Active Microwave (RaDAR)

Introduction to RaDAR Systems

RADAR technology is very complicated and we make no attempt here to cover the engineering or operation of these systems in any depth. Our goal is to only provide a brief overview of these extraordinary sensors then move on to how they have been used in forest and natural resource mapping. We highlight some recent research findings that may shed light on the capabilities or potential applications of current or future RADAR systems in forest mapping or monitoring.

RADAR is an acronym for Radio Detection and Ranging. Radio or microwave wavelengths (million times the size of optical wavelengths, approximately 1mm to 1 meter) are sent out at constant intervals to detect surface targets and record their distance or range. Wave amplitude, phase and time of travel (related to distance from the target) is recorded. The first radar systems were developed by the military in the 1940s. RADAR is an “active” system thus providing its own source of illumination or radiation. The RADAR antenna acts as both a transmitter and a receiver. The transmitter sends out pulses and after the pulse reaches the surface, a return signal is recorded by the receiver. The system is side-looking sending out the pulses off nadir (look angles are usually between 10 to 60 degrees).

Side-looking airborne radar (SLAR) is of two types. The first RADAR systems were called Real Aperture RADAR (RAR) or nicknamed “brute force”. They were aircraft systems with a fixed antenna length and thus the ground resolution was dependent on the size of the antenna and the flying height of the aircraft (the higher the flying height the lower the resolution). The first major non-military RAR mapping project was conducted in 1967 over tropical forests in the Darien Province of Panama, Central America (Viksne, 1970). This was the first time that the region had ever been mapped because the continuous cloud cover over the region precluded any successful aerial photo mission. RAR systems were replaced in the 1980s by new technology ‘Synthetic Aperture RADAR” or SAR that utilizes advanced computer engineering, doppler frequency and phase histories that can synthesize a long antenna (sometimes miles long) and attain high resolution images even from earth orbiting space platforms. The Japanese Earth Resource Satellite (JERS-1) SAR mosaic image of Central America was prepared under a NASA funded research project (Sader et al. 2001). The JERS-1 carried an L-band SAR with HH polarization.

RADAR Wavelengths

RADAR wavelengths range in size and each has a code letter that is a carryover from the secret military applications so the enemy could not intercept the frequency and attempt to jam the radar signals. The letter representing wavelength is not correlated to wavelength size (not alphabetical). The table below lists the most common RADAR wavelengths and the letter codes associated with them.
### RADAR Wavelengths and Letter Codes

<table>
<thead>
<tr>
<th>Band Letter Code</th>
<th>Wavelength Range(cm)</th>
<th>Common Wavelength of Operation(cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>2.4 – 3.8</td>
<td>3.0</td>
</tr>
<tr>
<td>C</td>
<td>3.8 – 7.5</td>
<td>6.0</td>
</tr>
<tr>
<td>L</td>
<td>15.0 – 30.0</td>
<td>23.5</td>
</tr>
<tr>
<td>P</td>
<td>30.0 – 100.0</td>
<td>68.0</td>
</tr>
</tbody>
</table>

### RADAR Polarization

RADAR signals can be sent and received at different geometric orientations or polarizations, either horizontal or vertical. “Like” polarizations are horizontal send and receive (HH) or vertical send and receive (VV). “Cross” poles are horizontal-vertical (HV) or vertical-horizontal (VH) send-receive. Different polarizations can affect how well certain earth surfaces are detected by the RADAR sensor.

### RADAR Reflector Surfaces

RADAR reflectors represent the geometric orientation of the target that interact with the radar pulse angle, pole and size. For simplicity of description we can group the reflectors into 3 groups: specular, diffuse and corner or double-bounce. In general shrub and forest cover types and some crops represent diffuse reflectors where the RADAR pulse is diffused at different angles and some of the energy is directed back to the receiver thus the signal received is somewhat intermediate (not high or low). A specular reflector is a mostly flat or non rough surface (calm water, grass field, bare soil, beach, etc.). The pulse hits the flat surface and most of the energy is directed out away from the surface at a right angle (more or less) away from the receiver thus little energy is recorded (very low signal). A corner reflector usually involves two adjacent surfaces (double bounce) and is a combination of a specular surface and a vertical object (e.g. trees) or a surface with strong angles such as a building. The RADAR pulse hits the specular surface first and the signal going out at a right angle (1st bounce) then interacts with a vertical or angular surface (2nd bounce) thus directing most or nearly all of the energy directly back to the receiver. This is the highest signal thus the object (tree or building in this case) would have a bright or whitish appearance on a BW image. Tall objects and very steep terrain can block the RADAR pulse from reaching the backside of the object (the geometry is called foreshortening or layover). The null area is called a RADAR shadow and there is no return signal therefore the area and any lower lying objects in this zone of the image would be black on a BW image.

### RADAR Relationships to Forest Canopy Structure and Biomass

Investigations using SAR are of particular interest in forest mapping and applications because SAR can penetrate clouds and provide information about the structure of vegetation canopies that is less feasible to do using optical sensors like multispectral...
scanners. Early vegetation research focused primarily on agricultural crops to understand the relationships of microwave backscatter with plant and soil surfaces. Microwave scattering is highly dependent on the moisture content, size and orientation of vegetation and tree components (e.g., leaves, branches, trunks). At shorter wavelengths (X and C band), the scattering properties are associated with interactions with smaller leaves, twigs and branches in the canopy. At longer wavelengths (L and P band) microwave scattering and absorption are related to interactions with larger leaves, branches and trunks and the ground surface. Plant height, density, geometry and presence or absence of water at the surface will affect backscatter and the incidence angle and polarization will also have a significant effect. Strong topographic relief can complicate the radar backscatter and overwhelm the surface vegetation response due to layover and shadowing effects. Most studies avoid excessive terrain if vegetation mapping or modeling is the objective.

