Tornado Detection Capabilities and Limitations*

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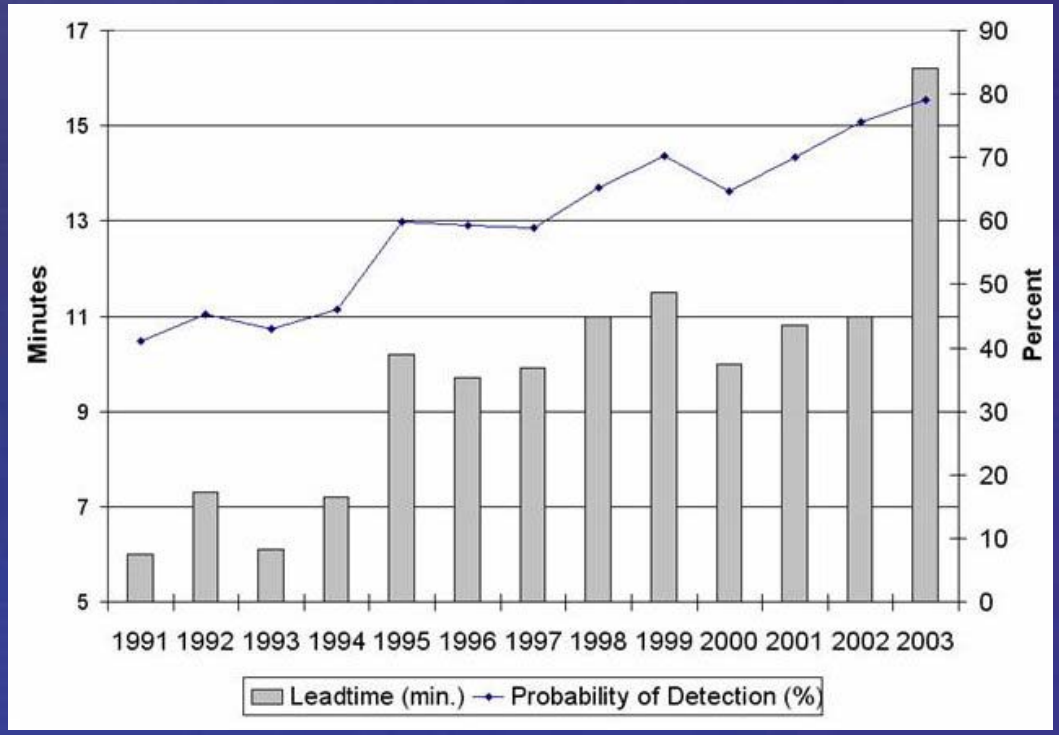
*This briefing covers the major limitations common to all Doppler weather radars

Overview

- Background
- Doppler Radar Limitations
- Examples
- Other Tornado Detection Capabilities
- Prepare & React Appropriately
- Bottom Line
- References

National Average Lead Times & Probability of Detection

- WSR-88D network installed early 1990s
  - Doppler technology
  - Greater sensitivity
  - Improved volume scanning & computer processing
- Training advancements
  - Improved local training on Doppler radars & storm structure/evolution
  - Four-week course in residence

