RADAR Meteorology

- **RADAR**: Radio Detection And Ranging

- Short bursts of radio energy (EM waves, $\lambda=3-10\text{cm}$) emitted from radar transmitter and focused by a parabolic antenna in a specific direction.

- EM waves are emitted in short bursts to allow returning signals (reflected, back-scattered) to enter radar system during listening time.

- Number of bursts or pulses = $150-900 \text{ s}^{-1}$

- Duration of pulse = $0.5-4 \times 10^{-6} \text{ s}$

- Radar is listening far more than it is transmitting
RADAR Meteorology

- RADAR Components

```
transmitter

automatic switch

receiver

indicator

antenna
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RADAR Meteorology

- **transmitter**: produces power at same frequency

- **antenna**: radiates power and intercepts reflected/backscattered signals

- **receiver**: detects, amplifies, and transforms signals into video form

- **switch**: closes off receiver during short period when transmitter is operating and protects receiver from tremendous burst of transmitting power

- **indicator**: displays returned signals

- **transmitted power** \( \sim 10^5 \text{ W} \) & min detectable signal \( \sim 10^{-13} \text{ W} \)
**RADAR Meteorology**

- **RADAR types**
  - **Non-Coherent**: No account is taken of the phase of the returning wave with respect to the phase of the transmitted wave (conventional RADAR).
  
  - **Coherent**: Does account for phase change. As target moves, phase changes at a rate $\alpha$ the velocity of the target toward/away from RADAR.

  - Velocity measurements made by noting rate of change of diff. btwn outgoing and received signals.
**RADAR Meteorology**

- Conventional Wx RADARs

<table>
<thead>
<tr>
<th>RADAR</th>
<th>Wavelength</th>
<th>Pulse length</th>
<th>Pulse duration</th>
<th>Pulse rep. freq.</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSR-57</td>
<td>10.3 cm</td>
<td>150/1200 m</td>
<td>0.5/4 * 10^{-6} s^{-1}</td>
<td>545/164 s^{-1}</td>
</tr>
<tr>
<td>WSR-74S</td>
<td>10.4 cm</td>
<td>300/1200 m</td>
<td>1.0/4 * 10^{-6} s^{-1}</td>
<td>545/164 s^{-1}</td>
</tr>
<tr>
<td>WSR-74C</td>
<td>5.4 cm</td>
<td>900 m</td>
<td>3.0 * 10^{-6} s^{-1}</td>
<td>259 s^{-1}</td>
</tr>
<tr>
<td>WSR-88D</td>
<td>10.7 cm</td>
<td>471 or 1350 m</td>
<td>1.57 or 4.5 * 10^{-6} s^{-1}</td>
<td>318 to 1403 s^{-1}</td>
</tr>
</tbody>
</table>

Note: The shorter the amount of time between pulses, the shorter the max range of the RADAR.
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\[ R = \text{desired RADAR range} \]
\[ C = \text{speed of E-M waves} \ (3.8 \times 10^8 \text{ ms}^{-1}) \]
\[ \text{PRF} = \text{pulse rep. frequency} \]

\[ C = 2R \times \text{PRF} \quad \text{or} \quad R = \frac{C}{2\text{PRF}} \]

so, \( R \) decreases as \( \text{PRF} \) increases
RADAR Beam

a. Shape:
   - cone
   - beam spreads out w/ distance
   - radar energy is displaced from centerline
   - vertical beam spreading is also affected by elev. angle of beam determines “how high” a beam sees
   - WSR-57 has 2° beam, WSR-74C has 1.6° beam, and WSR-88D has .86-.95° beam

b. Beam Width
   - angular distance btwn ½ power points
     \[ \theta \sim 70\lambda/D \]
RADAR Meteorology

For 1.) \( \lambda = 10.3 \text{ cm}, \ D = 12 \text{ ft} \) (WSR-57)
2.) \( \lambda = 5.4 \text{ cm}, \ D = 8 \text{ ft} \) (WSR-74C)
3.) \( \lambda = 11.1 \text{ cm}, \ D = 28 \text{ ft} \) (WSR-88D)
RADAR Meteorology

1.) \[ \theta = \frac{70(10.3\text{cm})}{(12\text{ ft})(12\text{ in/ft})(2.54\text{cm/in})} = \frac{721}{365.76} = 1.97 \text{ rad} \times \frac{180^\circ}{\pi} = 112.8^\circ \]

2.) \[ \theta = \frac{70(5.4\text{cm})}{(8\text{ ft})(12\text{ in/ft})(2.54\text{cm/in})} = \frac{378}{243.84} = 1.55 \text{ rad} \times \frac{180^\circ}{\pi} = 88.8^\circ \]

**Beam Width Resolution (BWR):** ability to distinguish between 2 targets at same range, with each target in different location

- BWR decreases as range increases.
- Target should be > 1 full beam width to appear separately on PPI.
c. Range resolution

