Basic Principles of Weather Radar

Basis of Presentation

- Introduction to Radar
- Basic Operating Principles
- Reflectivity Products
- Doppler Principles
- Velocity Products
- Non-Meteorological Targets
- Summary

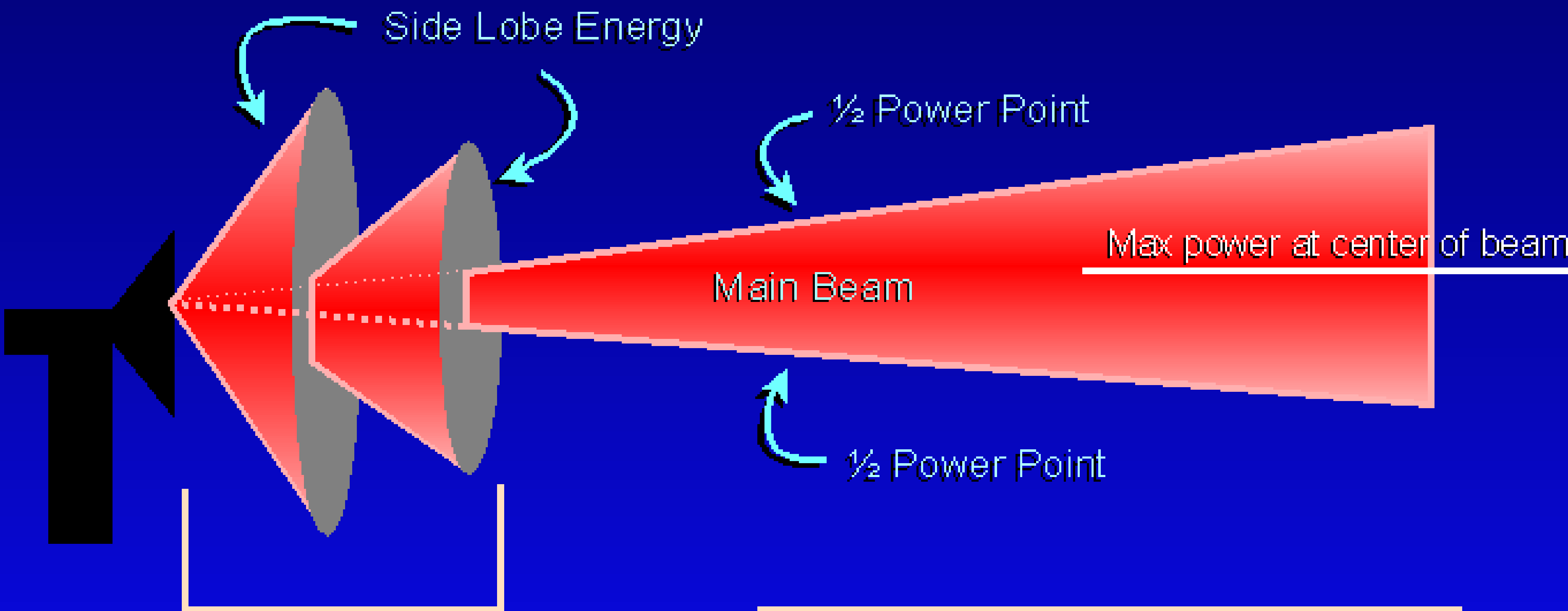
Radar

- RAdio Detection And Ranging
- Developed during WWII for detecting enemy aircraft
- *Active* remote sensor
  - Transmits and receives pulses of E-M radiation
  - Satellite is *passive* sensor (receives only)
- Numerous applications
  - Detection/analysis of meteorological phenomena
  - Defense
  - Law Enforcement
  - Baseball

Weather Surveillance Radar

- Transmits very short pulses of radiation
  - Pencil beam (narrow cone) expands outward
  - Pulse duration ~ 1 μs (7 seconds per hour)
  - High transmitted power (~1 megawatt)
- 'Listens' for returned energy ('echoes')
  - Listening time ~ 1 ms (59:53 per hour)
  - Very weak returns (~10^{-10} watt)
- Transmitted energy is scattered by objects on ground and in atmosphere
  - Precipitation, terrain, buildings, insects, birds, etc.
  - Fraction of this scattered energy goes back to radar

Beam Power Structure



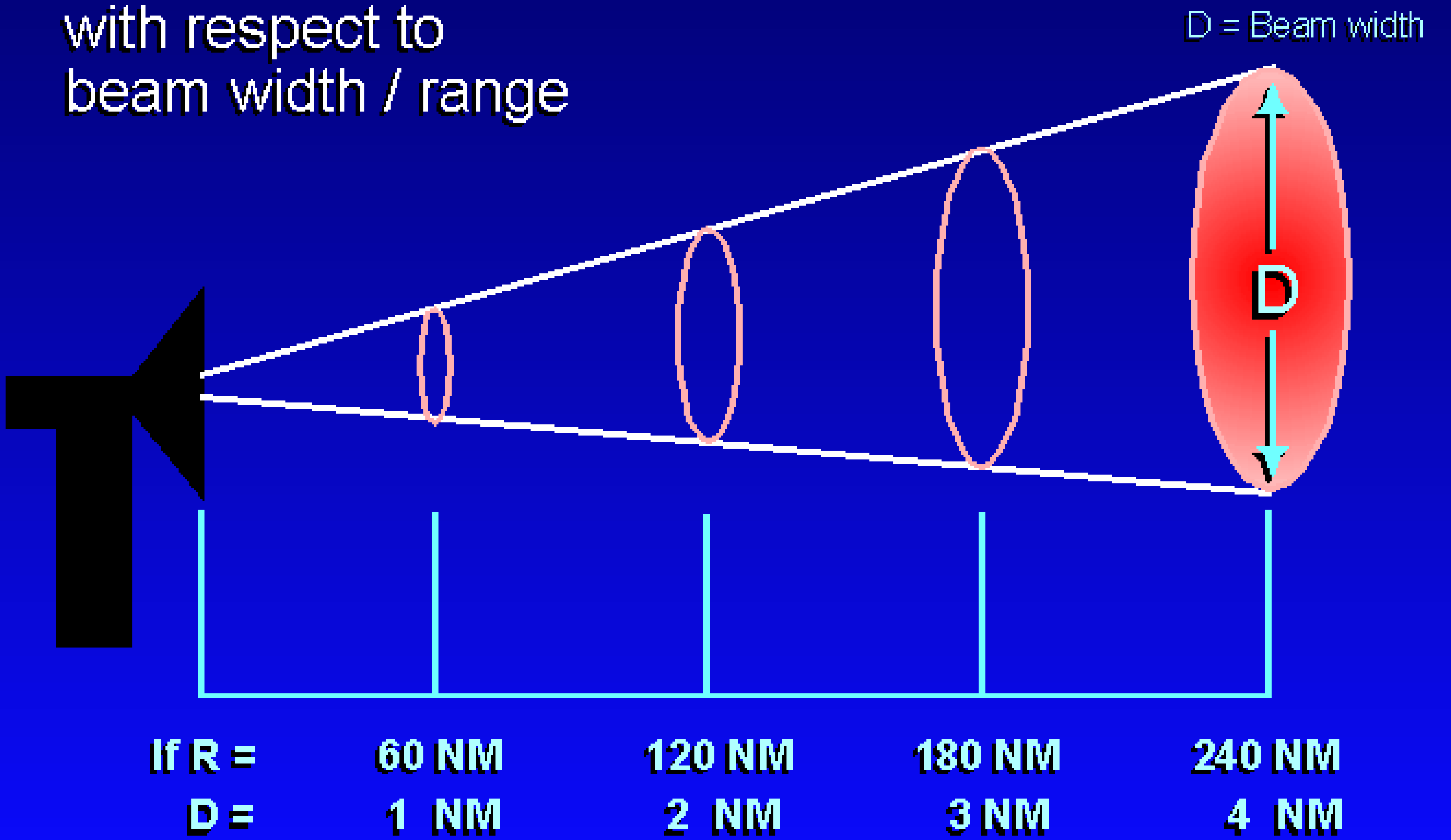
Side lobes cause most of the clutter in close proximity to the radar

The **Radar Beam** is defined by the ½ power points.

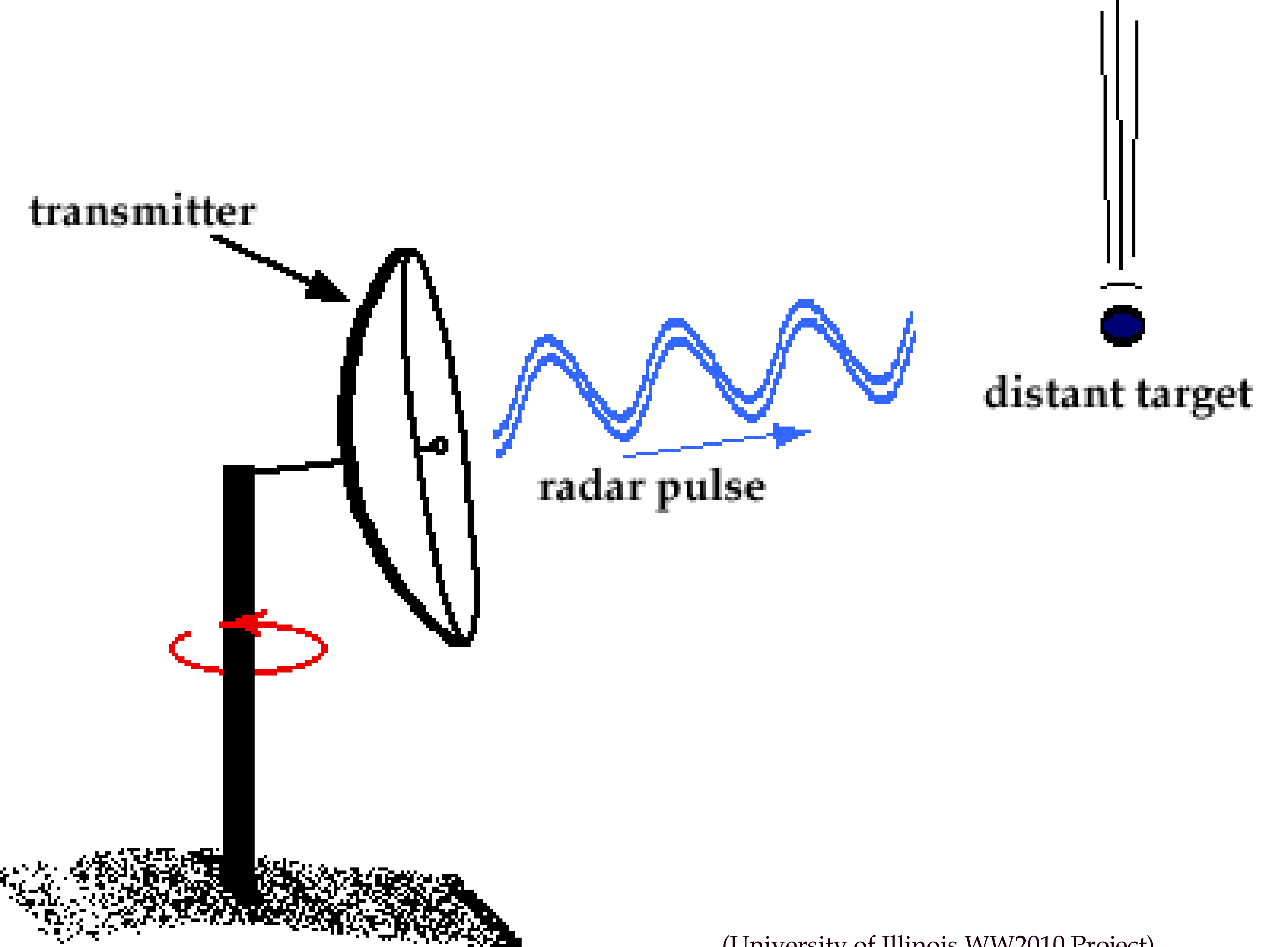
(http://www.crh.noaa.gov/mkx/radar/part1/slide2.html)

.96 Degree Beam Resolution

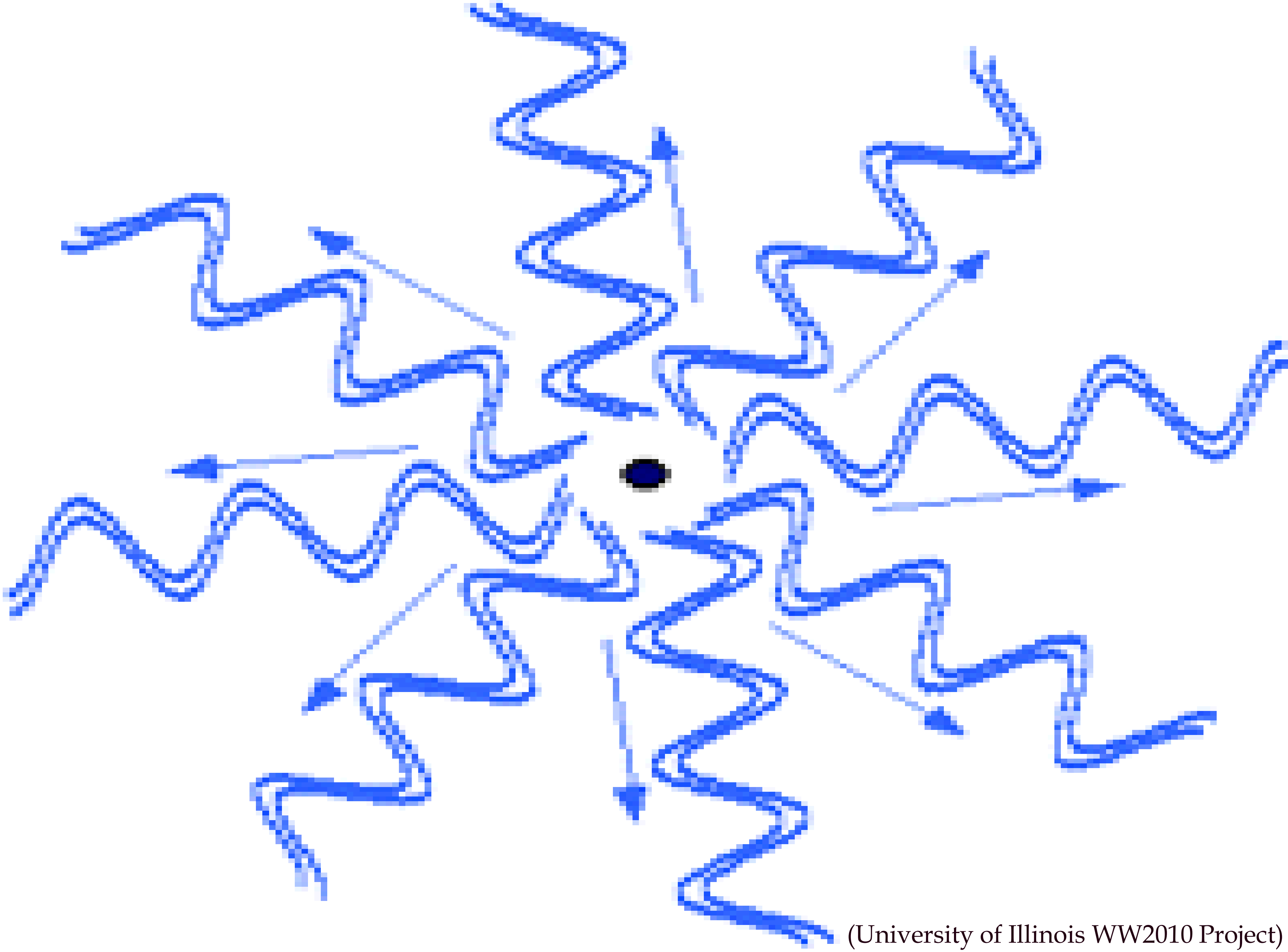
Radar resolution
with respect to
beam width / range



