Radar Meteorology

AOS C110/C227

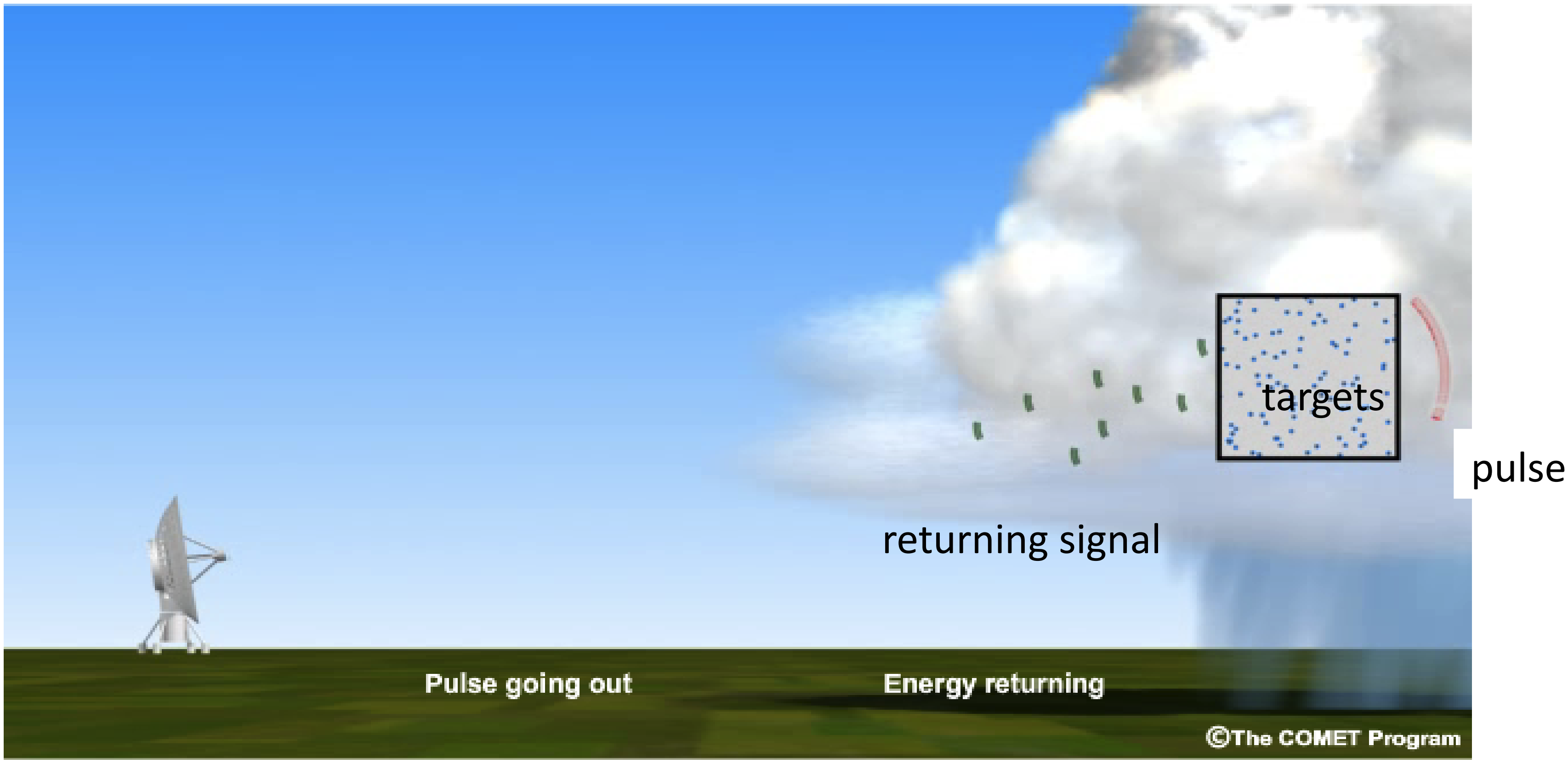
Goals

- Gain appreciation of uses and limitations of radar information
- **Summarize** materials available through Comet Program
  - Create free account at https://www.meted.ucar.edu
  - Access basic weather radar module at https://www.meted.ucar.edu/training_module.php?id=960
  - This module can be downloaded to your own computer, and viewed in your browser offline. Unzip the archive, go to folder comet/radar/basic_wxradar/, and open index.htm in your browser.

Radar types

- Radar = originally an acronym for **Ra**dio **D**etection **A**nd **R**anging
- Many different types of radar
- Focus on WSR-88D NEXRAD Doppler radar
  - 10 cm wavelength
  - Scans horizontally 360˚, at various elevation angles
  - Volume scan completed in about 5 min

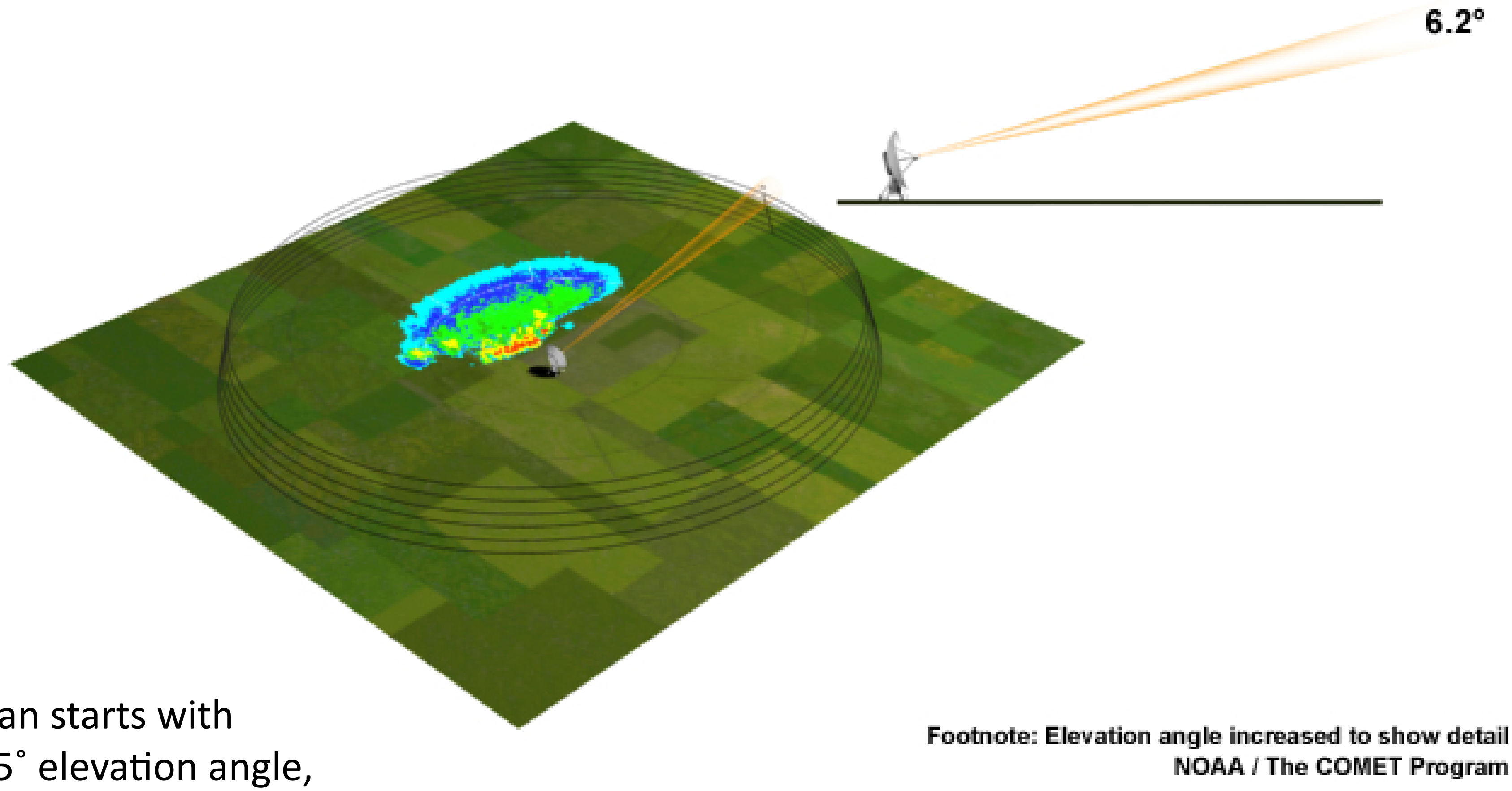
Radars emit pulses, listen for returns



Radars emit pulses of energy

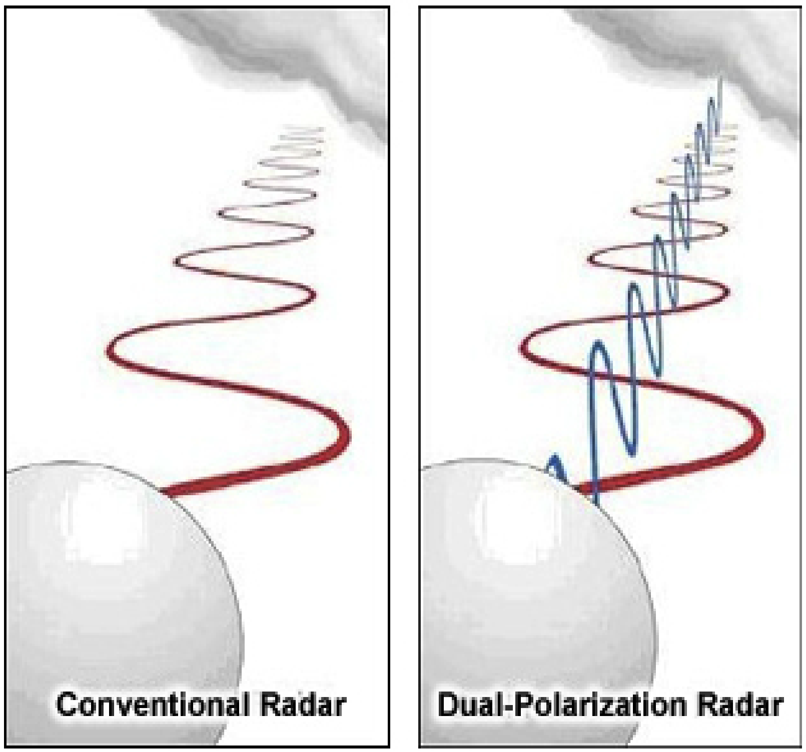
Only a small fraction of emitted energy is returned.
Returned energy = radar reflectivity.

Scanning pattern



Scan starts with
0.5˚ elevation angle,
goes up to 19.5˚

Dual polarization

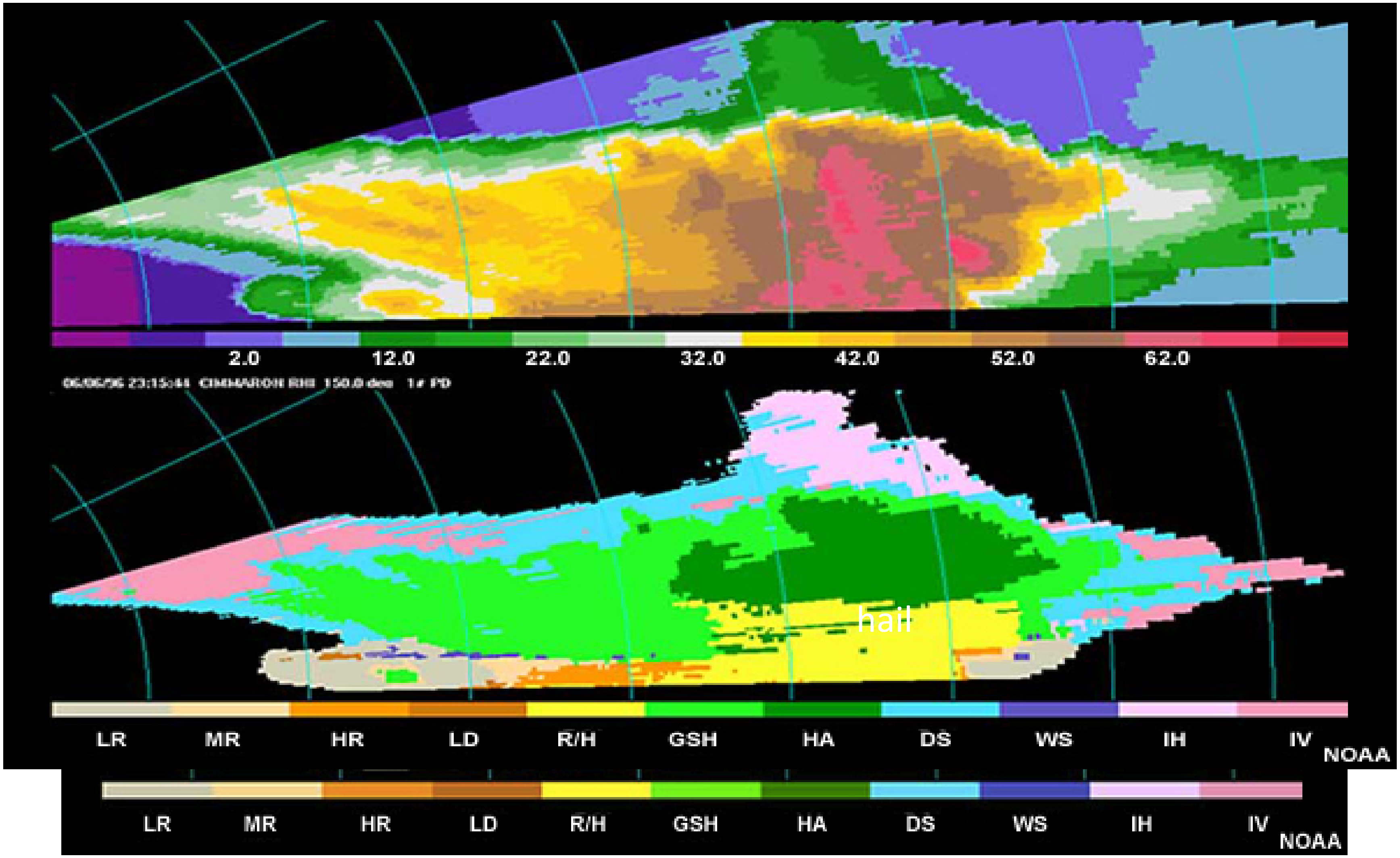


Dual-polarization radars improve:

- Identification of non-weather targets
- Determination of rain vs. snow vs. melting snow
- Hail detection
- Detection of areas of heavy rain
- Detection of debris from tornadoes

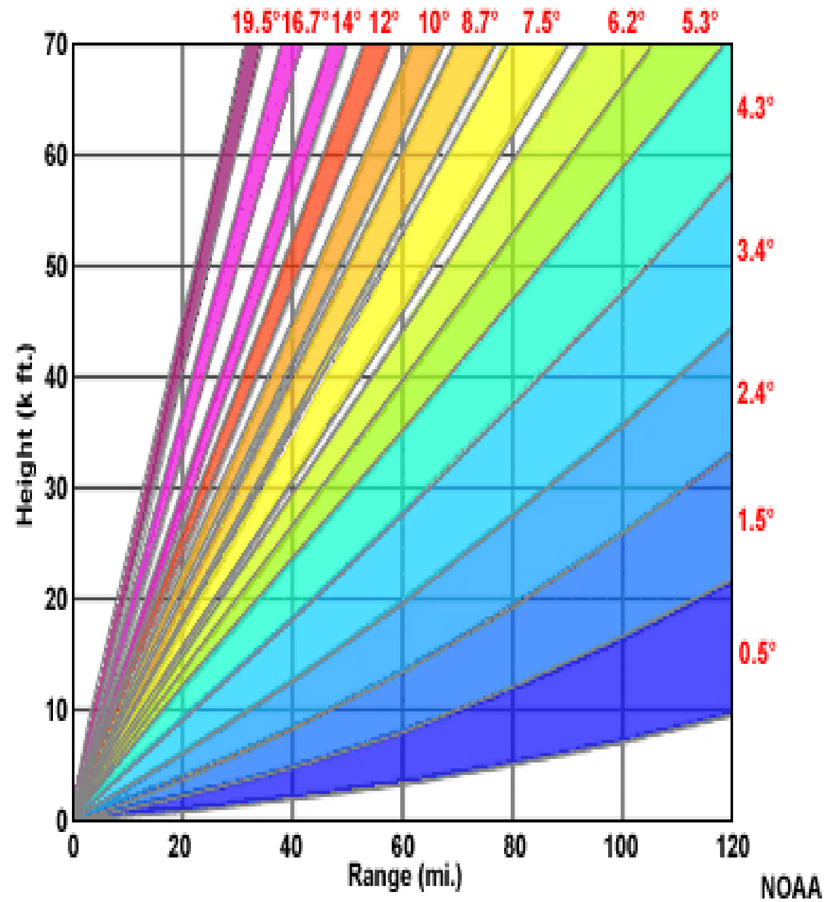
NOAA

Example

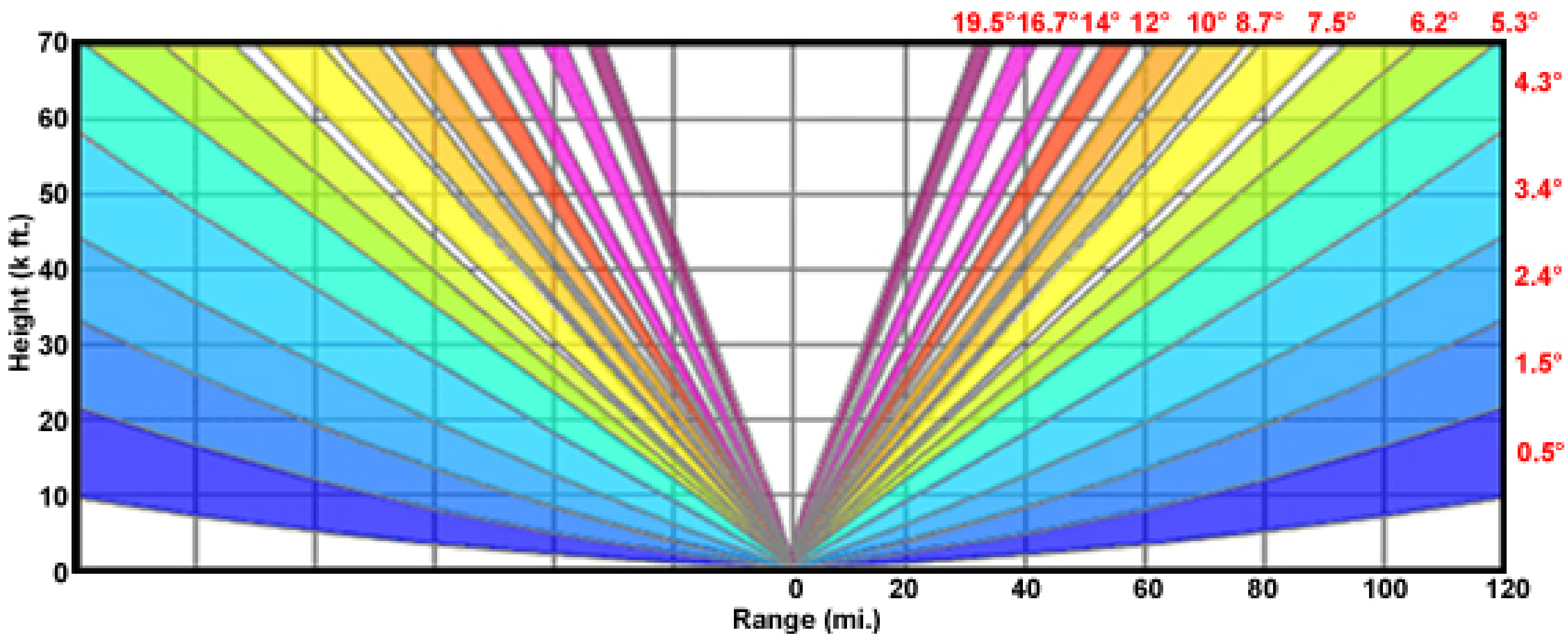

2.0
12.0
22.0
32.0
42.0
52.0
62.0
hail
LR
MR
HR
LD
R/H
GSH
HA
DS
WS
IH
IV
NOAA
LR
MR
HR
LD
R/H
GSH
HA
DS
WS
IH
IV
NOAA

Scanning modes

- Precipitation mode vs. clear-air mode
- Precip mode (illustrated at right) scans a wide variety of elevation angles
- Clear air mode (not shown) more slowly scans only up to 4.3˚, inclusive

