Weather Radar Imagery Interpretation in the Cockpit

SAWS II Workshop (2008)

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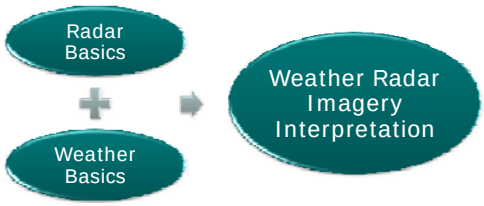
Overview

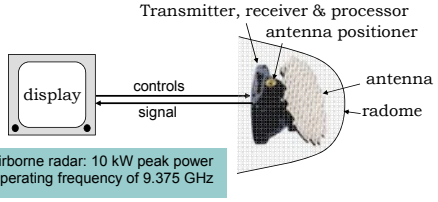


RAdio Detection And Ranging (RADAR)

- Radars transmit focused pulses of microwave light
  - NEXRAD: 10 cm
  - Airborne: 3 cm
- Solid & liquid scatterers return the signal
  - Precipitation (rain, snow, etc.)
  - Bugs / birds
  - Terrain
- Size and number of scatterers determines power returned
  - Clouds, dust have low reflectivity
  - Large hail has high reflectivity

Radar system (schematic)

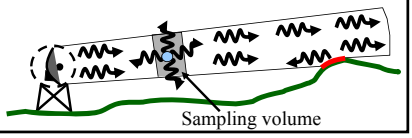
- Weather radars are pulsed and monostatic (i.e. antenna transmits and receives)
- Consist of transmitter/receiver, moveable antenna, radome, signal processor, display



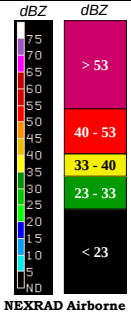
Airborne radar: 10 kW peak power
Operating frequency of 9.375 GHz

Key facts about scattering

- Depends on sum of diameter to the sixth power (D^6) of all particles in sample (assumed spherical)
- Water is more reflective than ice
- Smaller wavelengths (airborne radar) scatter more than longer wavelengths (NEXRAD)
- Reflectivity (Z) obtained from power returned [$dBZ = 10 \log_{10}(Z)$]
- Echo range computed from elapsed time between pulse transmission and reception



Reflectivity values / color tables



NEXRAD Airborne

dBZ	
> 53	**Very heavy rain or hail** > 2.0" per hour
40 - 53	**Heavy rain** 0.5 – 2.0" per hour
33 - 40	**Moderate rain** (heavy snow) – 0.17 – 0.5" /h
23 - 33	**Light rain** (light to moderate snow) 0.01" – 0.17" per hour
< 23	**Drizzle, cloud, dust or bugs**

Particle type identification

Particle type is related to reflectivity, but…

- Icing conditions may be undetectable
  - Clouds often invisible to radar (esp. airborne)
    - Icing occurs in clouds between 0 and -40°C
  - Need to know freezing level(s) in order to identify an echo that contains freezing rain
- Light snow often undetectable (airborne)
- Non-precipitation echoes often misleading
- NEXRAD will have polarimetric capabilities in about 5 years (better particle ID)

PPI—Plan Position Indicator

PPI display (120° sector viewed from above)

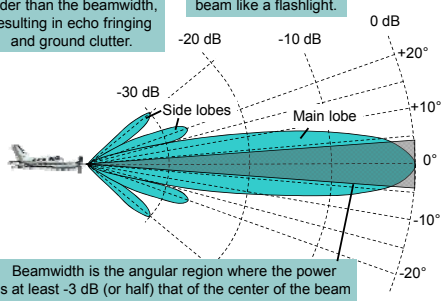
RHI—Range Height Indicator

RHI display (vertical cross-section)

Radar beamwidth

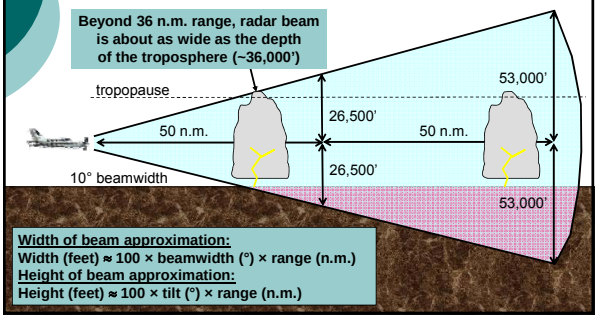
The actual radar beam is wider than the beamwidth, resulting in echo fringing and ground clutter.

Antenna focuses radar beam like a flashlight.