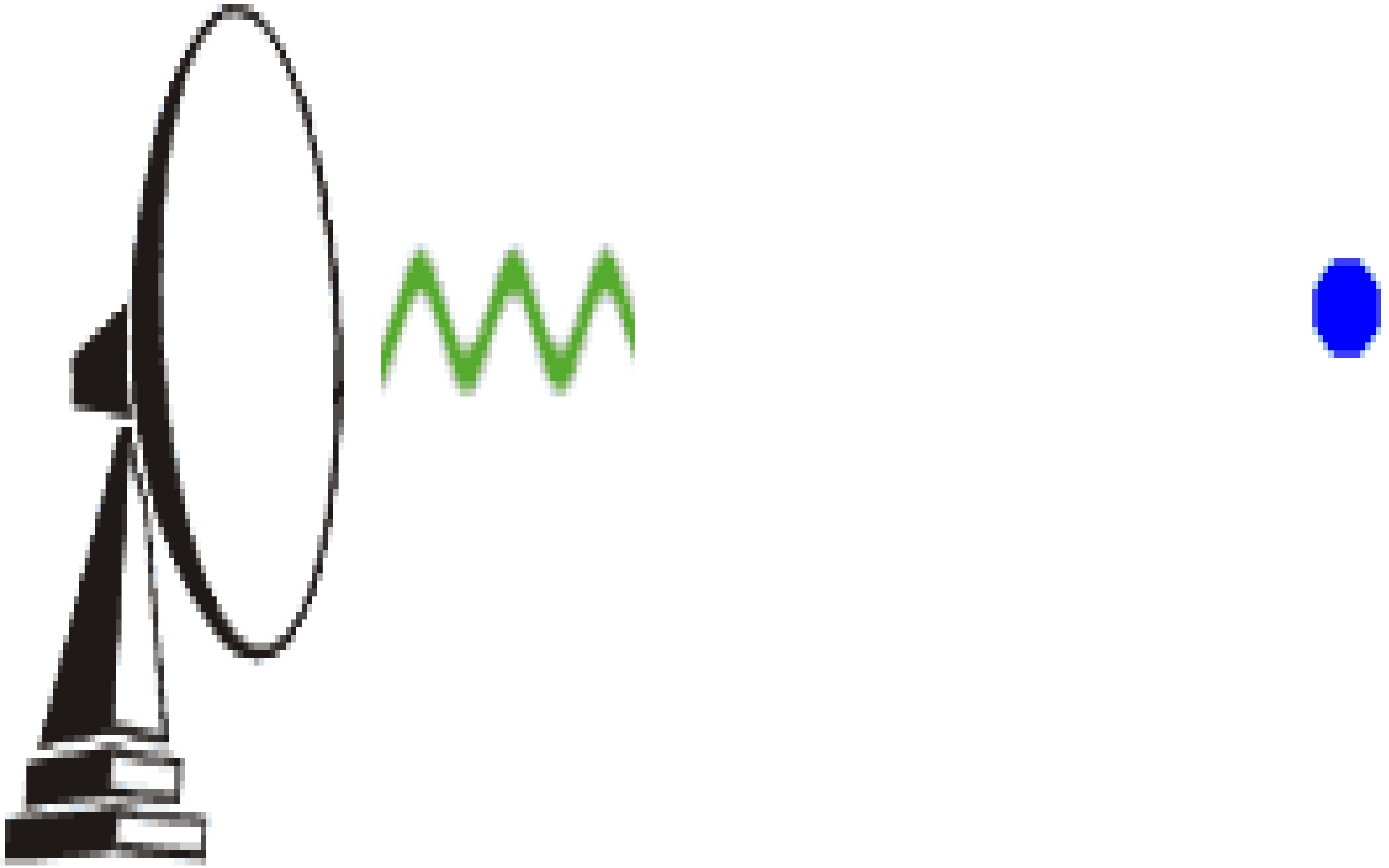
(http://www.crh.noaa.gov/mkx/radar/part1/slide3.html)



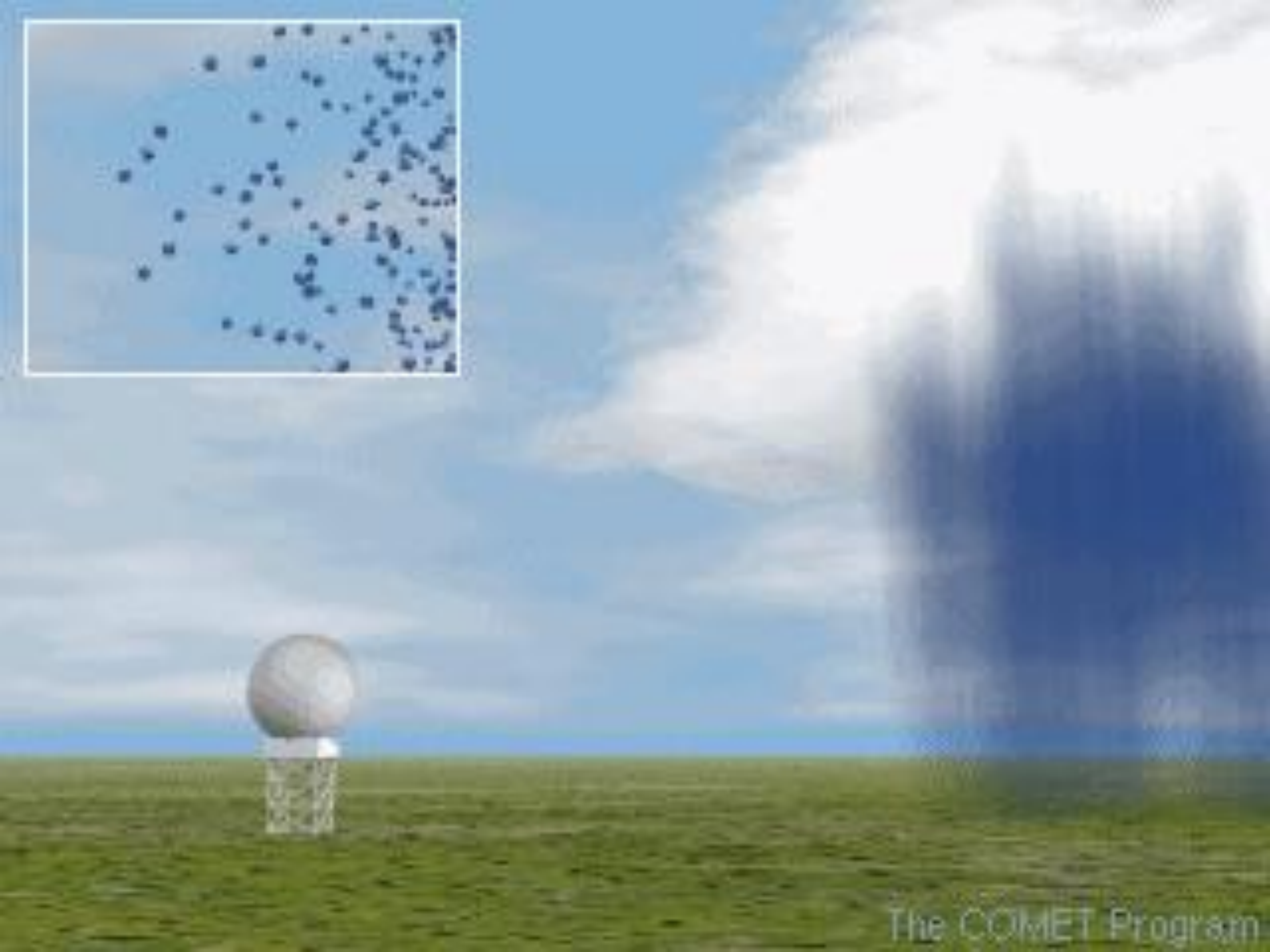
(University of Illinois WW2010 Project)



(University of Illinois WW2010 Project)



http://weather.noaa.gov/radar/radinfo/radinfo.html

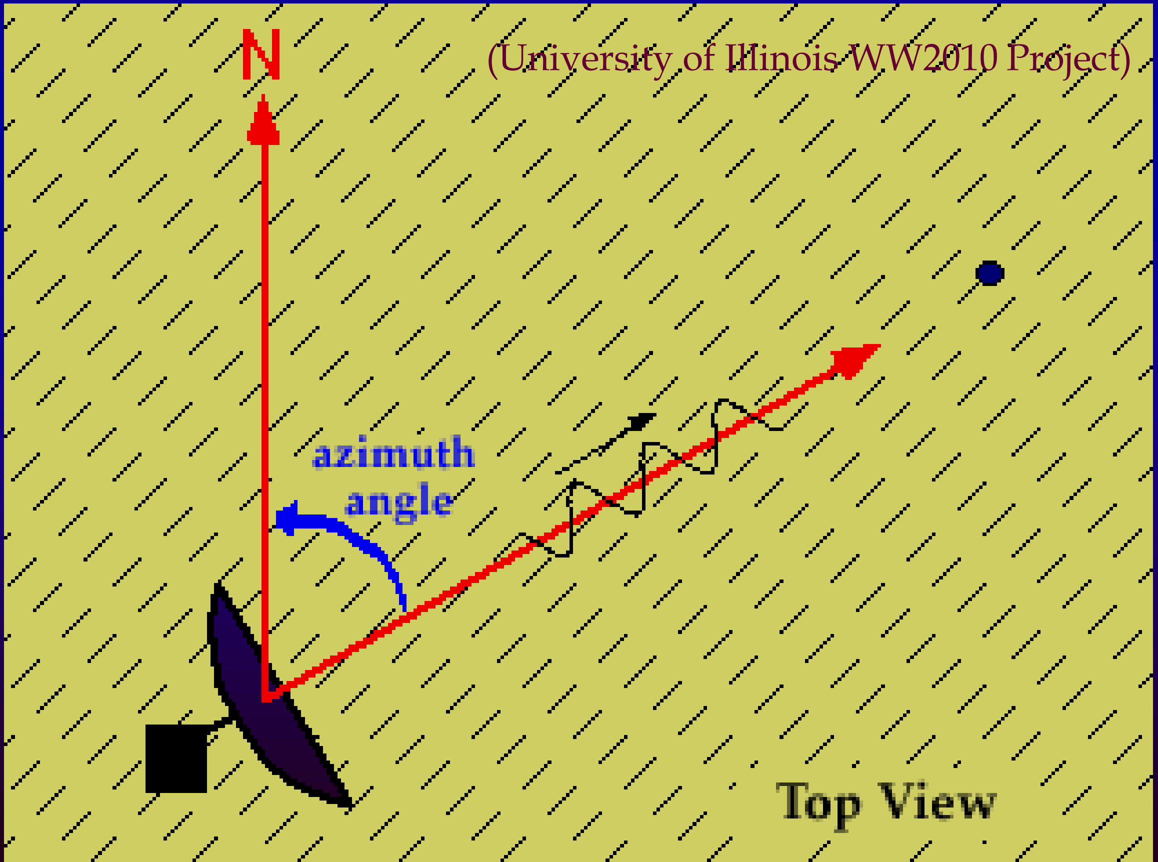

The COMET Program

Determining Target Location

- Three pieces of information
  - Azimuth angle
  - Elevation angle
  - Distance to target
- From these data radar can determine exact target location

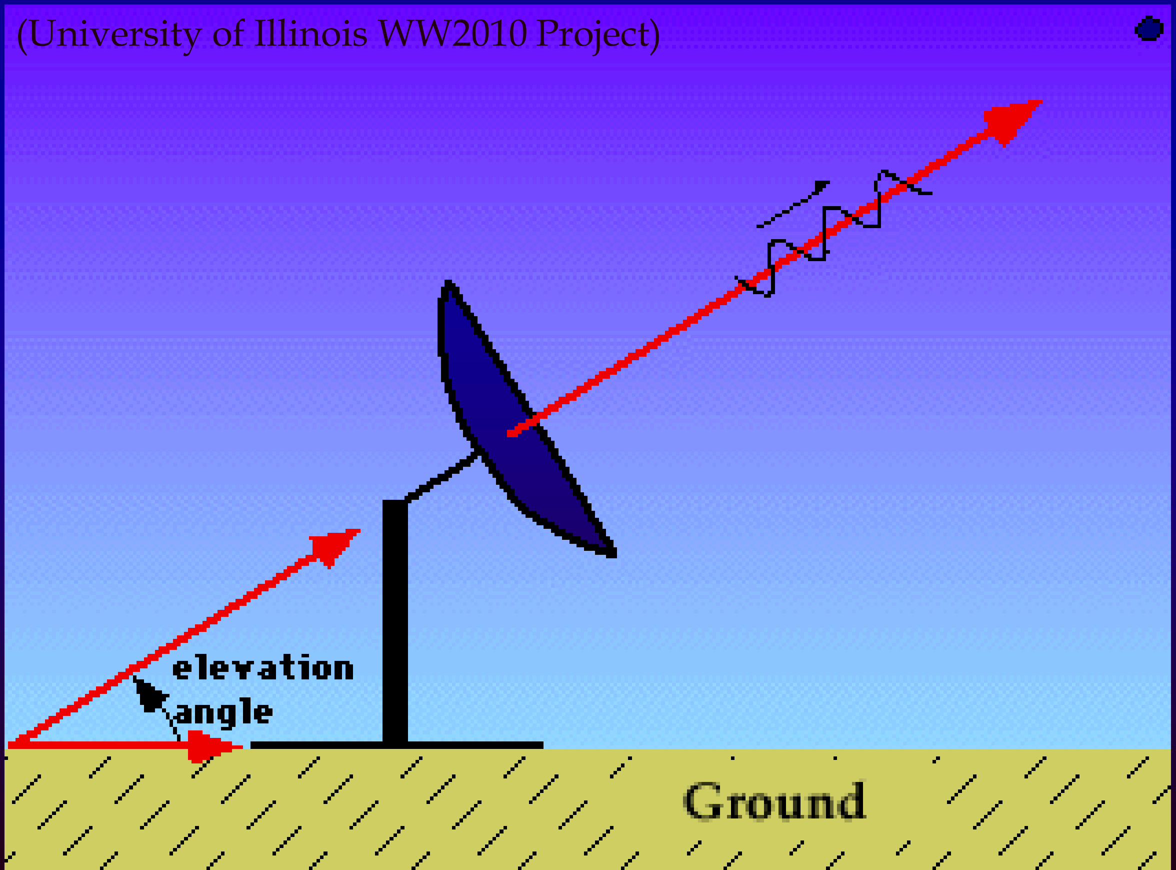
Azimuth Angle

- Angle of 'beam' with respect to north



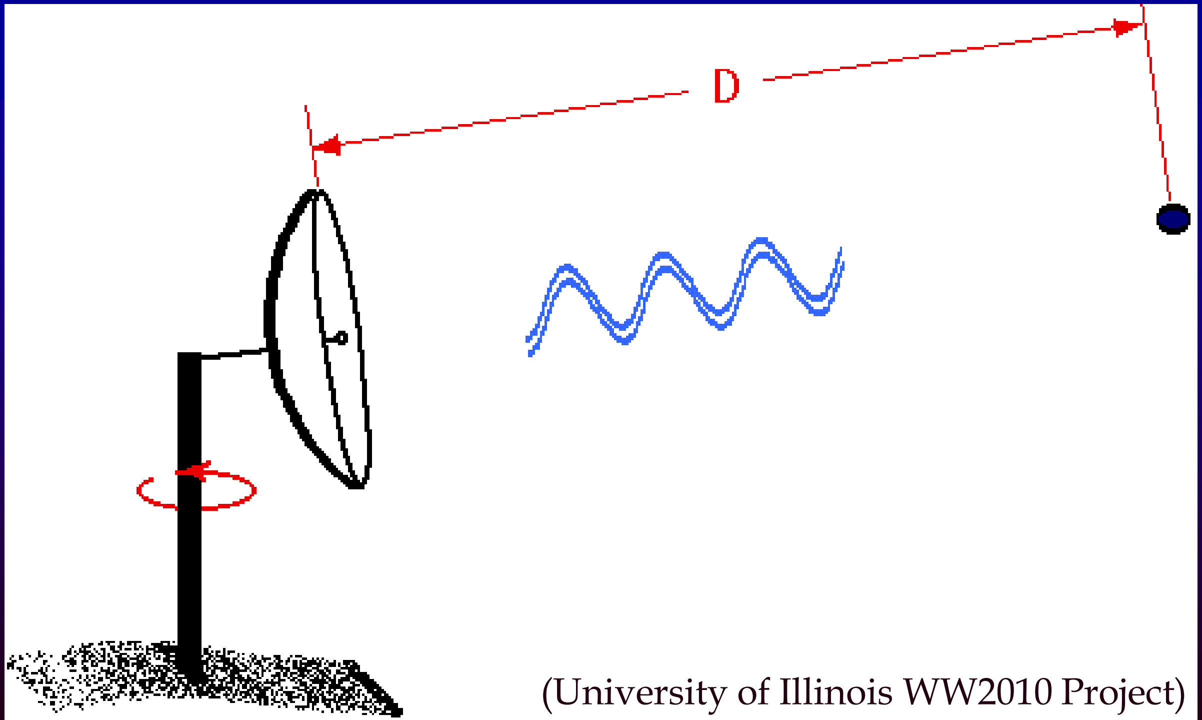
Elevation Angle

- Angle of 'beam' with respect to ground



Distance to Target

- $D = cT/2$
- $T \equiv$ pulse's round trip time



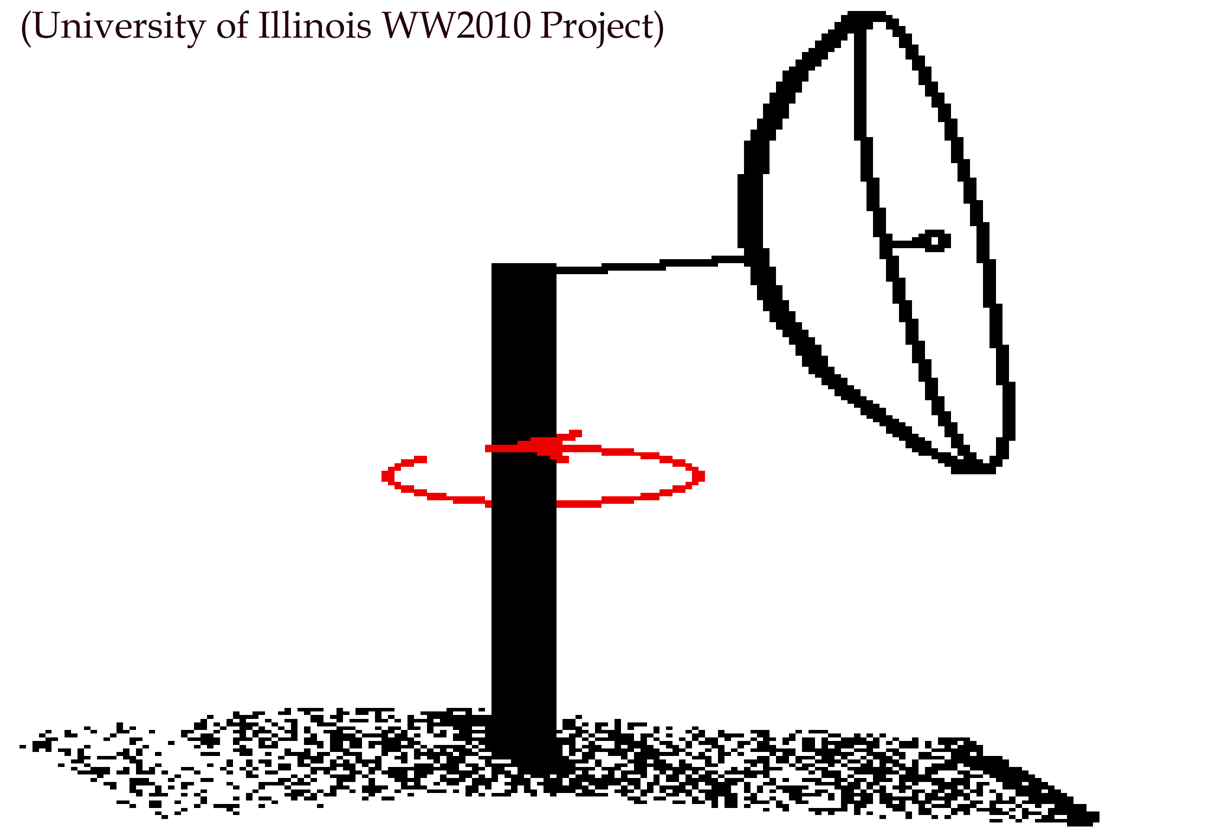
(University of Illinois WW2010 Project)