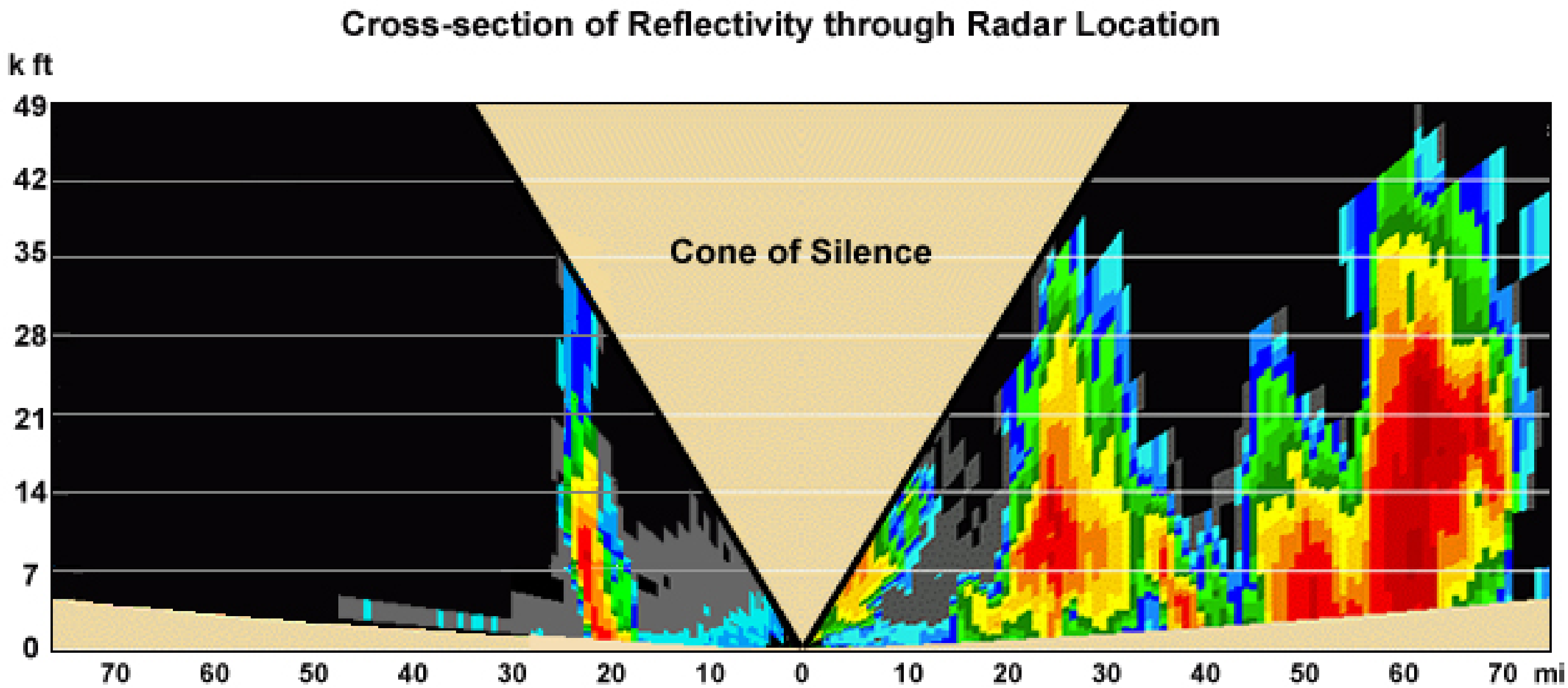


"Cone of silence" above radar



NOAA

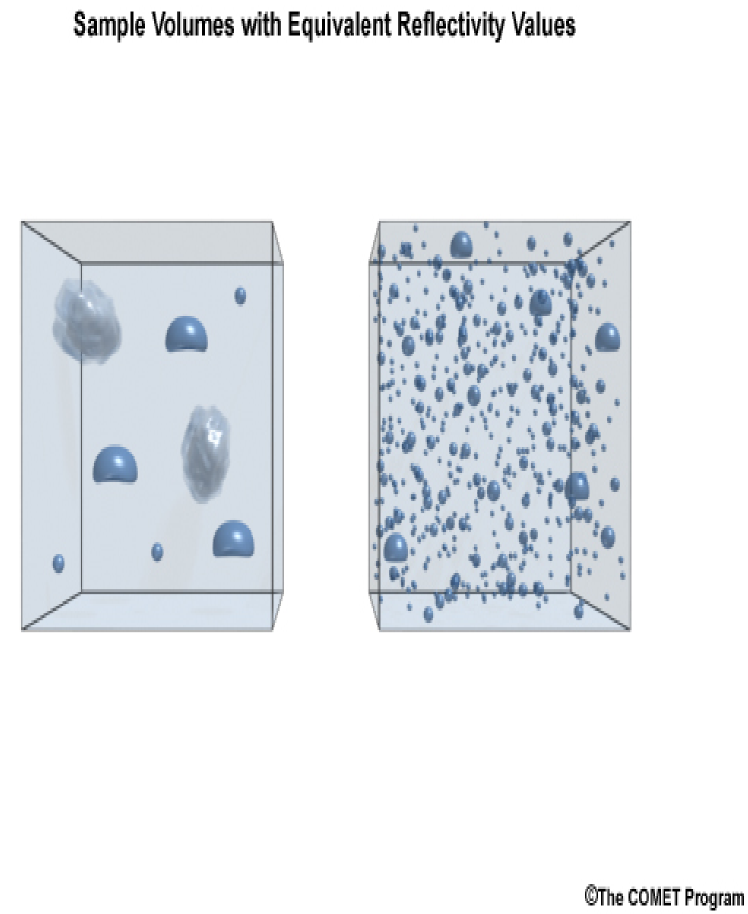
“Cone of silence” example



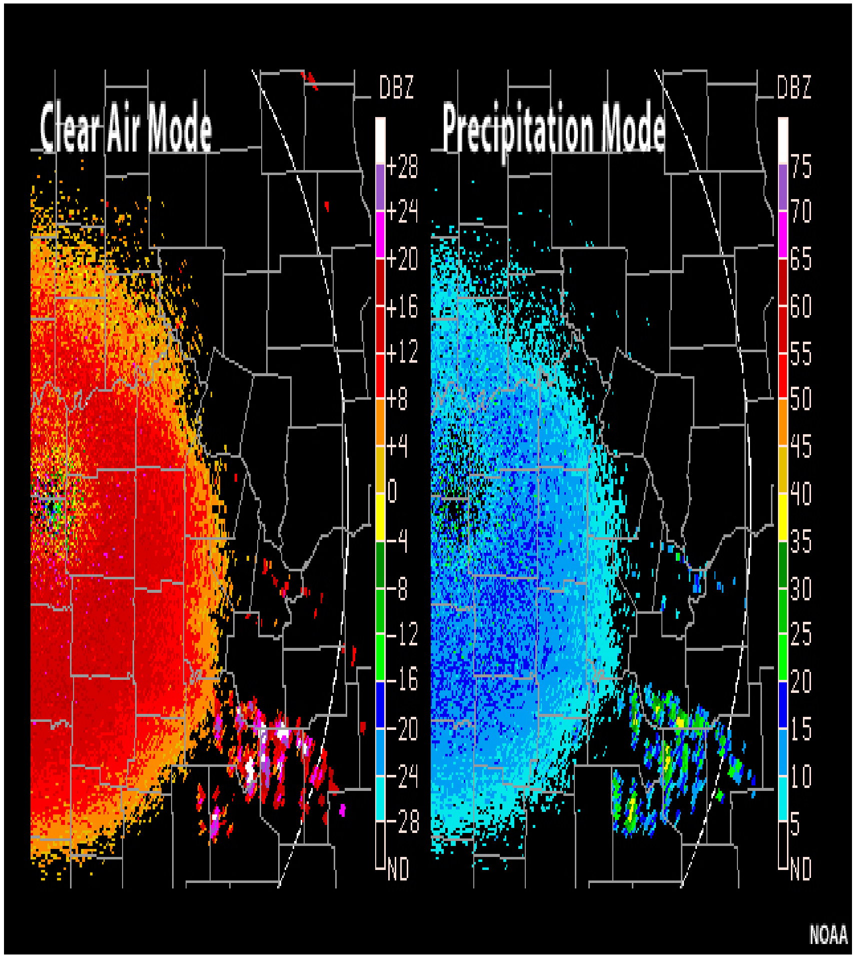
NOAA

Reflectivity

- Proportional to <u>sixth power</u> of target diameter
  - As a consequence, it takes a very large number of smaller particles to appear as "bright" as a few, large particles
- Measured as "Z" based on diameter to the 6th power (mm6) per cubic meter (m3)
- Further converted to "dBZ", a dimensionless, log-scaled value

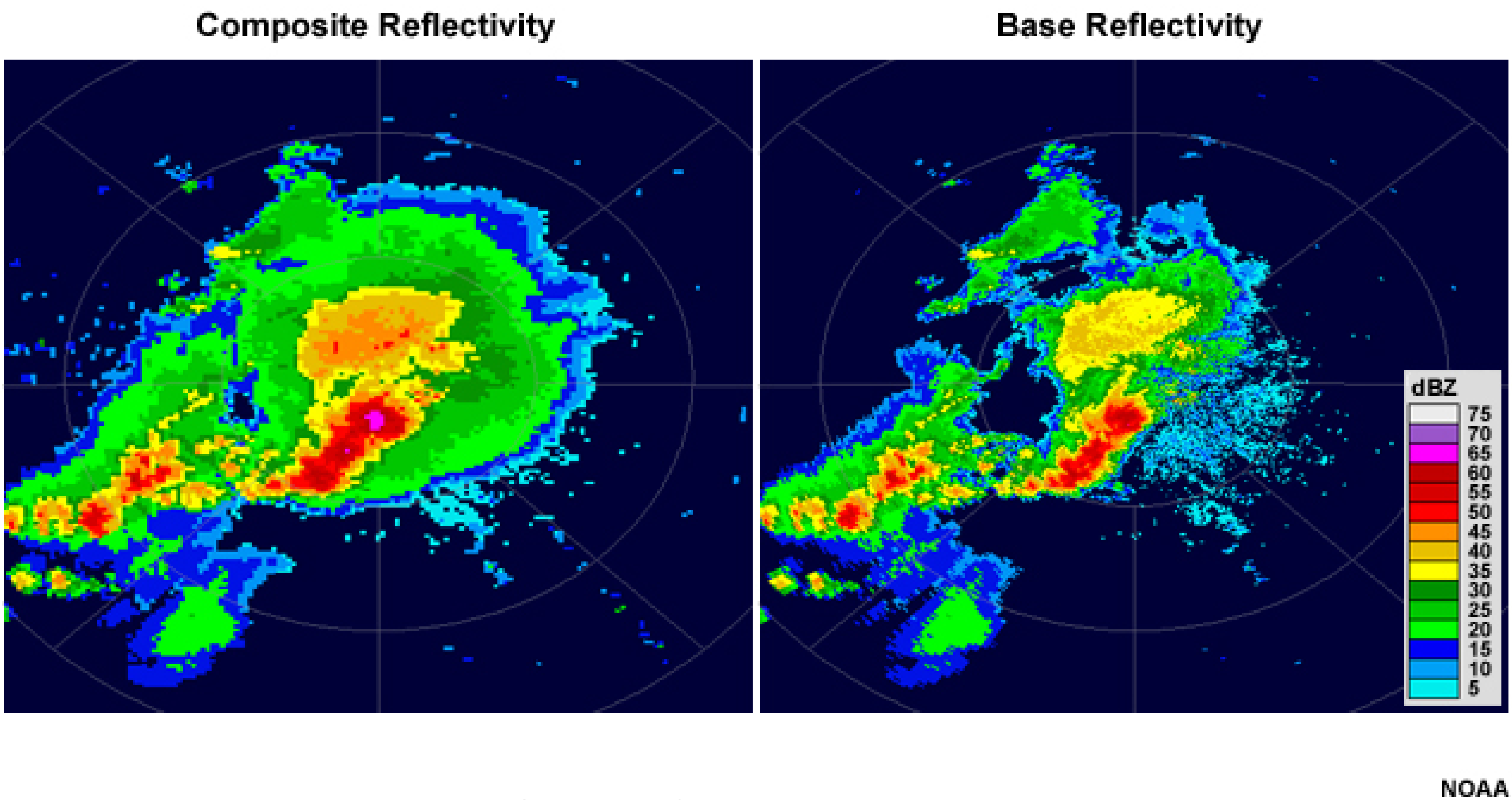


Characteristic values



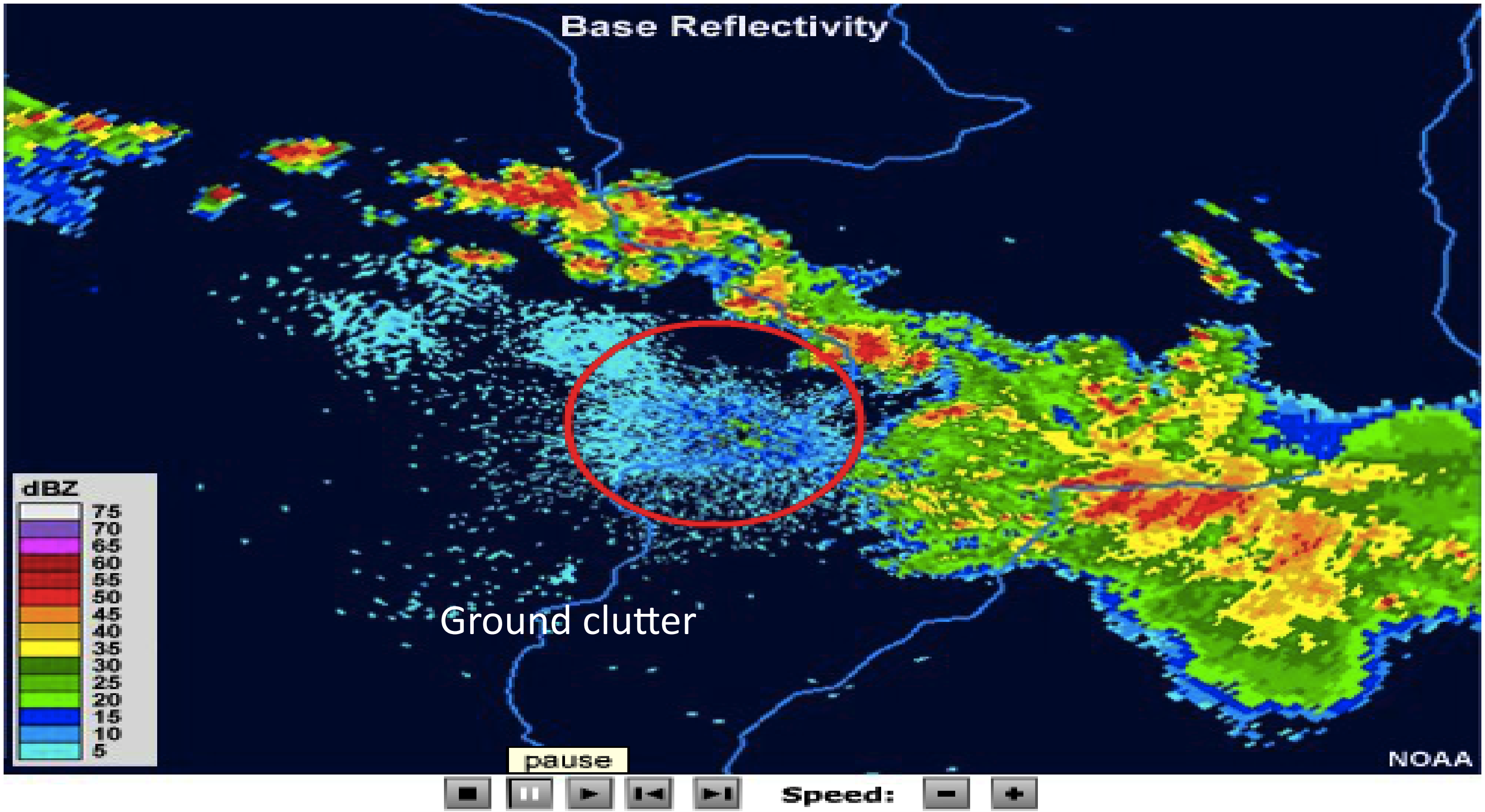
- Precip mode reflectivities can range up to about 75 dBZ
  - Above 45dBZ: intense precip
  - Above 60 dBZ generally indicates hail present
  - Ice is less reflective than liquid
  - Melting ice can be very bright on radar
- Clear-air mode uses a different scale, with red still being low values
  - Watch the scale!

Base vs. composite reflectivity



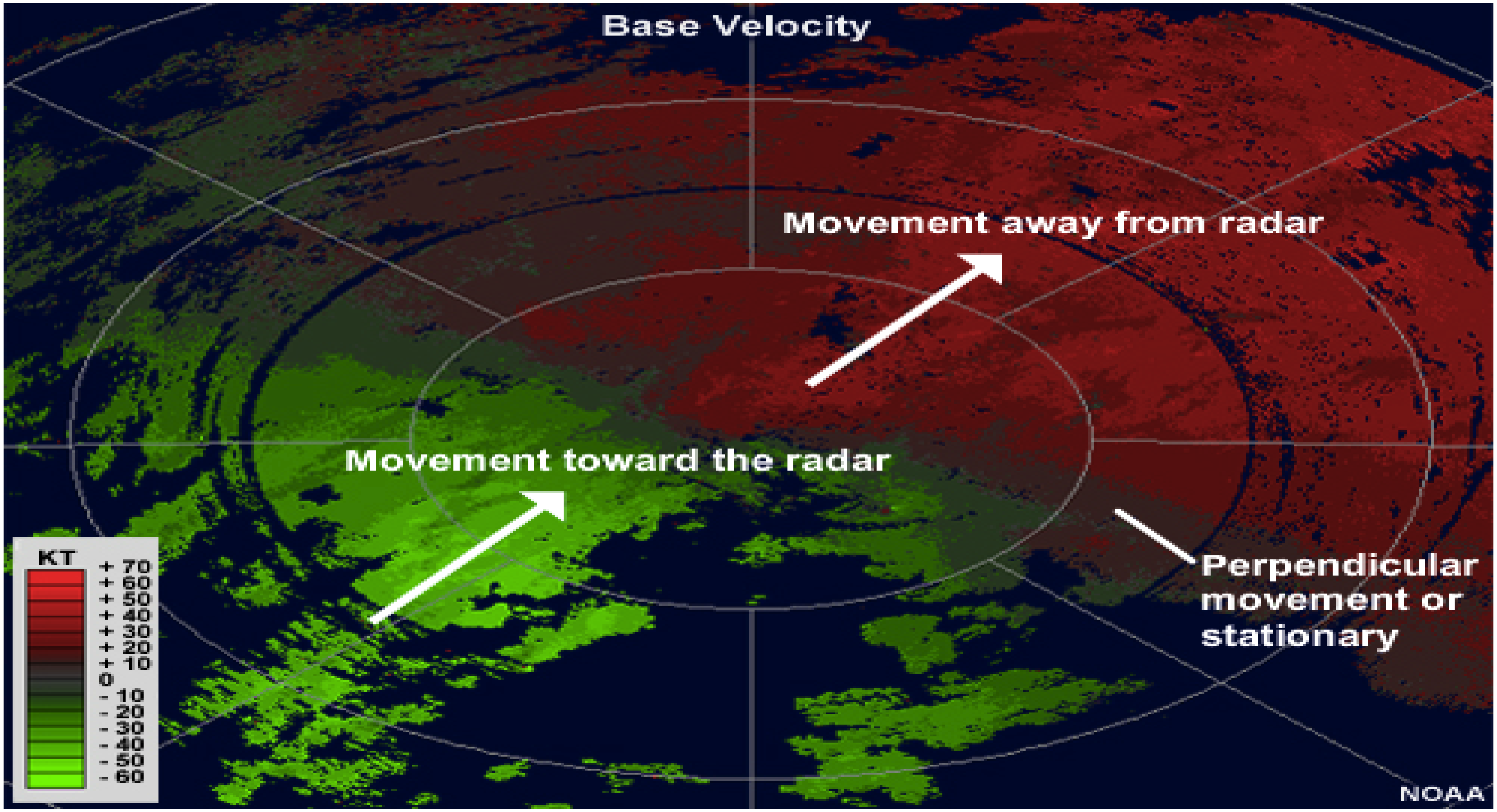
Base reflectivity from a single elevation scan.
Composite takes max value from all scans.

Precip mode example



Ground clutter from trees, buildings, other low-lying objects near radar

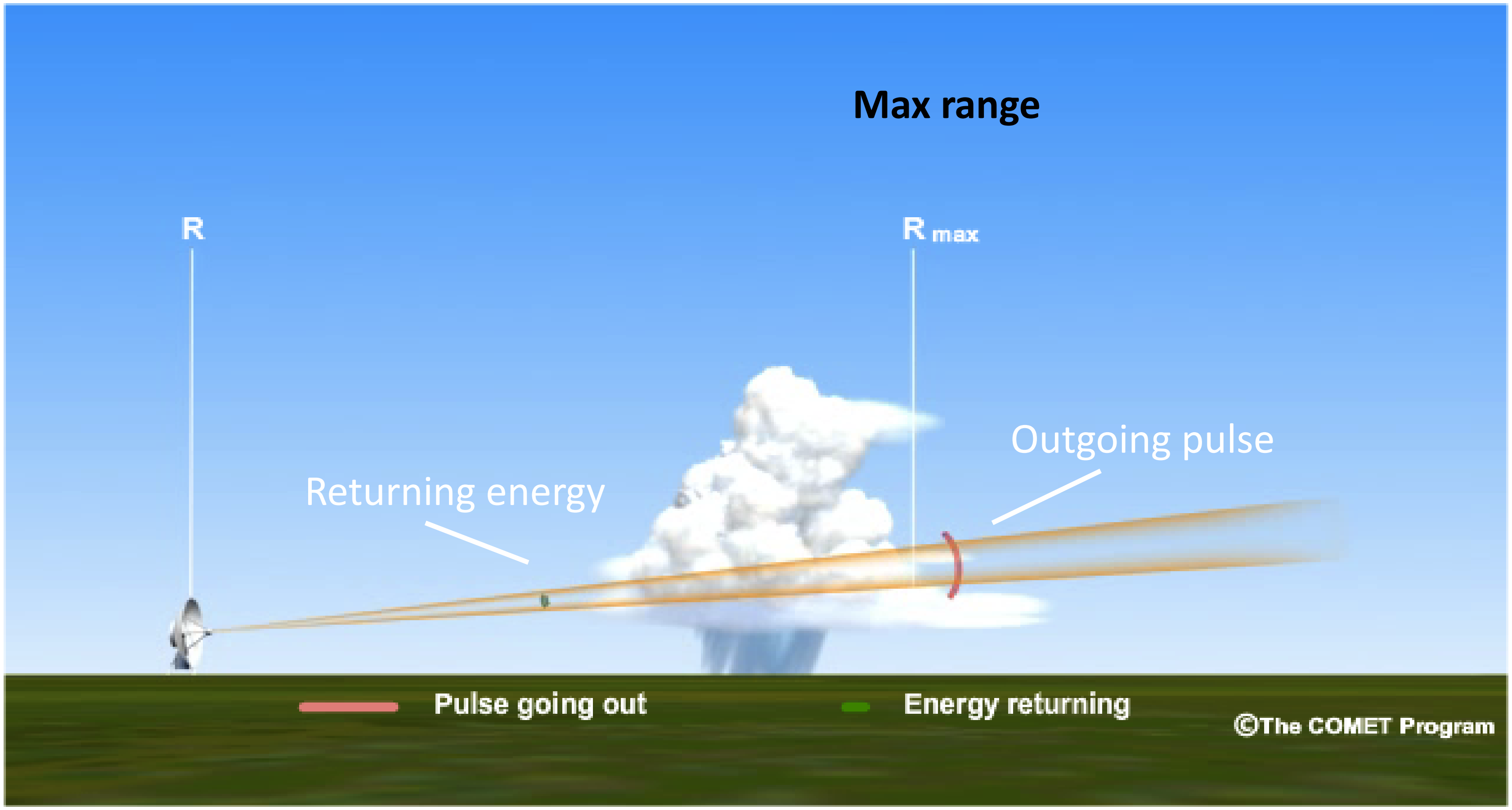
Doppler radial velocity



Cool colors = towards radar. Warm colors = away from radar.
Grey = no radial motion relative to radar.