Beamwidth is the angular region where the power is at least -3 dB (or half) that of the center of the beam

Airborne radar perspective



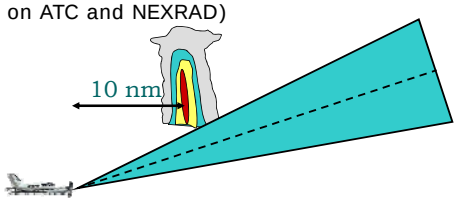
Width of beam approximation:
Width (feet) ≈ 100 × beamwidth (°) × range (n.m.)
Height of beam approximation:
Height (feet) ≈ 100 × tilt (°) × range (n.m.)

Tilt management (airborne radar)

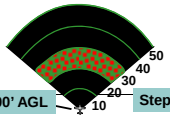
- Four useful tilt angles:
  - Terminal tilt
  - Zero tilt
  - Low-altitude tilt
  - Normal tilt
- However, it is best to regularly vary tilt, especially after turns
- Stratiform echo: Best viewed below bright band (freezing level)
- Convective: Best between 18-25 kft

Terminal tilt

- Leave tilt angle at maximum (~15°) to observe echoes above terminal areas.
- Within 10 nm of an airport, building echoes may be above 15° tilt (rely more on ATC and NEXRAD)

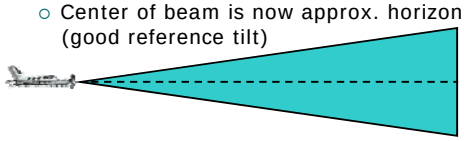


Zero tilt

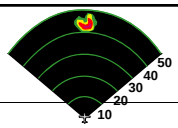


Alt: 20,000' AGL — Step 1

- How to find:
  1. Tilt beam down until strong ground clutter is seen at a range (in NM) equivalent to your altitude (in kft AGL)
     - Bottom of beam will be about 10° down
  2. Then, tilt beam upward by the angle 10° - (beamwidth / 2)
- Center of beam is now approx. horizontal (good reference tilt)

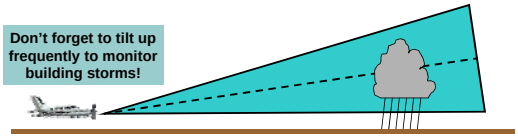


Low-altitude tilt

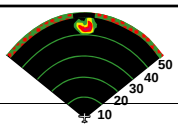


- How to find:
  - Tilt beam up half a beamwidth from zero tilt.
- Bottom of beam horizontal (helps identify precipitation at or above your altitude)

Don't forget to tilt up frequently to monitor building storms!

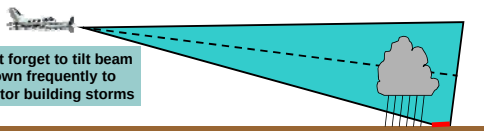


Normal tilt



- For smaller beamwidths: tilt beam down until strong ground returns are seen on outer range of radar scope.
- This is a great tilt when at cruise altitude.
- Shadows in ground returns indicate strong TS.

Don't forget to tilt beam down frequently to monitor building storms



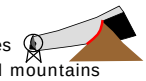
Results of improper tilt management

Capital Cargo International Airlines—Boeing 727-200. En route from Calgary to Minneapolis on August 10, 2006, encountered large hail over Alberta at an altitude between 30,000' and 35,000' MSL.
Source: *www.wunderground.com*

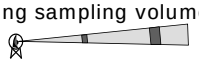
Sources of misinterpretation

- Anomalous propagation
  - Beam bends towards colder air

- Clutter and shadowing
  - Terrain reflects beam or side lobes
  - Shadowing (**blind areas**) beyond mountains



- Increasing sampling volume size with range



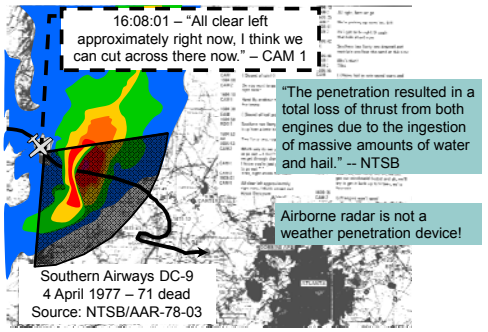
- Non-precipitation scatterers (birds, bugs)
- Second trip echoes
- **Attenuation**

Attenuation

- Loss of radar's power along radial due to absorption and scattering
- Larger particles and shorter wavelength → more attenuation
  - NEXRAD (10-cm wavelength): attenuation negligible
  - Airborne radar (3-cm wavelength): blind beyond first strong echo

RADOME CONSIDERATIONS:
- Class of radome (should transmit > 90%)
- Water, ice & paint on radome also attenuate!

