# Weather Radar

The NEXRAD WSR-88D

April 5, 2010
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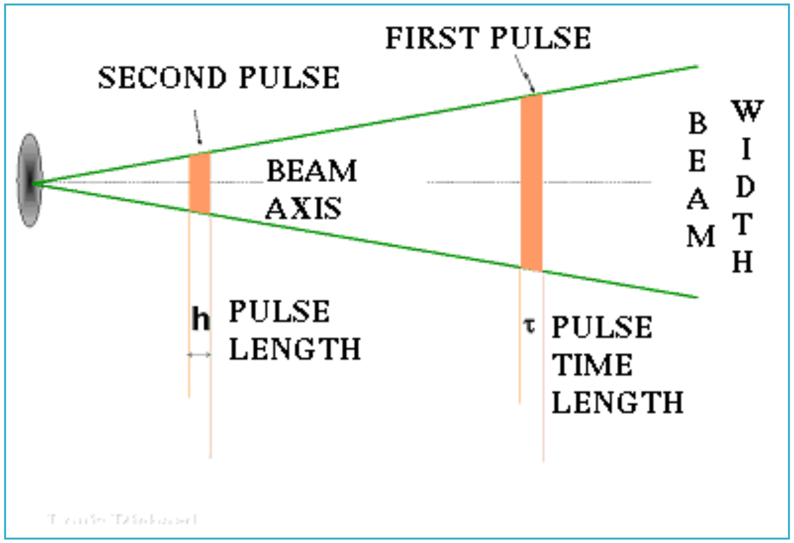
# Introduction

- 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

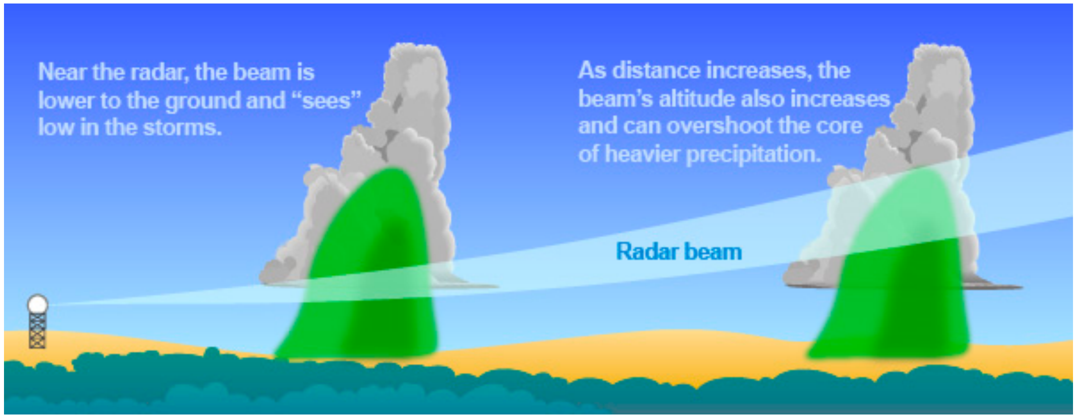



Beam Width is near 1°

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.

$$L_{\mathrm{dB}} = 10 \log_{10} \left( \frac{P_1}{P_0} \right)$$

P(0) = transmitted power , P(1) = returned power

The WSR-88D has an average transmitted power of 1.56 kW.

- 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.

# 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

λ = transmitted radar pulse wavelength and is 10 cm for the WSR-88D

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

R = distance from radar to target hydrometeor

# Doppler Effect and Wind Velocities

- The movement of radar targets produces a return signal shifted in frequency f(D), referred to as Doppler shift.

- $f(D) = -2V \div \lambda$
  - 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

