

WEATHER RADAR

This chapter will be devoted to the discussion of various types of radar, their characteristics, principles, and elements.

The first portion of our discussion will deal with characteristics and principles of nondoppler radar, followed by a discussion of principles, characteristics, and phenomena associated with doppler radar. Finally, we will look at the Next Generation Weather Radar (NEXRAD) system, principally the WSR-88D.

NONDOPPLER RADAR

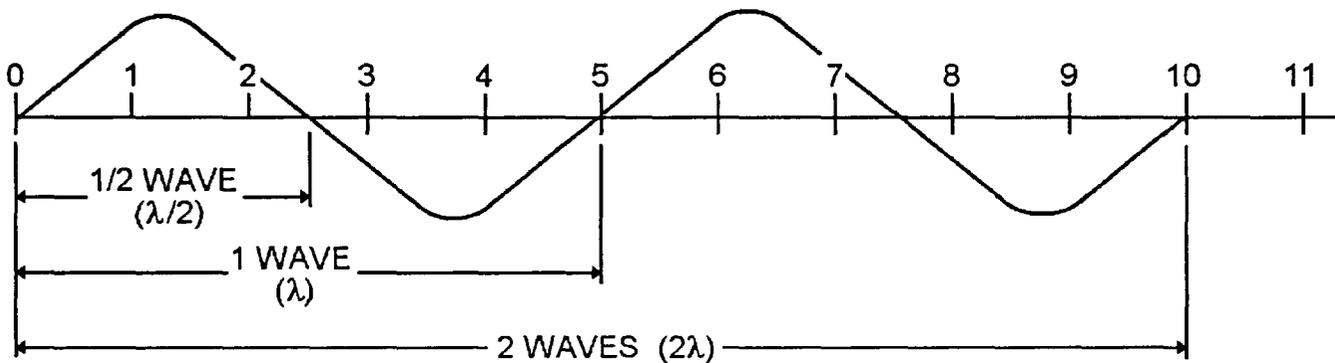
LEARNING OBJECTIVES: Interpret the effects of wavelength on nondoppler radar. Recognize principles of wavelength on nondoppler weather radars. Evaluate nondoppler radar beam characteristics.

Now let's begin our discussion of nondoppler radar. For additional information, refer to the Federal Meteorological Handbook No. 7, *Weather Radar Observations*, Part B, NAVAIR 50-1D-7.

EFFECTS OF WAVELENGTH AND FREQUENCY ON RADAR PERFORMANCE

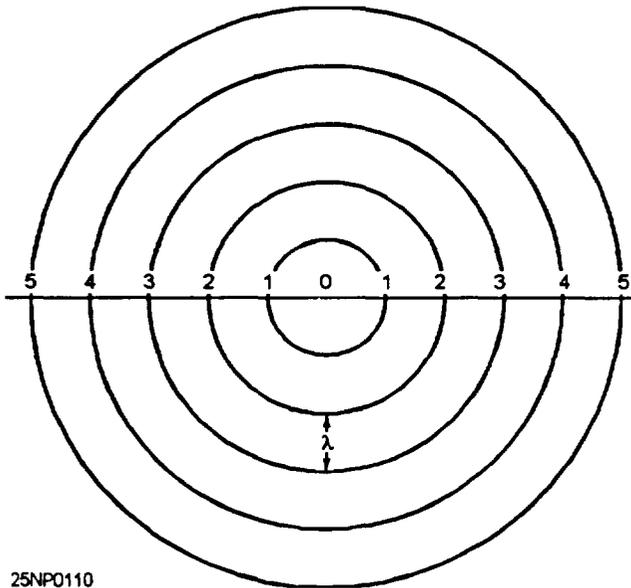
The concept of energy moving as waves through a medium such as water is easily understood because we can observe the oscillation of the material. Both

electrical and magnetic energy are transmitted by these waves. Viewed along the direction of transmission, the envelope containing vectors representing an electromagnetic field appears in wave form. Figure 12-1 shows the common method for representing radio energy waves. The radio energy waves have some semblance to water waves in that they retain their size while all traveling at the same speed. Therefore, they could also be represented as concentric circles about the generating device, as seen in figure 12-2. In this case, we could say that the circles represent wave fronts that move away from the source. In the case of focused waves, such as we have with weather radars, we could show the wave fronts moving along the beam path, as in figure 12-3. In all three illustrations, the distance from wave front to wave front, and from any part of a wave to the corresponding part of the next wave, remains constant. This distance is determined by two factors, the speed with which the waves move and the rapidity with which the generating device operates. The generating device is said to oscillate, and could be thought of as moving up and down, or back and forth. Each complete oscillation produces one complete wave. The waves move away from the oscillator as they are being generated so that the wave front will be 1 wavelength away from the oscillator when the next wave front is just being formed. Because the speed of wave travel remains constant, there is a constant, inverse relationship between the frequency of the oscillation and the length of the wave; the faster the oscillation (higher frequency), the shorter the wavelength.



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Figure 12-1.-Energy wave represented as oscillations. These are 5 cm long.



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Figure 12-2.-Flve 1-cm energy waves represented as concentric circles around the wave emittcr.

Thus, radar waves can be described either in terms of frequency or wavelength. The two are related by the following equation:

$$\text{FREQUENCY} = \frac{c}{\lambda}$$

where λ is the wavelength and c is the speed of light (300,000,000 meters per second or 3×10^8).

Wavelengths for Weather Radars

All the wavelengths commonly used for radars will be reflected by large objects such as buildings and airplanes, but some waves are so large they are not affected significantly by small objects such as raindrops, and, therefore, do not effectively detect their presence. Other waves are so small that they are completely scattered and absorbed by raindrops and, therefore, cannot penetrate beyond the first drops to detect others

far away. Any object that is easily detected by a particular wave is one that reflects, absorbs, or scatters that wave, decreasing its potential to detect more distant objects. The target for weather surveillance radars is the raindrop, with a diameter usually less than 5 mm. We must select a wavelength small enough to detect the raindrop, but large enough not to be completely reflected and absorbed by a large number of drops. The choice usually comes to either 5- or 10-cm waves.

Wavelength for Cloud Detection Radars

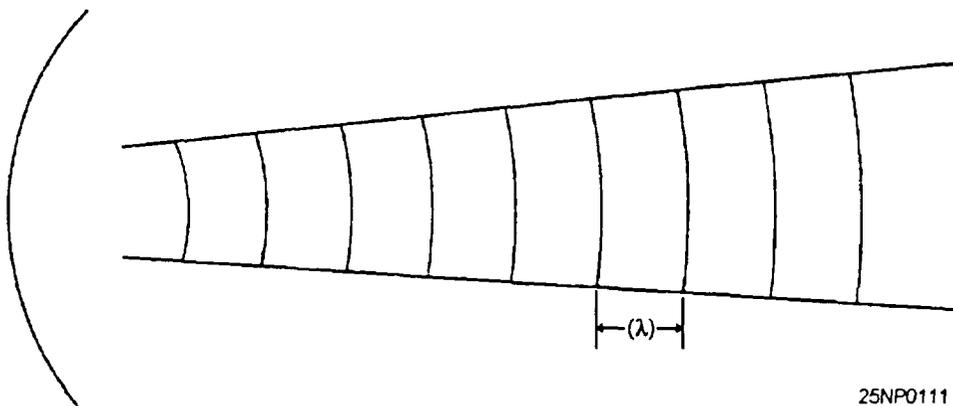
Wavelengths shorter than 3 cm will detect most cloud particles. The optimum wavelength for cloud detection is about 1 cm (anything shorter is too greatly attenuated).

