Weather Radar
The NEXRAD WSR–88D

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Introduction

- When did Weather Radar start?
  - First discovered near the end of WWII
  - Preliminary Research in the U.S. throughout the 1950’s and 1960’s
  - CPS–9 (3 cm) radar → WSR–57 → WSR–88D

- Where are we now?
  - NEXRAD, WSR–88D Radar Network used by the NWS
  - Planning for the next radar network?
The Physics of Weather Radar

- As EM wave propagate through the atmosphere, they interact with hydrometeors
  - Rayleigh Scattering and Absorption

- Radar emits pulsed EM energy at a particular pulse repetition frequency (PRF)

- Radar’s receiver intercepts back-scattered energy and measures
  - Amount of transmitted power that is returned
  - Frequency shift in return echo
  - Transit time
Beam Width is near 1°

Pulse time length (pulsewidth): 1.57 µs (short pulse) and 4.5 µs (long pulse)

Pulse Repetition Frequency

Display of radar volume coverage. Notice the problem of overshooting.
Reflectivity

- Ratio of transmitted power from antenna to the returned power at the receiver. Reflectivity is measured in decibels.

\[ L_{dB} = 10 \log_{10} \left( \frac{P_1}{P_0} \right) \]

- Reflectivity values allow Meteorologists to estimate rainfall rates and precipitation types.

- In the radar’s precipitation mode, reflectivity values range from 5 to 75 dB. Light rainfall occurs near 20 dB and heavy rainfall near 55+ dB.

The WSR–88D has an average transmitted power of 1.56 kW.
Radar Equation

\[ P_r = \left[ P_t \frac{G^2 \lambda^2 \sigma^0}{(4\pi)^3 R^4} \right] \propto \frac{\sigma^0}{R^4} \]

\( P(r) = \) returned power and \( P(t) = \) transmitted power

\( G = \) antenna gain and is 45.8 dB for the WSR–88D

\( \lambda = \) transmitted radar pulse wavelength and is 10 cm for the WSR–88D

\( \sigma^\circ = \) cross-section of individual hydrometeors (summation includes all scatterers)

\( R = \) distance from radar to target hydrometeor
The movement of radar targets produces a return signal shifted in frequency \( f(D) \), referred to as Doppler shift.

\[
f(D) = - \frac{2V}{\lambda}\]

- The frequency shift will be positive if the hydrometeors are moving toward the radar (negative \( V \)) and negative if they are moving away (positive \( V \)).
  - \( V \) is the radial velocity either towards or away from the radar
  - \( \lambda \) is the transmitted wavelength from the radar, which is 10 cm for WSR-88D

Therefore, for a radial velocity of 20 m/s toward the radar, the corresponding Doppler shift would be an increase of 400 Hz.
WSR–88D Radar System

- Has an observation range of 460 km for reflectivity and 230 km for velocity.

- The main system components include a transmitter, an antenna, a receiver, and a signal processor.

- The transmitter has a frequency range of 2.7–3.0 GHz (~10 cm) and has a peak power output of 500 kW into the antenna.

- The antenna is a center-fed, parabolic dish that sends out the EM wave pulse.
  - Operates in the S-band (10 cm wavelength)
  - Beamwidth of 0.96° at 2.7 GHz and 0.88° at 3.0 GHz
  - Gain of 45.8 dB at 2.85 GHz (midband)
  - Linear horizontal polarization
WSR–88D Radar System Cont’d

- **Antenna Cont’d**
  - Covers a full 360° azimuth and has an angular elevation coverage from –1° to +20° (operational limit)
  - Rotation rate of 30° per second

- The receiver collects the back-scattered EM energy, amplifies it, and then converts it into a low frequency signal that is sent to the signal processor. This low frequency signal stores information about the properties of the reflecting hydrometeors.
  - Has a maximum range of 95 dB

- The signal processor derives three main parameters
  - Reflectivity
  - Mean Radial Velocity
  - Doppler Spectral Width
Currently there are 9 different VCP’s used by the NWS
  ◦ Two of these scans operate in Clear Air Mode (increased sensitivity) and the other seven are used in Precipitation Mode.

Clear Air Mode utilizes VCP’s 31 and 32
  ◦ It has a scan time of 10 minutes and operates at 5 different elevation angles (0.5°, 1.5°, 2.5°, 3.5°, 4.5°).
  ◦ Slow rotation allows for increased sensitivity. Used for detecting wind velocities when there are few radar targets, subtle atmospheric boundaries, and wintry precipitation.

