Introduction to Radar

Jul. 16, 2016
Objective

The objective of this tutorial is to provide a basic introduction to the use of synthetic aperture radar (SAR) images for terrestrial studies. We will cover a general summary of SAR, how to process the images and the type of information that can be extracted from them.
The Electromagnetic Spectrum

- The surface of the Earth cannot be imaged with visible or infrared sensors when there are clouds or when there is dense vegetation.
- Optical sensors measure reflected solar light and only function in the daytime.
- Microwaves can penetrate clouds and vegetation and can operate in day or night conditions.
Optical Remote Sensing: Advantages and Disadvantages

**Advantages**

![Picture of the Ground]

Optical Multispectral Remote Sensing

**Disadvantages**

![Picture of the Clouds]

Optical Remote Sensing Cannot Penetrate Clouds to the Earth’s Surface
Radar: Advantages
Remote Sensing Example of Optical vs. Radar
Volcano in Kamchatka, Russia

October 5, 1994
Basic Remote Sensing System
Teledetección de Sistemas Pasivos y Activos

Passive Sensors:
The Source of radiant energy arises from natural sources … sun, earth, other “hot” bodies

Active sensors:
Provide their own artificial radiant energy source for illumination … radar, synthetic aperture radar (SAR), LIDAR
Basic Concepts: Down Looking vs. Side Looking Radar
Basic Concepts: Side Looking Radar

- Each pixel in the radar image represents a complex quantity of the energy that was reflected back to the satellite.
- The magnitude of each pixel represents the intensity of the reflected echo.
Review of Radar Image Formation

RADAR MEASUREMENTS

1. Radar can measure time delay and strength of reflected echo
   ==> amplitude and phase measurements
2. Radar can only measure part of echo reflected back towards the antenna (backscatter)
3. Radar pulses travel at speed of light
4. Time delay ==> ability to image objects at different ranges from radar (range resolution)
5. Strength (amplitude) of reflected echo is called radar backscatter
Radar Parameters: Wavelength

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

*Wavelengths most frequently used in radar are in parenthesis*
Penetration is the primary factor in wavelength selection

Penetration through the forest canopy or into the soil is greater with longer wavelengths

<table>
<thead>
<tr>
<th>Frequency band</th>
<th>Frequency range</th>
<th>Application Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>VHF</td>
<td>300 KHz - 300 MHz</td>
<td>Foliage/Ground penetration, biomass</td>
</tr>
<tr>
<td>P-Band</td>
<td>300 MHz - 1 GHz</td>
<td>biomass, soil moisture, penetration</td>
</tr>
<tr>
<td>L-Band</td>
<td>1 GHz - 2 GHz</td>
<td>agriculture, forestry, soil moisture</td>
</tr>
<tr>
<td>C-Band</td>
<td>4 GHz - 8 GHz</td>
<td>ocean, agriculture</td>
</tr>
<tr>
<td>X-Band</td>
<td>8 GHz - 12 GHz</td>
<td>agriculture, ocean, high resolution radar</td>
</tr>
<tr>
<td>Ku-Band</td>
<td>14 GHz - 18 GHz</td>
<td>glaciology (snow cover mapping)</td>
</tr>
<tr>
<td>Ka-Band</td>
<td>27 GHz - 47 GHz</td>
<td>high resolution radars</td>
</tr>
</tbody>
</table>

Fuente: DLR
Penetration as a Function of Wavelength

Depending on the frequency and polarization, waves can penetrate into the vegetation and, on dry conditions, to some extent, into the soil (for instance dry snow or sand). Generally, the longer the wavelength, the stronger the penetration into the target. With respect to the polarization, cross-polarized (VH/HV) acquisitions have a significant less penetration effect than co-polarized (HH/VV) one.
Example: Radar Signal Penetration into Dry Soils

Different satellite images over southwest Libya. The arrows indicate possible fluvial systems.

