SAR for Mapping Land Cover

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Learning Objectives

By the end of this presentation, you will be able to understand:

- the advantages of SAR over optical systems for mapping land cover and land use change
- the information content in SAR images relevant to land cover characteristics
- the limitations of SAR for mapping land cover
- the optimal sensor parameters for land cover
- how to generate a land cover map from SAR
Advantages and Disadvantages of Radar Over Optical Remote Sensing

Advantages

• Nearly all weather capability
• Day or night capability
• Penetration through the vegetation canopy
• Penetration through the soil
• Minimal atmospheric effects
• Sensitivity to dielectric properties (liquid vs. frozen water)
• Sensitivity to structure

Disadvantages

• Information content is different than optical and sometimes difficult to interpret
• Speckle effects (graininess in the image)
• Effects of topography
Land Cover Mapping: Optical vs Radar

**Optical**

- Energy reflected by vegetation is dependent on leaf structure, pigmentation, and moisture.
- Products are available from visible to infrared wavelengths consisting of several bands of data.
- Optical sensors only see surface tops, because the canopy blocks the understory, limiting the inferences of land cover and land use to only when these are correlated well with the characteristics of top layers.

**Radar**

- Microwave energy scattered by vegetation depends on the structure (size, density, orientation), and dielectric properties of the target.
- Radar signals are typically only at a single wavelength for each sensor.
- The signal can penetrate through the canopy (wavelength dependent), providing information on soil conditions or inundation state.

Joshi et al., Remote Sens. 2016, 8(1), 70; https://doi.org/10.3390/rs8010070
Applications of Radar to Land Cover Mapping and Monitoring

- Mapping forests
- Mapping wetlands
- Mapping biomass
- Monitoring disturbances (e.g., fire, selective logging)
- Monitoring changes (e.g., deforestation, reforestation)
Parameters to Consider for a Land Cover Mapping Study

**Radar Parameters**
- Wavelength
- Polarizations
- Incidence Angle

**Surface Parameters**
- Structure
- Dielectric Properties
Radar Parameters: Wavelength

\[ \text{Wavelength} = \frac{\text{speed of light}}{\text{frequency}} \]

Higher Frequency

Shorter Wavelength

Lower Frequency

Longer Wavelength

<table>
<thead>
<tr>
<th>Band Designation*</th>
<th>Wavelength ((\lambda)), cm</th>
<th>Frequency (v), GHz (10^9 cycles sec^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ka (0.86 cm)</td>
<td>0.8 – 1.1</td>
<td>40.0 – 26.5</td>
</tr>
<tr>
<td>K</td>
<td>1.1 – 1.7</td>
<td>26.5 – 18.0</td>
</tr>
<tr>
<td>Ku</td>
<td>1.7 – 2.4</td>
<td>18.0 – 12.5</td>
</tr>
<tr>
<td>X (3.0 cm, 3.2 cm)</td>
<td>2.4 – 3.8</td>
<td>12.5 – 8.0</td>
</tr>
<tr>
<td>C (6.0)</td>
<td>3.8 – 7.5</td>
<td>8.0 – 4.0</td>
</tr>
<tr>
<td>S</td>
<td>7.5 – 15.0</td>
<td>4.0 – 2.0</td>
</tr>
<tr>
<td>L (23.5 cm, 25 cm)</td>
<td>15.0 – 30.0</td>
<td>2.0 – 1.0</td>
</tr>
<tr>
<td>P (68 cm)</td>
<td>30.0 – 100.0</td>
<td>1.0 – 0.3</td>
</tr>
</tbody>
</table>

* wavelengths most frequently used in SAR are in parenthesis
Penetration as a Function of Wavelength

- Penetration is the **primary factor** in wavelength selection.
- Generally, the longer the wavelength, the greater the penetration into the target.

