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Weather Journeyman

Volume 2. Weather Radar

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This is the second volume in CDC 1W051A, *Weather Journeyman*. In volume 1, you learned about general meteorology, synoptic scale systems, and surface weather observations. Now that you have the necessary dynamics background for weather systems, volume 2 introduces you to weather radar. The knowledge you obtain here is invaluable when it comes to analyzing weather systems and their horizontal and vertical profiles. The WSR–88D Doppler radar is considered by many the “eyes” and “ears” necessary to accurately analyze the atmosphere, especially since the lag time between radar observations and viewing the results is merely minutes. Few data sources come close to the near up-to-the-minute data the WSR–88D provides when it comes to issuing weather warnings that protect life, limb, and property.

The first unit in this volumes covers both conventional and Doppler radar principles and is necessary to understand before looking at the WSR–88D’s capabilities. Unit two provides an overview of the equipment and components that make up the WSR–88D radar system. Finally, unit three discusses the products available for the WSR–88D and how to use these products to identify atmospheric conditions and improve your forecast capability.

A glossary of terms, abbreviations, and acronyms is included for your use.

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This volume is valued at 24 hours and 8 points.

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then do the unit review exercises.

Page

Unit 1. Radar Principles

FOR MORE THAN A CENTURY, meteorologists have used existing weather conditions in an attempt to forecast the weather. Often, current weather information was based on the conditions visible to the naked eye from designated points on the ground, which resulted in large voids between observation points. Then, with the invention of weather radar came the ability to fill these undesirable gaps.

Radar observations are very often the basis for issuing a local weather advisory or warning. With conventional radar, these observations are useful only after severe storms develop and often must be supplemented with other data. Doppler radar can detect atmospheric motions, and motions within a storm cell or system. Imagine the benefits of seeing convective scale dynamics in real time. This eliminates much of the guesswork involved in pinpointing severe weather.

Radar systems used in meteorological research and operations provide information that could not be obtained over the same wide areas in any other way. To understand and apply this unique information, it is necessary to understand the radar's characteristics that determine its ability to detect and display atmospheric targets. You need to understand that the ability of radar to detect and display echo coverage, height, intensity, and type of precipitation is limited by design and cost factors of the system. A good understanding of the operation of a radar system helps you become proficient at radar operation and interpretation. With the WSR–88D radar, greater emphasis is placed on information supplied by the radar. Therefore, you must have a complete understanding of conventional radar principles before moving on to Doppler principles.

To make sure you have a complete understanding of Doppler principles, this unit begins with a review of conventional radar principles. From there, you learn about specific Doppler principles and dual-polarization radar principles to help you understand the inner workings of the WSR–88D discussed later in this volume.

1–1. Conventional Radar Principles

The idea for radar came about when a radio navigation system was being tested in June of 1930. Lawrence Hyland was conducting a test near Washington, DC when he noted that a radio signal meter was showing periodic and unexplained peaks. He soon realized airplanes in the traffic pattern at Bolling Field reflected a small part of the radio energy—an electromagnetic echo. From Hyland's discovery came the development of a system to detect targets using a narrow beam of electromagnetic energy. Of course, this is what we now call radar.

The radar beam is a series of short electromagnetic pulses directed along a path by a dish-shaped (parabolic) antenna. Targets struck by the pulse send some energy back to the antenna. In the time between pulses, the returned signal is detected, amplified, and processed for display on various screens. The position of the antenna measures the azimuth (direction) of a target. The time duration between emitted and returned pulses measures the range of a target.

Although this is a very simple concept, the characteristics of electromagnetic energy can cause several different types of problems.

201. Electromagnetic energy characteristics

Our ability to use radar for weather detection depends on the theory of electromagnetic energy. No matter how sophisticated the hardware, we are still stuck with these theoretical limitations.

In this lesson, you learn some facts about electromagnetic energy that gives you an understanding of why the radar can do what it does. Just as important, we examine why the radar is limited in what it can do.

Electromagnetic energy

You are probably familiar with the term electromagnetism. If not, electromagnetism is electrical current passing through a wire coiled around a metal bar producing a magnetic field. As the magnetic field (electromagnetism) is produced, the metal bar becomes polarized (equal and opposite charges on either end). The bar is then known as a dipole. If you change the direction of current flow through the coiled wire, the polarity of the magnetic field reverses. The reversal in magnetic polarity produces another electrical field that propagates away from the dipole at the speed of light (3×10^8 meters per second) as waves. If visible, these waves would look like a series of sine waves, as shown in figure 1–1.

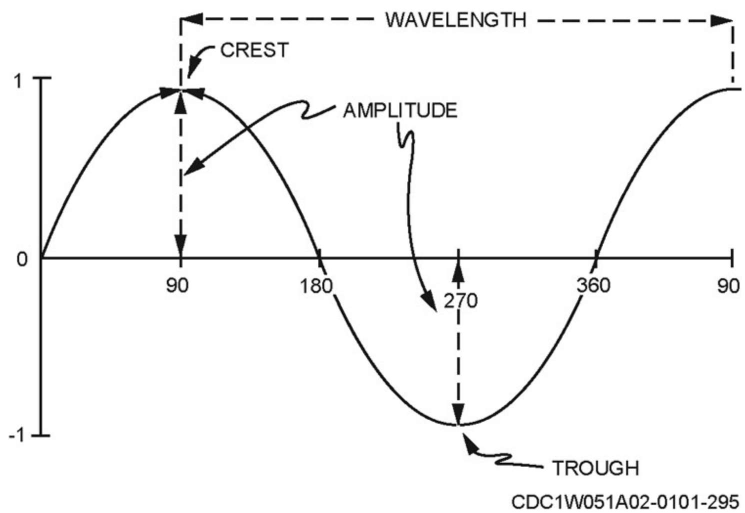

Figure 1–1. Characteristic sine wave.

This principle is employed in any device that radiates electromagnetic energy, including radar. Electromagnetic energy has three important characteristics that affect radar performance—wavelength, amplitude, and frequency.

Wavelength and amplitude

As stated earlier, electromagnetic energy propagates away from a dipole in sine waves. The wavelength of the energy is measured between successive troughs or successive crests in the sine waves (fig. 1–1). The height or amplitude of these waves represents power. Mathematically, the wavelength is represented by the Greek character lambda (λ). Wavelengths are typically expressed in centimeters (cm).

Modern radars used in meteorological applications operate in a part of the microwave region of the electromagnetic, or radio, spectrum from less than 1cm to approximately 11cm (fig. 1–2).

BAND	TYPICAL WAVELENGTH (cm)	PRIMARY APPLICATION
K	1	Cloud physics
X	3	Airborne
C	5	Previous weather radar
S	10	Current weather radar
L	23	Air traffic control

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Figure 1–2. Various radar wavelengths.

Other factors being equal, the echo returns from clouds or precipitation increase with shorter wavelengths. Within the range of wavelengths used for weather radar, the smaller droplets are more visible to the radar at the shorter wavelengths and are more transparent at the longer wavelengths. When you need to detect clouds, short wavelengths are desirable. When detecting snow or light to moderate rain, using the 3-cm wavelength radars is optimal. However, 3-cm radiation is severely affected by heavy rain. Thus, in regions where large thunderstorms or hurricanes frequently occur, using a 5cm or greater wavelength is more desirable. The WSR–88D wavelength is approximately 10 centimeters and meets this purpose. Attenuation or weakening of the energy in the beam, through rain, increases at shorter wavelengths.

Additionally, if the size of the antenna stays the same, the beam width is narrower when the wavelength of the beam is shorter. Therefore, the choice of a radar's operating wavelength depends upon its intended use. We'll see some specific examples of the importance in choosing the correct wavelength later in this section.

Frequency

The frequency of electromagnetic energy is the number of repetitions of the sine wave (cycle) per unit of time. If one cycle is generated in one second, the frequency is one cycle per second. The most common unit of expression is one hertz, named after the discoverer of electromagnetic radiation—Heinrich Hertz. One hertz is equal to one cycle per second.

Wavelengths and frequency are related. As the polarity of the dipole makes two complete changes in polarity, one wavelength is generated. The rate at which the dipole repeats this cycle is the frequency. As successive waves are generated, the previous wave is one wavelength away from the dipole.

Because the speed of the wave is constant (the speed of light), an inverse relationship exists between frequency and wavelength. Mathematically, it looks like this:

$$\text{Frequency} = \frac{c}{\text{wavelength}}$$

Because the speed of propagation (c) remains constant, the frequency of the radiating device is the same if the wavelength remains unchanged. For example, to have a wavelength of ten centimeters, a radar must have an oscillating frequency of 3×10^9 Hertz or 3,000 megahertz (MHz). Engineers usually speak in terms of frequency, but meteorologists prefer wavelength because of its relationship to the size of water droplet detection.

Atmospheric attenuation

As electromagnetic waves emitted from a radar travel through the atmosphere, some of their energy is lost. This is the result of interaction with atmospheric phenomena such as hydrometeors (clouds and precipitation), gases, and lithometeors (smoke, dust, haze, and so forth). This loss of energy because of interaction with atmospheric phenomena is called attenuation. Attenuation of radar waves depends on two related factors: the wavelength of the emitted radio waves and the size and composition of the particle encountered by these waves. Depending on the relationship between these two factors, the emitted energy is attenuated by absorption or scattering.

Attenuation due to absorption

Absorption occurs when electromagnetic energy encounters a particle, interacts with molecules of the particle, and disturbs the motion of its bound electrons (fig. 1–3). The electrons absorb some electromagnetic energy and the atoms within the molecule are said to be in an excited state. This is how a microwave oven heats food. Radar energy is transmitted into food containing water molecules. The water molecules absorb some energy and heat up (they enter a more excited state).

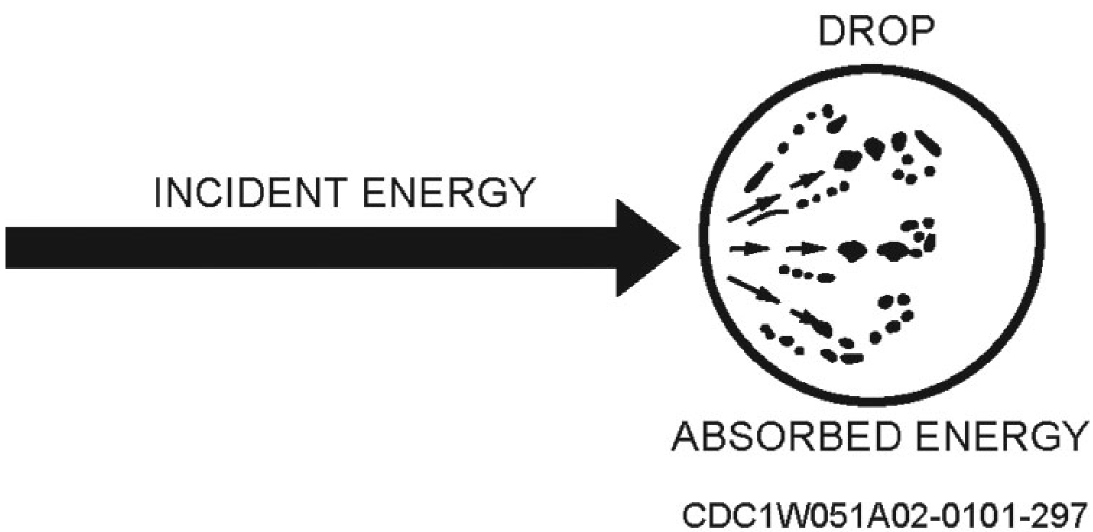

Figure 1–3. Absorption.

Energy absorbed by a molecule may be reradiated by the particle later. However, when this energy is at a different wavelength (such as heat), the energy is unrecognizable to the radar that originally transmitted it.

Generally, absorption by gases is negligible for radars with wavelengths equal to or greater than one centimeter. For radars with wavelengths equal to or greater than five centimeters, absorption by cloud droplets is negligible. For radars with wavelengths equal to or greater than ten centimeters, absorption by precipitation particles is very small.

The wavelength for weather radars is chosen to minimize atmospheric absorption while simultaneously preserving enough sensitivity to small particles to detect weather phenomena.

Attenuation due to scattering

As stated previously, bound electrons of atoms and molecules absorb electromagnetic radiation that has been emitted from the radar. The molecules act as forced oscillating dipoles, and the excited atom or molecule emits some electromagnetic energy at the same wavelength that struck it. This process is called scattering.

When an atmospheric particle scatters electromagnetic energy, it redirects the energy in many different directions, including directly back at the radiating antenna. This energy return is called backscattering and is what the radar detects (fig. 1–4). The remainder of the energy is then said to be *lost*; in other words, attenuated due to scattering. (Only a small fraction of the incident energy is returned to the antenna for detection).

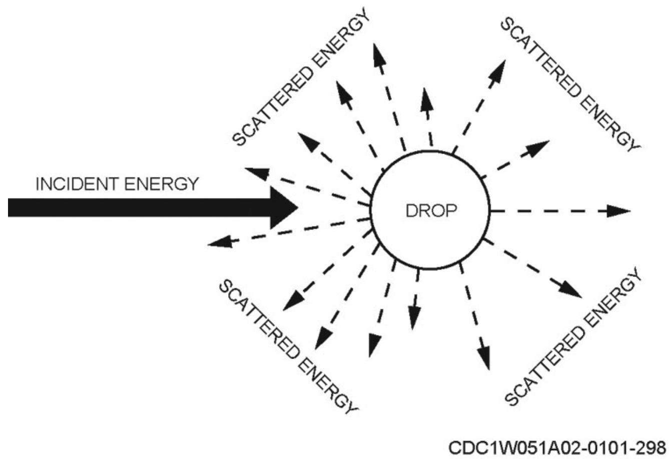

Figure 1–4. Backscatter versus lost scattering.

The relationship between wavelength and target diameter is also critical when considering attenuation due to scattering. Provided the target diameter is smaller than 0.03 of the wavelength of the emitted energy, it *scatters* energy in all directions. This is called Rayleigh scattering and the particle is called isotropic; that is, the scattering in all directions is equal.

As the target diameter increases (with respect to the wavelength), Rayleigh scattering increases much faster than the size of the particle would suggest. Thus, we get dramatically stronger backscattering from larger particles.

However, this increase in backscattering does not continue forever. As the particle reaches a size equal to 0.03 of the wavelength, another type of scattering occurs—Mie scattering. With Mie scattering, most of the energy is forward-scattered and thus lost to the radar for detection. This is a problem in shorter wavelength radars.

202. Pulsed electromagnetic energy characteristics

Having discussed some basic ideas dealing with electromagnetic energy, it is time to take a closer look at the characteristics of a pulsed radar beam. Recall that radars emit electromagnetic energy in short powerful pulses. Pulsed energy allows for a system to determine the range or distance to a target. This is done by measuring the elapsed time between the transmission of a pulse and the detection of returned energy from a target.

The fundamental characteristics of the radar pulse beam are shown in figure 1–5. An important aspect of radar is the transmission of definite pulses of energy at prescribed intervals that include a silent period or *listening time* between pulses.

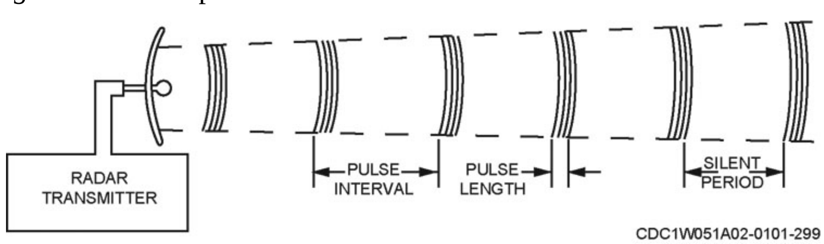

Figure 1–5. Radar pulse characteristics.

Pulse length

The pulse length is measured as the distance from the front (leading) edge to the back (trailing) edge of the pulse as it travels in space. Also, the pulse length may be measured in the unit of time it takes the transmitter to send one pulse. To avoid any confusion as we proceed in examining the various motions and measurements involved in radar, let's relate the emission of pulses of a given duration to the velocity of the radio energy through space.

The velocity of propagation of radio energy is equal to that of light—approximately 186,000 miles per second. Because the second is too long to use conveniently in radar computations, time is usually expressed in microseconds, symbolized by µsec or microsec. A µsec is one-millionth of a second. Therefore, the speed of light may be expressed as 0.186 miles/µsec. When this is converted to the metric system, we can express the speed of light as 300 meters/µsec. Pulse length then can be expressed in either µsec or meters. The duration of the pulse, for example, might be 2.0µsec, representing a pulse length of approximately 600 meters. Remember that pulse length, no matter whether long or short, does not affect the velocity of the emitted radio energy.

The pulse length does, however, affect the amount of power returned from a target. The amount of energy in each transmitted radar pulse depends among other things on the duration or length of the pulse. In other words, if one pulse is ten times the length of another pulse, it has ten times the energy. This allows more illumination of an echo and a stronger signal returned to the radar. However, as we'll see later, this causes resolution to suffer, and determining the characteristics of a target may become impossible. Pulse length also determines the minimum range of the radar, since the transmitter must shut off by the time the signal returns. The ideal radar would use short, powerful pulses; however, it is impossible to get powerful pulses that are short without large physical equipment. Another way in which the amount of energy can be transmitted by the radar is to increase the number of pulses transmitted per second.

Pulse repetition frequency

The pulse repetition frequency (PRF) is the rate at which the pulses are transmitted—the number of pulses per second (pps). Weather radar systems use only one antenna. During the transmission of the pulse, the antenna serves as the method of focusing the pulse and directing it in a concentrated beam. After the pulse has been transmitted, the antenna serves as the *ear* to listen for any returning signals from targets that may have been intercepted.

Listening time

The period of waiting for a returned signal, the listening time, determines the maximum range of the radar. Listening time permits the energy that has backscattered from the target to be received before the next pulse is transmitted. Listening time must be long enough for a transmitted pulse to reach the target and return. The range of any radar is equal to one-half the maximum distance (round-trip) the signal can travel during the listening time—the time between pulses.

The radar depends on this combination of pulse length and listening time. They determine some capabilities of the radar to detect the weather.

Choosing the correct PRF

Although the PRF must be kept low to allow for the maximum range desired, it must also be kept high enough to allow enough pulses to be returned from a distant target. Remember, the power of the returned signal is very low and many returns are needed to present a target accurately and with enough detail to be interpreted. If only one pulse were transmitted to and received from a given target, the reliability of the radar presentation would be poor. Therefore, radars are designed so that many pulses are returned from a single target.

Antenna motion

An important consideration in determining the number of pulses reflected from a target is the rate of angular motion of the antenna. If the antenna moves through too great an angle between pulses, not only is the number of pulses per target too low, but there may be regions not probed for targets. The antenna motion may also be expressed by the number of pulses per degree of antenna rotation.

Maximum unambiguous range

The maximum distance electromagnetic energy can travel round trip between pulses defines the maximum range of a radar system. This range limit, called the maximum unambiguous range, is limited by how often pulses are broadcast—the PRF. The reciprocal of PRF (1/PRF) is called the pulse repetition time (PRT) and is the time between pulses.

The greater the PRF (pulses per second), the shorter the PRT, and the shorter the maximum unambiguous range of the radar. This can be shown using the formula below:

$$R_{max} = \frac{[c(\frac{1}{PRF})]}{2} \text{ or } \frac{[c(PRT)]}{2}$$

where R_{max} = unambiguous range in kilometers

c = speed of light (3×10^5 km/sec)

PRF = pulse repetition frequency in seconds

PRT = pulse repetition time in seconds

Therefore, if the radar had a PRF equal to 1,300 pps, its unambiguous range would be approximately 115 kilometers (a little more than 60 nautical miles). A PRF of one half that, 650, yields a range of 230 kilometers or 120 nautical miles.

Short intervals between pulses restrict the range of the radar. Short pulses and short-pulse intervals provide the utmost accuracy and detail of targets. Long-pulse intervals increase the range of the radar and long pulses increase its sensitivity.

Range folding (second-trip echoes)

As you know, a pulsed radar system measures distance by keeping track of pulse travel time. However, the radar cannot distinguish one pulse from another. That is, all returned pulses look the same to the receiver—it cannot distinguish energy of a previous pulse from a more recent pulse. The radar depicts a target as though the energy were returned from the most recent pulse.

When energy is received from an old pulse after transmission of the next pulse, the radar assumes the returned energy is from the latest pulse—it gave up looking for the old pulse and sent a new one. Therefore, the displayed echo is at a distance equal to one-half the distance traveled by the latest pulse. The target azimuth is correct but the range is incorrect. This phenomenon is known as range folding or second-trip echoes as it was called in the past.

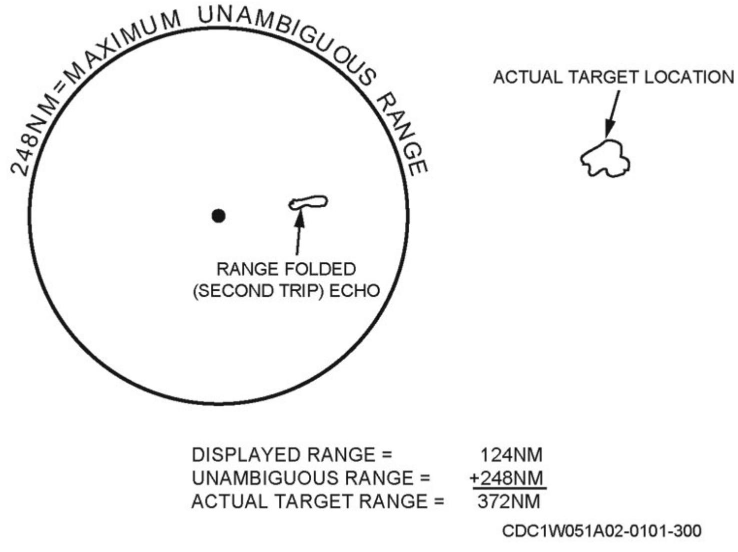

Figure 1–6. Range folding.

The basic idea of range folding is shown in figure 1–6. The fictitious echo is indicated at a range equal to its distance beyond the unambiguous range of the radar.

Pulse 1 is transmitted and it strikes a target beyond the unambiguous range of the radar and some energy is backscattered. However, before the backscatter reaches the antenna, pulse 2 is transmitted. When pulse 1 reaches the antenna, it is processed as though it were pulse 2. The result is a target at the proper azimuth but at a false range.

Range-folded echoes can be identified if you are aware of their characteristics. They are typically elongated along a radial, indistinct in appearance, but most intense on the side nearest the radar. They disappear with a change in antenna elevation angle, and change display range if the PRF is changed.

Echoes displaying second-trip characteristics can be unfolded in range by adding their indicated range to the unambiguous range of the radar (fig. 1–6). The echo appears at a distance equal to its distance beyond the unambiguous range.

203. Effect of radar beam characteristics on radar performance

We have already said that electromagnetic energy from the radar travels in a focused beam. Now let's examine some specific characteristics of the radar beam that affects how radar *sees* a target. As a radar operator, you must always be aware that the image you see displayed by the radar is not necessarily a perfect representation of the actual situation. Really, it's not a bad idea to be suspicious and assume that the radar may be lying to you.

Radar beam

Electromagnetic energy is carried to the antenna from the transmitter by way of a metal duct called a wave guide. The wave guide ends at a device called a feed horn that is at the focal point of a parabolic reflector or dish.

Ideally, energy leaving the feed horn is directed at and reflected off the dish in a *pencil beam*, as shown in figure 1–7. However, because of the refraction of the energy at the edge of the dish, the radar beam is more cone-shaped.

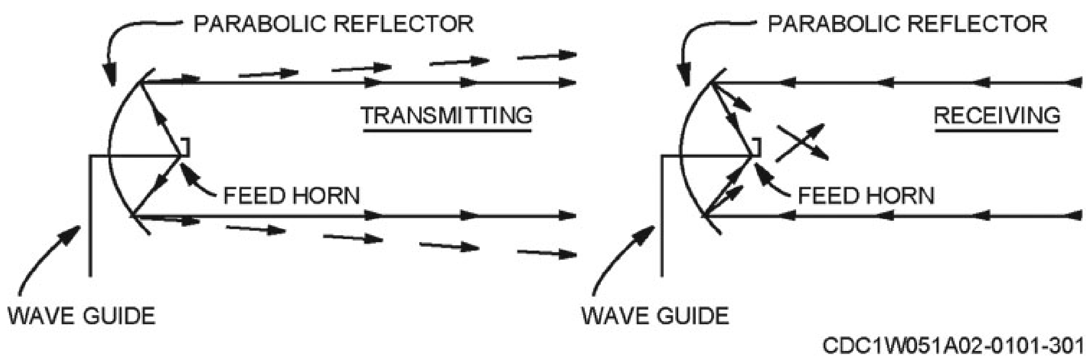

Figure 1–7. Pencil beam.

Backscattered energy follows much the same path in reverse. Notice in figure 1–7 that some energy misses the focal point and the feed horn due to diffraction at the edge of the antenna. Actual loss of energy because of this diffraction is quite small; however, keep in mind the beam is not perfect. Later, when we look at side lobes, we see that some of this diffraction can be important.

Beam width

To properly interpret data from the weather radar, it is necessary to define the radar beam in terms of half-power points. To show this, look at figure 1–8 as we explain.

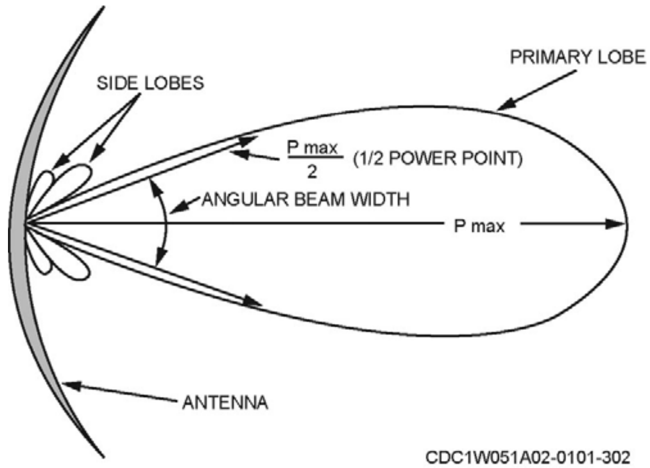

Figure 1–8. Half-power points.

Maximum power density (power per unit area) exists along the centerline of the beam. To each side of this beam centerline the power drops off gradually at first, then more sharply as the distance from the centerline increases. For a given range, a half-power point exists at a distance where power density is one-half that of the centerline. Because of this power concentration along the centerline, nearly 80 percent of the total radar energy is contained inside these half-power points. Because the beam is cone-shaped, half-power points combine to make a circle. The diameter of this circle is the beam width or diameter. This bounded area is the *radar beam*. Under most circumstances, this *radar beam* is the area where enough backscattered energy is available to detect a target. Backscattered radiation from outside this area usually is too weak to be detected by the radar.

Angular distance between the half-power points of a radar beam is called the angular beam width. It is measured in degrees. Since the beam is conical, the angular beam width is the same whether measured vertically or horizontally. Angular beam width varies directly with the wavelength and inversely with the diameter of the parabolic reflector. This means we can get a narrower beam width by either choosing a shorter wavelength or by building a larger antenna.

Although the angular beam width remains constant with distance from the radar, the distance between half-power points (diameter of the beam) increases. This is called the linear beam width. For example, a radar with an angular beam width of 1° has a diameter or linear beam width of 2,654 feet at a distance of 25 nautical miles from the antenna. At 50-nautical-mile range, this beam has a diameter or linear beam width of 5,308 feet. Remember, this increasing diameter reduces the power density of the radar beam. For most purposes, the smaller the angular beam width, the more desirable the radar system is. This is because the energy concentration per volume can be maintained at greater distances and it improves azimuth and height resolution, which are discussed later.

Beam illumination

The portion of the beam through which the pulse is traveling is said to be illuminated by the pulse or to be the illuminated volume of the beam. Within this area the radar detects electromagnetic energy. The following is a breakdown of how electromagnetic energy is propaged and distributed along the radar beam's path and how electromagnetic radiation is detected by the radar.

Pulse volume

The radar beam is a path along which the electromagnetic energy pulse travels, as shown in figure 1–9. Unlike a flashlight that continuously radiates energy, only a short segment of the radar beam contains electromagnetic energy at any instant. The pulse volume is the segment which contains energy (the pulse). It has the dimensions of one pulse length in range and one beam diameter in width and height.

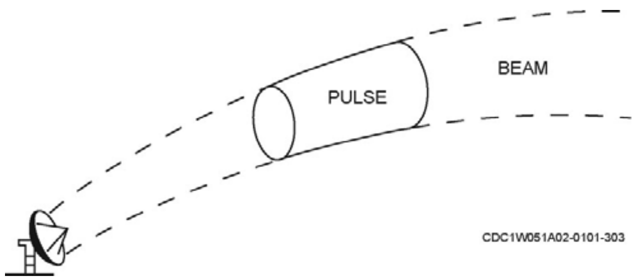

Figure 1–9. Pulse volume.

You may also consider pulse volume to be the volume of the atmosphere occupied by the radar pulse. The shape of the pulse volume is that of a frustum—the shape created if you cut the point off a cone.

The pulse volume increases with increasing range although pulse length remains constant. The increase in volume is caused by the increase in the beam diameter with distance. As a result, power density decreases within the pulse volume as distance from the radar increases. This is one factor that contributes to the decreased sensitivity of the radar at increased ranges.

Sample volume

We defined the pulse volume as the volume of the atmosphere occupied by the pulse of electromagnetic energy. But, what about the volume of atmosphere that is instantaneously sampled by the radar? This is called the sample volume. It is called "sample volume" because this is the smallest area sampled by the radar. It is equal to one-half the pulse length and the beam diameter. Since the sample volume is comparatively large, individual targets are much smaller than the sample volume. This means all targets within that volume contribute to the backscattered radiation received by the radar. In other words, the individual character of a target is averaged among the characteristics of other targets. If all the targets are similar to each other, this is not a problem. However, if a few targets are very different, their special characteristics can be lost among the total average.

Partial beam filling

Partial beam filling is the effect when a target fills only a small portion of the radar beam. Keep in mind that as the radar beam propagates away from the radar, it continually becomes wider—quite wide at distant ranges. As a result, targets occupy a much smaller portion of the beam at these distant ranges. This results in the return of comparatively small amounts of energy. Our displayed echo is weaker than the true echo. Anytime a target occupies only a small portion of the beam, the true characteristics of that target may be hidden or altered during display.

In shallow precipitation regimes, the effect is even greater. Due to the comparatively low vertical extent of precipitation echoes, only a small portion of the beam may be encountering targets at distant ranges. The result could be an absence of precipitation echoes being displayed though substantial rainfall is occurring.

While detecting showers or thunderstorms, beam filling must be considered both horizontally and vertically. Some showers are less than one mile in width and may not completely fill a narrow 1° beam at ranges beyond 60 miles. Additionally, the most intense core of a storm may cover only a small percentage of the entire storm. This also results in a comparatively weaker return.

Below beam effect

Below beam effects are the result of evaporation or growth of precipitation below the radar beam. At greater ranges with larger sampling volumes and increasing beam heights, the accuracy of these measurements diminishes—radar estimates of rainfall rates become less reliable at greater distances.

Virga, the total evaporation of precipitating water, is an extreme example of below beam effects. This is shown in figure 1–10.

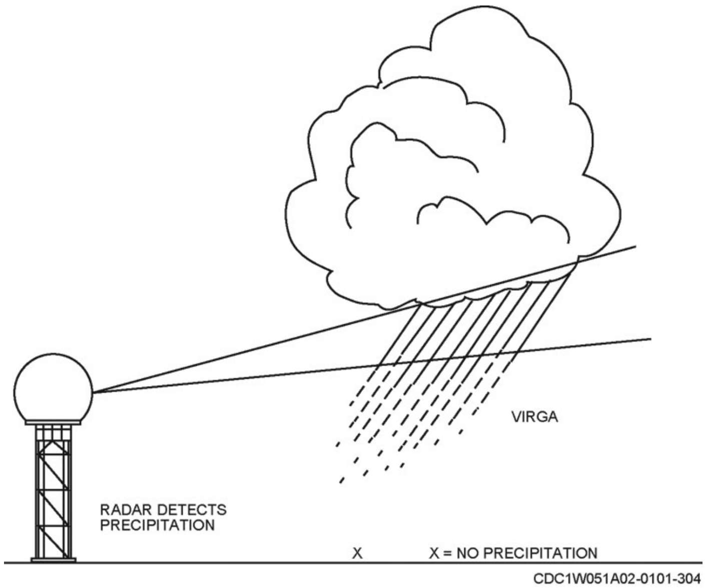

Figure 1–10. Virga.

In this situation, precipitation displayed at long range by the radar is not reaching the ground. Only from actual surface observations could you tell that precipitation was not reaching the ground.

Large, low-based thunderstorms can cause the opposite effect (fig. 1–11). Here, the area of maximum reflectivity is below the radar beam. Therefore, little or no precipitation is being shown. In reality, surface observations indicate heavy rainfall rates.

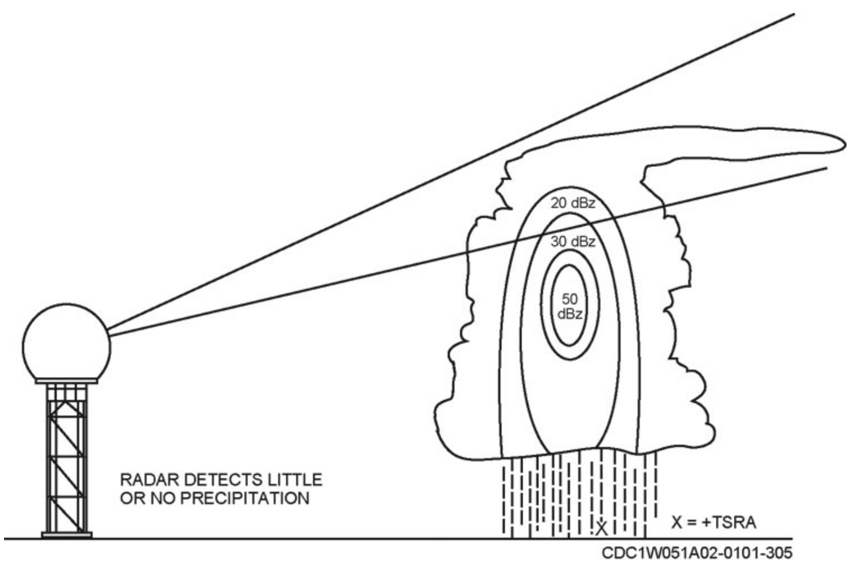

Figure 1–11. Thunderstorm rainfall.

With these examples in mind, you should see the value of consulting other data sources to confirm radar displays. Surface observations, pilot reports (PIREP), meteorological satellite (METSAT) imagery, and nearby radar imagery are all helpful tools in overcoming this limitation.

Beam blockage

Beam blockage is another potentially serious source of error affecting the radar beam. Blockage is not a shortcoming of the radar. Instead, it is caused by obstructions of the beam by targets close to the antenna. The result of blockage can often be seen as part of the ground clutter pattern.

Blockage affects all ranges of the radar. As the radar beam propagates, it becomes wider and ascends. Therefore, ground targets will be overshot by the beam or only fill a small portion of the beam at greater ranges. However, when blockage does occur it results in a reduction of the effective transmitted power. This leads to less available energy to reach targets beyond the source of the blockage.

Resolution and distortion

Resolution describes the ability of the radar to show or display targets separately. Two resolution problems exist—azimuth and range resolution. Distortion, while different from resolution, is affected by the same factors that determine a radar's resolution. Just as with resolution, there are two separate problems—azimuth and range distortion.

Azimuth resolution

Azimuth (often called bearing) resolution is the ability of the radar to distinguish between two targets at the same range, but at different azimuths or directions from the radar. This ability to resolve targets at different azimuths but identical ranges depends on beam width. When the radar detects backscattered energy, it assumes it is being returned from a target on the centerline of the radar beam. However, the radar begins detecting backscattered energy when the target is within the sample volume and continues detecting it while it remains within the one-half power points of the sample volume.

Therefore, if two targets are side-by-side at the same range and are spaced less than the beam diameter apart, they appear as one target. Conversely, if two targets are separated by a distance greater than the beam diameter, then the radar resolves them as individual targets. Figure 1–12 shows this.

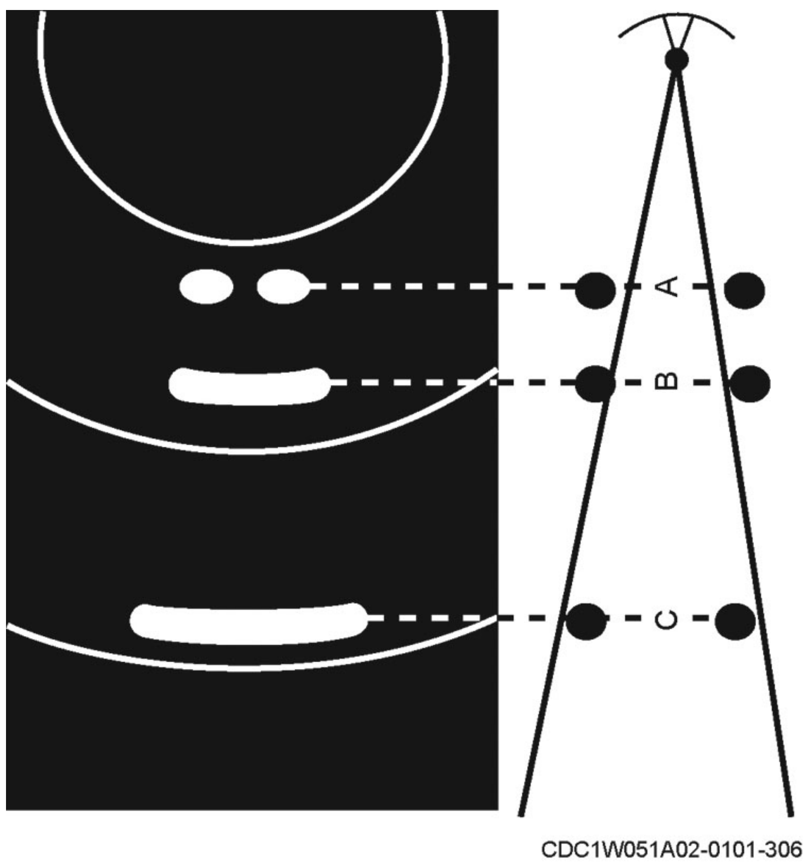

Figure 1–12. Azimuth resolution.

Azimuth resolution changes with target distance from the radar. Because the beam diameter is less at closer ranges, the ability to *resolve the azimuth* of two closely spaced targets improves at shorter ranges, as shown in figure 1–12.

Remember, azimuth resolution depends on the diameter of the radar beam. Therefore, it also refers to resolution of targets at different elevations. That is, targets at the same range but different elevations must be separated vertically by greater than one beam width to be resolved as separate targets.

Azimuth (beam width) distortion

The result of the radar's limited azimuth resolution is distortion. Azimuth or beam width distortion is an apparent stretching or elongating of a target in azimuth. Just as with azimuth resolution, it depends on the beam width (fig. 1–13).

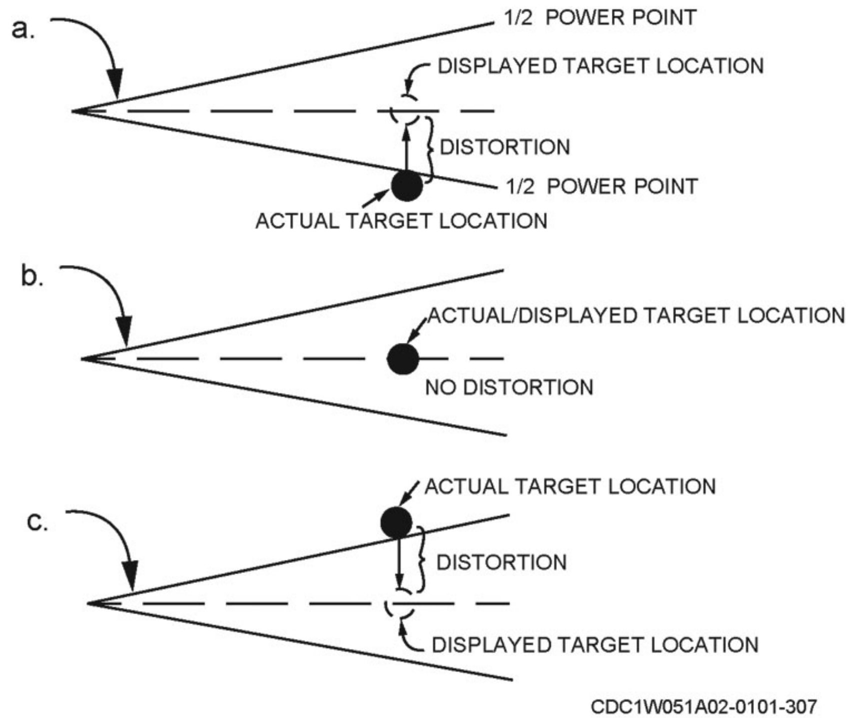

Figure 1–13. Azimuth distortion.

Remember that radar detects backscattered energy when a target is within the one-half power points of the radar beam. It assumes the target is on the centerline of the beam. In other words, as the half-power point encounters a target, a return is detected as though it were in the center of the beam. This is an error of one-half the beam width. As the radar beams sweeps through the target, it continues to detect returns as if they were at the beam centerline. This continues until the target is out of the opposite half-power point, resulting in another error on the opposite side of the target equal to one-half beam width. Therefore, displayed echoes are distorted in azimuth by a total of one beam width. Since the distortion is in terms of beam width, it increases at greater ranges as the diameter of the beam increases.

Although distortion is technically different from resolution, the effect on the radar operator is to limit the ability to resolve two targets. Most often, operators refer to both azimuth resolution and azimuth distortion collectively as resolution problems.

Range resolution

Range resolution is the ability of the radar to distinguish between two targets at the same direction from the radar but at different ranges.

Earlier, we saw how the pulse length determines the size of the sample volume the radar is simultaneously sampling. The same type of reasoning shows why the smallest precipitation (or cloud) area that can be resolved by the radar along an azimuth is equal to one-half the pulse length. Echoes within this distance reach the radar receiver simultaneously and display as one target.

Figure 1–14 shows how range resolution depends on half the pulse length for the same reasons. Since there is only one-half pulse length between the two targets in figure 1–14, the signal returned from the leading edge of the pulse striking the more distant target (target B), returns to the first target (target A) just as the backscattered energy of the trailing edge of the pulse, is leaving the nearer target. The result is that the energy backscattered from both targets travels back to the radar together and one large target appears on the display, although two targets actually exist.

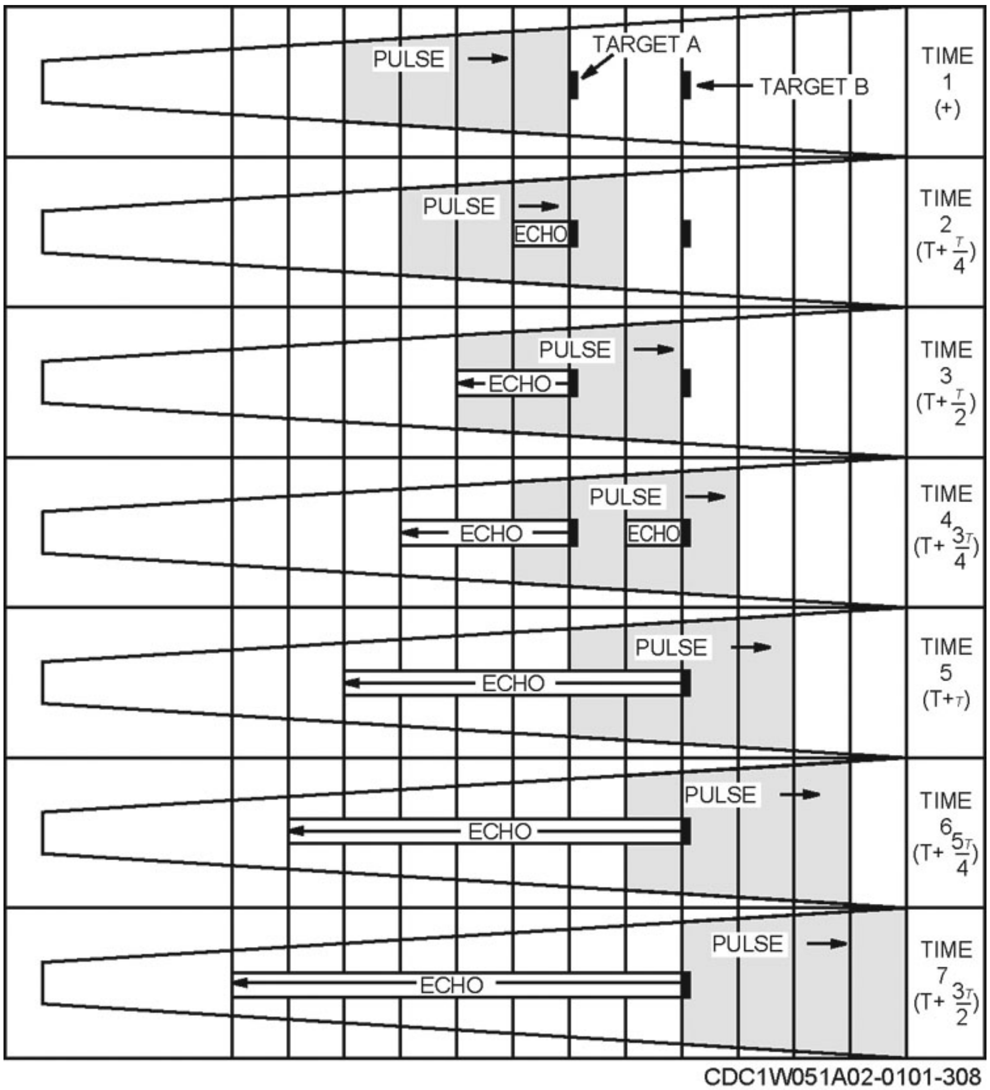

Figure 1–14. Range resolution.

Conversely, if two targets are separated by more than one-half pulse length in distance, both echoes are displayed as individual returns. By the time the leading edge of the radar pulse strikes the more distant of the two targets, the trailing edge of backscattered energy has already left the nearer target. This results in two separate areas of backscattered energy returning to the radar and two separate radar echoes being displayed.

Range resolution depends on pulse length. The shortest distance between two targets must be more than one-half the pulse length in order for the echoes to appear separate on the display.

Unlike azimuth resolution, range resolution is the same at any distance. This is because pulse length does not vary with range. The separation necessary for resolution is the same at any range.

Side lobes

Due to diffraction of the electromagnetic energy at the edges of the antenna, only about 80 percent of the radiated energy is contained between the half-power points of the radar beam. Most of the remaining 20 percent of the energy is broadcast in other directions in spikes or side lobes. These lobes extend outward only a short distance with power densities far less than are found between the half-power points. Figure 1–15 shows an example of a radiating pattern from a radar dish.

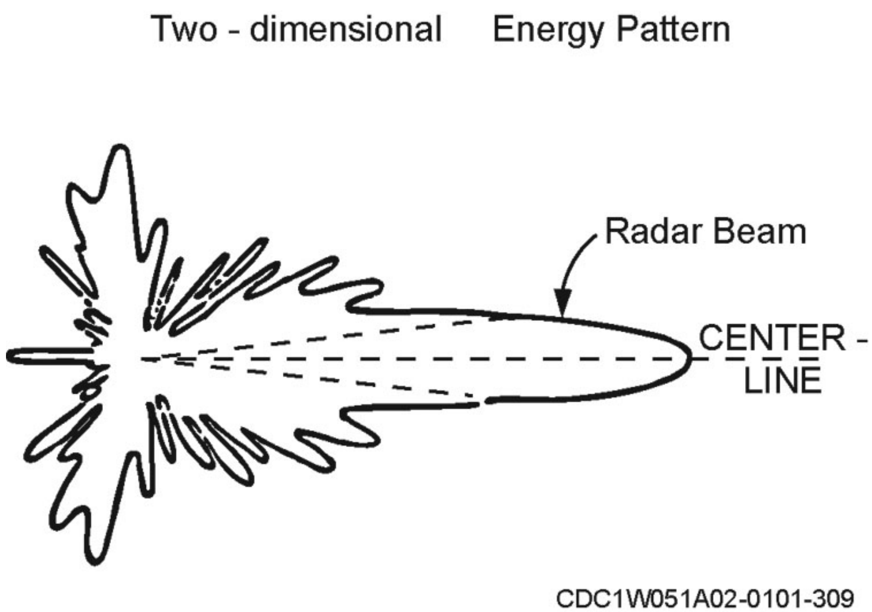

Figure 1–15. Side lobes.

Side lobes are presently an unavoidable and detrimental part of any weather radar system. While side lobe patterns for radars are similar, each type of system has its own unique pattern.

Side lobes cause certain side effects of which you should be aware. They do contain low power density and thus their effective range is quite short, so most of their effects are seen only at close range. Here are some effects:

- Multiple displays of a single target.
- Ground clutter.
- False echo tops.

Cone of silence

The cone of silence is associated with radars having upper-elevation angle limitations. It is the area above the radar antenna that is not sampled because it’s beyond the maximum elevation angle. Figure 1–16 shows the cone of silence and points out the importance of having the radar antenna located far enough away from your installation. This ensures the cone of silence does not influence power returns from meteorological phenomena affecting your area of interest.

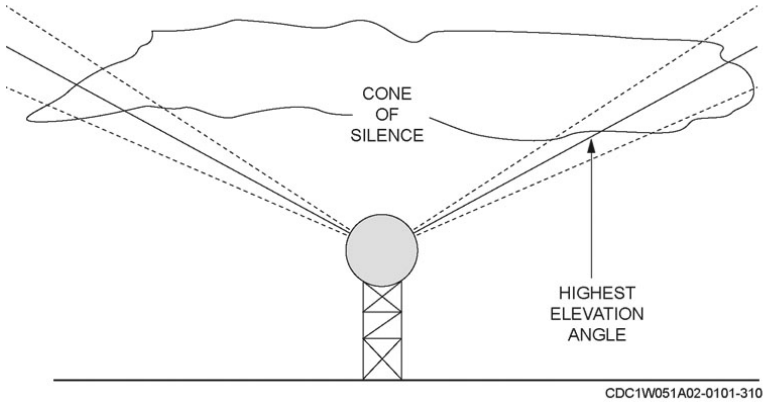

Figure 1–16. Cone of silence.

Typically, the effect of the cone of silence is seen on radar displays when meteorological targets move into the cone of silence or overhead of the radar antenna. Precipitation targets seem to weaken and disappear as they move into the cone of silence. Then, as the targets move through and out of the cone of silence they seem to rebuild and strengthen. When meteorological targets are hampered by the cone of silence it is best to use another nearby radar, if available, to interrogate them.

204. Atmospheric refraction effects

Detecting weather phenomena by radar is quite different from other detection processes. We cannot move our radar to the location of a thunderstorm to detect the strength. Instead, we must remain many miles away and make *indirect* measurements.

Because we have so much space between our radar and the weather phenomena we need to detect, many things can go wrong. This lesson reviews some atmospheric effects that can alter the path of our radar beam. Seeing as how this radar beam is our only source of information, we should suspect that our displayed information may also have been altered in some way.

Propagation of the radar beam

The propagation of energy along a radar beam does not coincide with a straight-line path from the transmitter. Figure 1–17 shows the difference between the propagation of a radar beam and the straight-line path along which the beam is directed. As you can see, the actual path of the radar beam is curved. This curved path is the effect of refraction, or bending, as the beam passes through the atmosphere.

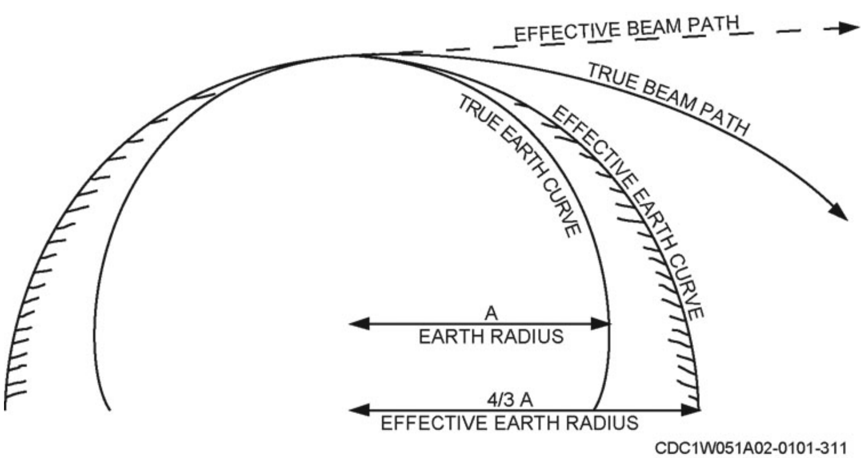

Figure 1–17. Radar beam propagation.

The most common method of estimating the height of the beam above the earth's surface, at a distance from the radar's antenna, follows. Assume the change of refractive index (air density) is constant with height and that the beam reaches a curve larger than the curve of the earth. In order for the beam to travel in a straight line, the earth's curvature would have to be enlarged to 4/3 its true value. This is called the effective earth radius model or 4/3-earth radius model (fig. 1–17).

In the real atmosphere, the refractive index does not remain constant with height. Therefore, under normal conditions the radar beam's true curvature is a little less than that of the earth's surface (fig. 1–17). This explains why the radar beam gets higher above the ground, even if the angle of the antenna is zero, as its distance increases from the antenna.

Standard refraction

The bending of a radar beam through the atmosphere is caused by air density differences. Under normal atmospheric conditions, the temperature and water vapor content gradually decrease as height increases. Under normal conditions, the radius of curvature of the radar beam for nearly horizontal propagation is about one third greater than the radius of the earth's curvature.

Nonstandard refraction and anomalous propagation

Anomalous means abnormal, unusual, or irregular. Wave propagation's that deviate from standard occur under abnormal or special atmospheric conditions. When wave propagation differs from standard, it is known as nonstandard refraction or anomalous propagation (AP).

Under certain atmospheric conditions, the refraction of the beam is so distorted that the radar shows echoes when there are no echoes causing the phenomena. The most significant effect of AP is to display targets at a shorter or more distant range than the actual target. This is a result of the beam's curvature either increased or decreased by certain atmospheric conditions.

Superrefraction

When the curvature of the radar beam is greater than the earth's curvature, the propagation is termed superrefraction. This occurs when warm, dry air overlies comparatively cool, moist air, as in an inversion. Here, the radar beam is refracted below its normal path, as shown in figure 1–18.

The greater the increase of temperature and decrease of moisture, or both, with height, the greater the degree of superrefraction. In an extreme case, a radar beam becomes trapped in a *duct* beneath the inversion and may travel for long distances without appreciable attenuations. Figure 1–18 shows the ducting phenomenon. Under such conditions, low-level targets a few hundred miles distant, and not normally detected, may be displayed by the radar.

Several meteorological conditions may lead to superrefraction. Over land, superrefraction is most noticeable at night under conditions favoring strong radiation of heat from the earth. Superrefraction may occur in the late afternoon or evening when warm air drifts over the cool sea. The cool air outflow from a thunderstorm may also produce favorable superrefraction conditions. However, during precipitation, the conditions necessary for superrefraction are normally absent. Ducting occurs frequently in subtropical, high-pressure zones. It is useful for each radar location to collect color hardcopies during such abnormal (AP) conditions for future reference in identifying targets and distinguishing AP from precipitation echoes.

Superrefraction may also cause precipitation echoes to be observed on the display at locations where no precipitation exists. Recall, these are called range-folded echoes, or echoes detected from a previous pulse. The nature of radar is such that all echoes are detected in the interval between transmitted pulses. During superrefraction, echoes detected at long ranges by a previous pulse may appear on the graphic display at short range.

Another effect of superrefraction is the displayed height values on the radar are overestimated. The radar has the ability to display the height of echoes when they are selected on the screen. This displayed height is based upon standard refraction. However, when superrefraction occurs, the phenomena will be detected lower than the radar interprets the radar beam. Therefore, the radar displayed heights will be higher (overestimated) than the actual height of the echoes.

Subrefraction

When the curvature of the radar beam is less than normal, the propagation is termed subrefraction. Straightening of the beam upward, or subrefraction, may occur during atmospheric conditions where the water vapor content increases with height and the temperature decreases with height. This subrefraction, shown in figure 1–18, is the opposite of superrefraction.

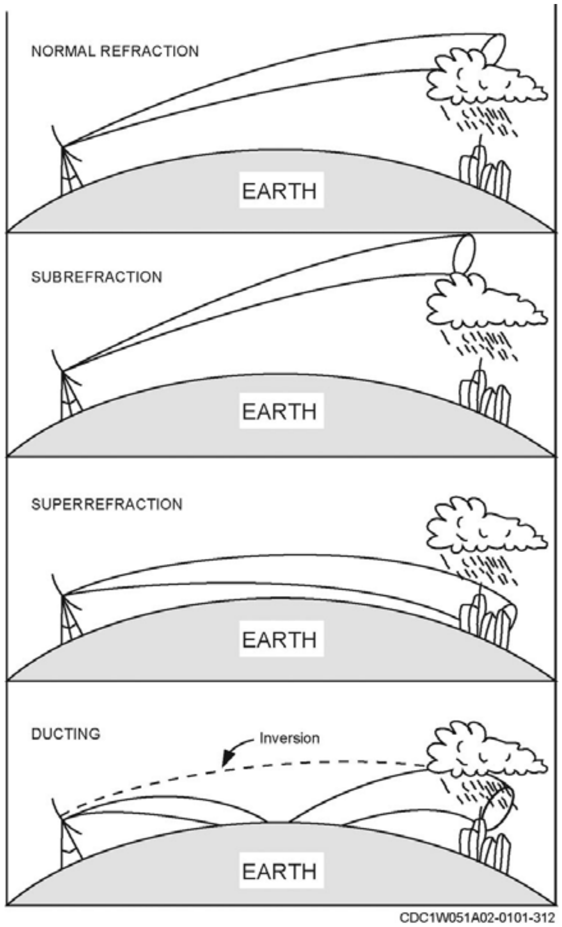

Figure 1–18. Anomalous propagation.

Subrefraction reduces the maximum range of detection of low-level targets because the beam quickly overshoots these low targets. Such a condition may occur in certain types of fog, but it does not occur in precipitation. This abnormal condition is comparatively unimportant for storm detection.

Subrefraction also affects the interpretation of displayed echo heights on the radar. This affect is the opposite of superrefraction. Subrefraction results in the radar displayed height values being underestimated or lower than the actual phenomena. Again, the radar displays the height of echoes based on standard refraction. However, in this case the radar beam is higher than normal and the radar interprets the echoes to be lower than they actually are. In situations where you expect subrefraction may be occurring it is important to supplement your height readings with other data such as PIREPs, METSAT, and weather observations.

205. Backscattered energy (reflectivity) and decibels

One of the core functions of the WSR–88D is to detect and estimate the intensity of meteorological targets. Moreover, radar operators rely on reflectivity returns to determine the strength of storms and evaluate storm structure. Backscattered energy that returns to the radar set is measured in decibels. In order to understand how decibels may be displayed on the radar screen, you must learn some of the equations involved.

Theory of reflectivity

The radar simply measures the amount of electromagnetic energy backscattered to the antenna from targets illuminated by the beam. But, how does the radar assign a meteorological intensity value to this—which, therefore, tells us how strong the storm is or how hard it's raining at a given location? What if the radar simply showed that the backscattered energy was 1.0×10^{-6} milliwatt? This would probably not mean much to a weather forecaster or observer and would certainly not help you do your job. There must be some way to process this returned energy into useful meteorological information.

Assumptions of the radar equation

If nature were to always cooperate and conform to our precise mathematical equations, we could easily calculate reflectivity values (Z) based on the average power being returned to the antenna. Unfortunately, in the real world, too many variables exist that tend to render our nice equations ineffective. The basic radar equation makes many assumptions that are rarely the case in the natural atmosphere. These assumptions include:

1. The particles are small, homogeneous spheres whose diameters are much smaller than the radar's wavelength (Rayleigh scattering).
2. The particles are spread uniformly throughout the contributing region (sample volume).
3. Precipitation throughout the sample volume is the same (all rain or all snow—radar equation does not handle mixed precipitation).
4. The main lobe of the antenna beam pattern is adequately described by mathematical notation.
5. Attenuation and multiple scattering are negligible.

If all assumptions could be met, and if no measurement errors existed, the radar measured Z would conform exactly to the meteorologically defined Z that comes from the radar equation. However, since this is not true, we must settle for something a little less perfect known as the equivalent radar reflectivity factor (Z_e). As a result of these assumptions it could be said the accuracy of radar's measurements are decreased.

Equivalent radar reflectivity factor

Let's look at a simplified version of the radar equation to see how Z_e is derived. The basic form is:

$$Pr = \frac{R_c Z_e}{r^2}$$

where:

Z_e = equivalent radar reflectivity factor.

P_r = average returned power in watts.

R_c = a combination of all known constants in the original long form of the radar equation.r = range to target.

The preceding equation can also be written as follows, since we want to solve for Z_e:

$$Z_e = \frac{P_r r^2}{R_c}$$

Our equation now yields what we are looking for—Z_e. As stated earlier, the radar carefully measured the amount of energy backscattered to the antenna that gives us our P_r. It also calculates the time between the transmission and reception of each pulse to determine range to target (r). Each radar, for a given operational mode, has a set of constants such as wavelength, pulse length, antenna design, and other engineering factors. All these elements compose the radar constant (R_c) term of our equation. This provides enough information for the WSR–88D processors to compute a value of Z_e for each sample volume.

Now that we have a reflectivity measurement for each sample volume in our radar coverage area, what do we do with it? At this point, the value is still in a form like that in our example above. It is merely a measurement of power, probably expressed in watts. We must now take this measurement and convert it into something more familiar for use in our daily customer support.

Units of measure

Since values of Z_e typically span many orders of magnitude, equivalent reflectivity is usually expressed in decibels (dBZ_e, or just dBZ for short). In the world of weather radar, we refer to echo intensity in terms of dBZs. We say things like: "Wow, that storm is 65dBZs," or "How many dBZs is that storm?" A logical question now arises. What is a dBZ?

The decibel system is used to compare two power values using the logarithm of their ratio. It is a matter of mathematical convenience to use the decibel system for comparison purposes. The decibel system is useful for comparing power values that differ greatly, such as the difference between the transmitted and returned power of weather radar. The returned power is used to estimate the equivalent reflectivity factor Z_e. Since values of Z_e also vary greatly, it is more useful to express these values in decibels.

A very important fact about dBZ comparison is that every change of 3dBZ corresponds to doubling or halving the equivalent power return. Therefore, consider the implications of the following example.

You were viewing an area of stratiform precipitation with returns of around 25dBZ and later those returns strengthened to 28dBZ. Although the return has doubled its intensity, 28dBZ is probably still just light rain. Now consider a thunderstorm with a return of 55dBZ that increased to 58dBZ. Again, the strength has doubled; still, think of the quantity we have doubled! Compare this to a case where you were asked to touch a wire containing one volt of electricity. If we double the voltage, the thought of two volts probably doesn't scare you much. But, what if the wire has 110 volts and we double it to 220? Now you're probably getting a little worried. Keep the significance of these increases or decreases of 3dBZ in mind while you are using any weather radar. Remember, by using dBZs to compare returning energy, we are increasing and decreasing logarithmically, not simply linearly. Therefore, always consider the significance of each small change.

Display characteristics

The base reflectivity product displays backscattered electromagnetic energy from targets illuminated by the radar beam. The three resolutions and corresponding ranges of base reflectivity products are:

Resolution	Coverage
0.54 nm by 1°	124 nm radius
1.1 nm by 1°	248 nm radius
2.2 nm by 1°	248 nm radius

Generation

The best resolution for base reflectivity products is 0.54 nautical miles (nm). This is representative of a 0.54 nm by 1° volume of the atmosphere. In order to generate this data, the power from **four successive** 0.13 nm bins is **averaged** (fig. 1–19). This averaged power is then converted to decibels (dBZs) at the radar data acquisition (RDA). The averaging of the bins makes.54nm product the most accurate.

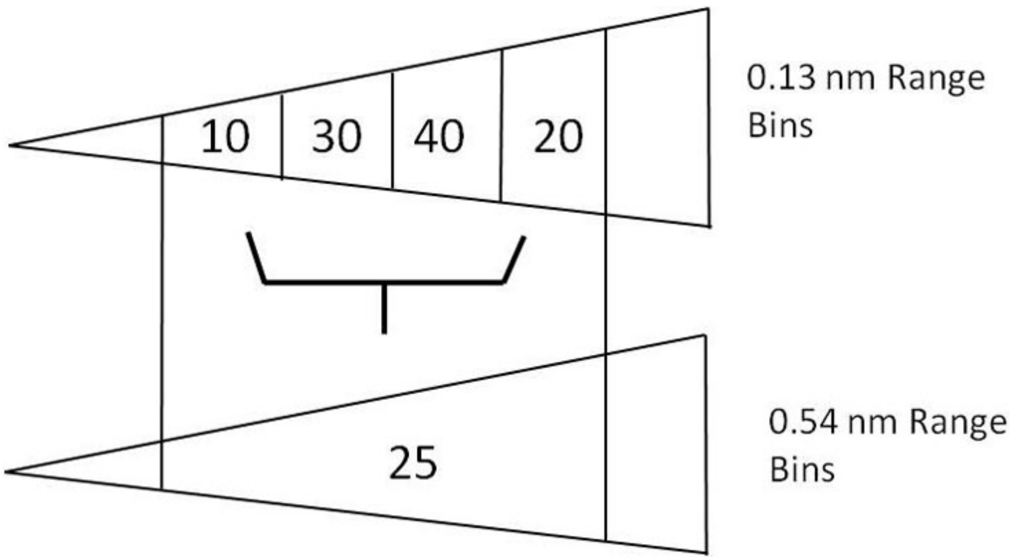

Figure 1–19. Base Reflectivity Generation.

The 1.1-nm resolution product displays the maximum of two consecutive 0.54-nm data values. In other words, because it does not average the bins, the resolution and accuracy is less than the.54nm product. The 2.2-nm resolution product displays the maximum of four consecutive 0.54-nm data values and like the 1.1nm product, does no averaging (fig. 1–20). That makes this data the least accurate as far as displaying base reflectivity data is concerned.

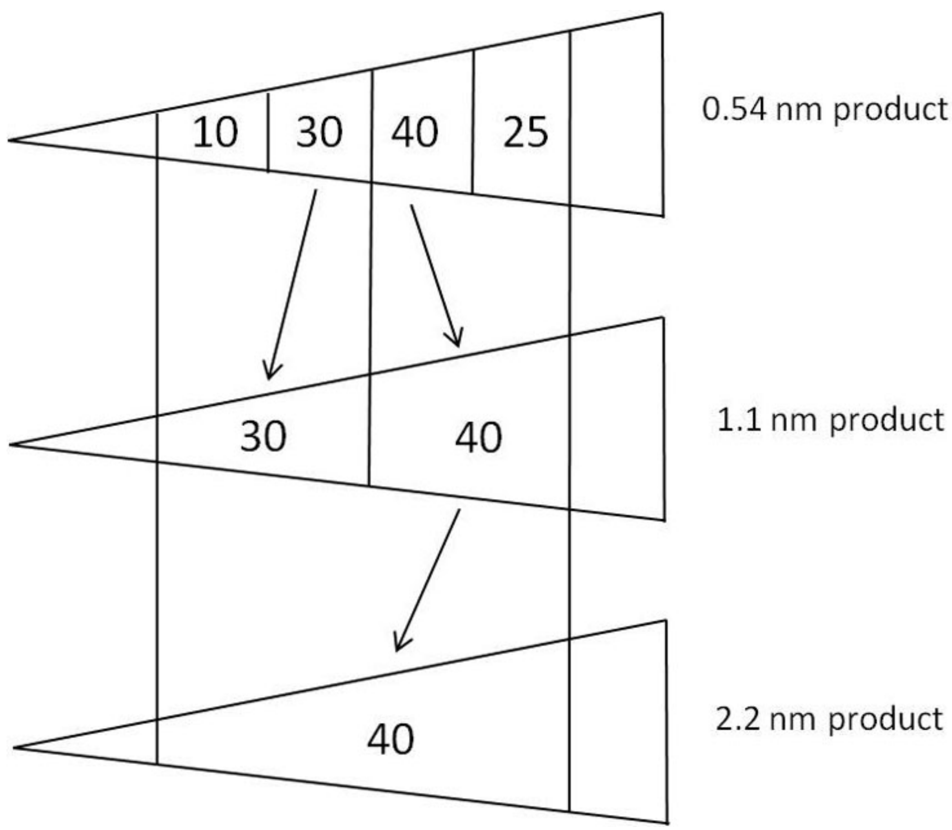

Figure 1–20. Base Reflectivity Generation (1.1 and 2.2 nm Product)

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

201. Electromagnetic energy characteristics

1. What is electromagnetism?

2. If electromagnetic waves were visible and moving, describe what pattern they would have?

3. What is the effect of wavelength on attenuation?

4. How are frequency and wavelength related?

5. What does the attenuation of radar waves depend on?

6. Explain why absorbed energy that is later re-radiated back to the antenna is not recognized.

202. Pulsed electromagnetic energy characteristics

1. Name two ways to measure pulse length.

2. What does the amount of energy transmitted by the radar depend on?

3. Define pulse repetition frequency (PRF).

4. What is the effect of pulse length and PRF on radar range?

5. Match the radar term in Column B with its description in Column A. Items in column B may only be used once.

Column A	*Column B*
____ (1) Measured from the leading edge to the back edge of the pulse.	a. Pulse length.
____ (2) The rate at which pulses are transmitted.	b. Range folding.
____ (3) The period of waiting for a returned pulse.	c. Listening time.
____ (4) Is limited by how often pulses are broadcast.	d. Maximum unambiguous range.
____ (5) Occurs when energy is received from an old pulse after transmission of the next pulse.	e. Pulse repetition frequency (PRF).