Fuente: A. Perego
Example: Radar Signal Penetration into Dry Soils
Example: Radar Signal Penetration into Vegetation

C-band
R: HH G: HV B: VV

P-band
R: HH G: HV B: VV

Frequency and Polarisation Diversity
Example: Radar Signal Penetration into Wetlands

- L-Band is ideal for the study of wetlands because the signal penetrates through the canopy and can sense if there is standing water underneath.
- Inundated areas appear white in the image to the right.
Radar Parameters: Polarization

- The radar signal is polarized (usually horizontally or vertically)
- The polarizations are controlled usually 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 be used to determine physical properties of the object observed.
Example of Multiple Polarizations for Vegetation Studies

Pacaya-Samiria Forest Reserve in Perú
Images from UAVSAR (HH, HV, VV)

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

- Incidence Angle: is the angle between the direction of illumination of the radar and the Earth’s surface plane. Depending on the height of the radar sensor above the surface of the Earth, the incidence angle will change in the range direction. This is why the geometry of an image is different from point to point in the range direction.

- Local incidence angle: that accounts for local inclination of the surface. The incidence angle influences image brightness.
Questions

1. What are the advantages of radar sensors?
2. What are three main radar parameters that need to be considered for a specific study?
3. What is the relationship between wavelength and penetration?
4. What’s the usefulness of having different polarizations?
5. What’s the effect of varying incidence angle?
Backscattering Mechanisms of the Radar Signal
Radar Backscatter

• The radar echo contains information about the Earth’s surface, which drives the reflection of the radar signal.
• This reflection is driven by:
  – The frequency or wavelength: radar parameter
  – Polarization: radar parameter
  – Incidence angle: radar parameter
  – Dielectric constant: surface parameter
  – Surface roughness relative to the wavelength: surface parameter
  – Structure and orientation of objects on the surface: surface parameter
Backscattering Mechanisms

Density

Size in relation to the wavelength

Dielectric Constant

Size and Orientation
Surface Parameters: Dielectric Constant

The diagram illustrates the dielectric constant of various materials as a function of frequency in GHz. The x-axis represents frequency (GHz) ranging from 1 to 1000, and the y-axis represents the dielectric constant ranging from 0 to 100. Different materials are represented by distinct curves:
- **WATER**
- **Rocks**
- **Soil**
- **Vegetation**
- **Snow**
- **Piedras**
- **Suelo**
- **Vegetación**
- **Nieve**

Dielectric Properties of Materials are shown with curves for L-band, S-band, C-band, and Ku-band, each with different symbols:
- **Re(\(\epsilon_r\)); T = O C**
- **Im(\(\epsilon_r\)); T = O C**
- **Re(\(\epsilon_r\)) Ice**

The diagram helps in understanding how different materials affect radar signals at various frequencies.
Dielectric Properties of the Surface and its Frozen or Thawed State

During the land surface freeze/thaw transition there is a change in dielectric properties of the surface, which cause a notable increase in backscatter,
Radar Backscatter Sources: Part 1

• The radar signal is primarily sensitive to surface structure.
• The scale of the objects on the surface relative to the wavelength determine how rough or smooth they appear to the radar signal and how bright or dark they will appear on the image.
Radar Backscatter Sources: Part 2

Backscattering Mechanisms

- Double-bounce
- Vegetation Layer
Dominant backscattering sources in forests: (1) crown volume scattering, (2) direct scattering from tree trunks, (3) direct scattering from the soil surface, (4a) trunk-ground scattering, (4b) ground-trunk scattering, (5a) crown-ground scattering, (5b) ground-crown scattering.
Radar Interaction Types

Mirror like reflection (specular reflection)

Pixel Color

No reflections/echo

HH  CS  VV

Source: Natural Resources Canada

Salinas Valley, California
Octubre 24, 1998
L-Band Image

Smooth, level surface
(water, road)

Source: Natural Resources Canada

Source: Natural Resources Canada
Radar Interaction Types

Rough Surface Reflection

Source: Natural Resources Canada

Salinas Valley, California
Octubre 24, 1998
L-Band Image
Radar Interaction Types

Furrowed Surface Reflection

Requires that rows be perpendicular to radar illumination

Salinas Valley, California
Octubre 24, 1998
L-Band Image

Pixel Color

HH CS VV

Source: Natural Resources Canada

National Aeronautics and Space Administration
Radar Interaction Types
Volume Scattering by Biomass

