity. More importantly, weather is listed as the primary cause of nearly 35 percent of general aviation accidents. In this light, Weather Essentials for Pilots, runs the gamut of aviation weather topics including the ins and outs of the most critical weather guidance you need to utilize when planning any cross country flight. As an added bonus, it also provides the most comprehensive primer available on how to properly use the Skew-T log (p) diagram as supplemental weather guidance. **Why the Skew-T?**

In a nutshell, the Skew-T log (p) diagram like the example shown in Fig. 1-1 is a great tool to learn about weather. No, I don't mean to learn what weather has occurred, is occurring, or is expected to occur at a particular time and place. Yes, it is a power tool that does provide that kind of useful information which will be covered throughout this text. More importantly, it is also a tool to learn the basic principles and building blocks of aviation meteorology. As you learn how to correctly use this tool, you will quickly recognize that you are also learning more about weather than you ever imagined.

Since I began teaching pilots how to use the Skew-T log (p) diagram back in the late 1990s, I found that I could use it as a canvas or backdrop to teach pilots about what causes the formation of clouds, fog, airframe icing, turbulence, and thunderstorms, just to name a few. In other words, my students needed to understand these basic principles of weather first, before understanding how to interpret most weather reports and forecasts including the Skew-T log (p) diagram. Instead of typing out **Skew-T log (p) diagram** for each reference, in this text I will just refer to this simply as the **Skew-T** or **Skew-T diagram** unless otherwise necessary.

Online learning

There are dozens of free resources online that will help you better understand how to interpret the Skew-T diagram. However, most of these are not geared to the needs of a pilot making a cross country flight. The target audience of these online programs tend to be meteorologists or those that are looking to become meteorologists. In other words, topics such as airframe icing, turbulence and nonconvective low level wind shear are not usually covered. But they are covered in depth in this text.

There's no doubt that the Skew-T diagram is not for everyone. Certainly, any pilot can be taught how to extract some basic information such as finding the height of the lowest freezing level, determining the winds aloft at cruise altitude or even finding the depth of a stratus cloud deck. Simple applications like these require a dearth of knowledge about the diagram and can be taught to just about any pilot in a short sit-down or online lesson. However, some of the more complex techniques such as finding the tops of a cumuliform-type cloud deck, or the potential for vertically-propagating lee waves, or the possibility of supercooled large drop (SLD) icing does require a substantial amount of knowledge and practice as well as a good grasp of the basic principles of weather, also known as meteorology. ■

3-The base Skew-T diagram

Given the **Skew-T diagram** will be sprinkled all throughout this text, let's do a quick overview of the base diagram to provide a very brief foundation. Don't panic, however, more details will follow later. The Skew-T is one of several thermodynamic diagrams available and is designed to aid in the interpretation of the vertical structure of temperature, humidity and wind in the atmosphere and used widely throughout the world meteorological and aviation community. It has the property that equal areas on the diagram represent equal amounts of energy. When temperature, humidity and wind are plotted on the diagram, this enables the calculation of a wide range of atmospheric processes to be carried out graphically. Going back many decades, Fig. 3-1 is a depiction of the original coordinate system of the Skew-T log (p) diagram.

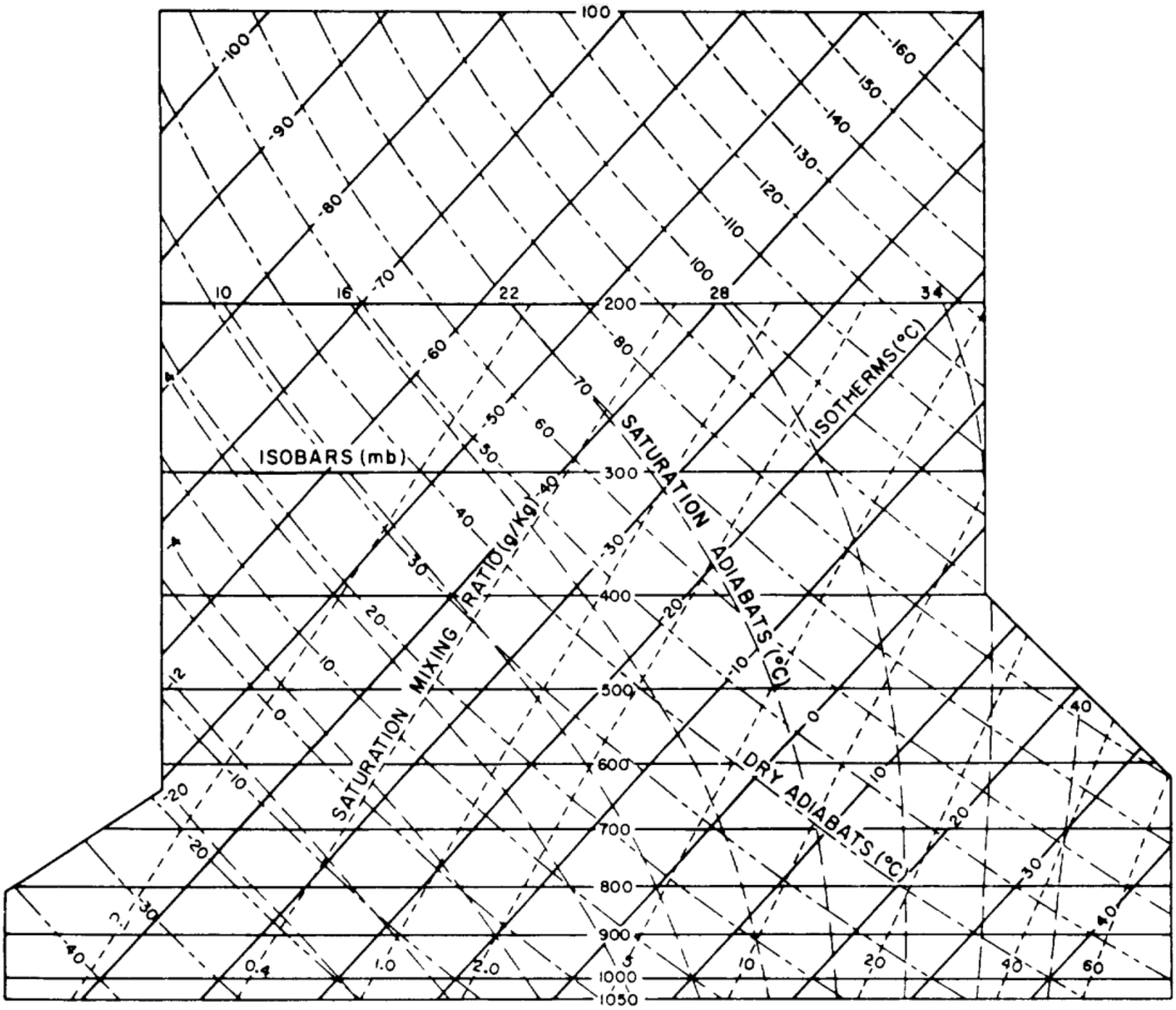

Fig. 3-1: *Original coordinate system of the Skew-T log (p) diagram without a hodograph. In those days, all of the data was plotted manually.*

There are *four* basic thermodynamic diagrams used by meteorologists, including the Stüve, Tephigram, Emagram, and the Skew-T log (p) diagram. You may hear the term "pseudo-adiabatic diagram" used as well. All these thermodynamic charts are "pseudo-adiabatic diagrams," in that they are derived by assuming that the latent heat of condensation (to be discussed later) is used to heat the air, and that condensed moisture falls out immediately. All four present the same information and physical relationships and show isobars, isotherms, pressure altitude, dry-adiabats, moist-adiabats, and saturation mixing ratio lines. They differ only in the arrangement of these coordinates. The coordinate system of the Skew-T was first suggested by N. Herlofson, a Norwegian meteorologist. However, if you are a purist, the Tephigram is regarded as near perfect for strict thermodynamic calculations. In short, each type of thermodynamic diagram has its own "twist." To avoid getting bogged down in the differences, we'll exclusively focus on the Skew-T in this text given that it is the most referenced diagram in U.S. aviation. From time to time, though, you may run across one of these other thermodynamic diagrams online or in other texts or articles on the subject.

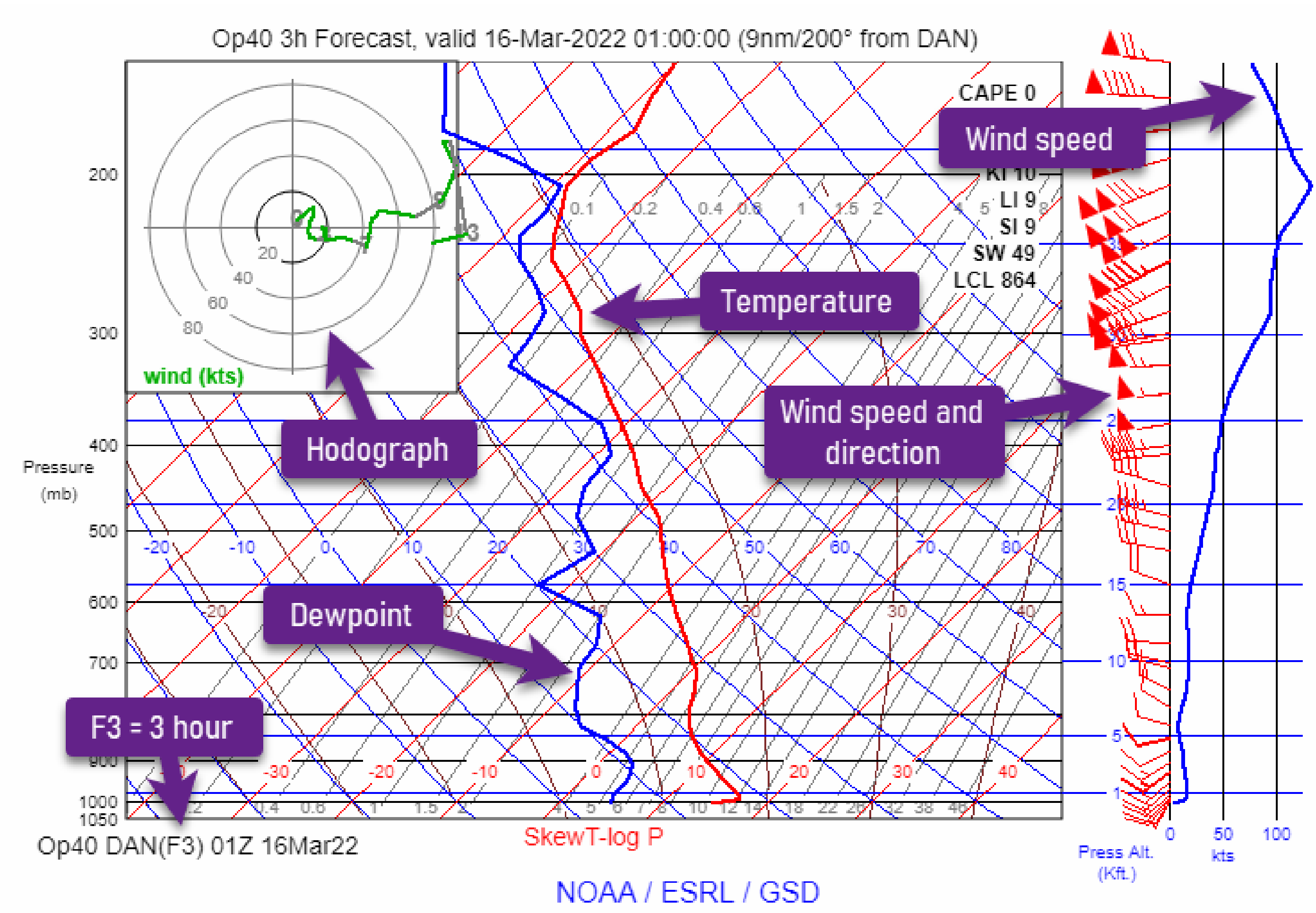

Fig. 3-2: *A 3-hour forecast sounding (F3) for Danville, Virginia from the Rapid Refresh (RAP) model.*

The temperature, dewpoint temperature and wind data plotted on a Skew-T diagram can come from multiple sources that we will explore in more detail later. This includes data generated by a weather balloon, also known as a radiosonde, depicting observed environmental data and forecast data from a numerical weather prediction (NWP) model. While it is nice to view the actual radiosonde sounding data, it is the forecast that concerns many pilots. For example, the Skew-T in Fig. 3-2 depicts forecast weather conditions *near* the Danville Regional Airport (KDAN) with a 3-hour lead time denoted by **F3**. Note that using other sites, it may designate the forecast hour in a different way.

It is important to reiterate that this is *not* data from a weather balloon (radiosonde). Instead, it is a *forecast* of temperature, dewpoint temperature and wind from a numerical weather prediction model called the Rapid Refresh (RAP) model. We'll discuss the source data from radiosondes and numerical weather prediction models later and how they can be used when planning a flight.

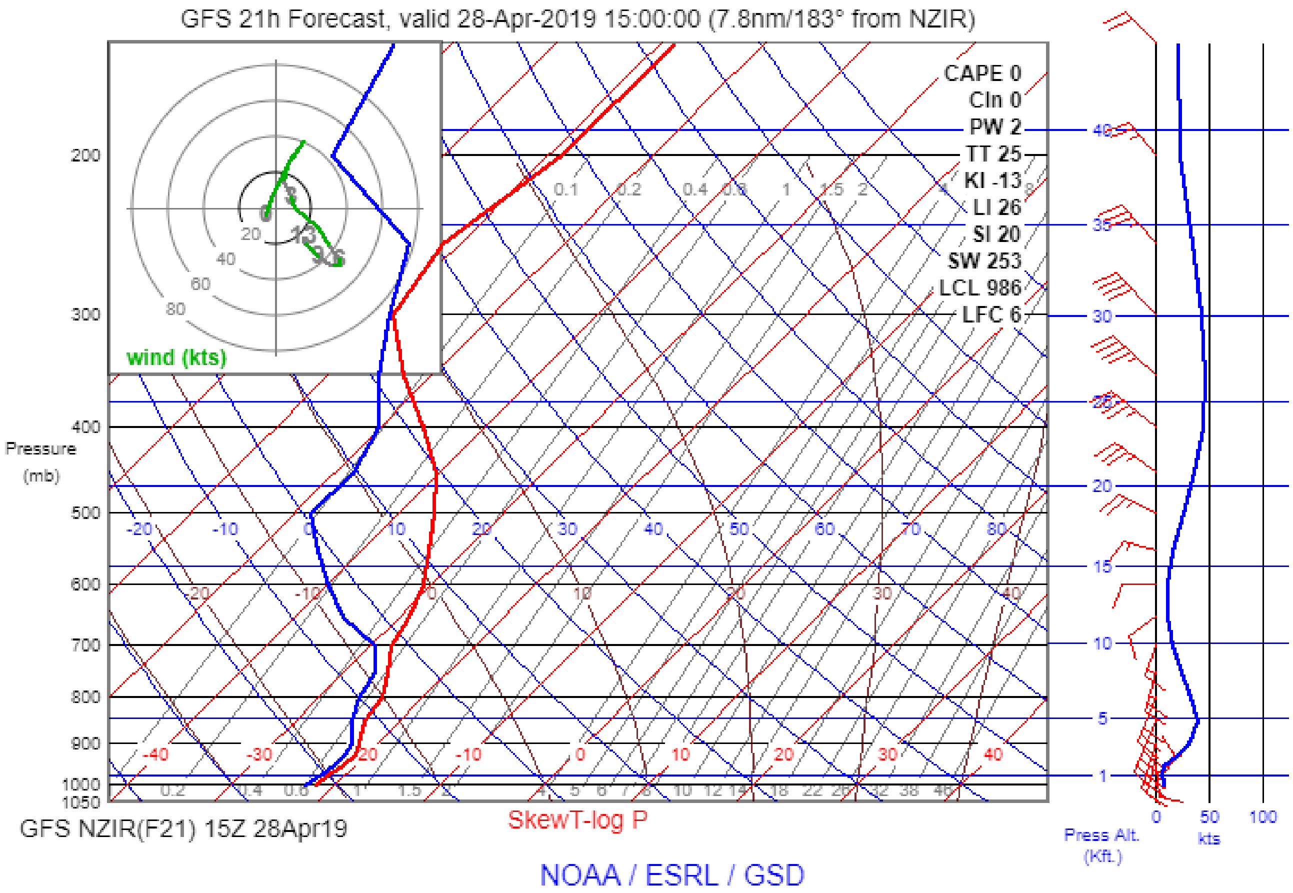

Fig. 3-3: *A 21-hour forecast sounding (F21) from the Global Forecast System (GFS) model near McMurdo Station in Antarctica (NZIR).*

Unlike a radiosonde which is released at very specific locations twice a day, forecast model data can be plotted on a Skew-T at some time interval *near* just about any airport in the United States—or even the world—depending on the NWP model utilized. This is referred to as a forecast sounding. For example, the Skew-T diagram in Fig. 3-3 is a *forecast* sounding with a 21-hour lead time (F21) near McMurdo Station in Antarctica using the Global Forecast System (GFS) NWP model.

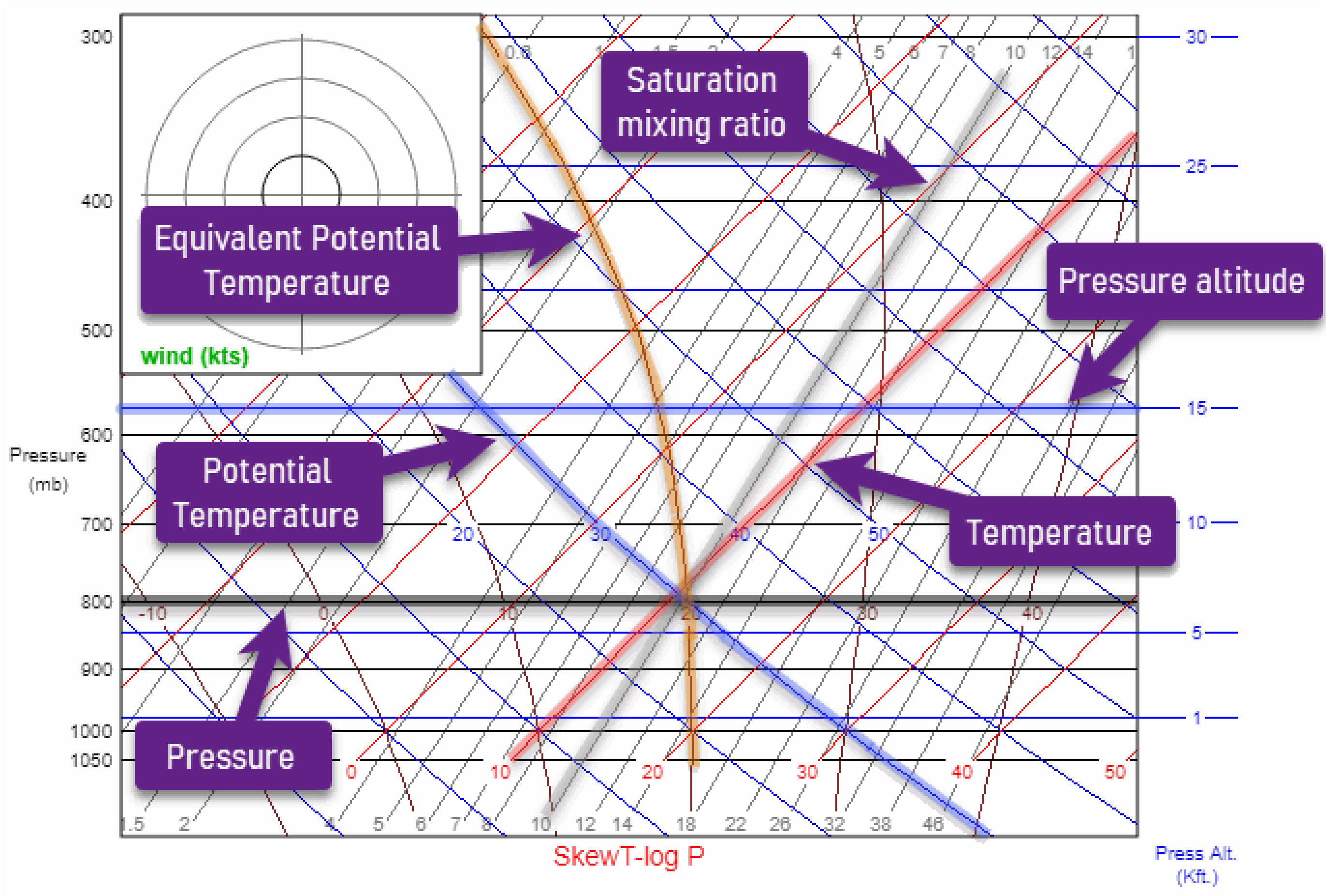

Fig. 3-4: *Five principal quantities found on the Skew-T log (p) diagram plus pressure altitude.*

If we turn our attention to Fig. 3-4, notice that there are six different reference lines on the Skew-T base diagram. This is common. You may find that some websites or apps use a "simplified" version of the Skew-T that has less than six reference lines—and still, others might utilize more than six reference lines. It is also common to see pressure altitude represented in kilometers on some diagrams versus thousands of feet as they are in the diagrams used in this text.

There are five principal quantities indicated by constant value lines: pressure (black), temperature (red), constant potential temperature (θ) (blue), saturation mixing ratio (gray), and constant equivalent potential temperature (θ_e) (brown) for saturated air. The sixth reference line on the chart is the pressure altitude (also blue). Yes, many of these terms are likely unfamiliar to the average pilot. Not to worry, all these important terms will be defined and explained as you progress through this text.

Each constant value line on the base diagram is typically coded in some fashion. In some instances, the lines are color-coded as they are in Fig. 3-4, and others may use line type or line thickness to distinguish between the various quantities. Unfortunately, there are no industry standards, so how this is depicted largely depends on the website or application you are using.

Temperature (represented in degrees Celsius) is depicted on the **abscissa** (X-axis) and shown in red with warmer temperatures at the right and colder temperatures on the left. Pressure (represented logarithmically in millibars) is depicted on the **ordinate** (Y-axis) and shown in **black** with higher pressures at the bottom and lower pressures at the top. And for those millibar-challenged pilots, pressure altitude (represented in thousands of feet) is depicted in blue, also on the Y-axis. From these two variables of temperature and pressure, three different equations can be solved to represent three other lines on this diagram. First, let's take a closer look at the three lines just introduced.

The red lines that are slanted or "skewed" at a 45-degree angle are the lines of constant temperature also called isotherms, hence the name "Skew-T" diagram. The 10-, 20- and 30-degree Celsius isotherms are highlighted in Fig. 3-5.

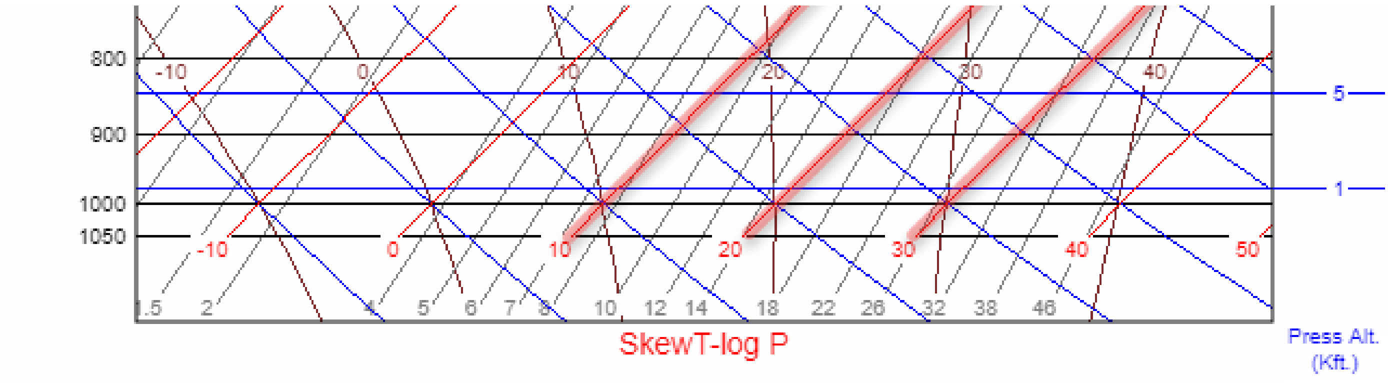

Fig. 3-5: *Temperature reference lines or isotherms in degrees Celsius (°C) highlighted on the base Skew-T diagram.*

Why are the isotherms skewed? Arguably, the primary reason they are skewed is for convenience and utility. That is, meteorologists often desire to have a diagram on which:

a) The important lines are straight rather than curved.

b) The angle between moist and dry adiabats (to be discussed later) and isotherms is large enough to facilitate estimates of stability.

c) The ratio of area on the chart to thermodynamic energy is the same over the whole diagram.

d) An entire sounding to levels inside the lower portion of the stratosphere can be easily plotted.

Next, the **black** horizontal lines are the lines of constant pressure, also called isobars, which are represented in millibars (mb) or sometimes hectopascals (hPa). For reference, the isobars for 1,000, 900, and 800 mb are highlighted in Fig. 3-6.

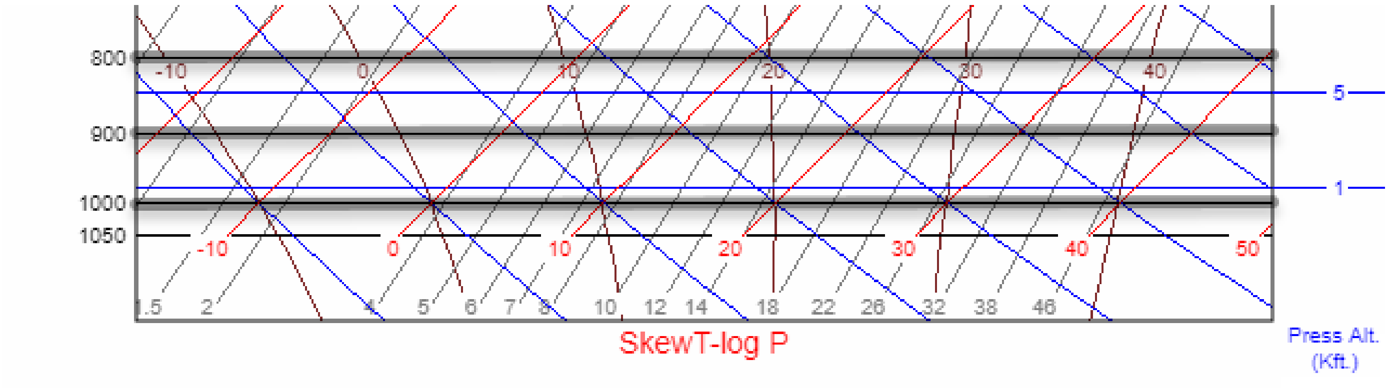

Fig. 3-6. *Pressure reference lines or isobars in millibars (mb) highlighted on the base Skew-T diagram.*

Notice that on the "blank" Skew-T diagram in Fig. 3-7, pressure surfaces are at a greater distance from each other as pressure *decreases* vertically. In the dark gray highlighted area, each pressure slice has the same 100 mb top-to-bottom pressure difference (900 to 800 mb, 700 to 600 mb, and 500 to 400 mb), but you can see the altitude spread or thickness of each of these layers occurs over a greater depth with *increasing* altitude. This is because the atmosphere is said to be compressible under its own weight; that is, lower layers are compressed more than the upper layers.

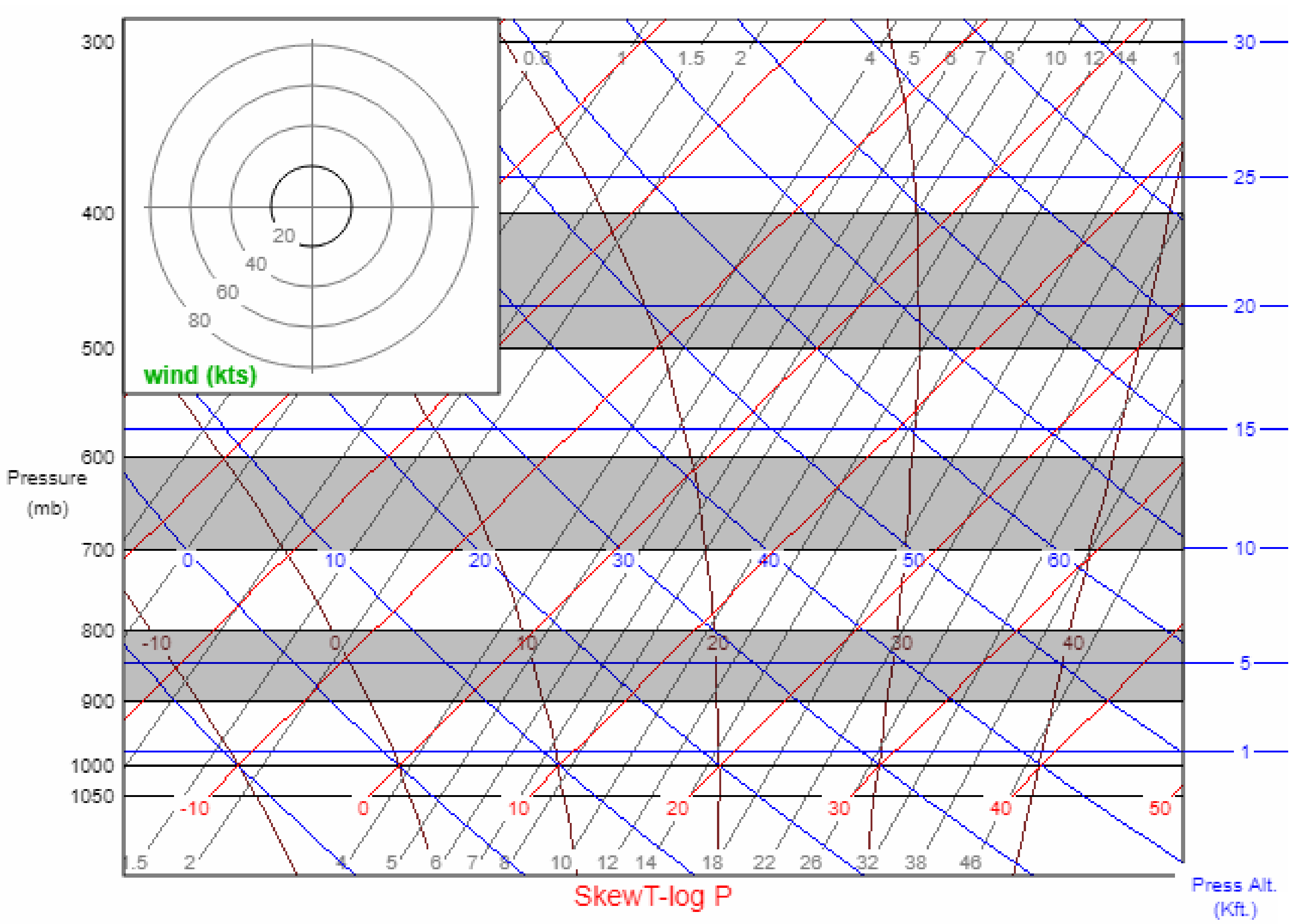

Fig. 3-7: *The logarithmic or log (p) nature of pressure due to atmospheric compression.*

As a result, atmospheric pressure and air density both decrease *exponentially* with height. This illustrates the logarithmic or "log (p)" nature of pressure with altitude. From the discussion above, now you know why it is called a Skew-T log (p) diagram. That is, the temperature reference lines (isotherms) are skewed at a 45° angle and pressure (isobars) is represented on a logarithmic scale.

Millibars or hectopascals?

While it is true that a hectopascal (hPa) is the standard pressure unit used in meteorology, most weather forecasts quote atmospheric pressure in millibars (mb) instead. You will see millibars used on a surface analysis chart and a prog chart in the U.S. Constant pressure charts are also referred to in millibars (e.g., 500 mb). To keep it simple, this text will use millibars exclusively.

Lastly, the blue horizontal lines are the lines of constant height that represent pressure altitude in thousands of feet. Remember that pressure altitude is the resulting altitude on your digital or analog altimeter when the altimeter setting is adjusted to 29.92" Hg (1013.25 mb). This setting is equivalent to the atmospheric pressure at mean sea level (MSL) in the International Standard Atmosphere (ISA).

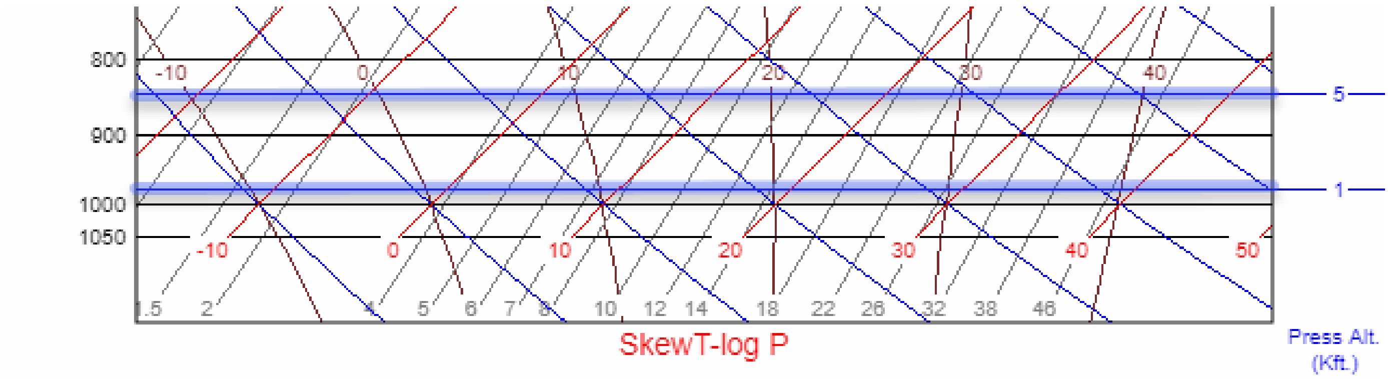

Fig. 3-8: *Pressure altitude reference lines in thousands of feet (Kft) are shown in blue on the base Skew-T diagram.*

In Fig. 3-8, the 1,000-foot and 5,000-foot heights are highlighted in blue for reference. Note that this is pressure altitude, not true altitude, height above mean sea level (MSL), or height above ground level (AGL). Other than extreme weather situations, mean sea level height and pressure altitude are close enough that the difference can be ignored. **In this text, all altitudes are provided as MSL height unless otherwise noted as AGL.**

A common reference

There are many references to height used by both meteorologists and pilots. This includes mean sea level height (MSL), true altitude, pressure altitude and above ground level (AGL). Cloud bases are always represented as AGL, unless being reported by a pilot who will use MSL.

