Chapter 8

Radar Interpretation

Weather radar is a critical piece of equipment in the meteorologist’s toolbox. Operationally it is used to detect the coverage and intensity of precipitation and is the basis for severe thunderstorm and tornado warnings issued by the National Weather Service. For the research community it is tool to probe the structure of the atmosphere and discover its secrets.

The word, radar, is an acronym that stands for **RA**dio **D**etection **A**nd **R**anging. Although the term was officially coined during World War II (1939-1945), the concept was discovered and demonstrated prior to the war. Radar development and usage expanded during the war and its ability to sense weather was discovered. Weather was unwanted “noise” that interfered with the radar’s primary purpose, detection of aircraft and ships. After the war the availability of surplus radars lead to research efforts to apply radar to weather detection and eventually in the early 1950s to operational weather radar.

How Radar Works

Radar emits a pulse of electromagnetic energy that is scattered by the atmosphere. Some of this energy is returned to the radar antenna and used to display a variety of information about the atmosphere, e.g., the location of precipitation.

Weather radars operate in the S, C and X bands of the electromagnetic spectrum. These energy bands correspond to wavelengths of 2.5 to 4 cm for X-band, 4 to 8 cm for C-band, and 8 to 15 cm for S-band radars. Most operational radars have wavelengths around 10 cm (3 GHz frequency) in order to minimize the attenuation issues associated with the shorter wavelengths.

Radar energy is emitted by an antenna that directs the energy in a particular direction. This emission is referred to as the *radar beam*. Typical beam width is 1 degree. Although the majority of energy is directed along the beam, some energy spreads out in other directions. This pattern of emission is referred to as the *antenna beam pattern* and is composed of several intensity maxima called *side lobes*. In processing the returned energy, it is assumed that all the energy comes from the aimed direction of the beam.

Weather radars do not continuously emit energy but emit a brief burst of energy, referred to as a pulse. The radar then listens for that energy to return. A typical energy burst lasts from 1 to 4 microseconds (μs). Because electromagnetic energy travels at the speed of light ($3*10^8$ m/s), the emission creates a packet of energy of finite length (pulse length) travelling along the beam. This packet is referred to as a sample volume (Figure 8-1). It is the energy in the sample volume that interacts with the atmosphere and returns energy to the antenna. The WSR-88D uses a pulse duration of 1.57 μs; this creates a sample volume that is 471 meters long.

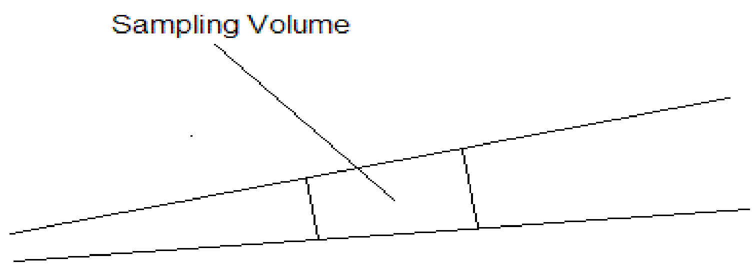

Figure 8-1: Example of a Sample Volume

The *pulse repetition frequency* (PRF) refers to how often the radar emits energy pulses. The WSR-88D has a minimum PRF of 318 Hz. If it emits 318 pulses of energy per second, this means that it transmits only 0.000499 seconds out of each second, i.e., it listens much longer than it transmits.

The listening time between pulses determines the maximum range of the radar. The time it takes for a pulse to travel out and back during the listening period determines the maximum range of the radar. If you know the PRF and the speed of light, you can calculate maximum range. Typical maximum range is around 400 km (250 nm).

A complete picture of the atmosphere is obtained by rotating the antenna through a full 360^o circle at a rate of about 10^o per second, and raising and lowering the antenna to obtain three-dimensional coverage. The strategy of sampling the atmosphere is referred to as a *volume scan*. The volume scan used depends upon the weather. For example, for the WSR-88D, volume coverage pattern (VCP) 11 is used for precipitation (Figure 8-2) while VCP 31 is used in clear air conditions (Figure 8-3).

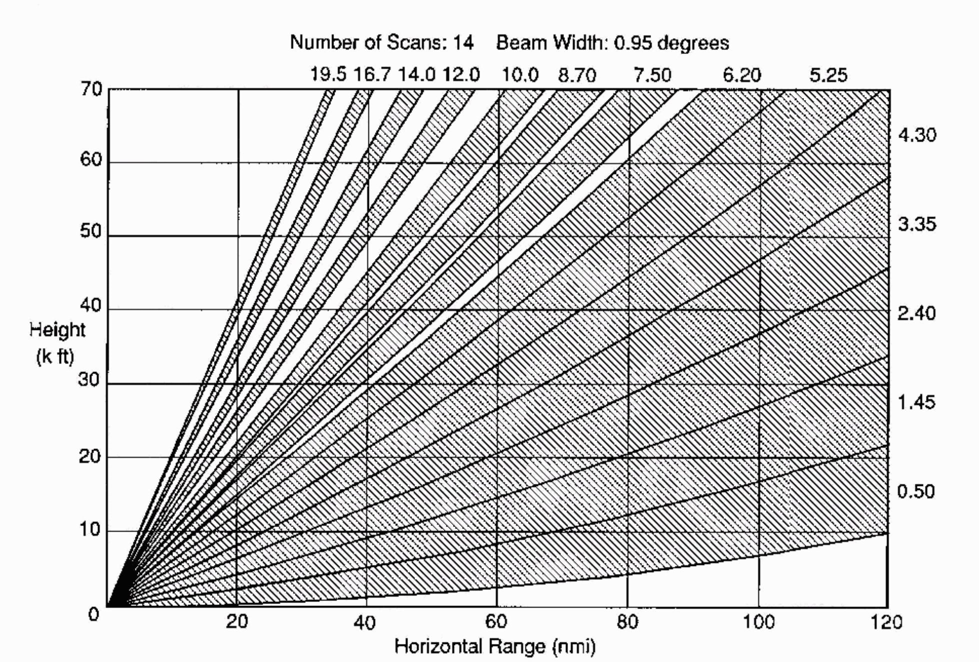

Figure 8-2: VCP-11 [*source*: FMH 11]