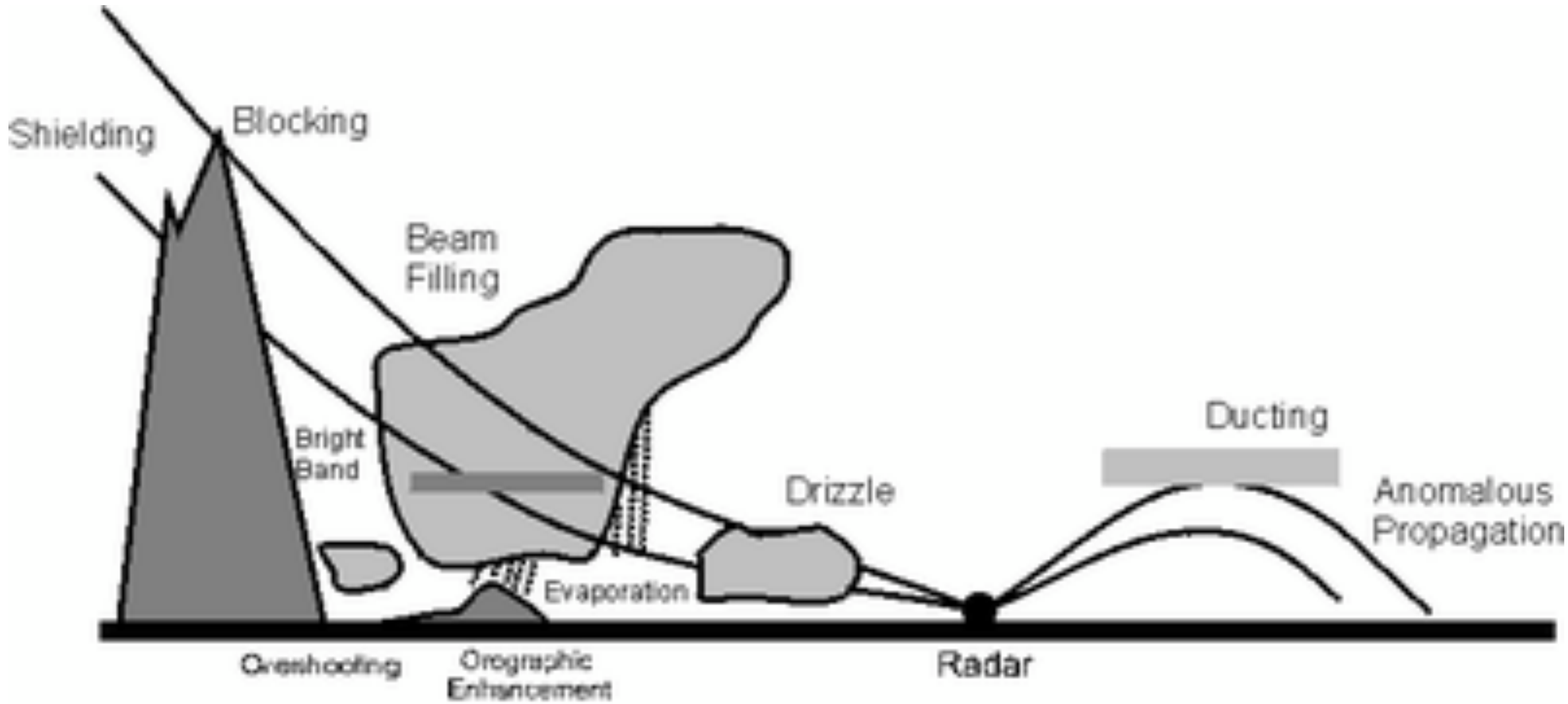
- Has an observation range of 460 km for reflectivity and 230 km for velocity.
- The main system components include a transmitter, an antenna, a receiver, and a signal processor.
- The transmitter has a frequency range of 2.7-3.0 GHz (~ 10 cm) and has a peak power output of 500 kW into the antenna.
- 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


Shielding
Blocking
Beam
Filling
Bright
Band
Drizzle
Ducting
Anomalous
Propagation
Evaporation
Overshooting
Orographic
Enhancement
Radar