Both the skewed version of the Tephigram and the Skew-T have most of these advantages, but the latter is preferred because its isobars are parallel, which makes it easier to quickly estimate pressure altitudes, something pilots appreciate more than using pressure in millibars.

Let's take a moment to review what we have discussed so far. The Skew-T log (p) diagram depicts the temperature, dewpoint, and wind as a function of pressure or altitude. Plotting data from a radiosonde observation depicts the measured temperature, measured dewpoint, and "measured" wind as a function of pressure or altitude. The same kind of data could also come from the output of a numerical weather prediction model to represent the current or future state of temperature, dewpoint temperature, and wind. Pressure and pressure altitude are depicted on the Y-axis as horizontal and parallel **black** and blue lines, respectively. Lastly, the temperature is depicted on the X-axis, represented by red lines skewed at a 45-degree angle.

Up to this point we have tackled three of the six reference lines on the base Skew-T diagram. In the end, a thermodynamic chart such as the Skew-T represents a point observation or forecast over a particular location at a specific time. Because it describes a very narrow view of the atmosphere, it is best served as a tool to "drill down" and uncover important details not discovered on other maps, charts, or forecast guidance that are more likely to provide a much broader scale overview in time and space.

In the remainder of this text, you will learn how to utilize many essential weather products and learn techniques of how to use the Skew-T diagram to quantify and describe the potential for adverse weather elements such as airframe icing, turbulence, and convection, just to name a few. Note that some dialogue contained in the sections to follow will be complex and challenging for many pilots but it is necessary to fully appreciate the complexity of all that Mother Nature has to offer. ■

4-Internet data resources

There are literally dozens of online resources that provide access to these thermodynamic diagrams. The primary resource for Skew-T diagrams utilized throughout this text was **https://rucsoundings.noaa.gov**. This impressive interactive tool was created and is maintained by developers at the National Oceanic and Atmospheric Administration (NOAA) Global Systems Division (GSD) of the Earth System Research Laboratory (ESRL). **Unfortunately, as of September 30, 2024, NOAA management has retired this site permanently and it will no longer be available for public use.** Unfortunately, nearly all of the Skew-T diagrams presented in this text are from this NOAA site. Even so, Skew-T diagrams from other sites (shown below) will have similar characteristics.

A simple Internet search and search on the Apple's App Store or Google's Play Store will reveal many websites and apps that provide access to these diagrams. Nevertheless, listed below are a few websites that are worth mentioning. Please note that for some of the website's access to these diagrams may require selecting a point on a map to show the model's forecast sounding at that location. **Of course, some of these URLs may change or be unreachable in the future.**

- https://www.spc.noaa.gov/exper/soundings (radiosonde)
- http://weather.rap.ucar.edu/upper (radiosonde)
- http://weather.uwyo.edu/upperair/sounding.html (radiosonde)
- https://vortex.plymouth.edu/mapwall/upperair/raob_conus.html (radiosonde)
- https://skewtlogpro.com (app)
- http://www.twisterdata.com (forecast soundings only through map selection)
- https://www.pivotalweather.com/model.php (forecast soundings only through map selection)
- https://www.tropicaltidbits.com/analysis/models (forecast soundings through map selection).

6-The big weather picture

The key to a good preflight briefing is to understand the “big weather picture” or what a meteorologist calls the “synoptic weather overview.” While it can be valuable to view a series of Skew-Ts along your proposed route of flight to gain a sense of the weather at those points, it can be difficult, or fundamentally impossible, to ascertain what is driving the weather by simply using an evenly spaced series of Skew-T diagrams.

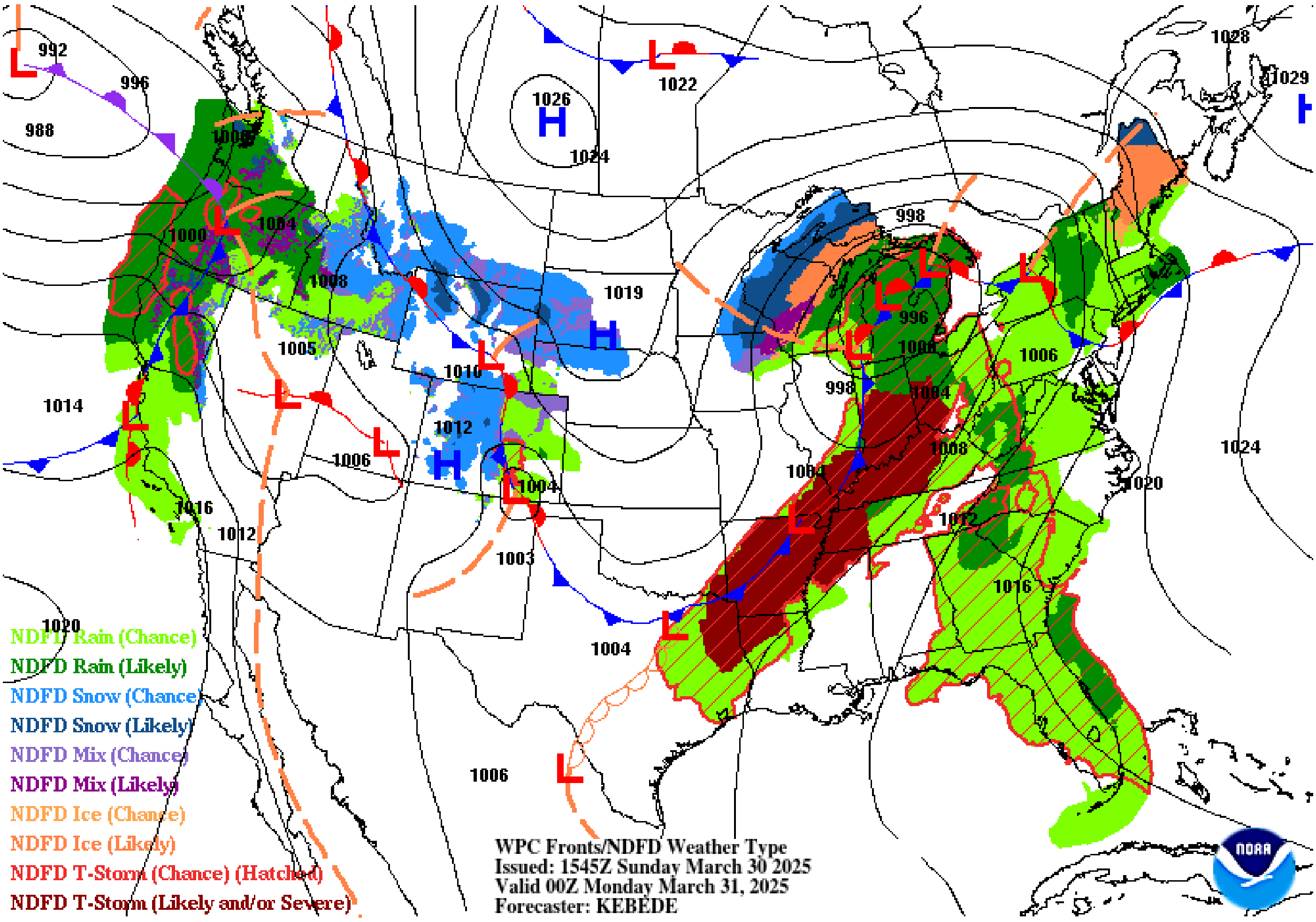

Fig. 6-1: *Use a prog chart issued by the Weather Prediction Center (WPC) to get a grasp of the big weather picture. Visit https://www.wpc.ncep.noaa.gov or use the* ***EZWxBrief*** *progressive web app static weather imagery at https://ezwxbrief.com.*

Even so, if the Skew-T diagrams all along the route appear to look similar, then it is very likely you will experience the same weather (fair or otherwise) at your departure and destination airports and at all points in between. For example, if a strong cold front moved through your route laying down a widespread stratocumulus cloud deck (to be covered later) then you may see the same stratocumulus signature, more or less, depicted on each location you chose along your proposed route.

On the other hand, if the Skew-Ts you chose are drastically different at some point along the route, then it is time to evaluate what might be driving that difference (e.g., a frontal system). If it is the latter, you should review the prog charts if you haven't already.

First, there is a similar set of prog charts that you may find on the Aviation Weather Center (AWC) website (see https://aviationweather.gov/gfa/#progchart). However, like the one shown in Fig. 6-1, the source of the prog charts used in this text are those created by the Weather Prediction Center (WPC) pictured in Fig. 6-2. Although the prog charts from the AWC website have a similar look and feel, the discussion to follow is strictly directed toward the forecasts found on the WPC website and should NOT be carried over to the AWC progs due to the subtle differences.

Fig. 6-2: *The Weather Prediction Center (WPC) located in College Park, Maryland. Photo courtesy of NOAA.*

Prog charts from the WPC come in a short- and extended-range variety. This discussion will focus on the short-range progs which are those with a forecast lead time of 6 to 60 hours. These short-range forecasts are issued twice a day and include the expected surface pressure patterns (isobars), circulation centers (highs and lows) and fronts. You may also see surface troughs, drylines and squall lines depicted as well. This forecast extends over most of North America and is produced by highly trained meteorologists at the WPC in College Park, Maryland.

There's more to it than just reading surface progs

Understanding the big weather picture is more than just evaluating what is occurring at the surface. The surface prognostic charts (referred to as "prog" charts) aim to depict the evolution of major weather systems over the next several days but only tell a small part of the overall weather story. Upper air charts called constant pressure charts can help you complete that story and identify the magnitude of these major weather systems.

A color mosaic included on the prog charts depict the weather type, coverage (extent) and likelihood of precipitation. They are extracted from the National Digital Forecast Database (NDFD) and prepared by forecasters at the NWS local weather forecast offices (WFOs) in collaboration with the WPC. The geographic extent of the county warning areas (CWAs) for the WFOs are included on the map in Fig. 6-3. The precipitation forecast depicted on these prog charts is strictly limited to the conterminous U.S. and immediate coastal waters and does *not* extend into Canada or Mexico since there are no NWS WFOs in these two countries.

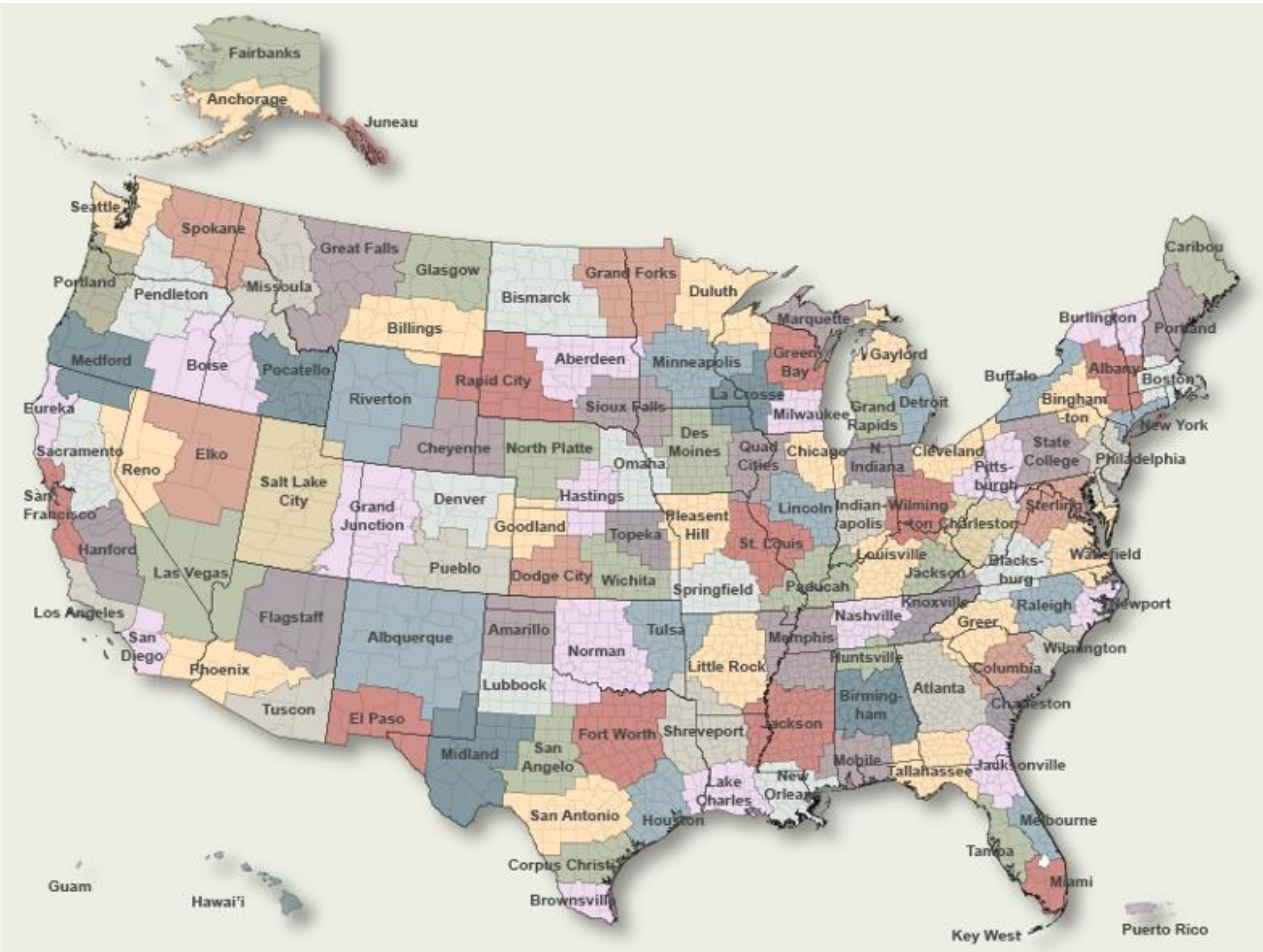

Fig. 6-3: *These are the county warning areas (CWAs) for the local weather forecast offices (WFOs) throughout the United States and its territories. Not to be confused with center weather advisories (CWA) covered later in the text.*

Here's how that precipitation forecast is built. The first distinction is that the precipitation on a prog chart is issued by 116 forecasters located at the various WFOs throughout the conterminous U.S. like the meteorologist picture in Fig. 6-4. At prescribed times throughout the day, forecasters create "grids" that get ingested into the NDFD. Once in the NDFD, these grids have a horizontal resolution of 2.5 km. Two of the grids they construct are weather type and precipitation probability...the same one rendered on the WPC prog charts.

The good news here is that this weather type forecast should match the Terminal Aerodrome Forecasts (TAFs) issued within the CWA. That's because these TAFs are issued by the same staff at the WFO. Therefore, if there's a forecast for freezing rain in the prog chart valid at 12Z, then the TAF should also have a forecast group for freezing rain at that same time. If a TAF is amended, it may no longer match the data in the NDFD since it is not also amended. There may be other reasons, these two do not match especially as it relates to convective forecasts. More on this later when TAFs are discussed in greater detail.

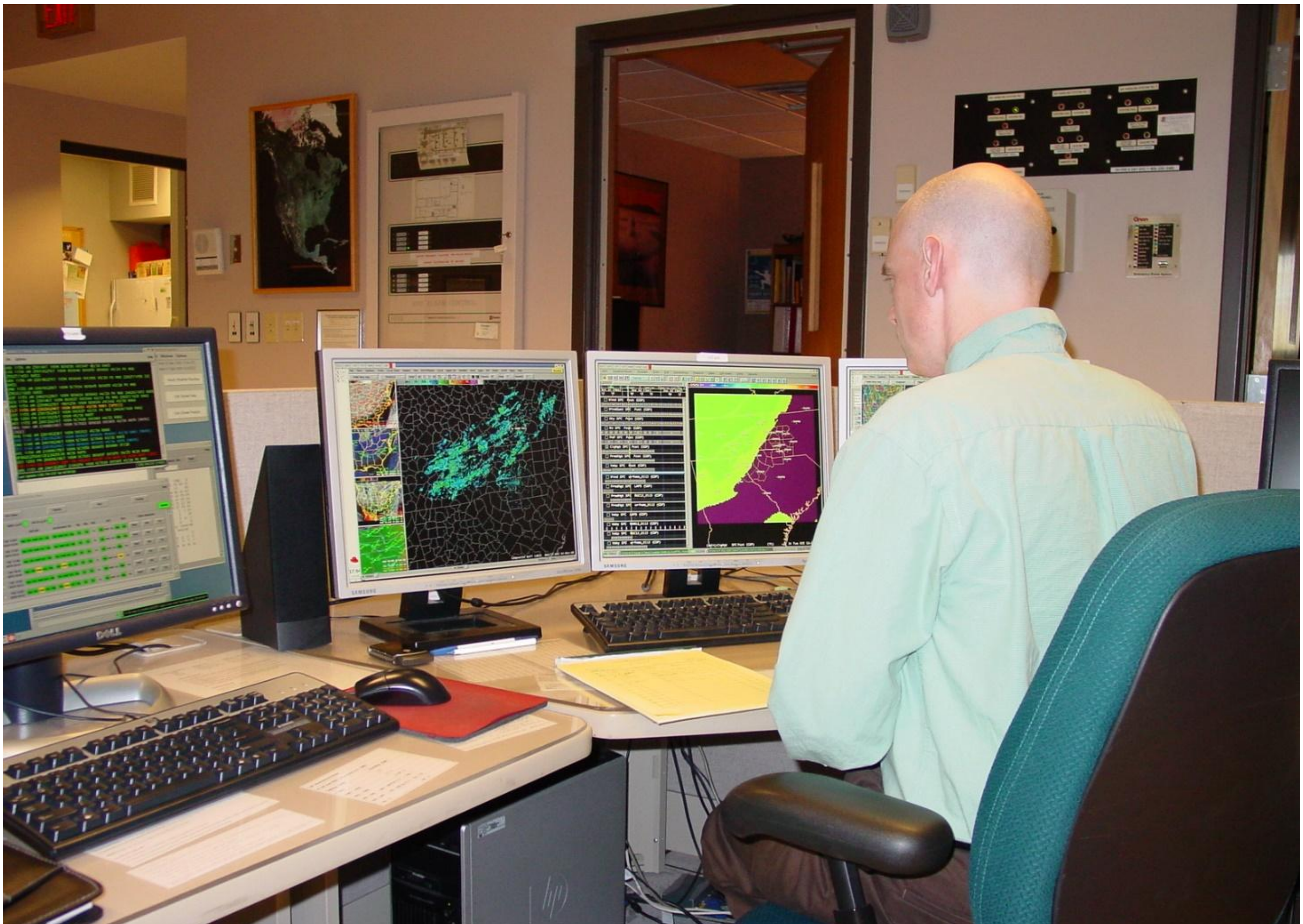

Fig. 6-4: *Forecaster at the weather forecast office (WFO) in Greer, South Carolina is updating the gridded precipitation forecast for the Greenville-Spartanburg (GSP) county warning area (CWA).*

The second distinction is that the weather type mosaic is valid at the time printed on the chart. As a result, this is considered instantaneous precipitation *coverage*. In other words, it's not a "time-smeared" forecast valid over a range of time, but a snapshot valid at the time stamped on the chart. In other words, it attempts to address where it will most likely be precipitating at that moment in time.

In addition to precipitation coverage, this is also a probabilistic forecast. Using the legend in the lower-left corner of the forecast, the precipitation mosaic depicted on these prog charts is shown using two shades of color (light and dark) for each precipitation type (e.g., rain, snow, etc.) that represents the *likelihood* of measurable precipitation (i.e., more than a trace) reaching the surface at the valid time. Rain, for example, is depicted by a light and dark green color and snow by a light and dark blue color. Dark colors represent a greater likelihood. Please understand that this is a "likelihood" and not a calibrated probability forecast. This will be explained shortly.

- NDFD Rain (Chance) - There is chance of measurable rain (≥0.01") at the valid time.
- NDFD Rain (Likely) - Measurable rain (≥0.01") is likely at the valid time.
- NDFD Snow (Chance) - There is chance of measurable snowfall (≥0.01" liquid equivalent) at the valid time.
- NDFD Snow (Likely) - Measurable snow (≥0.01" liquid equivalent) is likely at the valid time.
- NDFD Mix (Chance) - There is a chance of measurable mixed precipitation (≥0.01" liquid equivalent) at the valid time. "Mixed" can refer to precipitation where a combination of rain and snow, rain and sleet, or snow and sleet are forecast.
- NDFD Mix (Likely) - Measurable mixed precipitation (≥0.01" liquid equivalent) is likely at the valid time. "Mixed" can refer to precipitation where a combination of rain and snow, rain and sleet, or snow and sleet are forecast.
- NDFD Ice (Chance) - There is a chance of measurable freezing rain (≥0.01") at the valid time.
- NDFD Ice (Likely) - Measurable freezing rain (≥0.01") is likely at the valid time.
- NDFD T-Storm (Chance) - There is a chance of thunderstorms at the valid time. Areas are displayed with diagonal hatching enclosed in a dark red border.
- NDFD T-Storm (Likely and/or Severe) - Thunderstorms are likely and/or the potential exists for some storms to reach severe levels at the valid time.

Fig. 6-5: *National Digital Forecast Database (NDFD) weather types as they appear on the prog charts.*

All weather types shown in Fig. 6-5 are treated the same, but here is how it breaks down for rain:

> ***Rain (Chance)****—There is a* ***15%*** *to less than 55% likelihood of measurable rain (≥0.01") at the valid time of the forecast.*
>
> ***Rain (Likely)****—There is a 55% or greater likelihood of measurable rain (≥0.01") at the valid time of the forecast.*

Therefore, the "chance" precipitation forecast in the prog chart shown in Fig. 6-6 for central and western New Mexico, indicates that there's a 15-55% chance of measurable rain (light green) reaching the surface. Given that this light green area has a red-hatching, it suggests that the precipitation will be generated by convection. The dark red area in eastern New Mexico and western Texas indicates that there's a 55-100% chance of convection, and it may or may not be severe.

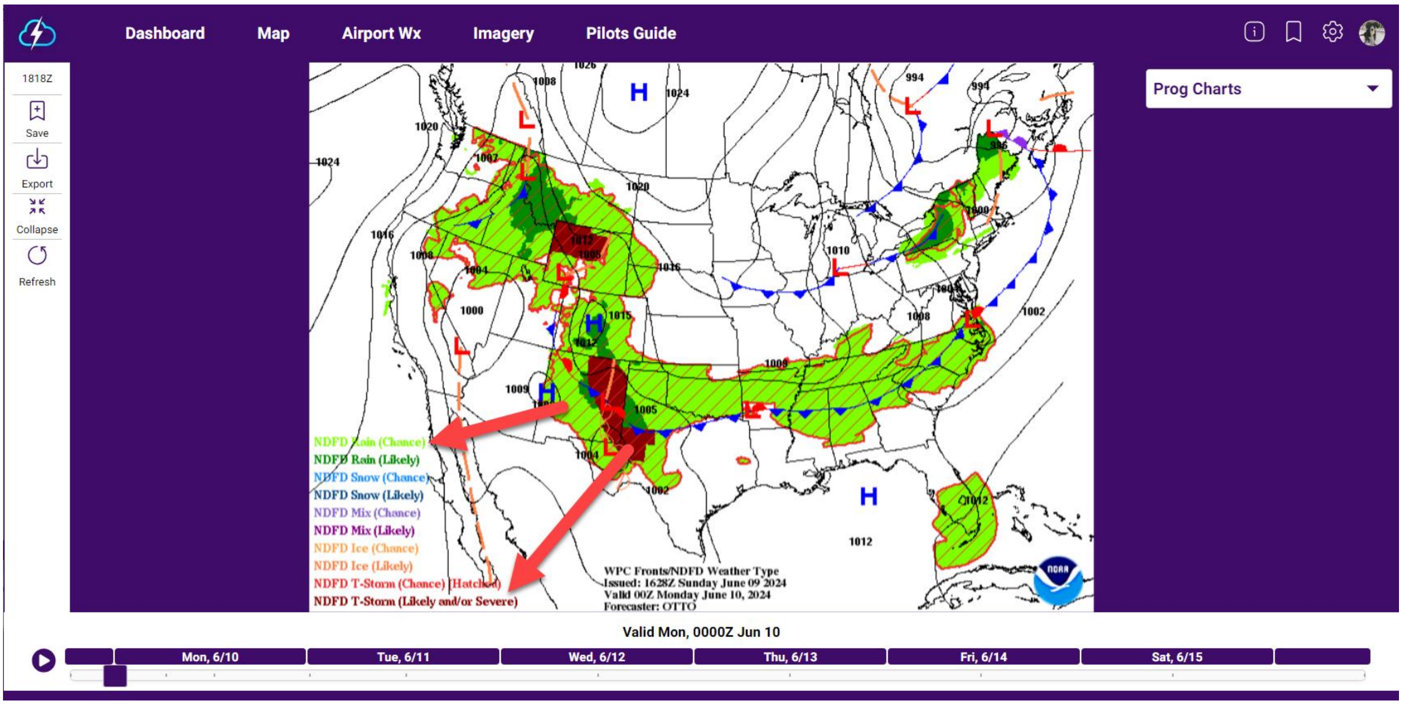

Fig. 6-6: *This short-range prog chart from the EZWxBrief progressive web app valid at 00Z shows a chance for convective rain for central and western New Mexico as depicted by the light green area that includes red hatching. A red-hatched region indicates a chance of convective rain (showers/thunderstorms). The dark red area in western Texas indicates a* ***likely*** *chance of convective rain (showers/thunderstorms).*

Forecasters from neighboring WFOs have an edict to coordinate their forecasts so it appears that the forecast mosaic you see on the prog charts isn't constructed by over a hundred independent forecasters. However, you may occasionally see the precipitation forecast terminate abruptly at these CWA boundaries. In Fig. 6-7, notice the light blue rectangular area for a chance of snow (left) in the panhandles of Oklahoma and Texas that look remarkably like the Amarillo CWA boundary (right).

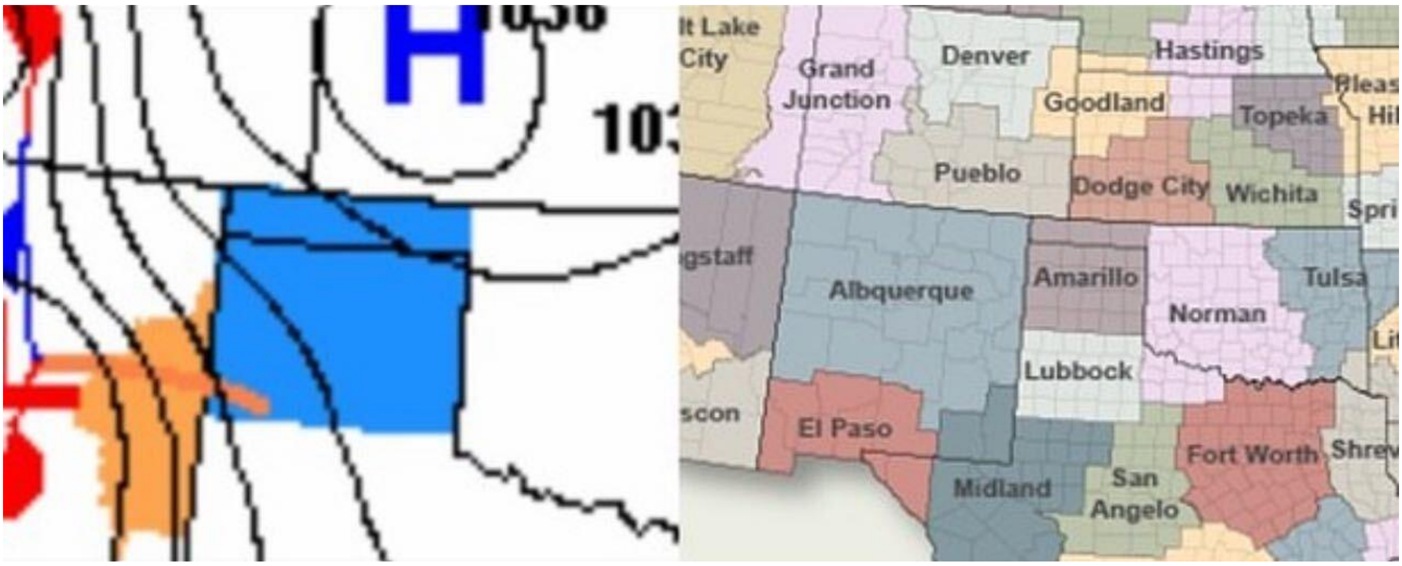

Fig. 6-7: *Coordination between weather forecast offices should prevent cases where the weather type field abruptly ends at county warning area boundaries as it does here for Amarillo.*

Now this is where the dialog gets even more complex. The NDFD currently provides information on precipitation probability for 12-hour periods. The Precipitation Potential Index (PPI) captured in Fig. 6-8 is used by WFOs to derive 12-hour Probability of Precipitation (PoP12) forecasts and provide details on precipitation timing up to an hourly resolution. Essentially the PPI is the likelihood, expressed as a percentage, of a measurable precipitation event at a grid point during the indicated valid time. Using the term "likelihood" rather than "probability" is a way to get around the fact that the value is not calibrated to a 1-hour period (like a PoP01 would be). If it were calibrated to a 1-hour period, the values would be very much lower.

Probability category	Potential index
None	0 – 14
Slight chance, isolated	15 – 24
Chance, scattered	25 - 54
Likely, numerous	55 – 74
Definite	75 - 100

Fig. 6-8: *The likelihood values used to determine the light or dark colors stem from the precipitation potential index (PPI) that ranges from 0 to 100.*

From the table in Fig. 6-8, the NDFD products and those used on the WPC prog charts combine the chance and slight chance forecasts into a single "chance" category and the likely and definite into a "likely" category. According to David Ruth a meteorologist at the NWS, "in 2014 the WPC had values associated with the four categories, but it was later suggested to remove these since the probability categories are calibrated to 12-hour periods while the display of the weather grids is meant to convey the potential (likelihood) at the valid time. Otherwise, the values would be technically inaccurate. Also, the directives state that for convective situations, areal coverage can be a substitute for the probabilities, which muddies the waters even further."

In addition to prog charts, the WPC also issues another valuable precipitation forecast called **QPF** which stands for Quantitative Precipitation Forecast. This is an accumulated precipitation forecast valid over a range of time that could be 1 hour, 3 hours, 6 hours or even 7 days. Therefore, QPFs depict the amount of liquid precipitation expected to reach the surface in a defined period. In the case of snow or ice, QPF represents the amount of liquid that will be measured when the precipitation is melted. Typically, 12 inches of snow when melted down is about one inch of rain. Precipitation amounts can vary significantly over short distances, especially when thunderstorms occur, and for this reason QPFs issued by the WPC are defined as the expected "areal average" (on a 20 x 20 km grid) in inches. For the QPF forecast in Fig. 6-9, the period is six hours, so the forecast is called a 6-hour QPF. These are available within the EZWxBrief progressive web app or can be viewed on the WPC website at https://www.wpc.ncep.noaa.gov/#page=qpf.

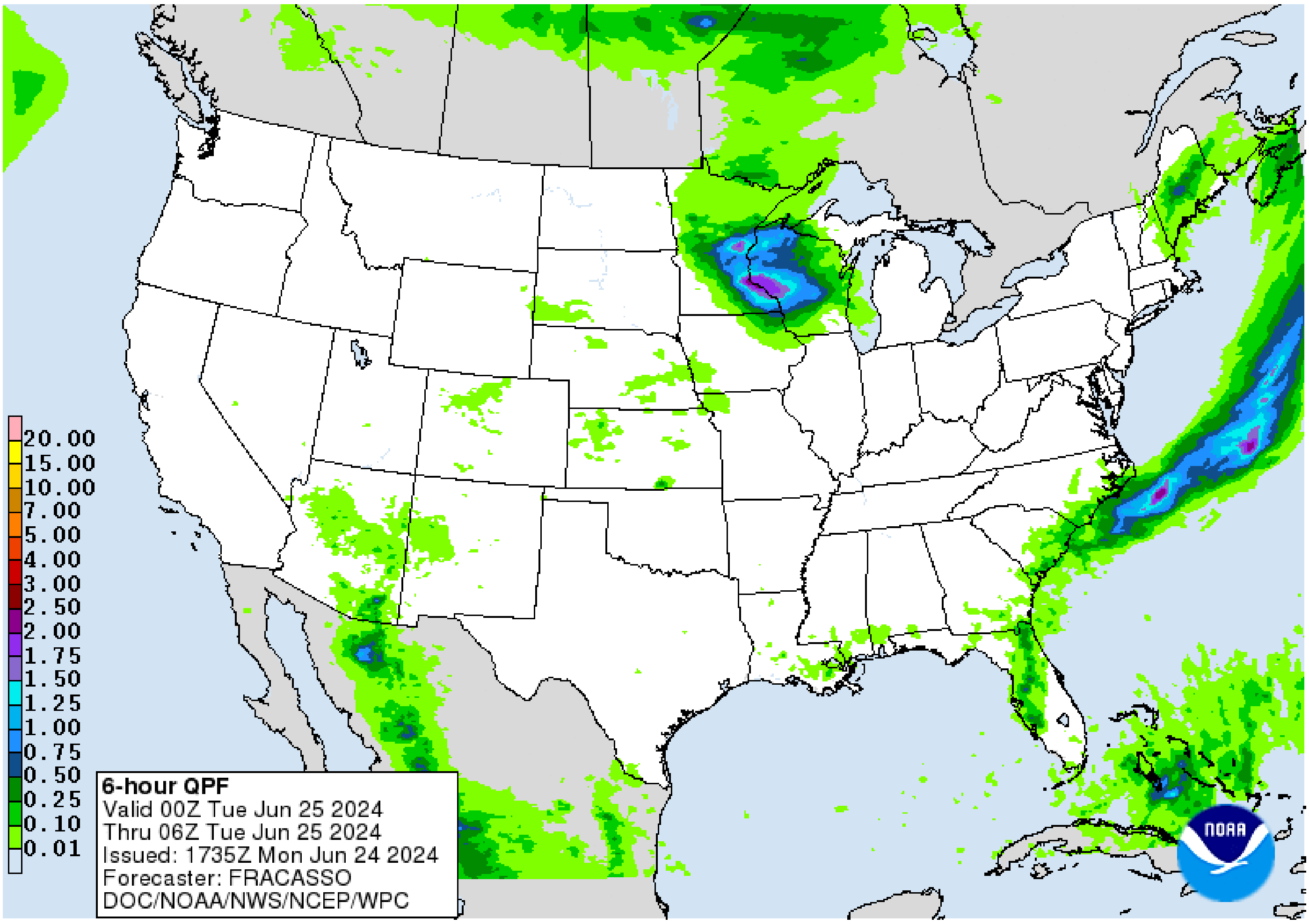

Fig. 6-9: *The 6-hour Quantitative Precipitation Forecast (QPF) issued by forecasters at the WPC depicts the amount of precipitation in inches that is expected to reach the surface over a six-hour period.*

It is important to note that QPF does not distinguish between the type of precipitation, nor does it tell you if the precipitation is the result of deep, moist convection or thunderstorms. Solid-filled color contours are drawn based on the scale shown on the left of the chart in inches. Think of this as the quantity of liquid expected to fill a rain gauge in the QPF valid period.