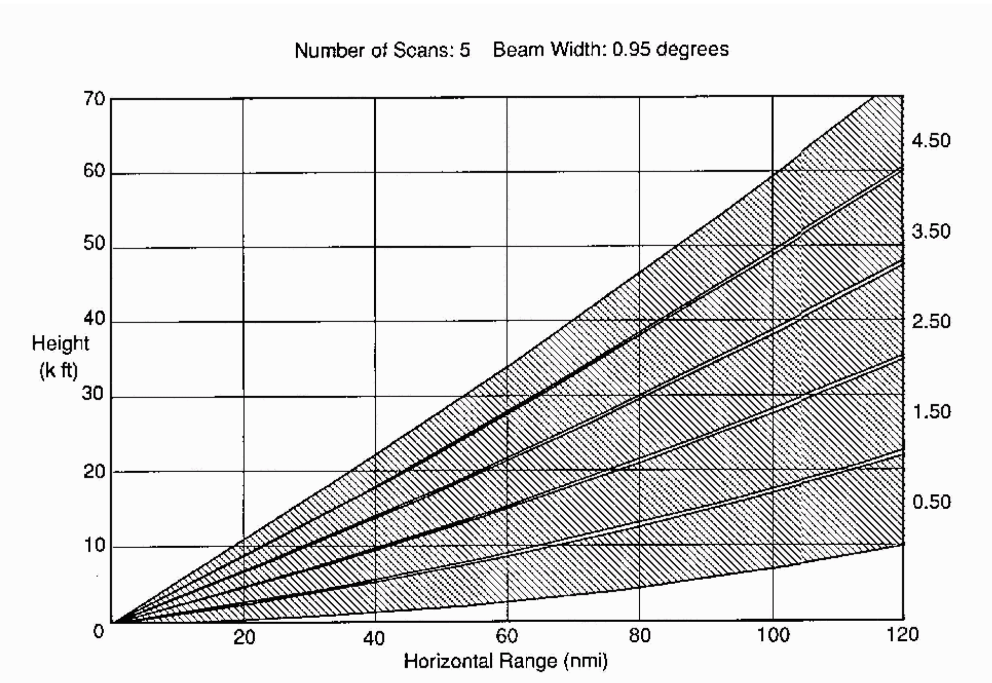

Figure 8-3: VCP-31 [*source*: FMH 11]

Figures 8-2 and 8-3 show how much of the atmosphere is sampled by the WSR-88D as the antenna rotates horizontally and scans vertically. There is an area directly above the radar site that is not sampled. This area is called the *cone of silence*. You must depend upon nearby radar sites to see what is happening directly above your radar. The time that it takes to complete one VCP scan depends upon the scan, typically 6 to 10 minutes.

Radar Propagation

As radar energy travels through the atmosphere it does not propagate in a straight line but is refracted by the air. The amount of deviation depends upon the index of refraction of atmosphere. The index of refraction is a function of air temperature, atmospheric pressure, and the humidity. Standard propagation is defined in terms of the standard atmosphere and represents the typical path taken by a radar beam. Figure 8-4 shows this beam relative to the Earth’s surface. It propagates downward as it moves away from the radar, but at a rate less than the curvature of the Earth’s surface.

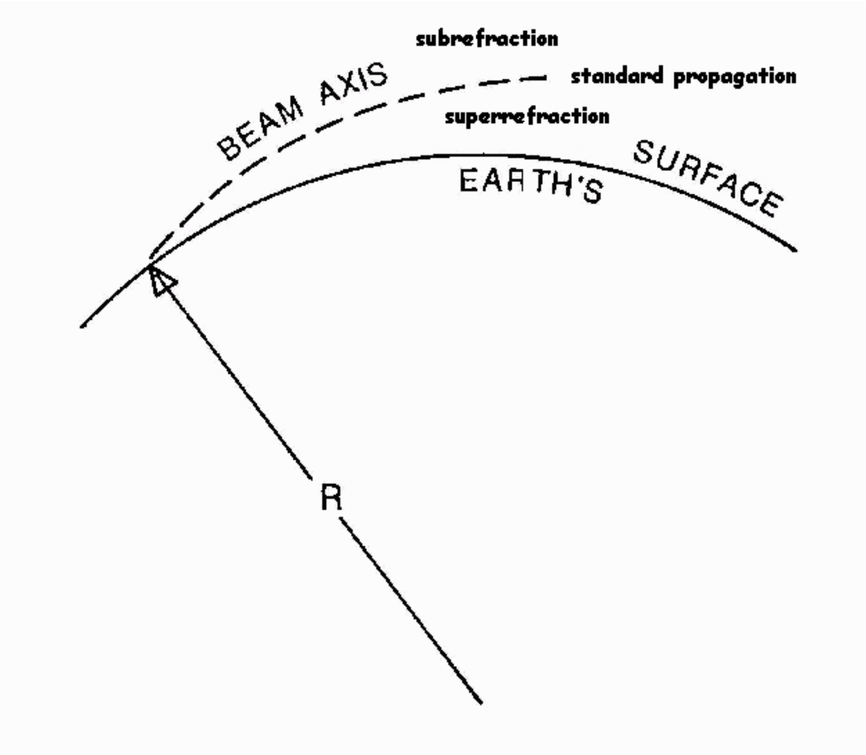

Figure 8-4: Propagation of a radar beam.
[*source*: modified from FMH 11 illustration]

If the radar beams bends less than the standard propagation path, the propagation is referred to as *subrefraction*. If the radar beam bends more than the standard propagation path, the propagation is called *superrefraction*.

Figure 8-4 shows beam propagation from a space perspective, but you live on the Earth's surface and need to look at propagation from an Earth-relative viewpoint. Figure 8-5 shows the elevation of the radar beam above the Earth's surface as a function of distance from the radar (range).

