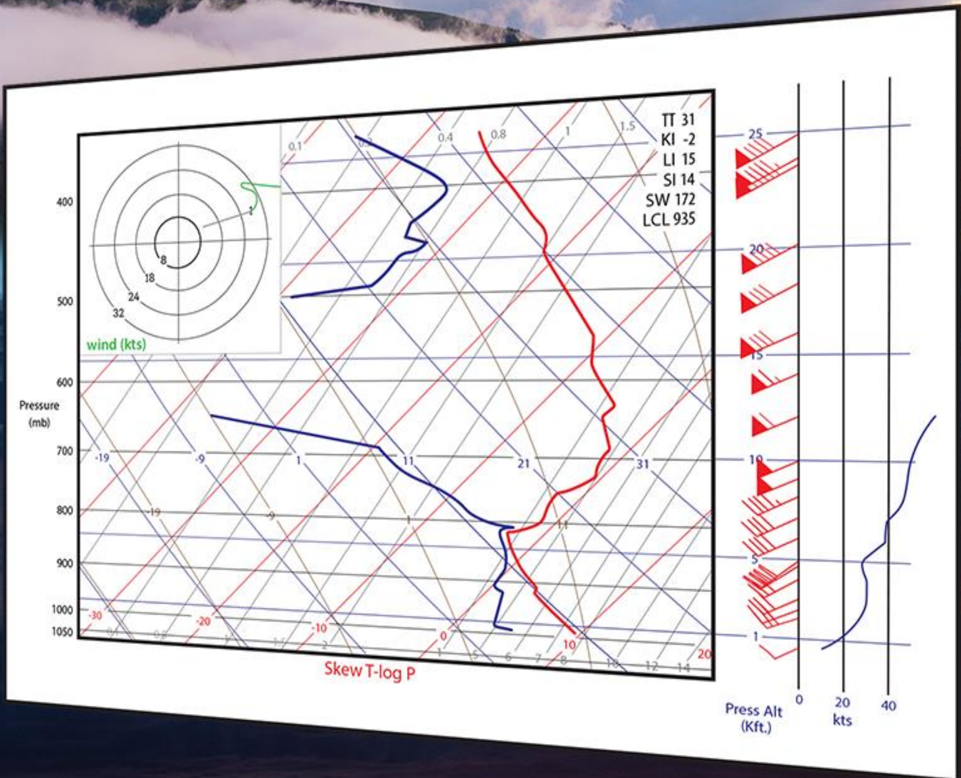
The Skew-T log (p) and Me

A Primer for Pilots



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“The Skew-T log (p) diagram is the best kept secret in aviation if you know how to unlock its 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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Preface

When I was learning to fly in the mid-1990s, I quickly discovered that the Federal Aviation Administration (FAA) was not a huge proponent of the Skew-T log (p) diagram. This is not likely on purpose. It is more likely due to the oversight of its intrinsic value to pilots. In fact, as a budding pilot, I was astonished that the non-regulatory guidance contained in the Aeronautical Information Manual (AIM), and various FAA handbooks and advisory circulars did not make any mention of it. In fact, only the Glider Flying Handbook (FAA-H-8083-13A) gave it an honorable mention in the glossary, simply defining it as a thermodynamic diagram and nothing more.

As a meteorologist for over 40 years and certified flight instructor (CFI) for over 25 years, this is still quite a disappointment. Nevertheless, the FAA is making some attempt to rectify their actions based on the Aviation Weather Services Advisory Circular AC 00-45H, Change 2 that states in the revision memorandum issued in November 2016:

> *"The experience of listening to a weather briefing over a phone while trying to write down pertinent weather information becomes less tolerable when the reports are easily obtainable on a home computer, tablet computer, or even a smart phone. To see weather along your route using a graphic of plotted weather reports combined with radar and satellite is preferable to trying to mentally visualize a picture from verbalized reports. Although most of the traditional weather products, which rolled off the teletype and facsimile machines decades ago, are still available, some are being phased out by the National Weather Service (NWS) in favor of new, Web-based weather information."*

I could not agree more.

Given the critical nature of weather, I aimed to set the bar higher for general aviation pilots. To that end, I co-authored a book entitled, Pilot Weather: From Solo to the Airlines. I was proud to publish this book on October 4, 2018, and readers frequently commented that they were disappointed that the Skew-T log (p) diagram did not have more emphasis in the book. Given the nature of this complex diagram, I felt that it deserved its own comprehensive text which you are reading now.

Yes, the dialogue in this text can be a bit challenging but is necessary to learn how to properly utilize the Skew-T log (p) diagram. Even though you may not completely understand a pseudo-adiabatic process or what the saturation mixing ratio tells you, there are still many basic applications that almost any pilot can master with just a few hours of education that this book provides. For those that really want to master the Skew-T log (p) diagram, I recommend that you read each section more than once to unlock its deep, and perhaps dark secrets or potentially do some 1-on-1 online training with me after you have had a chance to digest what you have read. Spoiler alert…there is quite a bit more weather education contained between the covers of this book than you might imagine.

One word of warning. Be careful of what you read online or in aviation magazines. Look at the source. If the author does not have any training in meteorology, it's probably best to skip it or subject it to a little more scrutiny. Most of what you might have learned already about the Skew-T log (p) diagram is probably worthless. A good deal of what I hear or read is laced with misconceptions and outright nonsense.

One thing is clear: many pilots attempt to learn the Skew-T log (p) diagram on their own without reading a formal text such as this. That's the best way to end up in a compromising situation in flight. The result is that bad assumptions trickle into their briefing with no one to look over their shoulders. Moreover, some pilots have said bizarre things like:

> *"There's never been an accident because the pilot failed to consult the Skew-T."*

This is likely because these pilots do not want to take the time to learn how to effectively use the Skew-T log (p) diagram and are envious of those who do make the time to learn and unlock its secrets. If you are reading this book, congratulations! You have taken the first step to a long yet rewarding journey.

It seems quite common to hear a pilot to incorrectly compare a Skew-T log (p) diagram with a vertical route profile such as the one found in my **EZWxBrief** progressive web app (see ezwxbrief.com). It's as if they believe the Skew-T is some kind of "primary" source of data. For example, here is a common comment that shows a deep misunderstanding of the differences between the two when referring to a specific application's vertical route profile:

> *"I thought they [vertical route profiles] used soundings as their base engine, but I guess not. I'd rather everything be based off soundings."*

Both the vertical route profile and the Skew-T log (p) diagram are specific visualization tools that do overlap and draw their base data from similar sources (e.g., numerical weather prediction models). While forecast wind speed and direction at any segment point along the route is like the wind forecast depicted on the Skew-T log (p) diagram, it is hard to easily quantify the actual lapse rates on a vertical route profile. Also, you cannot "lift a parcel" of air on a vertical route profile to determine the presence of moist instability or derive other useful thermodynamic parameters such as Convective Available Potential Energy (CAPE) or Lifted Index (LI).

Lastly, it is hard to quantify uncertainty on a vertical route profile since these vertical profiles often make undocumented assumptions about the altitude of where clouds exist. We'll talk about quantifying uncertainty later in the text. Knowing just how quickly the temperature and dewpoint diverge is key to knowing how certain we are of where the tops of a stratiform cloud deck may be located. Consequently, it is still important to learn how to use the Skew-T, given that it has other features that a vertical route profile cannot offer.

You will find that the Skew-T log (p) diagram is the centerpiece for discussion in this book, but to get a better appreciation on how to utilize the diagram, this text dives deeply into some of the basic principles of weather that pilots attempt to avoid or have never been properly taught. Therefore, be prepared for a well-rounded education in weather. Furthermore, if you want to do a deeper dive, I am available for personalized one-on-one online training as well.

Since I began to introduce this amazing tool to general aviation pilots in the late 1990s, it is refreshing to see that the Skew-T log (p) Diagram has become important guidance to a subset of pilots when making critical operational decisions. As you wind your way through this text, consider the fact that you may never take advantage of all its capabilities, but if you invest the time, I am sure it will enhance your preflight briefing in a way that few other tools can. Who knows…you may even become a Skew-T junkie?

Please let me know your thoughts.

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Why the Skew-T?

In a nutshell, it's 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 does provide that kind of useful information, but it is also a tool to learn the basic principles and building blocks of meteorology. Since I first began teaching pilots 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, 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 the Skew-T log (p) diagram for their preflight weather planning and analysis. 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 needed.