RADAR BEAM CHARACTERISTICS

In the following section we will deal with some of the characteristics of the radar beam.

Beam Height and Width

Although we must always keep in mind that the radar energy discussed here is emitted in short pulses rather than in a steady stream, it is useful to think of the path of the pulses as a beam much like a flashlight beam. Each pulse has three dimensions within the beam-height, width, and length-and each pulse is composed of a number of waves of energy. The beam is created when the energy waves are directed onto the reflector, which focuses them in a desired direction and a predetermined shape. The height and width of each radar pulse is determined by the radar beam shape and size, and the beam, in turn, is determined by the shape and size of the antenna reflector. For weather radars, we almost always use a narrow cone, or "pencil beam," so that we can concentrate the energy in a small spot and make both vertical and horizontal measurements of the



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Figure 12-3.-Energy waves represented as concentric arcs inn a radar beam.

location of the targets. This kind of beam is created with a parabolic reflector, the end of the waveguide being at the focal point of the parabola.

Radars display targets on the scope as if the targets are at the center of the beam, even though the target may have been illuminated by energy that has been scattered outside the beam. This means that any object illuminated sufficiently by the radar energy to return to the antenna some of that energy will be shown on the indicators as being directly in front of the antenna, while it actually maybe several degrees to the side. Although this sometimes leads to inaccurate interpretation of the radar-scope information, the problem usually concerns strong targets fairly close to the radar that are masked in the ground clutter.

Pulse Length and Pulse Repetition Frequency

The length (h) of a radar pulse in space is determined by the product of the pulse duration (τ) and the speed of light (c):

$$h = \tau c = \tau(3 \times 10^8 \text{ m sec}^{-1})$$

For instance, a pulse of 1-second duration would have a length of

$$\begin{aligned} h &= (1 \text{ sec})(3 \times 10^8 \text{ m sec}^{-1}) \\ &= 3 \times 10^8 \text{ m} \\ &= 300,000 \text{ km.} \end{aligned}$$

Beam Resolution and Target Distortion

Resolution describes the ability of the radar to show objects separately. There are two distinct resolution problems:

1. Range resolution—The ability to distinguish between two targets in the same direction from the radar, but at different ranges.
2. Beam-width resolution—The ability to distinguish between two targets at the same range, but in different directions.

Both resolution problems arise from the fact that the radar pulse occupies considerable space, and any part of the pulse may illuminate a target sufficiently for detection. If two targets are detected at the same time, the radar will present only one echo on the scope.

Range Effect on Signal Strength and Echo Definition

The cross-sectional area of the radar beam is proportional to the range from the radar, becoming larger as the range increases. Accordingly, the energy incident on a unit area of the beam cross section decreases with range, being inversely proportional to the square of the range. This is often called range attenuation, although the term *attenuation* is more properly applied to the dissipation of energy by the medium through which it passes.

Now let's look at the history of doppler weather radar, as well as a discussion of principles, characteristics, and phenomena associated with doppler radar. Information on doppler radar maybe found in the Federal Meteorological Handbook No. 11 (FMH-11), *Doppler Radar Meteorological Observations*, parts B, C, and D. Additional information maybe found in *The Doppler Radar Glossary, Thunderstorm Morphology and Dynamics*, and *Doppler Radar Principles*, KWXN-5002, KWXN-1005, and KWXN-1002, which are practical training publications produced by the United States Air Force Training School at Keesler Air Force Base, Mississippi.

DOPPLER RADAR

LEARNING OBJECTIVES: Discuss the history of doppler radar. Recognize velocity-aliased data, range-folded data, and ground clutter and assess their impact on radar interpretation. Evaluate doppler velocity and wind shear patterns. Interpret radar presentations of cloud layers and the bright band.

In the following we will be discussing a brief history of Doppler Radar from the first real-time Doppler display in 1967, to the present day Weather Surveillance Radar 1988 – Doppler (WSR-88D).

HISTORY

In 1967, the first simultaneous observations of atmospheric flow patterns by two doppler radars were made. This was performed in central Oklahoma by the National Severe Storms Laboratory (NSSL) and Cornell Aeronautical Laboratory and concurrently in England by the Royal Radar Establishment. Data in these studies was stored in real time and analyzed later. At about the

same time, the first real-time doppler radar display, The Plan Shear Indicator, was developed by the Air Force Cambridge Research Laboratories.

In the early 1970s, a unique new class of high-powered, sophisticated S-band doppler weather radar appeared, incorporating integrated circuitry and advanced computer processing. Two were built by the NSSL. Others were built by the National Center for Atmospheric Research and by the University of Chicago in cooperation with the Illinois State Water Survey in Champaign, Illinois. By the mid 1970s, technological advances allowed real-time processors to be linked to color displays.

Joint Doppler Operations Project (JDOP)

Studies conducted by NOAA Environmental Research Laboratories for the National Weather Service (NWS) during 1975 and 1976 showed that it was not feasible to convert existing network radars to suitable doppler systems. As a result, the historic Joint Doppler Operations Project (JDOP) was conducted from 1977 to 1979 at the NSSL by the Air Force, the Federal Aviation Administration (FAA), and the NWS. This was the true birthplace of the WSR-88D.

JDOP demonstrated the meteorological utility of operational doppler radars and also benchmarked the engineering requirements for the NEXRAD. The NEXRAD program formally began with the establishment of the Joint System Program Office (JSPO) at NWS headquarters in 1979. Since this time, NEXRAD has been officially renamed the (WSR-88D).

A detailed discussion of the WSR-88D PUP and its capabilities is beyond the scope of this text. For a detailed discussion of capabilities and procedures refer to the technical manual, *Operation Instructions Principal User Processor (PUP) Group/Doppler Meteorological Radar WSR-88D*, NAV EM400-AF-OPI-010/WSR-88D.

We will now discuss velocity-aliased data, followed by a discussion on it's recognition.

VELOCITY ALIASED DATA

Doppler radar uses the change in frequency between the outgoing signal and the returning signal (*doppler shift*) to determine radar velocities. However, limitations in velocity measurements do exist. We now will take a look at an example to see what can go wrong.