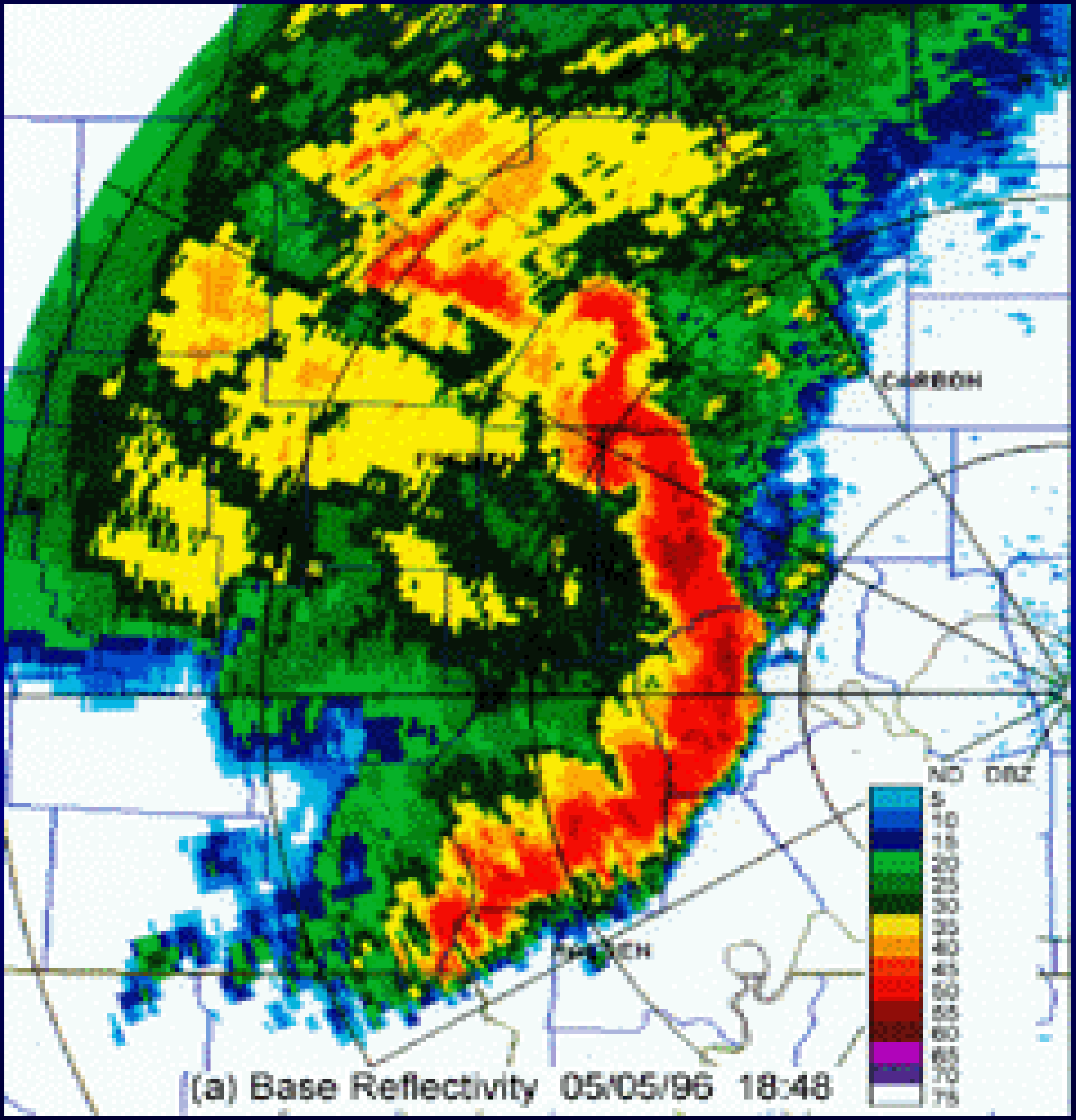
Scanning Strategies 1

- Plan Position Indicator (PPI)
  - Antenna rotates through 360° sweep at constant elevation angle
  - Allows detection/intensity determination of precipitation within given radius from radar
  - Most commonly seen by general public
  - WSR-88D performs PPI scans over several elevation angles to produce 3D representation of local atmosphere

Plan Position Indicator

- Constant elevation angle
- Azimuth angle varies (antenna rotates)

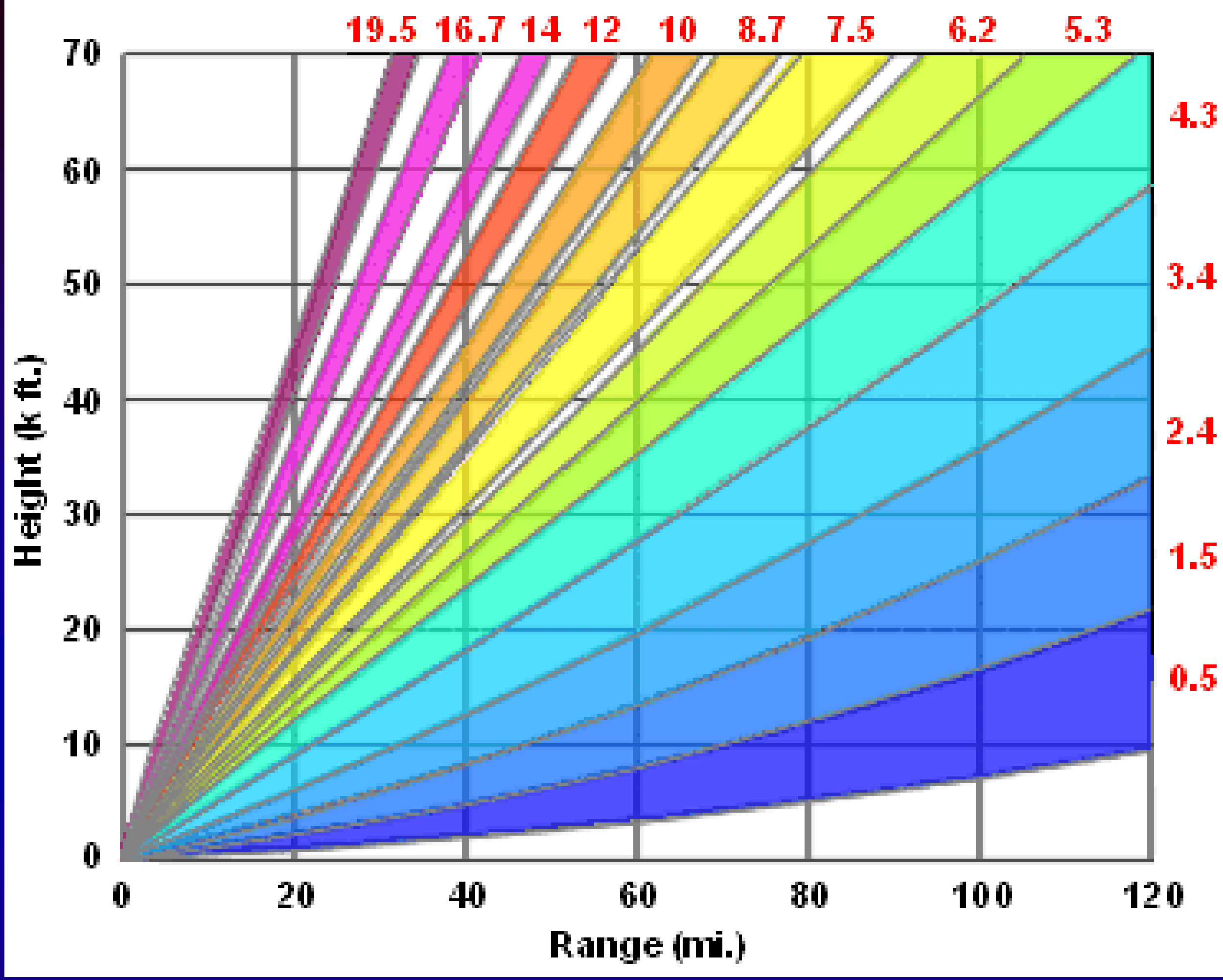




(a) Base Reflectivity 05/05/96 18:48

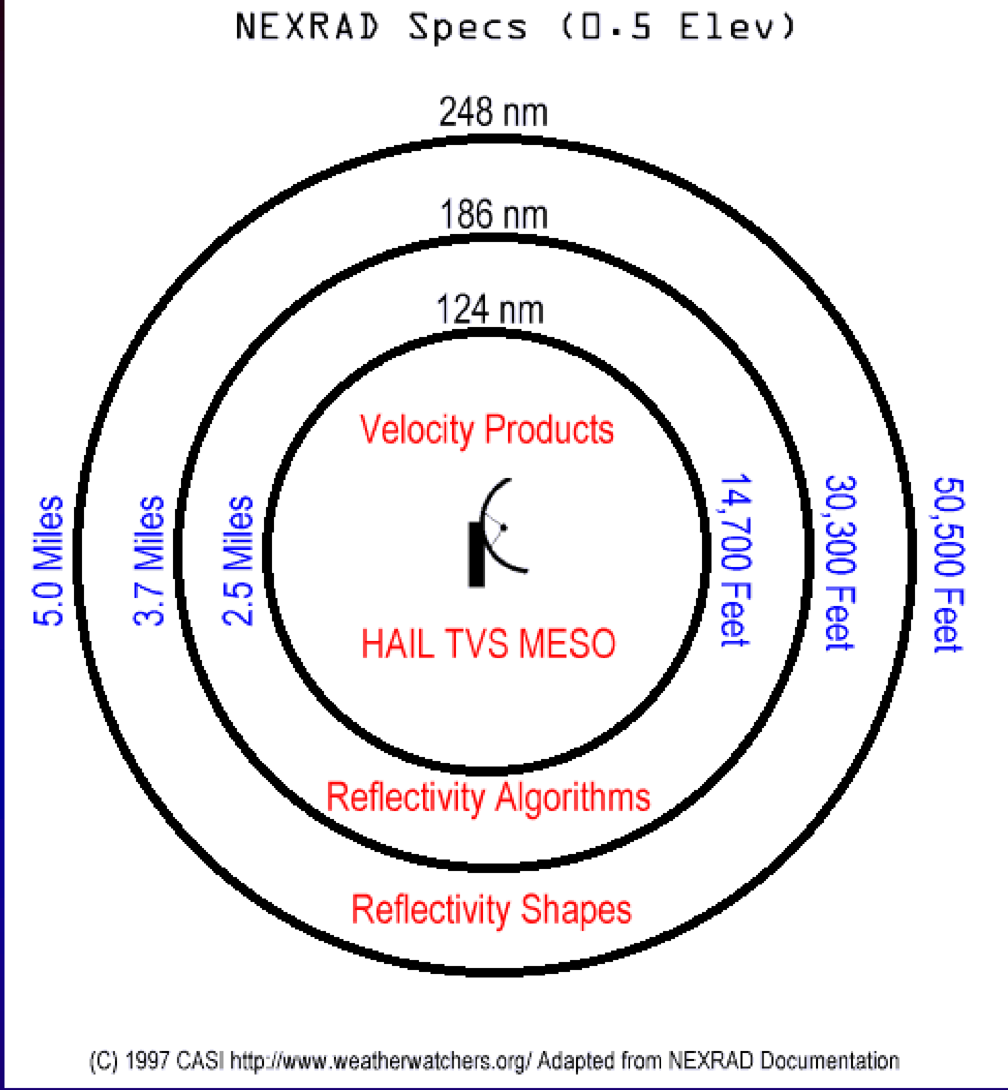
Elevation Angle Considerations

- Radar usually aimed above horizon
  - minimizes ground clutter
  - not perfect
- Beam gains altitude as it travels away from radar
- Radar cannot 'see' directly overhead
  - 'cone of silence'
  - appears as ring of minimal/non-returns around radar, esp. with widespread precipitation
- Sample volume increases as beam travels away from radar

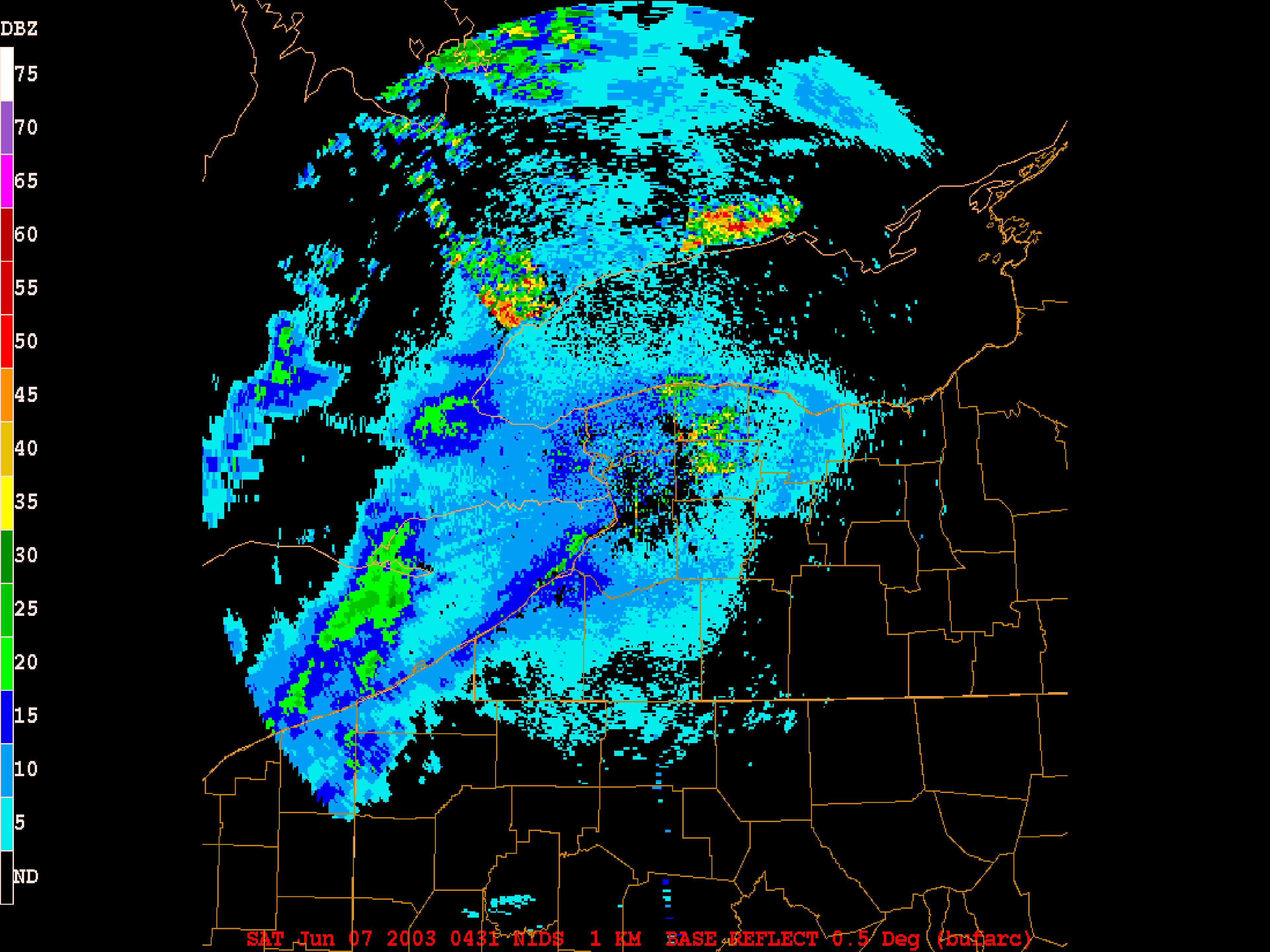


(http://weather.noaa.gov/radar/radinfo/radinfo.html)

- Red numbers are elevation angles
- Note how beam (generally) expands with increasing distance from radar