6. What happens if an antenna moves at too great an angle between pulses?

7. Explain range folding.

203. Effect of radar beam characteristics on radar performance

1. Where can the maximum power density of the radar beam be found?

2. What occurs when a target occupies only a small portion of the beam, thus hiding or altering the true characteristics of the target during display?

3. Explain the term “below beam effects.”

4. What is beam blockage the result of?

5. How far should two targets be separated, in order to be displayed as separate targets?

6. What is the ability of the radar to distinguish between two targets at the same direction but at different ranges called?

7. How does the cone of silence affect the viewing of meteorological targets that move into it?

204. Atmospheric refraction effects

1. Normally, what does the radar beam do with respect to height as it moves away from the antenna?

2. List the two types of anomalous propagation (AP) and briefly describe the atmospheric conditions that cause each to occur.

3. When the radar beam is being refracted below its normal path, what is this process called?

4. What is the straightening of the radar beam upward called?

5. What effect does superrefraction have on the displayed echo heights on the radar?

6. What effect does subrefraction have on the displayed echo height on the radar?

205. Backscattered energy (reflectivity) and decibels

1. List five assumptions that the basic radar equation makes?

2. The reflectivity measurement received for each sample volume is simply a measurement of what?

3. The strength of a thunderstorm return increases from 49dBZ to 52dBZ. By how much has the strength increased?

4. How does the use of the decibel system, to compare returned radar energy, allow increases or decreases to be expressed?

5. What is the best resolution for base reflectivity product and how are the sample bins averaged?

6. Describe how the 1.1nm base reflectivity product is displayed.

7. Describe how the 2.2nm base reflectivity data is displayed.

1–2. Doppler Radar Principles

In 1842, Austrian physicist Johann Christian Doppler first related the observed frequency changes in sound and light to motion of the source or observer. Doppler developed mathematical formulas to describe this phenomenon now called the *Doppler effect*. The first radar to employ Doppler's discovery was developed during World War II. This radar could detect the location and velocity of enemy targets.

The meteorological application of Doppler radar came about in the late 1950s. Using a modified, military surplus radar, the Weather Bureau detected 200 miles per hour (mph) winds apparently associated with a tornado near El Dorado, Kansas on June 10, 1958. During this period, Doppler radars were used in Europe to gather data on velocities and droplet size distribution in precipitation.

Research and development on meteorological Doppler radars continued. By the early 1970s integrated circuitry and advanced computer processing appeared in a new class of high-powered Doppler weather radars. Later in the decade, real-time processors were linked to color displays. Unlike previous systems, this allowed instantaneous output of Doppler derived data.

The next step was to develop a plan to network Doppler weather radars. This led to the Joint Doppler Operations Project (JDOP) conducted from 1977 to 1979 by the United States Air Force (USAF), the Federal Aviation Administration (FAA), and the National Weather Service (NWS). JDOP showed the meteorological utility for operational Doppler radar and determined the engineering requirements for such a system. This system became the Weather Surveillance Radar 1988–Doppler (WSR–88D). The program to develop the WSR–88D formally began with the creation of the Joint System Program Office (JSPO) at NWS headquarters in 1979.

The WSR–88D has capabilities and functions that previous operational weather radars lack. For instance, the sensitivity of this radar far exceeds the capabilities of the FPQ–21, FPS–77, or FPS–106 radars. Because of this, we now see reflectivity patterns that were never possible before with other systems. In addition this radar adds velocity and spectrum width data that was not available on the previous radars.

206. Doppler radar detection

So far, we’ve discussed the same principles that have always determined our weather radar’s capabilities. Now, we have added such things as velocity detection to our radar’s requirements. What have we added to the WSR–88D that allows us to satisfy this new requirement? This lesson introduces some basic principles the WSR–88D uses during its detection of velocity.

You have probably experienced the Doppler shift at one time or another in your life. For example, the change in pitch of the sound of a train’s whistle as it passes in the distance is the result of the Doppler shift, sometimes called the Doppler effect. It is an observed change, or shift, in the frequency of sound or light waves due to the relative motion of the source and/or observer.

Doppler radars like the WSR–88D make use of this phenomenon. The apparent shift in the electromagnetic waves is used to determine velocities. Let’s take a simplified look at an electromagnetic (EM) wave and see what type of problems and information we can obtain from its interaction with the atmosphere.

Electromagnetic waves and the Doppler shift

Remember, from an earlier section that each electromagnetic wave is transmitted as an arrangement of a crest and trough as shown in figure 1–21. If the returning waves have been displaced, they are said to have undergone a phase shift (fig. 1–22).

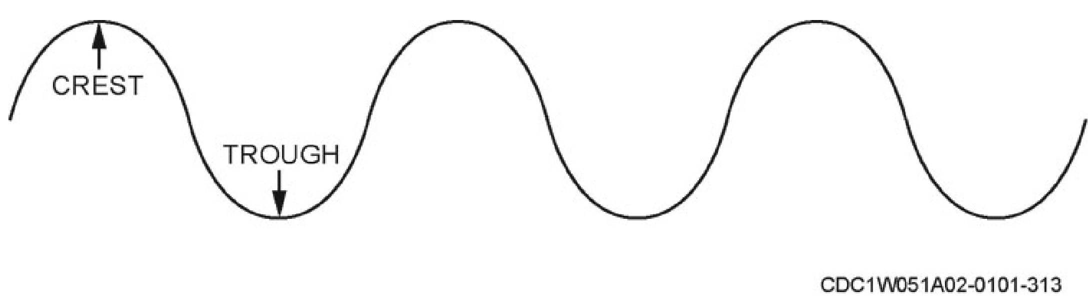

Figure 1–21. Crests and troughs.

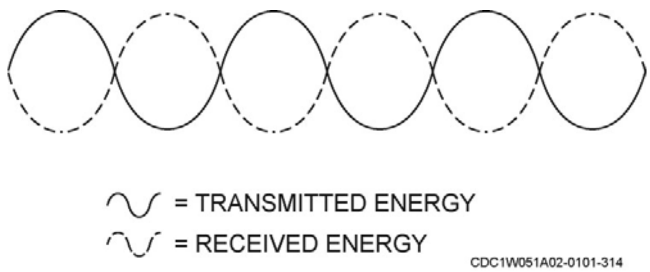

Figure 1–22. Displaced wave.

As long as the phase shift is less than 180° (one-half wavelength), the amount of change can be related to a correct velocity. However, at 180° of phase shift and beyond, the velocities become ambiguous or aliased—interpretable as two or more very different values. Let's look at some examples of transmitted and received wave forms that have undergone a phase shift. The examples in figure 1–23 should help illustrate this point. The solid lines represent transmitted energy and the dashed lines represent energy received by the radar. The shift in the received energy determines the phase shift.

If the transmitted energy strikes a stationary target, the electromagnetic energy experiences no phase shift, and its waveform looks identical to the original wave. If the energy strikes a moving target, then the backscattered waves exhibit some amount of phase shift. Figure 1–23,a depicts a 90° phase shift resulting from energy striking a target that is moving away from the radar. Since this phase shift is less than 180°, or one-half wavelength, we can unambiguously measure this shift.

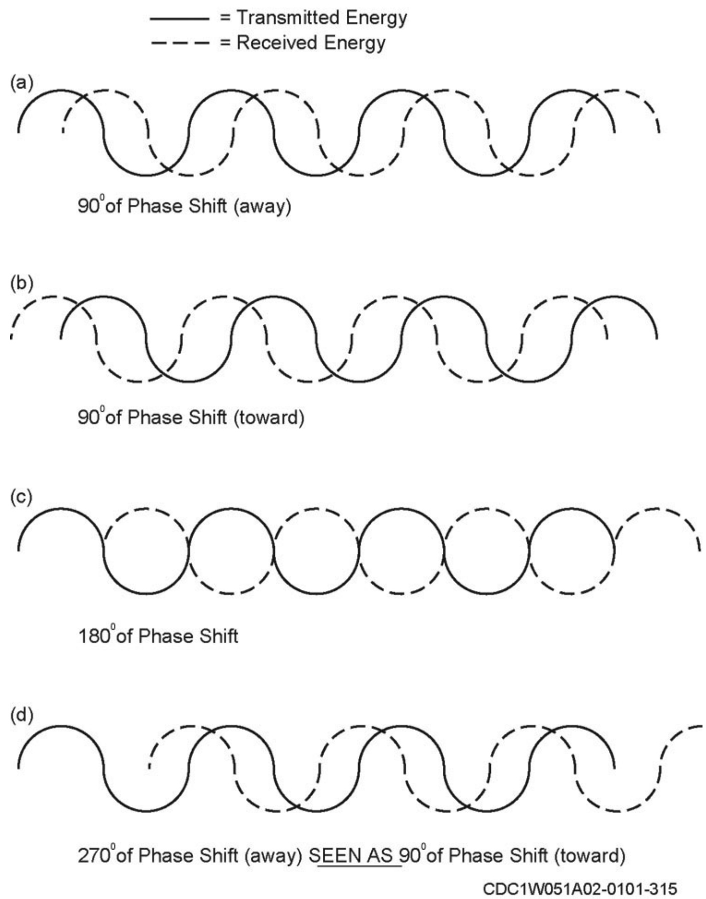

Figure 1–23. Several phase shifts.

Example 1–23,b is the same as before except this time the energy strikes a target moving toward the radar. Once again, we can unambiguously measure this shift.

Example 1–23,c now depicts a phase shift of 180°. Here is where the problems begin. Remember, to unambiguously measure the phase shift, the shift must be less than one-half the wavelength. In this case we cannot distinguish whether the 180° shift represents motions toward or away from the radar. This measurement is ambiguous.

One final example, 1–23,d, depicts a phase shift of 270° resulting from energy striking a target that is moving away from the radar. Since a shift of 270° is more than one-half wavelength (180°)—it is ambiguous. This 270° shift is seen as a 90° phase shift of motions toward the radar. This could result in an aliased velocity being displayed.

Wavelength and frequency

By now you should realize that velocity detection is limited by the wavelength of the radar. As soon as we pass the 1/2 wavelength limit or 180°, the determination of velocity becomes ambiguous—the radar may not display the true velocity.

Of course, anytime we speak of wavelength, the same arguments hold for frequency since they are inversely related by the speed of light. In addition to referring to the limits for unambiguous velocity detection as 1/2 wavelength, we can also say the maximum phase shift the radar can discern is two times the radar frequency.

Radar coherency

You may have wondered why older, conventional radars such as the FPS–77 or FPS–106 could not make wind velocity measurements. To make these measurements, a radar must be able to produce each pulse at the same frequency as the preceding ones. Just as important, the radar must be able to *remember* a specific frequency. Coherent radars such as the WSR–88D can compare the frequency of successive received signals to determine the frequency shift, and therefore, the radial velocity.

Pulse pair processing

The WSR–88D’s computer processors take advantage of coherency by comparing the frequency of each new pulse with that of the pulse immediately preceding it. Anytime we measure the speed of something, whether it’s a car, runner, or precipitation particle, we must compare at least two positions. In other words, we must sample it at least twice. The more often we take a measurement or sample, the more accurate our reading. Doppler radar must do the same thing. In order for it to make a measurement of speed, the radar must calculate the difference between at least two successive samples. This is known as pulse pair processing because the radar compares the frequencies of each pulse pair.

207. Radial velocity detection

We now know that the WSR–88D’s sensitivity enables it to detect extremely weak reflectivities. This sensitivity allows the radar to determine the wind speed from the size of the phase shift—a result of the Doppler effect. A combination of the radar’s sensitivity and the presence of pollution particles, insects, dust, and differences in atmospheric density, allows it to detect wind speeds even in optically clear air.

Can the WSR–88D display the rotation within convective cells or measure the crosswind near the runway? Yes, but unfortunately, the WSR–88D does not always detect every motion in the atmosphere, nor does it always display them with little or no confusion. Therefore, the operator is required to know the radar’s limitations to accurately interpret velocity displays.

This lesson describes some limitations inherent in velocity determination. Through a clear understanding of what the radar *sees* and why the displays appear as they do, you can construct a three-dimensional (3-D) model of the current atmosphere.

Frequency shift and a single dipole

Remember from our discussion on the Doppler shift that all the WSR–88D can detect is the phase shift caused by a target's motion toward or away from the radar. Refer to figure 1–24, which shows changes in electromagnetic waves reflected from a dipole. In figure 1–24, a, notice the dipole is stationary. Scattered electromagnetic waves remain constant in all directions: forward, backward, and sideways. Here, the radar recognizes no motion.

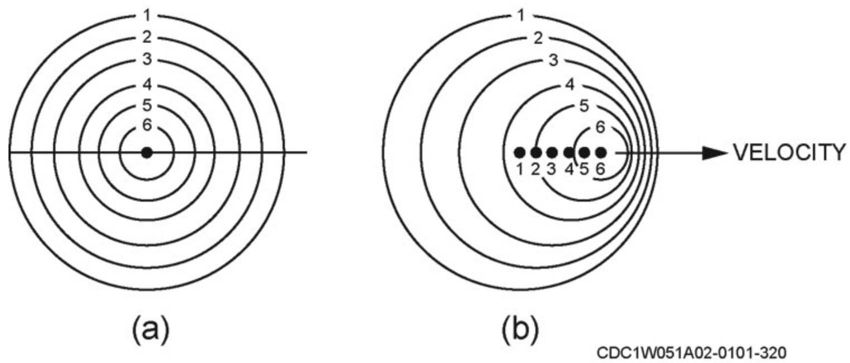

Figure 1–24. Radiating dipole.

Now look at figure 1–24,b. In this example our dipole is moving. Notice how the waves emitted from the dipole are compressed in the direction of motion, and spread out in the opposite direction. More importantly, notice the aspect of the waves perpendicular to the direction of movement does not change. This is why the radar only detects a frequency change, or for our purposes a velocity change, if the motion is toward or away from the radar. The component of motion directly toward or away from the radar is known as the radial component.

If the motion is across or perpendicular to the viewing angle of the radar, you can see from the diagram that no frequency shift is detected. More importantly for the radar operator—zero velocity is detected.

Unfortunately, in the real world, motion is not always directly parallel or perpendicular to the radar's viewing angle. What happens when the radar encounters motions that are not? You will notice in figure 1–24, b, that as you move from directly toward to directly perpendicular to the viewing angle, a smaller and smaller portion of the shift is detected.

If what you've just read about the radiating dipole is a bit confusing, let's take another look, but this time we'll look at the dipole with respect to the radar antenna.

The radar is quite limited in its ability to detect motion—only the component of the motion toward or away from the radar is measured. Let's see how this affects radar measurements.

A dipole radiates energy in all directions. A stationary dipole radiates energy equally in all directions. A dipole in motion causes the waves to either compress or stretch depending on the relative movement of the dipole. This compression or stretching results in an apparent frequency shift that the radar translates into speed.

Motion directly along the radial

If the dipole is moving directly toward the radar, the maximum amount of compression is sampled. Thus, the maximum frequency shift is occurring along the radar beam (fig. 1–25).

This maximum frequency shift is correctly translated into the *TRUE* speed of the dipole.

We can also see that the true speed is detected when the dipole is moving away from the radar, directly along the radar beam. Here, the waves are stretched and the frequency appears lower. Again, the beam is sampling an area where the maximum frequency shift is occurring and the radar calculates a speed equal to the true speed of the dipole.

However, we must not forget that this true speed is detected *ONLY* in the instances where the target's motion (the dipole) is directly toward or away from the radar's antenna.

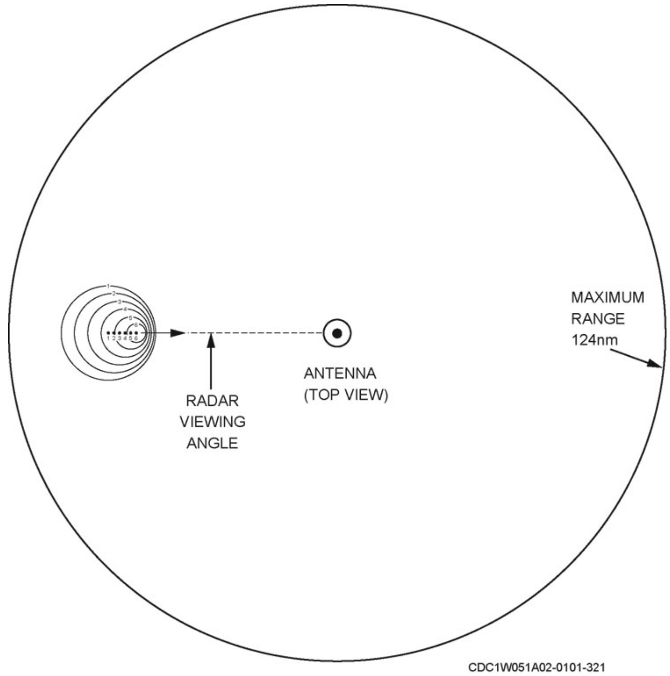

Figure 1–25. Movement toward the antenna.

Motion across the radial

Now let's change the position of our dipole in relation to the antenna. This time the radiating dipole is not moving directly toward the radar but instead is moving at an angle (fig. 1–26). As always, the maximum compression of the waves still occurs along the target's direction of movement. Since the radar views this dipole from an angle, it detects waves that have been compressed less than the maximum amount we see along the target's direction of movement.

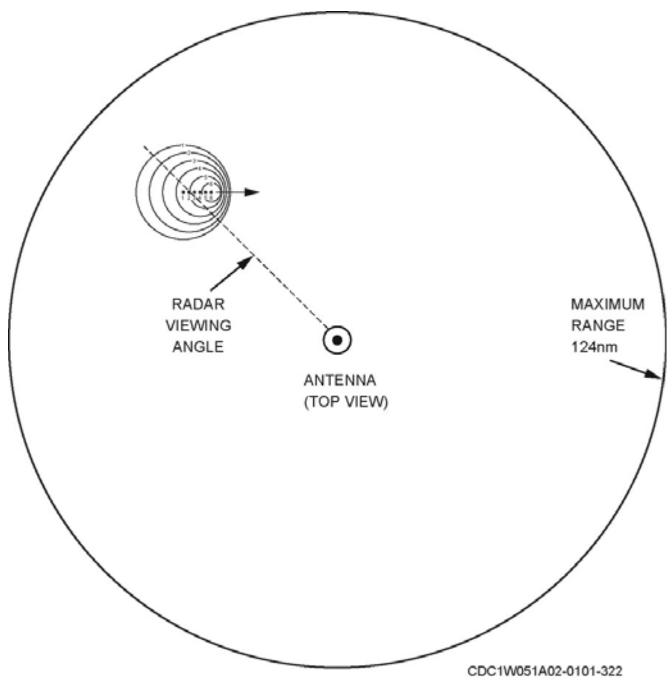

Figure 1–26. Angular movement of dipole.

The radar doesn't have any information about the dipole. It doesn't know where it came from, where it is going, or how it gets to where it is going. The only information the radar can obtain is the size of the frequency shift where the sample is being taken—along the radar beam.

Since this frequency is less than the maximum shift we saw earlier, the radar translates this frequency into a correspondingly lower speed. The true speed of our target has not changed, only the speed *DETECTED* by the radar has changed.

Motion perpendicular to the radial

The extreme case is if the dipole is moving perpendicular to the radar beam. Again, we'll use the same dipole, but move its position in relation to our antenna (fig. 1–27).

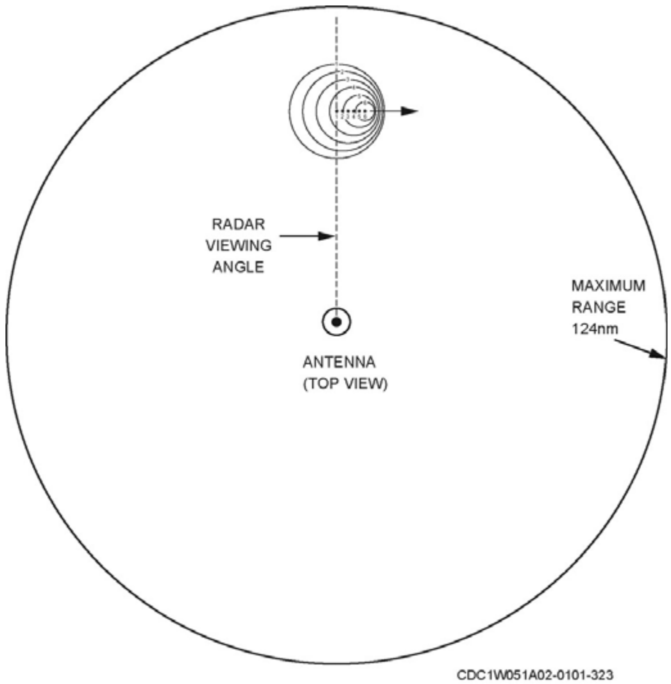

Figure 1–27. Perpendicular movement of dipole.

Now our radar is sampling energy from a target that has *NO* motion away or toward the antenna. Notice that the radiation from the dipole is not shifted in the area where the radar is sampling. In this area the apparent frequency of the moving dipole is no different from that of a stationary dipole (fig. 1–27).

Again, the radar doesn't have any information about the real motion of the dipole. It only *knows* what it can sample about the size of the frequency shift. Here, due to the viewing angle, no frequency shift is detected.

Since the radar has not detected a frequency shift, it has not detected any motion. From the radar's point of view, the frequency shift is the same as the speed of the target. This is why the radar shows a stationary target if that target is moving perpendicular to the antenna.

Frequency shift and target motion

The three examples just described show three different possibilities.

1. If the target (or wind) is directly toward or away from the radar, the true wind speed is detected.
2. If the target (or wind) is moving across the beam at an angle, the detected wind speed is less than the true wind speed.
3. If the target (or wind) is directly across the radar beam, the detected wind speed is zero, whatever the true wind speed.

Understanding radial velocity is the most important idea that you'll learn about Doppler velocity interpretation. Since the WSR–88D has only one antenna, it only measures the component of the wind that is parallel to the beam. The direction in which the beam is pointed is known as the radial, thus the term *radial velocity*.

For simplicity, our discussion of motion and the Doppler frequency shift has so far involved only a single target. However, Doppler weather radars depict the overall motion of the many raindrops, snowflakes, or other scatterers within the radar's range. The radar gives us displays that instantaneously depict the entire radar coverage area. Next, we look at how the radar views the wind field using the many atmospheric scatterers present.

Interpretation of radial velocity

Figure 1–28 represents a uniform, horizontal wind blowing from the west (270°) at 25 knots. When the antenna is pointing due west (point A), the wind is parallel to the beam and the radar can measure the entire 25 knots. Since the wind is blowing toward the radar, this is expressed as –25 knots. By convention, motions toward the radar are expressed as negative values while motions away are expressed as positives.

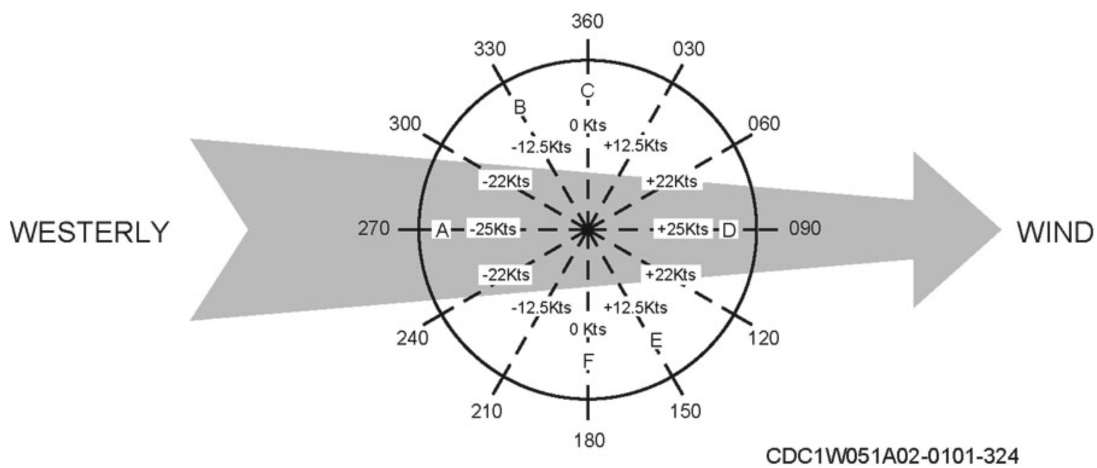

Figure 1–28. Radial velocity.

Now, notice the velocity at point B is shown as –12.5 knots. We said earlier that our wind was uniform from the west at 25 knots. Why are we only measuring 12.5 knots? This is the critical point to understanding radial velocity. Let's look closely at this example.

First, remember that we express motions toward the radar as negative, therefore our value is negative. But, why is it only 12.5 knots? You must always remember that the WSR–88D can only measure the component of the wind parallel to the beam. Look back at figure 1–26 in our previous discussion of a single dipole. When the radar beam encounters a component of the wind less than the full component, only part of the true wind is measured—here 12.5 knots toward the antenna.

Next, refer to point C on figure 1–28. Notice the velocity is now measured as zero knots. Did our 25-knot wind suddenly go calm? No. Now, since the antenna is pointing toward 360°, the radar beam is directly perpendicular to our westerly wind. Therefore, the parallel component is zero and as a result, the WSR–88D detects zero velocity. In addition, notice when the antenna points toward 180° (point F) the beam is again perpendicular to the westerly wind flow and zero velocity is again detected. Later, we'll learn how important this zero velocity is for determining the wind direction.

Now refer to point D. Notice the radar measures the full 25 knots here just as it did at point A. This is because the full component of the wind is again parallel to the radar beam as it points to the east. This is expressed as +25 knots since motions are away from the antenna. Remember, motions toward are expressed as negative while motions away are expressed as positive.

One final example is point E. Here, the antenna points toward 150°. This example, like point B, is similar to figure 1–24 of our previous single dipole discussion. Since we are only measuring part of the frequency shift, then only part of the wind is detected—here 12.5 knots away from the antenna. The value is expressed as positive because it represents motions away from the radar.

Looking back at figures 1–25 through 1–27, it is easy to see how the radar only detects part of the total frequency change. You may still wonder how we arrived at the particular wind speeds. Actually it's fairly easy with the help of trigonometry; the following equation was used to derive these radial velocities and is further shown in figure 1–29.

$$V_r = V_a \cos\theta$$

where: V_r = radial velocity.

V_a = actual wind velocity.

θ = angle between full wind component and the antenna radial.

From our discussion of radial velocity, you should now understand that the WSR–88D, or any other single antenna Doppler radar, can only measure the component of the wind parallel to the radar beam. Later, you'll learn about velocity products that take this into account and provide you with a wealth of information.

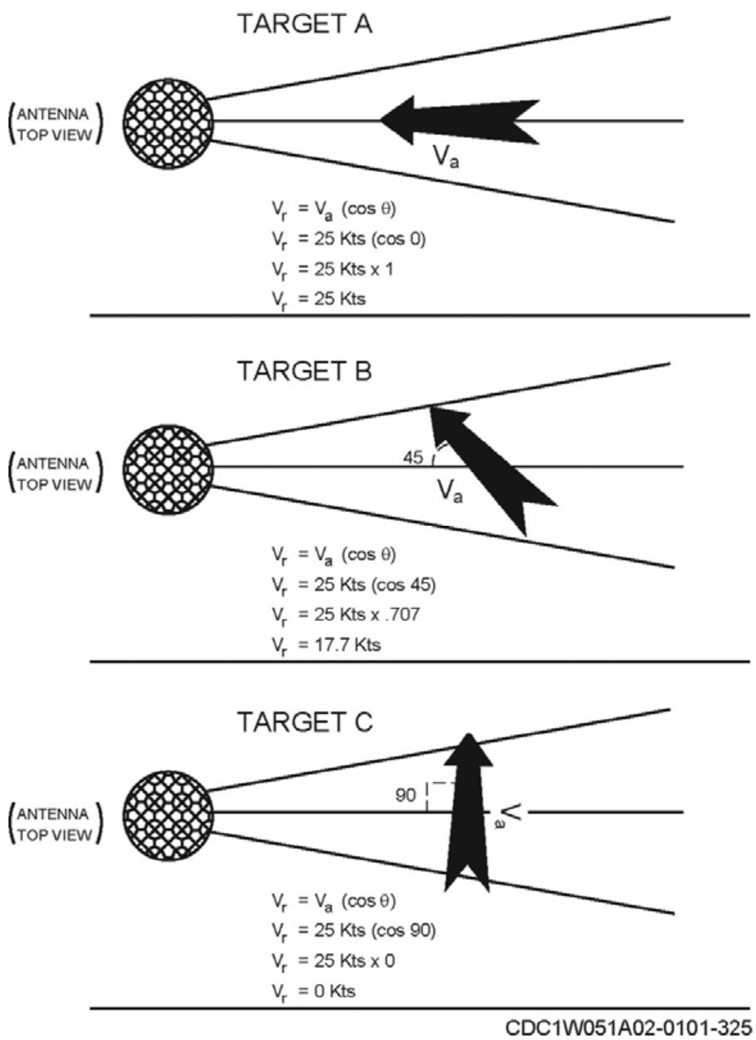

Figure 1–29. Radial component.

208. Velocity aliasing and dealiasing

During the discussion of conventional radar principles in the previous section, the term *range folding* was used. Range folded or second-trip echoes result from the radar hearing a previous pulse while listening for the most recent pulse. This problem can be alleviated by reducing the PRF and allowing for a longer listening time. However, in Doppler radars, this low PRF creates a problem called velocity aliasing when determining radial velocities.

The WSR–88D is equipped with sophisticated computers that attempt to solve this velocity aliasing problem. However, computers are not perfect and velocity aliasing may still occur. Therefore, the operator must be able to identify when aliasing might occur, and recognize aliasing when it does occur to correctly interpret the displays.

Velocity aliasing

During earlier discussions of the Doppler shift and mean radial velocity, we overlooked one small item: we might not always obtain the correct velocity.

Doppler radars use the Doppler shift (change in the phase of the returned signal) to detect velocities. The radar can use this information to make very precise measurements of speed. However, limitations in velocity measurements do exist. Let's look at a simple example of velocity measurement and see what can go wrong.

Choo-choo train

Imagine riding along in the engine of a freight train. Have you ever noticed the engines may be hooked together facing opposite directions? This does not present a problem because train engines have the unique ability to go just as fast in forward as they can in reverse.

Imagine that the locomotive has a speedometer that looks like figure 1–30. This speedometer was designed to show both forward and reverse speeds. The forward speeds are located to the right while the reverse speeds are on the left side of the speedometer.

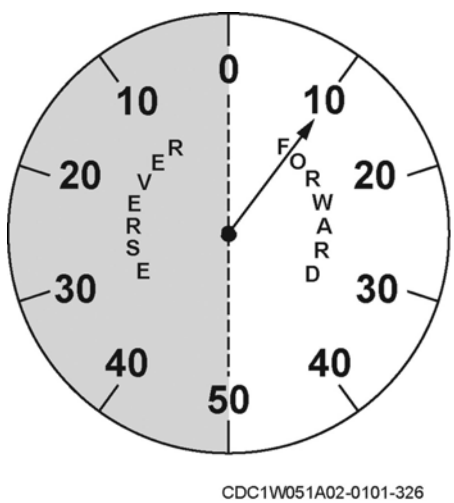

Figure 1–30. Speedometer I.

Notice that reading speeds of 0 to 49 mph in either forward or reverse is easy and leads to little or no confusion. However, when speeds reach or exceed 50 mph, the speedometer reading becomes difficult. Because it's impossible to tell, by the speedometer alone, whether or not the train is going forward or backward. Well, the radar also has a similar limit. Depending on the operational settings, there is a maximum velocity the WSR–88D can detect without confusion. When velocities exceed this velocity they are termed unambiguous velocities or aliased.

We'll look more at radar's unambiguous velocities later, for now let's make sure you understand the concept of the train's speedometer.

Let's put our train in motion until it is traveling at 40 mph in the forward direction (fig. 1–31,a). Notice the speedometer correctly displays the true speed of 40 mph. Now, let's add 20 mph to the forward speed so the train is traveling 60 mph (fig. 1–31,b).

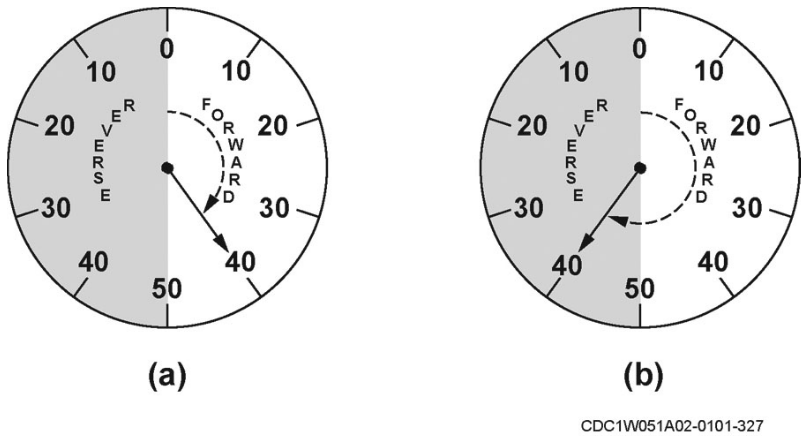

Figure 1–31. Speedometer II.

Notice the speedometer now reads 40 mph in reverse. What happened? No, the train didn't stop and reverse its direction. What really happened is we exceeded the maximum forward limit on the speedometer. Therefore, speeds of 49 mph or less in this example are unambiguous. In radar terms, speeds that exceed the maximum unambiguous velocity are said to be aliased and are called aliased velocities. They are called aliased because their true velocity is masked.

Since our radar obviously doesn't use a speedometer to measure velocities, it must employ another method. Instead of using a speedometer, the radar tracks the phase change of backscattered electromagnetic waves. This concept of phase change was discussed in the previous lesson. Using the formula for velocity it is apparent that the amount of phase shift is proportional to the strength of the winds. However, this determination cannot be precisely determined for the range of all possible phase shifts. There is a limit and it's dependent upon the wavelength of the radar.

Wavelength and frequency

Velocity detection is limited by the wavelength of the radar. When we pass the one-half wavelength limit, the determination of velocity becomes ambiguous—the radar may not display the true velocity.

Of course, anytime we speak of wavelength, the same arguments hold for frequency since they are inversely related by the speed of light. Besides referring to the limits for unambiguous velocity detection as one-half wavelength, we can also say the maximum frequency shift that the radar can discern is twice the radar frequency.

Velocity dealiasing

To compensate for radar's inability to detect frequency shifts of greater than one-half the wavelength, the radar's computers employ a velocity dealiasing technique. When data is aliased, the true velocity is either hidden or unknown. Dealiasing then, implies that the radar algorithms will determine the true velocity. Velocity dealiasing is accomplished by testing for velocity continuity along a given radial. It uses the assumption that true wind velocities are more or less continuous. In other words, adjacent velocities should not change drastically over a small linear distance.Figure 1–32 shows the need for velocity dealiasing. Phasor information is provided with each velocity sample for clarification.

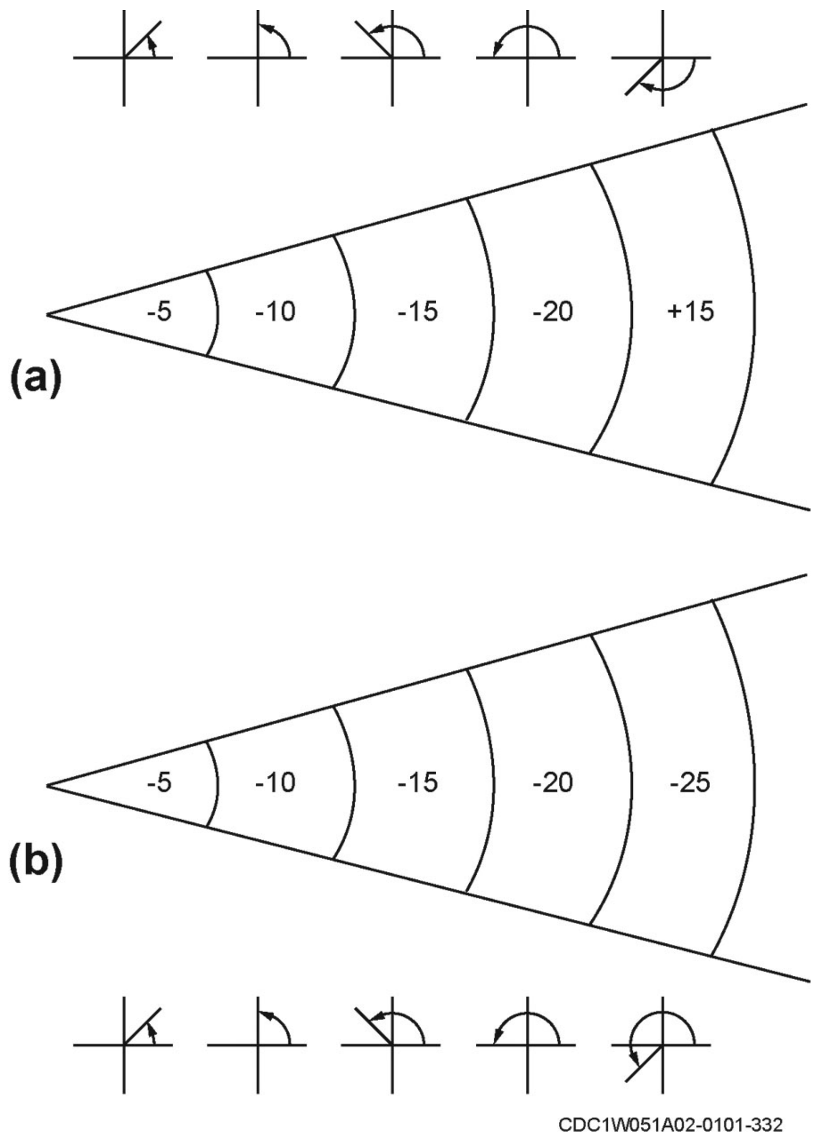

Figure 1–32. Dealiasing along a radial.

Figure 1–32, a depicts detected velocities along a single radial. Notice the velocities increase uniformly until we reach the fifth sample where a velocity of 15 knots away from the radar is detected. Compare this to the fourth sample where we see a velocity of 20 knots toward the radar. Normally, we would not expect this to happen. Obviously the radar has incorrectly interpreted the wind. Without the use of dealiasing, these aliased values would be incorporated into the velocity product leading to a confusing display.

Figure 1–32,b depicts the same radial except this time velocity dealiasing was employed. Here, the radar's computer can correctly measure the velocity although it exceeds the one-half wavelength limit. This is because the radar's computers are using a velocity dealiasing technique that compares the current aliased velocity with the preceding values and adjusts accordingly.

This is a very simplified explanation of the dealiasing technique used by the WSR–88D. In the next unit, when we break down the system components, we'll take a closer look at dealiasing. For now it is important you realize that when velocity differences greater than a specified value occur from sample to sample, velocity aliasing is assumed to have occurred and the WSR–88D attempts to solve this problem through dealiasing.

Aliasing and PRF

We have now seen that aliasing, the misrepresentation of velocities, depends on both the wavelength and the PRF. The longer the wavelength, the greater the allowable shift before aliasing occurs. Sampling frequency, or PRF, determines how well we can resolve the actual frequency shift.

The wavelength remains fixed in the WSR–88D radar, so another method of reducing aliasing is to increase the PRF. Increasing the PRF increases the Nyquist co-interval, which decreases the chances of aliasing. Figure 1–33 portrays some maximum velocities that different PRFs allow for a given wavelength (or frequency).

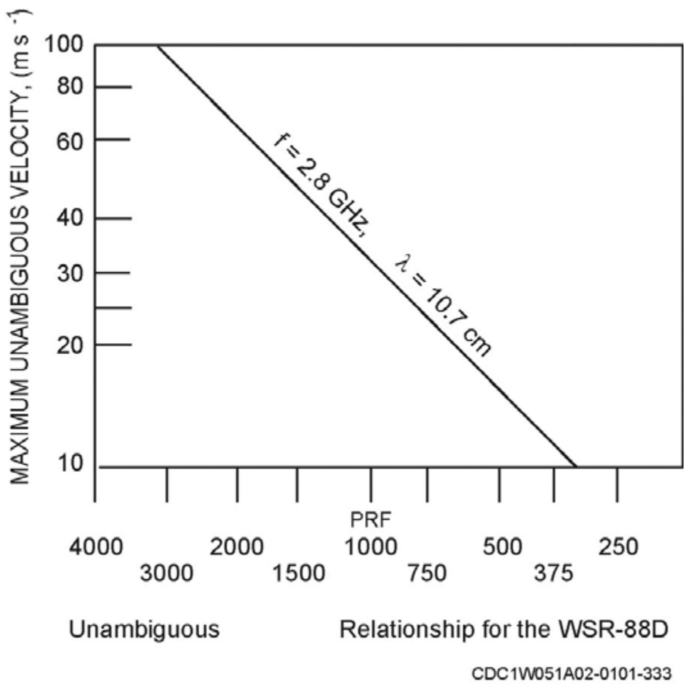

Figure 1–33. Maximum velocities and PRF.

The apparent solution to velocity detection is to increase the PRF to a level that provides us with the desired velocity measurements. Unfortunately, many desired features of radars cannot be easily incorporated. Most features that are desirable for one reason tend to negatively affect other areas. In other words, radar design is a continual compromise. One of the most prevalent compromises in radar meteorology is—*the Doppler dilemma*.

209. The Doppler dilemma

Have you ever noticed that life seems to be a series of give and take situations? Guess what—Doppler radar is no different. The radar operator wants to see as far away as possible yet still be able to correctly detect very high wind velocities. Unfortunately we can’t have our cake and eat it too. This interdependency of range and velocity on the PRF is often called *the Doppler dilemma*.

Effects of PRF changes

From the radar principles discussed so far, we know of two features that are very desirable for radar operations—comparatively long ranges and high velocity measurements. Now, let’s look at the two factors that cause the Doppler dilemma.

Maximum unambiguous range

In the lessons on conventional radar principles, range folding was described as occurring when a pulse transmitted from the radar exceeds the maximum unambiguous range, strikes a target, and returns to the radar after a subsequent pulse has been transmitted.

Thus, the radar incorrectly plots the target within the unambiguous range because it is now listening for the second pulse. This range folding problem can be solved if the PRF is decreased until the maximum unambiguous range is beyond all the scattering regions. This can be shown by an equation:

$$\text{Max range} = \frac{c}{2 * \text{PRF}}$$

where: c = speed of light

PRF = pulse repetition frequency

Maximum unambiguous velocity

Now compare this to the velocity aliasing problem we just discussed. The solution to the aliasing problem is to increase the PRF until all actual velocities are within the Nyquist co-interval.

$$\text{Max velocity} = \frac{\text{PRF} \times \text{wavelength}}{4}$$

As you may have probably guessed by now, maximum range and velocity are ideal. However, PRF changes have opposite effects on each. This leads us to the infamous Doppler dilemma.

Doppler dilemma

High PRFs are required for high velocity measurements and low PRFs are required for long ranges. Thus, the Doppler dilemma—finding a balance between the effects of velocity aliasing and the effects of range folding.

In order for the WSR–88D to detect radial velocities of 200 mph without aliasing, the PRF would have to be about 4,000 pps. However, this would reduce the maximum unambiguous range of the radar to about 20 nautical miles. To have an unambiguous range of 100 nautical miles, the PRF would have to be approximately 810 pps. This would cause the maximum unambiguous velocity to decrease to 45 mph. Figure 1–34 shows the various velocity/range values.

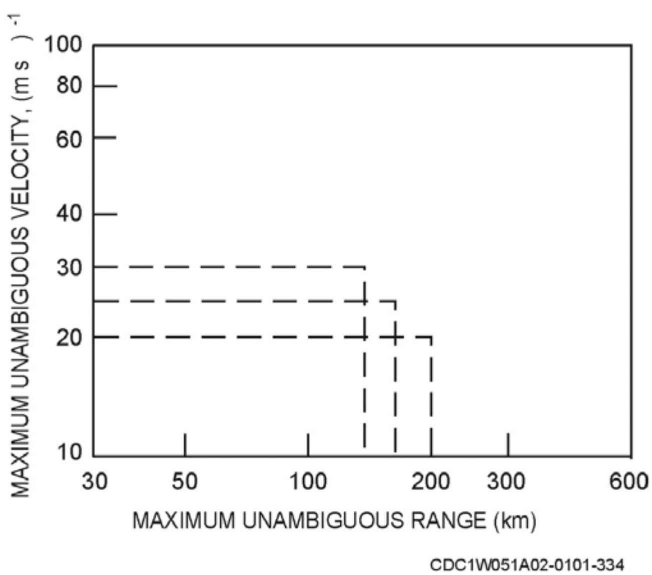

Figure 1–34. Unambiguous range—velocity relationship for the WSR–88D.

The Doppler dilemma can also be described by an equation:

$$(\text{Max velocity}) \times (\text{max range}) = \frac{(\text{wavelength} \times c)}{8}$$

From this equation you can see that maximum unambiguous velocity and maximum unambiguous range are inversely related. The right side of the equation is constant for our radar since its wavelength and the speed of light do not change. To maintain equality, if the maximum velocity increases, then maximum range decreases and vice versa.

The Doppler dilemma is caused by physical restrictions based on the laws of nature. To solve this dilemma, the WSR–88D uses several methods to work around these restrictions. For example, one method the WSR–88D uses is to operate at variable PRFs, collecting reflectivity information at low PRFs, and velocity information at high PRFs. The two sets of information collected are then compared and processed to estimate true radial velocities and ranges.

Remember, however, that the Doppler dilemma still exists, the radar is limited, and a compromise between maximum range and maximum velocity detection is usually a factor.

210. Sample volume and spectrum width

To help you further understand atmospheric sampling by the WSR–88D, we’ll now look at the data being received by the radar at any one instant. Recall from our discussion of conventional radar principles that a sample volume is the volume of the atmosphere equal to one-half the pulse length times one beam width. In this lesson, we’ll increase our understanding of a sample volume, examine the contents within this volume, and then see what the radar does with this information.

WSR–88D sample volume

We defined the pulse volume as the volume of the atmosphere occupied by the pulse of electromagnetic energy. But, what about the volume of atmosphere that is instantaneously sampled by the radar? This is called the sample volume or sometimes the echo volume. It is equal to one-half the pulse length and the beam diameter. The sample volume is very important to interpretation.

A sample volume contains many particles. For example, if the target is precipitation, the volume contains particles of varying size, shape, and water/ice composition. Figure 1–35 shows an example where each of these particles may be moving in different directions—some upward, some downward, some laterally, and so forth.

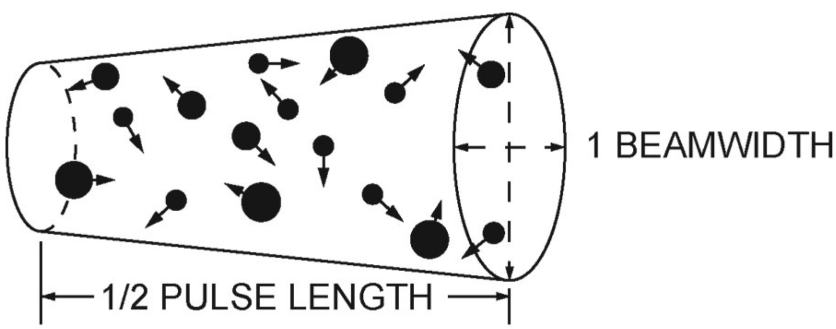

Figure 1–35. Sample volume.

Although a pulse volume is easy to imagine—an actual pulse of energy traveling through the atmosphere—the sample volume is a little different. The sample volume actually represents a volume of the atmosphere from which backscattered energy has originated. Energy sampled at any specific instant by the antenna originates from slightly different locations.

Doppler spectrum

Doppler spectrum is the distribution of power received by the radar at each frequency within the sample volume. The radar electronically analyzes the spectra to determine the frequency returning the maximum power. If plotted visually on a graph, the typical return would look like figure 1–36.

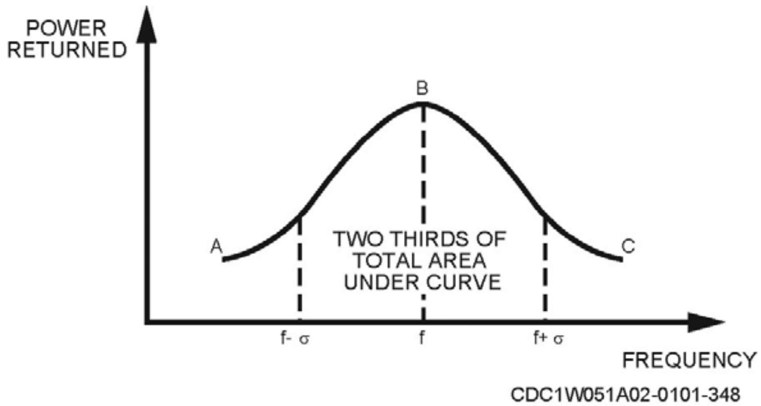

Figure 1–36. Power distribution.

Notice the distribution of power plotted against frequency results in a bell curve. This curve shows the amount of power returned to the radar at any frequency. (Remember, we can translate these frequencies into velocities.) The top of this curve is the maximum power returned to the radar (fig. 1–36, point B). Then you might assume the frequency representing the greatest power return represents the motion of the greatest number of particles within the sample volume. However, this is not necessarily true.

Since the radar receives proportionally much more reflected power from large drops than from small ones, the frequency with the maximum power returned is usually that of the largest particles within a sample volume.

Mean Doppler velocity

These larger particles tend to move with less effect from turbulent gusts and are a very good representation of the mean air flow. Therefore, the frequency of the maximum power returned is used to estimate the mean Doppler velocity. This velocity approximates the average airflow within the sample volume as indicated by the motion of the largest particles, thus the term *mean* Doppler velocity.

Spectrum width

The motion of smaller particles within the sample volume can be determined from portions of the spectrum right or left of the center of the curve (fig. 1–36, points A and C). In other words, information on the most variable short-term gustiness or turbulence within the sample volume is in the extremes of the spectrum.

Spectral shape and variance

Variance is used as a mathematical description of spectral shape. The WSR–88D uses the variance to describe the range of frequencies received by the radar. Radar derives this variance by normal statistical rules, and then translates this statistical data into spectral shape information as a product you can view graphically.

Spectral shape information can be described in terms of the standard deviation of a distribution. If the frequency (f) in figure 1–36 corresponds to the mean Doppler velocity, then half the total area under the curve falls both right and left of *f*. The standard deviation is that distance right and left of the *f*, which includes about 2/3 of the area of the curve.

The square of the standard deviation is called the variance, and it changes as spectrum width varies.

Remember, a wider spectra generally indicates more turbulent targets. Since we said that variance changed with the spectrum width, larger values of the variance also correspond to more turbulent targets. Use this variance as an indication of spectral shape.

The variance is displayed by the WSR–88D as a graphic product in a similar way it displays reflectivity or velocity. During interrogation, you can simultaneously examine patterns of mean Doppler velocity, reflectivity, and variance (spectrum width). From this, you can determine whether you should have confidence in your mean air flow and turbulence evaluations for various portions of a precipitation target.

For example, the most reliable estimates of mean motion within or near a precipitation target are obtained from spectra with narrow widths (small variance) and relatively sharp peaks (high reflectivity). Let’s see why this is true.

Target characteristics and spectral shape

The actual shape of the Doppler spectrum varies with the character of the target being sampled. For example, precipitation echoes with very large particles and large internal wind shears (thunderstorms) result in a broad, flatter appearing spectrum. However, the spectrum for these targets has much more area under the curve than other targets since the particles are larger and reflect more power back to the radar. Targets with smaller particles and weaker wind shears produce a sharper spectral shape with much less area under the curve. Generally, wider spectra denote more turbulent atmospheres. Figure 1–37 represents spectral shapes for various precipitation characters.

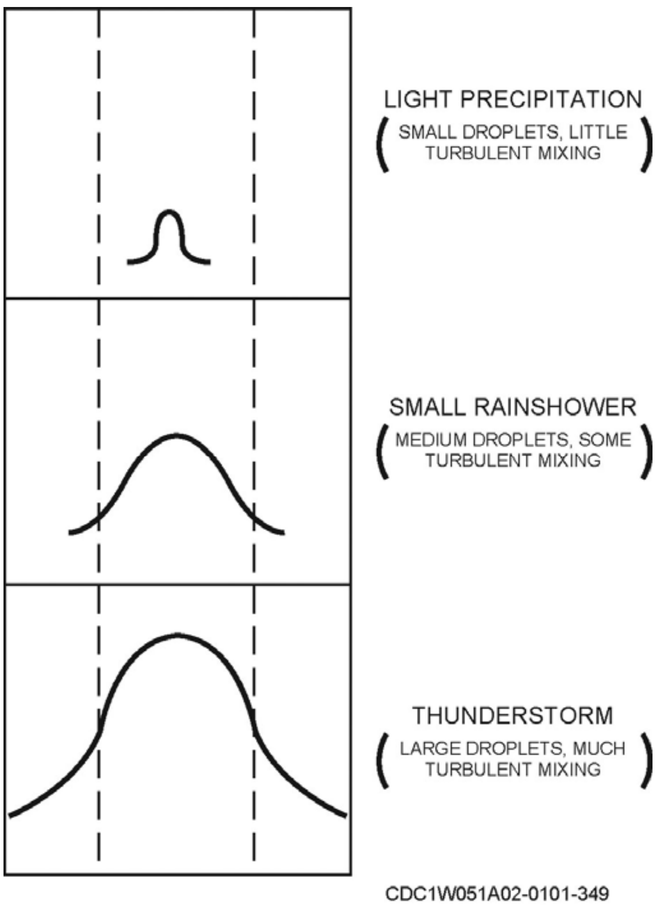

Figure 1–37. Spectral shape.

Radar characteristics and spectral shape

The Doppler spectral shape is determined by the nature of both the target and the radar. In the generalized discussion of spectral shape that follows, keep in mind that characteristics of precipitation targets vary widely, and thus, their Doppler spectra vary widely. Effects of target characteristics upon spectral shape are summarized in figure 1–37.

We noted earlier spectra that are narrower and sharper produce more reliable estimates of mean velocity of the sample volume. However, some variance seen in spectra may be caused by the radar and shouldn't be interpreted as turbulence. For example, stabilizing the Doppler velocity estimate (a narrower spectrum width) can also be achieved by increasing the antenna size. This reduces the beam width, which in turn reduces the sample volume and amount of variability. Also, slowing the antenna's rotation stabilizes the velocity estimates by allowing repeated sampling of a given atmospheric volume. This produces a better estimate of velocity because a slower rotation allows for more sequential samples, and therefore, a more reliable estimate of mean velocity. The WSR–88D uses this slower rotation for sampling in clear air.

Also realize that a high spectrum width does not always equate to turbulence and/or wind shear. Always keep in mind that a high spectrum width may be due to weak reflectivity causing a poor signal-to-noise ratio. Remember, we tend to see higher spectrum widths along the edges of echoes where power return drops off rapidly.

211. Relationship between spectrum width and meteorological phenomenon

Spectrum width interpretation is not always straightforward. Though many times assumptions are made based on spectrum width values, when it comes to weather, some assumptions may pay big dividends when it come to forecasting phenomenon.

Turbulence

Since spectrum width measures the combination of motions within a sample volume, we can assume turbulence or shear within areas of high spectrum width. This relationship helps verify the existence or nonexistence of turbulence.

Using velocity alone, a forecast of light to moderate turbulence from the surface to a point above the abrupt change in wind direction, is logical. However, by using the spectrum width product we can refine our turbulence forecast.

Icing

Although there is currently no WSR–88D product specifically designed to help in forecasting icing, spectrum width can help. Due to the increased variance in the velocities of the particles within the melting level, the result is high spectrum widths. This area of high spectrum width appears as a ring or partial ring centered on the radar. Armed with this information, the forecaster can monitor the height of the melting level (bright band) to help in forecasting icing, and precipitation type.

Convective development

Convective development is often seen on the spectrum width product before any significant returns show up on a reflectivity product. Consider a reflectivity product having a return of 15dBZ. Using reflectivity alone, this echo is considered insignificant. However, if this 15dBZ echo is displayed when spectrum width is displaying high values, closer interrogation is warranted. Since spectrum width measures the variance of motions within a sample volume, these high spectrum width values may be indicating the motions associated with convective currents. High spectrum width with low reflectivities may be your first indication of storm development.

Stratiform precipitation and embedded convection

With stratiform precipitation, it stands to reason that spectrum width values will be fairly low and uniform in coverage. You should recall that stratiform cloudiness occurs in a stable environment without much atmospheric mixing. However, in some cases, you may observe widespread low spectrum width values with isolated areas of unusually higher values. What might cause this to occur? If you guessed embedded convection, you are probably correct. However; to be sure, it would be wise to investigate further because spectrum width values should never be used alone.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

206. Doppler radar detection

1. What are the maximum degrees of phase shift in electromagnetic energy that can be related to a correct velocity?

2. At how many degrees of phase shift do velocities become ambiguous?

3. If radar energy strikes a stationary target, what kind of phase shift is experienced?

4. If a target moving toward the radar causes the energy to be backscattered, will it be at a higher or lower frequency?

5. What is the Doppler shift?

6. What is meant by the term radar coherency?

7. The ability of the radar to compare the frequency of each new pulse with that of the preceding pulse is known as what?

207. Radial velocity detection

1. By convention, how are velocities toward the radar expressed?

2. By convention, how are velocities away from the radar expressed?

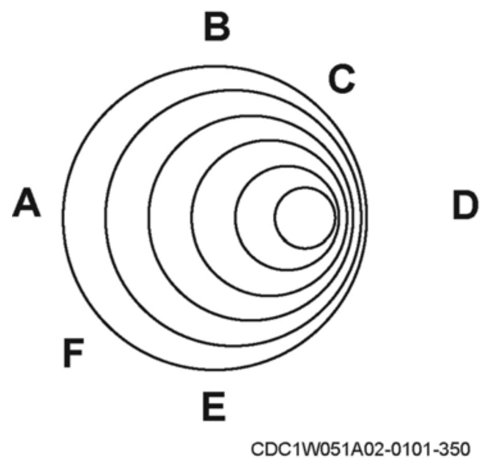

Figure 1–38. Lesson 207, self-test question 3 through 6

Figure 1–38 represents a single dipole exhibiting a frequency shift; use it to complete questions 3 through 6.

3. If the antenna is at point B and facing directly toward E, how is the radar detecting the target velocity?

4. If the antenna is at point A and facing directly toward D, how is the radar detecting the target velocity?

5. If the antenna is at point F and facing directly toward C, how is the radar detecting the target velocity?

6. If the antenna is at point D and facing directly toward A, how is the radar detecting the target velocity?

7. If the environmental wind is from 240° at 30kt and the antenna is pointing toward 180°, what is the velocity the radar detects?

208. Velocity aliasing characteristics

1. Define unambiguous velocity.

2. In radar terms, what are the speeds that exceed the maximum unambiguous velocity called?

3. What limits velocity detection?

4. How does increasing the PRF affect the chances of aliasing?

209. Doppler dilemma

1. Define Doppler dilemma.

2. What is the Doppler dilemma a compromise between?

3. A PRF of 4,000 pulses per second results in what kind of velocity detection and range?

210. Spectrum width and sample volume

1. What is the square of the standard deviation of the distribution known as?

2. The sample volume represents the smallest amount of the atmosphere that can be instantaneously sampled by the radar. Why is this?

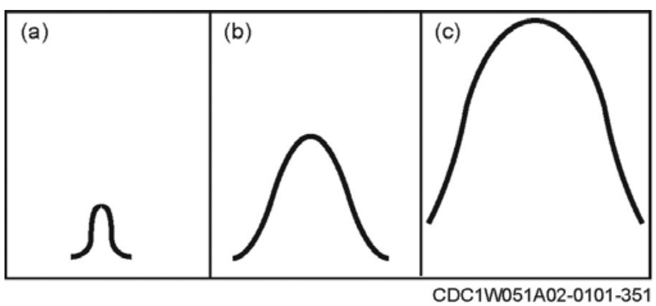

Figure 1–39. Lesson 210, self-test question 3.

Use figure 1–39 to answer the following question.

3. Which of the diagrams best shows a precipitation echo with large particles and high internal shear?

211. Relationship between spectrum width and meteorological phenomenon

1. What is most likely occurring when you observe low base reflectivity values with high spectrum width values?

2. What is most likely the most likely cause of uniform spectrum width values with isolated areas of higher values?

Answers to Self-Test Questions

201

1. Magnetism developed by an electrical current passing through a wire coiled around a metal bar that induces a magnetic field.
2. Like a series of sine waves.
3. Attenuation has a greater affect on a shorter wavelength and weakens the energy of the beam.
4. Inversely, because wave speed is constant.
5. The wavelength of the emitted waves and the size and composition of the particles encountered.
6. Energy is absorbed and reradiated at a different wavelength. This energy that is different and unrecognizable to the radar the energy that was originally transmitted.

202

1. In units of time it takes the radar to send one pulse (expressed in microseconds) or in units of distance (horizontal) from the front edge to the back edge of the pulse (expressed in meters).
2. The duration or length of the pulse.
3. The rate at which the pulses are transmitted in a unit of time.
4. *Pulse length* affects the minimum range of the set, because the transmitter must be shut off by the time the reflected signal returns. *Pulse repetition frequency* affects the maximum range. The signal must have time to return to the set before the next pulse is transmitted.
5. (1) a.
   (2) e.
   (3) c.
   (4) d.
   (5) b.
6. The number of pulses returned per target will be too low, and some regions may not be probed for targets.
7. Range folding occurs when energy is received from an old pulse after transmission of the next pulse.

203

1. Along the centerline of the beam.
2. Partial beam filling.
3. Missed targets below the beam.
4. The radar beam striking large obstructions near the antenna site.
5. By *more* than one beam width.
6. Range resolution.
7. Meteorological targets appear to weaken and disappear as they move into the cone of silence.

204

1. Increases.
2. Superrefraction—which occurs when warm, dry air overlies cool, moist air, as in an inversion. The result is that the radar beam bends below its normal path. Subrefraction—occurs when water vapor content increases and temperature decreases with height. The result is that the radar beam travels above its normal path.
3. Superrefraction.
4. Subrefraction.
5. Displayed echo heights are overestimated.
6. Displayed echo heights are underestimated.

205

1. The particles are small, homogeneous spheres whose diameters are much smaller than the radar's wavelength (Rayleigh scattering). The particles are spread uniformly throughout the contributing region (sample volume). Precipitation throughout the sample volume is the same (all rain or all snow—no mixed precipitation). The main lobe of the antenna beam pattern is adequately described by mathematical notation. Attenuation and multiple scattering are negligible.
2. Power, expressed in watts.
3. 100 percent.
4. Logarithmically.
5. The.54nm reflectivity product. Average of four successive.13nm bins.
6. Displays the highest of every two.54nm bins.
7. Displays the highest of four.54nm bins.

206

1. 179º or less than 180º.
2. Greater than or equal to 180°.
3. The electromagnetic energy experiences no phase shift.
4. Higher.
5. The change in position of the backscattered wave as the radar interprets it to be moving is called the Doppler shift.
6. It is when a radar produces a pulse at the same frequency as the preceding ones and can remember the specific frequency to determine the frequency shift, and therefore, the radial velocity.
7. Pulsed-pair processing.

207

1. Negative values.
2. Positive values.
3. It shows the target as stationary because the motion is perpendicular to the beam; therefore, the target's velocity is depicted as zero.
4. The motion is directly away from the beam. Therefore, the full component or full velocity is detected.
5. The motion is neither parallel nor perpendicular to beam, therefore only part of the target's velocity is detected. 6. The motion is directly toward the beam. Therefore, the full component or full velocity is detected.
7. Using the equation $V_r = V_a (\cos \theta)$. Since $\theta = 60°$ (the difference between 240° and 180°) and $V_a = 30$ knots. Then:
   (1) V_r = 30kt (cos 60°).
   (2) V_r = 30kt (0.5).
   (3) V_r = 15kt.
   (4) Since the motion is toward the radar it is expressed as a negative, therefore the answer is –15kt.

208

1. The limit to the speeds the WSR–88D can measure without error.
2. Aliased velocities.
3. The wavelength of the radar.
4. Increasing the PRF increases the Nyquist co-interval.

209

1. It is the tradeoff where an increase in PRF increases the maximum unambiguous velocity but decreases the maximum unambiguous range.
2. The maximum range and the maximum velocity.
3. Since 4,000 pulses per second is a high PRF, velocity detection will be high, but the range will be very short.

210

1. Variance.
2. The energy returned from particles separated by less than the sample volume’s dimensions will be averaged together as a single return.
3. Figure C, since large particles reflect more power back to the radar there will be more area under the curve.

211

1. Early stages of convective development.
2. Stratiform precipitation with embedded convection.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field Scoring Answer Sheet.

Do not return your answer sheet to (Extension Course Institute).

1. (201) An electrical current passing through a wire coiled around a metal bar that induces a magnetic field is called
   a. a dipole.
   b. frequency.
   c. polarization.
   d. electromagnetism.

2. (201) Which wavelength is *best* when you are trying to detect light to moderate rain?
   a. 3 centimeters (cm).
   b. 5 cm.
   c. 7 cm.
   d. 10cm.

3. (201) Which wavelength would be *best* for you to use when large thunderstorm or hurricanes frequently occur?
   a. 2.0 cm.
   b. 3.4 cm.
   c. 4.2 cm.
   d. 10.7 cm.

4. (201) The number of cycles per a given unit of time is called
   a. a hertz.
   b. frequency.
   c. wavelength.
   d. propagation.

5. (201) As electromagnetic waves are emitted from radar and travel through the atmosphere, some of their energy is lost. What is the loss of energy because of the interaction with atmospheric phenomena called?
   a. Distortion.
   b. Attenuation.
   c. Propagation.
   d. Frequency shift.

6. (201) What are the two related factors that attenuation of radar waves depends on?
   a. Frequency of the emitted radio waves and size and composition of the particle encountered by these waves.
   b. Wavelength of the emitted radio waves and size and composition of the particle encountered by these waves.
   c. Pulse length of the emitted radio waves and size and composition of the particle encountered by these waves.
   d. Pulse repetition frequency of the emitted radio waves and size and composition of the particle encountered by these waves.

7. (202) The amount of time it takes the radar to send one pulse is known as
   a. wavelength.
   b. propagation.
   c. pulse length.
   d. listening time.

8. (202) What decides the *minimum* range of the radar?
   a. Pulse length.
   b. Listening time.
   c. Antenna rotation.
   d. Pulse repetition frequency.

9. (202) Another term for second-trip echoes is
   a. range folding.
   b. velocity aliasing.
   c. pulse paired processing.
   d. pulse repetition frequency.

10. (203) How does the radar beam width vary with the wavelength; how does it vary with the diameter of the parabolic reflector of the antenna?
   a. Directly; directly.
   b. Inversely; directly.
   c. Directly; inversely.
   d. Inversely; inversely.

11. (203) Sample volume is equal to
   a. the pulse length times the beam diameter.
   b. the pulse volume times the sample volume.
   c. one-half the pulse length and beam diameter
   d. one-half the pulse volume times the sample volume.