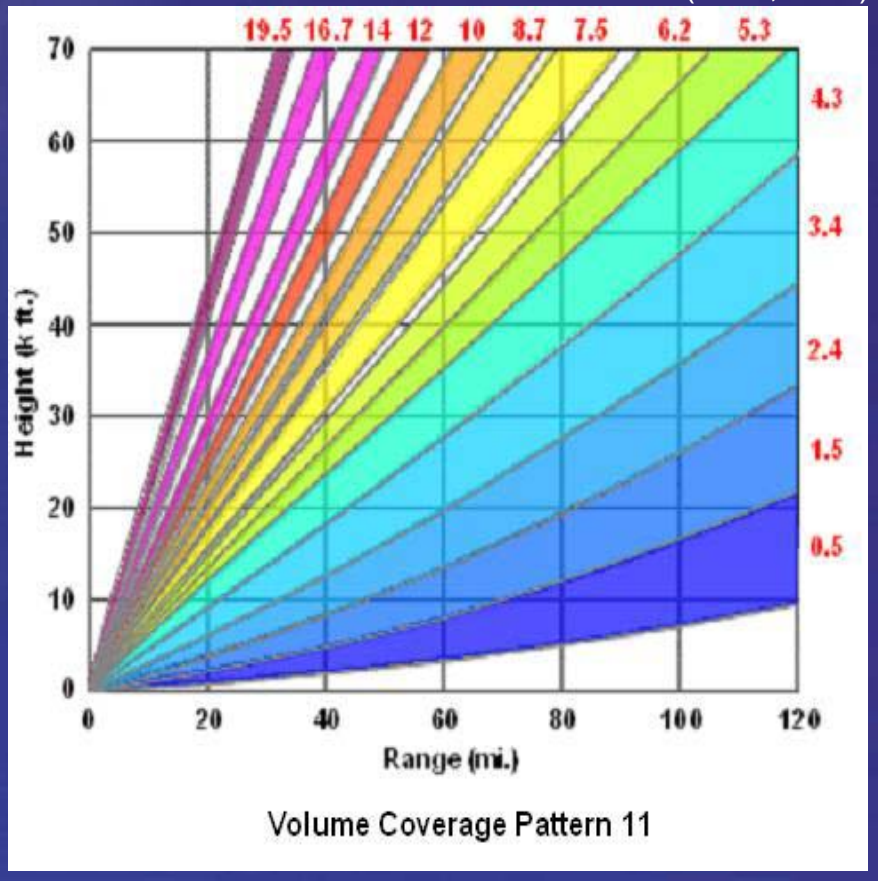


Significant improvement in the last 10 years

Weather Radar Basics

- Doppler radars obtain data by:
  - Transmitting electromagnetic energy in brief pulses at specific angles
  - Energy returns from precipitation, cloud droplets, mountains, etc.
  - Doppler measures strength of return and the component of object motion toward and away from the radar

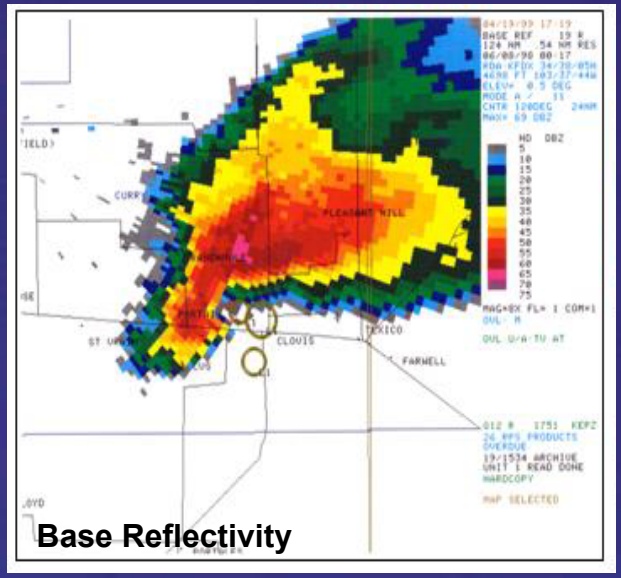
(NWS, 2003)