Pixel Color

Salinas Valley, California
Octubre 24, 1998
L-Band Image

Source: Natural Resources Canada
Radar Interaction Types

Double Bounce Reflection

Salinas Valley, California
Octubre 24, 1998
L-Band Image

Source: Natural Resources Canada

National Aeronautics and Space Administration

Applied Remote Sensing Training Program
Example: Detection of Oil Spill on Water

UAVSAR (2 metros)
HH, HV, VV
Example: Landcover Classification

Brazil
JERS-1 L-band
100 meter resolution
Geometric and Radiometric Distortion of the Radar Signal
Geometric Distortion

Layover

Foreshortening

Source: Natural Resources Canada

National Aeronautics and Space Administration
Foreshortening

Before correction  

After correction  

Source: ASF
Shadow

Source: Natural Resources Canada
Radiometric Distortion

The user must correct for the influence of topography on backscatter. For example, this correction eliminates high values in areas of complex topography.

Before correction

After correction

Source: ASF
## Radar Data from Different Satellite Sensors

<table>
<thead>
<tr>
<th>Sensor Name</th>
<th>RADARSAT-2</th>
<th>Sentinel-1A</th>
<th>RISAT-1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agency</strong></td>
<td>Canadian Space Program (CSP)</td>
<td>European Space Agency (ESA)</td>
<td>Indian Space Research Organization (ISRO)</td>
</tr>
<tr>
<td><strong>Instrument</strong></td>
<td>C-band SAR (5.4 GHz)</td>
<td>C-band SAR (5.4 GHz)</td>
<td>C-band SAR (5.35 GHz)</td>
</tr>
<tr>
<td><strong>Incidence Angle</strong></td>
<td>Side-looking, 15-45° off-nadir</td>
<td>Side-looking, 15-45° off-nadir</td>
<td>36.85°</td>
</tr>
<tr>
<td><strong>Polarization</strong></td>
<td>HH, HV, VV, &amp; VH</td>
<td>(VV &amp; VH) or (HH &amp; HV)</td>
<td>HH &amp; HV</td>
</tr>
<tr>
<td><strong>Sensor Height at Equator</strong></td>
<td>798km</td>
<td>693km</td>
<td>542km</td>
</tr>
<tr>
<td><strong>Orbit</strong></td>
<td>Sun Synchronous (dusk/dawn)</td>
<td>Sun Synchronous (dusk/dawn)</td>
<td>Sun Synchronous (dusk/dawn)</td>
</tr>
<tr>
<td><strong>Revisit Time (Orbit Repeat Cycle)</strong></td>
<td>24 days</td>
<td>12 days</td>
<td>25 days</td>
</tr>
</tbody>
</table>
### Datos de Radar de Diferentes Satélites

<table>
<thead>
<tr>
<th>Sensor Name</th>
<th>RADARSAT-2</th>
<th>Sentinel-1A</th>
<th>RISAT-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>100m</td>
<td>5m x 20m</td>
<td>~25m</td>
</tr>
<tr>
<td>Swath Width</td>
<td>500km (ScanSAR mode)</td>
<td>250km (IWS mode)</td>
<td>115km (MRS)</td>
</tr>
<tr>
<td>Mean Local Time</td>
<td>6:00 a.m. descending</td>
<td>6:00 a.m. descending</td>
<td>6:00 a.m.</td>
</tr>
<tr>
<td>Launch</td>
<td>14 Dec 2007</td>
<td>3 April 2014</td>
<td>26 Apr 2012</td>
</tr>
<tr>
<td>Planned Lifetime</td>
<td>7 years minimum</td>
<td>7 years</td>
<td>5 years</td>
</tr>
</tbody>
</table>
Questions

1. What are the two surface parameters to which radar is sensitive?
2. Which are the three main backscattering mechanisms?
3. What type of distortions do radar images have?
4. Which are the geometric distortions?
5. What type of products can you generate from radar images?
6. How can you use radar images for your specific application?