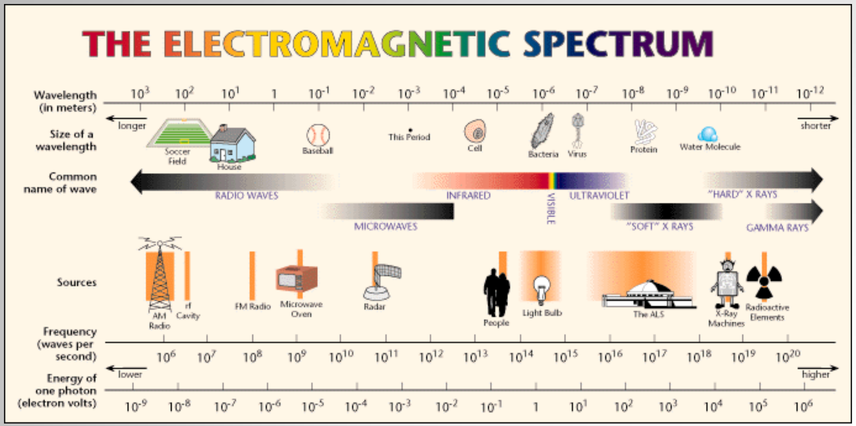
Satellites, Weather and Climate Module 43:

Radar Basics and Imagery Examples

Introduction to Radar



EM spectrum. http://www.lbl.gov

http://www.nssl.noaa.gov/about/events/40thanniversary/talks/doviak/slide7.html

- RaDAR

Radio ***D***etection ***A***nd ***R***anging

- Radar is a form of electromagnetic energy characterized by speed (C), wavelength (λ) and frequency (f)

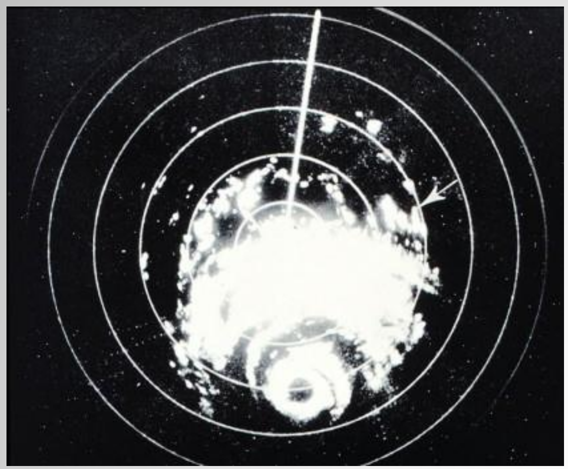
- $\lambda = C/f$

WSR-88D λ=10cm , $C=3x10^{-8}$ m/s

- PRF = **Pulse Repetition Frequency**

long distance detection requires a low PRF (allows time for the radar energy to reach target and be reflected back to the radar antenna before the next pulse). For shorter ranges, a higher PRF can be used and provides more detail. **The WSR-88D has alternate PRF's.**

Evolution of radar in the computer age

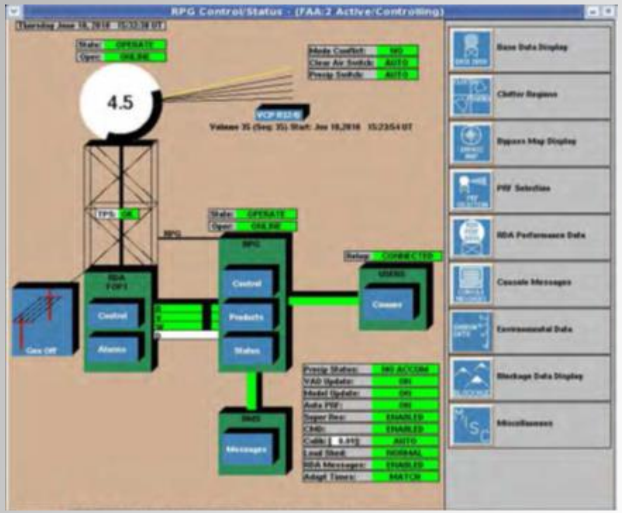


Hurricane Carla in September 1961. The eye is visible on the Galveston WSR 57 radar. This was the first hurricane on radar that TV viewers had seen.
http://blogs.agu.org/wildwildscience/2009/10/11/how-to-interpret-weather-radar-a-short-course-with-no-math/

WSR-57 Unit and operator.
http://www.medialine.com/ubb/NonCGI/ultimatebb.php?ubb=get_topic;f=3;t=008758;p=1/www.crh.noaa.gov

- Previous generation radar units required an operator to draw overlays and manually transmit data
- Today's radar is all computerized

WSR-88D Data Flow diagram

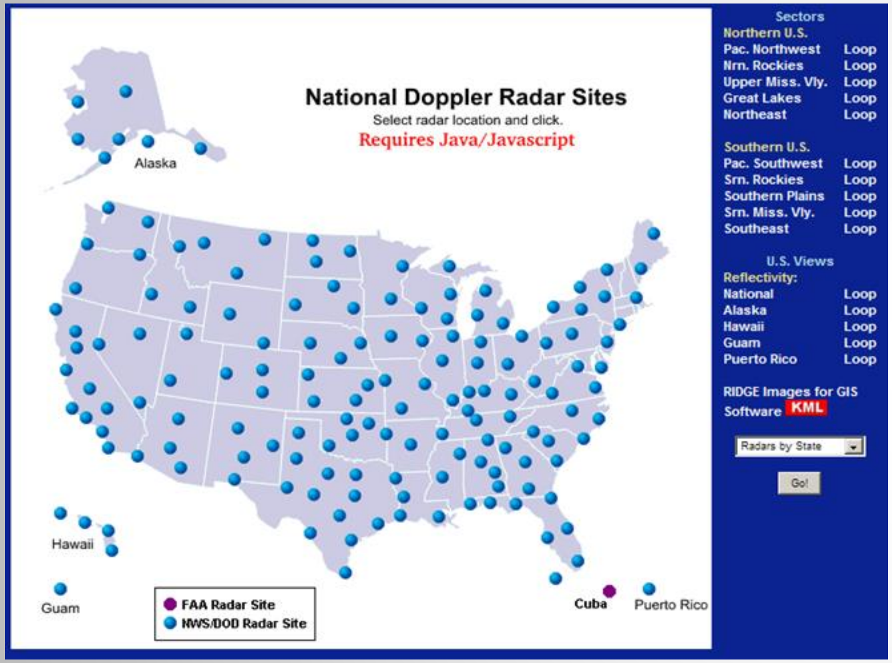


http://cdn.intechopen.com/pdfs/35106/InTech-Doppler_radar_for_usa_weather_surveillance.pdf

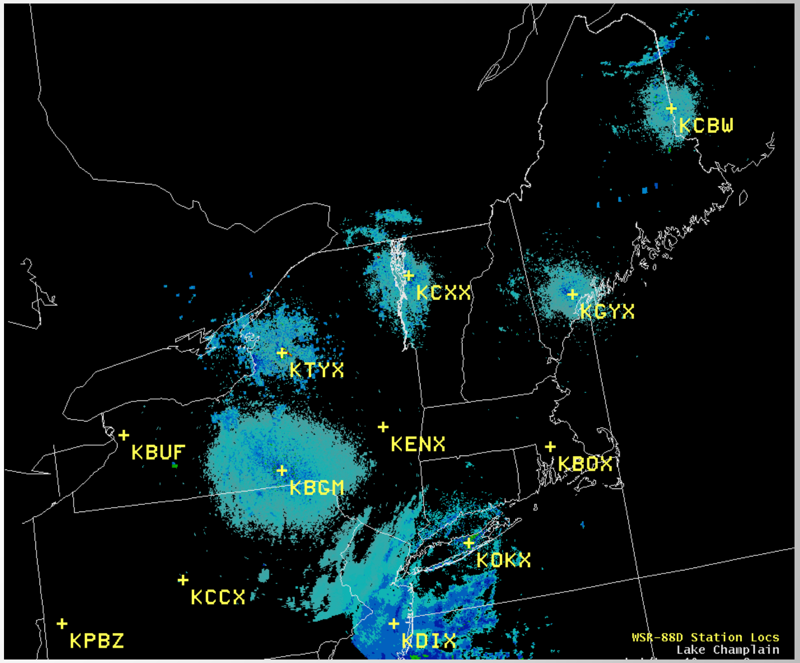
HTTP://www.crh.noaa.gov

- Raw data computer processed
- Processed radar data displayed on PC work stations
- Forecaster can display 1 large image or up to 4 smaller images per screen
- This allows meteorologist to compare various radar products

National and Northeast regional NWS Weather Radar Locations



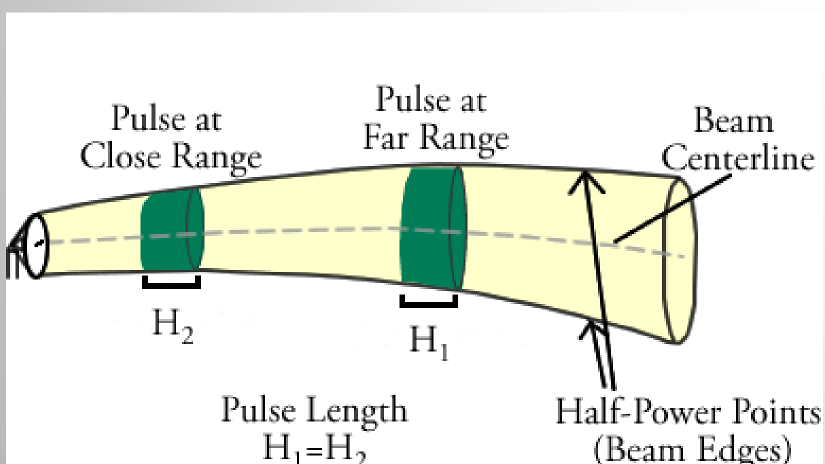
http://www.erh.noaa.gov/btv/research/Wind_Farm/



http://www.erh.noaa.gov/btv/research/Wind_Farm/

How Radar Calculates Target Location

http://www.srh.noaa.gov/jetstream/doppler/how.htm



http://www.wdtb.noaa.gov/courses/dloc/topic3/lesson1/Section1/Section1-3.html

- Antenna rotates 360 degrees in horizontal, then raises and rotates 360 degrees through numerous ***vertical slices***…total scan takes 4 to 8 minutes.

- Very short pulses of EM energy (1.57us sec) followed by short listening period (998.43 usec). Most of the time (~99 percent) the radar is listening.

- **Using D = RxT**, we know the following:

Speed R = C = speed of light, and

Time (T) = the time for signal to reach target and return.