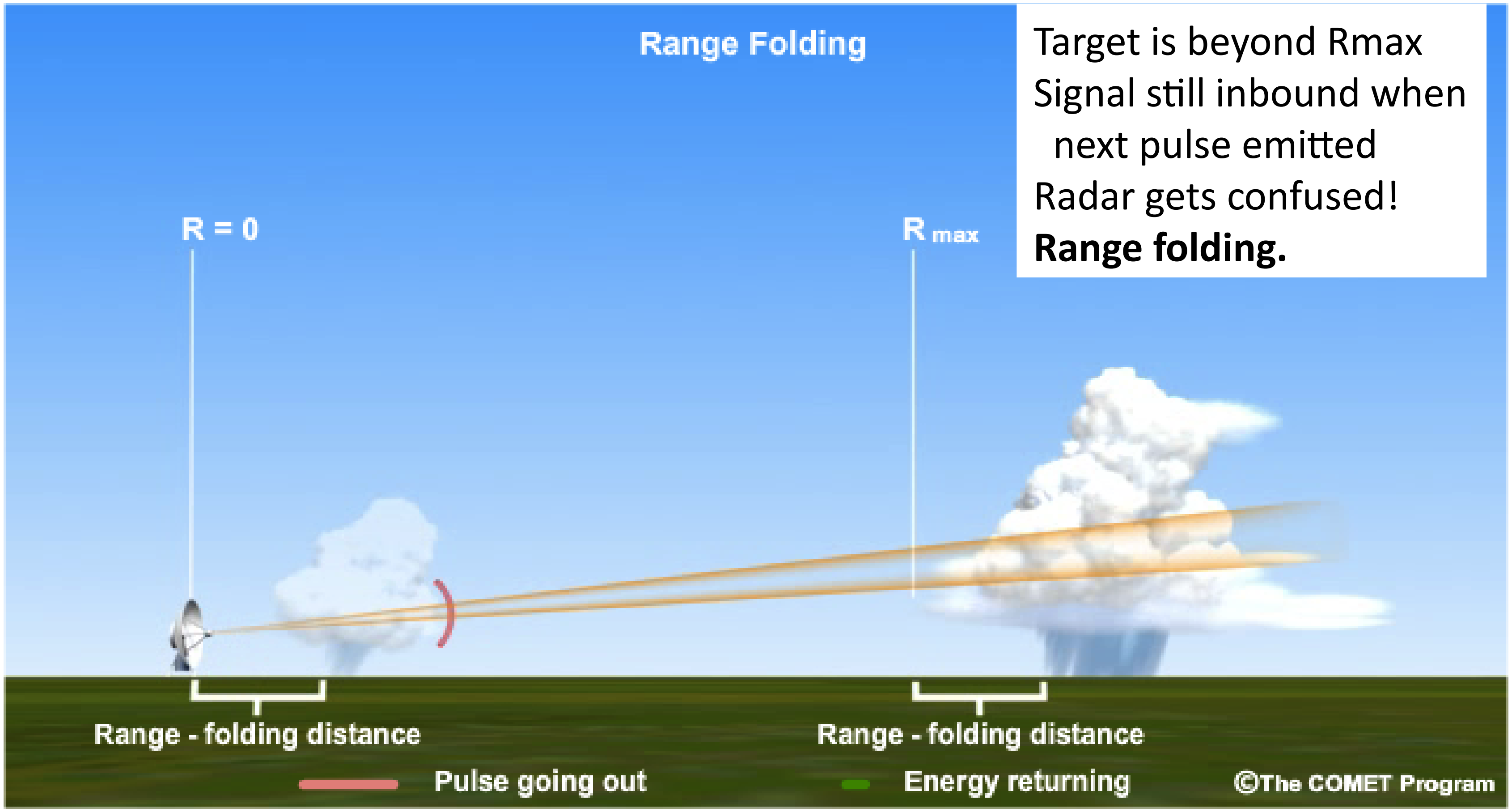
Limitations and artifacts

Pulses emitted in sequence; separation time determines max range

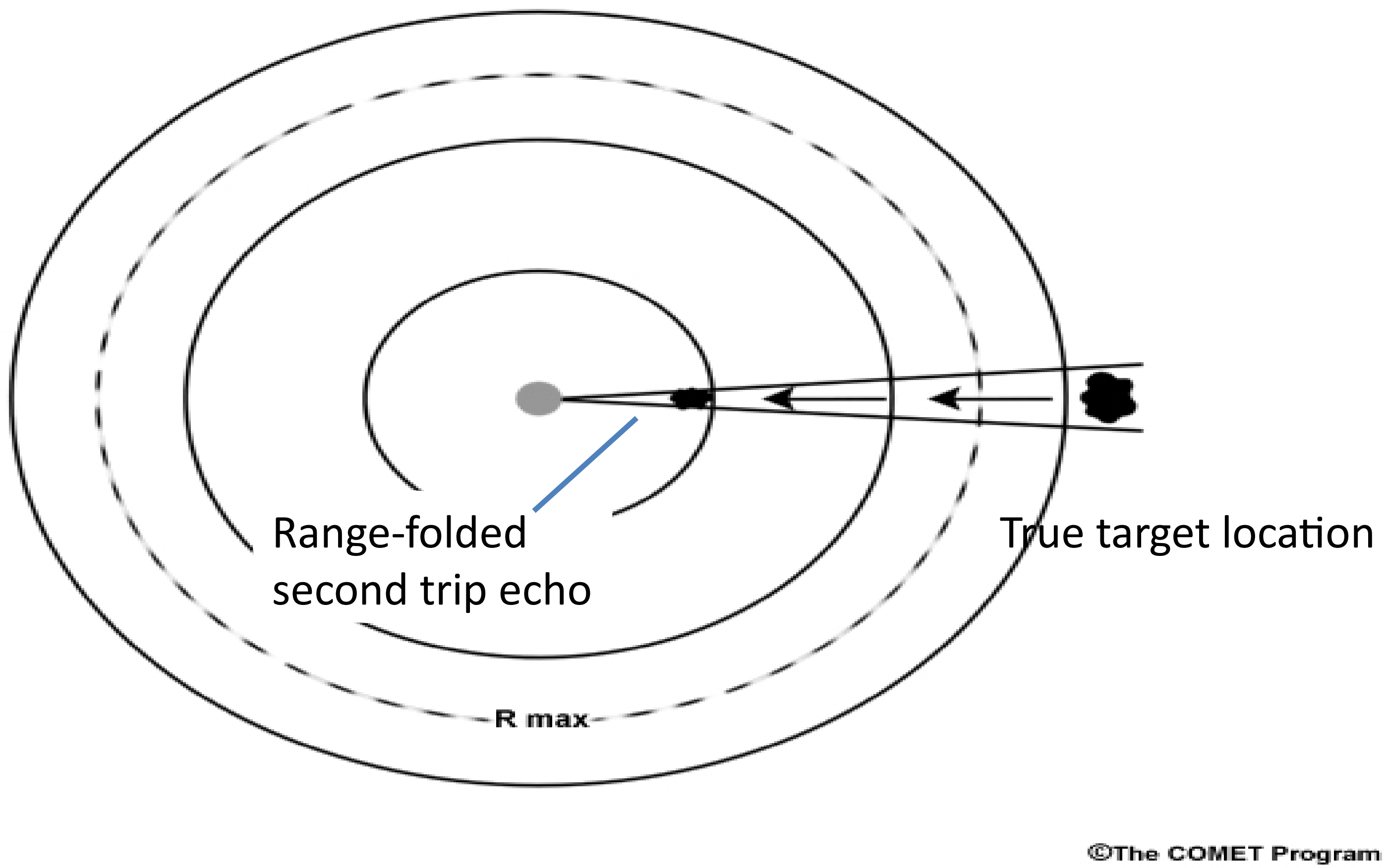


“Second trip” echoes

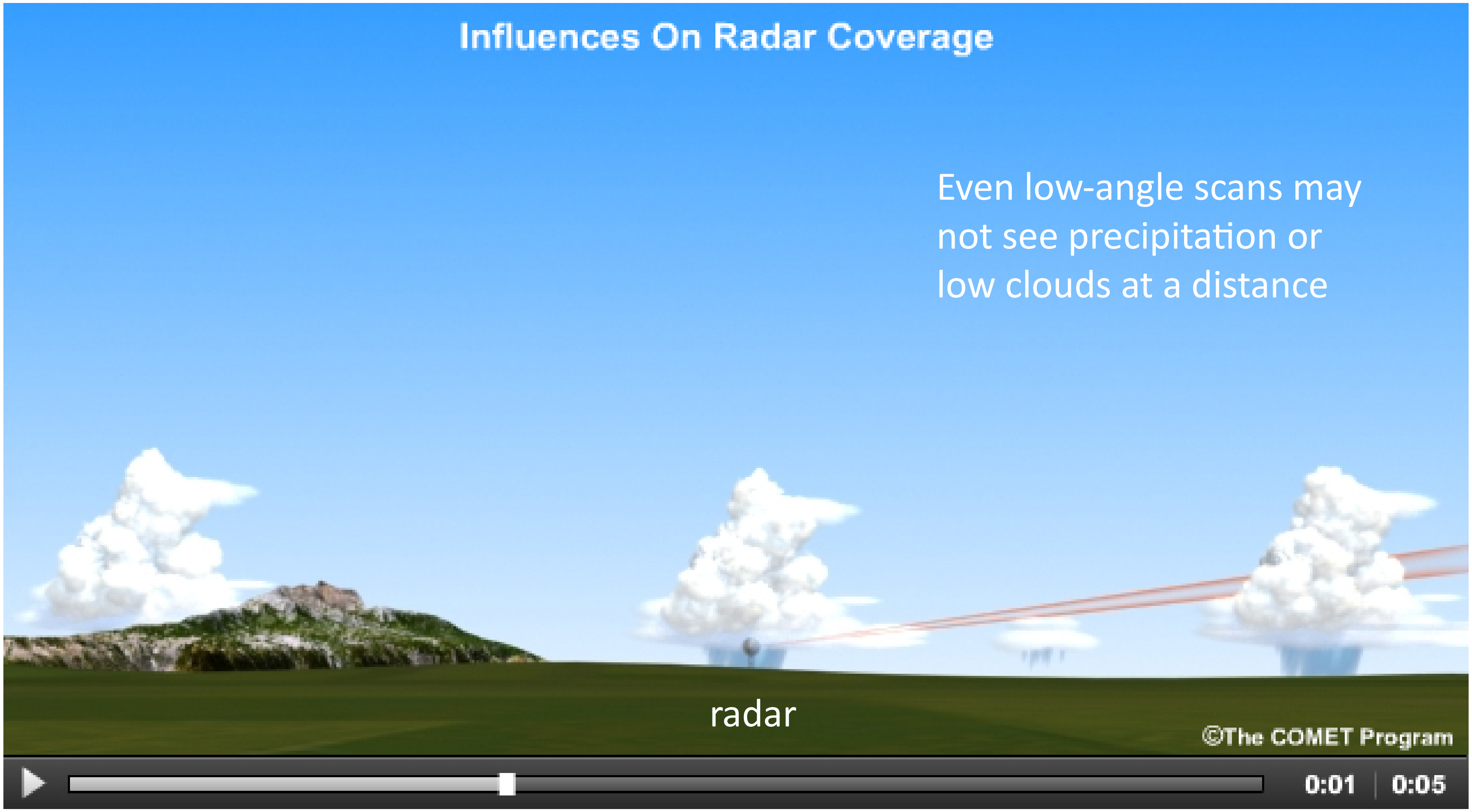
Target is beyond Rmax
Signal still inbound when
next pulse emitted
Radar gets confused!
Range folding.



"Range folded" echoes often look oddly elongated, in radial direction

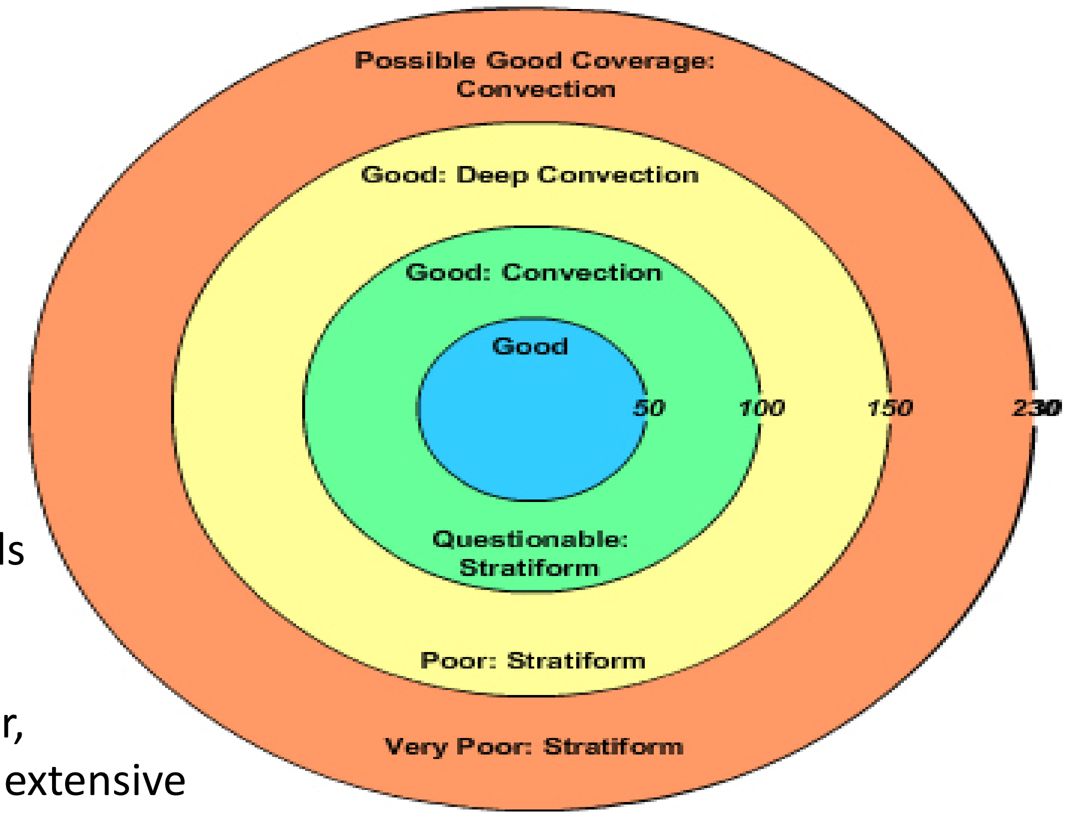


Incomplete coverage



Coverage quality by precip type

Radar Coverage of Precipitation with Range (km)—Assuming No Beam Blocking

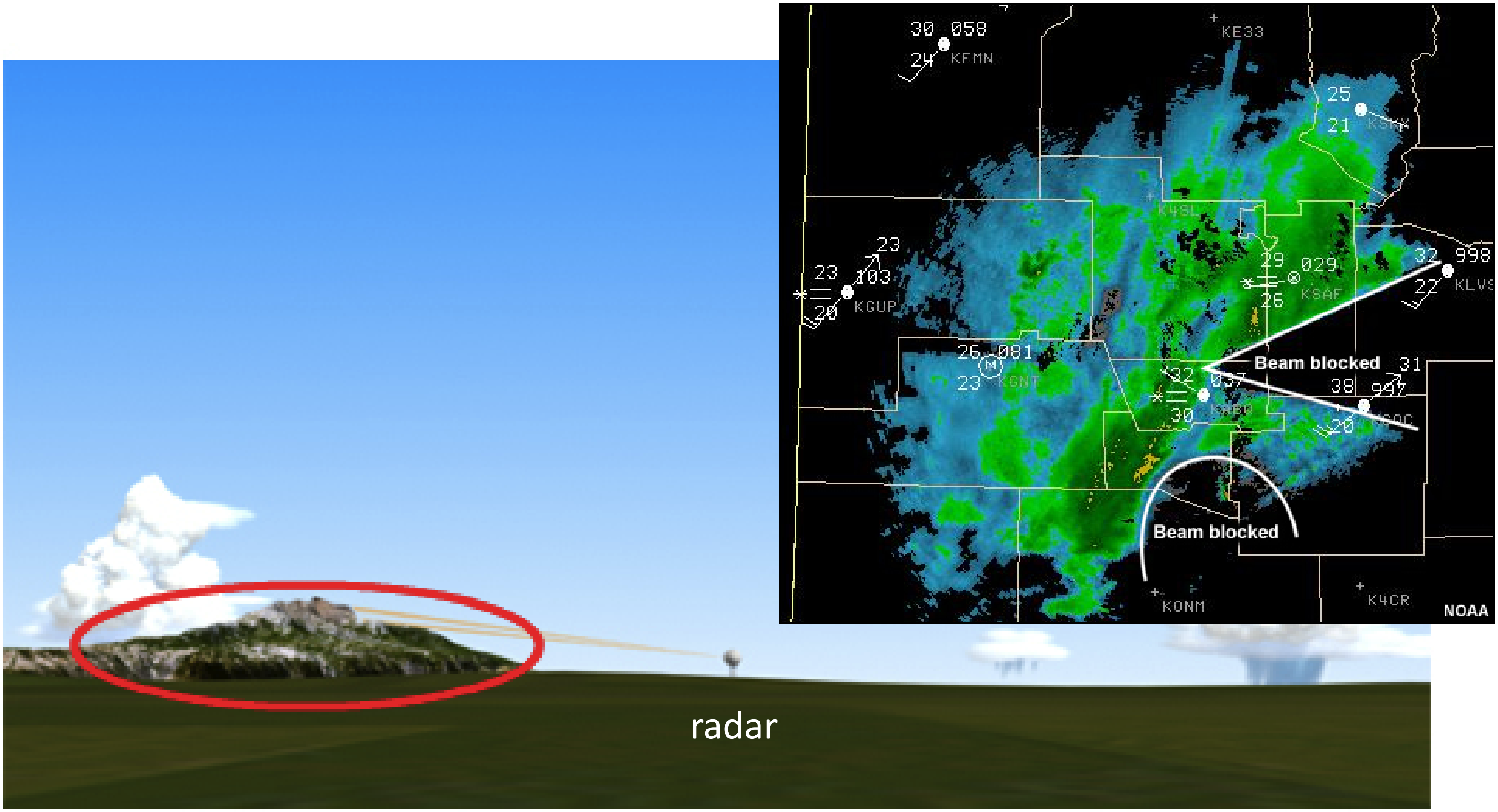


Convective precip
= from deep clouds

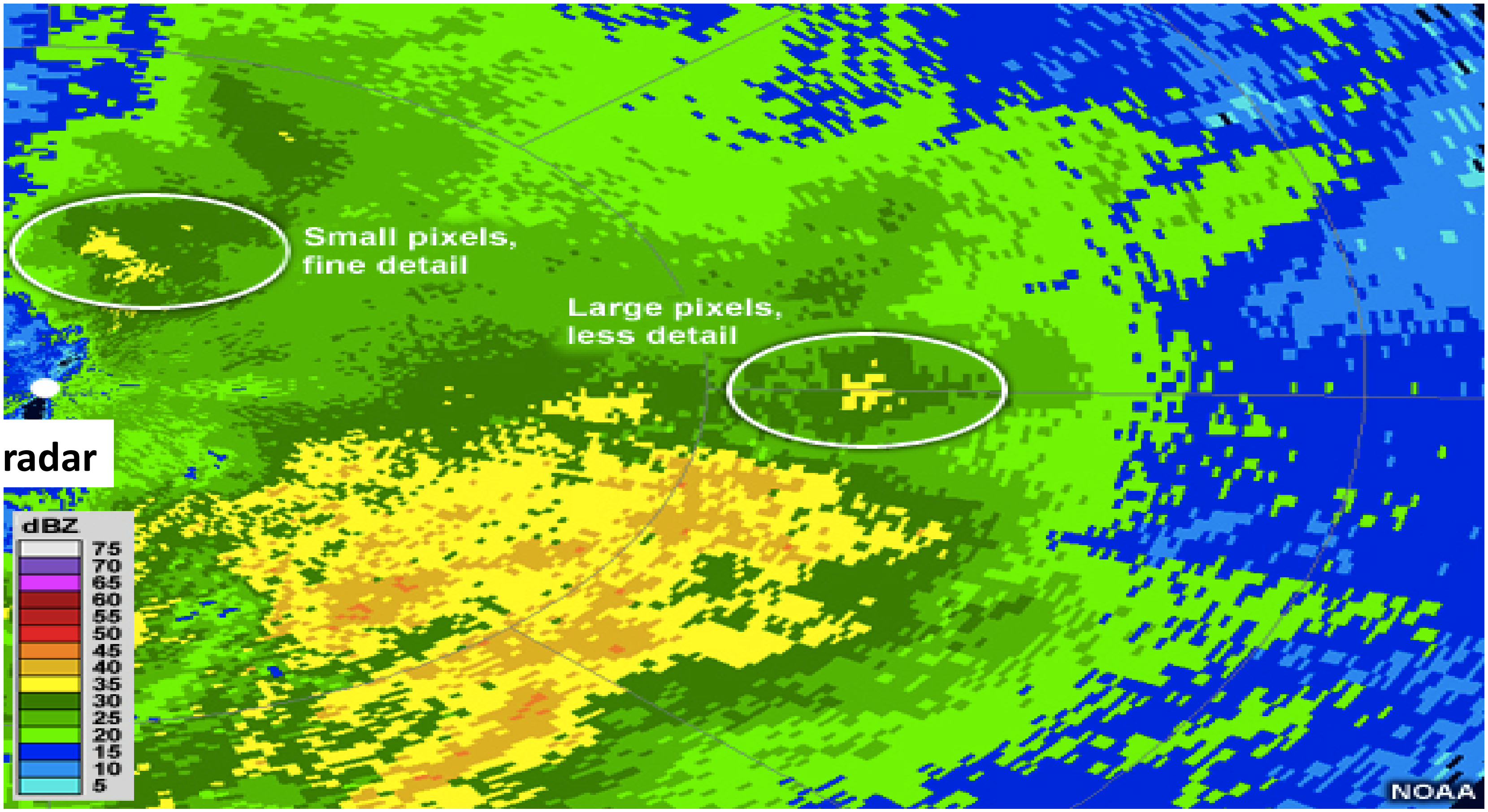
Stratiform precip
= lighter, shallower,
more horizontally extensive