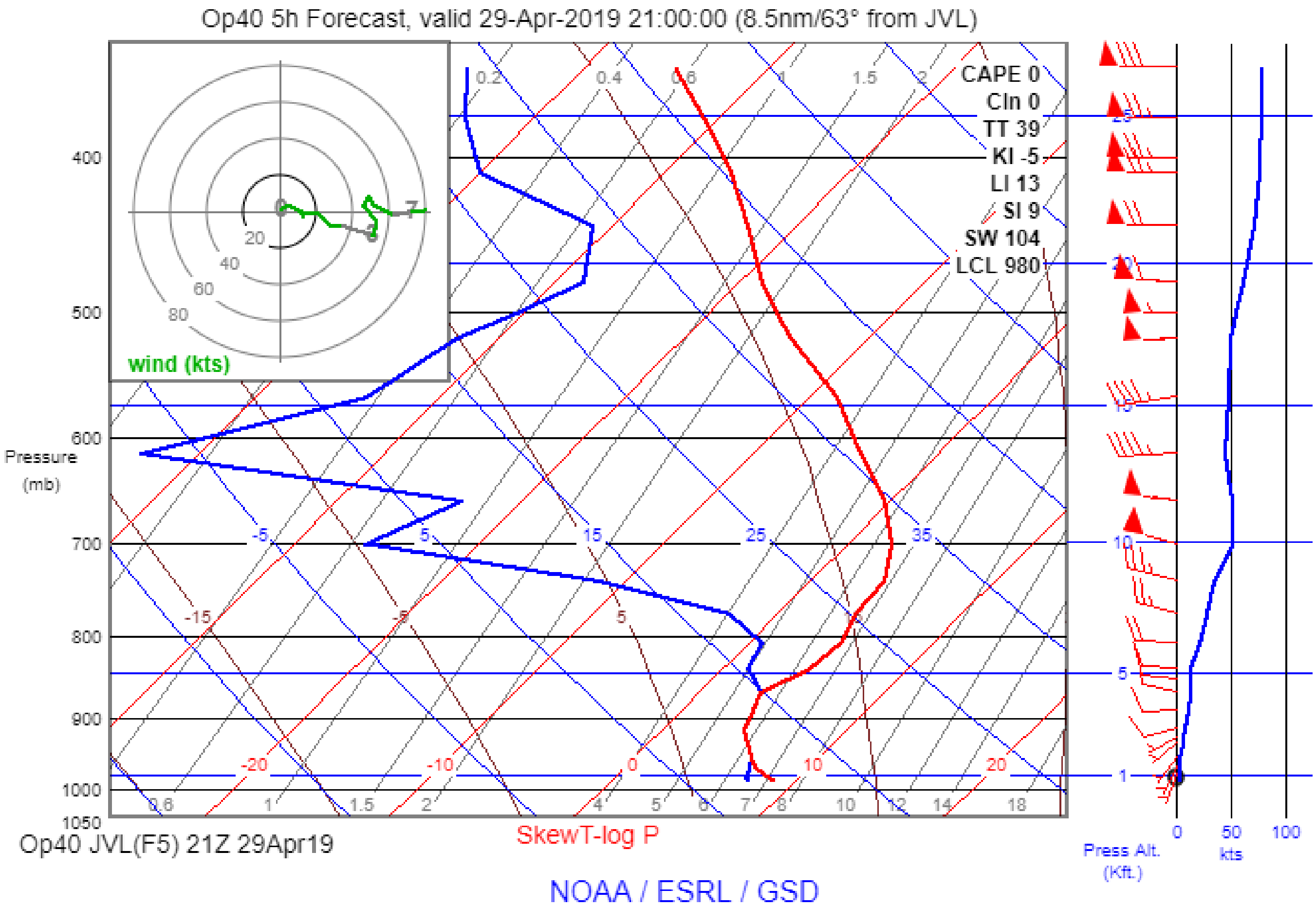

Fig. 1: Temperature, dewpoint temperature and wind plotted on a Skew-T log (p) diagram.

First and foremost, using the Skew-T diagram (Fig. 1) 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 or determining the winds aloft at cruise altitude over a particular location. Simple applications like these require a dearth of knowledge about the diagram and can be taught to just about any pilot in a short period of time. However, some of the more complex techniques such as finding the tops of a cumuliform cloud deck, or the potential for trapped 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.

Key points –

“The Skew-T is also a tool to learn the basic principles and building blocks of meteorology.”

“You need to understand the basic principles of weather first, before understanding how to use the Skew-T log (p) diagram for your preflight weather planning and analysis.”

Valid times

When using any weather observations, forecasts, or analyses, it is of utmost importance that you check and recheck the valid time of that guidance before using it. Failure to do so may result in weather you did not anticipate, leading to an unpleasant outcome once you are airborne. Weather depictions overlaid on charts and maps and other textual observations and forecasts may be valid over a range of time (e.g., accumulated precipitation forecasts), or they may be valid at a single time. The latter is the case for a Skew-T diagram, although data plotted from a radiosonde observation covers the period during its ascent.

General aviation pilots prefer local time even though most observations and forecasts throughout the world use Coordinated Universal Time (UTC) which is the successor of Greenwich Mean Time (GMT). Where did Zulu come from? The military and the North Atlantic Treaty Organization (NATO) assigned each time zone throughout the world a single phonetic letter. There are 24 time zones with the International Date Line utilizing two phonetic letters, namely "M/Mike" and "Y/Yankee." The letter "J" was reserved for the local time of the observer. And the letter "Z" for "Zulu" was assigned the time zone at the Prime Meridian. In a nutshell, Zulu time is the time at the Prime Meridian that runs through Greenwich, England. This represents zero degrees longitude in both hemispheres.

Sometimes it's easier to compromise

You might be wondering why UTC is the abbreviation for Coordinated Universal Time. Simply put, nothing is ever easy. The acronym came about as a compromise between English and French speakers: Coordinated Universal Time would be abbreviated by scientists in the U.S. as CUT, and the French name, Temps Universel Coordonné, would be TUC. Of course, scientists compromised, and UTC was born. It is interesting to note that several proposals in recent years have been made to replace UTC with a new system that would eliminate the need for leap seconds. A decision whether to remove them altogether has been deferred until 2023.

Aviation centric or not, most weather guidance throughout the world in the form of observations and forecasts depict the valid time in UTC (or Zulu). Therefore, to keep it simple, Zulu time will be used exclusively throughout this text unless otherwise necessary. For example, 1400 UTC will be abbreviated as 14Z, and 0030 UTC will be abbreviated as 0030Z.

Key points –

"Zulu time will be used exclusively throughout this text unless otherwise necessary."

The Earth system

As you learn how to utilize the Skew-T diagram in your preflight briefing, for better or for worse, you will undoubtedly be exposed to the basic principles of meteorology. This is a good thing. Meteorology is the study of the physical state of the atmosphere driven by the sun. Therefore, the atmosphere surrounding Earth is a heat engine transporting energy from the warm surface to cooler locations. This is done both vertically and horizontally (pole to equator). While both the vertical and horizontal nature of heat transport are extremely important to weather forecasting, the primary topic we will discuss in this text is related to the *vertical* transport of energy.

Shortwave radiation coming directly from the sun is absorbed primarily at the earth's surface, not by the atmosphere it passes through. Some of that incoming solar radiation (called insolation) is reflected to space by clouds, snow cover and large bodies of water such as the oceans. That is referred to as the earth's albedo. The atmosphere acts like a fluid, which distributes heat by motion systems on all space and time scales. Longwave radiation escapes to outer space which acts as the heat sink. Some of that longwave radiation is absorbed by the atmosphere through the help of greenhouse gases. It turns out that these greenhouse gases essential and make this planet habitable.

Outgoing radiation is key

The atmosphere for which we live and breathe is called the troposphere. It receives most of its energy not by the incoming solar radiation as is usually taught but is absorbed by the outgoing longwave radiation. In other words, the atmosphere is inefficient in absorbing the primary wavelengths of energy emitted by the sun but is a sponge when it comes to those wavelengths in that outgoing longwave radiation emitted by Earth.

It will become readily apparent while reading this text that Mother Nature abhors extremes. This imbalance in the atmosphere creates a temperature difference that, in turn, creates pressure differences (gradients), that drive the wind and circulations in the atmosphere. The Skew-T is a way to visualize the result of this intricate interaction over this complex planet.

This Skew-T primer will not teach you to become a meteorologist so you can forecast the weather. However, to master the Skew-T, you will need to learn more meteorology than you were likely taught during your primary flight training. This is akin to learning how to play a musical instrument. You may learn enough to play the piano, guitar, or violin very well, but you may never feel comfortable enough to write a line of original music. Writing music takes a special talent, creativity, and a lot more effort. The same is true for meteorology. You should be able to learn enough meteorology to read the diagram well but may never use the diagram along with other meteorological guidance to forecast the weather.

The good news is that you do not have to be a budding meteorologist to leverage the power the Skew-T diagram has to offer. But it is imperative to have a solid foundation to avoid the wrong interpretation. The primary goal of this book is to give you that foundation so you can continue to learn to integrate this diagram into your preflight planning analysis.

Key points –

“The atmosphere acts like a fluid, which distributes heat by motion systems on all space and time scales.”

“Mother Nature abhors extremes. This imbalance in the atmosphere creates a temperature difference which, in turn, creates pressure differences (gradients), which drive the wind and circulations in the atmosphere. The Skew-T is just a way to visualize the result of this intricate interaction over this complex planet.”

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, if not fundamentally impossible to ascertain what is driving the weather by simply using an evenly spaced series of Skew-T diagrams.