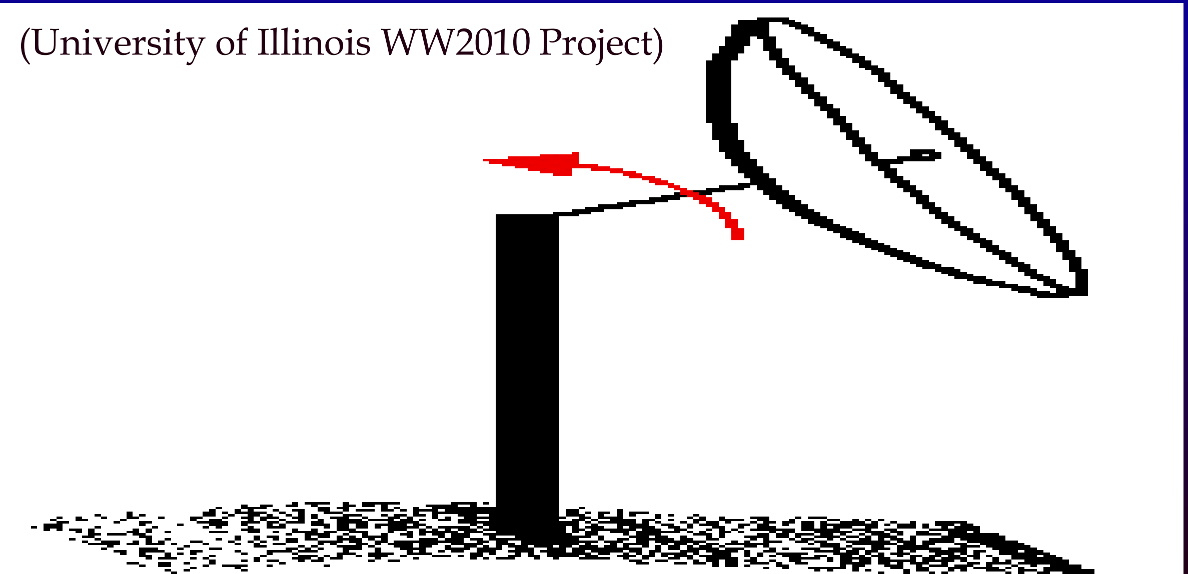


- Blue numbers are heights of beam AGL at given ranges
- Most effective range: 124 nm

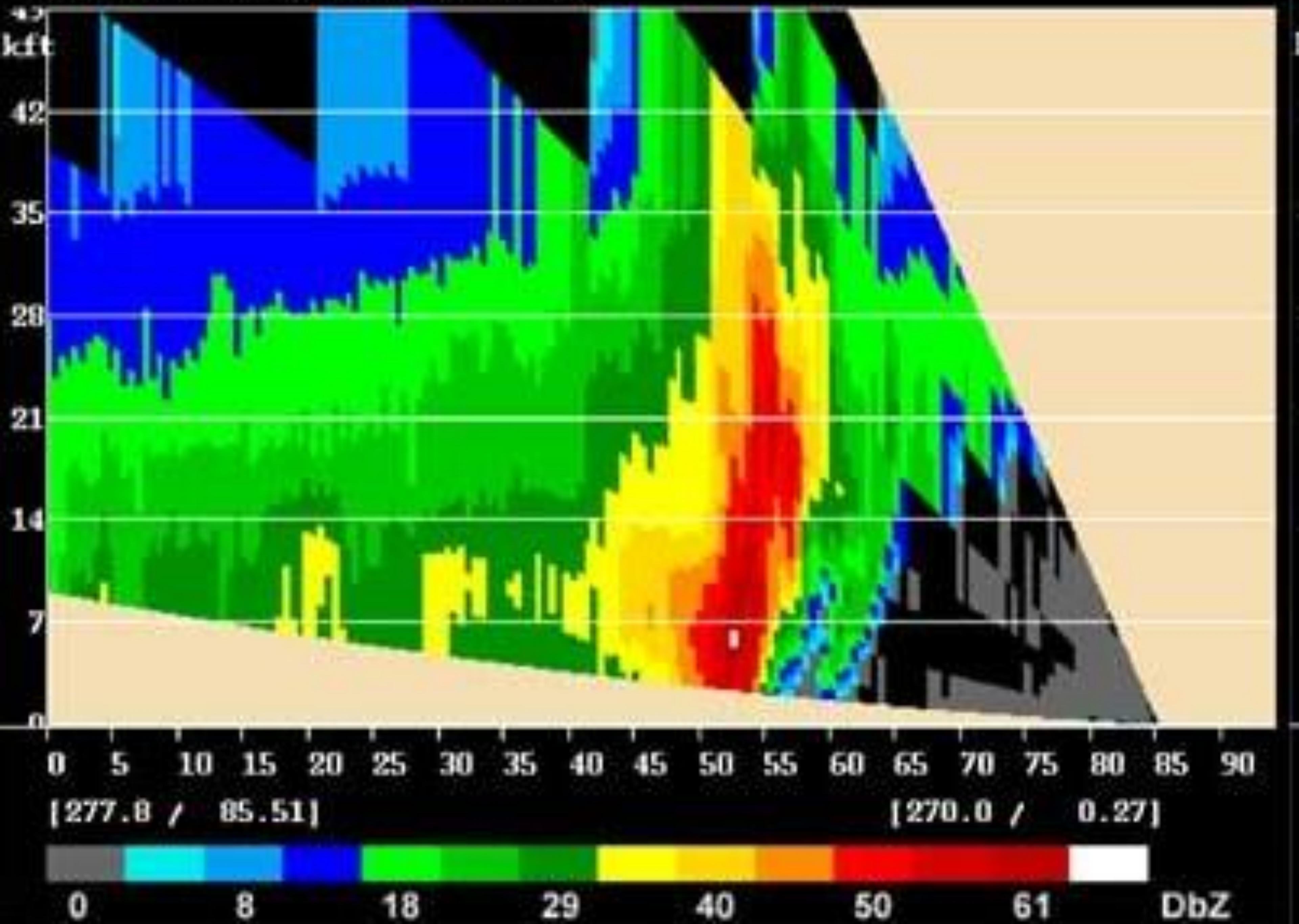

DBZ
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
ND
SAT Jun 07 2003 0431 NIDS 1 KM BASE REFLECT 0.5 Deg (bufarc)

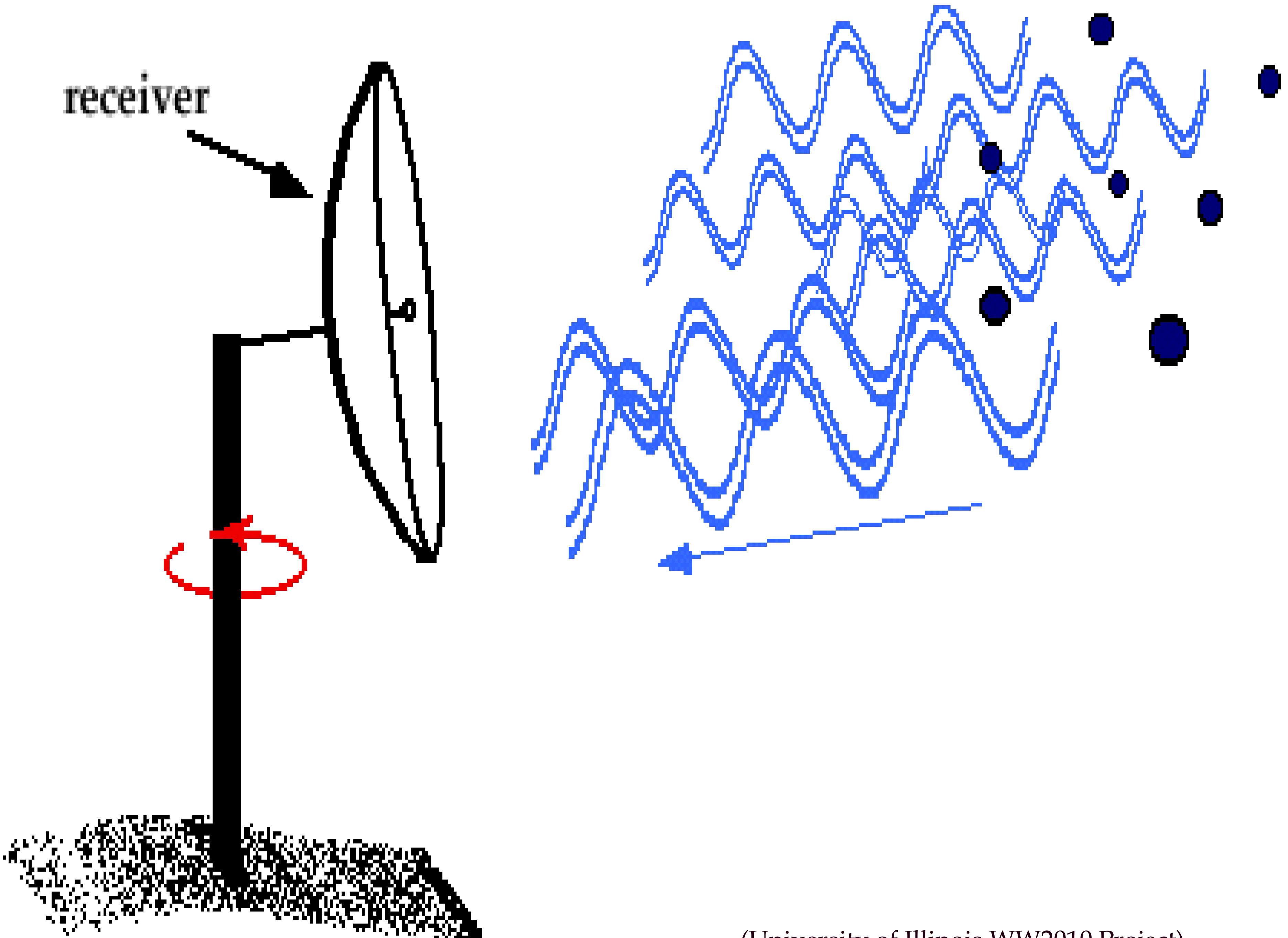
Scanning Strategies 2

- Range Height Indicator (RHI)
  - Azimuth angle constant
  - Elevation angle varies (horizon to near zenith)
  - Cross-sectional view of structure of specific storm



a) Cross-section (Reflectivity)





(University of Illinois WW2010 Project)

dBZ

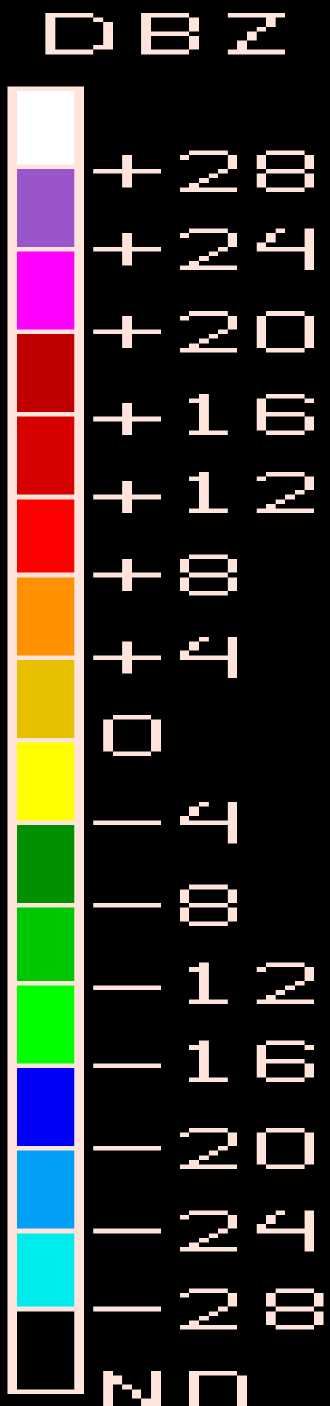
$$dBZ = 10\log_{10}\frac{Z_e}{1mm^6m^{-3}}$$

- Typical units used to express reflectivity
- Range:
  - –30 dBZ for fog
  - +75 dBZ for very large hail

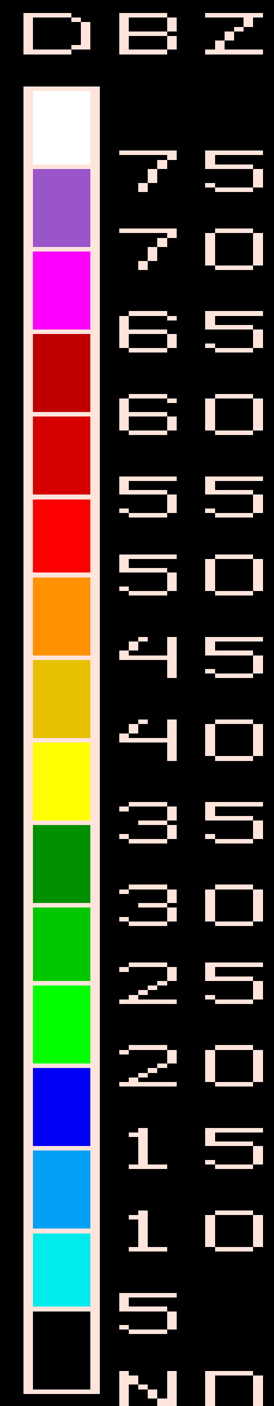
Scanning Modes

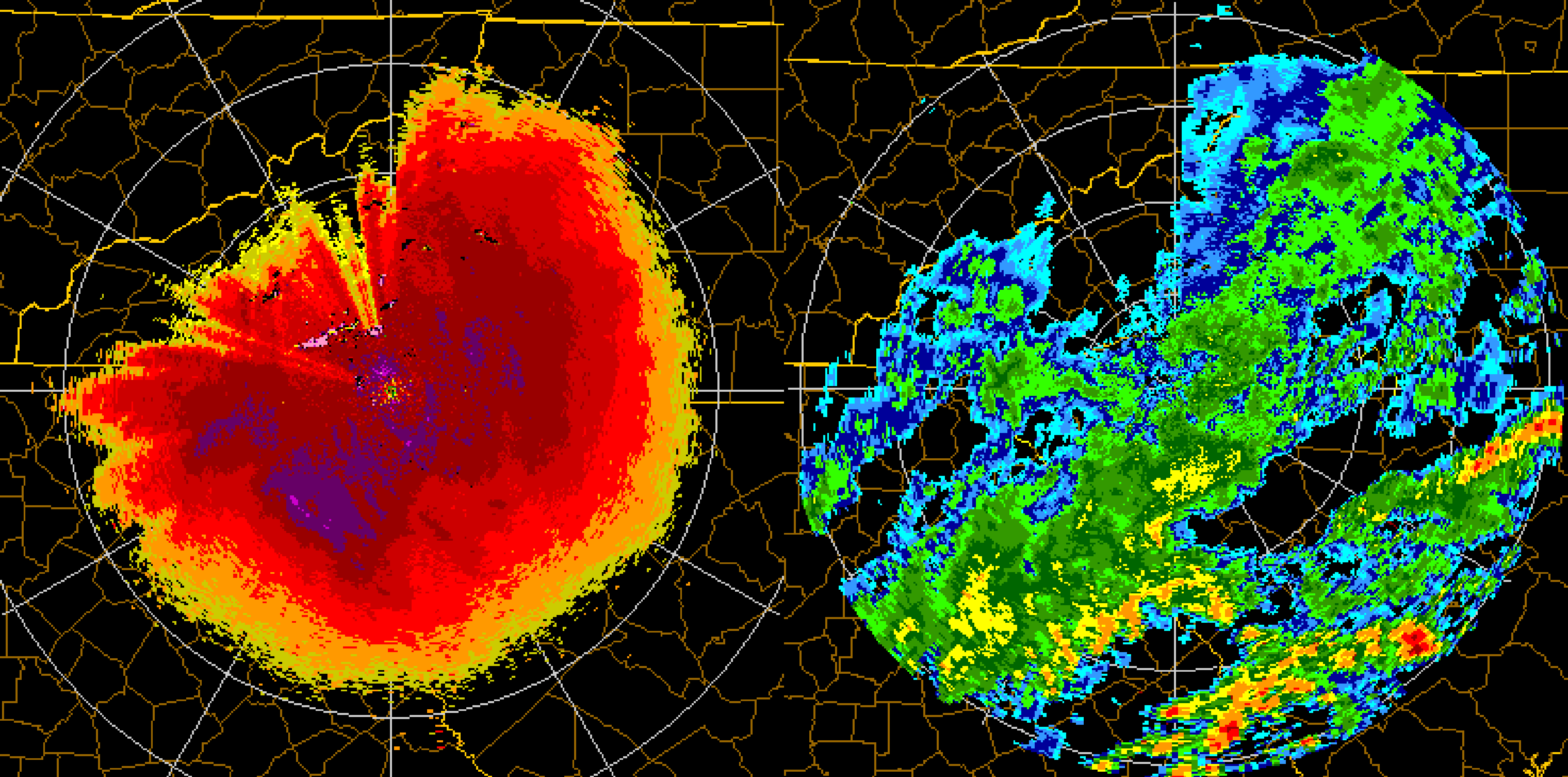
- Clear-Air Mode
  - slower antenna rotation
  - five elevation scans in 10 minutes
  - sensitive to smaller scatterers (dust, particulates, bugs, etc.)
  - good for snow detection
- Precipitation Mode
  - faster antenna rotation
  - 9-14 elevation scans in 5-6 minutes
  - less sensitive than clear-air mode
  - good for precipitation detection/intensity determination

Clear-Air Mode



Precipitation Mode





Clear-Air Mode

Precipitation Mode

Greer, SC (KGSP)