Note: Coverage is worse for snow, and in areas of rugged terrain

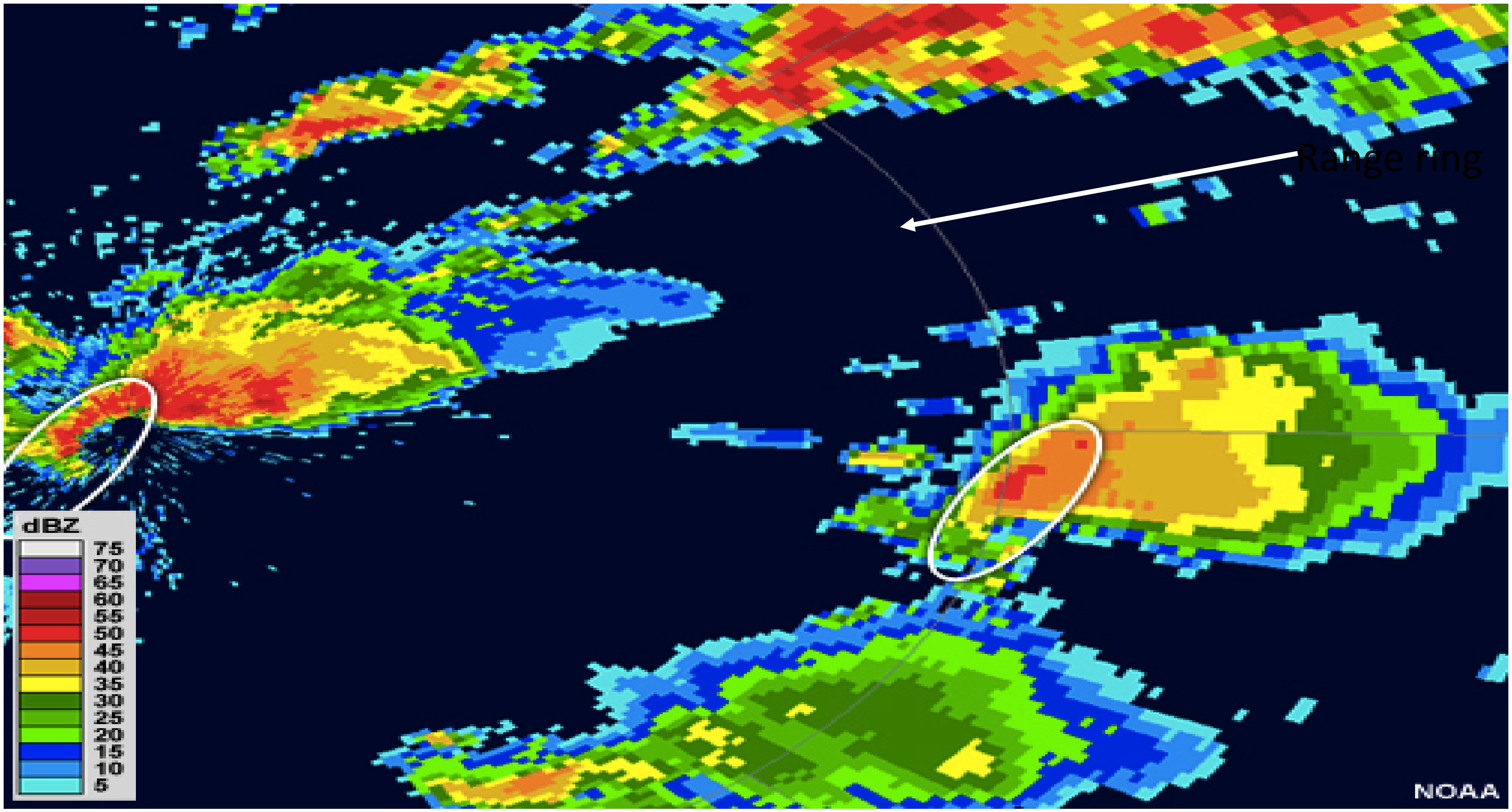
Beam blocking by obstacles



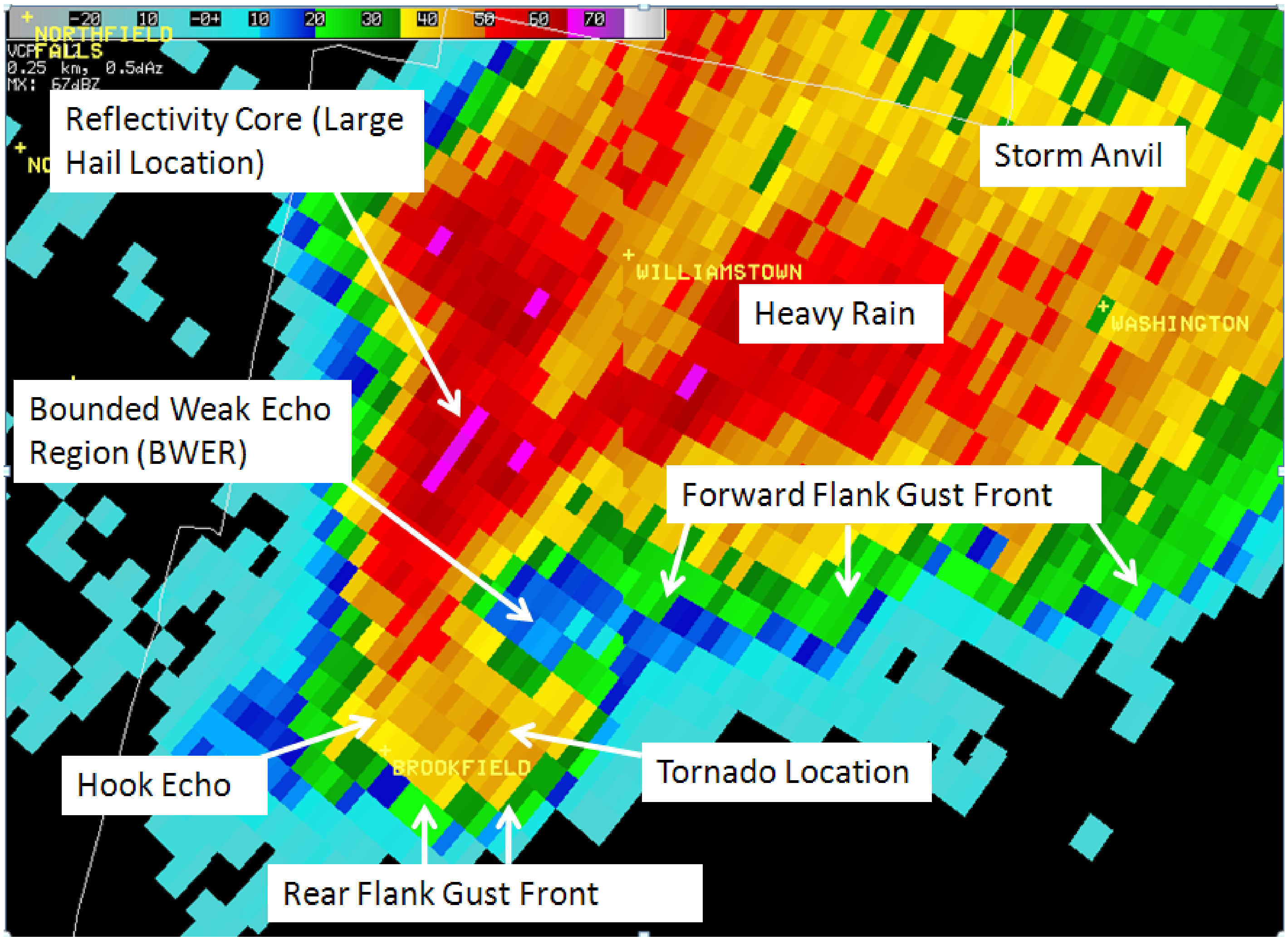
Beam spreading reduces resolution with distance from radar



Example: hook echoes closer to radar are better resolved



Supercell Thunderstorm as seen by Radar



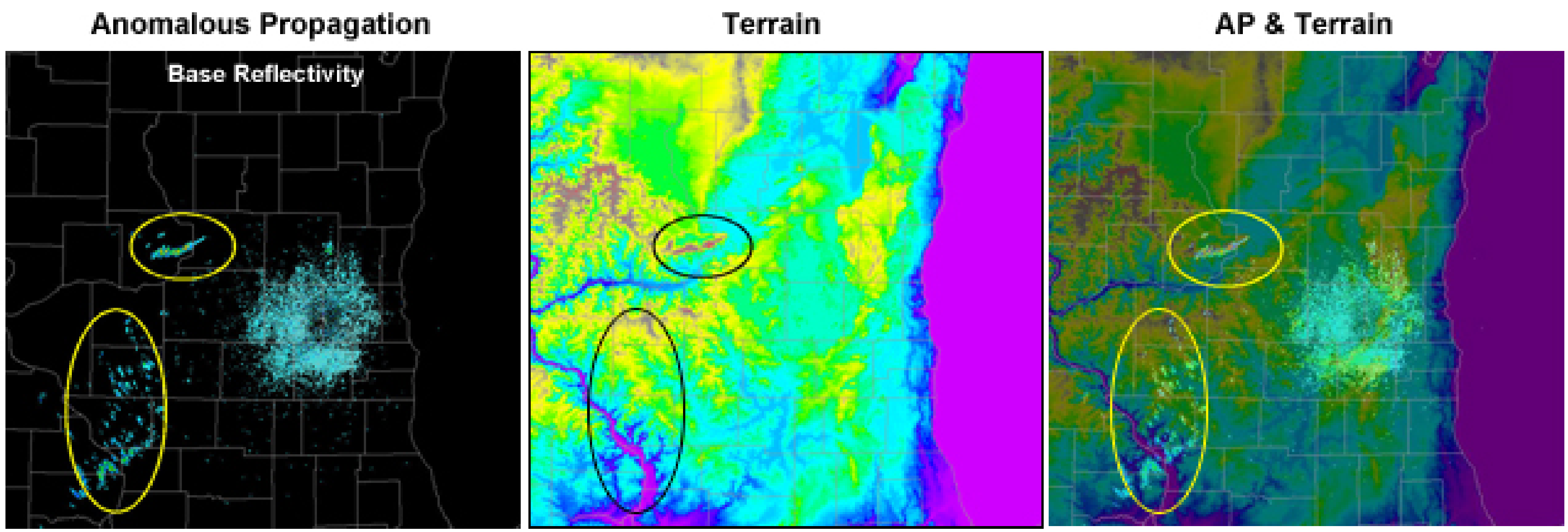
Radar assumptions

- Beam travels at original angle
- Targets absorb little radar energy
- Targets are small (relative to radar wavelength) and spherical
- Targets are liquid or solid, not a mixture
- Targets uniformly distributed in volume

Radar assumptions

- Beam travels at original angle
  - Temperature inversions and/or sharp vertical moisture variations can refract the radar beam, perhaps bending it back down
  - Downward refracted beams can become trapped in lower atmosphere or intercept ground targets, causing “anomalous propagation” (AP).

AP example

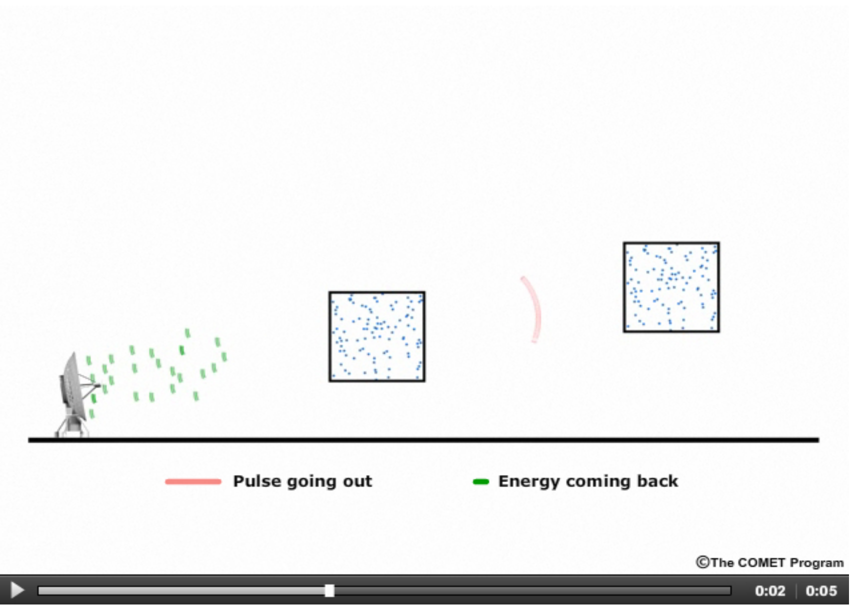


Owing to downward refraction, radar is seeing terrain features at a distance, well beyond the usual range of ground clutter

NOAA

Radar assumptions

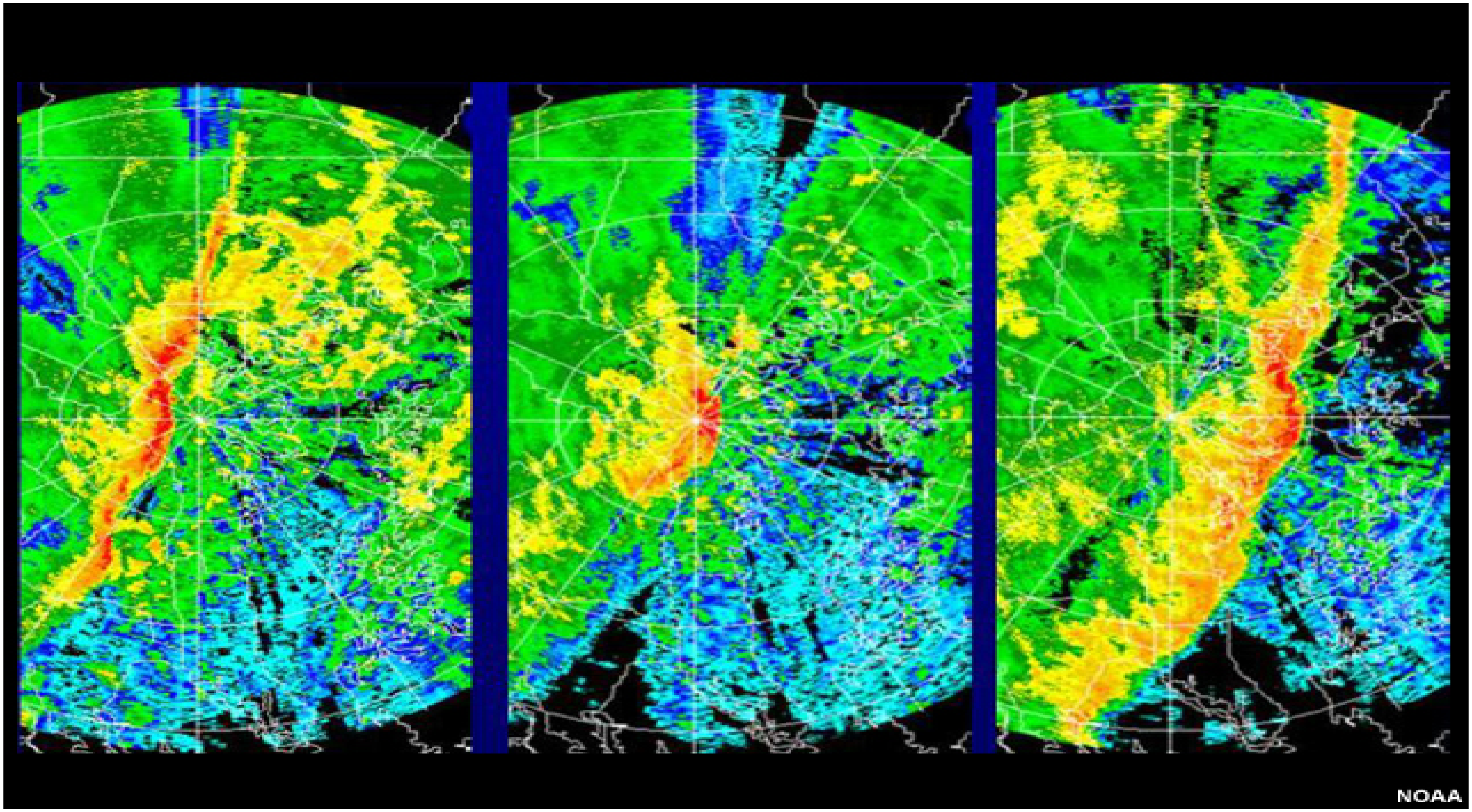
- Targets absorb little radar energy
  - In reality, attenuation of signal through closer precipitation reduces ability to see more distant targets



10 cm radar like WSR-88D experiences relatively little attenuation.
Shorter-wavelengths used with airplane, airport and mobile radars suffer significant attenuation

Attenuation example

5 cm airport radar example

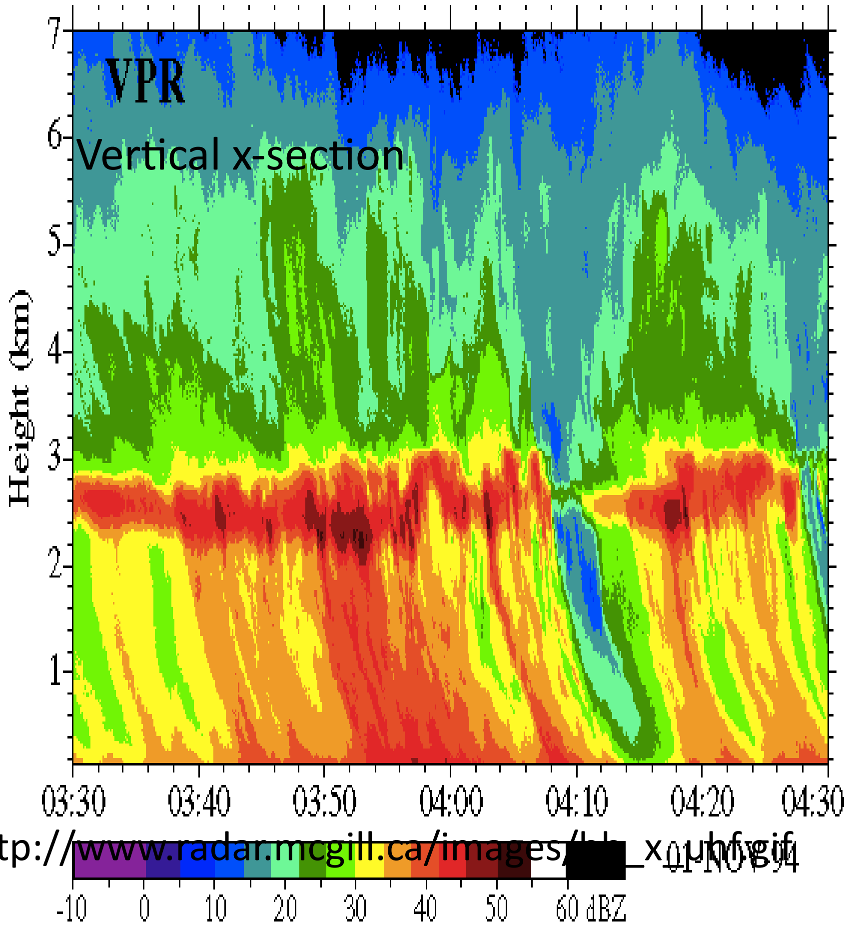


Convective line changes appearance as it passes over radar. In middle panel, beam attenuation as it passes through heavy rain causes N and S ends to appear to "disappear"

Radar assumptions

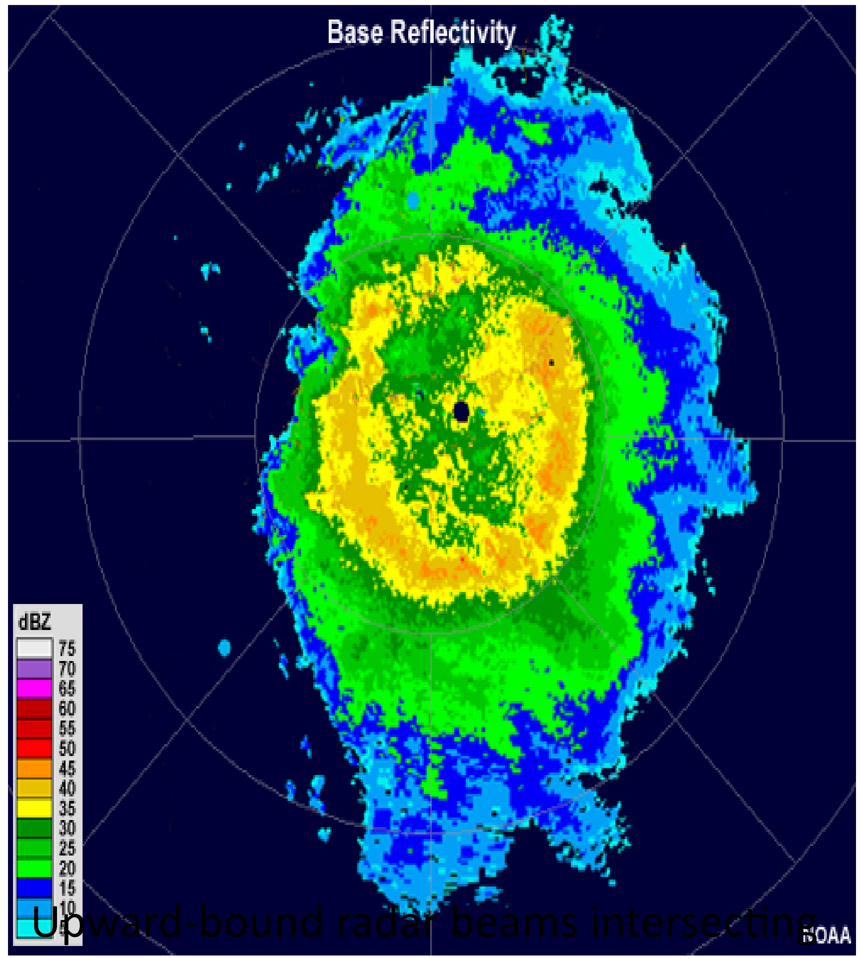
- Targets are small (relative to radar wavelength) and spherical
  - Large targets (birds, incects, large hail) greatly complicate assumptions used to calculate reflectivity
  - Departures from sphericity distort reflectivity values
- Targets are liquid or solid, not a mixture
  - Pure ice is less reflective than liquid by 7 dBZ
  - Melting ice appears as very large liquid particles

Bright band examples



Vertical x-section

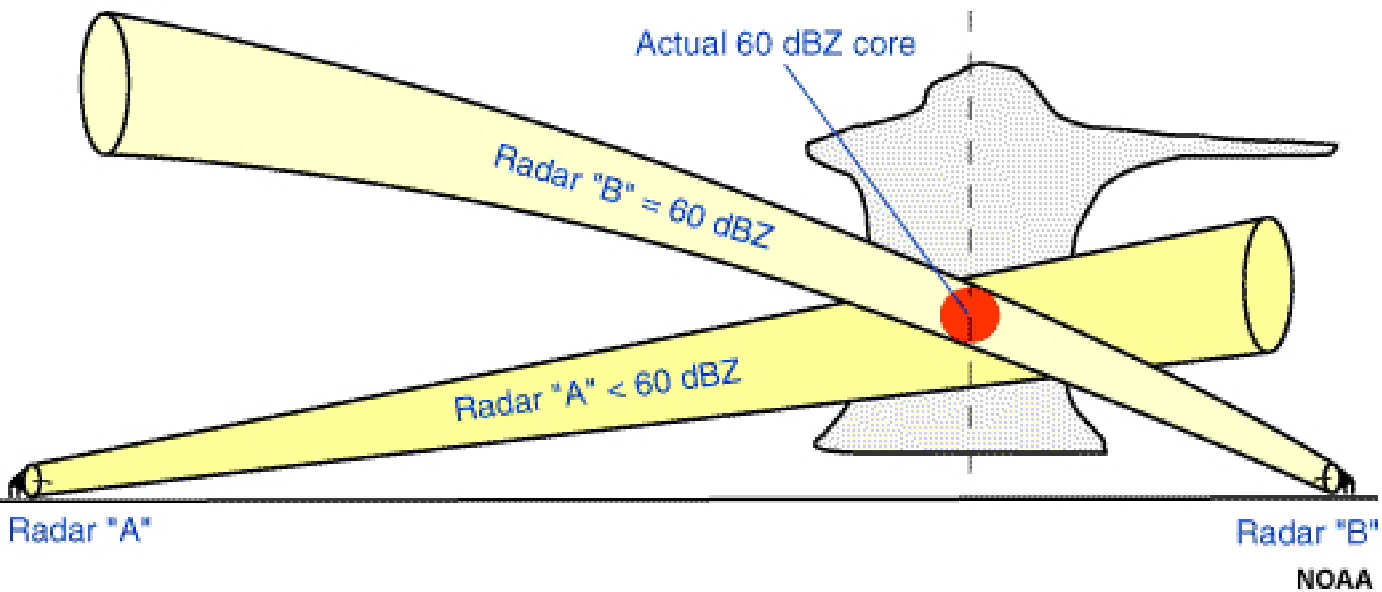
http://www.radar.mcgill.ca/images/bb_x_uhf.gif



