Lecture 24

Applications of the synthetic aperture radars: Sea ice mapping

Objectives:
1. Basics of imaging radars.
2. Basics of a synthetic aperture radar (SAR).
3. SARs in space: ERS-1 and ERS-2, JERS-1, RADARSAT-1 satellites

Additional/advanced reading:
Tutorials on SAR
http://www.asf.alaska.edu/sitemap.html
http://www.ccrs.nrcan.gc.ca/ccrs/learn/tutorials/stereosc/chap1/chapter1_1_e.html

1. Basics of imaging radars.
Recall lecture 20 in which non-imaging and imaging radars were introduced.

Two main types of imaging radars:
- SLAR (side-looking radar airborne radar)
- SAR (synthetic aperture radar)

SLAR is a real aperture radar.

Side-looking viewing geometry of SLAR:
Swath (C);
Range (D) refers to the across-track dimension perpendicular to the flight direction;
Azimuth (E) refers to the along-track dimension parallel to the flight direction.
Slant range vs. Ground rage

At all ranges the radar antenna measures the radial line of sight distance between the radar and each target on the surface. This is the slant range distance. The ground range distance (D) is the true horizontal distance along the ground corresponding to each point measured in slant range.

Unlike optical systems, a radar's spatial resolution is a function of the specific properties of the microwave radiation and geometrical effects.

Azimuth resolution, \( R_a \), is defined as

\[
R_a = \frac{H \lambda}{L \cos \theta} \quad [24.1]
\]

Cross-track resolution, \( R_r \),

\[
R_r = \frac{ct_p}{2 \sin \theta} \quad [24.2]
\]

where

\( H \) is the height of the antenna (height of the airplane);
\( \lambda \) is the wavelength at which the antenna emits with pulse duration \( t_p \),
\( L \) is the length of the antenna, and
\( \theta \) is the incidence angle

**Example:**

For the antenna with the following characteristics: \( \lambda = 1 \) cm, \( L = 5 \) m, \( t_p = 30 \) ns, \( H=6000 \) m, and \( \theta = 59^0 \) (10 km from the ground track) \( \Rightarrow \) \( R_a = 23 \) m and \( R_r = 5.2 \) m
• Because $R_a$ is proportional to $H$ (see Eq. [24.1]), a long antenna (i.e., large $L$) would be required to achieve a good resolution from a satellite $\Rightarrow$ need for SAR

Recall the radar equation (Eq. [21.13])

$$\frac{P_r}{P_i} = \frac{A^2 \sigma_r}{4\pi R^4 \lambda^2}$$

where $\sigma_b$ is the radar cross-section (or backscattering cross-section).

• Radar measures backscattering from surface (e.g., ocean, sea-ice, land, etc.) $\Rightarrow$ cross-section is due to reflection from the surface and hence depends on the incident angle, polarization, and surface state, etc.

In remote sensing of the surfaces, it is common to express the radar equation in the differential form

$$dP_r = \frac{A^2}{4\pi R^4 \lambda} \frac{1}{\lambda^2} \sigma^0 dS$$ \[24.3\]

where $\sigma^0$ (called sigma nought) is the dimensionless backscattering cross-section per unit surface area (also called normalized backscattering cross-section), and $dS$ is the element of the surface area.

**NOTE:** $\sigma^0$ depends on scattering characteristics of the surface, polarization, incident angle among other factors.
The backscatter response, and thus the appearance of an object on a radar image, strongly depend on surface roughness.

**NOTE:** Other factors affecting the radar backscatter: changes in the moisture content; size of the scatterers, polarization of the pulse, and observation angles.

Radar images consist of pixels which represent the radar backscatter for that area of the ground: darker areas represent low backscatter, while bright areas represent high backscatter.

Flat (smooth) surface => low backscattering => dark images
Rough surface => high backscattering = bright images

### 2. Basics of a synthetic aperture radar (SAR)

SAR overcomes the problem of a decrease of the of the azimuthal resolution of SLAR (i.e., large $R_a$) with increasing altitude.

SAR relies on the speed of the platform to achieve the higher resolution in the azimuth (along-track) direction and on greater sophistication in the processing of the return signal. **Strategy:** Store the radar returned signal, as amplitudes and phases, for the time period $T$ => possible to reconstruct the signal which would have been obtained by an antenna of
length \( VT \), where \( V \) is the platform speed \( \Rightarrow \) making \( T \) large makes “the synthetic aperture” large and hence a higher resolution can be achieved.

*How SAR works:*

As a target (A) first enters the radar beam, the backscattered echoes from each transmitted pulse begin to be recorded. As the platform continues to move forward, all echoes from the target for each pulse are recorded during the entire time that the target is within the beam. The point at which the target leaves the view of the radar beam some time later, determines the length of the simulated or **synthesized** antenna (B). The expanding beamwidth, combined with the increased time a target is within the beam as ground range increases, balance each other, such that the resolution remains constant across the entire swath.

