Problems to Solve when Trying to Use SAR Data for Geophysical Analysis

- **Problem 1:** SAR data suffers from geometric distortions owing to the side-looking observation geometry
  - **Solution:** We will identify the distortions and look for ways to remove them
- **Problem 2:** SAR images appear very noisy, making interpretation harder
  - **Solution:** We will describe the noise and talk about filtering methods
- **Problem 3:** SAR data is in the acquisition coordinate system defined by the Azimuth and Slant Range directions
  - **Solution:** We will talk about Geocoding

Example of a Geometric and Radiometric Distortions in SAR Imagery

- **Evident Geometric Distortion:**
  - One side of the mountain seems shorter than the other
- **Evident Radiometric Distortion:**
  - One side of the mountain seems much brighter
Geometric Distortions are Caused by the Slant Observation Geometry of SAR Systems

For SAR images processed to ‘zero-Doppler’ geometry:

\[
\begin{pmatrix}
    x \\
    y \\
    z
\end{pmatrix} \rightarrow \begin{pmatrix}
    X \\
    Y \\
    Z
\end{pmatrix}
\]

where

\[
R = \sqrt{x^2 + y^2 + z^2}
\]

Three Types of Geometric Distortions Occur As a Consequence of Oblique Look Angle

- **Foreshortening**
  - Sensor-facing slope foreshortened in image
  - Foreshortening effects decrease with increasing look angle

- **Layover**
  - Mountain top overlain on ground ahead of mountain
  - Layover effects decrease with increasing look angle

- **Shadow**
  - Area behind mountain cannot be seen by sensor
  - Shadow effects increase with increasing look angle
Geometric Distortions of SAR Images

1. Foreshortening

[Diagram showing foreshortening with labels A, B, C, and A', B', C'.]

ERS-1
θ = 23 deg

Geometric Distortions of SAR Images

2. Layover

[Diagram showing layover with labels A, B, C, D, and A', B', C', D'.]

ERS-1
θ = 23 deg

Geometric Distortions of SAR Images

3. Shadow

[Diagram showing shadow with labels A, B, C, and labels for azimuth and radar shadow.]
Example of a Geometric and Radiometric Distortions in SAR Imagery

- Questions:
  - Which direction is range and which is azimuth?
  - Where (if at all) do you see foreshortening?
  - Where (if at all) do you see layover?
  - Where (if at all) do you see radar shadow?

Analysis of Complex Structures

Simulation of SAR Signatures (Dr. H. Hammer, S. Kuny)

Range incidence angle ≈ pyramid slope

Optical images © Berthold Werner, Jon Bodsworth (Wikipedia)
Analysis of Complex Structures

Simulation of SAR Signatures (Dr. H. Hammer, S. Kuny)

TerraSAR-X image (Giza, Egypt)

Courtesy A. Thiele, KIT & Fraunhofer IOSB, DE

Contact author @: https://www.ipf.kit.edu/mitarbeiter_thiele_antje.php

Another Cool Example of Geometric Distortions

RADIOMETRIC PROPERTIES OF SAR IMAGERY
Think – Pair – Share

• Geometric Distortions can be challenging...
  – Try to explain this scene. What object are you seeing? What is the observation direction in this scene. What causes all the different bright spots?

• Speckle is not noise, he says ...
  – I am claiming that Speckle is not noise in the traditional sense but rather a consequence of the imaging process resulting from the big two principles in SAR, Interference & Coherence. Try to discuss how interference effects in coherent imaging systems may naturally cause speckle?
  – Can you think of other sensors (other than SAR) that also may suffer from Speckle?

SAR Images Often Appear a Bit Noisy

• Do you see the noise?

• This noise is caused "Speckle" and is an inherent property of all coherent imaging systems

• Technically speaking, it is not noise but an interference pattern

http://www.astronomy.com/news/2015/02/a-new-way-to-view-titan-despeckle-it

Coherent Waves and Speckle
Coherent Waves and Speckle

- Random positive and negative interference of wave contributions from the many individual scatterers within one resolution cell
  - Varying brightness from pixel to pixel even for constant $\sigma^2$
  - Granular appearance

Speckle Statistics

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Amplitude</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability distribution</td>
<td>$\sqrt{I_1^2 + I_2^2}$</td>
<td>Rayleigh</td>
</tr>
<tr>
<td>Exponential</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Important:

1. Noise level depends on radar cross section $\sigma^2$ → Higher $\sigma^2$ causes more noise!
2. Noise is highly non-Gaussian!
**Speckle Statistics**

<table>
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<tr>
<th>Quantity</th>
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<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_0^2 + N_e^2$</td>
<td>Rayleigh</td>
<td>$I =</td>
</tr>
</tbody>
</table>

1. Noise level depends on radar cross section $\sigma^2 \rightarrow$ higher $\sigma^2$ causes more noise!
2. Noise is highly non-Gaussian!
3. Averaging of $N_0$ independent samples (looks) $\rightarrow$ more Gaussian

\[
pdf(I|N_0) = \frac{1}{\sqrt{2\pi \sigma^2}} e^{-\frac{I^2}{2\sigma^2}}
\]

**Important:**

1. Noise level depends on radar cross section $\sigma^2 \rightarrow$ higher $\sigma^2$ causes more noise!
2. Noise is highly non-Gaussian!
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**Speckle Example**

**Time Series of SAR Images**

- **Right image:** shows how speckle can vary over time and in space
- **Left image:** shows that on average, the backscatter from an area is equal to its radar cross section $\sigma^2$.