Attenuation example



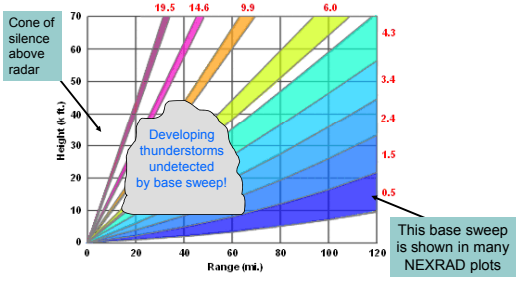
Airborne radar: What you MUST know

- Key meteorological information
- Maximum Permissible Exposure Level
  - MPEL = 10 mW/cm² (typically ~10' from radar)
- Radar's antenna size (beamwidth)
  10" → 10°; 12" → 8°; 18" → 6°; 24" → 4°
- Tilt management (pilot controls tilt)
- Radar's limitations (e.g. attenuation)

WHEN IN DOUBT:
- Refer to NEXRAD data (if available)
- Contact ATC for guidance

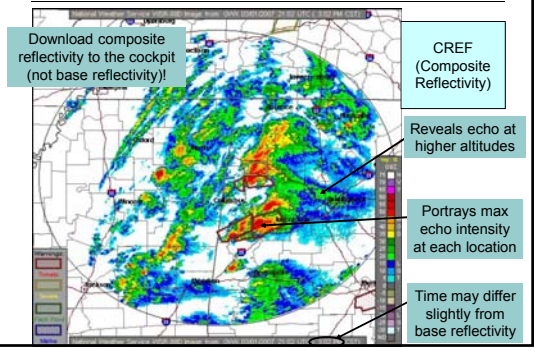
NEXRAD Weather Radar Network

NEXRAD Volume Coverage Pattern



Shown: Most common scan strategy used by NEXRAD.
Time required: About 5 or 6 min per volume
Sweep curvature is due to sphericity of earth (minus refraction)

NEXRAD Composite Reflectivity



NEXRAD in the cockpit: What you MUST know

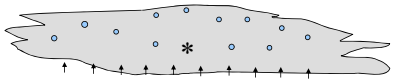
- Whether you have composite or base reflectivity data
- The age of the data
- Where data void regions are located
- Key meteorological information
  - Freezing level(s) for anticipating icing
  - Anticipated weather and trends (e.g. thunderstorms, turbulence, fronts)
  - If precipitation may mix with dry air (T-DP > 10°C) → microbursts

Precipitation

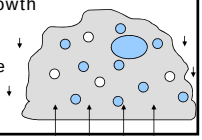
- Clouds consist of *visible* moisture (small liquid drops or ice crystals)
  - Form when moist air rises and cools
- Liquid water droplets exist in clouds at temperatures from 0 to -40°C
  - ICING!
- Most clouds do not precipitate
  - It takes a million cloud drops to make one rain drop!
  - Precipitation forms in 15–30 min.

Two types of precipitation

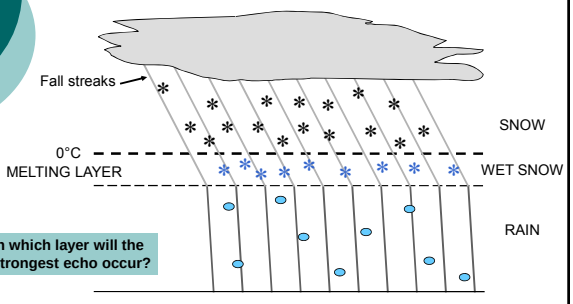
- Two basic ways that precipitation grows:
  - Ice crystal growth
    - Layered or "stratiform" precipitation
    - Weak updrafts, usually smooth flight



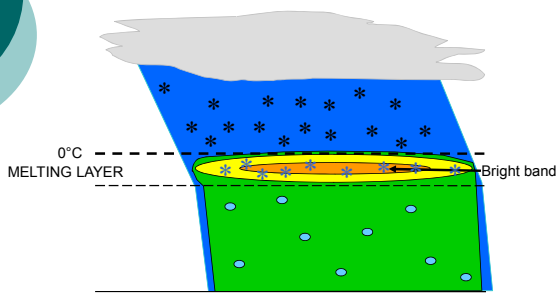
  - Collision and coalescence growth
    - "Convective" precipitation
      - Heavier rain rates or hail
    - Strong updrafts, turbulence
    - Stay clear!