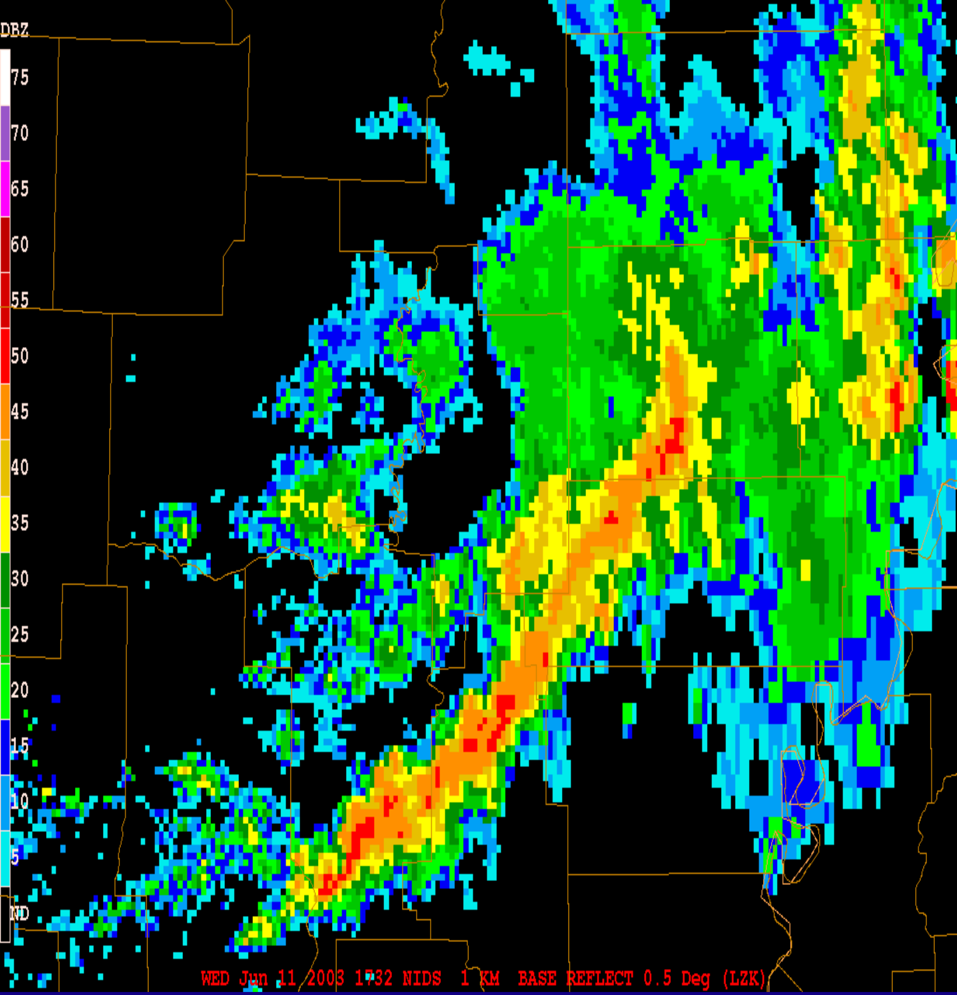
(http://virtual.clemson.edu/groups/birdrad/COMMENT.HTM)

Reflectivity Products 1

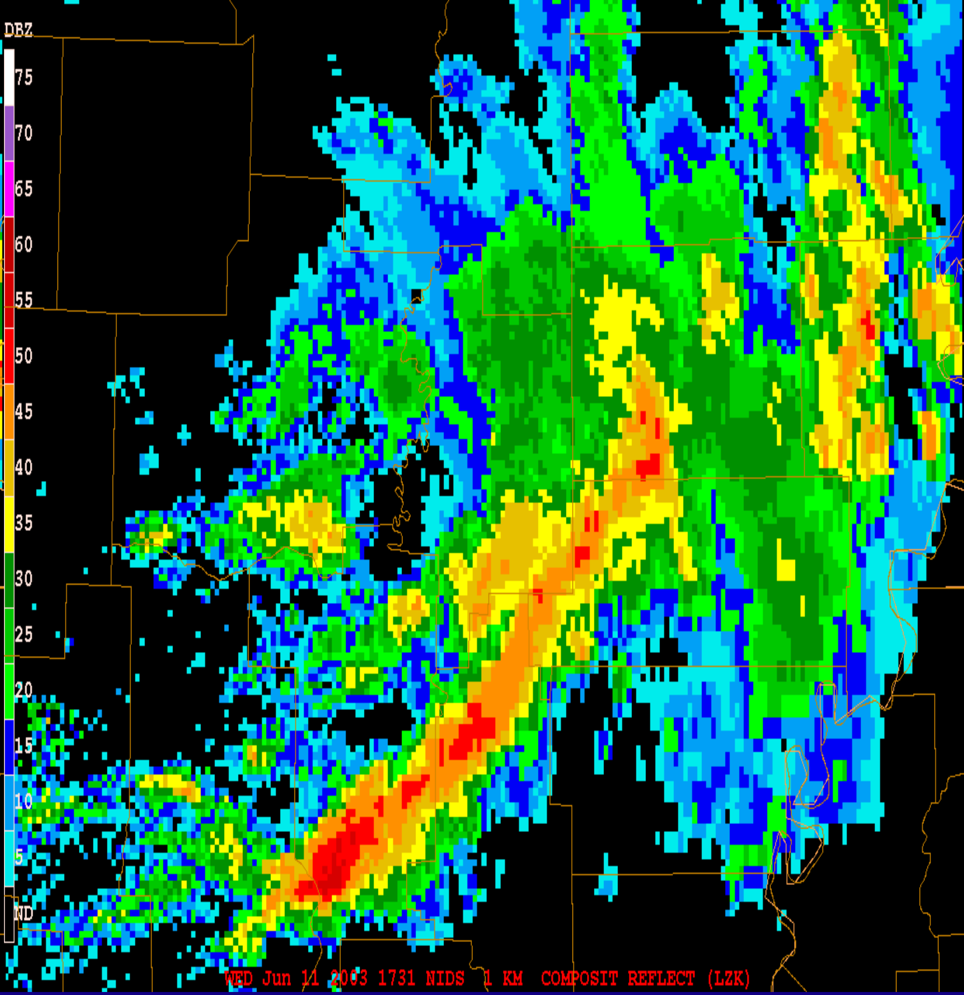
- Base Reflectivity
  - single elevation angle scan (5-14 available)
  - useful for precipitation detection/intensity
    - Usually select lowest elevation angle for this purpose
  - high reflectivities $\rightarrow$ heavy rainfall
    - usually associated with thunderstorms
    - strong updrafts $\rightarrow$ larger raindrops
    - large raindrops have higher terminal velocities
    - rain falls faster out of cloud $\rightarrow$ higher rainfall rates
    - hail contamination possible > 50 dBZ

Reflectivity Products 2

- Composite Reflectivity
  - shows highest reflectivity over all elevation scans
  - good for severe thunderstorms
    - strong updrafts keep precipitation suspended
    - drops must grow large enough to overcome updraft



Base Reflectivity



Composite Reflectivity

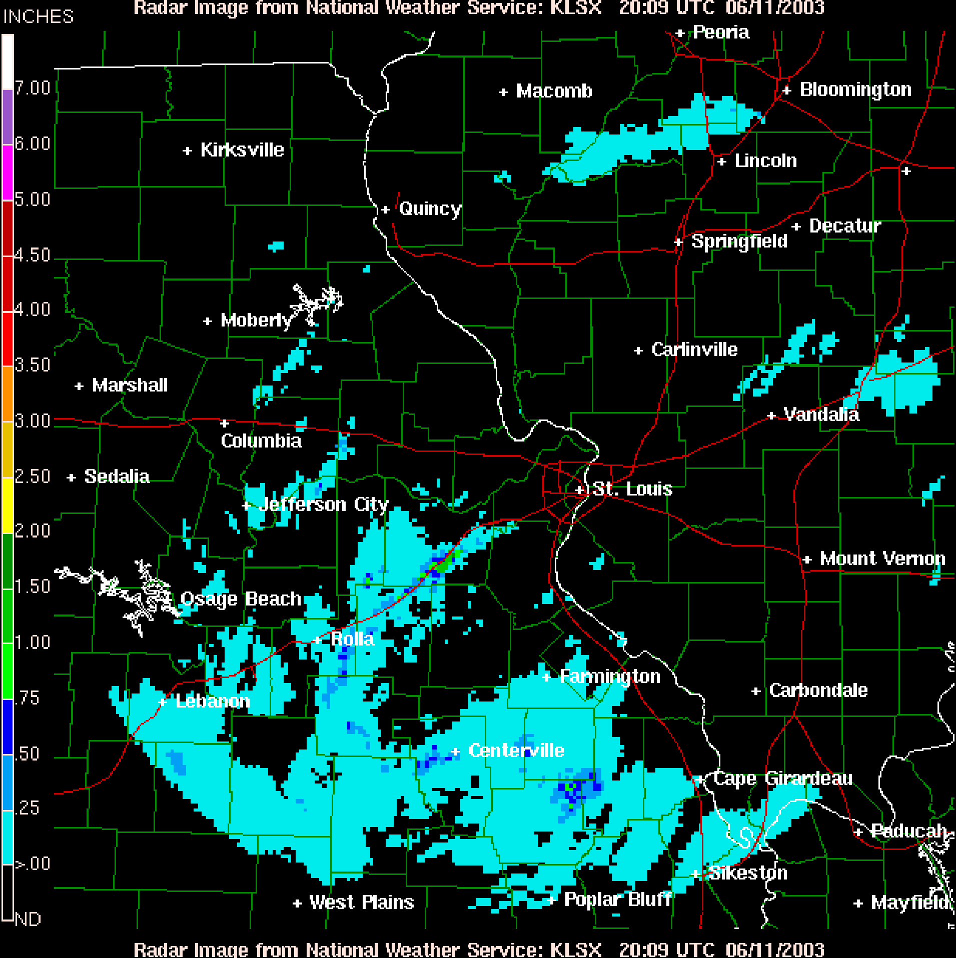
Little Rock, AR (KLZK)
Precipitation Mode

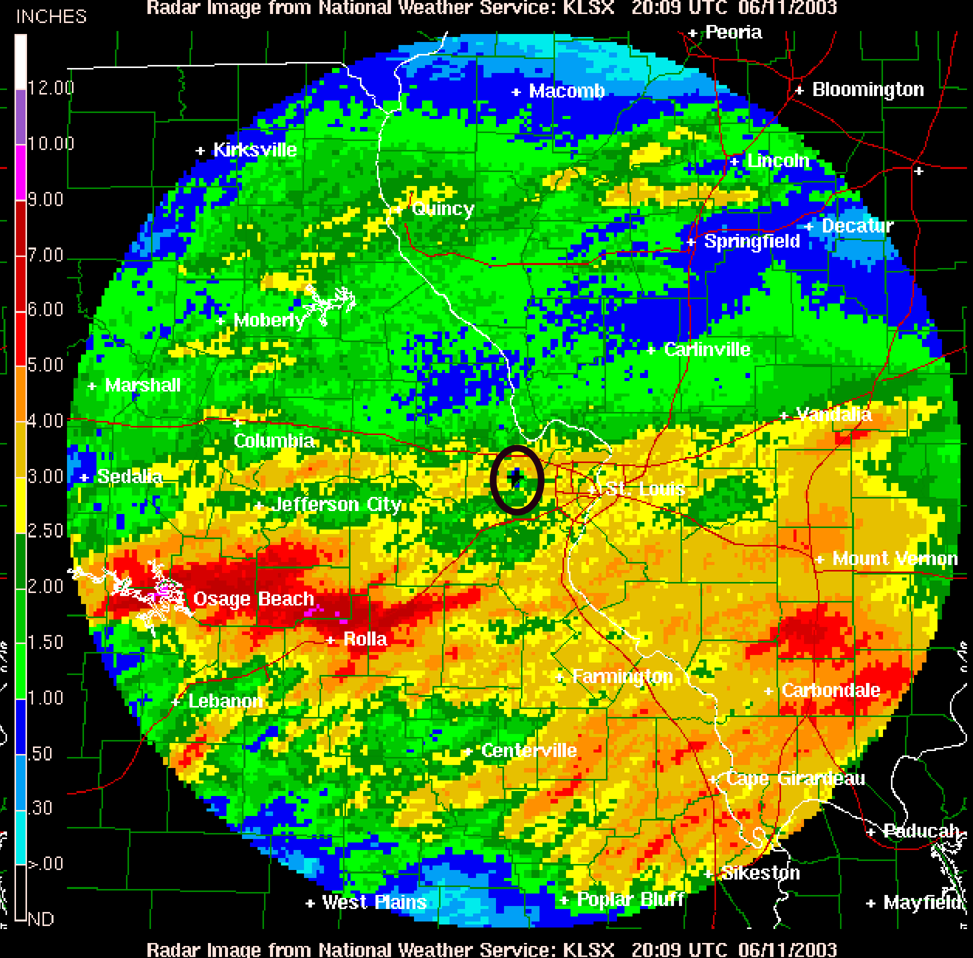
Radar Precipitation Estimation 1

- 1-/3-h Total Precipitation
  - covers 1- or 3-h period ending at time of image
  - can help to track storms when viewed as a loop
  - highlights areas for potential (flash) flooding
  - interval too short for some applications

Radar Precipitation Estimation 2

- Storm Total Precipitation
  - cumulative precipitation estimate at time of image
  - begins when radar switches from clear-air to precipitation mode
  - ends when radar switches back to clear-air mode
  - can help to track storms when viewed as a loop
  - helpful in estimating soil saturation/runoff
  - post-storm analysis highlights areas of R+/hail
  - no control over estimation period





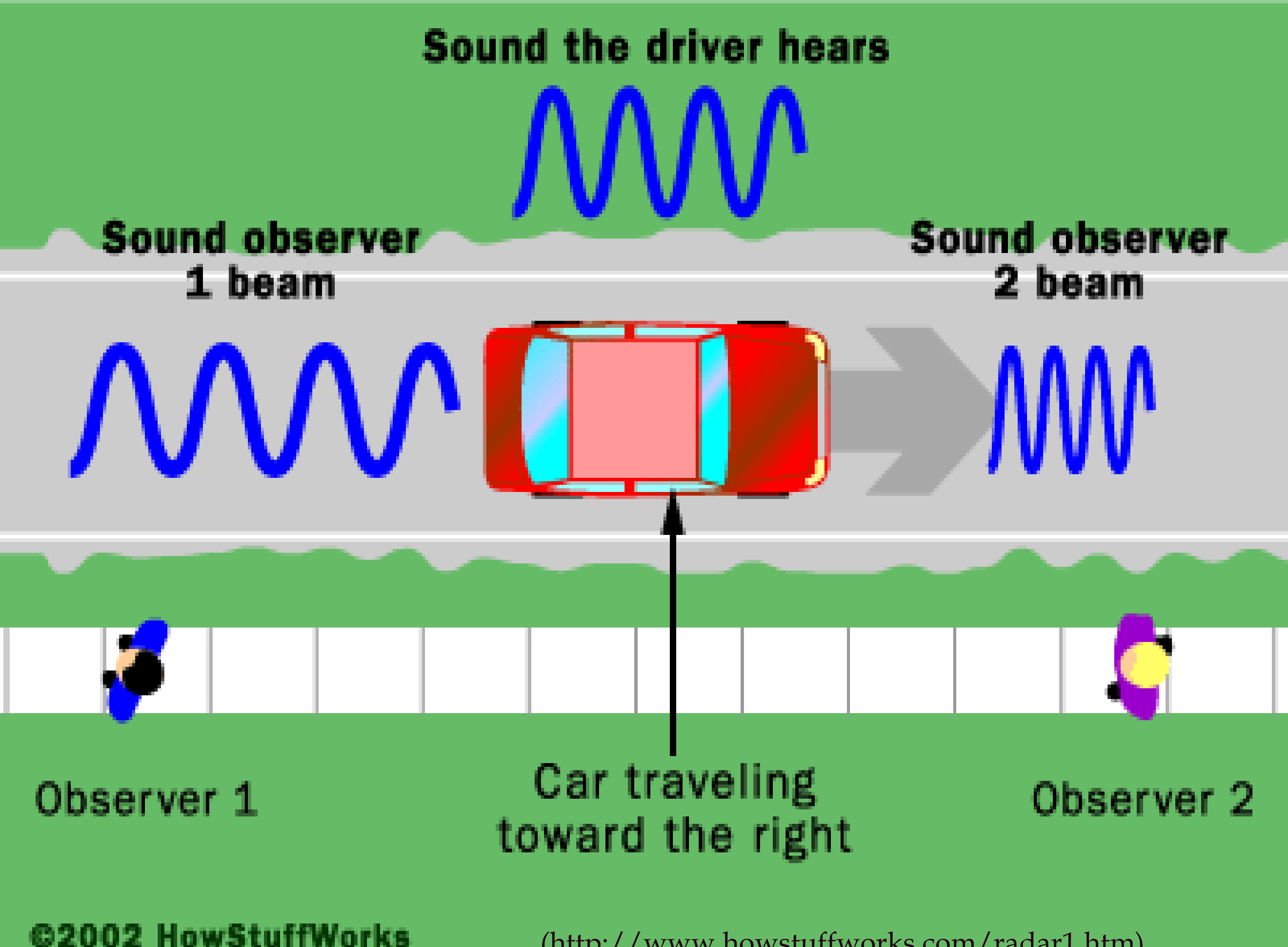
1-h Total Precipitation
(ending at 2009 UTC 11 June 2003)

Storm Total Precipitation
(0708 10 June 2003 to 2009 UTC 11 June 2003)

