Introduction to RADAR Remote Sensing for Vegetation Mapping and Monitoring

Wayne Walker, Ph.D.
• What is RADAR (and what does it measure)?

• RADAR as an active sensor

• Applications of RADAR to vegetation mapping/monitoring

• What determines RADAR backscatter from vegetation?
  ✔ System parameters (Sensor)
  ✔ Target parameters (Ground)

• What is Speckle?

• Photographic review of forest structure
What is RADAR?

RADAR is an acronym that stands for:

Radio Detection and Ranging
What is RADAR?

RADAR is an acronym that stands for:

Radio Detection and Ranging

- Running time: \( t = \frac{2R}{c} \)
- Distance: \( R = \frac{ct}{2} \)
What is RADAR?

**SAR** is an acronym that stands for: **Synthetic Aperture RADAR**

All imaging RADAR sensors used for remote sensing are **Synthetic Aperture Radars**.
What does RADAR measure?

- Amplitude depends on target properties (structure and dielectric properties).
- Phase is a function of the distance between sensor and the target as well as target properties.
Passive sensors:
- Rely on the sun as an energy source
- Detect only naturally occurring energy

Active sensors:
- Act as their own energy source
- Detect backscattered energy
Applications of RADAR to vegetation mapping/monitoring

- Applications
  - Mapping forest/land cover
  - Mapping wetlands (inundated/flooded versus non-flooded)
  - Mapping structural attributes (height, basal area, biomass, volume)
  - Monitoring disturbance (logging, fire, windthrow, insect damage)
  - Monitoring change (deforestation, degradation, reforestation)
  - Monitoring photosynthetic processes (growing-season length)
What determines radar backscatter from vegetation?

- **System Parameters (Sensor)**
  - Wavelength/Frequency (X, C, L, and P bands)
  - Polarization (HH, VV, and HV)
  - Incidence angle
  - Resolution

- **Target Parameters (Ground)**
  - Structure (size, orientation, and distribution of scattering surfaces)
  - Surface roughness (relative to wavelength)
  - Dielectric constant (moisture content)
  - Slope angle/orientation
What determines radar backscatter from vegetation?

- **System Parameters (Sensor)**
  - Wavelength/Frequency (X, C, L, and P bands)
  - Polarization (HH, VV, and HV)
  - Incidence angle
  - Resolution
Scattering from vegetation

Types of scattering from a pine stand

- Surface scattering from the top of the canopy
- Volume scattering
- Surface and volume scattering from the ground
Scattering mechanisms

- Surface scattering
  - water
  - soil, rock

- Volume scattering
  - vegetation
  - snow

- Volume surface scattering

- Double Bounce
  (Corner Reflector)

One possible natural occurrence - reflecting off two smooth surfaces, grass and a freshly-cut tree's stump
### Table 1: Microwave frequency bands

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency, GHz</th>
<th>Wavelength, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-band</td>
<td>0.225 - 0.39</td>
<td>133 - 77</td>
</tr>
<tr>
<td>L-band</td>
<td>0.39 - 1.55</td>
<td>77 - 19</td>
</tr>
<tr>
<td>S-band</td>
<td>1.55 - 3.90</td>
<td>19 - 7.7</td>
</tr>
<tr>
<td>C-band</td>
<td>3.90 - 6.20</td>
<td>7.7 - 4.8</td>
</tr>
<tr>
<td>X-band</td>
<td>5.75 - 10.9</td>
<td>5.2 - 2.8</td>
</tr>
<tr>
<td>K_u-band</td>
<td>10.9 - 18.0</td>
<td>2.8 - 1.7</td>
</tr>
<tr>
<td>K_a-band</td>
<td>18.0 - 36.0</td>
<td>1.7 - 0.8</td>
</tr>
</tbody>
</table>
The primary scatterers in a tree canopy are elements (leaves, branches, and stems) with a size on the order of the wavelength or larger and an orientation similar to that of the incoming signal polarization.

Elements smaller than the wavelength produce little backscatter but can attenuate the signal.
The longer the wavelength, the greater the sensitivity to the vertical structure of vegetation.
Polarization

Polarization

Vertical

Horizontal

C = Crown
T = Trunk

Radar Scattering Intensity

Short Wave

Long Wave
Depolarization occurs mainly over vegetation, hardly over open ground. Cross polarization (HV or VH) is very sensitive to vegetation parameters.
Polarization

HH, VV, HV and color composite of linear polarization images of agricultural fields in southern Manitoba (© CCRS 1993). Acquired by the CV-580 C-band SAR. Processed and provided by CCRS.
Incidence angle

Figure 3-37. Typical radar backscatter curves for smooth, moderately rough and very rough surfaces. As the incident angle ($\theta$) decreases, the probability of greater backscatter increases, especially as the target becomes smoother. (NASA, 1989).
Resolution

Sensitivity to Type Boundaries

50 m

15 m
Resolution

Sensitivity to Type Boundaries

50 m

15 m
Resolution

Sensitivity to Individual Trees

50 m

15 m
What determines radar backscatter from vegetation?