**Speckle Reduction**

- **SPECKLE** is a scattering phenomenon and not noise. However, speckle can be modeled as multiplicative noise for distributed targets (Lee, IGARSS-98)
- Speckle “masks” underlying image
- Speckle filtering:
  - **GOAL:** Reduction of the speckle noise without sacrificing information content (including the spatial resolution)
  - **PRINCIPLE:** Select homogeneous neighboring pixels and then average
- Simplest form of speckle reduction: averaging of adjacent pixels (box filter) or multi-looking $\rightarrow$ loss of resolution
- More complex models (try to limit resolution degradation)
Speckle Reduction Example

- Original 4-look amplitude
- 5x5 Median
- Lee refined (7x7)

Example for Bayesian Speckle Reduction

- Original SAR Image
- Speckle filtered Bayesian Algorithm

GEOCODING, GEOMETRIC & RADIOMETRIC CORRECTION
Definitions

- **Geocoding**
  - geometric transformation of an image into a cartographic map projection

- **Georeferencing**
  - relating image coordinates to map coordinates by defining control points (usually image corners); image remains in native image geometry

Geocoding Using a Sensor Model

- **Sensor model**
  - sensor specific
  - analytical reconstruction of image formation using orbit and sensor parameters
  - Digital Elevation Model (DEM) required to correct image globally

Geocoding Steps

1. Relation between image coordinates and geographic coordinates using image and sensor geometry and DEM information
   - line / sample $\rightarrow$ latitude / longitude
2. Conversion of geographic coordinates into map-projected coordinates
   - latitude / longitude $\rightarrow x_{map}$, $y_{map}$
   - choice of map projection and datum
3. Determination of a transformation function to map image coordinates into projection coordinates
4. Resampling using mapping function
   - determination of pixel value in the map projected using one of the interpolation methods
Geometric Terrain Correction

- Geometric terrain correction (GTC) describes how to remove geometric distortions by using a DEM in the geocoding process:
  - To make sure that all pixels appear at their proper geographic location.
  - To allow for overlaying SAR data onto remote-sensing data from different sensors.

- GTC problem: What are the image gray values in every pixel of the output (geocoded) image given the input image and the DEM?

- Two main approaches for geocoding including GTC are shown in the following:
  - Backward Geocoding
  - Forward Geocoding

Forward Geocoding

- Forward geocoding starts from a pixel in the slant-range image for which the location on ground is determined.
- This results in an irregularly distributed point cloud on ground and a subsequent resampling step is necessary.
- Terrain correction is done in image space.

Backward Geocoding

- "painting the DEM in map-projection space"
- Starting from a predefined pixel location in the geocoded output image, the corresponding column and line in the slant-range image are calculated using the DEM information.
- The grey value for the output pixel is calculated through interpolation in the slant-range image.
A Second Look At Forward Geocoding

1. Forward Geocoding:
   - Step 1: Project pixels \( [x_i, y_i] \) into output image \( g_o \) using DEM
   - Step 2: Determine gray values in output image by interpolation between projected pixels

1. Project into output image

2. Interpolate gray value in output image

A Second Look at Backward Geocoding

2. Backward Geocoding:
   - Step 1: Project output image pixels \( [x_o, y_o] \) into input image \( g_i \) using DEM
   - Step 2: calculated gray value of projected pixel by interpolation and assign to \( [x_o, y_o] \) in output image

1. Project into input image

2. Interpolate gray value in output image

3. Assign gray value to pixel in output image

Only Inverse Mapping guarantees that ALL pixels in the output image receives a gray value (no holes) — inverse mapping is standard approach

Geometric Terrain Correction Example (I)

Original Image
Radiometric Terrain Correction

- **Problem:** Sensor facing slopes appear overly bright in radar images.
- **Cause:** Pixel Size on sensor-facing slopes is larger → more ground is integrated into pixel → brightness goes up

- **Solution:** Radiometric Terrain Correction (RTC)
  1. Using DEM and observation geometry, calculate exact equivalent area $A_e$ covered by each pixel
  2. Normalize radar cross section by $A_e$ to arrive at terrain normalized data $\sigma_f$
Radiometric Terrain Correction Example (II)

Image after RTC

What’s Next?

- Next lecture (Tuesday 3/8/16) we will talk a bit more about SAR
  - Other SAR modes
  - Existing SAR sensors and how to get to data
- Then we will start talking about InSAR, a method for topographic mapping and deformation analysis

- In preparation please read in Woodhouse (2006):
  - Interferometric SAR: 313-331