12. (203) What kind of resolution is it called when the radar can distinguish between two targets at the same range but different directions from the radar?
   a. Beam.
   b. Range.
   c. Bearing.
   d. Elevation.

13. (203) The ability of the radar to differentiate between two closely spaced targets at the same range and bearing but at different elevations depends on
   a. beam width.
   b. wavelength.
   c. beam length.
   d. beam illumination.

14. (203) Range resolution depends on
   a. beam width.
   b. wavelength.
   c. pulse length.
   d. pulse repetition frequency.

15. (203) Side lobes can cause certain side effects. Which of these is one of the side effects?
    a. Subrefraction.
    b. Superrefraction.
    c. Ground clutter.
    d. Beam blockage.

16. (204) Superrefraction is when the curvature of the radar beam is
    a. zero.
    b. less than the earth's curvature.
    c. parallel to the earth's curvature.
    d. greater than the earth's curvature.

17. (204) Another effect of superrefraction is the displayed height values are
    a. correct.
    b. overestimated.
    c. underestimated.
    d. off an amount equal to the target's range.

18. (204) Straightening of the radar beam upward *best* defines
    a. ducting.
    b. subrefraction.
    c. superrefraction.
    d. second trip echoes.

19. (204) What does subrefraction do?
    a. Produces ducting.
    b. Causes anomalous propagation.
    c. Reduces the maximum range of detection of low-level targets.
    d. Usually occurs at night under conditions of strong radiational cooling.

20. (205) Computation of the equivalent reflectivity factor (Z_e) depends on
    a. decibel values produced by the WSR–88D processors.
    b. each specific weather situation, and can rarely be computed accurately.
    c. maximum returned power, the diameter of the antenna, and the logarithm of their ratio.
    d. average returned power, range to target, and a set of known factors called the "radar constant."

21. (205) While performing a radar metwatch, the operator notices a storm that has increased from 40 to 43 dBZs at one elevation slice. The operator *must* assume the intensity of this storm has
    a. doubled.
    b. tripled.
    c. not changed
    d. not changed significantly.

22. (206) The factor that allows a Doppler radar to remember the frequency of transmitted energy for later comparison to returning energy is
    a. coherency.
    b. redundancy.
    c. dipole processing.
    d. velocity dealiasing.

23. (207) The WSR–88D has only one antenna, it only measures the component of wind that is
    a. parallel to the radar beam.
    b. perpendicular to the radar beam.
    c. at a 45° angle to the radar beam.
    d. at a 15° angle to the radar beam.

24. (208) Which action is an effective means of decreasing velocity aliasing?
    a. Decrease the pulse repetition frequency.
    b. Increase the pulse repetition frequency.
    c. Decrease the antenna gain (power).
    d. Increase the antenna gain (power).

25. (209) The Doppler dilemma is a tradeoff between
    a. range and height.
    b. height and speed.
    c. range and velocity.
    d. speed and direction.

26. (209) What kind of pulse repetition frequencies (PRF) are required for high velocity measurements and long ranges?
    a. High PRFs are required for high velocity measurements for long ranges.
    b. Low PRFs are required for high velocity measurements and for long ranges.
    c. High PRFs are required for high velocity measurements, and low PRFs are required for long ranges.
    d. Low PRFs are required for high velocity measurements, and high PRFs are required for long ranges.

27. (210) What is the Doppler spectrum?
    a. A sampling of power received by the radar at each velocity within a sample volume.
    b. A sampling of velocities received by the radar at each PRF within a sample volume.
    c. The distribution of power received by the radar at each frequency within a sample volume.
    d. It is the distribution of the actual velocities received by the radar at each frequency within a sample pulse.

28. (210) The spectral slope of the Doppler spectrum of a large thunderstorm with hail appear
    a. broad and flat.
    b. broad and sharp.
    c. narrow and flat.
    d. narrow and sharp.

29. (211) The spectrum width product is useful for the early detection of thunderstorm development because
    a. the spectrum width product has not been identified for this use.
    b. it scans the mid-levels of the atmosphere for pockets of moisture.
    c. it is more sensitive than base reflectivity and can display the first occurrence of moisture.
    d. the detection of high spectrum widths may be indicative of currents present in a convective atmosphere.

30. (211) Widespread low spectrum width values with isolated areas of higher values is most likely indicative of
a. icing.
b. lightning.
c. embedded storms.
d. anomalous propagation.

Please read the unit menu for unit 2 and continue ➔

Student Notes

Unit 2. Radar System Concepts

THE WEATHER SURVEILLANCE RADAR 1988–Doppler (WSR–88D) system provides you with exciting new perspectives to apply in operational forecasting and observing. The WSR–88D is much more than just a radar—it is a carefully integrated system of basic radar components, sophisticated computer hardware and software, and an intricate communications network. To fully use its many features, you first must have a basic understanding of the WSR–88D system itself.

The WSR–88D is a tri-agency radar designed to serve the Department of Defense (Air Force and Navy), the Department of Commerce (National Weather Service), and the Department of Transportation (Federal Aviation Administration). To best serve all the users, the WSR–88D produces many products, some of these products you use routinely, some occasionally, and others not at all.

Each WSR–88D unit consists of a radar data acquisition (RDA) unit, a radar product generator (RPG), several remote principal user processors (PUP) or Open Principle User Processors (OPUP) workstations, and the necessary wideband and narrowband communications to link them together. This unit introduces you to many of the WSR–88D's major components and their functions.

2–1. Radar Data Acquisition

The RDA unit consists of the antenna, pedestal, radome, transmitter, receiver, and data processor cabinet (fig. 2–1) necessary to control the radar and acquire three-dimensional (3-D) radar data. Unanalyzed basic measurements of reflectivity, mean radial velocity, and spectrum width collected by the RDA are called "base data." The WSR–88D operates at an S-band wavelength of approximately 10 centimeters with an operating power of 750 kilowatts and a peak power of one megawatt.

212. Hardware description

The RDA includes the antenna and all other necessary hardware to control the antenna and preprocess meteorological data. It provides for the detection and measurement of meteorological and hydrological phenomena. This includes anything from raindrops, to dust, to insects, to refractive gradients. In other words, we want to see any scatterers in the atmosphere that can give us information to help with a forecast, observation, or warning. The RDA performs signal processing of Doppler weather radar data and transfers this data as reflectivity, velocity, and spectrum width base data to the RPG. The RDA provides the capability to monitor and control the WSR–88D antenna, and provides a maintenance control terminal in support of both operations and maintenance activities. There are six basic subcomponents that make up the RDA. They are the antenna, pedestal, radome, transmitter, receiver, and signal processor.

Figure 2–1. RDA.

Antenna

The WSR–88D antenna is a parabolic dish 28 feet in diameter that produces a beam width of approximately 1°. In the WSR–88D's operational mode, the antenna rotates continuously in azimuth at a maximum speed of 5 revolutions per minute (rpm) (while the pedestal is capable of 6 rpm) and moves in predetermined incremental steps in elevation from 0.5° to 19.5°. The elevation steps are determined by the particular volume coverage pattern (VCP) being used.

Pedestal

The pedestal is an aluminum and cast iron structure that positions the 2,600-pound antenna with extreme accuracy (fig. 2–2). During maintenance operations, the pedestal can move the antenna from –1° to +60° and rotate it at up to 10 rpm.

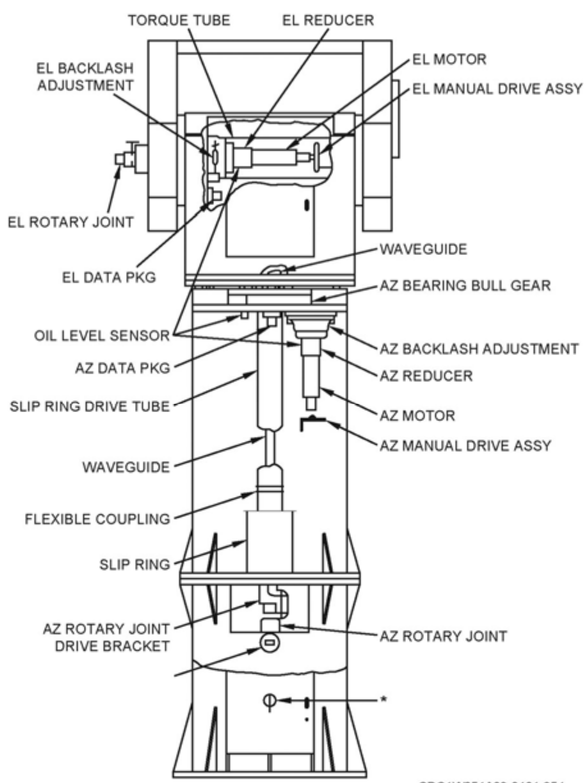

Figure 2–2. Pedestal.

Radome

The radome (fig. 2–3) is nearly 39 feet in diameter and is made of rigid fiberglass. Figure 2–1 shows an actual photograph of the radome. Its purpose is to protect the antenna and pedestal from the hazards of weather. With a two-way signal loss of only 0.6dB at 2,800 MHz, it is practically transparent to the radar beam. The radome, antenna, and pedestal are on top of a steel tower up to 98 feet in height. This height can be altered depending on the location of the RDA in relation to nearby obstructions.

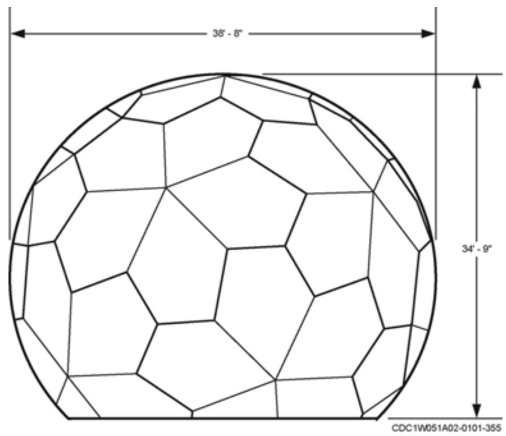

Figure 2–3. Radome.

Transmitter

The transmitter is a high-power, S-band, pulse amplifier that generates the rf pulse for transmission through the antenna. Input to the transmitter is a gated, low-power (10 milliwatts) rf drive signal with a frequency range of 2,700 to 3,000 MHz, which is generated by the receiver. The signal provides coherency (phase reference) for the return signal from which to compute the Doppler phase shift. The Klystron transmitter then transmits a burst of high-power rf energy of either 1.57 or 4.7 microseconds (μs) in duration, with a peak operating power of approximately 750 kilowatts. The high-power rf energy is transmitted to the antenna through a waveguide.

Receiver

The receiver is a highly sensitive device that amplifies the R-F energy returned to the antenna and transfers this analog data to the signal processor.

Signal processor

The signal processor's main job is to take the raw analog data from the receiver and process it into a digital base data. It also does other functions such as ground clutter filtering, range unfolding, data thresholding, archive storage (level II), and allowing RDA control to maintenance personnel.

213. RDA data flow and processing

Notice that when a pulse returns, three types of information can be extracted (fig. 2–4). Past radars could only detect and analyze one type of data—the intensity of the returning energy or reflectivity. These radars are commonly referred to as surveillance radars. With Doppler radar we can also detect the change in frequency between successive pulses and the amount of variance of target motions within each pulse. The RDA analyzes these three factors and converts them into "base data." Base data consists of reflectivity, mean radial velocity, and spectrum width data.

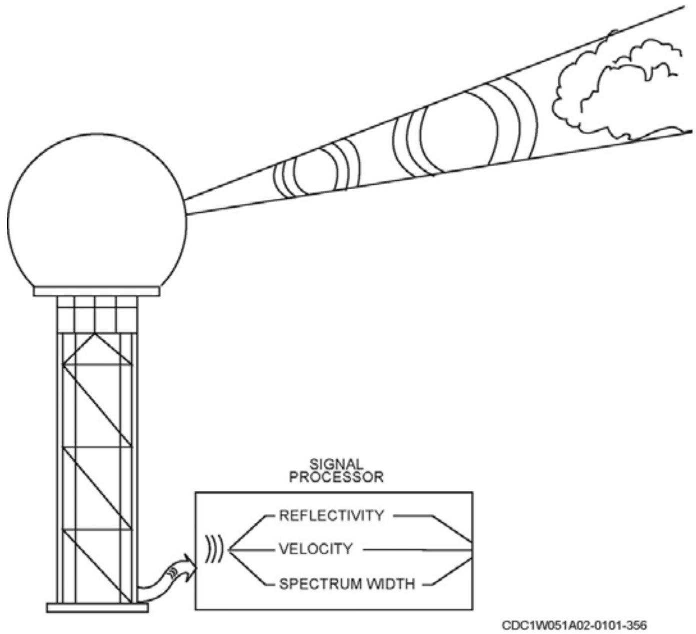

Figure 2–4. Information in returning pulse.

Signal generation

Conventional or incoherent radars use a special amplifier tube called a magnetron to generate large amounts of power (up to 100 kilowatts or more) at prescribed frequencies. Unfortunately, the phase of each pulse from most magnetrons is random and consequently, it is not possible to measure the difference of the returned signal's phase with that of the transmitted signal.

The WSR–88D can make this measurement by using a powerful klystron amplifier to highly amplify (normal at 750 kilowatts) the radar signal. The klystron is a very stable, coherent amplifier which assures each new pulse is at the same phase as the preceding ones. Once the signal is amplified, this energy is then released through the 28-foot parabolic antenna where it is broadcast into the atmosphere.

Processing the returned signal into base data

When the transmitted energy returns to the radar antenna, the components and software of the RDA determine and process the reflectivity data. Additionally, Doppler frequency shifts created by target motions encountered by the transmitted signal are also processed. Of course, let's not forget that spectrum width data is determined as well. Once the RDA has produced the critical base data (reflectivity, velocity, and spectrum width) used by the RPG to build the meteorological products you need, this data may still be contaminated with things such as ground clutter, unwanted electromagnetic noise, and range-folded returns. Therefore, the RDA cleans up this data before it goes to the RPG.

Before the base data are ready for clutter filter, range unfolding, signal-to-noise threshold, and so forth, it must first be converted from analog data to digitized data. This is the very first task accomplished on base data at the signal processor.

Clutter filtering

Ground clutter is radar return produced from environmental features other than atmospheric scatterers (for example, buildings, hills, and trees). Because the radar beam increases in height with range, clutter is usually restricted to within 30 miles of the RDA site. The clutter bypass map is a clutter suppression strategy defined during the RDA software operability test (RDASOT). The bypass map is usually adequate for clutter suppression in most weather situations. However, anomalous propagation

(AP) can affect radar displays if atmospheric conditions are right (superrefraction). Selective clutter suppression in individual defined areas can also occur at the Master System Control Function (MSCF) to suppress clutter missed by the bypass map. This is accomplished using clutter suppression regions. The unit radar committee (URC) has the authority to change clutter suppression regions.

The WSR–88D attempts to filter out most ground clutter long before you ever see the finished product on the screen. It does this by taking advantage of two very distinct properties common to most clutter. First, ground clutter is usually stationary, or has near zero Doppler velocity. Second, it has a small dispersion or spectrum width. Spectrum width data is used in clutter filtering to distinguish between these fuzzy vs. solid returns. The solid (ground clutter) return has very low spectrum width values ranging from 0.1m/sec to 0.5m/sec. Typical precipitation returns have width values from about 1.0m/sec for snow and stratiform rain to about 4.0m/sec for convective storms. The WSR–88D combines two features, a near zero Doppler velocity and small spectral dispersion, to distinguish between meteorological targets and unwanted clutter. The MSCF operator is authorized by the URC to modify the clutter suppression regions if environmental factors make it necessary to do so.

Data thresholding Data thresholding occurs at the RDA and is the process of suppressing those data points whose signal-to-noise ratios (usually about 3dB) fall below a user specified value. This is our way of telling the RDA to ignore data that doesn't measure up to our standards rather than have it contaminate future processing at the RPG.

Range unfolding

Range folded (second-trip) echoes can have extremely adverse affects on our meteorological products. The RDA employs a process that eliminates *most* range folding problems. This process involves comparing all returns encountered at high PRFs to those received at a low PRF to find which echoes are range folded. Remember that folding is likely to occur at high PRFs, but is rare at low PRFs. The RDA uses the target ranges determined from the low PRF to properly place the velocity and spectrum width data gathered at high PRFs.

Scan strategies

Another function done by the RDA is the execution of the various scan strategies available. Remember that a scan strategy is a predetermined sequence of elevation slices and PRFs the antenna accomplishes during the completion of a volume scan. The WSR–88D is capable of eight different scan strategies (volume coverage patterns) of which four have been defined. Recall that VCPs are the WSR–88D's computer-controlled sampling patterns. The terms scan strategy and volume coverage pattern are typically used interchangeably, however, there is a conceptual difference. You can think of a volume coverage pattern as that area of the atmosphere that gets sampled. The scan strategy on the other hand is the actual mechanical and electrical processes employed by the radar. These include things such as the use of variable PRFs, sampling the lowest two elevation angles twice and slower rotation rates for clear-air sampling. Refer to figure 2–5 for a graphical depiction of the VCP scan strategies.

VCP 11	VCP 11 performs 14 elevation slices every 5 minutes and is in the deep precipitation/convection group. This VCP is used for severe and non-severe convective events. Fewer low elevation angles make this VCP less effective for long-range detection of storm features when compared to VCPs 12 and 212.
VCP 211	VCP 211 performs 14 elevation slices every 5 minutes and is in the deep precipitation/convection group. This VCP is best used for widespread precipitation events with embedded, severe convective activity.
VCP 12	VCP 12 performs 14 elevation slices every 4.2 minutes and is in the deep precipitation/convection group. This VCP is best used for severe convective events. Extra low elevation angles increase low-level vertical resolution when compared to VCP 11. However, high antenna rotation rates slightly decrease accuracy of the base data estimates.
VCP 212	VCP 212 performs 14 elevation slices every 4.2. This VCP is best used for rapidly evolving, widespread severe convective events such as squall lines.
VCP 21	VCP 21 performs 9 elevation slices every 6 minutes and is in the shallow precipitation group. This VCP is best used for non-severe convective precipitation events. A limitation of this VCP is the gaps in coverage above 5º.
VCP 121	VCP 121 performs 9 elevation slices every 6 minutes. This is the VCP of choice for hurricanes. Another use is for widespread stratiform precipitation events. A limitation of this VCP is the gaps in coverage above 5º.
VCP 221	VCP 121 performs 9 elevation slices every 6 minutes. This VCP is best used for widespread precipitation events with embedded, possibly severe convective activity. A limitation of this VCP is the gaps in coverage above 5º.

Precipitation mode

This mode should be used when significant weather echoes are present or severe weather is occurring or is anticipated. Usually, this mode will have been selected automatically due to the detection of reflectivity exceeding the predefined threshold. At times, however, such as during the early, mid-level formation of convective echoes, the RPG Human-Computer Interface (HCI) operator may choose to enter the precipitation mode manually.

Clear-air mode

In the clear-air mode, we have VCP 31 and VCP 32 (fig. 2–5). Both VCPs complete five elevation slices in ten minutes. Notice this is a slower scan than in the precipitation mode. The antenna rotation rate must be slow enough to allow increased signal returns from the clear air to reach the antenna for detection. VCP 31 uses a longer pulse and a lower PRF to allow more power per pulse resulting in increased sensitivity.

VCP 32 uses a shorter pulse and a higher PRF to increase the Nyquist co-interval, and therefore increases the velocity resolution of the sample. However, this shorter pulse results in less sensitivity because it contains much less energy than the long pulse, and therefore results in a weaker signal return to the antenna.

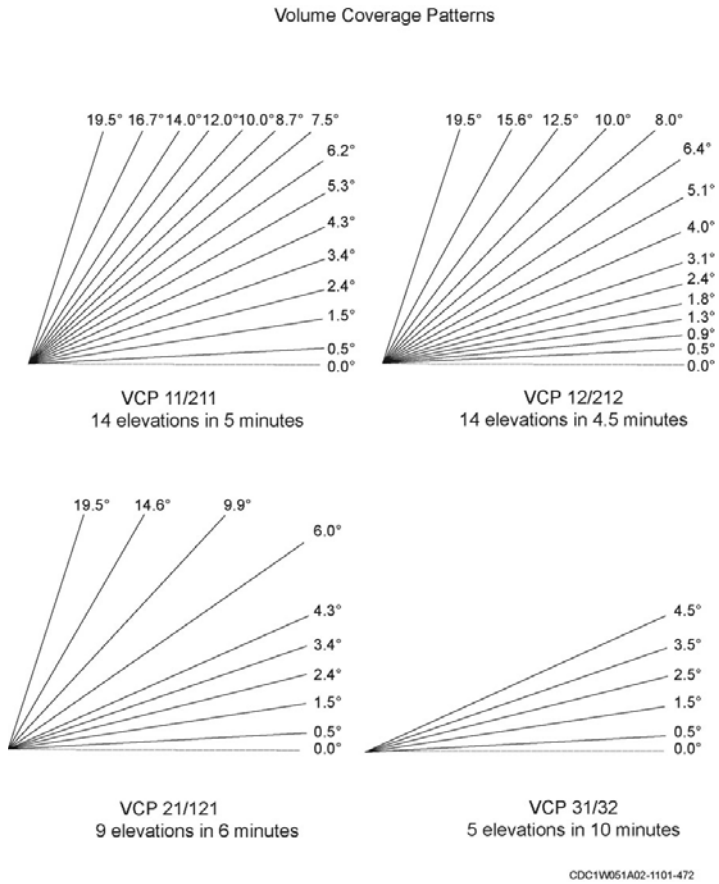

figure 2–5. VCP scan strategies.

Pulse length

The choice between using the long pulse mode or the short pulse mode depends on the meteorological situation and is not always an easy one to make. For instance, on a day with ample low-level moisture and high winds (such as immediately behind a strong cold front with stratocumulus present), you may want to use the short pulse mode to increase the maximum wind speed you can measure without aliasing.

On the other hand, on a cold and dry winter day, you may need the long pulse mode to get a strong enough signal return from this excessively dry air. Some decision making is taken out of this whole scan mode process because the WSR–88D is designed to operate continuously in the clear-air mode but automatically switches to precipitation mode when sufficient precipitation is detected.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

212. Hardware description

1. Where does control of the WSR–88D antenna occur?

2. Name the six basic subcomponents that make up the RDA.

3. What determines the elevation steps used by the RDA's antenna?

4. Why would the height of the radome be different for each RDA location?

5. Describe the signal processor's main job.

213. RDA data flow and processing

1. The WSR–88D combines what two features during the clutter filtering process to distinguish between unwanted clutter and meteorological targets?

2. Explain the process the RDA employs that can eliminate most range folding problems.

3. Which VCP is in the shallow precipitation group?

4. The clear air mode contains two VCPs—VCP 31 and VCP 32. Both scan five elevations in ten minutes. What is the difference between the two?

2–2. Radar Product Generator and Open Radar Product Generator

The RPG is considered the "brains" of the WSR–88D unit. It includes high-speed computers, extensive memory capacity, and provides computer control to the RDA. Its primary job is to generate as many useful products as possible for the operator to use in near real-time.

Data received from the RDA is used to produce a set of meteorological products. Product generation is accomplished by the execution of meteorological algorithms stored in the RPG computer. Algorithms are the individual computer programs that enable the RPG to produce usable products from the base data received from the RDA. Additionally, the RPG provides for product storage and distribution, alert processing, RDA control, and status monitoring.

214. Hardware description

The RPG may not look too impressive from the outside but what really counts is what takes place on the inside. We can break the RPG down into several functional areas. Let's take a quick look at what each area is and what it does.

Central processing unit

The CPU receives digital base data from the RDA, processes the data into meteorological and hydrological products through the execution of algorithms, then stores and distributes these products. Velocity dealiasing and certain system algorithms such as auto PRF, alert processing and loadshedding/product priority are carried out within the CPU as well. The CPU supports the loading of operating software from an external disk into the RPG's shared memory.

Shared memory

The processing equipment provides shared memory of eight megabytes. Shared memory enables the RPG to do many processing tasks simultaneously. These tasks include velocity dealiasing, product generation, loadshedding, alert processing, one-time product requests, and other functions critical to operational demands.

Mass storage

The mass storage device is a fixed media, 600-megabyte magnetic disk. This disk has self-diagnostics and automatic error checking and correction capabilities. The mass storage provides a place to read and write both programming and product information.

JAZ drive (level III)

The RPG processing cabinet includes a 2 Gigabyte JAZ cassette drive. It has the capability to hold about 450 hours of product data if run continuously. These cassettes can be accessed later for training or operational review. In a later section, we discuss archiving in more detail.

Floppy drive

The floppy drive stores system and application files such as adaptation data, command substitution systems, etc.

215. Master Sysytem Control Function

The term Master System Control Function (MSCF) can have two meanings. It can be used to describe the equipment which controls the RPG or it can be used to describe the monitoring function, formerly known as the unit control position (UCP). Control of the RPG is accomplished from a computer terminal known as the Master System Control Function. Access and control of the RPG effectively means control of the entire system. The unit with the MSCF is the unit that has primary responsibility for the RDA and the RPG. It can be either a NWS WFO or a DOD weather station. The MSCF provides an appropriate operator interface from which control and monitoring functions are carried out.

At the majority of CONUS locations, a National Weather Service forecast office owns the MSCF. This means that a good working relationship with the NWS is very important. Unit Radar Committees are established for each system site and written guidance is available to help make this inter-agency coordination a little easier. As we stated earlier, the MSCF is the interface to the RPG.

The MSCF consists of one terminal that is typically located outside the RPG cabinet in the operations area. The terminal provides the user with complete control of the radar. It employs a windows based control system to allow the operator to easily move from one functional area to another. Figure 2–6 is an example of the MSCF's RPG control/status menu.

In addition to the MSCF, control of the radar can be accomplished through a maintenance terminal. The maintenance terminal is a computer terminal collocated with the RPG if the MSCF is remotely located. It is capable of communicating with both the RPG and the RDA and is used solely by maintenance personnel.

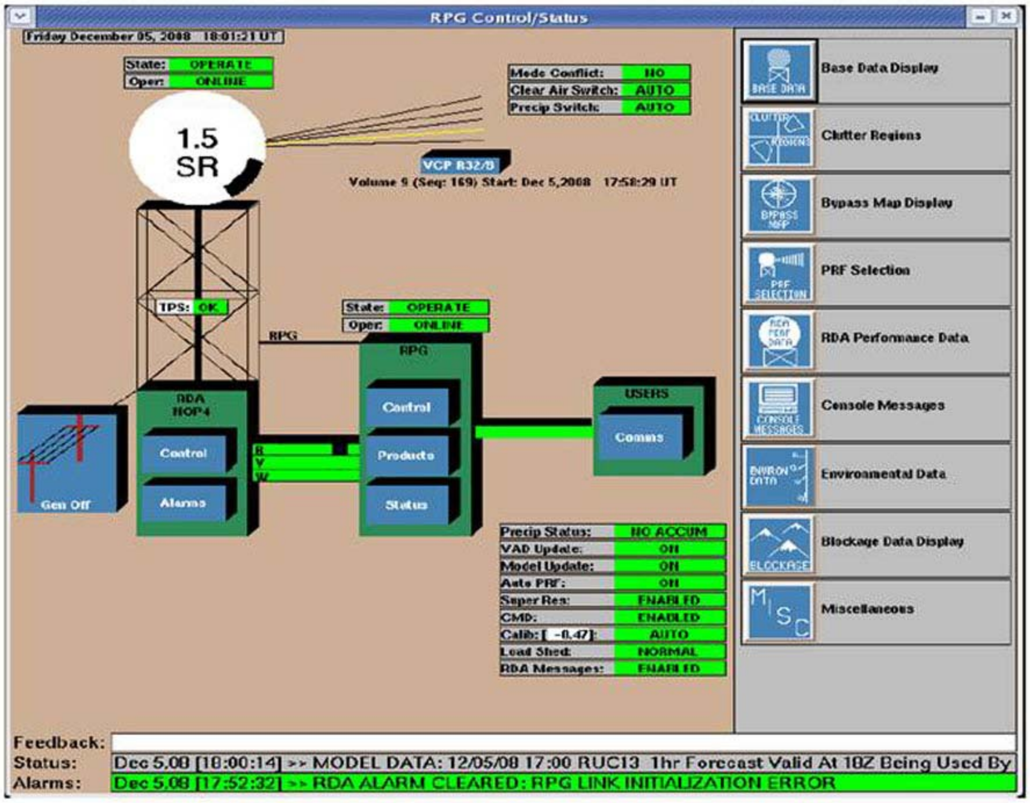

Figure 2–6. MSCF RPG control/status menu.

216. RPG data flow and processing

As you know, the RPG receives radar base data (reflectivity, radial velocity, and spectrum width) from the RDA by way of the wideband communications link. To this point, the RDA has done such functions as clutter filtering, data thresholding, and range unfolding. However, more processing must be accomplished before accurate, useful products can be generated.

Meteorological algorithms

The radar uses numerous meteorological algorithms to build and develop radar products. These algorithms are essentially formulas used to develop the products that are sent to the Open Principal User Processor (OPUP) for the radar operator to interperit. The limitations of these algorithms can also result in the limitations of the products they develop. For more information about these algorithms, refer to the FMH-11 Part C.

A closer look at these algorithms explained in FMH-11 will reveal their complexity. Many researchers have spent years developing these algorithms, but they are not perfect. Additionally, many algorithms such as those dealing with severe weather have been developed using Oklahoma storm data. Because of this, they need to be adjusted and modified to adapt to different weather regimes around the United States and overseas as well.

Signal processing algorithms

In addition to meteorological algorithms, the RPG processes WSR–88D signal processing system algorithms. These algorithms perform a series function including clutter filtering, range unfolding, and velocity dealiasing. Again, for a detailed explanation on these algorithms refer to FMH-11 Part C.

The RPG is responsible for most of the WSR–88D data processing. Other data such as status messages and alert processing information are also generated here. The RPG accomplishes literally millions and millions of complex calculations each minute.

From our discussion of the RPG, you can begin to appreciate the automation of the WSR–88D and the advantages of having a lightning fast computer analyze basic radar data in real time. Now that our data has been processed into the various meteorological products, weather alerts, and status messages, we’ll continue to follow its flow through the WSR–88D system.

Narrowband communications

Narrowband communications include all other communication between the WSR–88D components. It includes modem interfaces to and from the RPG and OPUP, the MSCF, and any other external users of WSR–88D data. Ports for narrowband links are designated as either dedicated, which is a full-time connection, or dial-up, which refers to dial-in, part-time connections.

Products and messages from the RPG are transferred to the OPUP through the narrowband. Likewise, the OPUP transfers data such as alert definitions and routine product set lists to their associated RPG. The MSCF at DOD sites is also connected to the RPG with a dedicated narrowband line. They are constantly transferring data to and from the RPG.

2–3 Open Principal User Processor (OPUP)

Though the components, mechanics, and principles of the WSR–88D are truly amazing, neither the radar antenna nor the radar product generator (RPG) are any use to us unless we can view the final product. As weather personnel we need the ability to view and manipulate the radar products available to us so that we can make the best weather decisions possible. The Open Principle User Processor is just that tool.

217. Description

The Open Principal User Processor (OPUP) is your workstation. At the OPUP, you request and control WSR-88D products, manipulate the products to suit your needs, make hard copies, monitor the status of the WSR-88D system, and a number of other user interface functions. The OPUP also provides for multiples dedicated and dial-in RPG communication links, provides services for product storage and retrieval, and supports multiple workstations for product display and manipulation.There are three OPUP configurations, large, medium, and small. Each configuration is designed to cost-effectively meet radar data acquisition and display requirements for the specific support location. Each OPUP includes all the communications and data processing hardware and software required to acquire, manage, and manipulate WSR–88D product data.

Now that you have a brief understanding of the OPUP and what its capabilities are, let’s break down the configurations.

Large OPUP

The large OPUP hardware description consists of narrowband communication equipment, a local area network Smart Switch, and a server. The Large OPUP supports direct connections to up to 24 WSR–88Ds. They are located at four centralized forecast facilities across the United States. The large OPUP consists of up to 10 workstations along with communications hardware and a server

Narrowband communication equipment

All narrowband communications equipment to support dedicated and dial-out (OPUP-to-RPG) communications is included as part of the OPUP system. The major communications components include the Dedicated Modem Nest Assembly, modems (dedicated), and a Cisco router.

The dedicated modem nest assembly

The dedicated modem nest assembly consists of two modem chassis. They are used to house, provide in-cabinet connections, and supply power to the dedicated narrowband communications modems. The modems are rack mounted dedicated modems which use TCP-IP protocol to transfer data to and from the RPG by way of dedicated phone lines. These modems support transmission speeds up to 14.4 kbps across 4 wire-dedicated circuits.

Router

The Large OPUP router has two auto-sensing 10/100 Ethernet ports, four 8-port dedicated communication modules, and one 8-port dial module. The router provides the interface to transfer the data between the modem chassis and the server. The router also provides for the data transfer between the OPUP system and local base LAN.

LAN switch

This LAN switch provides inter-process communication and data transfer between OPUP components. The LAN switch directs all inter-component messages and commands to the appropriate destination.

Sun 280R server

The Large OPUP uses one server. The server is a multi-processor system that uses two UltraSparc 1.2 Gigahertz (GHz) processors and includes 2 Gigabytes (GB) of Random Access Memory (RAM). To load software, an internal Compact Disc-Read Only Memory (CD-ROM) drive is included.

Two hard drives, a primary system drive and secondary storage drive, are installed in each server. The primary and secondary hard drives perform processes required by the OPUP software and store WSR-88D product and message data. The secondary hard drive maintains a mirror image of the data on the primary hard drive. This allows the Data Server to read the data stored on the two hard drives faster, and if the primary hard drive fails, the secondary hard drive can continue the data server processing functions.

Maintenance monitor and keyboard

Along with the SUN server the large OPUP uses a SUN 17-inch color monitor, keyboard, and mouse for system maintenance and administration. The monitor, keyboard, and mouse are used to access both servers by way of a keyboard, video, and mouse (KVM) switch.

Archive IV device

Archive IV data and the site's adaptation data are recorded to CD media using a Compact Disc-Rewritable (CD-RW) drive installed in the communications cabinet.

Printer

A network-capable, postscript color printer is part of the standard configuration.

Uninterruptible power supply (UPS)

The UPS provides uninterrupted alternating current (AC) power for all components within the OPUP cabinet. Each UPS comes with software which supports automatic shutdown of the attached servers.

Medium OPUP

The medium OPUP hardware description is very similar to the large OPUP. The medium OPUP supports direct connections to up to seven WSR–88Ds. They are located at centralized forecast facilities in the Pacific for the Air Force, and the East and West coasts for the Marine Corps. The medium OPUP consists of up to three workstations along with communications hardware and server.

Small OPUP

The small OPUP is a direct replacement for the legacy PUP at select Air Force locations. It consists of a single workstation. The small OPUP is designed to fit on a desktop.

Processor

The WSR–88D product and message data are processed on the server. A standard floppy diskette drive is included; however, this drive is disabled by the operating system. To load software, an internal CD-ROM drive is included.

Two hard drives, a primary system drive and a disabled secondary drive, are installed in the system. The primary hard drive is used for system programs and product and status message storage. The secondary hard drive has been disabled by the operating system.

Narrowband communication equipment

All narrowband communication equipment supports dedicated and dial-out communications between the RPG and OPUP and is included as part of every small OPUP system. The communication components consist of two modems and a router.

Modems

The small OPUP uses up to desk top dedicated modems for dedicated communications. The modems use TCP-IP protocol to transfer data to and from the RPG by dedicated phone lines. The modems support transmission speeds up to 14.4 kbps.

Router

A router provides the interface to transfer the data between the dedicated modem and the OPUP server. The router has one auto-sensing 10/100 Ethernet port, two dedicated ports, and an eight-port dial module.

LAN switch

The LAN switch provides for inter-processor communications for the OPUP components in the OPUP. The LAN switch directs all inter-component messages and commands to the appropriate destination.

Archive IV device

Archive IV data and a site's adaptation data are recorded to CD media using a CD-RW drive.

Printer

A network-capable, postscript color printer is part of the standard configuration.

Uninterruptible power supply

An UPS provides uninterruptible AC power for the small OPUP equipment, except the printer and secondary monitor, if supplied. The UPS comes with Powerchute software which supports automatic shutdown and also allows the OPUP Manager to monitor the UPS performance.

Monitor

The small OPUP, being a stand-alone system, includes a dedicated 21" CRT or 19" LCD color monitor for product data display and for system maintenance and administration.

218. User Interfacing

The OPUP processors use the UNIX operating system. One advantage of UNIX is its ability to perform multi-task processing, which enables the OPUP system to perform a variety of tasks simultaneously. User interaction is done through the Common Desktop Environment (CDE) Graphic User Interface (GUI) by a keyboard and mouse.

Keyboard

A keyboard is required for the entry of user logins, adaptation, routine product set (RPS) lists names, etc. The alphanumeric keyboard has a number of different types of keys used to enter and/or manipulate alphanumeric data on the GUI. These keys work the same way they do on a standard PC.

Mouse

The main cursor control/command selection device for the OPUP is the three button SUN Micro-system mouse. This mouse tracks and responds like any other standard PC-type mouse, with the exception that this mouse has three buttons.

Left button

Generally, the left button is the "selection" button. Placing the cursor over the desired icon/selection and pressing the left button "executes" that selection.

Right button

Depressing the right button displays application-specific properties menus.

Middle button

Like the left button, the middle button may be used as a "command selection" button in some applications. For this version of the OPUP, the middle button is seldom used.

The use of graphic icons to execute commands and functions is used extensively. The design is based on the familiar window-like graphical user interface that is prevalent throughout the computer world. The Status and Control Function and the Product Display Function are two GUIs that you need to be familiar with in order to operate the system. We will get more in depth in a later unit.

Status and Control GUI

The Status and Control GUI (fig 2–7) was designed to support operations and management by providing a single application interface for system status monitoring, communications, alert, and product acquisition control for the OPUP system. It is divided into three areas: the launch bar, the tab display area, and the status area. The launch bar hosts buttons that launch other OPUP applications. Activation of the Product Request GUI and Alert Request GUI can be done from either the launch bar or the Front Panel Icons.

Product Display GUI

The WSR–88D products are displayed and manipulated for analysis and interrogation by the Product Display GUI (fig 2-8). The display technology incorporated into the OPUP applications software will allow up to 12 independent product display windows per screen. The operator has the ability to specify size and screen location and treat each window as an "autonomous" display allowing the operator to specify the product type, source RPG, magnification, overlays, loop, and so forth.

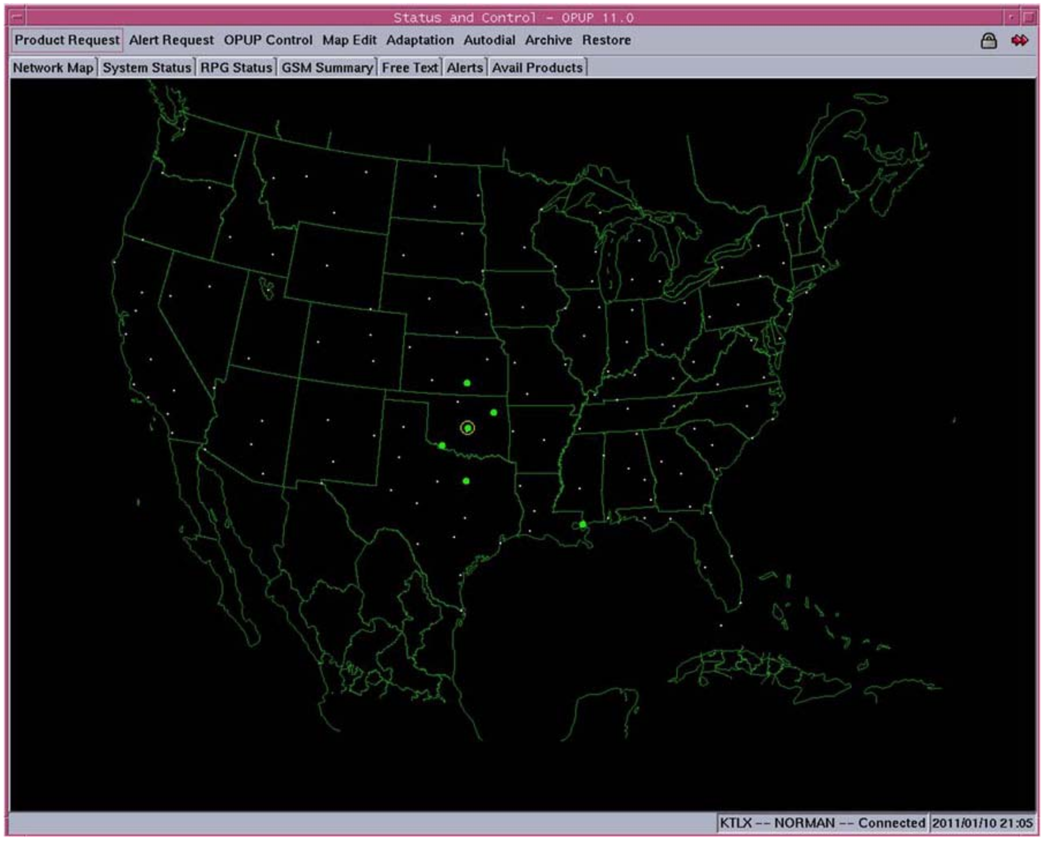

Figure 2–7. Status and Control GUI menu.

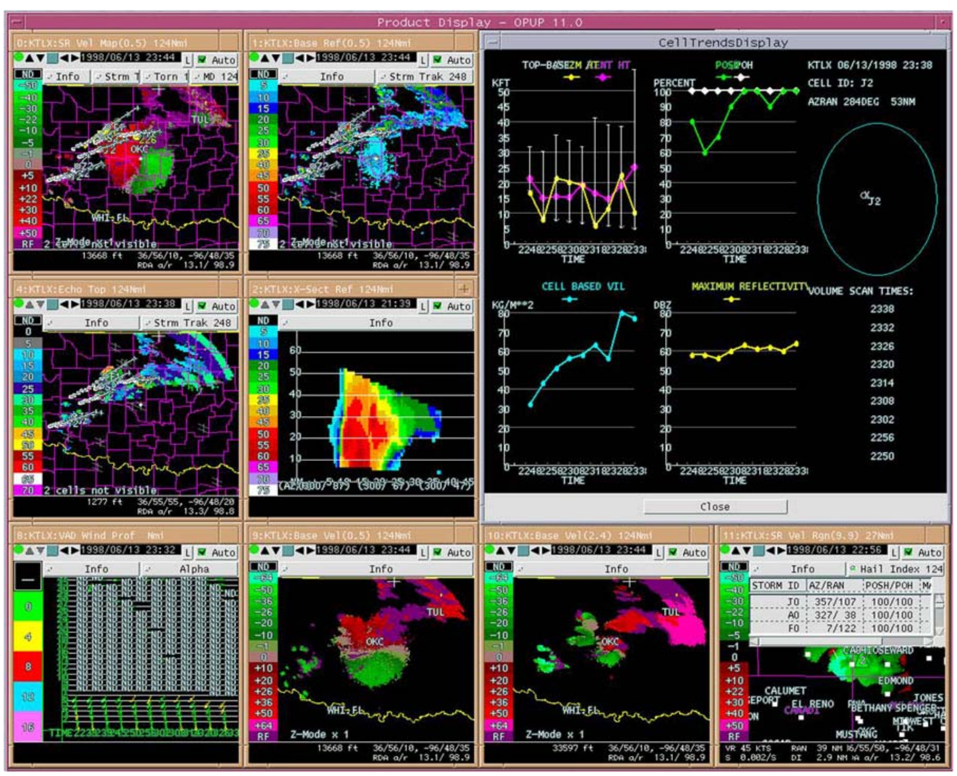

Figure 2–8. Product Display.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

214. Hardware description

1. Which algorithms are processed within the central processing unit?

2. What RPG storage device can store up to three months or over 600 megabytes of product data?

215. Master system Control Function (MSCF)

1. Where is control of the RPG executed?

2. Name two functions used by the MSCF to interface with the RPG.

216. RPG data flow and processing

1. What are the different types of base data the RPG receives from the RDA via wideband communications link?

2. What functions are performed by the signal processing algorithms?

3. What are ports for narrowband links designated as?

217. Description

1. Match the description in column B to its correct Large OPUP component in column A. Column B items may be used more than once.

Column A	Column B
____ (1) Narrowband communication equipment.	a. Supports transmission speeds up to 14.4 kbps.
____ (2) Dedicated modem nest assembly.	b. Directs all inter-component messages.
____ (3) Router.	c. Ensures non-stop Alternating Current (AC) power.
____ (4) LAN switch.	d. Uses 2 UltraSparc 1.2 Ghz processors.
____ (5) Sun 280R server.	e. Provides data transfer between OPUP system and local base LAN.
____ (6) Uninterruptible power supply.	f. Includes dedicated nest assembly, dedicated modems and a Cisco Router.

2. What are the three OPUP configurations and where are they located?

218. User Interfacing

1. What is the advantage to using the UNIX operating system?

2. What are the three areas that the Status and Control GUI is divided into?

Answers to Self-Test Questions

212

1. At the RDA.
2. The antenna, pedestal, radome, transmitter, receiver, and signal processor.
3. The particular volume coverage pattern (VCP) being used.
4. The height depends on the location of the RDA to any nearby obstructions.
5. It takes the raw analog data from the receiver and processes it into a digital base data.

213

1. A near zero Doppler velocity and small spectral dispersion.
2. It uses the target ranges found from the low PRF to properly place the velocity and spectrum width data gathered at high PRFs.

3. VCP 21.
4. VCP 31 uses a longer pulse and a lower PRF to allow more power per pulse, resulting in increased sensitivity. VCP 32 uses a shorter pulse and a higher PRF to increase the Nyquist co-interval, therefore increasing the velocity resolution of the sample.

214

1. Velocity dealiasing and system algorithms: auto PRF, alert processing and loadshedding/product priority.
2. Magnetic disks.

215

1. The Master System Control Function (MSCF).
2. A monitoring function and an RPG system control function.

216

1. Reflectivity, radial velocity, and spectrum width.
2. Clutter filtering, range unfolding, and velocity dealiasing.
3. Dedicated and dial-up.

217

1. (1) f.
   (2) a.
   (3) e.
   (4) b.
   (5) d.
   (6) c.
2. Large OPUP located at four centralized forecast facilities across the United States. Medium OPUP located at centralized forecast facilities in the Pacific for the Air Force and East and West Coasts for the Marines. Small OPUP at select Air Force locations.

218

1. Its ability to perform multi-task processing. This enables the OPUP system to perform a variety of tasks.
2. The launch bar, the tab display area, and the status area.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

31. (212) The beam width of the WSR–88D is *approximately*
    a. 0.1°.
    b. 0.5°.
    c. 1.0°.
    d. 10°.

32. (212) Which subcomponent of the radar data acquisition (RDA) takes raw analog data from the receiver and process it into a digital base data?
    a. Antenna.
    b. Receiver.
    c. Transmitter.
    d. Signal processor.

33. (213) Solid (ground clutter) return has very low spectrum width values ranging from
    a. 0.1 to 0.5m/sec.
    b. 1.5 to 2.5m/sec.
    c. 3.0 to 4.0m/sec.
    d. 4.0 to 5.0m/sec.

34. (213) Data thresholding occurs at the
    a. graphic user interface (GUI).
    b. volume coverage pattern (VCP).
    c. radar data acquisition (RDA).
    d. principal user processor (PUP).

35. (213) How many elevation slices does both volume coverage pattern (VCP) 31 and VCP 32 (clear air mode) complete in ten minutes?
    a. Three.
    b. Five.
    c. Seven.
    d. Nine.

36. (214) How many hours does the JAZ drive have the capability to hold?
    a. 300.
    b. 450.
    c. 600.
    d. 1200.

37. (215) Control of the radar product generator (RPG) is accomplished from a computer terminal known as the
    a. routine product set (RPS).
    b. radar data acquisition (RDA).
    c. principal user processor (PUP).
    d. Master system control function (MSCF).

38. (215) Who owns the MSCF at a majority of the CONUS locations?
    a. Operational Weather Squadron (OWS).
    b. National Weather Service (NWS).
    c. DOD Weather Station.
    d. Air Force Weather Agency (AFWA).

39. (216) How is data transferred from the radar product generator (RPG) to an Open Principal User Processor (OPUP)?
    a. By satellite.
    b. Through a high frequency antenna.
    c. By the wideband communications link.
    d. By the narrowband communications link.

40. (217) What is the *maximum* number of workstations a large Open Principal User Processor (OPUP) can consist of?
    a. 5.
    b. 7.
    c. 10.
    d. 15.

41. (217) Which system supports direct connections to up to seven WSR–88Ds?
    a. Large OPUP.
    b. Medium OPUP.
    c. Small open principal user processor (OPUP).
    d. Master system control function (MSCF).

42. (218) The open principal user processor (OPUP) uses which operating system and user interaction is done through the common desktop environment (CDE) Graphic User Interface (GUI) by
    a. Unix; graphic tablet and puck.
    b. Windows; graphic tablet and puck.
    c. Unix; keyboard and mouse.
    d. Windows; keyboard and mouse.

43. (218) The open principal user processors (OPUP) product display window can display up to how many windows per screen?
    a. 4.
    b. 8.
    c. 12.
    d. 16.

Please read the unit menu for unit 3 and continue ➔

Unit 3. Radar Products

THIS UNIT PROVIDES an operational description of the Weather Surveillance Radar 1988–Doppler (WSR–88D) base and derived meteorological products. The first section deals with base products and the second, strictly with derived products. The lesson covering each product contains its description and its operational characteristics, information covering the product's intended operational use, and the known operational considerations. The third section in this unit is a brief overview of dual polarization radar and the products available with this emerging technology.

3–1. Base Products

The three base products of the WSR–88D are reflectivity, velocity, and spectrum width. In this section we look at all three products, including a description of the products and some operational uses of those products.

219. Base reflectivity

The WSR–88D produces over 60 different products and base reflectivity is one of most widely used. It's the oldest of all the products available on the radar, dating back to the 1940s, when the only radar data was an image of backscattered energy (reflectivity). It was a breakthrough product back then, and today it's still an integral part of the radar's output. In this lesson, we look at the base reflectivity product and discover the vast amount of meteorological information it can provide.

Product description

The base reflectivity product provides displays of reflectivity in a geographical (map-like) presentation for each elevation angle of the particular volume coverage pattern in use. The displays are presented on the OPUP monitor and provide much higher resolution than previous radars.

One base reflectivity product is available for each resolution per elevation slice. The presentation is a polar coordinate pixel image of the reflectivity data (fig. 3–1).

The base reflectivity has a resolution and coverage of 0.54nm (1km) out to 124nm, and 1.1nm (2km) out to 248nm. A 2.2nm (4km) product is also available.

The base reflectivity product is used for a *bird's eye* view of meteorological events within the 248nm coverage area. It provides an easy correlation between meteorological targets and their geographical location.

Use of base reflectivity

Use and interpretation of WSR–88D base reflectivity products is really no different from previous radars. Since the WSR–88D uses high-resolution color displays, it is easier to analyze for features that previously hid themselves on old monochrome radars. Features such as high reflectivity storm cores, strong reflectivity gradients, and embedded thunderstorm activity show up quite nicely on the color displays. With the WSR–88D's extreme sensitivity, you may even see reflectivity returns from optically clear air. In clear-air mode, the radar looks as low as –28dBZ for reflectors such as insects, pollen, dust, salt, density discontinuities, and anything else that may backscatter even the smallest amount of energy. This information can allow you to see things like dry frontal boundaries, outflow boundaries from distant storms, sea breezes, and more.

Reflectivity signatures

For practical applications, most returns of less than 18dBZ are considered non-precipitable and are often just cloud droplets or other minute scatterers. However, besides the uses mentioned above, you can use these returns to estimate cloud heights. During operational testing of the WSR–88D, pilot reports were used to verify these height measurements. It was found that the radar could provide accurate heights of most cloud decks, even that of cirrus. As you can see, reflectivity data collected by the WSR–88D allows you to analyze for a vast number of meteorological elements, some of which were absolutely invisible to you in the past. Now let's take a closer look at some of these useful reflectivity features.

Hook echoes

The hook echo (fig. 3–2), or figure six as it is sometimes called, is a classical radar signature often associated with tornadic activity. The hook is formed by a cyclonic swirl of precipitation around the intense, rotating updraft of the tornado vortex. The hook is not the actual tornado, but rather the return from this precipitation wrapped around the vortex. Often the actual hook echo is obscured by surrounding precipitation, thus making detection difficult at best. Figure 3–2 displays multiple hook echoes. Obviously this is a textbook case and not all tornadoes produce hooks this evident. Notice the storm northwest of the radar. It has a core and strength of >60dBZ and the hook shows a return of about 55dBZ. Let's look at some more facts concerning the hook echo.

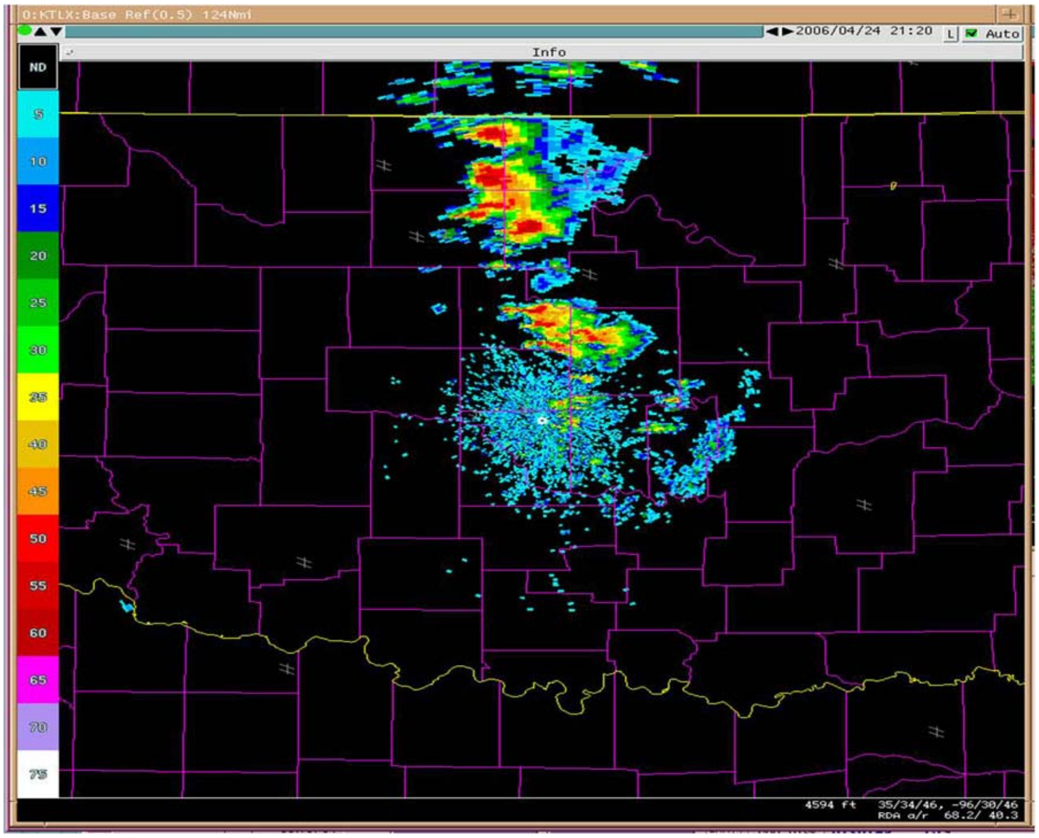

Figure 3–1. Base reflectivity.

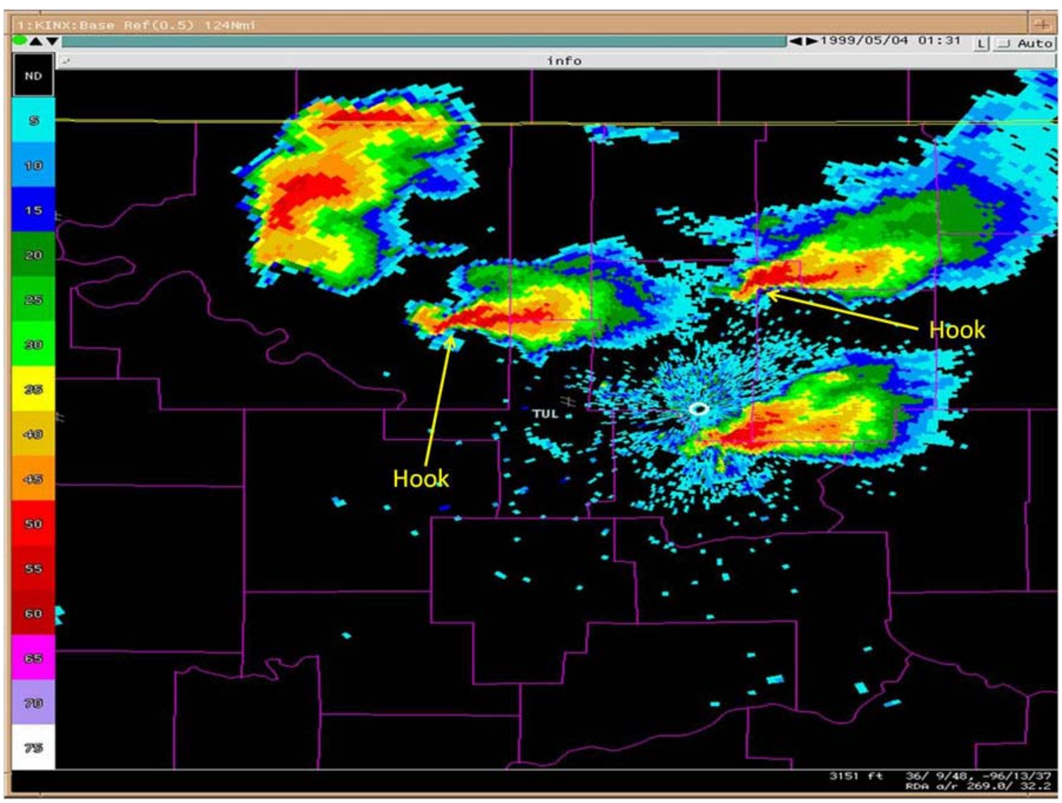

Figure 3–2. Base reflectivity (hook echo).

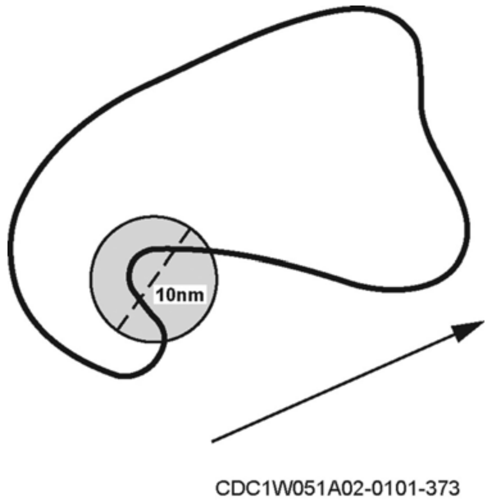

Figure 3–3. Hook location in parent storm.

Location and size

The hook is located in the trailing half of the parent echo with respect to its motion and occurs most often in the right rear quadrant. It is a small-scale feature having a dimension of about 10nm or less from the main body of the storm to the farthest extremity of the hook (fig. 3–3). This distance should never exceed 15nm. Vertical extent can be through the mid-level of the storm sometimes exceeding 35,000 feet. Normally we look for it at the lowest elevations possible.

Hook vs. tornado occurrence

Several studies have been done to correlate hook recognition and actual tornado occurrences. One study reported that of 46 hooks identified, 40 had confirmed tornadoes; the other six produced either a funnel cloud or large hail. Keep in mind there are several factors that make the hook echo a difficult signature to identify. These include: its relatively small size and short duration, the possibility of being hidden in surrounding precipitation, likelihood of being missed completely at longer ranges because of beam broadening, or simply that the tornado decides not to provide us with this nifty classical signature. As you'll see later, the WSR–88D's velocity products provide a more reliable tornadic signature. However, if you can find evidence on more than one product, that is all the better.

Strong reflectivity gradients

In-depth studies by Mr. Leslie R. Lemon have pointed out the importance of strong reflectivity gradients in the low levels of a thunderstorm (fig. 3–2). These gradients are especially important when related to upper-storm features such as overshooting tops or mid-level overhang. In the past, locating strong gradients with non-color radars was very difficult. Refer again to the storm northwest of the radar in figure 3–2. You can see the strong gradient of reflectivity values on the southwest side of the storm. Notice the values decrease from the core of >60dBZ (darker red), to 55dBZ (lighter red), through the yellows, greens, and blues. Values continue to decrease until they are below the threshold of 5dBZ. The key here is that values decrease from 56dBZ to near zero in a very short distance, thus creating a very strong reflectivity gradient.

According to research by Lemon and others, if the mid-level overhang of the storm extends at least 3.2nm (6km) beyond this low-level gradient and the highest echo top is on the storm flank that possesses the overhang, an extremely high potential exists for severe weather occurrence. As you monitor the development of individual thunderstorms, keep an eye on this important gradient. Usually, as the storm becomes stronger and potentially more deadly, this gradient becomes more evident and may eventually exhibit the classic hook shape.

Line echo wave patterns

A line echo wave pattern (LEWP) (fig. 3–4) is simply a line of radar echoes subjected to acceleration along one portion of the line. LEWPs show up quite nicely on WSR–88D displays because the actual line of convection is displayed even if it's surrounded by stratiform precipitation. With non-color displays, the radar operator tended to merge all the activity into one large area and overlook the pattern of the echoes within.

A LEWP indicates a favorable environment for severe weather development. Although a LEWP hardly guarantees severe weather will occur, if other factors are favorable, it can be interpreted to indicate tornadoes, hail, and high winds. The most severe weather is normally expected at, and slightly south of, the crest. Severe weather occurs along this portion of the line because it is being pushed further and faster than adjacent portions. This acceleration is often caused by a meso-high located behind the LEWP. The speed of the LEWP can be an indicator of its severity since the fastest moving convective echoes tend to be the most severe.

Embedded thunderstorms

Have you ever had the unpleasant surprise of hearing thunder from what you thought was only a stratiform cloud deck? The WSR–88D helps you get rid of this menacing problem. The higher reflectivity values and color gradients allow you to see these embedded thunderstorms easily (fig. 3–5). Also, since the WSR–88D uses a 10cm wavelength, less attenuation occurs in the stratiform precipitation. As a result, these embedded storms are quickly located and their intensities accurately measured. This improves your ability to identify and track these once hidden thunderstorms. Pilots of aircraft not equipped with airborne radar appreciate this unique briefing tool.

Outflow boundaries

An outflow boundary (fig. 3–6) is the leading edge of horizontal airflow resulting from cooler, denser air sinking and spreading out at the ground.

Currently, we rely on satellite data to detect these outflow boundaries. However, often we cannot see them, because of high cloud cover or poor resolution. Also, to see outflows on METSAT imagery, clouds must be present. With the WSR–88D, we can see the outflow even if no clouds are present because of the gradient in the refractive index. The WSR–88D detects signal returns down to –28dBZ. Remember that precipitable moisture usually provides a minimum return of +18dBZ. These outflow boundaries were usually invisible on previous radars unless the density contrast was very abrupt, or some clouds or precipitation accompanied them. Now, using the WSR–88D, we can locate and track the movement of these outflows to better predict phenomena, such as enhanced thunderstorm development, low-level wind shear, and strong straight-line winds.

Melting level

The WSR–88D can detect the melting level (fig. 3–7) during the presence of a widespread stratiform cloud deck. The melting level is that level where frozen precipitation particles melt during their descent to the surface. When the frozen particles begin to melt, they become coated with water and provide a much stronger return than either the frozen particles above or the liquid droplets below. This level may be seen on WSR–88D reflectivity displays. It appears as a ring, or partial ring, of enhanced reflectivity around the radar data acquisition (RDA). Factors that may preclude seeing the melting level include: too few clouds present at the melting level, disruption of the melting level by some form of turbulence or convection, and heavy precipitation that may saturate the display.

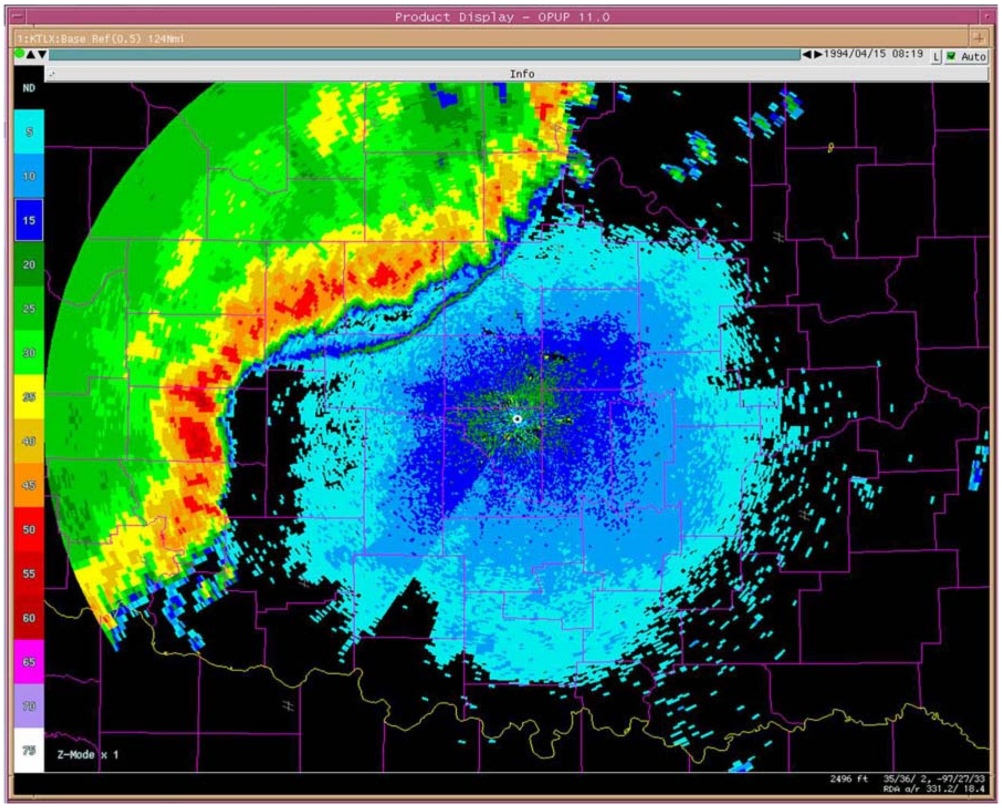

Figure 3–4. Base reflectivity (LEWP).

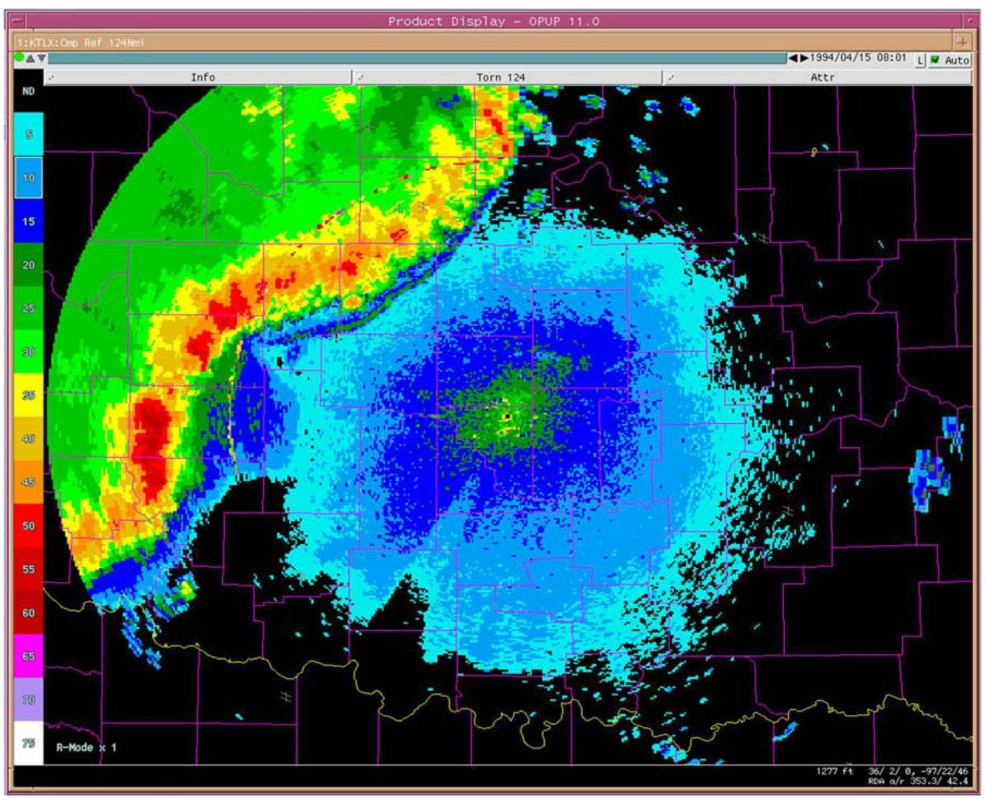

Figure 3–5. Composite reflectivity (embedded thunderstorms).

