Ground-Based Weather Radar

Uplinked weather data is coming to a panel near you. But if you don't know how to interpret it, you're just looking at pretty cartoons.

by Scott C. Dennstaedt

Before every instrument flight, most of us take a quick peek at the radar picture along our entire route of flight. It's something we've just grown to do. What does this ubiquitous weather product tell us? One might think that interpreting ground-based radar is intuitive. Well, think again.

If you asked 100 instrument pilots what single weather product they'd like to see in the cockpit, the majority might answer—ground-based radar.

Below: *National Weather Service Nexrad weather surveillance radar tower. The antenna is inside of the radome protected against the elements.*

A ground-based radar image has a high *glance value* because it provides weather information, not just raw data. Whether ground-based or airborne, interpretation of radar images has a few hidden challenges, and few pilots really understand the product and its limitations.

With the advent of datalink systems from companies such as Satellink, Avidyne, Garmin, and Echo Flight, pilots can now monitor the radar picture nearly continuously in the cockpit, both while on the ground and in the air. This can have some serious implications unless the weather radar technology is understood.

If you asked those same 100 instrument pilots to interpret an active radar picture, you'd get a wide variety of so-so answers. Sure, truly active radar—as opposed to a delayed presentation that might be several minutes old—has the ability to provide you with up-to-the-minute details that you would not otherwise have in the cockpit.

However, don't become complacent and think the radar image is telling you the full story. Just as an instrument pilot shouldn't fixate on any one instrument, radar must be utilized in the context of other ground-based and airborne weather products.

Doppler Radar

Next Generation (Doppler) Weather Radar (NEXRAD) generates most of the radar images we see. Nexrad is a network of Weather Surveillance Radar-1988 Doppler (WSR-88D) radars that cover nearly the entire contiguous United States, Alaska, Hawaii and a few selected overseas locations.

Doppler radar is unique in that not only can it detect the presence of an airborne object such as a raindrop, but it can also detect the direction of motion of that object relative to the radar. The radar makes use of a phenomenon referred to as the Doppler effect, named after the Austrian physicist, Christian Doppler, who discovered it. As a result, Doppler radar provides the meteorologist with an estimate of the motion of the wind. This enables the National Weather Service to issue tornado warnings without ever sighting a funnel cloud.

Pilots don't really care as much about the relative motion of the raindrops as they do the location, intensity and movement of the areas of precipitation. So, what's so hard about that? It is true that in most cases, what you see is what you get, but not always.

Hydrometeors

Radar (Radio Detection And Ranging) is a simple concept. Like many other radars, weather radar is a rotating or scanning transceiver. First, the antenna transmits a pulse of energy out from the radar at a specific frequency. Second, the radar listens to the energy that is reflected back toward the collocated receiver. Transmission of the pulse and reception of the returned energy are collectively called the radar data acquisition phase. During its short trip, the pulse of energy strikes various airborne objects referred to as hydrometeors. This process is known as Raleigh scattering.

Hydrometeors are simply the liquid or solid particles suspended or falling through the atmosphere that the radar can see. In other words, the radar can see any object that will scatter or reflect the energy coming from the radar. This object could be a raindrop, snowflake, sleet, hailstone, airborne dust, insect, migratory bird, or an aircraft. This reflected energy is interchangeably referred to as a radar echo, radar return or backscattered radiation.

The amount of energy directed back to the radar is measured and recorded in a logarithmic scale called decibels of Z (dBZ), where Z is the reflectivity parameter. Next, these base data are processed by a radar product generator to produce hundreds of meteorological and hydrological products including a few near and dear to pilots. Finally, these products are stored and distributed to multiple WSR-88D users.

Radar Range

You can think of the pulse of energy coming from the radar much like a beam coming from a flashlight. The radar beam is three-dimensional; the beam has height, width and length. For weather radars the shape of the beam resembles a narrow cone and is referred to as a pencil beam.

The radar beam increases in height above the earth's surface when moving away from the radar site because of the earth's curvature. Additionally, the radar is tilted at various elevations such that the center of the beam increases with height as range increases. As the radar makes one full 360-degree sweep, it has only captured precipitation data at one horizontal planar area through the atmosphere.

All radars have range limitations. WSR-88D radar can detect just about any kind of precipitation within 80 miles of the radar site. Once you get beyond 80 miles, light rain, drizzle, or snow may not be detectable as extremely little energy is reflected back to the radar site.