Also, the QPF doesn't specify when the precipitation is expected within the valid range of time; it could fall all in the first hour, all in the last hour or it could be continuous light rain falling throughout the entire forecast period. This is especially important to understand when the precipitation may be from convection. Often during the warm season, the precipitation forecast may fall within an hour or two and that could be near the beginning or end of the forecast period leaving much of the valid time free of precipitation. Moreover, local events from convection may create higher precipitation amounts in isolated areas.

QPF offers one distinct advantage over the instantaneous precipitation forecasts found on the prog charts. Given that precipitation forecasts on prog charts represent coverage and are valid at a single time, QPF can highlight areas of precipitation that may occur between prog chart forecasts. In other words, the represent a “time smeared” forecast. For example, it is possible that an area of showers and thunderstorms may be expected to develop at 1900Z and dissipate by 2300Z. This area of precipitation would not be shown on the prog charts valid at 1800Z and 0000Z, however, it would show up on the QPF. So, the QPF is a complementary forecast to help fill in the gap in between prog chart forecasts.

While not a probabilistic forecast like the prog chart, another distinct advantage of the QPF is that the forecaster must believe that there’s a 50% or greater chance of precipitation reaching the surface over the valid period. This tends to filter out many of the lower probability events you will see on prog charts. Given that this forecast is issued by a forecaster at the WPC and the weather type forecast on the prog charts are issued by forecasters at the 116 WFOs, at times they will differ, sometime significantly.

Another valuable precipitation forecast issued by forecasters at the WPC is the 12-hour Probability of Precipitation (PoP) forecast or 12-hour PoP. This is an extended-range forecast covering the conterminous U.S. It's designed to show the forecaster's confidence of where precipitation will likely reach the surface within a 12-hour forecast period.

As depicted in Fig. 6-10, probabilities are contoured using solid colors based on the legend at the bottom of the chart. Green colors denote higher probabilities with brown being the lowest probability. Numbers shown on the map define a probability for a particular city over the valid forecast period, in this case 12 hours. Higher numbers demonstrate high forecaster confidence that measurable precipitation will reach the surface within the valid forecast period. Conversely, lower numbers denote high forecaster confidence that measurable precipitation will **not** reach the surface within the valid forecast period.

It's important to understand the date-time stamp on this forecast. Like the QPF, this forecast is valid over a range of times. In this case, the period is 12 hours. Where the QPF chart lists the start and ending time of the valid period, the PoP forecast lists a single time. The valid time positioned in the bottom left-hand corner of the chart is the **ending time** of the 12-hour period. For the 12-hour PoP forecast in Fig. 6-10, the forecast is valid from Thursday, 12Z June 27 and **ending** Friday, 00Z June 28. The latter time is listed on the chart. This essentially covers the “daytime” hours on June 27 for much of the conterminous U.S.

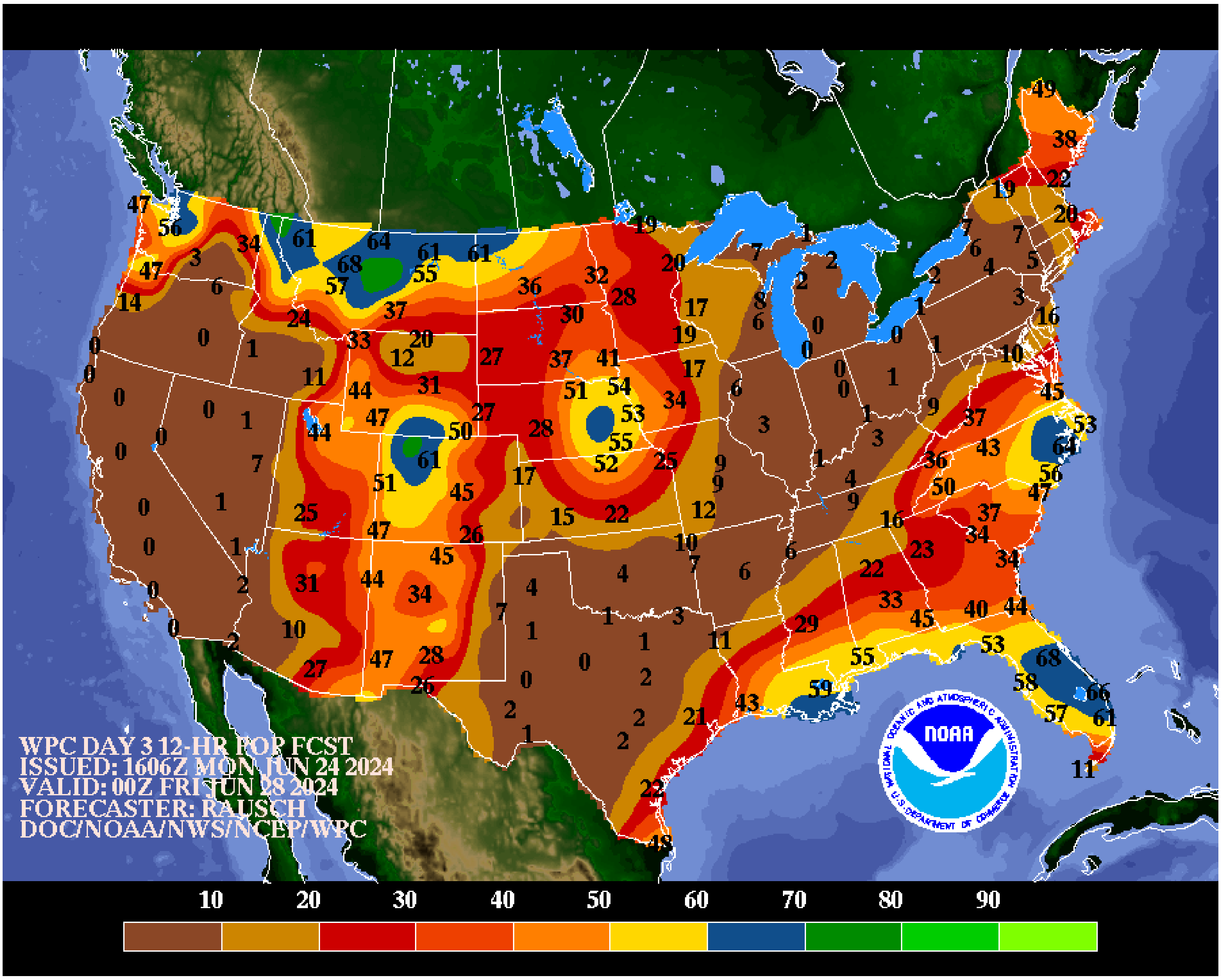

Fig. 6-10: *The 12-hour Probability of Precipitation (PoP) is extended-range guidance and shows the forecaster’s confidence that precipitation will reach the surface within the previous 12 hours ending at the valid time on the chart.*

While the short-range surface prog charts generally cover the weather features and precipitation expected over the next 60 hours or short-range forecast, the 12-hour PoP forecast describes the extended-range forecast. It starts with Day 3 (the day after tomorrow) and runs through Day 7 with 12-hour forecasts ending at 00Z (for the daytime) and 12-hour forecasts ending at 12Z (for the nighttime). This should always be used together with the WPC extended-range prog charts that show the evolution of major weather systems.

18-Showers and thunderstorms

Engrained in every pilot's primary training is that thunderstorms and airplanes don't mix! The message is first driven home to student pilots in flight school and reinforced as you step through additional certificates and ratings—if you decide willingly or unwillingly to take on a thunderstorm like the one pictured in Fig. 18-1, you will invariably be taking on the ride of your life and that ride might not end well.

Fig. 18-1: *A thunderstorm can be a beautiful thing to watch from a distance whether on the ground or in the air.*

Even though we collectively know much about thunderstorms nowadays, pilots still find a way to tangle with these deadly monsters every year. Even experienced air crews with thousands of hours of flight experience can find themselves in an environment not conducive for flight. In fact, on August 2, 1985, while on approach to the Dallas-Fort Worth International Airport (KDFW), the engines couldn't spool up fast enough on Delta Flight 191, an L1011 Tristar widebody aircraft, to recover from severe low-level wind shear (LLWS) caused by a microburst (more about microbursts later in this text).

This tragic lesson brought to the forefront of people's minds the phenomenon of LLWS attributed to deep, moist convection. Because of this incident, many high-impact airports throughout the U.S. are now equipped with a Low-Level Wind Shear Alert System (LLWAS) that gives pilots advanced warning and time to react. Actual data taken from this accident has been used in simulators to help pilots hone their ability to escape LLWS.

Before we get too deep into the subject of thunderstorms, it's important to acknowledge that the primary concern is not *thunderstorms*, but limiting exposure to deep, moist convection. Here's the perfect definition of a thunderstorm from the National Severe Storms Laboratory (NSSL).

> *"A thunderstorm is a **rain shower** during which you hear thunder. Since thunder comes from lightning, all thunderstorms have lightning."*

The key message here is that all thunderstorms begin as **rain showers**. This means even before the first lightning strike occurs, showery precipitation can produce dangerous convective turbulence. In fact, not all rain showers develop into mature thunderstorms, but can still be just as deadly.

Perhaps the most important point to make is that *showery* precipitation is driven by a convective process. Therefore, any forecast for showers should get your attention. While a forecast for showers may seem completely benign to the average person, just keep in mind that they are a form of deep, moist convection and avoidance is strongly encouraged. Even more important, most microbursts do not occur because of a supercell thunderstorm; many occur from benign-appearing rain showers without lightning.

Three components are required for deep convective development or thunderstorms are moisture, outside energy contribution (lift) and unstable air. In other words, you need high dewpoint temperatures (moisture), unstable air to high levels (high lapse rates) and a lifting source to set things in motion. Put all three ingredients together and you will get deep, moist convection and perhaps a thunderstorm. Even deep, moist convection that contains no lightning still creates the risk of severe turbulence, LLWS and severe icing.

Tis the season

Are thunderstorms just a summertime event? Not in the least. Yes, the southern tier of states do experience convection all year, but even in the dead of the winter it's still possible to have a severe thunderstorm in the northern Plains. Perhaps one of the most fascinating things to experience is thundersnow. This is much more common downwind of the Great Lakes or during a rapidly intensifying nor'easter.

What initiates the rising air required for thunderstorm development? Thunderstorms develop at a particular time and place for a reason, even though it is often incredibly difficult or fundamentally impossible to diagnose those reasons for any given situation. But there are some quantifiable elements that due contribute to their development.

The first of these is daytime heating. Insolation creates dry convection often referred to as thermal activity. This is less about lift and more about buoyancy. That is, heated air becomes buoyant and then rises. This is most pronounced when the sun is strongest during the day or during the seasons such in late spring, summer and early fall. This dry convection alone isn't enough to create deep, moist convection. It's just the first stage.

If you do much flying in mountainous regions, you've probably experienced thunderstorms that tend to develop over mountain ranges. This occurs due to orographic lift. That is, air that is moving horizontally over steep terrain ascends up and over the mountains. These mountain-induced thunderstorms most commonly develop in the afternoon hours and are usually assisted by daytime heating in the presence of unstable air.

Frontal convection generally occurs along and ahead of frontal boundaries. As discussed earlier, as air masses move from one source region to another, they create density discontinuity called a frontal boundary between warm and cold air. The movement of air over this boundary creates lift. Assuming there is available moisture and instability, thunderstorms may form.

As air moves from high pressure to low pressure near the surface, it often converges at these boundaries as shown in Fig. 18-2. If air converges, it will be forced upward where the pressure aloft is lower. Lifting occurs when low-level flow meets at the center of a low pressure system or pressure trough such as a frontal boundary.

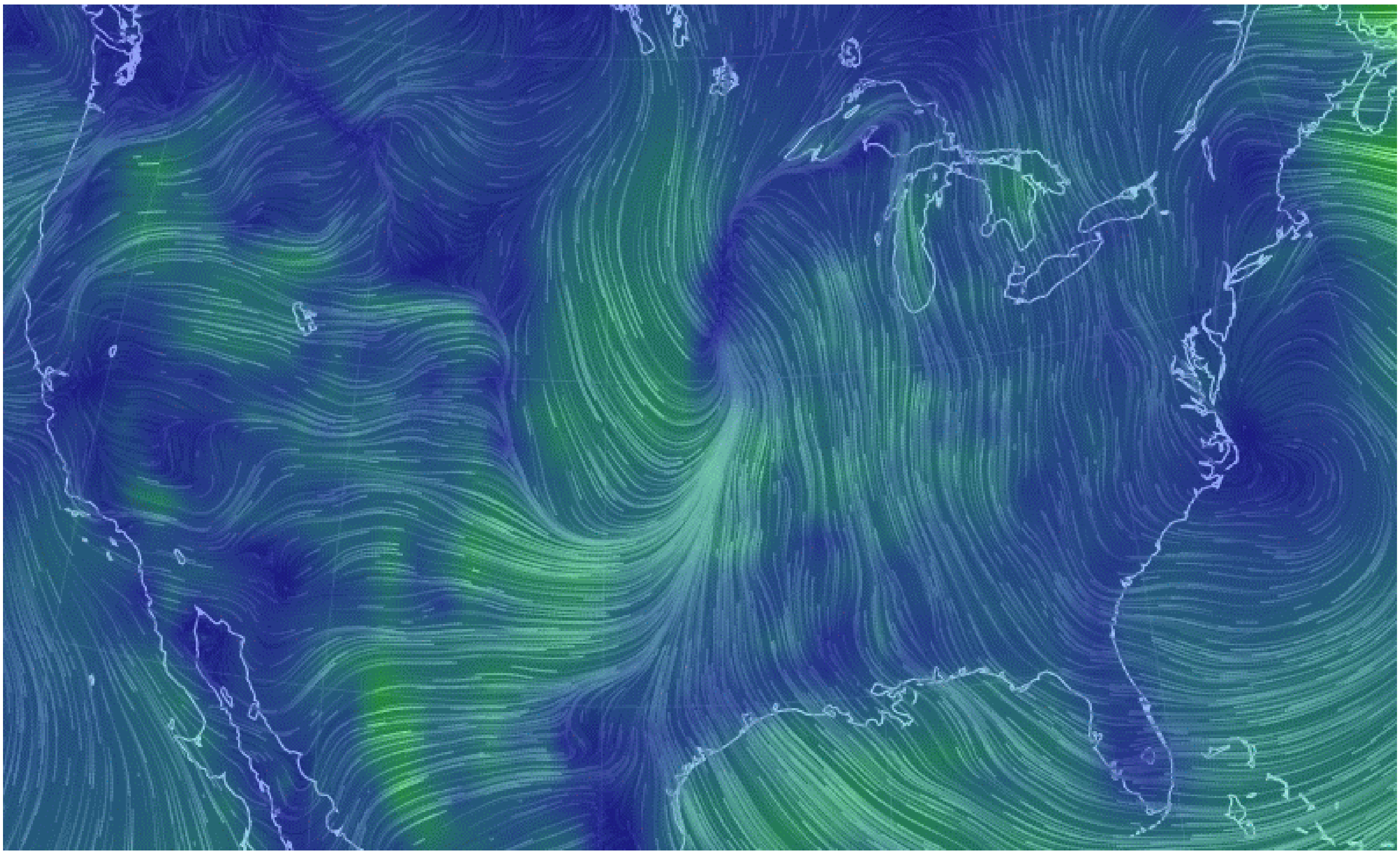

Fig. 18-2: *Using a wind particles chart, it's easy to visualize areas of convergence. The air is flowing from south over Texas and from the west over the southern High Plains. These two flow patterns then converge further north into the central and southern Plains. Visit https://earth.nullschool.net.*

The weather is three dimensional, of course. So, something like divergence where air is flowing outwards, or diverging at higher levels of the atmosphere, creates opportunity for air to ascend from below to fill the void that divergence creates. Because a jet stream corkscrews like a helical vortex, there tends to be lift (divergence) at the right entrance and left exit of a jet streak axis.

Tropical clouds and thunderstorms, known as tropical convection, are often organized into clusters maintaining many individual cells. This organized convection spans a range of scales, from squall lines to mesoscale convective complexes, to tropical storms and finally hurricanes. Hurricanes are powerhouse weather events that suck heat from warm tropical waters to fuel their fury. These violent storms form over the ocean, often beginning as a tropical wave—a low pressure area that moves through the moisture-rich tropics, possibly enhancing shower and thunderstorm activity.

As this weather system moves westward across the tropics, warm ocean air rises into the storm, forming an area of low pressure underneath. This causes more air to rush in. The air then rises and cools, forming clouds and thunderstorms. During the summer and early fall, these clusters of storms can congeal into a circulation. If the circulation does not interact with significant shearing winds aloft, it may deepen rapidly and become an intense area of low pressure and eventually achieve tropical storm or hurricane status. Hurricanes are convective machines.

Sea breezes are very common along the Gulf of Mexico and the southeast Atlantic coastal regions. Sea breeze showers and thunderstorms develop due to a temperature difference between land and sea, triggering a local circulation that can lead to lifting and thunderstorm formation, especially during the summer months. The land heats up faster than the sea, creating a low-pressure area over land and a high-pressure area over the sea. This pressure difference drives a sea breeze onshore, which can meet rising warm air over land and create a sea breeze front, triggering inland thunderstorms. Of course, at night, the land cools and the ocean or Gulf waters are warmer, and the convection tends to occur offshore.

Outflow boundaries (to be discussed shortly) can lay down low-level boundaries produced from thunderstorms or thunderstorm complexes. This provides a pool of cold, dense air (a mini cold front of sorts) that moves outward and can add enough lift to spawn new convection. Each day's thunderstorms often lay down these outflow boundaries that will almost certainly play a role in the next day's activity.

Sometimes two or more lifting agents can be present at the same time, compounding thunderstorm development. For example, a well-developed cold front moving quickly over hilly or mountainous terrain coupled with summer daytime heating may result in widespread areas or lines of thunderstorms.

Thunderstorms produce a variety of adverse weather, most of which are significant to aviation. Expect moderate to severe, possibly extreme, turbulence. The air is moving violently below, near, in and sometimes above a thunderstorm. Updrafts can occur in the range of 5,000 to 6,000 feet per minute and maybe even faster! To put this in perspective, this may exceed the maximum climb rate of most commercial airliners. At the other extreme, a Cessna 172 climbs 800 to 1,000 feet per minute *on a good day*.

The downdrafts aren't quite as severe, but can easily create an unpleasant experience, with downward rushing air at rates of 1,500 to 2,500 feet per minute. A downdraft can rapidly rob you of altitude and that's especially problematic when you are close to the surface during landing or takeoff.

Because convective updrafts can support large quantities of supercooled liquid water, penetration into deep, moist convection is conducive to moderate to severe clear icing at flight levels above 0°C. In fact, the range of convective icing includes static air temperatures as cold as -37.5°C based on evidence provided by research aircraft. As will be discussed later, convection is the most common producer of supercooled large drop (SLD) icing.

Fig. 18-3: *This aircraft-induced a lightning strike occurred in a region where there were no convective SIGMETs anywhere close by. The lightning strike entered or exited a mirror that is positioned under this Cessna's wing. This resulted in a bit of black charring on the right side of the mirror. Photo courtesy of Kenneth McLauchlan.*

Flying near a thunderstorm always heightens the risk of falling victim to a lightning strike. A lightning strike to a metal aircraft will usually enter an aircraft and exit without damaging it structurally. In some cases, you may simply notice a burn mark or charring as pictured in Fig. 18-3. It may also damage sensitive avionics. Without proper lightning strike protection, the carbon fiber/epoxy composites can be significantly damaged, particularly at the entry and exit points of the strike. Approaches have been developed to protect the composite structures from lightning's direct effects to reduce damage to acceptable levels by using conductive foils or meshes in the outer layer of the composite system. Some aircraft also have static wicks on the wings or tail to dissipate the energy from that strike.

Tragic accidents create opportunity for improvements

On December 8, 1963, while flying from Baltimore to Philadelphia, the Boeing 707-121 crashed near Elkton, Maryland. All 81 passengers and crew on the plane were killed. An investigation by the Civil Aeronautics Board concluded that a lightning strike had probably ignited fuel vapor in one of the aircraft's fuel tanks, causing an explosion that destroyed the left wing. The exact manner of ignition was never determined, but the investigation increased awareness of how lightning can damage aircraft, leading to new regulations that resulted in safety improvements.

However, lightning has been known to leave small pinholes in the fuselage, usually in the nose or tail, with rare cases of more substantial damage. When a known lightning strike occurs, the points of attachment and detachment on the aircraft surface are visually inspected and checked for damage to ensure continued flight safety. Repairs may be required to replace damaged composite sections per FAA procedures.

A pilot can have *two* kinds of lightning encounters in flight. The first one can be described as "being in the wrong place at the wrong time." Literally, the flight path of the aircraft intercepts a lightning stroke that is already in progress within or near an active thunderstorm. While this is rare, it normally occurs down low during the approach to land or climbing out after takeoff.

The other more likely encounter is one induced by your own aircraft. As the aircraft moves through the air, it builds up a charge that can trigger a lightning strike (aircraft induced). Because huge volumes of air are moving around, areas of positive and negative charges develop. When these charges accumulate sufficiently, the electric potential builds up to a critical point and discharges with a lightning flash.

There are many observed cases of lightning strikes to aircraft inside or near clouds that had not previously produced natural lightning. Studies show that about 90% of the lightning strikes to aircraft are thought to be initiated by the presence of the aircraft itself. The scary statistic, however, is that 40% of all discharges involving airborne aircraft occurred in areas where no thunderstorms were observed. A typical airliner is struck once for each 3,000 flight hours...or about once a year.

Remember Apollo 12?

One of the more famous cases of aircraft-induced lightning is the Apollo 12 launch at the Kennedy Space Center in 1969. The Saturn V rocket was struck not once, but twice on its way into orbit. However, it did not affect the mission. According to the NASA report, other than these two strikes, there was no other lightning activity reported six hours before or six hours after the launch. However, broken towering cumulus (Tcu) topping out at 23,000 feet with moderate rain showers were reported in the area at the time of the launch.

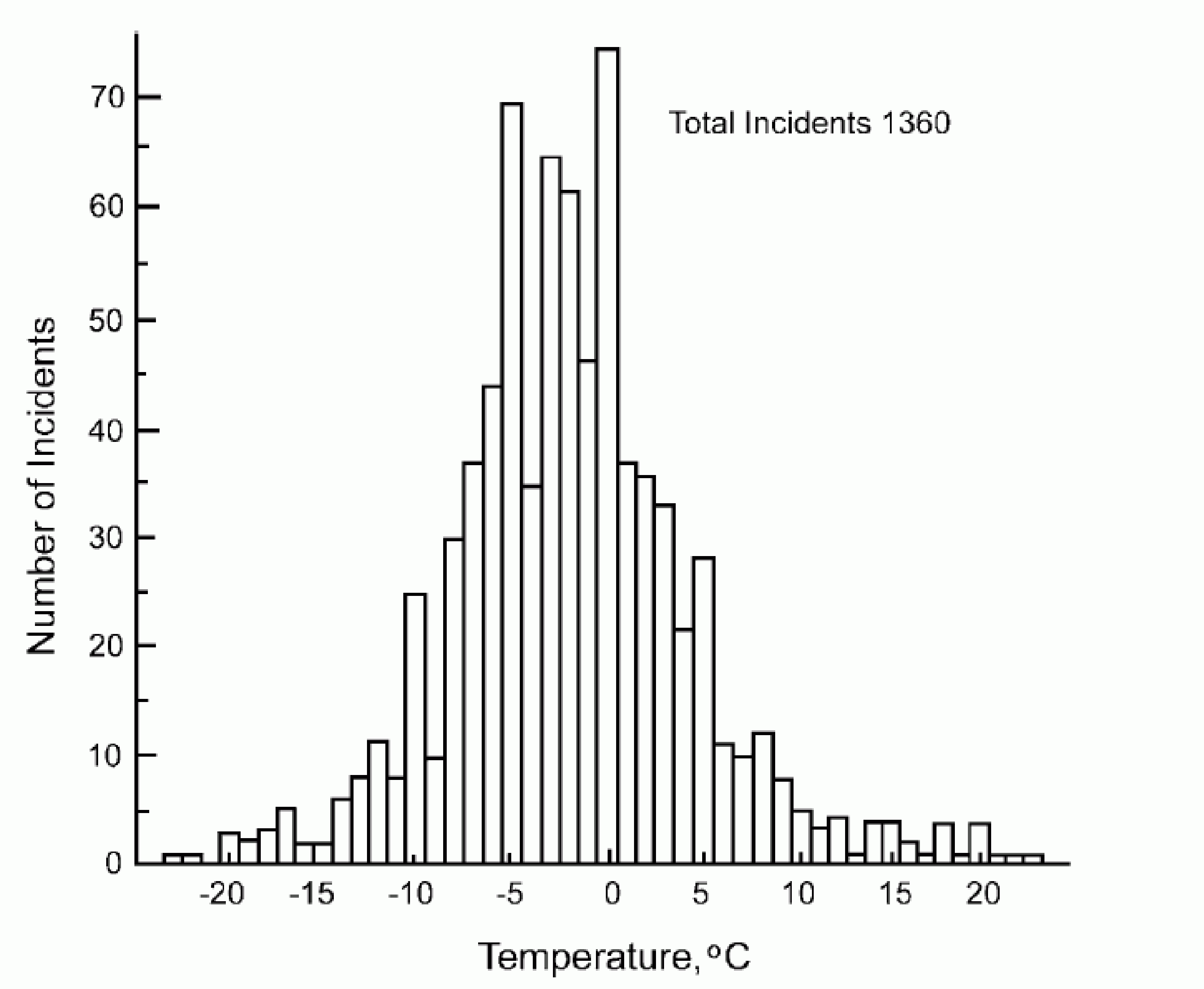

Fig. 18-2: *Most aircraft-induced lightning strikes occur when the aircraft is flying when the static air temperature is near 0°C. From M.A. Uman, et.al.*

While aircraft-induced lightning is still being actively studied, there are a few important characteristics to consider. Based on the current research it doesn't take flying in or near a thunderstorm to become the victim of a lightning strike. Any weather situation producing precipitation appears to be capable of causing electrical discharges to aircraft in flight. In other words, the mere presence of the aircraft in an environment conducive to an electrical discharge is all that is necessary. Most of the aircraft-induced lightning discharges during the warm season occur when the aircraft is at an altitude close to the melting level. As shown on the graph in Fig. 18-2, the preferred temperatures include a range of +3°C to -7°C, with the highest number of incidents occurring right at the freezing level (0°C). Fig 16.3 demonstrates the preferred altitudes where aircraft-induced lightning strikes occur during the warm season. This makes perfect sense since it tends to map well with the height of the freezing level for this time of the year.

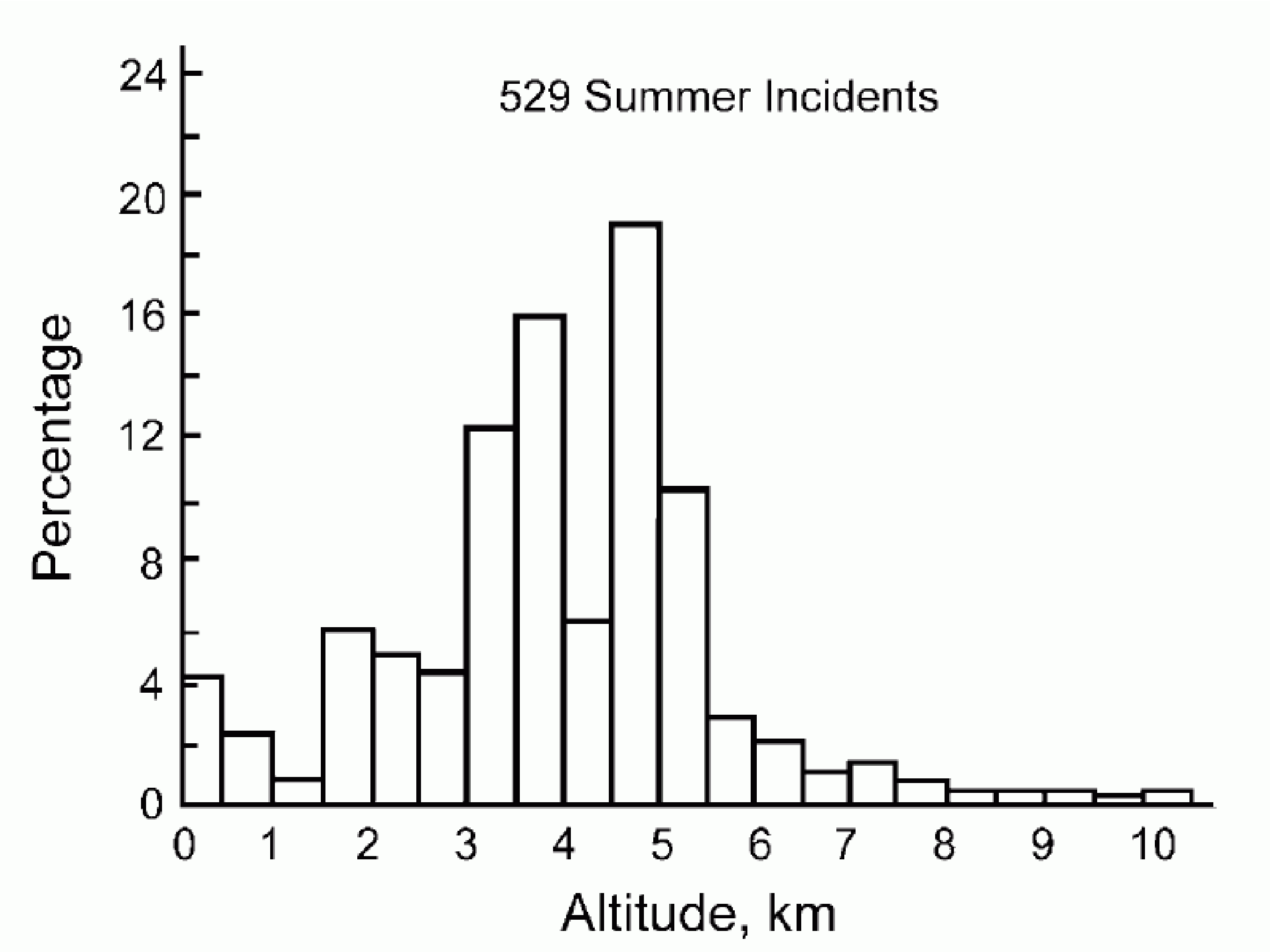

Fig. 18-3: *During the summer, aircraft flying between 10,000 to 16,000 feet are more prone to an aircraft-induced lightning strike. From M.A. Uman, et.al.*

Of course, thunder is produced by the rapid expansion of air as lightning tunnels through the atmosphere. The air surrounding the lightning channel or pathway expands explosively and creates a shockwave, producing the sound waves of thunder. Even though it poses no physical threat, it sounds the alarm that deep, moist convection is nearby. If you are doing your preflight walkaround and you hear thunder, it's best to go indoors. If you can hear thunder, you are close enough to be struck by lightning.

I'm not shocked that thunder is a hot topic

Thunder is the sound of the shockwave that lightning produces as it heats the air to a whopping 30,000°C in less than a second. This is five times the temperature on the surface of the sun! Like all gases, air expands when heated. The faster it is heated, the faster the rate of expansion. When air is heated to 30,000°C in a fraction of a second, a phenomenon known as "explosive expansion" occurs – air expands so rapidly that it compresses the air in front of it, forming a shock wave similar to a sonic boom produced by supersonic aircraft. On a much smaller scale, that static shock you get during the winter on cold, dry days will also produce a "tick" sound which is just a mini version of thunder. It is usually followed with an audible, ouch!

Convective LLWS is one of the biggest hidden threats to aircraft in and around regions with thunderstorms. With updrafts and downdrafts twisting and intertwining, you can get sudden changes in wind speed and direction. Aircraft that are on approach or departing an airport are especially vulnerable to a low-level wind shear event. If showers or thunderstorms are within 20 miles, keep a close eye on the latest surface observations paying particular attention to local winds. Gusty winds or squalls (SQ) are of the most concern as shown in Fig. 18-4 as low-topped convection passed through the Rock Hill/York County/Bryant Field (KUZA) terminal area.

METAR - ROCK HILL/YORK COUNTY/BRYANT FLD (KUZA)

KUZA 291413Z AUTO 20023G45KT +RA SQ BKN010 OVC016 14/14 A2995
RMK AO2 PK WND 22045/1407 P0027 T01440144

Fig. 18-4: *Low-topped convection moved through south Charlotte that included gusty southwest winds (2002345KT), heavy rain (+RA) and squalls (SQ) shown in the EZWxBrief progressive web app. This line of convective weather had no lightning due to its low-topped nature.*

In flight, heavy rain showers beating on the airframe can be so loud you won't be able to hear yourself talk on the radios. The windscreen will be covered in a significant layer of water and your wipers (if you have them) will barely be able to keep up. Jet engines may flame out. Hydroplaning (dynamic) can be expected during landing, and flooding may be an issue, with possible power outages occurring. More importantly, rain showers are triggered by a convective process, so treat these the same as if they were a thunderstorm.