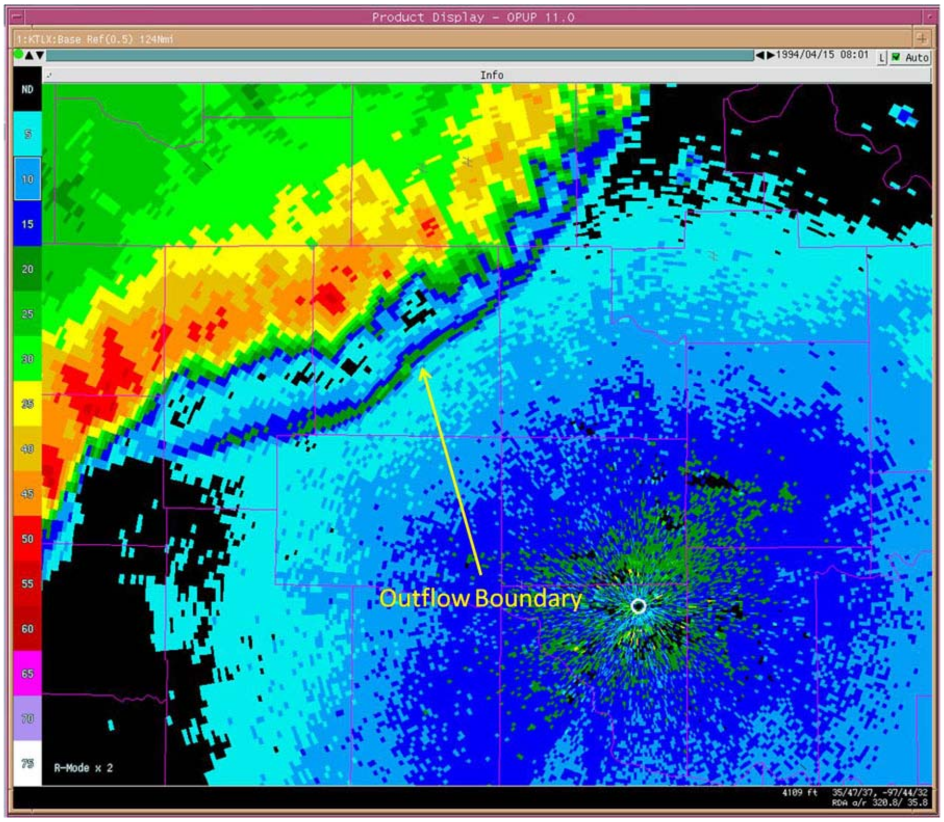

Figure 3–6. Base reflectivity (outflow boundary).

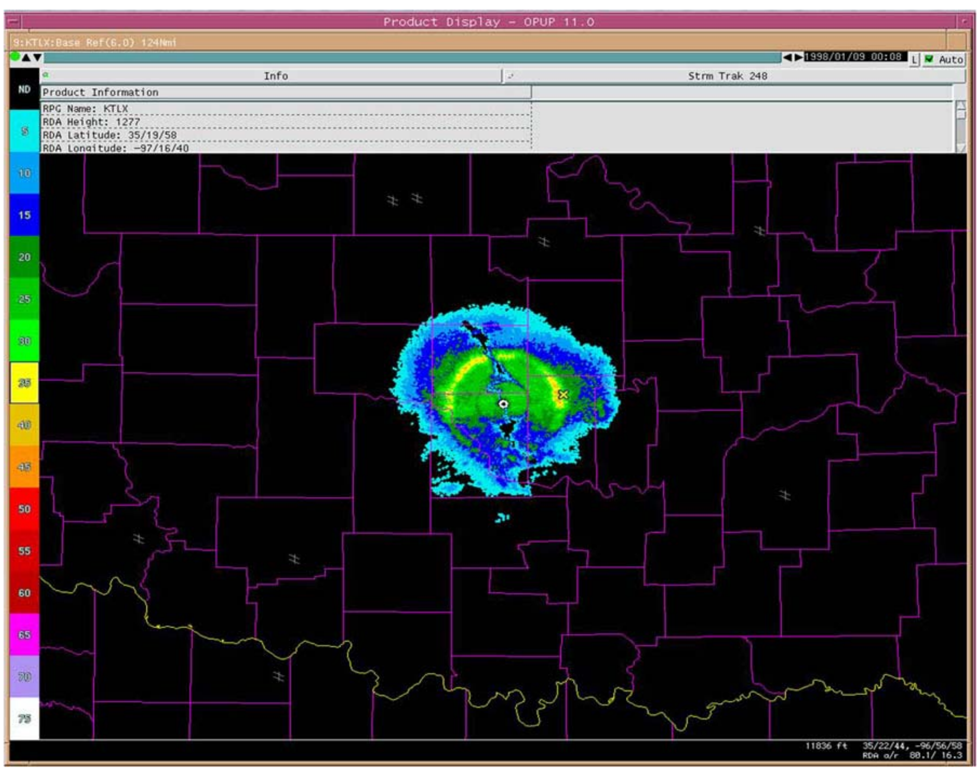

Figure 3–7. Base reflectivity (melting level).

220. Base mean radial velocity

Decision time is rapidly approaching—what kind of warning will you issue? Can this thunderstorm produce a tornado? What is happening inside this storm? These were questions you could only ponder with the previous weather radar systems. Today, the WSR–88D brings us a new dimension in severe weather forecasting. Using the base velocity product, the radar operator can now interrogate motions in and around potentially severe weather-producing storms.The WSR–88D not only aids in severe weather forecasting, it also aids in everyday forecasting decisions. Imagine being able to interrogate the vertical wind profile every couple of minutes; the WSR–88D gives you this capability. With the mere click of a button, an up-to-date velocity display is available for your inspection.

Although a single Doppler radar measures only the component of the wind parallel to the beam, a great deal of horizontal and vertical weather features are identifiable. In this lesson we describe the velocity product and cover some of its uses.

Product description

The base velocity product presents the mean radial velocity data. By measuring the Doppler shift of the reflected radiation, the radial component of the velocity toward and away from the radar antenna is determined. This product is displayed in several combinations of coverage and display resolution; each product is available for 8 and 16 data levels. A separate product is available for each elevation angle in the current volume coverage pattern (VCP).

The presentation of the mean radial velocity data is by a polar coordinate pixel image (fig. 3–8).

The resolution and coverage are 0.13nm × 1° out to a 32nm radius, 0.27nm × 1° out to a 62nm radius, and 0.54nm × 1° out to a 124nm radius.

Mean radial velocity data is used to detect and locate rotating thunderstorms, determining wind field characteristics, and as a supplement to derived products.

The effective use of the mean radial velocity data requires a high skill in data interpretation. Below threshold reflectivities, range folding and aliasing (if present) limits the data coverage.

Theory

Previously, you learned that the base velocity product exists because the WSR–88D can detect Doppler phase shifts based on the radial motion of targets in the radar viewing area. If you must, refer to the lesson on Doppler radar principles to refresh your memory on the concepts of Doppler shift, radial velocity, Doppler dilemma, range folding and velocity aliasing and dealiasing.

Uses of base radial velocity product

As mentioned earlier, use of base velocity products ranges from everyday routine weather station operations to severe weather forecasting. Determining vertical wind profiles is accomplished using the entire product display, while individual storm features are determined by focusing in on a small area of the display. During this lesson, we provide an introductory look at velocity interpretation, then specific uses of the velocity product.

Identify vertical variations

While examining the WSR–88D velocity display for vertical variations in the wind field, several significant features can be identified. Although the atmosphere produces millions of differing vertical profiles, time restraints allow us to only look at a few. They are veering and backing winds, low-level and mid-level jets, turbulence, frontal boundaries, and overrunning. Remember that cool colors indicate inbound velocities while warm colors indicate outbound velocities. Also remember that to determine wind direction, the radar operator must reference the Doppler zero line.

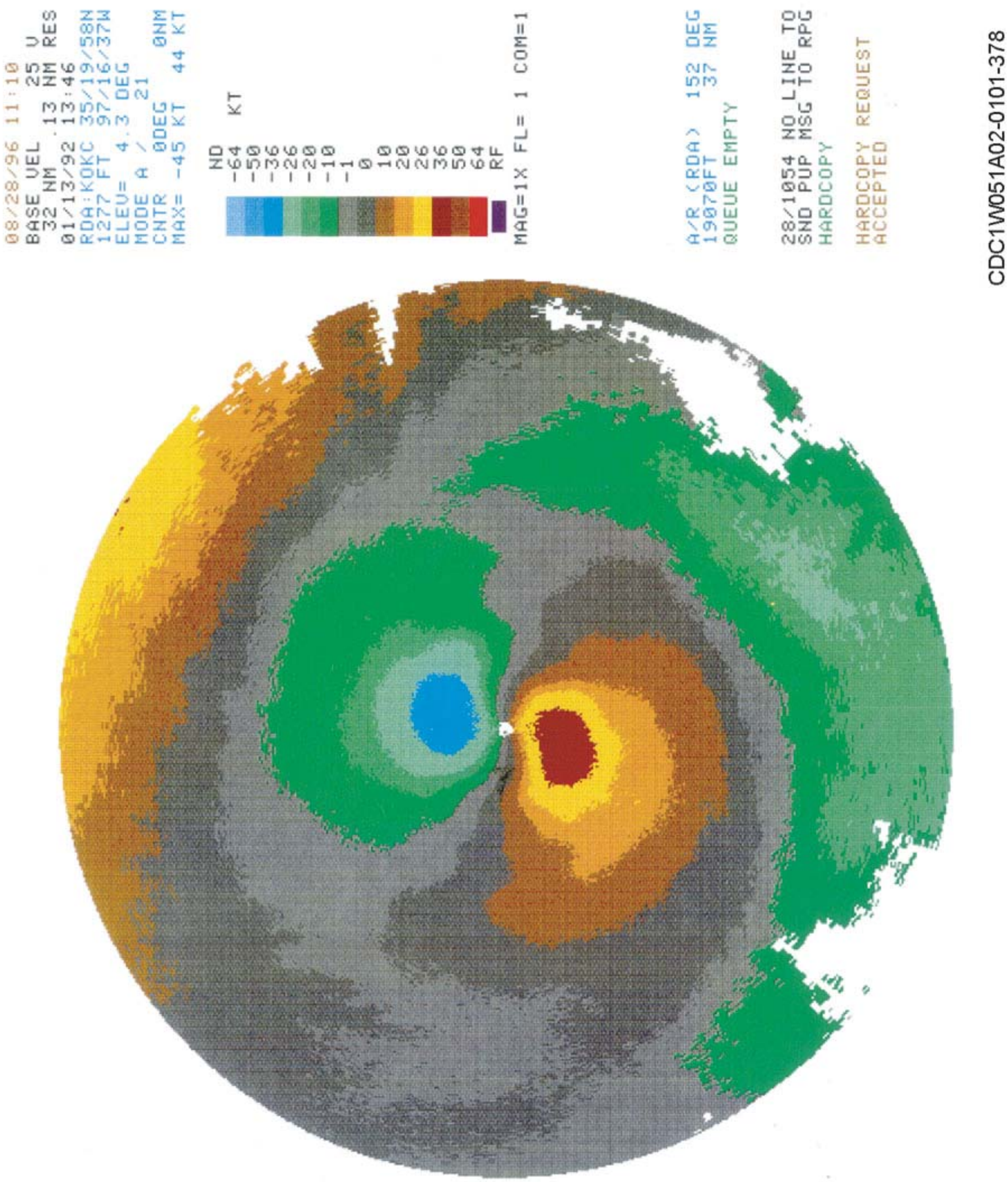

Figure 3–8. Base velocity.

Veering winds with height

Veering winds with height (representative of warm-air advection) produce a very distinct pattern. Whenever veering winds are encountered, the Doppler zero line takes on a noticeable S-shaped pattern (fig. 3–8).

Backing winds with height

Backing winds with height (representative of cold-air advection) also produce a distinct pattern. Whenever backing winds are encountered, the Doppler zero line takes on a noticeable backward S-shaped pattern (fig. 3–9).

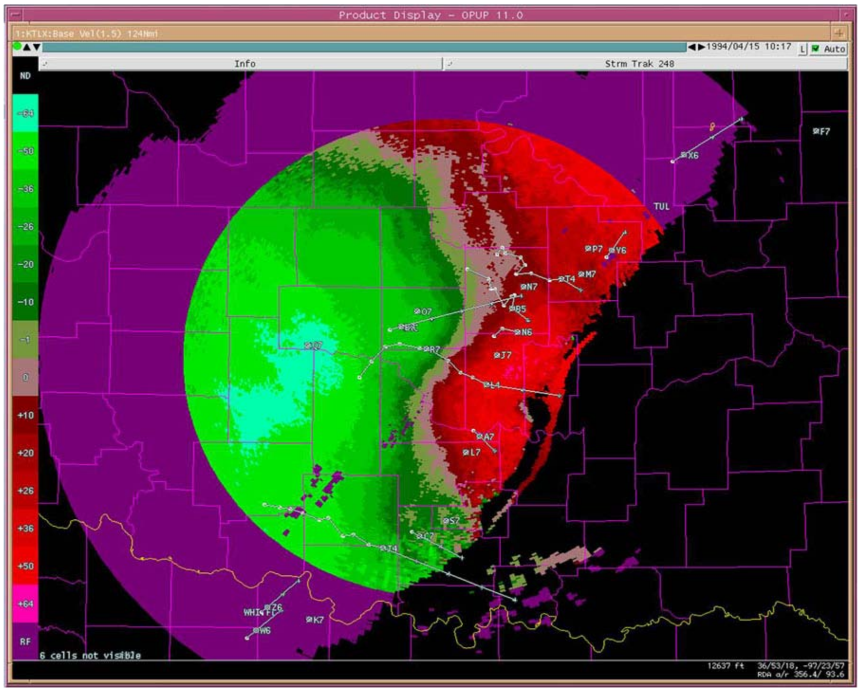

Figure 3–9. Base velocity (backing winds).

Low-level and mid-level jets

Whenever the speed profile has a speed maximum or jet within the display, there is a pair of closed contours 180° (directly opposite) from each other (fig. 3–10 contains both a low-level and mid-level jet). The height of the maximum value is computed using the antenna elevation and the slant range to that point. The WSR–88D, on request, calculates this for you and displays it in the legend area.

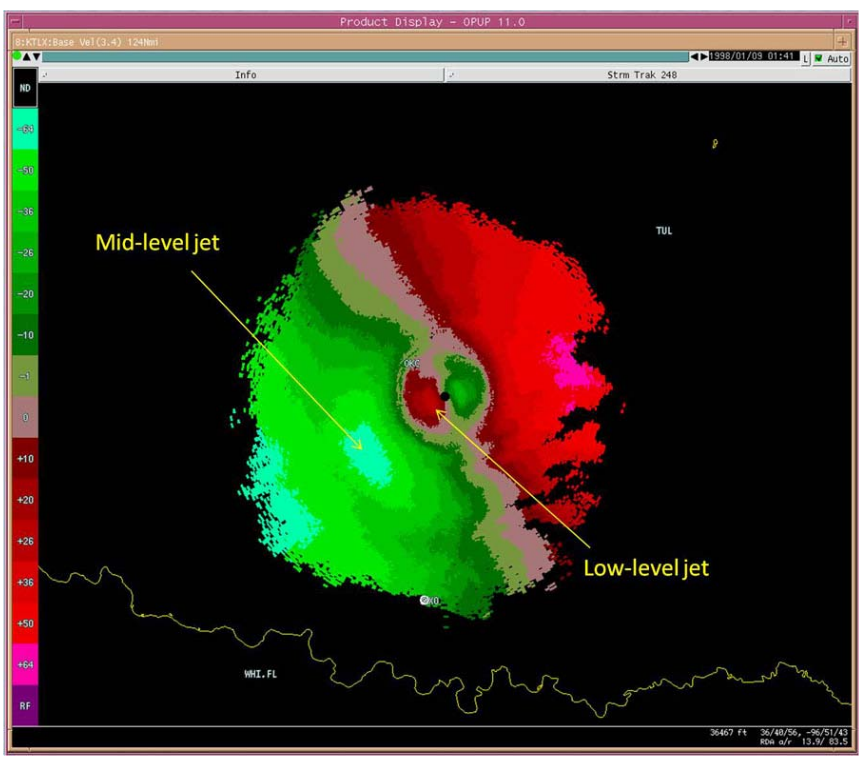

Figure 3–10. Base velocity (low-level and mid-level jets).

Turbulence

Abrupt changes in wind speed and/or direction are associated with turbulent air (fig. 3–8). The depth and height of the turbulent layer are obtained using antenna elevation and slant range to that point.

Frontal boundaries

With adequate radar returns, it is possible to determine the wind field both ahead of and behind a front. Figure 3–11 clearly shows a frontal zone transitioning from northwest-to-southeast of the radar location. The frontal zone is marked by a rapid change in wind direction over a very short transition region. In all three examples, wind direction is northwesterly behind the front and southwesterly ahead.

Overrunning

Wide-scale overrunning, signifying the dynamics for a large-scale precipitation event, is readily seen using the WSR–88D's velocity display. Figure 3–8 shows overrunning conditions over Oklahoma City (OKC) that lead to a significant precipitation event (over 2 inches at OKC). Note the strong northeast-to-east winds in the lower levels with strong southwesterly winds aloft.

Identify horizontal variations

Doppler velocity displays, when focusing in on a small area, are used to determine individual storm signatures. Horizontal variations of the wind within convective storms produce single Doppler velocity patterns that reveal important storm characteristics. Three important identifiable storm signatures are convergence, divergence, and rotation. Let's take a closer look at each of these signatures and learn how to identify them using the following figures As discussed in the following paragraphs.

Rotation

Figure 3–12 depicts a zoomed-in area of a rotational signature, as seen on a velocity product. The rotational signature is termed a rotational couplet because the WSR–88D detects the inbound and outbound rotation associated with the signature, which results in a pairing of opposite signed velocities next to one another; hence, the name rotational couplet. In this radar image, the RDA is located to the northwest of the rotational area. Although not oriented perfectly with the picture, the diagram beside it depicts the airflow associated with the signature. In this scenario, this particular rotational area is associated with a mesocyclone, which is a prominent producer of severe weather.

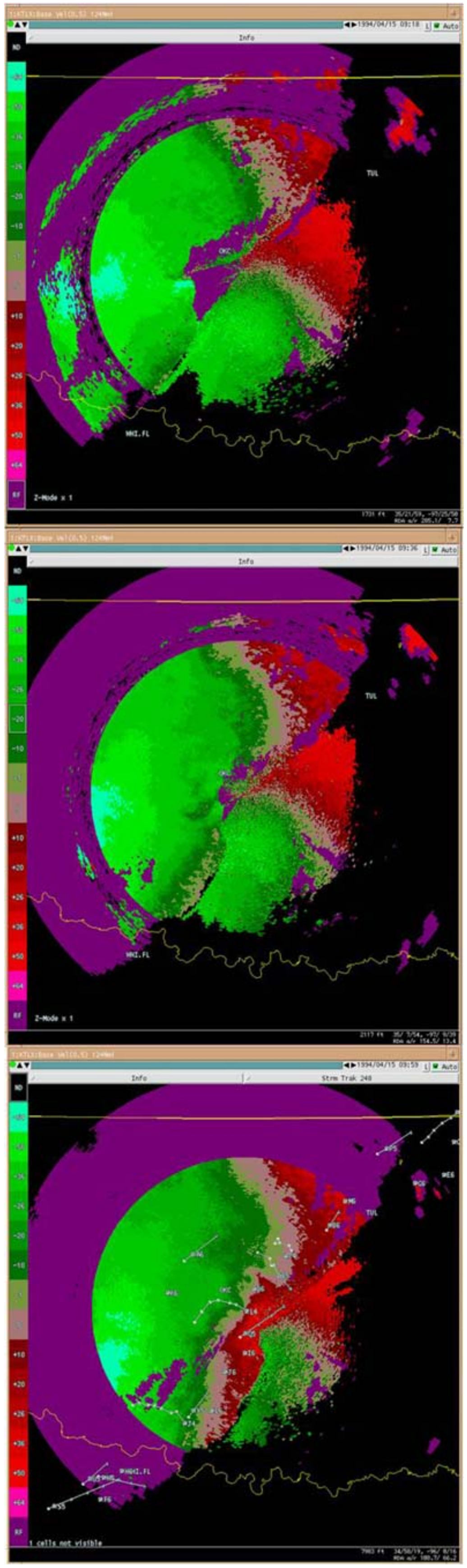

Figure 3–11. Base velocity (frontal passage).

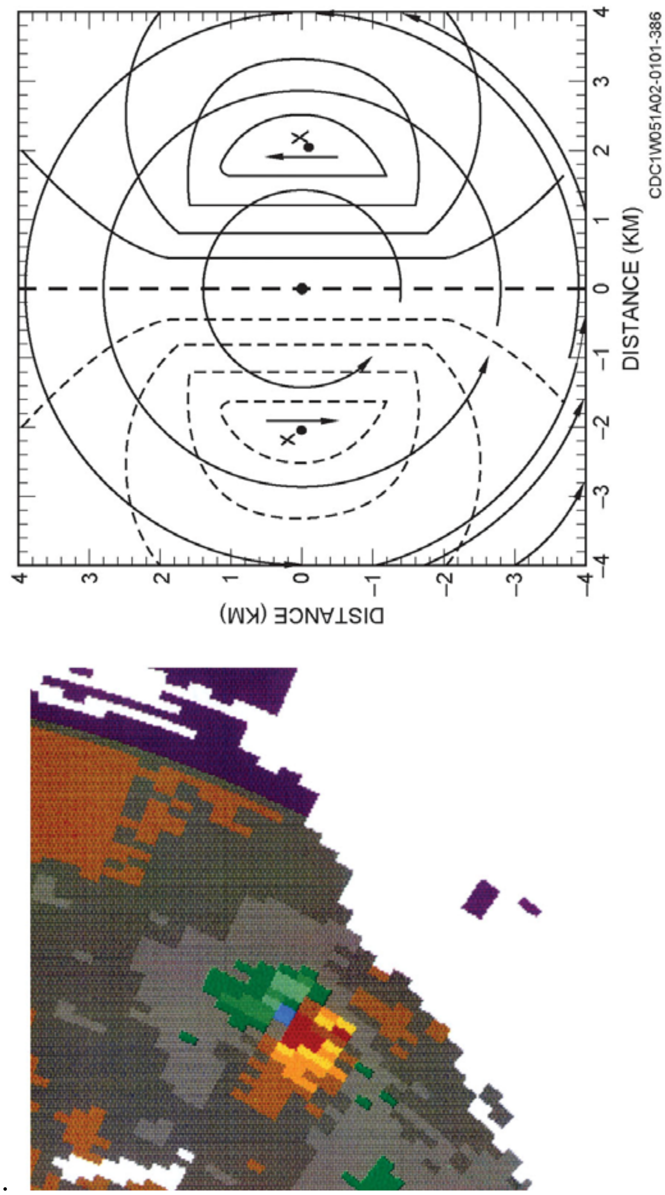

Figure 3–12. Rotation.

Notice the Doppler zero line in the diagram it is oriented parallel to the viewing direction. To the right of the zero Doppler line, flow is away from the radar and the flow on the left is toward the radar. Since a Doppler radar measures only the radial component of the wind, it does not sense all the rotation; it senses only that flow either side of the zero Doppler line, as mentioned above. Due to the rotation, the velocity at the center is zero and increases linearly to a maximum value at the core (point x) and then decreases linearly to the edge, on both sides of the signature.

Therefore, the single Doppler velocity signature of a mesocyclone (or any vortex) has a pattern that is symmetric about the radar viewing direction and has peak values of opposite sign at the core on either side of the circulation center.

Many times the area of perpendicular motion in the signature is smaller in size than the resolution of the radar. When this happens the Doppler zero line is not depicted on the image. This is the case with the rotational couplet in figure 3–12. When the Doppler zero line is not depicted within a rotational couplet it is called an "inferred zero line." If the Doppler zero line were there, it would be located between the inbound and outbound velocity areas.

Divergence

Depicted similarly to rotation, figure 3–13 is a zoomed-in area of a divergent couplet on a base velocity product. The divergent field occurred at the top of a thunderstorm and is accompanied with a black and white diagram detailing the wind flow. In the picture the radar is located to the southeast of the divergent couplet. In a divergent signature, the zero line is perpendicular to the radar viewing direction because the radar does not sense motion toward the left or right of the divergence center.

As with rotation, the zero line may not be depicted and is termed an inferred zero line. Maximum flow toward and away is measured along the viewing direction. Divergent signatures are found near the storm top, above the updraft and near the ground in the precipitation downdraft.

Convergence

The convergence signature in figure 3–14 is a good example of the convergent portion of a thunderstorm. The radar is located to the northwest of the convergent couplet. As with the divergent signature, the convergent signature's zero line is perpendicular to the radar viewing direction and may not be depicted. Convergence signatures are normally found near the surface below the storm's updraft.

As you can see from the three previous examples, the signatures for rotation, divergence, and convergence are all basically the same. The only difference between the signatures is the direction at which you view them. Knowing the location of the radar is crucial to identifying whether a storm signature is convergence, divergence, or rotation.

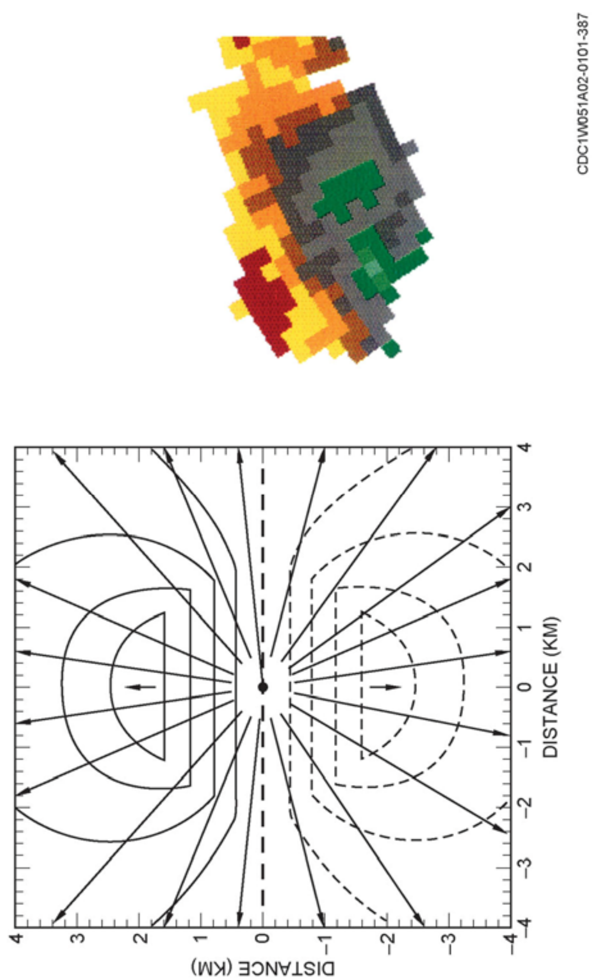

Figure 3–13. Divergence.

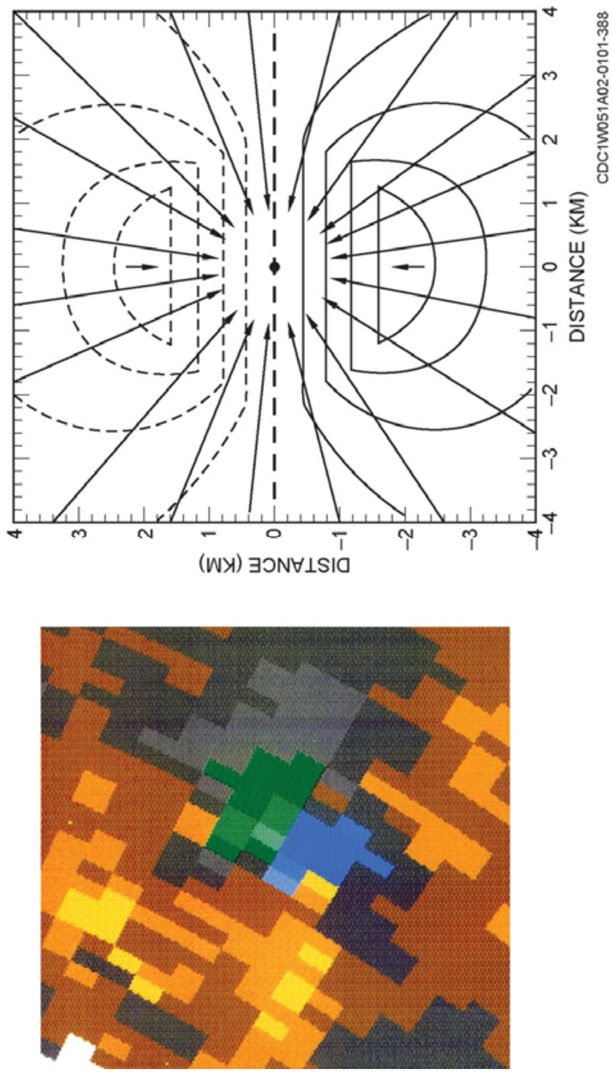

Figure 3–14. Convergence.

Uses of the horizontal variations

While examining the WSR–88D for horizontal variations in the wind (individual storms), several significant features can be identified. They include mesocyclones, tornadic vortex signatures, hail size, microburst/downburst, and much more. Let's look at each of these and see how we go about identifying them.

Mesocyclones

A mesocyclone is a 3-D region in a storm that rotates and is closely correlated with severe weather (fig. 3–15). Notice in the figure, the mesocyclone changes from convergence (upper-left quadrant) to rotation (upper-right quadrant) and finally to divergence (lower-left quadrant) at the top of the storm.

By interrogating several slices of a storm and correlating them three-dimensionally, we can verify the existence of a mesocyclone. Later, in the lesson on the mesocyclone product, you learn the importance of identifying mesocyclones.

Tornadoes

Using the velocity product and locating a rotational field does not alone signify the existence of a tornado. Most tornadoes exist within a preexisting mesocyclone and are usually found in or near the mesocyclone's core (fig. 3–16). Note the tight rotation (point A) within the center of the larger area of rotation. This area of tight rotation is known as a tornadic vortex signature (TVS) and is explained in greater detail in the section on the TVS product.

Hail size

You may be asking yourself how do we determine hail size through the velocity field. Since hail size is directly related to the strength of the updraft within the storm, we can determine size by measuring the updraft. We can measure the updraft by correlating it to the amount of divergence aloft.

The National Severe Storms Laboratory (NSSL) developed a hail size nomogram (fig. 3–17 with step-by-step procedures for determining hail size. (This nomogram was developed for the Oklahoma area and needs adjusting for your location).

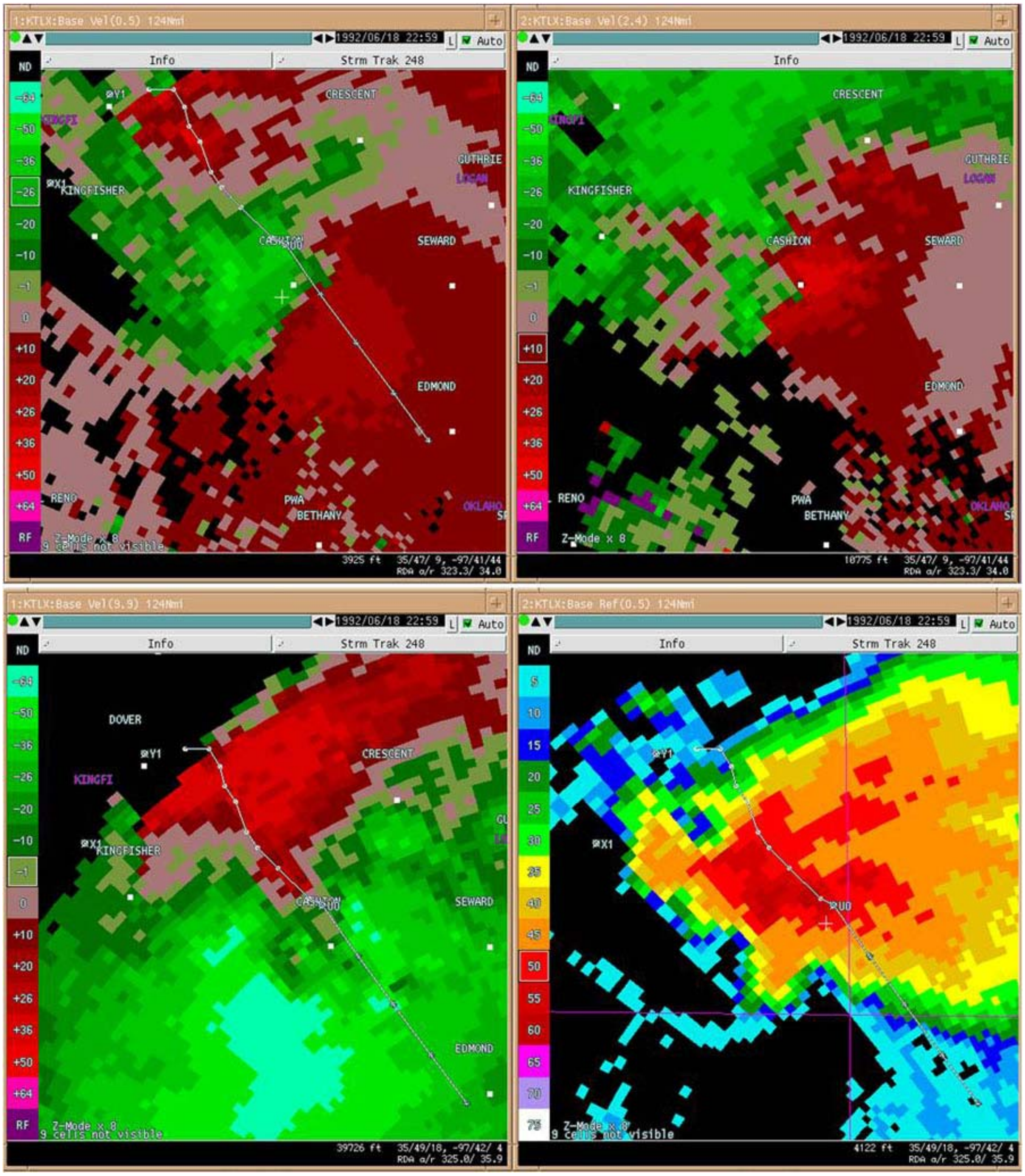

Figure 3–15. Base velocity (quad display of mesocyclone).

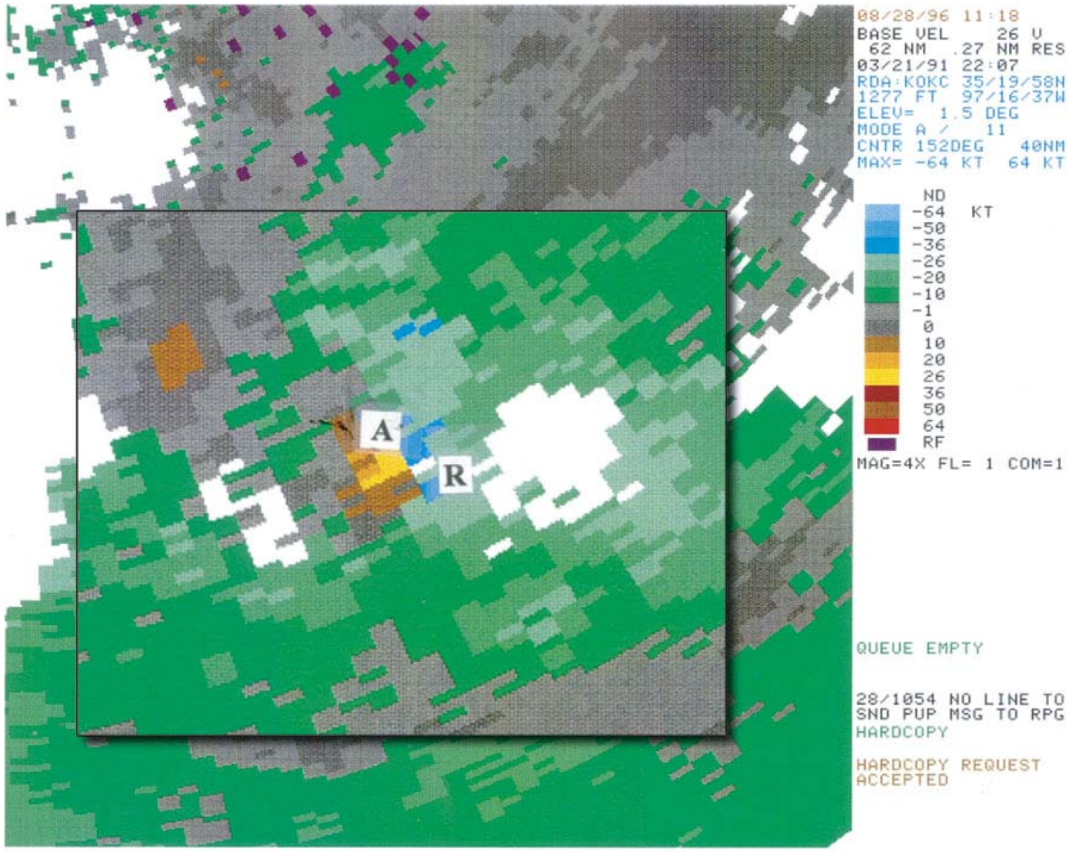

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Figure 3–16. Base velocity (tornado).

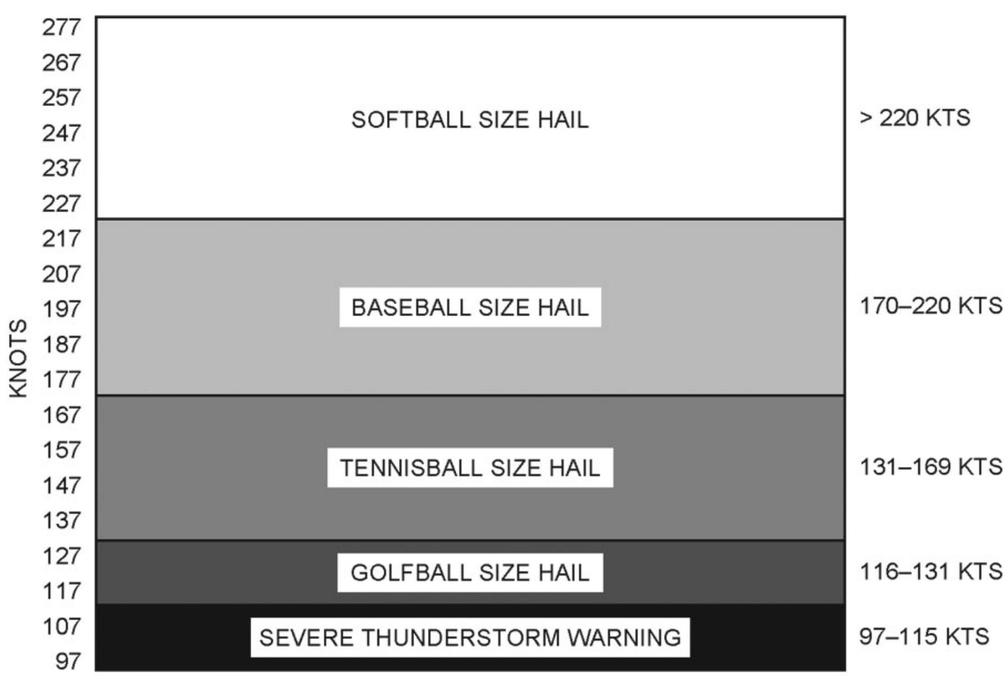

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Figure 3–17 Hail nomogram.

221. Spectrum width

The spectrum width (SW) product is probably the most under-used of the three base products. This is not because it doesn't provide valuable information. It's generally due to the fact that the product is not as straightforward to interpret as the other two base products. Interpretation of the spectrum width is difficult and, as with a lot of things, requires operator skill and experience to really fully exploit its potential. In this lesson, we'll begin with a brief description of the product, and then look at some operational uses.

Product description

The spectrum width product provides displays of the variance of motions within the mean radial velocity field. The product is available for each elevation angle of the particular volume coverage pattern in use. Spectrum width is available in several combinations of display resolution and coverage and is presented in eight data levels using a polar coordinate pixel image (fig. 3–18).

The spectrum width's resolution and coverage are 0.13nm × 1° out to a 32nm radius, 0.27nm × 1° to 62nm, and 0.54nm × 1° to 124nm.

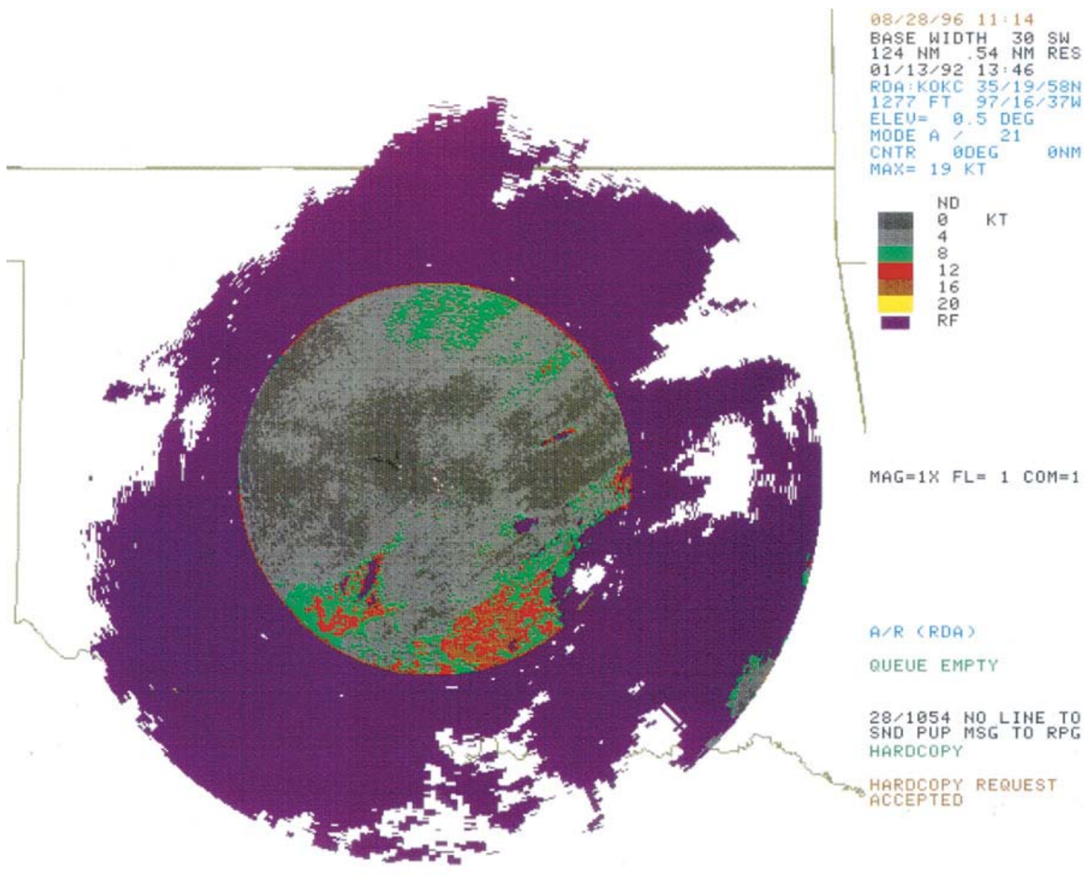

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Figure 3–18. Spectrum width.

Spectrum width is most effective when used in tandem with other products. Some examples are estimating turbulence associated with thunderstorms, frontal boundaries, and clear air. It can also be used to show the validity of mean radial velocity estimates and provides a first look at possible convective development.

Spectrum width requires comparison and verification with other products for maximum utility. Weak signal returns near the noise threshold lead to erratic spectrum estimates and noisy spectrum width data. Antenna size, rotation speed, and the target's characteristics affect the spectrum width values.

Unlike a simple reflectivity display, understanding the spectrum width product is not entirely straightforward. Spectrum width provides information from which you can make inferences about various atmospheric occurrences such as turbulence, wind shear, and the early stages of convective development. It provides assistance in your analysis of atmospheric motions, but it's best used with velocity and reflectivity products.

Review of spectrum width theory

Recall that within a sample volume (fig. 3–19), many particles of varying size, shape, and composition move in different directions and speeds. Within a single sample volume, the Doppler radar doesn't sense each individual motion, but rather, a combination of all the motions. The spectrum width product measures these motions.

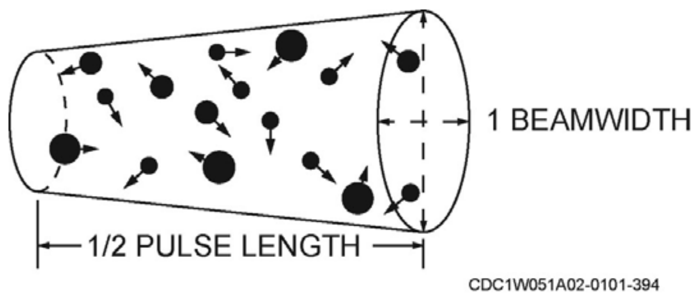

Figure 3–19. Particles in a sample volume.

Use of spectrum width

Despite the fact the spectrum width product is not straightforward, there are many meteorological applications for the product. In this lesson, we look at four specific uses for this product. The uses are verifying areas of suspected turbulence, discovering or monitoring icing conditions, identifying areas of possible convective development, and checking data reliability.

Turbulence

Since spectrum width measures the combination of motions within a sample volume, we can assume turbulence or shear within areas of high spectrum width. This relationship helps verify the existence or nonexistence of turbulence.

Referring back to figure 3–8 you can see a velocity display containing abruptly veering winds and a low-level jet. Using velocity alone, a forecast of light to moderate turbulence from the surface to a point above the abrupt change in wind direction is logical. However, by using the spectrum width product we can refine our turbulence forecast.

Figure 3–18 shows a spectrum width product at the same elevation angle and approximately the same time as our velocity product. Note the high spectrum width values to the northeast and south of the RDA. These high values correspond with the abrupt change in wind direction seen on the velocity product. Note however, that areas associated with the low-level jet maxima contain very low spectrum width values. Therefore, we can assume that there is little or no turbulence associated with the low-level jet itself and our turbulence forecast can be adjusted accordingly.

Icing

Although there is currently no WSR–88D product specifically designed to help in forecasting icing, spectrum width can help. Due to the increased variance in the velocities of the particles within the melting level, the result is high spectrum widths. This area of high spectrum width appears as a ring or partial ring centered on the radar (much like the rings you saw on the reflectivity products). Armed with this information, the forecaster can monitor the height of the melting level (bright band) to help in forecasting icing, and precipitation type.

Convective development

Convective development is often seen on the spectrum width product before any significant returns show up on a reflectivity product. Consider a reflectivity product having a return of 15dBZ. Using reflectivity alone, this echo is considered insignificant. However, if this 15dBZ echo is displayed when spectrum width is displaying high values, closer interrogation is warranted. Since spectrum width measures the variance of motions within a sample volume, these high spectrum width values may be indicating the motions associated with convective currents. High spectrum width with low reflectivities may be your first indication of storm development.

Data reliability check

Spectrum width data is useful for evaluating the validity of mean radial velocity estimates. Because of the motion variability of individual contributing particles, velocity estimates in areas of high spectrum width may be less accurate than those obtained in low width areas. Also, data reliability tends to drop near the edges of echoes where the signal-to-noise ratio can become less than desirable. This effect is often seen by high spectrum width values along the outer edges of these returns.

Limitations

The spectrum width product is not always reliable. Other products, such as the Skew-T diagram and centrally prepared products should be analyzed along with the various WSR–88D products available. Phenomena, such as turbulence, are often localized, transient features that require more than a quick glance at spectrum width to find. Additionally, spectrum width information collected from weak signal returns near the noise threshold leads to erratic spectrum estimates and noisy spectrum width data.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

219. Base reflectivity

1. A hook echo radar signature is formed by what?

2. Where is a hook echo usually located in relation to the parent storm?

3. In what level of the storm should the radar operator look for a hook?

4. The WSR–88D’s 10cm wavelength makes finding embedded thunderstorms in stratiform precipitation easier by reducing what atmospheric problem?

5. How does the melting level appear on WSR–88D single-slice reflectivity products?

6. What factors may prevent detection of the melting level on WSR–88D reflectivity products?

7. Below what measurement of dBZs are most returns considered non-precipitable?

220. Base mean radial velocity

1. A backward S-shaped velocity pattern suggests what type of advection is occurring?

2. What is most likely occurring when a base velocity product displays a rapid change in velocity values over a very short distance with a directional change?

3. The radar is to the south of a velocity pattern with inbound velocities on the left side and outbound velocities on the right side as you look at the pattern. There is a Doppler zero velocity line, oriented north-to-south, separating the inbound and outbound velocities. What does this pattern suggest?

4. The radar is to the north of a velocity pattern with a Doppler zero line oriented west-to-east. On the north side of the zero line, closest to the radar, there are inbound velocities. On the south side of the zero line, farthest from the radar, there are outbound velocities. What does this pattern suggest?

5. What is the best WSR–88D product to use to identify veering winds with height?

221. Spectrum width

1. What does the spectrum width product provide a display of?

2. What can the spectrum width product be used for?

3. Within a sample volume, what does the WSR–88D sense?

4. The maximum returned power is usually at what frequency?

5. In a geographical area where turbulence is suspected, what type of spectrum width values would you expect?

6. What can the spectrum width product identify to aid in forecasting icing?

7. For which product can the spectrum width product be used as a data reliability check?

3–2. Derived Products

All products are generated in the radar product generator (RPG) from processed base data (reflectivity, velocity, and spectrum width). These products are then distributed to open principle user processors (OPUP) where they are stored, displayed, and archived. The RPG produces and transmits the various meteorological products. These products are derived from several fundamental relationships between reflectivity, spectrum width, and radial velocity patterns through use of algorithms. They provide operators with conclusions concerning the locations, movement, and severity of meteorological phenomena. These conclusions are only as reliable as the data from which they derive. Therefore, it is imperative that the operator understands the application and limitation of each derived product.

222. Composite reflectivity

During our lesson on reflectivity, we made the point that the base reflectivity products give us a “birds-eye” view of the radar coverage area. However, never forget that each reflectivity display is only giving us a small sample of the radar coverage area. Each product only gives us a single slice of the atmosphere. If you want to sample the entire volume of your radar coverage, you need to sample each elevation scan. A product that could display all the echoes present, despite where they are in our radar coverage area, would definitely be useful. Composite reflectivity (CR) is one product that can do this for us.

Product description

For a given area on the earth’s surface, the CR product displays an image of the maximum reflectivity above that area. Thus, the value displayed for a given location of the product could come from any of the elevation slices comprising the current VCP. Further, values displayed in adjacent product locations could come from different elevation slices. The product is available in two versions—one with eight data levels and one with 16 with one product per volume scan. The CR presentation is a Cartesian pixel image of reflectivity values (fig. 3–20).

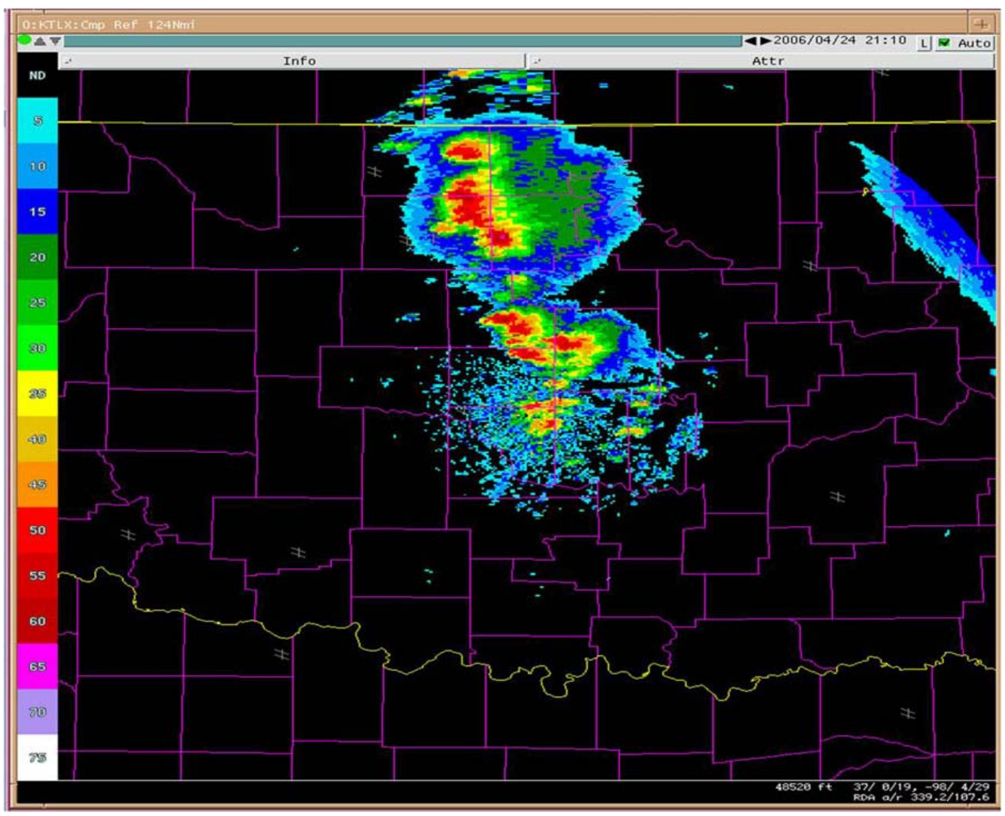

Figure 3–20. Composite reflectivity.

CR resolution and coverage are 0.54 × 0.54nm out to 124nm radius, and 2.2 × 2.2nm out to a 248nm radius.

CR permits a view of the maximum reflectivity levels within the range of the radar. It can be displayed by itself or as a background for overlays. Composite reflectivity allows the user to quickly establish the real extent of reflectivity.

The composite reflectivity product may give non-weather related values because of residual point clutter or anomalous propagation. Some horizontal plane signatures (for example, hook echoes, and outflow boundaries) may not be distinguishable and the CR loses altitude information of the 3-D structures.

The composite reflectivity product is teamed with a detailed overlay, called the combined attributes table, which may provide the information missed by not being able to distinguish horizontal signatures. The combined attributes table is displayed in tabular format directly above the products image (fig. 3–21). It lists the output from several storm algorithms. The attributes of up to 100 storms can be listed in this table. However, only four storms are visible at one time. Storm information from meteorological elements are included in the table. Here is a list of the elements.

- Cell-based vertically integrated liquid water.
- Hail index.
- Maximum DBZ and height of maximum DBZ.
- Mesocyclone Detection Algorithm strength ranking.
- TVS.
- Storm cell tracking information (STI).
- Storm Top.

If one algorithm fails, the combined attributes table will not accompany the product. Storms are rank ordered in the table according to severity. The highest priority cell being one containing a TVS, then elevated tornadic vortex signature (ETVS), mesocyclone detection algorithm (MDA), three-dimensional shear (3DCO), two-dimensional shear (UNCO), probability of severe hail, and finally cell-based vertically integrated liquid (VIL).DOUBLE CHECK

An exciting feature of the combined attributes table is the ability to select the geographical location of a storm using the table. By using the mouse, you move the cursor over a storm's identification number in the tabular table and click on the storm. Then, the geographical location of that storm can be used for cell trends, cursor home define, recenter/magnify, and azimuth and range (AZRAN) select—applications that you will become familiar with as you learn to operate the OPUP.

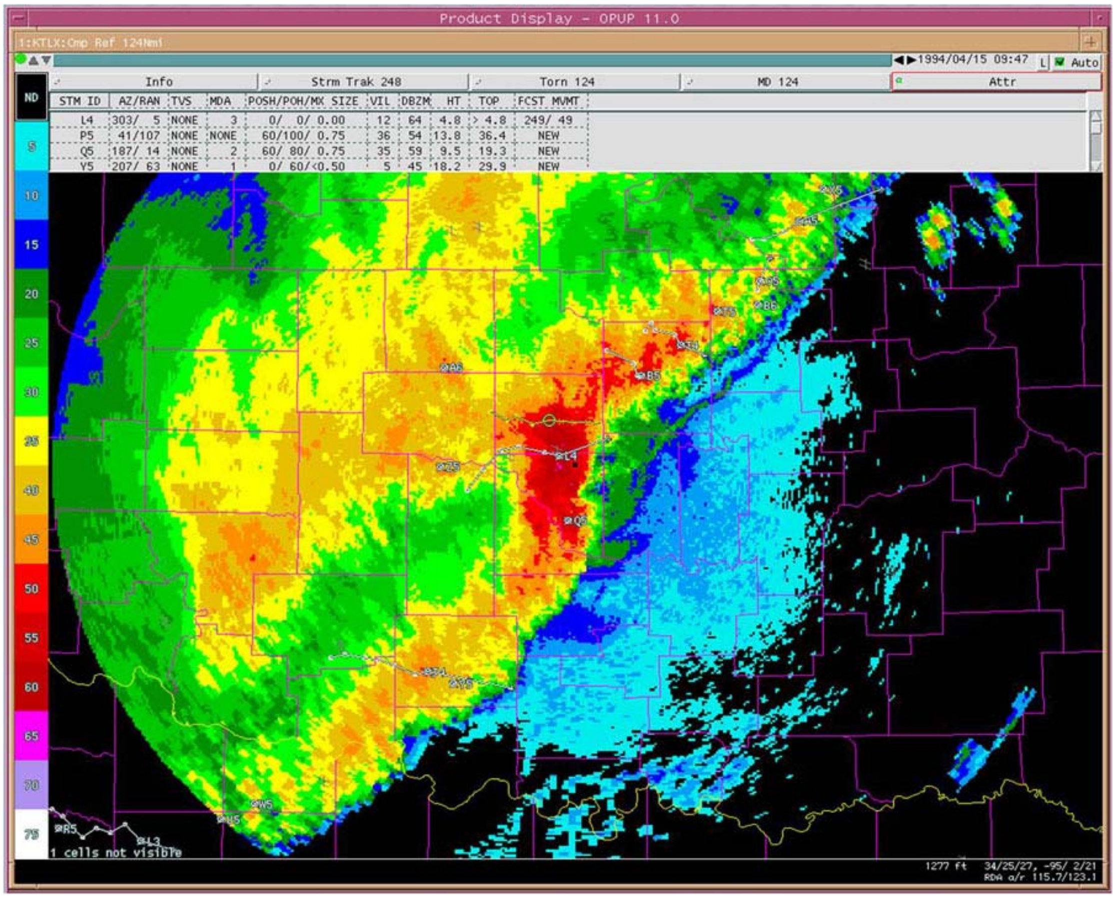

Figure 3–21. Composite reflectivity overlaid with the combined attributes table.

Theory of composite reflectivity

The CR product contains basically the same information we find in the base reflectivity product. However, one very important difference exists—composite reflectivity displays information collected from all the elevation angles, not just one. The WSR–88D's extensive memory and lightning fast processing provides the capability to produce this useful composite product.

Identification of strongest reflectivities

Imagine a volume coverage pattern of three elevation slices (fig. 3–22). The RDA is detecting different reflectivities at each elevation slice, 30dBZ, 50dBZ, and 25dBZ.

The CR product compares all the reflectivities above a location on the ground and identifies the strongest. All the other reflectivities at this location are discarded and the remaining reflectivity of 50dBZ is displayed. Now, the CR does this for the entire area of radar coverage and displays the strongest reflectivity found over each individual location. So what we have is a display of only the strongest reflectivities observed over the radar coverage area.

We can now easily identify the location of strong echoes, but we do have to keep several points in mind. First, the dBZ value displayed for any location could have come from any of the elevation slices or heights. Second, values displayed side-by-side also could have come from different elevation slices. Let's look at this side-by-side problem a little closer.

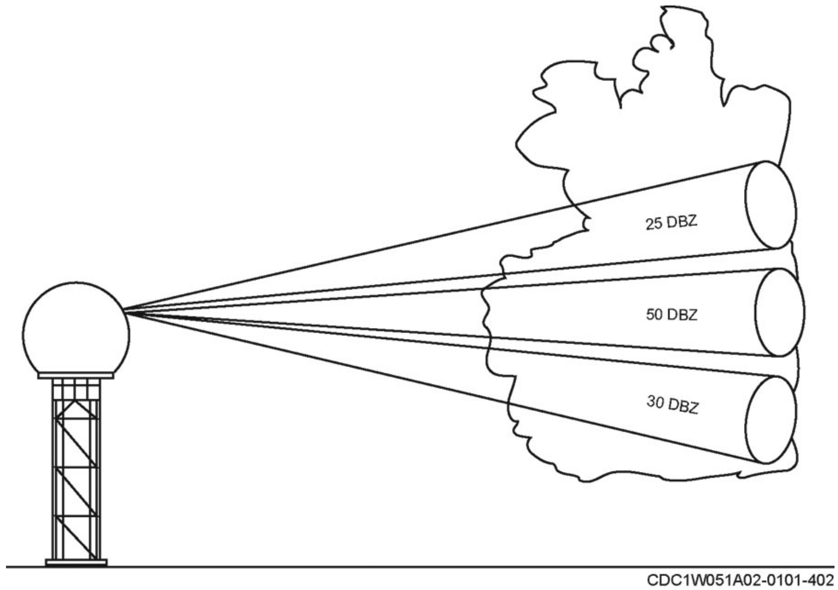

Figure 3–22. CR's search for highest dBZs.

Side-by-side reflectivity values

The CR product displays the strongest reflectivities regardless of the height or elevation scan in which they were detected. Because of this, reflectivity values displayed side-by-side by the CR product may truly be detected at different heights (see fig. 3–23).

At location A in figure 3–23, the reflectivity is 25dBZ near the surface and 50dBZ aloft. But, at location B, the situation is reversed; the reflectivity is 50dBZ near the surface and 25dBZ aloft. For both locations, the CR algorithm would identify and display 50dBZ as the strongest reflectivity. At times, you may be tempted to assume certain structures or features exist because of the way the CR product appears. However, since the reflectivities displayed may be coming from different elevations, you cannot confidently identify traditional radar signatures such as hooks or LEWPs.

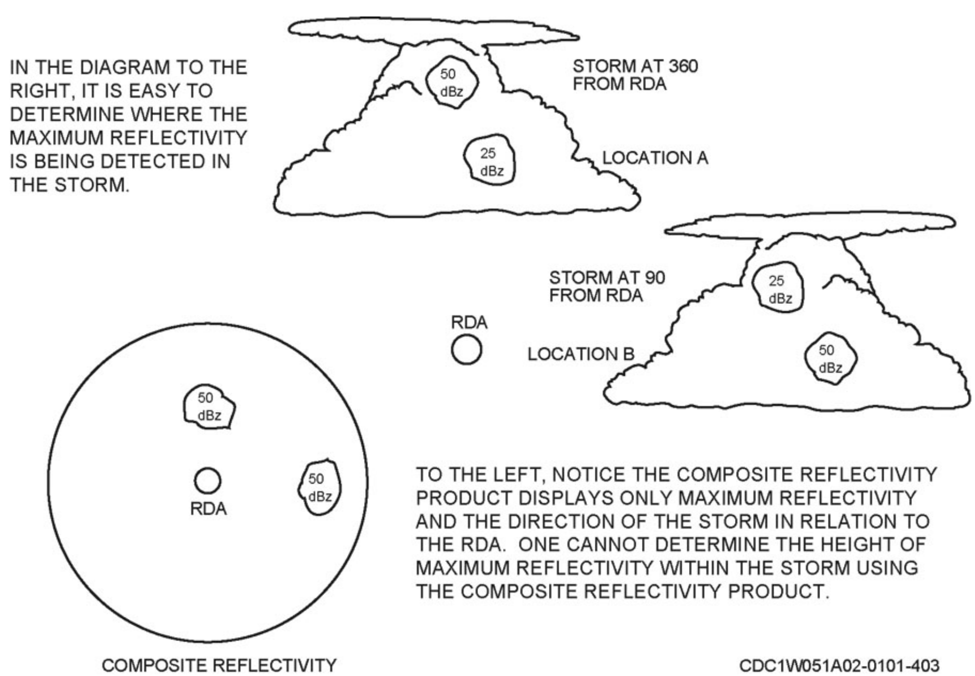

Figure 3–23. CR presentation of different storms.

Volumetric products

Composite reflectivity requires data from every elevation scan. This means that the CR product is ***not*** available until after the RDA has completed one entire volume scan—all elevations from lowest to highest. The CR product looks for the strongest reflectivity from bottom to top and all elevation slices must be completed before the CR is assimilated. Since the entire "volume" of the radar coverage must be scanned before the CR product can do its work, we call the CR a volumetric product. Thus, the CR becomes available to us only after each of the individual base reflectivity products has already been completed.

Use of composite reflectivity

The CR product permits a view of reflectivity levels for the total range of the radar. Because of this, it provides an instant snapshot of the most important reflectivity features. However, typical signatures, such as hooks and curvature, are not easily identified since reflectivities from many different elevations may be presented side-by-side.

Correlation of the CR with other products

Composite reflectivity can be your first step in identifying significant weather features. Further information, such as height above ground or the 3-D structure of the reflectivity pattern, must be determined by using other products. For instance, refer back to figure 3–23. Notice at location A, a reflectivity value of 50dBZ is located in the middle to upper levels of the storm. At location B, the 50dBZ reflectivity core is located near the surface. The CR product simply displays two storms of 50dBZ. As you know, the storm at location A, with its core held at a higher level is potentially more dangerous. Looking only at a CR product, how can you determine the significance of these returns? It should now be obvious that you need the help of other products, such as base reflectivity, to properly interrogate this situation.

Quick check

The CR product is also used as a quick check on the overall reflectivity pattern. You may routinely view only a few of the total available slices of base reflectivity data. Thus, you are not sampling the entire vertical range of the radar. Here, you can display the CR as a check of whether any new echoes have developed in an area not covered by the particular elevation slices you are currently using.

Melting level

Under favorable conditions, features that have strong reflectivities, at approximately the same height over the radar coverage area, are detected. In the past, the melting level in the atmosphere was often identified on a range/height indicator (RHI) scope by a feature called the bright band. On the CR product, you are also able to identify the melting level from the distinctive circles of higher reflectivities (fig. 3–24).

Unfortunately, with the CR product this is more of a hindrance than a benefit—the multiple rings tend to clutter the display. You cannot determine the height of the melting level using CR since it is a volumetric product. However, the CR quickly shows the melting level is detectable in a given situation. You can then use an appropriate slice of base reflectivity to further investigate. As you can see in figure 3–24, each elevation slice that detects the melting level is depicted at the range or distance from the RDA where the melting level is encountered. This results in multiple rings of enhanced reflectivity around the RDA. Remember that with the base reflectivity products, you can easily determine the height of this enhanced ring. At any given elevation angle, the WSR–88D computes range and cursor height almost instantaneously.