At greater distances from the radar site, the radar beam may overshoot shallow precipitation events and may not be displayed on the radar image. However, given sufficient intensity and height, the WSR-88D radar will process reflectivity returns with an effective range of 248 miles.

Modus Operandi

Before you can understand the products generated by the radar, you must first understand how the radar operates. The WSR-88D radar can operate in one of two modes: Precipitation or clear air.

The NEXRAD image you see will normally provide an appropriate label suggesting the mode of operation. If not, the clear air mode is typically dominated by bright red, orange, and brown colors, whereas the precipitation mode is dominated by mostly green and blue. It's worth noting that the colors you see on any particular radar image are highly dependent on the site producing the radar image.

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Clear air is the more sensitive of the two modes. In clear air mode the radar operates at its slowest rate. It's able to sample a particular volume of air for a longer period, thus detecting much smaller hydrometeors.

As a result, images in clear air mode are generated every 10 minutes, whereas in precipitation mode, images are updated every five or six minutes. As previously mentioned, clear air mode is useful when you need to detect particles with poor reflectivity, such as light snow or drizzle. Snow doesn't reflect the energy from the radar nearly as well as raindrops do. However, any frozen hydrometeors with an outside wet coating are the absolute best reflector.

Whether the radar is in clear air or precipitation mode, wet snow, wet hail, and wet sleet will cause a distinguishable bright band on the radar image giving you a false indication of the intensity of the precipitation. These water-coated hydrometeors produce the highest reflectivity and often have a stronger reflectivity than the snow above or the rain below. This occurs as snow, sleet, or hail falls into temperatures just above the freezing level and begins to melt. Knowing the distance of these bright band echoes from the radar site and elevation angle of the radar image, you can estimate the freezing level.

Volume Scans

The WSR-88D radar doesn't make just one sweep. Instead, it's sampling a volume of air called a volume coverage pattern (VCP). A VCP consists of the radar making many 360-degree azimuthal sweeps of the atmosphere at increasing elevation angles.

The radar operator determines the best mode of operation given the spatial scales of the meteorological phenomena of interest. In other words, if light snow or drizzle is forecast, the radar operator might set the radar to

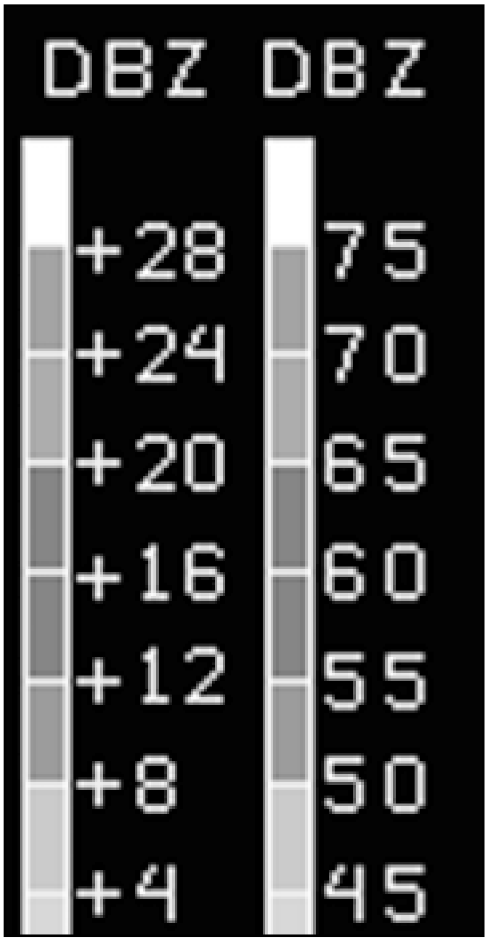
Who Said The Earth Was Flat?

Due to the curvature of the earth and the elevation angle of the radar, even the 0.5-degree elevation radar beam rapidly increases in height with an increase in range from the radar site.

Even as close as 75 miles from the radar site, the center of the beam rises to 8000 feet above the earth. A shallow precipitation event can be missed even by the lowest elevation scan capabilities of the WSR-88D radar. Similarly, a growing thunderstorm with significant updrafts can suspend raindrops aloft.