***Distance* D = (C x T)/2 why divide by 2 ?**

- The ***direction*** in which the antenna is pointed determines the target's azimuth direction

Volume Coverage Patterns - VCP

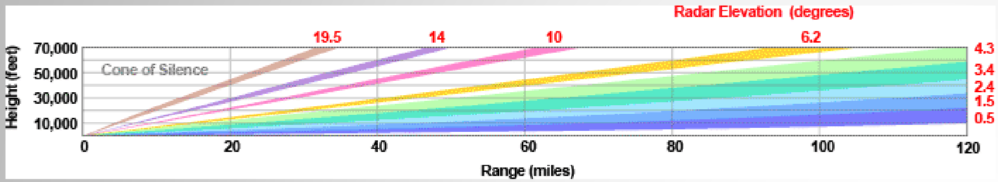


Fig : VCP 11 takes 5minutes severe weather

weatherhttp://www.srh.noaa.gov/jetstream/doppler/vcp_max.htm

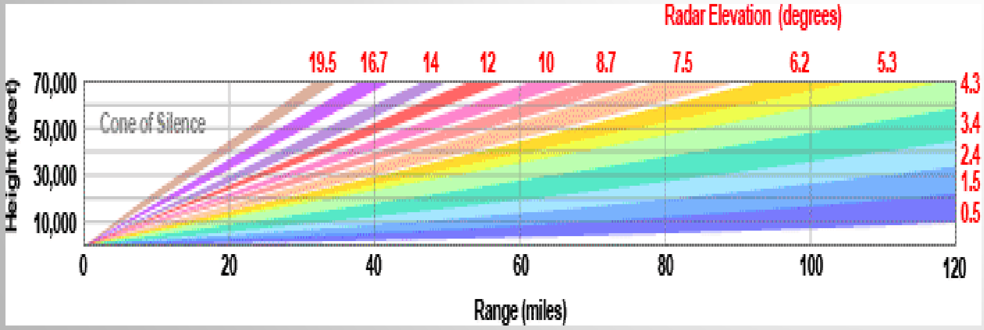


Fig : VCP 21 takes 6 minutes general rain
http://www.srh.noaa.gov/jetstream/doppler/vcp_max.htm

- VCP 11 used during severe weather provides more detail and is fast.
- VCP 21 is used during stratiform precipitation with less detail in vertical and is slower
- Other scan strategies are also used (6 VCP's)

Refraction of radar beam

Standard or Normal refraction most frequent - beam is rising due to curvature of earth and atmosphere

Radar beam bends more than normal (super) – Inversions most frequent cause – will underestimate tops

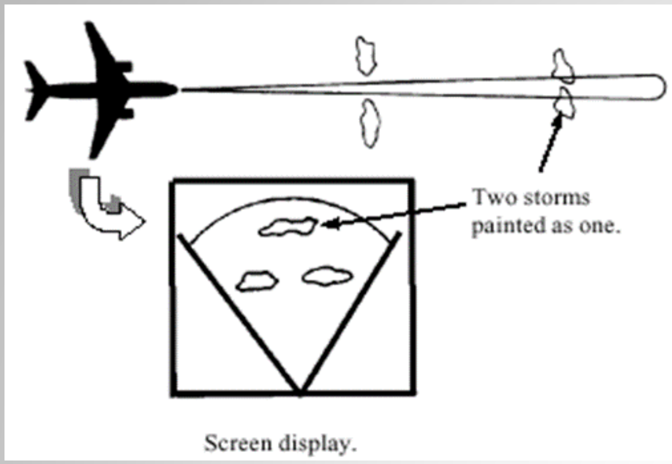
Radar beam bends less (sub) than normal will overestimate tops.

Standard refraction most common and is radar default.

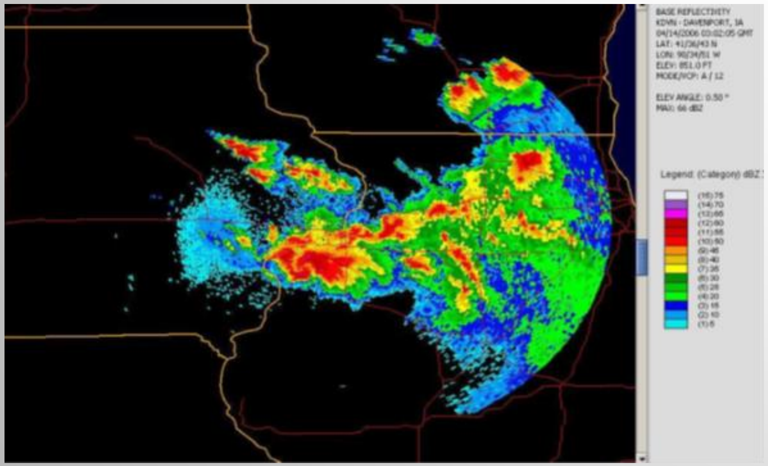
Superrefraction (inversions) – The radar assumes Standard refraction

https://www.meted.ucar.edu/radar/basic_wxradar/index.htm

Narrow beams are attenuated or weakened by precipitation while longer wave lengths give better coverage



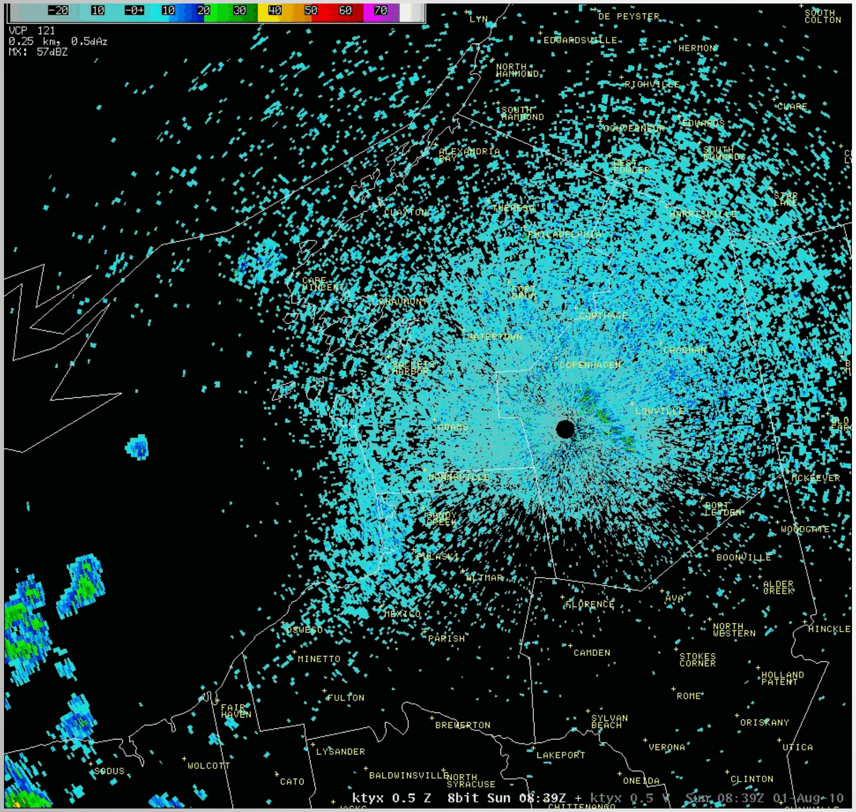
Example of azimuth or beam width resolutionhttp://www.robavery.com.au/editorial/wxradarIII/index.asp



http://www.meteor.iastate.edu/~jdduda/portfolio/How%20to%20read%20and%20interpret%20weather%20radar.pdf

- The radar beam is determined by the half power points on edge of beam.
- **Targets separated by full beam width resolve as separate echos.**
- **Targets separated by less than a beam width resolved as single echo.**
- **This aspect is more of a problem at long distances as the beam spreads.** As a large solid echo moves closer it may appear as 2 smaller echoes with more detailed depiction. Distant echoes are more blocky.

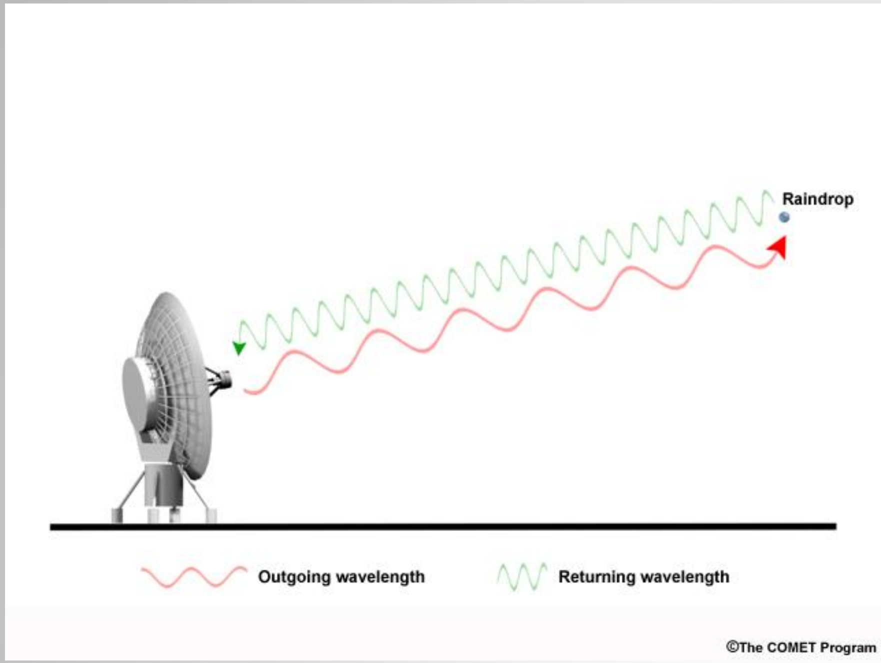
What do you see in this loop???



http://www.erh.noaa.gov/btv/research/Radar_Artifacts/

- Imagery from KTYX radar (northern NY) 0.5° base reflectivity
- Loop is from Aug 1, 2010 - 2:39 AM EDT to 6:16 AM EDT
- Birds tend to rest overnight near bodies of water and takeoff around sunrise.

** The Doppler Dilemma: There is no single PRF that maximizes both Range and Velocity data **



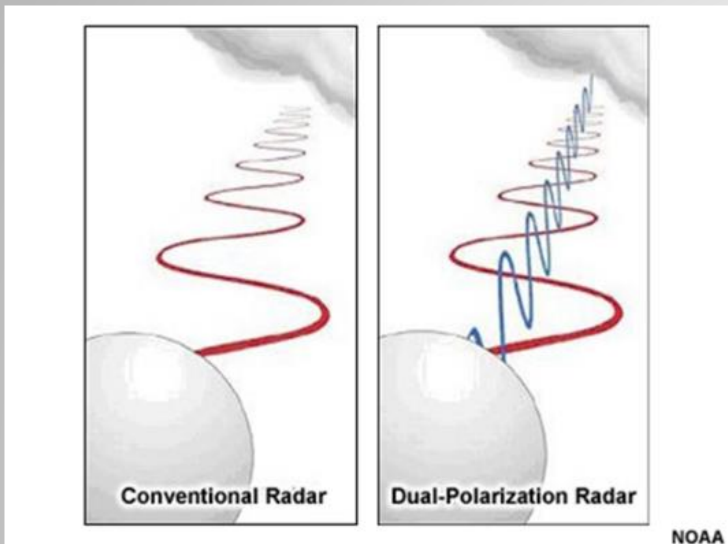
WSR-88D compares transmitted wavelength with the received wavelength to calculate velocity or the shift in phase.