Trains are designed to go as fast forward as in reverse. The speedometer shows both forward and reverse speed. Refer to figure 12-4 throughout this discussion. Direct reading of speeds between 0-49 mph, whether forward or reverse is quite easy. As with a train's speedometer, radar has limits to speeds that it can measure without error. These speeds that can be measured without error are known as *Unambiguous Velocities*.

In part (a), the train is traveling at 40 mph in a forward direction. The speedometer indicates the correct speed. In part (b), the speed of the train has increased by 20 mph, so that the train is now traveling at 60 mph, but, the speedometer indicates 40 mph in reverse. The maximum forward speed was exceeded on

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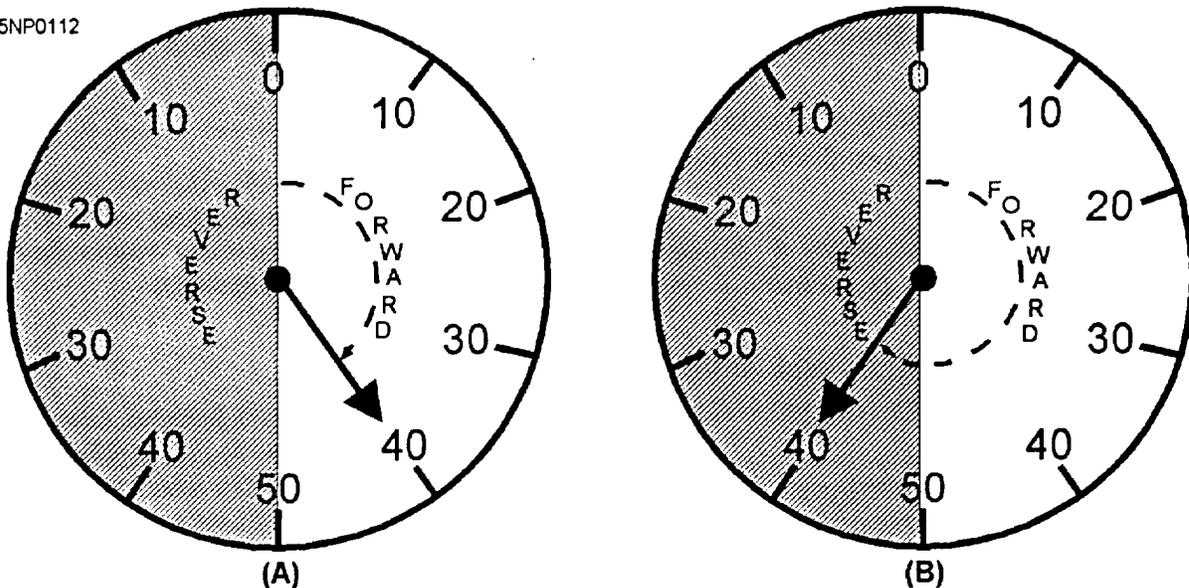


Figure 12-4. Speedometer.

the speedometer, therefore, speeds of 0-49 mph are unambiguous. Radar speeds that exceed the maximum unambiguous velocity are said to be *aliased*, and referred to as *aliased velocities*.

Velocity aliasing occurs when frequencies too high to be analyzed with the given sampling interval appear as a frequency less than the Nyquist frequency (the highest frequency that can be determined in data that has been sampled). In other words, wind speed greater than the unambiguous velocity (Nyquist co-interval [the entire range of detectable velocities]) for the current pulse repetition frequency (PRF) are wrapped around into the incorrect Nyquist co-interval. A sophisticated velocity-dealiasing technique is implemented in the WSR-88D (referenced in part D of the FMH-11). However, it is expected that improperly dealiased data will occasionally occur.

Recognition of Velocity-Aliased Data

Data that are incorrectly dealiased can be difficult to ascertain. However, understanding the limitations of the algorithm should help to recognize improperly dealiased data.

If the suspected data is in an area isolated from other data and there is a large variation in the subsynoptic or mesoscale wind field, the algorithm may not be able to initially assign the correct velocity. Other instances of incorrect dealiasing may occur when there are shifts in the inward- and outward-bound velocities along the radials of data that do not fit those allowed by the algorithm. In these cases, the actual values maybe off by a factor of twice the unambiguous velocity of the PRF in use at the time. Typical unambiguous velocities for the WSR-88D, in the Precipitation mode, range from 40 to 60 kts. Occasionally, groupings of data appear along a small set of ranges that could not be successfully dealiased. These should be obvious.

Assessing Impacts of Velocity Aliasing

Incorrectly dealiased velocity data can seriously impact certain WSR-88D algorithms and products. Mean Radial Velocity products will be difficult to analyze when contaminated with incorrectly dealiased data. To determine the extent of the dealiasing problem, it is recommended that earlier displays of these products be examined to determine if there is time or space continuity. In addition, other elevation angles of the Mean Radial Velocity products may be used to determine if there is vertical continuity.

Algorithms and products that ingest mean radial velocity data can output incorrect results when such data are used. In the case of the mesocyclone detection algorithm, there will likely be a lack of vertical continuity of incorrectly dealiased data. Consequently, only uncorrelated shears should result from using aliased data. In the rare event of a tornadic vortex signature being output in the vicinity of an identified mesocyclone because of vertical continuity of incorrectly dealiased data, other products should be examined to verify the existence of a severe thunderstorm.

It is expected that incorrectly dealiased data will not have a large impact on Combined Shear products because of the amount of averaging of data done by the algorithm.

RANGE-FOLDED DATA

Second trip echoes (*range folding*) occurs when the radar hears a previous pulse, while listening for the most recent pulse.

Due to the sensitivity and narrow beam width of the WSR-88D, precipitation echoes beyond 250 nmi will occasionally appear in closer range due to range folding. However, far more significant are the range ambiguities in the doppler velocity and width fields caused by the WSR-88D'S pulsed doppler sampling interval (referenced in part B of the FMH-11). For any pulsed doppler system, the product of the unambiguous range and the doppler Nyquist interval is a constant function of the wavelength of the radar and the speed of light. Decreasing the PRF allows for a longer listening time, thus increasing the unambiguous range, but, this lower PRF creates a problem in determining radial velocities.

THE DOPPLER DILEMMA

High PRFs are required for high velocity measurements and low PRFs are required for long ranges. The solution to this dilemma lies in finding a balance between the effects of velocity aliasing and range folding. This dilemma is caused by physical restrictions based on the laws of nature. To solve this dilemma, the WSR-88D will use several methods to work around these restrictions. One method is to operate at variable PRFs; the second is to collect refractivity information at low PRFs and velocity information at high PRFs. The two sets of information collected are compared, then processed to estimate true radial velocities and ranges.