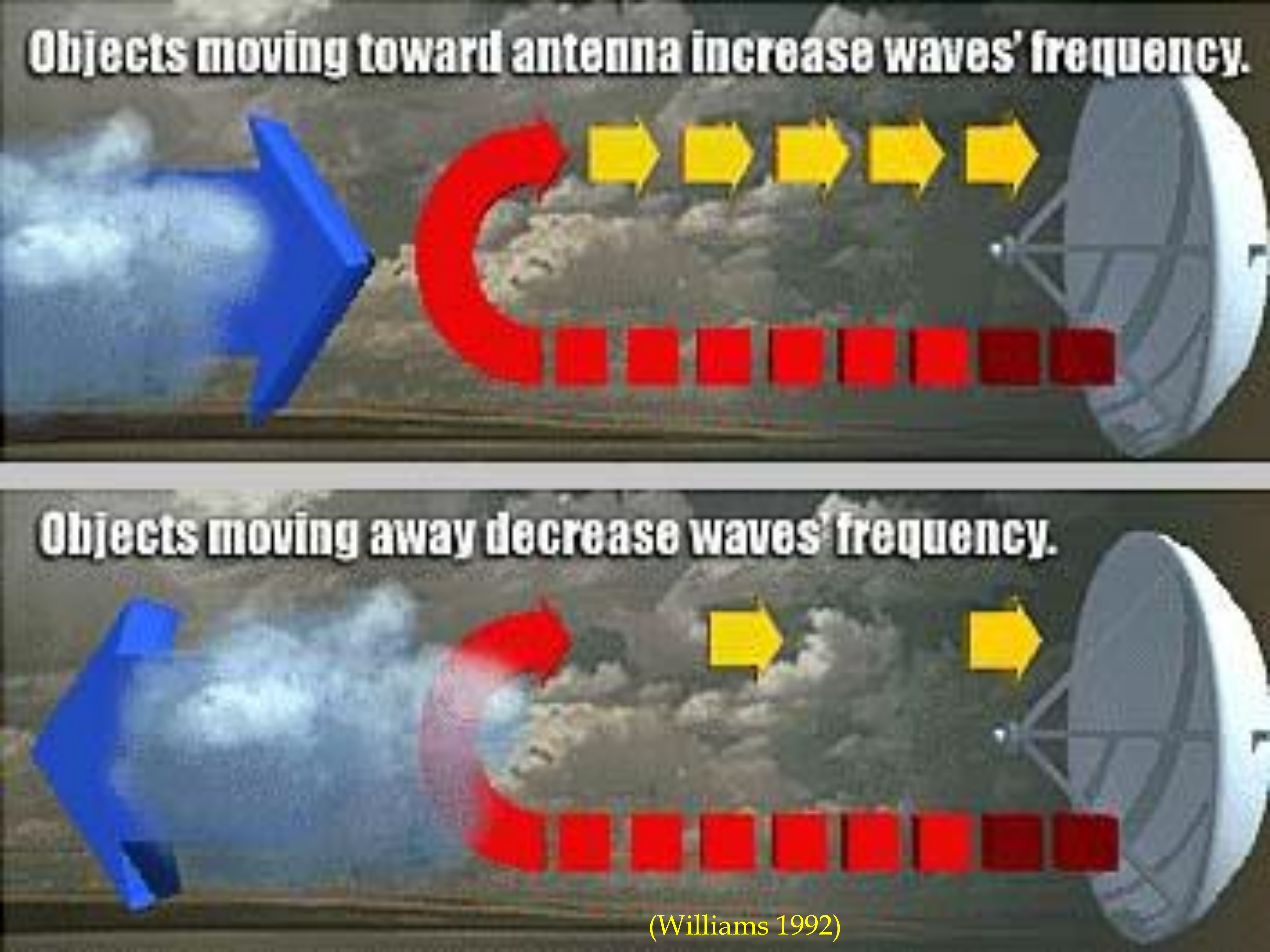
St. Louis, MO (KLSX)

Doppler Effect

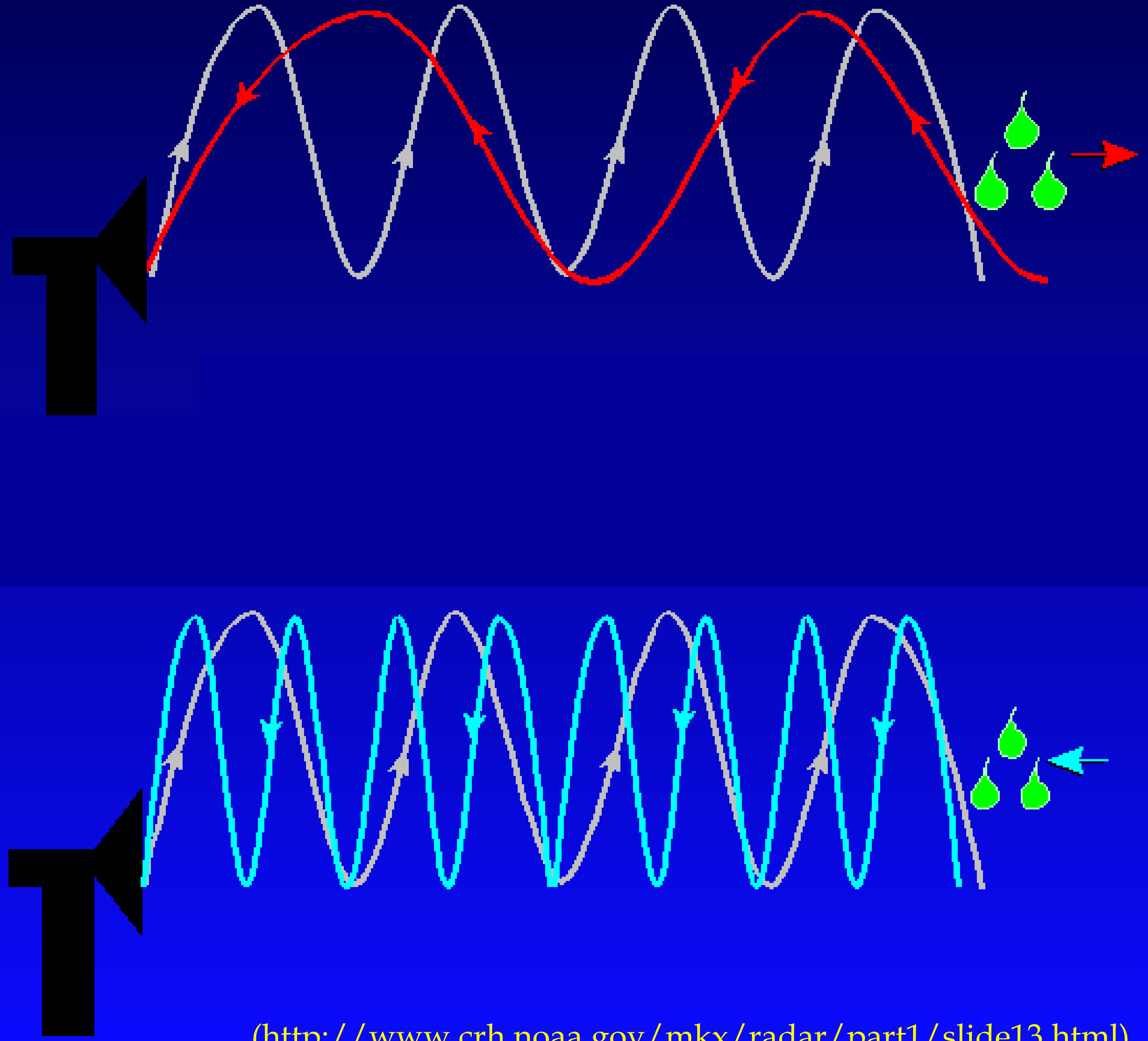
- Based on frequency changes associated with moving objects
- E-M energy scattered by hydrometeors moving toward/away from radar cause frequency change
- Frequency of return signal compared to transmitted signal frequency $\rightarrow$ radial velocity



(http://www.howstuffworks.com/radar1.htm)



(Williams 1992)



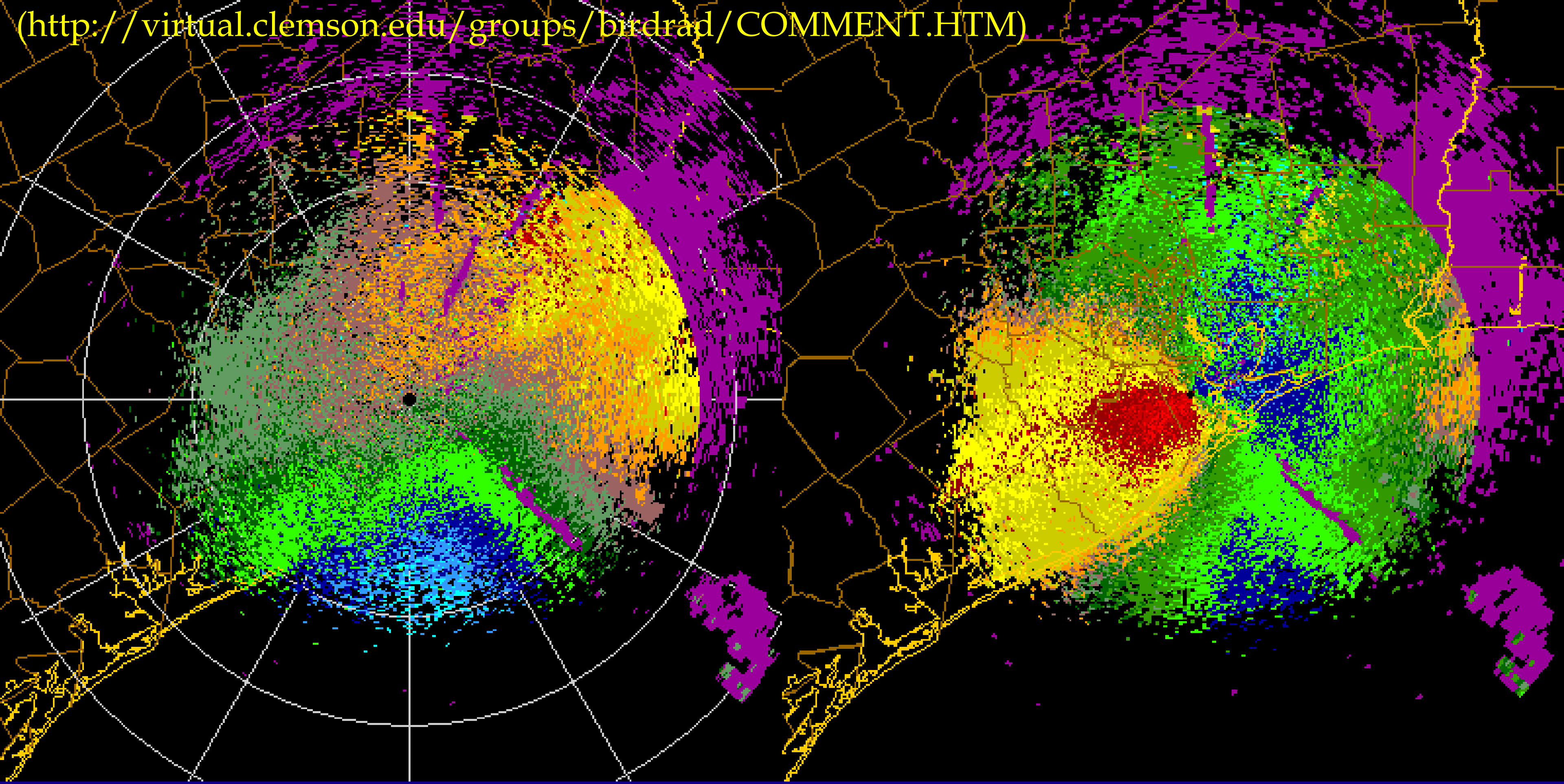
(http://www.crh.noaa.gov/mkx/radar/part1/slide13.html)

Radial Velocity 1

- Hydrometeors moving toward/away from radar
  - Positive values ⇒ targets moving *away* from radar
  - Negative values ⇒ targets moving *toward* radar
- Can be used to ascertain large-scale and small-scale flows/phenomena
  - fronts and other boundaries
  - mesoscale circulations
  - microbursts

Radial Velocity 2

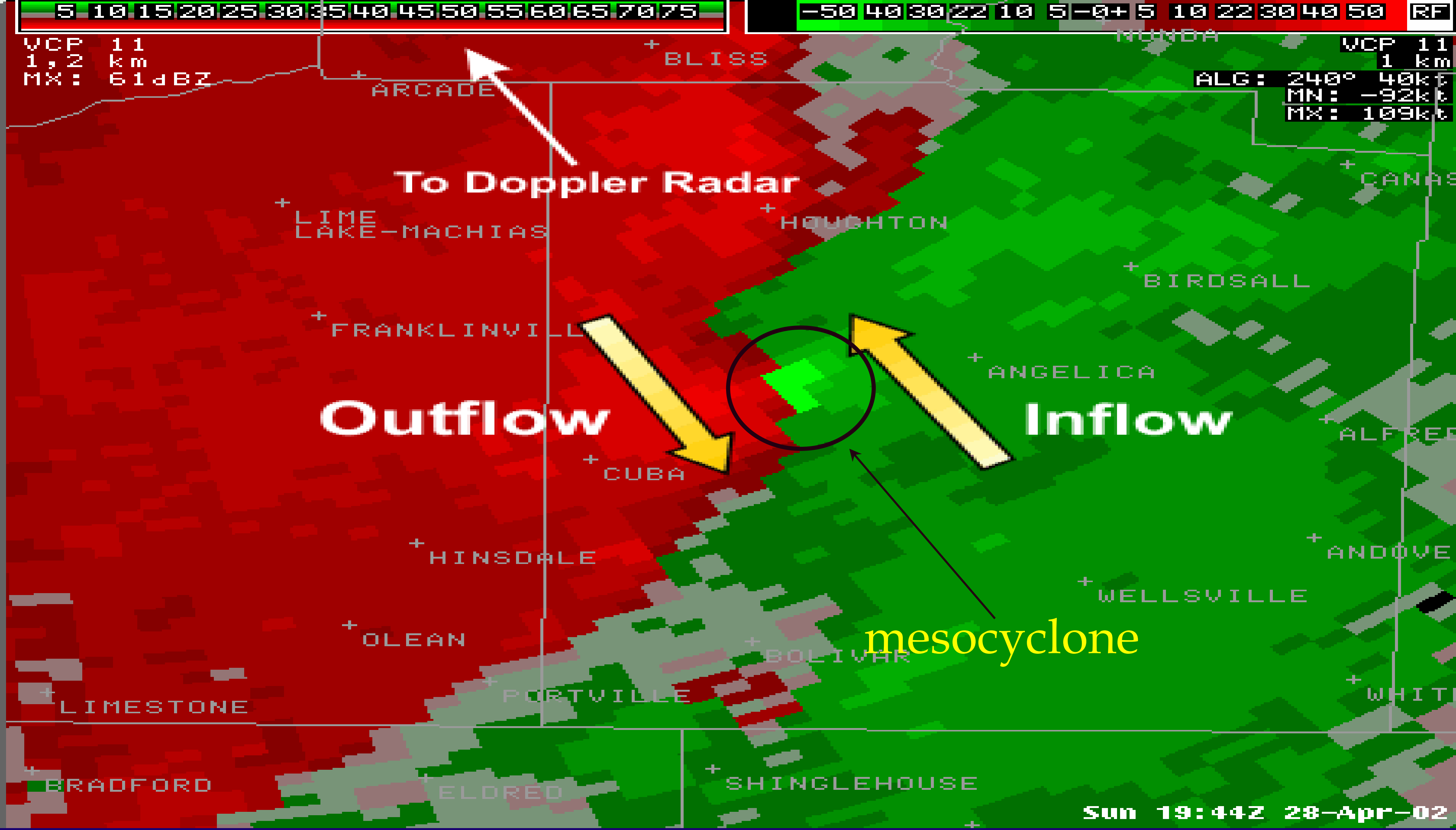
- Base Velocity
  - ground-relative
  - good for large-scale flow and straight-line winds
- Storm-Relative Velocity
  - storm motion subtracted from radial velocity
  - good for detecting circulations and divergent/convergent flows



Base Velocity

Storm-Relative Velocity

Houston, TX (KHGX)
warm colors away from radar
cool colors toward radar



Buffalo, NY (KBUF)
1944 UTC 28 April 2002
Storm-Relative Velocity

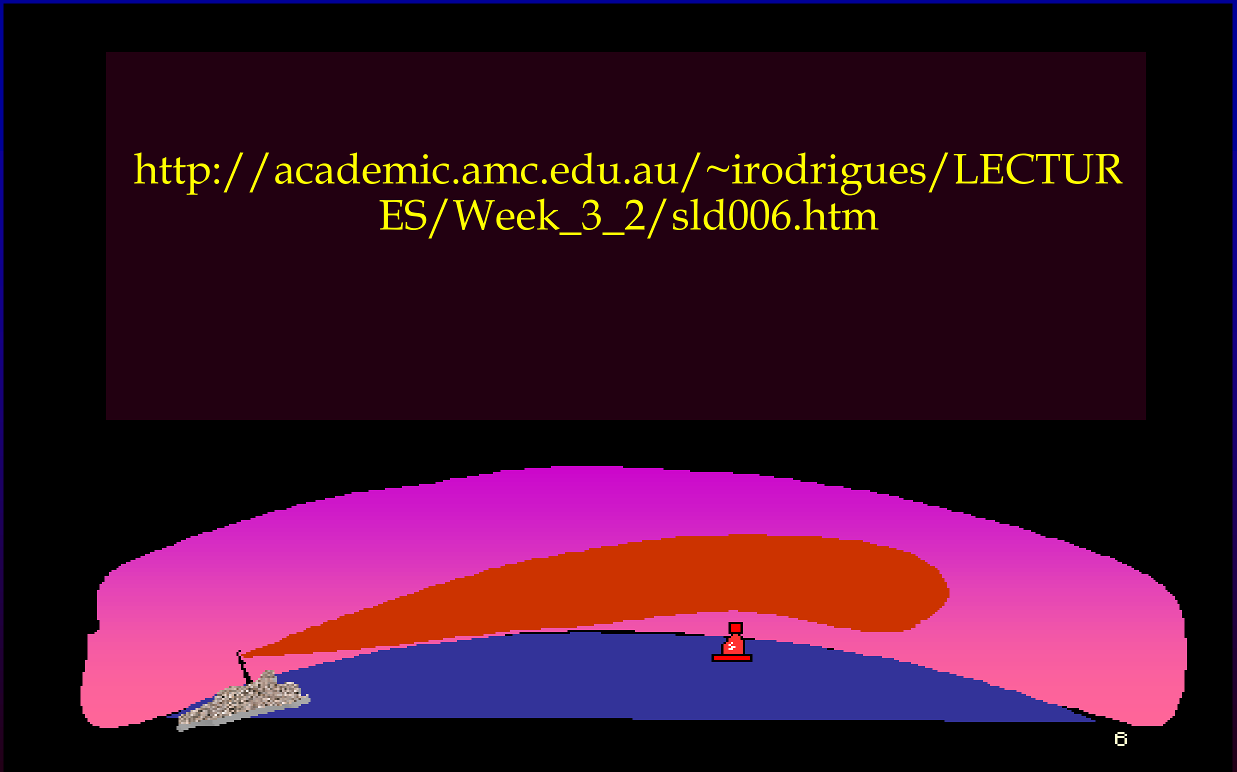
(http://www.srh.weather.gov/jetstream/remote/srm.htm)