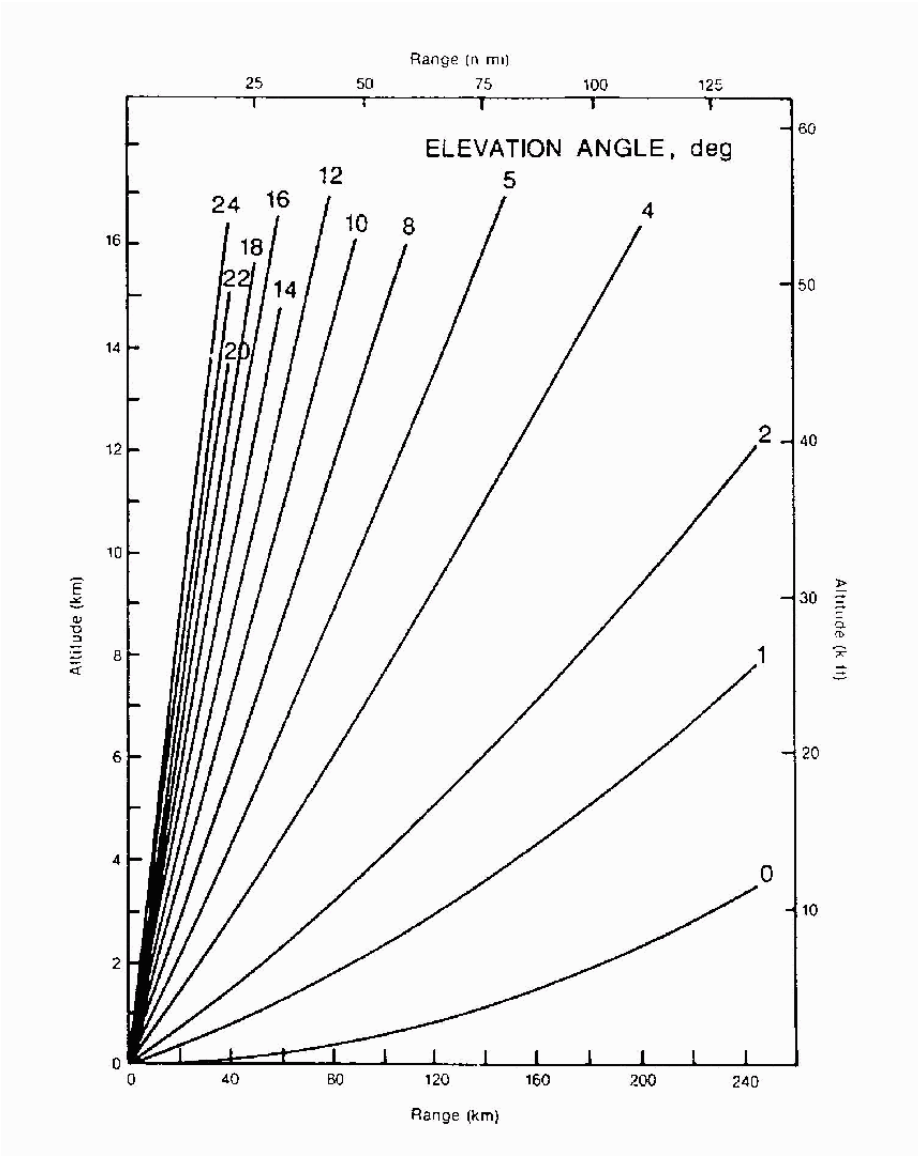

Figure 8-5: Beam height as a function of distance from the radar [*source*: FMH 11]

A beam, initially oriented at 0^{o} elevation, is some 11 or 12 thousand feet above the Earth’s surface at 240 km from the radar.

Types of Radar Data

The electromagnetic signal returned to the radar is processed by the radar software into three types of data: reflectivity; Doppler velocity; and spectrum width.

Reflectivity: Reflectivity (Z) is a measure of the radiation returned by atmospheric scattering to the radar. It is expressed in decibels of reflectivity (dBZ). It is essentially a measure of the intensity of the scattering medium (usually clouds or precipitation). The stronger the scattering, the stronger is the intensity of precipitation detected by the radar, and the higher is the reflectivity value.

Doppler Velocity: Doppler radars have the ability to detect the change in the frequency between the emitted and received signals. This shift in frequency is due to the motion of the scattering medium along the beam and is converted to a Doppler velocity. This radial velocity measures the motion of the scattering medium along the beam, not the total motion of the medium. Figure 8-6 illustrates this.

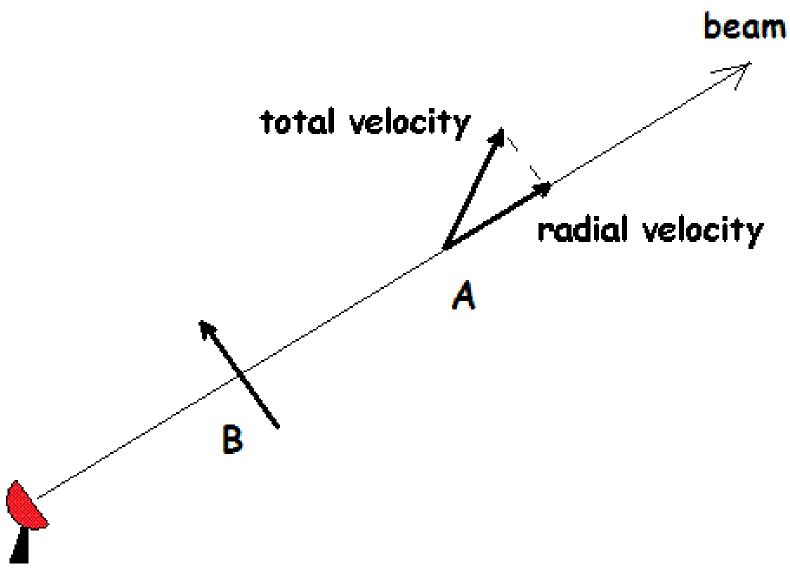

Figure 8-6: Example of Doppler Velocity Detection

At point A, the motion vector (labeled “total velocity”) crosses the radar beam at about a 40^o angle. The component of the vector along the beam (labeled “radial velocity”) is what the Doppler radar detects. If the motion is perpendicular to the radar beam, point B, the radar sees no radial velocity because there is no component of that motion along the beam.

Doppler velocity is usually measured in meters/second (m/s). It is convention that inbound radial velocities have negative values while outbound radial motion has positive values. The mnemonic “IN” can be used to easily remember “inbound negative” (IN).

Spectrum Width: Spectrum width (W) is “a measure of dispersion of velocities within the radar sample volume” (FMH 11). It is essentially the standard deviation of the velocity measurements. Large spectrum width values indicate the presence of strong turbulence or large wind shear, both of which decrease the ability of the radar to accurately define a radial velocity. This chapter will not discuss spectrum width.

Radar Displays

Weather radar information is usually displayed in two forms: on a polar coordinate system with the radar location at the origin; or in cross-section format with horizontal distance along the x-axis and height above ground level on the y-axis. The former is the more common display.

In the analog radar days the signal coming from the radar was displayed directly on a cathode ray tube (CRT). The radar was located at the center of the CRT display and the rotation of the antenna was simulated as a line rotating about that location. When the radar detected a return signal, it was displayed on the CRT at the proper azimuth and range. By placing a map of the local area over the CRT display, the radar meteorologist could geographically locate the precipitation.