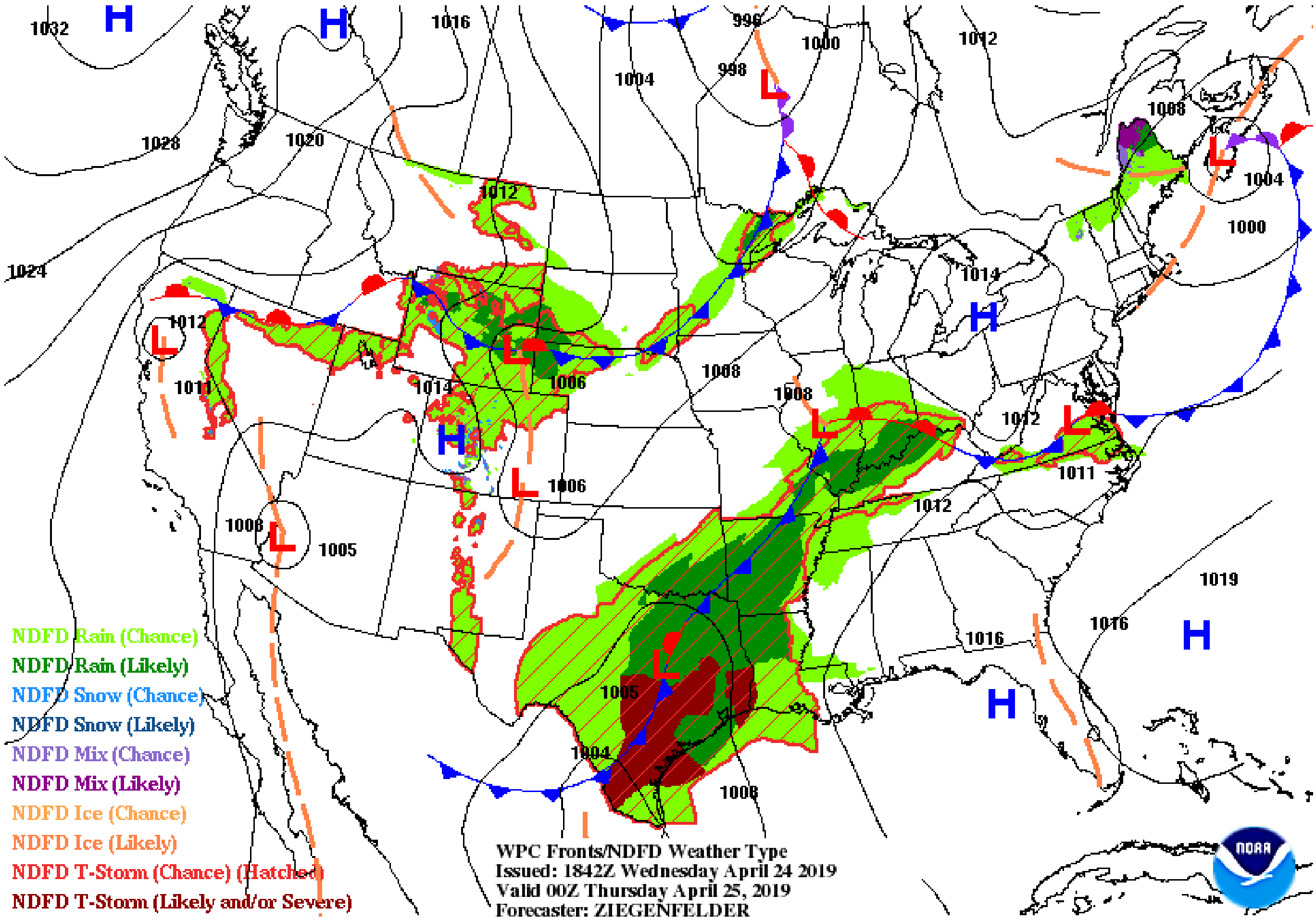

***Fig. 2:** Use a prog chart issued by the Weather Prediction Center (WPC) to get a grasp of the big weather picture. Visit https://www.wpc.ncep.noaa.gov or use the **EZWxBrief** static weather imagery.*

More than just reading progs

Understanding the big weather picture is more than just evaluating what is occurring at the surface. Surface analysis or 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.

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 (good or bad) 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 will see the same stratocumulus signature depicted on each location you chose along your proposed route.

On the other hand, if the Skew-Ts look 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 (Fig. 2). The frontal and isobaric forecasts are issued by highly trained meteorologists at the Weather Prediction Center (WPC) located in College Park, Maryland and the precipitation type forecasts are generated from meteorologists located at the 100+ National Weather Service (NWS) weather forecast offices (WFOs) throughout the conterminous U.S.

Key points –

“It can be difficult, if not fundamentally impossible to ascertain what is driving the weather by simply using an evenly spaced series of Skew-T diagrams.”

“If the Skew-Ts look drastically different at some point along the route, then it is time to evaluate what might be driving that difference (e.g., a cold front).”

Drill down tool

The Skew-T is a graph that provides a point observation or point forecast. It is not designed to give you big picture weather guidance as discussed above. As such, it should be used strictly as a “drill down” tool to help you better understand the details of the weather at a particular time and location. Therefore, it is best used to augment your briefing to fill in the gaps in both time and space for important weather guidance that is harder to decipher or extract using the typical low resolution weather observations and forecasts.

For example, after the passage of a strong cold front, you look at the satellite image and notice that there is a solid and expansive cloud deck along your proposed route. Let’s assume there are no recent pilot weather reports (PIREPs) in the immediate area that would be relevant, and you would like to know the altitude you may break out to be on top of this overcast cloud deck. The Skew-T diagram is an excellent tool to help determine the tops of that overcast stratiform cloud deck for planning purposes.

Practice makes perfect

Pilot weather reports (PIREPs) are often a good way to practice using the Skew-T diagram. For example, when there’s a recent report from a pilot that climbed through a stratus deck and reported the altitude of the tops, it's always a good practice to pull up a Skew-T analysis in that area and attempt to corroborate the pilot reported tops to what you see in the diagram. Or perhaps the pilot or crew reported airframe ice climbing through that layer. Pulling a forecast sounding analysis for that location and time might better illuminate how an icing signature may look on the diagram. In the end, exercises such as this can help with your interpretation skills using the Skew-T.

Is there an advantage by choosing several points along your route of flight to get a sense of what to expect while en route? That’s a common question from pilots who are trying hard to get the most from the diagram. While picking a bunch of equidistant points along a proposed route of flight may illuminate a common theme when the weather is tranquil and homogeneous, doing so is like driving down the highway while looking only through a drinking straw. Nobody would ever do this since it is unsafe. The data rendered on a Skew-T diagram is an extremely narrow view of the weather and it is not uncommon that 50 miles on either side of your route can make a huge difference between a flight that is benign and one that is fraught with serious adverse weather. Be sure to always consult the big weather picture.

Key points –

"It is best to use the Skew-T to augment your briefing to fill in the gaps in both time and space of important guidance that is harder to decipher or extract using the typical weather observations and forecasts."

"The data rendered on a Skew-T diagram is an extremely narrow view of the weather."

The base diagram

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 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, shown below is an example of the original coordinate system of the Skew-T log (p) diagram (Fig. 3).