The Doppler Dilemma 1

- Pulse can only travel so far and return in time before next pulse is transmitted
  - Distant targets may be reported as close, and/or
  - Velocities may be aliased
- Pulse Repetition Frequency (PRF)
  - transmission interval
  - typical values 700-3000 Hz (cycles s^{-1})
  - key to determining maximum unambiguous range (R_{max}) and velocity (V_{max})

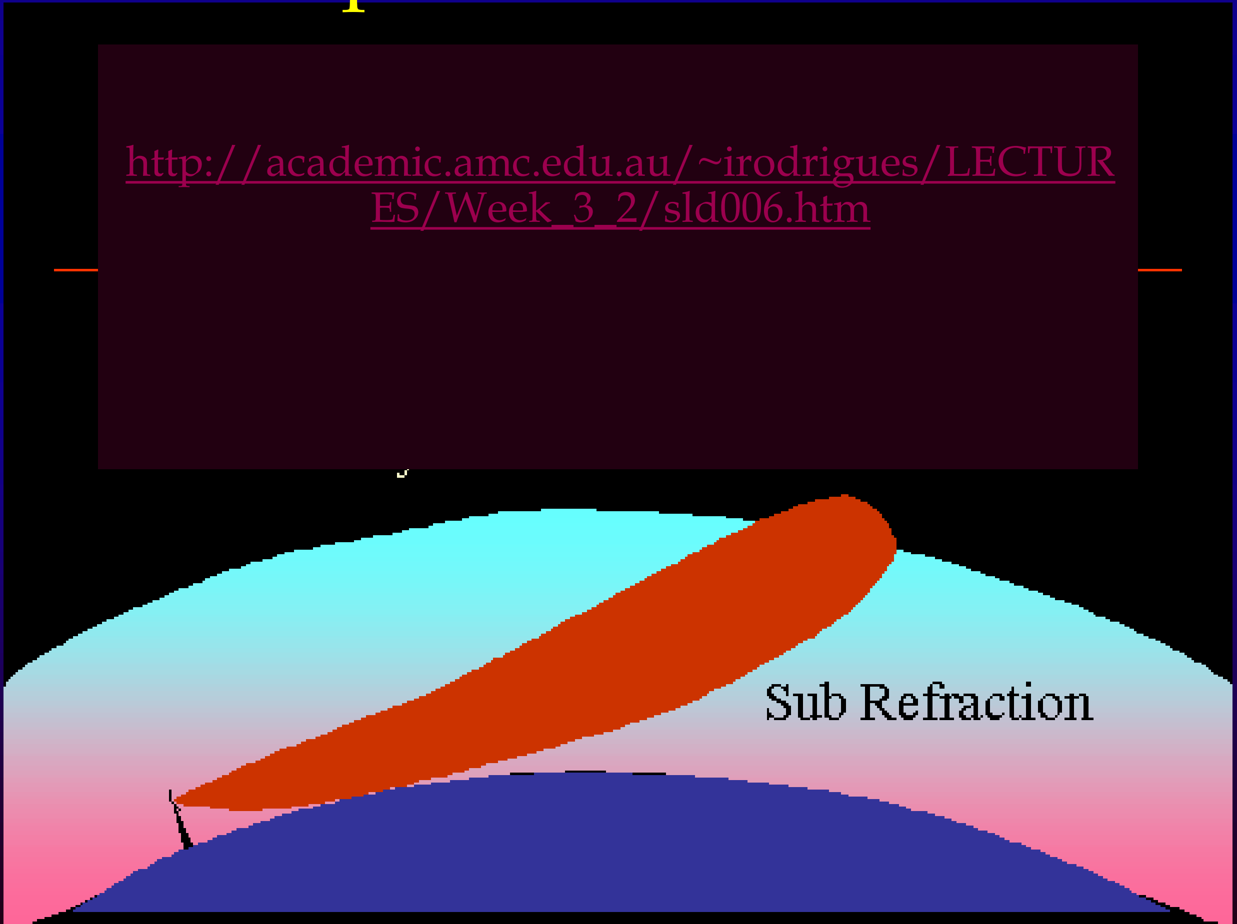
Refraction

- Radar 'beam' typically follows Earth's curvature



Subrefraction

- Beam tilts upward

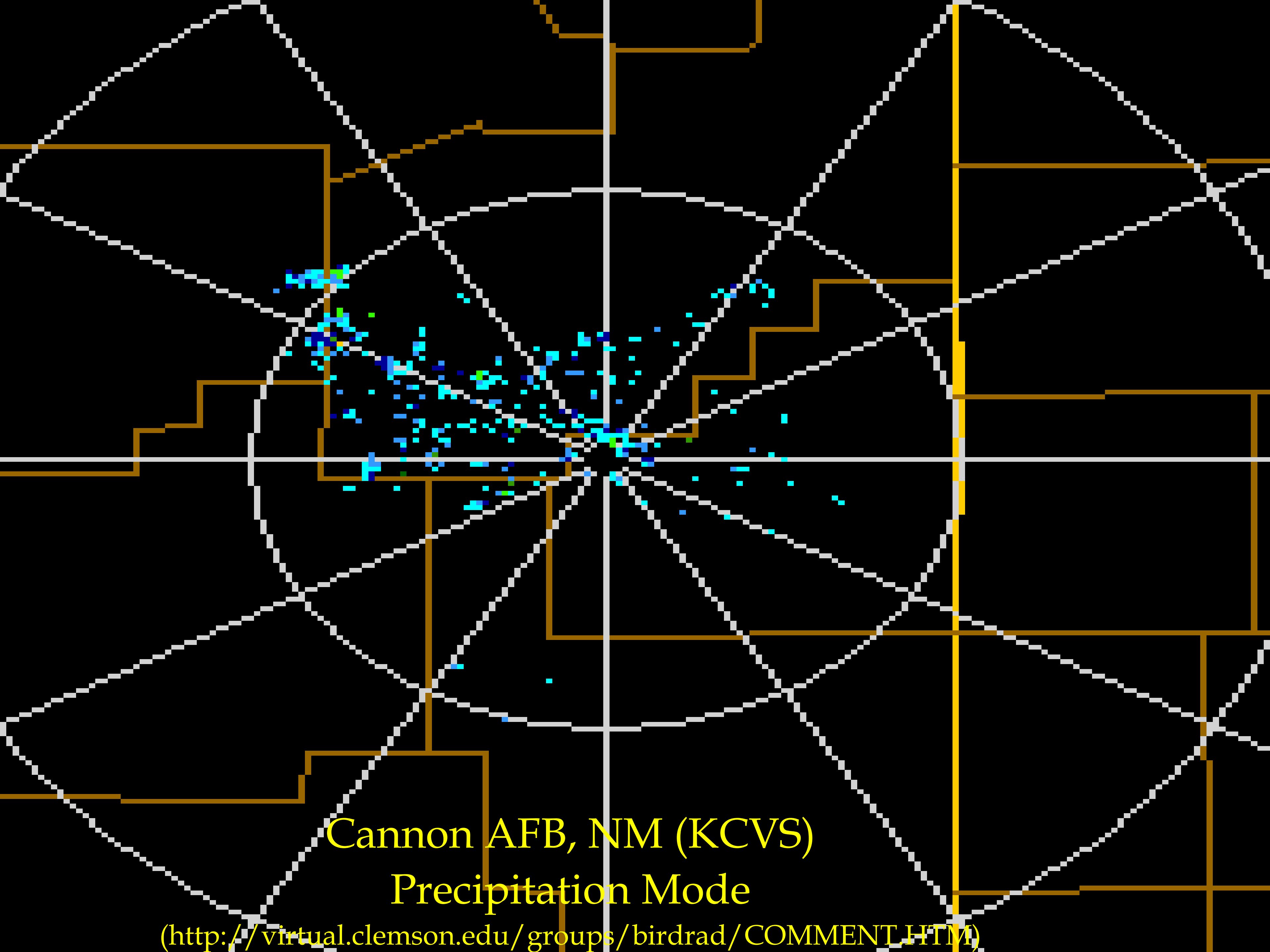


Non-Meteorological Targets

- Ground Clutter
  - trees
  - mountains
  - buildings
- Other Targets
  - sun strobes
  - anomalous propagation (AP)

Ground Clutter

- Stationary objects usually filtered out
- Swaying trees or towers may show up
- Look for drifting high reflectivity returns near radar



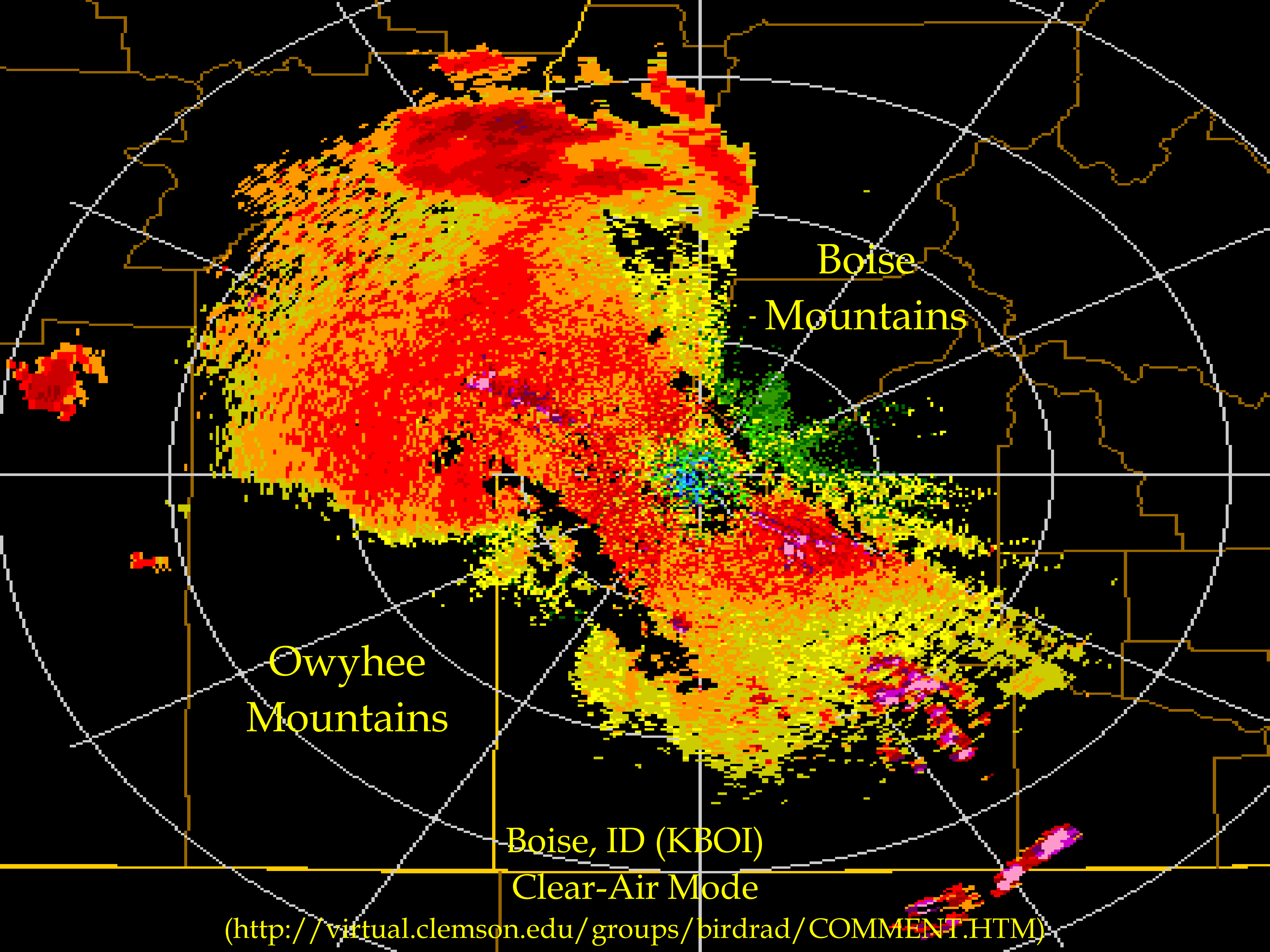
Cannon AFB, NM (KCVS)

Precipitation Mode

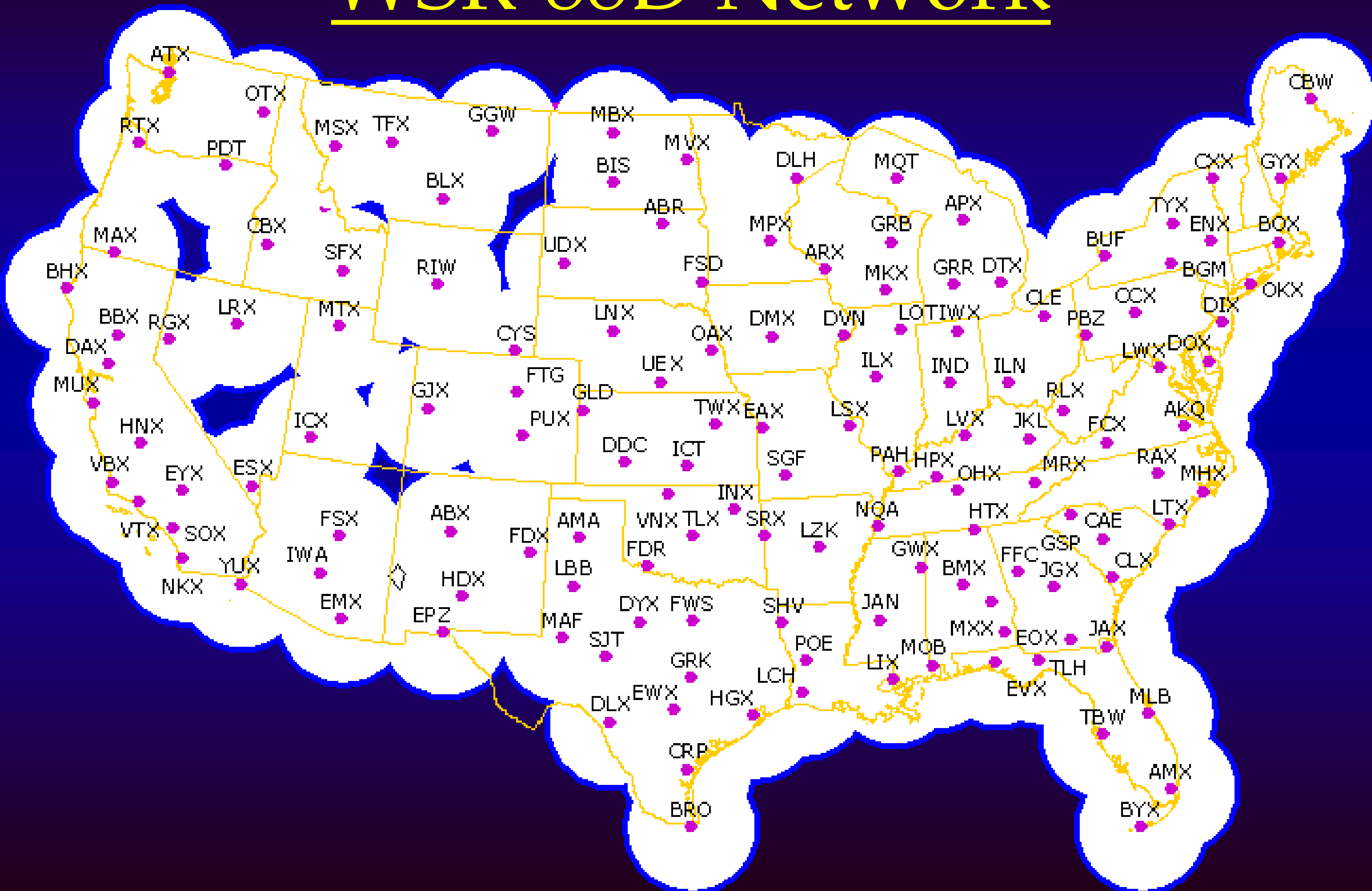
(http://virtual.clemson.edu/groups/birdrad/COMMENT.HTM)

Mountain Blockage

- Low elevation angle scans blocked by terrain
- ‘Shadows’ appear consistently in imagery
- Mainly a problem in western U.S.