- **System Parameters (Sensor)**
  - Wavelength/Frequency (X, C, L, and P bands)
  - Polarization (HH, VV, and HV)
  - Incidence angle
  - Resolution

- **Target Parameters (Ground)**
  - Structure (size, orientation, and distribution of scattering surfaces)
  - Surface roughness (relative to wavelength)
  - Dielectric constant (moisture content)
  - Slope angle/orientation
What determines radar backscatter from vegetation?

- **Target Parameters (Ground)**
  - Structure (size, orientation, and distribution of scattering surfaces)
  - Surface roughness (relative to wavelength)
  - Dielectric constant (moisture content)
  - Slope angle/orientation
Structure

- Conifer - Excurrent
- Dead snag
- Broadleaf - Decurrent
- Taper
### SAR Fundamentals

<table>
<thead>
<tr>
<th>Growth Form</th>
<th>Herbaceous</th>
<th>Woody</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gramineous</td>
<td>Excurrent</td>
</tr>
<tr>
<td></td>
<td>Stalk Dominated</td>
<td>Gymnosperms (i.e., pine)</td>
</tr>
<tr>
<td></td>
<td>Shrubs</td>
<td>Decurrent</td>
</tr>
<tr>
<td></td>
<td>Trees</td>
<td>Columnar</td>
</tr>
</tbody>
</table>

#### Structural Characteristics

<table>
<thead>
<tr>
<th>Trunks</th>
<th>Branches</th>
<th>Foliage</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>Non-woody stems</td>
<td>Blade-like</td>
</tr>
<tr>
<td>None</td>
<td>Non-woody stems</td>
<td>Blade-like erectophile</td>
</tr>
<tr>
<td>Many small trunks with characteristic orientations</td>
<td>Many small branches and stems</td>
<td>Blade-like or broad leaves</td>
</tr>
<tr>
<td>Conical trunk with layered dielectric</td>
<td>Branch size and orientation varies with height.</td>
<td>Needles</td>
</tr>
<tr>
<td>Cylindrical, forked trunk with layered dielectric</td>
<td>Branches tend to be long and thin</td>
<td>Broad leaves</td>
</tr>
<tr>
<td>Cylindrical trunk of homogeneous dielectric</td>
<td>Branches forked, few horizontal elements.</td>
<td>Blade-like clump at top of trunk.</td>
</tr>
</tbody>
</table>
• As wavelength increases, greater height variation is required for roughness

• As incidence angle increases, greater height variation is required for roughness
Dielectric constant (moisture content)

- Dielectric constant is controlled by the amount of moisture content
- Most common materials have dielectric constants from 1-100
- Radar backscatter is influenced by the amount of moisture in vegetation and soil by affecting the absorption and propagation of electromagnetic energy
- Increasing the moisture content reduces the penetration of the radar signal through a vegetation canopy or into soil.

<table>
<thead>
<tr>
<th>Material</th>
<th>Dielectric constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>1 (by default)</td>
</tr>
<tr>
<td>Air</td>
<td>1.0005</td>
</tr>
<tr>
<td>Paper</td>
<td>3.5</td>
</tr>
<tr>
<td>Pyrex glass</td>
<td>4.7</td>
</tr>
<tr>
<td>Water (20°)</td>
<td>80.4</td>
</tr>
<tr>
<td>2t = 0°</td>
<td>80.4</td>
</tr>
</tbody>
</table>
Different vegetation types will all have different backscatter properties. In addition, the basic reflectivity of the soil, called the "dielectric constant" will change depending on the amount of water that the soil contains. Dry soil has a low dielectric constant and low radar reflectivity. Saturated soil is a strong reflector. Moist and partially frozen soils will have intermediate values.
Dielectric constant (moisture content)

SAR double-bounce scattering from flooded forest
Relief changes the local angle of incidence. This leads to:
- increase of $\sigma_i$ in fore slopes
- decrease of $\sigma_i$ in backslopes
Resolution cells are made up of many scatterers with different phases, leading to interference and the noise-like effect known as **speckle**.
Speckle filtering always results in a loss of spatial resolution since it is carried out within moving windows.
What is speckle?

Speckle filtering always results in a loss of spatial resolution since it is carried out within moving windows.
Structure at the individual tree level
Structure at the individual tree level
Structure at the landscape level (natural landscapes)
Structure at the landscape level (disturbed landscapes)
Structure at the landscape level (managed landscapes)
Structure at the landscape level (ice/snow)
Structure at the landscape level (fire)
Structure at the landscape level (moisture influences)
Thank you!