Flying into hail (even pea-sized hail), particularly at high speed, will prove detrimental to the airframe. Leading edges can be severely damaged; pain removed; windshields broken; radomes beaten; various parts, including antennae, broken. Hail may not always fall to the ground as a solid piece of ice, since it often melts on the descent, but these clumps of ice particles can be found inside most thunderstorms.

While most hail shafts occur within the primary core of the storm, hail can be spewed out of a thunderstorm into clear air. This is another reason why it can be dangerous to fly directly *downwind* of a storm where hail is often encountered. It may look clear and seem like a good place to fly, but a surprise hail shaft may be in the making. Also, be leery of thunderstorm overhangs where hail can fall from.

The severe downward rush of cold air is accompanied by damaging winds and is called a downburst. These winds are further labelled based on their diameter. Macrobursts have a diameter of more than two nautical miles whereas the smaller microbursts have a diameter of two nautical miles or less; both phenomena last on the order of 5 to 10 minutes.

Microbursts which will be discussed in more detail later in the text are further subdivided into dry and wet microbursts. Dry microbursts are associated with virga, precipitation that evaporates before it hits the ground and thus cools the air causing it to rush downwards and hit the ground. Virga may be a weather signpost (indicator) of these significant downdrafts. Dry microbursts are more typical in dry climates like the desert Southwest or when the base of the convection is 10,000 feet or higher above ground level. If you have a ring of dust on the ground beneath deep, moist convection, it's a good indication of a dry microburst. Wet microbursts can also occur in regions of very dry air and high cloud bases but often occur in regions with a moisture rich environment.

During the mature stage of a thunderstorm, strong downdrafts called outflow boundaries (that will be discussed in more detail shortly) occur near the surface out ahead of the line or area of thunderstorms that produced it. The turbulence associated within the outflow boundary can be severe. In some cases, strong gusty winds exceeding 40 knots can occur within seconds with these outflows. This kind of outflow boundary is also called a gust front.

Fortunately, not all thunderstorms produce tornadoes—in fact, only one percent or fewer thunderstorms produce a tornado. But thunderstorms that do produce tornadoes are considered severe and demand more respect. While the FAA suggests that you keep a 20 mile distance from any thunderstorm, that advice is naïve. It is wise to keep a 50 mile distance from a severe thunderstorm.

High ice water content (HIWC) occurs in thunderstorm anvils as concentrated areas of ice crystals and has had a documented impact on aircraft engine performance and instrumentation such as pitot tubes. This situation occurred with the tragic accident of Air France Flight 447 as the Airbus A330 crossed the Atlantic traversing through the intertropical convergence zone (ITCZ) where areas of high ice water content existed and clogged all three pitot tubes on the airframe.

A tornado is a violently rotating column of air (mostly counterclockwise but sometimes clockwise) that originates within a thunderstorm and is in contact with the ground. If the rotation does not make it to the ground, it is called a funnel cloud. Tornadoes over water are called waterspouts although most waterspouts form in rather benign weather like the one pictured in Fig. 18-5 and are more closely related to their land counterpart, the dust devil.

Most tornadoes are generally spawned from severe thunderstorms called rotating supercells. A supercell thunderstorm can persist for several hours due to its organized internal structure, which is characterized by a large, single, rotating updraft. Supercells form in regions with a highly unstable air mass, significant low-level moisture (humidity) and strong vertical wind shear—a change in wind speed and/or direction with height. Vertical wind shear induces a horizontal rolling effect near the surface. This rolling effect becomes important when a thunderstorm forms, because the updraft pulls the horizontal vortex upward and causes a thunderstorm to rotate. In rising, the hot air cuts across winds of varying directions and speeds and causes a spiral movement.

Fig. 18-5: *Mature waterspout offshore. These are common along coastal regions like Key West, Florida. Photo courtesy of Brandon Hull.*

Most pilots are taught that there are *three* stages of thunderstorm development as illustrated in Fig. 18-6. Generally speaking, this is correct, but it's not as clear cut as it sounds.

The first stage is called the cumulus stage. This may also be known as the "towering cumulus stage" or "developing stage." Strong updrafts dominate in this stage, with tops reaching into the 20,000-foot range. The upper portion of the developing cloud has the greatest updraft rate, with speeds reaching 3,000, perhaps 4,000 feet per minute. You can even watch these grow vertically in real time. At this altitude, the top of the cloud is now above the freezing level, with temperatures colder than −20°C. Although there is plenty of supercooled liquid water in these clouds, these colder temperatures create ice crystals which help raindrops to form.

As the raindrops grow, they will eventually fall as showers, denoting the onset of the thunderstorm's mature stage. As mentioned earlier, not all rain showers make it to the mature stage. The updrafts are enhanced twofold by the release of latent (stored) heat. The first enhancement occurs as water vapor condenses into water drops and the second as water drops nucleate and freeze into ice crystals higher in the cloud. The release of latent heat is also a huge driving force in the development of hurricanes. The average life span for the cumulus stage is 20 minutes. The cumulus cloud usually grows higher than it is wide, becoming a towering cumulus cloud (Tcu).

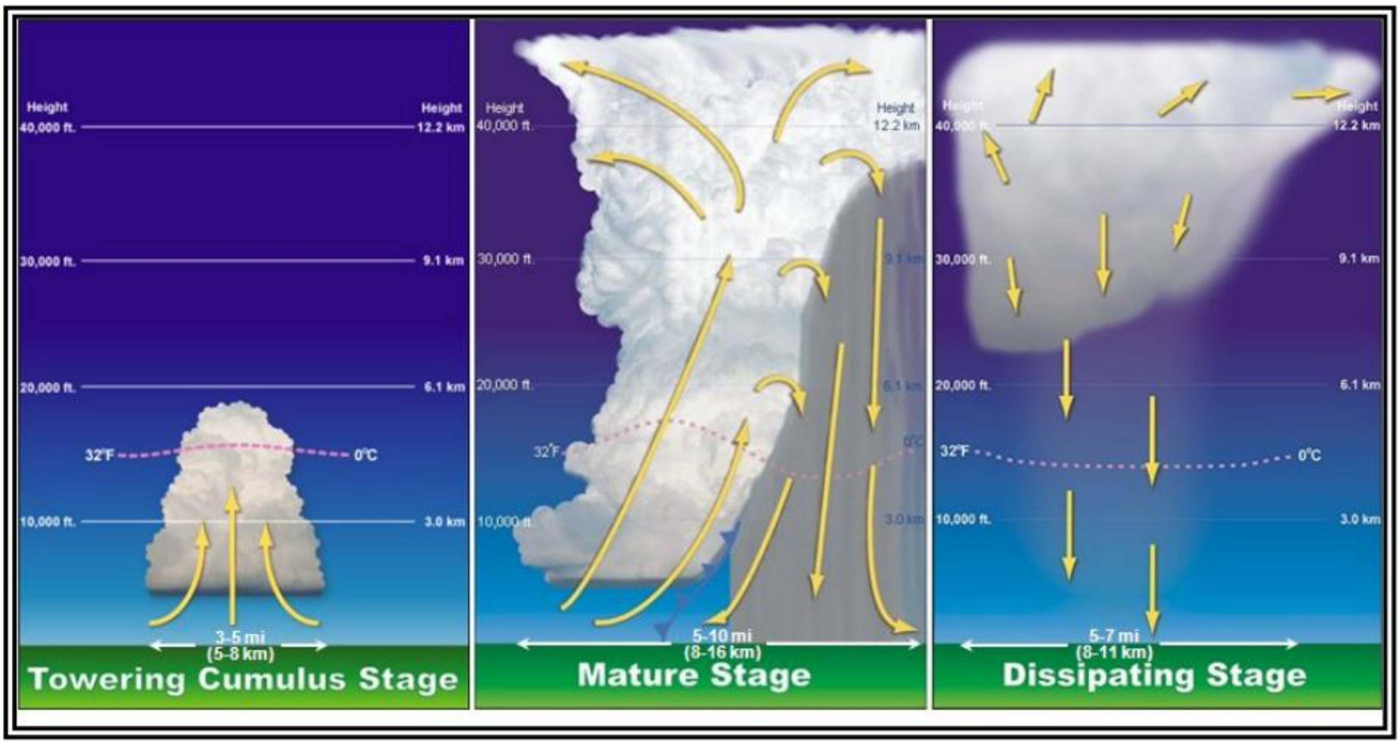

Fig. 18-6: *Three stages of thunderstorm development include the towering cumulus stage, mature stage and dissipating stage. Image courtesy of the Aviation Weather Handbook, FAA-H-8083-28A.*

The mature stage starts with the onset of rain as the precipitation core gets heavy enough to overcome the extreme updraft. The cloud begins to grow in width and height. The maximum height reached at this stage will depend on many variables, but 25,000 to 45,000 feet is the norm, with some thunderheads (Cbs) exceeding 55,000 feet. They are between 5 and 30 miles wide. Updrafts are clocked at 6,000 feet per minute. That's 60 knots—highway speed!

Fig. 18-7: *The author snapped this picture while flying at 15,000 feet in a Columbia 400 over South Carolina. This shows a mature thunderstorm topped with the classic anvil as the storm tops reach the tropopause and flatten out.*

An "anvil," a flattening effect that creates a shape like a blacksmith's anvil, occurs as updrafts poke into the stratosphere as pictured in Fig. 18-7. At the tropopause the rising air tends to flatten out. The tropopause is the interface between the troposphere and the stratosphere. The stratosphere (read stratified or stable) is characterized by a deep temperature inversion or at least an isothermal layer where the temperature no longer increases or decreases with height. As will be discussed later, air that expands and cools to rise into a warmer environment aloft in the lower stratosphere (the inversion) will slow its vertical motion.

If the updrafts are extremely strong, the cloud can penetrate (overshoot) the tropopause by 5,000 to 10,000 feet. Not all thunderstorms make it as high as the tropopause. In this case, they will not have the classic anvil shape like these low-topped thunderstorms pictured in Fig. 18-8. However, by knowing the height of the tropopause, you will have some idea as to the upper limit or what is called the equilibrium level (to be discussed later).

Fig. 18-8: *The author snapped this picture while flying at 22,000 feet in a Columbia 400 over Utah. Based on the SiriusXM satellite weather shown on a G-1000 multifunction display, there were dozens of lightning strikes throughout this area. Notice that there's no anvil on this low-topped convection.*

What goes up must eventually come down. Downdrafts of 2,000 to 3,000 feet per minute develop because of cooling, which is caused by evaporation. Furthermore, falling raindrops drag (entrain) cold air with them, enhancing the downdrafts. The rising and falling of air in thunderstorms can cause lightning, microbursts, gust fronts, wind shear, hail, and possible tornadoes to occur. Just think of the shear on an airplane when descending winds of 3,000 feet per minute meet explosive updrafts of 6,000 feet per minute! The storm will move under the influence of the upper winds and there will be tilting or shearing of the clouds in the direction of the increasing wind with height. During the mature stage, thunderstorm hazards reach their greatest intensity.

In the dissipating stage falling precipitation tends to cool things at the lower levels and the thunderstorm cell begins to die a slow death, but the top of the thunderstorm may be quite active for some time thereafter. The widening and spreading of the thunderstorm anvil usually occurs at this stage of development.

Thunderstorms as individuals may only be tens of miles wide, but clusters of storms will consist of cells in different stages of their life cycles, meaning that the cumulus, mature, and dissipating stages are all transpiring within the cluster. They can take on different guises, forming and reforming within minutes. Sometimes just when you think you have cleared the tops, these monsters will engulf you. Flight underneath thunderstorms is not advisable, as severe turbulence may be encountered. The sure bet and safe method is always avoidance, and that means going around and upwind of most thunderstorms so they are moving away from you. Beware of the sucker hole; many pilots think they can "pick" their way through an opening, only to find themselves quickly engulfed. If you are going to pick your way through a line or area of thunderstorms, you should have onboard radar and understand how to use it.

The rule of thumb is to deviate around thunderstorms early, about 80 to 100 miles ahead. Datalink weather broadcasts can help with this. Deviations around weather will often translate into more distance over the ground and thus tap into your fuel reserve. A 10-to-15 degree "cut" may be all that is required for deviation. Always try to deviate on the upwind side of a storm if at all possible.

Don't be slow nor timid with air traffic control to ask for a heading change. Remember, there may be others deviating, and the controllers are busy. Sitting on the edge of your seat patiently trying to get a word in as the ominous cloud gets closer and closer is nerve racking.

Most importantly, don't blindly assume that controllers can always see the weather directly in front of you. Most air traffic controllers are not pilots. They also can't see clouds and their radar cannot directly detect turbulence. Consequently, they don't see that building towering cumulus cloud that you are about to penetrate that may contain severe or extreme turbulence as you fly through it. Unless it is producing some form of precipitation, without reports from pilots, the controller sees this as perfectly clear air. Moreover, that airspace then becomes fair game for the controller even though it might be a really rough ride for you. Essentially, they are in the dark until a pilot speaks up. In times of extreme weather or in busy airspace, the controller may have to turn down or even turn off the weather radar just to clearly see aircraft returns on their scope, so you can't always rely on their help for weather avoidance.

Controllers are people too

Even though a controller may sound as cool as a cucumber, they can get task saturated at times. This is especially true when convection starts to erupt closing down airspace quickly. Aircraft can't just "pull off the side of the road" and wait it out. All of those aircraft will need to be rerouted and that may require the controller to coordinate this with other sectors within their facility and coordinate with other facilities. It's very dynamic given the chaotic nature of convection. So, don't be too surprised when controllers don't respond immediately to your request or when you check in after a handoff. They may be talking with their cohort on another line to develop a plan of attack to keep us all safe.

If you must deviate around convective weather, do not wait until the very last minute. Ask for deviations and advice long before you need it. Here's a pro tip: if you find yourself regularly needing heading changes of more than 30 degrees, you are too close to the weather and making decisions too late. In most cases you should be deviating by 10 to 15 degrees while en route. Yes, if you need a 60 degree deviation to maneuver around a building cell, do it. But just keep that habit to a minimum. It will help lower your blood pressure and make the controller's job much easier when deviations are small and deliberate. And if you have onboard radar, let the controller know when you request a deviation.

First and foremost, be assertive. That is, don't just say, "I need a deviation around weather." Tell the controller how far you need to deviate left or right of course during your first transmission. Also, let them know how long you will need this deviation (e.g., 15 miles). Your call should sound something like this, "Jax center, Cessna 34B needs 10 degrees left for weather for the next 15 miles." Even better, look at your multifunction display or iPad and find a fix or intersection they can use. For example, "Jax center, Cessna 34B needs 10 degrees left for weather until passing the Chesterfield VOR in 15 miles." This helps them coordinate your route with other facilities and it may require that your route be amended in the system or handed off to another controller if the deviation places you outside of their sector.

Thunderstorms primarily move with the mean wind in the lower part of the atmosphere (troposphere). The movement of thunderstorms tend to be associated with two motion vectors. The first vector is the movement of the controlling air mass. This is usually associated with a frontal boundary (e.g., cold front). The second vector is the upper-level wind direction. This is usually controlled by the winds at and below the 500-millibar (18,000 feet) level (5 to 7 km).

Think about a train on tracks. The train is the convective cell. The tracks represent the 500 mb level winds. However, imagine that the train tracks are not stationary but are also shifting while the train is moving. Each cell in that line or area of thunderstorms will move on a path that combines both vectors. For example, if the air mass is moving from the northwest to southeast and the upper-level winds are blowing from the southwest, then the cell's motion is likely to be to the east.

There are *three* types of thunderstorms, namely, pulse type, frontal and supercell. Pulse-type thunderstorms are colloquially referred to in the media as air mass, triggering, garden variety, pop-up or single-cell thunderstorms. In stagnant situations where there's no important change of air mass, every day's heating is usually sufficient to get a new round of pulse-type thunderstorms going assuming there is enough moisture and instability.

These develop in the afternoon and early evening and tend to be isolated or scattered. Single-cell storms are short-lived (30 – 60 minutes) with one updraft that rises rapidly through the troposphere. Precipitation begins to fall as the cell grows from the towering cumulus stage to the mature stage. The precipitation core gets so heavy that it falls back down through the updraft, cuts it off, and the storm "rains" itself out and dissipates. Tornadoes are rare with short-lived high wind events and small hail are possible.

They typically disperse at night once the sun has set. Cold moist air passing over warm water may lead to thunderstorms, but these seldom get as large as the ones that form over land. If an unstable flow of moist air is lifted over a hilly terrain or mountain range (an orographic thunderstorm), the thunderstorms will form along a line and persist on the windward side.

Frontal thunderstorms develop on cold, warm or even occluded fronts. Beware of a well-defined, fast-moving cold front in the middle of a summer day. Thunderstorms can form night or day and over sea or land. They tend to form along a line, possibly extending hundreds of miles. This is where any deviation you make can translate into hundreds of miles, requiring lots of extra fuel. Flight dispatchers will slate extra fuel for these events. Sometimes a prefrontal squall line of thunderstorms can develop 100 to 200 miles ahead of an active cold front, becoming downright violent.

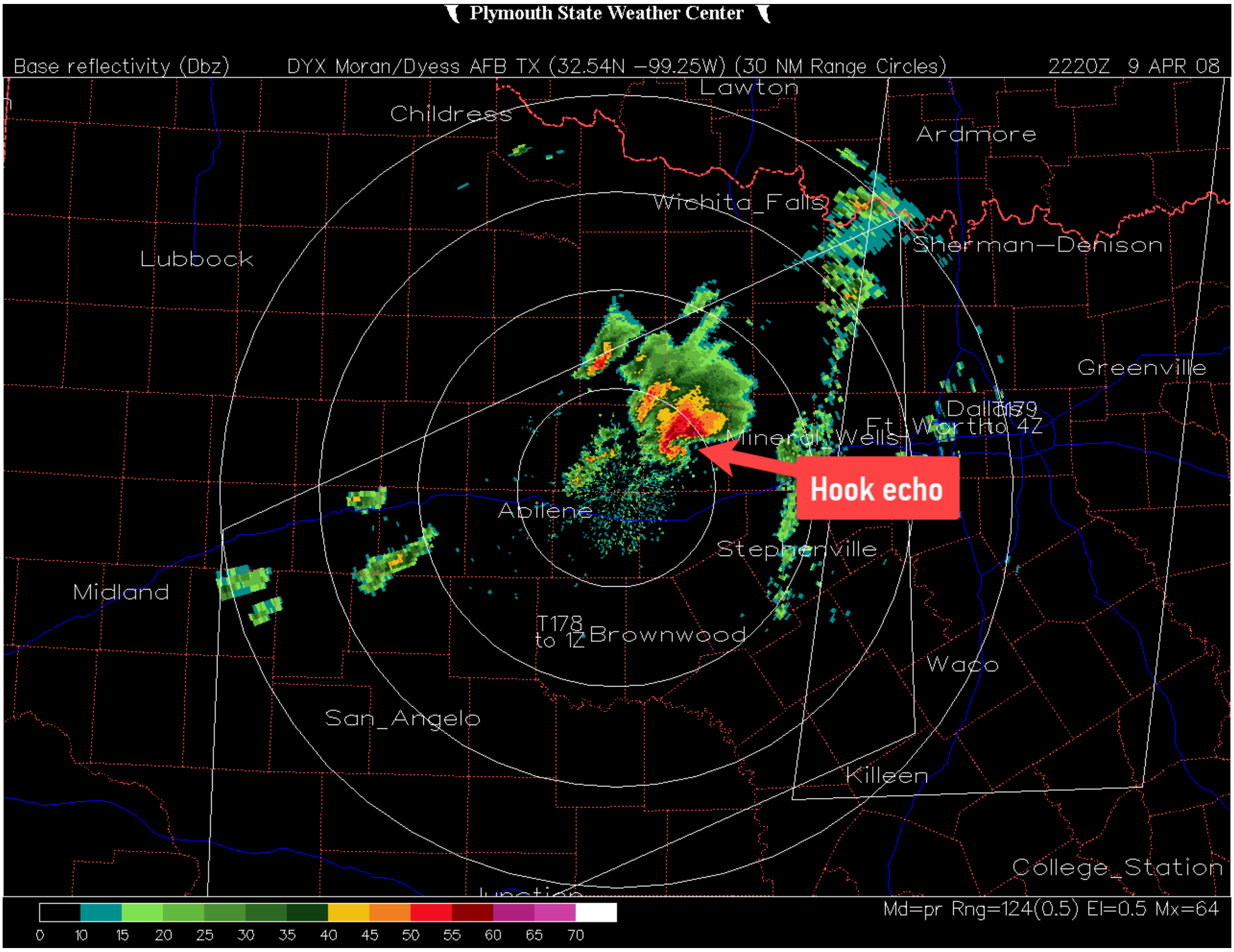

Fig. 18-9: *Class supercell thunderstorm near Abilene, Texas is identified by a "hook echo" in the 0.5° base reflectivity pattern. This may also create a tornadic vortex signature on the Doppler base velocity data.*

Supercell storms demand your deepest respect. They consist of one quasi-steady rotating updraft, forward flanking downdraft that forms the gust front, and a rear-flanking downdraft. These storms persist for several hours and are frequent producers of severe weather creating strong straight-line winds, large hail and destructive tornadoes. There are generally three accepted types of supercells, namely, classic, high-precipitation (HP) and low-precipitation (LP). They can be embedded along a line or in an area. Often supercell thunderstorms have a hook echo in the low-level reflectivity pattern like the one shown in Fig. 18.9.

Here are a few dos and don'ts with respect to deep, moist convection, The number one rule is to avoid, avoid, avoid! But sometimes, that option is a challenge. Don't land or take off in the face of a thunderstorm. A thunderstorm is its own wind generator, changing from light and variable winds to intense gusts and shears with huge directional changes. You may think you can beat the line of weather, only to face extremely challenging winds on landing or takeoff.

Don't try to fly underneath deep, moist convection. Turbulence could be malicious and there may be hail! More importantly, if the base of the convection is greater than 10,000 feet and the dewpoint depression at the surface is greater than 20°C, then a microburst could be a real threat even for convection that contains no lightning.

***Fig. 18-10:** In cell mode the Stormscope attempts to cluster strikes around the location of the cell as shown here on a Garmin 530 GPS.*

Don’t penetrate an area of thunderstorms without a serviceable onboard weather radar which you know how to use. A sferics device such as a Stormscope provides real-time lightning strike information like the one pictured in Fig. 18-10. Most small aircraft do not have onboard radar or sferics device, and that means turn around, divert, or stay away!

The rule of thumb for avoidance is to stay 20 miles away! You may read that if you are below the freezing level, you should stay 10 miles away from a visible sighting or radar return. This may work for the average pulse-type thunderstorm. For thunderstorms that are exhibiting severe characteristic such as large hail, strong winds and/or tornadoes, 50 miles is a more comfortable distance.

Obviously, you will tighten your seatbelt and secure loose articles. Loose articles and cause physical injury to you and your passengers and can break glass like the Bonanza shown in Fig. 18-11 that encountered extreme turbulence in a convective cell. Slow the aircraft down to turbulence penetration speed to ride out the pending jolts. It is frequently suggested to turn up cockpit lighting to lessen the danger from temporary blindness due to lightning.

Fig. 18-11: *This Beechcraft Bonanza ended up flying into a building low-topped convective cell at 7,000 feet that contained no lightning. The pilot recovered the aircraft at 1200 feet AGL. Notice the shattered pilot-side window. This could have been caused by a loose object inside the cockpit.*

If you happen to "stumble" into a storm, many official sources like the Aeronautical Information Manual (AIM) will tell you that it's not advisable to turn back in this situation, because the load from turning may stress the aircraft. Essentially the guidance is to maintain level wings and accept altitude deviations. They believe that you'll hopefully pop out on the other side of the storm in short order. Well, that's fine if you enter the storm in such a way that this works. But what happens if you are flying essentially parallel to the line? It may be a hundred miles or more before you "pop out" of the line. Assuming the aircraft is controllable, turning off the "altitude hold" on the autopilot and accepting any altitude deviations while doing a slow and consistent "180" is going to get you out of the cell the fastest.

Remember the golden rule: aviate, navigate and communicate. If you are flying under instrument flight rules, the last thing to worry about is trying to key the mic and letting the ATC know that you can't hold altitude. They will figure it out…and besides, there are likely no other aircraft above or below you anyway to create a loss of separation. If they can't immediately help you, then don't waste your time adding another distraction from your real emergency. Also, remember that you can have an emergency without actually declaring an emergency. Regulations allow you to break any rule to meet that emergency.

Last, but not least, are mesoscale convective systems (MCSs). They are a collection of storms that behave as a system. They were first identified in satellite imagery in the mid-1970s before being named mesoscale convective complexes (MCCs) – basically large versions of an MCS. An MCS normally begins as several isolated thunderstorm cells form in the late afternoon or early evening. By late evening, the thunderstorm's anvil cloud tops merge creating the signature circular or oval shape to the clouds you see on the enhanced infrared satellite imagery as shown in Fig. 18-12. This cloud shield can be as large as the state of Wyoming. This cloud shield masks what can be seen as a bow-shaped line of returns on radar imagery like those shown in Fig. 18-13. It is not uncommon for them to occur in pairs.

A beast of burden

A mesoscale convective system (MCS) is a prolific lightning generator. A late-April 2014 MCS along the Gulf Coast produced 6,076 cloud-to-ground lightning strikes in just 15 minutes. Given all that thunder and lightning, an MCS can certainly lead to a sleepless night. Particularly insidious about an MCS is its ability to generate lightning well after the area of heaviest rain has passed, sometimes lingering for an hour or more in a region called the stratiform rain shield. Some of these lighter-rain MCS lightning strikes contain more current than an average bolt, with a greater potential to start a house fire.

MCSs are nocturnal beasts and normally persist into the early morning hours and have a lifespan of several hours to beyond a day. These complexes are typically not fast moving and can become nearly stationary. They can produce torrential rains, flash flooding and hail. Some MCSs might produce tornadoes; however, mature MCSs can produce severe windstorms called “derechos.” Bow-shaped radar echoes are often observed with a derecho. A derecho (pronounced deh-REY-cho) is a long-lived convective windstorm that is normally associated with a rapidly moving line of thunderstorms or MCS. It can persist through the night, traveling hundreds of miles covering a 250 mile-wide path with winds that vary in strength, but can exceed 60 knots at times. Often these derechos are associated with curved signatures similar to a bow echo.

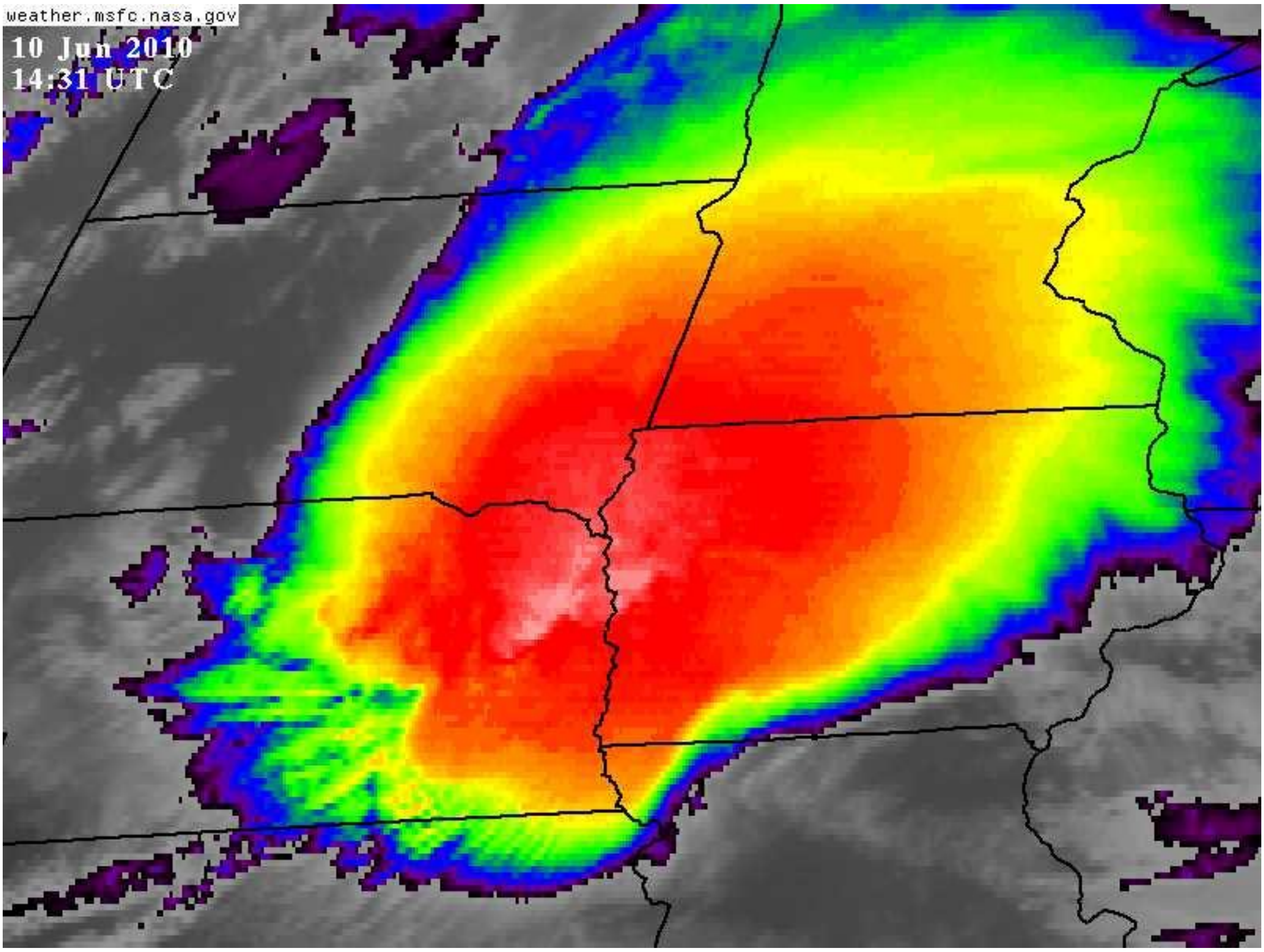

Fig. 18-12: *Example of a mesoscale convective complex (MCC) over the central Plains as seen on the color-enhanced infrared satellite imagery. It’s oval or circular pattern with very cold cloud tops create its signature.*

One such derecho in August 2020 traveled 770 miles from southeastern South Dakota into western Ohio, with winds over 100 mph over central and eastern Iowa. It inflicted over $12 billion in damage to homes, vehicles, businesses and crops, making it one of the most damaging severe thunderstorm events since 1980. Even so, MCSs provide the Great Plains with much needed rain to support growing corn and other crops.

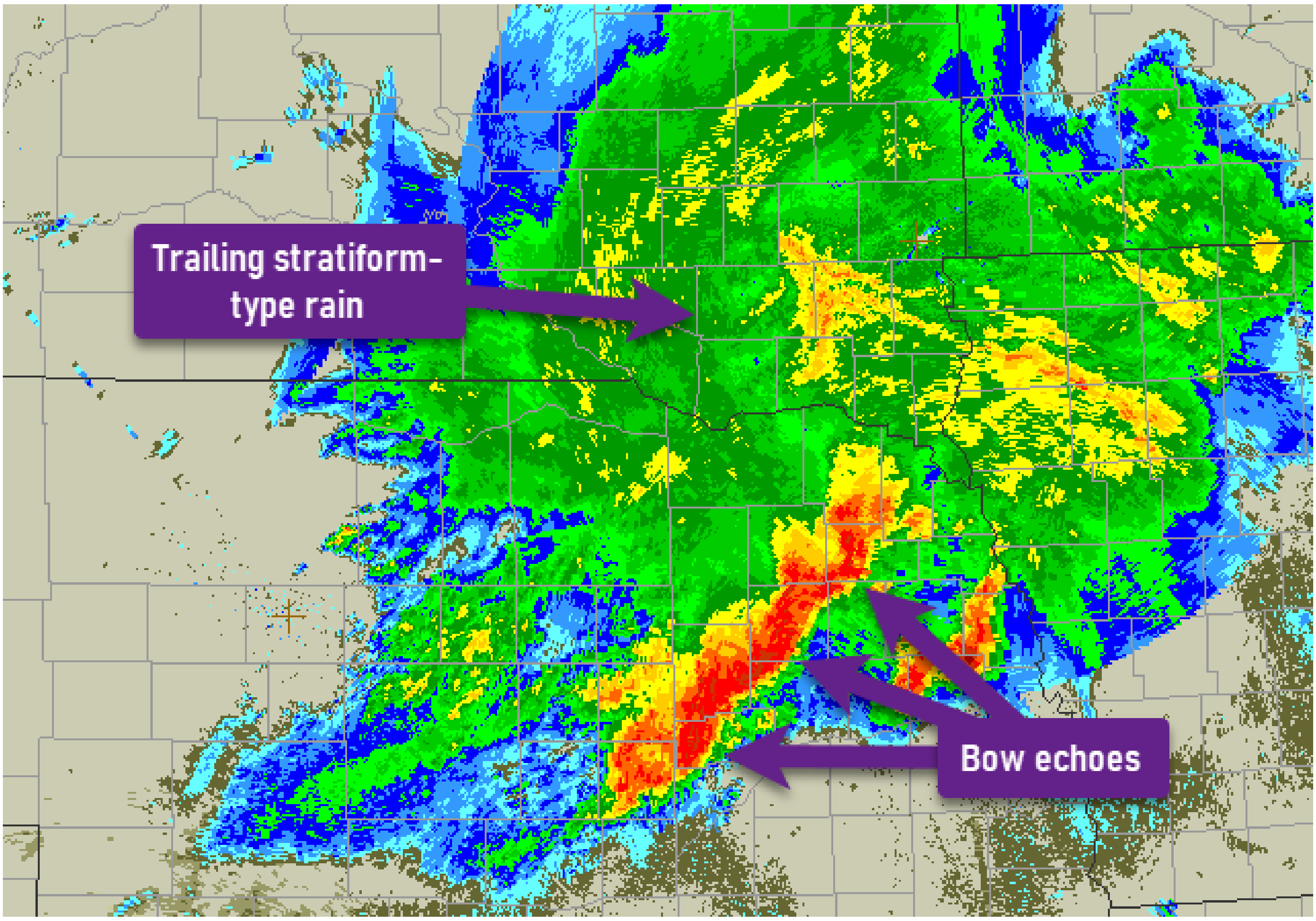

Fig. 18-13: In a mature MCS it is common to a line of one or more bow-shaped echoes indicative of strong straight-line winds. In many MCSs, there's also a large trailing stratiform-type rain that can contain a significant amount of lightning.