# Radar Scans: Volume Coverage Patterns

- 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

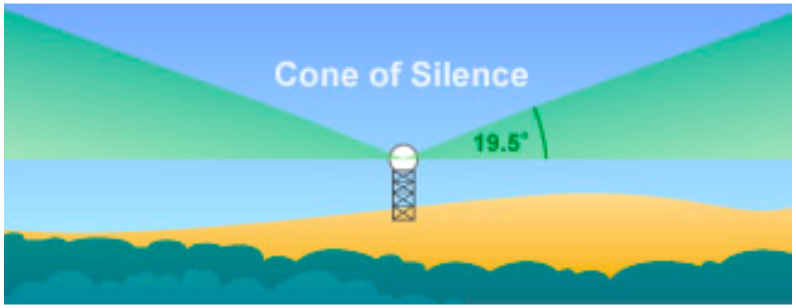
# Radar Scans Cont'd

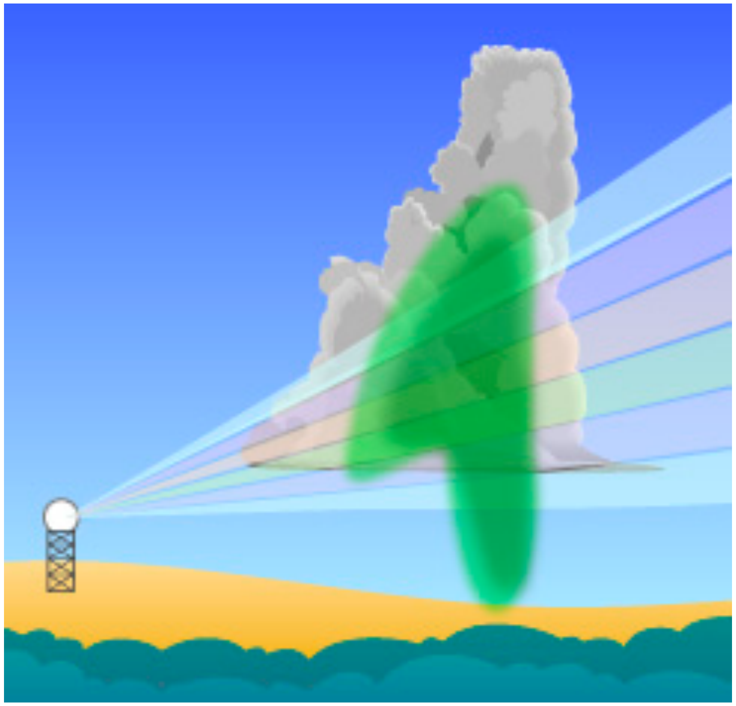
- VCP's 11 and 211
  - Has a scan time of 5 minutes and operates at 14 elevation angles (0.5°, 1.5°, 2.4°, 3.4°, 4.3°, 5.3°, 6.2°, 7.5°, 8.7°, 10°, 12°, 14°, 16.7°, 19.5°).
  - Used when precipitation is close to the radar. Has the best overall volume coverage.
- VCP's 12 and 212
  - Has a scan time 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° and 19.5° 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)

- $R_a = c \div (2*PRF)$

- 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.

- $f_a = PRF \div 2$

- Maximum Doppler radial velocity, $V_a$ , Nyquist Velocity, dependent on PRF.

- $V_a = \pm (PRF * \lambda) \div 4$

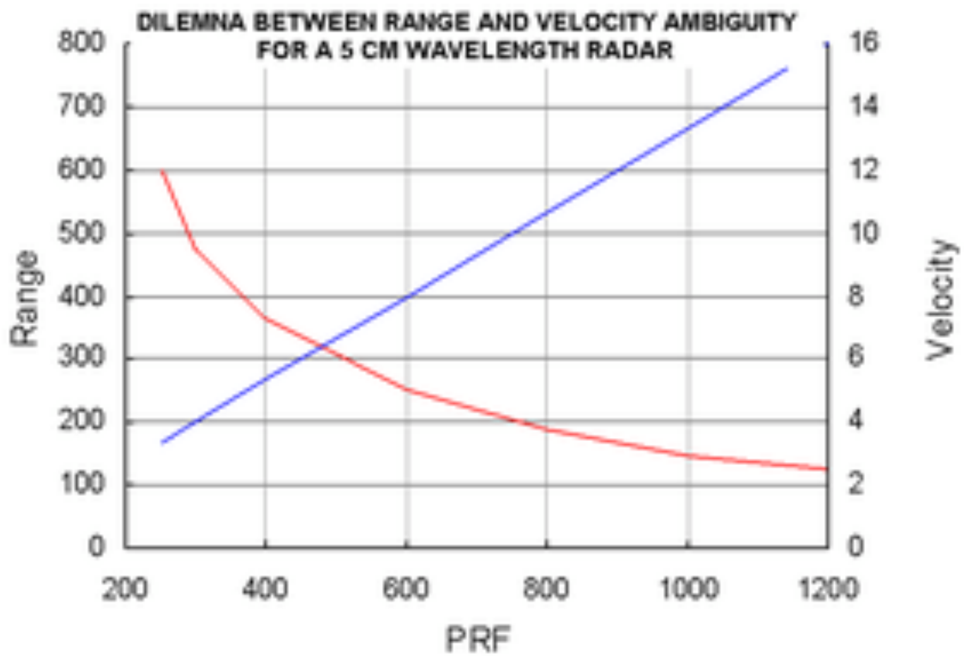
- Velocities outside the Nyquist interval of $2V_a$ are referred to as folded.

- WSR-88D: Max $V_a = 32$ m/s (1282 Hz) , Min $V_a = 8$ m/s (322 Hz)

# Range/Velocity Relationship

There is an inherent, inverse relationship between the range and velocity ambiguities.

$V_a = (\lambda * c) \div (8 * R_a)$



# Super-Resolution

- Current Legacy-resolution base data on a 1km-by-1deg polar grid
  - Improve base data resolution on a 250m-by-1deg 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???