A positive shift (Green) implies motion toward the radar and a negative shift (Red) indicates motion away

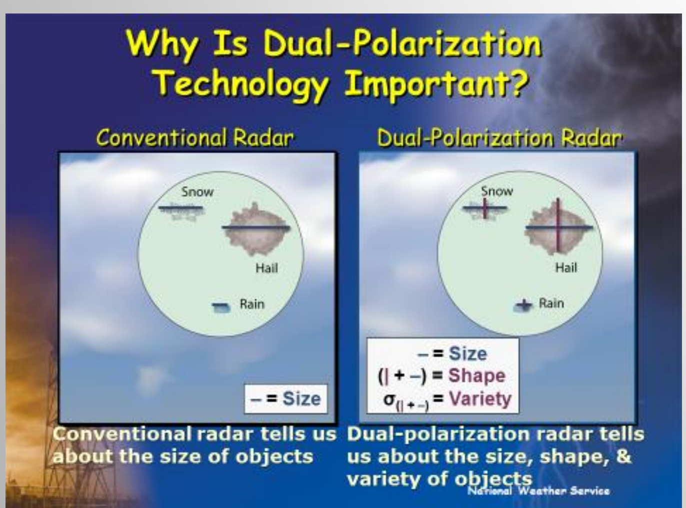
- Pulse Repetition Frequency (PRF) is the number of energy pulses transmitted per second.
- If the PRF is low (longer time between pules), detection distance is maximized.
- If the PRF is high (shorter time between pules) detection distance is minimized but detail (velocity etc) is increased.

- **Range max** = C/2PRF **inversely related to PRF**
- **V max** = (PRF) * (λ)/4 is **directly related to PRF** [2f=prf]

Yes, the WSR-88D has been upgraded

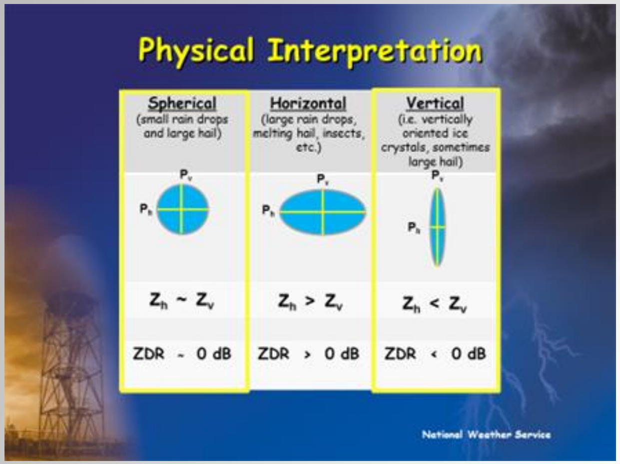


http://www.wdtb.noaa.gov/courses/dualpol/Outreach/non-mets-intro/player.html

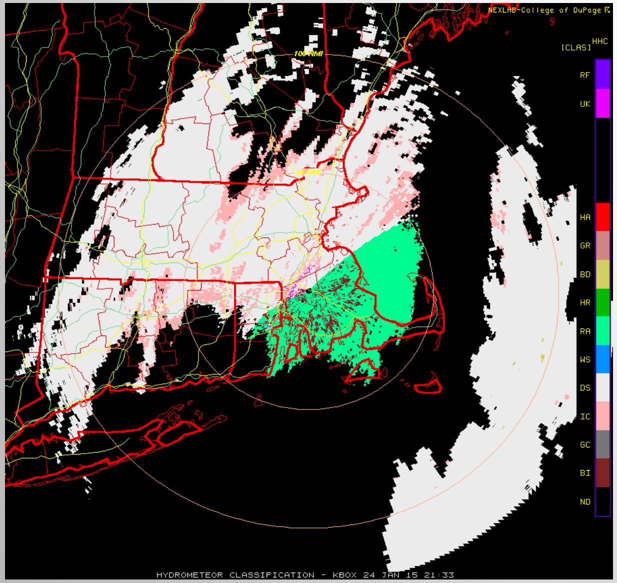


- **With Dual-polarization (Dual-Pol), a horizontal and vertical pulse of energy is emitted at the same time to gather information.**
- **This more detailed and accurate picture of what is occurring in the clouds, allows for a more comprehensive interrogation of storms.**
- **Dual-polarization** radar provides details about the **size** and the **shape** of hydrometeorological objects

Precipitation Type Algorithm



http://www.wdtb.noaa.gov/courses/dualpol/Outreach/non-mets-intro/player.html



Hydrometeorological type KBOX Jan 24, 2015 2133Z http://weather.cod.edu/satrad/

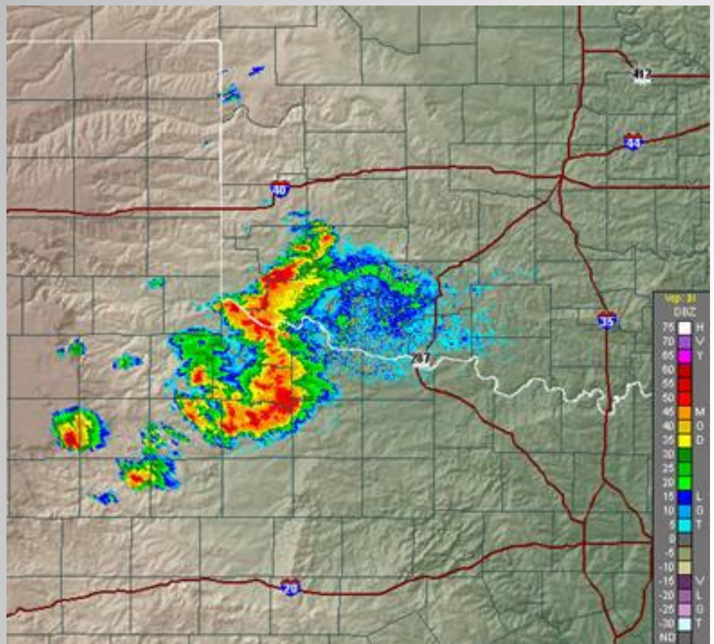
- Large rain drops are oblate - horizontally orientated
- Large hail tends to be spherical
- **Dual pulse provides information about weather type**

So…Really…Why dBZ

- Once returned power is measured, Reflectivity "Z" can be estimated using $Z = PrR^2/C$
- Also Z ~ 6^{th} power of raindrop diameter D^6
- **Z results in large unwieldly numbers, but the $\log_{10}$ Z is very convenient**

z Radar reflectivity factor from the radar equation. (linear scale of reflectivity)	**$10^x = z$**	**$x = \log_{10} z$**	**Z dBZ = 10 $\log_{10}$ z (decibel scale of reflectivity)**
0.001	10^{-3}	-3	-30
0.01	10^{-2}	-2	-20
0.1	10^{-1}	-1	-10
1	10^0	0	0
10	10^1	1	10
100	10^2	2	20
1,000	10^3	3	30
10,000	10^4	4	40
100,000	10^5	5	50
1,000,000	10^6	6	60
10,000,000	10^7	7	70

dBZ values and rainfall – use with other data (satellite, surface reports, etc)



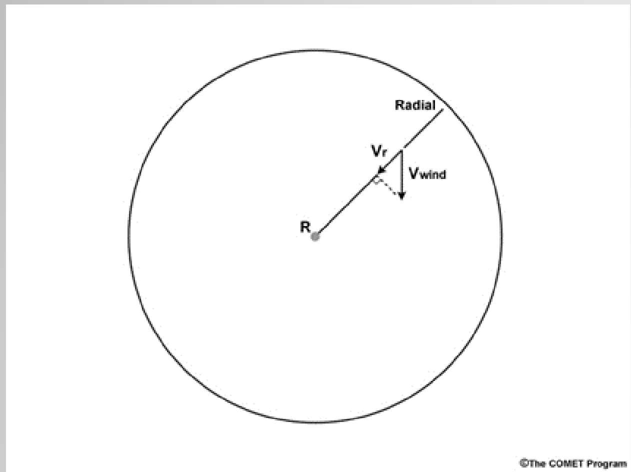
dBZ	Rain Rate (in/hr)
65	16+
60	8.00
55	4.00
52	2.50
47	1.25
41	0.50
36	0.25
30	0.10
20	Trace
< 20	No rain

http://www.srh.noaa.gov/jetstream/doppler/baserefl.htm

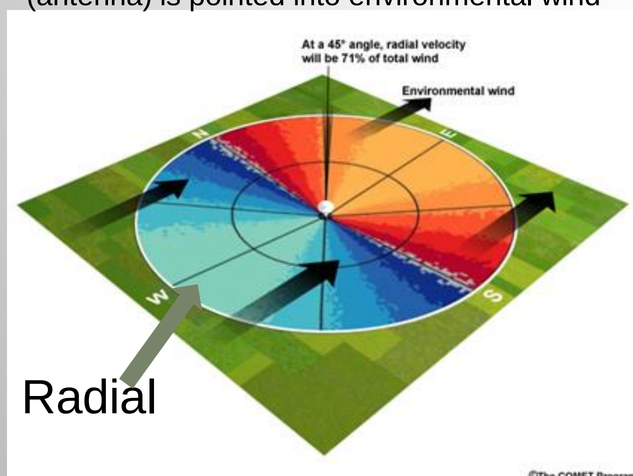
- In precipitation mode, low dBZ values (blue and green colors) 15-30dBZ indicate light precipitation.
- As the dBZ values increase (35-55), yellow, orange, and red colors associate with moderate to heavy rain.
- Values above about 45 dBZ are frequently associated with thunderstorms.
- **dBZ values 60 dBZ and above generally means that the sample volume contains some hail** as well as heavy rain.

Doppler Radial Velocity

Images courtesy: https://www.meted.ucar.edu/radar/basic_wxradar/index.htm



True velocity is measured when the radial (antenna) is pointed into environmental wind



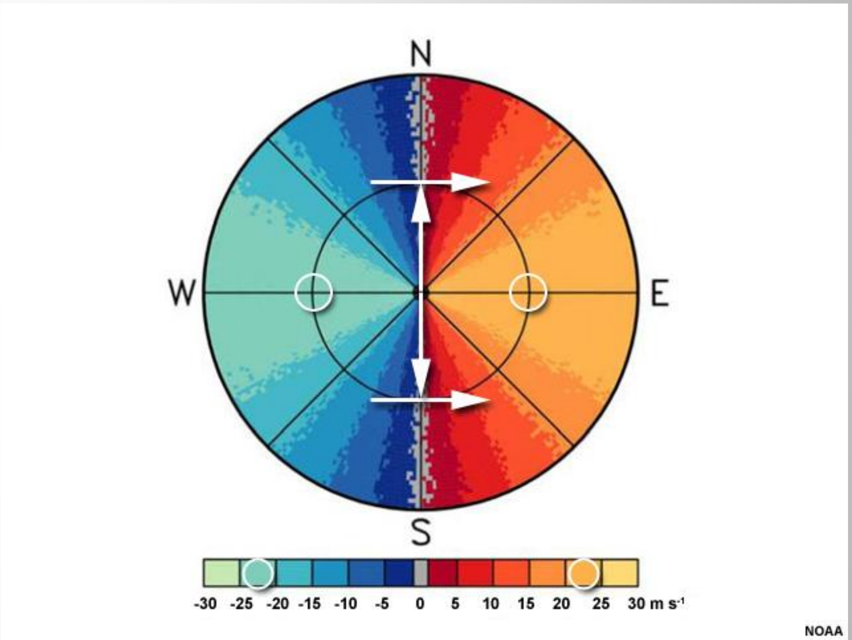
Otherwise, through trigonometry we know it will be somewhat less depending upon the angle and ZERO when perpendicular (90 deg)

- The WSR-88D measures Doppler velocity down the radial – radial velocity.
- When the radial is pointed directly into the wind we receive the true wind velocity (parallel).
- When the radial is at an angle to the wind we get some percentage less than the true velocity
- An isodop is a contour of constant Doppler velocity. At the zero isodop the wind is zero because the wind is perpendicular to the radial