These will typically only occur east of the Continental Divide but are rarely seen east of the Appalachian Mountains. As nocturnal systems, they tend to feed off a warm, moist low-level jet stream a few thousand feet above the ground that moves over cooler, stable air at the surface. Their "season" is from late April to late September. They tend to form in a zonal (west to east) upper-air flow pattern along a somewhat benign frontal boundary. As the jet stream retreats north into Canada, the area of development and their track tend to also move north. In the months of April and May, MCSs are most common in the southern Plains and southern Mississippi Valley. June, they tend to occur in the central Plains and middle Mississippi Valley. By July and August, they are typically found in the northern Plains and northern Mississippi Valley.

27-Relative humidity & saturation

One of the key reasons why pilots learn to use the Skew-T is to determine the location and altitude of clouds and cloud coverage, especially during the cold season when airframe icing is more likely to occur. How to determine the presence or absence of clouds solely based on a Skew-T depends on how to properly recognize when the atmosphere is saturated. Knowing whether the air is saturated can be incredibly easy to determine for warm stratiform-type clouds, or incredibly difficult for cumuliform clouds or cold stratiform-type clouds. This depends on many factors that will be discussed soon, but the first important concept to learn is how to measure or forecast the quantity of water vapor in the atmosphere.

What is relative humidity? As mentioned earlier, the earth's atmosphere is composed of mainly molecular nitrogen (N_2) and molecular oxygen (O_2). What about water vapor? In the presence of nitrogen and oxygen, water vapor is considered a trace gas. Even as a trace gas, it has a vital role and is responsible for two-thirds of the greenhouse effect. Most importantly, it is responsible for the formation of clouds and precipitation which is vital to our existence on the planet. While this is not usually covered in the pilot's primary training, it is also responsible for one-sixth of the energy transport from the earth's surface into the atmosphere. This is done via evapotranspiration of water at the ground (storing energy through the latent heat of fusion and vaporization) and ultimately resulting in condensation and freezing in the atmosphere that produces cloud formation and the release of that stored energy. As we will see later, the release of latent heat is vital for the formation of deep, moist convection including thunderstorms and plays a significant role in the production of airframe icing.

The amount of water vapor can be quantified in several ways. A common approach is to measure the exact amount of water vapor by counting the number of water vapor molecules per volume or per mass of air. This simply describes the *absolute* amount of water vapor, and therefore, is referred to as absolute humidity. Perhaps the most common scale familiar to pilots and the general population is relative humidity. You have probably heard your local broadcast meteorologist mention the *relativity* humidity during their segment. But you probably have never heard them mention the *absolute* humidity.

This is because relative humidity has distinct advantages over absolute measures of water vapor in the atmosphere. We know that relative humidity is expressed as a percentage, usually in a range between 0% (totally void of water vapor) and 100% (saturated). An absolute scale, on the other hand, must be much wider because the amount of water molecules at a given location decreases from the surface to the top of the troposphere or tropopause (~36,000 feet) by roughly a factor of 10,000. More importantly, cloud formation through condensation or deposition is controlled by relative humidity, not by absolute humidity.

A tale of two cities

Imagine being at Key West, Florida on a winter day and the surface temperature is a balmy 78°F with a relative humidity of 60 percent. On that same day in International Falls, Minnesota the temperature is a chilly 14°F, but the relative humidity is 100%. Which of these two environments contain more water vapor? Even though the relative humidity is higher in Minnesota, the amount of water vapor in the atmosphere is significantly less than at Key West if you were to compare the absolute humidity.

Relative humidity is defined as the ratio of the actual amount of water molecules to the amount of water molecules when saturation is reached. Saturation is a common term for many applications but is often fraught with misconception when applied to the atmosphere. For example, when a rag or sponge is saturated, it can no longer "hold" any more liquid water. On the other hand, it is incorrect to say that when the air is saturated, it can no longer "hold" any more moisture (i.e., water vapor). That's because nitrogen and oxygen molecules do not have any holding capacity for water vapor any more than they have a holding capacity for carbon dioxide or other trace gases. To be clear, relative humidity is only used in the context of water vapor.

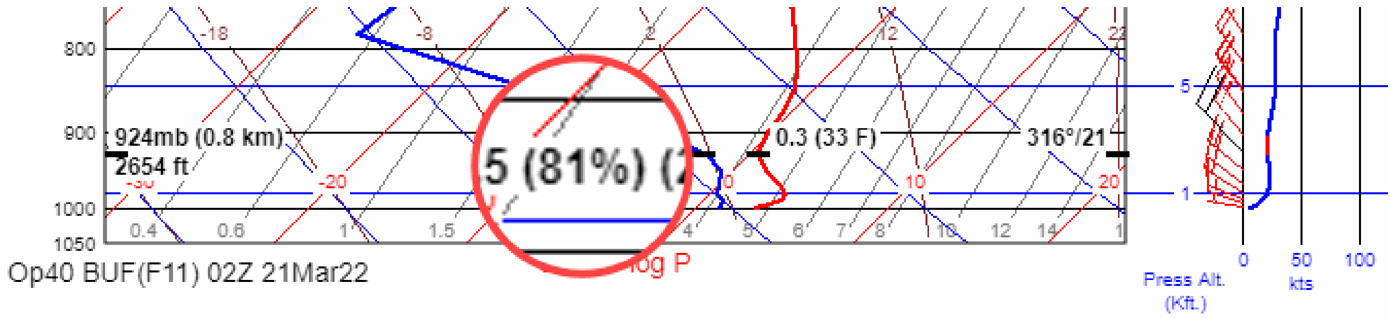

Fig. 27-1: *NOAA's interactive soundings tool automatically calculates the relative humidity for the altitude selected. In this case, the relative humidity is 81% at an altitude of 2,654 feet.*

Surface observations (METARs) do *not* provide the relative humidity directly; only the temperature and dewpoint are provided. Unfortunately, it is not a simple back-of-the-envelope calculation, however. When an observation is decoded, some weather applications will calculate the relative humidity for you. Nevertheless, using NOAA's interactive soundings tool (to be discussed in greater detail later) you can move your cursor up and down over the diagram as depicted in Fig. 27-1 and it will calculate and display the relativity humidity at the altitude where your cursor is positioned.

Keep in mind that this is the relative humidity with respect to *liquid* water. At colder subfreezing temperatures, the air may be saturated with respect to ice (water in the solid state) even though the relative humidity may be less than 100%. For example, in the forecast sounding near the Hartsfield-Jackson Atlanta International Airport (KATL), notice in Fig. 27-2 that the relative humidity is calculated to be **82%** at FL300. However, given a temperature of **-25.7°C** at this altitude, the atmosphere is most likely saturated with respect to *ice* even though the temperature and dewpoint are *not* equal.

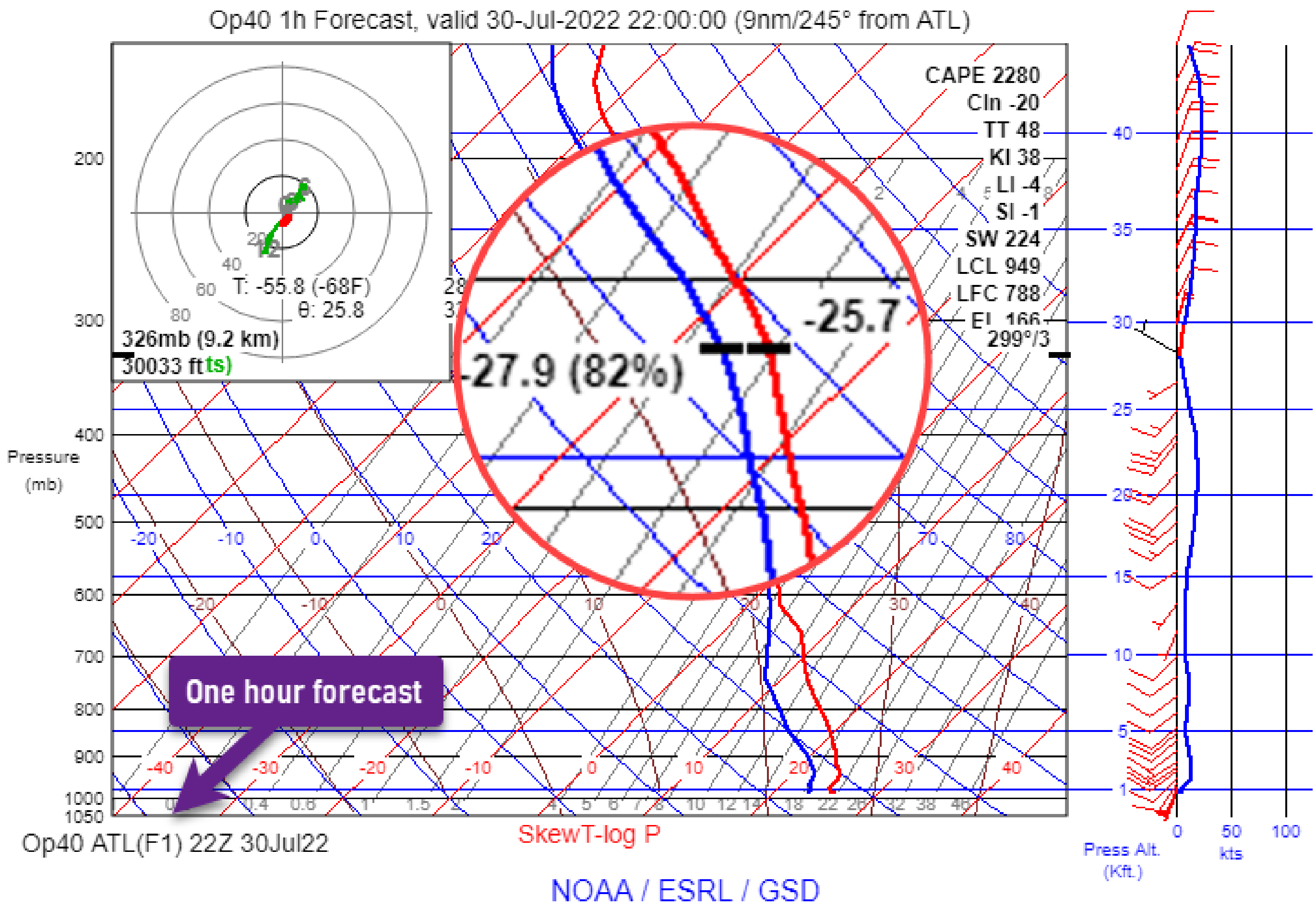

Fig. 27-2: *In this 1-hour forecast sounding (F1) near the Hartsfield-Jackson Atlanta International Airport (KATL) the conditions are likely saturated with respect to ice at 30,000 feet even though the relative humidity is only 82%.*

If you ask a meteorologist to describe saturation, they will likely use the expression "dynamic equilibrium" in their definition. To better understand saturation, let's do a brief thought experiment. Consider an open container of water sitting on your kitchen counter. If you were to leave your house and return two weeks later, do you expect the level of the water in the open container to increase, decrease or stay the same upon your return? Of course, the water level decreases. Why? Simply put, there is a net *evaporation* of liquid water. In other words, while you were gone there was more liquid water evaporating from the surface of the liquid than there was water vapor condensing back into the liquid state (yes, both evaporation and condensation are occurring in this situation). In this case, there isn't an equilibrium, so saturation does not occur.

Now, let's do the same thought experiment, but instead of the container being left open, let's put a lid on it. What do you expect the level of water to be upon your return after two weeks? In this case, the water level in the container will be nearly the same as when you left. After you cap the container, the liquid begins to evaporate into the air between the surface of the water and the lid. At some point, the air in the container reaches saturation. That is, the number of molecules of water leaving the liquid state to become vapor is the same as the number of water vapor molecules condensing back onto the surface of the water. Therefore, the water level stays the same in the capped container because dynamic equilibrium is reached. The water vapor in this case is said to be saturated with respect to liquid water and the relative humidity reaches 100% in the air *just above* the water's surface. The air just below the lid may still be unsaturated.

Water molecules in liquid form in such a container are in constant motion. In their motion, they exhibit energy and collide with each other as well as the walls of the container itself. Some of these molecules gain enough energy during a collision to leave the surface of the water and enter the vapor space above it. **This is evaporation.** At the same time, water molecules in the vapor phase just above the water's surface are also in constant motion, and sometimes some of them store energy and enter the liquid below.

The science behind it

In liquid form (e.g., a cup of water), the amount of water molecules varies only slightly with temperature and pressure. On the other hand, the amount of water vapor molecules immediately above the surface of the liquid varies quite a bit and is highly dependent on temperature (and pressure). Warmer air is less dense which allows for a higher concentration of vapor. Said another way, the flux of water molecules that move out of the liquid state into the vapor state is nearly constant, whereas the flux from the vapor state into the liquid state increases with the amount of water molecules in the vapor state. Dynamic equilibrium is a fancy way of saying that these two opposite fluxes are the same so that the net between evaporation and condensation is zero.

This is condensation. This becomes a continuous exchange of water molecules between the liquid in the container and the vapor space above the water's surface.

We can do the same thought experiment with an ice cube in your freezer. If you keep the ice at a temperature colder than 0°C, then it will remain frozen. Let's say you leave that ice cube in the freezer for a period of six months. Do you believe the ice cube will have grown, remained the same size, or decreased in size? After six months in a frost-free freezer, the ice cube will likely have decreased in size. Why? This is like the open container of water, except the process is much slower due to the colder temperature in the freezer. Essentially, a molecule of solid water (ice) will leave the solid state to become water vapor, even at these colder temperatures. **This is sublimation.**

Phases changes of water

Water naturally occurs in the atmosphere in a vapor, liquid, and solid state. When it moves between these various states, we say it is changing its phase. Phase changes include evaporation (liquid to vapor), condensation (vapor to liquid), freezing (liquid to solid), melting (solid to liquid), sublimation (solid to vapor), and deposition (vapor to solid). Any time a change of phase occurs, water must either store energy or release energy in the form of heat. Often you may hear the term latent heat of condensation when water vapor condenses. This phase change is what drives deep, moist convection that leads to dangerous convective turbulence.

At the same time, water vapor will deposit on the ice cube to become solid. **This is called deposition**. In a frost-free freezer there will be a slow, but sure, net sublimation so the ice cube will get smaller and smaller with time. This is also why snow in colder climates can disappear without melting. Now this must be applied to the atmosphere where liquid (or solid) water is not in a container, but in tiny droplets and ice crystals suspended in the atmosphere. This will be covered in greater detail later as it relates to airframe ice.

Preserve hailstones in the freezer?

Imagine a severe thunderstorm moves over your house and dumps hailstones in your yard the size of a golf ball or tennis ball. You "bravely" run outside and quickly scoop up a dozen hailstones and pop them in your freezer so you can impress your friends and relatives over the next several months. Will they last that long? Certainly, they won't *melt* in the freezer. However, hailstones have a lot of air pockets and over a couple months in the freezer, you will find that those hailstones are now quite small and will eventually disappear over time due to sublimation and your friends and relatives will not be all that impressed. Don't ask me how I know this!

If you happened to climb through a layer of icing conditions and managed to pop out in between cloud layers, can sublimation work in your favor to remove that ice you collected in the climb? Yes. But sublimation is a very slow process, especially if the air is very cold. If you are in subfreezing temperatures, how quickly the ice sublimates will depend on many factors to include the type of ice, static air temperature, humidity, and speed of the aircraft. ■

37-Temperature inversions

From an earlier exploration of the standard lapse rate, we know that in the troposphere, temperature normally *decreases* with *increasing* height. However, temperature can also *increase* with *increasing* height. This is called a temperature inversion. Inversions are limited to somewhat shallow layers and are manifested by several physical processes in the atmosphere that include subsidence, radiative cooling and overrunning.

Subsidence inversion: First, let's look at a couple common ways that a *subsidence* inversion is realized. Subsiding air creates an inversion aloft, which can trap moisture and pollutants, producing hazy conditions we sometimes experience during the warm season. Subsidence inversions from sinking air are normally found under an upper level ridge during fair weather events as shown in Fig. 37-1. As air subsides from higher altitudes it is compressed as it moves from an area of low pressure aloft to high pressure.

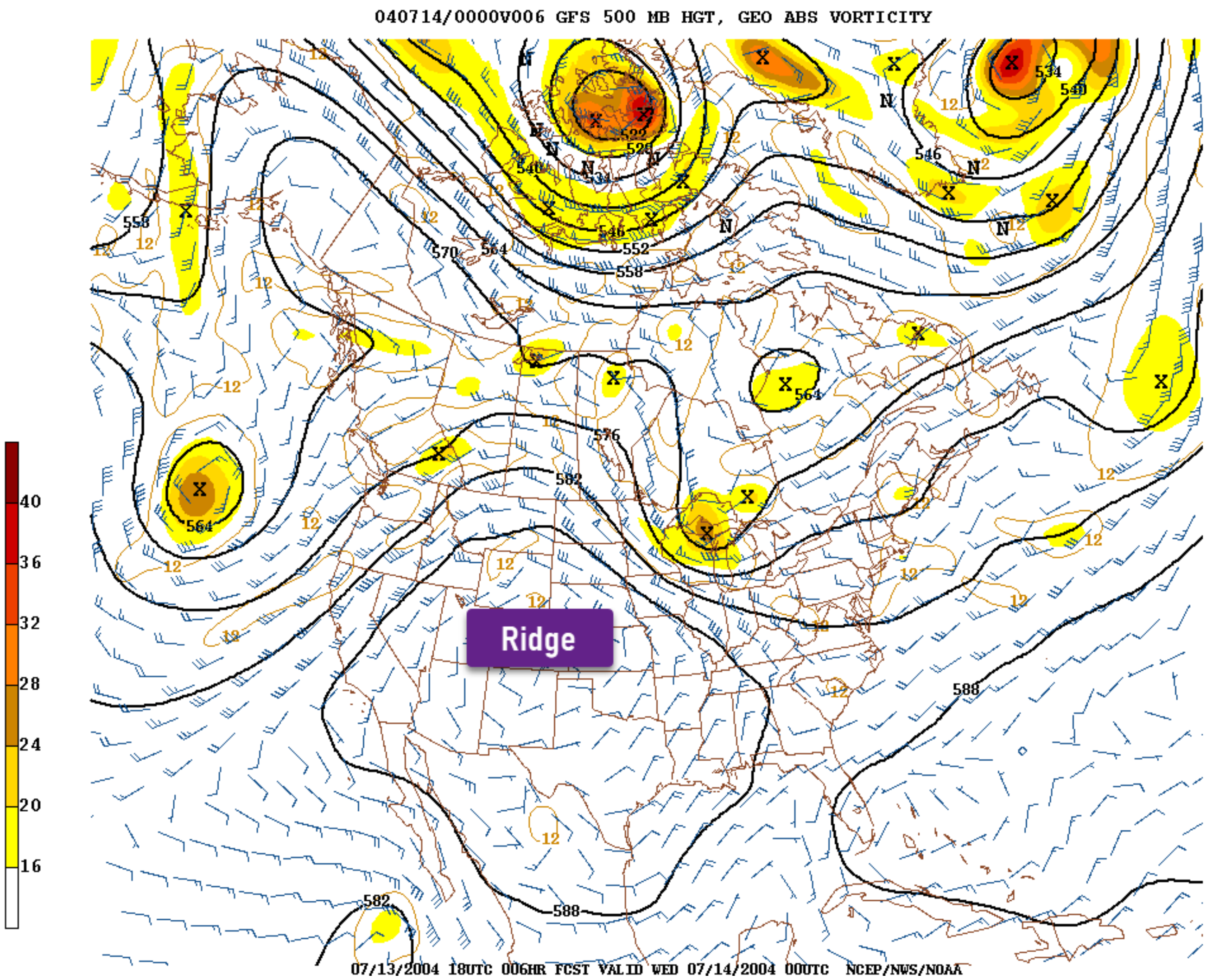

Fig. 37-1: *A ridge is best seen on the 500 mb constant pressure chart. The ridge is a region where the height (measured in decameters) of the 500 mb surface is relatively high where the flow of air is clockwise.*

Hazy hot and humid

While high pressure generally means fair weather, it can also create a hazy sky during the warm season. Flying below the subsidence inversion often means poor or reduced flight visibility. It is better to try to fly above such an inversion whenever practical.

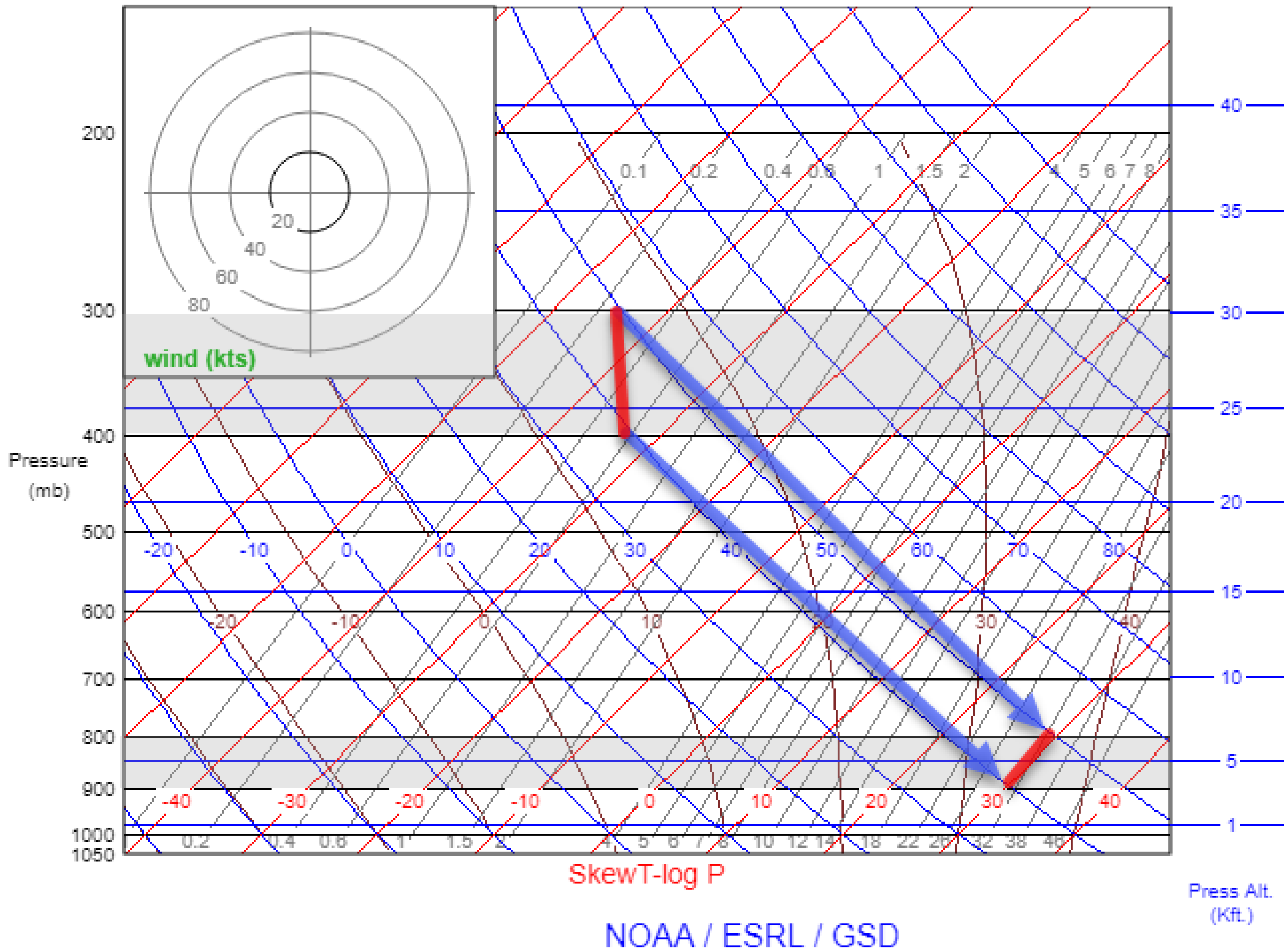

Fig. 37-2: *Visualization of how the **top** of a 100 mb thick layer is compressed more than the **base** of the layer creating a subsidence inversion.*

Unsaturated air that is compressed will increase in temperature dry adiabatically at 3°C for every 1,000-foot *decrease* in altitude. Remember, this is exactly the opposite of rising unsaturated air, which *cools* at this same rate. Assume a 100 mb-thick layer of air aloft between 300 mb and 400 mb subsides until it reaches the 800 mb to 900 mb layer (also a depth of 100 mb). Notice in Fig. 37-2 that the top of the upper layer undergoes more adiabatic compression, given that it must subside a greater distance than the base, causing it to warm at a greater rate. This, in turn, produces a subsidence inversion.

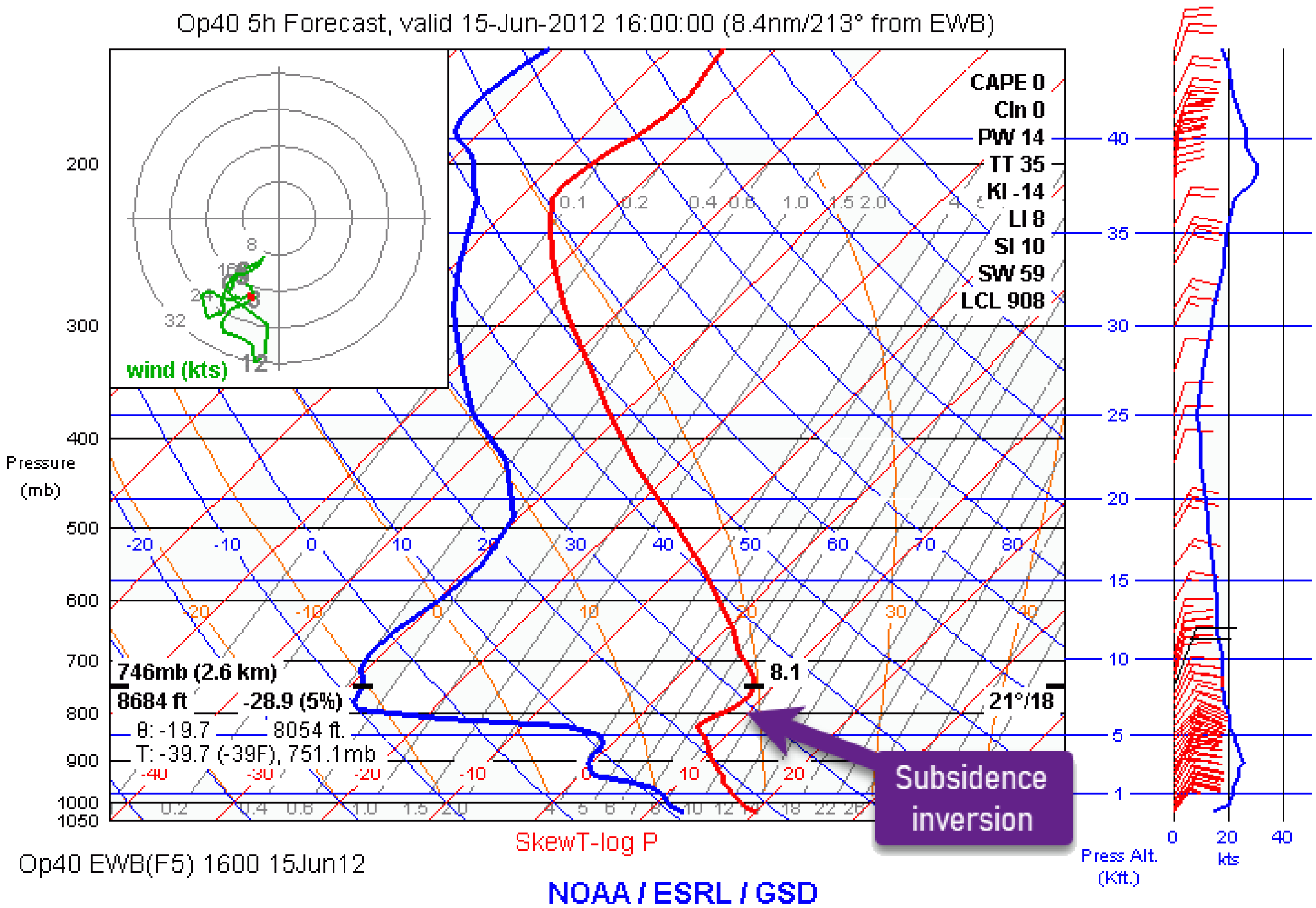

Fig. 37-3: *A subsidence inversion between 5,000 and 8,000 feet depicted on this 5-hour forecast sounding (F5) near the New Bedford Regional Airport (KEWB) in the middle of June.*

A subsidence inversion can vary in height and depth and will often trap moisture and pollutants below it, producing haze, smog, and reduced visibility. Flying above this inversion results in increased flight visibility and smooth conditions in most cases. This 5-hour forecast sounding (F5) in Fig. 37-3 depicts a subsidence inversion near the New Bedford Regional Airport in Massachusetts. In the middle of June, a ridge was parked over the Northeast, creating this subsidence inversion between 5,000 and 8,000 feet.

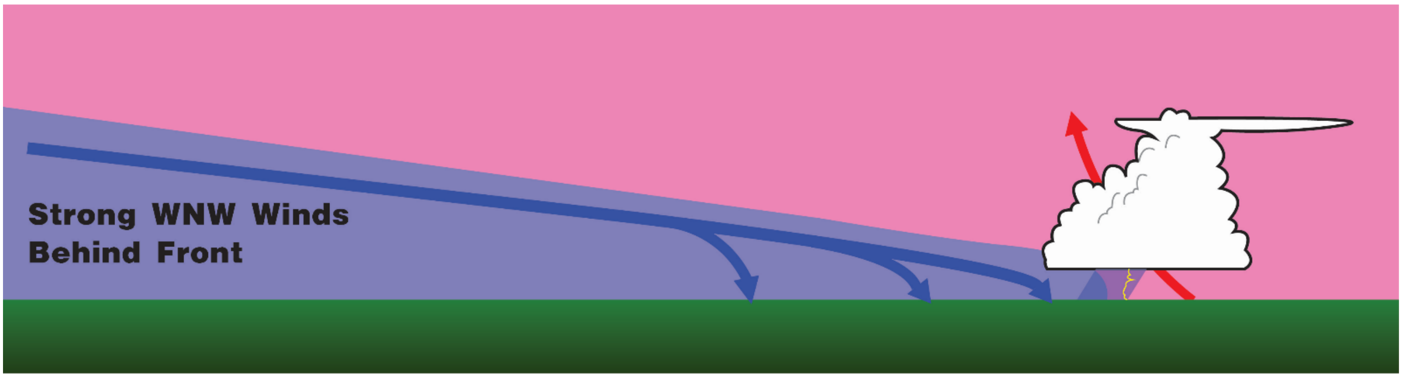

Fig. 37-4: *Rendition of cold, dense air pouring in behind a strong cold front. This cold air as it subsides goes through an adiabatic compress and creates this subsidence inversion.*

Normally, we associate the passage of a cold front with improving conditions as colder, drier air leads to an abundance of clear skies behind the front. As illustrated in Fig. 37-4, once the front passes, the wind typically shifts around to the west or northwest, bringing in cold, dense air aloft. This cold air is said to have negative buoyancy, meaning that the air will tend to sink or subside behind the front to produce a subsidence inversion.

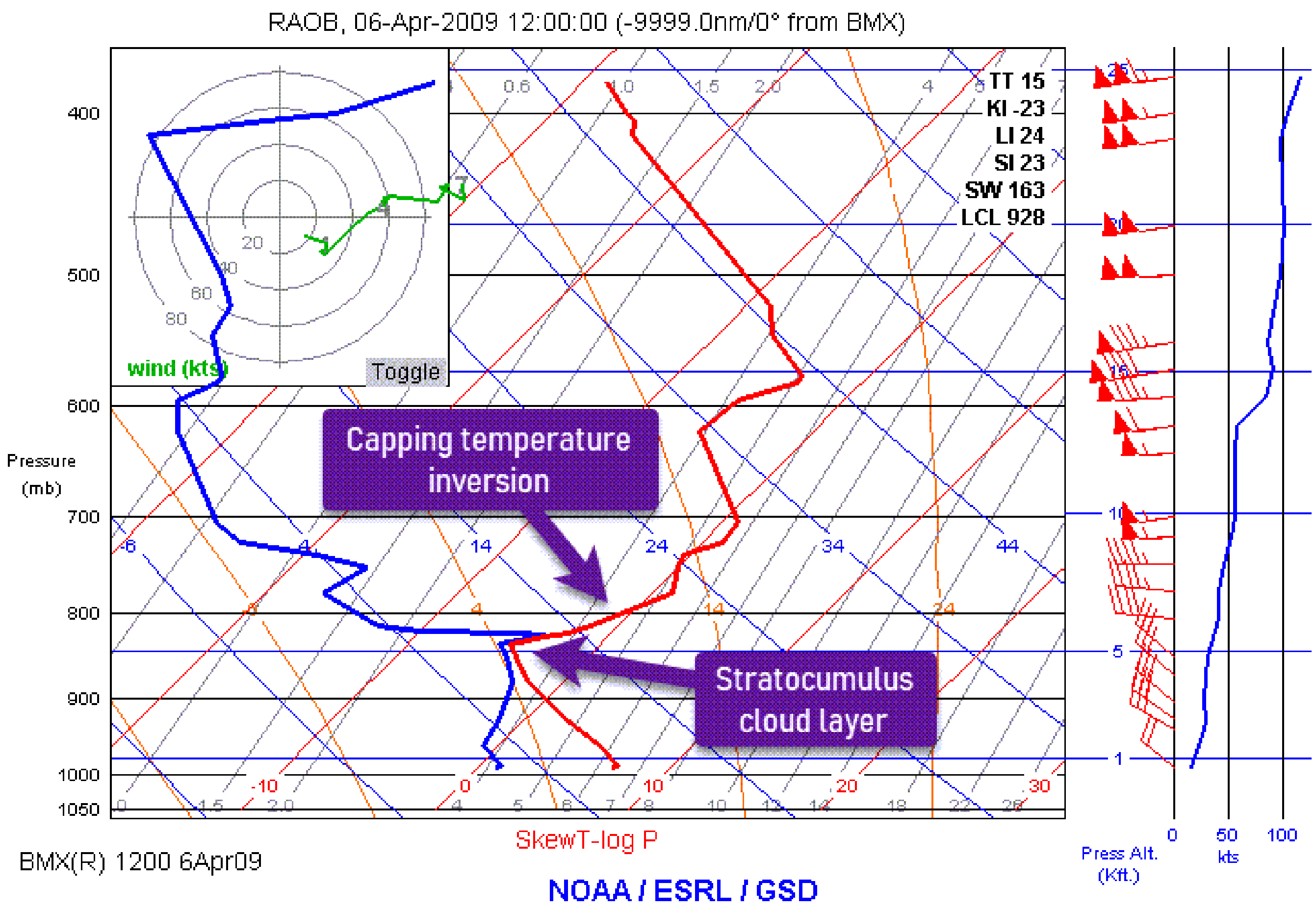

Fig. 37-5: *Stratocumulus signature on the Skew-T after the passage of a strong cold front in Birmingham, Alabama (BMX).*

For example, in early April, a strong cold front passed through the lower Mississippi Valley and Southeast, ushering in much colder temperatures. As this dense air poured in behind the front, it compressed as it sank, which created a deep inversion aloft. With a warm ground and strong insolation, it is quite common to see a stratocumulus cloud deck form in the wake of a cold front as shown in Fig. 37-5 in this RAOB for Birmingham, Alabama.