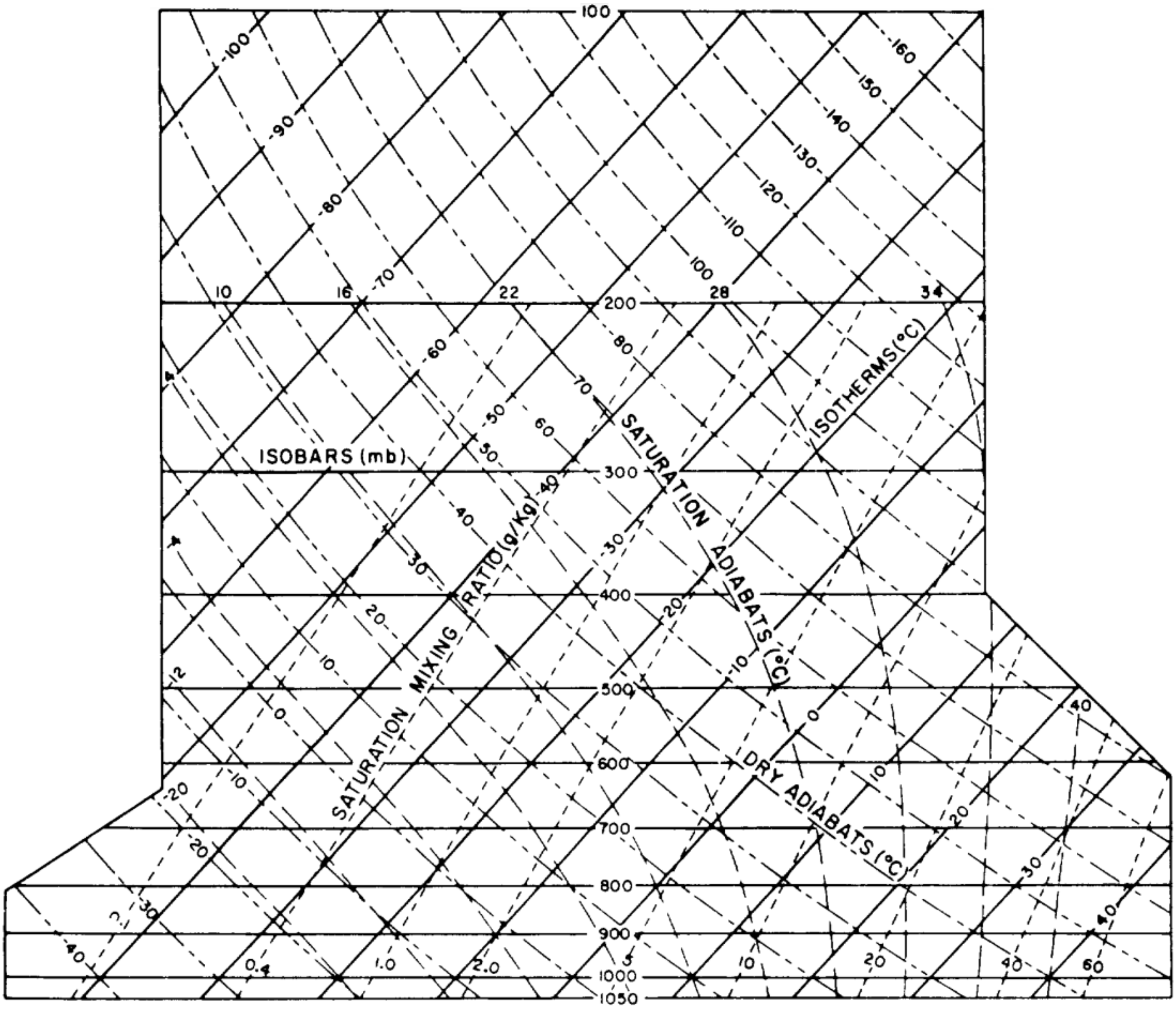

Fig. 3: *Original coordinate system of the Skew-T log (p) diagram without a hodograph.*

There are *four* basic thermodynamic diagrams used by meteorologists, including the Stüve, Tephigram, Emagram, and the Skew-T log (p) diagram. You may also 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, saturation (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 of the diagrams in U.S. aviation today. From time to time, though, you may run across one of these other thermodynamic diagrams online or in other books on the subject.

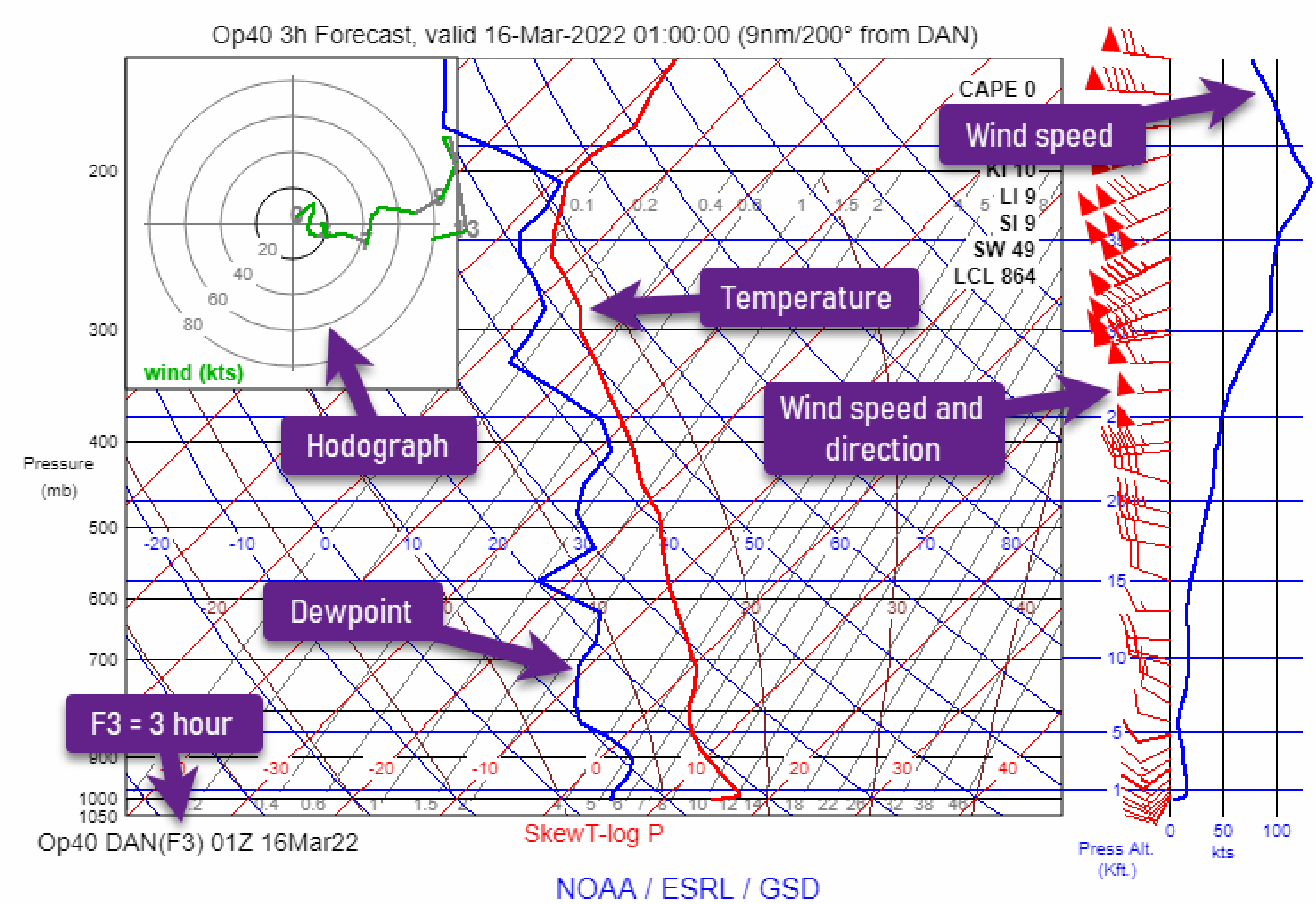

Fig. 4: *A 3-hour forecast sounding (F3) for Danville, Virginia from the Rapid Refresh (RAP) model.*

Thermodynamic diagrams are considered nomograms. That is, they are diagrams having lines that show the solutions to a set of equations, in this case, thermodynamic equations. The base diagram describes the thermodynamic laws of nature and their physical relationships. You do not have to plot the base diagram and the base diagram never changes. Think about the base diagram as a sophisticated form of graph paper. By the way, the bull's-eye diagram in the upper-left corner of the Skew-T shown above is called a hodograph. This portion of the diagram depicts environmental wind shear, which influences thunderstorm evolution and severity. This does not have much value to pilots, so we will only touch on this briefly in a later section for those that are interested.

On the Skew-T diagram (Fig. 4), meteorologists plot environmental temperature shown in red and environmental dewpoint shown in blue. Also plotted on the right side of the diagram are wind speed and wind direction in red using standard wind barbs symbology that are represented in knots. Additionally, a graphical presentation of wind velocity is depicted in blue. All three of these parameters, namely, temperature, dewpoint and wind are plotted as a function of pressure or altitude.