Precipitation Mode utilizes VCP’s 11, 12, 21, 121, 211, 212, and 221.
  ◦ VCP’s 11, 12, 211, and 212 are used during convective precipitation.
  ◦ VCP’s 21 and 221 are used during shallow precipitation
  ◦ VCP 121 is used when better velocity data is needed
Radar Scans Cont’d

- **VCP’s 11 and 211**
  - Has a scan time of 5 minutes and operates at 14 elevation angles (0.5°, 1.5°, 2.4°, 3.4°, 4.3°, 5.3°, 6.2°, 7.5°, 8.7°, 10°, 12°, 14°, 16.7°, 19.5°).
  - Used when precipitation is close to the radar. Has the best overall volume coverage.

- **VCP’s 12 and 212**
  - Has a scan time of 4.5 minutes and operates at 14 elevation angles (0.5°, 0.9°, 1.3°, 1.8°, 2.4°, 3.1°, 4.0°, 5.1°, 6.4°, 8°, 10°, 12.5°, 15.6°, 19.5°).
  - Used for convection at long ranges and widespread severe convective events.
  - Low elevation angles allow radar to better sample lower levels of severe storms.

- **VCP’s 21 and 221**
  - Has a scan time of 5 minutes and operates at 9 different elevation angles (0.5°, 1.5°, 2.4°, 3.4°, 4.3°, 6.0°, 9.9°, 14.6°, 19.5°).
  - Shallow precipitation and widespread rainfall with embedded convection.
Radar Volume Coverage Problem

The angular elevation of VCP scans is limited to a range between $0.5^\circ$ and $19.5^\circ$ mainly to provide acceptable scan update rates.

The result is a “cone of silence” above the radar and gaps in vertical coverage due to coarse vertical beam spacing.
Ground Clutter vs. Attenuation

- The use of long wavelengths (10 cm or more) eliminates attenuation errors caused by precipitation.

- If antenna size remains constant, the beam spreading at 10 cm is twice as large as at 5 cm, resulting in more ground clutter and reduced spatial resolution at long ranges.

- A 3 cm radar would reduce ground clutter, but would suffer from large attenuation problems.

- Solution? 10 cm. Why? The beam spread cannot be overcome. However, ground clutter can be suppressed by 30, 40, and 50 dB by using filters.
Range Folding

- Transit time of the return echo is fixed by the period between successive radar pulses. Any echo which returns after the transmission of the next pulse is referred to as a “second-time-around” echo. This produces a misleading range that is closer to the radar.

- Maximum unambiguous range, $R_a$, is determined by the Pulse Repetition Frequency (PRF) of the radar.
  - WSR-88D: 322–422 Hz (long pulse) and 322–1282 Hz (short pulse)

- $R_a = c \div (2 \times \text{PRF})$

- WSR-88D: maximum (322 Hz) $R_a$ of 466 km and a minimum (1282 Hz) $R_a$ of 117 km
Velocity Folding

- The maximum Doppler shift frequency, $f_a$, which can be detected unambiguously is related to the PRF as well.
  
  $f_a = \text{PRF} \div 2$

- Maximum Doppler radial velocity, $V_a$, Nyquist Velocity, dependent on PRF.
  
  $V_a = \pm (\text{PRF} \times \lambda) \div 4$

- Velocities outside the Nyquist interval of $2V_a$ are referred to as folded.

- WSR–88D: Max $V_a = 32 \text{ m/s (1282 Hz)}$, Min $V_a = 8 \text{ m/s (322 Hz)}$
There is an inherent, inverse relationship between the range and velocity ambiguities.

\[ V_a = (\lambda c) \div (8R_a) \]
Super-Resolution

- Current Legacy-resolution base data on a 1 km-by-1 deg polar grid
  - Improve base data resolution on a 250m-by-1 deg polar grid and reduce size of corresponding resolution volumes.

- Super-resolution requires an effective antenna beamwidth that is about 25% narrower than the one used for legacy-resolution data
  - Better resolution, but reduction in quality of base data.

- Must maintain volume update times, max unambiguous range and velocity, compatibility with clutter filtering, and other signal processing functions.

- Best solution? Selective data windowing
  - Collect overlapping 1 deg radials every 0.5 degrees.

- Importance?
Radar Polarization

- Use of linear horizontal and linear vertical polarization makes significant improvements to data quality issues.

- Naturally suppresses second trip echoes by 15–20 dB.

- Back-scatter between both polarizations has a high degree of coherency (>0.98 in rain). This can be used to filter out contamination from noise and false echoes.

- Differential Polarization Variables used to identify different types of precipitation (boundaries) and particle size.
  - Improved accuracy in estimating rainfall rates and rainfall totals.
Questions???