GEOS 657 – MICROWAVE REMOTE SENSING

GRADUATE-LEVEL COURSE AT THE UNIVERSITY OF ALASKA FAIRBANKS

Lecturer:

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Lecture 9: Geometric & Radiometric Properties of SAR Data; Geocoding, Geometric & Radiometric Correction

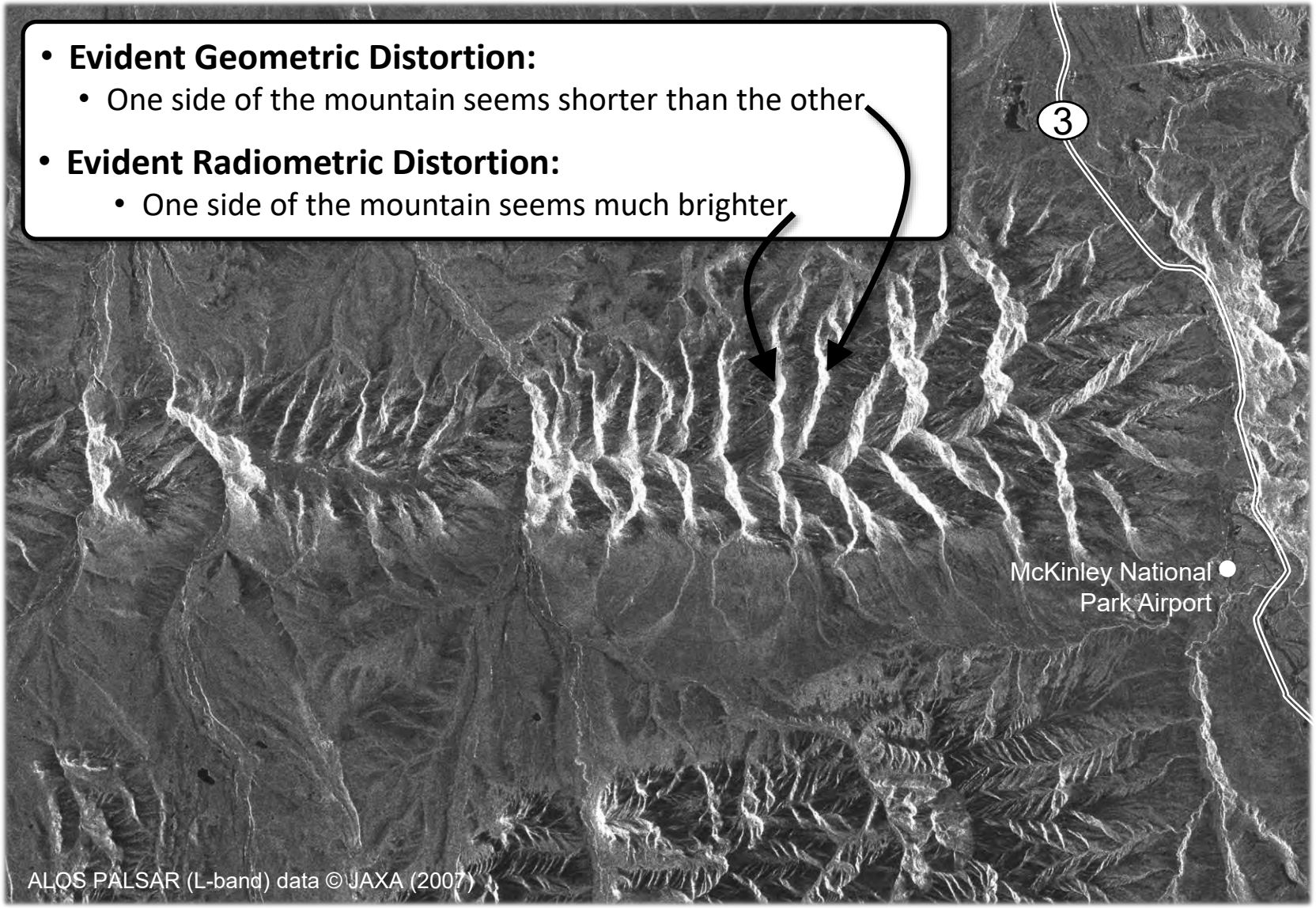
Problems to Solve when Trying to Use SAR Data for Geophysical Analysis

- **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

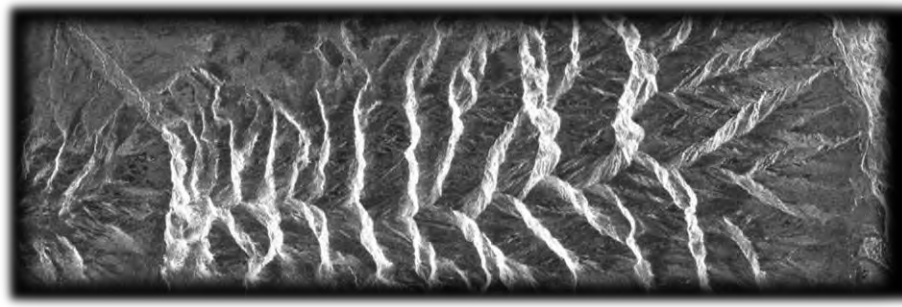
- **Problem 2:** SAR images appear very noisy, making interpretation harder
- **Solution:** We will describe the noise and talk about filtering methods

- **Problem 3:** SAR data is in the acquisition coordinate system defined by the Azimuth & Slant Range directions
- **Solution:** We will talk about Geocoding

Example of a Geometric and Radiometric Distortions in SAR Imagery



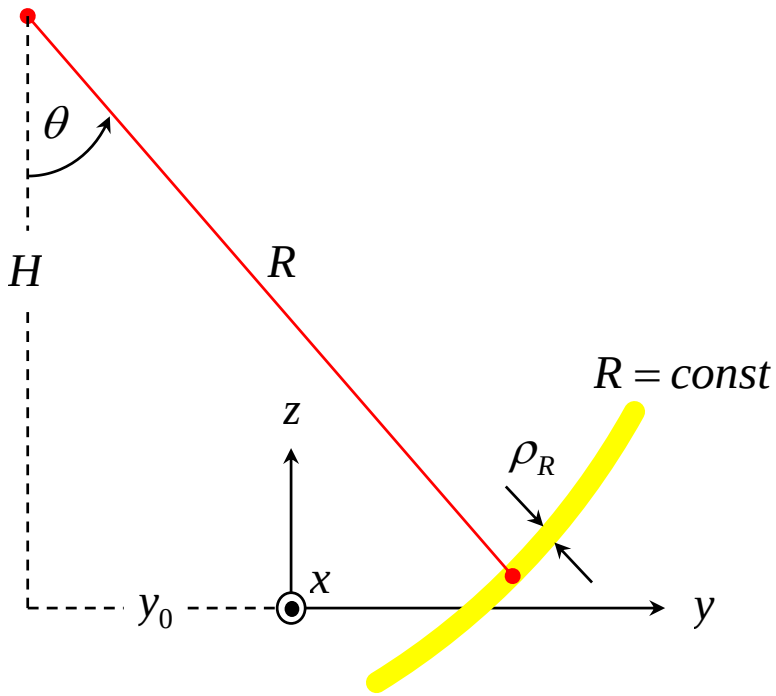
- **Evident Geometric Distortion:**
  - One side of the mountain seems shorter than the other
- **Evident Radiometric Distortion:**
  - One side of the mountain seems much brighter



GEOMETRIC PROPERTIES OF SAR IMAGERY

Geometric Distortions are Caused by the Slant Observation Geometry of SAR Systems

For SAR images processed to 'zero-Doppler' geometry: $\begin{pmatrix} x \\ y \\ z \end{pmatrix} \rightarrow \begin{pmatrix} x \\ R \end{pmatrix}$

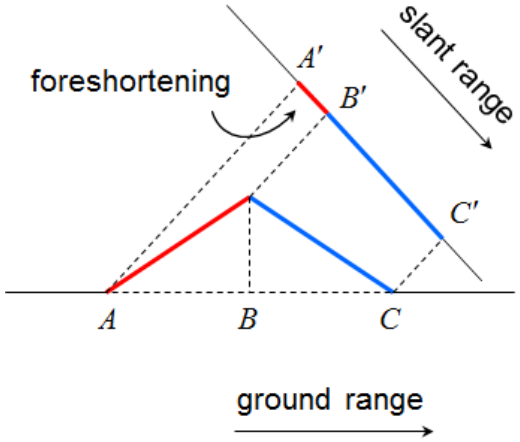


where $R = \sqrt{(y_0 + y)^2 + (H - z)^2}$

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

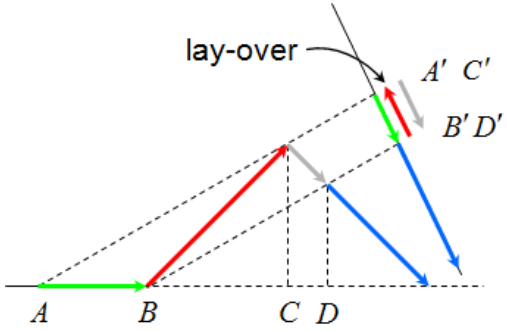
Foreshortening

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



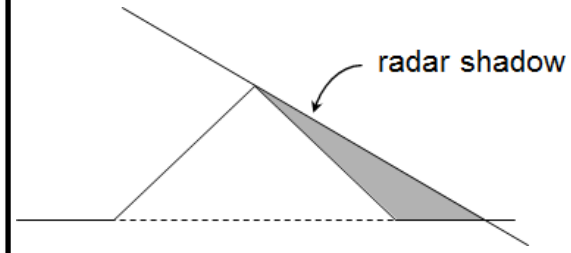
Layover

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



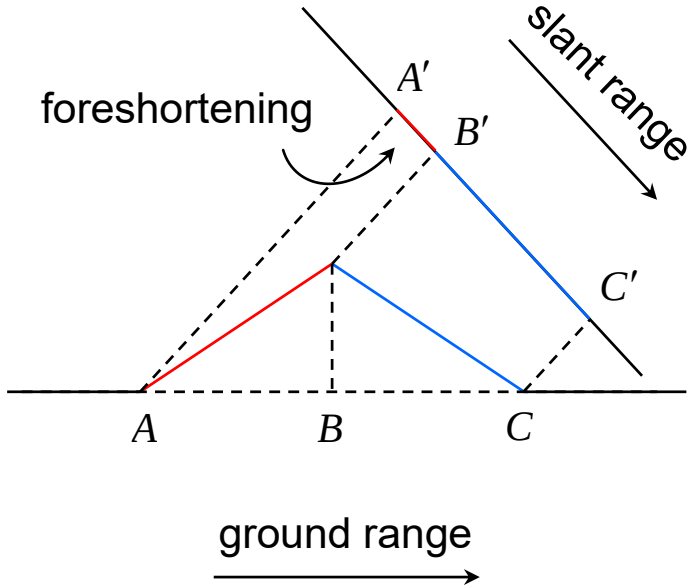
Shadow

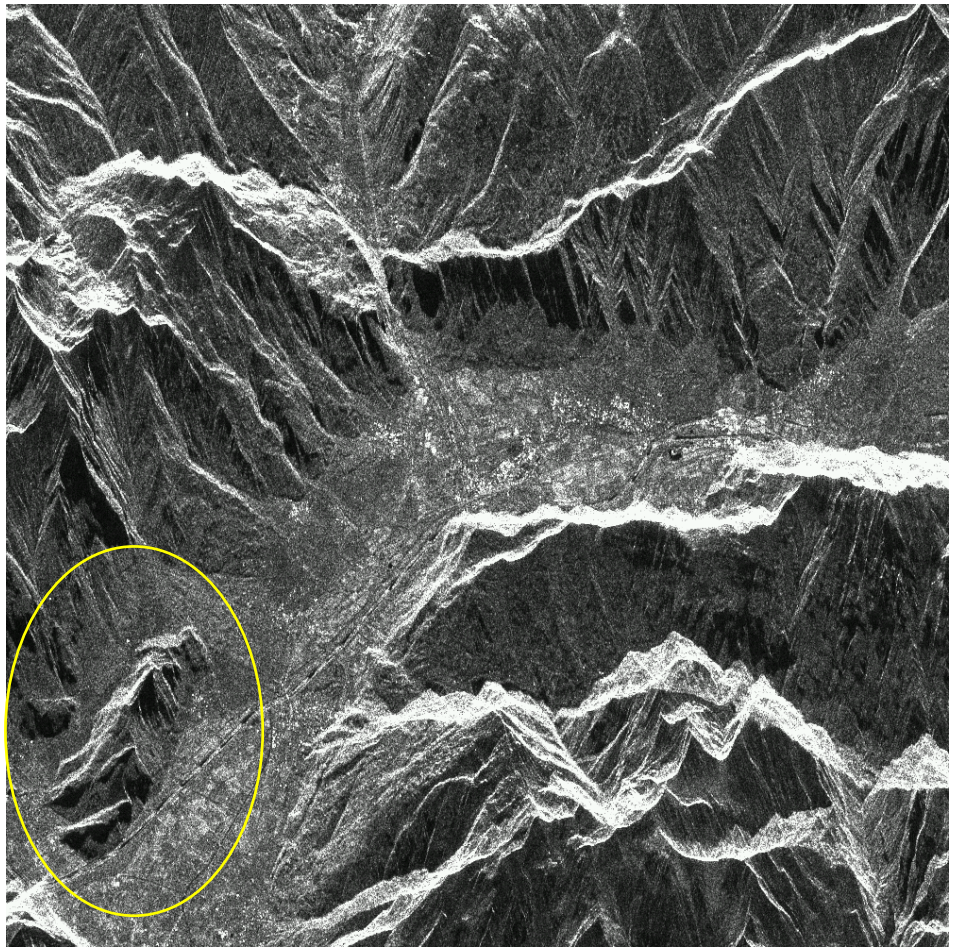
- Area behind mountain cannot be seen by sensor
- Shadow effects *increase* with increasing look angle