Simple unidirectional wind

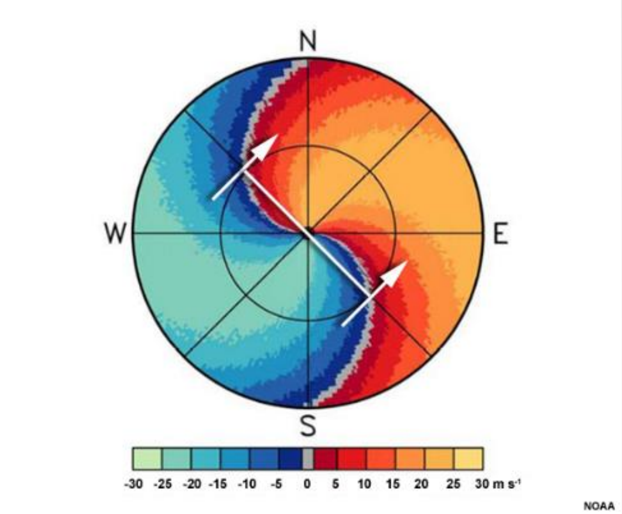
Images courtesy: https://www.meted.ucar.edu/radar/basic_wxradar/index.htm

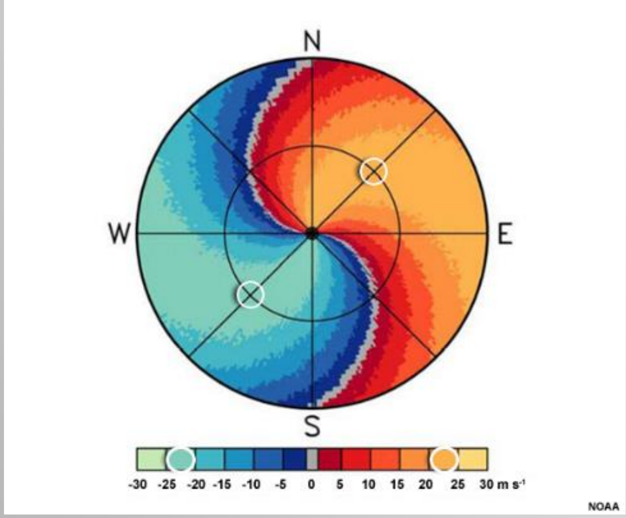
- **Cool colors (blue, green) are toward the radar**
- **Hot colors (red, yellow) are away from the radar.**
- The grey/white line is the zero Doppler velocity or zero isodop (perpendicular to wind)
- To calculate wind direction draw a line from radar site to a point (such as a range marker) on the zero isodop.
- The wind direction is perpendicular to the line you drew…and the velocity is the maximum velocity anywhere at that point distance around radar display.



For varying winds - a curved zero isodop

Images courtesy: https://www.meted.ucar.edu/radar/basic_wxradar/index.htm

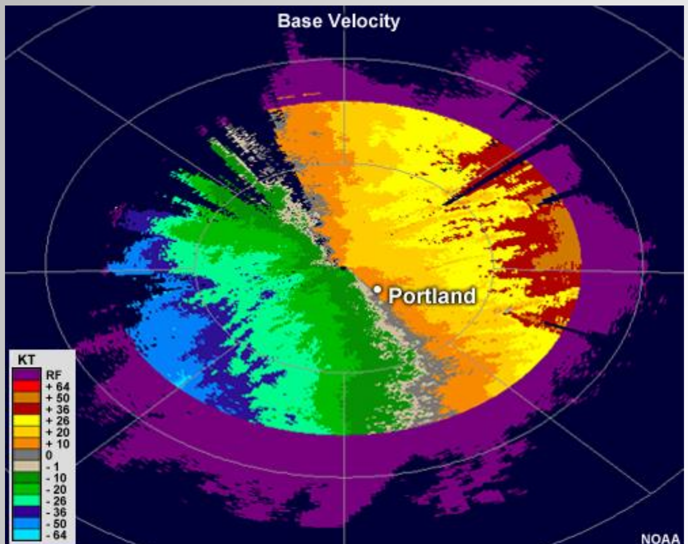


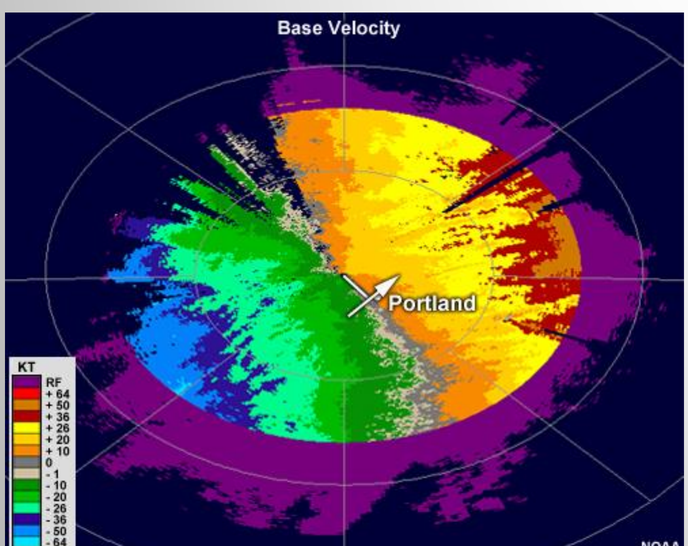


- Pick a point of interest, and again draw a line from radar site to the zero isodop at the same distance as the point of interest.
- Wind direction is perpendicular to this line
- Wind speed is the maximum value on the display at that distance range

POP QUIZ !!!

Images courtesy: https://www.meted.ucar.edu/radar/basic_wxradar/index.htm

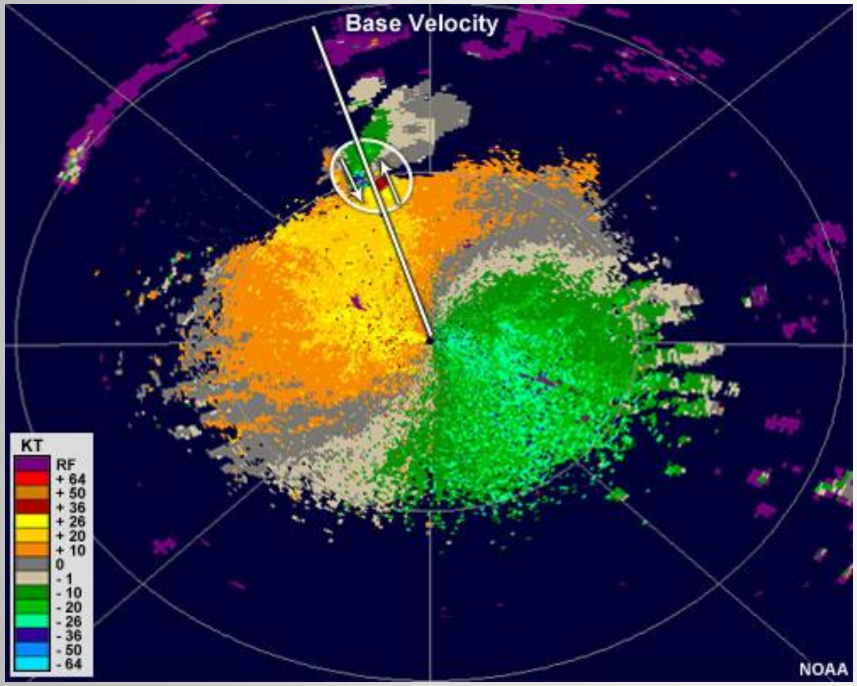




https://www.meted.ucar.edu/radar/basic_wxradar/index.htm

- Class exercise:
- What is the Doppler derived wind **direction** and **velocity** at Portland?
- a) Northwest at 0-10 kt
- b) West at 10-20 kt
- c) Southwest at 10-20 kt
- d) Northeast at 50-60 kt
- e) Southeast at 0-10 kt

In areas where there is no available zero isodop due to small scale gate to gate velocity



https://www.meted.ucar.edu/radar/basic_wxradar/index.htm

- A well-defined couplet is clearly evident north-northwest of the radar - thunderstorm.
- In this case, ***there is no zero isodop between the two maxima, which is often the case with thunderstorm*** or tornado (gate to gate) environments.
- Drawing on the radial from the radar site to the echo, we note that maximum inbound velocities (GREEN) are found to left while maximum outbound velocities (RED) are to the right.
- ***The circulation may be rotational as in this case,*** or could be divergent/convergent depending upon orientation to radial.

Radar Imagery and Actual Weather

Hurricane Arthur July 4, 2014

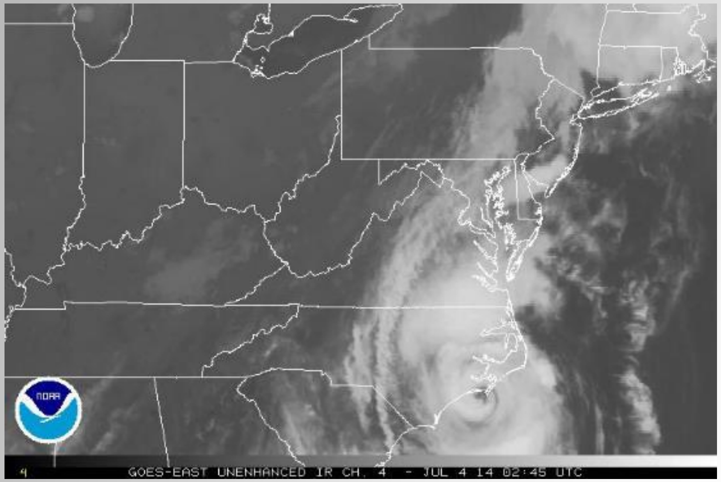


Fig 1: IR Satellite 0245z Jul 4. 2014
http://www.ssd.noaa.gov/GOES/EAST/NOAA.gov

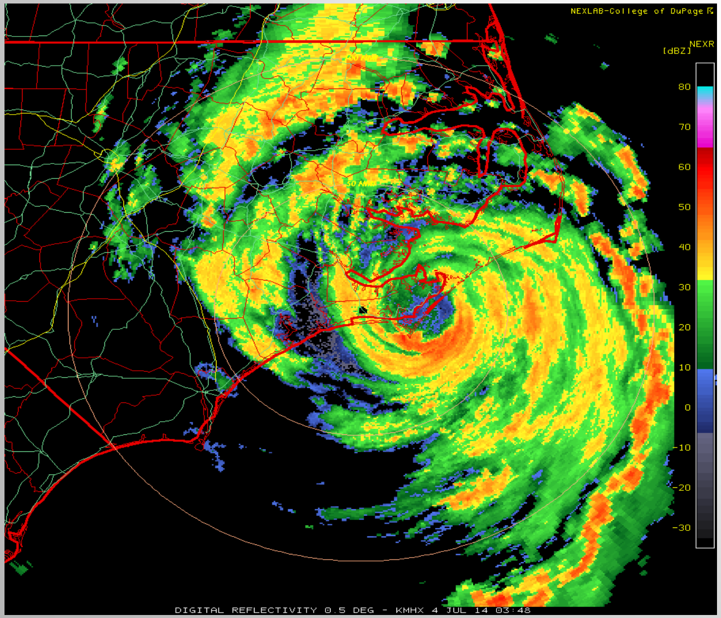
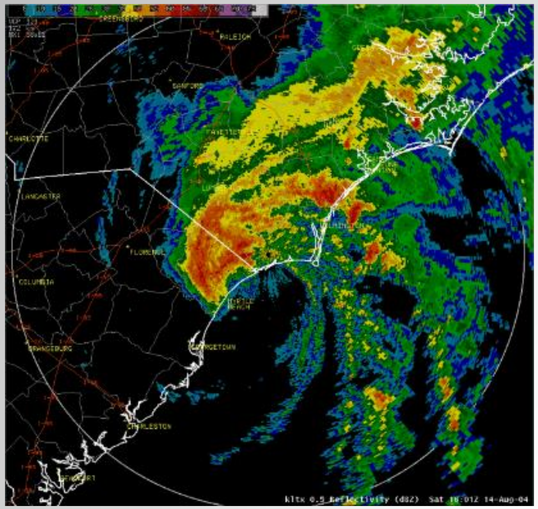