Upward-bound radar beams intersecting bright band, creating arc-like pattern

Radar assumptions

- Targets uniformly distributed in volume



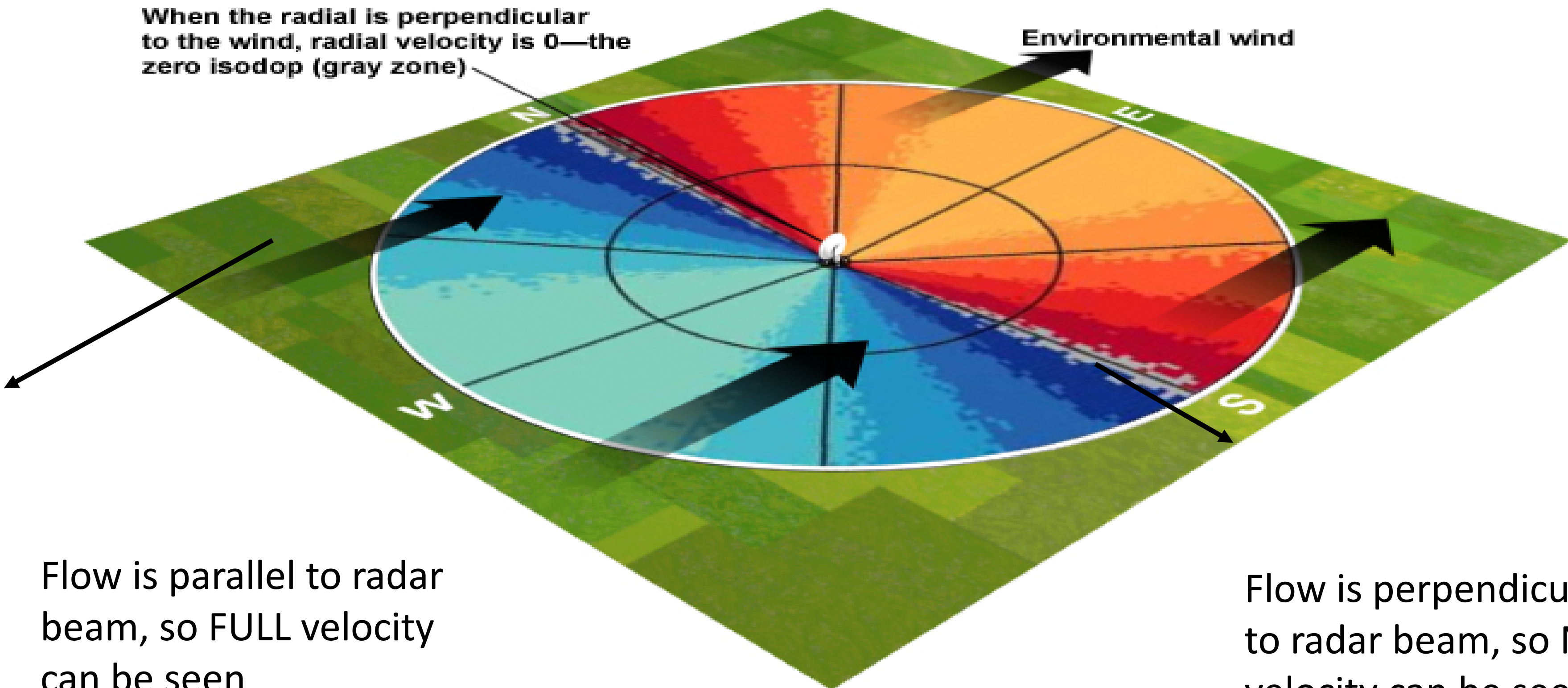
Radar “A” sees less than 60 dBZ at the same range as Radar “B” as the high reflectivity core does not fill the beam volume

Doppler velocity measurement

Doppler effect

- Radar exploits the Doppler shift that occurs when waves are reflected by moving targets
  - An object moving toward (away from) radar increases (decreases) the wave frequency slightly
  - From the sign and magnitude of the shift, velocity towards/away from radar is diagnosed
  - Note this technique permits only determination of **radial velocity**

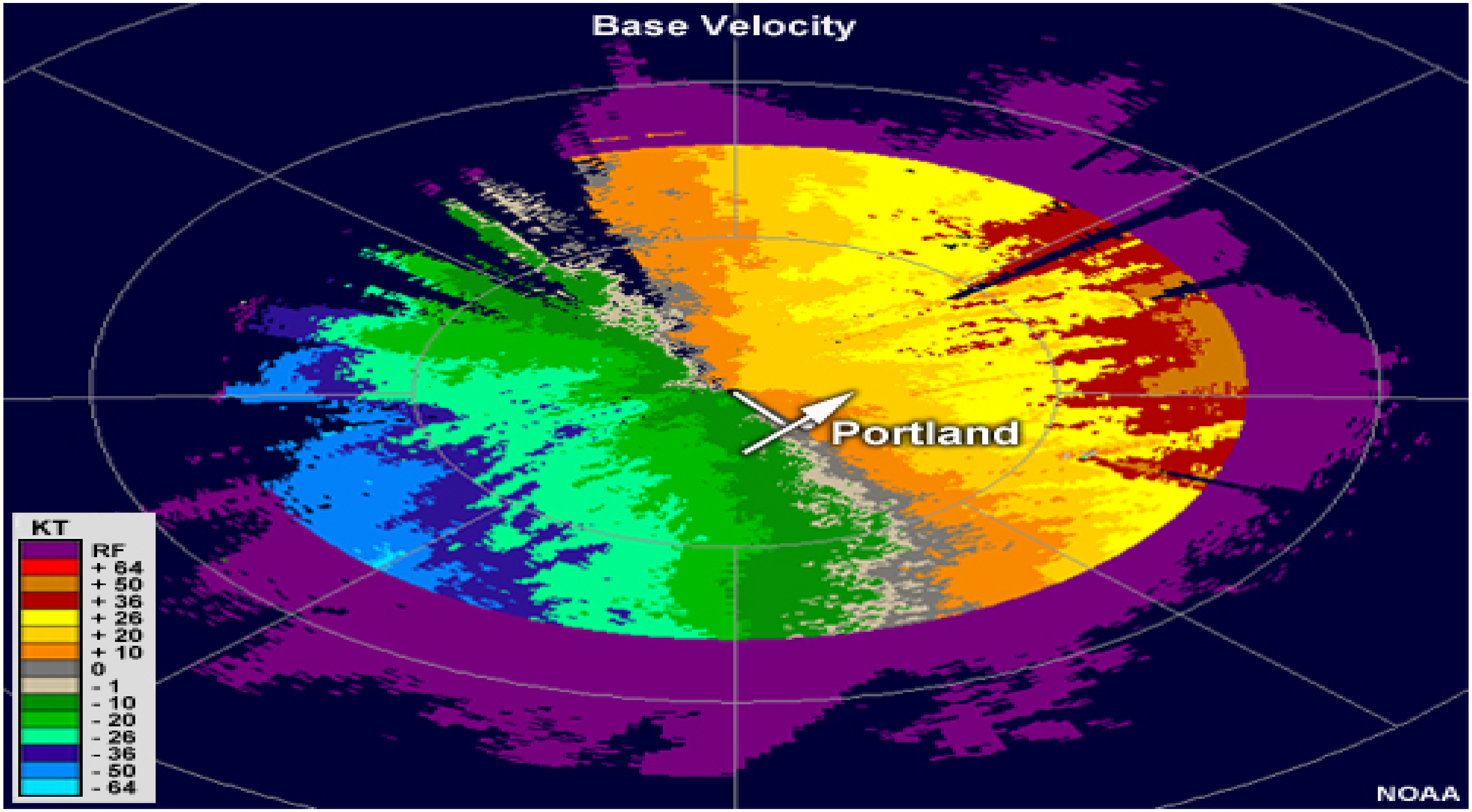
How a constant velocity wind is seen on radar



Flow is parallel to radar beam, so FULL velocity can be seen

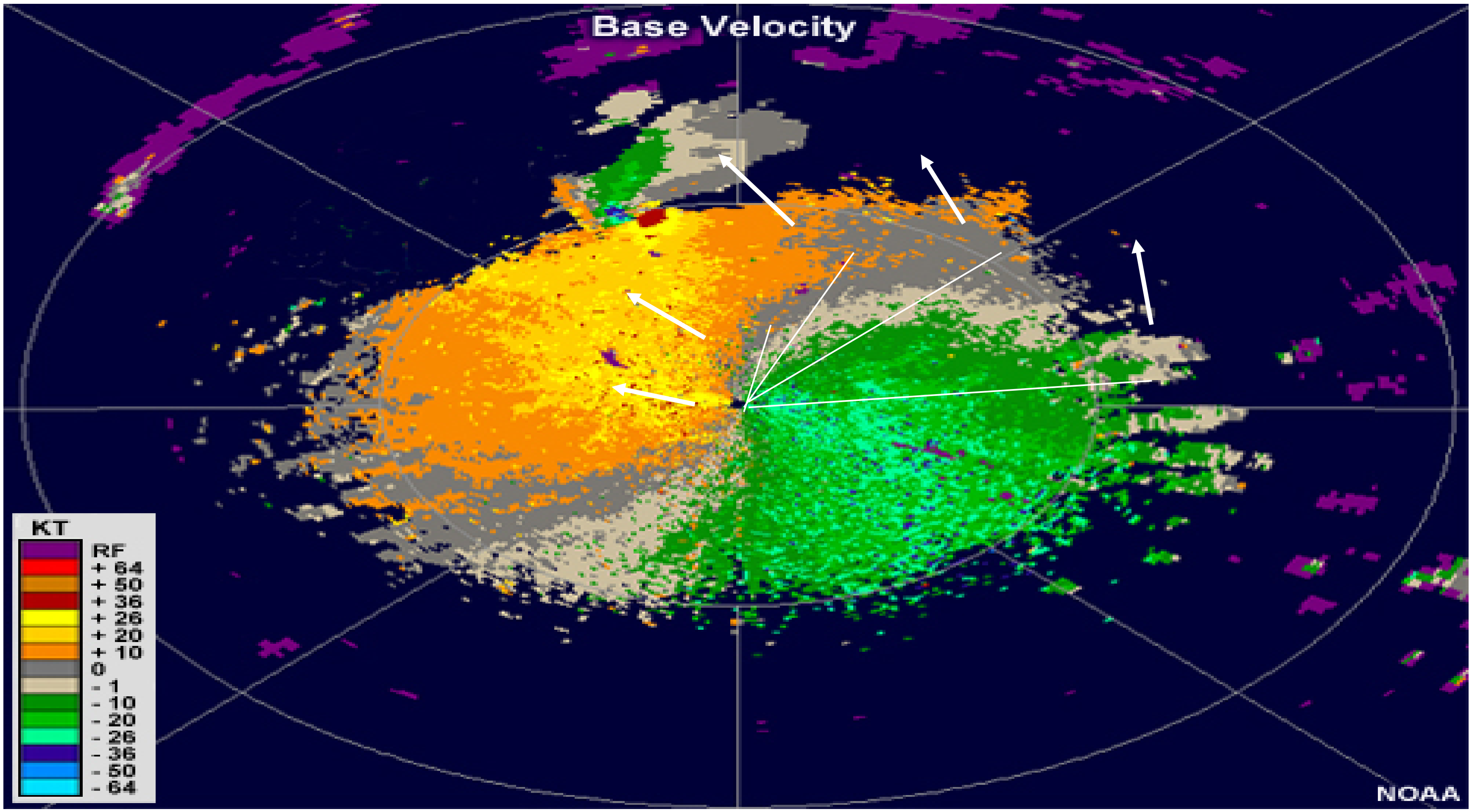
Flow is perpendicular to radar beam, so NO velocity can be seen

Radial velocity example



Cool colors = TOWARDS radar. Warm colors = AWAY from radar**. First task is to find radar**.
Purple area is range-folded; velocity cannot be determined.

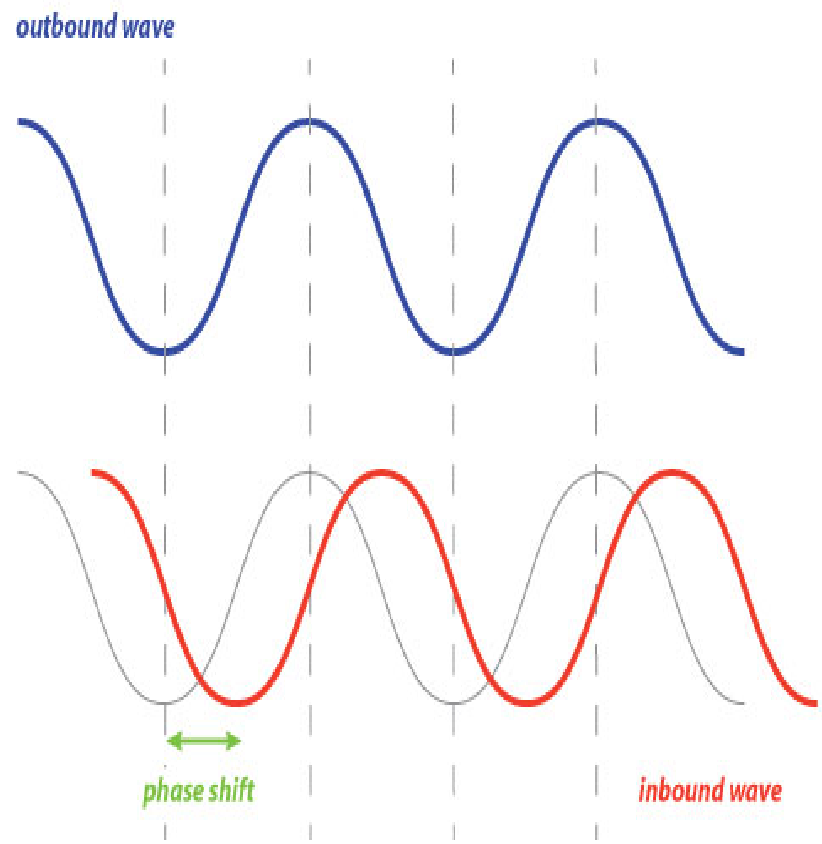
Echo revealing veering with height



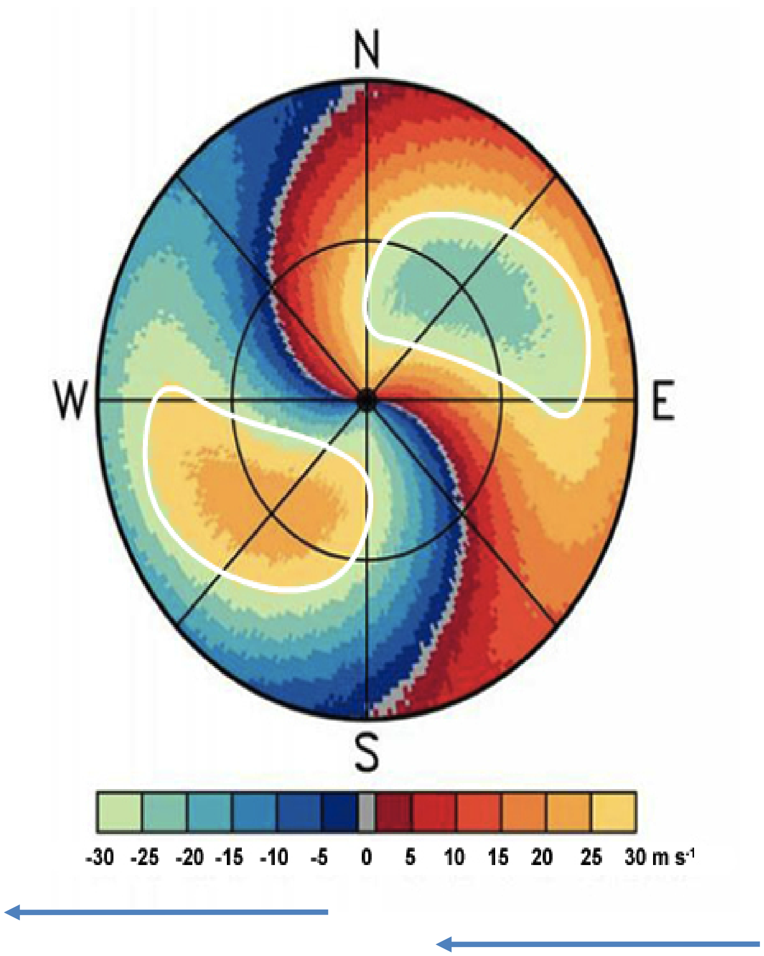
Use the zero radial velocity (grey) band. Know that beam elevation increases away from radar.
This example shows veering (CW turning) of wind with height.

A technical detail

- Doppler effect is a frequency shift, but radar receiver only samples a single frequency, so effect is manifested as a *phase* shift
  - Radar sends out a waveform
  - Based on return time, it expects a certain waveform back
  - Difference in phase between expected and observed related to velocity, which causes the shift

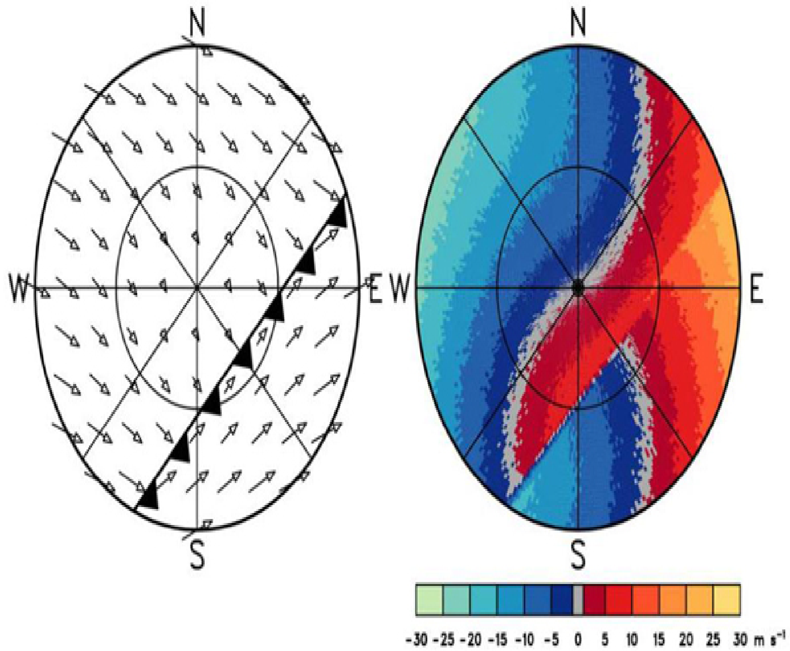


Velocity aliasing



- **Maximum** unambiguous phase shift is ±180˚, implying a Vmax
- Velocities larger than that become **aliased**, or velocity-folded
- Example contains wind at an elevation of first range ring that exceeds Vmax
  - In flow towards radar to SW, large outbound velocities appear owing to aliasing
  - Velocities just beyond –Vmax appear as just below +Vmax
- Often, but not always, corrected in radar post-processing
- (Note veering with height in the winds. What would backing look like?)