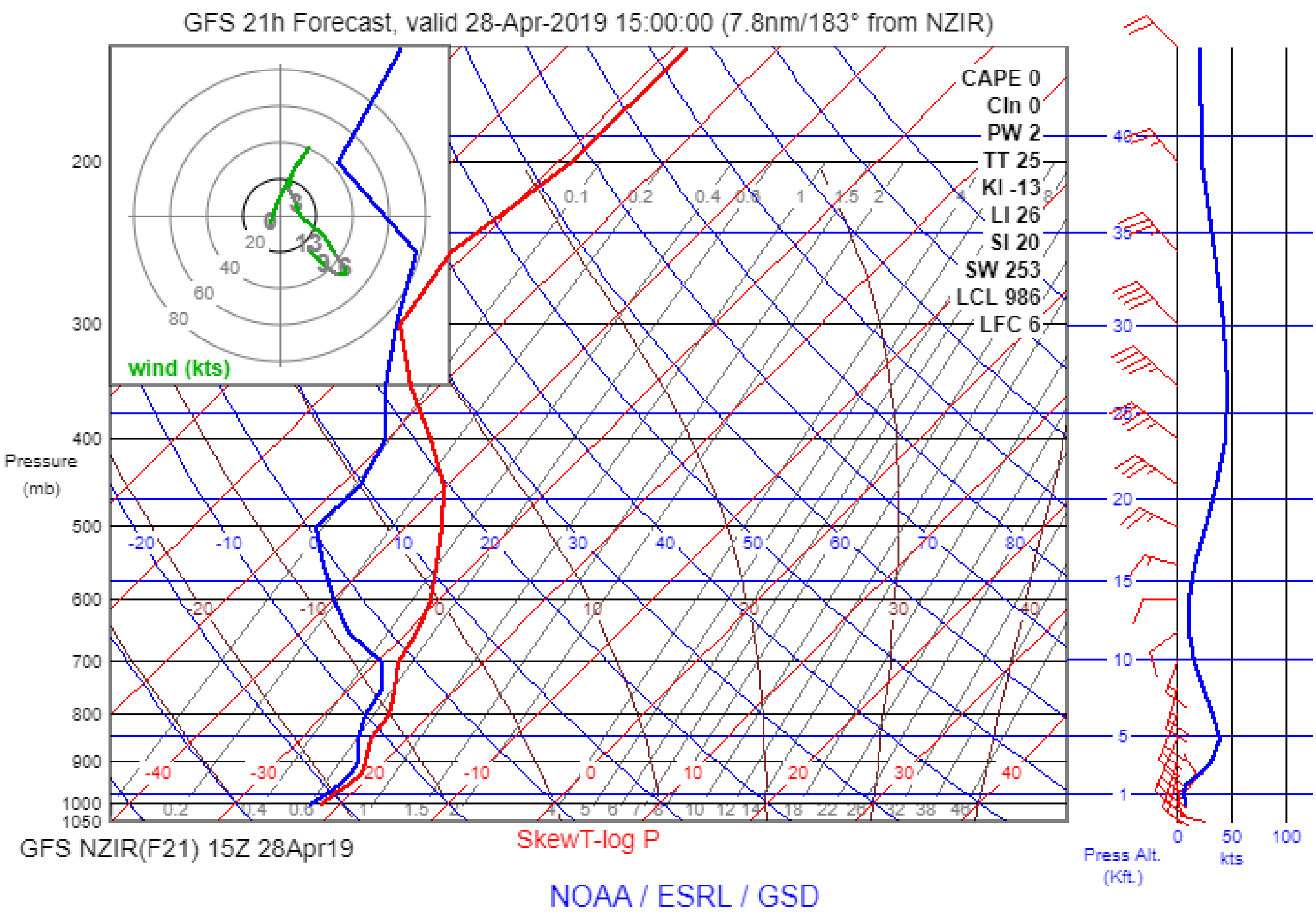

Fig. 5: A 21-hour forecast sounding from the Global Forecast System model near McMurdo Station in Antarctica (NZIR).

The temperature, dewpoint temperature and wind data plotted on a Skew-T diagram can come from multiple sources, which 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 data from a numerical weather prediction model depicting analysis or forecast data. While it is nice to view the actual radiosonde sounding data, it is the forecast that concerns many pilots. For example, the Skew-T shown above (Fig. 4) depicts forecast weather conditions *near* the Danville Regional Airport (KDAN) with a 3-hour lead time denoted by **F3**. 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 these numerical weather prediction models later and how they fit into the overall picture.

Unlike a radiosonde which is released at very specific locations twice a day, forecast model data depicted on a Skew-T diagram (called a forecast sounding) can be plotted at hourly intervals *near* just about any airport in the United States—or even the world—depending on the model utilized. This Skew-T diagram is a *forecast* sounding (Fig. 5) with a 21-hour lead time (F21) near McMurdo Station in Antarctica using the Global Forecast System (GFS) numerical weather prediction model.

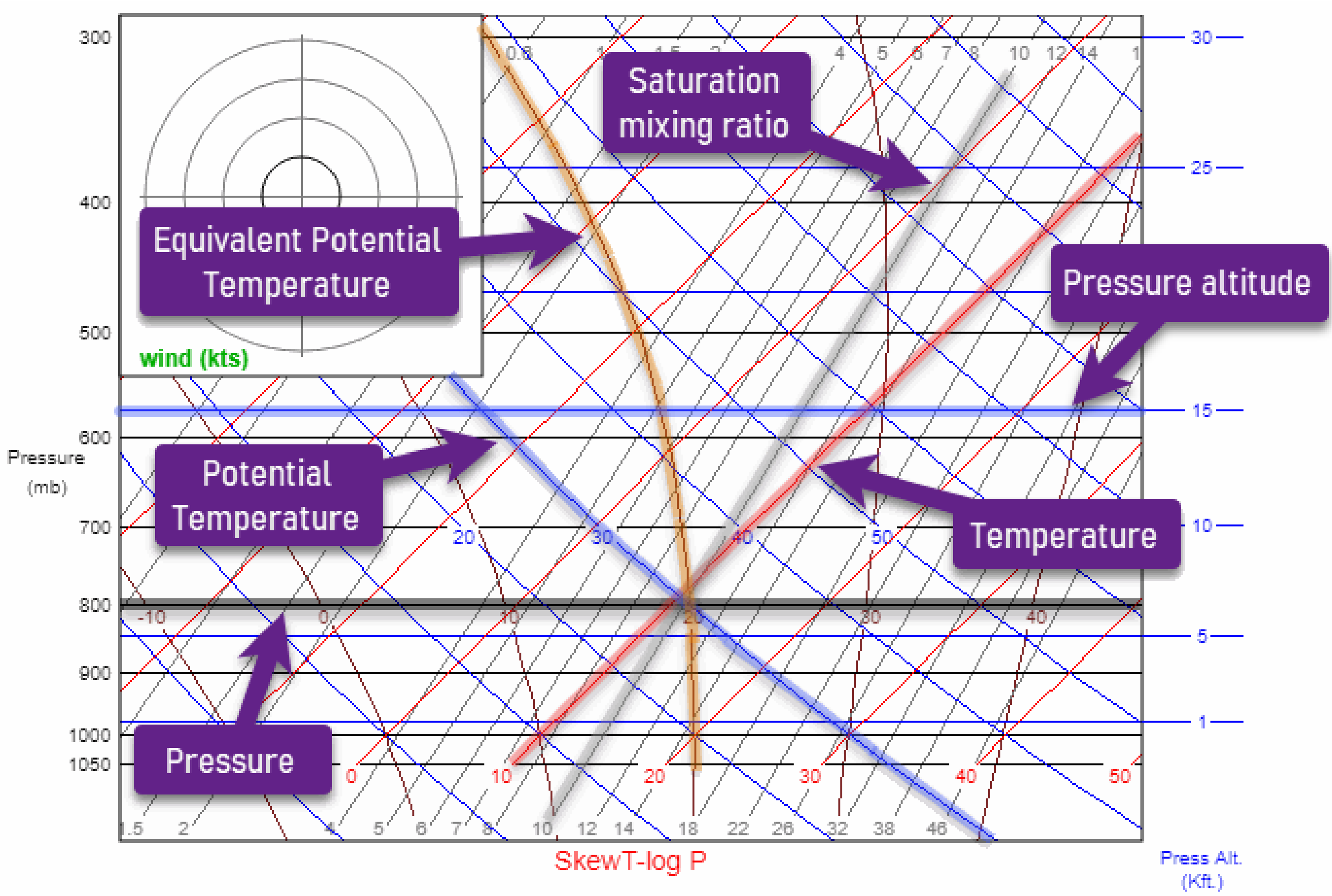

Fig. 6: *Five principal quantities found on the Skew-T log (p) diagram plus pressure altitude.*

Let's zoom in on the base Skew-T diagram for the moment (Fig. 6). You will notice that there are a total of six different reference lines on the base diagram. That is common. You may find that some websites or apps might 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.

There are five principal quantities indicated by constant value lines: pressure (black), temperature (red), potential temperature (θ) (blue), saturation mixing ratio (gray), and 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 the diagram above, and others may use line type or line thickness to distinguish between the various quantities. Unfortunately, there are no industry standards, so this largely depends on the website or application (or app) 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 (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 (Fig. 7).

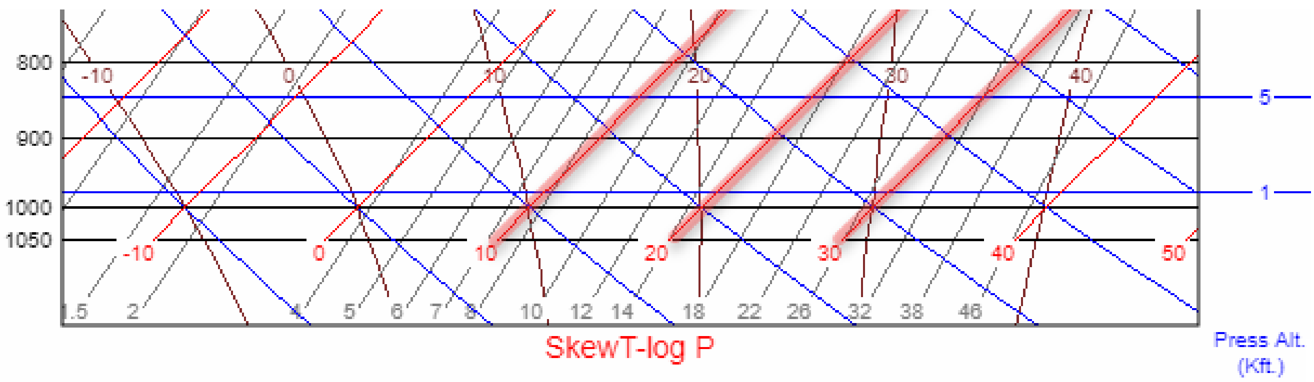

Fig. 7: *Temperature reference lines or isotherms in degrees Celsius (°C) highlighted on the base Skew-T diagram.*

Why are the isotherms skewed? Arguably, the reason they are skewed is primarily for convenience and utility. That is, meteorologists 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 the 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 stratosphere can be easily plotted.

e) The vertical in the atmosphere approximates the vertical coordinate of the diagram.