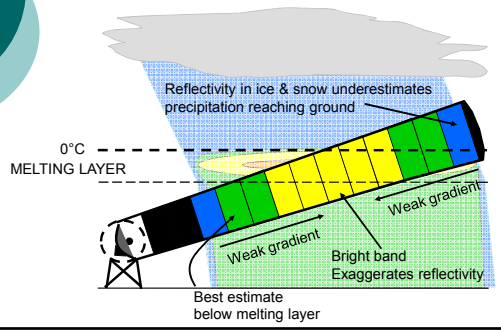
Stratiform precipitation (schematic representation)



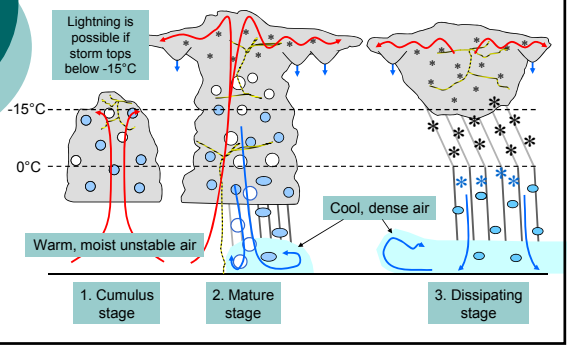
Stratiform precipitation (reflectivity representation)



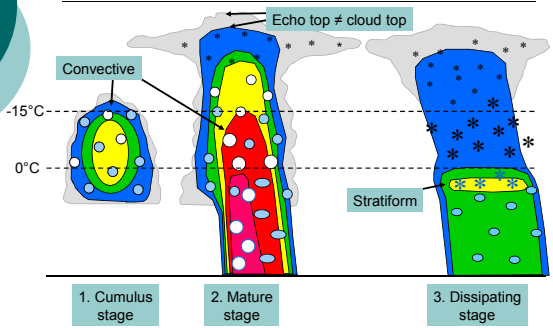
Stratiform precipitation (NEXRAD representation)



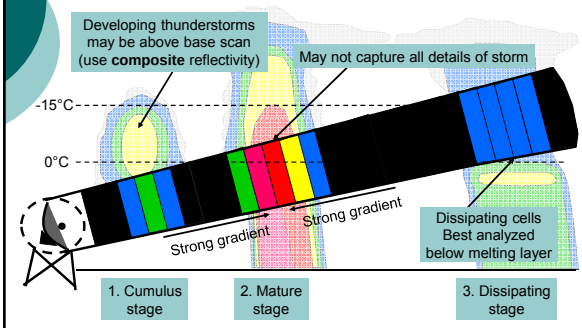
Life cycle of convective precipitation (schematic representation)



Life cycle of convective echoes (reflectivity representation)



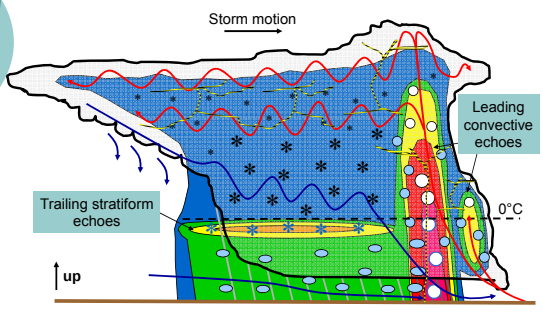
Life cycle of convective echoes (NEXRAD representation)



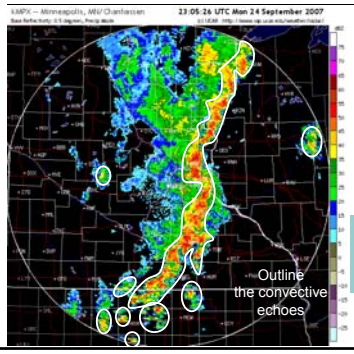
Mesoscale Convective Systems

- Thunderstorms often form in groups
  - Lines (squall lines) or clusters (MCS or MCC)
- Contain convective & stratiform echoes
  - The convective echoes are in their cumulus and mature stages (strong updrafts)
  - The stratiform echoes are dissipating cells (downdraft regions)
- Unsafe to penetrate stratiform echoes that are connected to convective ones!