The subsidence inversion limits or caps the vertical growth of these clouds, giving them a rather even, but quilted look when viewed from above. Strong capping inversions such as this also provide for strong atmospheric stability in the air immediately above the clouds. The air is unable to mix vertically within the altitudes defined by the inversion which results in a glassy smooth ride above the cloud tops. Cloud types will be discussed a bit later, but this stratocumulus signature is one to remember especially as it relates to airframe ice. A stratocumulus deck can often dish out some serious supercooled liquid water during the cold season, especially near the cloud tops.

Radiative cooling: Some pilots raise an eyebrow when they hear the daunting word "radiation." Earlier in the text we learned "radiation" means the giving off (emission) of heat and can be used to describe something as innocuous as a house radiator. Radiation-fog, also called ground fog, is the most common kind of fog that forms overnight or in the early morning hours under a cloudless sky as the earth radiates its heat to the atmosphere. (Conduction also plays a small role in this process). Moist air near the surface and clear skies (or close to it) with light winds are typically required to enable the surface temperature to cool down. When the air cools to its dewpoint temperature, condensation may take place. This may only cause dew (or frost) to occur on exposed upward facing surfaces, but if there is enough moisture in the potential fog layer, radiation-fog may form.

As you might imagine, airlines are very concerned about widespread fog events. UPS Airlines (the freight carrier), in fact, performed an independent study and discovered that the traditional way meteorologists forecast fog had some pitfalls. They found that a parameter such as "light winds" or "winds not too strong" isn't easy to quantify consistently. They also discovered that, "the real requirement for radiation-fog is not the lack of wind per se, but the lack of turbulent mixing which can result from various combinations of stability and boundary layer wind speeds." Essentially, the study stated if the atmosphere is "mixy", radiation-fog has a tough time forming. On the other hand, if the atmosphere near the surface is "decoupled" from the low-level winds aloft (very stable), it tends not to mix and will promote an environment for fog to form. Keep in mind that even if ground fog doesn't form, a low stratus deck (i.e., 200-foot overcast) may still be the result.

Thick as pea soup

Radiation-fog is perhaps the most common fog that can occur just about anywhere in the U.S. It's also typically the thickest fog…sometimes thick as pea soup, a term Londoners have been using it since at least the mid-1800's to describe their own fog they are so famous for.

If clouds move in, they may impede radiative cooling and fog formation. Even then, UPS Airlines observed that even though the presence of a cloud layer reduced radiative cooling, it wasn't completely eliminated. Thus, a stratus layer can "build down" to the surface creating fog, especially when the cloud layer is thin. They further mention, "the top of the stratus layer itself becomes a radiative cooling surface in the absence of clouds aloft. Mixing redistributes this heat loss downward, cooling the air below the cloud layer and lowering the condensation level."

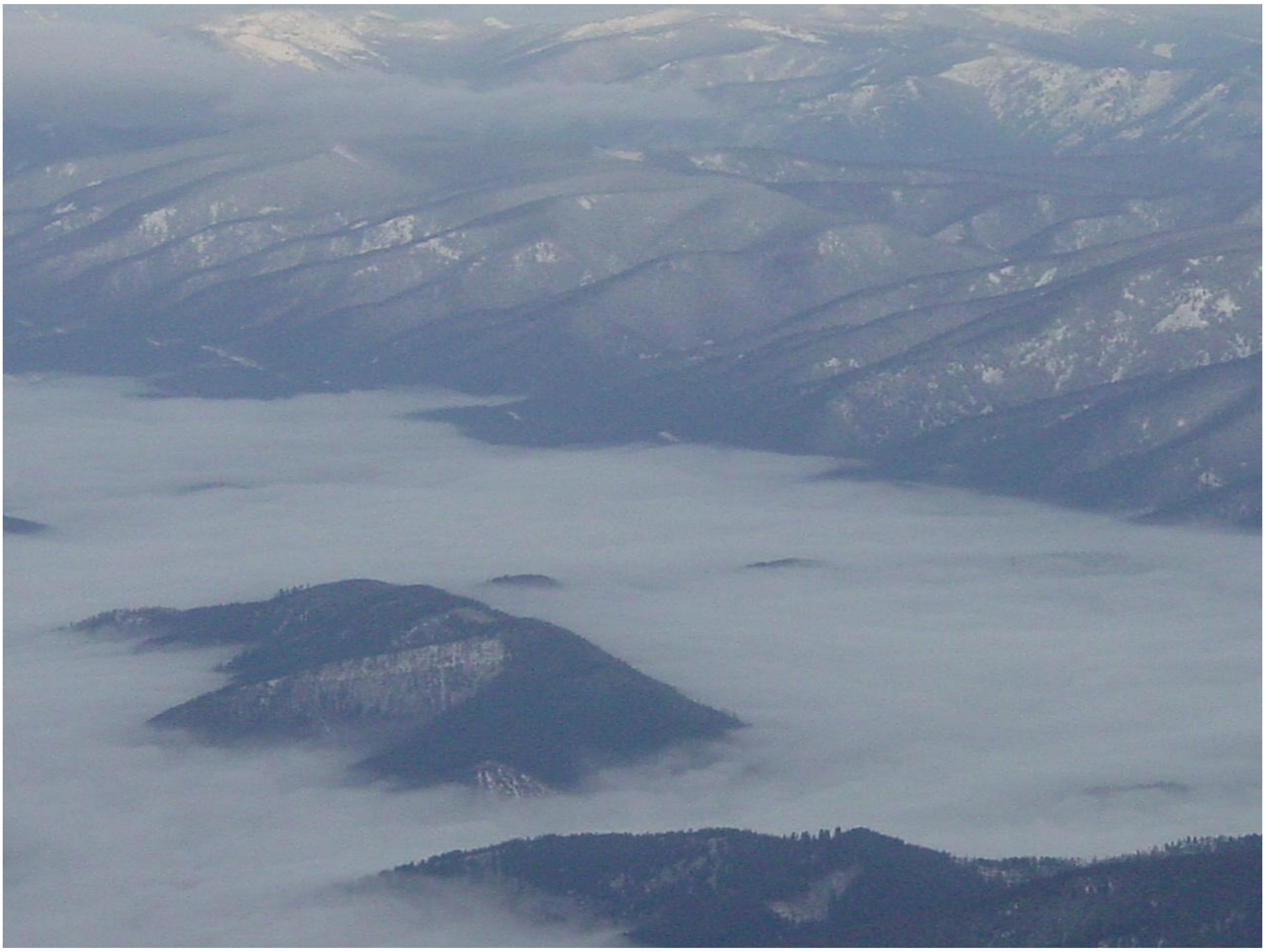

Fig. 37-6: *Morning radiation-fog filling the valleys in western Montana.*

Don’t get burned by the fog

“The fog is expected to burn off in a few hours.” Have you heard a similar statement from a TV weather broadcaster? Even the most astute meteorologists will often throw around the term “burn off” to mean that the fog is expected to dissipate. However, that’s not what really happens. During the morning hours, the sun begins to provide thermal energy, which, as the morning progresses, penetrates through the fog layer, causing the surface temperature to slightly increase and lowers the relative humidity at that point. This allows some of the cloud drops near the surface to evaporate and creates a shallow layer of instability. This instability causes the air near the surface to begin to mix, creating some overturning of the air in the fog layer. Eventually, drier air above the fog layer begins to mix in from the top, which also decreases the relative humidity even more. Although the sun does play a role, it is this “mixing” of the atmosphere that causes the fog to dissipate. So, it’s more accurate to say that “the fog is expected to mix out in a few hours.”

Remember from an earlier discussion, it’s the earth that does the heating and cooling of the overlying air. The longer nights of autumn allow for a longer period of cooling and thus increase the likelihood of radiation-fog. Sometimes, this fog does not form until just before sunrise. This is typically because it may be the coldest time of the morning, and the dewpoint temperature reaches it diurnal maximum. Pilots should pay attention when the dewpoint depression approaches zero during these clear sky and light wind conditions. An abundance of condensation nuclei, such as pollutants, may also enhance fog formation. Also, wet soil from an earlier rain event may help as well. Soil temperature is also important. Perhaps suburban areas are more susceptible than urban regions due to the heat island effect. Snow cover can also play a role in whether fog will form.

Radiation-fog is dependent on topography and gravitates toward valleys and hollows, so in some areas it may be deemed valley fog depicted in Fig. 37-7. The moisture sources (like rivers, lakes, streams or ponds) in valleys may enhance fog formation. Airports in the Hudson River Valley in New York come to mind as places that are prone to ground fog. Radiation-fog can be very patchy, extending from only a few feet to a few hundred feet thick, but it can cause zero horizontal visibility.

Fig. 37-7: *Thick radiation-fog at the Napa County Airport (KAPC) lowering surface visibility to 1/4SM.*

Note that, since radiation-fog is formed by the earth's surface losing heat and thereby cooling the overlying air, you won't see this type of fog forming over large bodies of water. Water surfaces cool much more slowly than land surfaces, preventing this type of weather effect.

Radiation-fog, also known as ground fog, as seen in Fig. 37-7, is perhaps the most common stratiform-type cloud. It is also the densest fog on the planet, lowering surface visibility to a quarter mile or less in many instances. There are very few locations in the world where radiation-fog does not occur over land. The basic requirements for radiation-fog are clear skies, light wind (low turbulent mixing in the fog layer as mentioned above), and high humidity. These conditions allow the earth to efficiently emit longwave radiation (hence the term radiation-fog) to the atmosphere after sunset and through the overnight hours. This causes the temperature near the surface to cool rapidly, producing a nocturnal temperature inversion. If the humidity is high, the temperature will cool down to the dewpoint temperature, creating saturated conditions that may allow for a low stratus deck, reduced surface visibility, and sometimes dense fog. Radiation and turbulent mixing at the top of the stratus deck can also enhance vertical growth of a shallow layer of stratus clouds.

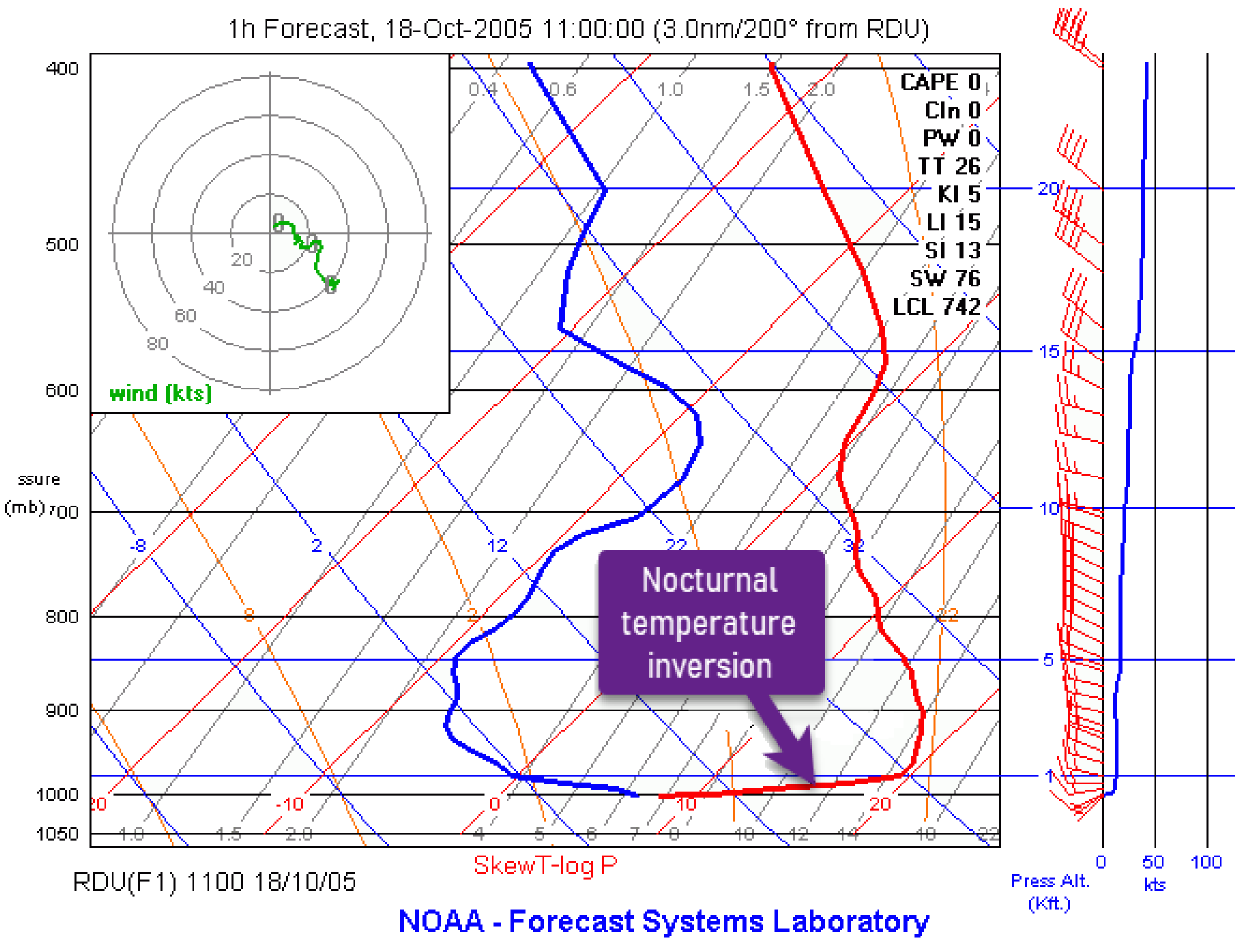

Fig. 37-8: *A 1-hour forecast sounding (F1) in the early morning hours near the Raleigh-Durham International Airport (KRDU) showing a shallow nocturnal temperature inversion without a favorable hydrolapse.*

In the overnight hours with clear skies and calm winds near the surface, radiative cooling can produce a very pronounced and often shallow temperature inversion hugging the surface. Essentially after sunset, the ground radiates the heat it absorbed during the daytime hours toward outer space in the form of long-wave radiation. This sets the stage for significant cooling at the ground level to produce a surface-based *nocturnal* temperature inversion.

Fig. 37-8 is a 1-hour forecast sounding (F1) near the Raleigh-Durham International Airport (KRDU) in Raleigh, North Carolina. The surface temperature at 11Z is forecast to be **8°C** (46°F) and the temperature at 1,000 feet is nearly **20°C** (68°F)—a difference of 12°C or 22°F within 700 feet of the surface! At daybreak the sun rises and quickly warms the ground, and the surface temperature begins to increase. This causes the cooler air near the surface to mix with the much warmer air aloft, quickly eroding the inversion through the early morning hours.

The result of radiative cooling and freezing temps

When the sky is clear in the overnight hours and the surface temperature is expected to be below freezing, don't be surprised if you get to the airport early in the morning to find out that you should have put the plane in the hangar overnight. The good news is that it will likely be sunny and will melt that frost off the plane in a jiffy.

Looking at this nocturnal temperature inversion near Raleigh-Durham, notice that the temperature and dewpoint are nearly equal right at the surface. While this shallow saturated condition may engender some very patchy ground fog near rivers and wetlands, it usually only results in reduced surface visibility. Said differently, it is not a condition that sounds an alarm for a widespread radiation-fog event. In fact, the sky remained perfectly clear at Raleigh-Durham on this day. In the end, there's more to producing fog than just high relative humidity, clear skies, and calm winds. Radiation-fog routinely develops in various regions of the U.S. and Canada throughout the year and can be some of the densest fog you will ever encounter. When a nocturnal temperature inversion is coupled with a favorable hydrolapse and little or no turbulent mixing exists in the potential fog layer, radiation-fog is usually the result. A favorable hydrolapse is a condition when the dewpoint temperature *increases* with *increasing* altitude. It is common for it to lower the ceiling and/or visibility into the very low instrument flight rules (VLIFR) flight category.

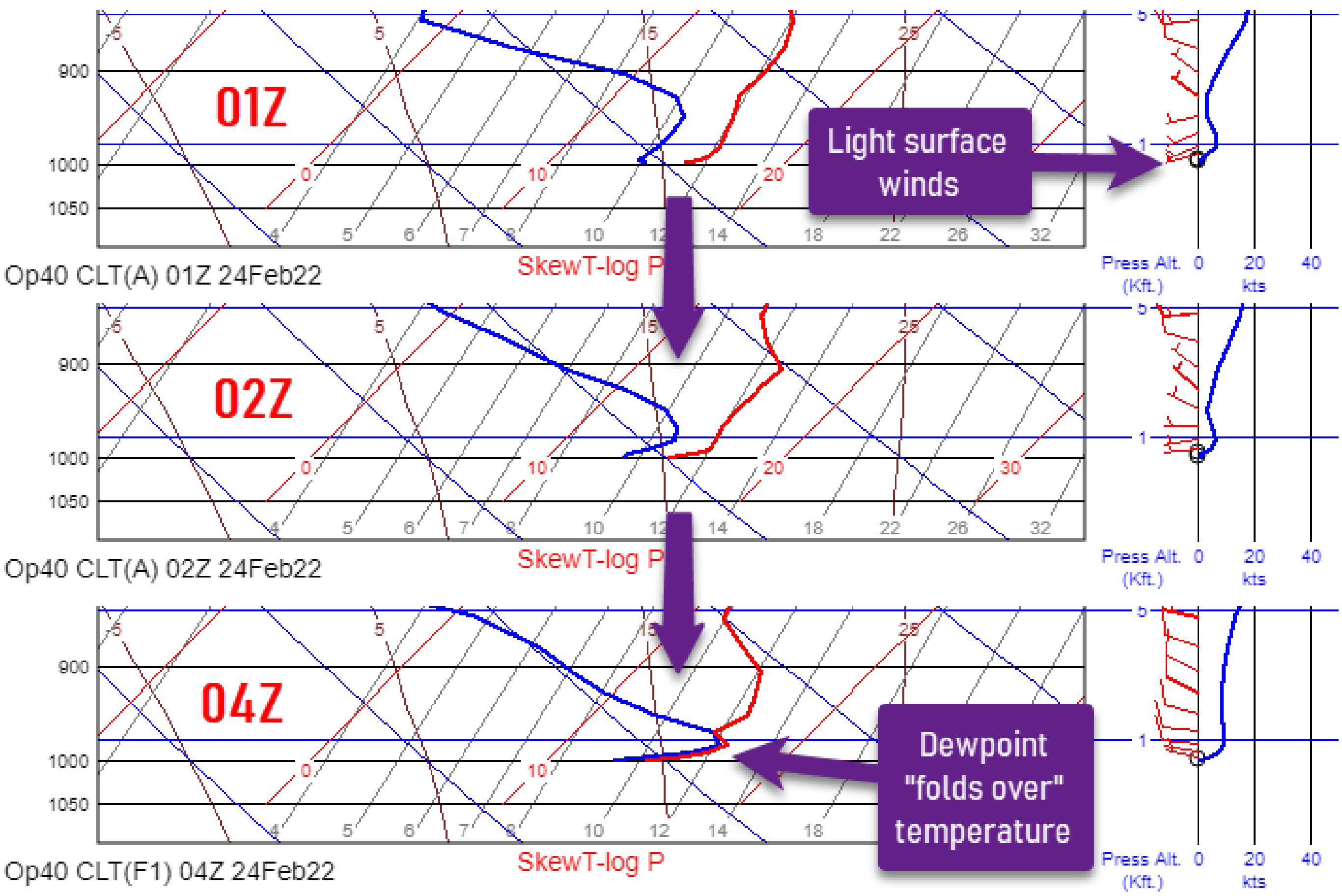

Fig. 37-9: *Radiative cooling event is created when the dewpoint "folds over" the temperature in the potential fog layer.*

You may recognize this series of forecast soundings and analysis in Fig. 37-9 from the beginning of this text where we discussed trends of weather reports and forecasts. This time series of diagrams near Charlotte Douglas International Airport in Charlotte, North Carolina that starts out at 01Z (top) and runs through 04Z (bottom), the temperature inversion deepens through the evening as radiative cooling starts to become well established. By 04Z, the dewpoint temperature essentially "folds over" the temperature, initiating a shallow radiation-fog event. Compare this to the *unfavorable* hydrolapse in Fig. 37-8 for the Raleigh-Durham forecast sounding.

Clouds are radiative blackbodies, and they emit infrared radiation like the surface of the earth. Through the overnight hours near Charlotte, radiative cooling continued from the top of the stratus deck and deepened the fog layer even further. Without this favorable hydrolapse or "folding over," radiation-fog isn't likely to occur, even when the relative humidity at the surface is at or near 100%.

In some instances, radiation-fog can occur even when there's a low overcast cloud deck present as the sun is setting. While it is true that in the presence of stratus clouds that surface radiative cooling is often greatly reduced, it is generally not eliminated. This is especially true when the stratus cloud deck is rather thin (less than a 300-foot depth). The top of a lower stratus cloud deck can itself become a radiative cooling surface when there are no other higher cloud decks aloft. In the 18-hour forecast sounding (F18) near the Wilmington International Airport (KILM) in Wilmington, North Carolina depicted in Fig. 37-10, this produces what meteorologists often refer to as an elevated temperature inversion.

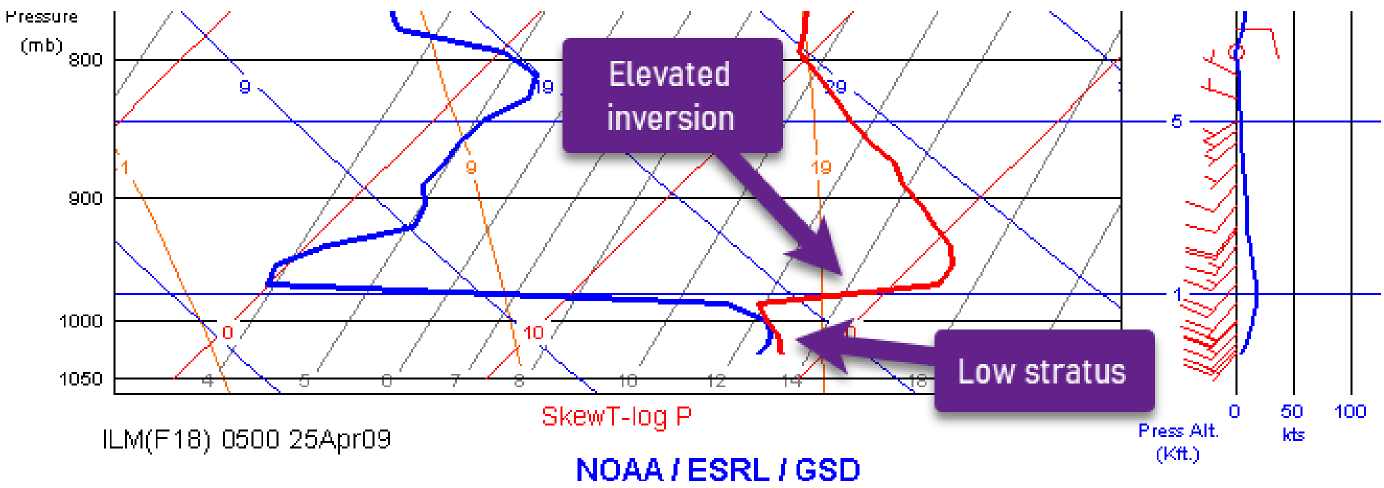

Fig. 37-10: *Elevated nocturnal inversion with radiative cooling from the top of a low stratus deck.*

If there's a high cirrus cloud deck above, it often acts to limit how much radiative cooling can occur and may reduce the probability of radiation-fog or delay its onset. Moreover, snow cover and the heat island effect near large cities can limit fog formation. From the earlier discussion, fog formation requires a stable layer of moist air—high relative humidity—in the lowest part of the atmosphere near the ground. But warm urban areas can reduce the relative humidity, making less moisture available to allow fog to form.

Clouds act like a blanket...hardly

You've probably heard your local broadcast meteorologist at some point hastily explain how broken or overcast cloud cover can "act like a blanket" to prevent overnight temperatures from plummeting as compared when the sky is clear. Sound familiar? Unfortunately, that's just bad meteorology. Sure, both clouds and blankets keep things warmer, but that's where the similarities end. Yes, clouds do have an effect on surface temperatures, but using a blanket is a really bad (incorrect) analogy.

When you put on a blanket, it helps greatly reduce the escape of convective thermals away from your skin, thus reducing the loss of some of your body heat. Moreover, the blanket must be close to your body for it to be effective. If you hung that blanket near the ceiling, would it do as good of a job? Of course not.

Clouds, on the other hand, have no ability to suppress convection or trap warm air near Earth's surface. Furthermore, at night, there's typically no thermals to suppress anyway. So, clouds *can't* act like blankets. Instead, they are simply sources of downwelling infrared radiation that is absorbed by the earth's surface, reducing (or sometimes eliminating) the ground's typical nighttime radiation deficit, which helps keep surface temperature higher than it would be on a clear night.

Radiative cooling and a nocturnal temperature inversion can also wreak havoc on ground-based weather radars like the WSR-88D NEXRAD Doppler radars, causing an unwelcomed phenomenon called anomalous propagation (AP). AP can occur whenever there is a strong temperature inversion near the surface like the one in Fig. 37-11. This is a sounding from a radiosonde launched by a forecaster at the Wilmington, Ohio (ILN) WFO in early August.

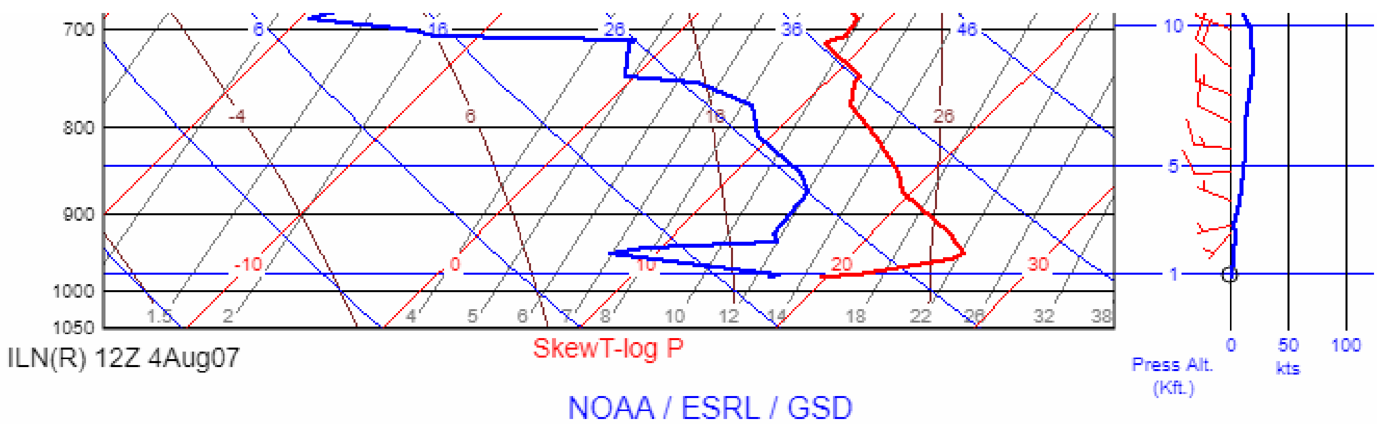

Fig. 37-11: *Nocturnal temperature inversion creating anomalous propagation (AP) for the NWS WSR-88D Doppler weather radars.*

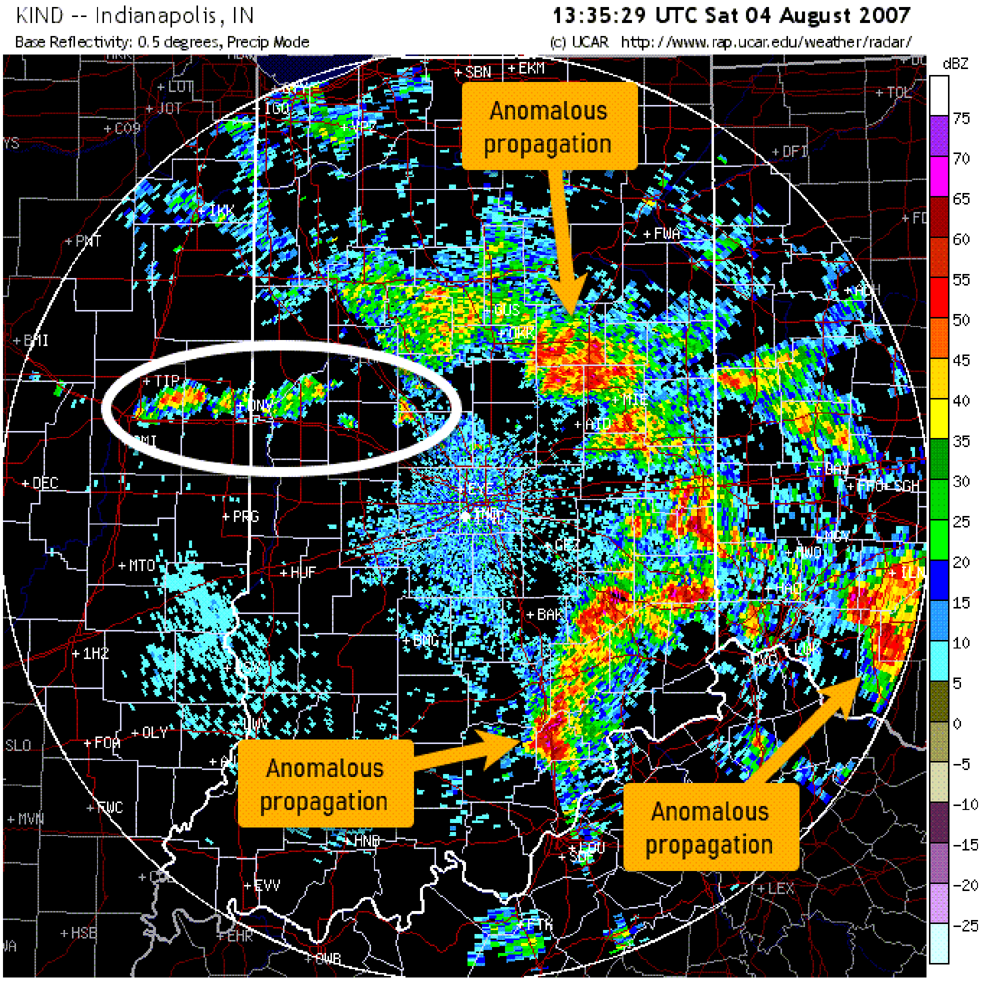

Fig. 37-12: *The Indianapolis WSR-88D Doppler weather radar in the early morning hours depicts a large area of anomalous propagation (AP) caused by a surface-based nocturnal temperature inversion in the area. Actual returns are shown in the white oval, and the rest is AP or other forms of ground clutter.*

The sidelobe of the radar beam is bent down or ducted back toward the earth, causing it to strike objects on the surface farther in the distance. The reflected energy follows the same path back to the radar, where it is received and interpreted as a reflectivity value. This nocturnal inversion created a large area of AP with intense reflectivity that is indicative of deep, moist convection. Even though the returns depicted on this radar image in Fig. 37-12 from the Indianapolis NEXRAD Doppler radar look very real, most of them are AP. There were a few cells on the northwest side of Indianapolis, shown in the white oval, that are actual areas of real precipitation validated using a satellite image.

Filtered like a champ...sometimes

Most anomalous propagation (AP) can be easily filtered such that the resulting ground-based radar mosaic consists mostly of real areas of precipitation. AP will occasionally slip through the best filters and end up in the satellite weather broadcast (SiriusXM) you receive in the cockpit. It also may slip into the Flight Information System-Broadcast (FIS-B), but that's even more rare due to the more accurate multi-radar/multi-sensor (MRMS) mosaic it now uses.