Next, the **black** horizontal lines are the lines of constant pressure, also called isobars, which are represented in millibars. For reference, the 1,000, 900, and 800 mb isobars are highlighted below (Fig. 8). While hectopascals (hPa) is used in meteorology, most weather forecasts quote atmospheric pressure in millibars instead.

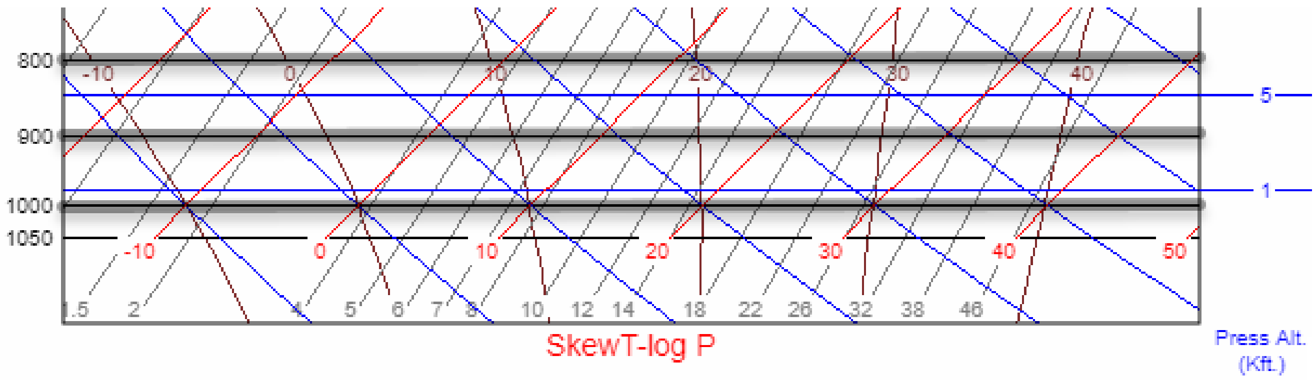

Fig. 8. *Pressure reference lines or isobars in millibars (mb) highlighted on the base Skew-T diagram.*

Notice that on the Skew-T diagram, pressure surfaces are at a greater distance from each other as pressure decreases (altitude increases). In the dark gray highlighted area (Fig. 9), 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 easily see the altitude spread is 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. 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 or isotherms are skewed at a 45° angle and pressure is represented on a logarithmic scale.

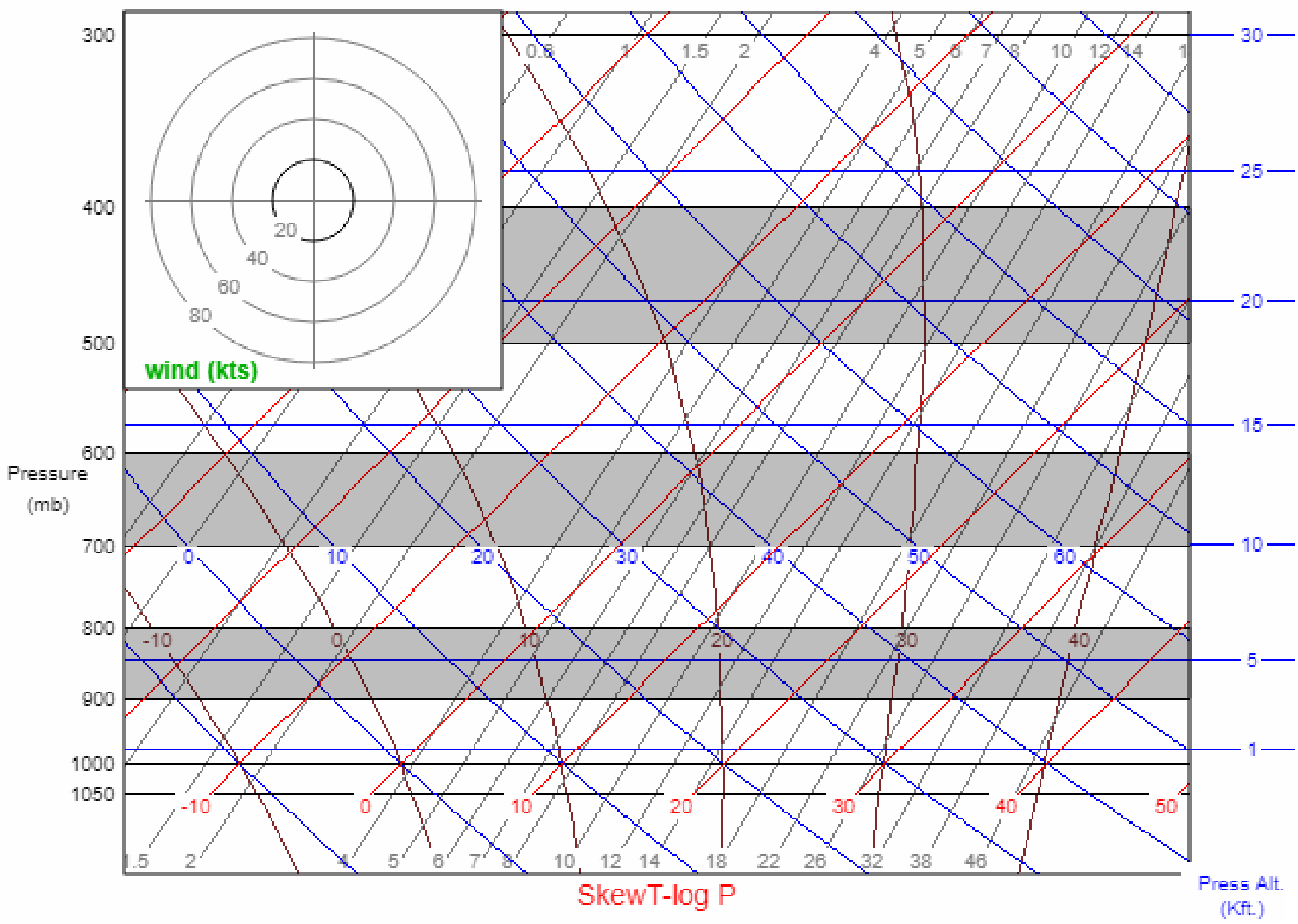

Fig. 9: *The logarithmic nature of pressure due to atmospheric compression.*

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 in the cockpit 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).

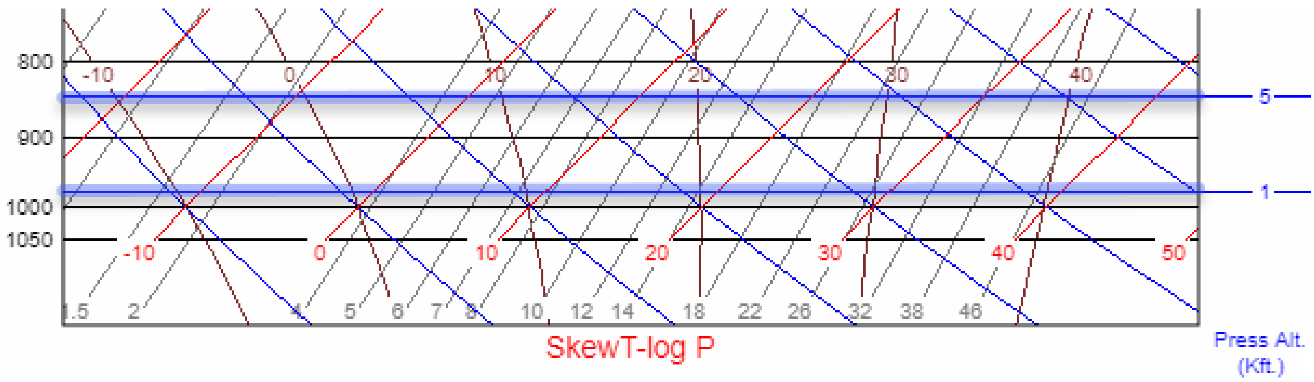

Fig. 10: *Pressure altitude reference lines in thousands of feet (Kft) highlighted on the base Skew-T diagram.*

For reference, the 1,000-foot and 5,000-foot heights are highlighted (Fig. 10). 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 isn't statistically significant. In this text, all altitudes are assumed to be mean sea level (MSL) height unless otherwise noted as AGL.

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. Given that it describes a very narrow view of the atmosphere, it is best served as a tool to "drill down" and uncover important details not easily 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 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 thunderstorms, just to name a few. Before this can be achieved, we need to first delve into the basic properties of the atmosphere that often dictate what adverse weather is the most probable. Note that some of the following dialogue will be complex and challenging for many pilots but is necessary to fully appreciate the complexity of all that Mother Nature has to offer.

Key points –

“The temperature, dewpoint temperature and wind data plotted on a Skew-T diagram can come from multiple sources. This includes data generated by a weather balloon, also known as a radiosonde, depicting observed environmental data and data from a numerical weather prediction model depicting analysis or forecast data.”