With the conversion of operational radars to Doppler capability, weather radar data became digital. As a result radar displays are now digital images and no longer simulate antenna rotation.

The polar coordinate display has been traditionally called the *plan-position indicator* (PPI) display. The radar is located at the origin of the coordinate system and radar information from one antenna elevation scan is shown at the proper range and azimuth. With the conversion of these data to digital images, the ability to overlay a wide variety of information exists. For example, the traditional political boundaries of cities and counties can be supplemented with highways or street locations, or your favor restaurants.

The use of digital data also allows the intensity of the radar return to be color coded to easily show where the stronger returns are located. This will be discussed in more detail below.

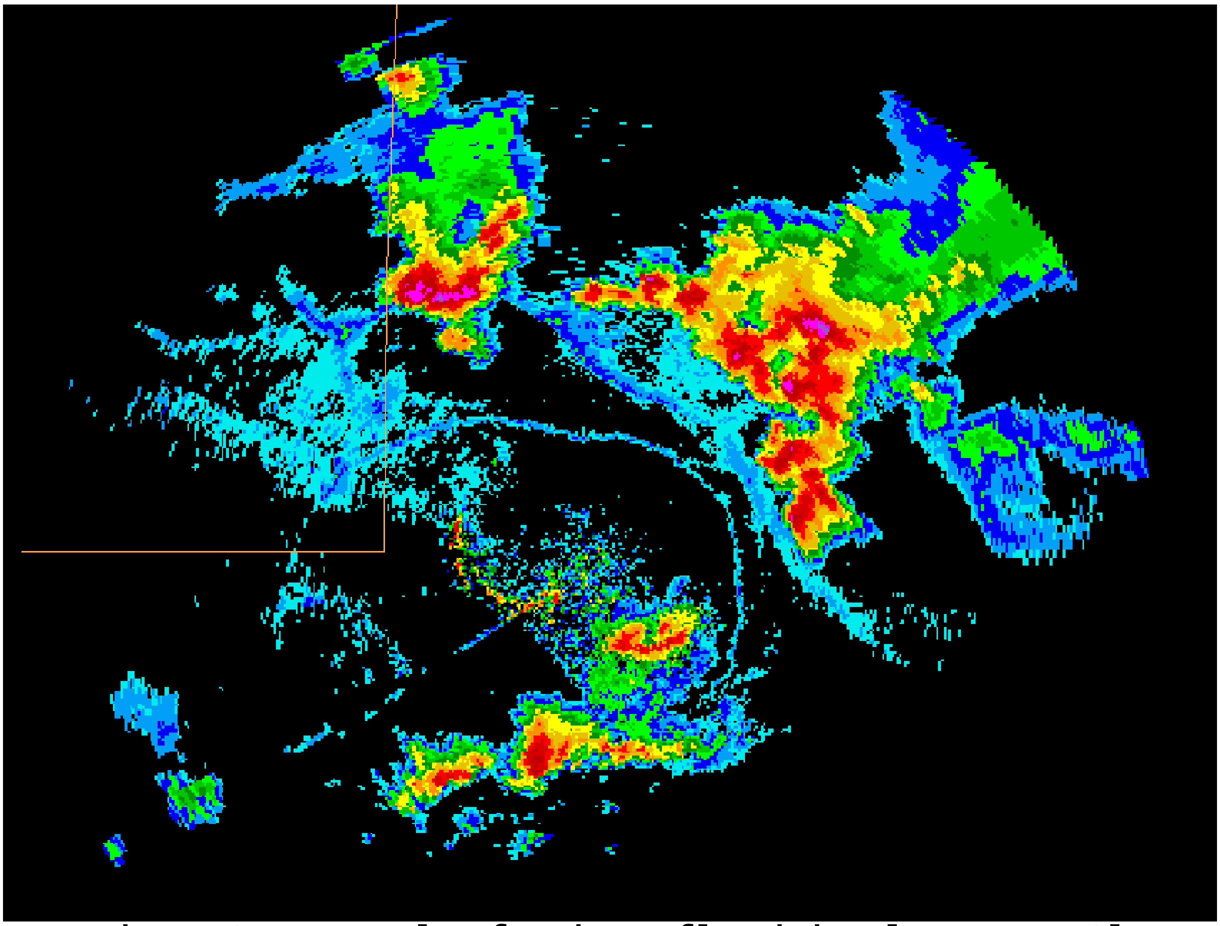

Figure 8-7: Example of Radar Reflectivity [*source*: NWS]

Figure 8-7 is an example of a color-enhanced radar reflectivity display for a 0.5^{o} elevation angle of the antenna. Stronger energy returns are shown in red while weaker returns are in light blue. In this particular example (over west Texas) there are several clusters of thunderstorms (in red and purple). Outflow boundaries from these storms can be seen in light blue.