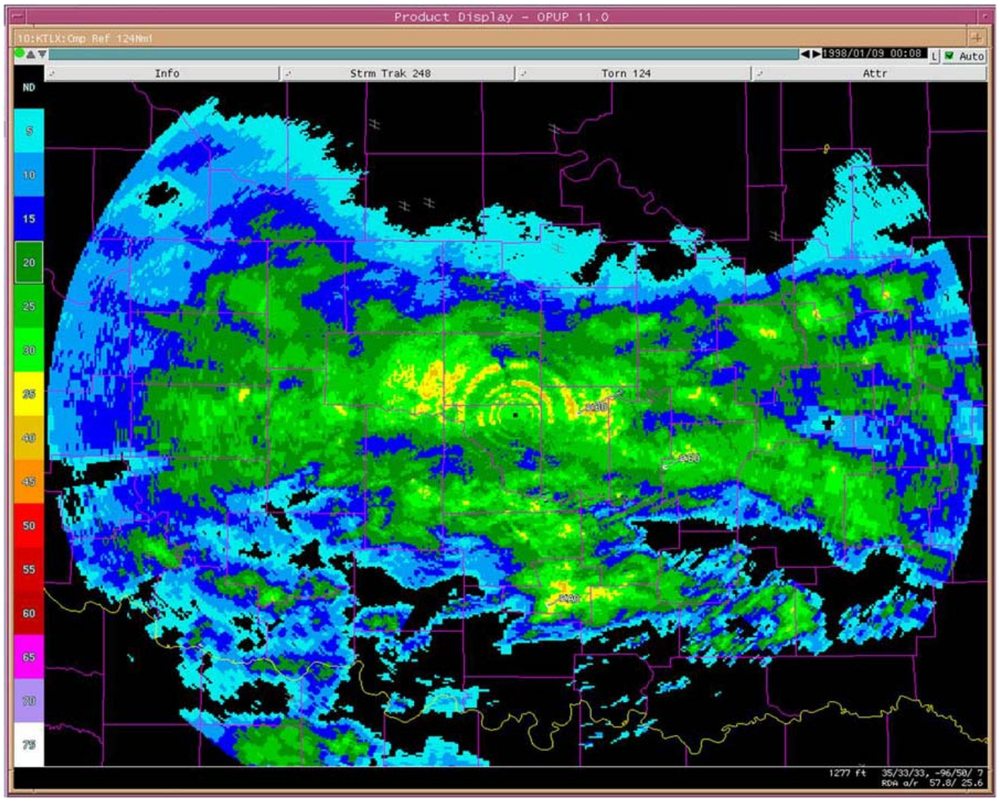

Figure 3–24. Composite reflectivity (melting level).

Limitations

The CR gathers its values by picking the strongest reflectivity from any height—meaning many of our typical signatures are not visible on the CR product. Do not use the CR product for identification of horizontal plane signatures that don't typically exhibit high reflectivities such as hook echoes. Other features, such as outflow boundaries and bounded weak echo regions (BWER), may also be disguised on the CR product. If you detect a classical feature on the CR, investigate it further by using appropriate slices of base reflectivity. Besides the loss of traditional patterns in the CR product, other points should be kept in mind. For instance, altitude information regarding the 3-D structure of reflectivity is lost. Use other products, like base reflectivity and storm structure, to obtain the height of the maximum reflectivity.

Further, note that since the CR is made up of information that comes from the base reflectivity products, many of the same situations that affect the quality of reflectivity data also cause problems with CR. For instance, ground clutter and AP can cause problems in the reflectivity displays and, therefore, may also give non-weather-related values to the CR product.

223. Layered composite reflectivity maximum

When evaluating reflectivity signatures on the radar, we often categorize features as being in the low, mid, or upper levels of a storm. You have learned from previous lessons that we can look at one elevation slice at a time using base reflectivity products, or you can look at the maximum reflectivity values using the composite reflectivity product. At times, you may be concerned with the maximum reflectivity values within an area (that is, the mid-levels of a storm)—the layered composite reflectivity maximum gives you this ability.

Theory of layered composite reflectivity maximum

The layered composite reflectivity maximum (LRM) product is comparable to the composite reflectivity in that it gives the maximum reflectivity for a particular grid box. The major difference is that the CR product is produced by using the entire volume scan. This makes it difficult to determine the approximate altitude of a particular reflectivity value. The LRM however, uses three layers—low, mid, and high—in the production of the product. This allows you to look at maximum reflectivities for a specific section of the storm.

Layered products

The LRM is a layered product, which means it uses a combination of elevation slices to acquire data for an operator selected layer. Figure 3–25 shows the method used to collect the data for the three layers available. Similar to the composite reflectivity product, the LRM uses the maximum reflectivity values in a vertical column; however, the LRM only uses the elevation slices that fall within the heights specified for the layer product.

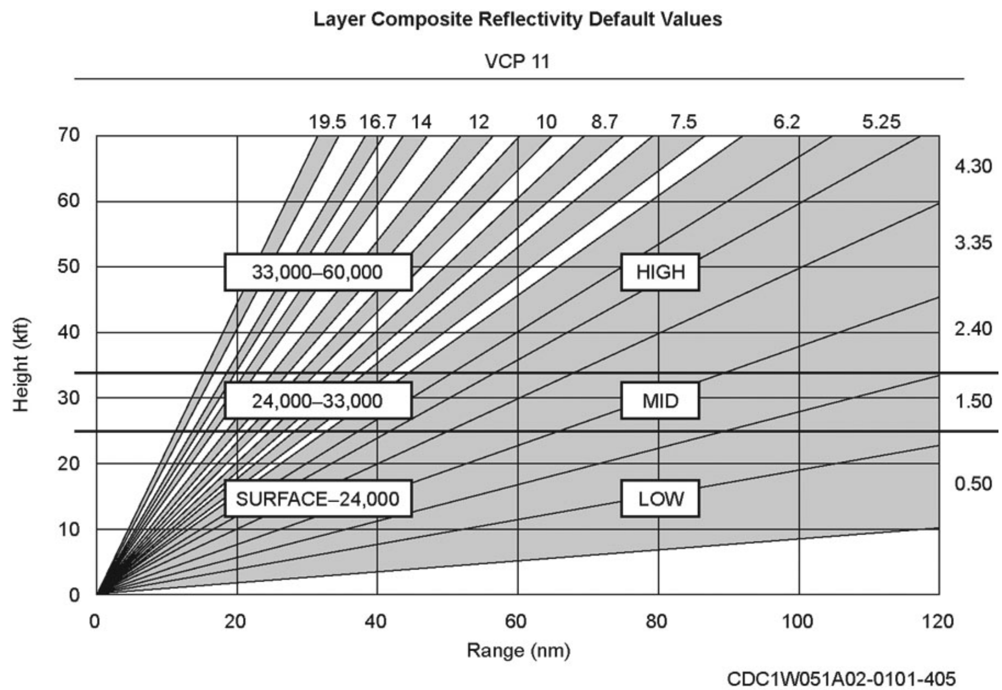

Figure 3–25. LRM default values.

Product description

The layered reflectivity maximum product (figs. 3–26 and 3–27), abbreviated "LRM," displays maximum reflectivity data for layers defined as low, medium, or high. This product is only available as an eight data level product—one product for each layer per volume scan, available in eight data levels only, with thresholds set at 5 to 57dBZ. Layers are set at low surface (sfc) to 24 thousand feet (kft), mid (24 kft to 33 kft), and high (33 kft to 60 kft). The low altitude LRM may be modified to change the bottom level of the layer. The level is changed at the Master System Control Function (MSCF) and when changed, affects all the users of the product. The layer must maintain at least 6,000ft of thickness. This feature is excellent for radar sites in mountainous regions.

The LRM presentation is a Cartesian pixel image of layered composite reflectivity values. LRM's resolution and coverage is 2.2 × 2.2nm out to 124nm.

The product legend contains the same information as the product legend for other reflectivity products with the exception that the LRM lists the altitude used for generating the product.

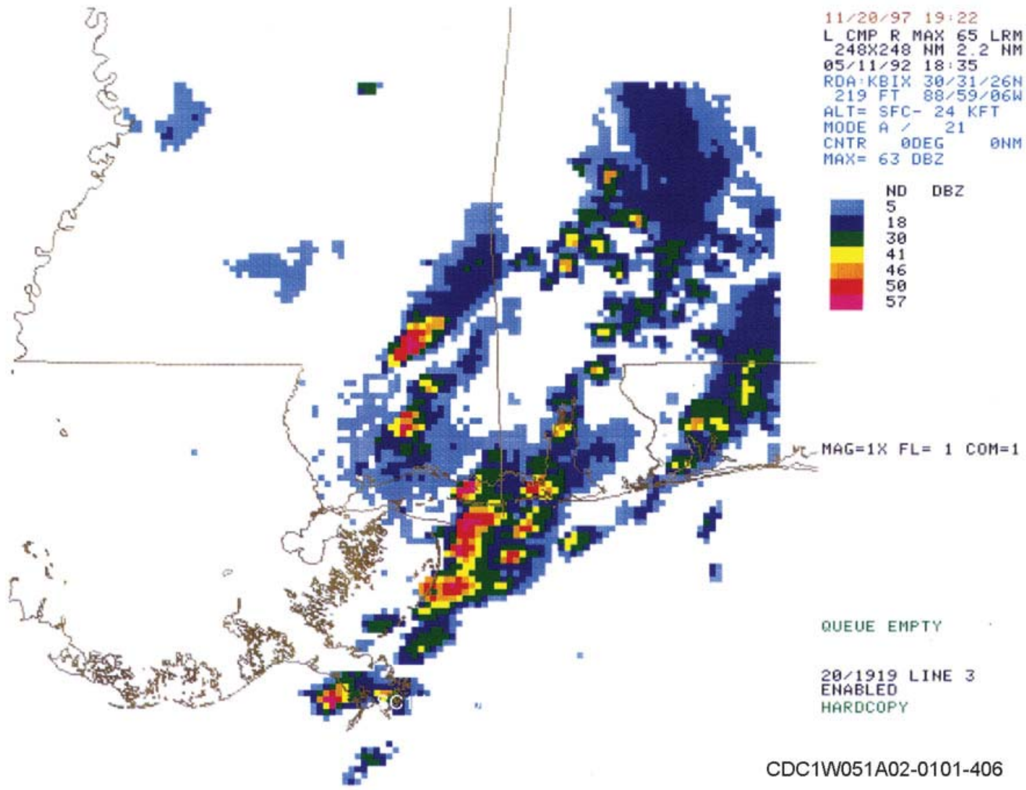

Figure 3–26. Layered reflectivity maximum (low layer).

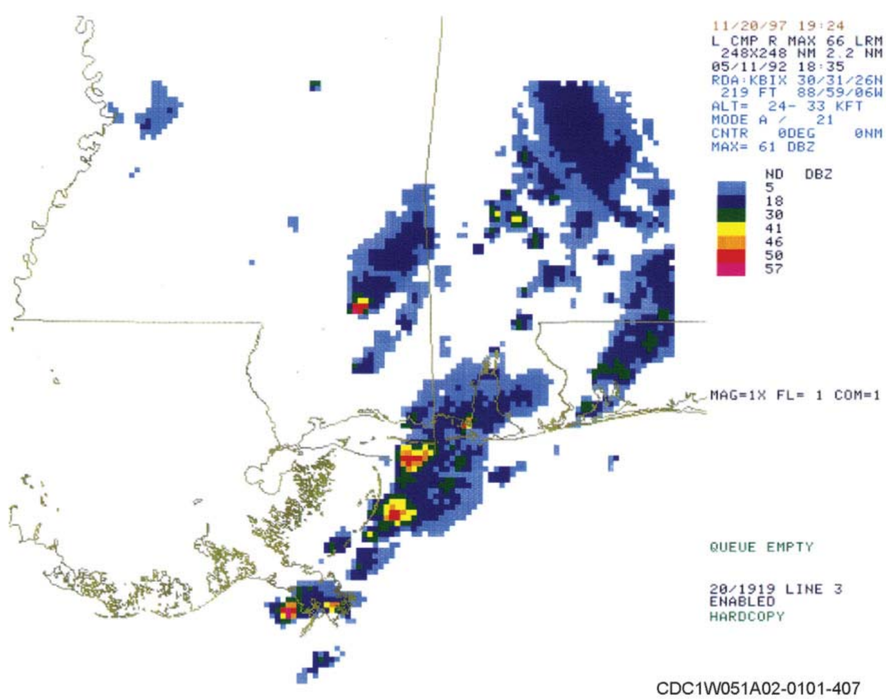

Figure 3–27. Layered reflectivity maximum (middle layer).

Use of the layered composite reflectivity maximum

The LRM is useful in giving you a quick look at significant reflectivity values for a specified layer. This enables you to quickly identify the stronger storms and those areas with a greater propensity for convection.Figure 3–26 is a display of convection as seen at the low layer. Figure 3–27 is a middle layer display of the same area of convection at the same date and time.

Notice that the low layer LRM product shows a larger area of strong convection below 24,000 feet than does the middle layer LRM product at 24,000 to 33,000 feet. Figure 3–27 also plainly shows two convective cells that are stronger in the middle levels. These are the significant storms that the radar operator should continue to monitor for intensity changes.

Convective regimes

The LRM is an excellent way of tracking the intensity trends of convection. For example, if an operator notices reflectivity values or the size of an area increasing rapidly in the mid-layer, it could indicate the storm is intensifying. Inversely, if an operator notices a sudden decrease of reflectivity values in the mid-layer, with an increase of reflectivity values in the low-layer, the storm is decaying and has the potential for a microburst. Pulse convection or rapidly building isolated thunderstorms also show up well on the LRM product.

Correlation of reflectivity maximum with height

As we learned earlier, the height of the maximum reflectivity can be used to identify the severity of storms. A storm containing strong dBZ values (>50dBZ) in the high altitude layer indicates an intense updraft and strong likelihood for severe weather. Also, high reflectivity values in the mid-altitude layer can be correlated with heavy precipitation in tropical regimes, as well as stratiform regimes.

Limitations

As stated earlier, the LRM uses only those elevation angles that fall within the altitude of the layer specified. As you can imagine, the LRM is adversely affected at distant ranges from the radar, where the layer may only encompass one or two elevation slices. At close ranges, mid and high layer altitude products are ineffective because of the cone of silence.

As with the CR, individual characteristics of severe storms may be lost because of the LRM’s use of several elevation slices. Signatures such as hook echoes, BWERs, and weak echo regions (WER) may not be detectable. For this reason, compare the LRM with other products before drawing conclusions.

224. User selectable composite reflectivity

In addition to the layered reflectivity maximum product, the user selectable composite reflectivity (ULR) product enables the radar operator to tailor the CR capabilities to their specific needs.

Product description

The ULR presentation is a Cartesian pixel image of composite reflectivity values for a user defined layer of the atmosphere.

ULR has a resolution of .54nm compared to LRM’s 2.2nm resolution

Theory of layered composite reflectivity maximum

The user selectable composite reflectivity (ULR) product is comparable to the composite reflectivity in that it gives the maximum reflectivity for a particular grid box. The major difference is that the CR product is produced by using the entire volume scan. The ULR product allows the radar operator to define the layer of the atmosphere for which CR values can be displayed. This product enables the radar operator to select a layer from the surface up to 70,000 ft. The depth of layer must be at least 1000 ft. The user selected layer displays the composite reflectivity maximum for the entire depth of the layer.

Use of user selectable reflectivity

As stated earlier, the user selectable composite reflectivity product allows the radar operator to select the composite reflectivity layer's base and top. This flexibility enhances monitoring storm growth, severe storm warning operations, and forecasts of aircraft icing and convective storms. Because viewing this product is similar to viewing a constant height chart it can be a helpful tool when performing a mission watch for an aircraft at flight level.

Limitations

LRM uses the same strategy as CR subjecting this product to some of the same limitations. ULR displays the maximum reflectivity for the entire layer selected; the maximum reflectivity within that layer is unknown. Additionally severe weather signatures such as hooks and BWER's are typically masked by higher reflectivity values being displayed over weak echo regions.

225. LRM anomalous propagation removed

The LRM anomalous propagation removed (APR) product is similar to the standard LRM product except for one thing—an algorithm is used to remove reflectivity readings from ground targets.

Theory of the LRM APR

The algorithm was developed to identify ground targets by following the principle that ground targets affect mainly the lowest antenna tilts, and typically have low radial velocity and spectrum width. The algorithm separates the atmosphere into three regions based on distance from the RDA and altitude above radar level (ARL). Different clutter identification rules are applied to each region based on known observations of the appearance and location of clutter. The three regions are shown in figure 3–28.

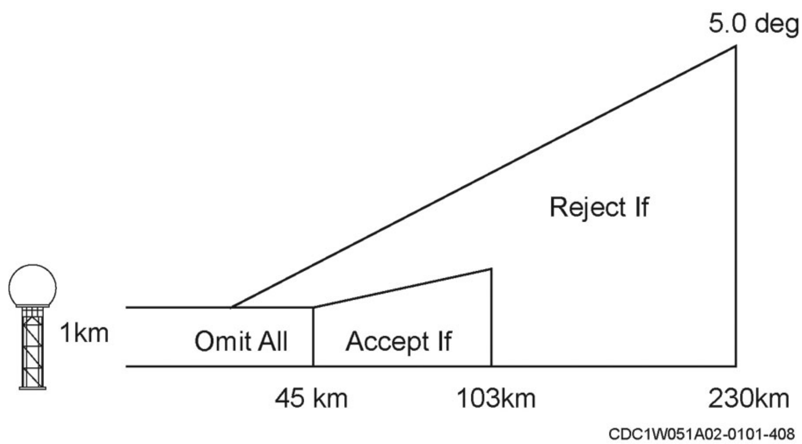

Figure 3–28. AP removal regions.

Omit all region

The omit all region is defined as the portion of the atmosphere within 45km of the RDA and below 1km in altitude. The algorithm discards all reflectivity returns from this region, thereby deleting them from the product display.

Accept if region

The accept if region is defined as the portion of the atmosphere within 103km of the RDA, on the 0.5º elevation slice and below 3km in altitude, and not within the omit all region. A target in the *accept if* region is accepted for inclusion in the product if its velocity is $\geq$ 1.0m/s and its spectrum width is $\geq$ 0.5m/s. Essentially a target in this region is deemed by the algorithm *not* to be clutter as long as it has slight movement.

Reject ‘ if’ regionThe reject ‘if region’ is defined as the portion of the atmosphere within 230km of the RDA and below 5º in antenna elevation. In addition, a target is only considered to be within this region if it is not within the omit all or accept if regions. A reflectivity return from the reject if region is assumed to be clutter and discarded if its velocity is < 1.0m/s and spectrum width < 0.5m/s. Here again the algorithm considers reflectivity returns to be meteorological, only if they possess movement.

Product description

The LRM APR product looks identical the low altitude LRM, except the name is different on the legend (fig. 3–29). The display is a Cartesian pixel image of layered composite reflectivity values in full or quarter screen format. It’s only available in eight data levels, with thresholds set at 5 to 57dBZ. The altitude of the product is set at surface to 24,000ft.

LRM APRs resolution and coverage are 2.2 × 2.2nm out to 124nm radius.

The product legend contains the same information as the product legend for other reflectivity products with the exception that the LRM APR lists the altitude used for generating the product.

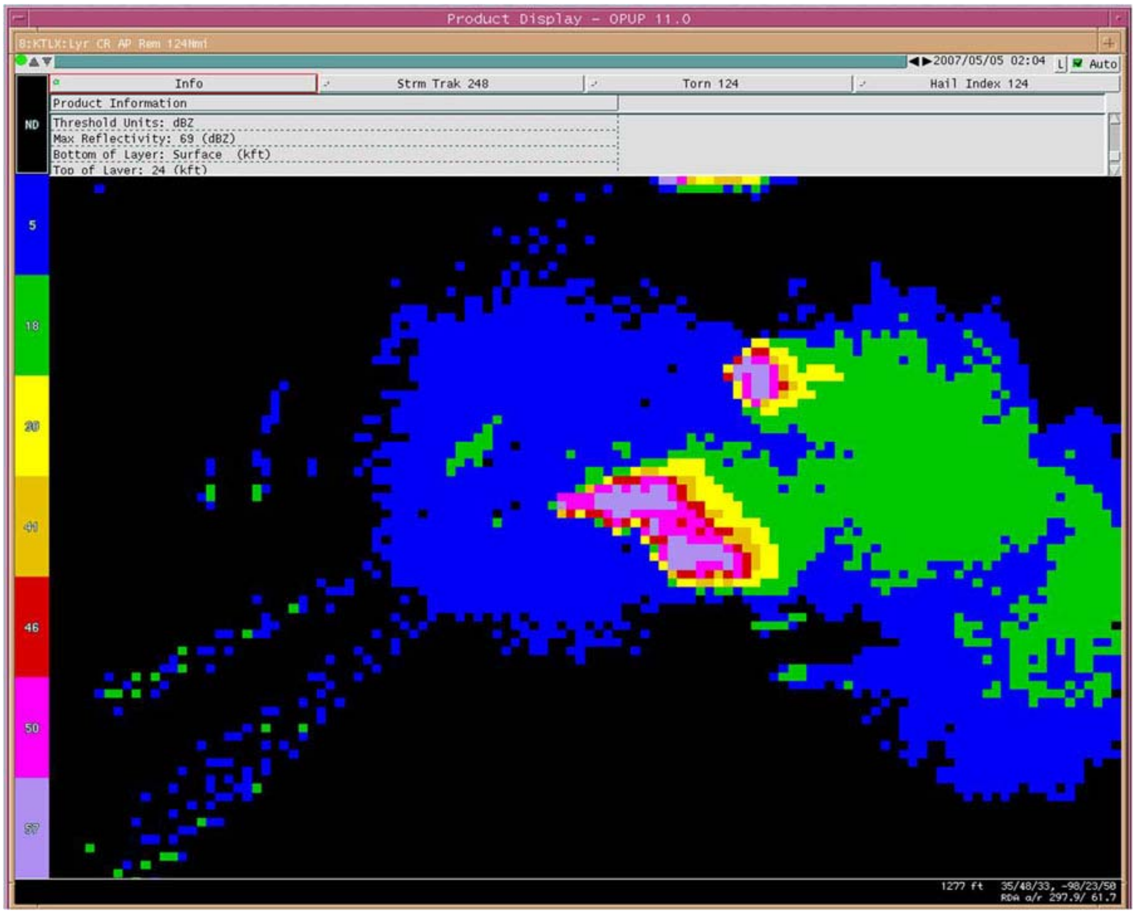

Figure 3–29. LRM anomalous propagation removed.

Use of the LRM APR

The LRM APR algorithm attempts to distinguish meteorological targets from clutter targets. This product may be used the same way as the low altitude LRM (for example, appearance of first convective echo).

Limitations

The algorithm works best if traditional clutter filtering is applied before the algorithm begins processing data. The algorithm assumes all reflectivity returns below 1km in altitude and with 45km of the RDA to be clutter. This could result in valid meteorological data being removed. Current parameters may not be the optimum settings and further testing may be needed to enhance the algorithms processing.

226. Vertically integrated liquid water

The WSR–88D receives a reflectivity signal from a distant target and then produces color displays of that signal. You can interpret these displays and make determinations on the severity of the storm, direction and speed of motion, amounts of rainfall, and so on. Base reflectivity and composite reflectivity display the reflectivity in a straightforward manner through dBZs. However, other methods of displaying information are possible and can be designed to help you identify potentially severe convective activity. Vertically integrated liquid water is one such product.

Product description

The vertically integrated liquid water product, abbreviated "VIL," displays its values as a graphic image. Its output depends on processing by the VIL algorithm. The product displays 16 data levels that are updated once per volume scan.

The VIL presentation is a Cartesian pixel image of VIL values (fig. 3–30). VILs resolution and coverage are 2.2 × 2.2nm out to 124nm radius.

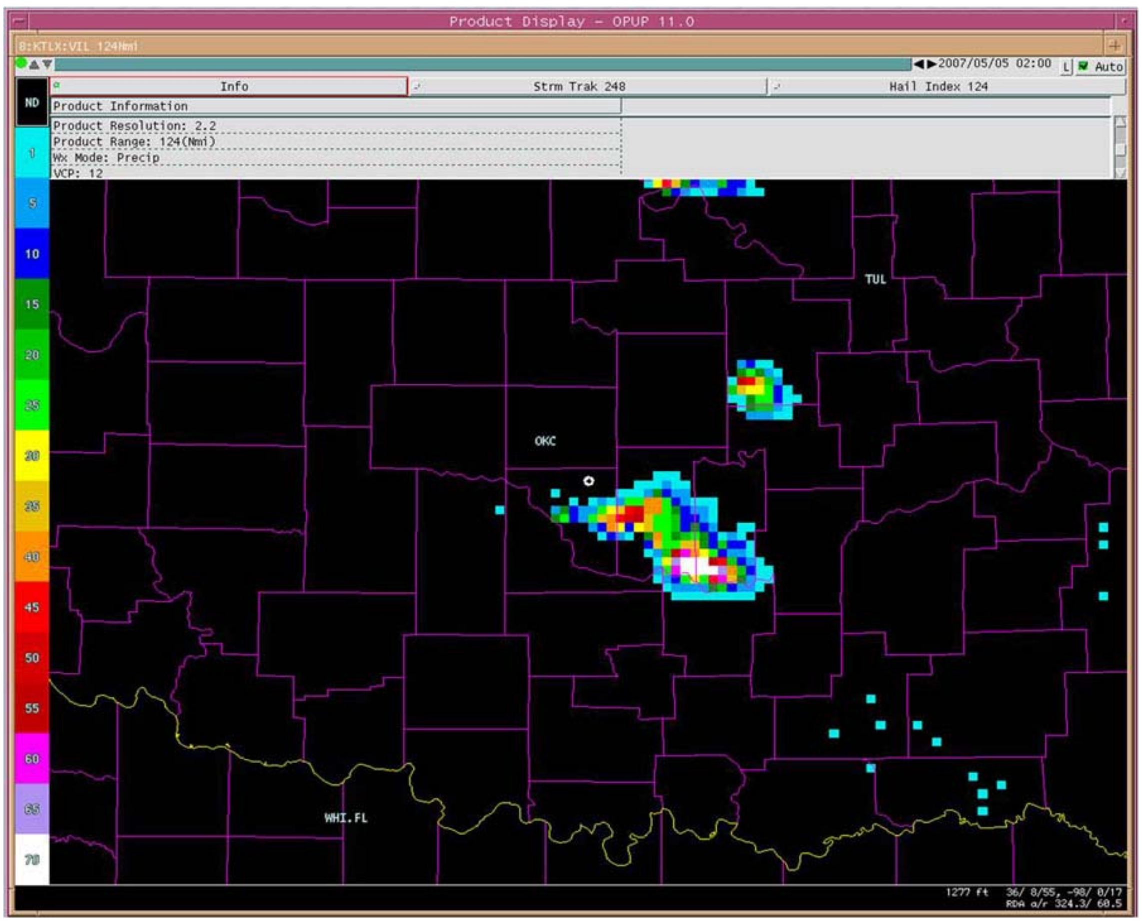

Figure 3–30. Vertically integrated liquid.

VIL is very useful in monitoring the general radar echo pattern for the beginning stages of significant convective development. Significantly high VIL values should be reviewed with other severe weather guidance products. Inaccuracies may occur when analyzing fast-moving storms. Storms with a high degree of tilt may be measured inadequately. The relationship of VIL to severe weather needs to be quantified for different meteorological situations.

Theory of VIL

The VIL product is the result of analysis done by the VIL algorithm. The function of the VIL algorithm is to estimate the amount of liquid water contained in a storm, and then display that value in a graphical form for your use. The magnitude of the VIL value in convective situations is related to the strength of the updraft, which in turn, is related to the severe weather potential of the storm. The VIL product is an excellent tool that can enhance your ability to distinguish severe storms from non-severe storms.

Vertical integration

The vertically integrated liquid water algorithm converts weather radar reflectivity data into liquid-water content values. These values are based on theoretical studies of drop-size distributions and empirical studies of the relationship between the reflectivity factor and liquid-water content. The algorithm uses a mathematical equation to make these relationships. This VIL value is simply an indication of how much water is contained in the storm. Values of VIL are calculated for each location in the radar coverage for each elevation scan. This is the first step. The second step uses a process much like what you saw with the CR product.

Remember how the CR product compared the reflectivity values above a location and selected the maximum value? The VIL algorithm does a similar job, but instead of selecting the maximum value, it adds them together. This gives you the "integrated" part of vertically integrated liquid. The result—for any location on the earth, you now have an estimate of how much liquid water is suspended in the atmosphere above that point. As you may suspect, VIL is also a volumetric product, like the CR, which requires a complete volume scan before the product can be displayed.

The VIL product is measured in units that specify mass per volume. Since we are calculating the amount of water in a vertical column, the values of VIL are expressed in metric units of kilograms per square meter (kg/m^2 or $kg\ m^{-2}$). For each elevation slice these values are linear, but once the vertical column is integrated they represent a volumetric measure. Of course, you probably won't ever hear anyone use these units. Instead, people usually say, "VIL values of 40" or "VIL values of 65."

Use of VIL

As mentioned earlier, the VIL product's primary function is identifying strong storms that may become severe. VIL is very useful in monitoring the general radar echo pattern for the beginning stages of significant convective development and for helping to distinguish thunderstorms from rain showers. As convective development progresses, relative values of VIL are useful in distinguishing strong, possibly severe, thunderstorms from those not likely to be severe.

Significant VIL values

What we call "significant" or high VIL values vary from location to location, season to season, and from one weather system to another. In Oklahoma, operators have found critical VIL values (when a storm becomes potentially severe) vary from values of 35 in late fall or winter to values of 60 or more in summer. This might sound pretty confusing, but you quickly get a feel for VIL values by using other products along with VIL. For instance, comparing values of reflectivity in dBZs to VIL values for the same storm helps determine the range of values you need to be aware of. Other products available on the WSR–88D are also useful. (**NOTE:** These products are discussed later, specifically the hail index, storm structure, mesocyclone and tornadic vortex signature products).

VIL gradients

The gradient of the VIL values is also important. Strong but continuous VIL gradients are significant just as is true with reflectivity values. On the other hand, very abrupt, erratic changes are seldom observed in nature and therefore should be viewed with skepticism when seen on WSR–88D products such as VIL.

VIL trend

A final point when observing VIL is that the upward trend over several volume scans should be consistent. Storms generally require a certain amount of time to develop; thus, the VIL values should never abruptly jump from low to high values.

Limitations

The VIL product is a valuable tool that provides you with a method to differentiate between potentially severe storms and those that never rise above garden variety. However, no product is without its limitations. Here are a few to be aware of concerning VIL.

Seasonal and diurnal variations

Already, you know that VIL values change with the seasons and from location to location. More specifically, VIL values change from diurnal and air-mass variations as well. This is not a straightforward process—under different weather conditions the minimum VIL value associated with severe weather varies by different amounts—but general trends can be expected. For instance, warm, moist air masses tend to exhibit higher VIL values during severe weather occurrences, while cool, dry air masses produce much lower values. What are good VIL values? A value of 40 or 80 doesn't tell you much alone. You need to know the typical values for your specific location and synoptic situation. Figure 3–31 indicates VIL values increasing over time beginning with the upper left image and advancing to the lower right image.

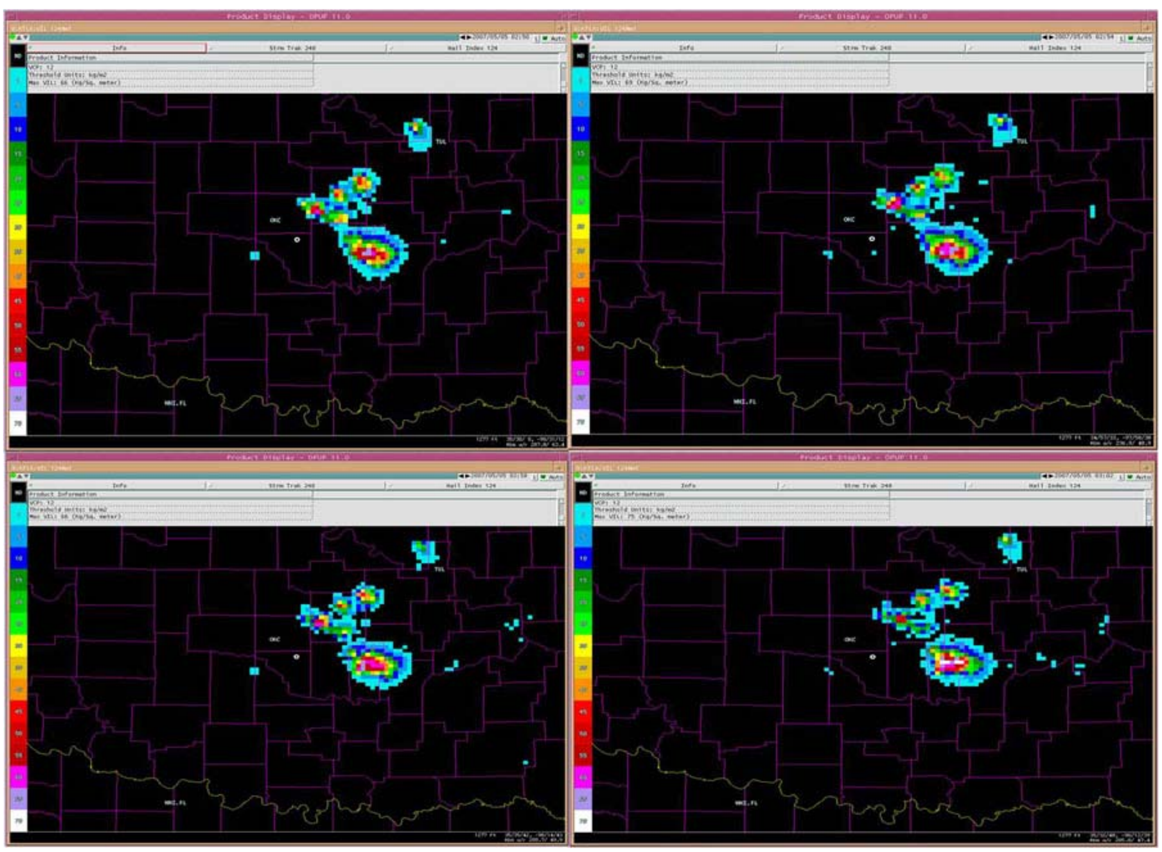

Figure 3–31. Vertically integrated liquid (increasing).

Tilted and fast-moving storms

Another problem may also cause unrepresentative values of VIL (fig. 3–32). The VIL algorithm calculates values for grid boxes (stacked in the vertical) that are 2.2 × 2.2 nautical miles. A storm that is strongly tilted may not have all of its vertical extent within the same stack of grid boxes. So what happens? The VIL algorithm does not know that the storm is tilted. It just follows the same rules it always uses. But near the top of the stack of boxes, the storm is not in the same vertical stack that it is in at the bottom. In a bad case, the algorithm could be adding up "empty" boxes, and thus a low value of VIL would be reported for a large storm.

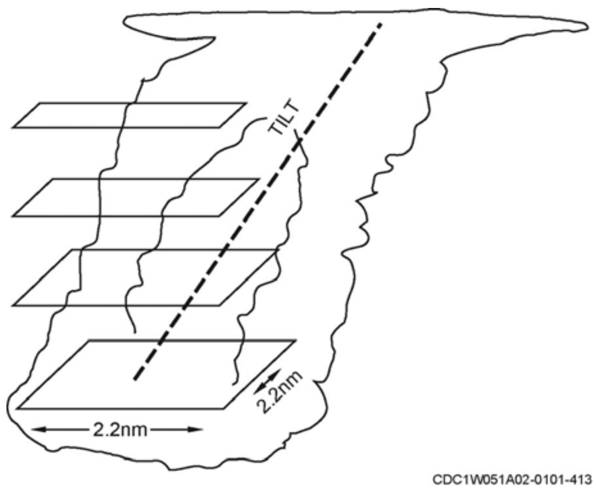

Figure 3–32. Vertical stacking.

The same problem of low VILs occurs with storms that move much faster than the average of the other storms present in the radar coverage area. Here, the VIL algorithm is again calculating values using a vertical stack of boxes. But realize that at least five minutes is used to scan from the lowest elevation to the highest. As you can imagine, a fast-moving storm has traveled enough to move through and even exit the stack of boxes, thus fooling the VIL algorithm. The result is an underestimation of the true severity of the storm. As you can see, the VIL algorithm, or any other for that matter, works best when storms closely approximate the norms on which the algorithm was based.

227. Echo tops

Most of the WSR–88D products depict data with an emphasis on horizontal detail. The vertical structure often must be inferred from other sources. However, several derived products are designed to present data in a specific manner. The echo tops (ET) product is one example. The display is simple and easy to interpret. However, the price you pay for this convenience is a specialization that limits the number of ET product applications.

Product description

The ET product is a reflectivity-based product depicting the level of the highest echo detected over a specific geographical location. Like the CR product, ET provides a quick look over a large area and includes all elevation angles. The ET product uses 16 data levels to represent categories of echo top heights. All heights are referenced to mean sea level (MSL) with one product per volume scan.

ET presentation is a Cartesian pixel image of echo top heights (fig. 3–33). The ET resolution and coverage are 2.2 × 2.2nm out to 124nm radius with a vertical range of 5,000 to 70,000 feet.

Echo top heights are primarily useful as part of briefings prepared for aviation interests and the public. They can be useful to the user in defining a strong updraft region or the presence of vertical tilt within a storm. Observing collapsing echo tops can aid in timing the onset of a severe weather event.

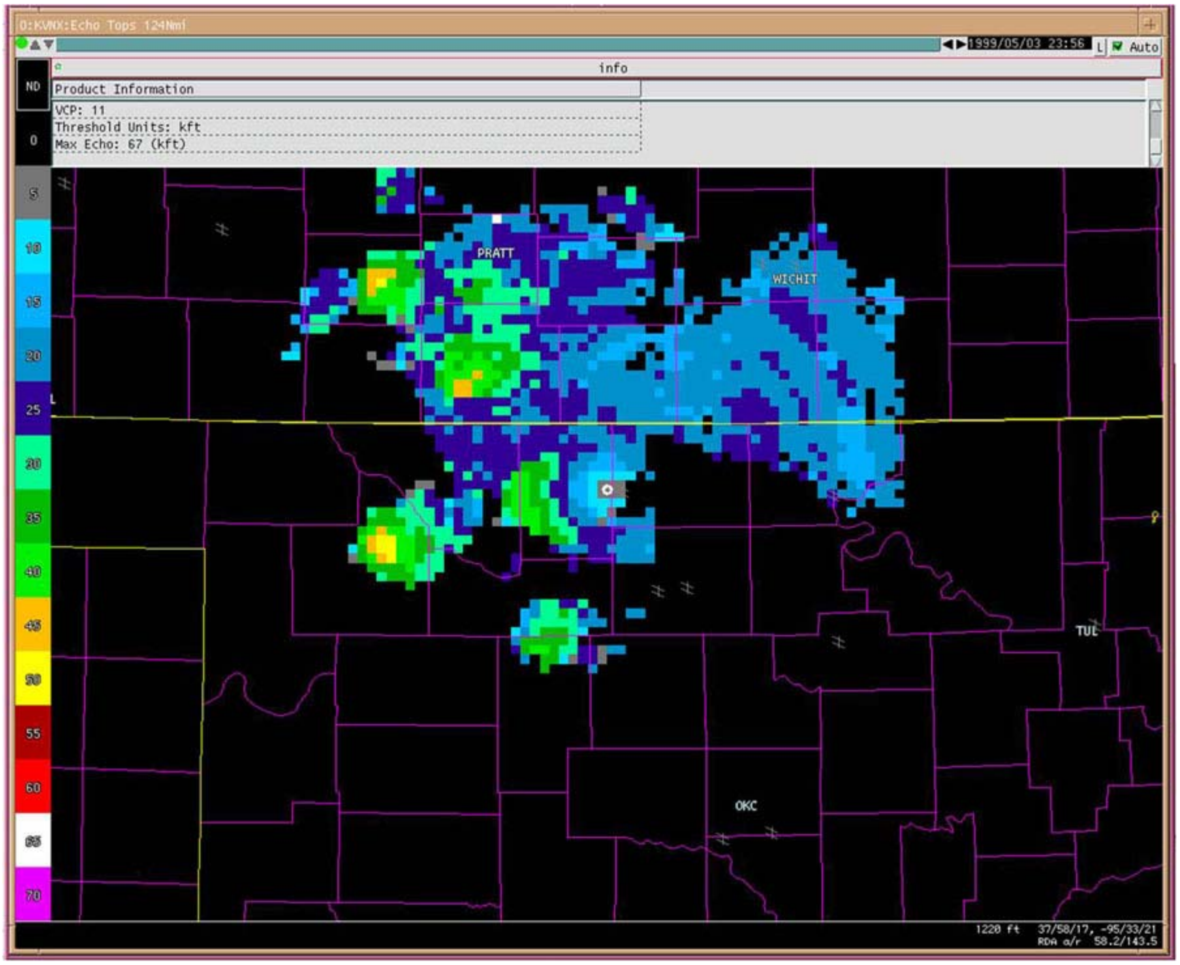

Figure 3–33. Echo tops.

Theory of echo tops

The ET product shows the heights of echoes, in hundreds of feet above MSL, by using different colors to represent heights. The echo top height is particularly useful to those supporting aviation or encoding radar reports. The ET product, like composite reflectivity, is a volumetric product that uses information gathered in the entire VCP to display a final product. Any cloud tops providing a reflectivity return stronger than an adaptable threshold value (current default is 18.3dBZ) are considered by the product's algorithm.

Echo top height calculations

The ET algorithm computes echo top height in the following manner. First, the horizontal area underneath the radar coverage pattern is divided into 2.2 × 2.2nm grid boxes. The radar begins with the first (lowest) elevation scan and whenever a reflectivity greater than 18.3dBZ is detected, the height of that reflectivity is assigned to the appropriate grid box. Of course, for the first elevation scan, any 18.3dBZ reflectivity detected is the current "echo top."

Next, a second elevation slice begins and whenever 18.3dBZ reflectivity is detected, a new echo top is assigned to that box. In other words, whenever an 18.3dBZ reflectivity is detected at a higher elevation, the height of the new reflectivity replaces the old value and becomes the new echo top for that stack of grid boxes (fig. 3–34).

This process continues repeatedly for each elevation slice until the highest slice is completed. Thus, the final height entered for a stack of grid boxes remains as the echo top. This height is the value you see displayed on the graphic screen.

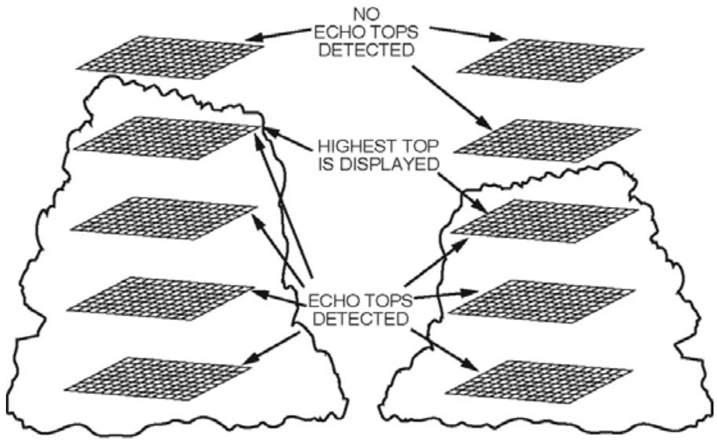

Figure 3–34. Echo top grid boxes.

Use of echo tops

The ET product allows the radar operator to monitor the echo tops throughout the radar viewing area. The height of the echo tops is a concern for forecasters and aviators and is used as an indicator of various atmospheric dynamics. For instance, an echo top of a thunderstorm increasing in height is probably increasing in intensity while a decreasing thunderstorm echo top could suggest a weakening storm. If the echo top collapses very quickly it may be an indication of a downburst occurring on the surface. Other volumetric products such as VIL, used in correlation with ET, can be of additional help in understanding what is happening in the atmosphere. Since ET is a volumetric product, volumetric overlays such as hail and mesocyclone may be placed on it if desired.

Identification of updrafts and downdrafts

Since the echo top is directly related to the updraft, you can monitor the ET product to gain some insight into the actions of the updraft. A lowering or collapsing of the echo top may indicate a sudden weakening of the updraft—and thus you can time the onset of severe weather events at the surface (much like you can with the VIL product). Look at figures 3–35 and 3–36. Note that you can use both the VIL and ET products together to provide some assurance and/or verification that your interpretations are supported by actual cell dynamics and not by some aberration of the algorithms.

For example, as seen in figure 3–35, a drop of VIL values alerts you to the possibility that the updraft has suddenly weakened and allowed large amounts of precipitation to drop out of the updraft. You then expect a similar drop in the height of the echo tops to occur (fig. 3–36) since they also relate to a strong updraft. In figure 3–36, you can see the areal coverage and heights of the highest echo tops decrease correspondingly to the decreases in VIL. Slight differences in time between these events are expected, but this type of correlation is your assurance that your assumptions are correct. This storm generated 61-knot surface winds and 1.75-inch hail at Harrah, Oklahoma during the collapse shown in these photos.

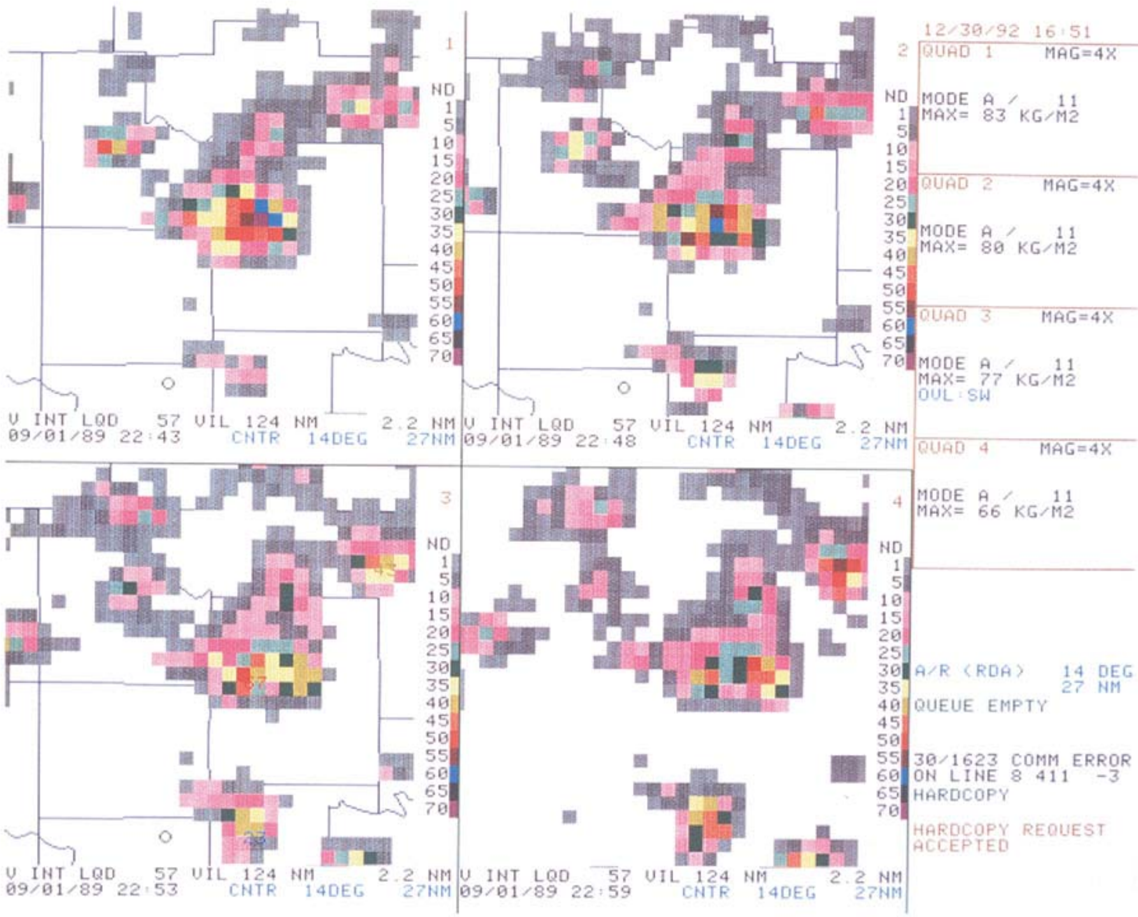

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Figure 3–35. Vertically integrated liquid (comparison).

Beginning of convective development

If a stratiform situation exists and convective clouds start to develop within the stratiform clouds, the echo tops are usually detected before any indications on base reflectivity. As the updrafts develop and push the tops of the cloud higher, these higher tops are seen as mid-level echo tops on the ET product. Correlation with base reflectivity and VIL is recommended, as reliance solely on one product is discouraged.

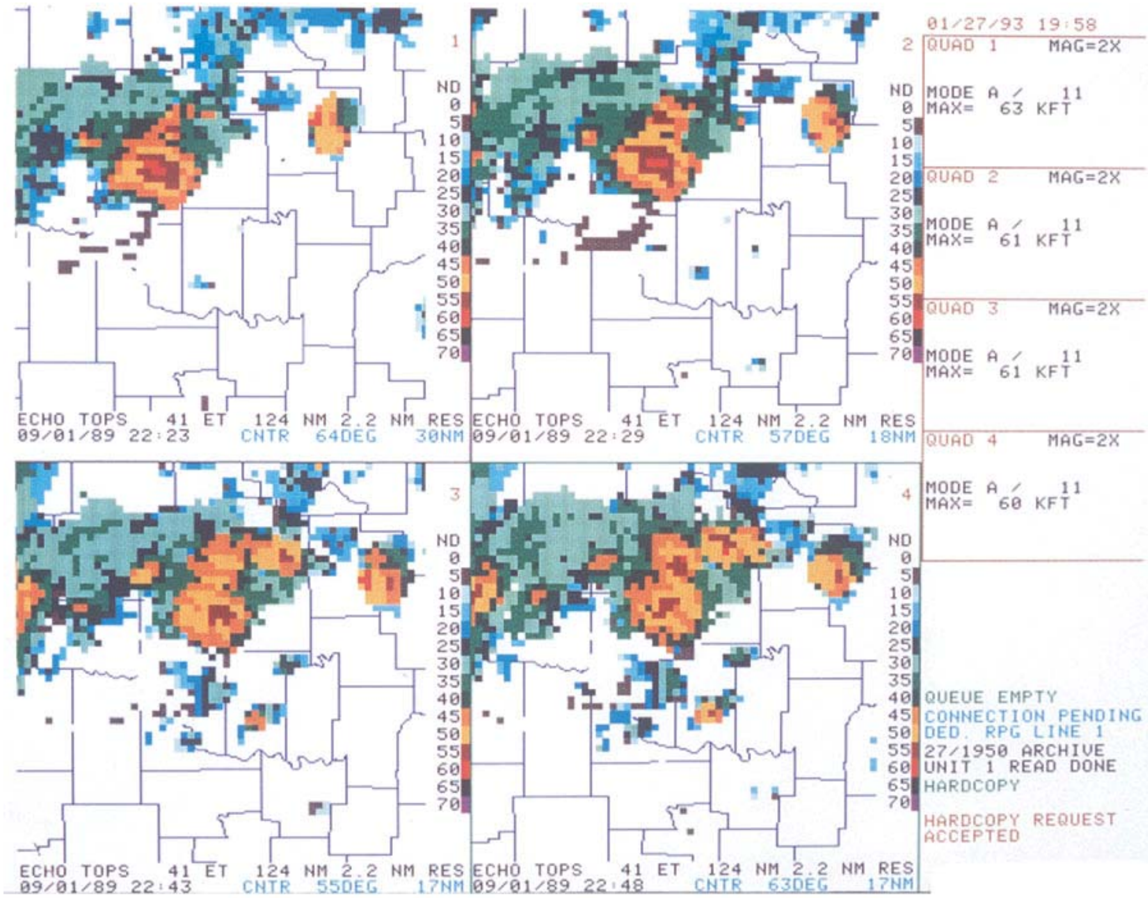
Limitations

The ET product does have some limitations you must consider when using the product.

Inaccurate ET height calculations

The ET product provides a simple, easy-to-view display of the height of the echo tops. But as the saying goes, "if it looks too good to be true…" And of course, correct interpretation of even a simple product like ET requires that you be aware of possible drawbacks.

Since an ET may be the result of an updraft, you may think of several ways in which ET can be used to support other radar operations besides just aviation interests. For example, since the maximum echo tops are assumed to be above the updraft of a thunderstorm, ET might be used to help identify strong updraft areas. Or, on the other hand, you might also use this technique to identify the amount of storm tilt or stacking by comparing the ET to displays of lower elevations.Another basic point to keep in mind is that the "echo tops" displayed by the WSR–88D are probably ***not*** the actual cloud tops. Remember that the ET algorithm discards reflectivities below a preset threshold (the default is 18.3dBZ). Quite possibly, the cloud tops do extend beyond the heights the ET product displays. A minimum significant reflectivity threshold needs to be established before you can use ET to safely estimate actual cloud tops.



CDC1W051A02-0101-419

Figure 3–36. Echo tops (comparison).

Stair-step pattern

Another commonly seen problem is the apparent “stair-step” appearance of the ET product—the echo tops abruptly increase in height with range. This problem has two causes. First, remember the antenna’s maximum elevation angle is 19.5°, and thus a limited height capability close to the radar. At these close ranges, the product reports a limited ET no matter how tall the storm is. The result is a series of heights encircling the RDA site, with increasingly higher echo tops farther from the antenna.

A second cause also adds to this stair-step pattern and is most easily observed in weather systems with uniform tops. Since the beam is spreading vertically and horizontally with distance, the resolution of the beam is decreasing with range. The result is possible errors in the ET heights.

Looking at figure 3–37, note how the ET product plots echo tops at the height of the center of the beam. This happens despite whether the echo is detected throughout the beam, at the very center of the beam, or from just the lower edge of the beam. The result—identical heights are displayed although some variation is occurring. Now, when the next higher elevation is used, another set of identical heights is displayed. This effect, a sudden jump from one height to the next higher height, occurs at the same range from the RDA. This uncertainty in the accuracy of height measurements can be quite significant (at 124nm, errors of 6,500ft are possible).

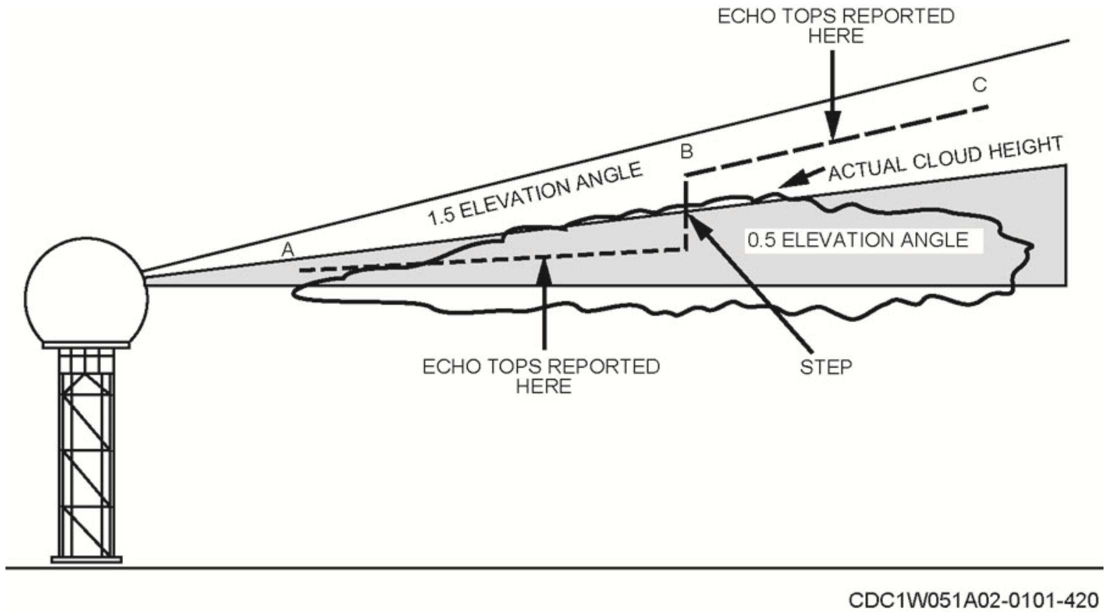


Figure 3–37. Echo top beam limitations.

Data contamination

The ET product also does not correct for data contamination from side lobes. This contamination causes overestimation of tops in areas of strong reflectivity. Further, incorrect estimations occur when the actual storm top occurs between gaps in the volume coverage pattern, or especially if the true tops are above the highest elevation slice.

228. Hybrid scan reflectivity

The hybrid scan reflectivity (HSR) product is the foundation for the WSR–88D precipitation products. The reflectivities displayed are the result of an algorithmic process to isolate precipitable echoes. In other words, this product gets rid of reflectivities from ground clutter, clouds, and other scatterers to show just the precipitation echoes. The HSR product assists you in determining the accuracy of the WSR–88D precipitation products.

Product description

The HSR product displays similar to the 124nm base reflectivity product, as a polar coordinate image of reflectivity data. The resolution and range of the product is.54nm out to 124nm radius. The product is updated once per volume scan with 16 data levels ranging from 5 to 75dBZ. It is available in full or quarter screen format. A legend is displayed with the product, in either full or quarter screen. Figure 3–38 is an example HSR product.

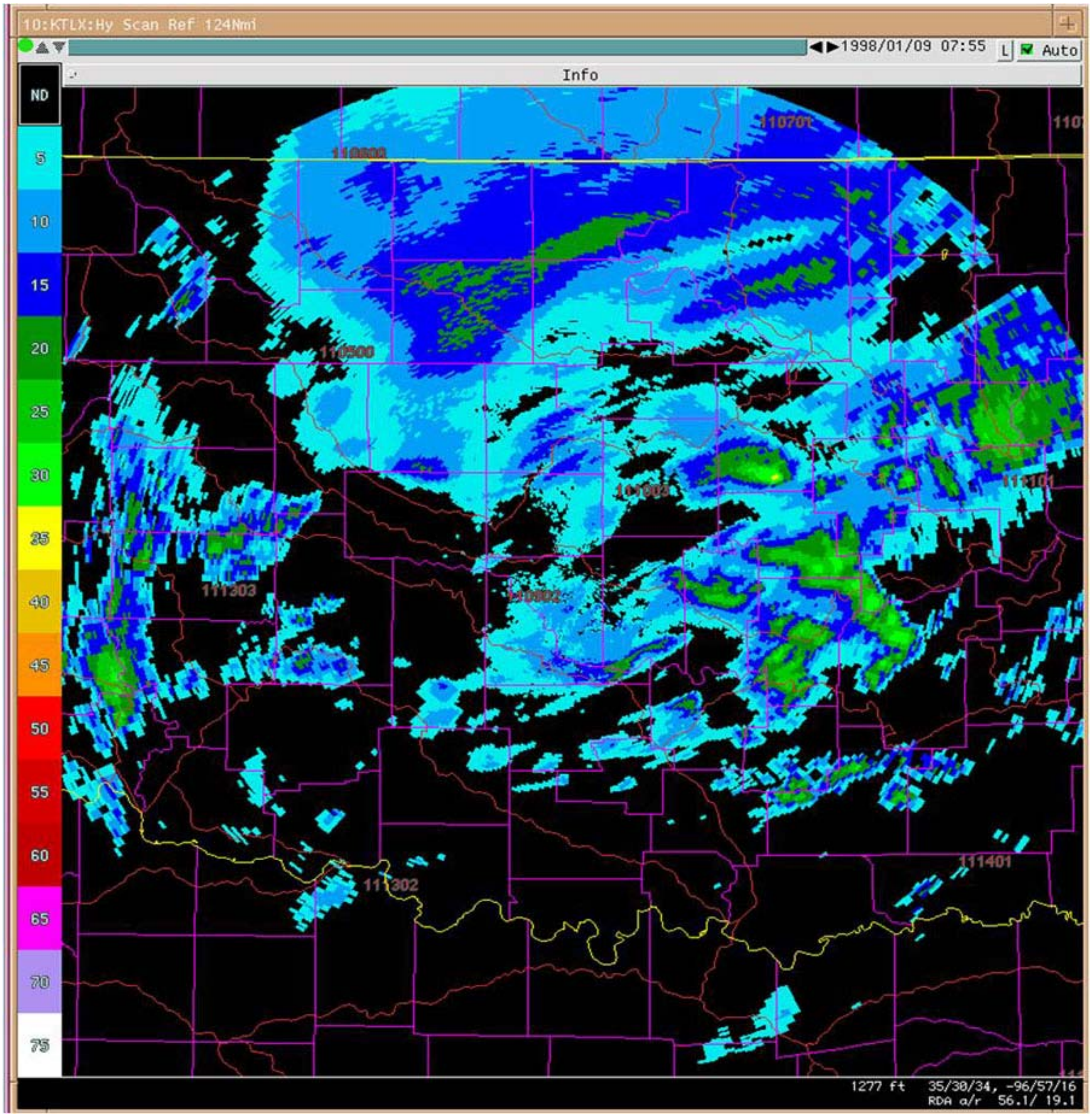


Figure 3–38. Hybrid scan reflectivity product.

Theory of HSR

The overall purpose of the HSR algorithm is to search for low-level reflectivities (possibly precipitation) while eliminating ground clutter and correcting for beam blockage. The RPG is responsible for executing the algorithm. The RPG generates the HSR internally before creating the precipitation products. Reflectivity data displayed on the HSR product originate from the four lowest antenna elevations. In order for the data to be displayed, it must be selected by the terrain based hybrid scan and pass a tilt test.

Terrain based hybrid scan

The terrain based hybrid scan also uses data from the lowest four elevation angles. However, correcting for beam blockage is the only requirement for elevation selection. The lowest elevation slice (0.5º) is used wherever the bottom of the beam clears the terrain. If the algorithm detects beam blockage at that level, it then moves up to 1.5º elevation slice to collect its data. The algorithm follows this technique of moving up to the next level when beam blockage occurs to a maximum 3.4º elevation (fig. 3–39).

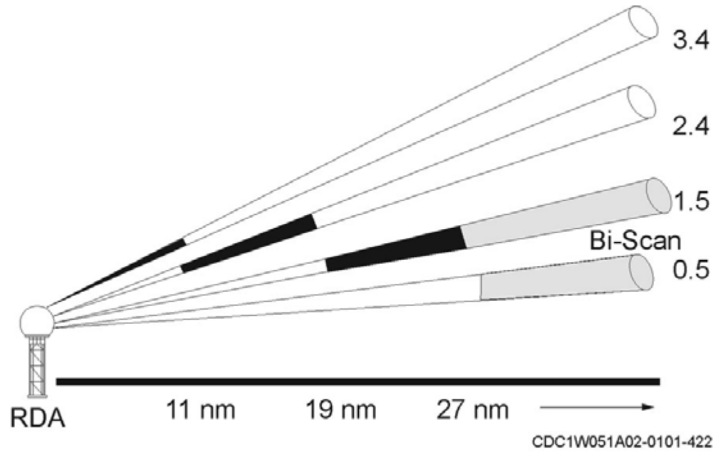


Figure 3–39. Terrain base hybrid scan.

Tilt test

A tilt test is accomplished by the HSR algorithm, which compares the areal coverage of echoes at 0.5º and 1.5º elevation slices. If a 75 percent (default value) or greater reduction is found in the echoes at 0.5º slice as compared to the 1.5º slice, then the algorithm assumes the echoes to be clutter and removes them from further processing. When this occurs, the message "LOWEST TILT UNUSED" is displayed in the status and annotations area just above the data level in the product legend.

Limitations

The HSR product may display abrupt changes in reflectivity values at hybrid scan ranges. In some instances, especially at RDAs located at higher elevations, it is possible the tilt test may eliminate valid precipitation echoes during stratiform precipitation events.

229. Storm total precipitation accumulation

This product gives us information on the total amount of precipitation over a certain amount of time. At first glance, you may wonder why we need a product like this. Let's take a closer look.

Product description

The STP provides a graphic image of continuously updated precipitation accumulations within 124nm of the radar. The storm total precipitation is the total precipitation accumulated since the last one-hour break in significant precipitation over the total area of coverage.

The STP product is available one product per volume scan. The presentation is a pixel image of precipitation accumulations (fig. 3–40) with a resolution of 1.1 × 1.1nm out to 124nm radius. The STP product is centered at the radar location with a 16-level display—ranging from 0 to >25.4 in.

The STP product is used in the following ways:

- Aids in the monitoring of total precipitation accumulations, whatever duration.
- Estimate of total basin runoff due to a single storm.
- Estimate of basin saturation due to previous rainfall events.
- Evaluation of flood reports.
- Post storm analysis.

The STP product has limitations though. Extended WSR–88D system outages during precipitation events compromise the data. Breaks in precipitation of more than one hour reset the system. Non-precipitation reflectivity, such as clutter or anomalous propagation, may contaminate data. The algorithm, therefore the product, does not account for snow or frozen precipitation, bright bands, reflectivity gradients, or attenuation. Also, small-scale or isolated convection degrades the accuracy.

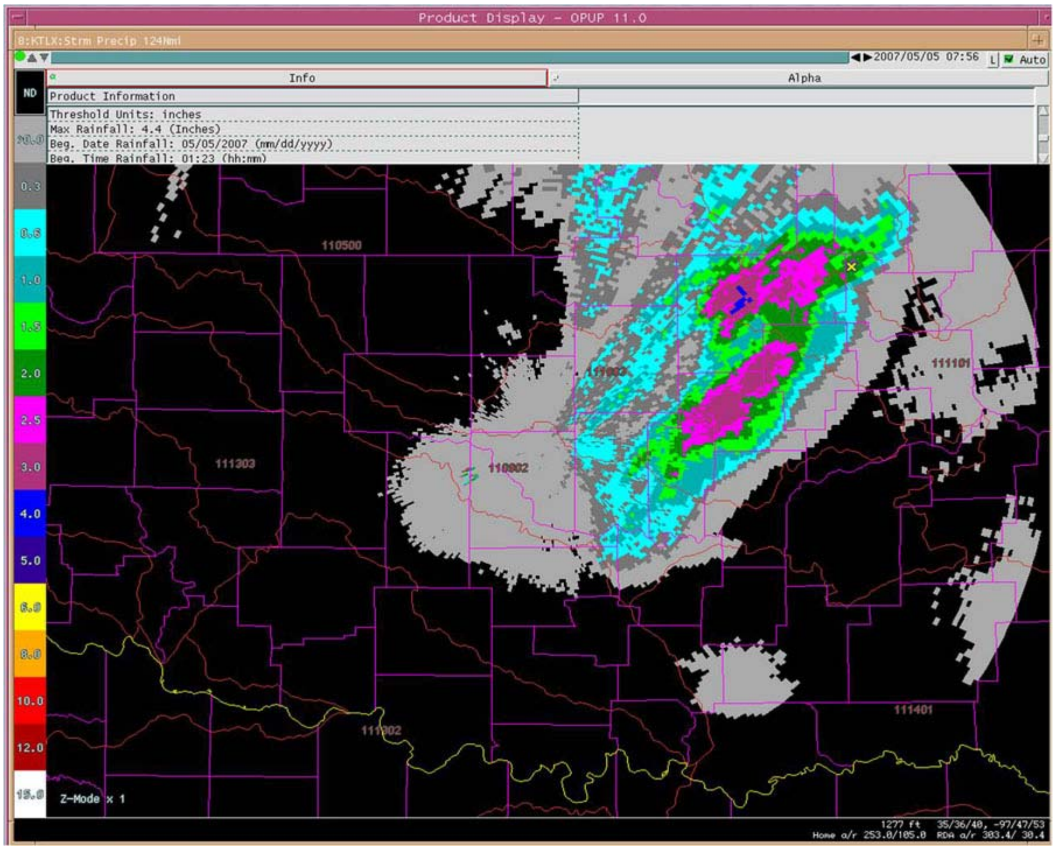


Figure 3–40 Storm total precipitation product.

Theory of STP product

The STP provides us with an objective assessment of rainfall rates over a longer period than the other two precipitation products. It is valuable to the National Weather Service (NWS) for flash flood warnings. Still, it can be a useful tool for DOD personnel. The key is to use it and observe how it may benefit you.

The STP extends from initial detection of precipitation within 124nm until one hour after no precipitation is detected within 124nm. It may exceed 24 hours. The product displayed is the total rainfall accumulation. It becomes available from the first volume scan of detected rainfall. It then updates precipitation accumulations each volume scan. The precipitation accumulations are most accurate for large-scale precipitation systems.

230. User selectable precipitation accumulation

Now we're going to take a look at another precipitation product called the user selectable precipitation (USP) accumulation product. The main difference between the precipitation products is the period of time the products use to accumulate precipitation amounts. As the name of the USP implies, the operator can select the duration for which USP collects rainfall estimates.

Theory of user selectable precipitation accumulation

The user selectable precipitation accumulation product allows you to assess rainfall amounts for a specific duration and time. In the past, we could only look at the total accumulation from when the radar first detected precipitation (STP product), amounts for the past hour (OHP), or amounts for the past three hours (THP). Of course, with a one-hour break in precipitation, the product would reset to zero. The USP product gives us the flexibility to look at precipitation amounts for only the period we're concerned with.

Product description

The USP product (fig. 3–41) provides precipitation accumulations using the end hour specified by the operator, and includes all hours specified as duration. Accumulations are available for the latest whole hour that data was collected, and covers a 124nm area from the RDA.

The USP product is available for up to 10 products per volume scan with 16 data levels. Data levels are the same as the OHP/THP product. If accumulations are greater than the OHP/THP data levels, the USP uses data levels from the STP. The presentation is a polar coordinate pixel image of precipitation accumulations with a resolution of 1.1nm × 1^{o} out to 124nm radius, centered at the RDA. The product is available in full or quarter screen modes.