The radar interprets velocity and spectrum width returns from beyond the ambiguous range as occurring within the range. Range dealiasing software has been implemented in the Radar Data Acquisition (RDA) component preprocessor. The purpose is to attempt to replace range-folded doppler data to its proper range. This software compares radar power returns from the possible ranges of doppler velocity and spectrum width data. If the power at one possible range is more than the power at the other ranges, the data are assigned to that range and the doppler data from the other ranges are considered ambiguous. If the power from the different cringes is within 10 dB, the doppler data at all those ranges are considered unambiguous. Ambiguous doppler data are flagged as range folded, treated as missing by all algorithms, and are displayed as purple (adaptable) at the principal user processor (PUP).

Recognition of Range-Folded Data

Range-folded data should be easily recognized in a Reflectivity product. Range-folded data have a “spiky” appearance in the radials where they appear. In addition, the reflectivity values where the data are folded will not be similar to those surrounding them.

Range-folded data are detectable by comparing Reflectivity and Mean Radial Velocity products, as well as comparing current displays with previous products for time and space continuity.

Range folding may occur under conditions of anomalous propagation where the radar beam is constrained to follow a path close to the Earth’s surface, or when strong convection occurs beyond the first trip (250 nmi).

When possible, the range dealiasing software will place the doppler velocity and spectrum width data at the proper range. When this software cannot determine the proper range, the data will be flagged and displayed as range folded.

Assessing the Impact of Range-Folded Data

Range-folded data can impact products and algorithms that use reflectivity data. When range-folded data are present, corrupted data are displayed with valid data. Products using multiple reflectivity scans may be affected as well.

The impact of doppler velocity and spectrum width range folding is significant, both in the radar’s unambiguous range limits and in areas of significant velocity data lost due to ambiguous returns. In addition,

range ambiguous values are treated as missing by the velocity-based algorithms and can, therefore, seriously impact those algorithms.

Assessing Impacts of Range-Folded Data on Velocity Products

The presence of range-folded (overlaid) data on Mean Radial Velocity products is inevitable. The inability to determine velocity estimates for the sample volumes results from the inability of the range unfolding algorithm to distinguish between power returns from two or more sample volumes at the same relative location within different trips. Therefore, valid velocity estimates can be derived for only one corresponding sample volume along each radial. The ring of range-folded (overlaid) data at the beginning of the second and subsequent trips is caused by the first trip ground clutter and is a common result of this range unfolding limitation.

NON-METEOROLOGICAL RADAR ECHOES

This section will briefly describe methods of identifying and assessing the impacts of ground clutter, anomalous propagation, sidelobes, and solar effects.

Ground Clutter

Prior to calculation of reflectivity, velocity, or spectrum width, return signals from ranges within the radar’s normal ground clutter pattern are processed to remove most of the signal returned from targets that are stationary (part B of the FMH-11). The portion of signal not removed, called residual clutter, will remain as part of many of the products.

RECOGNITION OF RESIDUAL GROUND CLUTTER.— A low-elevation Reflectivity product will show ground clutter close to the radar or distant mountainous terrain. It will normally appear as a cluster of points (having a speckled nature) or as a large area of contiguous returns. Errors are recognizable as wedges having sharp radial discontinuities from adjacent regions and whose predominant colors differ markedly. Errors may also appear as radial spikes several volume samples in length, whose velocities are shifted toward high positive or negative values. A time lapse of Reflectivity products will show no movement of these returns. With increasing antenna elevations, ground clutter returns will disappear. Generally, mean velocities will be near zero and spectrum widths will be very narrow.

ASSESSING IMPACTS OF RESIDUAL GROUND CLUTTER.— Residual ground clutter near the radar may be recognized by its speckled appearance. When it is imbedded in a meteorological signal over the radar, the velocity dealiasing algorithm may introduce errors in the velocity field due to radial and azimuthal gate-to-gate shears greater than the Nyquist velocity. This problem is most likely to occur in the Clear Air mode using VCP (volume coverage pattern) 31, where the Nyquist velocity is about 21 kts. If this problem occurs in the Precipitation mode, the induced shears may be picked up by the mesocyclone algorithm and carried as a feature.

Ground Clutter Returns from Anomalous Propagation

Anomalous propagation of the radar beam is caused by nonstandard atmospheric temperature or moisture gradients (part B of the FMH-11). Super refraction, which is frequently caused by temperature inversions, bends the beam toward the earth and can cause the radar to detect ground returns from distances far exceeding the normal ground clutter area.

RECOGNITION OF GROUND CLUTTER RETURNS FROM ANOMALOUS PROPAGATION.— With increasing antenna elevation, these returns will usually disappear. A time lapse of Reflectivity products may show apparent motion or changing patterns. There can be a 20 dBZ_e (a decibel of the equivalent radar reflectivity factor) or more difference between adjacent returns in the absence of precipitation, mean velocities maybe near zero, and spectrum widths may be narrow. Ground returns from anomalous propagation mixed with precipitation may result in large spectrum width values and low velocities. Erratic movement of ground returns from anomalous propagation, in comparison with the motion of precipitation echoes, may also be seen.

ASSESSING IMPACTS OF GROUND CLUTTER RETURNS FROM ANOMALOUS PROPAGATION.— Ground return from anomalous propagation mainly affects interpretation of reflectivity echoes in the affected areas. It can cause erroneous output and increase edit time of the radar coded message in these areas. It may also affect algorithmic output; for example, if reflectivity is greater than 30 dBZ_e, erroneous identification of a storm may occur and precipitation accumulation values may be degraded. Super refraction of the radar beam frequently occurs behind the cold air outflow regions of thunderstorms. In these instances, the precipitation processing algorithms may

erroneously interpret the ground returns as precipitation echoes and significantly overestimate the precipitation.

REMOVAL OF GROUND CLUTTER RETURNS FROM ANOMALOUS PROPAGATION.— Anomalous propagation can be removed, to a large extent, by application of the clutter filter to the elevation angles affected. This is accomplished by overriding the clutter map resident in the RDA through editing of the Clutter Suppression Regions menu at the Unit Control Position. Up to 15 clutter suppression regions can be edited in which three levels of suppression can be defined for the reflectivity and doppler channels. Unit Radar Committee guidance on the use of the clutter map editor must be obtained.

If weather is not a factor, that is, when operating in the Clear Air mode or when ground clutter or anomalous propagation is in a precipitation-free sector in the Precipitation mode, it is reasonable to apply the clutter filter. If anomalous propagation is mixed with precipitation, the filter should not be applied.

Sidelobes

An occasional source of data contamination is simultaneous reception of signals at comparable power levels through both the main antenna pattern and its sidelobes (part B of the FMH-11).

RECOGNITION OF SIDELOBES.— Sidelobes are found to the right, left, above, and below high reflectivity areas. Potential interference from sidelobes can be diagnosed by knowing how much difference in power there is between the main beam and the sidelobe. The location of potential sidelobe interference will be specified by a particular number of degrees between the axis of the main beam and the sidelobe. The velocity field of sidelobes will display noisy or erratic values. Spectrum widths will achieve extreme values and are the best indicator of sidelobe interference.