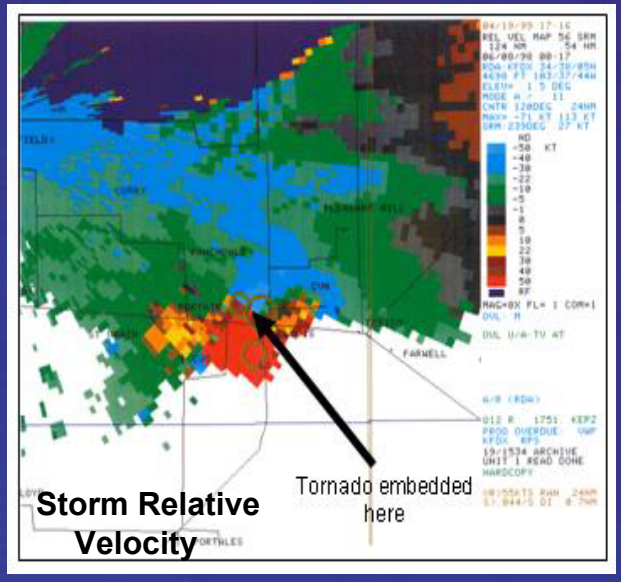


Angles used by the WSR-88D

Weather Radar Basics

- Technically, radar shows larger shear zones, not the actual tornado
- Base reflectivity shows hook echo due to precipitation thrown out of/around rotating updraft core
- Storm relative velocity
  - Speed of wind toward (cool colors) and away (warm colors) from radar
  - The stronger, tighter, & deeper (more than one elevation angle) the rotation, the greater the likelihood a tornado is present
  - Time continuity is also important (more than one volume scan)





Supercell Thunderstorm

Supercell Tornadoes

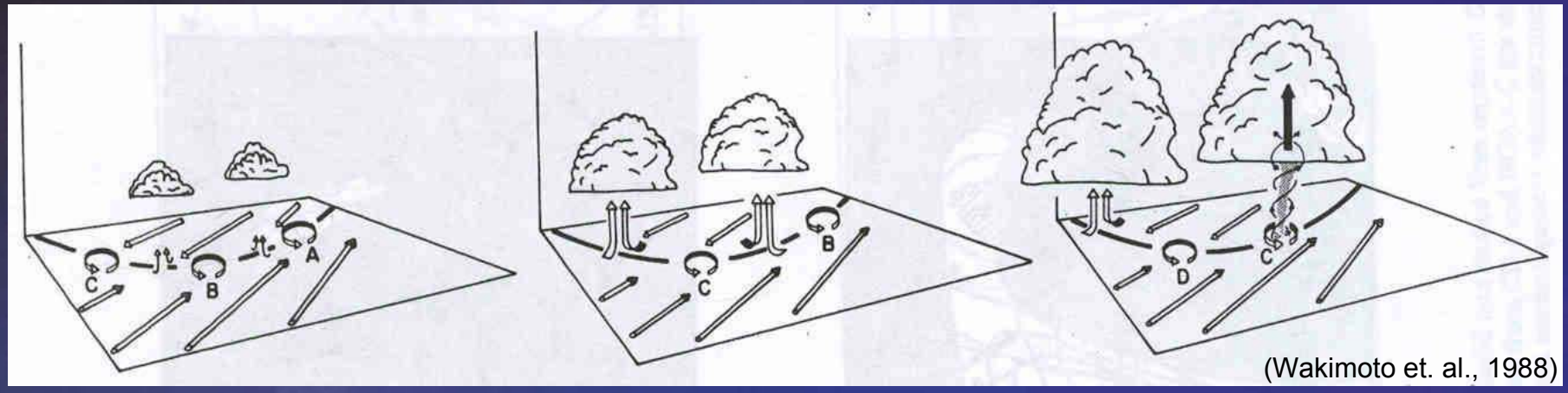
- Occur during a supercell thunderstorm's mature stage
- Preceded by strong mid-level [15-25,000 feet (ft)] rotation (where radars have a better view)
- In NM, occur mostly along eastern border with TX during May, June, and July
- WSR-88Ds earned excellent reputation with these
- Supercell thunderstorms produce the majority of NM's confirmed tornadoes each year, but not all of them

Non-Supercell Tornadoes
A.K.A. landspout, gustnado, or spin-up

- Probably more frequent in Western U.S.
- Often unseen or unreported
- Form early in thunderstorm lifecycle, sometimes before lightning strikes
- May form rapidly near surface then extend upward
- May form simultaneously at low and mid levels
- Shallow and/or narrow (rarely exceed F-2 intensity)
- Larger atmospheric circulations usually cause these to dissipate in only a few minutes