Geometric Distortions of SAR Images

1. Foreshortening





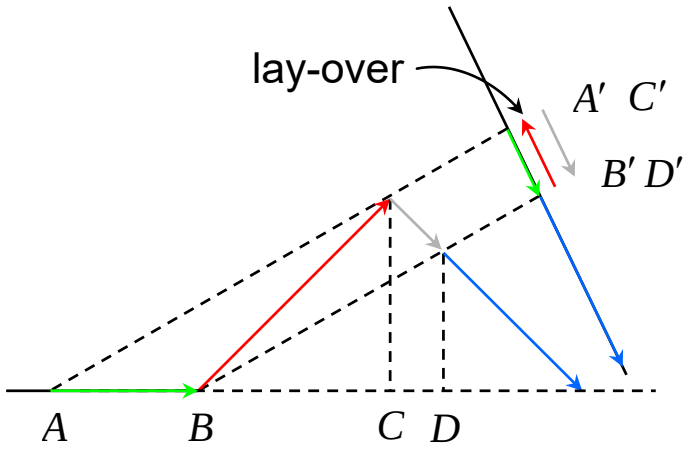
ERS-1

$\theta = 23\,\mathrm{deg}$

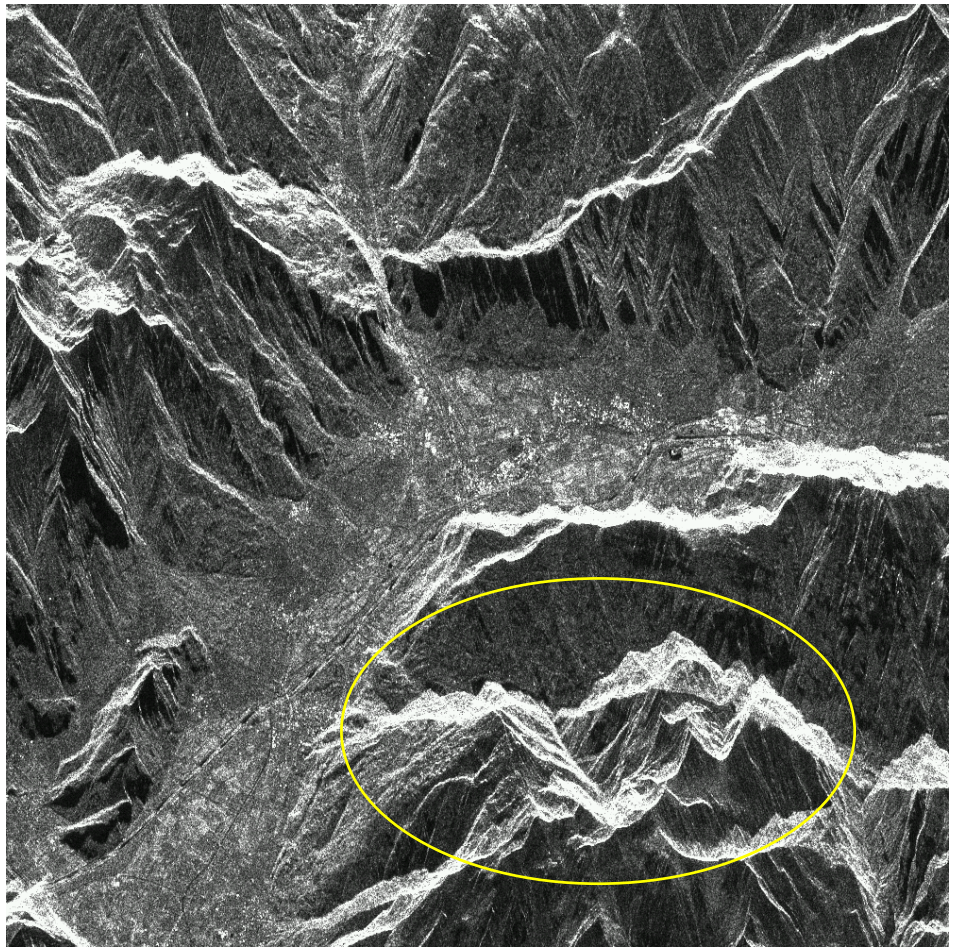
data © ESA

Geometric Distortions of SAR Images

2. Layover



range



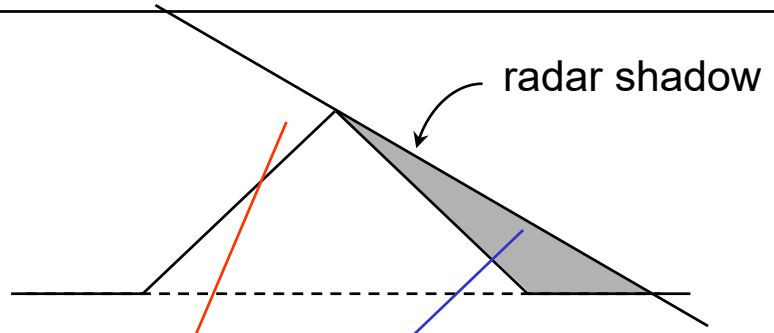
ERS-1

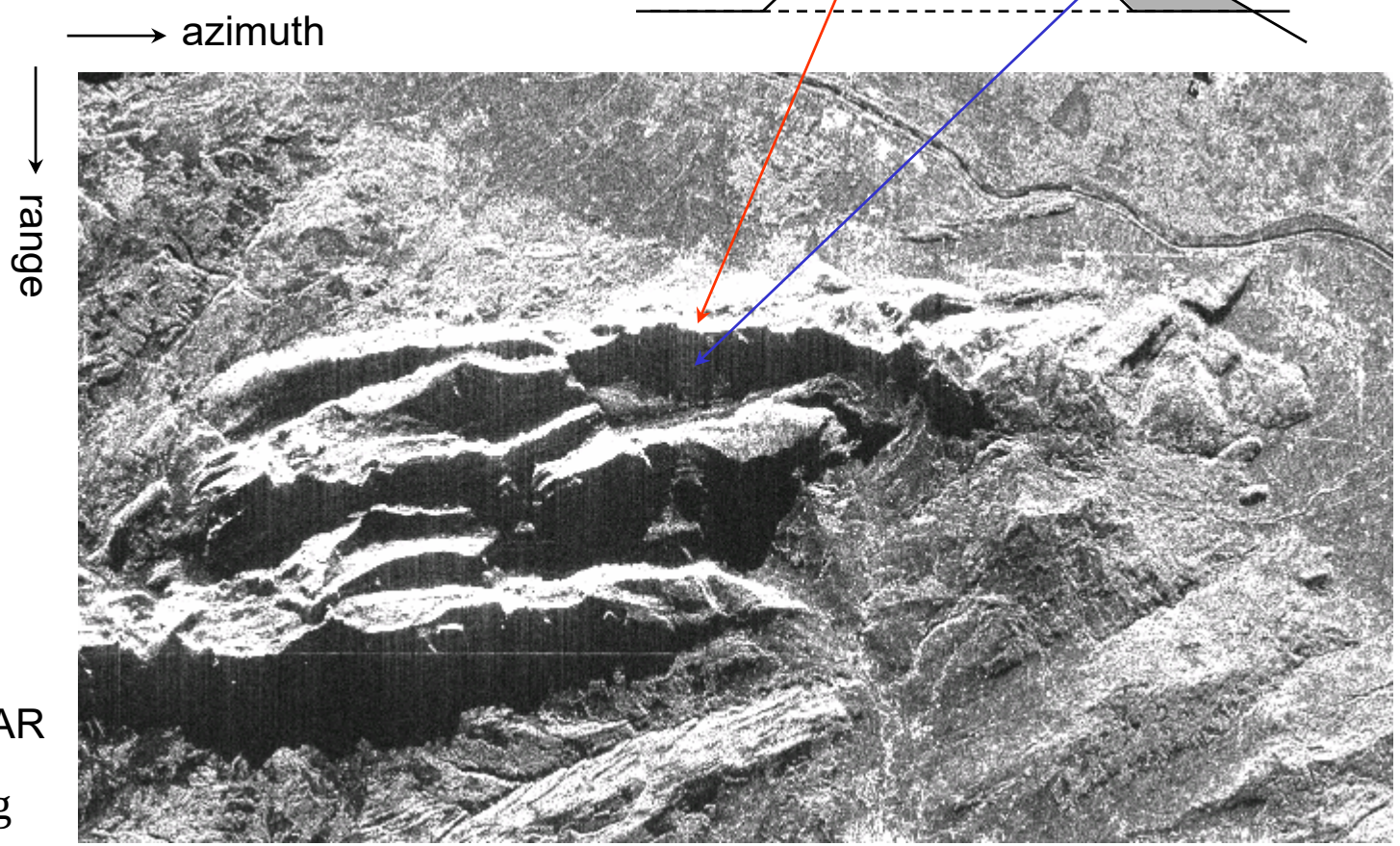
$\theta = 23\,\mathrm{deg}$

data © ESA

Geometric Distortions of SAR Images

3. Shadow



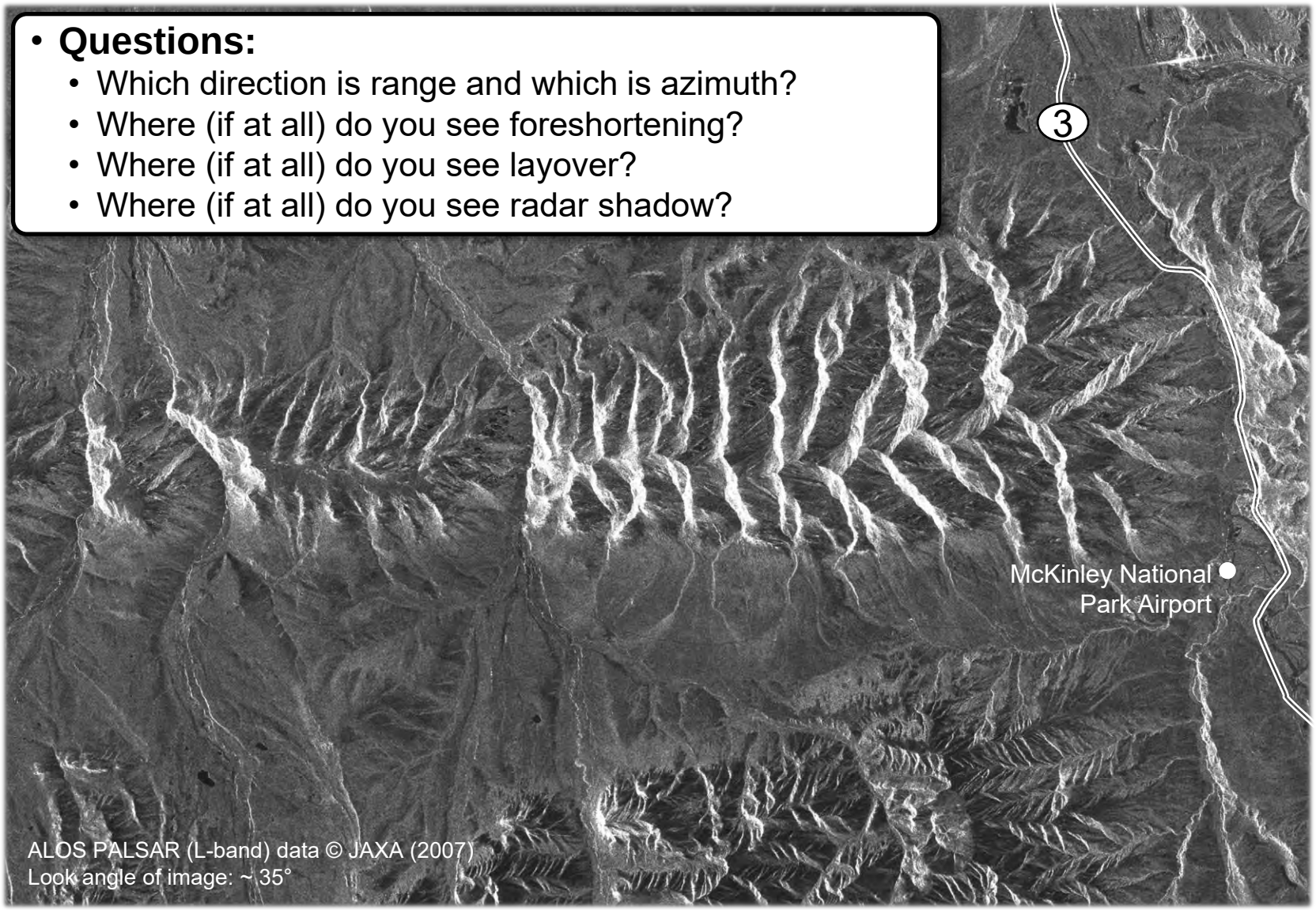


SRTM/X-SAR

$\theta = 54\,\mathrm{deg}$

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

Courtesy A. Thiele, KIT & Fraunhofer IOSB, DE
Contact author @:
https://www.ipf.kit.edu/mitarbeiter_thiele_antje.php

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

TerraSAR-X image (Giza, Egypt)

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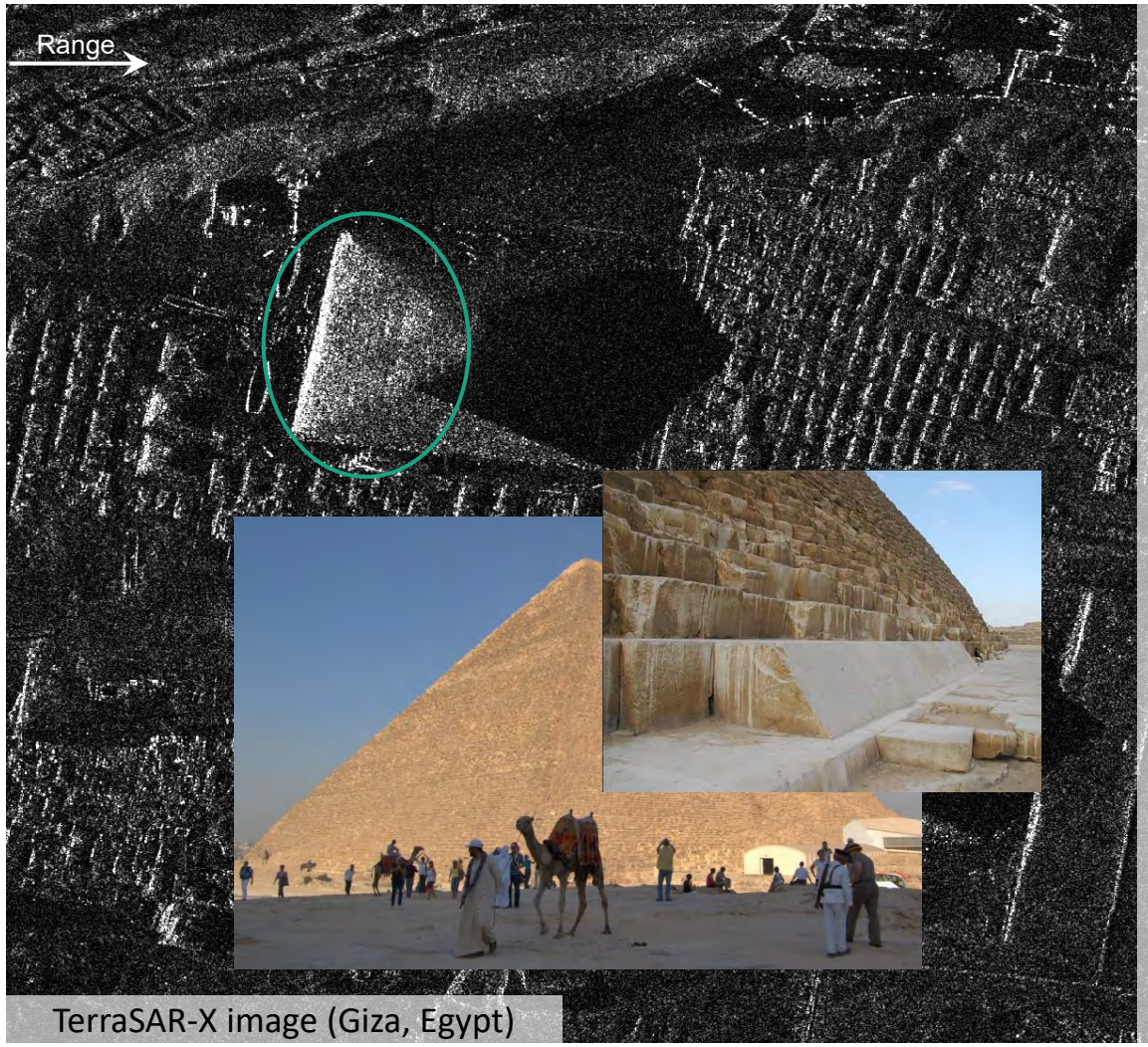
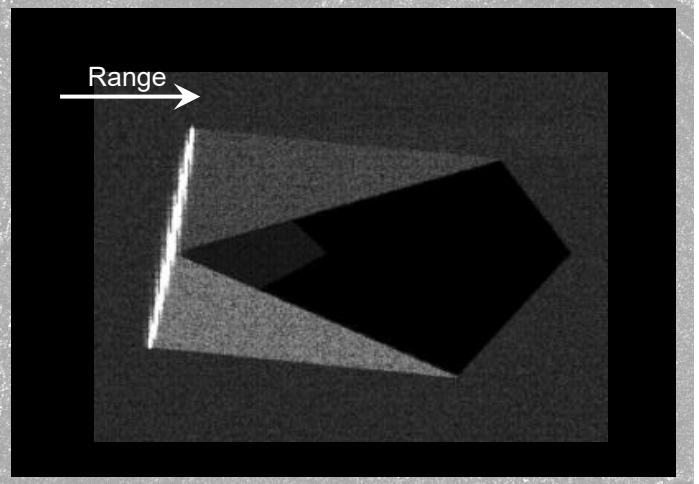
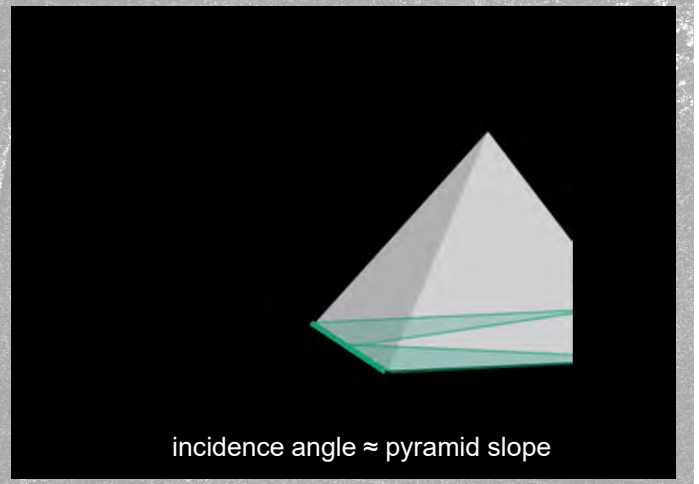