ASSESSING IMPACTS OF SIDELOBES.— The presence of sidelobes may indicate erroneously high storm tops or new storm growth where there is none. Sidelobes can also impact velocities in a weak echo region, where mesocyclones occur, by providing noisy or erroneous values that mask true velocity patterns. Algorithmic output may be affected.

Solar Effects

Due to the sensitivity of the WSR-88D, anomalous returns near sunrise or sunset usually appear for several radials. These returns are generated because the sun

radiates energy in the same microwave region of the electromagnetic spectrum that is used by the WSR-88D.

RECOGNITION OF SOLAR EFFECTS.— These echoes may be expected to appear as continuous returns, in a narrow “baseball bat” shape, out one or two radials at the solar attitude. Reflectivity values generally range between 10 and 20 dBZe. See figure 12-5. Solar effects will appear for one or two volume scans at a single elevation of the Reflectivity, Mean Radial Velocity, or Spectrum Width product and up to 30 min on a Composite Reflectivity product.

ASSESSING IMPACTS OF SOLAR EFFECTS.— In the absence of other echoes, typical reflectivity values from solar effects are from near zero dBZe in close to the radar, to 20 dBZe or higher at 250 nmi. The apparent reduction in the sun’s signal nearer the radar is due to the range normalization correction applied to reflectivity. The velocity and spectrum width fields indicate range-aliased data out to the maximum range of these products, that is, 124 nmi. Other Reflectivity-derived products that will show this

contamination are the Echo Tops, Composite Reflectivity, and Layer Composite Reflectivity. The Storm Series algorithms will generally not be affected since the reflectivity values are below the thresholds used to detect storms.

Velocity-derived products that will be contaminated are the Storm Relative Mean Radial Velocity Map, and Region. At longer ranges, the contaminated radial may disrupt pattern vectors used to identify circulations in the mesocyclone algorithm, where the sun’s signal is stronger than the corresponding storm echo. At close-in ranges, the sun’s signal is too weak to impact the Tornadoic Vortex Signature algorithm.

The solar effects can also cause erroneous output and increase edit time of the radar-coded message in these areas.

INTERPRETATION OF DOPPLER VELOCITY PATTERNS

Although a single doppler radar observes only the component of the wind in a radial direction from the

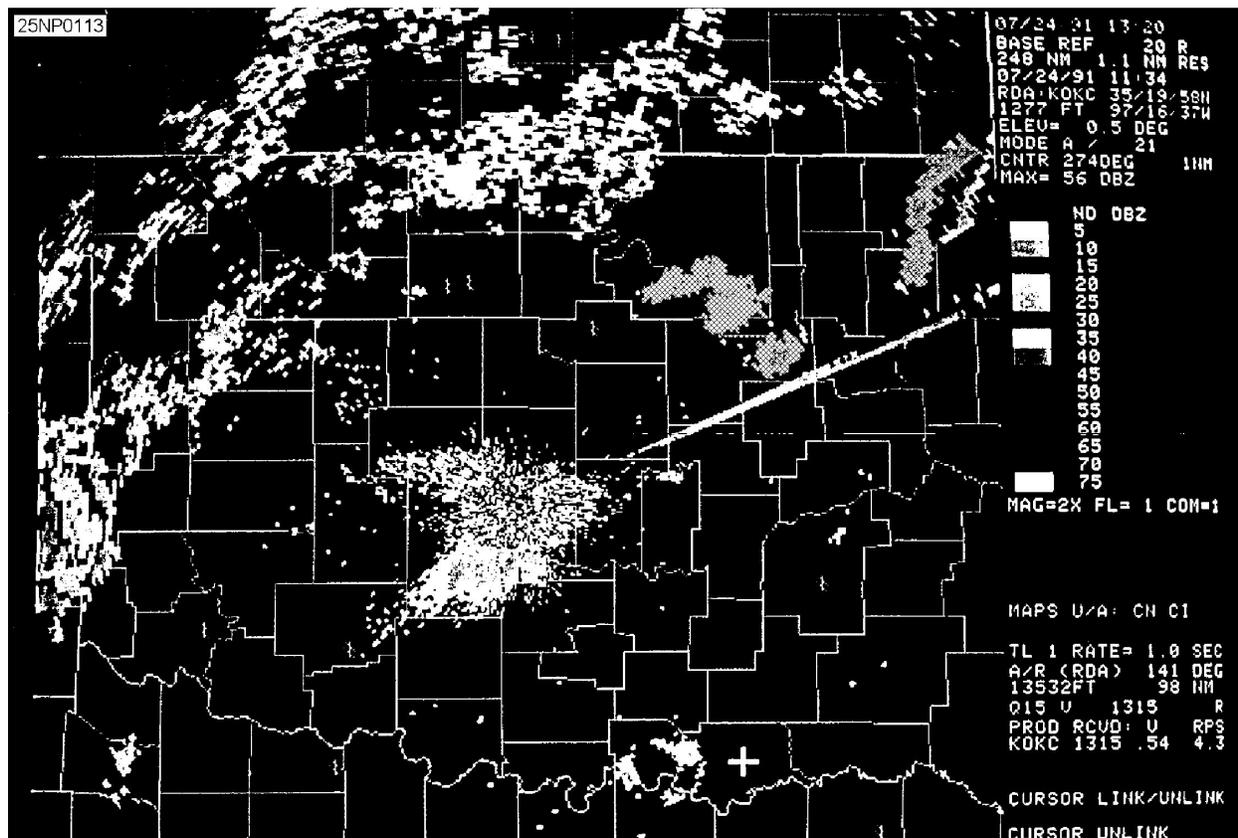


Figure 12-5.-Streaks of low reflectivity extending outward for two radials to the northeast of the radar caused by solar effects.

radar, a wide variety of weather features of great importance can be identified. It is beyond the scope of this manual to describe the interpretation of doppler velocity patterns. For a detailed explanation of the interpretation of doppler velocity patterns refer to the FMH-11 (part B).

MESOCYCLONE SIGNATURE DETECTION

Mesocyclones have been found to be precursors to many tornadoes. They generally have a core diameter of 1.5 to 5 nmi, maximum tangential velocities of 40 kts or greater, and time and height continuity. Previous doppler experiments have found that weak mesocyclone signatures generally result in severe thunderstorms. Stronger signatures generally produce tornadoes, especially if a tornadic vortex signature is present.

If an alert is received that a mesocyclone exists, or if there is no alert, but a mesocyclone is suspected, there are several products that can be used to confirm its presence. These products and how they might be used are discussed in the following paragraphs.

Recognition of a Mesocyclone Signature

A mesocyclone typically will develop at the midlevels of a tomadic storm and build down to lower levels as the storm matures. It may be possible to monitor development of storm rotation or a mesocyclone in the velocity field. The time lapse capability with continuous update may be useful in monitoring this development. In the velocity field, the feature will appear as two velocity peaks of opposite signs, separated azimuthally.

Interrogation of different elevation scans of the Mean Radial Velocity product (at 2000 ft intervals between 15,000 and 19,000 ft) can aid in determining the height continuity of a mesocyclone. The Quarter Screen mode can be useful for this purpose.