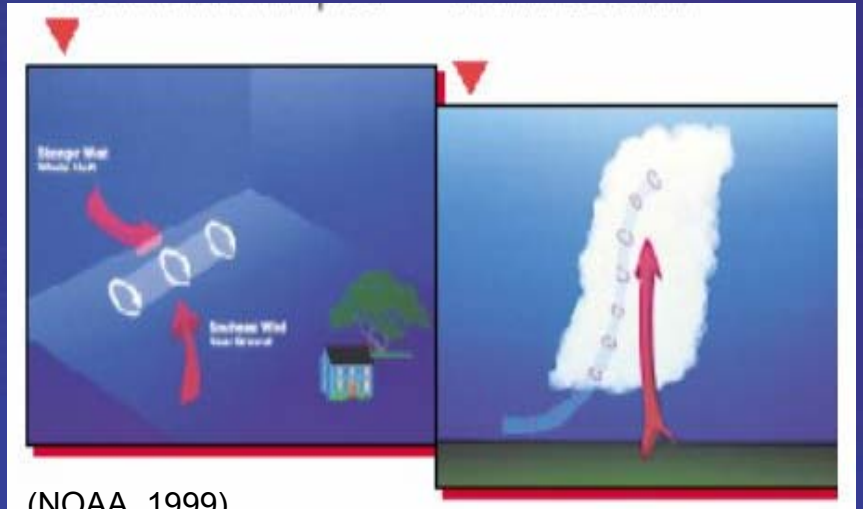
Spin-Up Tornado Formation

- Cause 1: small and shallow circulations along surface convergence zone, stretched upward by strong updraft



(Wakimoto et. al., 1988)

- Cause 2: horizontal vorticity roll downwind of mountains, tilted to vertical when crossed by a strong updraft



(NOAA, 1999)

Doppler Radar Limitations

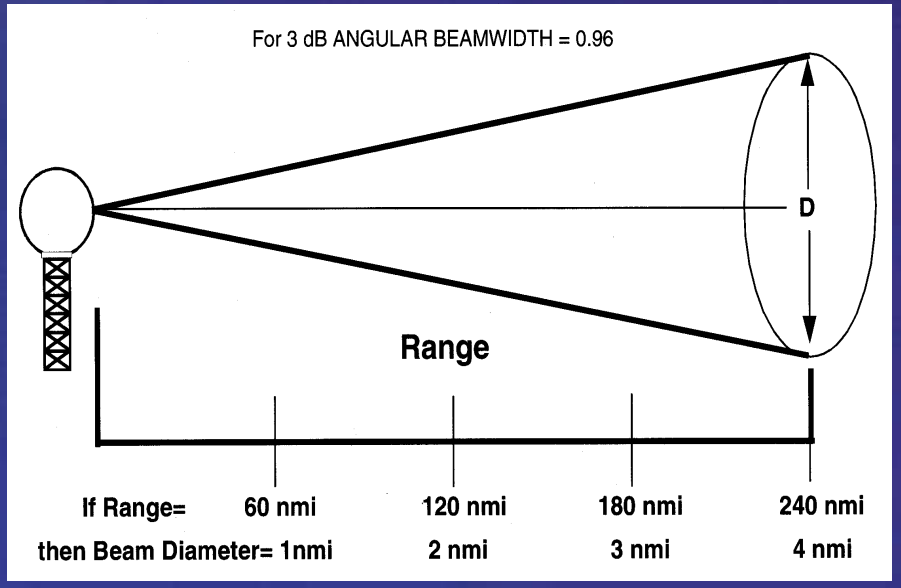
All Doppler radars have difficulty detecting circulations...