Information contained in the product legend is similar to the other precipitation products with the exception of the USP listing the beginning hour (in whole hours) and the duration used for accumulations.

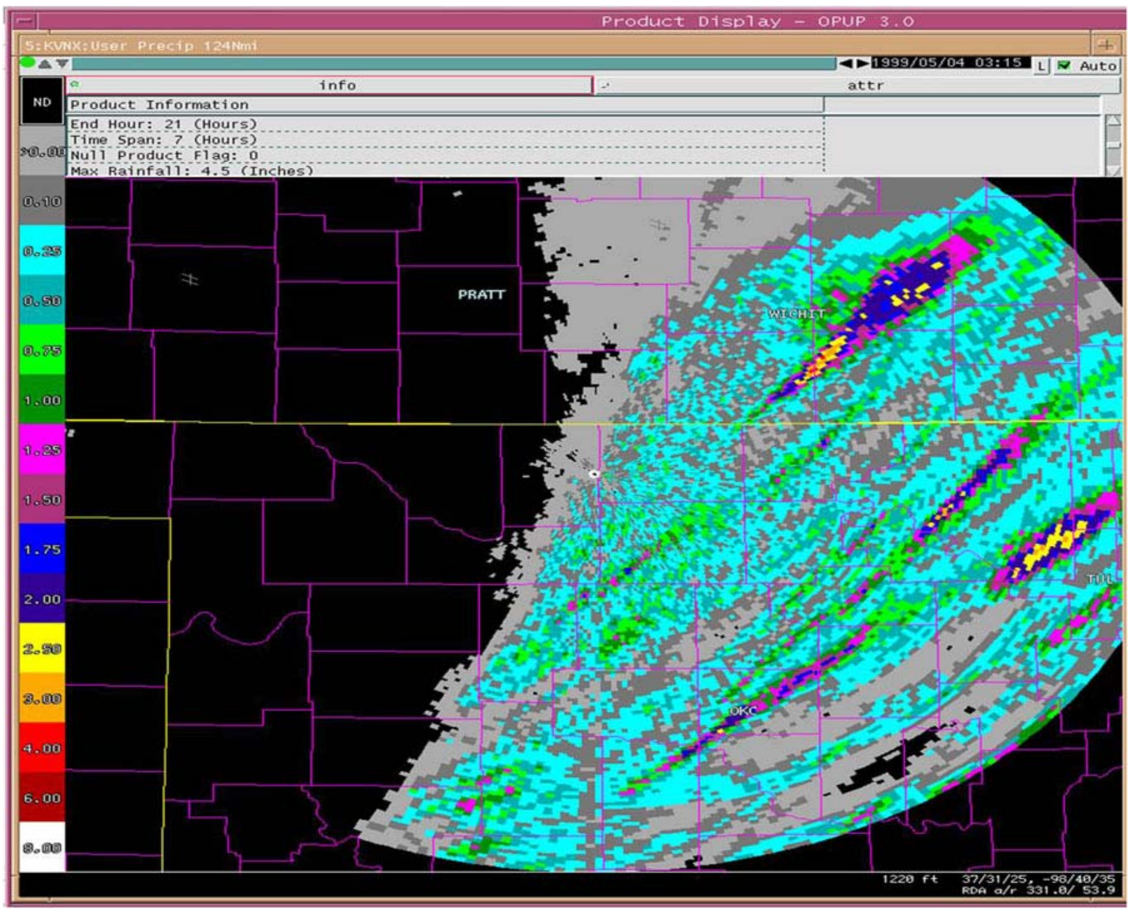


Figure 3–41. User selectable precipitation product.

Attribute table

An attribute accompanies the USP product, and is displayed when the product is in full screen mode. The table gives the following information: whether or not the gage bias is applied, the total number of hours used to build the product, the end times of each hour used, the gage bias (if bias isn't applied, the multiplicative factor is 1.00), and whether or not that specific hour was included in generation of the USP product. If the product isn't built, the reason and a list of available hours is listed in place of the attribute table.

Product formulation

The USP product is built from a 30-hour database, stored at the RPG. The operator inputs the end-time and the duration used for building the USP product. At least two-thirds (2/3) of the specified hourly accumulations must be available in order to create the product. The USP product is only built for a duration of 24 hours or less.

Use of user selectable precipitation

There are five uses for this product.

1. Monitoring precipitation for a specified time period.
2. Post storm analysis.
3. Estimation of basin run-off for a specified time.
4. Estimation of basin saturation.
5. Evaluation of flood reports.

Limitations

The same limitations that affect the storm total precipitation accumulation product effect the user selectable rainfall accumulation product. Keep in mind that the USP product is a customized product (requires operator input); therefore, the RPG only satisfies 10 unique USP requests per volume scan.

231. Products derived from the Snow Accumulation Algorithm

The snow accumulation algorithm (SAA) was developed to provide water equivalent and snow depth products. The adaptable parameters of the SAA have been optimized for dry snow, or snow that is not melting before hitting the ground. The storm total snow products provide radar algorithm estimated storm total snow water equivalent accumulation images and snow depth.

Product description

The products available from SAA are one-hour snow water equivalent (OSW), one-hour snow depth (OSD), storm total snow water equivalent (SSW) and storm total snow depth. The products update every volume scan. They are available as 16 data level products, annotations for product name, radar ID, date, starting and ending time of the accumulation, type and range/height correction applied to the accumulation, max data value, and the azimuth/range to the max data, radar position, radar elevation and the operational mode.

Product use

Product will provide the forecaster an estimate of water equivalent or depth of snow during dry snow events.

Product limitations

SAA algorithm assumes dry snow in all events. Bright bands and snow rain mixes causes over estimations. Also of note is the fact that SAA does not reset to zero after the enhanced precipitation algorithm has detected no precip for the past hour. It is best to reset the algorithm to zero at the beginning of an event to give the best estimate. The snow products are always accumulating and are only useful during actual dry snow events. Additionally, the SAA tends to overestimate snow depth when compared to snowfall that was subject to melting below the radar beam, including snow on the ground.

232. Mesocyclone detection

The mesocyclone detection (MD) product uses a combination of the WSR-88D’s extensive computer processing capabilities along with the base velocity information to build an extremely valuable product. This product is designed to take the burden of constant interrogation off the shoulders of the operator by continually searching for the rotating fields associated with mesocyclones.

The mesocyclone detection product provides information regarding the existence and nature of vortices associated with thunderstorms. This product is derived from the mesocyclone detection algorithm (MDA). The MD product provides information regarding identified cyclonic shear circulation features. Circulations are assigned a strength rank number based on the rotational velocity of each of its component 2D features. The strength rank values range from 1 (the weakest) to 25 (the strongest). Any circulation with a strength rank of 5 or greater is classified as a Mesocyclone. Typical strength rank values for well-defined mesocyclones are between 5 and 9, and values exceeding 13 are exceptionally rare. The product is generated in a format that provides an alphanumeric tabular display for all identified circulations simultaneously, a graphic display, or a graphic overlay to other products. One MD product is available per volume scan. The MD product can be graphically displayed in two separate ways.

1. The symbol for a circulation having a strength rank less than 5 is a thin, yellow, open circle centered at the position of the circulation's base 2D component.
2. The symbol for a circulation having strength rank greater than or equal to 5 is a thick, yellow, open circle centered at the position of the circulation's base 2D component. Given a minimum display filter strength rank of 5, a circulation with a strength rank of 5 or above detected on the lowest elevation angle (or a base is detected at or below 1 km ARL), is shown with four spikes added to the yellow circle.

Attribute table

The MD attribute table contains in order from top to bottom the following information for each identified mesocyclone.

- CIR STMID: the MDA identification number between 0 and 999, and the nearest SCIT identified storm ID relative to the circulation. Storms are listed first by strength rank.
- SR LLRV: the strength rank and low-level rotational velocity in kts at the lowest elevation angle of the 3-D feature.
- AZ RAN: the azimuth and range to the mesocyclone.
- HGT MXRV: The height in kft at which maximum rotational velocity occurs, and the value in kts of that max rotational velocity.
- BASE DEPTH: The altitude (in kft ARL) of the lowest 2-D feature, and the total depth of the 3-D mesocyclone. In addition to the attribute table at the top of the graphical product (see Fig. 5–111 on page 5–231), MD also has a text version available.

Mesocyclone detection algorithm

The MDA uses pattern recognition techniques to detect mesocyclones. These techniques define a process used for searching through Doppler velocity data for symmetric regions of large azimuthal shear. The MDA is based on the extraction of significant attributes which characterize mesocyclones.

The major steps in MDA are as follows:

1. Threshold velocity data by reflectivity value.
2. Identify MDA 1D features.
3. Identify MDA 2D features.
4. Identify MDA 3D features.
5. Classify MDA 3D features.
6. Track MDA 3D features.
7. Trend MDA 3D features.

Threshold velocity data by reflectivity vaule

To help limit the search for circulations to those associated with storm cells, the algorithm only searches velocity data from sample volumes that have reflectivities above THRESHOLD (minimum Reflectivity) and are below THRESHOLD (maximum shear segment height).

Identifying MDA 1D features

Shear segments, 1D features, are identified on each elevation scan from velocity data in azimuthally adjacent radials, meaning side by side directionally. For each shear segment the following information is computed: beginning Az (azimuth), ending Az, beginning velocity, ending velocity, shear segment delta V (Ending velocity – beginning velocity), length of the shear segment (distance between beg Az and end Az), shear (delta V / length of the shear segment), max gate-to-gate delta V of any two adjacent radials, azimuth of the max gate-to-gate delta V, range, and strength rank.

Identifying MDA 2D features

Once all shear segments have been identified on an elevation scan, they are combined into potential two-dimensional (2D) features. This is an extensive process and more information can be found in FMH 11 Part C. At the end of 2D processing, 23 attributes are saved for each 2D feature.

Identifying MDA 3D features

The algorithm vertically correlates the 2D features from different elevation scans into vertically-associated 3D features. There are distances and strength rank limitations to make sure 2D features on higher tilts are used only once or not at all. More in depth information can be found in the FMH11 Part C. Fifty-seven attributes, some derived from 3D features themselves and some calculated, are saved for later use. Ten attributes and their height values from 2D features that are components of 3D features are saved for time-height cross-sections.

Classifying MDA 3D features

A mesocyclone strength index (MSI) is calculated for each 3D feature and core base, core top, and core depth are calculated.

Tracking MDA 3D features

After all 3D mesocyclone features have been identified, features are time associated. A first guess location is made, using a motion vector from the previous volume scan. 3D features within a certain radius of the first guess point become association candidates. Additional 3D features are also added as potential candidates for association as radii are increased around the first guess point. The best candidate for time association is found by sorting the candidates within each distance threshold first by strength rank and then by circulation type. The 4D detections are classified by vortex type (for example, mesocyclones, low-core mesocyclones) and the classifications are saved for display purposes.

Trend MDA 3D features

Attributes of 4D detections are used to calculate time trends. Trend and time height information of tracked 4D detection attributes are saved for display purposes.

External interfaces

MDA interfaces with the SCIT [Centroids] algorithm to obtain an average storm depth of the 10 strongest storm cells. Storm cell strength is based on SHI and maximum reflectivity. The average storm depth is used to determine if a 3D velocity feature meets criteria to classify the MDA detection as a low-core circulation.

MDA also uses SCIT information to associate each 3D velocity feature with a storm cell. This association information can be used in the storm attribute table to let the user know that a storm cell has a mesocyclone associated with it.

Adaptable parameters

The MDA has many adaptable parameters to allow maximum flexibility in fine-tuning algorithm performance. The vast majority of the parameters are intended for Radar Operations Center (ROC) use only, not for users to change during operations. Users are allowed to activate or deactivate a display filter and to specify a minimum strength rank value, below which 3D features are marked for non-display. Users are also allowed to activate or deactivate a switch that allows forecasters to define their own mesocyclone criteria. By default, MDA requires mesocyclones to have predefined values for minimum strength rank, maximum base height, and minimum depth.

233. Tornadic vortex signature product

Like the mesocyclone product, the TVS product is produced by an algorithm (tornado detection algorithm (TDA)) that analyzes the base velocity data to detect regions of strong, localized, cyclonic shear. The TDA is designed to identify and classify areas of cyclonic shear that exhibit the strength, depth, and size characteristics associated with tornadic circulations.

In this lesson, we look at the TVS product description, the theory of TDA and its limitations, and finish with visual TVS identification guidelines using the base velocity product.

Product description

The significant shear regions identified by the TDA algorithm are classified as a TVS or ETVS depending on the height of the lowest shear component within the three-dimensional feature. The TVS product provides the location of each identified TVS and ETVS, along with significant attributes associated with each. The TVS product is provided once per volume scan as graphical presentation or as an alphanumeric list of algorithm output.

The alphanumeric presentation is a formatted table of significant parameters associated with each identified feature (figs. 3–42 and 3–43). The graphic presentation symbols are an inverted, red-filled, isosceles triangle for TVS and an inverted, open, red, isosceles triangle for ETVS (fig. 3–44). The graphical presentation of the TVS product can be displayed as an overlay or as a stand-alone product.

ALPH PRODUCT 61 (TVS KBIX 18:29 05/11/92) PAGE 1 OF 2

COMMAND:

FEEDBACK: EXECUTED - F11 : ALPHANUMERIC HARDCOPY

TORNADO VORTEX SIGNATURE

RADAR ID 572 DATE/TIME 05:11:92/18:29:50 NUMBER OF TVS/ETVS 2/ 1

FEAT TYPE	STORM ID	AZ/RAN (DEG,NM)	AVGDV (KT)	LLDV (KT)	MXDV/HGT (KT,KFT)	DEPTH (KFT)	BASE/TOP (KFT)	MXSHR/HGT (E-3/S,KFT)
TVS	J1	155/ 35	28	39	43/ 9.6	> 7.0	< 2.5/ 9.6	20/ 9.6
TVS	C0	152/ 34	36	35	52/ 5.9	>10.2	< 2.5/ 12.5	25/ 5.9
ETVS	E0	354/ 33	32	45	52/12.8	10.3	5.8/ 16.2	25/12.8

Q10 HI KBIX 1818

30/1504 RPG ALERT THRESHOLD RCVD. PROD RCVD: SRM RPS KBIX 1835 6.0

CDC1W051A02-0101-429

Figure 3–42. TVS alphanumeric product, page 1.

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                 ALPHA PRODUCT 61 (TVS  KBIX 17:54  05/11/92)        PAGE 1 OF 1
COMMAND:  D,A,
FEEDBACK:  EXECUTED - F11:  ALPHANUMERIC HARDCOPY

                TORNADO VORTEX SIGNATURE ADAPTATION PARAMETERS

   0 (DBZ).MIN RELFECTIVITY                 2.5 (KM)..CIRCULATION RADIUS #1
  11 (M/S).VECTOR VELOCITY DIFFERENCE       4.0 (KM)..CIRCULATION RADIUS #2
 100 (KM)..MAX PATTERN VECTOR RANGE          80 (KM)..CIRCULATION RADIUS RANGE
10.0 (KM)..MAX PATTERN VECTOR HEIGHT        600 ......MAX # OF 2D FEATURES
2500 ......MAX # OF PATTERN VECTORS           3 ......MIN # OF 2D FEAT/3D FEATURE
  11 (M/S).DIFFERENTIAL VELOCITY #1         1.5 (KM)..MIN 3D FEATURE DEPTH
  15 (M/S).DIFFERENTIAL VELOCITY #2          20 (M/S).MIN 3D FEAT LOW-LVL DELTA VEL
  20 (M/S).DIFFERENTIAL VELOCITY #3          25 (M/S).MIN TVS DELTA VELOCITY
  25 (M/S).DIFFERENTIAL VELOCITY #4          35 ......MAX # OF 3D FEATURES
  30 (M/S).DIFFERENTIAL VELOCITY #5          15 ......MAX # OF TVSS
  35 (M/S).DIFFERENTIAL VELOCITY #6           5 ......MAX # OF ELEVATED TVSS
   3 ......MIN # OF VECTORS/2D FEATURE      0.6 (KM)..MIN TVS BASE HEIGHT
 0.5 (KM)..2D VECTOR RADIAL DISTANCE        1.0 (DEG).MIN TVS ELEVATION
 1.5 (DEG).2D VECTOR AZIMUTHAL DIST         3.0 (KM)..MIN AVG DELTA VELOCITY HGT
 4.0 (KM/KM).2D FEATURE ASPECT RATIO       20.0 (KM)..MAX STORM ASSOCIATION DIST