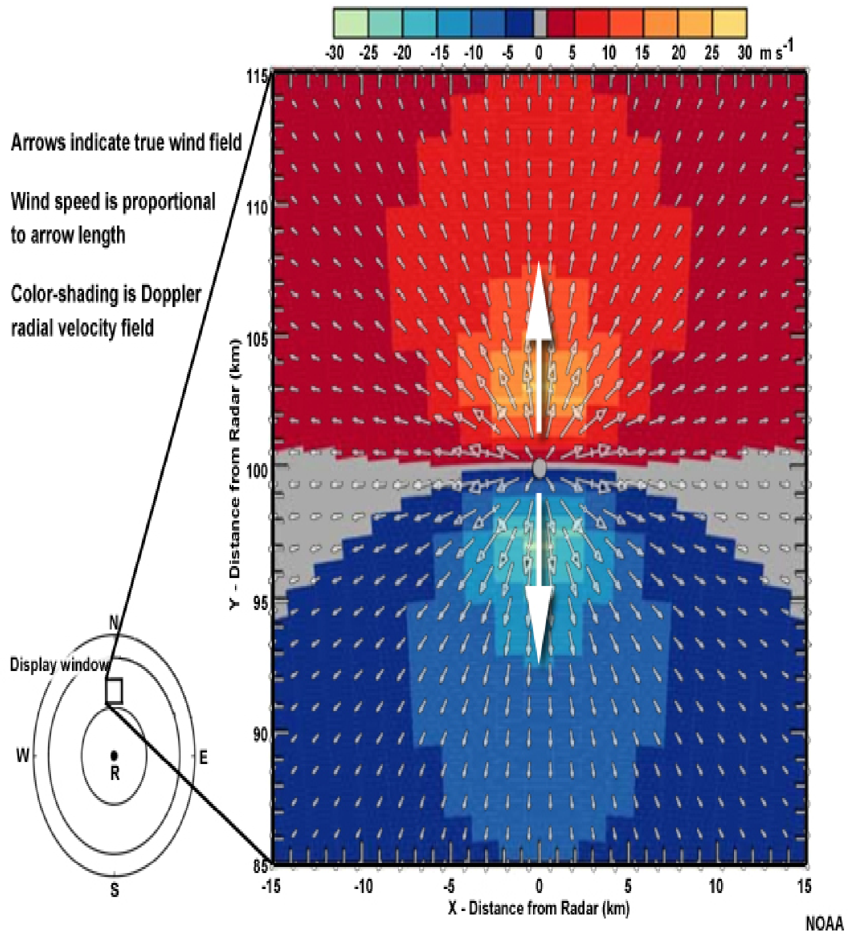
Front seen on radar



NOAA

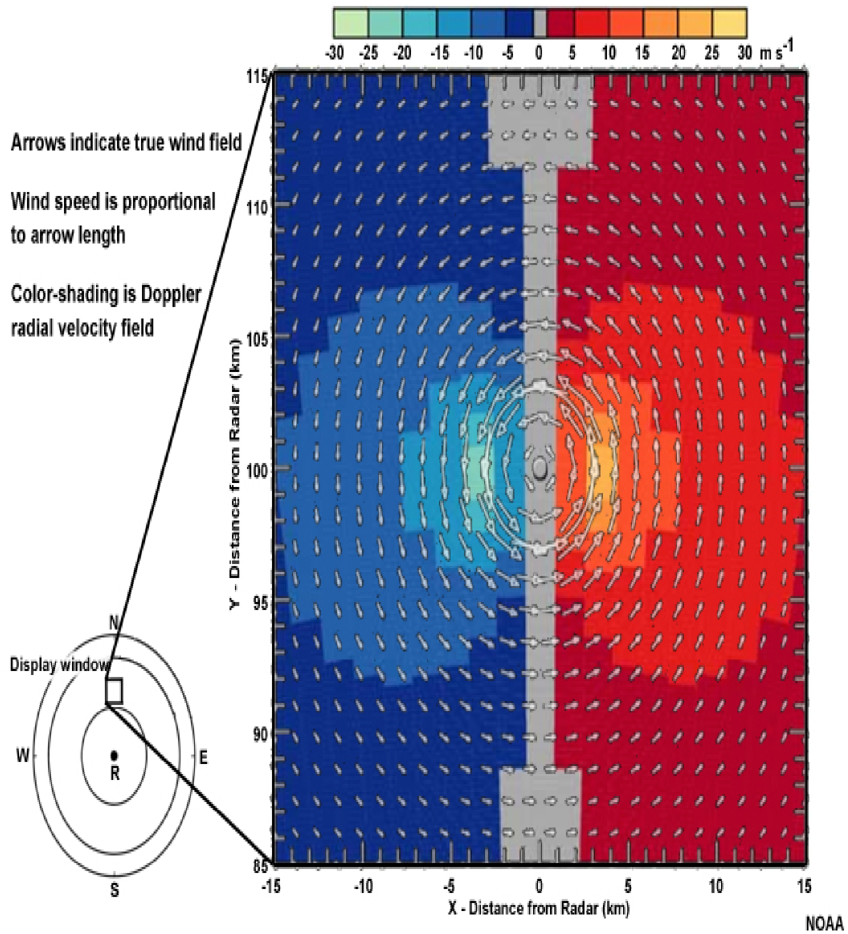
- Discontinuity in velocity associated with front
- Backing winds in cold air sector
- Veering in warm air sector

Velocity couplets



- Velocity couplets can represent rotation or convergence/divergence, depending on orientation relative to radar beam
- Here, couplet is N of radar and consists of outbound just beyond inbound flow. Divergence signature, perhaps of a downburst/downdraft

Velocity couplets

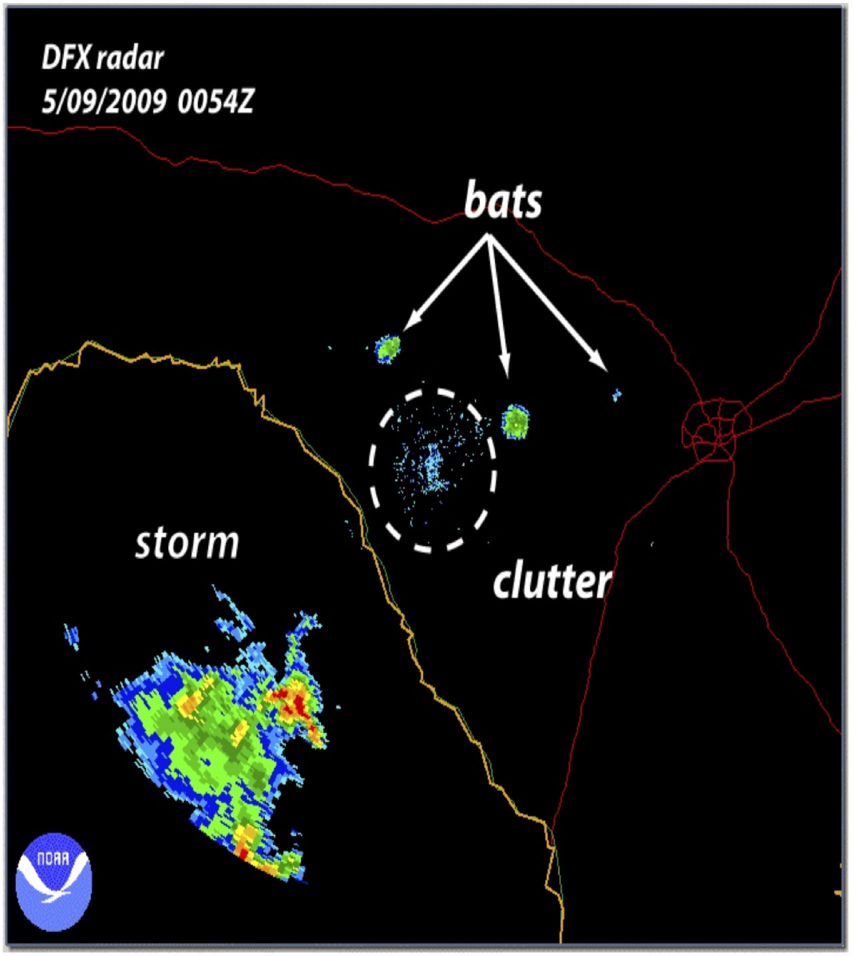


- This couplet is also N of radar, but rotated 90˚. This makes for inbound flow to the west of outbound flow. Cyclonic rotation.

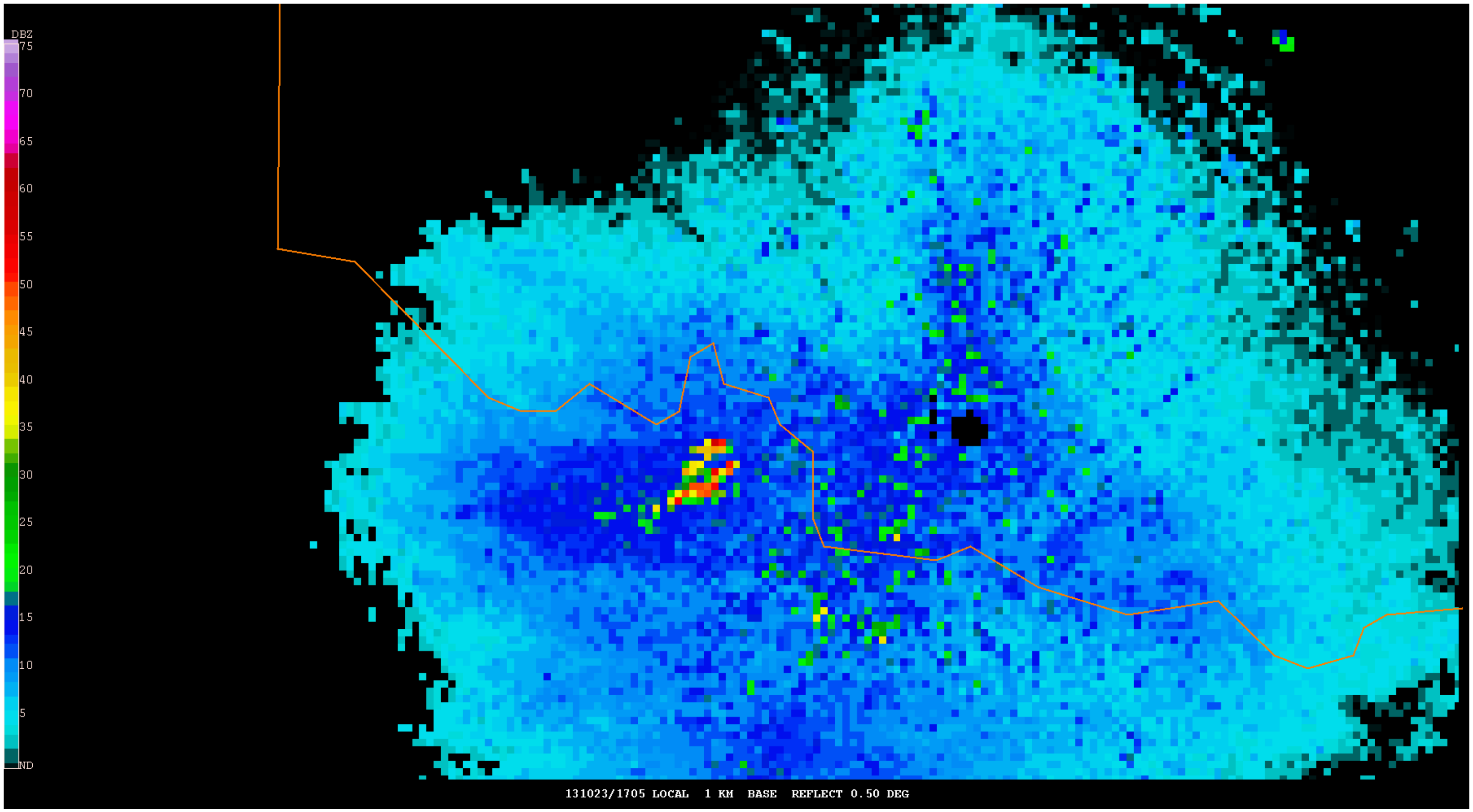
Some radar features

Not everything you see is meteorological!

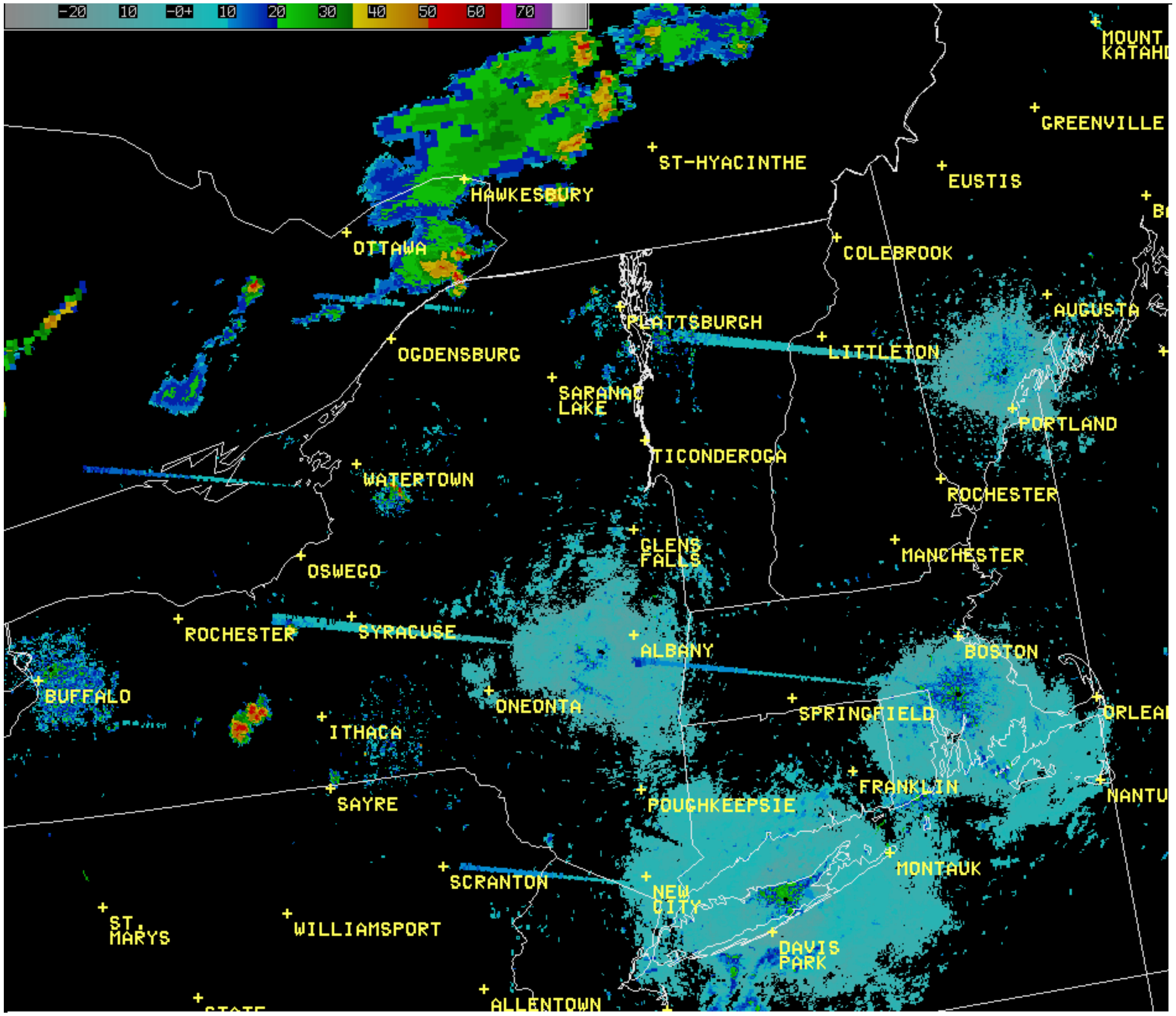
- High reflectivity to SW of radar is precipitation
- Ground clutter near radar represents trees, buildings, insects, dust, smoke, ocean/lake waves, etc..
- This image was taken just after sunset, and captured bats emerging from caves
- Expanding circular patterns around sunrise can be created by birds



Echoes from a Wind Farm



Sun Spike



-20
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-0+
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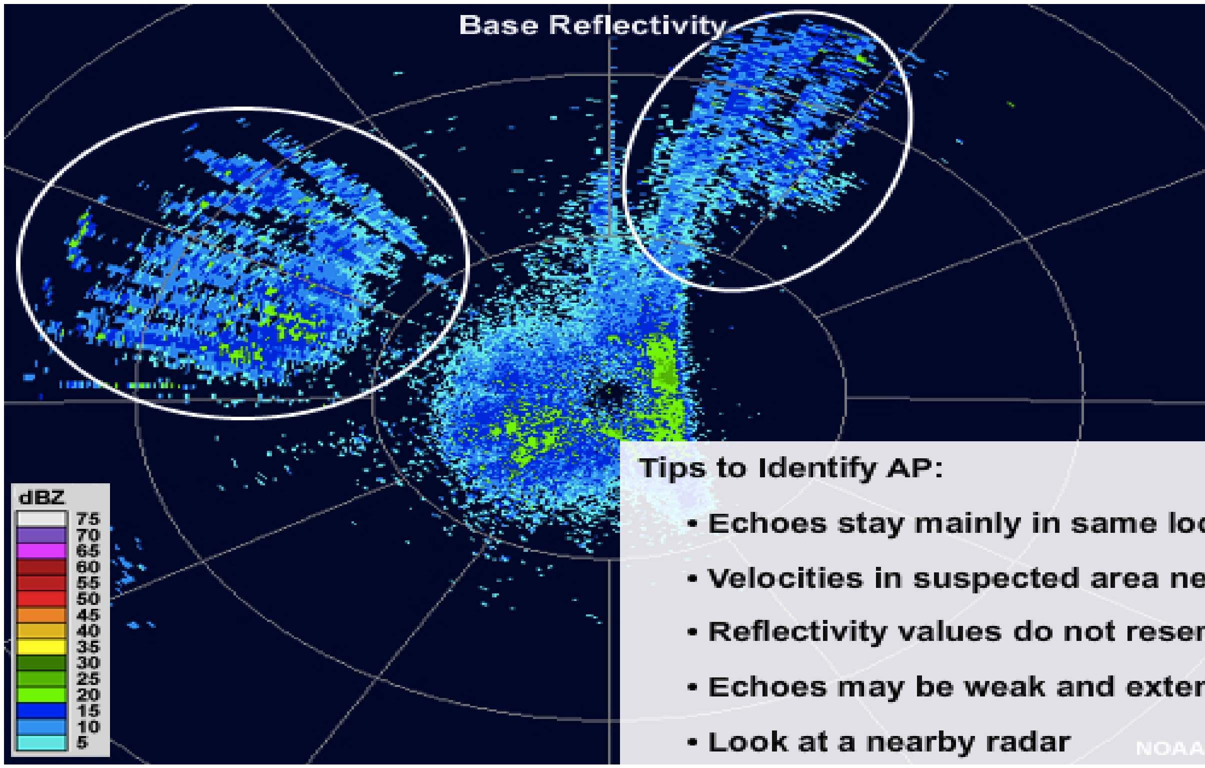
70
MOUNT
GREENVILLE
ST-HYACINTHE
EUSTIS
HAWKESBURY
OTTAWA
COLEBROOK
AUGUSTA
PLATTSBURGH
LITTLETON
OGDENSBURG
SARANAC
LAKE
PORTLAND
TICONDEROGA
WATERTOWN
ROCHESTER
GLENS
FALLS
MANCHESTER
OSWEGO
ROCHESTER
SYRACUSE
ALBANY
BOSTON
BUFFALO
ONEONTA
SPRINGFIELD
ITHACA
FRANKLIN
SAYRE
POUGHKEEPSIE
MONTAUK
SCRANTON
NEW
CITY
ST.
MARYS
WILLIAMSPORT
DAVIS
PARK
ALLENTOWN

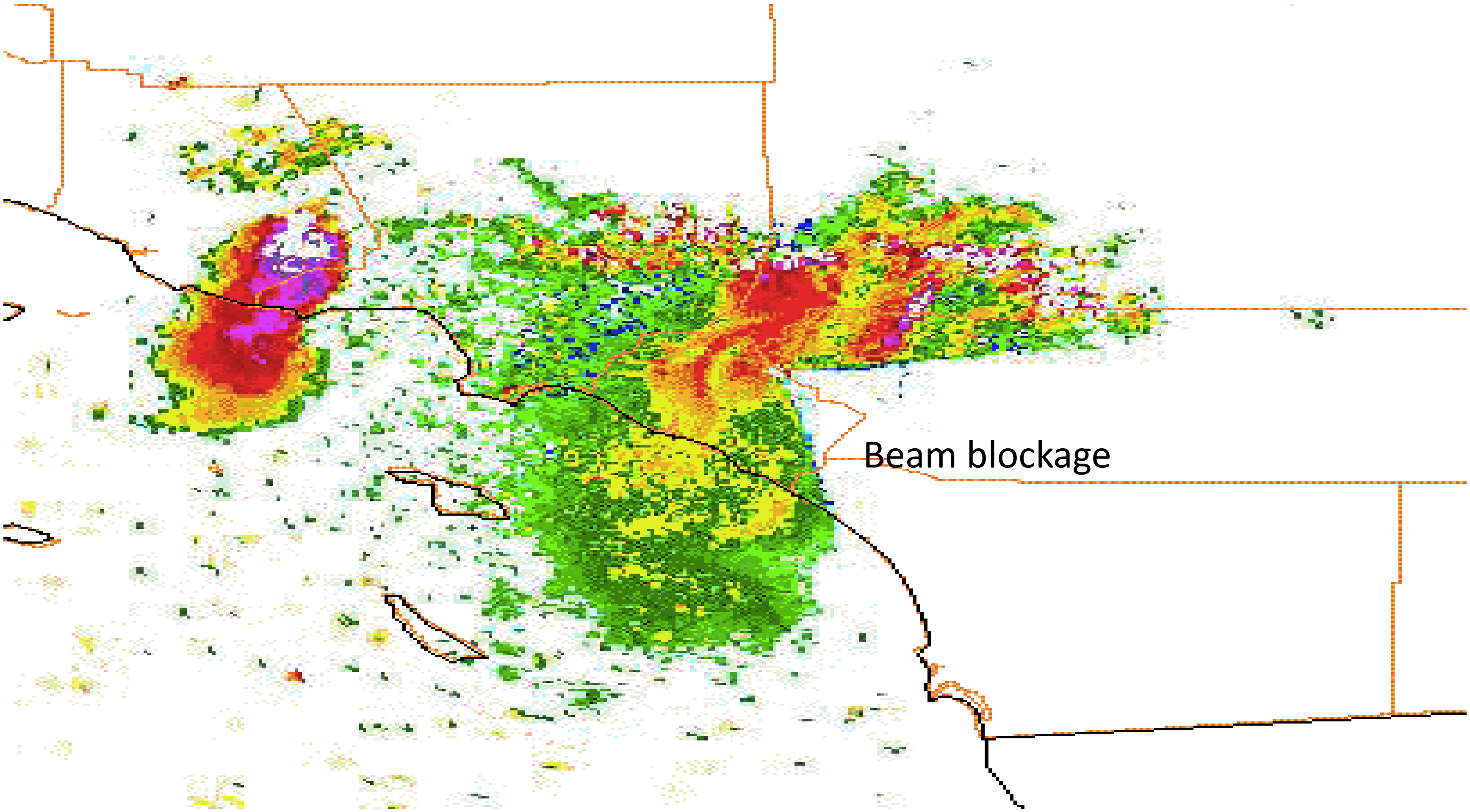
Anomalous Propagation



Tips to Identify AP:

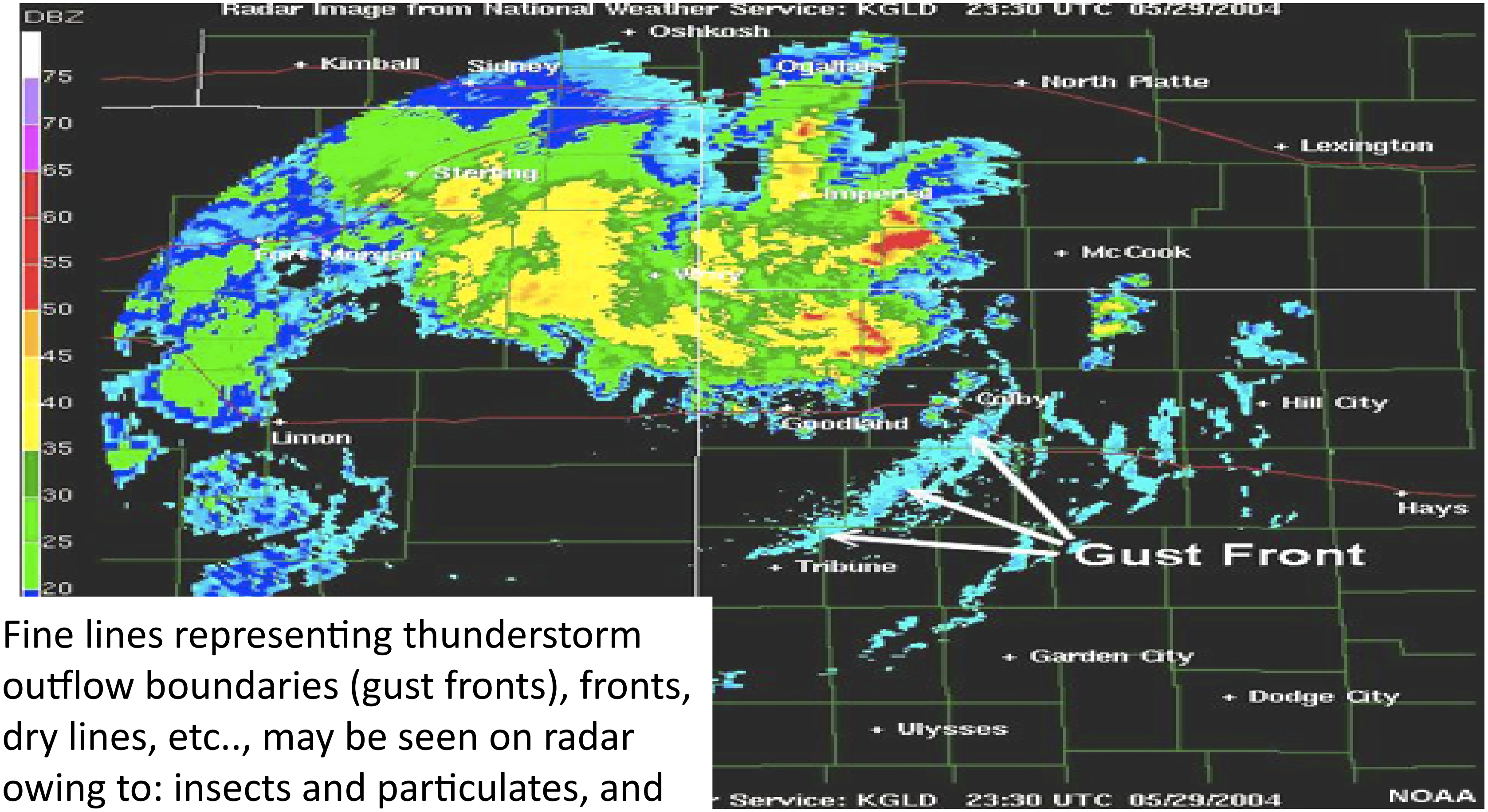
- Echoes stay mainly in same location
- Velocities in suspected area nearly zero
- Reflectivity values do not resemble precipitation patterns
- Echoes may be weak and extend for great distances
- Look at a nearby radar
- Look at recent satellite data
- Look at most recent local sounding
- Look at a map of local topography