TerraSAR-X image (Giza, Egypt)





Optical images © Berthold Werner, Jon Bodsworth (Wikipedia)

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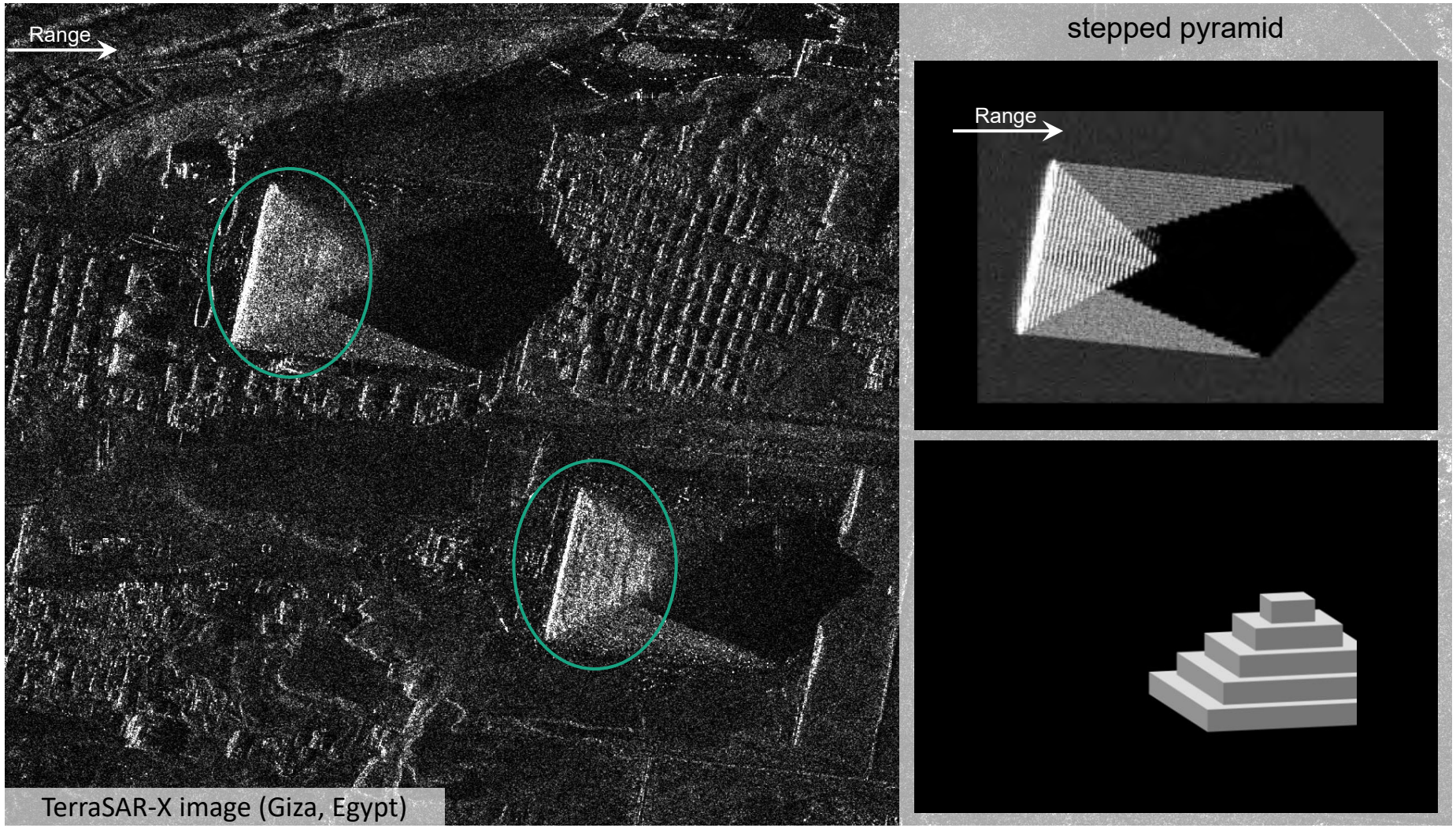


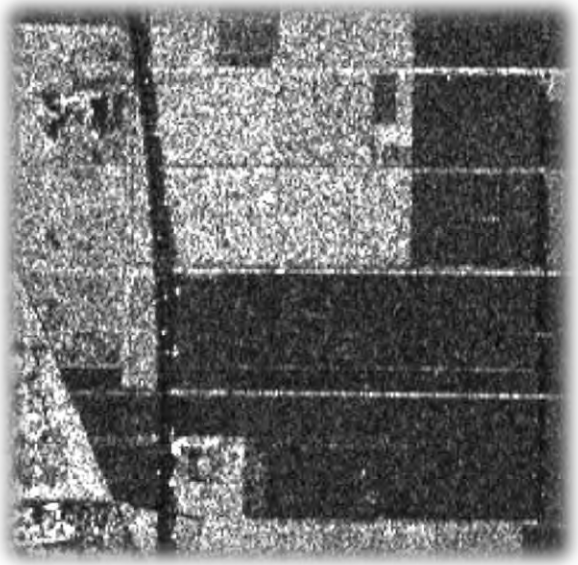
Another Cool Example of Geometric Distortions

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?

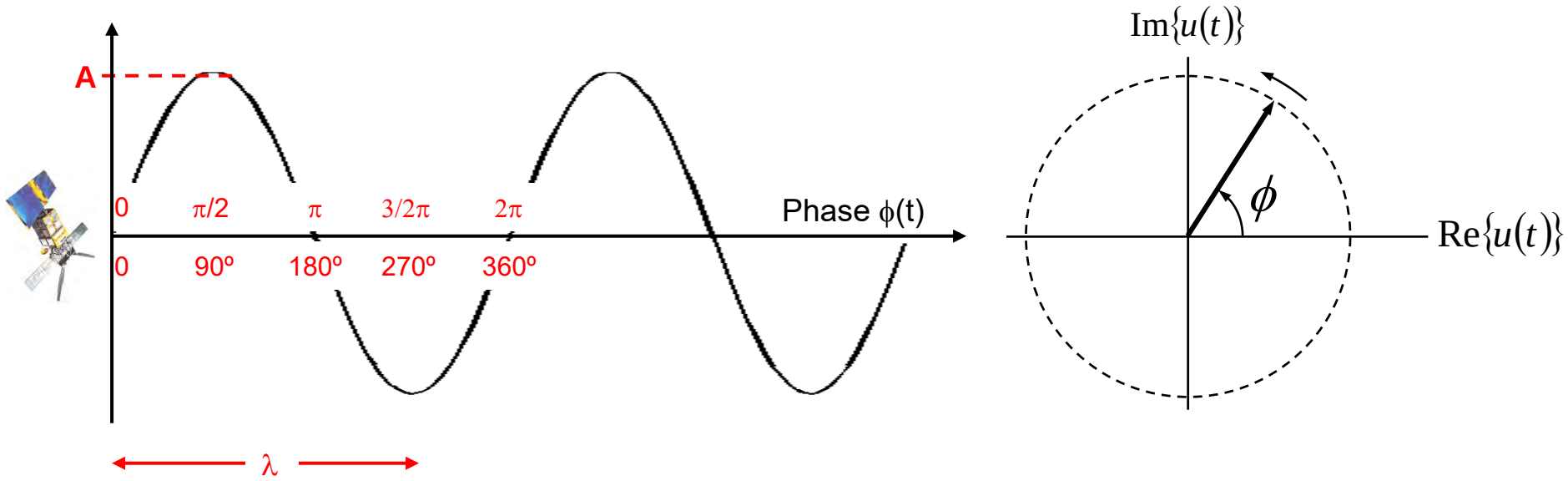


SAR Images Often Appear a Bit Noisy

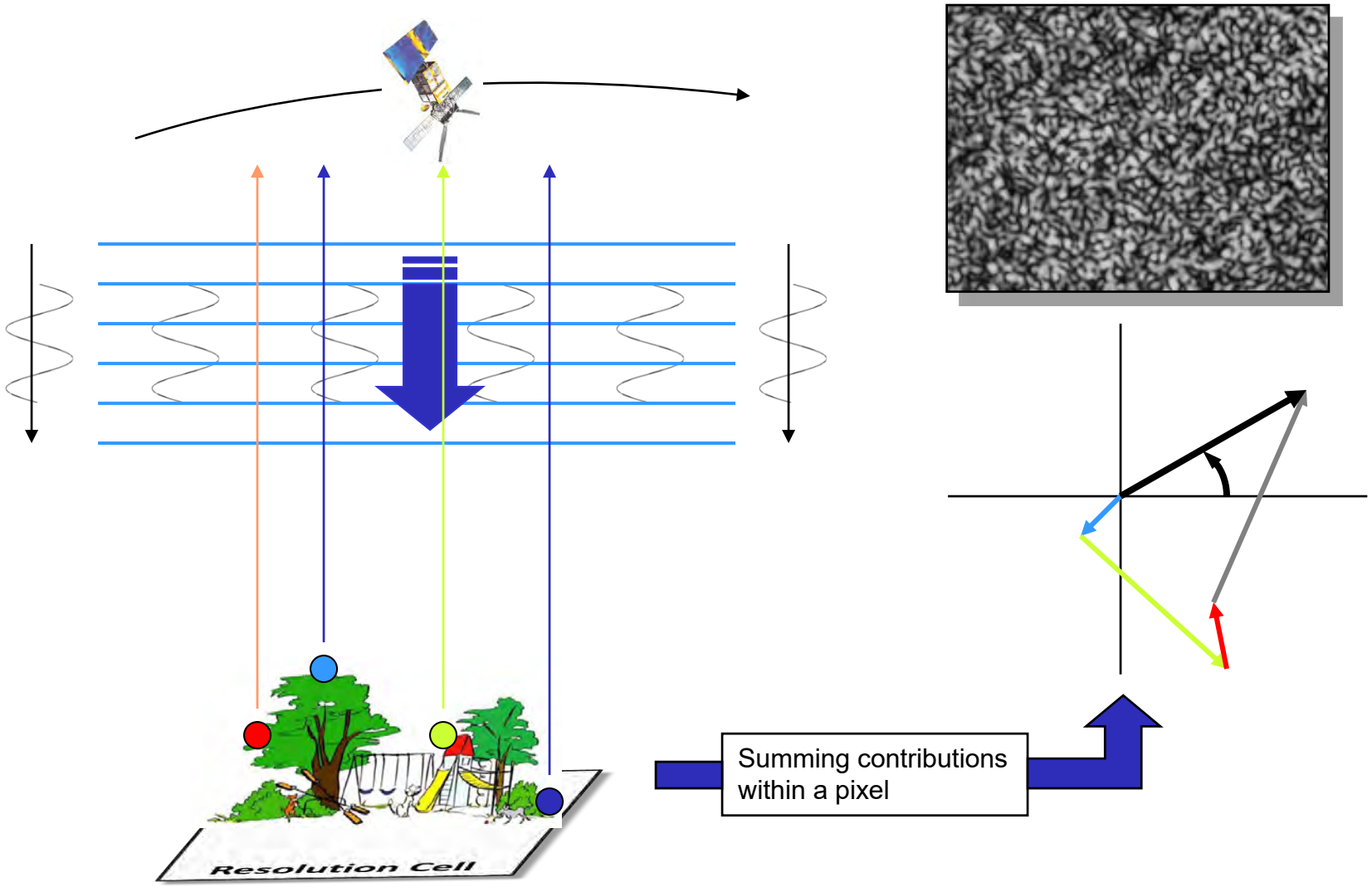
- Do you see the noise?
- This noise is caused “Speckle” and is an inherent property of all coherent imaging systems
- Technically speaking, it is not noise but an interference pattern

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

Coherent Waves and Speckle

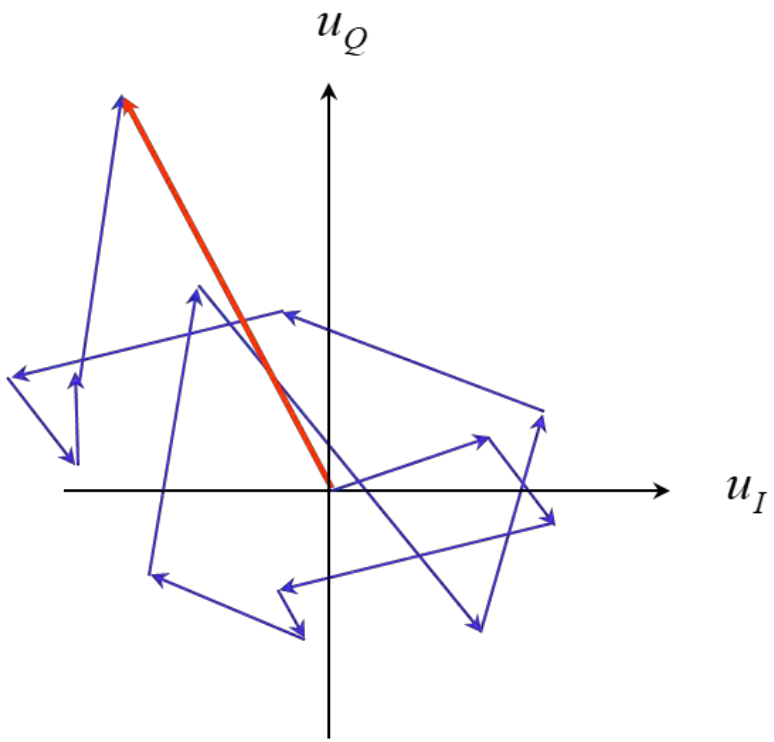


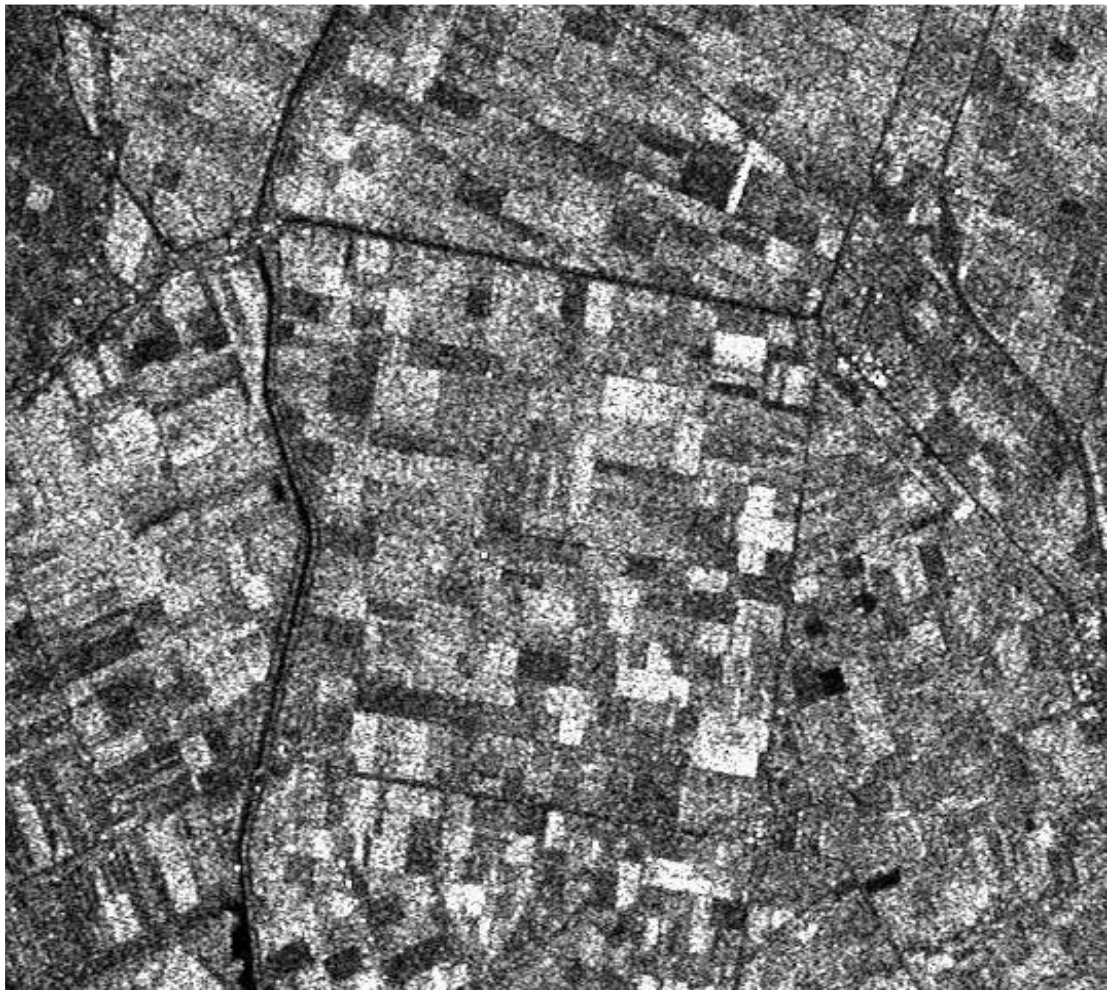
Coherent Waves and Speckle



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 σ^0
  - → granular appearance