                                           Q10 HI  KBIX 1749
30/1403 PROD STAT = AVAILABLE              PROD RCVD:  SRM RPS KBIX 1800        6.0
```

CDC1W051A02-0101-430

Figure 3–43. TVS alphanumeric product, adaptation parameters.

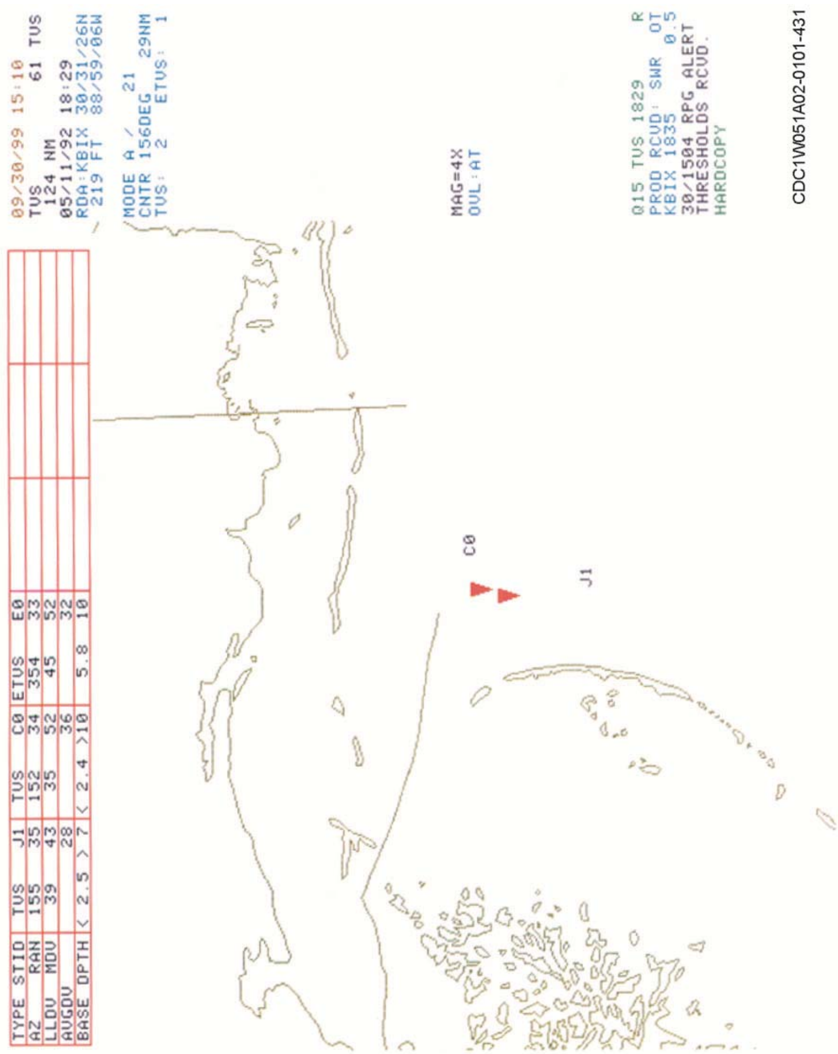

Figure 3–44. TVS graphic product.

Included with the graphic presentation is the TVS attribute table (fig. 3–44). Some of the definitions and abbreviations in the table are:

- LLDV: Low-level delta velocity, in knots, which is the greatest velocity difference of the lowest 2-D circulation.
- MDV: Maximum delta velocity, in knots, which is the greatest velocity difference of all 2-D circulations.
- AVGDV: Average delta velocity, in knots, which is the average weighted velocity difference of all 2-D circulations. (The weighting gives more importance to lower circulations).
- BASE: Lowest altitude of the 3-D circulation, in thousands feet (kft), which corresponds to the lowest 2-D circulation.
- DPTH: Depth of the 3-D circulation, in kft, which is the height difference between the lowest and the highest 2-D circulation.

Tornado detection algorithm theory

The TDA was designed to detect the cyclonic shear regions associated with tornadoes. Tornadic-like shear regions identified by the TDA algorithm are classified as either TVS or ETVS based on the following criteria:

- TVS. A tornadic vortex signature is defined as a three-dimensional circulation with a base located on the 0.5º slice or below 600 meters ARL. The depth of the circulation must be at least 1.5km. Additionally the maximum shear detected anywhere in the circulation must be at least 36m/s (≅ 72 knots), or at least 25 m/s (≅ 50 knots) at the base of the circulation.
- ETVS. An elevated tornadic vortex signature is defined as a three-dimensional circulation with a base above the 0.5º and above 600 meters ARL. The depth of the circulation must be at least 1.5km. Additionally, the delta velocity at the base of the circulation must be at least 25m/s (≅ 50 knots). Delta velocity is the difference between the maximum negative velocity (inbound) and maximum positive (outbound). For instance, an ETVS with a maximum inbound velocity of minus 25 knots and a maximum outbound velocity of positive 25 knots has a delta velocity of 50 knots.

The values just specified for TVS and ETVS are default values, and may be changed by the RRRAT, upon approval by the unit radar committee (URC).

TDA algorithm

The function of the TDA is to search the base velocity data to identify regions of significant cyclonic shear and classify them as either TVS or ETVS. Although most violent tornadoes form from a parent mesocyclonic rotation, the TDA does not rely on the mesocyclone algorithm to identify a MESO before processing.This is an important feature of the TDA algorithm. Many times during tornado production a supercell thunderstorm’s mesocyclone signature can tighten and shrink, which could cause the MESO to be missed by the mesocyclone algorithm. Plus, many tornadoes form near the surface coincident with a strengthening circulation aloft, reducing the period from mesocyclone identification to tornado touchdown. However, in either case, since the TDA is an independent algorithm the odds are increased that the TVS or ETVS will still be detected.

The TDA’s method of detection is modeled after the storm cell identification and tracking algorithm. The TDA uses a three-step process of detection, with each step named after its dimensional plane: one-dimensional (1-D) step, 2-D step, and 3-D step.

- 1-D step: In this step the algorithm searches for 1-D pattern vectors. A 1-D pattern vector is a region of gate-to-gate shear, located on adjacent azimuths. Gate-to-gate shear is Doppler velocities of opposite sign, located on adjacent sample volumes. Figure 3–45 depicts gate-to-gate shear and the algorithm’s search for 1-D pattern vectors. A minimum shear value is required for a pattern vector to be identified, a value which is adaptable by the RRRAT operator. The TDA searches for patterns of velocity indicating cyclonic rotation. The TDA will not detect anticyclonic shear regions.

1-D Pattern Vector
(Shear Segment)

RADIAL	rad #1	rad #2	rad #3	rad #4	rad #5	rad #6	rad #7
33.00km	-7	-10	-10	-7	1	2	1
32.75km	-10	-15	-13	-11	4	3	0
32.50km	-4	-11	-14	-18	12	22	13
32.25km	-11	-19	-22	13	18	11	-1
32.00km	-4	-9	-19	3	18	17	12
31.75km	-10	-14	-22	1	21	9	9
31.50km	-10	-25	-19	-6	6	2	1
31.25km	-7	-3	-5	-6	7	13	10
31.00km	-1	2	1	-3	-4	-4	-6

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Figure 3–45. 1-D pattern vector and gate-to-gate shear.

- 2-D step: In this step the algorithm combines 1-D pattern vectors into 2-D features. At least three 1-D pattern vectors are required to declare a 2-D feature. Figure 3–46, illustrates the algorithm grouping 1-D pattern vectors, into 2-D features. The TDA uses six velocity difference thresholds to identify the 2-D features. Without bogging you down with complicated criteria, let's just say this technique allows the algorithm to isolate core circulations. Circulations that may be embedded within regions of long azimuthal shear. An example would be a radially oriented gust front or squall line. Finally, if the 2-D feature passes a symmetry test (length to width ratio), then it's declared a 2-D circulation.

2-D Features
(Combine 1-D Pattern Vectors and Trim)

RADIAL	rad #1	rad #2	rad #3	rad #4	rad #5	rad #6	rad #7
33.00km	-7	-10	-10	-7	1	2	1
32.75km	-10	-15	-13	-11	4	3	0
32.50km	-4	-11	-14	-18	12	22	13
32.25km	-11	-19	-22	13	18	11	-1
32.00km	-4	-9	-19	3	18	17	12
31.75km	-10	-14	-22	1	21	9	9
31.50km	-10	-25	-19	-6	6	2	1
31.25km	-7	-3	-5	-6	7	13	10
31.00km	-1	2	1	-3	-4	-4	-6

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Figure 3–46. TDA 2-D step.

- 3-D step: In this step of the TDA, it combines 2-D features vertically to form 3-D circulations (fig. 3–47). Processing begins at the strongest 2-D circulations first, then moves to the progressively weaker circulations. If a feature contains at least three vertically correlated 2-D circulations, it is declared a 3-D circulation and identified as either TVS or ETVS. Ideally there will be no gaps in elevation angles between vertically correlated 2-D components. However, a one-elevation angle gap is permitted to account for base data problems such as range folding and velocity dealiasing failures.

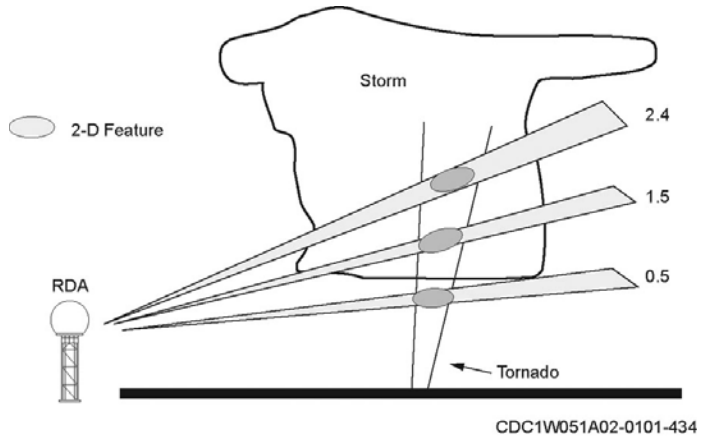


Figure 3–47. TDA 3-D step.

Limitations

The TVS product helps keep a forecaster on top of a severe weather situation especially when the workload is high. However, to effectively use this product you must be aware the TDA does have some limitations.

Beam broadening

Beam broadening may cause features to be missed or improperly identified, especially at ranges past 100 km from the RDA. Recall, studies suggest about 50 percent of all mesocyclones produce tornadoes.

Adaptable parameters

Adaptable parameters need more research. The default parameters may be right for some locations/meteorological situations and wrong for others. As more data comes in on the performance of the algorithm, it can be studied to determine if the parameters need to be modified.

False alarms

The increased sensitivity of the TDA allows it to detect locally intense, high-shear vortices associated with developing tornadoes. Therefore, the TDA triggers more frequently than the old algorithm. However, not all high-shear vortices are associated with tornadic damage on the ground; thereby, this higher sensitivity will increase the number of false alarms. False alarms may result in an over-warning, or desensitizing of forecasters. Forecaster processes and algorithm adaptable parameters may need to be adapted to keep the false alarm ratio low.Combine the knowledge of TDA's limitations with your knowledge of thunderstorm dynamics and you can effectively use the TVS product. When a TVS or ETVS is identified, consider the ambient environmental winds and thermal profile, the signatures position in relation to the storm, time continuity, and the storm's range from the radar. Since the TDA works independently of the mesocyclone algorithm, the detection of MESO coincident with a TVS may support issuing a tornado warning. If the TVS is adjacent to a strong reflectivity gradient especially near the rear of the storm, near a notch, or near an appendage attached to the right rear quadrant of the storm, then the forecaster should give great consideration to issuing a tornado warning.

Use of the TVS product

Like the mesocyclone product, the primary use of TVS is to identify areas of significant cyclonic shear. The TVS product should not be used as a stand-alone product; instead it should be used to alert the user when to intensify his or her metwatch. Once the TVS product has identified a potential area, then turn your attention over to other products, such as base velocity or storm relative mean radial velocity for further investigation.The NSSL in Norman, Oklahoma has developed a three-step procedure for visual TVS identification using velocity (storm relative mean radial velocity) products. A TVS signature on the WSR–88D appears as a small-scale, abnormal region of high shear. JDOP investigators noted that the signature is detectable, up to 20 minutes before tornado touchdown (based on strong tornadoes located near the radar). Note, however, that not all tornadoes produce a detectable signature. The following is a condensed version of that procedure.

Step 1

Significant localized shear must exist between azimuthally adjacent display bins within a mesocyclone. Localized shear is a velocity difference of at least 90kt (range <30nm) or at least 70kt (range >30nm <55nm) across adjacent azimuths at the same range. TVS detection beyond 55nm is difficult due to beam limitations and the size of the TVS.

Step 2

Localized shear should extend several thousand feet in the vertical, at least two elevation angles, not necessarily adjacent.

Step 3

Localized shear should have time continuity. This should be present for at least five minutes or the period of two volume scans.

Tornado vortex signature rapid update product (TRU)

In addition to the TVS product, the WSR-88D employs a rapid update strategy. The TRU product displays information about the product generated by the Tornado Detection Algorithm once per volume scan time. This enables the radar operator to make warning and other related decisions before competition of the radar volume scan. TRU has several display formats; it can be displayed as a standalone product, as an overlay on other graphic products, or in alphanumeric format. Much like the TVS product, the graphic presentation symbols are an inverted, red-filled, isosceles triangle for TVS and an inverted, open, red, isosceles triangle for ETVS. The TRU product uses storm tracking to extrapolate the position of the TVS or ETVS. The Extrapolated TVS and ETVS symbols are displayed similarly to the TVS and ETVS symbols except they are yellow.

234. Velocity azimuth display winds

One of the most useful and unique products generated by the WSR–88D are the velocity azimuth display (VAD) winds profile (VWP). The VAD winds product, or simply VWP, is similar to having real-time rawinsonde data at your disposal every five or six minutes.

Product description

The VWP shows the radar operator wind velocities at various altitudes MSL in 1,000-foot increments. The VWP provides a time-height profile of VAD-derived winds similar to a series of Skew-T diagrams with one VWP product available per volume scan. The VWP has a graphic display of up to 11 vertical wind profiles. Wind shafts are used to show direction; barbs are used to show speed, and color is used to show the root mean square (RMS). Up to 30 different altitudes can be displayed on each vertical wind profile (fig. 3–48). The VAD displays the true wind direction and speed, which differs from the radial velocities provided by other velocity products. The resolution and coverage of the VWP are from 1,000 feet to 70,000 feet in height with a minimum altitude interval of 1,000 feet. Up to 30 height levels and 10 previous volume scans can be displayed on each vertical wind profile.

VWP provides timely determination of the boundary layer wind profile. It also provides an easy-to-read display of climb winds for pilot briefing purposes. The operator can monitor significant changes in the vertical wind profile due to temperature advection or other meteorological mechanisms.

The displayed wind estimates are biased when the actual sampled wind fields are non-uniform (that is, convergence, divergence over the radar site). Whenever the sampled data fails any of the internal algorithm thresholds, “ND” (no data) is displayed. In clear air above the boundary layer, an insufficient amount of scatterers may be present for reliable returns.

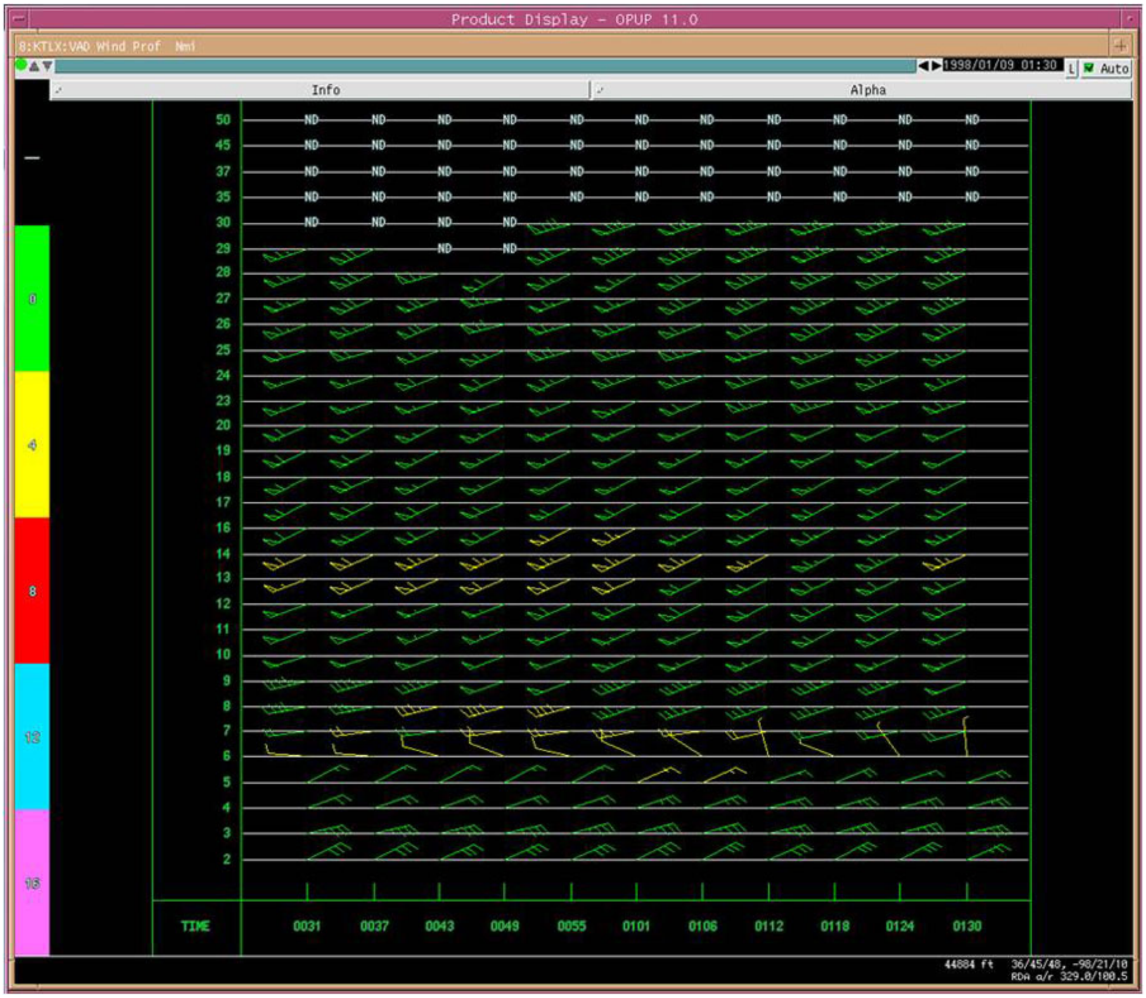


Figure 3–48. Velocity azimuth display wind profile.

Theory of VAD

The VWP is a weather observer and forecaster’s dreams come true. Now, with VWP, we are not limited to two upper-air soundings a day, but have vertical wind profiles available at the rate of a volume scan completion, depending on which VCP the radar is in. Although reading the VWP display is quite simple, calculation of the wind information is a complicated process. Fortunately, the VAD algorithm does most of the work for us. However, to best use the VWP product, being familiar with how the product is made and where the algorithm gets its data is essential.

VAD algorithm

The VAD algorithm is used to obtain the vertical profile of horizontal wind speed and direction, divergence, and vertical velocity for the region of the atmosphere surrounding a WSR–88D. The VWP is produced from this analysis. The radar scans 360° and gathers velocity data for the specific VAD analysis range. This velocity data is used to compute horizontal winds at altitude levels required to support the VWP. The algorithm obtains the vertical wind profile of both wind speed and direction. The VAD algorithm provides actual velocity measurements. All other radar velocity measurements are the radial components only.

Gathering the data

The VAD algorithm uses velocity and reflectivity data that were collected and processed by the RDA and RPG in the same manner as all the other products we have discussed. No surprises here. However, to understand how the VAD algorithm works, we must now look at this data from a little different perspective.

Let's assume the true wind is uniformly from the west at 30 knots in a given layer (fig. 3–49). For a fixed elevation angle and range corresponding to the height of that layer, radial velocity equals zero when the radar is scanning due north and due south, and all motion is perpendicular to the beam. Radial velocity is greatest when the radar is scanning due east and due west, and all motion is parallel to the beam. For a complete antenna rotation while sampling within the layer of uniform winds, the VAD profile is sinusoidal (lower portion of fig. 3–49).

Remember that velocities toward the radar are negative, and velocities away from the radar are positive. It is clear from the VAD in figure 3–49 that the wind is from the west, since the greatest negative velocity (toward the radar) is detected when the radar is scanning at 270°. Correspondingly, notice that the greatest positive (away) velocity is detected when the radar is scanning at 90°. The amplitude of the VAD shows the speed of the wind, here, 30 knots.

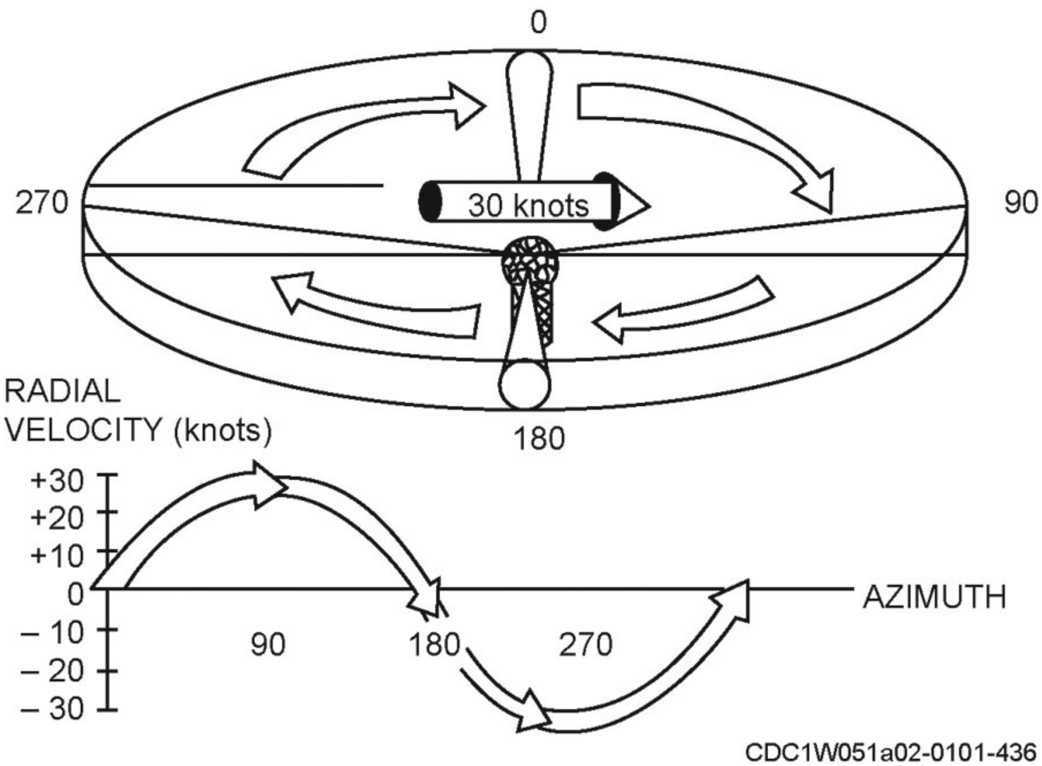


Figure 3–49. VAD velocity profile.

Radial velocity versus azimuth plot

The VAD algorithm produces a plot of radial velocity as a function of azimuth. The ideal plot would appear as a sine wave. First, the VAD algorithm plots wind direction versus velocity as simple points on a velocity vs. azimuth axis (fig. 3–50, a).

Secondly, the algorithm places a "best fit" sine wave curve to the plotted data points (fig. 3–50,b). Thirdly, the algorithm computes the root mean squared (RMS) of all the velocities located outside the curve (fig. 3–50, c). The actual radial velocities are scattered about the sine wave. The RMS is the velocity difference between wind data points and the sine wave. The further a velocity is away from the curve, the greater its RMS value. As you can see, the smaller the RMS, the more accurate or reliable the velocity value. After the RMS is calculated, the next step is to compute the "offset" (fig. 3–50, d).

To compute the offset, the amplitude of the sine wave is divided exactly in half by a line called the "zeroth harmonic." The distance between the velocity zero line and the zeroth harmonic is the offset. The algorithm uses the offset to determine the symmetry of the fitted sine wave. If the offset is greater than the symmetry threshold, the algorithm judges the velocity data at that particular altitude unreliable. If there is no difference between the zero velocity line and the zeroth harmonic, then the offset is zero.

A zero offset indicates a uniform wind field at the VAD analysis range. If the zeroth harmonic is located in the negative velocity area, it is called a negative offset. A negative offset is an indication of greater inbound flow than outbound flow—otherwise known as speed convergence. If the zeroth harmonic is located above the zero velocity line, the offset is said to be positive. A positive offset indicates greater outbound flow than inbound flow, or speed divergence.

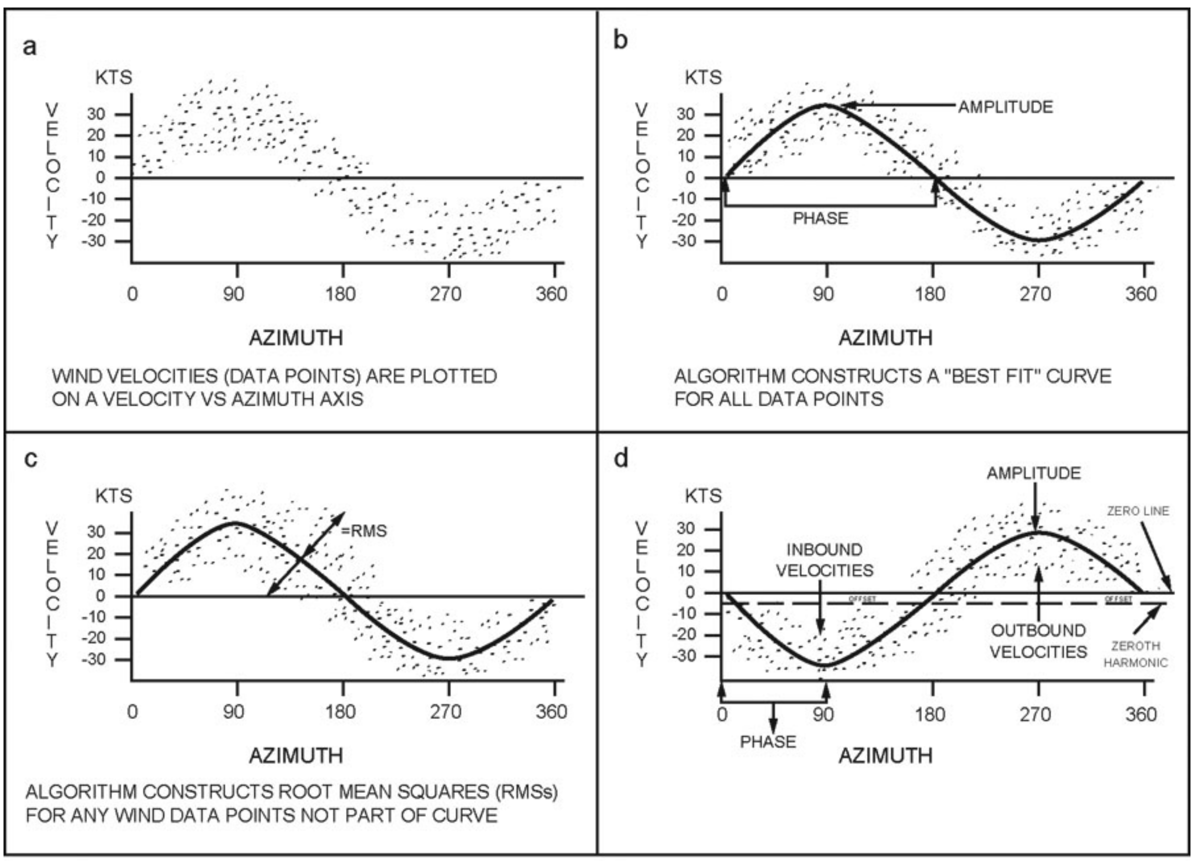


Figure 3–50. VAD plot.

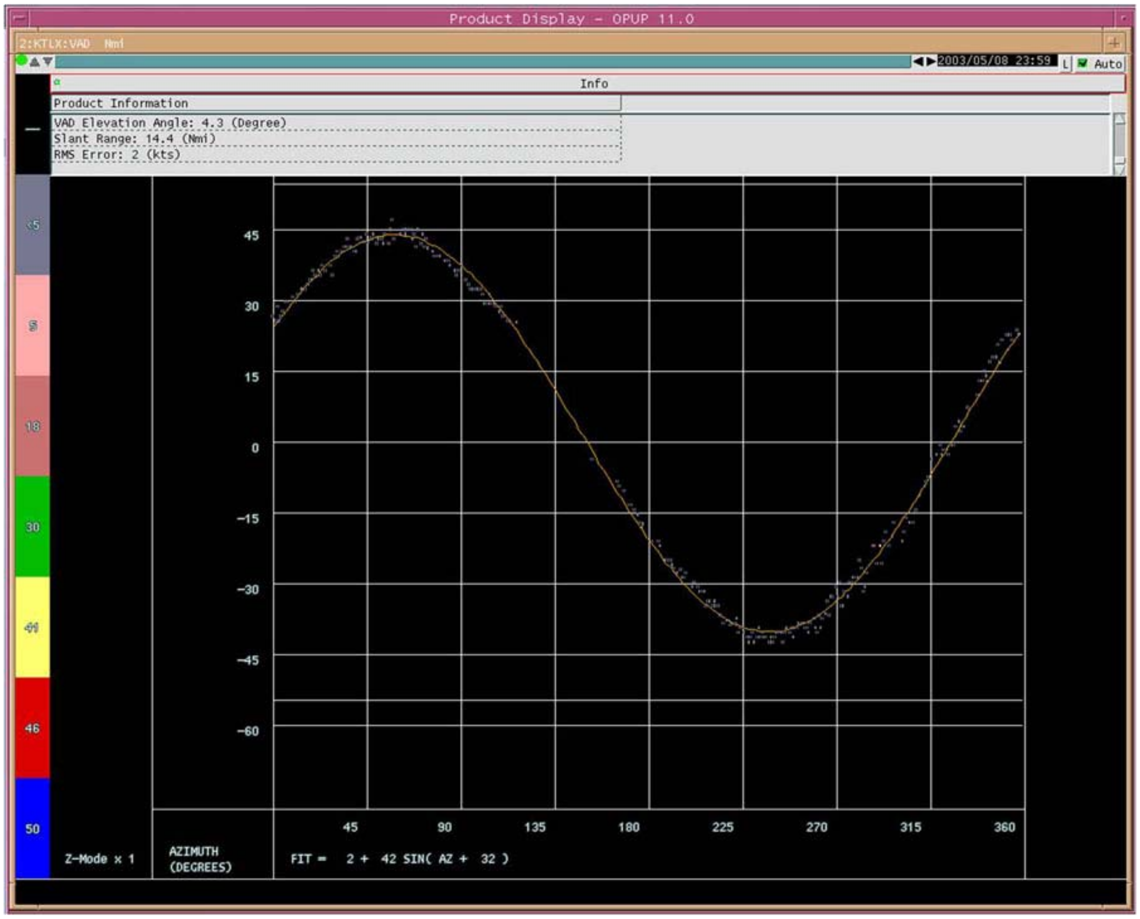


Figure 3–51. VAD product.

The VWP does not display any of the steps involved in the algorithm processing just described. What the VWP shows are the wind velocities for specified altitudes (just like you see them plotted on a Skew-T). There is, however, a product that shows you the actual wind velocity data points, the constructed best fit sine curve, the zero velocity line, the zeroth harmonic and the offset. That product is the VAD. The VAD product for each altitude is displayable (fig. 3–51).

Algorithm limitations

The VWP algorithm has a couple of limitations, non-uniform winds and data thresholds; we'll examine them at this time.

Non-uniform winds

The VWP collects its velocity data from a series of levels or planes. An example of one of these planes is shown in figure 3–52. Each elevation slice samples a plane that looks similar to the one shown. The VAD analysis range (slant range) changes depending on the wind altitude levels selected for display on the VWP. If the true wind is not uniform throughout this plane, the VWP winds may be incorrect. Consider the following example.

Let's say the VAD analysis range is 20 miles. If the wind flow at 20 miles west of the antenna is 270° at 40 knots, but the wind flow at 20 miles east of the antenna is 270° at only 20 knots, a bias occurs. As you already know, this represents speed convergence. This situation would be discernible on the VAD plot product but not on the VWP itself. If this difference is not too great, an average wind speed is reported. However, if this difference exceeded the predetermined symmetry threshold for the algorithm, winds for this layer would not be reported.

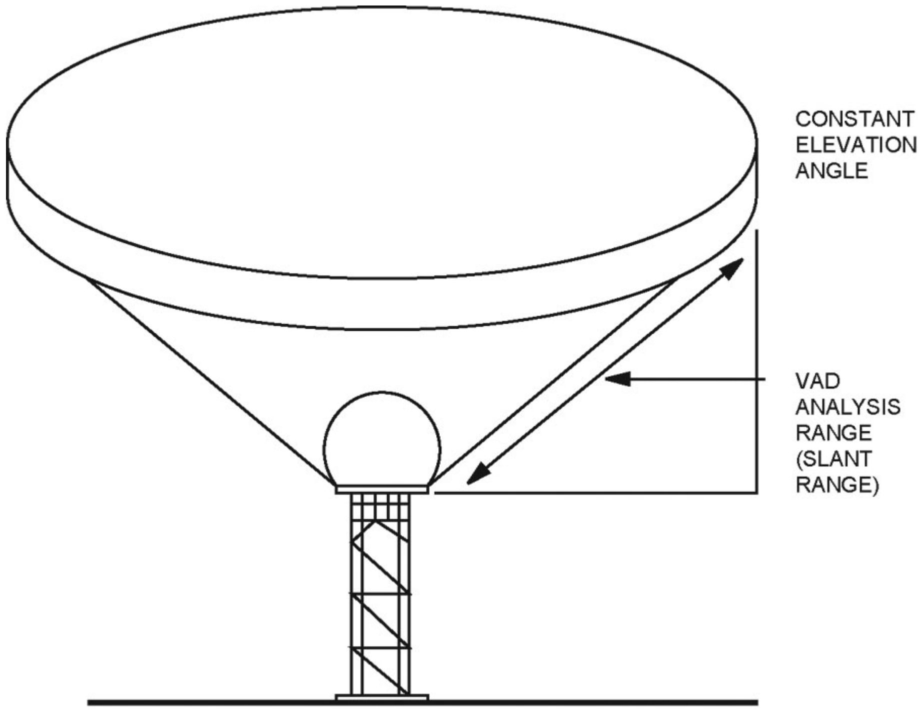


Figure 3–52. VAD analysis range.

Data thresholds

Like other algorithms, the VAD algorithm contains several adaptable parameters from which the Master System Control Function (MSCF) operator can establish and change data threshold values. Some parameters establish thresholds not to be exceeded, while others establish minimum values that must be met or surpassed. If these thresholds are not satisfied during algorithm processing, the result may be that no wind data are reported for that particular altitude. When this happens, an ND is displayed for that altitude on the VWP.

Remember that in order for weather radar to receive information about atmospheric phenomena, there must be a sufficient amount of scatterers available in the region being sampled. In very dry air above the boundary layer, there may be an insufficient amount of scatterers available to produce VAD data. This is another instance where ND is displayed.

Use of the VAD winds product

Interpreting the VAD winds profile is just like interpreting the winds on any Skew-T diagram. Wind shafts point in the direction from which the wind is coming. The wind barbs show wind speed with the longer barbs showing speed closest to every 10 knots and the shorter barbs showing speeds nearest to every five knots. For instance, if a wind shaft at 5,000 feet extends to the west and contains two long barbs and one short barb, the wind direction is westerly with a speed of 25 knots. A scale relating the RMS of wind velocities to color shade is displayed in the product legend. Remember that the RMS is a test of the velocity reliability. Winds are not encoded if RMS error or symmetry thresholds are exceeded. ND will be plotted if RMS exceeds 9.7 kts or symmetry exceeds 13.6 kts regardless of data levels. (fig. 3–48). The VWP can display vertical wind profiles from up to 11 different times. This helps you in identifying several meteorological conditions that evolve over time, such as inversions, wind shifts, and the development of jet streams.

Inversions

An example of detecting the presence of an inversion using the VWP is something like this. You are the WSR–88D operator at the beginning of a day shift with high pressure dominating, clear skies, and ground fog present. Surface winds are calm. You request and display the latest VWP.

On examination of the product, you notice wind speeds below 2,000 feet decreased from 25 knots just after midnight to less than six knots currently. During the same period, wind speeds above 2,000 feet remained unchanged. This scenario describes a radiational inversion setting up in the area of the RDA. As the inversion breaks during the day, frequent monitoring of the VWP shows increasing wind speeds below 2,000 feet as upper winds subside or transfer toward the surface. With this information, more accurate forecasts can be made concerning gusty winds following the dissipation of an inversion.

Wind shifts

A cold front is moving southeastward toward your weather station. The RDA site is 25 miles west of the weather station and the VAD analysis range is set at 30 miles. As the low-level winds begin to veer (shift from southwest-to-northwest) with frontal passage, you can see this on the VWP. As the cold layer deepens, you'll see the winds become northwesterly at higher and higher altitudes. The VWP allows you to monitor this progression at five-minute or six-minute intervals depending on the particular VCP in use. This is only one example of the many wind shift scenarios you can analyze using the VWP.

Jet streams

As a jet stream develops, the wind velocities at a given altitude are seen increasing on successive wind profiles of the VWP. Similarly as a jet stream dissipates, the VWP allows you to monitor the decreasing wind speeds at the affected altitudes. With this information, the accuracy of climb winds, turbulence, and other related data is enhanced.

235. Storm relative mean radial velocity map (SRM) and region (SRR)

In a previous lesson, we learned that velocity signatures are associated with severe thunderstorms; however, we omitted one important point. What if these storms are moving rapidly? Won't this have an impact on our velocity measurements? Yes it will, but help is here! Two important products that can greatly help us with this problem are SRM and SRR.

Product description

The storm relative mean radial velocity products provide an estimate of mean radial velocity for: (a) the entire area of radar coverage (to 124nm) with the storm motion removed (SRM), or (b) a small geographic area centered on or near an identified storm with the storm motion removed (SRR).

The storm relative mean radial velocity products are available on request for any elevation angle for a full coverage velocity product (SRM) and a window centered on a single storm (SRR). The SRM and SRR are polar coordination pixel images of derived mean radial velocity values (figs. 3–53 and 3–54). The SRM has a resolution and coverage of 0.54nm × 1° out to 124nm radius, centered at the radar location. The SRR resolution is 0.27nm × 1°. The coverage is a 27 × 27nm window. The SRR is centered on an operator-selected point.

These products are used to aid in the visual identification of storm rotation in the mean radial velocity field when rotational signatures are obscured by storm motion.

For a line of thunderstorms or a convective system where storm motions are similar, an average storm motion (computed or user input) can be removed.

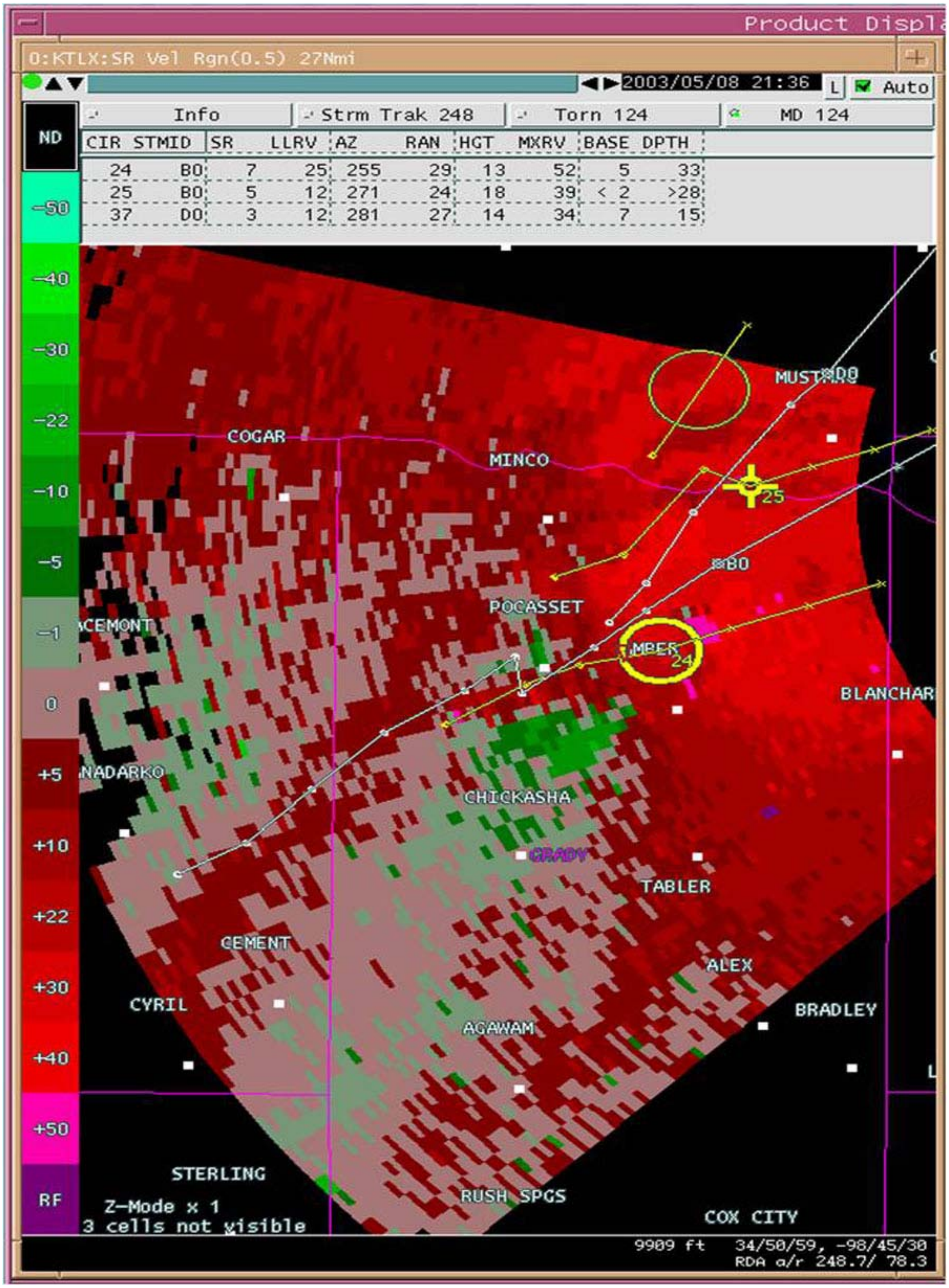


Figure 3–53. Storm relative velocity map product.

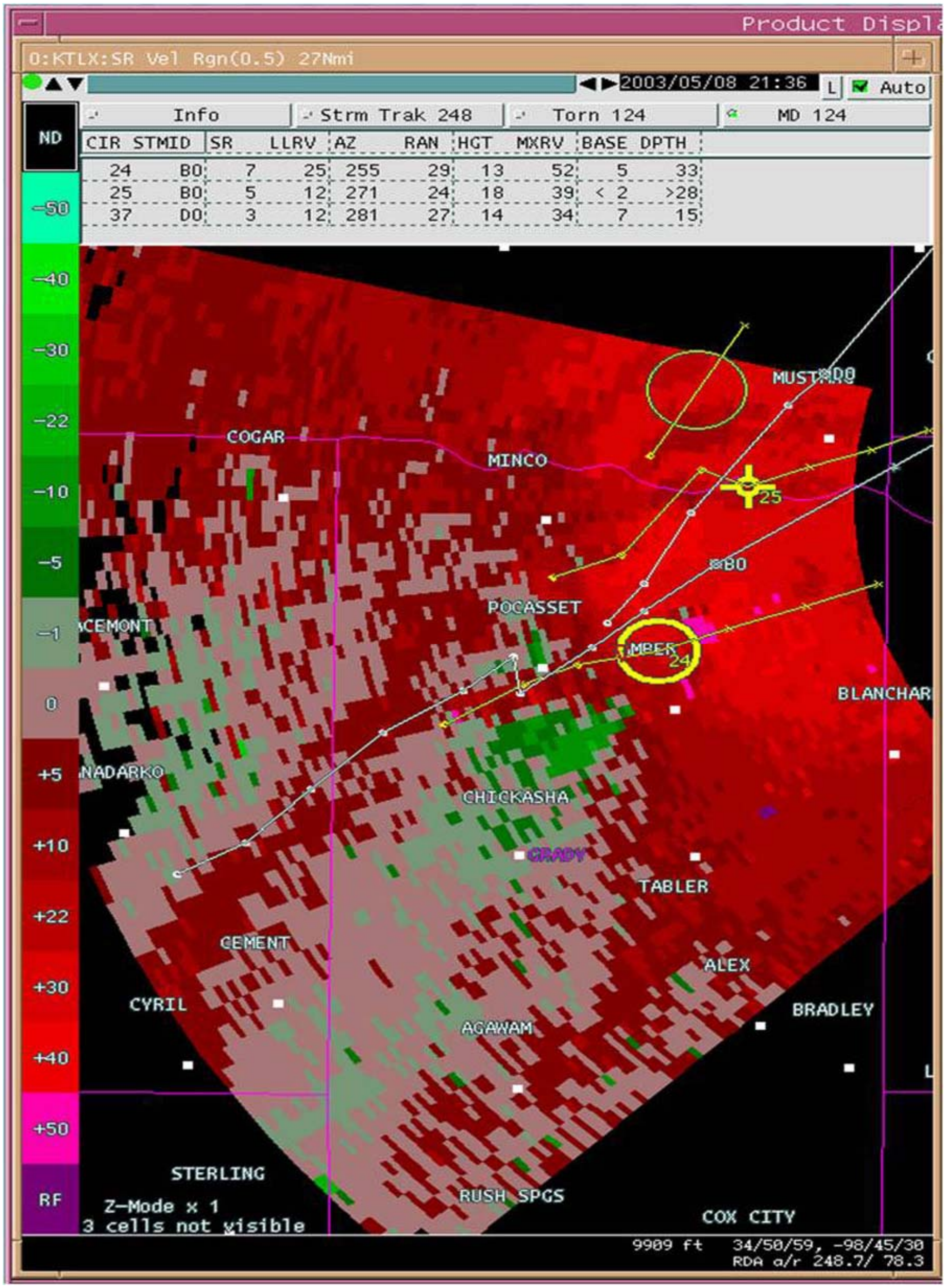


Figure 3–54. Storm relative velocity region product.

The SRR and SRM do have limitations. Storm rotational signatures are further obscured if the computed storm motion is significantly wrong, or a vector average of storms moving in a widely divergent pattern is used. Data levels differ from the base velocity product. All limitations of the base velocity product also apply to SRR and SRM. The storm relative mean radial velocity products (SRM/SRR) provide clearer looks at the base velocity products. This is done by subtracting storm motion from the base velocity product. Let’s take a closer look at these very useful products.

The SRM and SRR products are derived from the base velocity product. They greatly aid in determining the convective currents and intensities within storms. Problems arise when storm motion obscures actual values on velocity products. The SRM/SRR products simply make the storms look like they're standing still. This product provides you a detailed look at potential severe weather by balancing out the velocity couplets and making the signatures more readily identifiable.

Interpretation

One of the most difficult tasks a new Doppler radar operator has is to locate an area of rotation when a classic rotational couplet does not exist. Let's look at how to use the SRR and SRM products to aid in identifying severe storm characteristics. First, we'll look at SRR, then SRM.

SRR

Imagine a day with isolated thunderstorms dotting the radar coverage area. A particular storm displays a very strong reflectivity return with what might be a pendant. At this point, it is difficult to discern if a severe storm exists. On interrogation of the base velocity product, you note an isolated area of strong outbound velocities (>50kt) right next to an area of zero or near zero velocities. To the untrained operator, no signature exists. However, what is causing the high area of shear?

This is the perfect time to use the SRR product. By requesting an SRR product over the storm of interest, a wind vector equal to the storm motion is subtracted resulting in a balanced rotational couplet. Now, computing rotational shear is easy and sound warning decisions can be made.

SRM

Now picture a large line of thunderstorms using the same scenario as above. As it approaches, you notice it is taking on the appearance of a bow. Higher reflectivities appear at the crest and at the southern end of the line. While studying the base velocity product you notice two areas of strong outbound velocities (>50kt) right next to corresponding areas of near zero velocities.

To the operator with little experience, there is no signature. But there is! The SRM looks out 124nm and calculates the average of all storm motions. A wind vector equal to that average is subtracted from the entire display. Now we have a true picture of the storm's rotations, allowing us to make a more informed warning decision.

Computation of SRM and SRR

Data values displayed are the maximums for a given resolution. For example: for the SRR, data resolution is 0.27nm × 1°, but the value displayed is the maximum value contained in a pair of 0.13nm gates.

The SRM/SRR products depend on the storm tracking algorithm. If it is off, then the SRM/SRR products are off unless the user inputs correct direction and speed values. The inputs to the SRM/SRR are as follows:

1. For SRR, storm motion defaults to the motion determined by the storm track algorithm for the centroid *nearest* the product center if a storm is identified within the 27 × 27nm window. Otherwise, it defaults to the SRM value when no storms are identified within the window.
2. For SRM, storm motion defaults to the *AVERAGE* track found by averaging *ALL* tracks calculated by the storm track algorithm.

236. Cross-section products

Cross-section products allow us to view the atmosphere in the vertical to get a different perspective on storm structure or other properties of the environment. The WSR–88D provides the capability to view reflectivity and velocity vertically by cutting at any angle within 124nm of the RDA. This unique capability allows us to examine the atmosphere in a way that far surpasses conventional radar sets.

Product description

Cross-section products provide a vertical cross-section of the particular base moment on a height (in the vertical) versus distance (in the horizontal) axis. The end points of this axis are OPUP operator-defined and can be up to 124nm apart. Both points must be within 124nm of the RDA.

Cross-sections are available on user request (one-time product request). The data are presented in Cartesian pixel image (figs. 3–55, and 3–56). The resolution is 0.54nm horizontally by 0.27 vertically. The products display up to 70,000ft in the vertical and as much as 124nm in the horizontal. Cross-sections are an excellent tool to examine the vertical structure of many meteorological features. However, there are limitations. Because the highest elevation angle in any VCP is 19.5°, mid and upper regions of echoes near the RDA are not visible. The reflectivity of layers may be reduced because of partial beam filling. Both end points of the cross-section must be within 124nm of the RDA, and the cross-section does not compensate for beam broadening at long ranges.

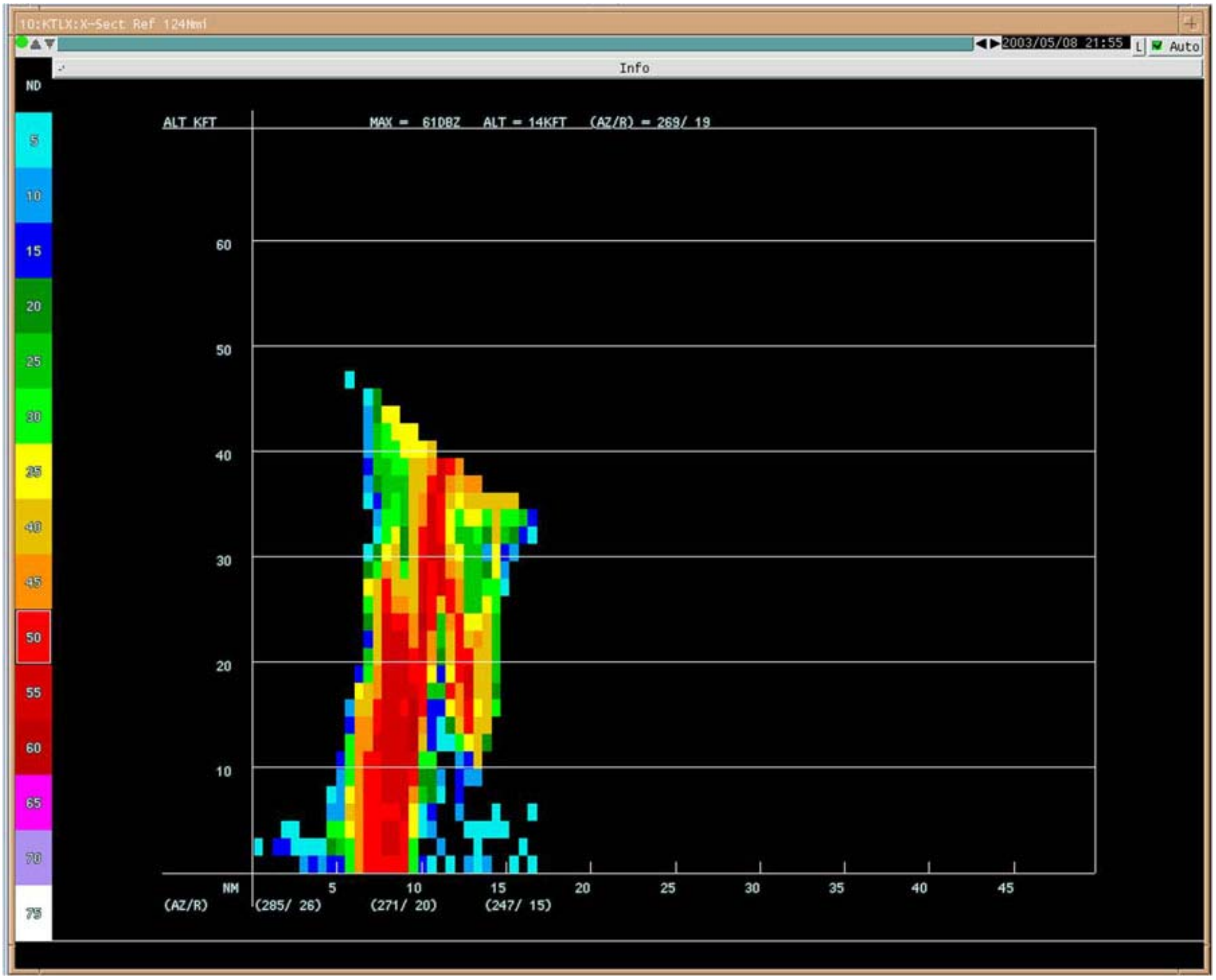


Figure 3–55. Reflectivity cross-section product.

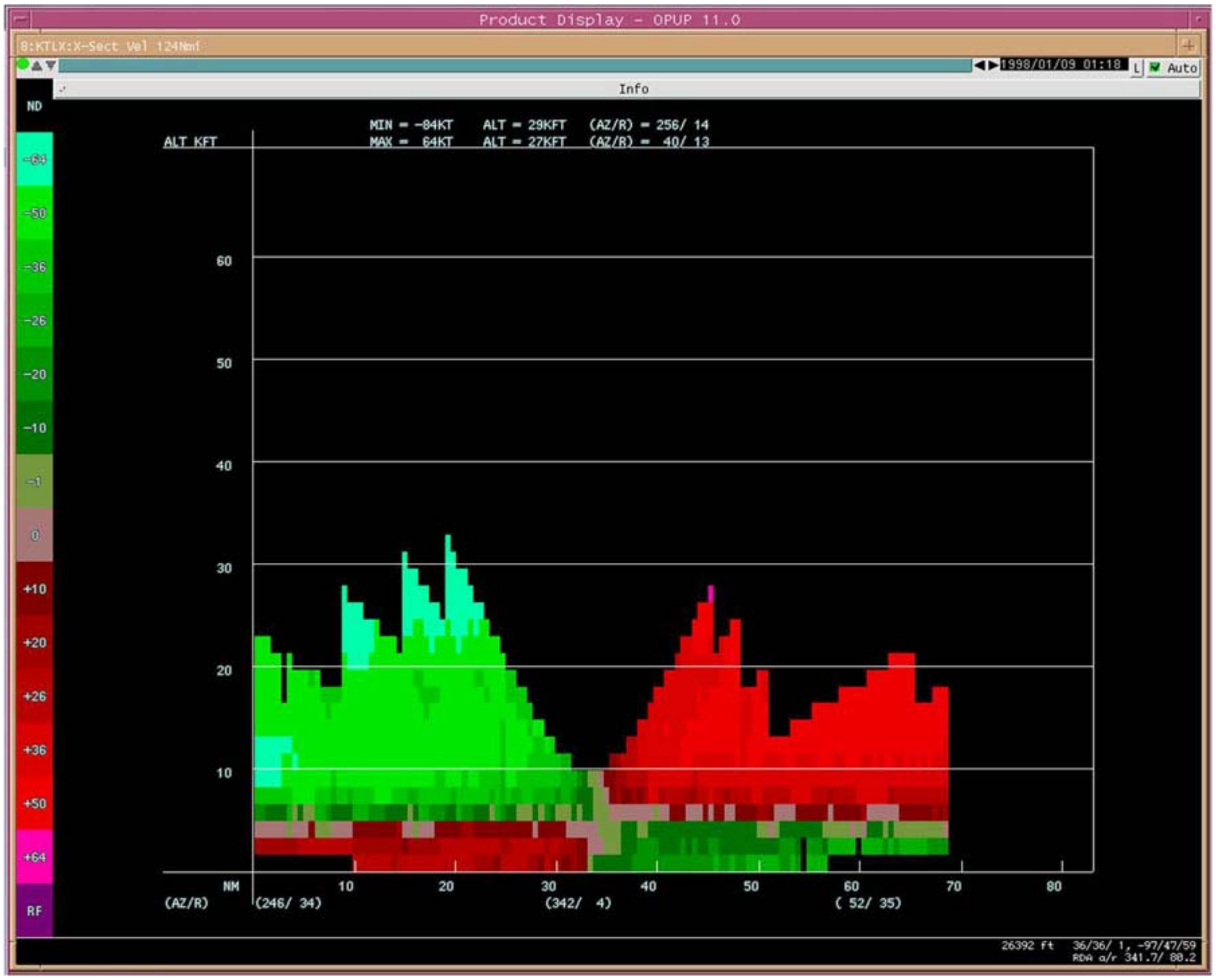


Figure 3–56. Velocity cross-section product.

Theory of cross-sections

Cross-section products provide a vertical cross-section of one of the base moments as a Cartesian pixel image along a user-defined vector; the plane is on a height-versus-distance axis. It does this by mapping the nearest value from the current volume scan for each point in the plane, then performing linear interpolation to fill the gaps.

Display format

The legend display for the cross-section products provide information on:

1. RPG name.
2. RDA height.
3. RDA latitude and longitude.
4. Product resolution.
5. Mode/VCP.
6. Western- or northern-most user-selected end point/eastern-most user-selected end point.
7. Product display state, status, and alert areas (the same as in other products).

In the product display area, the following supplemental information is also provided:

1. Above the product, the maximum data level(s) is/are displayed. Also, the maximum reflectivity in dBZ or inbound/outbound velocity at the altitude at which this value was found, and the AZRAN from the RDA of the maximum data level.
2. Below the product you'll find the AZRAN (from the RDA) of the western-most user-selected point, mid point, and eastern-most point along which the cross-section was built, or the northern-, mid-, and southern-most points if it is cut straight north/south.
3. The vertical axis is labeled 0 to 70 in thousands of feet.
4. The horizontal axis is labeled in 5, 10, or 15nm increments, depending on the user-selected length of the cross-section.

Range and resolution combinations

The resolution is always 0.54nm in the horizontal and 0.27nm in the vertical. The range can vary from 1 to 124nm depending on the operator-selected end points. Both points must be within 124nm of the RDA.

Data levels are the same as in the base product that corresponds to the cross-section requested. Reflectivity is available in 8 or 16 data levels ranging from 5 to 75dBZ in precipitation mode or from –28 to +28dBZ in clear-air mode. Velocity is available in 16 data levels ranging from –64 to +64kt.

Application and interpretation

Primarily, the cross-section products are used to examine the vertical structure of potentially severe storms. However, they are also useful in determining important meteorological information during nonconvective, even clear-air events. Let's examine and see how they work together.

Reflectivity cross-section

The first moment we'll look at is the reflectivity cross-section product.

Clear-air mode

In clear-air mode, some important features can be analyzed.

Depth of the moist layer

Using a reflectivity cross-section, the operator can determine the depth of the moist layer by analyzing the vertical extent of scatterers.

Frontal slope

A reflectivity cross-section cut perpendicularly across a dry frontal boundary allows the operator to view the frontal slope. Even if no scatterers exist, the change in refractive index reflects enough energy to be seen.

Changes in refractive index

The height of many refractive-index changes (inversions, freezing levels, and so forth) may be determined. They appear as areas of enhanced reflectivities on the cross-section.

Cloud bases and tops

For observing purposes, the reflectivity cross-section provides an objective means to measure cloud bases and tops. They appear as layers of well-defined returns.

Precipitation mode

In precipitation mode, all clear-air applications are relevant. The following features can also be identified.

Weak echo regions and bounded weak echo regions

When interrogating the vertical structure of convective storms, the operator can determine the existence and/or vertical extent of WER or BWER. They are caused by intense updrafts creating an area of little or no precipitable echoes within a thunderstorm. WER appears on cross-sections as an area of significantly weaker reflectivities extending vertically through a storm (fig. 4–55).

Location of the maximum reflectivity core

The height and intensity of the maximum reflectivity core help to evaluate the severe weather potential. A well-defined core of extremely high reflectivities suspended in the mid- and upper-levels of a storm results from an intense updraft. The stronger the updraft, the more likely the storm is to produce severe weather.

Hail spikes

Another significant feature to look for is when hail spikes due to side lobe contamination. For a side lobe to return enough energy to be detected, it must have encountered an extremely intense scatterer resulting in a narrow spike of elongated reflectivities above the storm's top. This is a good indicator of a hail-producing storm.

Reflectivity gradients, mid-level overhangs, max top position

In the lesson on base reflectivity, we discussed strong horizontal reflectivity gradients and their relationship to mid-level overhang. Reflectivity cross-sections are useful in determining the extent of mid-level overhang. Hand-in-hand with strong reflectivity gradients and mid-level overhang is the location of the maximum echo top in respect to the location of the storm's low-level maximum reflectivity gradient (inflow). All these features are examined in the reflectivity cross-section product and add immeasurably in the evaluation of a storm's potential to produce severe weather. But, the WSR–88D not only provides reflectivity cross-sections, it also builds velocity cross-sections.

Velocity cross-section

To analyze significant storms, we should always include an analysis of the velocity cross-section. There is one important point to keep in mind when requesting velocity cross-sections. The plane along which the cross-section is built *MUST* be either parallel or perpendicular to the radar viewing direction. If the cross-section is cut at any other angle, you are viewing the radial component of radial velocities. This makes the data extremely hard to interpret.

Clear-air mode

In the clear-air mode, you can interpret for turbulence, the height of the boundary layer and frontal slope.

Turbulence

In clear-air mode, velocity cross-sections are used to determine the existence and depth of turbulent layers. Turbulent layers contain strong velocity gradients in the vertical. The shear is computed by calculating the difference in velocities per thousand feet.

Boundary layer

Boundary layers are also easily seen. They appear as the point where significant change in velocity occurs, or often they are determined as the top of the scattering region. The vertical extent of the boundary layer can be of great significance to forecasters in timing the onset of convection.

Frontal slope

Frontal slope may be easier to determine on the velocity cross-section.

Precipitation mode

In precipitation mode, all the uses found in clear-air mode apply. In addition, the following phenomena are often evident.

Vortical flow fields (spiraling wind fields)

The existence, strength, and vertical depth of vortices are analyzed. This allows classification of these vortices as mesocyclones, TVSs, or other less significant features. When correlated with features found on reflectivity cross-sections, a strong case for severe weather exists. It is imperative the operator knows where the cross-section was cut to correctly identify these features.

Divergence

In the lesson on base velocity, we learned to determine hail size based on storm summit divergence. Velocity cross-sections provide a quick place to determine the strength of that divergence which in turn can be used to determine hail size.

The vertical velocity structure of many other features, such as outflow boundaries, can be examined in velocity cross-sections.

237. Storm cell identification and tracking algorithm

The storm cell identification and tracking (SCIT) algorithm was added in the build 9.0 of the software. It is actually a combination of several algorithms that work together to provide information such as individual storm cell ID numbers, storm cell tracking and forecast, and output used by the hail detection algorithm and the storm structure product. The SCIT is comprised of the following algorithms: storm cell segments, storm cell centroids, storm cell tracking, and storm cell position forecast (fig. 3–57). These algorithms work together to produce the storm tracking information product, as well as providing needed input to produce the hail and storm structure products. Now we'll take a look at how each of these algorithms work, and how they tie in with other algorithms downstream.

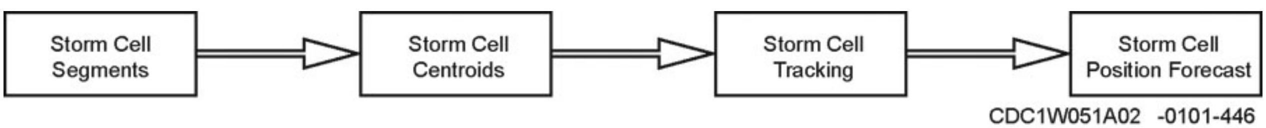


Figure 3–57. Storm cell identification and tracking algorithm flow.

Storm cell segments

Storm cell segments are the first algorithm employed within the SCIT. The primary purpose is to identify sets of reflectivity levels along each radial. To be considered a segment, sample volumes must meet or exceed specific reflectivity thresholds. This algorithm searches for segments out to a range of 248nm/460km.

Algorithm description

Storm cell segments uses base reflectivity data to identify runs of contiguous sample volumes along a radial. There are some important variables, known as adaptable parameters, that determine how the reflectivity data is reshaped into identified segments. The default values are shown with each adaptable parameter.

First, storm cell segments searches for segments of up to seven different minimum reflectivities (30, 35, 40, 45, 50, 55, 60 dBZ). Searches are done starting with the lowest minimum reflectivity threshold (30dBZ). All sample volumes **not** meeting the minimum reflectivity threshold are discarded, and not used for further processing. The sample volumes must meet the minimum segment length threshold (1.9km/1.1nm) to be considered a segment. When processing segments, the algorithm also allows sample volumes below the minimum reflectivity threshold to be included in the segment if the sample volumes meet the dropout reflectivity difference (5dBZ). The storm cell segments algorithm also uses a dropout count (2 sample volumes). The dropout count is the number of sample volumes below the minimum reflectivity threshold but meeting the dropout reflectivity difference that may be included in a storm cell segment.

After searching the radial for the minimum reflectivity threshold (30dBZ) and checking the minimum segment length threshold (1.9km/1.1nm), a search is made of the detected (30dBZ) segment for segments of the next minimum reflectivity threshold (35dBZ). Then a search of those (35dBZ) segments is made for segments of the next threshold (40dBZ), and so on through the seventh threshold (60dBZ).

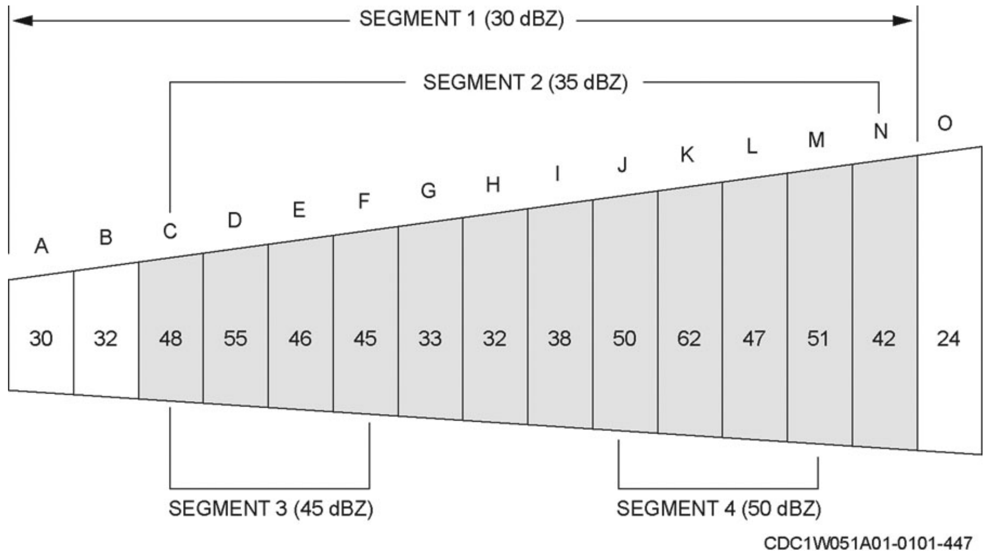


Figure 3–58. Identifying storm cell segments.

Segment run

The figure demonstrates how the storm cell segments identify sample volumes to be included as a segment. The algorithm first starts collecting data for the lowest reflectivity threshold (30dBZ). This is demonstrated by segment 1 of the figure. If these sample volumes meet the minimum segment length threshold, it is identified as a storm cell segment. Next, the algorithm searches segment 1 for the next reflectivity threshold (35dBZ). This is represented by segment 2. This process continues for all of the reflectivity thresholds. In the diagram (fig. 3–58), try to identify the sample volumes for the minimum reflectivity threshold of 40dBZ. If you chose sample volumes C–F and sample volumes J–N, you are absolutely correct! Also, notice that sample volume D was not labeled as a segment for the 55dBZ threshold because it did not meet the segment length threshold. Output is sent to the storm cell centroids algorithm.

Limitations

One consideration is the potential large number of (cell) segments detected. Because the algorithm is searching for seven different minimum reflectivity thresholds, the workload on the RPG is affected by the number of segments found. Another limitation is that the algorithm makes no attempt to prevent non-meteorological targets (that is, ground clutter) from being considered as segments.

Storm cell centroids

The storm cell centroids (fig. 3–59) algorithm identifies the center points of identified storm components. It serves as a very important step when building products that are dependent on the SCIT algorithm.

The storm cell centroids algorithm operates in a two-step process. The first step groups set reflectivity thresholds (segments) into 2-D storm cell components (fig. 3–59). The individual components are considered 2-D because the algorithm looks at one elevation angle at a time. The process starts by combining segments of the same reflectivity threshold into storm components. To be combined, segments must meet the number of segments per component threshold (default=2 segments). This is the minimum number of adjacent segments needed to be considered a component. In addition, the segments must meet an overlap threshold of two sample volumes. The overlap threshold is the minimum number of sample volumes that must overlap before adjacent segments are identified as part of the same storm component (fig. 3–60). Once the segments meet these thresholds and the minimum size of component threshold (default=10km^2), they are combined into 2-D storm cell components. If a higher reflectivity threshold is found within the lower (weaker) component, the weaker component is discarded. This causes a "bulls-eye" effect of the higher reflectivity areas. Figure 3–59 demonstrates how components are identified at each elevation angle.

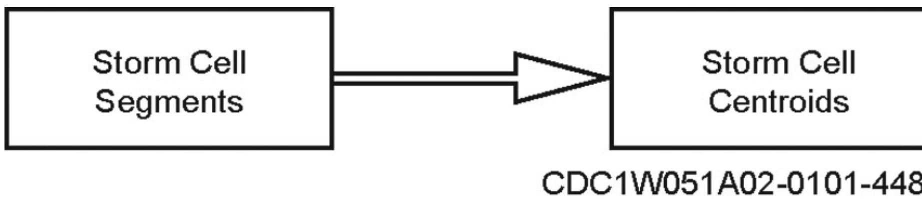


Figure 3–59. Storm cell centroids.

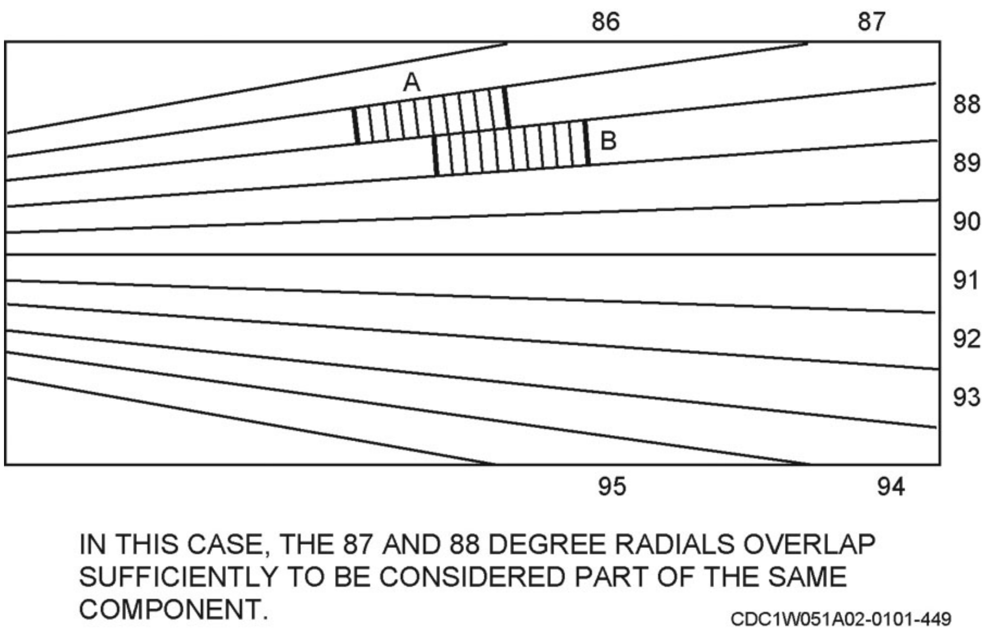


Figure 3–60. Overlapping segments algorithm description.

Step two builds 3-D storm cell components by correlating components in the vertical, working from the bottom to the top of the volume scan. Components with the largest masses are compared first. If a component at the next adjacent elevation angle is detected within a specified distance of the lower component, the components will be vertically correlated, creating a cell. This process continues for each elevation angle throughout the volume scan. Keep in mind that the component must be found at the **next** higher elevation angle to be vertically correlated. Also, there must be at least two components present to create a cell. Figure 3–61 illustrates the vertical correlation of components, creating two cells.

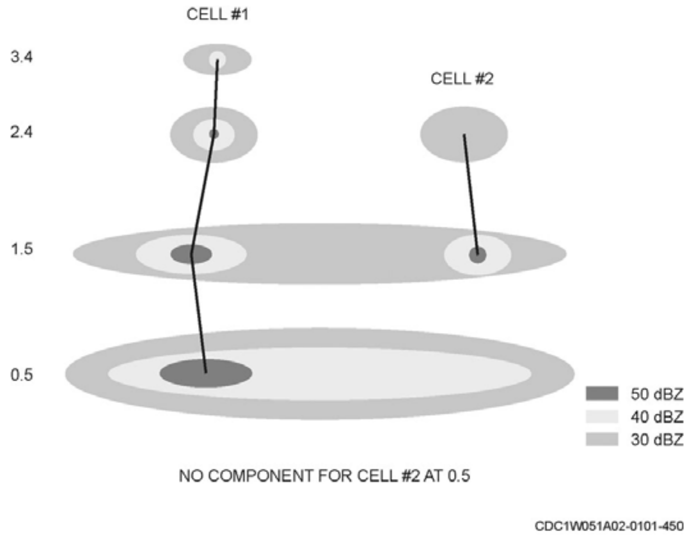


Figure 3–61. Storm cell centroids.

Cell-based VIL

A calculation of VIL is made for each cell identified by the storm cell centroids algorithm. The cell-based VIL algorithm vertically integrates the maximum reflectivity values of a cell's correlated components. This is a different calculation than produced by the gridded VIL algorithm. As shown in figure 3–62, a fast-moving or highly tilted storm usually has a higher cell-based VIL than grid-based VIL. Up to 100 cells can be identified by the storm cell centroids algorithm. The cells are ranked by their cell-based VIL.

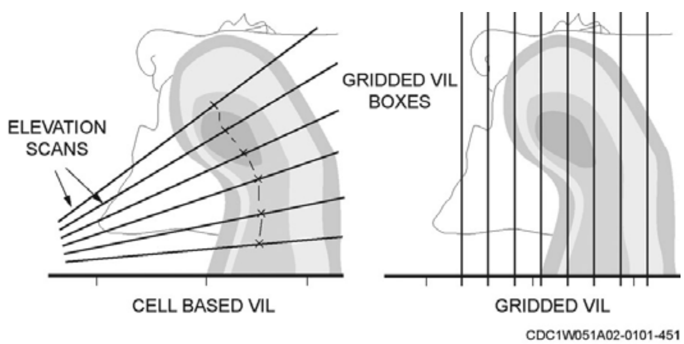


Figure 3–62. Cell-based versus. gridded VIL.

Cell merging

When cells are within close proximity, a check is done of their horizontal distance, and the vertical and angular separation between bases and tops. If they fall within a specified threshold, the cells will be merged. When merging two cells, one of the cell's attributes is added to the other cell, and a new cell centroid is calculated. Next, to reduce the crowding when two cells are still within spatial proximity and cannot be merged, the cell with the lower cell-based VIL is deleted.

Output

Output of the storm cell centroids includes: centroid location, height of base/top, maximum reflectivity value and height, cell-based VIL, and number of components detected. Output is sent to the hail detection, storm cell tracking, and storm position forecast algorithms.

Limitations

This algorithm performs best with isolated, well-defined storms. Height components may be incorrect in large areas of uniform reflectivity values. Range is another factor to consider when speaking of limitations. Due to VCP limitations, the cone of silence affects cell attributes close to the radar. At greater distances from the radar, bases may be overestimated because of the beam height above ground.

Storm cell tracking

Storm cell tracking (fig. 3–63) monitors the movement of up to 100 storm cells by matching cells found in the current volume scan to the cells from the previous volume scan. Starting with the cell with the highest cell-based VIL, a comparison is made of the cell's current centroid location with the projected (based on past movement) location from the previous volume scan. The closest projected centroid, within a threshold distance, is considered the same cell. The ID assigned to a storm consists of a letter-number combination (A0–Z0, A1–Z1, etc.) If the algorithm is unable to correlate a centroid with a centroid from the previous volume scan, it labels the storm as "NEW" and does not forecast a track.

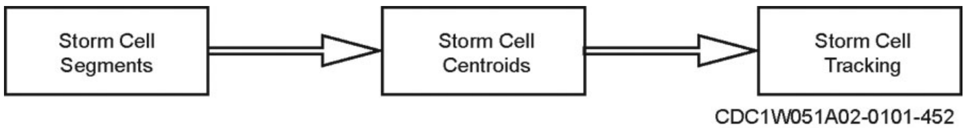


Figure 3–63. Storm cell tracking.

Storm position forecast

Storm position forecast predicts the future centroid location of storm cells based on a history of the storm's movement. The algorithm uses an identified cell's previous movement over several volume scans to output a forecast movement up to 60 minutes in the future. The length of a forecast (0, 15, 30, 45, or 60 minutes) is based on the accuracy of the previous volume scan's forecast.

238. Storm tracking information and product description

The Storm Tracking Information (STI) product is the output of the Storm Cell Identification and Tracking (SCIT) algorithm. It provides the user with information about the past, current, and forecast positions of thunderstorms. It can be produced in a tabular format of alphanumeric values, as a stand alone graphic product, or as a graphic overlay to other products.

Graphics product

Data developed by the SCIT algorithm is directly input to the STI product. This product displays up to 100 storms' past, present, and future locations. The OPUP operator has the option, to determine how many cells they want displayed on the product (covered in the manager's portion of the course). For example, if the OPUP operator selected to have 10 cells displayed on the product and 16 cells are present, the first 10 cells (ranked by cell-based VIL) are displayed on the product, and a message "**6 CELLS IN WINDOW NOT DISPLAYED**" is displayed in the lower left hand corner of the product. The current position is displayed as a circled "X," past positions are displayed as a solid dot, and the future positions are displayed as an "X." Cells with movement of less than the minimum specified speed (default=5kts) are circled, indicating little or no movement. The STI attribute table appears at the top of the STI product (color-coded cyan) and contains information on all identified cells. The table lists the cells in order of cell-based VIL from left to right. The attribute table consists of the storm ID, storm location, forecast movement, tracking error, maximum dBZ value, and its height. On the first volume scan a storm is identified, the word "NEW" is placed on the line representing forecast movement.

Alphanumeric product

The STI alphanumeric product contains information on the position and forecast of all identified cells. Again, as with the graphic product, cells are ranked by cell-based VIL. The product includes storm ID, current cell position, direction and speed of movement, AZRAN for the 15, 30, 45, and 60 minute forecast positions, and the mean and forecast tracking error.

Applications

The SCIT algorithm shows a high level of skill in identifying distinct individual cells occurring in lines or clusters. This ability to identify individual cells leads to better tracking and forecast results. Better storm identification leads to better cell attribute calculations and an improved hail index product.

Limitations

Recall from previous discussions that storm cells are defined by areas of highest reflectivity. If stronger reflectivity values exist in a storm above the lowest component, the algorithm may misconstrue that component as the lowest component (fig. 3–61/cell #2). This would cause a misinterpretation of the storm's overall mass and would affect other algorithm calculations. Also, when in VCP 21, large errors may occur in the cell attributes of storms. Storm calculation can be adversely affected by what the radar is **not** sampling in the data gaps associated with this VCP.

Linear motion

Linear motion is an overlay used to manually identify storms that have escaped detection by the storm cell tracking algorithm and for nonconvective echoes. Linear motion was created to manually compute 60 minutes of forecasted motion on base and composite reflectivity products.

Procedure

To use linear motion, first toggle on the echo of interest, then, using the product back (or product forward) function box, select the same echo on an earlier (or later) product. This action results in the automatic display of the linear motion in the lower right hand portion of the screen.

239. Hail detection algorithm

The hail detection algorithm (HDA) is used to identify which storms have the potential to produce hail. The algorithm can detect hail independent of the storm type, tilt, or overhang.

Algorithm detection

The HDA is designed to search for high reflectivity values above the freezing level. The reflectivities used are the maximum reflectivities for cell components and any reflectivity below the freezing level is not considered. The algorithm provides the following three estimates: probability of hail, probability of severe hail, and maximum expected hail size.

Probability of hail

This portion of the algorithm searches for hail of any size. First, the algorithm looks for reflectivity values > 45dBZ above the freezing level. Then it computes the height from the freezing level to the highest component meeting the > 45dBZ threshold. The greater the height, the greater the probability of hail (POH).

Probability of severe hail

The probability of severe hail (POSH) portion of the algorithm looks for hail > 3/4 inch. In the calculation of POSH, reflectivities greater than 40dBZ that exist above the freezing level are used. In addition, a weighted factor is used, such that, the greater the reflectivity values above 40dBZ, and the higher the altitude at which these values exist, the greater the weighted factor used. Reflectivities greater than 50dBZ that exceed the –20° C isotherm carry the most weight. These values are used to compute the Severe Hail Index (SHI). This illustrates the need for the MSCF operators to update the altitude of the 0° C and –20° C levels regularly, especially when significant changes to the atmosphere are experienced near the radar coverage area.

Maximum expected hail size

The maximum expected hail size (MEHS) is the estimate of the largest hail size identified anywhere in a storm, displayed in 1/4 inch increments. It uses the same data as POSH.

Graphics product

The hail index graphics product presents several symbols. The POH is identified with a small, open, or solid green triangle (fig. 3–64). Whether the triangle is open or solid depends on a “fill-in” threshold set by the OPUP operator for a specific percentage of occurrences. The POSH is represented by a larger, open or closed green triangle. POSH also depends on a “fill-in” threshold. The MEHS is displayed in the center of the POSH symbol rounded to the nearest inch from 1 to 4. If a storm has hail identified less than 3/4 inch, then an asterisk (*) is placed in the center of the POSH symbol.

The hail index attribute table, colored in green, is available at the top of the graphics product. The table lists Storm ID, AZRAN, POSH/POH, MEHS (to the nearest 1/4 inch), and the altitudes of the $0^{\circ}/-20^{\circ}$ C temperatures. Each page of the table can contain up to six storms. Cells are ordered by POSH first, then by POH.

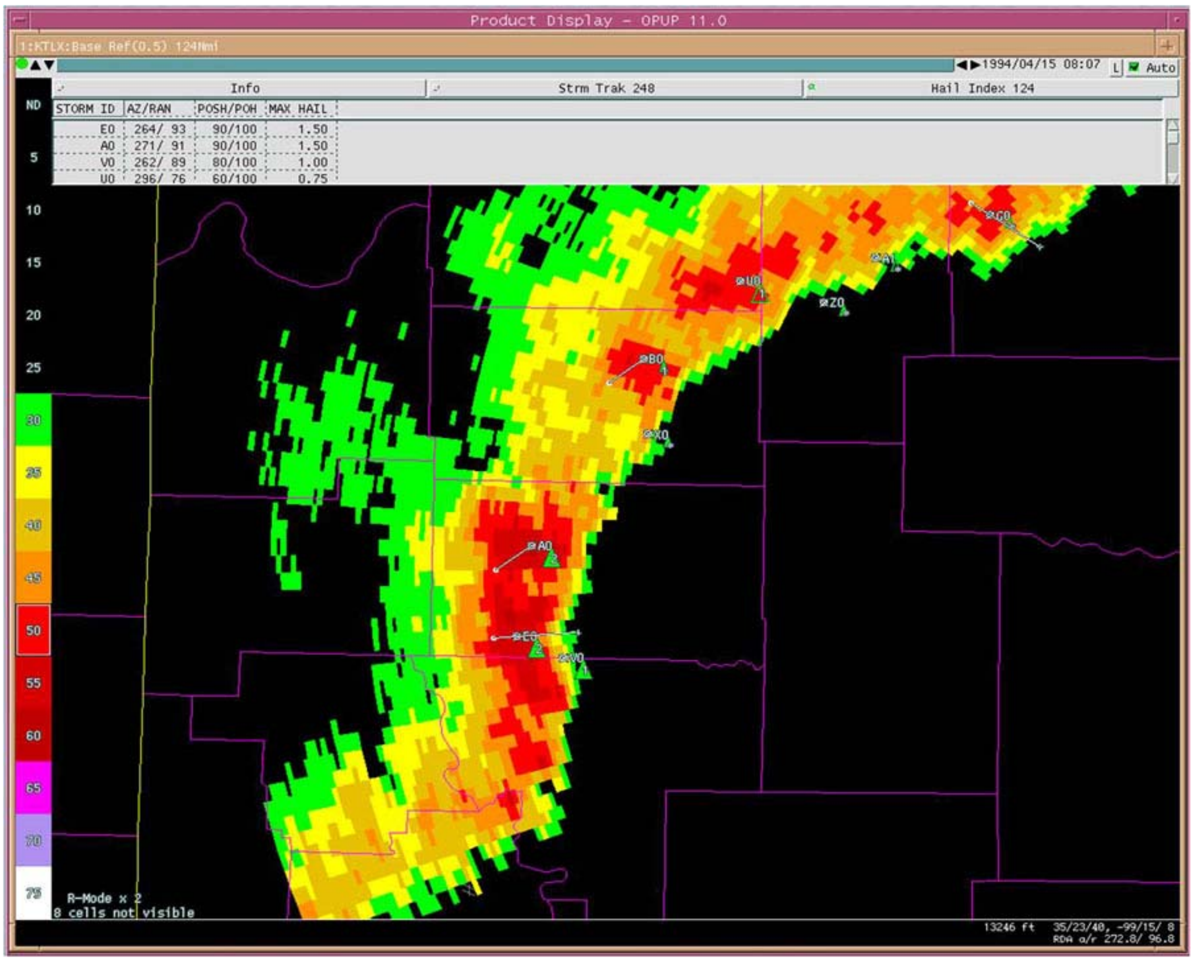


Figure 3–64. Hail graphic product and attribute table on base reflectivity product.

Alphanumeric product

The hail index alphanumeric product is available using the alphanumeric table. The product display includes: storm ID, POH, POSH, and MEHS (rounded to the nearest 1/4 inch).

Applications

The HDA has shown a very high probability of detection of cells that contain severe hail, especially greater than 1 inch in diameter. While false alarms may be a limitation, the display parameters are adaptable at the OPUP, and local adjustments to thresholds may reduce false alarms.

Limitations

The HDA needs accurate and timely measurements of the MSL altitudes for the 0° C and $–20^{\circ}$ C levels. **Failure to update this information degrades the algorithm's performance.** In limited operational use, the POSH and MEHS have tended to overestimate the chances and size of hail in weak wind and tropical environments. The accuracy of the hail estimates partially depends upon the accuracy of the cell component information provided to the algorithm.

240. Storm structure product

Imagine someone giving you a piece of paper with important information about a specific storm's characteristics. The storm structure product does exactly that! This product is displayed in an alphanumeric format at the applications terminal, and supplies pertinent information on a storm's structure using output from the SCIT and hail detection algorithms (figs. 3–65 and 3–66). Storm structure also provides input for a graphic display of storm characteristics that we'll discuss later. For this reason, the storm structure product should be placed on your routine product set list.

Product description

The storm structure product lists the following information:

1. Storm ID – in descending order of cell-based VIL.
2. AZRAN of centroid.
3. Storm cell base (KFT) – lowest component detected. Prefaced by "<" if detected at the 0.5° slice.
4. Storm cell top (KFT) – highest component detected. Prefaced by ">" if detected at the 19.5° slice.
5. Cell-based VIL (KG/M^2).
6. Maximum reflectivity in the cell (dBZ).
7. Height of maximum reflectivity (KFT).

These parameters may seem familiar. If so, it means you were paying attention when we previously discussed some of the derived products. Storm ID, AZRAN, maximum reflectivity and height of the maximum reflectivity are available on the STI graphic product. Storm ID, AZRAN, storm cell top, cell-based VIL, maximum reflectivity, and maximum reflectivity height are available in the combined attribute table of the composite reflectivity product.

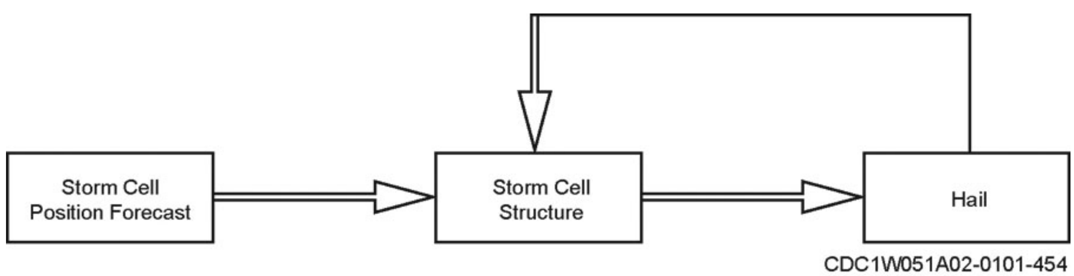


Figure 3–65. Hail and storm structure algorithms.

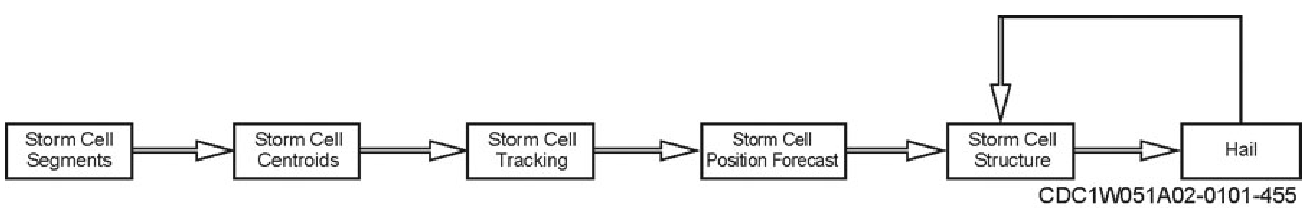


Figure 3–66. Output to storm structure algorithm.

Cell trends

As stated earlier, output of the storm structure product can be viewed as a graphic display called *cell trends*. Cell trends is a graphic display that gives up to a 10-volume scan history of cell parameters for algorithm-identified storm cells. Cell trends is **not** an actual product. It has no product ID# or mnemonic. Cell trends cannot be archived; however, it can be generated from an archived storm structure product.

Presentation format

The cell trends display contains four separate quadrants and a legend area. The information contained in the quadrants is as follows:

Upper left quadrant	Storm top/base ARL, height of the centroid, and height of maximum dBZ.
Upper right quadrant	Probability of hail and probability of severe hail.
Lower left quadrant	Cell-based VIL.
Lower right quadrant	Maximum reflectivity.
Legend area	Storm ID#, AZRAN, graphical plot of cell location, and volume scan times included in trend data.

Procedure

Use the following method to display cell trends:

1. Using right mouse button, click anywhere in the product display window. Select cell trends in the pop-up menu.
2. After step one, left click on the desired storm cell and the cell trends data will display.

Uses of cell trends

Cell trends provide continuity on individual storm cells over a period of time. By tracking the increase or decrease of storm tops, maximum reflectivity values, and cell-based VIL, you'll have a better idea of what to expect from storms in the area. The cell trends display provides an effective way of determining the life cycle of convective development. You can also determine the status of supercells and the potential for microbursts. After a weather event occurs, the cell trends display may be used for post-storm analysis.

Limitations

The volume coverage pattern employed has a direct impact on the cell trends display. VCP 21 has fewer slices, resulting in more variability of displayed data. Range to the cell is another concern when using the cell trends display. At far ranges, data may be unreliable due to the cell being sampled by only the lowest elevation slices and storm cell bases will be overestimated. Inversely, cells in close proximity to the RDA, may be affected by the cone of silence, resulting in the mid- and upper-levels of the storm not being sampled.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

222. Composite reflectivity

1. How can the CR product be displayed?

2. From how many elevations does the CR product provide the WSR–88D user with a composite of reflectivity?

3. At one geographical location, you have three elevation slices with reflectivity values of 35dBZ, 40dBZ, and 25dBZ. What reflectivity value will be displayed for that location on a composite reflectivity product?

4. What do reflectivity values displayed on a CR product represent?

5. Why can volumetric overlays be used with the CR product?

6. List three limitations of the CR product.

223. Layered composite reflectivity maximum

1. What is the major difference between the composite reflectivity and layered composite reflectivity maximum product?

2. In how many data levels is the LRM product available?

3. What are the data thresholds for the LRM product?

4. What is the height range of the low layer for the LRM product?

5. Describe a use of the LRM product.

6. Name some limitations of the LRM product.

224. User selectable composite reflectivity

1. What is the resolution of the ULR product?

2. List the limitations of the ULR.

225. LRM anomalous propagation removed

1. How is the LRM APR different from the standard LRM product?

2. Describe the omit all region used by the LRM APR algorithm.

3. Describe the accept if region used by the LRM APR algorithm.

4. Describe the reject if region used by the LRM APR algorithm.

5. What are the altitude settings for the LRM APR product?

6. Name some of the limitations of the LRM APR product.

226. Vertically integrated liquid water

1. How many data levels does the VIL product display?

2. The VIL product is derived from what base product(s)?

3. What is indicated by the values displayed on a VIL product?

4. VIL product values are in what units of measurement?

5. Can the VIL product be useful for monitoring radar echo patterns for the beginnings of significant convective development?

6. What are considered significant or high VIL values?

7. List two limitations for the VIL product.

8. What kind of VIL values do generally warm, moist air masses exhibit during severe weather occurrences? What about cool, dry air masses under the same circumstances?

227. Echo tops

1. The echo tops product is based on data from what other product?

2. What is the resolution of the ET product?

3. What is the ET product useful for?

4. How does the echo tops product provide the heights of cloud tops?

5. With the echo tops product, can a relationship be made between increasing and decreasing echo tops and the strength of the updraft?

6. Can the echo tops product be used to identify the beginning of embedded convective activity in a stratiform cloud layer? Explain.

7. Do you ever use the echo tops product as the sole indicator of what is taking place in the atmosphere?

8. List the sources of data contamination for the echo tops product.

9. What occurs if the true echo top height exceeds the maximum elevation of the radar antenna?

228. Hybrid scan reflectivity

1. The HSR product is the foundation for what products?

2. How do the HSR products assist forecasters?

3. What is the overall purpose of the HSR algorithm?

4. Describe the terrain based hybrid scan.

5. Describe the tilt test.

6. What does the radar display when the tilt test determines echoes on the 0.5° elevation slice to be clutter?

7. List some of the limitations of the HSR product.

229. Storm total precipitation

1. List uses for STP product.

2. When does the STP reset?

3. List the limitations of the STP product.

4. When is the STP product available?

230. User selectable precipitation

1. What is the difference between the storm total, one hour and three hour precipitation products, and the user selectable precipitation product?

2. How many data levels is the USP product available in?

3. What is the range of the USP product?

4. What accompanies the graphic product and provides the operator with the gage bias, the number of hours used to build the product and whether or not a specific hour was used in the generation of the product?

5. What is the maximum length of duration for which the USP product can be built?

6. List five uses of the USP product.

7. How many requests for the USP product, per volume scan, can the RPG satisfy?

231. Products derived from the Snow Accumulation Algorithm

1. Which products are available from the SAA?

2. What information will the SAA product provide the forecaster?

232. Mesocyclone

1. Through what technique does the mesocyclone algorithm locate a mesocyclone?

2. What is the range of the strength rank values for a well defined mesocyclone?

3. Indentify the seven major steps in MDA.

4. How are 4D detections classified?

233. Tornadic vortex signature product

1. The TVS product provides the location of what two signatures?

2. What is the graphic symbol for a TVS and ETVS?

3. The 2-D processor searches for cyclonic shear by identifying what?

4. What are pattern vectors?

5. How does the TVS product aid forecasters?

6. Describe a TVS.

7. Describe an ETVS.

8. List the steps of the TDA algorithm.

9. What is gate-to-gate shear?

10. Describe the limitations posed by beam broadening on the TVS product.

11. What may result when the TVS product gives false alarms?

234. Velocity azimuth display winds

1. What is the total number of vertical wind profiles that can be displayed on a single VWP?

2. What is the smallest altitude interval that can be selected for wind display purposes on the VWP?

3. If you want an estimate of the current climb winds, what is the best product to use?

4. What are the inputs to the VAD algorithm?

5. What does a low RMS at a particular height on the VWP mean?

6. To compute the RMS offset, what is the amplitude of the VWP sine wave divided in half by?

7. Whenever the VAD algorithm finds that velocity data for a particular altitude does not meet reliability thresholds, what symbol does the product display for that altitude?

235. Storm relative mean radial velocity map (SRM) and region (SRR)

1. What are the SRM/SRR products used for?

2. From what base product are the SRM/SRR products derived?

3. What algorithm does the SRM/SRR depend on?

4. For the SRM, how is storm motion determined?

236. Cross-section products

1. What do cross-section products provide?

2. Cross-section end points must be within how many nautical miles of the RDA?

3. In clear-air mode, what is the reflectivity cross-section used to determine?

4. What is the most important thing to keep in mind when requesting a velocity cross-section?

5. Which cross-section product is most often used with other cross-sections to verify the existence of turbulence?

6. The velocity cross-section is limited to how many nautical miles?

237. Storm cell identification and tracking algorithm

1. What algorithm uses the output of the SCIT algorithm?

2. What is the first algorithm employed within the SCIT algorithm?

3. What is the lowest minimum reflectivity threshold used to identify a storm cell segment?

4. What is the minimum segment length threshold used to identify a storm cell segment?

5. What algorithm processes the output of the storm cell segments algorithm?

6. What is the purpose of the storm cell centroids algorithm?

7. What is the maximum number of storm cells that can be identified by the storm cell centroids algorithm?

8. What is the purpose of the storm cell tracking portion of the storm cell tracking/position algorithm?

9. How does the storm cell tracking portion of the storm cell tracking/position algorithm label a storm if it is unable to correlate a centroid with a centroid from a previous volume scan? Is a track forecasted for this storm?

10. What is the determining factor for the length of a storm position forecast?

238. Storm cell tracking/position forecast

1. What product receives data developed by the SCIT algorithm?

2. What information is contained on the storm tracking information alphanumeric product?

3. List two limitations of the storm cell tracking/position forecast algorithm.

239. Hail detection algorithm

1. What is the purpose of the hail detection algorithm?

2. What three estimates does the hail detection algorithm provide?

3. How is the probability of hail represented graphically?

4. What information is displayed on the hail index alphanumeric product?

5. Name two limitations of the hail detection algorithm.

240. Storm structure product

1. What information does the storm structure alphanumeric product display?

2. What is the cell trends product?

3. List three uses of the cell trends product.

4. Describe a limitation of the cell trends product.

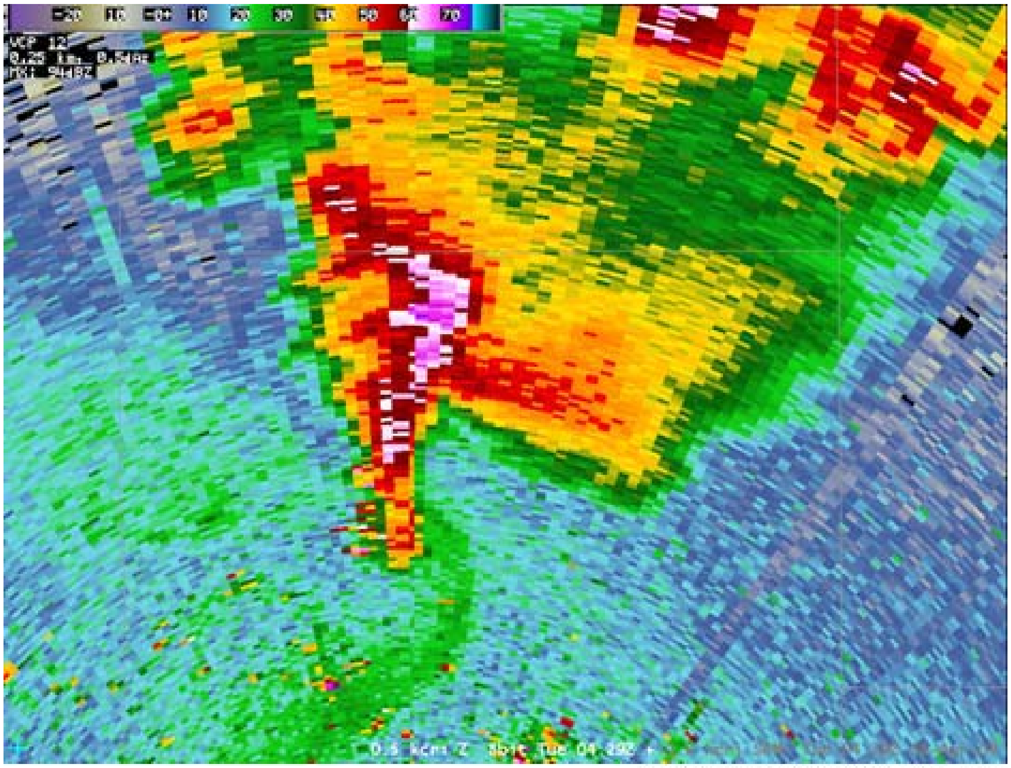
3–3. Dual Polarization Radar

The most current technology for weather radar is dual polarization, also known as dual-pol or polarimetric. Conventional radars and older versions of the WSR-88D were only able to transmit horizontal pulses. Polarimetric radars transmit both a horizontal and vertical pulses. They compare the vertical pulse returns to the horizontal pulse returns enabling the radar to obtain data pertaining to shape, size, and ice density of cloud and precipitation particles. There are numerous benefits for using dual polarization radar. These benefits include: improved hail detection for severe thunderstorm warnings, improved rainfall estimation for flood and flash flood warnings, rain and snow discrimination for winter weather warnings and advisories, data retrieval from areas of partial beam blockage to improve services in mountainous terrain, and removal of non-weather artifacts such as birds and ground clutter to improve overall data quality for algorithms and numerical model input. Dual polarization radar products are not intended to replace the legacy products of the WSR–88D. However, when used in tandem with the legacy products these products can produce a more accurate depiction of the atmosphere.

The following products discussed are scheduled to be phased in over an unspecified time period. All of these products may not be currently available to DOD users. This section provides a brief overview of dual polarization radar products.

241. Dual polarization base data products

The RPG produces three new base data products from the recombined and preprocessed dual polarization base data fields. These base products are a current addition to the primary base products you previously learned about in this volume. Each product is available in both 16 data levels and 256 data levels, which is provided at .54nm and .13nm range resolution, respectively. Default color tables were designed so that important data value transitions are apparent and that the product type is quickly recognized so that they are not mistaken for existing product types. The reflectivity field corresponding to the following dual polarization base product examples is shown in Figure 3–67.



CDC1W051A02-1012-481

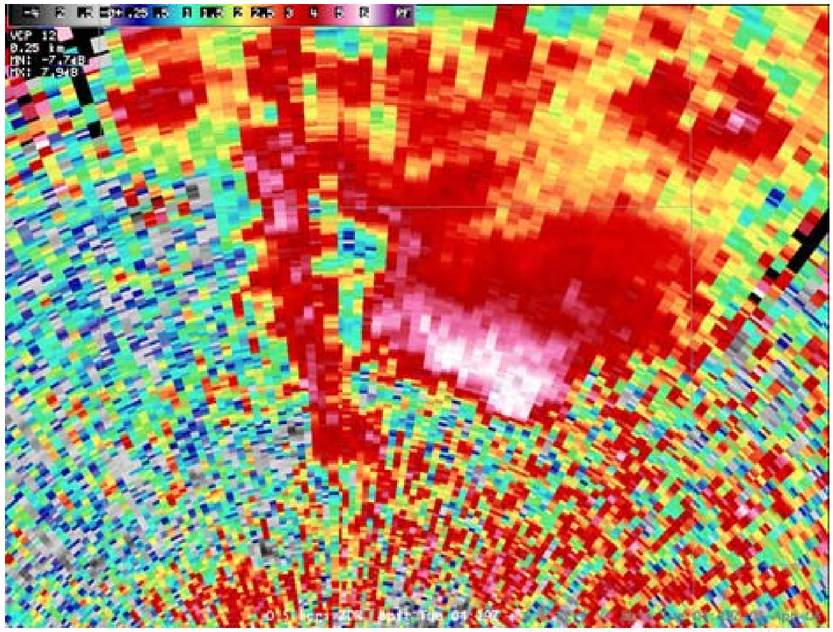
Figure 3–67 KOUN, 4/8/2008, Z product at 0.5° elevation.

Differential reflectivity (Zdr)

Differential reflectivity is the ratio of the reflected horizontal and vertical power returns and is expressed in decibels. It is a good indicator of the median shape of the reflecting particles, which in turn can be a good estimate of particle size. Differential reflectivity can be useful in detecting hail, the location of updrafts, the melting layer and some non-meteorological scatterers.

When comparing the ratio of the vertical pulse to the horizontal pulse, a mean drop shape can be estimated. Positive Zdr values are associated with horizontally elongated targets. Negative Zdr values are associated with vertically elongated targets. A Zdr value of 0 is depicts a spherically shaped target. If the drop shape is spherical, drizzle or small hail can be expected. In the event of hail, a typical scenario would depict high base reflectivity values coupled with a Zdr value near zero. If the drop shape is horizontally elongated, rain or melting hail can be expected. The appearance of ice crystals is associated with a vertically elongated drop shape.

To generate the differential reflectivity product, the RPG uses data from its dual polarization preprocessor, not directly from the RDA. Figure 3–68 contains a Zdr product for the same time and elevation as the reflectivity product in Figure 3–67.

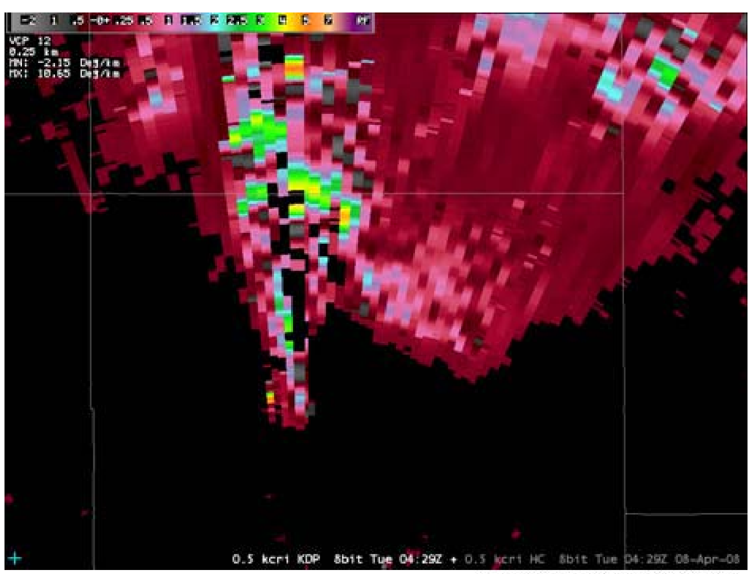


CDC1W051A02-1012-482

Figure 3–68 KOUN, 4/8/2008, Zdr product at 0.5°.

Correlation coefficient (CC)

Correlation coefficient is a dimensionless measure of the similarity between the reflected horizontal and vertical power returns within each radar pulse volume. This is an indicator of the homogeneity of scatterers within the sample volume, where values close to 1.0 are nearly uniform. CC values range between .2 through 1.05. Areas with low correlation coefficients are a good indicator of regions of mixed precipitation types, non-meteorological scatterers, or large hail. Correlation coefficient products have non-linear data levels to enhance discrimination of correlation coefficient values near 1.0, the upper end of the data range. In this region it is important operationally to distinguish small variations of correlation coefficient to help in identifying the extent of the melting layer, regions of mixed phase precipitation and the presence of non-meteorological echoes. Low correlation coefficients in meteorological echo can be indicative of very large hail. Figure 3–69 contains the CC product corresponding to Figure 3–67.

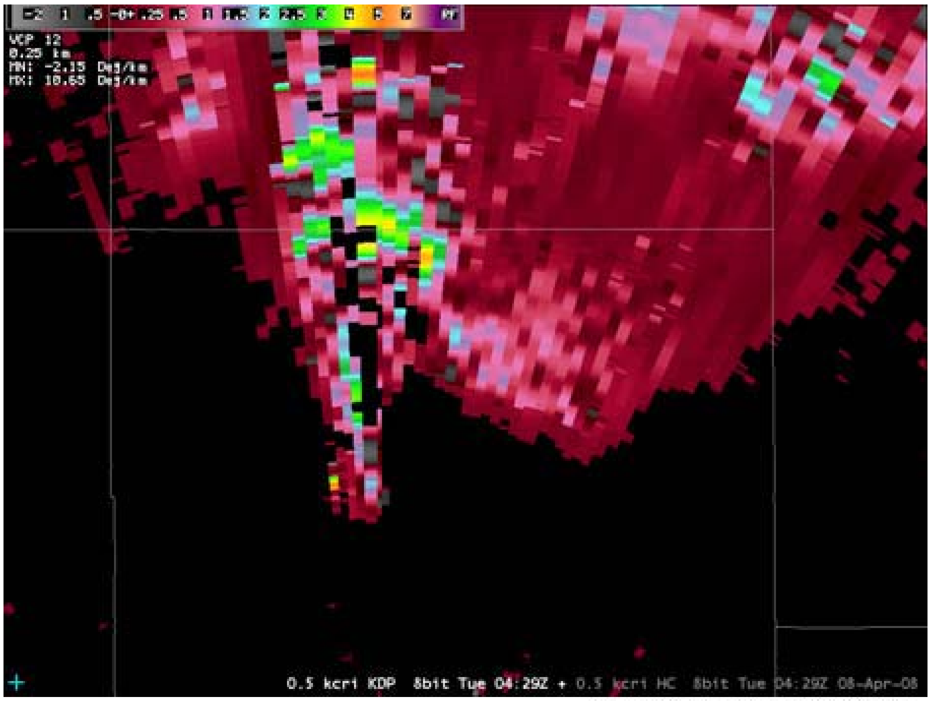


CDC1W051A02-1012-479

Figure 3–69 KOUN, 4/8/2008, CC product at 0.5°.

Specific differential phase (Kdp)

The specific differential phase is a comparison of the returned phase between the horizontal and vertical pulses. This phase differential is caused by the difference in the number of wave cycles (or wavelengths) along the propagation path for horizontal and vertically polarized waves. It should not be confused with the Doppler frequency shift, which is caused by the motion of the cloud and precipitation particles. The specific differential phase product is a very good estimator of rain rate. Figure 3–70 contains the Kdp product corresponding to Figure 3–67.



CDC1W051A02-1012-479

Figure 3–70 KOUN, 4/8/2008, Kdp product at 0.5o.

242. Hydrometeor and precipitation products

In addition to the base products available with dual polarization radar there are many other products available for use to help improve your analysis of the atmosphere. Knowing how to properly use these products can be vital to your forecast and enhance the resourse protection capability of your unit.

Hydrometeor classification product (HC)

The hydrometeor classification product is derived from the hydrometeor classification algorithm (HCA). The purpose of the HCA is to determine the echo type. Upon determination from the HCA, the echo is classified and color coded as one of the following:

- Biological scatterers (BI).
- Ground clutter/ anomalous propagation (GC).
- Ice crystals (IC).
- Dry snow (DS).
- Wet snow (WS).
- Light/moderate rain (RA).

- Heavy rain (HR).
- Big drops (BD).
- Graupel (GR).
- Hail possibly mixed with rain (HA).
- Unknown (UK).
- Range folding (RF).

The HC product can be used to supplement the base reflectivity product and provides a quick look of possible areas of concern. Figure 3–71 shows the HC product corresponding to the same time and elevation as Figure 3–67.

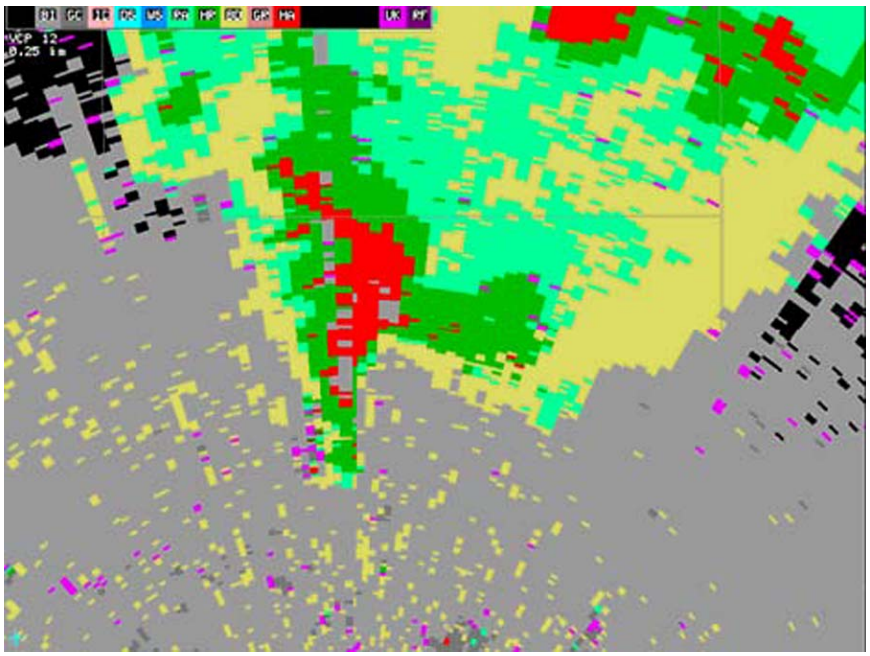


Figure 3–71 KOUN, 4/8/2008, HC product at 0.5°.

Melting layer product (ML)

This elevation-based overlay product graphically shows the locations where the radar beam intersects with the melting layer as determined by the melting layer detection algorithm (MLDA). In a typical meteorological situation with an elevated melting layer, the product consists of four lines, each describing an approximate circle. Closest to the radar is a dashed circle representing the point along the radial where the top of the radar beam first intersects the bottom of the melting layer. In the region from the radar to this first dashed line, the radar beam is entirely below the melting layer and contamination from frozen hydrometeors is not expected. Respectively, two solid line circles represent the beam center's intersection with the bottom and top of the melting layer. An outer dashed circle represents the point along the radial beyond which the beam is entirely above the melting layer.

One-hour accumulation (OHA) and digital accumulation array (DAA)

The OHA and DAA products are an estimate of precipitation accumulation over the last hour in inches. Figure 3–72 contains an example of an OHA product. The OHA product has 16 data levels which are adaptable and a range resolution of 1.1nm. The DAA product has 256 data levels and a range resolution of .13nm.

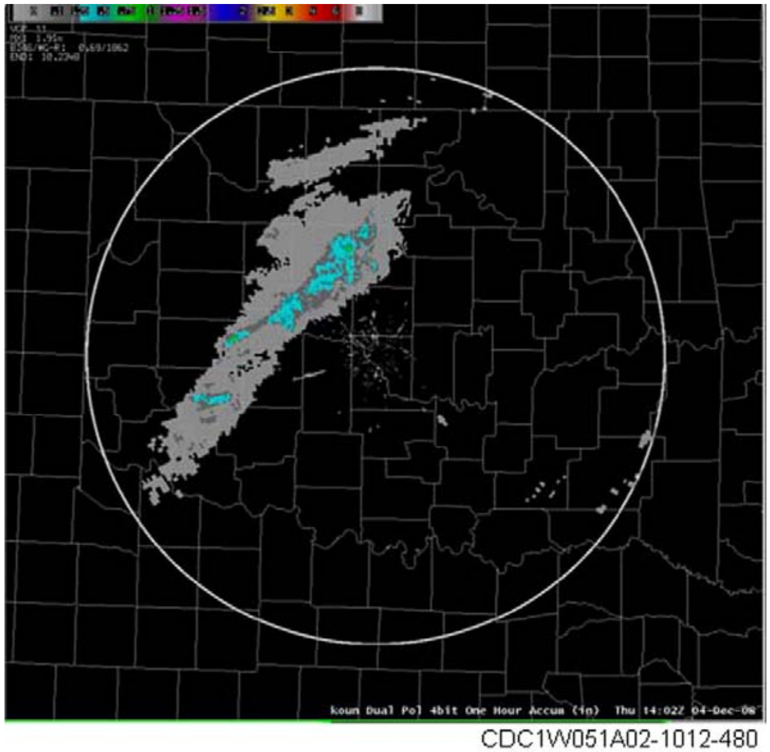


Figure 3–72 KOUN, 6/10/2003. OHA product on AWIPS.

Storm total accumulation (STA) and digital storm total accumulation (DSA)

The STA and DSA products are both an estimate of the precipitation accumulation since the beginning of a precipitation event. The STA product has 16 data levels which are adaptable and a range resolution of 1.1nm. The DSA product has 256 data levels and a range resolution of .13nm. If there has not been any precipitation in the last hour, the products are empty (that is, they show no accumulation). The products also includes adaptable parameter values, rain-gage bias information (for future implementation), and other supplemental (precipitation status) data. Figure 3–73 contains an example of a DSA product.