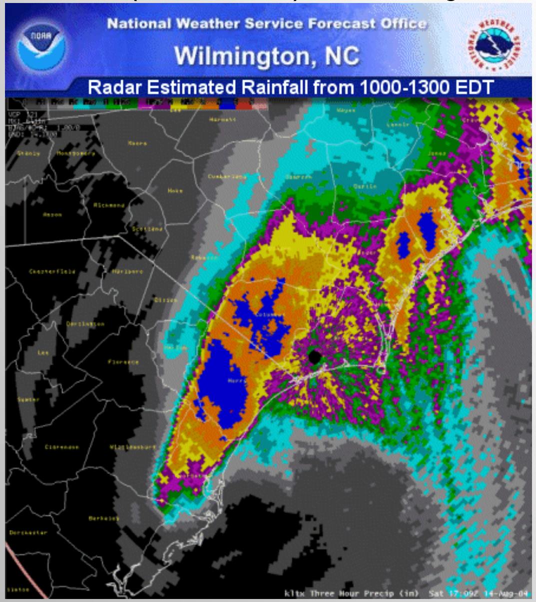
Fig 2: KMHX Radar Base Ref 0.5 deg
http://weather.cod.edu/satrad/

- Remote observing by satellite (top) and radar (bottom) allow tracking of hazardous weather in data spare areas.
- Equipment operates 24/7 (we hope!!!)
- These remote sensing tools allow the meteorologist to fill in gaps between surface observations

Hurricane Charley Landfall Aug 14, 2004



KLTX Wilmington NC 14 Aug 2004
1601Z (12 noon EDT) REF 0.5 deg



Radar estimated precipitation 14 Aug 2004 1000-1300 EDT

Radar reflectivity helped forecasters point the landfall point near the NC-SC border with observed 75 mph wind in rain bands.

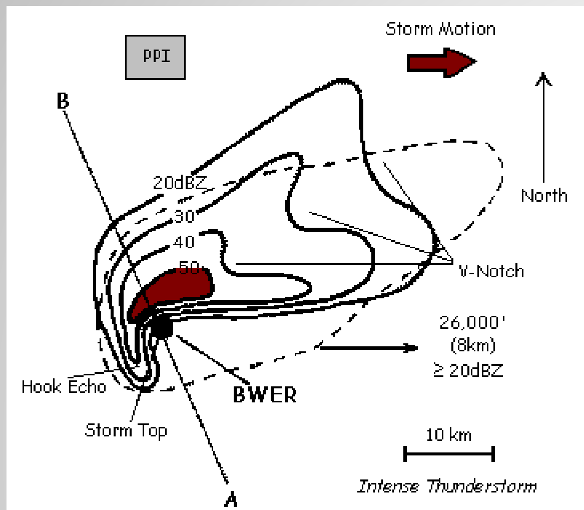
WSR-88D radar imagery from Wilmington, North Carolina estimated 3 hour precipitation of 3-6 inches (greatest observed 5.05 inches) between 10AM and 1 PM EDT

These images also assist emergency managers in evacuation and sheltering planning

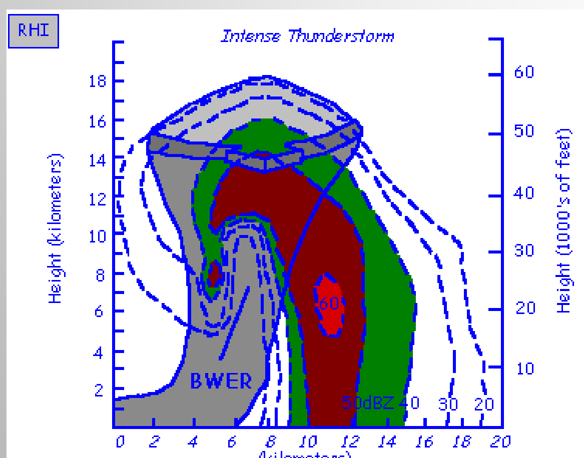
http://www.erh.noaa.gov/ilm/archive/08-14-04/index.shtml

Convection

Tornadic signature Hook and BWER (Boundary Weak Echo Region) Mulvane Kansas on 12 June 2004 - KICT WSR-88D



Horizontal (top) and Vertical (bottom) schematic of BWER and radar display



- The dry slot around the ***hook*** is a <u>B</u>oundary <u>W</u>eak <u>E</u>cho <u>R</u>egion or ***BWER*** – Upward motion so strong rain is held aloft thus echo free
- ***Very tight dBZ gradient*** (green-yellow-tan-red-dark red)

http://www.nws.noaa.gov/mdl/pubs/Documents/Papers/StumpfFSI2005.pdf

Narrow band of convection Evening of May 5

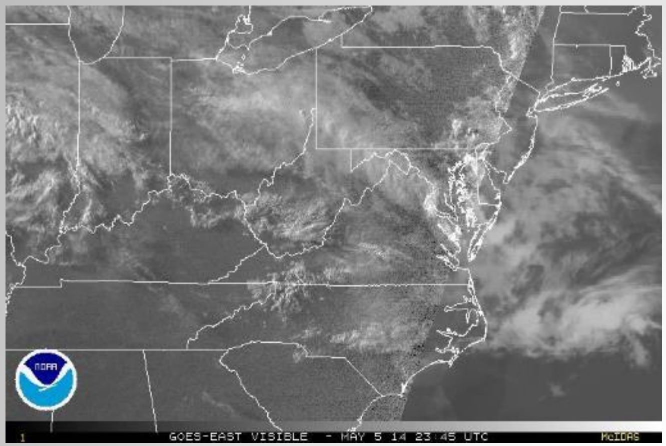


Fig 3: VIS Satellite 2345z May 5, 2014
http://www.ssd.noaa.gov/GOES/EAST/NOAA.gov

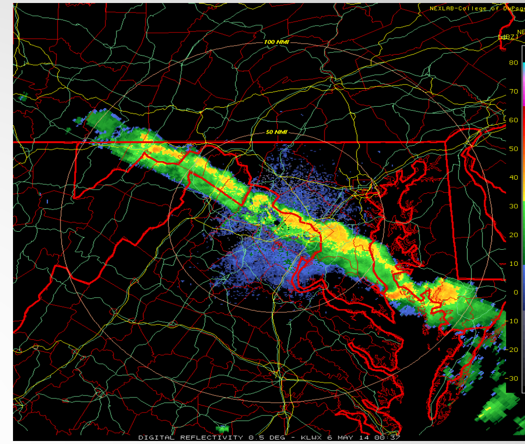


Fig 5: KLWX Radar Base Ref 0.5 deg
2345z May 5, 2014
http://weather.cod.edu/satrad/

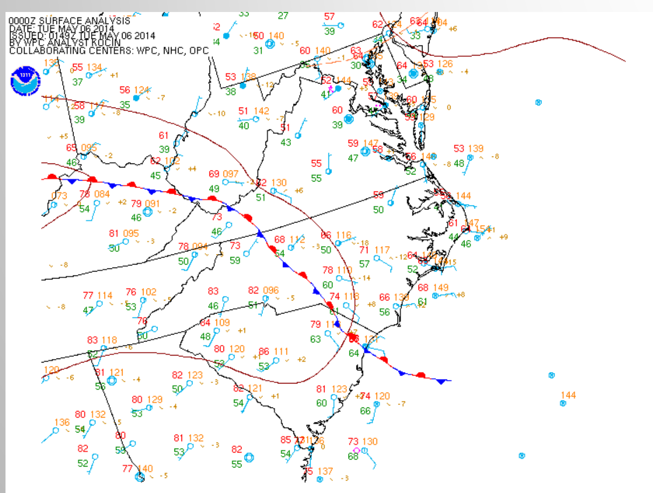


Fig 4: NOAA Surface Analysis 00z May 6, 2014.
http://www.hpc.ncep.noaa.gov/

- Convection extended northwest-southeast through Nation's Capital region into Chesapeake Bay
- Major metropolitan area and busy maritime interests
- Radar helps delinate the areas of greatest threat thus the meteorologist can fine tune the forecast

Set up- May 27, 2014 Severe thunderstorms northern New York into west central Vermont

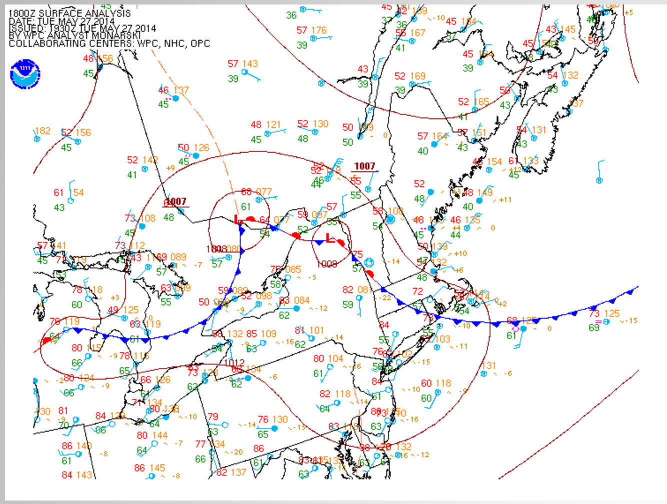


Fig 6: NOAA Surface Analysis 18z May 27, 2014.
http://www.hpc.ncep.noaa.gov

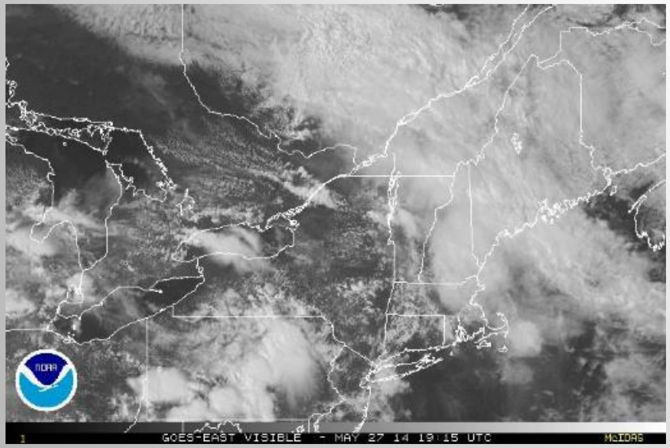
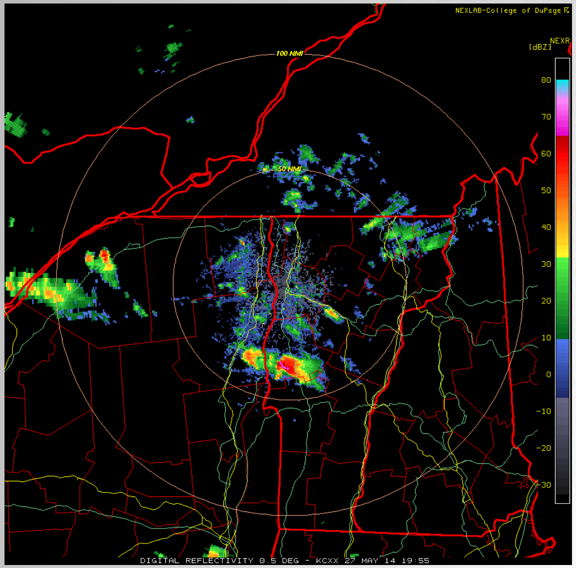