- Too far from radar
  - Beam broadening
  - Overshooting
- Too close to radar
- Blocked from radar view
- Dissipate too quickly

Limitation 1: Too Far From the Radar

- Beam grows too large compared to size of the circulation
  - Large # of slow wind returns outside tornado outweigh small # of fast wind returns within
  - Averaged away/toward velocities too small to represent a threat
- Effective detection range depends on circulation size; effective detection range ≤ 63 statute miles (sm) for the WSR-88D (WSR-88D Operational Support Facility, 1997)
- For very small tornadoes, or radars with larger beam diameters, the range shrinks even shorter

Cause 1: Beam Broadening

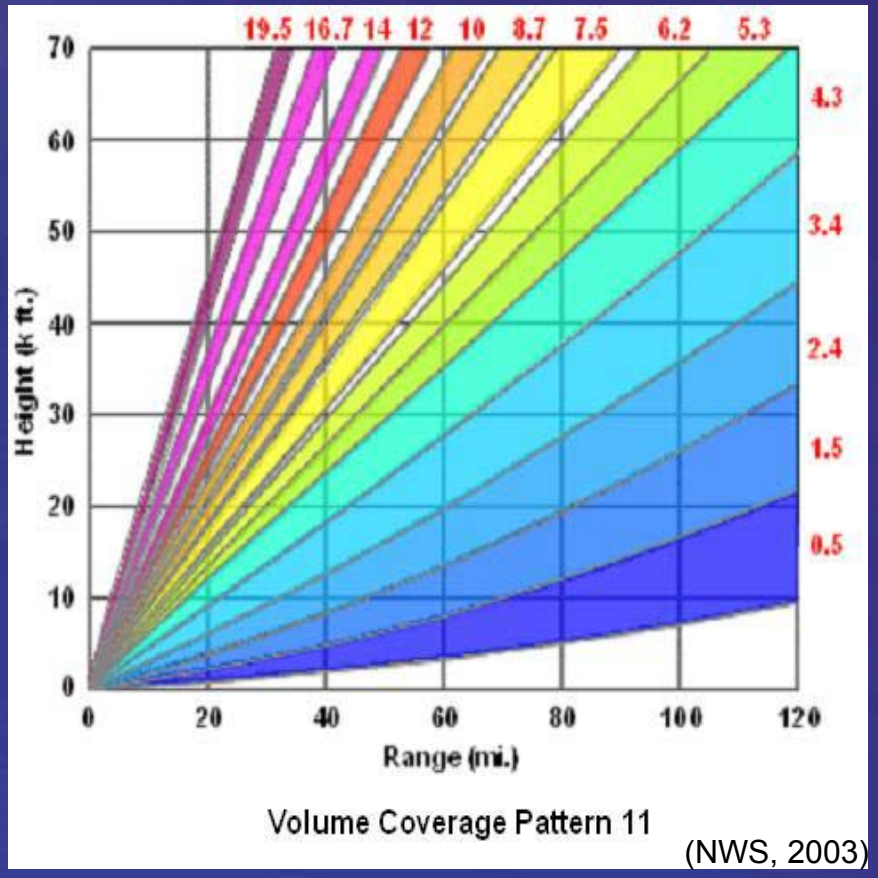


(WSR-88D Operational Support Facility, 1998)

Limitation 1: Too Far From the Radar

- Beams rise above low-level circulations because beams travel away from the radar at an angle
- Many NM spin-ups only extend up to about 3,000 ft
- Overshot by center of lowest beam at 40 sm from radar
- Overshot by center of second lowest beam at 29 sm, so spin-ups may only be detectable out to 29 sm (WSR-88D Operational Support Facility, 1997)
- New scan strategy coming
  - Adds 3 new angles at lowest levels
  - Better vertical display of low-level storm structure

Cause 2: Overshooting



(NWS, 2003)