<table>
<thead>
<tr>
<th>Vegetation</th>
<th>Dry Alluvium</th>
<th>X-band 3 cm</th>
<th>C-band 5 cm</th>
<th>L-band 23 cm</th>
</tr>
</thead>
</table>

### Frequency Band Application Example

<table>
<thead>
<tr>
<th>Frequency Band</th>
<th>Application Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>VHF</td>
<td>foliage &amp; ground penetration, biomass</td>
</tr>
<tr>
<td>P-Band</td>
<td>biomass, soil moisture, penetration</td>
</tr>
<tr>
<td>L-Band</td>
<td>agriculture, forestry, soil moisture</td>
</tr>
<tr>
<td>C-Band</td>
<td>ocean, agriculture</td>
</tr>
<tr>
<td>X-band</td>
<td>agriculture, ocean, high resolution radar</td>
</tr>
<tr>
<td>Ku-Band</td>
<td>glaciology (snow cover mapping)</td>
</tr>
<tr>
<td>Ka-Band</td>
<td>high resolution radar</td>
</tr>
</tbody>
</table>
Example: Radar Signal Penetration into Vegetation

Image Credit: A. Moreira - ESA
Radar Parameters: Polarization

- The radar signal is polarized
- The polarizations are usually controlled between H and V:
  - HH: Horizontal Transmit, Horizontal Receive
  - HV: Horizontal Transmit, Vertical Receive
  - VH: Vertical Transmit, Horizontal Receive
  - VV: Vertical Transmit, Vertical Receive
- Quad-Pol Mode: when all four polarizations are measured
- Different polarizations can determine physical properties of the object observed

Example of Multiple Polarizations for Vegetation Studies

Pacaya-Samiria Forest Reserve in Peru

Images from UAVSAR (HH, HV, VV)
Example of Multiple Polarization for Vegetation Studies

Pacaya-Samiria Forest Reserve in Peru

Images from UAVSAR (HH, HV, VV)
Radar Parameters: Incidence Angle

Local Incidence Angle:

- The angle between the direction of illumination of the radar and the Earth’s surface plane
- accounts for local inclination of the surface
- influences image brightness
- is dependent on the height of the sensor
- the geometry of an image is different from point to point in the range direction

Images based on: top: Ulaby et al. (1981a), bottom: ESA
Effect of Incidence Angle Variation

Sentinel-1

Incidence Angle (degrees)
Parameters to Consider for a Land Cover Mapping Study

**Radar Parameters**
- Wavelength
- Polarizations
- Incidence Angle

**Surface Parameters**
- Structure
- Dielectric Properties
Radar Signal Interaction

- The scale of the surface relative to the wavelength determines how rough or smooth they appear and how bright or dark they will appear on the image.
- Backscattering Mechanisms:

  - Smooth Surface
  - Rough Surface
  - Double Bounce
  - Vegetation
Surface Parameters Related to Structure

Density

Size Relative to Wavelength

Size & Orientation
Size in Relation to Wavelength

Austrian pine

X band
\( \lambda = 3 \text{ cm} \)

L band
\( \lambda = 27 \text{ cm} \)

P band
\( \lambda = 70 \text{ cm} \)

Image Credit: Thuy Le Toan
Size and Orientation

Polarization

Density

- Saturation Problem
- Data/Instrument
  - NASA/JPL polarimetric AIRSAR operating at C-, L-, and P-band
  - Incidence angle 40°-50°

- C-band ≈ 20 tons/ha (2 kg/m²)
- L-band ≈ 40 tons/ha (4 kg/m²)
- P-band ≈ 100 tons/ha (10 kg/m²)

Image Source: Imhoff, 1995:514)
Radar Backscattering in Forests

 Dominant backscattering sources in forests: (1) direct scattering from tree trunks, (2a) ground-crown scattering, (2b) crown-ground scattering, (3a) ground-trunk scattering, (3b) trunk-ground scattering, (4) crown volume scattering
Surface Parameters: Dielectric Constant

Dielectric Properties of Materials

Dielectric Constant

if ~ 1 GHz

water

rocks, soil, vegetation, snow

dry materials

Frequency (GHz)

Re(\epsilon); T=0°C

im(\epsilon); T=0°C

Re(\epsilon) Ice

L-Band

S-Band

C-Band

Ku-Band

Dielectric Constant

NASA's Applied Remote Sensing Training Program
Dielectric Properties of the Surface