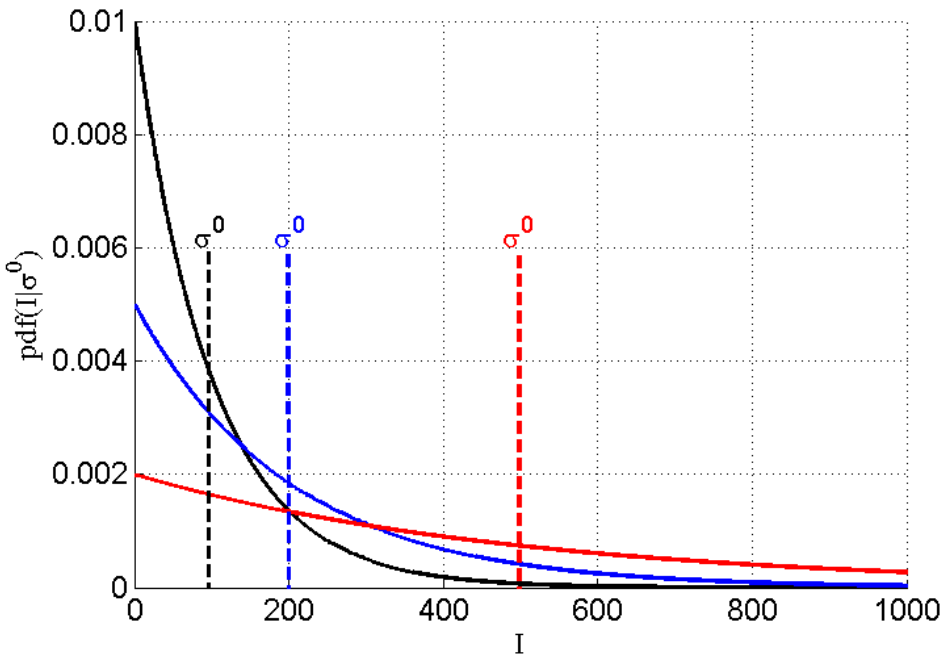
Speckle Statistics

	amplitude	power
quantity ⇨	$\sqrt{u_I^2 + u_Q^2}$	$I = u_I^2 + u_Q^2$
probability distribution ⇨	Rayleigh	exponential

Important:

1. Noise level depends on radar cross section σ^0 → higher σ^0 causes more noise!
2. Noise is highly non-Gaussian!

$$pdf_I\left(I \middle| \sigma^0\right) = \frac{1}{\sigma^0} \exp\left\{-\frac{I}{\sigma^0}\right\}$$



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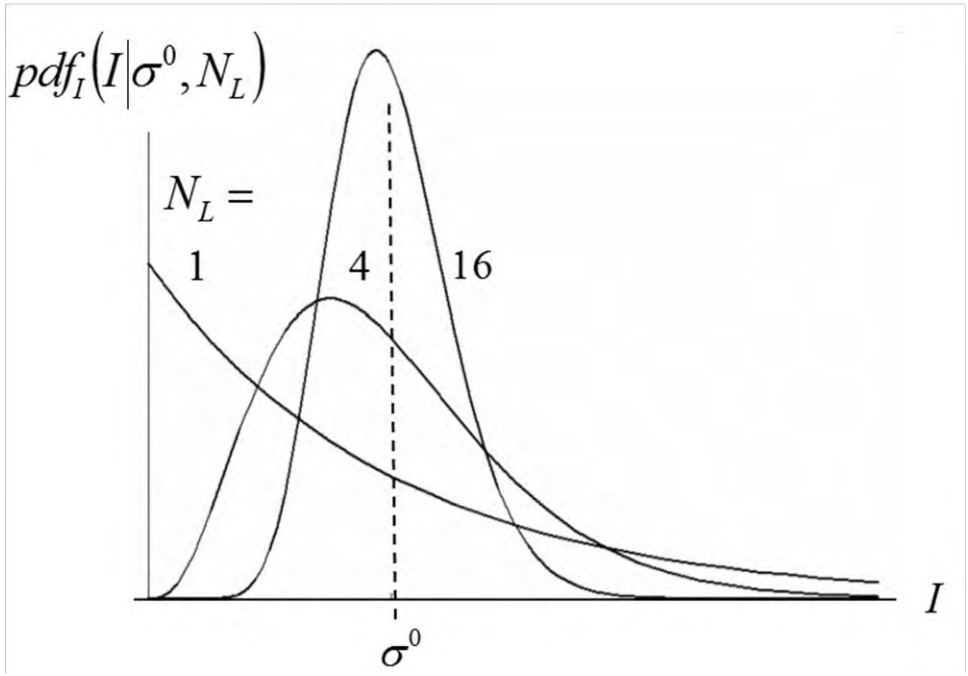
$$pdf_I\left(I \middle| \sigma^0\right) = \frac{1}{\sigma^0} \exp\left\{-\frac{I}{\sigma^0}\right\}$$

3. Averaging of N_L independent samples (looks) → more Gaussian

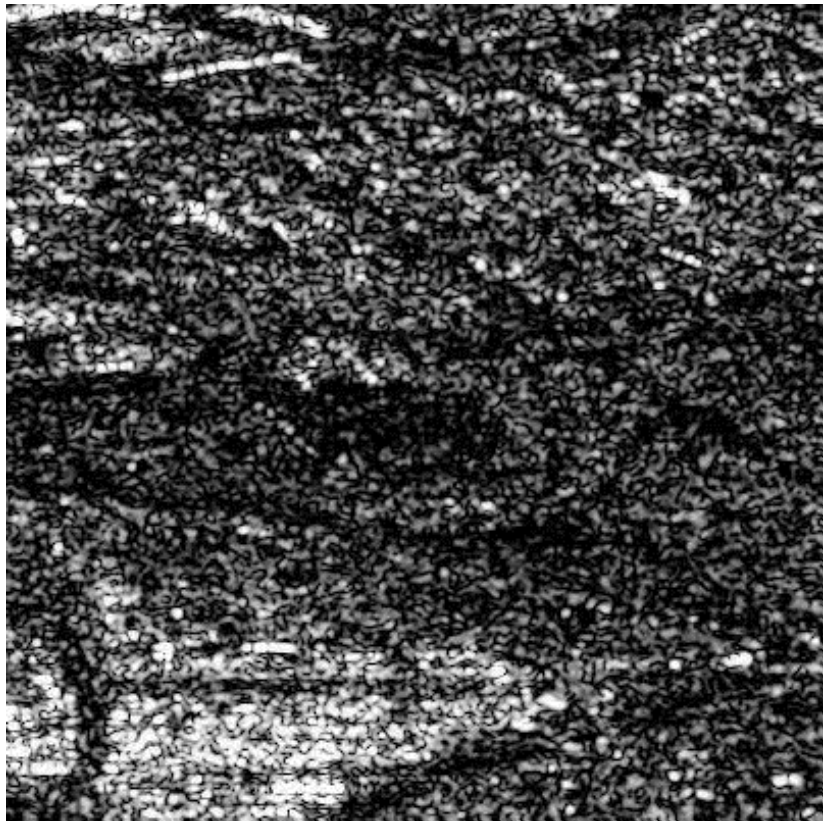
$$pdf_I\left(I \middle| \sigma^0, N_L\right) = \frac{I^{N_L - 1} N_L^{N_L}}{\Gamma(N_L)\sigma^{0 N_L}} \exp\left\{-\frac{I N_L}{\sigma^0}\right\}$$



Speckle Example

Time Series of SAR Images

incoherent average of 70 ERS SAR images



individual images (9 years)

- **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 σ^0

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***

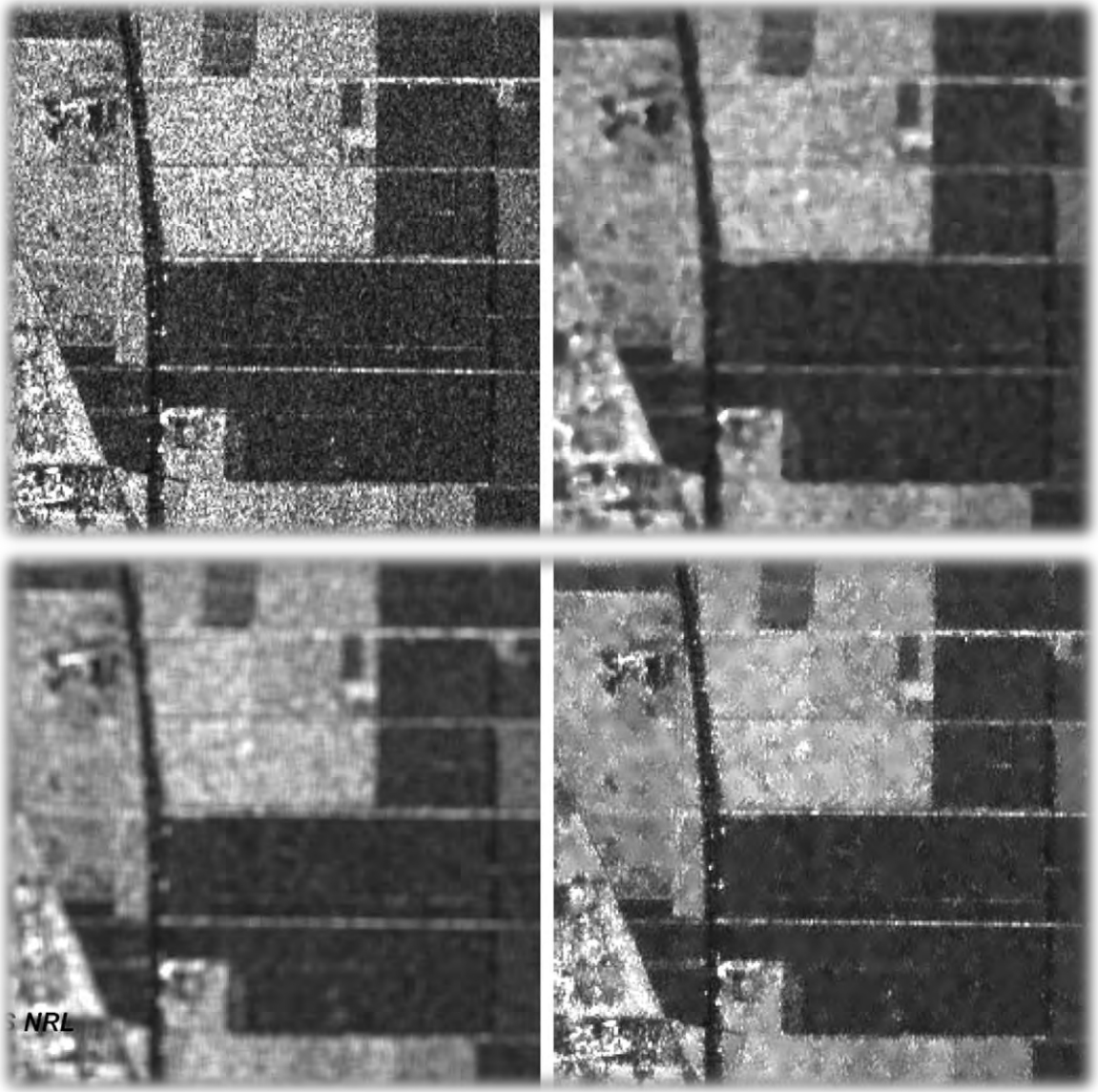
- **Simplest form of speckle reduction:** averaging of adjacent pixels (box filter) or **multi-looking → loss of resolution**

- More complex models (try to limit resolution degradation)