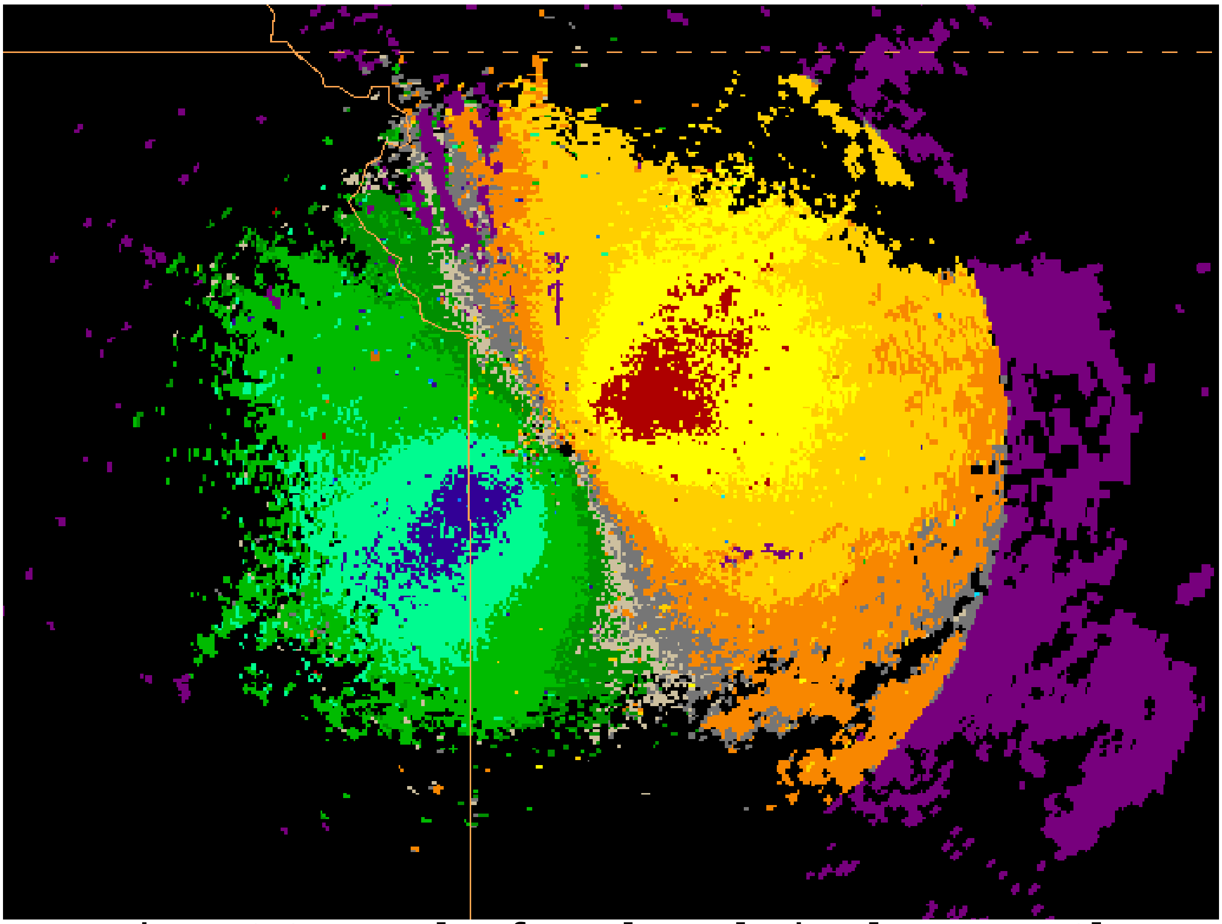

Figure 8-8: Example of Doppler Velocity [*source*: NWS]

Figure 8-8 is an example of the Doppler velocity display from the Kansas City (Pleasant Hill), MO site. The radar location can be seen as a small black circle near the center of the image. Inbound motion (negative values) is shown in blues and greens while outbound motion (positive values) is in reds and yellows. Near zero motion is in gray. The orientation of the maximum inbound to maximum outbound indicates that the low level winds are from the southwest and fairly consistent in direction with height. The purple shading shows areas where Doppler velocity cannot be determined.

In the analog radar days, cross-sections were created by stopping the horizontal antenna rotation and moving the antenna vertically, painting the vertical information on a *range-height indicator* (RHI) display. This allowed the radar operator to view the vertical structure of a storm. With Doppler radar volume scans collect a three dimensional data set. This data set allows today's meteorologist to view any cross-section within the limits of the data.

Digital data sets also allow the display of constant altitude information. Recall that a PPI display for one elevation angle shows data that increases in height with increasing distance from the radar. Digital data can show data from one altitude. This display is called a *constant altitude PPI* (CAPPI).

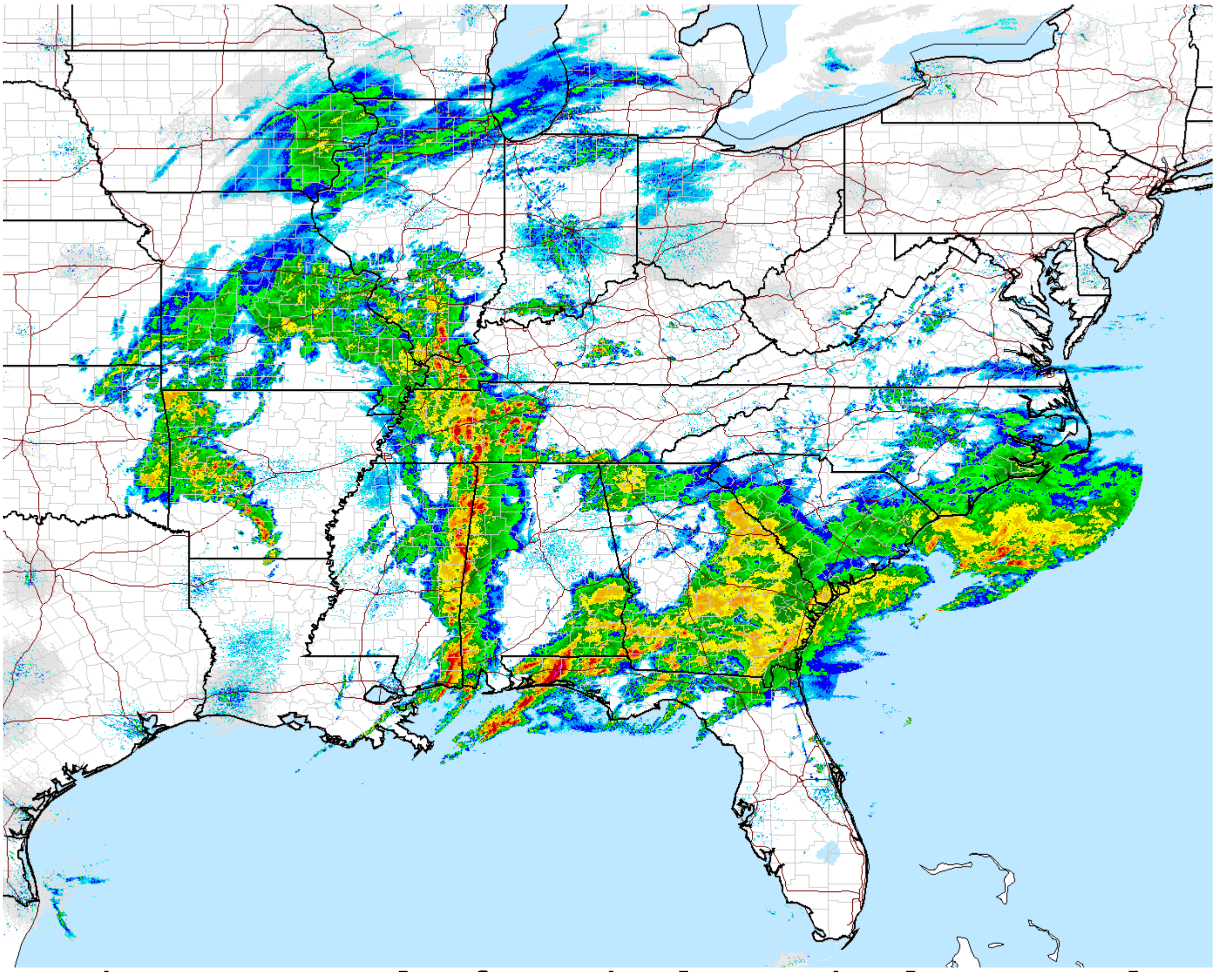

Figure 8-9: Example of a Regional Composite [source: NWS]

Composites: Radar data are collected from individual radar sites across the United States. These sites are placed to maximize radar coverage over densely populated areas and military installations. The polar coordinate displays discussed above are used to display information from one site. It is very useful to combine multiple radar sites onto one map. This display is referred to as a *radar composite*. Some composites are national while other regional in coverage. Figure 8-9 shows an example of a composite from a tornado outbreak over the southeastern United States. All composites are based on data from the National Weather Service (NWS) radar network.