If correctly oriented through the storm, storm rotation (cyclonic or anticyclonic) or a well-developed mesocyclone may be evident in the Mean Radial Velocity Cross Section product. The cross section should be generated perpendicular to the mean flow. If a mesocyclone is not evident in the Mean Radial Velocity product or the Severe Weather Analysis Mean Radial Velocity product, the Storm Relative Mean Radial Velocity Map or Region products may display this feature (part C of the FMH-11).

Removing the storm motion may aid in the detection of a mesocyclone, but the mesocyclone circulation

pattern will exist in the velocity field even if the storm motion is not removed.

In the presence of a strong rotational signature, the Combined Moment product can be very useful in determining the existence of a mesocyclone. In such a case, rotational phenomena should be clearly evident due to the relative position of the arrows in a given area. In addition, high reflectivity core and high spectrum width values may be evident in the area.

In a tornadic supercell, doppler data have indicated that a separation of the mesocyclone core from the bounded weak echo region occurs prior to or during the collapse of the bounded weak echo region. With the development of severe weather possible at this stage, the separation of the mesocyclone core from the bounded weak echo region may be monitored by displaying an appropriate Reflectivity product on one graphic screen and a Storm Relative Mean Radial Velocity Map product on the other. A time lapse of the Mean Radial Velocity or Storm Relative Mean Radial Velocity Map product, magnified on the storm under investigation, may prove very useful in determining the separation of the mesocyclone core from the bounded weak echo region. If a mesocyclone is evident in the Mean Radial Velocity product, this separation may be monitored using the time lapse capability with continuous update for the Mean Radial Velocity and Reflectivity products.

Considerations

The mesocyclone algorithm provides the position of the feature reflected onto the lowest elevation angle in which the feature was detected. This is due to the fact that mesocyclones are often tilted and are, therefore, displaced at higher elevations. Mesocyclones may not always be identified by the algorithm for high reflectivity core storms, for storms that produce downbursts, or for weak tornadoes produced as a result of convergence boundaries. Since there is no tracking algorithm for mesocyclone features, time continuity must be established. In addition, the Storm Relative Mean Radial Velocity Map and Region products display the maximum velocity sampled over four 0.13 nmi range bins. The peak velocity values, and thus the peak shear associated with a mesocyclone feature, are more likely to be displayed on these products than on the Mean Radial Velocity product, which simply displays every fourth 0.13 nmi range bin at the same resolution.

Depending upon selection of storm motion removal, the existence of a mesocyclone may be more evident in the Storm Relative Mean Radial Velocity Map and

Region products than in the Mean Radial Velocity product.

Due to beam broadening and an average mesocyclone size of 2.7 nmi, the range of detection is generally limited to about 124 nmi. Mesocyclones formed in vertical wind shear may not be detected beyond 38 nmi due to the small size vorticity maximum found at low levels, and initial formation in a precipitation-free environment.

Multiple mesocyclone cores can form within a storm complex, but not in the same cell.

WIND SHEAR

A major hazard to aviation is the presence of low-level wind shear. Wind shear may result from a variety of phenomena such as synoptic fronts, boundaries associated with thunderstorms, terrain, and nocturnal inversions.

Recognition of Wind Shear

Wind shear will appear as a discontinuity in the doppler velocity field and is frequently associated with wide spectrum widths. Monitoring changes in the velocity field over time is likely the best approach to recognition of wind shear phenomena. Low-level wind shear can be detected close to the radar in the Mean Radial Velocity product. An indication of extreme shear will show up in a narrow band in the velocity field. This narrow band will likely not be identified in the Velocity Azimuth Display Wind Profile product. However, this product can be useful in keeping track of significant wind speed and direction changes within about 16 nmi of the radar and provide an indication of shear in the vertical.

Variations in the spectrum width field are related to the mean wind shear across the radar beam; therefore, a shear layer(s) will usually show up as an enhanced area in the Spectrum Width product. Values of 14 kts, or higher, are usually associated with significant wind shear or turbulence, or both.

Considerations

The Combined Shear product could be useful for the detection of areas affected by strong wind shear. The product, however, tends to be “noisy” and, in the absence of strong signatures, may be of little use. The product does not take vertical shear into account. For indications of shear in the vertical, the Mean Radial

Velocity or Spectrum Width Cross Section products may be useful.

CLOUD LAYERS

The sensitivity of the WSR-88D provides the user the capability of detecting cloud layers. This information has application to such things as aviation forecasting and forecasting the evolution of precipitation.

The WSR-88D can detect large ice crystals that are present in middle and high-level clouds. These reflectivities may range as high as plus 20 dBZ_e. The Velocity Azimuth Display algorithm will use doppler velocity measurements from middle and high level clouds to generate profiles into the middle atmosphere. These wind profiles allow the operator to monitor the movement of synoptic and smaller scale waves and troughs.

Recognition of Cloud Layers

With the high sensitivity of the WSR-88D, it is possible to obtain reflectivity estimates of elevated clouds, which generally reflect at levels between minus 12 to plus 5 dBZ_e.

The depth of cloud layers maybe inferred from two processes. A four-panel display of the Reflectivity product for successively higher elevation scans can provide information on the depth as well as the structure of a layer. The top of a cloud layer and its depth can also be inferred from a Reflectivity Cross Section product, depending on the distance from the radar and the viewing angle. However, resolution is better with the Reflectivity product than the Cross Section product since the cross section integrates returns from the surface to 70,000 ft.

The following is a technique that will allow the determination of the top, base, and depth of a cloud layer. Using the Reflectivity product for the elevation that intersects the cloud layer, place the cursor at the point where the base appears to be and get a readout on the screen of azimuth, range, elevation, and height. Then, place the cursor at the apparent top of the cloud layer and get the same information. The depth can be computed from the difference in heights. If the cloud base or top is not uniform, this technique will have to be repeated several times to get average heights and thicknesses. This will also help ensure that the true radar cloud top and base are being observed.

An increasing moisture source and gravity waves in the velocity field can also be detected. Gravity waves should coincide with the alternating increases and decreases in reflectivity. This may also be apparent in the Echo Tops product if the minimum reflectivity threshold of 18 dBZ_e is met.

Considerations

In the Clear Air mode, cloud detection maybe best using VCP-31 due to a better signal-to-noise ratio. If the minimum reflectivity threshold of 18 dBZ_e is met, the Echo Tops product can provide an indication of the top of a cloud layer. Layer Composite Reflectivity products may show returns at given layers, indicative of clouds. These products should be supported with the use of the Reflectivity product to determine the existence and extent of the cloud layers. Stratus clouds and fog will usually not be detected by the radar due to small cloud particle size.

The Velocity Azimuth Display Wind Profile product may be useful in determining moisture advection for development of cloud layers, depending on distance from the radar.