When a cell like this is within 20 miles of the radar site, it may be missed entirely as well. The radar will not show this cell until the raindrops coalesce and become heavy enough to fall into the radar beam below.

Base Reflectivity—Decode The Colors



So what do all those colors you see on the legend next to the radar image represent? The partial legend—shown in glorious black-and-white above—shows the amount of transmitted energy that was reflected back to the radar antenna during each elevation scan. These echo intensities (reflectivity) are measured in dBZ or decibels of Z.

The dBZ values are directly related to the precipitation intensity. Higher dBZ values generally mean a higher rate of precipitation. Consequently, forecasters can translate these values into rainfall rates. A value of 20 dBZ, for example, means that light rain is probably occurring whereas a value of 52 dBZ is representative of an intense rainfall event.

Depending on the radar's current mode of operation, you may see one of two color scales. In clear air mode, the scale ranges from dBZ values of –28 to +28 (negative values not shown here). In precipitation mode, the scale ranges from +5 to +75 dBZ.

Independent of the mode, the color on each scale remains exactly the same; however, the dBZ scale changes depending on the mode. This is why in clear air mode, the image is dominated by red, orange, and brown colors and in precipitation mode the image is dominated by blue and green colors.

It is worth noting that the colors utilized are highly dependent on the site providing the actual radar image.

clear air mode, which implies a predefined volume coverage pattern or specific sequence of azimuthal sweeps and elevation angles. These are referred to as volume scan strategies.

Currently, there are four volume scan strategies to account for weather conditions ranging from clear air to severe storms. Two of the four strategies support clear air mode and the remaining two are precipitation mode strategies. The quickest operational mode is a precipitation mode VCP used during severe weather events. This scan strategy takes five minutes to complete.

Regardless of the volume scan strategy employed, the radar begins its first scan at an elevation angle of 0.5 degrees (0.5 degrees above the ground). The highest elevation scan in clear air mode is 4.5 degrees whereas the highest elevation scan in precipitation mode is 19.5 degrees.

At the two lowest elevation angles, the radar may make multiple sweeps at the same elevation angle before increasing to a higher angle. The radar will make one sweep in surveillance mode to map the reflectivity and another sweep in Doppler mode to measure radial velocity (relative motion of the precipitation). At higher elevation angles, both functions are done within the same scan (also called batch mode).

The total number of unique rotations in a VCP can be as many as 16 in severe weather mode or as few as seven in clear air mode.

Reflectivity-Based Products

Out of all of the radar products generated, the base reflectivity and composite reflectivity are the most familiar and useful to pilots. Few pilots realize that multiple reflectivity-based products are available. Even fewer pilots know the differences between these two products.

The composite reflectivity takes into account all elevation scans performed during the VCP. Therefore, only the *strongest* reflected energy (highest dBZ) encountered for *all* elevation scans is displayed. The base reflectivity product, on the other hand, simply shows the reflectivity for a single scan of the radar at a single elevation angle.

So why is this distinction important? In most cases, the distinction really won't matter. However, during thunderstorm season you may see significant differences between the two images. For example, a quick peek at the 0.5-degree elevation base reflectivity could show light rain showers along your route of flight. Due to strong updrafts in a developing storm, higher reflectivity may result in the composite image over the same flight path.

The mechanics are easy to understand. A strong updraft can trap heavier precipitation higher in the atmosphere over an area of lighter precipitation. Therefore, the lower elevation scan (base reflectivity) wouldn't show the onset of this developing storm. Having access to composite reflectivity, lightning data, satellite images, and pireps can help to confirm this potentially dangerous situation. It's not until the rain starts to fall that the base reflectivity will paint a more representative picture.

Obviously, nothing is ever perfect. Despite our best technological efforts, the radar image may not always be telling us the true or complete story. Normally it *is* easy to interpret however, there are a few additional nuances to consider when looking at any radar image.

Residual Ground Clutter

Anyone who has seen a ground-based radar picture is familiar with residual ground clutter. As the radar transmits its beam of energy, objects such as trees, buildings, towers, ocean waves, and distant hills or mountains will reflect some of the energy from outside of the central beam (side lobes) back toward the radar site. The reflected energy from the radar may be interpreted as an airborne object. Consequently, a low-elevation base reflectivity product will often display ground clutter. Of the two modes, clear air mode is the most affected by ground clutter.