Some Advantages and Disadvantages of RADAR for detecting or mapping forest and terrain features.

**RADAR Advantages:**

- Cloud and smoke penetration
- Night vision
- Forest canopy penetration reveals sub-canopy features and canopy structure using longer wavebands (for example, L and P bands)
- Complements visible/infrared sensors (sensitive to terrain features and moisture)
- Good for discrimination of terrain structure (roughness) and drainage patterns

**RADAR Disadvantages:**

- Interpretation requires knowledge of radar interaction with surfaces
- Speckle (dark and bright pixels) limits interpretation
- Satellite systems are not yet multispectral and multipolarization (usually one band/one polarization) on most satellite platforms (limits forest canopy information)
- Not good for discrimination and mapping of different vegetation types except at very general levels
- Data analysis can be hindered in steep topography and rough terrain due to extreme layover effects

Clearcuts can be separated from forest and some crops types using L band data (Wu and Sader, 1987). Microwave backscatter has been shown to be correlated with canopy structure components such as tree height, DBH, and basal area (Sader 1987; Hussin et al. 1991; LeToan et al. 1992; Ranson and Sun, 1994) using L and P band wavelengths. Conifers tend to have higher backscatter than deciduous forests (Wu and Sader, 1987;
Hoekman, 1990). The HV polarization produced better results than VV or HH. Height relationships were much better in pine plantations and even-aged stands than in all age and mixed forest (particularly hardwood) conditions (Sader, 1987). L and P band backscatter has been correlated with total above ground biomass in several studies including pine plantations (Sader, 1987; Wu and Sader, 1987; Dobson et al. 1992, and Kasischke et al. 1995), and mixed deciduous and/or coniferous forests (Sader, 1987; Ranson et al. 1994, Dobson et al. 1994). Again the cross polarization (HV) data had the strongest correlations with biomass. Earlier studies reported that the sensitivity of the L band backscatter to green weight biomass saturated at around 100 tons per acre (Sader, 1987; Hoekman et al. 1992; Dobson et al. 1992). Later studies with dual wavelength combinations and polarizations were able to estimate total above ground biomass at 200 to 250 tons per acre (Ranson et al., 1995, Dobson et al. 1995) using SIR-C data.

Characteristics of Selected Spaceborne Synthetic Aperture RADAR Systems

<table>
<thead>
<tr>
<th>Sensors</th>
<th>ERS-2</th>
<th>JERS-1</th>
<th>Radarsat 2</th>
<th>Envisat-1</th>
<th>ALOS(PALSAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Date</td>
<td>04/21/95</td>
<td>02/11/92</td>
<td>12/14/07</td>
<td>03/01/02</td>
<td>01/24/06</td>
</tr>
<tr>
<td>Waveband</td>
<td>C-band</td>
<td>L-band</td>
<td>C-band</td>
<td>C-band</td>
<td>L-band</td>
</tr>
<tr>
<td>Polarization</td>
<td>VV</td>
<td>HH</td>
<td>HH, VV, HV, VH</td>
<td>HH, VV, HV, VH</td>
<td>HH, VV, HV, VH</td>
</tr>
<tr>
<td>Look Angle (Degrees)</td>
<td>23</td>
<td>35</td>
<td>10-60</td>
<td>14-45</td>
<td>18-55</td>
</tr>
<tr>
<td>Resolution (m)</td>
<td>30</td>
<td>18</td>
<td>3-100</td>
<td>30-1000</td>
<td>10-100</td>
</tr>
</tbody>
</table>

Optimal Configuration of RADAR for Forest Mapping and Monitoring

Although no one configuration of a spaceborne RADAR system would be optimal for a wide range of applications in land cover and ecological mapping and monitoring, the current operational systems could be improved for monitoring forest environments. From the review of RADAR relationships to forest canopies, we know that waveband, polarization, look angle, and ground resolution are important factors affecting the ability to detect, map or measure forest characteristics.

If we consider an improved system to map general vegetation and land cover types, flooded forests, forest structure characteristic and estimate or predict above ground biomass, a dual waveband system would be needed. C and L band are most desirable (P band could be desirable for biomass estimation). The best single polarization would be cross-pole (HV) however HH would be a useful addition if more than one polarization
was feasible. The lower look angles (20 to 40 degrees) are clearly better than higher angles for forests. Finer resolution (e.g. 30 m or better) is desirable for stand level studies however coarser resolution (30-100m) would be useful for larger area or regional studies.

The RADAR science community has been advocating for a dual waveband and multipolarization system for several years. Radarsat-2 will contain multipolarization data which is a step in the right direction. Apparently the costs and complexity of designing such a system are not trivial and no such system is yet available. These capabilities have only been available on research aircraft like NASA’s AIRSAR or the one of a kind SIR B and C missions that enabled researchers to conduct the various experiments with different wavebands and polarizations that led to the knowledge that we currently have about forests and RADAR. Other researchers have simply combined data from different existing RADAR systems to work with dual waveband and/or multipolarization data.

References