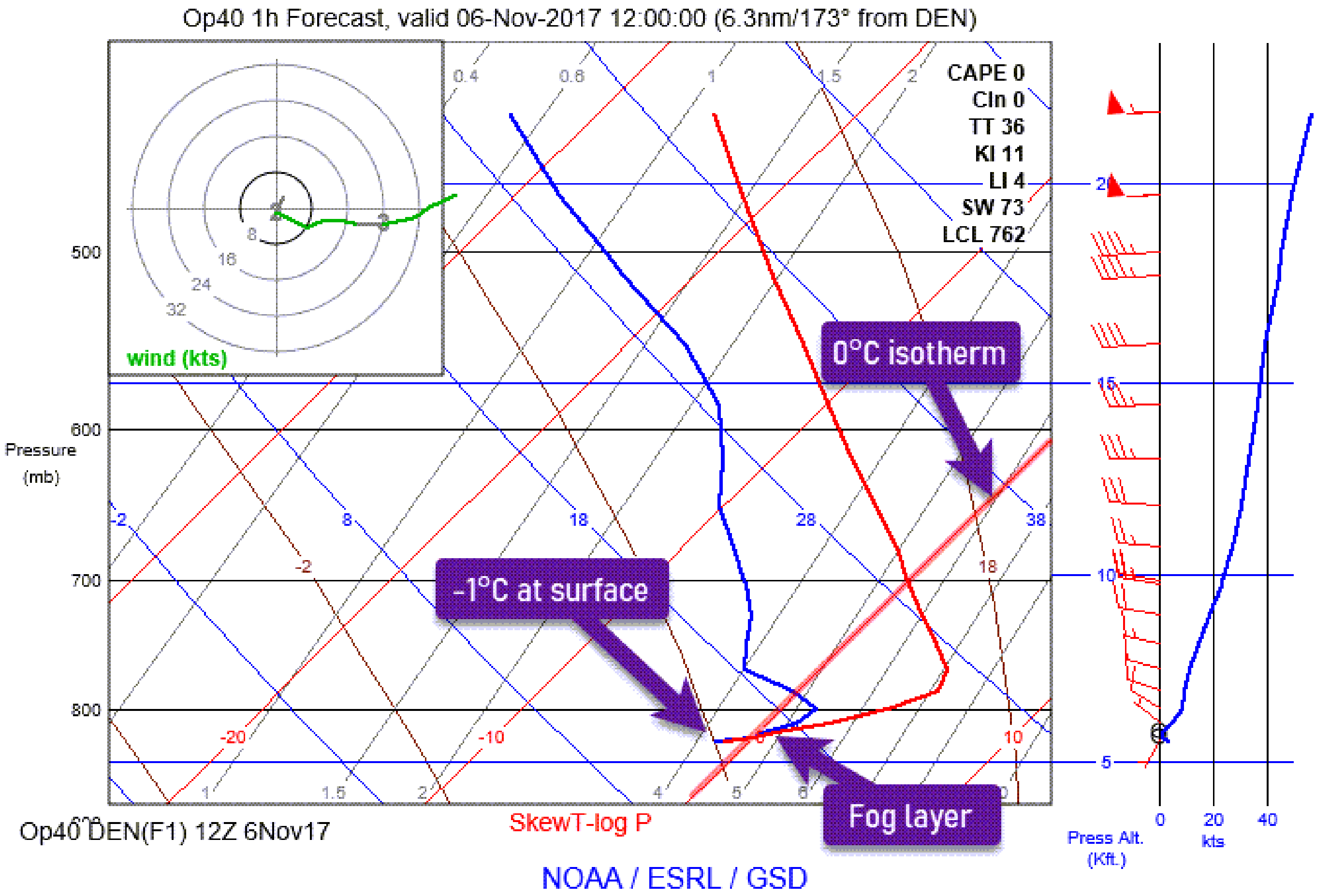

Fig. 37-13: *Freezing fog signature on a 1-hour forecast sounding (F1) near the Denver International Airport (KDEN).*

A radiation-fog event can also become freezing fog (FZFG) when the surface temperature is at or below 0°C. Fig. 37-13 is a 1-hour forecast sounding (F1) near the Denver International Airport (KDEN) and depicts a favorable hydrolapse where the dewpoint *folds over* the temperature. In this case, the surface temperature is **-1°C** and creates the obstruction to visibility of freezing fog. Freezing fog does not imply that supercooled liquid water will rime onto the airframe, only that the visibility is expected to be less than **5/8SM** and the temperature is *below* freezing or expected to be below freezing when issued in a terminal aerodrome forecast (TAF) as covered earlier.

Another way to produce an inversion is when warm moist air advects over a relatively cool surface (water or land). This can also lead to what meteorologists call advection fog (sometimes referred to as sea fog). Advection is the movement of air horizontally (not to be confused with convect, which is the movement of air vertically). Advection fog is not as dependent on wind speed as it is on wind direction. Many references claim that this fog can lift to a stratus layer under strong surface winds, and indeed this does happen. However, when the cooling is extreme, like it is over the very chilly waters off California's western shoreline, be prepared for very thick fog!

Advection fog forms when moist air moves from a warmer region of the ocean into a region of colder waters. One spot that is conducive to this type of fog formation is

Canada's East Coast, where the warm waters of the Gulf Stream collide with the cold Labrador Current. Pick a coastal airport on the Eastern Seaboard and you'll encounter advection fog when the winds are blowing from the right direction. Saint John, New Brunswick, Yarmouth, Halifax and Sydney, Nova Scotia and St. John's, Newfoundland—none are strangers to this type of fog.

The West Coast of Canada and the U.S also sees lots of advection fog. Cold waters hug British Columbia and the states of Washington, Oregon and California all the way south to the tip of the Baja Peninsula. While Seattle, San Francisco, and San Diego are also affected by advection fog. Residents of coastal California refer to this as the marine layer. Somewhat like the sea breeze, which reforms almost every day along the East Coast of the U.S. during the warm season, the marine layer also represents a difference between a cool, moist air mass and a warmer air mass. Unlike the sea breeze which can come and go on a day-to-day basis, the marine layer can persist for days and weeks along the west coasts of major continents in the Northern Hemisphere.

Fig. 37-14: *The Golden Gate Bridge shrouded in the coastal marine layer shortly after sunrise.*

Such a marine layer is common along the coasts of central and southern California. Pilots flying regularly in this area are aware of this phenomenon. The towers that suspend the Golden Gate Bridge pictured in Fig. 37-14 often get masked by this marine layer during the warm season. While there will always be some uncertainty, the marine layer and its impact are predictable on most days during the summer months. Meteorologists at the local NWS forecast offices who issue the TAFs for airports along the coastal regions do a reasonable job predicting the onset and dissipation of the marine layer on any given day.

The driving reason for the marine layer is that the water along the West Coast of the U.S. is comparatively cold to the same latitude along the East Coast where the Gulf Stream brings warm, tropical water from south to north. The California Current, a surface oceanic, southward-flowing continuation of the Aleutian Current along the West Coast of North America, brings in cold water along the West Coast of California. The surface temperature of the water off the California coast can be as much as 30°F (17°C) or more, colder than at the same latitude on the East Coast. The colder water means the air just above the ocean's surface is colder, and therefore denser.

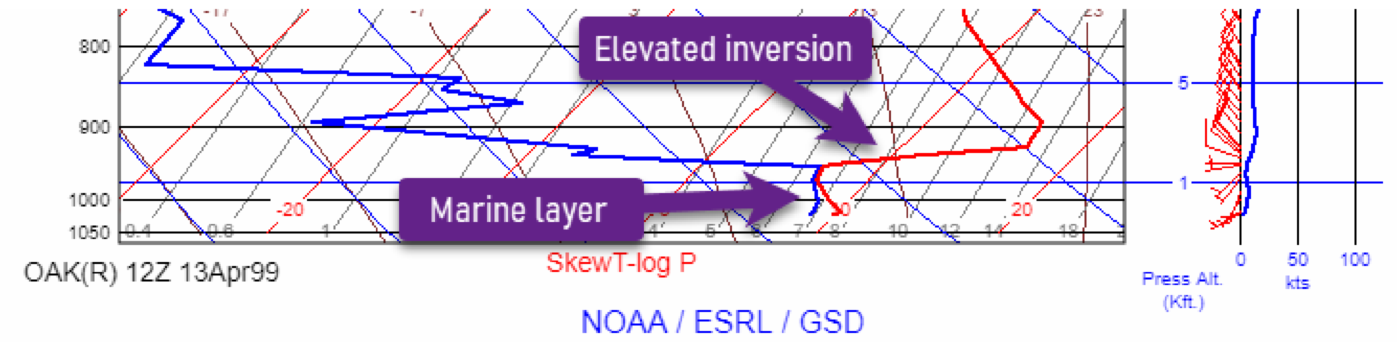

Fig. 37-15: *Marine layer evident on this RAOB from Oakland, California (OAK) resulting in an elevated inversion.*

As mentioned previously, air temperature normally decreases with increasing height. However, due to the cold waters of the Pacific Ocean, the air temperature often *increases* with height, resulting in a surface-based or elevated temperature inversion along coastal regions of California like the elevated inversion shown in Fig. 37-15. The shallow air below the inversion is called the "marine layer" and is cooled to the point which clouds can form. Just to be clear, this can occur near any large body of water such as the Great Lakes when the water temperature is significantly colder than the air moving over it. It's not as likely, however, along the Gulf of Mexico and eastern coastal regions of the U.S. due to warm sea surface temperatures that occur there.

Marine layer stratus is a feature that occurs entirely below the 925 mb level or roughly 2,500 feet AGL. The depth of the marine layer depends upon the synoptic-scale weather patterns controlling the weather. Sinking air, under an upper-level ridge of high pressure will compress the marine layer down toward the earth's surface. The strength of the

What you see is what you get

There are times when you arrive at the airport during the early morning hours just after sunrise and tune in the latest weather from the Automated Surface Observing System (ASOS) or Automated Weather Observing System (AWOS) broadcast, only to hear the temperature and the dewpoint to be equal. But as you scratch your head while looking at the sky around the airport in all directions, it might look a bit hazy and the visibility might be below five statute miles, but there are no clouds anywhere near the airport. So, what is going on? Perhaps a sensor error? No, it's not likely an error in the equipment. Getting clouds to form is quite complex and there are conditions where the sensor is reporting a dewpoint depression of zero, but fog or clouds are absent. Clouds form when there is ample moisture near the surface. When the moisture is shallow or there is some turbulent mixing in the potential fog layer, low stratus clouds may not form despite the dewpoint depression of zero recorded at the sensor.

sinking air impacts the depth of the marine layer. If the downward force of air is very strong, the marine layer can be very shallow, with low clouds and foggy weather confined to the immediate coastal regions and beaches. In this situation, warm, sunny conditions can be occurring just a mile or two inland.

Any decrease in downward forcing allows the marine layer to deepen and move farther inland. Near the beach the fog often lifts into a low cloud layer. The leading edge of the marine layer then extends farther inland, pushing the fog inland. On the Skew-T for Oakland from Fig. 37-15, the base of the elevated inversion is the maximum limit of where the surface cloud can extend to and will be the top of the marine layer (and stratus deck). This does not mean that saturation will occur all the way to the top of the inversion. If the inversion is high, the surface air can mix and lift and then an elevated stratus deck forms instead of fog. If the top of the inversion is shallow, the fog may not be deep, but it is usually quite dense.

Further lifting of the marine layer will allow cooler marine air to move over the coastal mountains and spill into the interior valleys. Because of this, the maximum daily temperatures in the San Joaquin and Sacramento Valleys of California will undergo a roller-coaster effect in the summer.

Glossary

A

Absolute Altitude: See AGL.

Accretion: Growth of a precipitation particle by the collision of an ice crystal or snowflake with a supercooled liquid drop. Term is also used to describe the freezing of supercooled liquid water on aircraft surfaces referred to as airframe icing.

Adiabatic Cooling: Cooling of a gas by expansion. Occurs when air is forced to ascend or ascends due to buoyancy.

Adiabatic Heating: Warming of a gas by compression.

Adiabatic Process: Change of temperature of a gas by expansion or compression without the transfer of heat, usually discussed within a parcel of rising or descending air.

Advection Fog: Formed when relatively warm moist air moves over a cool surface by the wind.

Advisory Circular (AC): Advisory Circulars are informational documents produced by the Federal Aviation Administration (FAA) to inform and guide institutions and individuals within the aviation industry, as well as the general public.

AGL (Above Ground Level): Actual height above the surface of the earth. Cloud heights are reported in AGL in both routine and special observations (METARs) and terminal aerodrome forecasts (TAFs). See also MSL.

Aircraft Flight Manual (AFM): A document issued by the aircraft manufacturer that describes the aircraft's systems in brief, gives checklists and procedures, and indicates the actions to be taken in various contingencies. It also contains operating limitations and markings/placards for the aircraft. Also see Pilot Operating Handbook (POH).

Air Density: It is the mass per unit volume of Earth's atmosphere. Air density, like air pressure, decreases with increasing altitude. It also changes with temperature and humidity. At sea level and 15°C, air has a density of approximately 1.225 kg/m^3.

Airframe Icing: Deposit of liquid water that freezes on an object, such as aircraft surface (wing, horizontal stabilizer, etc.). See Clear Icing, Rime Icing, Mixed Icing, Hoarfrost, and Frozen Dew.

Air Mass: An extremely large body of air with properties of temperature and moisture that are similar in any horizontal direction at any given latitude.

Air Mass Thunderstorm: Produced in stagnant situations where there's no important change of air mass where every day's heating is usually sufficient to get a new round of thunderstorms going. Sometimes called "garden-variety" afternoon thunderstorms or pop-up thunderstorms. These are more accurately termed *pulse-type* thunderstorms.

Air Traffic Control (ATC): These are the traffic cops in the air. This is a service provided by ground-based air traffic controllers who direct aircraft on the ground and through a given section of controlled airspace and can provide advisory services to aircraft in non-controlled airspace. The primary purpose of ATC is to prevent separate IFR aircraft from other IFR aircraft to prevent collisions, organize and expedite the flow of traffic in the air, and provide information and other support for pilots such as traffic an weather advisories.

AIRMET (Airmen's Meteorological Information): A legacy textual advisory of adverse weather occurring or expected to occur along an air route that may affect aircraft safety. They are valid for six hours with a six-hour outlook. This includes advisories for instrument flight rules (IFR) conditions, mountain obscuration, moderate nonconvective airframe icing and freezing level, moderate nonconvective turbulence, sustained surface winds over 30 knots, and nonconvective low level wind shear (LLWS). Also see Graphical AIRMET (G-AIRMET).

Albedo: Reflectivity of the earth's surface (e.g., snow and water) and its atmosphere (e.g., clouds).

Altimeter: Instrument that indicates the altitude of an aircraft, usually above mean sea level (MSL). Also see Pressure Altitude.

Altimeter Setting (QNH): The local pressure value set to the scale of a pressure altimeter to read altitudes in reference to mean sea level. It is calculated by adding the weight of a fictitious column of air between the elevation of the station and mean sea level, based on a temperature of 15°C and a standard lapse rate of 1.98°C/1,000 feet.

Altocumulus (Ac): Vertically developed cloud in the mid-levels of the atmosphere. Deeper altocumulus clouds may on occasion produce a light rain or snow shower.

Altocumulus Castellanus (Acc): Unstable middle cloud with a common base and turrets (castellations). If occurring in the morning, these are a sign of mid-level instability and possible convective activity later in the day.

Altocumulus Standing Lenticular (ACSL): Mainly, nonturbulent mid-level lens-shaped cloud indicating the presence of mountain wave activity and colloquially called "lennies." When these clouds have a torn or tattered appearance, they are likely turbulent and should be avoided.

Anafront: A front at which the warm air is ascending the frontal surface up to high altitudes. With anafronts, precipitation may occur to the rear of the front.

Analysis: Interpretation of the pattern of various weather parameters on a surface or upper air chart (e.g., surface analysis chart). These are always valid in the past. Also represents the initial conditions of a forecast model often referred to as the 0-hour forecast.

Anomalous Propagation (AP): False radar returns, or echoes usually observed when calm, stable atmospheric conditions exist, often associated with super refraction in a surface-based temperature inversion that direct the side-lobes of the radar beam toward the ground, where they strike objects on the surface and reflect strong energy back to the radar site.

Anticyclonic Flow: Clockwise rotation of air around an anticyclone (high pressure) in the Northern Hemisphere.

Anti-Icing Equipment: Aircraft equipment used to prevent or remove the accretion of airframe ice. The equipment can be certified for flight into known icing conditions or for inadvertent icing encounters. See Ice Protection System (IPS).

Anvil Cloud: Top portion of a cumulonimbus due to a flattening effect as it hits the tropopause, taking on the appearance of a blacksmith's anvil. This is usually marked at the equilibrium level of the rising saturated air.

Area Forecast Discussion (AFD): A forecaster-to-forecaster dialog written by meteorologists at the local weather forecast offices. These are the same forecasters who issue the terminal aerodrome forecasts (TAFs). Each AFD has an aviation section that is primarily written for pilots.

ASL (Above Sea Level): See MSL.

ASOS (Automated Surface Observing System): Weather observing system operated and controlled by the NWS, FAA, and DoD (Department of Defense). Routine observations are issued once an hour with a special observation (SPECI) issued when specific criteria are met.

ATIS (Automatic Terminal Information Service): A continuous broadcast of recorded aeronautical information (including weather) in busy terminal areas where air traffic is controlled in and out of these airports.

Atmosphere: The compilation of gases that surround Earth.

Atmospheric Moisture: The presence of water in vapor and visible elements to include water in the solid or liquid states.

Atmospheric Pressure: The weight of a column of air measured in inches of mercury (Hg), millibars (mb), hectopascals (hPa), pounds per square inch, and millimeters of mercury. Meteorologists use millibars, and pilots and air traffic controllers use inches of mercury.

Avgas: Aviation grade fuel for piston-powered aircraft.

AWC (Aviation Weather Center): The main aviation forecast center for the U.S., located in Kansas City, Missouri. They are responsible for issuing convective SIGMETs, nonconvective SIGMETs and G-AIRMETs.

AWOS (Automated Weather Observation System): Automated weather sensors sited at airports that are designed to serve aviation and meteorological observing needs for safe and efficient aviation/weather operations. Routine observations are issued three times a day. No special observations (SPECI) are issued by an AWOS.

B

Boundary Layer: The layer of the atmosphere near the surface where the ground has a primary influence over its depth. It varies with time of day and is characterized by a dry adiabatic lapse rate (DALR) and turbulent mixing.

Broken (BKN): Cloud layer covering 5/8th to 7/8ths of the sky and constitutes a ceiling.

Buoyancy: The property of an object that allows it to float on the surface of a liquid or ascend through air.

C

Calm: Absence of wind with speeds approaching zero.

Cap Cloud: A stationary cloud crowning a mountain or hill. It may be associated with a mountain wave.

CAT (Clear Air Turbulence): Associated with jet streams. CAT is mid- to high-level turbulence not associated with convective clouds. About 25 percent of all CAT occurs in and around cirrus clouds.

CCL (Convective Condensation Level): The point of intersection of a sounding with the saturation mixing ratio line corresponding to the average mixing ratio in the surface layer (usually below 1,500 feet). This is a reasonable weather estimator of cumulus cloud base heights on a sunny day.

Ceiling: The height of the lowest cloud base with summations 5/8th or more, or the vertical visibility extent into an obscuring phenomenon and referred to as an indefinite ceiling.

Center Weather Service Unit (CWSU): Monitors and provides weather forecasts and advisories to the nation's 21 Air Route Traffic Control Centers (ARTCC), producing specialized tailored forecasts and advisories of thunderstorms, turbulence, icing, and precipitation affecting the National Airspace System.

Chop: Mostly rhythmic bumpiness typically denoted as light, moderate, or severe. This is usually associated with clear air turbulence (CAT) in the flight levels.

Cirrus (Ci): A high, thin, wispy cloud composed of ice crystals. These clouds are often a precursor to an approaching weather system.

Clear Icing: Formed by large, supercooled water drops, which is hard, smooth, and glossy. It is the most dangerous type of icing because it is difficult to remove when it accretes behind the protected areas. It has a high accretion rate. It usually occurs in the warmer subfreezing temperature regimes, or when supercooled large drop icing (SLD) is occurring.

Cloud Coverage: The amount of cloud layer viewed from the ground, or the amount of sky covered by that layer and all other layers expressed in eighths (oktas).

Coalescence: Merging of smaller cloud drops into a single larger drop. Usually occurs as cloud drops rise and fall within a cloud.

Cold Front: Leading edge of advancing cold air. It tends to have a slope of 1:40 to 1:50.

Cold Soaked Wing: Wings containing fuel cooled at subfreezing temperatures, causing ice to form in visible moisture such as fog, drizzle, rain, or wet snow to ambient temperatures above freezing up to +14°C. Most light aircraft are not susceptible to adverse effects due to cold soaking.

Collision-Coalescence Process: Describes the mechanism that causes small cloud drops to grow.

Condensation Nuclei: Submicron-sized particles that have an affinity for liquid water whereby condensation of water vapor begins in the atmosphere.

Conditional Instability: State of a layer of unsaturated air when its temperature lapse rate is less than the dry adiabatic lapse rate (DALR), but greater than the moist adiabatic lapse rate (MALR).

Conduction: Transfer of heat from one substance to another or through a substance. Transfer is from warm to cold.

Constant Pressure Chart: A chart showing weather variables such as temperature, wind, absolute vorticity, relative humidity, and constant pressure height (contours). These are available at standard pressure levels such as 850 mb, 700 mb, 500 mb and 300 mb.

Contours: Any lines representing a constant value. This includes lines of constant height (isohypses) of a pressure surface (e.g., 500 mb) found on constant pressure charts.

Control Flight into Terrain (CFIT): When the pilot or crew unknowingly flies into terrain or obstructions that are normally obscured by poor visibility or clouds.

Convection: Vertical transport of heat in an unstable environment accompanied by dry and moist adiabatic expansion.

Convective Available Potential Energy (CAPE): The maximum buoyant energy of an undiluted air parcel, related to the potential updraft strength of convection measured in J/kg. On a Skew-T log (p) diagram, this is referred to as the positive area and can be seen as the area between the parcel lapse rate and the environmental lapse rate, from the parcel's level of free convection to its level of neutral buoyancy or equilibrium level.

There are several variants of CAPE to include mixed or mean layer (MLCAPE), surface-based (SBCAPE) and most unstable (MUCAPE) sometimes referred to as best CAPE.

Convective Condensation Level (CCL): See CCL.

Convective Inhibition (CINH): The amount of energy in J/kg needed to overcome an atmospheric cap, limiting convection. Often referred to as the negative area on the Skew-T log (p) diagram.

Convective SIGMET: Convection meeting specific criteria that includes an area of greater than 3,000 square miles, line more than 60 nautical miles in length, embedded or severe. These advisories imply severe icing, instrument flight rules (IFR) conditions, mountain obscuration, severe or extreme turbulence and low level wind shear. Once issued, they are valid for two hours.

Convergence: Horizontal movement of air inward usually associated with a low pressure system or trough.

Cumuliform Cloud: Also described as cumulus with a principal characteristic of vertical development with rising unstable air. This contrasts with stratiform clouds, which are associated with static stability.

Cumulonimbus (Cb): A massive cumuliform-type cloud of vertical development. It may or may not have an anvil depending on its height relative to the tropopause height. It is accompanied by heavy precipitation, severe or extreme turbulence, low level wind shear, severe icing, lightning, and sometimes hail and tornadoes. An extremely dangerous cloud for any aircraft to penetrate or fly under.

Cumulus Clouds: Clouds with vertical development often occurring when the atmosphere is unstable.

Cumulus Stage: Initial stage of development of a thunderstorm, characterized by updrafts and showery-type precipitation.

Cyclone: A closed circulating low pressure system rotating counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere.

Cyclonic Flow: Counterclockwise rotation of air around a low pressure system in the Northern Hemisphere and clockwise flow in the Southern Hemisphere.

D

dBZ (Radar Reflectivity): Expressed in decibels (dB) where Z is the reflectivity parameter.

Decameter (DAM): 1 decameter equals 10 meters. This is used to contour heights on constant pressure charts.

Deep, Moist Convection (DMC): This is the vertical transport of heat to form cumuliform-type clouds as air rapidly ascends to a great depth to become dangerous to all aircraft.

Density: Mass per unit volume of air.

Density Altitude: The altitude above MSL at which the observed atmospheric density occurs in the standard atmosphere. This is pressure altitude corrected for nonstandard virtual temperature.

Deposition: Change of state from water vapor directly to ice without passing through the liquid phase. Some chemistry books will also label this as sublimation.

Dewpoint: The temperature to which air must be cooled at constant pressure and constant water vapor content for saturation to occur. When this temperature is below 0°C, it is called the frost point. Often spelled as dew point.

Dewpoint Depression: This is also referred to as the temperature-dewpoint spread. It is the static air temperature minus the dewpoint temperature at the same location. A dewpoint depression approaching zero is indicative of saturated conditions.

Diabatic Process: A thermodynamic change of state of a system in which the system exchanges energy with its surroundings by virtue of a temperature difference between them. Also compare this to Adiabatic Process.

Diurnal: Daily, especially pertaining to actions that are completed within 24 hours and that recur every 24 hours; thus, most reference is made to diurnal cycles, variations, ranges, maxima, etc. For example, afternoon thunderstorms are said to occur diurnally.

Divergence: The opposite of convergence. This is usually associated with a horizontal outflow from high pressure. Divergence from above promotes convergence below.

Doppler Weather Radar: A radar system that detects hydrometeors that also includes a change in target velocity by measuring frequency shifts due to relative movement from the radar site. In the U.S. these are NEXRAD WSR-88D or Terminal Doppler Weather Radars (TDWR).

Downburst: A concentrated downdraft, usually severe in nature that produces an outward and downward burst of damaging winds striking the ground. Also see Microburst.

Downdraft: A downward motion of air sometimes felt during a mountain wave event.

Downslope: Wind blowing down a slope or side of a mountain and may cause the air ti dry out and clouds to dissipate as air is compressed and heated dry adiabatically.

Drizzle (DZ): Very small water drops that appear to float and have very low fall rates. Drops are in the range between 200 and 500 microns.

Drop Concentration: The amount or number of drops in a specific volume of air.

Dry Absolute Instability: See Super-Adiabatic Lapse Rate.

Dry Adiabatic Lapse Rate (DALR): Rate of temperature decrease of lifted air when unsaturated air ascends adiabatically. The rate is usually rounded to 3°C for every 1,000-foot increase in height. This rate is defined as one of the reference lines on the base Skew-T log (p) diagram.

Dryline: Sometimes referenced as "dry line" is a mesoscale moisture boundary that separates hot, dry air and warm, moist air. This is sometimes referred to as a dewpoint front. Drylines can be an important factor in severe weather frequency in the American Great Plains.

Dryline bulge: Areas along the dryline whose movement relative to the rest of the dryline is altered. This often accompanied by a well-defined jet streak underneath the jet. A bulge in the dryline can lead to a greater focus for surface moisture convergence and the potential for severe thunderstorms in the area around the bulge.

Dust (DU): Small particles suspended in the atmosphere that can act as cloud condensation nuclei.

E

Echo: For ground-based or airborne radar, it is the amount of reflected energy returned by a target such as a raindrop, ice pellet, hailstone or snowflake.

Eddy Dissipation Rate (EDR): An aircraft-independent measure of the intensity of atmospheric turbulence in m^2/s^3 represented by a value from 0 (smooth) to 1.0 (extreme). Sometimes multiplied by 100 for ease of use.

Entrainment Zone: This marks the top of the mixed layer and is the interface between the planetary boundary layer and free atmosphere.

Environmental Lapse Rate (ELR): The rate of change of temperature with height. This can be based on observations or forecast.

Equilibrium Level: Altitude where the temperature of a rising saturated air parcel becomes equal to the surrounding air temperature.

Evaporation: Change of state of water from a liquid to vapor. Evaporation stores heat energy and therefore is a cooling process.

EZWxBrief: A progressive web app (PWA) that is owned and operated by the author that is elegantly designed to blend high-resolution supplemental weather guidance with the pilot's personal weather minimums. All of this is seamlessly integrated with the EZDeparture Advisor™, a unique approach that quantifies your risk and instantly lets you know the most favorable time to depart based on the pilot's personal weather minimums. Visit ezwxbrief.com.

F

FA (Area Forecast): The aviation area forecast has been replaced by the Graphical Forecasts for Aviation (GFA).

FAA (Federal Aviation Administration): National authority that regulates all aspects of civil aviation in the United States and its territories.

Foehn Wind: Dry, warm, down-sloping wind that occurs in the downwind side of a mountain range. The Chinook and Santa Ana winds are Foehn winds. These down-sloping winds produces a clear-air gap in the cloud cover between the ridgeline of mountains and altocumulus standing lenticular clouds called a Foehn gap.

Fog: An obstruction to visibility that is associated with a low-lying stratus cloud with visibility lowering to less than 5/8th of a statute mile (SM). There are six types: advection, upslope, radiation (ground fog), ice fog, frontal (precipitation) and steam fog. When the static air temperature is below 0°C, it is termed freezing fog.

Freezing Drizzle (FZDZ): Drops with a size between 200 to 500 microns falling to the surface where the temperature aloft is colder than 0°C.

Freezing Fog (FZFG): See Fog.

Freezing Rain (FZRA): Drops with a size greater than 500 microns falling to the surface, where the static air temperature is colder than 0°C. Freezing rain can also occur aloft even when the surface temperature is at or below 0°C.

Front: Transition zone between two air masses. The main frontal types are cold, warm, occluded, and stationary.

Frost: The fuzzy layer of ice crystals on a cold object, such as grass, a window or the upward-facing surfaces of an aircraft that forms by direct deposition of water vapor to solid ice. At the surface, frost comes in two forms: namely, hoarfrost and frozen dew.

Frost Point: See Dewpoint.

Frozen Dew: Frost that forms due to the freezing of liquid water (dew). Initially, both the dewpoint and temperature are above freezing when dew forms. Radiative cooling on clear, calm nights gradually lowers the temperature to at or below freezing during the night. Once the temperature falls to the freezing point, the condensed dew drops freeze. Frozen dew looks different from hoarfrost. Frozen dew tends to look slicker and clear and more difficult to see. Frozen dew is not as common as hoarfrost.

G

GFA (Graphical Forecasts for Aviation): Replaced the legacy textual FA (Area Forecast).

Global Forecast System (GFS): A weather prediction model developed by the NWS that has a global domain.

Glory: Rainbow or two around an aircraft's shadow projected onto a cloud. This is caused by sunlight interacting with the tiny water drops in the cloud tops. A glory is an indicator that liquid water may lurk at the top of the cloud layer and may indicate the potential for airframe ice when subfreezing temperatures exist.

Gradient: Change of any quantity: height, pressure, and temperature with distance. When the pressure gradient is steep (close together) on a weather map, it means stronger winds.

Graphical AIRMET (G-AIRMET): An advisory issued four times a day by highly trained meteorologists at the Aviation Weather Center (AWC). Each issuance consists of five snapshots valid three hours apart for a total of 12 hours. Each snapshot is valid at a specific time, so it defines the coverage area of that hazardous weather. This includes a forecast for moderate nonconvective airframe icing, freezing level, IFR conditions, mountain obscuration, moderate nonconvective low turbulence, moderate nonconvective high turbulence, sustained surface winds greater than 30 knots, and nonconvective LLWS. Legacy textual AIRMETs and their outlooks are automatically generated from the five snapshots of G-AIRMETs. Also see AIRMET.

Graupel: Ice particle in the 2mm to 5mm diameter range that forms in a cloud often by the process of accretion. Sometimes it is called soft hail. This is needed along with supercooled liquid water and ice crystals for the formation of lightning.

Gravity Waves: Created when air is forced to rise in a stable atmosphere. The most common form of a gravity wave is a mountain-induced wave.

Greenhouse Effect: The capture of terrestrial radiation (longwave) by certain atmospheric gases. Water vapor is the most profound of the greenhouse gases.

Ground Clutter: Pertaining to ground-based radar, a cluster of echoes reflected from ground targets or by nonprecipitation targets such as insects, birds, cars, chaff, or even aircraft. Compare this to Anomalous Propagation (AP).

Ground Fog: Also known as radiation-fog formed under clear skies at night with low turbulent mixing in the potential fog layer.

Gust: A sudden increase in wind and is denoted with the letter G. Gusts shall be reported when the highest peak speed is at least 5 knots higher than the current two-minute average and the highest peak is at least 15 knots.

Gust Front: Sharp outflow boundary found at the edge of a cold dome of air that is conducive to downdrafts that spread out below a thunderstorm. Often gust fronts produce strong straight-line winds exceeding 50 knots ahead of severe convection.

H

Hail (GR): Precipitation composed of clumps of ice 5mm to 50mm, produced within the updrafts and downdrafts of deep, moist convection. Many confuse hail with ice pellets, which is formed by a completely different process.

Haze (HZ): Fine, dry particles suspended in the atmosphere. Haze may be man-made from pollution or formed over oceans and lakes called sea or lake haze. When these particles become wetted, they can begin to obstruct visibility.

Hectopascal (hPa): This equates to 100 pascals. 1 hectopascal is equivalent to 1 millibar and is a meteorological unit of pressure.

Height Above Ground Level (AGL): See AGL.

Heterogenous Nucleation: Freezing of a liquid drop into an ice crystal with the aid of an ice nuclei.

High: An area of high pressure, an anticyclone, denoted by an "**H**" on a surface analysis or prog chart; an abbreviation for a high pressure system.

High Ice Water Content (HIWC): A condition where high concentrations of ice crystals exist in clouds, often in regions surrounding large mesoscale convective systems.

Hoarfrost: A uniform, thin, white deposit of fine crystalline texture that forms due to deposition (sublimation) on exposed surfaces during calm, cloudless nights when the temperature falls below freezing and the humidity of the air at the surface is close to the saturation point.

Hodograph: Tool found on a thermodynamic diagram that looks like a bull's-eye that depicts environmental wind shear, which influences thunderstorm evolution and severity.

Homogenous Freezing: A condition where a supercooled liquid drop freezes without nucleation at a temperature colder than -40°C.

Homogeneous Nucleation: Spontaneous freezing. Freezing of pure water occurring at -40°C/F. Most aircraft manufacturers use this as the lowest threshold for the use of de-ice equipment.

Horizontal Pressure Gradient: Force that produces wind because of horizontal pressure differences.

Horizontal Wind Shear: Change in wind direction and/or speed over a horizontal distance. Not to be confused with vertical wind shear.

Hydrolapse: The rate of change of dewpoint temperature with height.

Hydrostatic Balance: The balance between the downward force of gravity and the upward force of a vertical pressure gradient.

I

ICAO (International Civil Aviation Organization): Specialized agency of the United Nations to manage the administration and governance of the Convention on International Civil Aviation.

Ice Crystal Growth: Process where cloud particles grow to precipitation size. Ice crystals grow by deposition as water droplets decrease by evaporation.

Ice Pellets: Small translucent, round, or irregular-shaped pellets of ice formed when snow partially melts in a shallow layer of temperatures above 0°C and then refreezes in a subfreezing layer. Not to be confused with hail that is often formed in updrafts and downdrafts in deep, moist convection. Ice pellets indicate conditions that may be conducive supercooled large drop (SLD) icing aloft.