Basics of Interpretation

Reflectivity: The radar reflectivity values can be interpreted in terms of possible precipitation type. As a general rule use the following values to imply specific precipitation type. Remember, however, that the pattern may also tell you something about the precipitation type.

dBZ Value	**Interpretation**
< 15	Clouds
15-20	Weak steady rain
30-40	Showers or heavier rain
>50	Strong thunderstorms

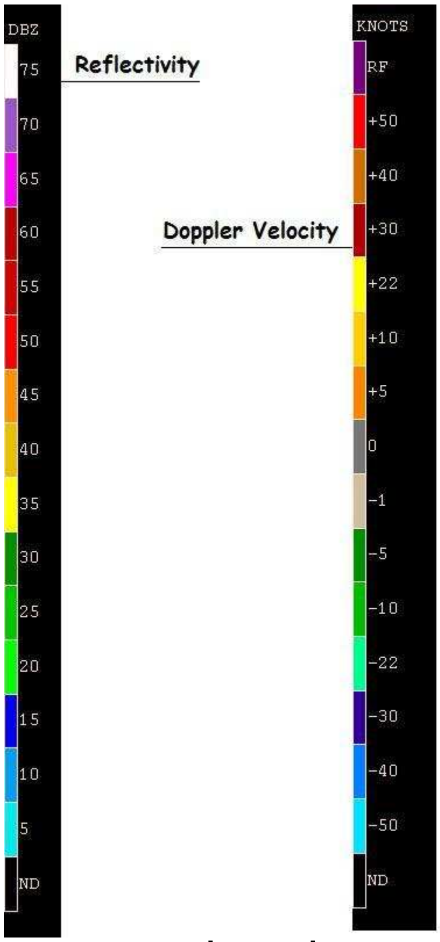

Figure 8-10: NWS Radar Enhancement Scales

Color Enhancement: Digital data sets allow specific colors to be displayed for specific bands of dBZ value. This allows relatively easy visualization of the image details. This process is called *enhancement* and is used with many digital images including the satellite imagery discussed in the previous chapter. Figure 8-10 shows the color enhancement scale used by the National Weather Service for both reflectivity and Doppler velocity. For reflectivity hotter colors (reds and purples) are used for stronger returns while cooler colors (blues and greens) are used with weaker returns.

All NWS radar displays use the same scale. So, if you see reds on an NWS display, you know that represents 50 dBZ return or the presence of thunderstorms.

On the other hand, television or Internet radar displays may not use the scale in Figure 8-10. Because data are digital colors can be changed to whatever the station or web site wants to use. Unless there is a dBZ scale displayed with the image, you cannot easily interpret what is shown. The bottom line: not all radar displays are created equal. TV red may not be the same as NWS red.

Radar Cautions

Although the main purpose for weather radar is to sense weather, there are other things that occasionally show up or interfere with this goal. Described below are several of these items.

Anomalous Propagation: When conditions are favorable for superrefraction, the radar beam bends downward more than usual. If the beam bends enough it can reflect off the ground and nearby objects. This reflection creates a radar return pattern called anomalous propagation (AP). The reflection pattern in the immediate vicinity of the radar is usually referred to as *ground clutter*. This pattern is common around sunrise when nocturnal inversions and high humidity levels are present in the boundary layer.

Figure 8-11 is an example of an anomalous propagation pattern. The ground clutter pattern around the Kansas City radar shows up as an irregular pattern of yellow, green and red pixels. The return to the west also appears to be false return from the vicinity of the Flint Hills. With digital data a known ground clutter pattern can be removed from the display.