Squall line (type of MCS)

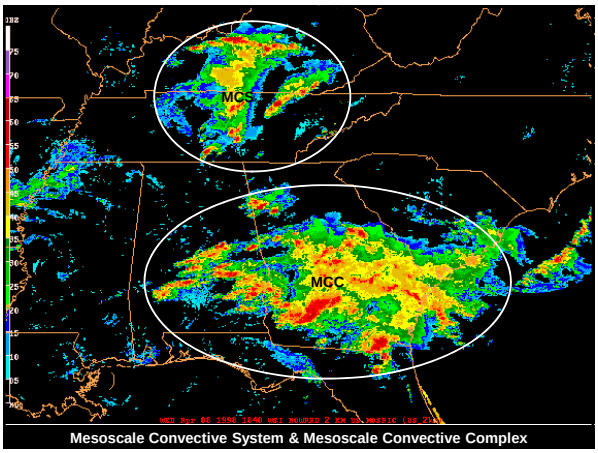


Squall line: Identify convective echoes



Circumnavigate convective echoes by at least 20 n.m.

Don't penetrate any stratiform echoes that are connected to convective ones.

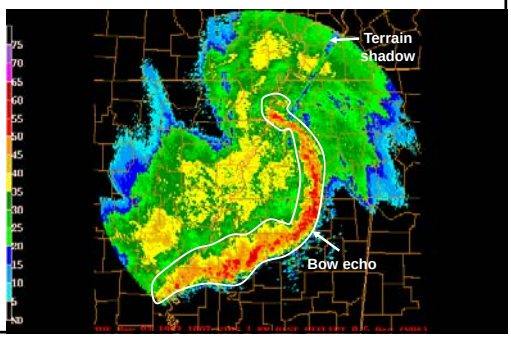


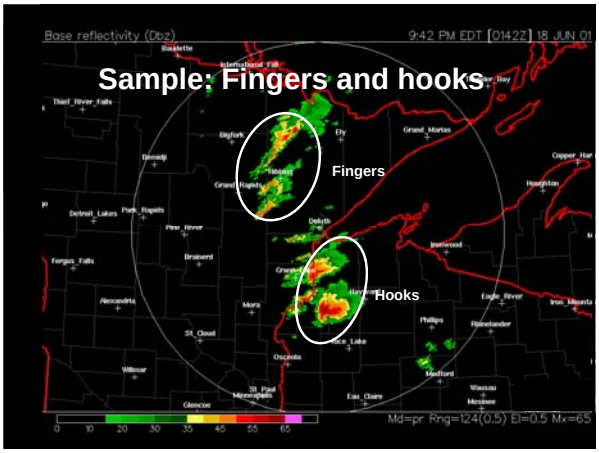
Mesoscale Convective System & Mesoscale Convective Complex

Beware of the following:

- Strong reflectivity gradients
- Strong reflectivity echoes (red and magenta)
- Severe storm patterns: Hooks (or pendants), bows, fingers, and crescent-shaped echoes
- Squall lines
- Cells that produce shadows or attenuation (airborne radar)
  - Blind alleys (airborne radar)

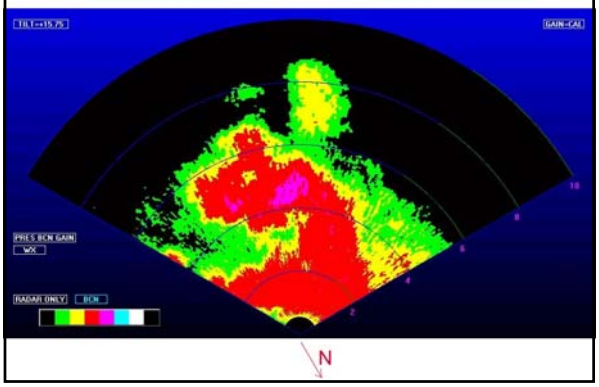
Sample: Bow echo





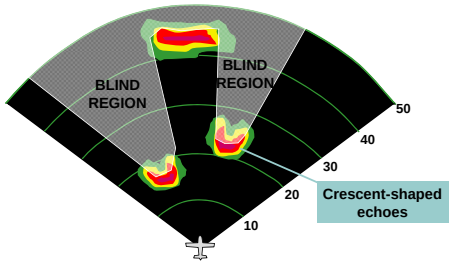
Finger echo (airborne radar)

Hook echo (airborne radar)



Blind alleys

Do not fly in blind alleys where you could potentially become surrounded by convective cells



In summary…

For safe interpretation of weather radar:

- Need key meteorological information
  - Freezing level(s), expected weather conditions, etc.
- Understand radar's characteristics & limitations
  - NEXRAD: (use composite reflectivity; recognize data void regions and shadows; check time stamp)
  - Airborne Radar: (know it's a crude instrument, use proper tilt management & beware of attenuation)
- Recognize stratiform & convective echo
  - Don't penetrate echoes associated with convection
- Recognize signs of severe weather