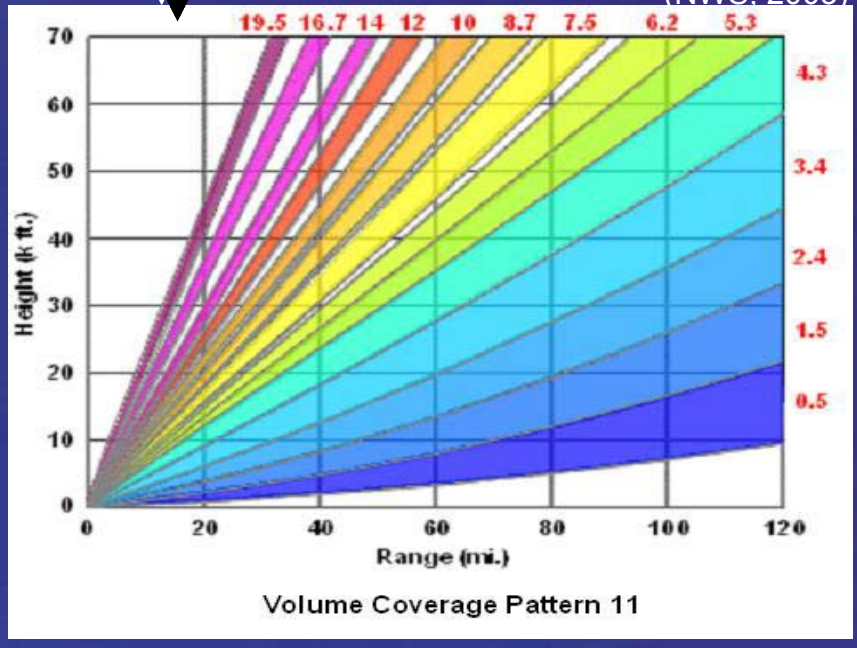
Angles used by the WSR-88D

Limitation 2: Too Close to the Radar

- Doppler radars don't sample the atmosphere directly above them
- Radars cannot detect circulations that move into the cone of silence
- WSR-88D's cone prevents detection of mid-level circulations within about 11.5 sm of the radar
- Neighboring radar beams overshoot the low levels and the lower portion of the mid levels over both the Albuquerque and Cannon AFB radars

Cone of Silence

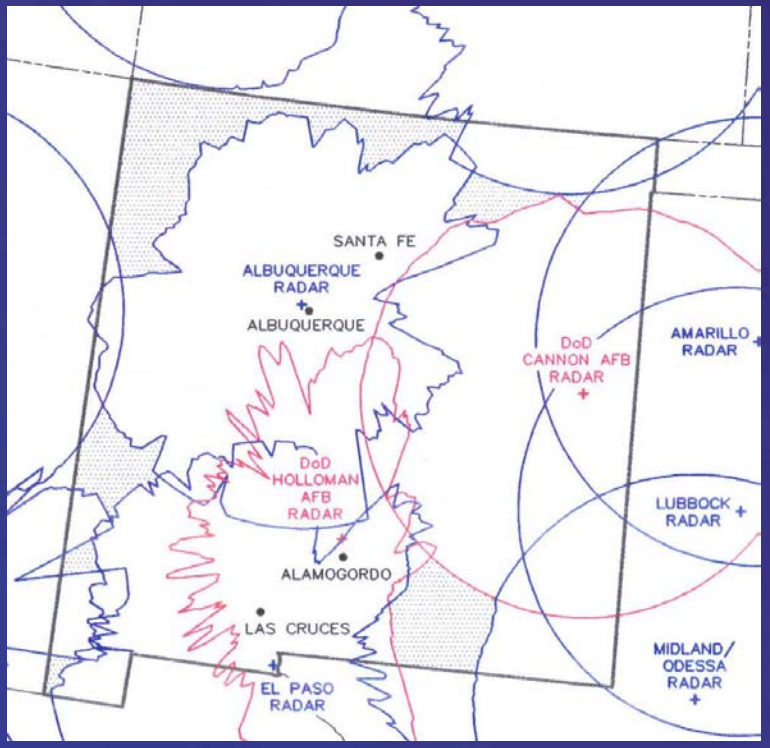
(NWS, 2003)