Smoke from fires



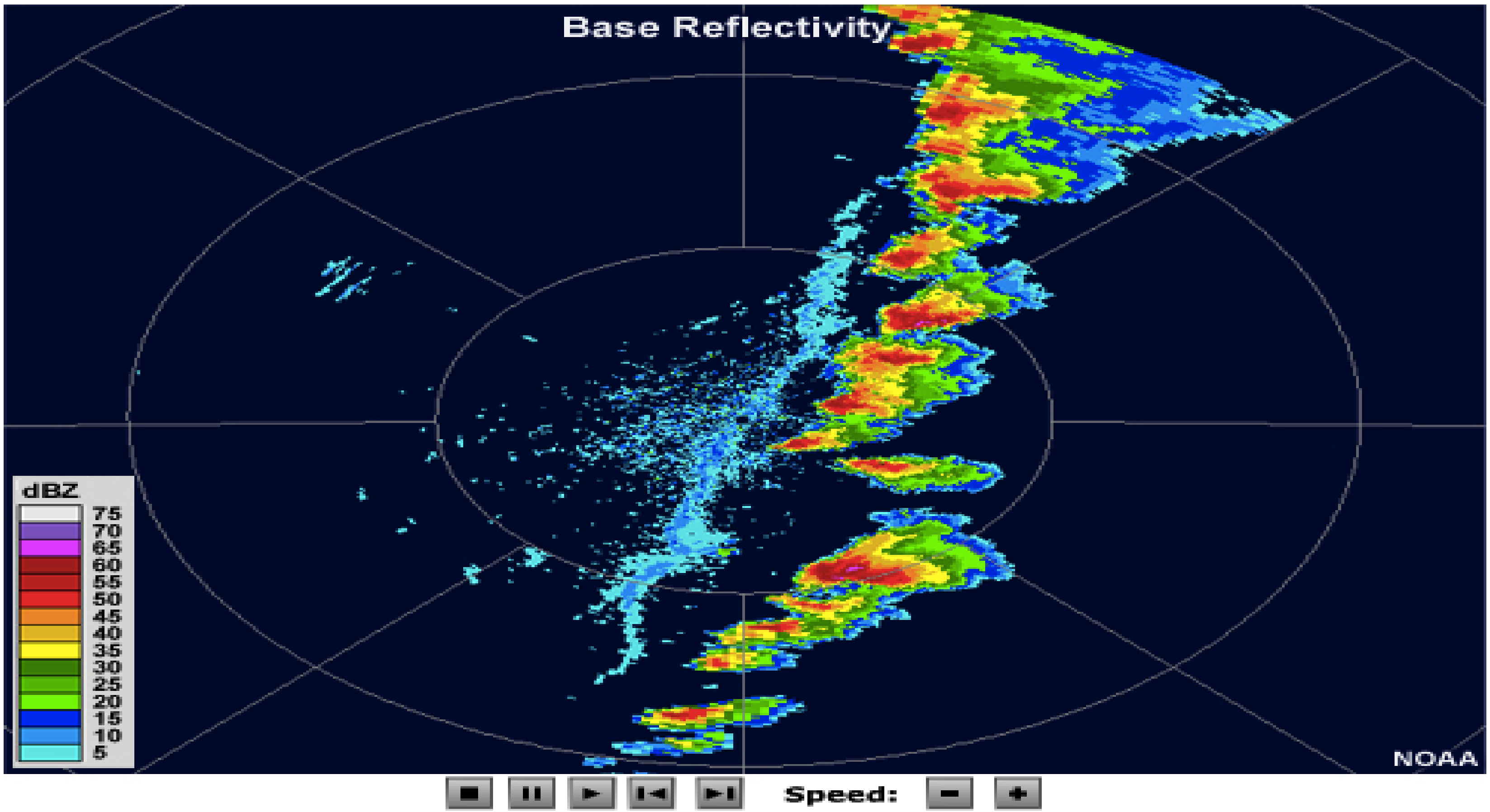
Oct 2003

Radar fine lines

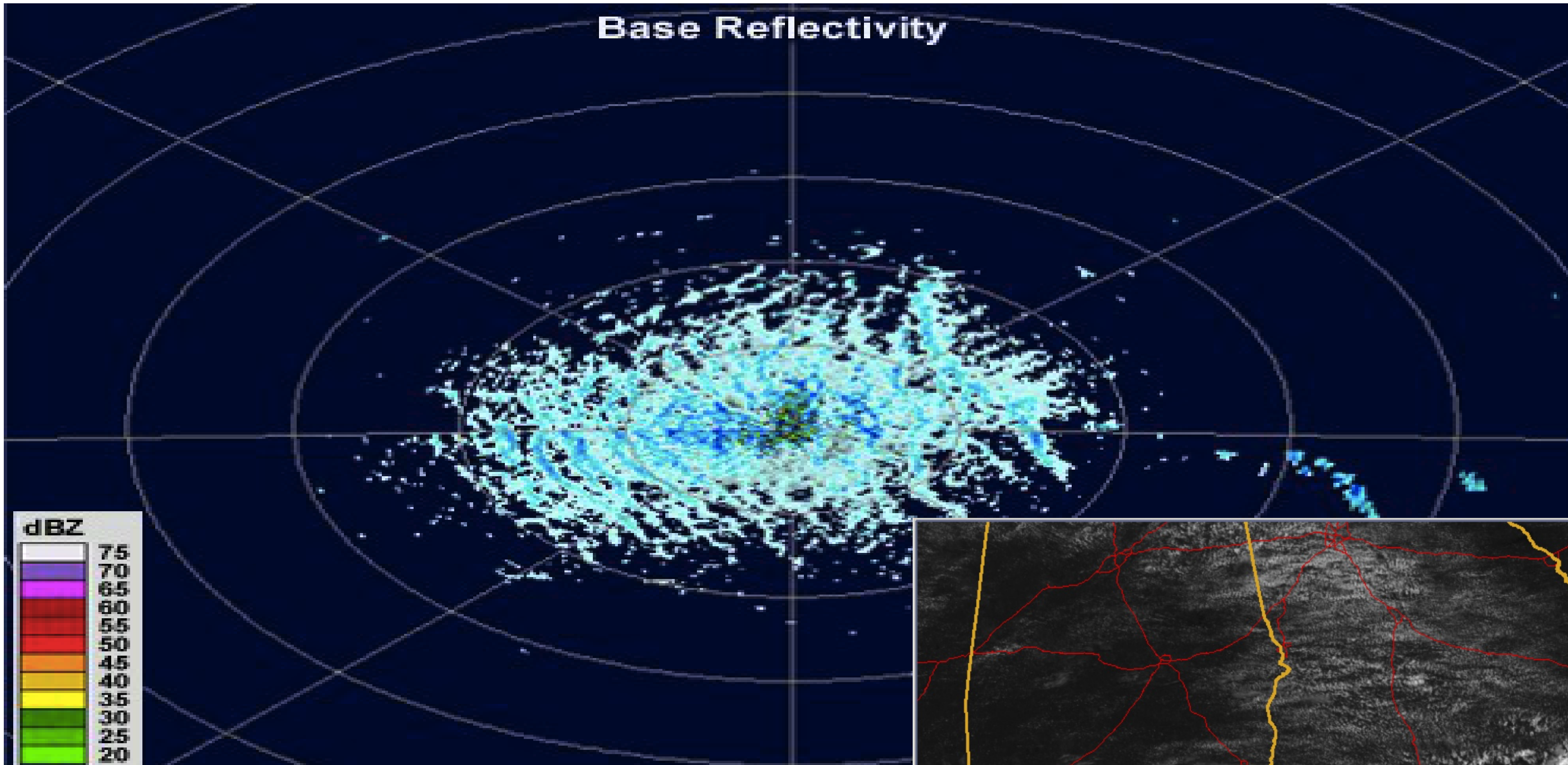


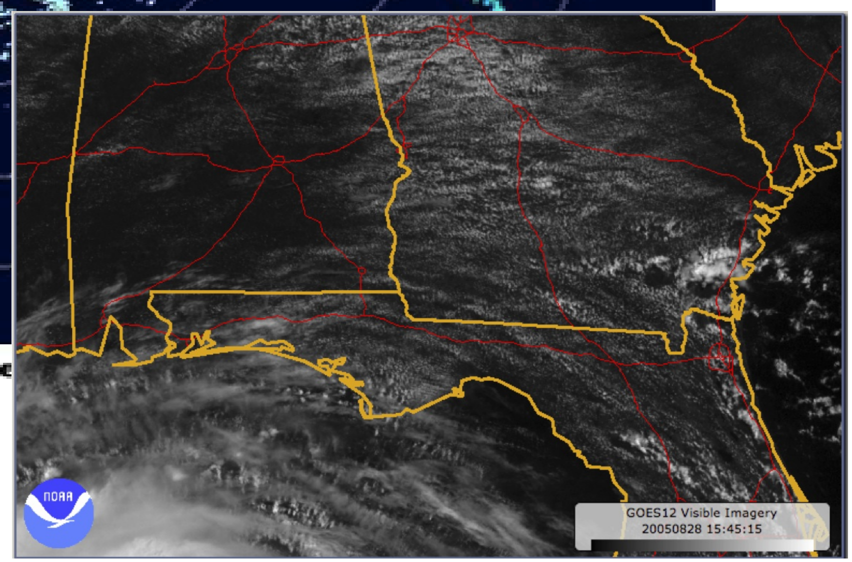
Fine lines representing thunderstorm outflow boundaries (gust fronts), fronts, dry lines, etc.., may be seen on radar owing to: insects and particulates, and refraction owing to inversions and moisture discontiuities

Storms ahead of a radar fine line

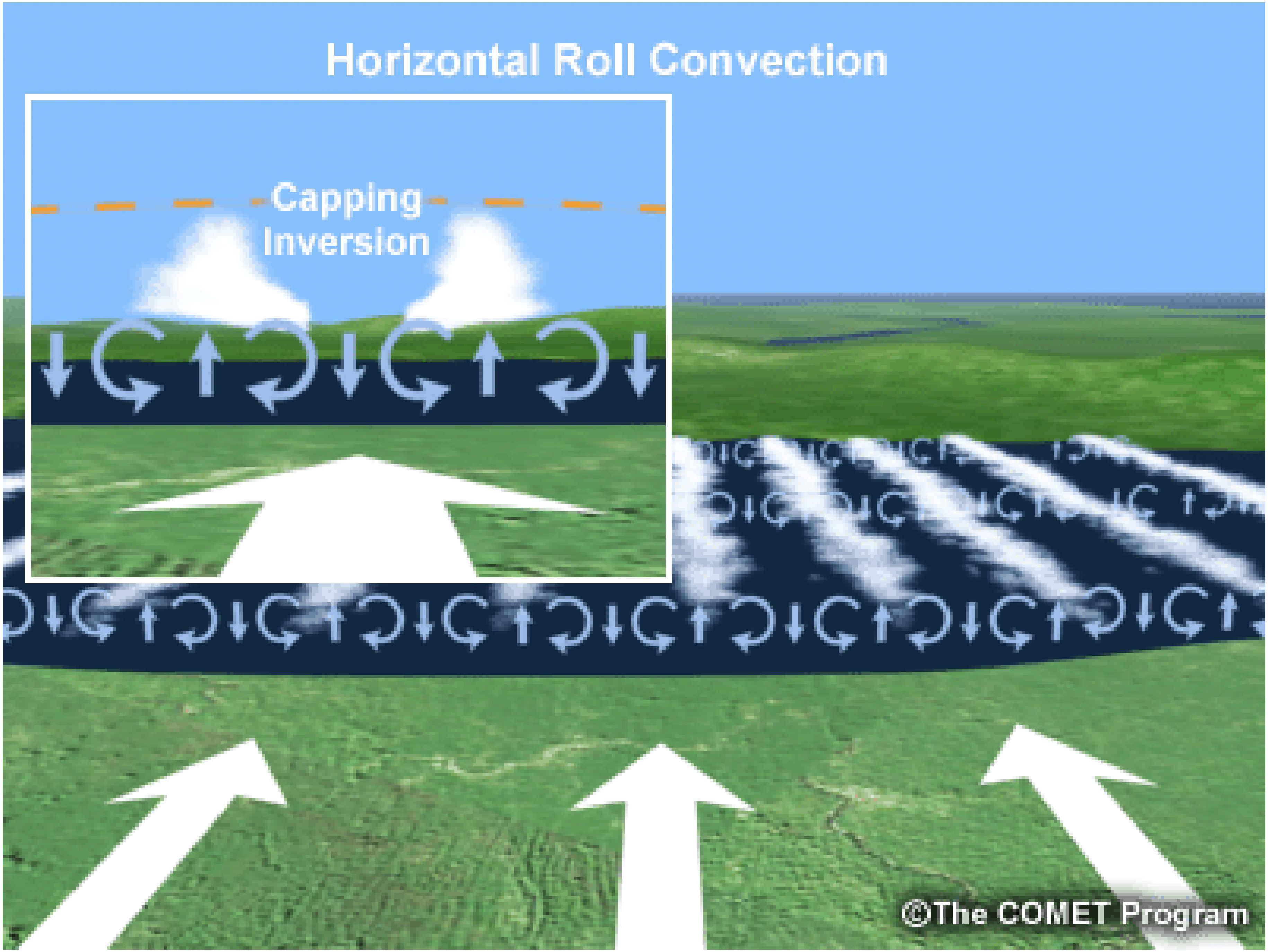


Horizontal convective rolls





HCRs seen on radar and satellite
(not the same case)



Horizontal Roll Convection
Capping
Inversion
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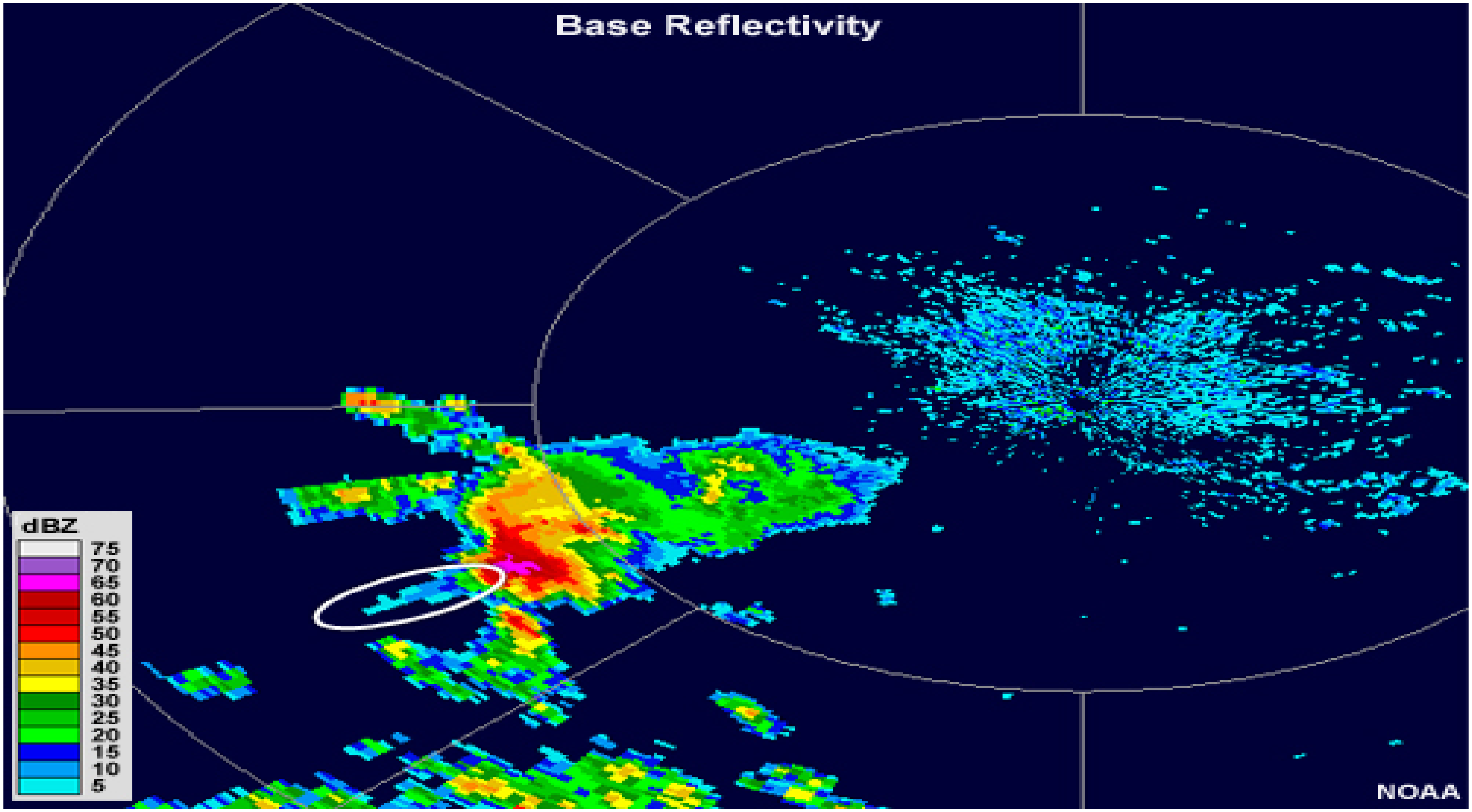
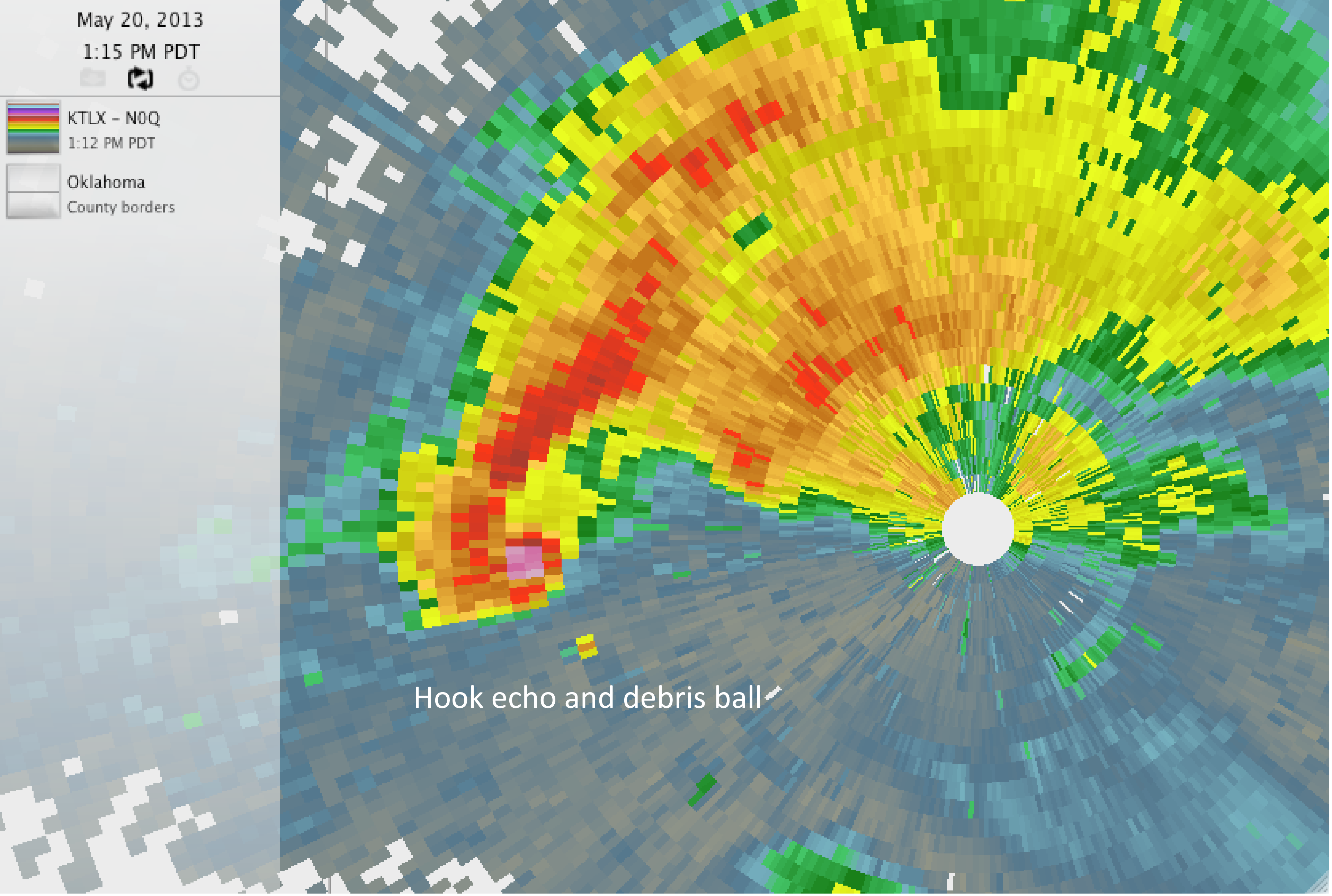
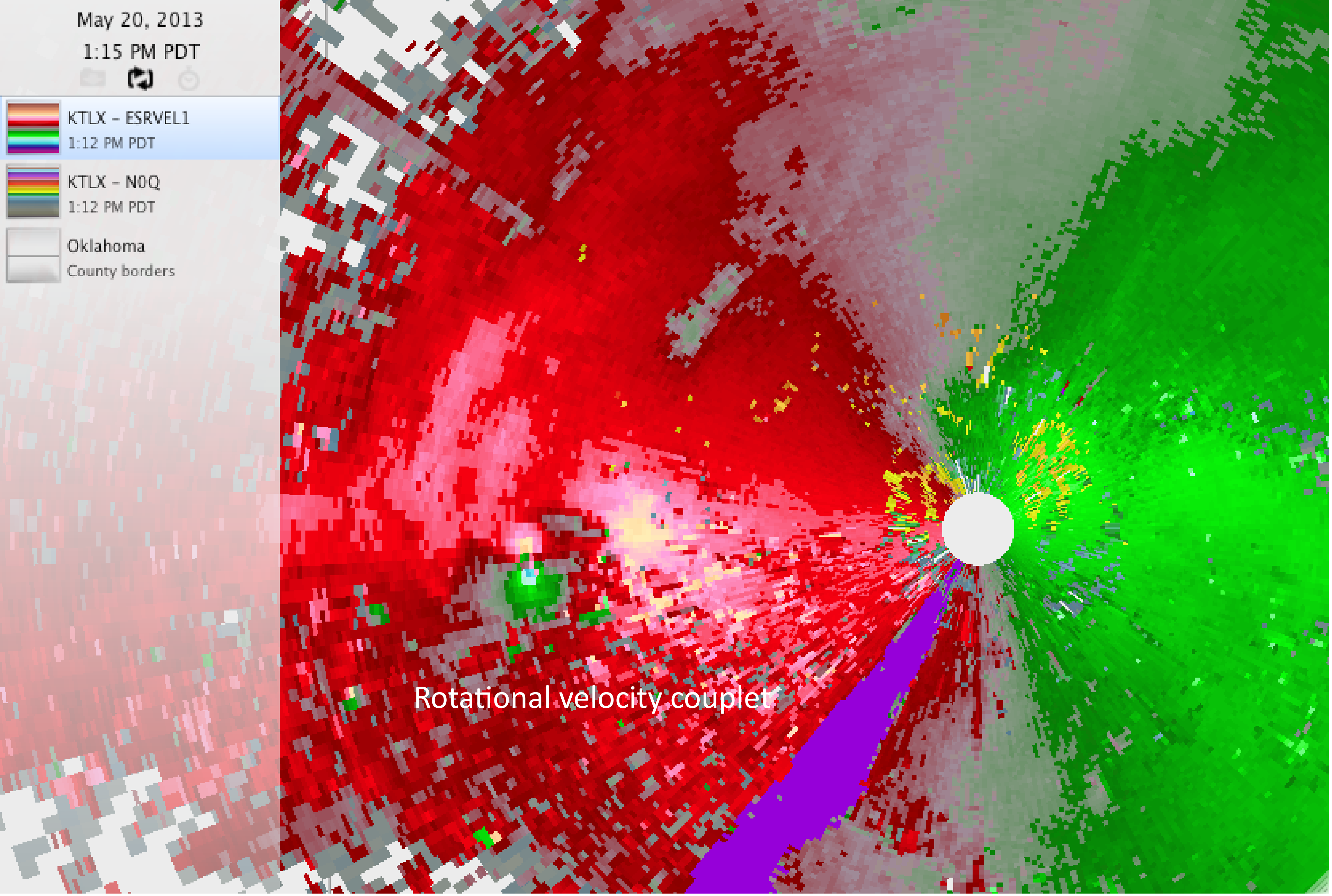
Scatter spikes



Scatter spike extending radially outward from a strong echo, caused by radar waves being scattered to surface by large hail, back into storm, and then towards radar. Large hail indicator.