Fig 7: VIS Satellite 1915z May 27, 2014
http://www.ssd.noaa.gov/GOES/EAST/NOAA.gov

- Backdoor cold front resulted in northwest-southeast boundary for thunderstorms to traverse. Weak upper level jet streak over area.
- Northern cloudy area cool as opposed to cloud free areas southwest (insolation)
- Moderately unstable airmass southwest of the front (thunderstorms in Pa)
- Afternoon thunderstorms formed in northern NY and moved into Vermont along boundary

May 27, 2014 Radar images

All radar images courtesy: http://weather.cod.edu/satrad



KCXX Radar Base Ref 0.5 deg 1955z May 27, 2014

Afternoon of May 27, 2014 Photo Green Mountain Power

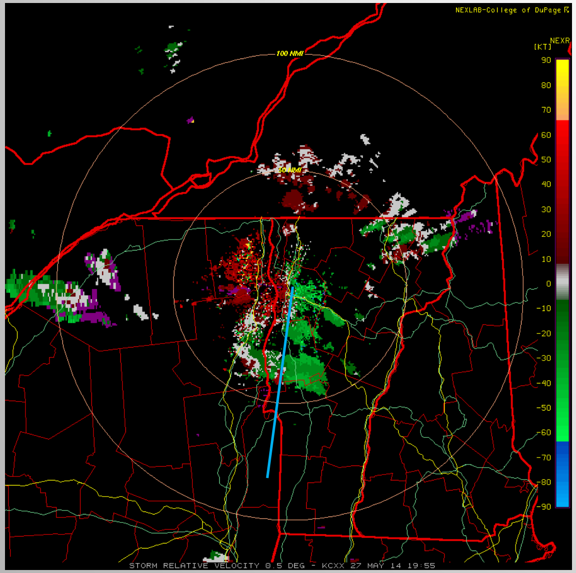


Fig 5: KCXX Radar Storm Rel Motion 0.5 deg 1955z May 27, 2014

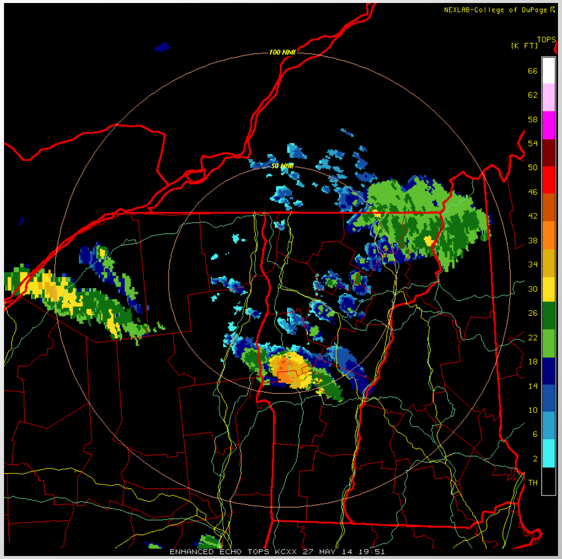
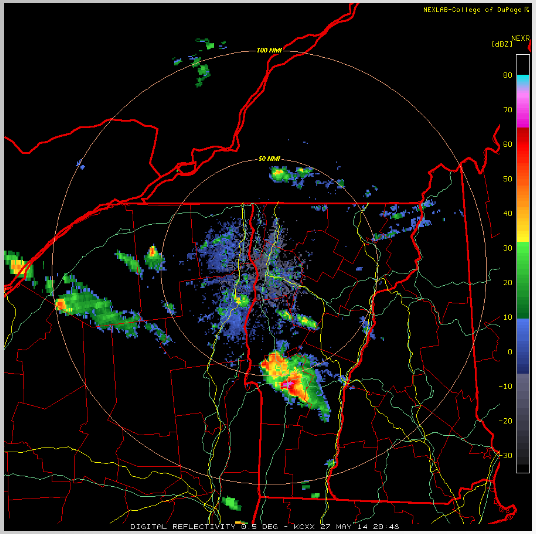


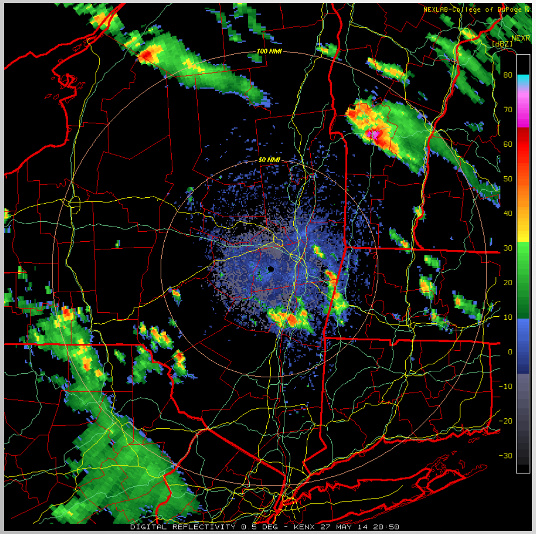
Fig 5: KCXX Radar Echo Tops 1951z May 27, 2014
ET 40-45K ft

Different radars view same thunderstorm

All Radar Images courtesy: http://weather.cod.edu/satrad



KCXX Radar REF 0.5 Deg 2048Z May 27, 2014



KENX Radar REF 0.5 Deg 2050Z May 27, 2014

- Same storm 2 minutes apart as viewed by Burlington (top) and Albany NY (Bottom) radar
- Note echoes along frontal boundary to northwest across Adirondacks into St Lawrence Valley of NY
- Both storms Exhibit high dBZ (65-70) indicating Very heavy rain and hail. Golf ball size hail (1.75 in diam) fell.

May 27, 2014 Thunderstorm track

http://www.weather.gov/media/btv/events/2014-05-27/Isolated_Supercell.pdf

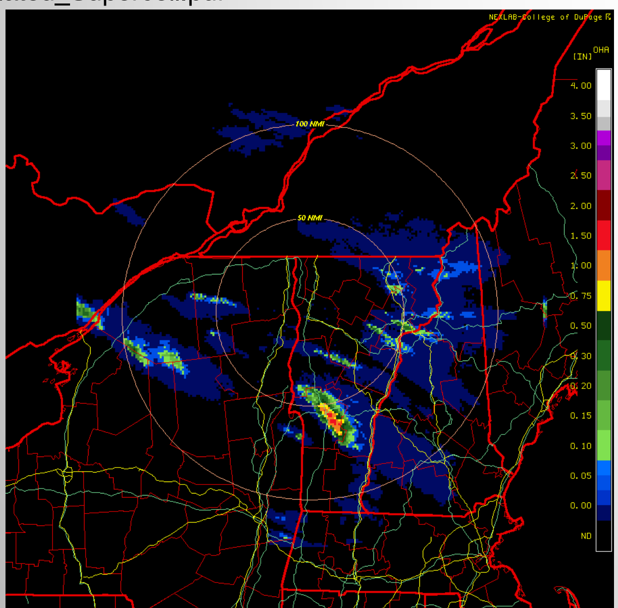
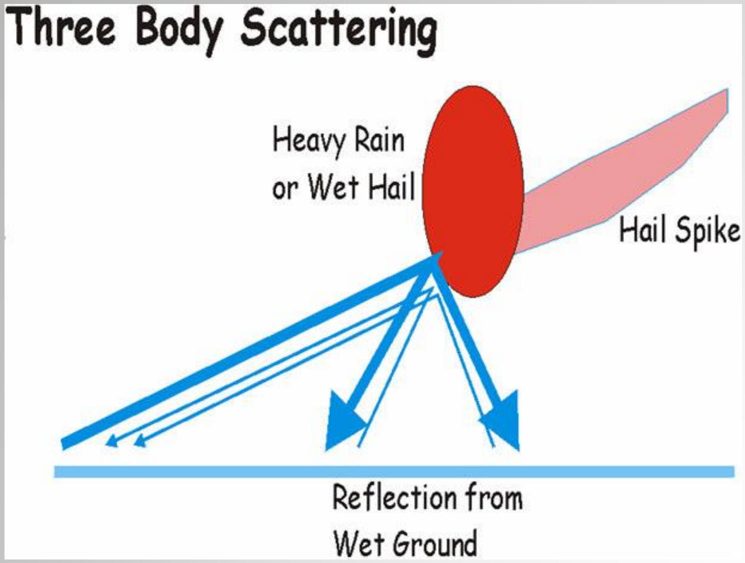
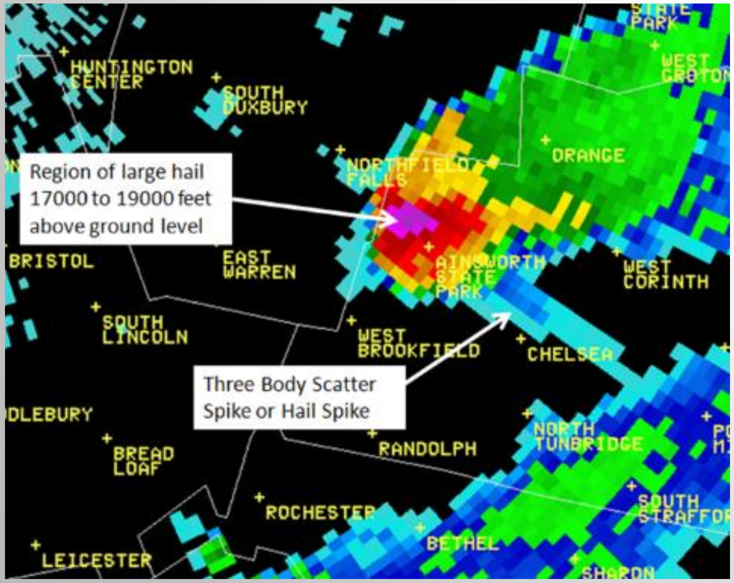


Fig 5: KCXX Radar Based one hour precipitation 2129z May 27, 2014 http://weather.cod.edu/satrad

- KCXX Radar loop May 27, 2014 from1924Z - 2104Z
- Thunderstorms on warm side of front Temperature differential of 25-30 degrees
- Supercell thunderstorm followed frontal boundary



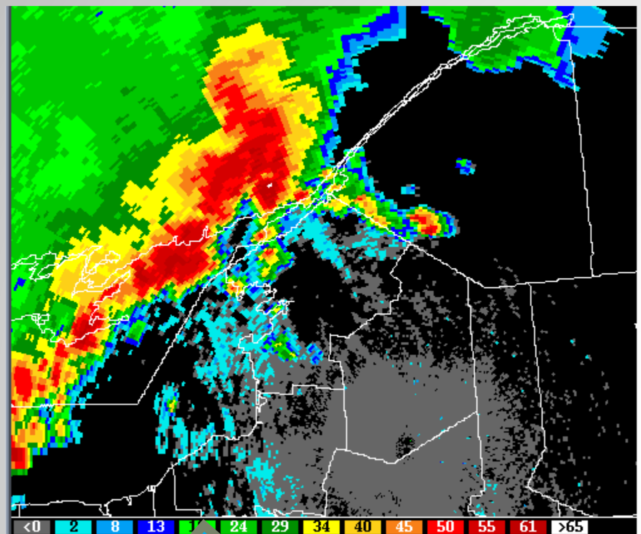
http://www.meteor.iastate.edu/~jdduda/portfolio/How%20to%20read%20and%20interpret%20weather%20radar.pdf