- During the land surface freeze/thaw transition there is a change in dielectric properties of the surface
- This causes a notable increase in backscatter
**Geometric Distortion**

**Layover**
- $AB = BC$
- $A'B' < B'C'$
- $RA > RB$
- $RA' > RB'$

**Foreshortening**
- $RA < RB < RC$
- $AB = BC$
- $A'B' < B'C'$

Images based on NRC images.
Shadow

Image (left) based on NRC
Radar Data from Different Satellites

Legacy:
- SeaSAT 1978
- ERS 1/2 1991-2011
- ENVISAT 2002-2012
- ALOS-1 2002-2012
- Radarsat-1 1995-2013

Current:
- TanDEM-X 2007
- Radarsat-2 2007
- COSMO-SkyMed 2007
- ALOS-2 2014
- Sentinel-1 2014
- PAZ SAR 2018

Future:
- SAOCOM 2018
- RCM 2018
- NISAR 2021
- Biomass 2021

Credit: Franz Meyer, University of Alaska, Fairbanks
Current and Future SAR Satellites

Current and Future SAR Satellites

Historical Analysis

TerraSAR-X & TanDEM-X

Monitoring

PAZ SAR

Cosmo-SkyMed 1st and 2nd generation

Sentinel

RADARSAT-2

Revital time (days)

ALOS2

Sentinel

RADARSAT-2

Revital time (days)

SAOCOM

NISAR

Biomass

Sentinel

RADARSAT-2

SAOCOM

NISAR

Biomass

Revital time (days)

2000

Present Day

Future

Natural Environment

Urbanized Environment

L-band

C-band

X-band

P-band

2000

Present Day

Future

NASA’s Applied Remote Sensing Training Program

Courtesy: A. Ferretti, TRE: modified version
NASA-ISRO SAR Mission (NISAR)

- High spatial resolution with frequent revisit time
- Earliest baseline launch date: 2021
- Dual frequency L- and S-band SAR
  - L-band SAR from NASA and S-band SAR from ISRO
- 3 years science operations (5+ years consumables)
- All science data will be made available free and open

<table>
<thead>
<tr>
<th>NISAR Characteristic</th>
<th>Would Enable</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-band (24 cm wavelength)</td>
<td>Low temporal decorrelation and foliage penetration</td>
</tr>
<tr>
<td>S-band (12 cm wavelength)</td>
<td>Sensitivity to light vegetation</td>
</tr>
<tr>
<td>SweepSAR technique with Imaging Swath &gt;240 km</td>
<td>Global data collection</td>
</tr>
<tr>
<td>Polarimetry (Single/Dual/Quad)</td>
<td>Surface characterization and biomass estimation</td>
</tr>
<tr>
<td>12-day exact repeat</td>
<td>Rapid Sampling</td>
</tr>
<tr>
<td>3-10 meters mode-dependent SAR resolution</td>
<td>Small-scale observations</td>
</tr>
<tr>
<td>3 years since operations (5 years consumables)</td>
<td>Time-series analysis</td>
</tr>
<tr>
<td>Pointing control &lt; 273 arcseconds</td>
<td>Deformation interferometry</td>
</tr>
<tr>
<td>Orbit control &lt; 500 meters</td>
<td>Deformation interferometry</td>
</tr>
<tr>
<td>&gt;30% observation duty cycle</td>
<td>Complete land/ice coverage</td>
</tr>
<tr>
<td>Left/Right pointing capability</td>
<td>Polar coverage, North and South</td>
</tr>
<tr>
<td>Noise Equivalent Sigma Zero ≤ -23 db</td>
<td>Surface characterization of smooth surfaces</td>
</tr>
</tbody>
</table>

Courtesy: Paul Rosen (JPL)
Hands-on Exercise
**Sentinel-1 Toolbox**

- A free and open source software developed by ESA for processing and analyzing radar images from Sentinel-1 and other satellites
- It can be accessed through the following site: [http://step.esa.int/main/download/](http://step.esa.int/main/download/)
- It includes the following tools
  - Calibration
  - Speckle noise
  - Terrain correction
  - Mosaic production
  - Polariometry
  - Interferometry
  - Classification