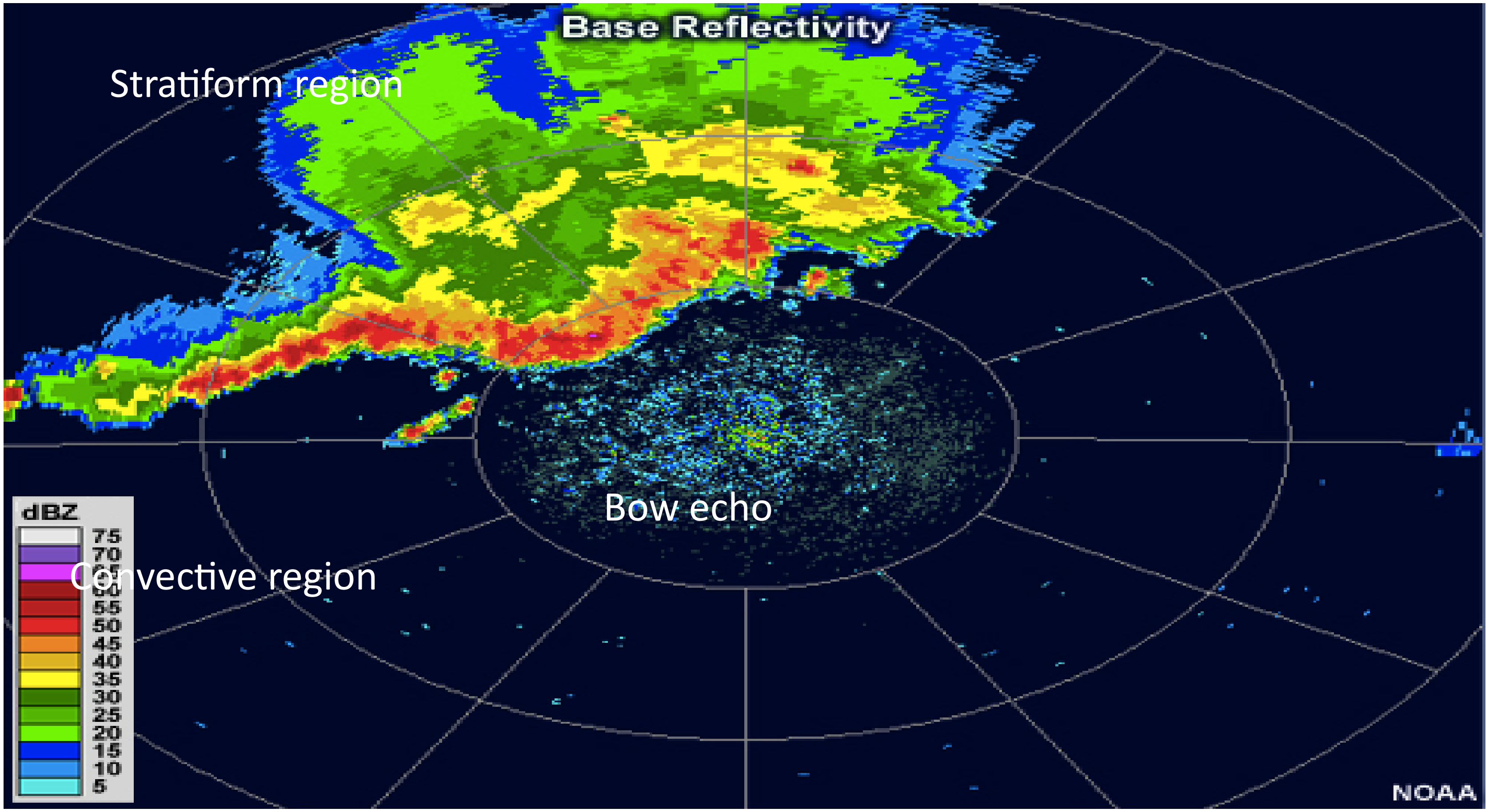


TLX radar (Oklahoma City) 2015Z – Newcastle/Moore tornado, 20 May 2013

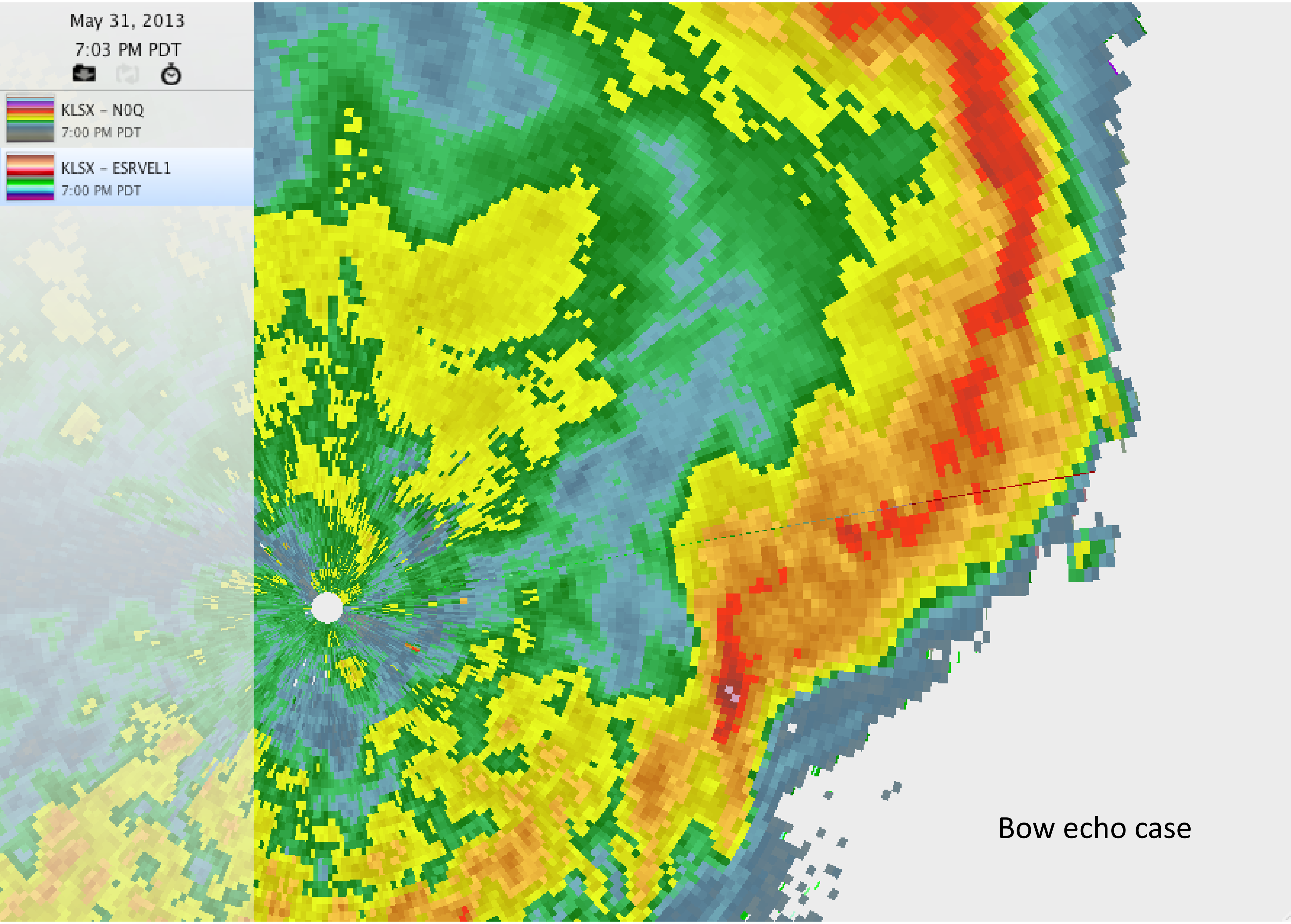


TLX radar (Oklahoma City) 2015Z – Newcastle/Moore tornado, 20 May 2013

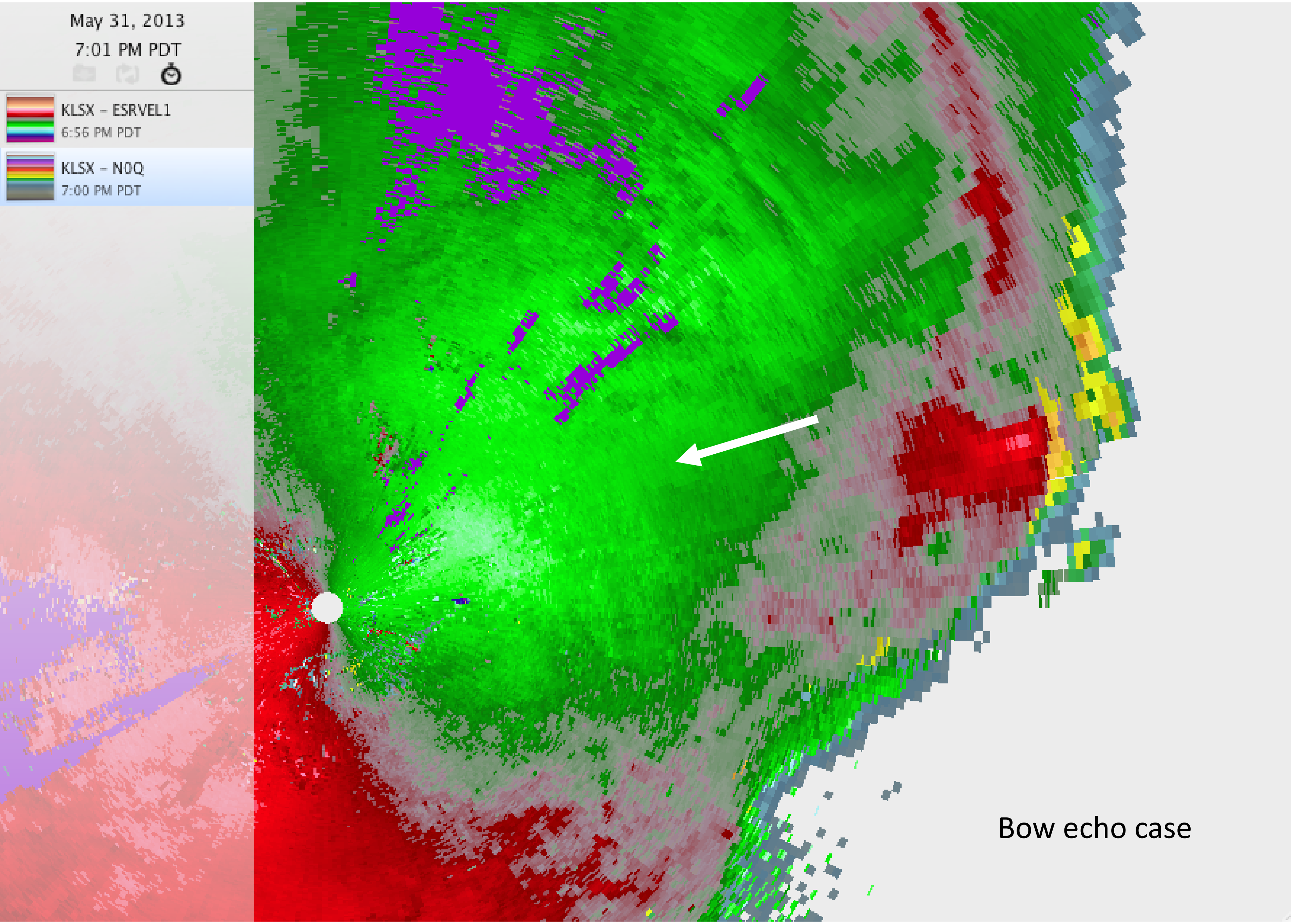
Line-oriented storms



Bowing segments often associated with strong (straight-line) surface winds

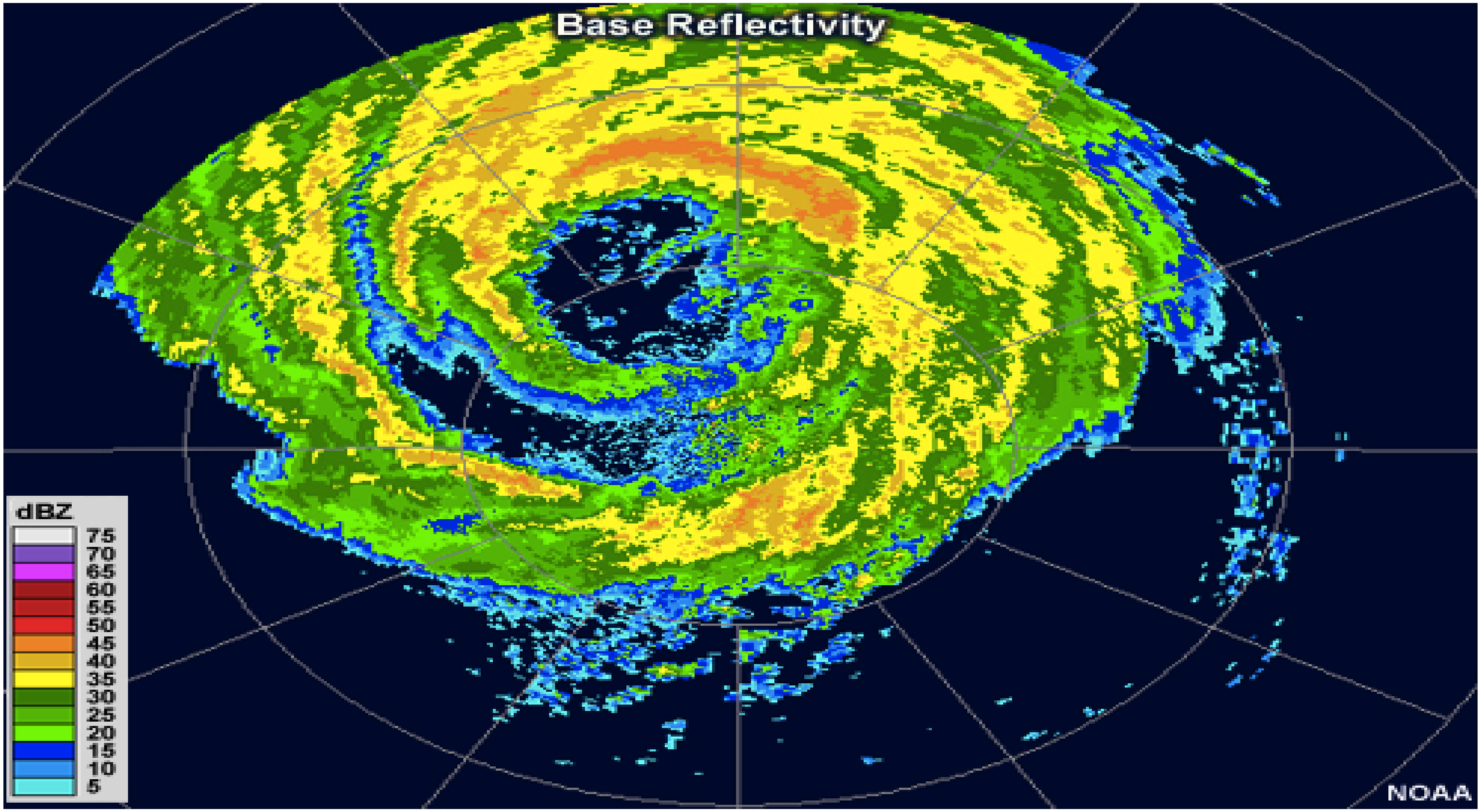


Bow echo case

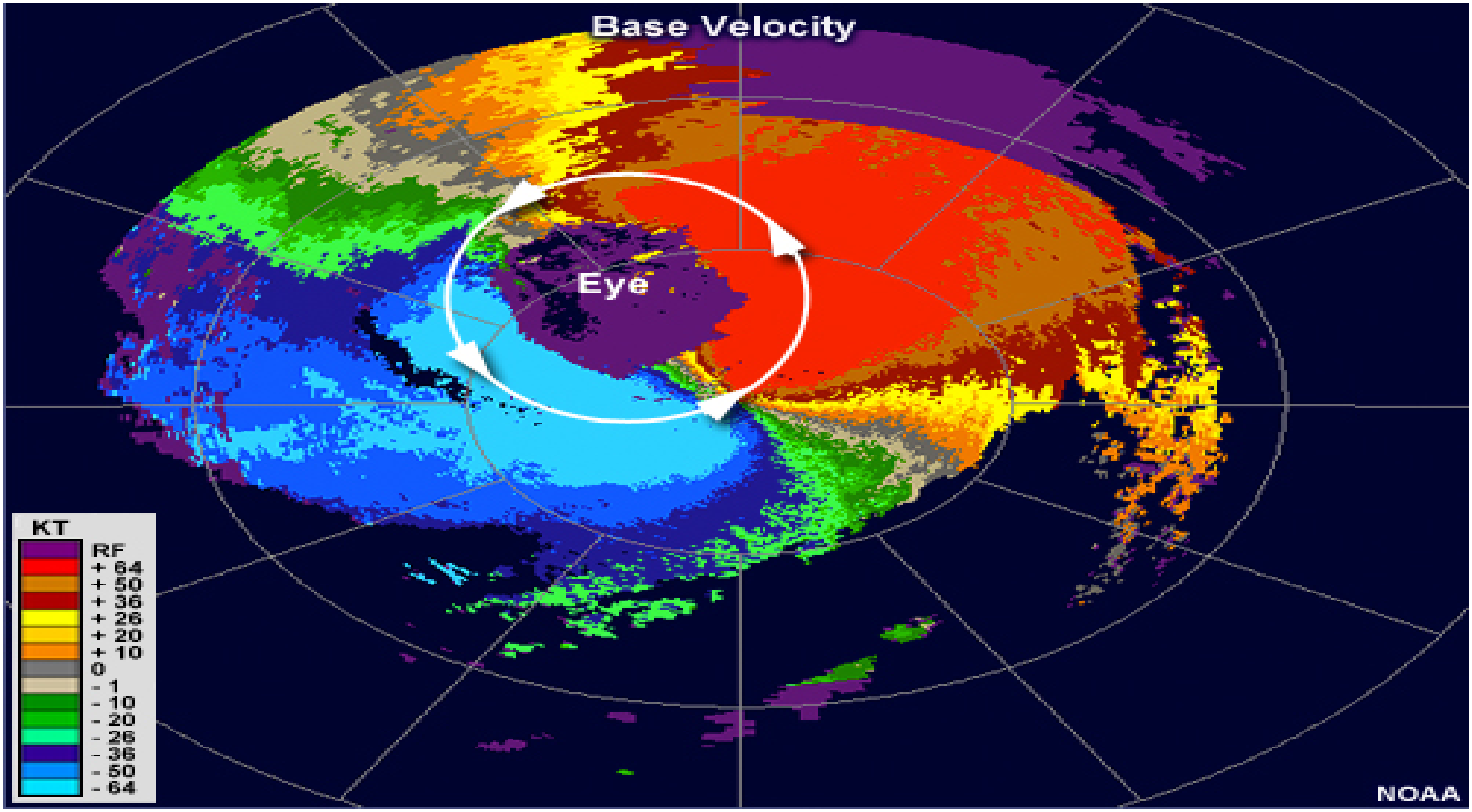


Bow echo case

Tropical cyclones



Tropical cyclones



Solid vs. liquid precipitation

- Snow echo often appears grainy or fuzzy, with weak reflectivity gradients, on radar
- Dry, powdery snow has relatively low reflectivity.
  - Considering only dBZ may lead to underestimating precipitation amounts and coverage.
  - Low dBZ snow banding can result in large snowfalls
- Wet snow has much higher reflectivity but gradients still usually weak and echoes fuzzy