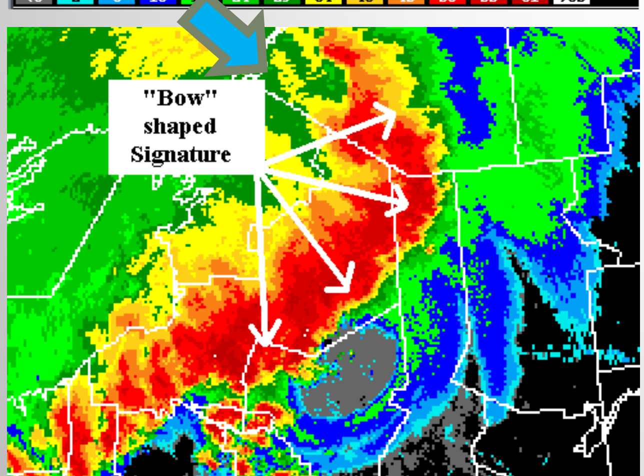


KCXX 4.0° Base reflectivity 16 July 2009 at 2250Z
http://www.erh.noaa.gov/btv/research/Radar_Artifacts/

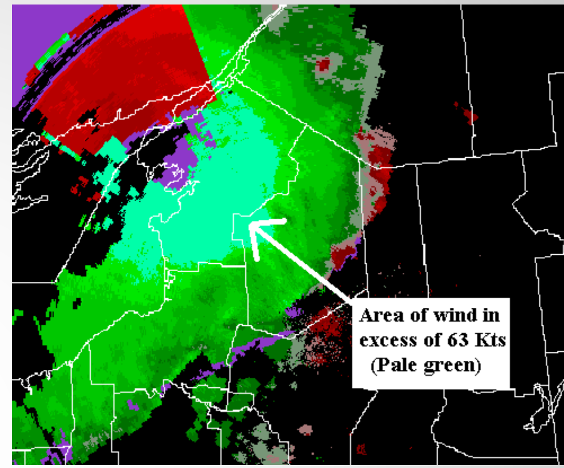
- KCXX Burlington VT Radar Ref 4.0° elev – high scanning angle.
- Base reflectivity showing a well-defined hail spike near Brookfield, VT on 16 July 2009 at 2250 UTC.

Derecho – Thunderstorm Bow Echo
Jul 15, 1995





NOAA NWS WSR-88D KRMX ref 0.5 deg 0906Z Jul 15, 1995 http://cstar.cestm.albany.edu:7773/research/dereclho.html



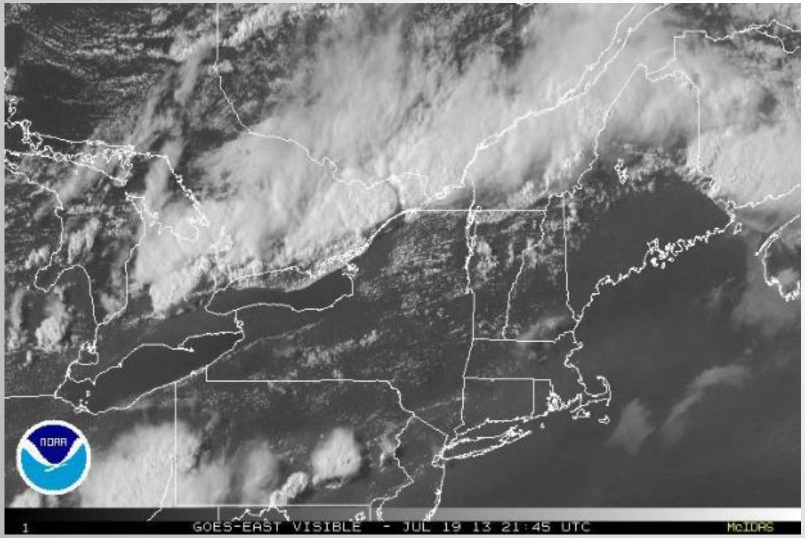
NOAA NWS WSR-88D KRMX base vel 0.5 deg 0906Z Jul 15, 1995 http://cstar.cestm.albany.edu:7773/research/derecho.html

- *Weak or dry notches on back edge* indicate descending air
- Leading edge BOWs forward as downburst winds push forward causing straight line wind damage
- *Tight reflectivity gradient* leading edge

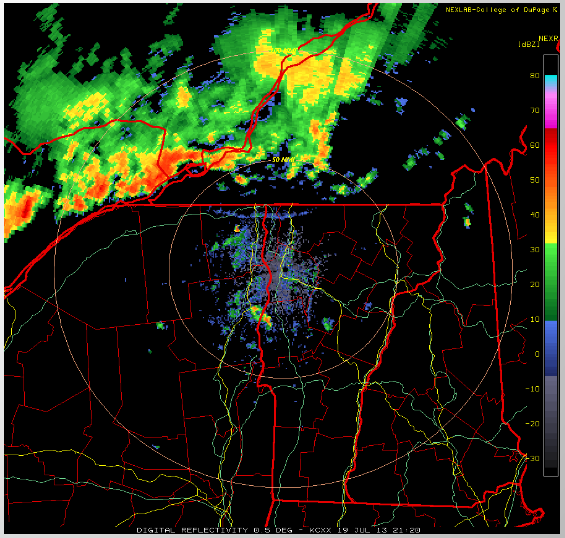
Visual and Remote Sensing Observations of *Outflow boundary*
July 19, 2013 530pm-730pm

- Thunderstorm complex along Canadian-USA border with mini bows embedded
- Note Fine line associated with thunderstorm outflow extreme northern Champlan Valley with wind gusts 35-52 kts

Photo: Outflow cloud line Jul 19 2013
720PM So. Burlington VT - Hogan



NOAA Vis Satellite Jul 19, 2013 2145Z
http://www.ssd.noaa.gov/GOES/EAST/NOAA.gov



Jul 19 2013 KCXX REF 2120Z
http://weather.cod.edu/satrad/

Winter

Low pressure comma cloud followed by Arctic outbreak – Feb 10-12, 2015

Comma Cloud on satellite tracked on radar mosaic

Western Great Lakes region Feb 10 2015

Fig : Radar Mosaic north Central US Feb 10 2015 1935Z http://weather.cod.edu/satrad/

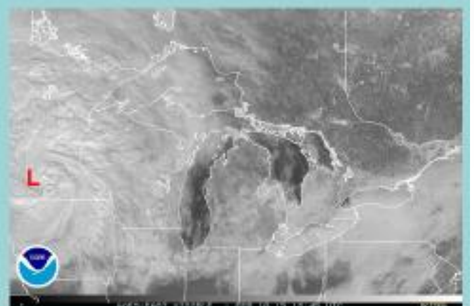


Fig : VIS Satellite 1845z Feb 10, 2015 http://www.ssd.noaa.gov/GOES/EAST/NOAA.gov

Lake Michigan Lake Effect Snow

Radar Echo tops 4-8K Ft … Inversion ~ 7K Ft

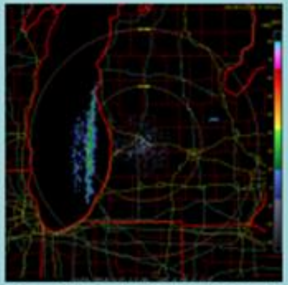
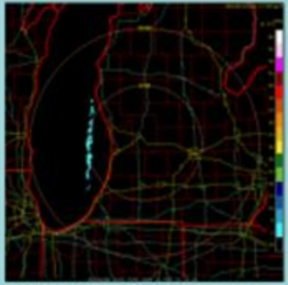


Fig : GRR Feb 12, 2015 1837Z 0.5 Deg Radar Reflec http://weather.cod.edu/satrad/



GRR Feb 12, 2015 1828Z Radar Enhanced Echo Tops (EET). http://weather.cod.edu/satrad/

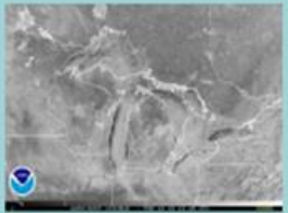
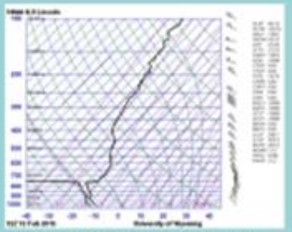
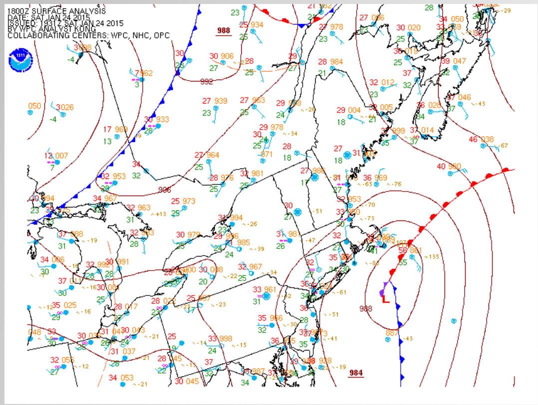


Fig 3: VIS Satellite 1845z Feb 12, 2014 http://www.ssd.noaa.gov/GOES/EAST/NOAA.gov

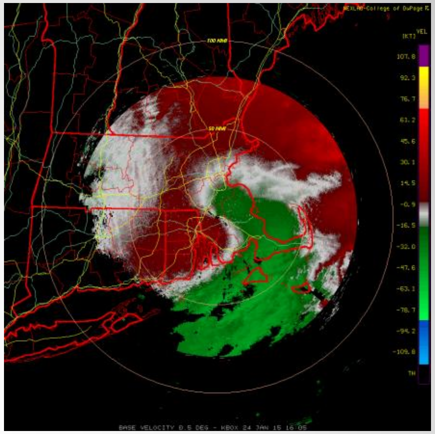


Feb 12 2015 12z CHI (Lincoln Il) Skewt http://weather.uwyo.edu/upperair/sounding.html

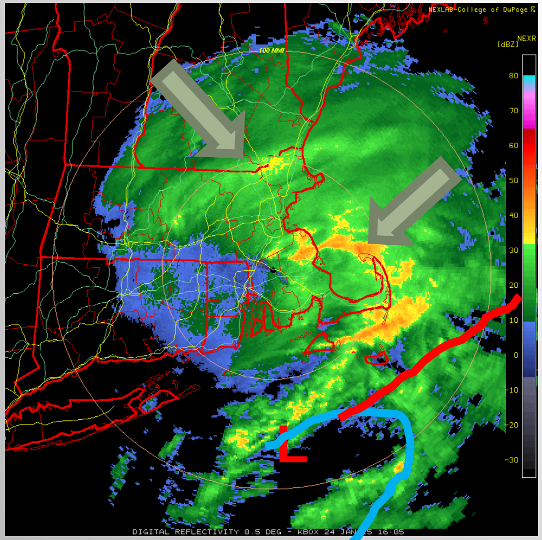
Jan 24, 2015 Southern New England Snowstorm