Speckle Reduction

Example

Original 4-look amplitude

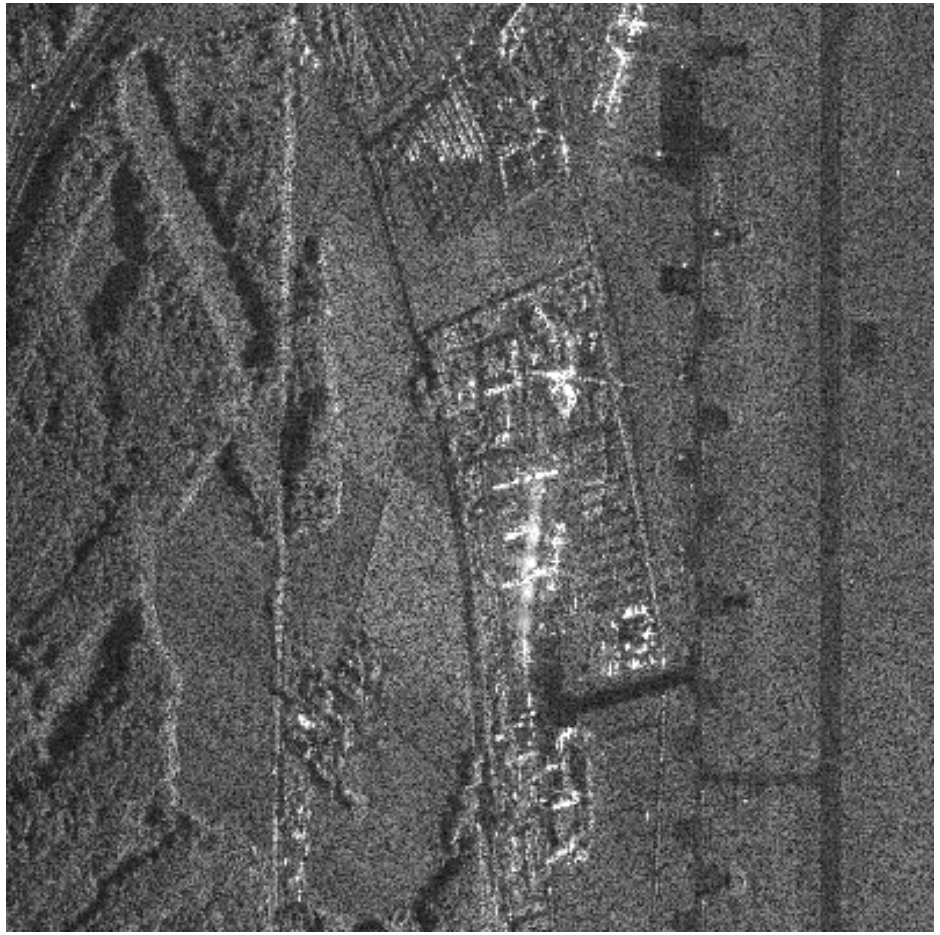


5x5 Median

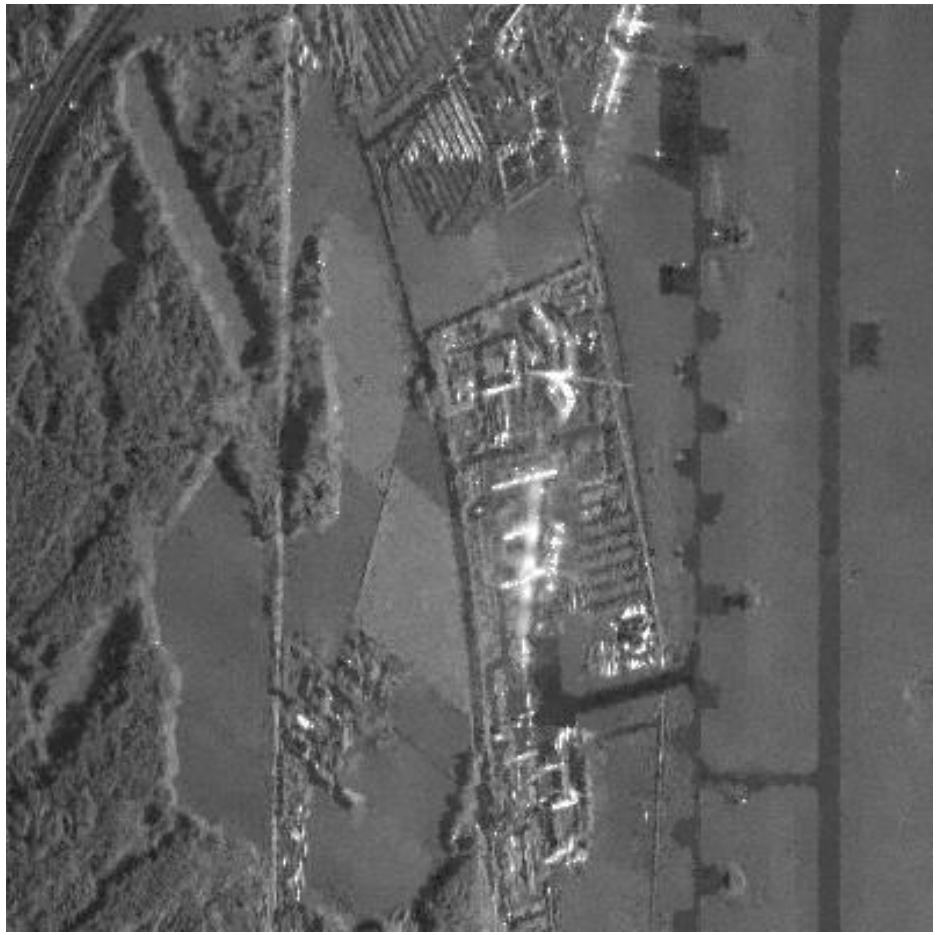
5x5 Boxcar

Lee refined (7x7)

Example for Bayesian Speckle Reduction



Original SAR Image
SAR data © AeroSensing GmbH



Speckle Filtered
Bayesian Algorithm

Selected Speckle Filters

SPECKLE FILTERS	DESCRIPTION	RELATED PUBLICATION(S)
Change-preserving multi-temporal Speckle filter	Filter for stacks of SAR images; reduces speckle while preserving changes in the time series (e.g., related to deforestation)	Quegan and Yu, 2001
Lee filter	Standard deviation-based (sigma) filter, filtering data based on statistics calculated from the data. Unlike a Gaussian or boxcar filter, the Lee filter and other similar sigma filters preserve image sharpness and detail while suppressing noise.	Lee, 1980
Enhanced Lee filter	The enhanced Lee filter is an adaptation of the Lee filter. Each pixel is put into one of three classes, which are treated as follows: Homogeneous: The pixel value is replaced by the average of the filter window. Heterogeneous: The pixel value is replaced by a weighted average. Point target: The pixel value is not changed.	Lopes et al., 1990
Frost and enhanced Frost filters	The Frost filter is an exponentially damped circularly symmetric filter that uses local statistics. The Enhanced Frost filter is an adaptation of the Frost filter. It classifies and filters pixels according to the logic explained in the row above.	Frost et al., 1982; Lopes et al., 1990
Non-local means filters	The basic idea behind non-local means filters is to provide an estimate of the clean image via a proper averaging of similar pixels or patches, found in the image. Essentially, the algorithm searches for image patches that resemble the area around the pixel to be filtered. Using some similarity criterion, these patches are found and averaged together to de-noise the image without losing resolution.	Buades et al., 2005; Chen et al., 2014; Di Martino et al., 2016; Martino et al., 2015

SAR Handbook: Comprehensive Methodologies for Forest Monitoring and Biomass Estimation. Eds. Flores, A., Herndon, K., Thapa, R., Cherrington, E. NASA. 2019. DOI: 10.25966/hbm1-ej07

GEOCODING, GEOMETRIC & RADIOMETRIC CORRECTION

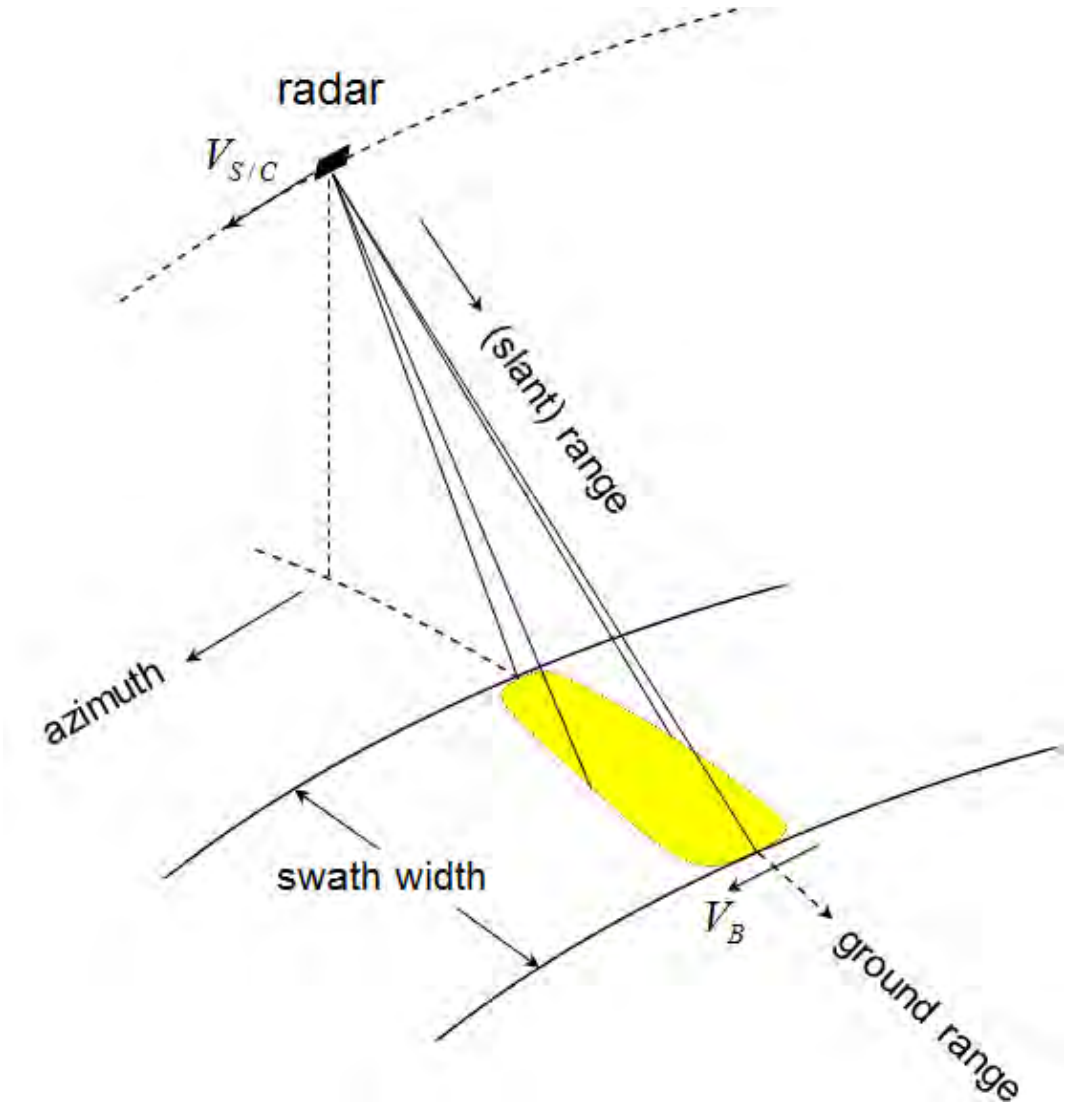
Definitions

- **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 → latitude / longitude

2. **Conversion of geographic coordinates into map-projected coordinates**
   - latitude / longitude → x_{map} / y_{map}
   - choice of map projection and datum

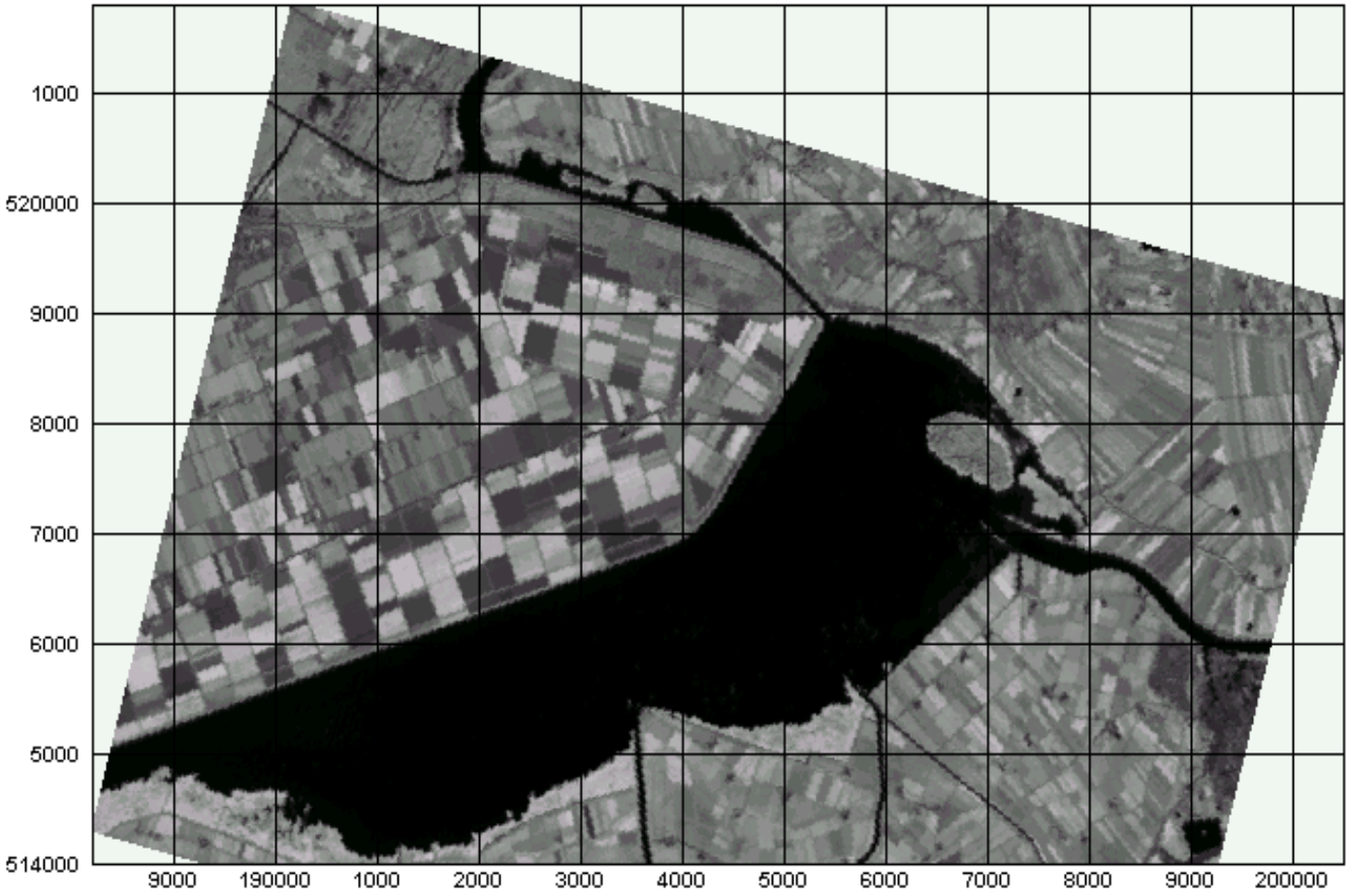
3. **Determination of a transformation function to map image coordinates into projection coordinates**

4. **Resampling using mapping function**
   - determination of pixel value in the map projected using one of the interpolation methods

Example: Original Image

Example: Transformed Image
(After Steps 1-3)

Example: Transformed Image
(After Steps 1-4)