“There are five principal quantities indicated by constant value lines: pressure, temperature, potential temperature (θ), saturation mixing ratio, and equivalent potential temperature (θ_e) for saturated air.”

“The base diagram describes the thermodynamic laws of nature and their physical relationships.”

“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.”

Internet data resources

There are dozens of online resources that provide access to these thermodynamic diagrams. The primary resource for Skew-T diagrams utilized throughout this text can be found at **https://rucsoundings.noaa.gov**. This 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). More about this interactive sounding tool will be discussed later. 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. There are dozens of others. Please note that for some of the website's access to these diagrams may require selecting a point on a forecast model map to show the forecast sounding at that location.

- 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://vortex.plymouth.edu/mapwall/upperair/raob_conus.html (radiosonde)
- https://vortex.plymouth.edu/myowxp/fx/fxsnd-conus.html (forecast soundings only)
- https://skewtlogpro.com (app) (forecast soundings only)
- http://www.twisterdata.com (forecast soundings only through map selection)
- https://www.tropicaltidbits.com/analysis/models (forecast soundings through map selection)
- https://ezwxbrief.com (distributes soundings through the interactive NOAA soundings site).

Key point –

“The primary resource for Skew-T diagrams utilized throughout this text can be found at https://rucsoundings.noaa.gov.”

Basic properties of air

Before we get knee-deep into explaining how to use the Skew-T diagram, it is extremely important to review the basic properties of the atmopshere. In fact, understanding what causes icing, turbulence and convection is very highly dependent on these fundamental principles.

Air is simply of a mixture of many gases. The three major constituents of “average” air near the surface are nitrogen (76.9 percent), oxygen (20.7 percent) and water vapor (1.4 percent) (Eagleman, 1980). The relative concentrations of nitrogen and oxygen are quite uniform with height for a considerable distance above the earth. In other words, the same *percentage* of nitrogen exists at 30,000 feet as it does at 1,000 feet. Water vapor, on the other hand, varies quite a bit in the atmosphere, especially with height. It rapidly decreases with height and is almost exclusively confined to the lowest 50,000 feet.

While the relative concentrations of nitrogen and oxygen are uniform with height, the atmospheric pressure and density of air decreases quite rapidly with increasing altitude as mentioned earlier. In fact, it decreases exponentially with height and is where the log (p) reference of the diagram gets its name. Because of this characteristic, we say that the atmosphere is compressible on itself and has higher pressure and density near the surface. Similarly, the altimeter used in most aircraft is an instrument that directly measures atmospheric pressure and displays that pressure as a function of height or altitude. Due to nonstandard temperature, pressure, and density (differences in moisture), pilots are required to update their altimeters to the local settings based on surface observations before they depart and during their flight. In the U.S. the altimeter is set to 29.92” Hg when flying at or above Flight Level 180 (18,000 feet MSL).

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).

The density of air is determined by the masses of atoms and molecules and the amount of space between them. It is calculated by the mass of air divided by the volume and represented as kilograms per cubic meter (kg/m^3). In other words, density tells us how much matter is occupying a given space or volume. As the temperature of the air is *increased*, the kinetic energy (activity or motion of the atoms and molecules in the volume of air) also increases. The added energy causes the molecules to spread further apart (Fig. 11, right) which, in turn, *decreases* the density of that warmer air. Conversely, as the kinetic energy is *decreased* by lowering the temperature, this slows down the motion of the molecules, allowing them to crowd closer together and air density subsequently *increases* (Fig. 11, left). **This leads us to the property that warm air is always less dense than cold air at a given static air pressure.**

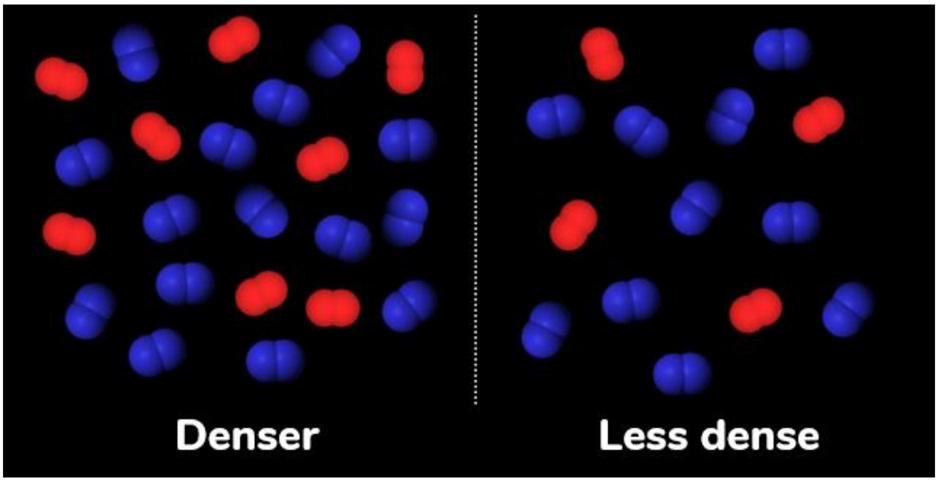

Fig. 11: *Oxygen (red) and nitrogen (blue) molecules in a volume if air with cold, dense air (left) and warm, less dense air (right).*

A perfect example

A hot air balloon is an excellent example of about how increasing the temperature of air will decrease the density and make the hot air balloon "lighter than air."

Water vapor is an especially important gas in the atmosphere for a variety of reasons. Not only is it the most important greenhouse gas, but it also stores much of the energy in the form of latent heat in our atmosphere (we will see this later when condensation and deposition are discussed). Of course, this is released at some later time to produce the most significant weather events on our planet.

To a lesser extent, the density of air is also affected by the amount or mass of water vapor in a volume of air. Water vapor is a relatively light gas when compared to nitrogen and oxygen molecules. Thus, as shown below (Fig. 12), increasing the water vapor within a volume of air causes it to displace the heavier nitrogen and oxygen molecules. The molecular weight of water vapor (H_2O) is approximately 18. Both nitrogen and oxygen occur in the atmosphere in molecular form as N_2 and O_2 and have a molecular weight of approximately 28 and 32, respectively. Other trace gases such as argon and carbon dioxide account for less than 1 percent of the total volume.

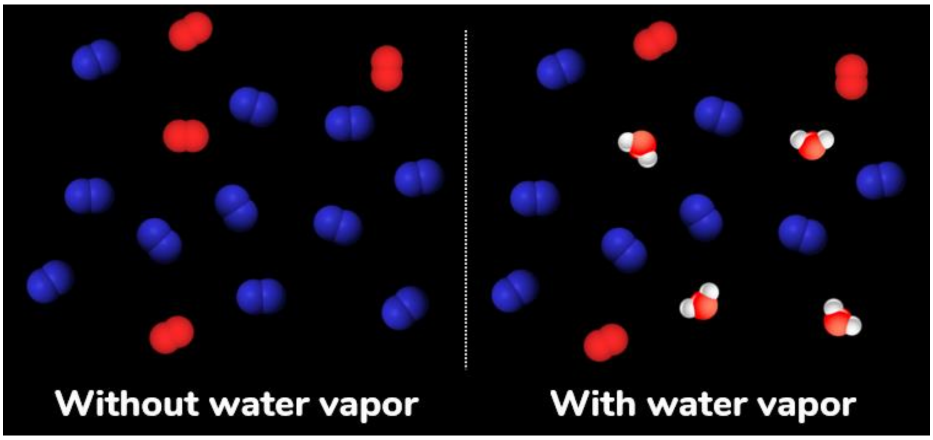

Fig. 12: *Adding water vapor (red and white) decreases the air density by displacing heavier nitrogen (blue) and oxygen (red) molecules.*

When water vapor increases within a volume of air, the amount of oxygen and nitrogen decrease per unit volume and the mixture becomes lighter or less dense. **This leads us to the property that moist air (or air with more water vapor) is always less dense than dry air (or air with less water vapor) given the same temperature and static air pressure.**

When you think of a fluid, you probably think of a liquid. A fluid is simply anything that can flow. This includes liquids at room temperature such as water or mercury, but gases are fluids, too. More importantly, two fluids with different densities tend to stay separated. This occurs when motor oil is mixed with water, for instance. The oil rises to the top since it is less dense than water.

The wedding dance

Imagine you are attending a wedding reception and the DJ calls all adults to join the bride and groom on the dance floor. The dance floor is crowded with people movin' and groovin' to the music. Next, the DJ asks all children to come join them. Since the dance floor is full already, the smaller children will force some of the larger adults to be displaced off the dance floor. The same thing occurs in the atmosphere; as the number of lighter water vapor molecule increase in the mixture, those will displace the heavier oxygen and nitrogen molecules making the mixture of air lighter or less dense.