NOAA Surface Analysis 18z Jan 24, 2015.
http://www.hpc.ncep.noaa.gov/



KBOX Jan 24 1605Z 0.5 Deg Radar base vel
http://weather.cod.edu/satrad/

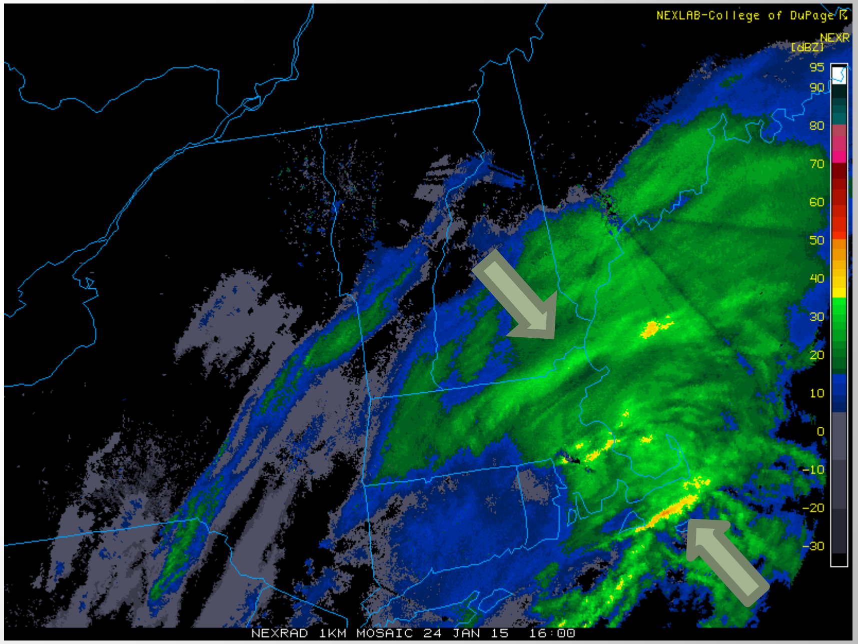


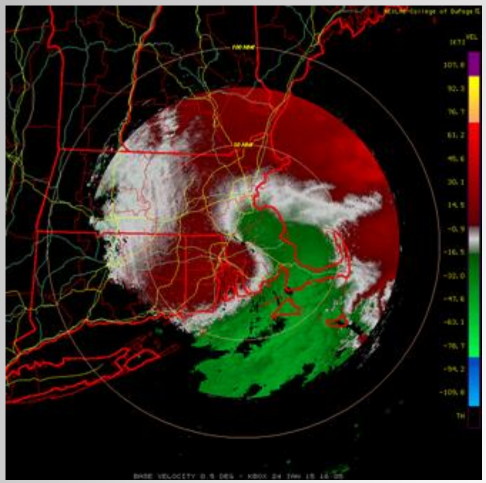
KBOX Jan 24 1605Z 0.5 Deg Radar Reflec
http://weather.cod.edu/satrad/

- Low pressure south of New England resembles Comma shape with dry slot
- Bright melting band over Cape Cod and eastern MA
- Snow band from coastal NH into northern MA
- Otherwise, no tight gradients and fuzzy edges typical of snow

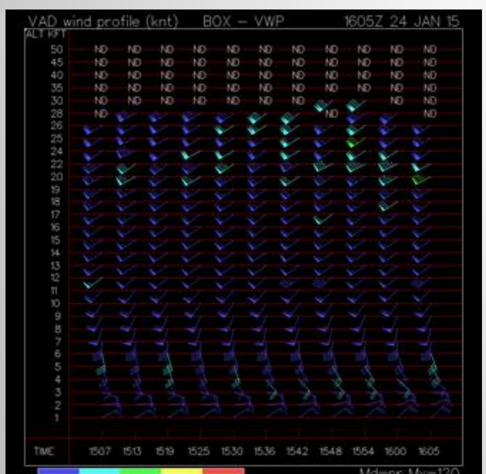
Northeast combined radar reflectivity Jan 24, 2015

- Northern edge of snow (blue) in NH and Me *appears fuzzy typical of snow*, with cold dry air to north.
- *Reflectivity Gradients are NOT tight.*
- *Snow bands* setting up southern Me into northern Ma
- *Bright band* south coastal New England north to Boston





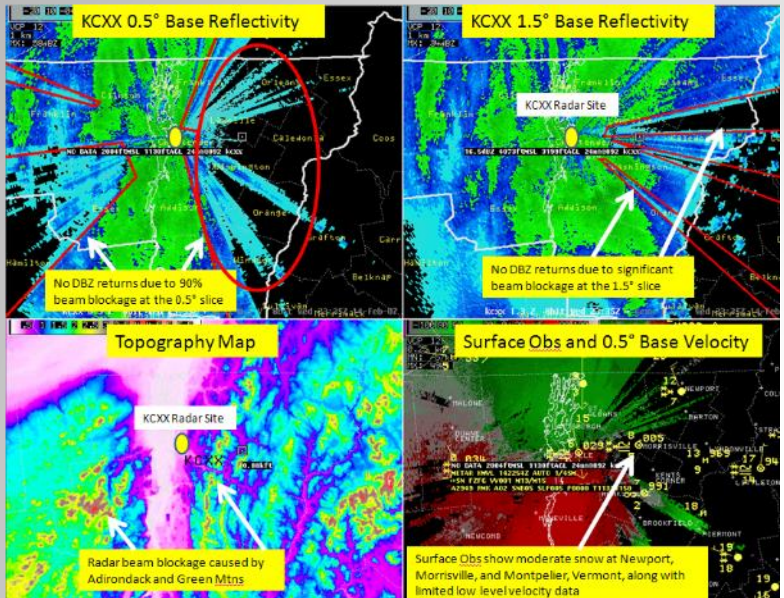
KBOX Jan 24 1605Z 0.5 Deg Radar base vel
http://weather.cod.edu/satrad/



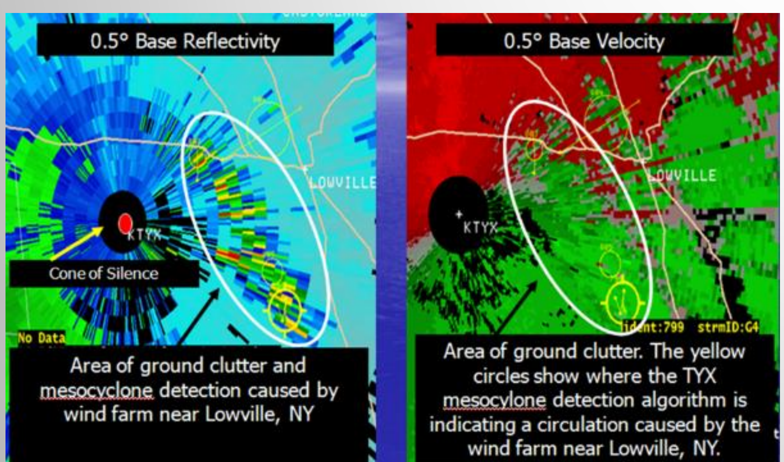
KBOX Jan 24 1605Z VAD Wind Profile low level northeast ... Above southeast
http://weather.cod.edu/satrad/

- Low level winds shifting into a cold northeast flow
- Just above the surface warmer air with southeast flow
- Bright band (Reflec) confirmed melting aloft with rain in Boston area south

Radar limitations in the Vermont area



http://www.erh.noaa.gov/btv/research/Radar_Artifacts/

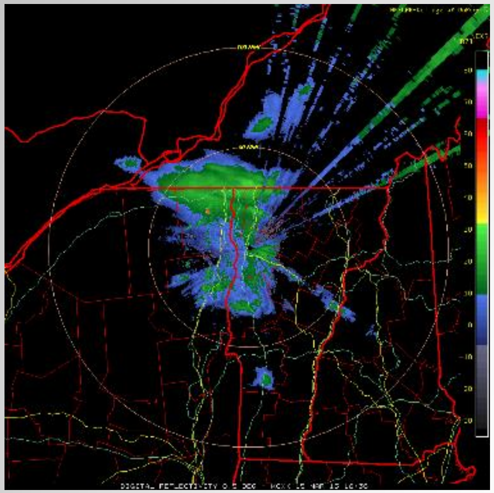


http://www.erh.noaa.gov/btv/research/Wind_Farm/

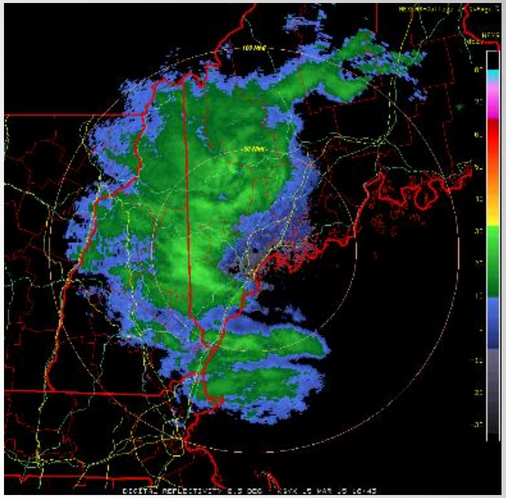
- Top image – **Beam blockage** where data blocked in lower scans by Green Mountains and Adirondacks
- Radar beam does shoot down Winooski and Lamoille river valleys
- Bottom Image - **Wind Turbine Clutter** created by rotating turbine blades impact Reflectivity and Velocity data and result in false alerts

Beam blockage "work-arounds" in Vermont and Northern New York

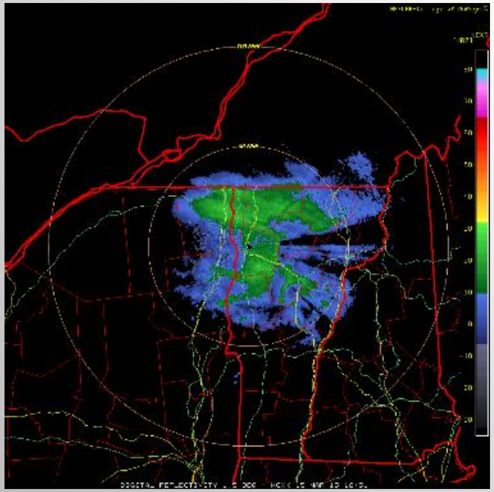
Images courtesy: http://weather.cod.edu/satrad



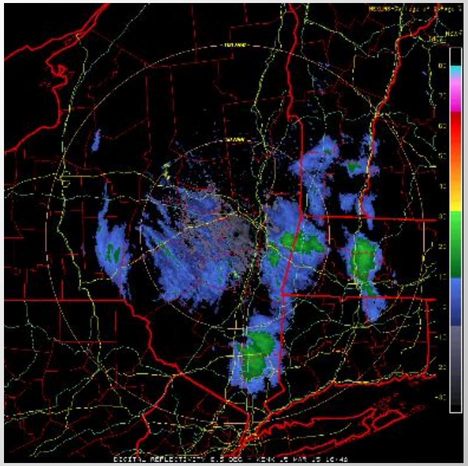
NOAA NWS KCXX radar REF 0.05 deg
Mar 15, 2015 1636z



NOAA NWS KGYX radar REF 0.05 deg
Mar 15, 2015 1643z



NOAA NWS KCXX radar REF 1.5 deg
Mar 15, 2015 1651z



NOAA NWS KENX radar REF 0.05 deg
Mar 15, 2015 1648z