For further discussion of preconvective, convective, multicell and supercell development as well as severe storm identification, refer to part D of the FMH-11.

THE STRUCTURE OF LARGE-SCALE PRECIPITATING WEATHER SYSTEMS

The character of precipitation is largely controlled by vertical air motions. Radar observations of the aerial extent, and lifetime of precipitation systems are evidence of the physical processes at work in the atmosphere. Depending on the dominant mechanism responsible for the vertical air motion, precipitation is usually classified into one of these two types:

1. Stratiform – Widespread, continuous precipitation produced by large-scale ascent due to frontal or topographical lifting or large-scale horizontal air convergence caused by other means.

2. Convective – Localized, rapidly changing, showery precipitation produced by cumulus-scale convection in unstable air.

The distinction between stratiform and convective precipitation is not always clear in practice. Widespread precipitation, for example, is often accompanied by fine-scale structures, or embedded convective elements. In fact, precipitation systems generally are composed of a wide spectrum of scales and intensities. Nevertheless,

it is usually possible to classify precipitation patterns by their dominant scale.

Stratiform Rain or Snow

Stratiform precipitation is most often produced in nimbostratus clouds or dissipating cumulus clouds. Upward air motions are weak and the vertical structure of the reflectivity pattern is closely related to the precipitation patterns by their dominant scale.

The presence of stratiform precipitation facilitates wind measurements with the velocity azimuth display (VAD) to much higher altitudes than possible in clear air (part B of the FMH-11). The wind profiles observed during precipitation may be useful in determining the nature of fronts. A layer of warm air advection (veering of wind with height) is evident from the “S” pattern near the surface (at close slant ranges). Cold air advection (backing with height) is present at greater altitudes (far slant ranges). Generally, the reflectivity pattern depicts stratiform precipitation without prominent small-scale features.

On some occasions, mesoscale precipitation bands form within the stratiform precipitation area. The band is just ahead of and parallel to the wind shift line marking the location of the cold front. Other bands have different orientations with respect to cold fronts. Bands also occur in the vicinity of warm fronts and in precipitation areas away from frontal locations, particularly in the warm sector of a large-scale system.

Mesoscale Convective Systems

Some large-scale precipitating systems begin as combinations of a number of convective elements. The resulting system, although still feeding on unstable air, takes on a character much different from typical cumulus-scale convection. Regions of strong convection and heavy showers can become randomly distributed within a larger area of developing stratiform precipitation, or the strong convection can be limited to the large system's leading edge with the rest of the system primarily composed of stratiform rain. When organized in a linear fashion, the convective cells are typically distributed along a band about 20 km (11 nmi) wide and hundreds of kilometers long. The bands are usually related to low-level convergence and wind shear, but the Earth's topography also affects the structure of the rain areas. The characteristics of precipitation bands have been categorized, but it is not completely understood why precipitation has the strong

tendency to become organized into the characteristic scales and patterns that are observed.

Precipitation areas can be grouped into categories of size and lifetime. Observations show that synoptic areas that are larger than 29,000 nmi² have lifetimes of one day or longer; large mesoscale areas that range from 2,900 to 29,000 nmi² last several hours; small mesoscale areas that cover 54 to 216 nmi² last about an hour; and elements that are about 5.4 nmi² in size usually last no longer than half an hour. Although the smallest elements have the highest rain rates, the major contribution to the total rainfall over large areas comes from the small and large mesoscale features.

The Mesoscale Convective System (MCS) includes all precipitation systems 11 to 270 nmi wide that contain deep convection. Examples in middle-latitudes are large isolated thunderstorms, squall lines, Mesoscale Convective Complexes (MCCs), and rainbands. The aerial extent of these systems is generally too large to be covered by a single radar. Examinations of composite maps from a network of radars is required to capture the full extent of most MCSs.

Refer to part B of the FMH-11 for further discussion of mesoscale convective systems.

THE BRIGHT BAND

In stratiform precipitation where lower portions of the echo are at above freezing temperatures, a thin layer of relatively high reflectivity (bright band) is often observed just below the level of 0°C. As snowflakes descend into this layer, they begin to melt and stick together. The radar reflectivity of the large wet snowflakes is higher, principally because of their large size and because the dielectric constant of water exceeds that of ice by a factor of five. Descending further below the bright band, the snowflakes become more compact, break up, and become raindrops. The raindrops fall faster than snowflakes so their concentration in space is diminished. This decrease in size and number density of hydrometers accounts for the lower reflectivity just below the bright band.

The last section of this chapter will deal with the Next Generation Weather Radar (NEXRAD) program.

WEATHER SURVEILLANCE RADAR 1988-DOPPLER (WSR-88D)

LEARNING OBJECTIVES: Recognize criteria for the three groups of alert thresholds. Understand data access procedures for the WSR-88D. Be familiar with the various user functions, as well as archiving procedures.

The following discussion will deal with weather radar alert areas and thresholds, the editing and sending of data, and the various user functions of the WSR-88D.

ALERT AREAS AND THRESHOLDS

Radar product generators (RPGs) can automatically issue alerts upon detection of user-specified meteorological phenomena. Automated alerts relieve the operator from constantly monitoring the Principle User Processor (PUP) for significant meteorological phenomena and allow automatic generation of paired products when a particular phenomena occurs. The forecaster determines various thresholds for meteorological phenomena. The PUP operator then selects which phenomena and associated threshold values to use, based upon local watch/warning criteria.

Alert Thresholds

Alert thresholds allow several individual PUPs to select agency unique alert threshold criteria. Alert threshold criteria are broken down into three groups preset at the Unit Control Positions (UCPs):

1. Grid Group- Alert areas based on geographical points or grid boxes that occur within a user-defined alert area. The first grid box within a defined alert area that meets or exceeds a phenomena threshold triggers the alert.

2. Volume Group – These are alerts occurring within a user-defined area requiring completion of a volume scan. Detection is based on meteorological phenomena meeting or exceeding an assigned threshold or algorithm output. If there is more than one storm exceeding a category threshold in the same alert area, the alert triggers on the stronger storm.

3. Forecast Group – Alert categories with this group are storm based only and are triggered when phenomena is located in or forecast to enter an active alert area. This group is storm oriented (based on the

movement of a storm associated with the phenomena) and requires a complete volume scan..

To enter the alert you first determine which of the three alert thresholds groups correspond to the geographically based alert area(s) you are considering.

DATA ACCESS

The following section will deal with the editing of products, annotations, maps, and alert areas.

Edit/Send Radar Coded Messages (RCM)

In general, there are two types of RCM products sent out by the RPG. One type is the operational RCM, which is called the post-edit alphanumeric RCM. This RCM is available to all PUPS and is displayed only on the alphanumeric terminal via the Display menu. It is requested from the RPG either via the Display menu or the RPS list. This is an alphanumeric-only product that may have already undergone editing at the PUP and been returned to the RPG for distribution.