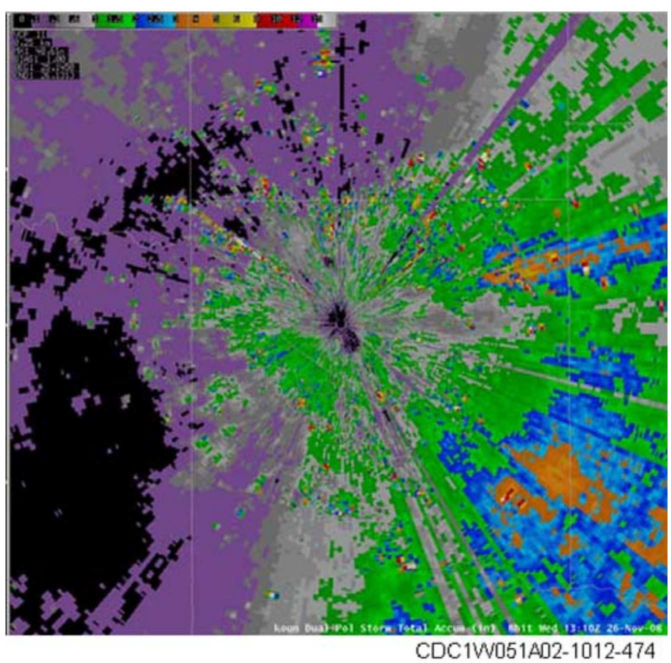


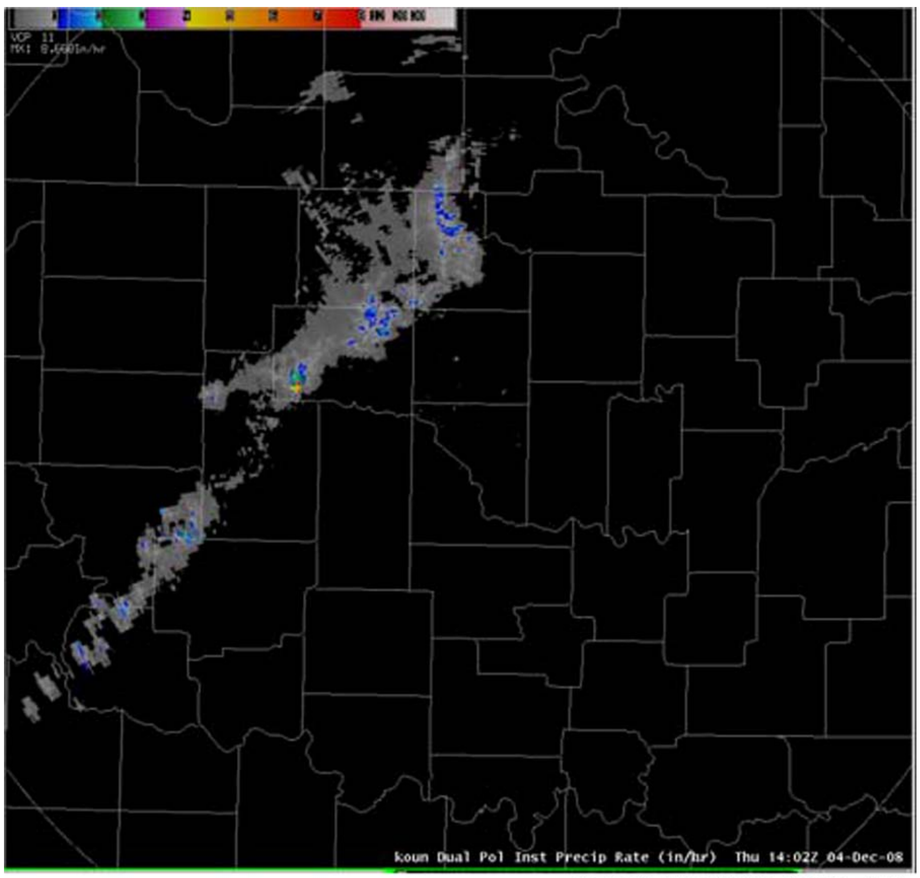
Figure 3–73 KOUN, 6/10/2003, DSA product zoomed-in near the radar.

Digital user-selectable accumulation (DUA)

The DUA product is an estimate of precipitation accumulation over a user-selected accumulation period. The accumulation period is of variable duration and defined using two parameters: the ending time (Z) in hh:mm format and the time span in hh:mm format (ranging from 15 minutes to 24 hours before the ending time). The product will usually be generated by request, but will also be generated daily by default at 12Z for a time span of 24 hours and every volume scan for a time span of 1 hour. The DUA product has 256 data levels and has a range resolution of .13nm.

Digital instantaneous precipitation rate (DPR)

The DPR is a polar grid of digital high-resolution instantaneous precipitation rates. The product has 65,536 data levels (that is, 16-bits) and has a range resolution of .13nm. Figure 3–74 shows an example of a DPR product at the same date and time as shown in figure 3–67.



CDC1W051A02-1012-472

Figure 3–74 KOUN, 6/10/2003, DPR product.

Hybrid-scan hydrometeor classification (HHC)

The HHC product contains the hydrometeor classification for each radar sample bin. This product will often resemble the 16 data level hydrometeor classification product at the elevation angle used in the hybrid scan. The product has 16 data levels and a range resolution of .13nm. (fig. 3–75).

Figure 3–75 KOUN, 6/10/2003, HHC product.

Digital one-hour difference (DOD) and digital storm total difference (DSD)

The DOD is a difference of one-hour-estimates, and the DSD is a difference of storm total estimates. Both products have 256 data levels (that is, 8-bits) and have a range resolution of 0.25 km. An example DSD product is shown in Figure 3–76, which depicts the difference between Figure 3–73 and Figure 3–77. The shades of purple show where clutter contamination was reduced by the quantitative precipitation estimate, an algorithm used by the WSR–88D.

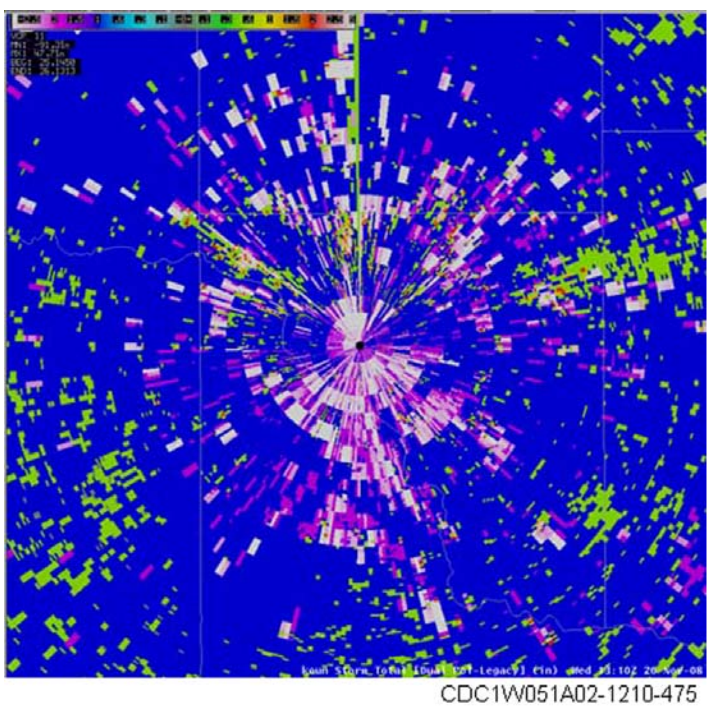


Figure 3–76 KOUN, 6/10/2003, DSD product zoomed-in near the radar.

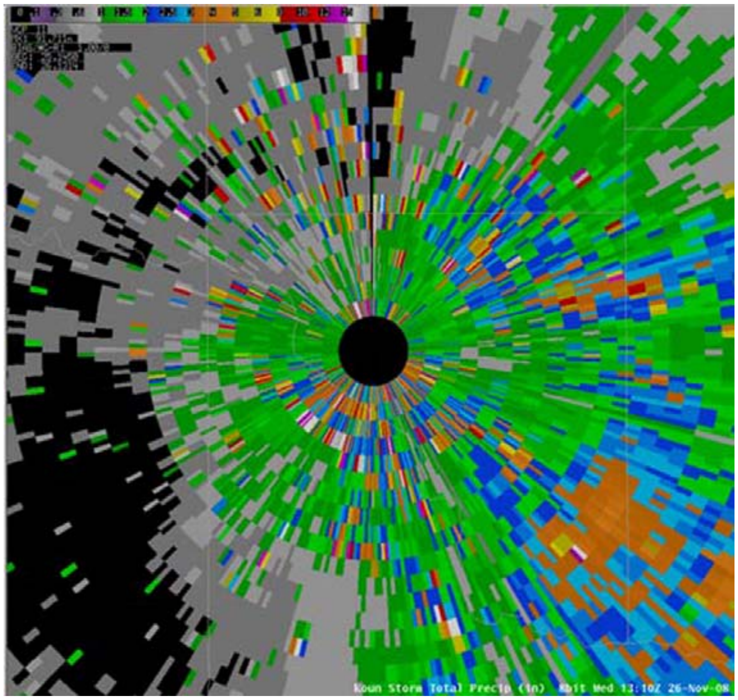


Figure 3–77 KOUN, 6/10/2003, DSP product from legacy PPS zoomed-in near the radar.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

241. Dual polarization base data products

1. What range resolutions are available for the dual polarization base data products?

2. Match the dual polarization base product in column B with its attribute in column A. Each item in column B may be used more than once.

Column A

____ (1) Values range between .2 and 1.05.
____ (2) Value of zero depicts a spherical target.
____ (3) Low values can be indicative of large hail.
____ (4) Good indicator of median shape of particle.
____ (5) Very good estimator of rain rate.
____ (6) A comparison of the returned phase between the horizontal and vertical pulses.

Column B

a. Differential Relectivity (Zdr).
b. Correlation Coefficient (CC.)
c. Specific Differential Phase (Kdp).

242. Hydrometeor and Precipitation Products

1. Which product is used to determine echo type?

2. Which algorithm is used to determine the melting layer product?

3. What unit of measurement is used for the OHA and DAA products?

4. Which two products are used to estimate precip accumulation since the beginning of a precipitation event?

5. What is the maximum time frame that can be selected using the DUA product?

6. What is the range resolution of the DPR product?

7. Which product contains the hydrometeor classification for each sample bin?

8. What does the color purple indicate when using the DOD and DSD products?

Answers to Self-Test Questions

219

1. Precipitation wrapped around the vortex.
2. In the right rear quadrant of the parent storm with respect to its motion.
3. In the lowest elevations possible.
4. Attenuation.
5. A ring or partial ring of enhanced reflectivity.
6. Too few clouds present at the melting level, a disruption of the melting level by some form of turbulence or convection, and heavy precipitation that may saturate the display.
7. 18dBZs.

220

1. Cold-air advection.
2. A frontal boundary.
3. Rotation.
4. Divergence.
5. Base velocity.

221

1. The variance of motions within the mean radial velocity field.
2. It is used with other products for estimating turbulence associated with thunderstorms, frontal boundaries, and clear air. It is also used to show the validity of mean radial velocity estimates and gives a first look at possible convective development.
3. A combination of different particle motions.
4. The frequency of the backscattered energy from the largest meteorological targets.
5. Comparatively higher values.
6. The increased variance in particle velocities.
7. Mean radial velocity.

222

1. By itself or as a background for overlays.
2. The entire volume scan.
3. 40dBZ.
4. The maximum reflectivity in the entire volume scan.
5. Because it is a volumetric product.
6. Many of the typical horizontal plane signatures that do not exhibit high reflectivities are not visible on the CR product (for example, hook echo). Other features may also be disguised on the CR product. If you detect a classical feature on CR, investigate it further by using base reflectivity. Altitude information about the 3-D structure of reflectivity is lost. Since CR is made up of information that comes from the base reflectivity products, many of the same situations that affect the quality of reflectivity data also cause problems with CR. (Any three limitations will suffice)

223

1. The CR product is produced by using the entire volume scan, which makes it difficult to determine the approximate altitude of a particular reflectivity value. The LRM uses three layers—low, mid, and high—in the production of the product. This allows you to look at maximum reflectivities for a specific section of the storm.
2. 8.
3. From 5 to 57 dBZ.
4. Surface to 24,000 feet.

5. In providing the operator a quick look at significant reflectivity values for a specified layer. The LRM is an excellent way of tracking the intensity trends of strong convection.
6. The LRM uses only three elevation angles that fall within the altitude of the layer specified; is adversely affected at distant ranges from the radar where the layer may only encompass one or two elevation slices. At close ranges, mid and high layer altitude products are ineffective due to the cone of silence. Signatures such as hook echoes, BWERs, and WERs may not be detectable because of the LRM's use of several elevation slices.

224

1. .54nm.
2. The ULR displays only the maximum return for the entire layer which makes it difficult to determine the location within the layer of the maximum reflectivity. Severe weather signatures are usually masked by higher reflectivity values being displayed over weak echo regions.

225

1. An algorithm is used to remove reflectivity readings from ground targets.
2. It is defined as the portion of the atmosphere within 45km of the RDA and below 1km in altitude. The algorithm discards all reflectivity returns from this region, thereby deleting them from the product display.
3. It is defined as the portion of the atmosphere within 103km of the RDA, on the 0.5° elevation slice and below 3km in altitude, and not within the omit all region. A target in this region is accepted for inclusion in the product if its velocity is $\geq$ 1.0m/s and its spectrum width is $\geq$ 0.5m/s.
4. It is defined as the portion of the atmosphere within 203km of the RDA and below 5° in elevation. The region does not include any of the omit all and accept if regions. A reflectivity return is rejected by the algorithm if its velocity is $<$ 1.0 m/s and its spectrum width is $<$ 0.5m/s.
5. Surface to 24,000ft.
6. The algorithm works best if traditional clutter filtering is applied before the algorithm begins processing data. The algorithm assumes all reflectivity returns below 1km in altitude and with 45km of the RDA to be clutter. This could result in valid meteorological data being removed. Current parameters may not be the optimum settings and further testing may be needed to enhance the algorithms processing.

226

1. 16.
2. The reflectivity product.
3. How much water is in the storm.
4. Kilograms per the mass squared (kg/m^2).
5. Yes.
6. Significant or high VIL values vary according to geographical location, season, and weather system.
7. Include any two of the following: VIL values change from seasonal variations, diurnal variations, and air-mass variations. A strongly tilted storm that may not have all of its vertical extent within the same stack of grid boxes. An underestimation of the severity of a storm, due to its traveling through and even exiting the stack of grid boxes. Factors that cause errors in reflectivity also cause errors with VIL.
8. Higher values exist with warm, moist air masses during severe weather occurrences, while cool, dry air masses generate lower values.

227

1. Base reflectivity.
2. 2.2 × 2.2nm grid boxes.
3. It is useful as part of briefings prepared for aviation interests and the public. It can be used in defining strong updraft regions or the presence of vertical tilt in a storm. Observation of collapsing echo tops can aid in timing the onset of a severe weather event.
4. By providing a reflectivity return stronger than an adaptable threshold value.

5. Yes, an increasing echo top is probably increasing in intensity while a decreasing thunderstorm echo top could suggest a weakening storm. If the echo top collapses very quickly it may be an indication of a downburst occurring on the surface.
6. Yes, if a stratiform situation exists and convective clouds start to develop within the stratiform clouds, the echo tops are usually detected before any indications on base reflectivity. As the updrafts develop and push the tops of the cloud higher, these higher tops can be seen as mid-level echo tops on the ET product.
7. No.
8. Side lobes, or if the true tops are above the highest elevation slice.
9. Incorrect estimations.

228

1. Precipitation products.
2. In determining the accuracy of WSR–88D precipitation products.
3. To search for low-level reflectivities (possibly precipitation) while eliminating ground clutter and correcting for beam blockage.
4. The algorithm begins collecting data from the 0.5° slice unless it detects beam blockage. If detected, it collects data from the slice above, the 1.5° slice. It follows this technique of moving up a level when beam blockage occurs, to a maximum 3.4° in elevation.
5. The tilt test compares the areal coverage of echoes at 0.5° and 1.5° elevation slices. If a 75 percent (default value) or greater reduction is found in the echoes at 0.5° slice as compared to the 1.5° slice, then the algorithm assumes the echoes to be clutter and removes them from further processing.
6. The message “LOWEST TILT UNUSED” will be displayed in the status and annotations area just above the data levels in the product legend.
7. The HSR product may display abrupt changes in reflectivity values at hybrid scan ranges. In some instances, especially at RDAs located at higher elevations, it is possible the tilt test may eliminate valid precipitation echoes during stratiform precipitation events.

229

1. Include any two of the following: Aids in the monitoring of total precipitation accumulations, whatever duration, to estimate total basin runoff due to a single storm, to get an estimate of the basin saturation due to previous rainfall events, aid in the evaluation of flood reports, and provide a post storm analysis.
2. If there has been no rainfall for more than one hour.
3. It has trouble with small-scale features and extended system outages during precipitation events, compromise the data. Breaks in precipitation of more than one hour reset the system. Non-precipitation reflectivity, such as clutter or anomalous propagation, may contaminate data. Also, the product does not account for snow or frozen precipitation, bright bands, reflectivity gradients, or attenuation.
4. From the first volume scan of detected rainfall.

230

1. The period of time the products use to accumulate precipitation amounts.
2. 16.
3. 124nm.
4. An attribute table.
5. 24 hours.
6. Monitoring precipitation for a specified time period, post storm analysis, estimation of basin run-off for a specified time, estimation of basin saturation, and evaluation of flood reports.
7. Up to 10 requests per volume scan.

231

1. One hour Snow Water Equivalent (OSW), One Hour Snow Depth (OSD), Storm Total Snow Water Equivalent (SSW).
2. An estimate of water equivalent or depth of snow during dry snow events.

232

1. A pattern recognition technique.
2. 5 - 9.
3. Threshold velocity data by reflectivity value, identify MDA 1D Features, identify MDA 2D Features, identify 3D Feature, classify 3D Features, track MDA 3D Features, trend MDA 3D Features.
4. Vortex type.

233

1. TVS and ETVS.
2. The TVS symbol is an inverted, red-filled isosceles triangle. The ETVS symbol is an inverted, red, open, isosceles triangle.
3. Pattern vectors.
4. Regions of gate-to-gate shear, located on adjacent azimuths.
5. It's use is to identify area of cyclonic shear in the identification, forecasting, and warning of severe weather associated with tornadoes.
6. A TVS is a three-dimensional circulation with a base located on the 0.5º slice or below 600 meters ARL. The depth of the circulation must be at least 1.5km. Additionally the maximum shear detected anywhere in the circulation must be at least 36m/s (≅ 72 knots), or at least 25m/s (≅ 50 knots) at the base of the circulation.
7. An ETVS is a three-dimensional circulation with a base above the 0.5º and above 600 meters ARL. The depth of the circulation must be at least 1.5km. Additionally, the delta velocity at the base of the circulation must be at least 25m/s (≅ 50 knots).
8. There are three steps: 1-D step, 2-D step, and 3-D step.
9. Doppler velocities of opposite sign, located on adjacent sample volumes.
10. Beam broadening may cause small scale features to be missed or improperly identified, especially at ranges past 100km from the RDA. Beyond 100km, the TDA will most likely trigger by a strong mesocyclone. Adaptable parameters need more research. The default parameters maybe right for some locations/meteorological situations and wrong for others. Increased false alarms.
11. False alarms may result in an over-warning, or desensitizing of forecasters.

234

1. Eleven.
2. 1,000 feet.
3. VAD winds profile product.
4. Velocity and base reflectivity.
5. The more reliable the wind data at that level.
6. The zeroth harmonic.
7. ND.

235

1. To aid in the visual identification of storm rotation in the mean radial velocity field when rotational signatures are obscured by storm motion.
2. The velocity product.
3. The storm tracking algorithm.
4. Storm motion defaults to the average track that is determined by averaging all the tracks calculated by the storm track algorithm.

236

1. A vertical cross-section of the particular base moment on a height (in the vertical) versus distance (in the horizontal) axis.
2. 124 nautical miles.
3. The depth of the moist layer, frontal slope, changes in the refractivity index, and cloud bases and tops.

4. It must be cut either parallel or perpendicular to a radial.
5. The velocity cross-section.
6. 124 nautical miles.

237

1. The hail algorithm.
2. Storm cell segments.
3. 30dBZ.
4. 1.1nm.
5. Storm cell centroids algorithm.
6. To identify the center points of identified storm components.
7. 100 storm cells.
8. To monitor the movement of storm cells by matching cells found in the current volume scan to the cells from the previous volume scan.
9. It labels the storm as “NEW” and does not forecast a track.
10. The accuracy of the previous volume scan’s forecast.

238

1. Storm track information product.
2. Storm ID, current cell position, direction and speed of movement, azimuth and range for the 15, 30, 45, and 60 minute forecast positions and the mean and forecast tracking error.
3. If stronger reflectivity values exist in a storm above the lowest component, the algorithm may misconstrue that component as the lowest component. This would cause a misinterpretation of the storms overall mass and would affect other algorithm calculations. Also, when in VCP 21, large errors may occur in the cell attributes of storms. Storm calculation can be adversely affected by what the radar is not sampling in the data gaps associated with this VCP.

239

1. To identify which storms have the potential to produce hail.
2. Probability of hail, probability of severe hail, maximum hail size expected.
3. With a small, open, or solid green triangle.
4. Storm ID, probability of hail, probability of severe hail, and maximum expected hail size.
5. Include any two of the following: the HDA needs accurate and timely measurements of the MSL altitudes for the 0°C and -20° C levels. Failure to update this information will degrade the algorithm’s performance**.** In limited operational use, the POSH and MEHS have tended to overestimate the chances and size of hail in weak wind and tropical environments. The accuracy of the hail estimates partially depends upon the accuracy of the cell component information provided to the algorithm.

240

1. Storm ID, azimuth and range of centroid, base height of storm, top height of storm, cell-based VIL, maximum reflectivity in the cell, height of maximum reflectivity.
2. A graphic display that gives up to a 10-volume scan history of cell parameters for algorithm-identified storms cells. Cell trends is not an actual product. It has no product ID# or mnemonic.
3. Cell trends provides continuity on individual storm cells over a period of time. By tracking the increase or decrease of storm tops, maximum reflectivity values, and cell-based VIL, you’ll have a better idea of what to expect from storms in the area. You can also determine the status of supercells and the potential for microbursts. After a weather event occurs, the cell trends display may be used for post-storm analysis.
4. Include any of the following: the volume coverage pattern employed has a direct impact on the cell trends display. VCP 21 has fewer slices, resulting in more variability of displayed data. Range to the cell is another concern when using the cell trends display. At far ranges, data may be unreliable due to the cell being sampled by only the lowest elevation slices. Storm cell bases will be overestimated. Inversely, cells in close proximity to the RDA, may be effected by the cone of silence, resulting in the mid and upper levels of the storm not being sampled.

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1. .54 and .13 nautical miles.
2. (1) b.
   (2) a.
   (3) b.
   (4) a.
   (5) c.
   (6) c.

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1. Hydrometeor Classification Product (HPC).
2. Melting Layer Detection Algorithm (MLDA).
3. Inches.
4. One-hour Accumulation (OHA) and Digital Accumulation Array (DAA).
5. 24 hours.
6. .13 nautical miles.
7. Hybrid-scan hydrometeor classification (HHC).
8. areas of reduced clutter contamination.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field Scoring Answer Sheet.

Do not return your answer sheet to (Extension Course Institute A4L).

44. (219) Which value is considered non-precipitable and are often just cloud droplets?
    a. –30dBZ.
    b. –18dBZ.
    c. +18dBZ.
    d. +30dBZ.

45. (219) Where would you look for a hook echo signature?
    a. Near the mid-levels of a severe thunderstorm.
    b. Near the upper-levels of a severe thunderstorm.
    c. In the right front quadrant of the leading half of the storm.
    d. In the right rear quadrant of the trailing half of the parent echo.

46. (219) Embedded thunderstorms are detected by the WSR–88D quite well because
    a. it uses airborne radar technology to seek out these storms.
    b. the storms move much faster than the surrounding precipitation.
    c. the storms move much slower than the surrounding precipitation.
    d. its 10cm wavelength can see through the stratiform precipitation because less attenuation occurs.

47. (219) Outflow boundaries may be seen on the WSR–88D even when no clouds are present because
    a. of the gradient in the refractive index.
    b. the WSR–88D can detect returns of greater than 18dBZ.
    c. precipitable water is present although it is not visible to the human eye.
    d. low-level wind shear is usually present with the boundary, making it more visible .

48. (220) Which product is used to detect and locate motions in and around potentially severe weather-producing storms?
    a. Base reflectivity.
    b. Severe weather analysis.
    c. Base mean radial velocity.
    d. Severe weather probability.

49. (220) When the Doppler zero line has a noticeable S-shaped pattern, winds are considered
    a. from 270°.
    b. backing with height.
    c. veering with height.
    d. increasing with height.

50. (220) When the radar detects pure cyclonic rotation, the Doppler zero line is oriented
    a. parallel to the viewing direction.
    b. perpendicular to the viewing direction.
    c. skewed to the left of the viewing direction.
    d. skewed to the right of the viewing direction.

51. (221) The spectrum width product is *most* effective when
    a. used alone.
    b. used with other products.
    c. displayed in 16 data levels.
    d. overlaid on composite reflectivity.

52. (221) The spectrum width product is useful for the early detection of thunderstorm development because
    a. the spectrum width product has not been identified for this use.
    b. it scans the mid-levels of the atmosphere for pockets of moisture.
    c. it is more sensitive than base reflectivity and can display the first occurrence of moisture.
    d. the detection of high spectrum widths may be indicative of currents present in a convective atmosphere.

53. (222) Data collected for generation of the composite reflectivity product is derived from
    a. one elevation slice.
    b. all elevation slices.
    c. selected elevation slices.
    d. slices identified at the unit control position (UCP).

54. (222) Which statement is *not* a use of the composite reflectivity (CR) product?
    a. It is the first step in identifying significant weather features.
    b. It can be used as a quick check on the overall reflectivity pattern.
    c. It can be used to show the 3-D structure of the reflectivity pattern.
    d. It provides an instant snapshot of the most important reflectivity features.

55. (222) The melting level is displayed on the composite reflectivity product as
    a. a straight line of higher reflectivities.
    b. multiple rings of enhanced reflectivity around the radar data acquisition (RDA).
    c. a series of ellipses centered over each snow shower.
    d. a series of spots that show ice forming on the radome.

56. (223) Which procedure is a *primary* use for the layered composite reflectivity maximum (LRM) product?
    a. Locating the height of the melting level.
    b. As a quick check of the overall reflectivity pattern.
    c. Quickly identifying stronger storms and areas with a greater potential for convection.
    d. To identify hooks and line-echo wave patterns in mid and high levels of the atmosphere.

57. (223) Which condition indicates an intense updraft and strong likelihood for severe weather on the layered composite reflectivity product?
    a. Strong reflectivity values (>50 dBZ) in the low altitude layer.
    b. Strong reflectivity values (>50 dBZ) in the high altitude layer.
    c. Strong reflectivity values (>50 dBZ) in the middle altitude layer.
    d. A trend of decreasing reflectivity values in the high altitude layer

58. (224) What is the *minimum* depth layer for the layered composite reflectivity product?
    a. 1,000 feet.
    b. 2,000 feet.
    c. 2,500 feet.
    d. 5,000 feet.

59. (224) What is the major difference between composite reflectivity and user selectable composite reflectivity?
    a. Composite reflectivity can accurately be used to identify bounded weak echo regions.
    b. Composite reflectivity can accurately be used to identify a hook echo.
    c. Composite reflectivity is produced by using the entire volume scan.
    d. Composite reflectivity has a higher resolution.

60. (225) Which is a *true* statement concerning ground clutter?
    a. Ground clutter principally affects upper elevations, and has low radial velocity and spectrum width.
    b. Ground clutter principally affects lower elevations, and has low radial velocity and spectrum width.
    c. Ground clutter is detected at close ranges to the radar and typically has high spectrum width.
    d. Ground clutter is detected at close ranges to the radar and typically has high radial velocity.

61. (225) Identify the three processing regions of the layered composite reflectivity maximum (LRM) anomalous propagation removed (APR) algorithm.
    a. Omit all, accept if, and reject if.
    b. Omit all, accept when, and reject if.
    c. Omit if, accept if, and reject all.
    d. Omit if, accept when, and reject all.

62. (226) As the strength of the updraft in a storm increases, the vertically integrated liquid (VIL) values of that storm
    a. increase.
    b. remain the same.
    c. decrease then dramatically increase.
    d. increase then dramatically decrease.

63. (226) Vertically integrated liquid (VIL) algorithm display VIL values for storms based on
    a. water droplet size converted to liquid water content.
    b. water droplet size converted to water vapor values.
    c. reflectivity data converted to water vapor values.
    d. reflectivity data converted to liquid water content values.

64. (226) A strongly tilted storm may cause what kind of vertically integrated liquid (VIL) values to be displayed?
    a. Lower.
    b. Higher.
    c. Taller.
    d. Shorter.

65. (227) The echo tops (ET) product is based on data from what other product?
    a. Vertically integrated liquid (VIL).
    b. Base velocity.
    c. Spectrum width.
    d. Base reflectivity.

66. (227) The echo tops (ET) product computes echo top height by using
    a. horizontal columns.
    b. complex trigonometry.
    c. 2.2 x 2.2nm grid boxes.
    d. 3.3 x 3.3nm grid boxes.

67. (228) What is the function of the tilt test in the hybrid scan reflectivity (HSR) algorithm?
    a. It determines the amount of shear at differing levels in the atmosphere.
    b. It compares the areal coverage of echoes at the 0.5° and 1.5° elevation slices.
    c. It determines the vertical tilt of thunderstorms to estimate precipitation amounts.
    d. It assumes returns without tilt are ground clutter and removes them from processing.

68. (229) The storm total precipitation (STP) product provides continuously updated information on precipitation accumulations within how many nautical miles of the radar?
    a. 120.
    b. 124.
    c. 200.
    d. 240.

69. (229) A limitation of the STP product is that it
    a. has trouble with large-scale features.
    b. has trouble with small-scale features.
    c. gives us a limited post storm analysis.
    d. displays total precipitation accumulations.

70. (230) What information is included in the attribute table that accompanies the user selectable precipitation (USP) product?
    a. The total number of hours used to build the product.
    b. The number of data levels and accumulation amounts for each.
    c. The reason the product couldn't be built and a list of available hours.
    d. The name of the operator who requested the product and beginning times of each hour used.

71. (230) How long is the database for the user selectable precipitation (USP) product?
    a. 24 hours.
    b. 30 hours.
    c. 36 hours.
    d. 48 hours.

72. (230) What is the *maximum* number of hours that the user selectable precipitation product can be generated for:
    a. 12.
    b. 24.
    c. 30.
    d. 36.

73. (231) When is the *only* time snow products are useful?
    a. During dry snowfall events.
    b. During wet snowfall events.
    c. When surface temperatures are less than 32º F.
    d. When surface temperatures are greater than 32º F.

74. (232) What are the *typical* strength rank values for a well defined mesocyclone?
    a. Between one and four.
    b. Between five and nine.
    c. Between 10 and 15.
    d. Any value over 15.

75. (232) The mesocyclone detection (MD) product can be graphically displayed, what symbol is displayed for a circulation having a strength rank less than 5?
    a. A thin yellow open circle.
    b. A thick yellow open circle.
    c. A think yellow closed circle.
    d. A thin yellow closed circle.

76. (233) The graphic symbol for a tornadic vortex signature (TVS) is a
    a. green-filled, inverted, isosceles triangle.
    b. green, open, inverted, isosceles triangle.
    c. red-filled, inverted, isosceles triangle.
    d. red, open, inverted, isosceles triangle.

77. (233) The graphic symbol for an elevated tornadic vortex signature (ETVS) is
    a. green-filled, inverted, isosceles triangle.
    b. green, open, inverted, isosceles triangle.
    c. red-filled, inverted, isosceles triangle.
    d. red, open, inverted, isosceles triangle.

78. (233) The *maximum* shear associated with a tornadic vortex signature (TVS) *must* be at least
    a. 36m/s (≅ 72 knots) at the base of the circulation.
    b. 36m/s (≅ 72 knots) anywhere in the circulation.
    c. 20m/s (≅ 40 knots) at the base of the circulation.
    d. 20m/s (≅ 40 knots) anywhere in the circulation.

79. (233) Which statement is *not* a limitation of the tornadic vortex signature (TVS) product?
    a. Detection of TVSs is limited due to beam broadening.
    b. It only identifies TVSs associated with mesocyclones.
    c. It is subject to all the limitations of the base velocity product.
    d. False alarms by the algorithm may desensitize or over-warn forecasters.

80. (234) The total number of vertical wind profiles that can be displayed on a single velocity azimuth display winds profile (VWP) is up to
    a. 11.
    b. 12.
    c. 13.
    d. 14.

81. (234) The velocity azimuth display (VAD) wind profile (VWP) displays
    a. the radial component of the wind.
    b. the true wind speed and direction.
    c. radial winds, provided the RMS is less than 4m/sec.
    d. only the component of the wind perpendicular to the beam.

82. (234) The color-coded root mean square (RMS) of displayed velocity azimuth display (VAD) winds is related to the
    a. strength of the winds.
    b. altitude of the winds.
    c. direction of the winds.
    d. reliability of the winds.

83. (234) Data thresholds for the vertical winds profile (VWP) can be changed
    a. by radar data acquisition (RDA).
    b. on the principal user processor (PUP).
    c. on the radar product generator (RPG).
    d. by the master system control function (MSCF).

84. (234) The velocity azimuth display (VAD) winds profile (VWP) can detect features such as
    a. inversions and microbursts.
    b. convergence and divergence.
    c. wind shifts and jet streams.
    d. thermal winds and forecasted time of a wind shift.

85. (235) The SRM/SRR (storm relative mean radial velocity (map) product/storm relative mean radial velocity (region) product) depends on what algorithm?
    a. Mesocyclone.
    b. Reflectivity.
    c. Storm series.
    d. Storm tracking.

86. (236) The velocity cross-section product is limited to a range within
    a. 32 nautical miles (nm).
    b. 64nm.
    c. 124nm.
    d. 240nm.

87. (236) Resolution of cross-section products
    a. vary depending on the product requested.
    b. vary with the height of the phenomena.
    c. vary with range from the RDA.
    d. remain constant.

88. (237) Which algorithm is the output of the storm cell segments algorithm directly sent to?
    a. Storm cell centroids.
    b. Storm cell tracking.
    c. Storm structure.
    d. Hail.

89. (237) The Storm Cell Identification and Tracking (SCIT) algorithm can track how many individual storm cells?
    a. 100.
    b. 130.
    c. 150.
    d. 175.

90. (237) How does the storm cell tracking algorithm handle a storm cell centroid when it can't correlate with a storm cell centroid from a previous volume scan?
    a. It doesn't label the storm at all.
    b. It labels the storm as "UNCORRELATED."
    c. It labels the storm as "NEW" and doesn't forecast a track.
    d. It labels the storm as "NEW" and forecasts a track based on other storm cells.

91. (237) What determines the length of a forecast made by the storm position forecast algorithm?
    a. Accuracy of previous volume scan's forecast.
    b. Storm's current speed of movement.
    c. Size of storm cell centroid.
    d. Storm's cell based vertically integrated liquid (VIL).

92. (238) The storm track information (STI) product algorithm provides data on
    a. past positions of thunderstorms.
    b. forecasted positions of severe thunderstorms.
    c. past and present positions of severe thunderstorms.
    d. past, present, and future locations of thunderstorms.

93. (238) How many minutes does the linear motion feature enable the radar user to manually compute a forecast position?
    a. 15.
    b. 30.
    c. 45.
    d. 60.

94. (239) What are the three estimates that the hail detection algorithm provides?
    a. Probability of hail, possibility of severe hail, and forecast hail size.
    b. Probability of severe hail, maximum hail size expected, and possibility of hail.
    c. Probability of hail, probability of severe hail, and maximum expected hail size.
    d. Probability of large hail (>3/4 inch), probability of severe hail, and forecast hail size.

95. (239) The probability of severe hail algorithm will look for hail
    a. >1/4 inch.
    b. >1/2 inch.
    c. >3/4 inch.
    d. >1 inch.

96. (239) What information needs to be routinely updated to increase the hail detection algorithm's performance?
    a. Wind speeds for 10,000 feet above ground level (AGL).
    b. Height of the wet bulb zero value.
    c. MSL altitudes for 0°C and –10°C.
    d. Mean sea level (MSL) altitudes for 0°C and –20°C.

97. (240) What is the *maximum* number of volume scans used for history in the cell trends graphic product?
    a. 5.
    b. 10.
    c. 15.
    d. 20.

98. (241) Which dual polarization product is the ratio of the reflected horizontal and vertical power returns and is expressed in decibels?
    a. Differential reflectivity (Zdr).
    b. Correlation coefficient (CC).
    c. Specific differential phase (Kdp).
    d. Hydrometeor classification product (HC).

99. (241) Which dual polarization product is a dimensionless measure of the similarity between the reflected horizontal and vertical power returns within each radar pulse volume?
    a. Differential reflectivity (Zdr).
    b. Correlation coefficient (CC).
    c. Specific differential phase (Kdp).
    d. Hydrometeor classification product (HC).

100. (242) The outer dashed circle on the melting layer product represents the
    a. point along the radial beyond which the beam is entirely above the melting layer.
    b. point along the radial beyond which the beam is entirely below the melting layer.
    c. range of the melting level product.
    d. center of the melting level.

Glossary

Terms

absorption—The process in which radiant energy is retained by a substance. Radar energy that is absorbed is effectively lost from the radar beam.

alerts—Plain language messages accompanied by an audio alarm that alerts radar operators to significant weather. Specific alert criteria are identified by the operator.

algorithm—A step-by-step procedure for solving a mathematical problem. Several algorithms may be combined as part of a larger computer program. The WSR–88D relies on algorithms while producing derived products.

alphanumeric display—(1) A computer monitor used to display text. (2) A presentation of material in a text format in contrast to a graphical presentation.

analog data—Output data that varies directly as a function of the input—strong signals are represented by large numbers and weak signals by small numbers.

angular beam width—The angle in degrees measured across the axis of the radar beam between half-power points.

angular motion—A representation of the rotation of a particle about an axis of rotation.

anomalous propagation—The abnormal bending of the radar beam as it passes through the atmosphere.

antenna—A conductor or system of conductors for radiating and/or receiving radio energy. The WSR–88D antenna is directional and includes both the radiating element (feed horn) and the reflector for focusing the energy.

archive level I—The storage of data from the receiver at the RDA. Archive Level I stores analog data.

archive level II—The storage of data from the signal processor at the RDA. This data is stored as digital data.

archive level III—The storage of RPG produced products at the RPG. This data has been processed by the meteorological algorithms.

archive level IV—The storage of products produced by the RPG and received by the PUP. Archive level IV is controlled by the PUP operator.

archiving—The storing of WSR–88D data. Archiving can be done at four levels: Archive Level I, Archive Level II, Archive Level III, and Archive Level IV.

aspect—The appearance when seen from a particular view; a position facing a given direction.

associated users—A principal user with dedicated communications within a WSR–88D unit.

attenuation—The reduction in power of a signal due to refraction, scattering, or absorption of energy.

auto PRF analysis—An algorithm that analyzes storm data and selects the best pulse repetition frequency (PRF) to use in a given meteorological situation.

automated alert—An alert generated by the RPG to provide the operator with notification of an operator selected weather phenomena in a particular area.

azimuth—The horizontal direction expressed in degrees, usually from true north. Any point on or above the horizon can be located by its angles of azimuth and elevation, and the range.

azimuth resolution—The ability of the radar to distinguish between two targets at the same range, but at different azimuths or directions from the radar.

background maps—Representations of geopolitical boundaries, roads, population centers, airports, rivers, and other physical features. Background maps are used at the PUP when geographic products are displayed.

backscattered signal—The scattering of radiant energy at 180° to the direction of the transmitted wave; scattering from a target back toward the antenna.

base data—Digital data sent from the radar data acquisition (RDA) computer to the radar product generator (RPG) computer. The data consists of the first three Doppler spectral moments—Z, v, and W. Those digital fields of reflectivity, mean radial velocity, and spectrum width data in spherical coordinates provided at the finest resolution available from the radar.

base reflectivity—A reflectivity product at a specific elevation that has been obtained directly from the base reflectivity data.

base mode—A technique used in a scan strategy in which the radar uses different PRFs at the same elevation. This mode uses returns from a high PRF to determine velocities while a low PRF is used for echo placement.

beam blockage—The physical obstruction to the radar beam, usually at close range, caused by buildings, mountains, and so forth.

Beam width—(1) The distance between half-power points of the radar beam. (2) A measure of the concentration of power of a radar beam.

below beam effects—The inaccurate radar measurements caused by incomplete sampling of the atmosphere. For example, evaporation or growth of precipitation below the beam will not be detected.

central processing unit (CPU)—The section of the computer that interprets and executes instructions.

clear air analysis—A term used to define two separate algorithms, velocity azimuth display (VAD) and velocity volume processing (VVP), which are used together to create the analysis.

clear air mode—A volume coverage pattern (currently VCP 31 or VCP 32) that is designed for use during periods when little or no precipitation is present.

clutter filter bypass—An operator-defined clutter filter map used to filter ground clutter at specific azimuths and ranges.

clutter filtering—Removing nonmeteorological echoes that interfere with the observation of desired meteorological signals.

clutter filter map—A portrayal or arrangement that indicates location and degree of clutter filtering applied to the echo power. This map may be modified and overridden by the UCP operator.

coefficient—A numerical algebraic factor. Many WSR–88D algorithms can be modified by the changing of the coefficients.

coherency—The ability of a radar to process a signal to permit comparison of the phase of successive received target signals. A coherent radar can detect the Doppler shift.

coherent radar—A type of radar that employs circuitry that permits comparison of the phase of successive received target signals. The WSR–88D is a coherent radar.

collapsing echo tops—A decreasing of the height of storm tops within a small number of volume scans.

color graphic displays—Two 19-inch color video monitors that allow the radar operator to display and view products. The monitors have high resolution screens and are part of the PUP workstation

component—(1) The portion of a storm at any one elevation angle. A stack of components forms the radar's depiction of a storm. (2) One part of a system; a vector pointing northwest is made up of a north component and a west component.

composite reflectivity—A WSR–88D volumetric product that displays the highest reflectivities detected above a given area on the earth's surface.

convective cells—Cumuliform clouds, usually with vertical updrafts in the center and sinking downdrafts in the outer regions.

convergence—Atmospheric flow approaching the same point from different directions.

data contamination—Bad or erroneous radar data mixed in with good data. For example, sidelobe contamination.

DBZ—A decibel of the equivalent radar reflectivity factor. dBZ = 10*Log (equivalent reflectivity)

decibel—A logarithmic expression for the ratio of two quantities, such as the ratio of power transmitted to the power received at the antenna. dB = 10*Log(A/B)

dedicated communications—Communications links that have no other purpose than to transmit data between components of the WSR–88D.

derived product—A product created from the computer processing of base data.

digital data—A series of discrete computer input numbers that vary as a function of the input data.

dipole—A pair of electrical charges or magnetic poles of equal magnitude and opposite sign. A precipitation particle becomes a dipole when engaged by radar energy.

dipole antenna—A type of antenna for radiating or receiving electromagnetic energy.

directional antenna—An antenna adapted for receiving signals from or sending signals in a particular direction.

dispersion—The process that separates radiation into its component wavelengths. Scattering is one cause of dispersion.

distortion—The apparent change (stretching) of the shape of a displayed radar echo.

divergence—Atmospheric flow leaving the same point in different directions.

Doppler dilemma—The problem encountered in arriving at a balance between maximum velocity determination and maximum detection range.

Doppler effect—The observed change in the frequency of sound or electromagnetic waves due to the relative motion of the source and observer.

Doppler moments—The three spectrum moments are the reflectivity or “the zero (Doppler) moment,” the mean Doppler velocity or “the first moment,” and the spectrum width or the square root of “the second moment.”

Doppler spectrum—The distribution of power received by the radar at each frequency within the echoing volume. A typical Doppler spectrum appears as a bell curve.

Doppler velocity—Velocity detected by using the Doppler process. Often used in the same sense as radial velocity.

downburst—A strong downdraft associated with thunderstorms that induces an outflow of damaging winds on or near the surface.

downdraft—A current of air with marked vertical downward motion.

drizzle—Drops of precipitation that are less than 0.5mm in diameter. Unlike fog, drizzle droplets fall to the ground.

ducting—A special condition of superrefraction in which the radar beam becomes trapped within a layer of the atmosphere. A condition of warm, dry air overlying relatively cool, moist air may result in ducting.

echo—Electromagnetic energy backscattered from a target and received by and displayed on a radar scope or color graphic display.

echo tops product—A product that displays the height of storm tops by using a color code that corresponds to various heights.

electromagnetic energy—Energy propagated through space or material in the form of an advancing disturbance in electric and magnetic fields. Often called radiation.

elevation angle—The angle between the horizon and a point above the horizon.

elevation slices—Rotations of the antenna at preprogrammed elevation angles.

embedded thunderstorms—Convective storms located in a stratiform cloud layer that show no visual signs of being present.

environmental wind—The predominant atmospheric wind flow in the area of the radar sampling volume.

equivalent radar reflectivity—A constant representing a concentration of uniformly distributed, small water particles that would return the amount of power received from an actual radar target; provides a common base for the comparison of different weather targets.

external user—Anyone, excluding a principal user, who has access to WSR–88D products.

feed horn—The end of the wave guide that focuses the electromagnetic energy into the radar antenna.

first moment—Also known as the mean Doppler velocity. The first moment of the power normalized spectra is equal to the mean motion of scatterers. For near-horizontal antenna orientations, this is essentially air motions toward or away from the antenna.

frequency—The number of recurrences of a periodic event per unit time. Radar waves have a frequency specified per second.

geographic product—Any product that presents meteorological data in relation to common geopolitical or topographic landmarks.

graphic tablet—A product selection and manipulation device connected electronically to the PUP. Its surface has color-coded groupings of function commands, maps, product selections, and edit functions. Used with a puck, this is the WSR–88D operator's primary interface.

grid box (alert)—A computer-referenced box, at surface level, to which radar data is interrogated.

ground clutter—Echoes resulting from physical obstructions such as buildings, trees and mountains.

ground clutter suppression—See clutter filtering.

gust front—An outflow boundary that consists of winds meeting gust criteria. On the surface, its passage resembles that of a cold front.

hail product—A derived product that indicates the possibility that a storm is producing large hail.

half-power points—The points on the radiation pattern of an antenna where the transmitted power is one-half that of the maximum (usually the center), both measured at the same range. The angle between half-power points defines the beam width.

hard copy device—A color printer that makes paper or transparency copies of displayed products on the graphic and alphanumeric monitors.

height of maximum reflectivity—The altitude (MSL) of the most intense reflectivity inside the storm.

hertz—A frequency defined as one cycle per second.

hook echo—A classical radar echo often shaped like a figure six. The hook echo is associated with tornadic activity.

hydrological—Related to the scientific study of precipitation and evaporation in the atmosphere.

hydrometeors—A product of condensation or sublimation of atmospheric water vapor: clouds and precipitation.

inbound velocity—Radial velocity toward the radar. By convention, inbound velocity is assigned a negative sign.

interlaced sampling—The method of switching between two different PRFs during base mode.

isotropic—Identical in all directions.

isotropic scatterer—A particle that radiates energy equally in all directions.

joint Doppler operations project (JDOP)—A project conducted by the USAF, FAA and NWS from 1977–1979 that proved the meteorological applicability for operational Doppler radar.

kinematic analysis—A computerized examination by the WSR–88D of atmospheric motion. It includes algorithms for shear, transverse wind, turbulence, mesocyclone (MESO), and tornadic vortex signature (TVS).

legacy PUP—The original components of the hardware suite that make up a Principal User Processor—a subcomponent of the WSR-88D Nexrad Radar.

linear beamwidth—The distance between the half-power points of the radar beam. Also referred to as the beam diameter.

line echo wave pattern (LEWP)—A line of radar echoes that has been subjected to an acceleration along one portion of the line. This results in a mesoscale wave pattern in the line.

linear extrapolation—The extension of a relationship between two or more variables beyond the range covered by knowledge. The calculation of values outside the observed range of values, which assumes no change in the numerical trend is taking place.

lithometeors—A general term for dry particles suspended in the atmosphere—dust, haze, smoke, sand, etc.

loadshedding—The process by which all tasked workloads cannot be satisfied and tasks are eliminated following a specific task prioritization list.

MESO product—A derived product that identifies rotations associated with thunderstorms that is available as a graphic product, alphanumeric product or a graphic overlay.

master cursor—A visual indicator consisting of cross hairs on the color graphic displays that move in correlation with the movement of the puck.

maximum unambiguous range—The maximum range to which a transmitted pulse of radar energy can travel and return to the radar before the next pulse is transmitted.

mean radial velocity—The average velocity of air flow parallel to the radar beam within a sample volume.

melting level—The level where frozen precipitation particles melt into water during their descent to the surface. The melting level usually appears on radar displays as a broad area of high reflectivity.

mesocyclone—A three-dimensional (3-D) region in a storm that rotates cyclonically, meets a series of criteria, and is closely correlated with severe weather.

mesocyclone algorithm—An algorithm that uses shear pattern recognition to detect mesocyclones. Detection can be displayed by the MESO product.

mesoscale—The scale of meteorological phenomena that ranges in size from 1 to 500 nautical miles. It includes thunderstorms, tornadoes, and local winds.

microburst—A small-scale downburst of about 0.5nm to 2.5nm in outflow size with peak winds lasting 2 to 15 minutes.

mid-level overhang—In the middle levels, the edge of a storm component that extends outward beyond the edge of the storm component at the lowest level.

mie scattering—The scattering that occurs when the diameter of a radar target approaches 0.2 times the radar's wavelength. Most of the energy is scattered forward and is useless to the radar for detection.

minimum mass volume ratio—The allowable change within the storm tracking information algorithm of the storm's mass, between volume scans, which still allows the storm to be correctly tracked between scan volumes.

minimum signal—The lowest power returned from a target that can be detected by the radar.

minimum significant reflectivity—A parameter that sets the minimum reflectivity value that will be used as a threshold value.

moment—Any of the three types of base data: reflectivity, mean radial velocity or spectrum width.

narrowband—A communications link used to disseminate meteorological products from the RPG to PUPs. This link is also used by the PUP to send requests to the RPG.

National Weather Radar Network—A chain or system of 136 weather radar sites interconnected with communications throughout the CONUS.

network site—A National Weather Service radar site that provides meteorological radar data in support of the National Weather Radar Network.

nonnetwork site—A WSR–88D site that doesn't qualify as either a network site or a supplemental site. Example: A DOD WSR–88D overseas site.

nonassociated user—A principal user who has only dial-in communications to a WSR–88D unit.

non-coherent radar—A radar that determines only the strength of a backscattered signal.

non-linear—A process that is not linear; the response is not directly proportional to the input. The last straw that broke the camel's back is a classic example of a non-linear response.

nyquist co-interval—The entire range of detectable velocities, both negative and positive. Example: –25kts to +25kts.

nyquist frequency—The highest frequency that can be determined in data that have been discretely sampled.

open systems—The practice of designing computing environments based on industry and government accepted standards. In most cases, an open system is comprised of off-the-shelf operating systems and hardware components.

Operational Weather Squadron (OWS)—A regionally focused weather operations hub that eliminates the redundant execution of a separate detailed analysis and forecast process, within a defined geographical location.

outbound velocity—Radial velocity away from the radar. By convention, outbound velocities are assigned a positive sign.

outflow—The low-level divergent air flow pattern, often resulting from a thunderstorm downdraft striking the earth's surface and spreading horizontally outward.

outflow boundaries—The leading edge of horizontal air flow resulting from cooler, denser air sinking and spreading out at the surface. Outflow boundaries often are caused by the downdraft of thunderstorms.

overrunning—A condition existing when an air mass is in motion aloft above another air mass, at the surface, of greater density. This term usually is applied in warm air ascending the surface of a warm or quasistationary front.

overshooting tops—Storm tops that exceed the main body of the storm in the vertical.

PUP applications terminal—A computer terminal that provides for the control of the applications software through computer menus. This terminal can be used to give commands to the PUP software and to view alphanumeric displays.

partial beam filling—The effect when a target fills only a small portion of the radar beam.

pattern vectors—A series of azimuthally adjacent sample volumes at the same range from the radar antenna that has a continual increase in Doppler velocities. Pattern vectors are used by the WSR–88D to identify closed rotation.

phasor—A vector that has an orientation that represents a specific position along the phase of a wave.

pixel—The smallest displayed element on a video display screen.

polar coordinate—In the plane, a system in which a point is located by its distance from the origin (or pole) and by the angle that a line joining the given point and the origin makes with a fixed reference line, called the polar axis.

polarization—A complete polar separation of positive and negative electrical charge in a molecular system.

power density—Power per unit area. The power density in the radar beam will decrease at increasing ranges.

precipitation mode—A volume coverage pattern (currently VCP 11 or VCP 21) that is designed for detecting precipitation.

principal user—The National Weather Service (NWS), Air Force weather service, Naval Oceanography Command (NOC), or the Federal Aviation Administration (FAA).

principal user processor—The operator workstation for the WSR–88D. The operator can request, control, and manipulate products, make hard copies, and monitor the status of the radar system.

propagate—Movement of electromagnetic energy through a medium or space.

puck—A mouse-like device with buttons that, when positioned over a function or command square on the graphic tablet, sends the function or command to the graphic processor.

Pulse interval—The time between the end of the transmission of one pulse to the beginning of transmission of the next pulse.

pulse length—The linear distance a pulse of electromagnetic energy occupies in the atmosphere.

pulse pair processing—A method of determining the Doppler shift by comparing the returned frequency shift of consecutive pulses.

pulse repetition frequency (PRF)—The rate at which the pulses of electromagnetic energy are transmitted by the radar; the number of pulses per second (pps).

pulse volume—The segment of the radar beam that contains electromagnetic energy at any instant. A volume equal to one pulse length by one beam diameter.

radar data acquisition (RDA)—The first major component of the WSR–88D after the antenna. The RDA functions as a transmitter/receiver subsystem, receiving analog data from the receiver and processing it into base data.

radar product generator (RPG)—The WSR–88D component that uses raw Doppler data to produce meteorological products. The RPG is the “brains” of the WSR–88D.

radar—An acronym for radio detection and ranging. An electronic instrument used to detect atmospheric scatterers such as precipitation.

radar beam—A focused conical-shaped beam of electromagnetic energy emitted from an antenna and used to detect meteorological and other targets.

radar reflectivity—Generally, the measure of the efficiency of a radar target in intercepting and returning radio energy. It depends upon the size, shape, aspect, and the dielectric properties at the surface of the target.

radial component—The part, or component, of the wind velocity that is parallel to the radar beam.

radial velocity—The component of velocity parallel to the radar beam.

radiation—Energy proceeding through the atmosphere as waves. The antenna transmits and receives energy as radiation.

range—The distance from the radar antenna to a target.

range distortion—The apparent stretching of a displayed radar echo.

range folded echoes—Echoes or targets that have been incorrectly displayed because of range folding.

range folding—The display of a multiple trip return that differs from the actual location of the target. A multiple trip return appears at the difference of the true range and a multiple of the unambiguous range.

range resolution—The ability of the radar to distinguish between two targets at different ranges from the radar, but at the same azimuth.

rayleigh scattering—The scattering that occurs when the target diameter is smaller than the wavelength; energy is scattered equally in all directions.

refraction—The process in which the direction of energy propagation is changed as the result of a change in density. Large changes in the refractive index of the atmosphere can cause subrefraction and superrefraction.

refractive gradients—Abrupt changes in temperature and humidity. These cause corresponding changes in the propagation of the radar beam and often result in observable radar signatures in optically clear air.

refractive index—The ratio of the wavelength or phase velocity of the radar waves in the atmosphere compared to the velocity in a vacuum. Changes in the refractive index will cause a change in the propagation velocity of the wave.

resolution—The minimum angular separation at the antenna at which two targets can be distinguished (a function of beam width); and/or the minimum range at which two targets at the same azimuth can be separated (one-half the pulse length).

rotation—Circular motion around an axis. In Doppler radar interpretation, a velocity signature that usually indicates a severe storm and the existence of a mesocyclone or tornado.

rotation velocity—A value obtained by averaging the maximum inbound and maximum outbound velocities of a mesoscale feature.

sample—To examine a specified volume of the atmosphere.

s-band—A frequency of microwave radiation that has a wavelength near 10cm. The S-band wavelength is especially well-suited for precipitation measurements.

sampling volume—The volume of the atmosphere that is being instantaneously sampled by the radar; the power returned at any one instant that is the total backscatter from a volume of atmosphere equal to 1/2 the pulse length by the beam diameter.

scalable —The ease with which a system or component can be modified to fit the problem area.

scan—One complete rotation of the antenna at a single elevation angle.

scan strategy—A programmed combination of antenna motions and switched PRFs.

scattering—The change in direction, frequency, or polarization of electromagnetic energy caused by small particles suspended in a medium.

scope—A display device, consisting of a cathode ray tube (CRT), used on older, conventional weather radars, to view radar echoes.

second moment—The square root of the second moment about the first one is the spectrum width. This is a measure of the velocity dispersion, i.e., shear or turbulence within the sample volume.

second-trip echo—A radar echo received from a target beyond the normal maximum range of detection. Also, called range folding.

sensitivity—The degree that the radar can detect a weak target.

severe weather probability (SWP)—An algorithm and product that uses information from the VIL algorithm to assess the probability for severe weather.

severe weather—Meteorological phenomena that cause destruction of resources. Examples of severe weather events are tornadoes, hail storms that produce hail 3/4-inch or larger in diameter, and thunderstorms with associated winds of 50 knots or greater.

shear—The speed or directional variation in a wind field.

shear algorithm—An algorithm that computes the combined shear of the radial velocities at a single elevation within a volume scan.

shear pattern—The characteristics of a region of shear that can be recognized and correlated to a meteorological feature.

side lobes—Concentrated elements of focused power outside the main radar beam. Backscatter from side lobes can be displayed as if it were in the main beam. Ground clutter is a common result from side lobes.

side lobe contamination—The display of reflectivity that is the result of sidelobe radiation. This reflectivity is indistinguishable to the radar from normal reflectivity and may present interpretation problems to the operator.

signal processor—A component of the transmitter/receiver subsystem, of the RDA, which receives analog data from the receiver and processes it into base data and sends it to the RDA control.

signal-to-noise ratio—A ratio of the intensity of the minimum signal capable of being detected (sensitivity) to the amount of interference generated by the radar.

slant range—The line of sight distance between two objects.

spectral dispersion—The small range (spread) of velocities within a radar sample volume.

spectral shape—Term used to refer to the relationship between power returned and variance; a bell-shaped curve that indicates the approximate character of a sampling volume.

spectrum—The series of radar energy that has been arranged according to wavelength (or frequency). A spectrum is created when energy is subjected to dispersion.

spectrum width—A measure of dispersion of velocities within the radar sample volume. Standard deviation of the velocity spectrum.

spherical coordinates—Location points in space consisting of a radius vector and two angles measured with respect to two arbitrary, fixed, perpendicular directions.

stair-step pattern—Increasing plateaus or tops, such as would occur if a flight of steps was represented. Often a result of the limited vertical resolution caused by the gaps between elevation scans.

standard refraction—The normal bending of the radar beam caused by the differences in atmospheric density of a standard atmosphere.

storm centroids—The centers of mass of thunderstorms.

storm segment algorithm—An algorithm that identifies segments used to form a storm component.

storm analysis—A computer program containing six algorithms that provides information about the dynamics, structure, and related atmospheric phenomena.

storm cell centroid—The center point of mass volume within a storm component. The vertical stacking of individual storm centroids is the computer model of a storm.

storm component—The circular, two-dimensional (2-D) representation of a series of adjacent storm segments. The center of mass of the storm component is the storm centroid.

storm cores—The inner portions of a convective storm.

storm mass—The calculated mass of a storm that the WSR–88D tracks as one of the storm's identifying features.

storm mean speed—The average speed at which a storm is moving.

storm pairs—Information that contains the previous storm location and the current storm location.

storm cell position forecast—An algorithm that forecasts storm centroid positions based on the storm's current and previous positions.

storm cell segment—A run of adjacent sample volumes that have met or exceeded the minimum reflectivity and length thresholds that allow its inclusion into the storm structure algorithm. Consecutive segments are used to build centroids.

storm segments—Sample volumes, located close to each other, which are greater than or equal to the minimum reflectivity threshold of 30dBZ. These sample volumes must have a combined length greater than or equal to 4.2km.

storm structure (SS)—A product that produces a 3-D perspective of identified storms through nine separate parameters.

storm cell tracking—A product/algorithm that provides the past, current and forecast positions of isolated thunderstorms.

stratified cloud layers—Clouds in sheet-like layers with very little vertical extent.

strong mesocyclone—A mesocyclone that has a rotational velocity of 50kts or greater (within a range of 80nm) or 40kts or greater (within a range of 80nm to less than 125nm).

subrefraction—Atmospheric conditions that cause a straightening of the radar beam upward.

supercell thunderstorm—Large, long-lived (up to several hours) thunderstorm cells, consisting of quasi-steady updrafts and downdrafts, that exhibit rotation and are producers of severe weather.

superrefraction—Atmospheric conditions that cause greater than normal downward bending of radio waves as they travel through the atmosphere.

supplemental site—A Department of Defense (DOD) WSR–88D site in the CONUS or an FAA WSR–88D non-CONUS site.

system console, PUP—A computer terminal that allows the operator access to the PUP's display processor and operating software.

target—Precipitation or other phenomena that produce radar echoes.

three-dimensional (3-D) shear—Wind shear at one height or level in the atmosphere that has been correlated at other levels in the atmosphere.

threshold value—An adaptable parameter that serves as a maximum value which must meet or exceed a threshold value to be accepted by an algorithm or displayed on a product (e.g., velocity equals or exceeds 50 knots).

tornadic vortex signature (TVS)—The radar "signature" of a vortex indicative of a tornado or tornadic circulation.

tornadic vortex signature (TVS) algorithm—An algorithm that detects the presence of shear patterns representative of tornadoes near a mesocyclone.

traditional radar signatures—Echoes displayed on non-Doppler radars that are associated with significant meteorological features.

transverse wind—The component of the wind velocity that is perpendicular to the radar beam.

turbulence—Irregular, random fluctuations in the wind velocity field in the horizontal and vertical planes.

turbulence algorithm—An algorithm that estimates the strength of turbulent motions from measurements of Doppler spectrum variance and radar reflectivity.

unambiguous range—The range to which a transmitted pulse wave can travel and return to the radar before the next pulse is transmitted.

UNIX®—The trademarked name of the multiuser, multitasking, time-sharing operating system developed at AT&T's Bell Labs in 1969.

VIL values—Units of kilograms per square meter (km/m^2) of liquid water content in a vertical column.

variance—In spectrum width, the variability of the frequencies in a sampling volume; an indication of spectral shape—turbulent targets generally have more variance and less turbulent targets have less variance.

velocity aliasing—The result of an incorrect solution of radial velocities when the actual velocity exceeds the Nyquist co-interval.

velocity azimuth display (VAD)—An algorithm and product that computes a vertical profile of horizontal wind velocity for a specified range around the RDA site.

velocity volume processing (VVP)—An algorithm that calculates the wind speed and direction over the radar's entire surveillance area.

vertical tilt—A storm is said to have tilt if a line connecting the centroid of a mid-level storm component to the centroid of the lowest storm component is to the right or rear of the direction of movement of the storm.

vertically integrated liquid (VIL)—The VIL algorithm estimates the total amount of liquid suspended in a vertical column of the atmosphere.

virga—Precipitation that falls from a cloud but evaporates before reaching the earth's surface.

volume coverage pattern (VCP)—A combination of elevation slices designed to provide radar coverage over a specific volume of the atmosphere.

volume scan—The process of completing a series of specified elevation angles in a specific sequence.

volumetric product—Any product the WSR–88D produces that requires data from the entire VCP before processing can be completed.

vortex—In its most general use, any flow possessing vorticity. More often the term refers to a flow with closed streamlines. A tornado is a vortex.

vorticity—A vector measure of local rotation in the flow of the atmosphere.

WSR–88D—Weather Surveillance Radar 1988–Doppler; the official designation of the radar commonly called NEXRAD.

wave equation—The relationship between frequency and wavelength.

wavelength = (speed of light)/(Frequency)—The measure between successive troughs and successive crests in energy sine waves commonly expressed in centimeters (cm)

waveguide—A metal duct that carries the electromagnetic energy from the transmitter to the antenna.

waveform—The pictorial representation of the wave showing the amplitude variations over time; a wave as it might be displayed on a CRT.

wave length—A length measured along the direction of propagation, usually from the midpoint of a crest (or trough) to the midpoint of the next crest (or trough).

weak mesocyclone—A mesocyclone that has a rotational velocity less than 50kts (within a range of 80nm) or 40kts (within a range of 80nm to less than 125nm).

weather Flight (WF)—A generic term that denotes a weather unit or team that creates a Mission Execution Forecast . WF's are also referred to as Combat Weather Teams (CWT). Both WFs and CWTs are formally known as a weather station.

weight—A numerical value assigned to a variable; coefficients.

wideband—A communication link connecting the RDA to the RPG that is capable of carrying 1.544 million bytes of data per second.

wind shear—The localized variation of the wind vector (or any of its components) in a given direction, height and time.

windows®—Trademark name of a computer operating system developed by the Microsoft® Corporation.

workstation—The part of the PUP consisting of color graphic displays, graphic tablet, an alphanumeric terminal and a hard copy device.

zero (Doppler) moment—Also known as the echo power and the first of the three Doppler moments. This moment indicates the liquid water content or precipitation rate of a sample volume of air.

Abbreviations and Acronyms

1-D	one-dimensional
2-D	two-dimensional
3-D	three-dimensional
3DC SHR	3-D correlated shear
3DCO	three dimensional shear
AC	alternating current
A/R	amplitude range scope
AFW	Air Force weather
AGL	above ground level
AP	anomalous propagation
APR	anomalous propagation removed
ARL	above radar level
AWDS	automated weather distribution system
AZRAN	azimuth and range
BD	big drops
BI	biological scatterers v
BWER	bounded weak echo region
C Language	a computer language used in open systems such as the UNIX operating system
CC	correlation coefficient
CDE	common desktop environment
CM	combined moment (product)
COHO	coherent oscillator
COMEDS	CONUS Meteorological Data System
CONUS	contiguous United States
CPU	central processing unit
CR	composite reflectivity (product)
CRC	composite reflectivity contour (product)
CRT	cathode-ray tube
CS	combined shear (product)
CSC	combined shear contour (product)
DAA	digital accumulation array
dBZ	decibels
DoD	Department of Defense
DOD	digital one-hour array
DPR	digital instantaneous precipitation rate
DS	dry snow
DSA	digital storm total accumulation
DSD	digital storm total difference
EM	electromagnetic
ET	echo tops (product)
ETC	echo tops contour (product)

ETVS	elevated tornadic vortex signature
FAA	Federal Aviation Administration
FMH	Federal Meteorological Handbook
GC	ground clutter
GUI	graphics user interface
GR	graupe
HA	heavy rain
HC	hydrometer classificatin (product)
HCI	human-computer interface
HDA	hail detection algorithm
HSR	hybrid scan reflectivity
HR	heavy rain
IC	ice crystals
JDOP	Joint Doppler Operations Project
JSPO	Joint System Program Office
kbs	kilobytes
Kdp	specific differential phase
kt	knots
KVM	keyboard video mouse
LAN	local area network
LEWP	line echo wave pattern
LRA	layered composite reflectivity average (product)
LRM	layered composite reflectivity max (product)
LTA	layered composite turbulence average (product)
LTM	layered composite turbulence average (product)
MD	mesocyclone detection
MDA	mesocyclone detection algorithm
MEHS	maximum expected hail size
MESO	mesocyclone (product)
METSAT	meteorological satellite
ML	melting layer
MLDA	melting layer detection algorithm
MLOS	microwave line of sight
MHz	megahertz
mph	miles per hour
MSCF	Master System Control Function
MSL	mean sea level
ND	no data
nm	nautical miles
NOC	Naval Oceanography Command
NSSL	National Severe Storms Laboratory
NWS	National Weather Service
OHA	one-hour accumulation

OHP	one-hour precipitation (product)
OPUP	open principal user processor
ORPG	open radar product generator
OSD	one-hour snow depth
OSW	one-hour Snow Water Equivalent
PIREP	pilot report
POH	probability of hail
POSH	probability of severe hail
POSIX	portableoperating system interface
pps	pulses per second
PRF	pulse repetition frequency
PRT	pulse repetition time
PUP	principal user processor
RA	light/moderate rain
RAREP	radar report
RCM	radar coded message (product)
RCS	reflectivity cross section (product)
RDA	radar data acquisition
RDASOT	RDA software operability test
RF	range folding
R-F	radio frequency
RMS	root mean square
ROC	radar operations center
RPG	radar product generator
RPGOP	radar product generator operational position
rpm	revolutions per minute
RPS	routine product set
RMS	root mean square
RRRAT	RDA/RPG remote access terminal
SAA	snow accumulation algorithm
SCIT	storm cell identification and tracking
SCS	spectrum width cross section (product)
sfc	surface
SHI	severe hail index
SRM	storm relative mean radial velocity (map) product
SRR	storm relative mean radial velocity (region) product
SS	storm structure (product)
SSW	storm total snow water equivalent
STA	storm total accumulation
STALO	stable frequency local oscillator
STI	storm track information (product)
STP	storm total precipitation (accumulation product)
SW	spectrum width (product)

SWA	severe weather analysis (product)
SWP	severe weather probability (product)
SWR	severe weather analysis display (reflectivity) (product)
SWS	severe weather analysis display (radial shear) (product)
SWV	severe weather analysis display (mean radial velocity) (product)
SWW	severe weather analysis display (spectrum width) (product)
TDA	tornado detection algorithm
THP	three-hour precipitation (accumulation product)
TRU	tornado vortex signature rapid update product
TVS	tornadic vortex signature (product)
UAM	user alert message (product)
UCP	unit control position
UK	unknown
ULR	user layered composite reflectivity (product)
UNC SHR	uncorrelated shear
UNCO	two dimensional shear
UNIX	a computer operating system or platform used with open systems
UPS	uninterruptible power supply
URC	unit radar committee
USP	user selectable precipitation (product)
VAD	velocity azimuth display (product)
VCP	volume coverage pattern
VCS	mean radial velocity cross section (product)
VIL	vertically integrated liquid (product)
VR/SHEAR	rotational velocity/shear (display)
VVP	velocity volume processing (product)
VWP	velocity azimuth display winds profile (product)
WER	weak echo region
WFO	NWS Warning and Forecast Office
WORM	write once read many optical disc
WS	wet snow
WSR-88D	weather Surveillance Radar 1988–Doppler
Zdr	differential reflectivity

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