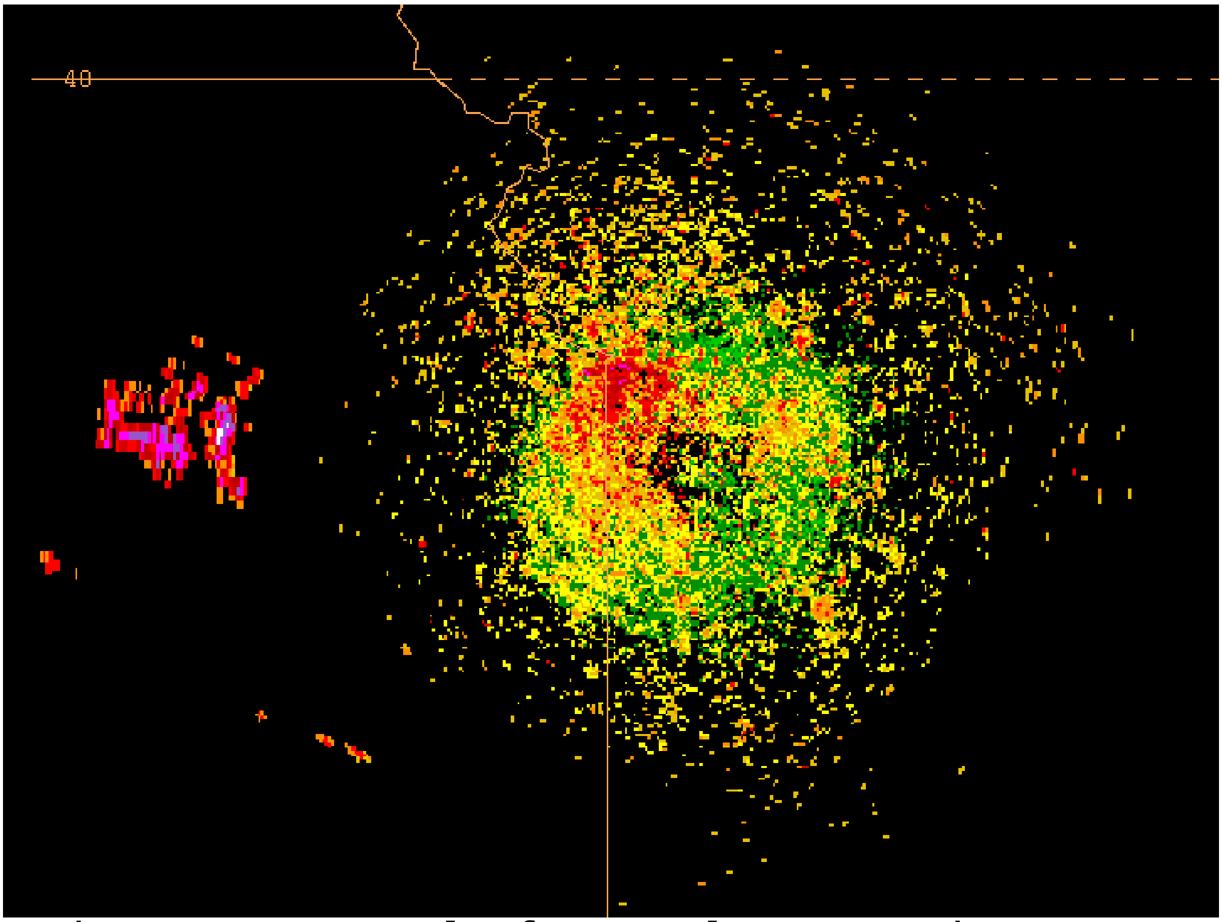

Figure 8-11: An Example of an Anomalous Propagation Pattern.

Topographic Effects: Related to anomalous propagation is the effect of topography on radar return. Essentially, the radar beam reflects off topographic features. This caution is more important in mountainous areas. Figure 8-12 shows the radar return from Phoenix, AZ. Along the line from A to B, there is a band of brighter return that occurs due to the mountain to the northeast of the city.

Terrain and Beam Blockage: If the terrain is high enough or if there is a tall object close to the radar site, the radar beam can be completely blocked. This shows up on a radar image as a radial line of missing data. Figure 8-13 shows an example of beam blockage on the island of Guam. The line of missing data is obvious to the south of the island. There also happens to be a typhoon to the east of the island.

Bright Bands: The highest reflectivity values are typically associated with either hail or a mixture of water and ice. The most likely place to find the water-ice mixture is just below the freezing level in clouds where falling snow is melting. If there is cloud layer completely around the radar site, the radar often shows a circular band of higher intensity return associated with this water-ice mixture. This band is referred to as a *bright band*. The top of this band should be at or near the freezing level. The bright band is best seen in a cross-section.

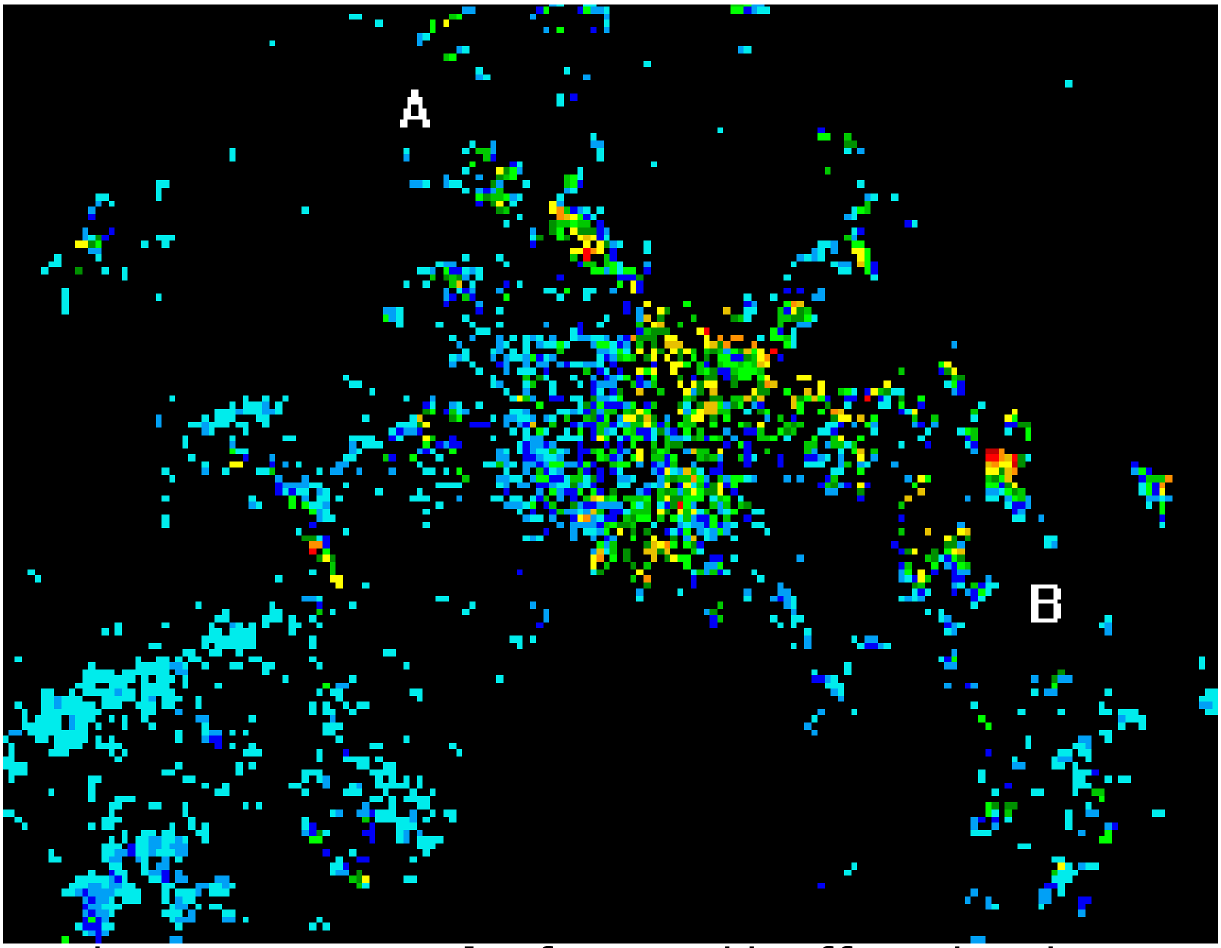

Figure 8-12: An Example of Topographic Effects in Arizona.