Angles used by the WSR-88D

Limitation 3: Blocked From View

- Mountains can shield low-level circulations from view
- If not for mountains, we'd see perfect circles of coverage like those in TX
- Since lower elevation angles intercept more terrain, coverage decreases below 10,000 ft
- Since higher elevation angles intercept less terrain, coverage improves above 10,000 ft
- When implemented, the new scan strategy will slightly improve detection capabilities by increasing sampling of the atmosphere just beyond and above mountain tops



Radar Coverage at 10,000 Ft

Limitation 4: Dissipate Too Quickly

- Many spin-ups may last only a few minutes
- Complete atmosphere scan may take 5 or 6 minutes
- Forecaster analysis of images and dissemination of a tornado warning takes extra time
- Even when detected, spin-ups frequently dissipate before a warning can reach people
- New scan strategies will shrink scans to 4.1 minutes

Example 1: Spin-Up Below Cumulus Cloud

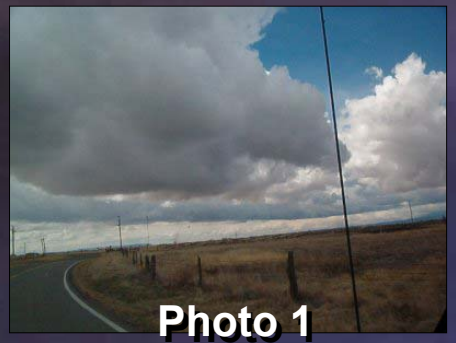


Photo 1


Photo 2


Photo 3


Photo 4

- March 2003, Torrance County, east of Manzano mtns.
- Not detected by forecasters for 3 reasons
  - Too far: 63 sm from Albuquerque radar and 128 sm from Cannon AFB radar
  - Manzanos blocked the lowest 1 1/2 beams from Albuquerque radar; radar sampled no lower than 6,000 ft above spin-up
  - No rain or thunderstorm activity on this day. Forecasters use the prominent returns from rain, hail and thunderstorm outflow boundaries to identify possible tornado locations.

Example 2: Spin-Up Below Thunderstorm

- May 2003, near Willard in Torrance County, east of Manzanos
- Storms nearly stationary this day
- Forecasters issued a severe thunderstorm warning about 40 minutes before this photo; this spin-up may have developed along the earlier storm's outflow boundary
- 59 sm from Albuquerque radar; this tornado may have been big enough to detect
- Manzanos blocked lowest 1 1/2 beams from Albuquerque radar; radar sampled no lower than about 5,000 feet above this spin-up

Other Tornado Detection Capabilities

- Storm Prediction Center guidance
- Weather models
- Satellites, profilers, soundings, upper-air data, surface obs
- Storm spotters
- News media, law enforcement and public reports
- Research collaboration
  - Testing new scan strategy
  - Will help confirm sonar's ability to detect tornadoes

Prepare & React Appropriately

- FEMA's tornado safety tips brochure: www.fema.gov/hazards/tornadoes/tornadof.shtm
- Watch for small tornadoes early with all thunderstorms; remember our first spin-up example
- Useful NOAA forecasts
  - U.S. hazards assessment
  - Severe weather outlook, mesoscale discussions, watches
  - Hazardous weather outlook & warnings
- Use NOAA weather radios
- Report tornadoes to NWS, if safely possible

Bottom Line

- WSR-88D's do a good job at what they're designed to do: detect strong mid-level circulations
- All weather radars have limitations
- Small tornadoes frequently exploit these limitations in New Mexico
- NWS forecasters use all available resources to overcome tornado detection limitations
- Weatherwise media & public can prepare for this dangerous threat and react appropriately when tornadoes strike

References

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- WSR-88D Operational Support Facility and Titan Systems Group, July 1998: *WSR-88D Principal User Processor Operator Handbook*. Volume II, Applications Terminal, Software Version 10.0, 267 pp.

Tornado Detection & Limitations*

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Questions for David Craft?

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*Limitations common to all Doppler weather radars