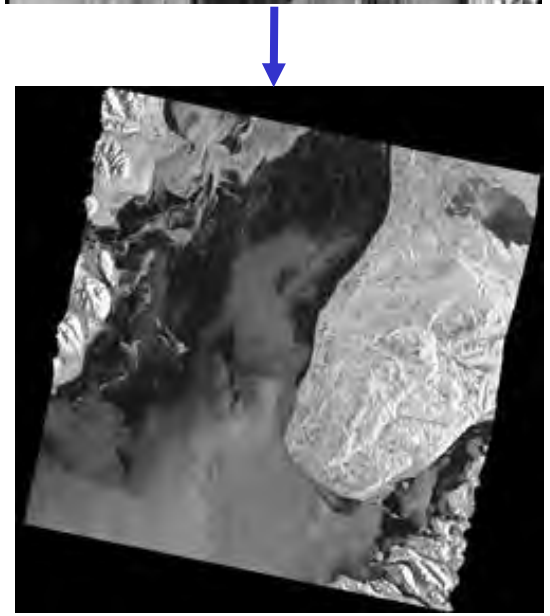
Geometric Terrain Correction

- **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

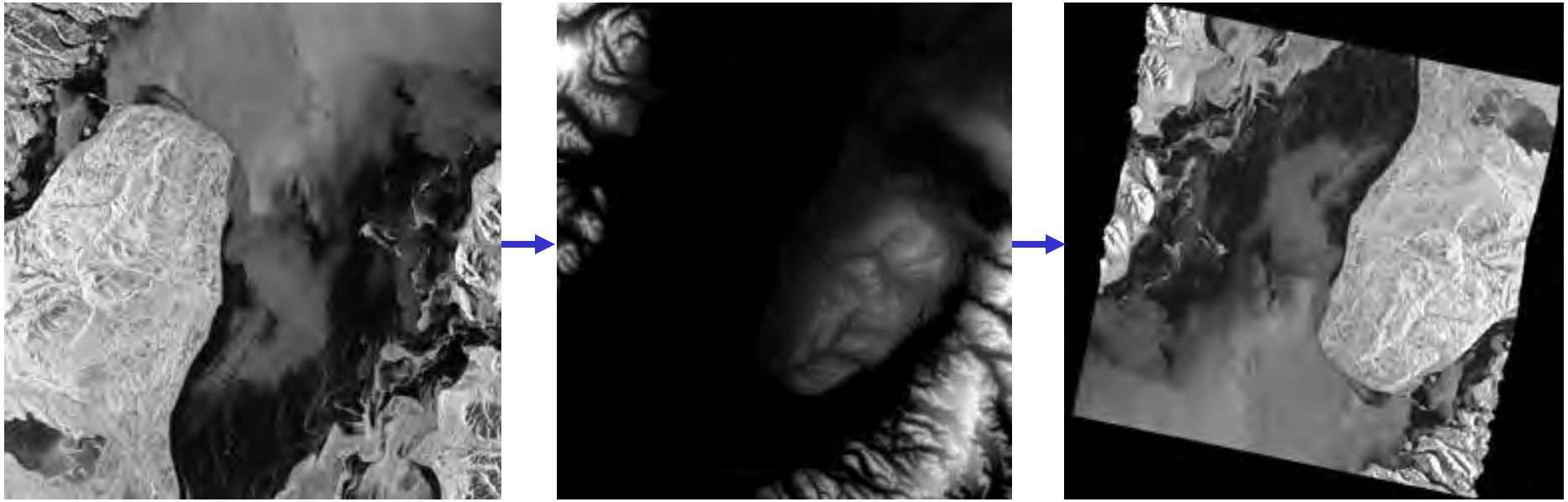
Forward Geocoding



Forward geocoding

- 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

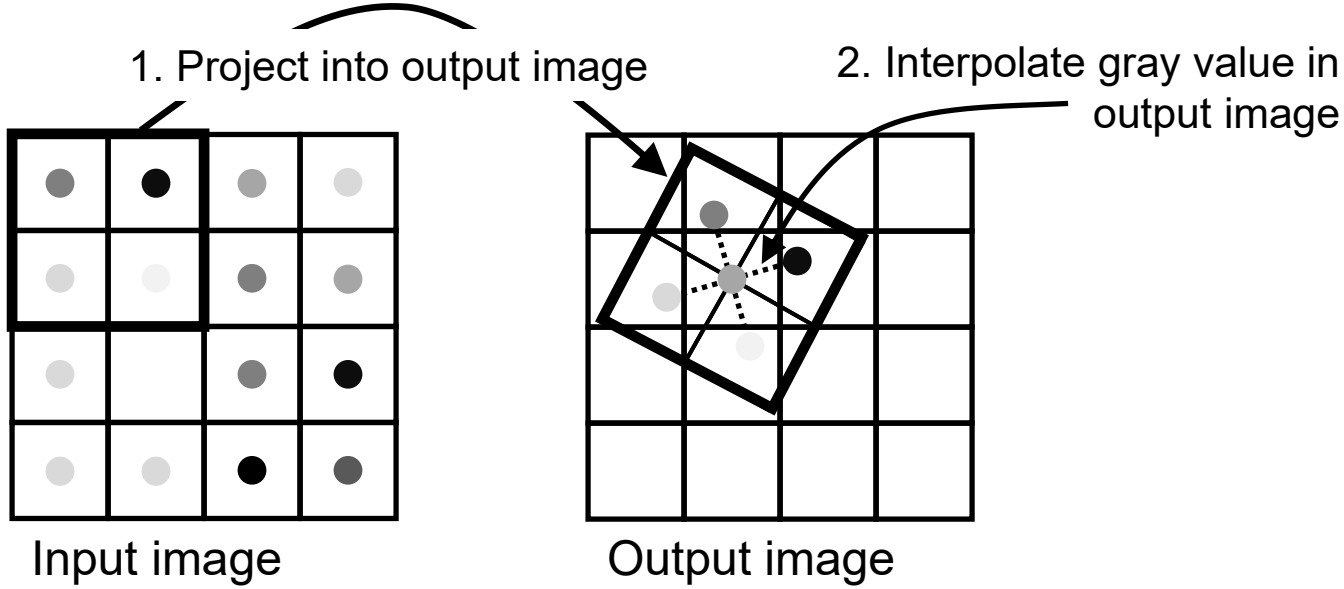


“painting the DEM in map-projection space”

- 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

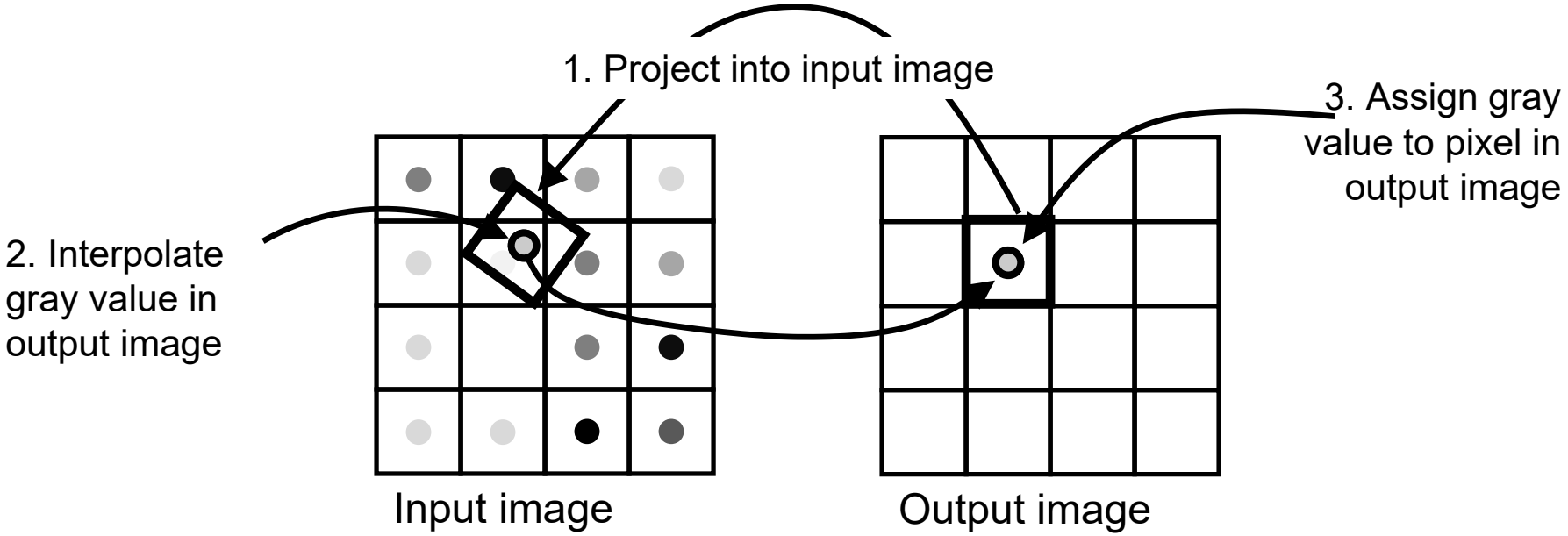
1. **Forward Geocoding:**
   - **Step 1:** Project pixels (x_i, y_i) into output image g_o using DEM
   - **Step 2:** Determine gray values in output image by interpolation between projected pixels



A Second Look At Backward Geocoding

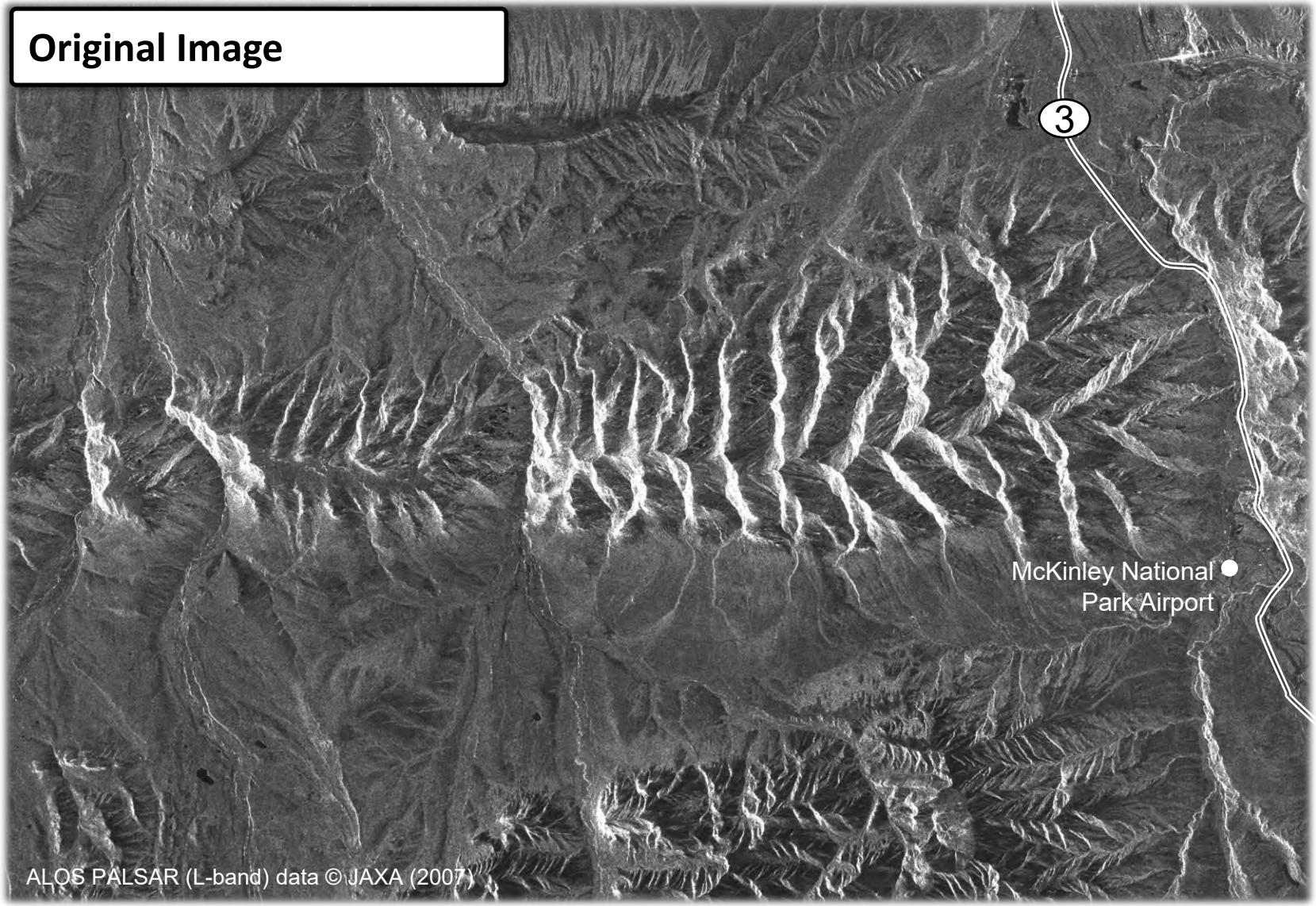
2. Backward Geocoding:

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

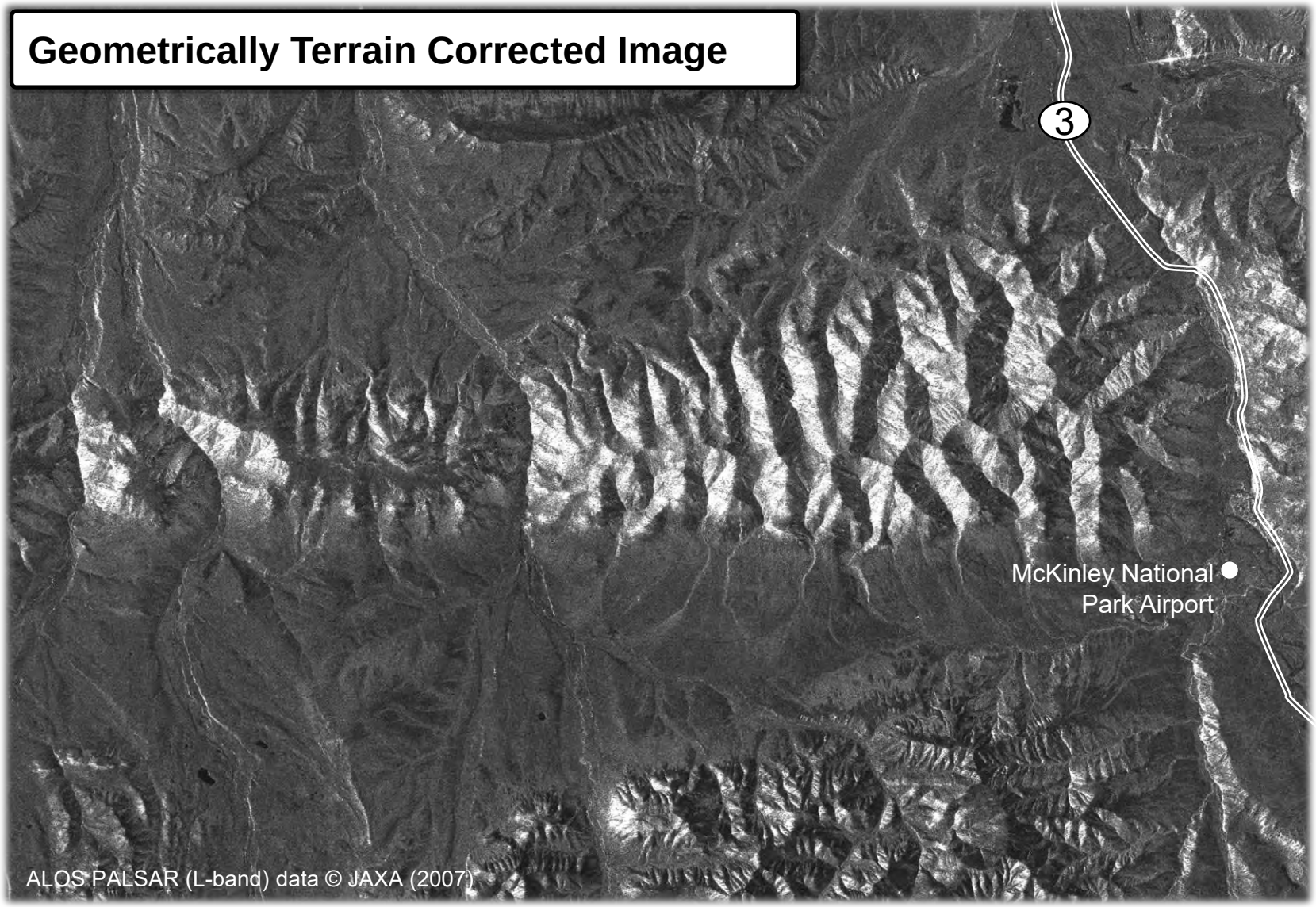


Only Inverse Mapping guarantees that ALL pixels in the output image receives a gray value (no holes) → inverse mapping is standard approach

Geometric Terrain Correction Example (I)



Geometric Terrain Correction Example (II)

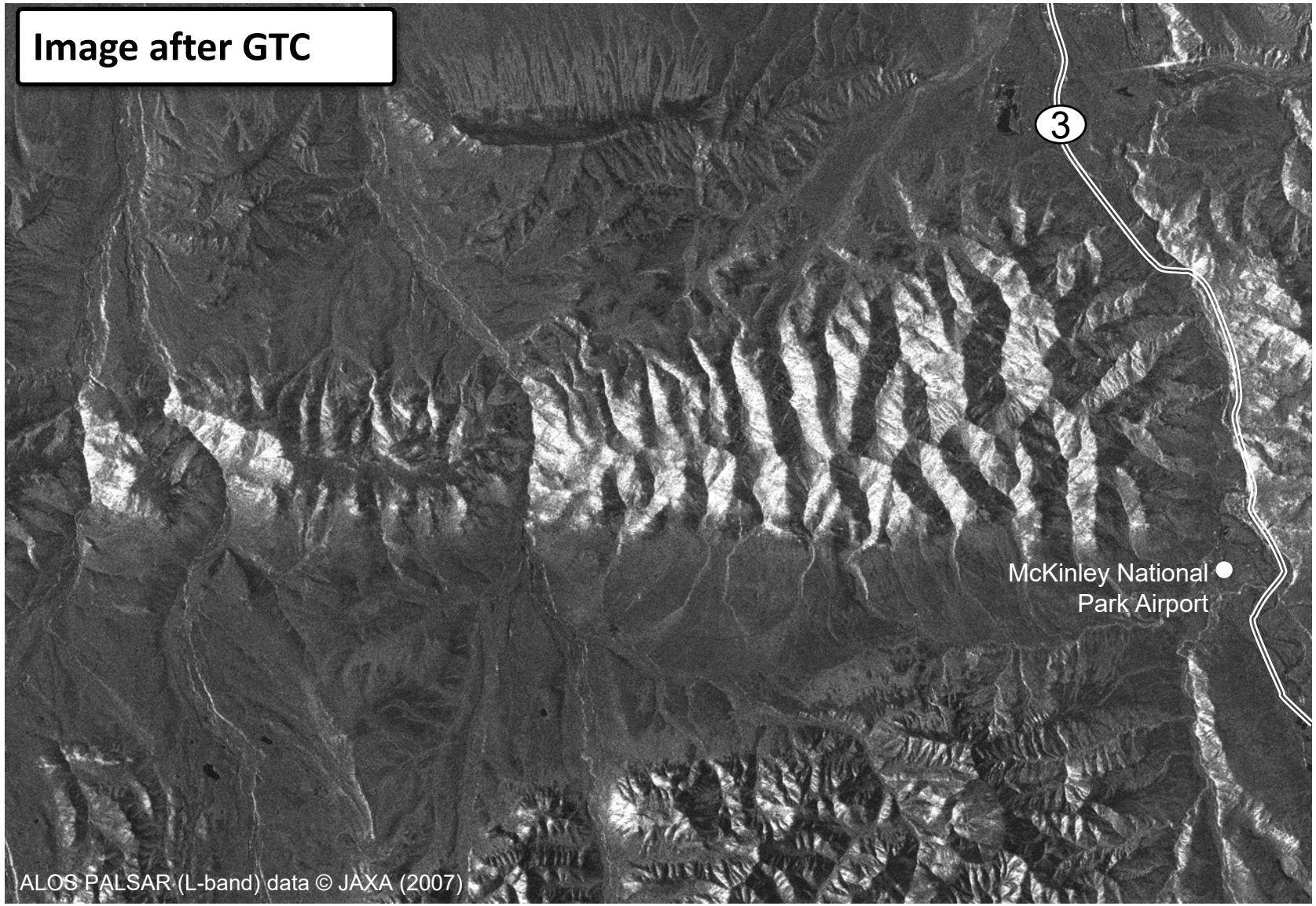


Radiometric Terrain Correction (RTC)