The viewing geometry of a radar results in geometric distortions on the resultant image: **Slant-range distortion** occurs because the radar is measuring the distance to features in slant-range rather than the true horizontal distance along the ground. This results in a varying image scale, moving from near to far range.

- **Foreshortening** occurs when the radar beam reaches the base of a tall feature tilted towards the radar (e.g. a mountain) before it reaches the top. Because the radar
measures distance in slant-range, the slope (a to b) will appear compressed and the length of the slope will be represented incorrectly (a' to b').

- **Layover** occurs when the radar beam reaches the top of a tall feature (b) before it reaches the base (a). The return signal from the top of the feature will be received before the signal from the bottom. As a result, the top of the feature is displaced towards the radar from its true position on the ground, and "lays over" the base of the feature (b' to a').

- The **shadowing** effect increases with greater look angles, just as our shadows lengthen as the sun sets.
3. SARs in space: ERS-1 and ERS-2, JERS-1, RADARSAT-1 satellites

*Examples of SAR applications* (main focus in on the Earth’s surfaces):

- Sea ice monitoring
- Ocean wave spectra
- Monitoring disasters such as forest fires, floods, volcanic eruptions, and oil spills
- Cartography
- Surface deformation detection
- Glacier monitoring
- Crop production forecasting
- Forest cover mapping
- Urban planning
- Coastal surveillance (erosion)

<table>
<thead>
<tr>
<th>Mission Dates</th>
<th>Seasat</th>
<th>AIRSAR (aircraft)</th>
<th>SIR-C (shuttle)</th>
<th>Almaz-1 Russian SA</th>
<th>ERS-1/2 European SA</th>
<th>JERS-1 Japanese SA</th>
<th>RADARSAT-1 Canadian SA</th>
<th>RADARSAT-2 Canadian SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength (cm)</td>
<td>23.5 (L)</td>
<td>23.5 (L)</td>
<td>23.5 (L)</td>
<td>10 (S)</td>
<td>5.7 (C)</td>
<td>23.5 (L)</td>
<td>5.6 (C)</td>
<td>5.6 (C)</td>
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<td>Polarization</td>
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<td>all</td>
<td>HH</td>
<td>VV</td>
<td>HH</td>
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<td>Incidence Angle</td>
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<td>20-60</td>
<td>15-55</td>
<td>30-60</td>
<td>23</td>
<td>35</td>
<td>20-59</td>
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<tr>
<td>Swath Width (km)</td>
<td>100</td>
<td>10-17</td>
<td>15-90</td>
<td>350</td>
<td>100</td>
<td>75</td>
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<td>Resolution (m)</td>
<td>25</td>
<td>2-8</td>
<td>10-60</td>
<td>10-30</td>
<td>30</td>
<td>18</td>
<td>10-100</td>
<td>3-100</td>
</tr>
</tbody>
</table>

**RADARSAT 2**

[Image of RADARSAT 2]

**Viewing capability of RADARSAT-1**
Sea Ice characterization:

*Principles:* the physical and chemical properties of ice affect the ice dielectrical constant in microwave and smoothness of ice surfaces and hence the interaction of ice with microwave radiation

**Ice Type Identification with RADARSAT:**
Gulf of St Lawrence, Prince Edward Island, Canada
March 6, 1996

*Compare the RADARSAT data with ground photographs:*

(A) Nilas ice is new ice which has a smooth matte surface. When this ice is formed, it has a relatively smooth surface and thus appears quite dark in the RADARSAT image.

(B) Pancake ice is young ice - "grey" and "grey-white", the next stage of ice development (approximately 50 cm in diameter each “pancake). This form of sea ice causes strong scattering of the incoming radar energy due to its surface roughness and high salinity content, resulting in a bright appearance in the RADARSAT image.

(C) Tears ice is "grey" to "grey white" ice and the conglomeration of "pancake" ice into a larger ice feature. Also visible in the photo are "tears" (open water cracks) which are clearly seen in the RADARSAT images.
Ocean waves

Imaging of the ocean with SAR is a complex process because both the radar and the target are moving. Moreover, waves on the ocean are very complex.

Bragg-resonant scattering is the primary scattering mechanism for imaging ocean waves with ripples (also called capillary waves).

For Bragg-resonant scattering, the radar signal selects a particular resonant ocean wavelength, \( L_B \), given by

\[
L_B = \frac{\lambda}{2 \sin \theta}
\]  

[24.4]

The main advantage of using SAR for imaging ocean waves is that this technique potentially provides more complete information on the wave field - the wave spectrum - than for example wave buoy data, or altimeter data (see overview http://www.geog.ucl.ac.uk/~mbomers/essay.html#Introduction)

Examples of ERS-1 SAR Images:

SAR Image of the gulf of Alaska showing the uniform appearance of ocean surface waves

This scene shows mesoscale features in the Shelikof Strait, between Kodiak Island and the Alaska Peninsula. An eddy is clearly identified in the image with a series of boundaries characterized by spiraling curvilinear features.