- Ability to distinguish between two targets in the same direction, but at different ranges.

- For better range resolution, targets should be $> \frac{1}{2}$ pulse length to prevent displayed target from merging into one echo.

- Targets $< \frac{1}{2}$ pulse length from antenna cannot be displayed, because the transmitter is still operating when echo returns from the target.

- Attenuation:
  - Power decreases due to scattering/absorption by targets.
  - When $\lambda$ decreases, attenuation increases.
  - Attenuation due to snow is $<<$ than due to rain.
**RADAR Meteorology**

- **RADAR Equation - Simple Form:**

  \[ \overline{P_R} = \frac{Z}{R^2} \times R_c \]

  \( \overline{P_R} \) = average power received

  \( Z \) = "reflectivity"

  \( R \) = the range to the target

  \( R_c \) = radar constant, which includes characteristics of radar involved in delivering signal to target and receiving echoes.
RADAR Equation - Full Form:

\[
\overline{P}_R = \left( \frac{\pi^3 \cdot p_t \cdot G^2 \cdot \theta^2 \cdot H \cdot K \cdot H^2}{1024 \cdot \lambda^2 \cdot (\ln 2)} \right) \left( \frac{Z}{R^2} \right)
\]

\(\pi = \pi i\)

\(p_t = \text{power transmitted}\)

\(G = \text{antenna gain (power amplification given to signal)}\)

\(\theta = \text{beam width}\)

\(H = \text{pulse length}\)

\(K = \text{dielectric const., relates to electrical conductivity of target}\)

\(\lambda = \text{wavelength of radar}\)
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$\bar{P}_R$ is measured

$Z$ is calculated

$R$ is measured

$Rc$ is a collection of much that is known about the radar

$$
\sum_{i=1}^{k} N_i D_i^6 \quad .001 \text{ mm}^6 / \text{m}^3 = \text{fog}
$$

$$
Z = \frac{1}{Volume} \quad 50,000,000 \text{ mm}^6 / \text{m}^3 = \text{large hail}
$$

So... $\text{dBZ} = 10 \times \log_{10} \left( \frac{Z}{1 \text{ mm}^6 / \text{m}^3} \right)$

$Z = .001 \rightarrow Z_e = -30$

$Z = 50,000,000 \rightarrow Z_e = 76.9$
Z-R Relationships:

- We say “reflectivity”, which is more appropriately called the Back-Scatter Efficiency of the Targets.

Meaning

- Back-Scatter Efficiency increases
- More/larger targets
- More rainfall/snowfall

So...We can derive empirical expressions to relate reflectivity, Z, to rain fall rates, R.

\[ Z = aR^b \]

\( a, b = \) empirical constants found through obs/exprmnt
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- Original Marshall-Palmer $Z-R_s$
  - Stratiform Precipitation
    - $Z = 200 \, R^{1.6}$
  - Cumuliform
    - $Z = 55 \, R^{1.6}$
now, many Z-R relationships for various environments (tropical, etc..)

- Z = 200 R^{1.6} gives:

<table>
<thead>
<tr>
<th>VIP Levels</th>
<th>Rain Rate (in/hr)</th>
<th>Reflectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.10</td>
<td>29.5</td>
</tr>
<tr>
<td>2</td>
<td>.25</td>
<td>35.9</td>
</tr>
<tr>
<td>3</td>
<td>.50</td>
<td>40.7</td>
</tr>
<tr>
<td>4</td>
<td>1.25</td>
<td>47.0</td>
</tr>
<tr>
<td>5</td>
<td>2.5</td>
<td>51.9</td>
</tr>
<tr>
<td>6</td>
<td>4.0</td>
<td>55.1</td>
</tr>
</tbody>
</table>
The Bright Band:
- $\text{reflectivity}_{\text{ice}} < \text{reflectivity}_{\text{water}}$
- $v_{t_{\text{snow}}} < v_{t_{\text{droplets}}}$ (terminal velocity)

- snowflakes melt at extremities first
  - large, irregular snowflake w/water
  - radar “sees” large drop
  - $\text{reflectivity}_{\text{water}}$ increases 7dB since $P_{R} \alpha K^{2}$

- flake melts, size decreases, $v_{t}$ increases
  - size decreases, reflectivity decreases
  - $v_{t}$ increasing means drops leaving from below move faster than those entering from above
  - # density decreases, reflectivity decreases
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- Results:
  - 5-15 dB increases in reflectivity from all snow to max in bright band
  - 5-10 dB decreases in reflectivity below
  - usually higher Z below than above
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WSR-88D Products

1. Reflectivity
2. Velocity
3. VIL (Vertically Integrated Liquid)
4. Echo Tops
5. Precipitation Accumulation