Ice Protection System (IPS): Mechanical, pneumatic, and/or electrical systems built into an airframe to remove or prevent ice accretion. This includes, but is not limited to pneumatic boots, weeping wings, heated wings, heated windscreen, bleed air, heated propellor blades and pitot heat. Some systems can be certified for flight into small drop icing environments.

Icing: See Airframe Icing.

IFR (Instrument Flight Rules) Flight Category: Defines a condition where the ceiling is less than 1,000 feet and/or surface visibility less than 3 statute miles.

IMC (Instrument Meteorological Conditions): A flight environment whereby operating an aircraft solely by visual references located outside of the cockpit are highly restricted or no longer available.

In-Cloud Turbulence: Turbulence experienced within the boundary of a cloud. This is normally associated with cumuliform-type clouds that produce convective-induced turbulence.

Indefinite Ceiling: A ceiling classification of vertical visibility into a surface-based obscuration such as fog or precipitation.

Indicated Altitude: The reading on the altimeter when it is set to the current altimeter setting.

Insolation: Incoming solar radiation reaching the earth and its atmosphere.

Instability: A state of the atmosphere. Generally, when cold air sits above warm air.

Intertropical Convergence Zone (ITCZ): Region that circles Earth, near the equator, where the trade winds of the Northern and Southern Hemispheres come together.

Inversion: An increase in temperature with height. There are nocturnal (radiation), frontal, subsidence, and tropopause inversions.

IR (Infrared): Wavelengths longer than visible light in reference to the electromagnetic spectrum. Used in detecting heat of the earth and clouds in satellite imagery.

ISA (International Standard Atmosphere): Standard temperature at sea level is 15°C, barometric pressure is 1013.25 millibars (hectopascals), 29.92 inches of mercury, standard lapse rate is 1.98°C/1,000 feet, with the tropopause height at 36,089 feet and the air is a dry gas.

Isobar: A line joining equal barometric pressure on a surface weather map, usually contoured every four millibars.

Isohumes: Lines of constant relative humidity. See Saturation Mixing Ratio.

Isopleth: A line on a map connecting points having equal incidence of a specified meteorological feature or value.

Isotherm: A line joining equal temperatures.

Isothermal Layer: A layer of stable air (usually shallow) having a constant temperature with height.

J

Jet Streak: A horizontal distribution of strong atmospheric winds near the tropopause.

Jet Stream: A narrow, meandering, fast current of air in the Northern and Southern Hemisphere, normally found near the tropopause because of differential heating between the polar and tropical regions of Earth.

K

Katabatic Wind: A wind that blows down a slope. It is also called a downslope wind, drainage, or gravity wind. Chinook, Bora, Foehn, etc. winds are colloquial names given to katabatic winds.

Katafront: A front (usually a cold front) at which the warm air descends the frontal surface (except, presumably, in the lowest layers).

Kinetic Energy: Energy of an object because of its motion.

Kinetic Heating: The temperature rise of the air in the boundary layer of the surface of an aircraft wing or leading edge. This rise in temperature is due primarily to adiabatic heating of air that is compressed.

Knot: Nautical mile (6,076 feet) per hour usually representing the velocity of the wind or wind gust. Also used in aviation to measure airspeed.

L

Lapse Rate: Rate of temperature change with height.

Latent Heat: Heat absorbed or released during a change of phase of water at constant temperature and pressure.

Lee Waves: Stable atmospheric gravity waves that flow over and downwind of a mountain barrier.

Lenticular Cloud: A lens-shaped cloud often referred colloquially as a "lennie." It is a sign of mountain wave activity.

Level of Free Convection (LFC): Level in which a lifted parcel of air becomes warmer than its surroundings in a conditionally unstable atmosphere.

LIFR (Low Instrument Flight Rules) Flight Category: Defines a condition where the ceiling less is than 500 feet and/or surface visibility less than 1 statute mile.

Lifted Condensation Level (LCL): Level at which a parcel of air being lifted dry adiabatically becomes saturated. Generally, where the base of a convective cloud starts. This is also referred to as the lifting condensation level.

Lifted Index (LI): Also referred to as the lifting index. This represents the difference in temperature in degrees Celsius between the environmental lapse rate and the parcel lapse rate at 500 mb on a Skew-T log (p) diagram. There are several variants of LI to include mixed or mean layer (MLLI), surface-based (SBLI) and most unstable (MULI).

Lightning: Electrical discharge produced by a thunderstorm. Lightning can also be induced by the aircraft itself, even when no natural lightning exists nearby.

LLWS (Low Level Wind Shear): Wind shear below 2,000 feet AGL caused by thunderstorms, frontal wind shifts, inversions, low level jets, microbursts, downdrafts, katabatic winds, etc.

Longwave Radiation: Radiation that is generated by the surface of the earth or other objects (e.g., clouds) to deep space.

Loss of Control (LOC): When the pilot or crew no longer has positive input to the direction, altitude, or speed of the aircraft.

Low: An area of low pressure, also known as a cyclone, where winds blow inward and counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere.

LWC (Liquid Water Content): Measure of mass of water in a cloud in a specified amount of dry air. It is typically measured per volume of air (g/m^3) or mass of air (g/kg).

M

Magnetic Winds: Winds referencing magnetic north. Magnetic winds are given from ATC, FSS and given on the ATIS.

Mammatus: An undulating, pouch-like appearance mostly commonly located hanging below the bottom of the anvil of a mature cumulonimbus cloud. They can also protrude under other cloud types, as well.

MCS (Mesoscale Convective System): A cloud system that occurs in connection with an ensemble of thunderstorms and produces a contiguous precipitation area on the order of 100 miles or more in horizontal scale in at least one direction. An MCS exhibits deep, moist convective overturning contiguous with or embedded within a mesoscale vertical circulation that is at least partially driven by the convective overturning.

Mechanical Turbulence: Turbulence due to strong flowing low-level winds flowing over rough terrain. Its intensity depends on wind strength, terrain, or obstructions and air stability with most mechanical turbulence diminishing from 6,000 to 8,000 AGL.

Melting: Change of state of water from a solid to a liquid.

Melting Level: See Freezing Level.

Meridional Flow: Upper-level winds that flow in a southerly/northerly direction to closely parallel the lines of longitude. Compare to Zonal Flow.

Mesoscale: Weather circulation with horizontal dimensions from 100 to 1,000 miles. Weather systems are smaller than synoptic scale, but larger than microscale.

METAR or (Aviation Routine Meteorological Report): A formatted description of weather usually represented by textual code. Also see Surface Observation and SPECI (Special Observation).

Meteorologist: An individual with specialized education using scientific principles to explain, understand, observe, or forecast the earth's atmospheric phenomena.

Meteorology: The study of the atmosphere and its phenomena derived from Greek meaning, "something high in the sky."

Micro: A micrometer (μ). 1,000 microns is equal to 1 millimeter. Used to define the size of cloud condensation nuclei or ice nuclei, as well as the size of cloud drops.

Microburst: A downburst with horizontal dimensions of 2 nautical miles or less. There are wet and dry microbursts.

Millibar (Mb): Unit of atmospheric pressure used in aviation. Standard pressure in millibars is 1013.25. Also see Hectopascals.

Mist (BR): This is an obstruction to visibility and is not an indication of precipitation. Used in a METAR or TAF when the visibility is 5/8th to 6 statute miles inclusive.

Mixed Icing: A combination of clear and rime icing. Usually occurs when transitioning between two different differing icing environments, such as during a climb or descent, as temperature or liquid water content changes cause the icing type to also change.

Moist Adiabatic Lapse Rate (MALR): The rate of cooling of saturated air that ascends in the troposphere. This is not a constant rate but varies with temperature. This rate is defined as one of the reference lines on the base Skew-T log (p) diagram.

Moisture: An all-inclusive term denoting the presence of water vapor, liquid water, and ice in the atmosphere.

Mountain Wave: An atmospheric gravity wave forming on the lee side of a mountain or hill. A mountain wave may create a cap cloud, rotor cloud, or lenticular cloud. However, the sky can be clear and yet a major wave causing airspeed fluctuations and altitude deviations can easily exist, as well as severe or extreme turbulence.

MSL (Mean Sea Level): It is calculated by adding the station pressure with the weight of a column of air between the elevation of the station and mean sea level, based upon an average temperature during the previous 12 hours. MSL is found on surface analysis charts. Also referenced as ASL (Above Sea Level).

MSLP (Mean Sea Level Pressure): Reference datum for altitude.

Multi-radar Multi-sensor (MRMS): A system with fully automated algorithms that quickly and intelligently integrate data streams from multiple radars and other sensors to produce a radar mosaic that is refreshed every two minutes.

MVD (Median Volumetric Diameter): The median size of drops of water in some volume of air.

MVFR (Marginal Visual Flight Rules): Defines a condition where the ceiling is from 1,000 to 3,000 feet and/or surface visibility 3 to 5 statute miles.

N

Nall Report: An annual report from the AOPA Air Safety Institute that examines and compiles aviation-related accidents and statistics.

NASA: (National Aeronautics and Space Administration): Agency responsible for science and technology related to air and space.

National Airspace System (NAS): The region across the U.S. that describes navigation facilities and airports along with their associated information, services, rules, regulations, policies, procedures, personnel, and equipment.

National Centers for Environmental Protection (NCEP): This is a branch of the National Oceanic and Atmospheric Administration (NOAA) comprised of nine distinct Centers. These Centers are critical in national and global weather prediction by providing a wide variety of national and international weather guidance products. These National Centers consist of the Aviation Weather Center (AWC), Climate Prediction Center (CPC), Environmental Modeling Center (EMC), NCEP Central Operations (NCO), National Hurricane Center (NHC), Ocean Prediction Center (OPC), Space Weather Prediction Center (SWPC), Storm Prediction Center (SPC) and the Weather Prediction Center (WPC).

National Digital Forecast Database (NDFD): This is a suite of gridded forecasts of sensible weather elements (e.g., cloud cover, maximum temperature). NWS field offices working in collaboration with the National Centers for Environmental Prediction (NCEP) are combined in the NDFD to create a seamless mosaic of digital forecasts.

Nautical Mile: 6,076 feet. Used for navigation distance in aviation.

Negative Lapse Rate: A condition where temperature increases with an increase in altitude/height. This is usually characterized in shallow layers.

NEXRAD (Next Generation Weather Radar): A network of high-resolution Doppler weather radars operated by the National Weather Service.

Nimbostratus: Cloud that is layered to great heights in a frontal system or low pressure center, producing steady nonconvective precipitation.

NOAA (National Oceanic and Atmospheric Administration): American scientific agency within the United States Department of Commerce that focuses on the conditions of the oceans, major waterways, and the atmosphere.

Nocturnal Inversion: Typically, a surface-based inversion due to radiative cooling at night.

Nocturnal LLJ (Low Level Jet): Localized maximum in the wind velocity due to a surface-based nocturnal inversion within 2,000 feet AGL. Wind velocities are typically less than 40 knots but may get as strong as 60 knots.

Nonconvective Low Level Wind Shear (LLWS): A form of vertical speed shear where the winds rapidly increase with height within the first 2,000 feet of the surface.

Nor'easter: An intense storm that tends to form near Hatteras, North Carolina, and tracks northeastward. Heavy precipitation (rain or snow) and strong winds accompany this system. The direction of wind, not the track, defines this storm.

North American Mesoscale (NAM): A weather prediction model developed by NOAA that has a North American domain.

NOTAM (Notices to Air Mission): Formerly Notice to Airmen. A notice filed with an aviation authority to alert pilots of potential hazards along a flight route or at a location that could affect the safety of the flight.

NWP (Numerical Weather Prediction): Forecast models run on supercomputers that provide predictions on many atmospheric variables such as temperature, pressure, wind, and precipitation.

NWS (National Weather Service): Branch of NOAA tasked with providing weather forecasts, warnings of hazardous weather, and other weather-related products.

O

OAT (Outside Air Temperature): Recorded by a sensor to determine the temperature outside of the aircraft. Most immersion thermometers used to record OAT have errors, especially when they get wet or accrete ice. Also see SAT.

Obscuration: Sky hidden by a surface-based obscuring phenomena such as fog or precipitation.

Occluded Front: Frontal result during or after an occlusion.

Occlusion: Process when the cold front overtakes the warm front, pushing the warm air aloft. It marks the mature and dying stages of a frontal low. There are also warm front occlusions.

Orographic Lift: Lifting of an air mass when it moves up or over a mountain ridgeline or hill.

Outflow Boundary: Created when cold, dense air falls out of the base of convection. The air strikes the ground and spreads out in all directions to a gust front. This is a lot like pouring pancake batter on a griddle with the edge of the pancake representing the gust front.

Overcast (OVC): Cloud layer covering 8/8 of the sky. Constitutes a ceiling.

Overrunning: When a warm air mass overrides a cooler air mass where the boundary is the warm front or stationary front.

Overshooting Tops: Overshooting air from violent updrafts within deep, moist convection, penetrating the tropopause and overshooting the equilibrium level by thousands of feet.

P

Parcel: A volume of air containing a uniform distribution of meteorological properties. The term parcel is used to simplify discussions on atmospheric stability.

Particulates: Very small liquid or solid particles and aerosols usually smaller than 1 micron in diameter.

Phase Change (Phase Transition) (Change of State): Transitions between solid, liquid, and gaseous states of matter. The six phase changes of water are: melting, freezing, evaporation, condensation, deposition, and sublimation. During any phase change of water, heat is either absorbed or released.

Pilot Operating Handbook (POH): See Aircraft Flight Manual (AFM).

PIREP (Pilot Weather Report): Designated as UA for routine or UUA for urgent reports. These are typically generated by pilots, but also may be relayed by air traffic controllers or dispatchers.

Positive Lapse Rate: A condition where temperature decreases with an increase in altitude/height.

Precipitation: Any form of water, snow, or ice that falls from the atmosphere.

Pressure: See Atmospheric Pressure.

Pressure Altitude: Reading on the altimeter as a flight level when it is set to standard barometric pressure of 29.92 in. Hg or 1013 mb.

Pressure Gradient: Generally, the pressure differential over a known geographic distance.

Pressure Tendency: Change of pressure over some time.

Prevailing Visibility: Horizontal distance observed which equals or exceeds half of the horizon circle.

Prevailing Winds: Direction from which the winds blow most frequently over some time.

Prog Charts (Prognostic Charts): Graphic display of forecast conditions usually at the surface. In the U.S. these are issued daily by forecasters at the Weather Prediction Center (WPC).

Pulse Thunderstorm: See Air Mass Thunderstorm.

Q

Quasi-Linear Convective Systems (QLCSs): A complex of thunderstorms or deep, moist convection that commonly develops during the night and poses the threat of strong/damaging winds and isolated tornadoes.

Quasi Stationary: A position that is nearly stationary.

Quasi-Stationary Front (Stationary Front): Frontal system that moves very little or undulates back and forth, moving at a speed generally less than 5 knots.

R

Radar (Radio Detection and Ranging): A device that transmits microwave energy toward areas of precipitation. Depending on the precipitation type, a certain amount of the reflected energy is returned and verified through the calibrated radar system where it is received.

Radiation: Transfer of energy in the electromagnetic spectrum.

Radiation-Fog: See Ground Fog.

Radiosonde or Rawinsonde: Meteorological device/sensors trailing a weather balloon that is filled with hydrogen (rarely helium), that ascends to about 100,000 feet before bursting. During its ascent, the radiosonde transmits meteorological data (temperature, pressure, and humidity) back to the station, and the instrument package track is monitored to determine wind speed and direction.

Rain: Form of precipitation with drops larger than drizzle. Rain is generally over 500 microns in diameter.

Ram Air Temperature (RAT): Temperature of the boundary layer air just in front of the leading edge of the aircraft surfaces while in flight.

Ram Air Temperature Rise: The increase in temperature of the air immediately above the aircraft's leading edge while in flight due to kinetic heating.

RAOB: Radiosonde (or Rawinsonde) observation. This is the data produced by the ascending weather balloon and captured by surface equipment through telemetry. This data can be plotted on a Skew-T log (p) diagram.

Reflectivity: Amount of returned radar energy, mostly based on size of the hydrometeor. Wet-coated hydrometeors such as wet-coated hail, ice pellets, or wet snow return the highest energy.

Relative Humidity (RH): Defined as the ratio of the actual amount of water molecules to the amount of water molecules when saturation is reached.

Ridge: Elongated area of high pressure on a surface analysis or constant pressure chart. Usually a sign of fair weather.

Rime Icing: Formed from small, supercooled water drops impinging on an aircraft appearing as white, grayish, milky, brittle, or granular.

Riming: A condition where liquid drops freeze onto an ice crystal or snowflake or onto the surface of an aircraft.

S

SALR (Saturated Adiabatic Lapse Rate): Rate of decrease of temperature with height as saturated air is lifted. Also see MALR.

Santa Ana Wind: Strong, extremely dry downslope winds originating inland and affect coastal Southern California and northern Baja California due to cool, dry high pressure air masses in the Great Basin.

SAT (Static Air Temperature): Actual temperature of the undisturbed air outside the aircraft. This is the temperature aloft that is forecast or measured by equipment such as a radiosonde.

Saturation: State of dynamic equilibrium of water molecules. Occurs when the temperature and dewpoint are equal, or the relative humidity is 100 percent.

Saturation Mixing Ratio: This defines the mass of water vapor divided by mass of dry air in grams per kilogram. This is a reference line on the Skew-T log (p) diagram.

Sea Breeze: A coastal breeze blowing from the sea to land during the day as the land heats up faster than the water.

Severe Thunderstorm: An area of convection or cell having a greater intensity. Gusts of 50 knots or more, hail of more than 1" in diameter and tornadoes can occur with severe thunderstorms.

SIGMET (WS) (Significant Meteorology Information): Weather advisory containing meteorological information concerning the safety of all aircraft. There are two types of SIGMETs: convective and nonconvective.

Skew-T log (p) diagram: A thermodynamic diagram that provides a vertical plot of the temperature, dewpoint temperature, and wind speed and direction as a function of pressure (altitude).

SLD (Supercooled Large Drop): This is an icing environment with drops that have a median volumetric diameter (MVD) of more than 50 microns, that exist at a liquid state in below freezing temperatures. SLD includes freezing rain and freezing drizzle and is often found in cumuliform clouds with significant vertical development.

Sleet: Colloquial name for ice pellets. In other countries sleet can also be a mixture of precipitation types such as rain and snow.

SLP (Sea Level Pressure): Atmospheric pressure at sea level.

Sounding: A vertical probe of the atmosphere usually obtained from a radiosonde (weather balloon). Can also be plotted from a forecast model, which is referred to as a forecast sounding.

SPECI (Special Observation): METAR code when significant weather changes occur between the hourly routine observations from an ASOS.

Standard Lapse Rate: A decrease of temperature at the rate of 2°C (1.98°C) per 1,000 feet up to 36,000 feet. Often used in performance tables in the Pilot Operating Handbook (or Aircraft Flight Manual) as it relates to a departure from standard. Should never be used to make meteorological decisions such as calculating the lowest freezing level.

Station Pressure: Weight of the atmosphere above a station as measured by a barometer.

Stationary Front (Quasi-Stationary Front): The warm air and cold air are moving parallel to each other, causing an undulation in the frontal position. The cold air neither advances nor retreats away from the warm air mass. These conditions can persist for days.

Statute Mile: A mile of 5,280 feet or 1,760 yards. The unit for surface visibility in the U.S. is the statute mile. Also see Nautical Mile.

Storm Prediction Center (SPC): Part of the National Centers for Environmental Prediction (NCEP). Forecasters provide forecasts and watches for severe weather over the contiguous U.S. that include convection that is likely to produce strong straight-line winds, large hail, and tornadoes. They also monitor hazardous fire weather and winter weather events across the U.S. and issue specific products for those hazards.

Stratocumulus (Sc): Low level cloud which spreads horizontally and has a quilted-like appearance when viewed from the top. Typically, very shallow with a depth of 500 to 4,000 feet.

Stratosphere: The atmospheric layer directly above the tropopause. It is very stable with low moisture content, thus few clouds.

Stratus (St): A uniform, featureless, low-lying layer of cloud that forms in a stable atmosphere. Drizzle may accompany a low stratus cloud deck.

Sublimation: Change of state from ice to water vapor. Some chemistry books state sublimation is also a change of state from water vapor to ice, but the more accepted term in meteorology for this is deposition.

Subsidence: Slow, descending air over a broad area, usually associated with a high pressure area. The descending air is compressed and heats up, causing relative humidity to decrease and thus causing clouds to dissipate.

Subsidence Inversion: Temperature inversion caused by sinking air or what is called subsidence. These inversions can trap pollutants and moisture, creating haze.

Super-Adiabatic Lapse Rate: When the observed or forecast environmental temperature lapse rate exceeds the DALR (Dry Adiabatic Lapse Rate). This rate of temperature change is very shallow and generally occurs within the first 500 to 1,000 feet of the surface.

Supercell (Supercell Storm): A violent thunderstorm that lasts for several hours, sometimes causing torrential rain, tornadoes, hail, and strong winds and is characterized by a deep, persistently rotating updraft.

Supercooled Liquid Water (SLW): Water in the liquid state at a temperature below 0°C that has yet to undergo freezing. This is responsible for airframe icing.

Supercooling: The cooling of liquid water at a temperature below 0°C.

Surface Charts: Analysis and forecast charts depicting conditions occurring or expected at the surface.

Surface Layer: The portion of the boundary layer that is touching the surface and ordinarily less than 1,000 feet deep.

Surface Observations: Routine meteorological aviation report in a standardized coded form available at weather observing stations (usually airports) throughout the world. Also see METAR.

Synoptic Scale: A scale of distance and time (on the order of days) used by a meteorologist to describe large weather phenomena such as highs, lows, fronts, and large hurricanes.

T

TAF (Terminal Aerodrome Forecast): TAFs are a textual product issued by highly trained meteorologists at the NWS every six hours for over 700 airports throughout the U.S. and its territories and represents the expected meteorological conditions significant to aviation at an airport for a specified period, ordinarily 24 hours. A complete TAF will include a forecast of surface wind speed and wind direction, surface visibility, weather, obstructions to visibility, cloud coverage, and cloud height or vertical visibility into a surface-based obscuration and nonconvective low level wind shear (LLWS). TAFs at airports with long haul operations are issued for a period of 30 hours.

TAT (True Air Temperature): Total Air Temperature is the corrected static air temperature due to kinetic heating of the boundary layer air immediately above the leading edge of the aircraft surface. Also referred to as the Ram Air Temperature (RAT).

Temperature: Measure of the average kinetic energy. Worldwide, the most common used scale is Celsius (°C). Both the Celsius and Kelvin scales are SI units (International System of Units). The Fahrenheit scale is used in public forecasts in the U.S. and some aircraft POHs (Pilot Operating Handbooks).

Terminal Area: The circular area within 5 statute miles of the center of the airport's runway complex. The terminal area's vicinity is the donut-shaped area from 5 to 10 statute miles and excludes the terminal area.

Thermal: Rising plume of warm air. An element of dry convection.

Thermal Turbulence: This is turbulence caused by atmospheric mixing in the planetary boundary layer. Also called dry convection.

Thunderstorm: A rain shower where thunder is heard. Since thunder comes from lightning, all thunderstorms have lightning.

Total Air Temperature (TAT): See Ram Air Temperature (RAT).

Trace: Immeasurable amounts of precipitation or airframe ice.

Tropopause: Boundary between the lower troposphere and the higher stratosphere characterized by a sudden temperature lapse rate change (i.e., isothermal or inversion). Standard height is 36,089 feet (11,000 meters), which varies with season, latitude, and weather systems.

Troposphere: The atmospheric layer from the earth's surface to the tropopause, about 36,000 feet. It is the layer in which we live and is characterized by decreasing temperature with height, and where most moisture occurs.

Trough: An elongation of low pressure at the surface or aloft.

True Altitude: The height above mean sea level (MSL).

Turbulence: Any irregular or disruptive flow in the atmosphere due to mixing. There are six (mechanical, convective, orographic, LLWS, frontal and CAT) naturally occurring and one man-made called wake turbulence.

Turbulent Mixing: Also known as atmospheric mixing that is primarily due to rising or descending air.

U

UA: Abbreviation for a pilot weather report (PIREP). Also see UUA.

Unstable: Instability; air with a steep lapse rate. Can be saturated or unsaturated. Usually when cold air occurs over warm air.

Updraft: Localized vertical movement of air usually associated with convection.

Upper Low: An enclosed contoured low at higher altitudes.

Upslope Fog: Fog forming when moist stable air flows upward over higher terrain.

UTC (Coordinated Universal Time): Time standard used in both meteorology and aviation.

UUA: Urgent pilot weather report (PIREP) for severe conditions such as icing, turbulence, and low level wind shear (LLWS). Also see UA.

V

Vapor Pressure (Equilibrium Vapor Pressure): Indication of a liquid's evaporation rate. It relates to the tendency of particles to escape from the liquid (or a solid).

Vertical Speed Shear: See Nonconvective Low Level Wind Shear.

Vertical Visibility (VV): Distance in feet an observer can see upward into a surface-based obscuration such as precipitation or fog. See Indefinite Ceiling.

Vertical Wind Shear: A sudden change in wind velocity and/or speed with height.

VFR (Visual Flight Rules): Rules that govern flights operating under visual conditions where reference to features outside of the cockpit is maintained.

Virga: Precipitation in the form of rain or snow that falls from a cloud but evaporates before it reaches the ground.

Visibility: Measure of horizontal visibility measured in statute miles in the U.S.

VMC (Visual Meteorological Conditions): Aviation flight category where VFR (Visual Flight Rules) flight is permitted. Conditions whereby pilots have sufficient visibility to fly the aircraft maintaining visual separation from terrain and other aircraft.

Vorticity: A clockwise or counterclockwise spin in the troposphere. Vorticity is an indicator of the vertical motion of air; positive vorticity indicates upward movement and negative downward. If positive vorticity advects into an area of low pressure, it will deepen (intensify the low). Negative vorticity would weaken a low pressure.

W

Warm Front: A front whereby warm air replaces the exiting cold air.

Warm Nose: Region where warm air overruns cold, stable air at the surface and marks the layer in the atmosphere where the temperature aloft is greater than 0°C, with subfreezing conditions above and below this layer. Snow falling into this layer is melted into rain.

Warm Sector: In the Northern Hemisphere, it is south of the warm front and east of the cold front.

Water Vapor: Gaseous form of water.

Weather Forecast Office (WFO): As of this writing, the National Weather Service (NWS) operates 122 weather forecast offices in the conterminous U.S. and its territories. Each office has a geographic area of responsibility, also known as a county warning area, for issuing local public, marine, aviation, fire, and hydrology forecasts. They also issue severe weather warnings, gather weather observations, and daily and monthly climate data for their assigned area. Some offices launch a radiosonde (weather balloon) twice a day.

Weather Prediction Center (WPC): Located in College Park, Maryland, this branch of the NWS issues storm summaries on storm systems, bringing significant rainfall and snowfall to portions of the U.S. They also forecast precipitation amounts for the lower 48 United States for systems expected to impact the country over the next seven days.

Wind: Horizontal motion of air.

Wind Shear: A marked change in wind direction and/or speed, either in the horizontal or vertical, over a short distance.

Z

Zonal Flow: Winds that predominantly flow from west to east, generally parallel to the lines of latitude.

Zulu Time (Z): The time at the Prime Meridian using a 24-hour clock. Formerly Greenwich Mean Time (GMT). See also UTC (Coordinated Universal Time).

References

Unless stated otherwise, all photos and graphics in this text were taken or created by Dr. Scott Dennstaedt. Below are the references used in this text.

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Acknowledgements

Finishing this book has been on my to-do list for almost a decade. Once my doctoral dissertation was in the rearview mirror, I felt like it was time to head back to my writer's sanctum and finish what I had started nearly two decades ago. While I chose to write this book myself, it was certainly a team effort over those years. I am indebted to a group of scientists and other professionals that I have come to know personally, many of whom are elite experts in their field.

There are too many to list, but a few of these professionals are people I greatly admire for their service to aviation and meteorology. This includes my good friend and colleague, Ben Bernstein, who is the leading expert in the world on airframe icing. Ben and I have met several times in person and exchanged a countless number of emails, and he is one of the humblest people I know in the industry. Ben has likely taught me most of what I know about the subject of icing.

Robert Sharman has helped guide me in one of the most complex subjects in aviation meteorology. He is likely the leading expert in the world on turbulence and his faithful guidance over the years has been truly remarkable. While we have never met in person, he has always made himself available when I needed some extra guidance.

Bill Moninger is the original web developer of NOAA's online interactive RUC soundings tool that has now been taken down from public access. Nearly all the Skew-T diagram screenshots captured for use throughout this book are generated from Bill's creation. While he didn't invent the Skew-T, his interactive tool was one of slickest of its kind. I first learned about the NOAA website in the late 1990s when it was developed in Java and later converted to html5. Bill has been steadfast to support this over the decades that followed, despite government shutdowns from time to time.

Lastly, I would be remiss if I did not acknowledge the support over the last two decades from all my weather students, customers, fellow aviation professionals, and other casual onlookers. You know who you are. Many of these people have encouraged me to set the bar higher and keep pressing on year after year after year despite my hardheadedness. While I have never been honored as the flight instructor of the year or have been recognized for any special award in the aviation industry, my reward is hearing pilots regurgitate the training I have provided to them over the years in some form or another. Hopefully the content I have provided here and in other forms will become the gold standard for pilot education for many generations to come.

About Scott

Dr. Scott C. Dennstaedt was born in Baltimore, Maryland. He grew up and attended grade school in Linthicum, Maryland about two miles north of Friendship International Airport. As that airport grew in popularity during the 1960s, it was renamed Baltimore/Washington International Airport in 1973. Living near an airport with a lot of aircraft flying overhead, Scott has always had a love for aviation and flying.

Throughout grade school, Scott was fascinated by the weather. To that end, he attended the University of Maryland at College Park (UMCP) to earn a bachelor's degree in Physical/Atmospheric Science where he also participated in a work-study program at the National Weather Service (NWS). After college, Scott was hired as a research meteorologist for the NWS working in the Development Division at the National Meteorological Center (NMC) in Camp Springs, Maryland later renamed the National Centers for Environmental Prediction (NCEP) now located in College Park, Maryland.

He left government service after five years to pursue a career as a software engineer for several aerospace giants that included McDonnell Douglas and Northrop Grumman. During that time Scott helped build various real-time software systems for weather radar, air traffic control, airport surveillance radar, air defense and even helped develop the software for a Level D flight simulator for a Beech 1900D. He received his Master of Science degree at the University of Maryland, University College in Computer Systems Management in the early 1990s.

In the mid-1990s, Scott decided to pursue his love for aviation and earn a private pilot's certificate and instrument rating. While he never intended to instruct, he purchased a ½ share in a Turbo Arrow IV and earned his commercial pilot certificate and became a part-time instrument flight instructor shortly thereafter. During the time he was honing his stick and rudder skills as a pilot and flight instructor, he quickly realized that certificated pilots had a very poor foundation in weather knowledge. He was able to marry up his love for aviation and meteorology and began to teach pilots at all experience levels how to minimize their exposure to adverse weather.

In 2001, Scott was instrumental in helping the Cirrus Owners and Pilots Association (COPA) to develop and launch their pilot proficiency program (CPPP). Moreover, Scott also helped to develop the proficiency program for the Cessna Advance Aircraft Club (CAAC). That experience led Scott to build several different weekend weather workshops for pilots that focused on increasing a pilot's weather acuity beyond the basics received during primary training. Ironically, the first workshop he held in 2002 was an "**Introduction to the Skew-T log (p) Diagram**" where four pilots paid to attend the half-day program at a small general aviation airport in Fort Meade, Maryland. In addition to logging thousands of hours as a full-time flight instructor, Scott toured the United States and Canada holding several other weekend workshops over the next 15 years.

Scott has also written over 400 articles published in various aviation magazines to include *IFR*, *IFR Refresher*, *Plane & Pilot*, *Twin & Turbine*, *Contrails*, *FLYING*, and *Aviation Consumer* just to name a few. At the time of this writing, he is a contributing editor for *FLYING* magazine. In 2006, Scott relocated to Charlotte, North Carolina and built a complementary training website called AvWxWorkshops.com. This subscription-based website offered a library of online content as well as an Internet briefing tool he called the *Internet Weather Brief Roadmap*. This domain was retired on March 1, 2023.

In 2018, Scott was accepted in the doctoral program at the University of North Carolina at Charlotte (UNCC). His dissertation was focused on studying how pilots consume weather guidance to prevent VFR into IMC accidents using a route-based approach and personal weather minimums. In March 2021, he successfully defended his dissertation, and his doctorate degree was conferred on May 13, 2021. Scott was pleased to graduate with a Ph.D. in Infrastructures & Environmental Systems (INES) and proudly finished his study with a 4.0 GPA! Although learning never ends, he's happy to have this achievement in his rear-view mirror.

The result of nearly four years of intense research spawned a new subscription-based progressive web app (PWA) for general aviation pilots called **EZWxBrief** (https://ezwxbrief.com). This new app went live on April 7, 2021, with a new and improved v2.0 released on May 28, 2024. Today he continues to extend the capabilities of **EZWxBrief** and remains committed to offer personalized online weather training to pilots at all experience levels who are flying in the U.S. and southern Canada.

Scott is married to his very supportive wife of over four decades with three adult children and is now enjoying the benefits of being a cool granddad and looking forward to retirement. 🕶

Weather Essentials for Pilots

While you may master playing one or more musical instruments during your lifetime, you may never write a single line of music. Similarly, you may never know enough meteorology to forecast the weather, but you can learn enough to be a safer pilot. Whether you are starting from scratch as a student pilot or you've logged thousands of hours, this will be the book you continue to reference until you decide to retire from flying. It covers a gamut of aviation weather topics including the ins and outs of the most critical weather guidance you may utilize when planning a cross country flight. As a bonus, it provides the most comprehensive primer available on how to correctly use the Skew-T log (p) diagram as supplemental weather guidance.

Even though some of the concepts and dialog presented in this book are quite challenging even for the most seasoned pilot, they are born out of the fundamental properties of our atmosphere. A thermodynamic chart such as the Skew-T log (p) diagram is clearly the best kept secret in aviation. Specifically, it allows you to "drilldown" over a particular location to identify or describe adverse weather better in time and space than any other single chart or diagram assuming you know how to unlock its plentiful secrets. Lastly, this book is written by an experienced flight instructor who is also an expert in teaching aviation weather.

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