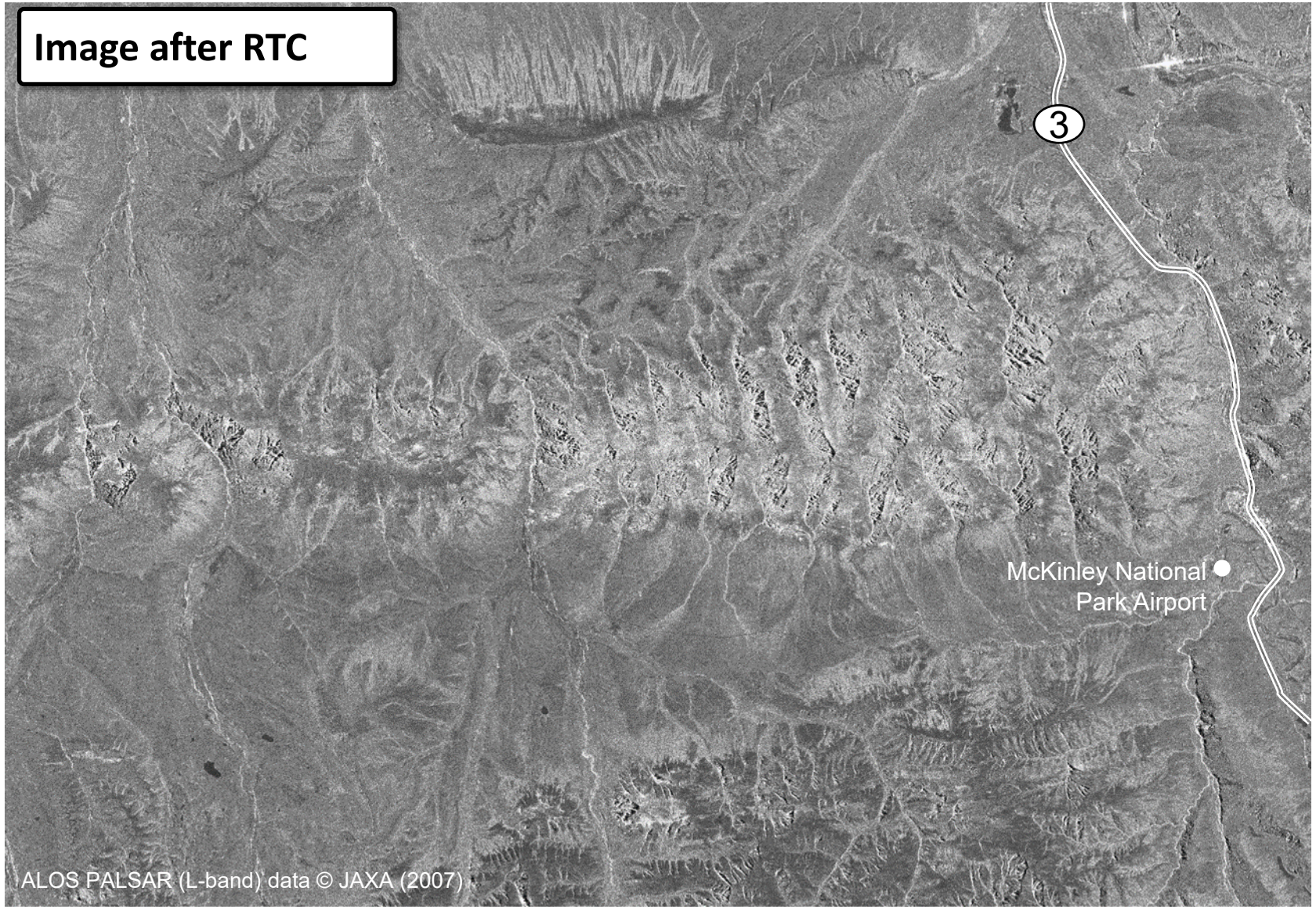
- **Problem:** Sensor facing slopes appear overly bright in radar images.
- **Cause:** Pixel Size on sensor-facing slopes is larger → more ground is integrated into pixel → brightness goes up

- **Solution:** **Radiometric Terrain Correction (RTC)**
  1. Using DEM and observation geometry, calculate *exact equivalent area* A_σ covered by each pixel
  2. Normalize radar cross section by A_σ to arrive at terrain normalized data σ_T^0

Radiometric Terrain Correction Example (I)

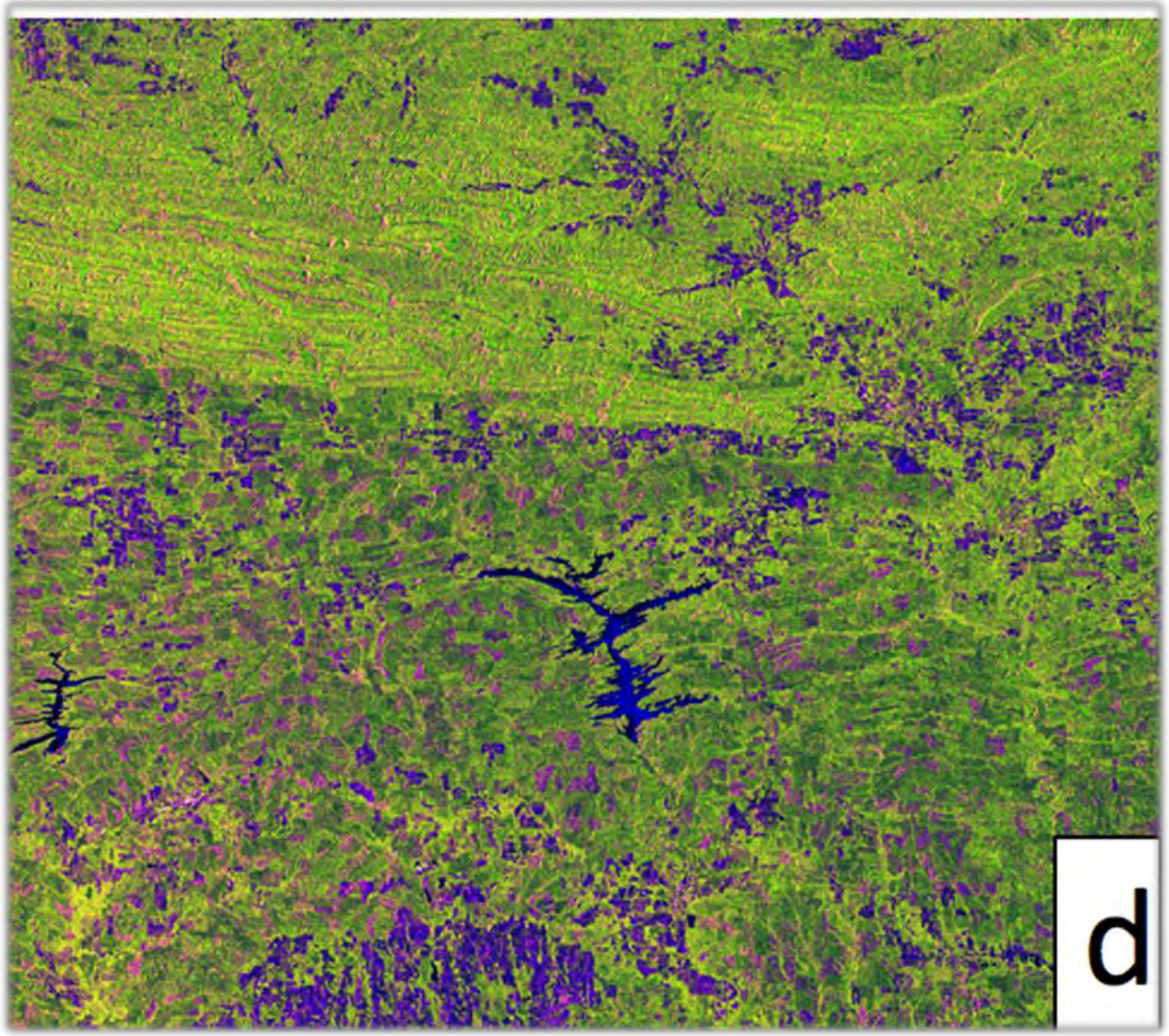


Radiometric Terrain Correction Example (II)



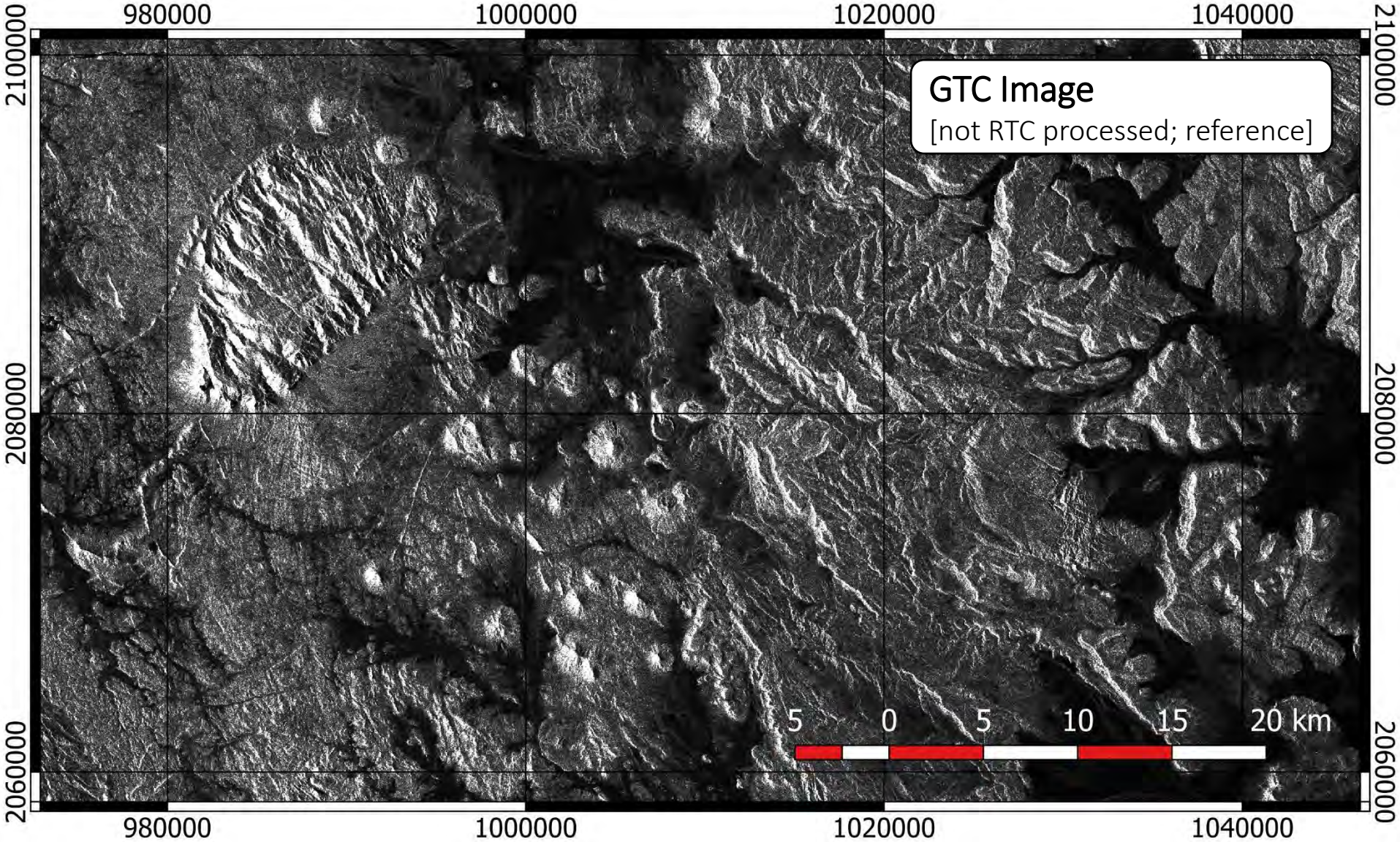
Example of RTC Normalization for an Area in Arkansas, USA