Attenuation: As a radar beam propagates through the atmosphere, some of its energy is dissipated by its interaction with the atmosphere. The amount of attenuation is related to the wavelength of the radar energy. For 10 cm network radars, this loss is small. For 5 cm radars heavy precipitation can significantly limit the radar’s ability to see addition rainfall in areas beyond heavy precipitation.

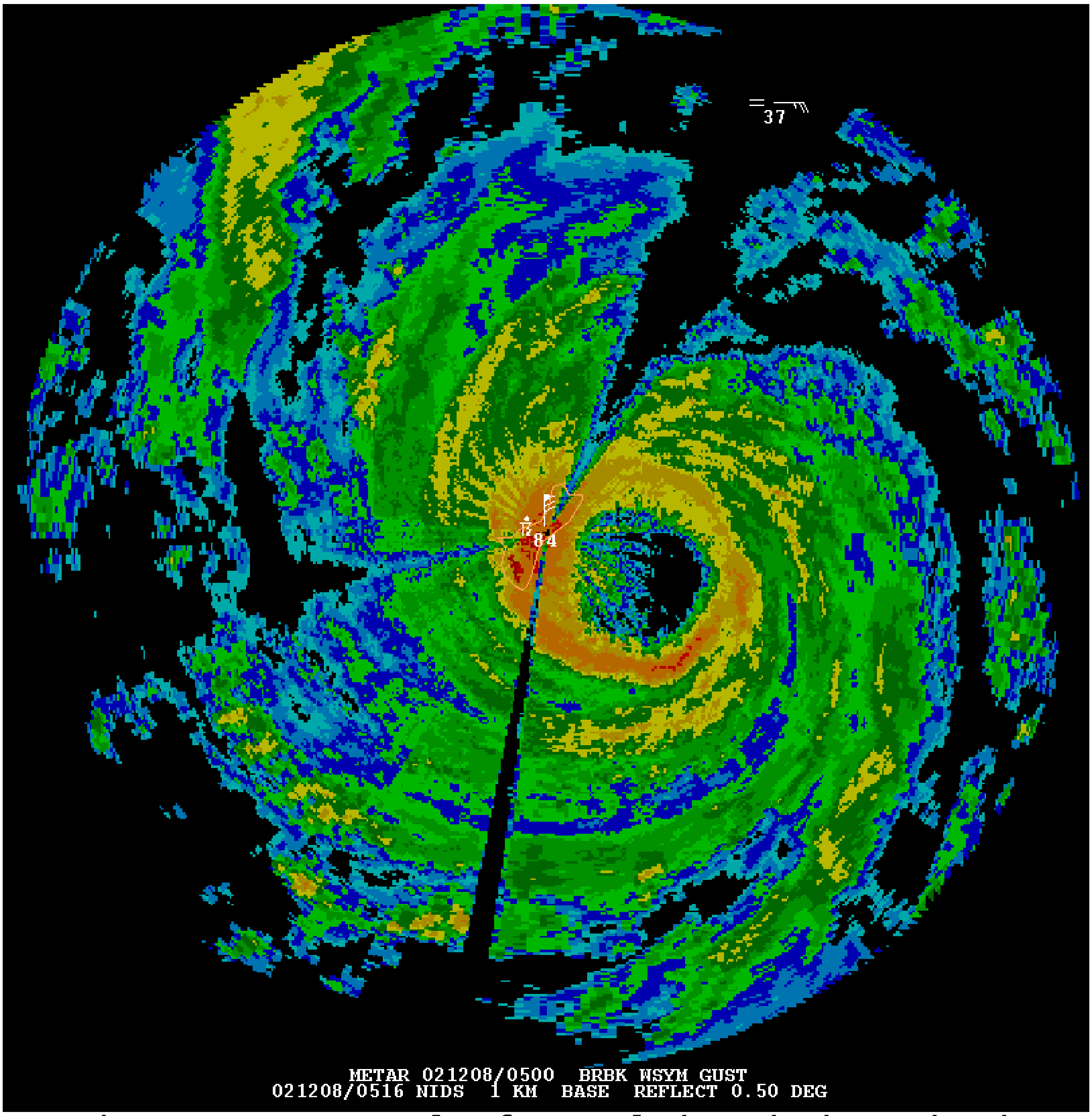

Figure 8-13: An Example of Beam Blockage (and a Typhoon)

WSR-88D Products and Algorithms

The WSR-88D (Weather Surveillance Radar, 1988 Doppler) has two main components: the Radar Data Acquisition (RDA) unit; and the Radar Product Generator (RPG). The RDA is the antenna and accompanying hardware/software that emits the radar beam and collects and processes the basic radar data. The RPG takes data from the RDA and uses a multitude of product creation algorithms to produce a series of products that help the radar user analyze what is happening in the atmosphere.

The WSR-88D routinely collects reflectivity, Doppler velocity, and spectrum width data every 6 to 10 minutes (depending upon the volume scan) for a three dimensional volume above the radar. This data set provides both spatial and temporal information that is processed by the radar using a variety of mathematical techniques. Some of these products are listed below:

- Composite reflectivity
- Echo tops
- Hail index
- Mesocyclone
- One-hour and three-hour precipitation accumulation
- Severe weather analysis
- Storm structure
- Storm tracking information
- Tornado vortex signature (TVS)
- Velocity azimuth display (VAD)
- Vertically integrated liquid (VIL) water

This is by no means a complete list of what is available from the WSR-88D. Refer to the latest version of FMH 11 for an updated list and description of each product and algorithm.

The meteorological algorithms can be used to track storm motion (storm tracking information) or to help access the severity of a particular storm cell (mesocyclone, tornado vortex signature, vertically integrated liquid water). Information on the average wind profile around the radar site is available (velocity azimuth display). Hydrologic information is also extracted from radar data for such things as hourly rainfall estimates. These algorithms provide information for flash flood situations as well as for hydrologic models.

Radar products are created in a specified order for each volume scans. When an expansive area of precipitation is occurring, the radar collects considerably more data than for non-precipitation events. These additional data increase the time it takes to process the items on the product list. If a new volume scan becomes available, the creation process stops where it is on the list and starts at the top of the list with the new data set. The term, *loadshedding*, is used to refer to the products that are not created due to lack of time between volume scans. This term has also been used to describe people who have difficulty managing time and want to dump their assignments on others.

Concluding Remarks

The purpose of this chapter has been to provide some basic information on weather radar that will be useful from a weather analysis perspective. For a more comprehensive description of weather radar check the texts listed in the references. They contain considerably more detail on radar hardware, radar software, radar propagation, etc., than is covered here.

Acknowledgement: All radar images are from National Weather Service sources.

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