The other type of RCM is the pre-edit version to be edited by one designated PUP per NEXRAD unit. There is adaption data at the PUP which specifies whether the PUP is designated for editing of the pre-edit version of the RCM. This is called the Edit RCM flag. It is located on the RCM Parameter edit screen which is accessible from the Extended Adaption Data menu, which, itself, is accessible via password from the Adaption Data menu. The RPG also has adaption data which specifies which PUP in the NEXRAD unit is designated to receive, edit, and return the pre-edit version of RCM. This adaption data must match the PUP adaption data as to who is to do the RCM editing.

Generation/Distribution of Free Text Messages

Any PUP can generate free text messages (FTM) and distribute them to other users. Only RPG OP can distribute messages to the RPG. While the message is being generated, it is called a PUP text message (PTM). This generated PTM is known as a FTM by the RPG after it is distributed. When messages are received from any RPG, they are considered FTMs.

Edit/Send Product Annotations (Graphic)

Product annotations for graphic products are overlays. These annotations can be selected for display by default whenever the annotated product is displayed using the Overlay Associations edit screen. A PUP or

RPG OP can annotate any graphic product Only an RPG OP can send a product's annotation to the RPG. When an annotation is generated for a particular product, the annotations are associated with only that one specific version of the product. After generation via the graphic screen, a graphic product's annotation can be distributed to the RPG by using an alphanumeric terminal command listed on the Gen and Distribute Products menu. Once the annotations are sent to the RPG, the RPG may distribute the annotated product to the PUPS, and the "Other Users" on its distribution list.

Edit Background Maps

To enable the editing of background maps, the System Option Command (P)ASSWORD, (E)DIT MAPS, (E)NABLE must have been selected previously (since the last PUP restart).

There are two versions of both the low- and high-detail maps; the original (which cannot be altered) and the modified (the latest edited version).

Edit Alert Areas and Alert Categories

There are two separate alert areas that are definable by each PUP for the NEXRAD unit coverage area via the graphic tablet and on one of the graphic screens. The other graphic screen will operate normally during this procedure.

Alert areas 1 and 2 are separate overlays displayable with products. When a product is displayed with an alert area overlay, only the included alert boxes are displayed.

Each alert area has its own set of up to 10 alert categories associated with it. These categories describe the types of alerts and the threshold level numbers that trigger alerts.

Section 12 of the technical manual, *Operation Instructions Principal User Processor (PUP) Group/Doppler Meteorological Radar* contains detailed guidance on editing/sending of RCMs, generation/distribution of FTMs, editing/sending product annotations (graphic), editing background maps, and editing of alert areas and alert categories.

USER FUNCTION OPERATIONS

User function operations provides a way for the operator to predefine up to 31 normal PUP operator selections into a single user function. Upon subsequent selection of a user function for execution, each of its predefine selections is performed in sequence, as

though they had been individually selected by the operator. This feature is particularly useful for function sequences that are time consuming and frequently performed.

User functions may be linked to other user functions at any sequence, or into a loop, so that they may run continuously until canceled. Time delays may be built into user functions to allow time for correct execution, operator observations, or prescheduled sequences.

Discussion of all PUP user functions are beyond the scope of this text. For a detailed discussion of user functions, time delays within user functions, end user function definitions, examining/editing user functions, executing user functions, and the canceling of user functions, refer to section 11 of the technical manual, *Operation Instructions Principal User Processor (PUP) Group/Doppler Meteorological Radar*.

STATUS AND ALERTS

There are two types of status and alerts: those that are selected and those that are automatically displayed.

The 11 operator selected status options are as follows:

1. NEXRAD Unit Status (operator selected and automatic display)
2. Types of Products Available in PUP Data Base
3. Products in PUP Data Base (by ID number)
4. Earliest time in PUP Data Base
5. RPG Products Available
6. Monitor Performance Display
7. System Status
8. Status of Archive
9. Communications Line Status
10. Status of Background Maps
11. Alert Status Display

All of these may be selected via the alphanumeric (S)TATUS or (M)ONITOR PERFORMANCE commands. The NEXRAD unit status is also available as a graphic display, selected from the graphic tablet.

Discussion of PUP status and alert functions are beyond the scope of this text. For a detailed discussion of status and alert functions, refer to section 8 of the technical manual, *Operation Instructions Principal*

User Processor (PUP) Group/Doppler Meteorological Radar.

ARCHIVING DATA

All archive functions may be selected via the alphanumeric (A)RCHIVE menu. The archive functions are used to record to optical disk and recall from optical disk: products, received background maps, and status message data. Only one non-auto archive function may be performed at a time per archive device. Monitor performance data is recorded onto a streamer tape rather than an optical disk.

PUP archived optical disks or RPG archived optical disks may be used at any PUP location. However, at a PUP or RPG, created optical disks can only be read, not written to. If archived products are to be read in by another PUP associated with a different RPG, it is possible to archive background maps with them. The background maps must be requested from the RPG over the dial-up communications line or read in from an optical disk in order to be able to archive them. Optionally, the other PUP may have the necessary set of maps prestored on optical disk. When reading an archive optical disk with products from another RPG, you must read the correct set of background maps off this or another optical disk before the products can be displayed with maps. Maps for the associated RPG can be read from optical disk into the associated background map file. Additionally, maps from up to three non-associated RPGs can be read from optical disk and be stored in auxiliary map files where they remain until they are replaced by retrieval of a selected map set from optical disk to a specified auxiliary map file.

Optical disks used in the Training mode are created using the write archive functions. If an optical disk is to be used for training, and the training is to be performed at a different PUP site than where the optical disk was made, follow the instructions in the previous paragraph on using optical disks at other locations.

There are two types of archive devices associated with a PUP system, optical disk and streamer tape. The optical disk is the main archive device and is used for writing to and retrieval from optical disk, background maps (received from an RPG over a dial-up line), status messages, and associated/auxiliary map sets. The streamer tape device is used only for the archive of monitor performance file data.

Discussion of archiving optical disk and tape usage is beyond the scope of this text. For a detailed discussion of archiving optical disk and tape usage, refer

to section 10 of the technical manual, *Operation Instructions Principal User Processor (PUP) Group/Doppler Meteorological Radar*.

SUMMARY

In this chapter, we first discussed nondoppler radar and the effects of wavelength and frequency on radar performance. Next we looked at wavelengths for weather and cloud detection radars followed by an examination of radar beam characteristics. A discussion of the development of Doppler radar was then presented, followed by an overview of the system's characteristics and many benefits. Some problems associated with

Doppler radar were also discussed. The last section of this chapter dealt with principles of the Weather Surveillance Radar (WSR-88D), including alert areas and thresholds, data access, user functions, status and alerts, and the archiving of data.

The practical training publications, *The WSR-88D System Concepts*, KWXN-1003, and *WSR-88D Products*, KWXN-1004, produced by the United States Air Force Training School, Keesler Air Force Base, Mississippi, offer additional guidance and technical reference for the WSR-88D system, concepts, and products.