VV/VH/Ratio RGB composite **after** pixel scattering area normalization



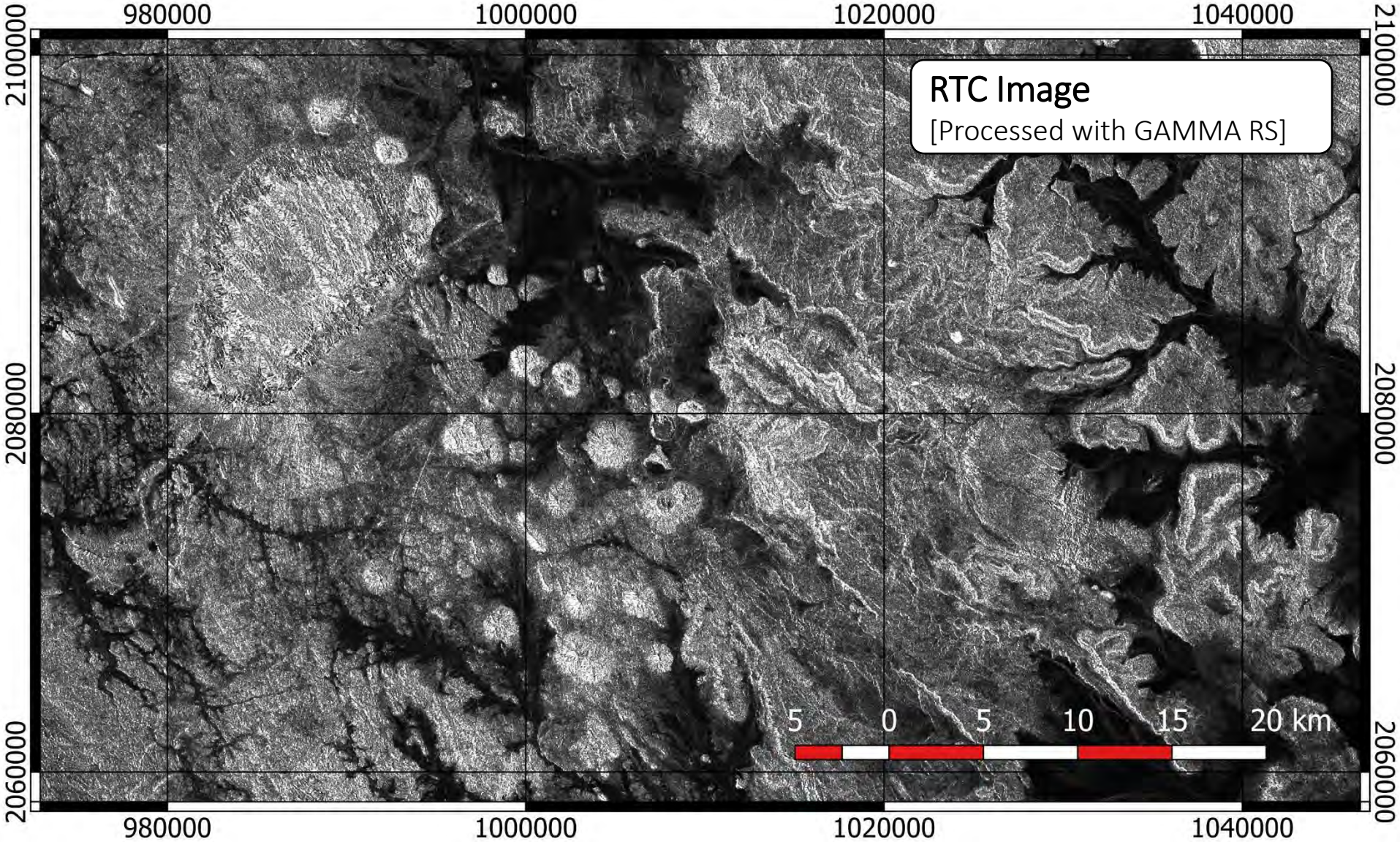
RTC Example

Comparison of Processing Techniques

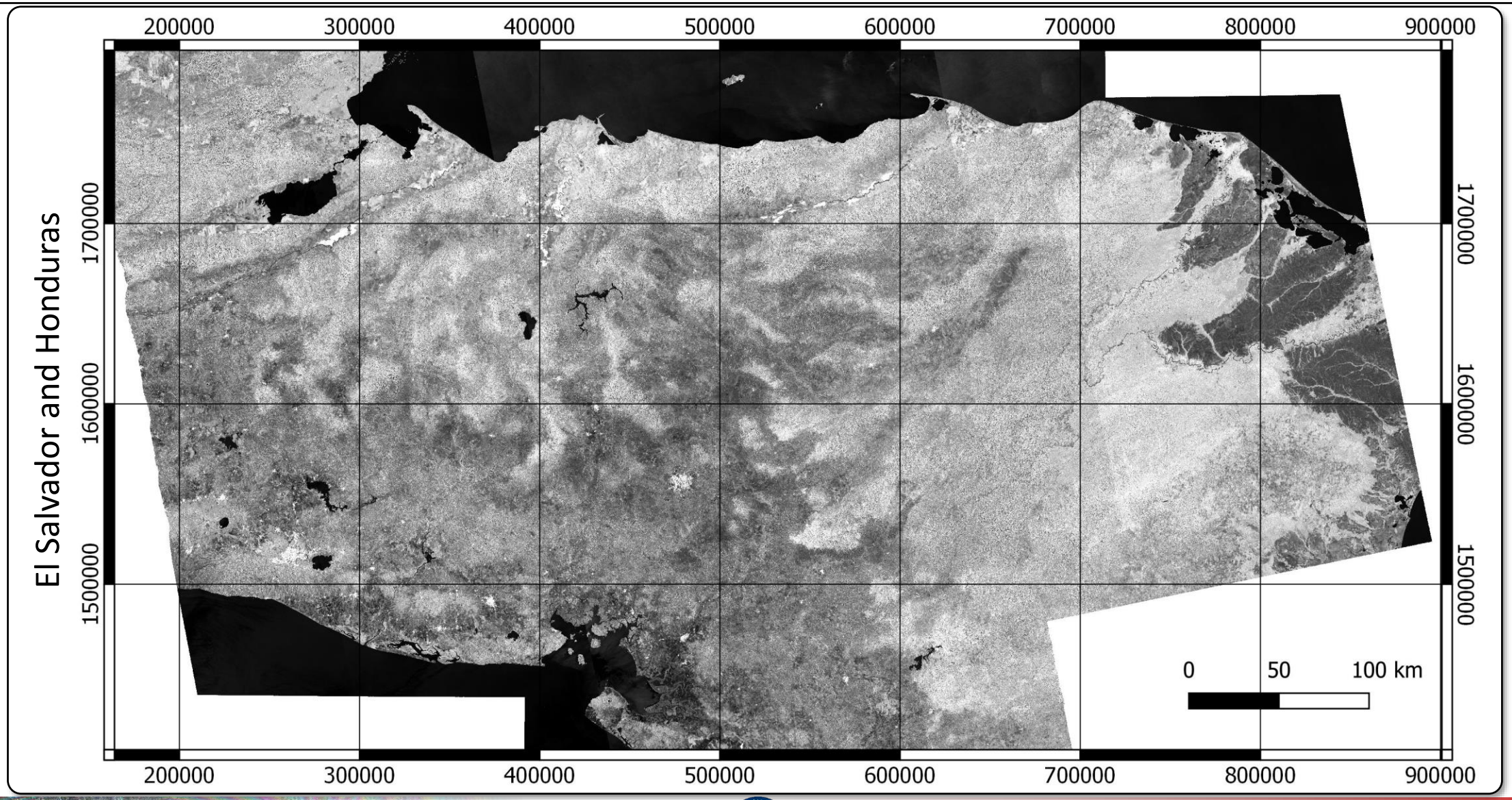


RTC Example

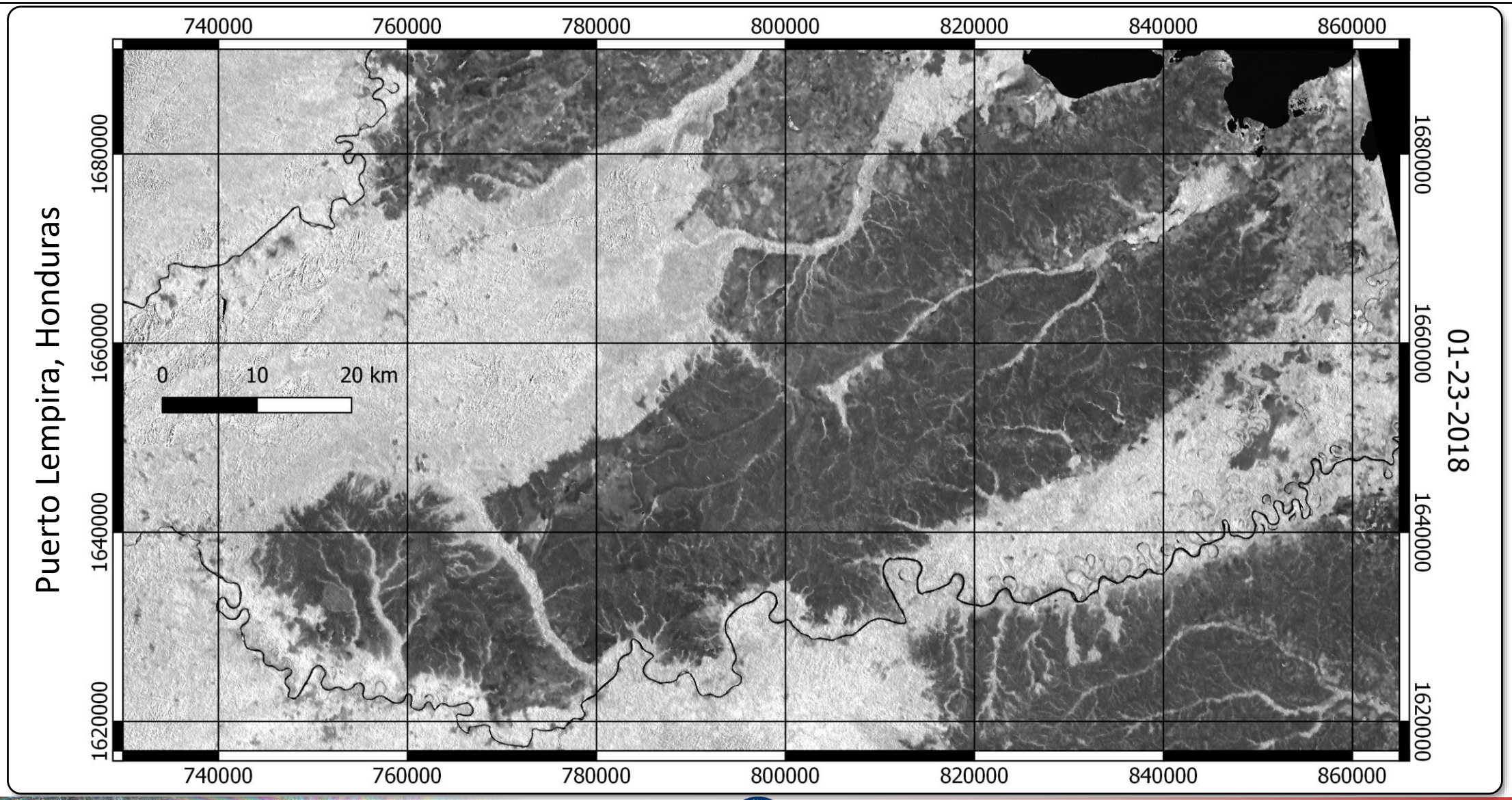
Comparison of Processing Techniques



Sentinel-1 RTC images over El Salvador and Honduras



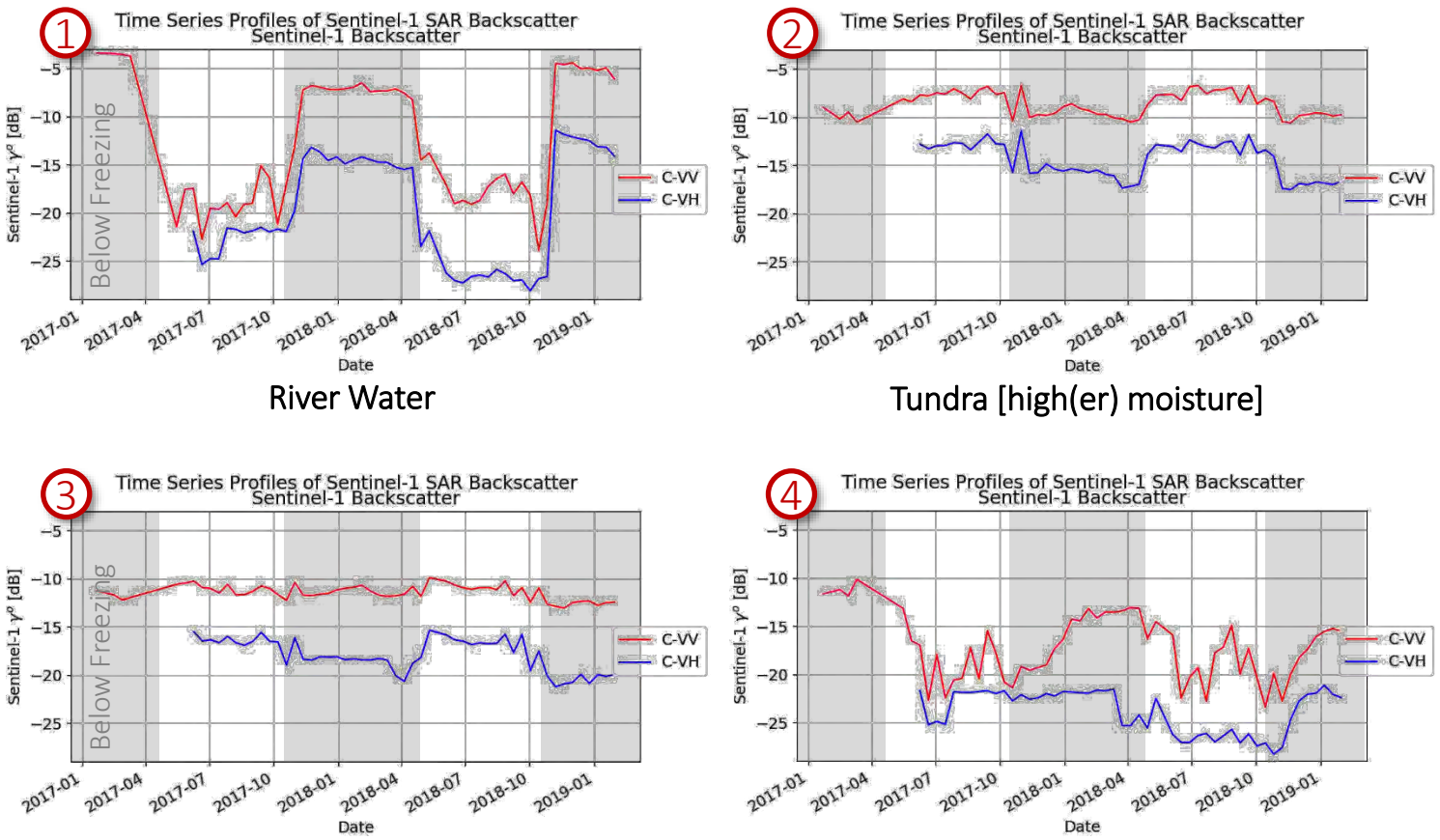
Sentinel-1 RTC images over El Salvador and Honduras



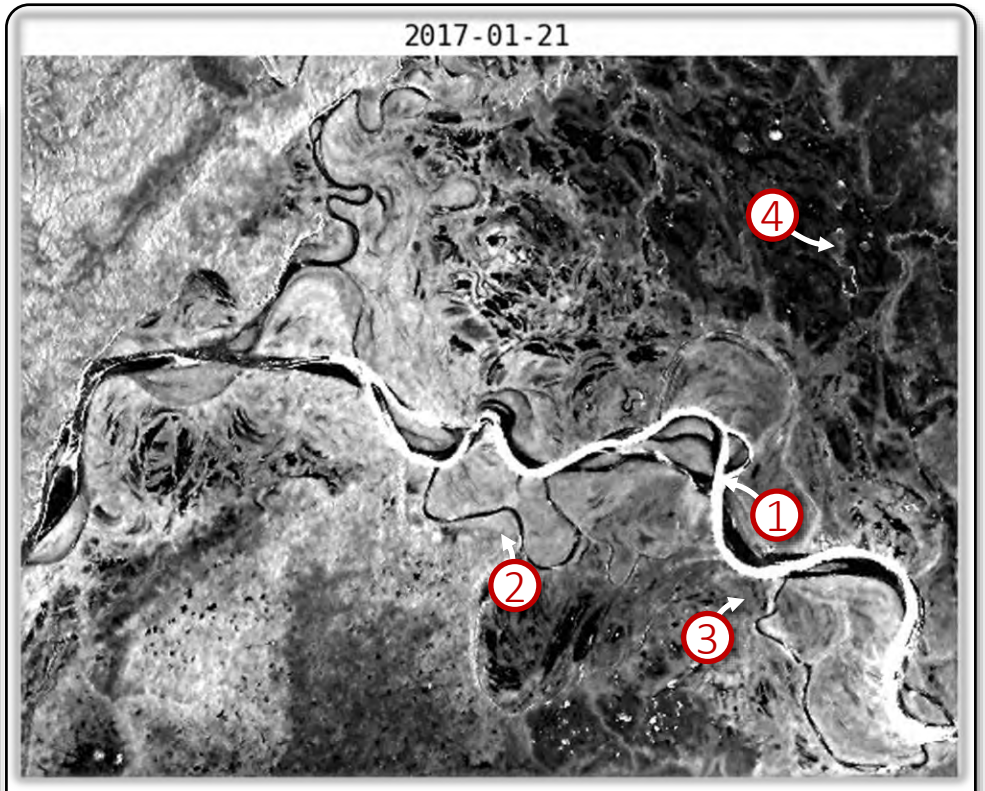
Environmental Monitoring using RTC Images

Example: Dynamics of Areas near Galena, AK

- **Radar brightness times series of locations near Galena, AK**



SAR Backscatter Time Series Information



Sentinel-1 SAR Time Series Yukon River, Alaska

What's Next?

- **Lab week:**
  - Labs on SAR image focusing and geocoding
  - Labs on SAR image time series visualization and analysis
- **After that, we will start talking about InSAR, a method for topographic mapping and deformation analysis**

- **In preparation for next week, please read the following information in the SAR Handbook:**
  - Chapters 2.1, 2.2, 2.5 & 2.6.1