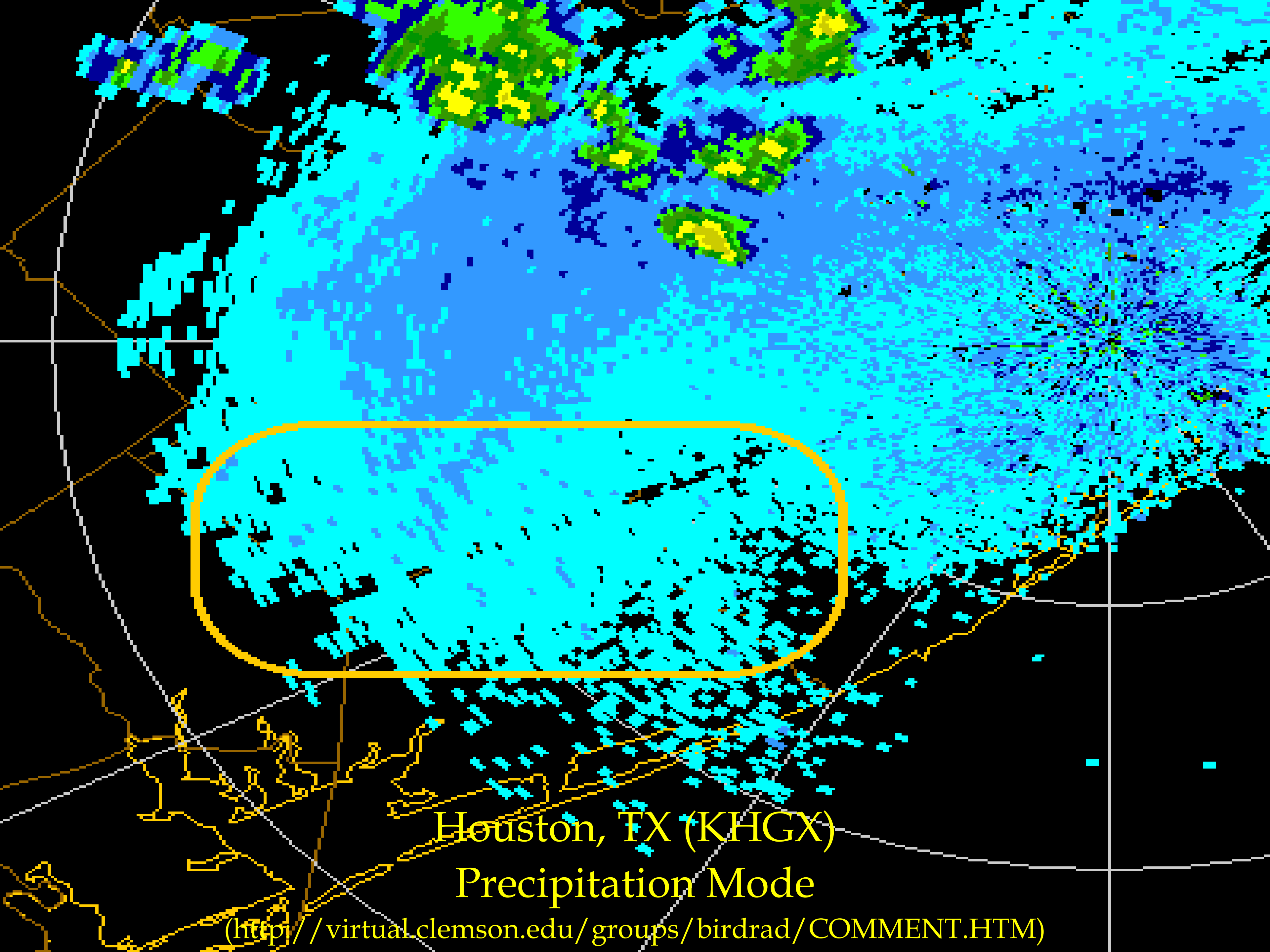

Boise
Mountains
Owyhee
Mountains
Boise, ID (KBOI)
Clear-Air Mode
(http://virtual.clemson.edu/groups/birdrad/COMMENT.HTM)

WSR-88D Network



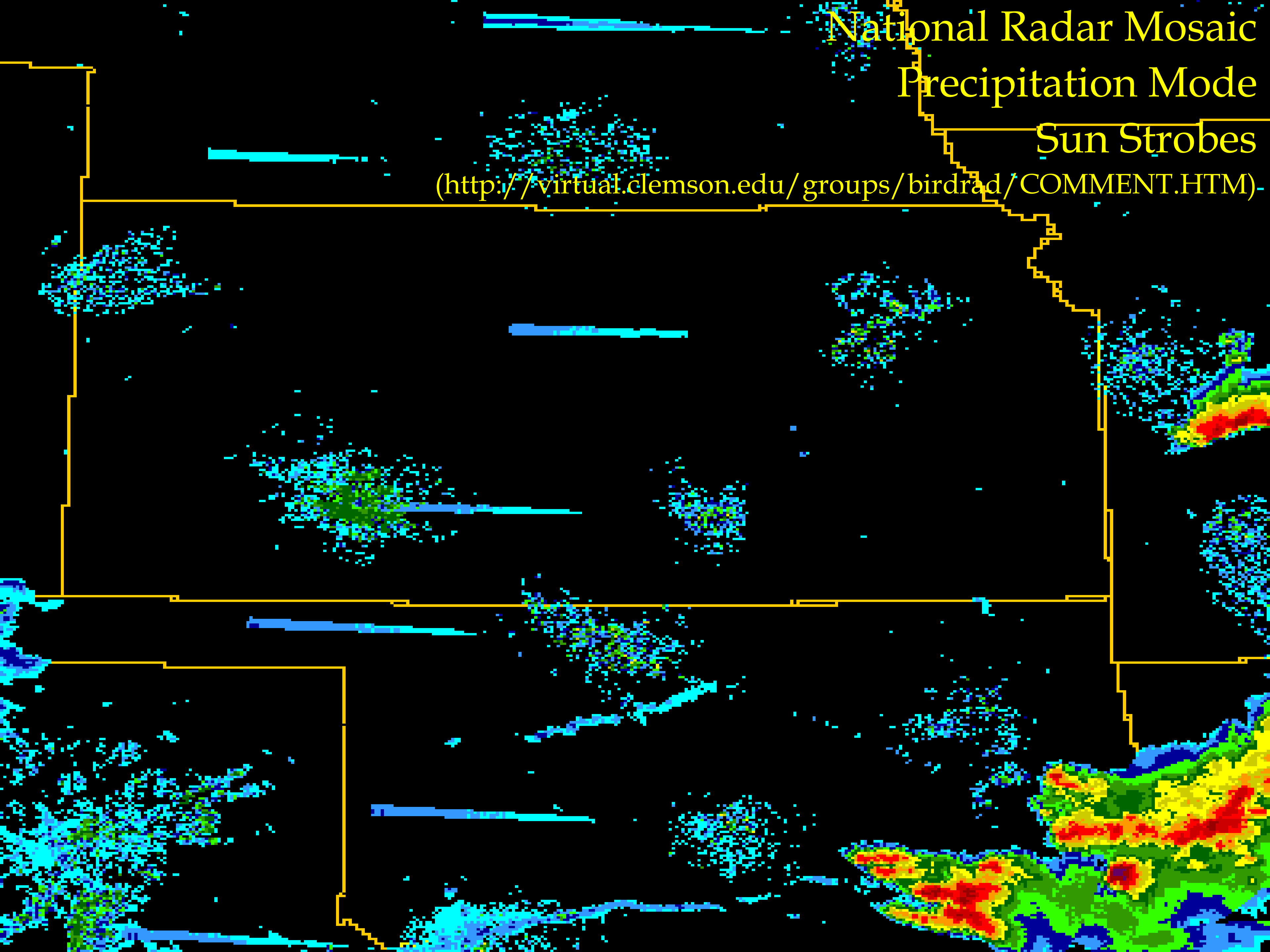
Building Blockage

- Nearby building blocks beam if building is taller than antenna (~100 ft)
- Narrow 'shadows' appear consistently in imagery
- Occurs in/near metropolitan areas


Houston, TX (KHGX)
Precipitation Mode
(http://virtual.clemson.edu/groups/birdrad/COMMENT.HTM)

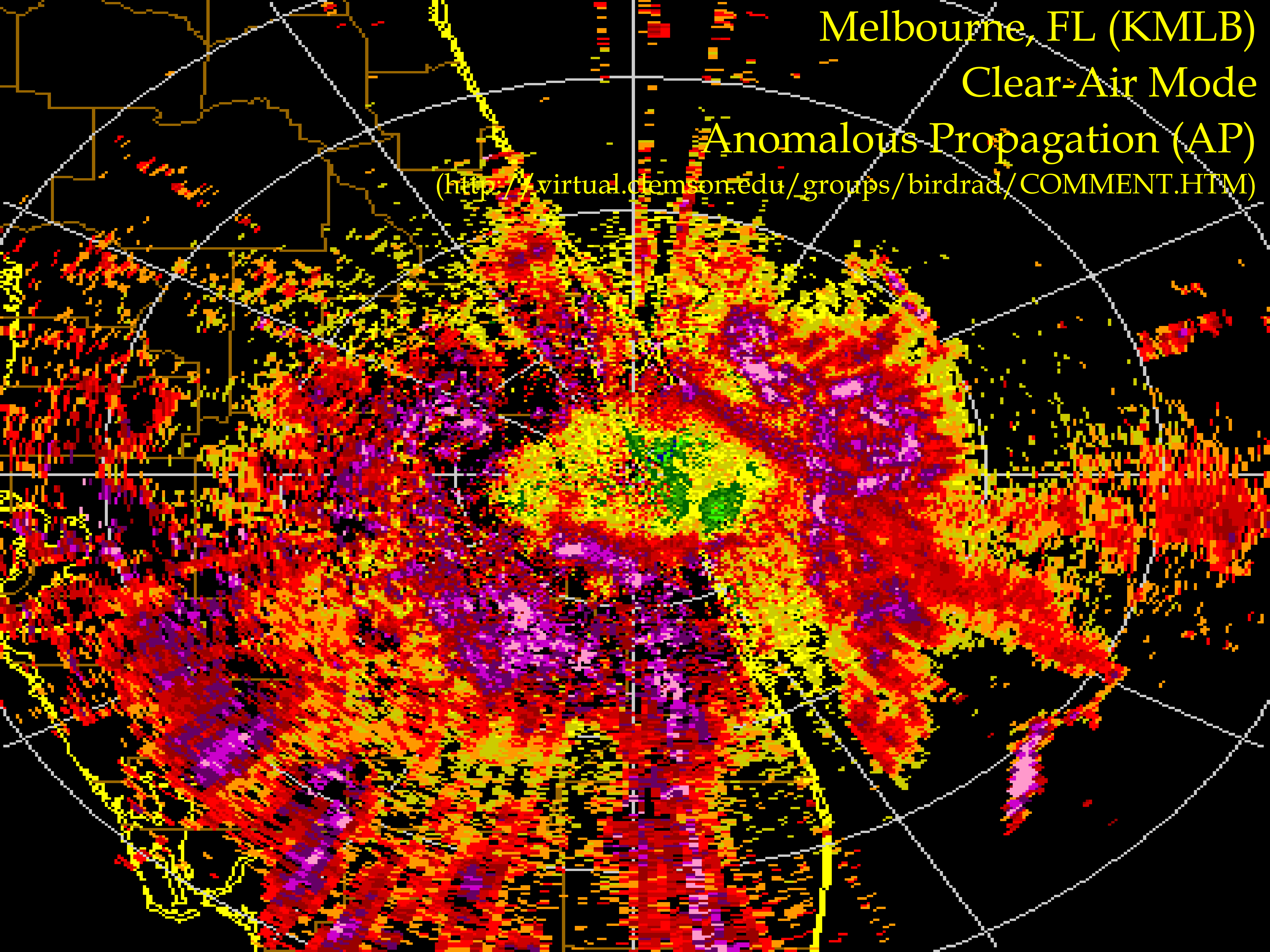
Other Targets 1

- Sun strobes
  - occur typically around dawn/dusk
  - radar receives intense dose of E-M radiation along narrow radials
  - similar strobes occur if beam intercepts intense source of microwave radiation
    - other radars
    - microwave repeaters

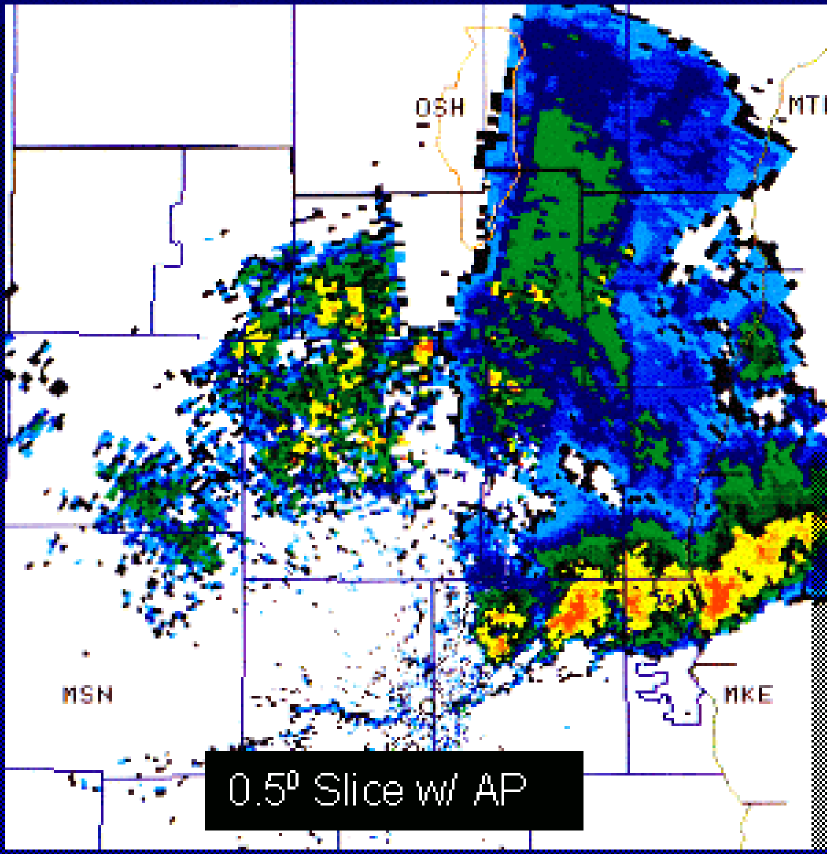

National Radar Mosaic
Precipitation Mode
Sun Strobes
(http://virtual.clemson.edu/groups/birdrad/COMMENT.HTM)

Other Targets 2

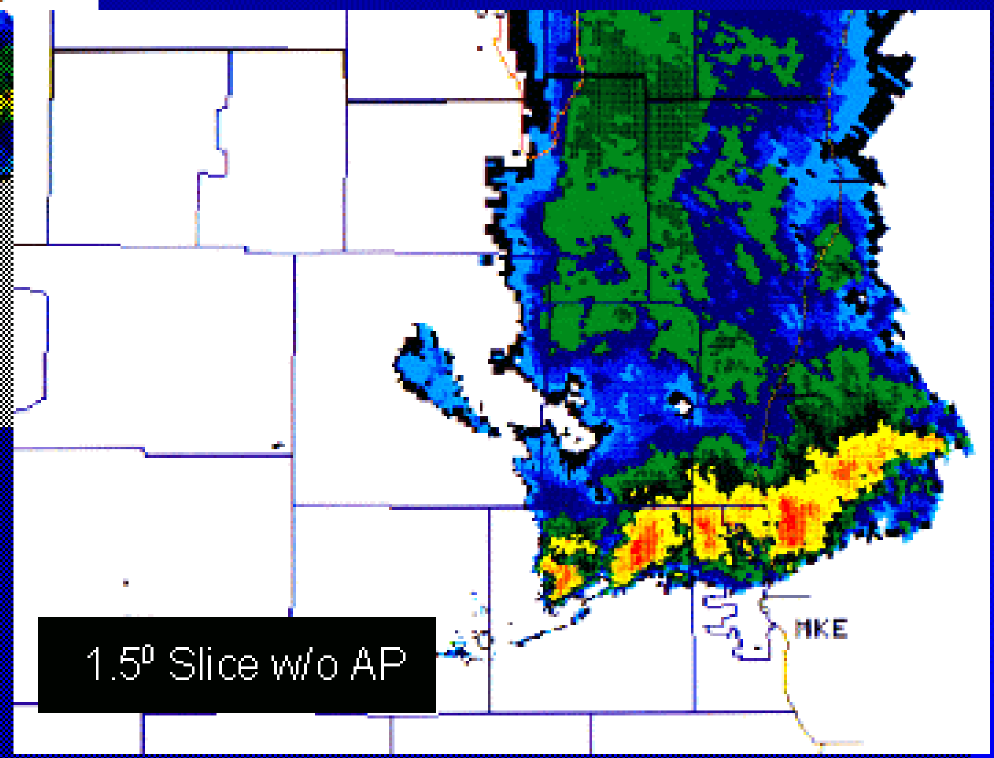
- Anomalous propagation (AP)
  - beam refracted into ground under very stable atmospheric conditions
    - inversions
    - near large bodies of water
    - behind thunderstorms
  - appear similar to intense precipitation
    - compare to surface observations
    - check satellite imagery
    - examine higher elevation scans


Melbourne, FL (KMLB)
Clear-Air Mode
Anomalous Propagation (AP)
(http://virtual.clemson.edu/groups/birdrad/COMMENT.HTM)

Multicell Line - AP mitigation



Anomolous Propogation in the wake of storms. Cold outflow produces superrefractive conditions.



Mitigate "wake AP" by raising elevation about 1 degree.

(http://www.crh.noaa.gov/mkx/radar/part2/slide31.html)

Summary

- Weather surveillance radar has varied uses
  - short-term weather forecasting
  - hazardous weather warnings
  - hydrologic applications
- Must be aware of radar's limitations
  - WYSINAWYG
  - What You See Is ***NOT ALWAYS*** What You Get!