A similar thing happens when two air masses of differing densities are forced to mix. For example, when warmer, less dense air is introduced within a cooler air mass, the warmer air will be lighter and will tend to rise within that cooler air. In fact, it only takes a few degrees difference between the two air masses to generate enough of a density discontinuity to stay separated. This property is known as buoyancy. Essentially, buoyancy is an upward force exerted by the differences in pressure, driven by differences in density—in this case, air density. In the end, buoyancy in the atmosphere is a term used to compare the relative density differences of air. **This leads us to the property that less dense air is more buoyant and will tend to rise, while more dense air is less buoyant and will tend to sink.**

A familiar example

Even a student pilot understands the buoyancy concept very well. Prior to a flight, it is important to always sump the fuel tanks to be sure any impurities such as water is removed. Even though water and avgas appear to be very similar in density, water is denser than avgas and will separate and sink to the bottom of the tank so it can be properly sumped and removed before flight.

Key points –

“Understanding what causes icing, turbulence and convection is very highly dependent on the fundamental properties of air.”

“Warm air is always less dense than cold air at a given static air pressure.”

“Moist air or air with more water vapor is always less dense than dry air or air with less water vapor given the same temperature and static air pressure.”

“Less dense air is more buoyant and will tend to rise, while more dense air is less buoyant and will tend to sink.”

Relative humidity and saturation

One of the key reasons why pilots learn to use the Skew-T is to determine the location and altitude of clouds, 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 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 and thunderstorms and plays a significant role in the production of airframe icing.

The amount of water vapor can be quantified in a 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.

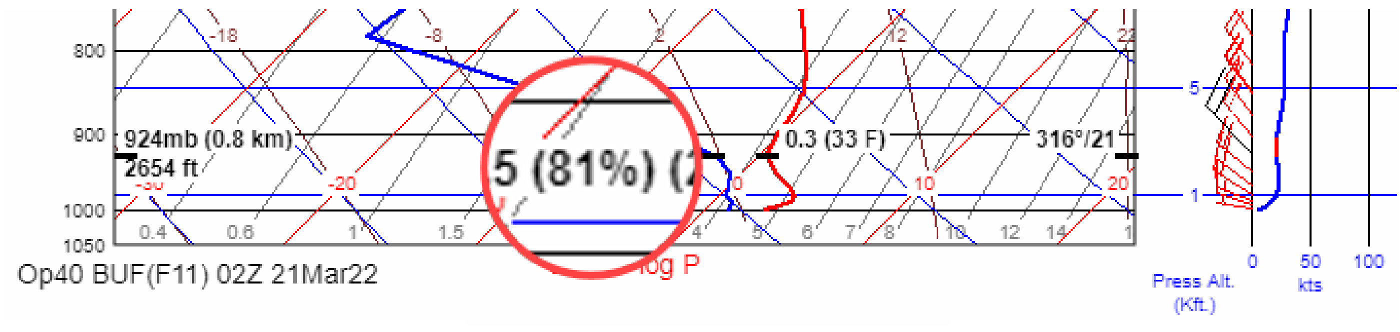

Fig. 13: *NOAA's interactive soundings tool automatically calculates the relative humidity for the altitude selected.*

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 and it will calculate and display the relativity humidity at the altitude where your cursor is positioned (Fig. 13).

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 as described above may only be 80%. For example, in the forecast sounding (Fig. 14) near the Hartsfield - Jackson Atlanta International Airport (KATL), notice 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.

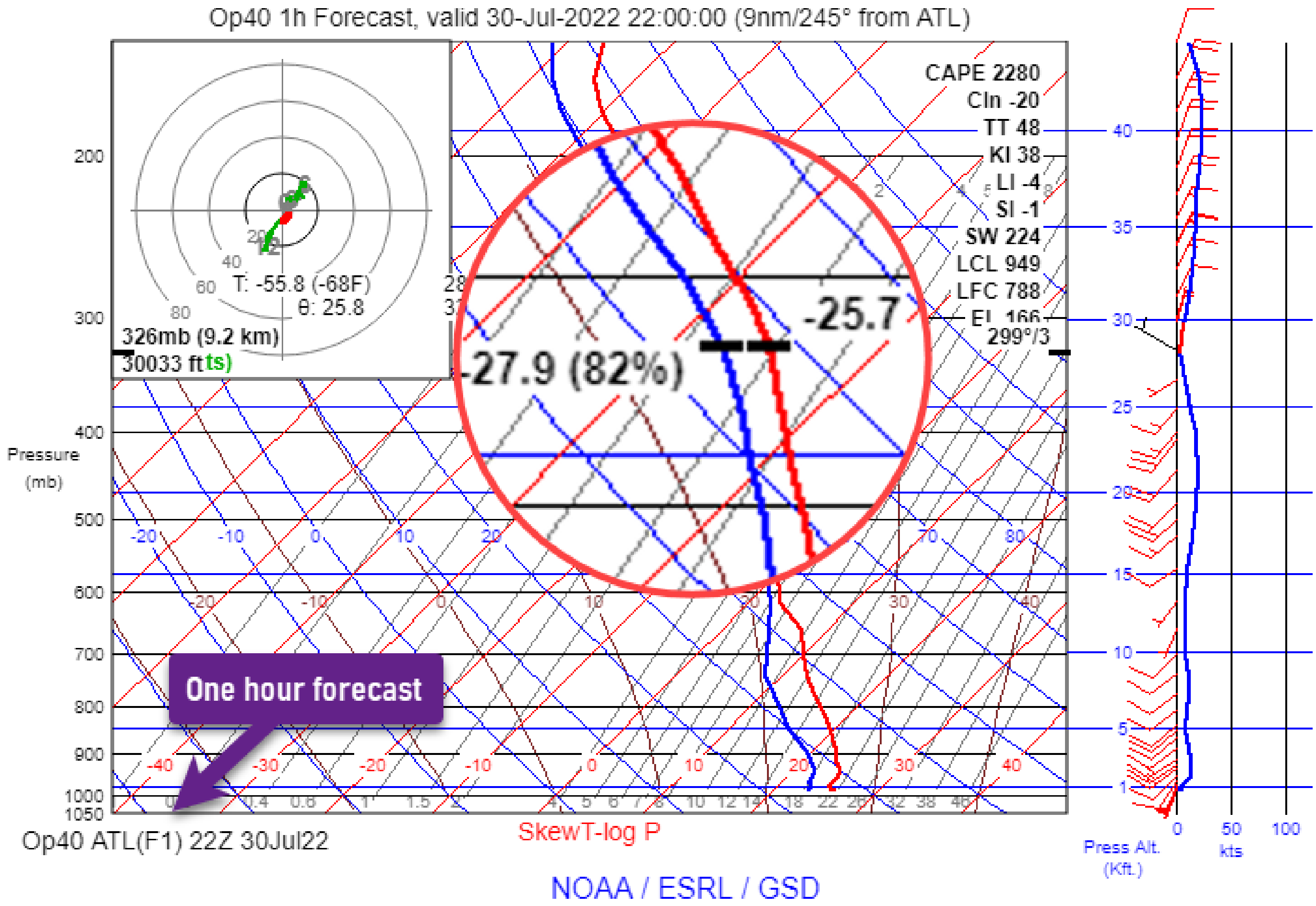

Fig. 14: *In this 1-hour forecast sounding (F1) near the Hartsfield - Jackson Atlanta International Airport (KATL) the conditions are likely saturated with respect to ice at 30,000 feet even though the relative humidity is only 82%.*

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 one of them stores energy and enters the liquid below. **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.

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.

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 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 that dumps hailstones in your yard the size of a golf ball or tennis ball. You bravely run outside and quickly scoop up a few 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 due to rapid sublimation over time 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.

Key points –

“One of the key reasons why pilots learn to use the Skew-T is to determine the location and altitude of clouds, especially during the cold season when airframe icing is more likely to occur.”

“Water vapor is said to be saturated with respect to liquid water and the relative humidity reaches 100% in the air above the water’s surface.”

“Relative humidity has distinct advantages over absolute measures of water vapor in the atmosphere.”

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.

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.

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.

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.

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.

Dry Line: A mesoscale moisture boundary that separates hot, dry air and warm, moist air. This is sometimes referred to as a dewpoint front. Dry lines can be an important factor in severe weather frequency in the American Great Plains.

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 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.

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

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 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).

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).

About Scott

Dr. **Scott 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 eventually 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 has always been fascinated by 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 (now the National Centers for Environmental Prediction 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 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 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 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 300 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. 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*.

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.

The result of three 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, and expanded his popular website, **AvWxWorkshops.com**. Today he continues to extend the capabilities of **EZWxBrief** and remains committed to offer personalized online weather training to pilots at all experience levels in the U.S. and Canada.

Scott is married to his very supportive wife of nearly four decades with three adult children and is now enjoying the benefits of being a cool grandfather.

The Skew-T log (p) and Me

To a large extent, the study of weather, better known as meteorology, is rooted in a few fundamental properties. It is these properties that are the key to unlocking all that the Skew-T log (p) diagram has to offer. Even though some of the concepts and dialog presented in this primer are quite challenging even for the most seasoned pilot, they are born out of these fundamental properties of air.

A thermodynamic chart such as the Skew-T log (p) diagram is clearly the best kept secret in aviation. This primer is the most comprehensive resource available for general aviation pilots that want to leverage its use as supplemental weather guidance for preflight route planning. Specifically, the Skew-T log (p) diagram allows you to "drill down" 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.

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