Even though the radar manages to eliminate some of these returns, it's easy to distinguish residual ground clutter from real precipitation returns especially if you're looking at a time-lapse radar loop. Residual ground clutter will normally appear within 20 miles of the radar site roughly as a speckled circular region with echoes that show little spatial continuity. Moreover, the returns will essentially remain anchored with little or no movement over time. Therefore, the relative motion (radial velocities) of these echoes is normally zero.

When is the atmosphere the most conducive for ground clutter? Fortunately for us, it's when a stable atmosphere exists close to the ground such as during a clear and calm night with a nocturnal temperature inversion present.

In this scenario, anomalous propagation (AP) can occur. AP is a much less common form of ground clutter that results from the radar beam being refracted almost directly into the ground at some distance from the radar. Therefore, AP results in areas of intense-looking echoes at a greater distance from the radar than where normal ground clutter appears.

One quick way to convince yourself that you're seeing ground clutter is by looking at an adjacent radar site with overlapping coverage. Short of any real precipitation, any false echoes in the area around the original radar site should not be present.

WYSIWYG—NOT

As rain or snow falls through a dry atmosphere, it may evaporate before reaching the surface. This phenomenon is called virga. The radar image may show this as light precipitation, but no precipitation will be reported at the surface. Virga can often occur during the onset of an approaching warm front (overrunning) or from upper-level instability after the passage of a cold front.

When you see a base reflectivity image, you're likely seeing the scan that was done at the lowest elevation angle. As the narrow beam of energy takes flight, it also increases in width and height. It cannot be emphasized enough that this may lead to missing shallow cloud weather systems in the distance. It's imperative that pilots utilize other data such as surface reports, pireps, and other overlapping radar images to fully understand the radar image they're viewing.

Every Doppler radar has an area above the radar site where data are unavailable. This area is called the cone of silence (sounds like it's from the *Get Smart* TV series). For instance, at the maximum elevation angle of 19.5 degrees, weather phenomena above 40,000 feet can't be detected even as close as 20 miles to the radar site.

Even the sun can add a wrinkle or two to the radar image. Not surprisingly, the sun radiates energy in the same part of the electromagnetic spectrum as is used by the radar. Therefore, at sunrise and again at sunset, these echoes appear on the base reflectivity as a one or two-degree wide continuous narrow radial spike. The spike usually lasts only one or two volume scans and doesn't represent a huge issue.

Whether you're looking at a NEXRAD image from a datalink source in the cockpit or while surfing the Internet in the comfort of your

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Beam Resolution

Think about being in a dark room with a flashlight…okay, in a dark hangar with a flashlight. Now, find your way to a wall and stand a couple of feet away. Next, point the flashlight towards the wall. What do you see? You should see a nice crisp circle. As you move away from the wall, the cross-sectional area of the circle will increase and will become fuzzier around the edges.

Similarly, a radar beam widens as it travels away from the radar. Widening of the radar beam causes the resolution of the data to decrease. You may even notice precipitation that is painted near the limits of the radar image is a bit grainy, similar to a poor resolution photograph.

What significance does beam spreading have? The rule of thumb is that at greater distances from the radar site rainfall intensity is underestimated, and precipitation coverage is overestimated.

The maximum power is at the center of the beam. The echoes returned after an energy pulse from the radar are all assumed to originate at the center of the beam. However, the beam is not a thin line; instead it is shaped more like a cone with the highest power at the center of the cone. The main beam itself is defined by volume enclosed within the half power point. Even beyond the half power point, the power continues to diminish to produce what are known as side lobes. These side lobes are responsible for most of the ground clutter close to the radar site.

MVAC Errors

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Concord, New Hampshire

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Quiz Answers

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Weather Radar

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FBO, it's critical to understand its limitations. It's one of the few weather products that provides the pilot with a dependable account of threatening or adverse weather.

However, pilots need to use it in the context of other airborne or ground-based weather products to be sure it's telling the full story. Due to the variety of potential vendors and bandwidth issues, the lag time in getting the radar data from the antenna to the customer could be six to 10 minutes. Hardly breaking news in a rapidly developing thunderstorm, but a good tool nonetheless.

Next month, Captain David Gwinn will add to the topic by explaining how the pilot can form the big weather picture using both ground-based and airborne radar.

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