GEOS 639 – INSAR AND ITS APPLICATIONS

GEODETIC IMAGING AND ITS APPLICATIONS IN THE GEOSCIENCES

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Lecture 4: Introduction to Geodetic Imaging III – Synthetic Aperture Radar

COLLEGE OF NATURAL SCIENCE & MATHEMATICS
University of Alaska Fairbanks

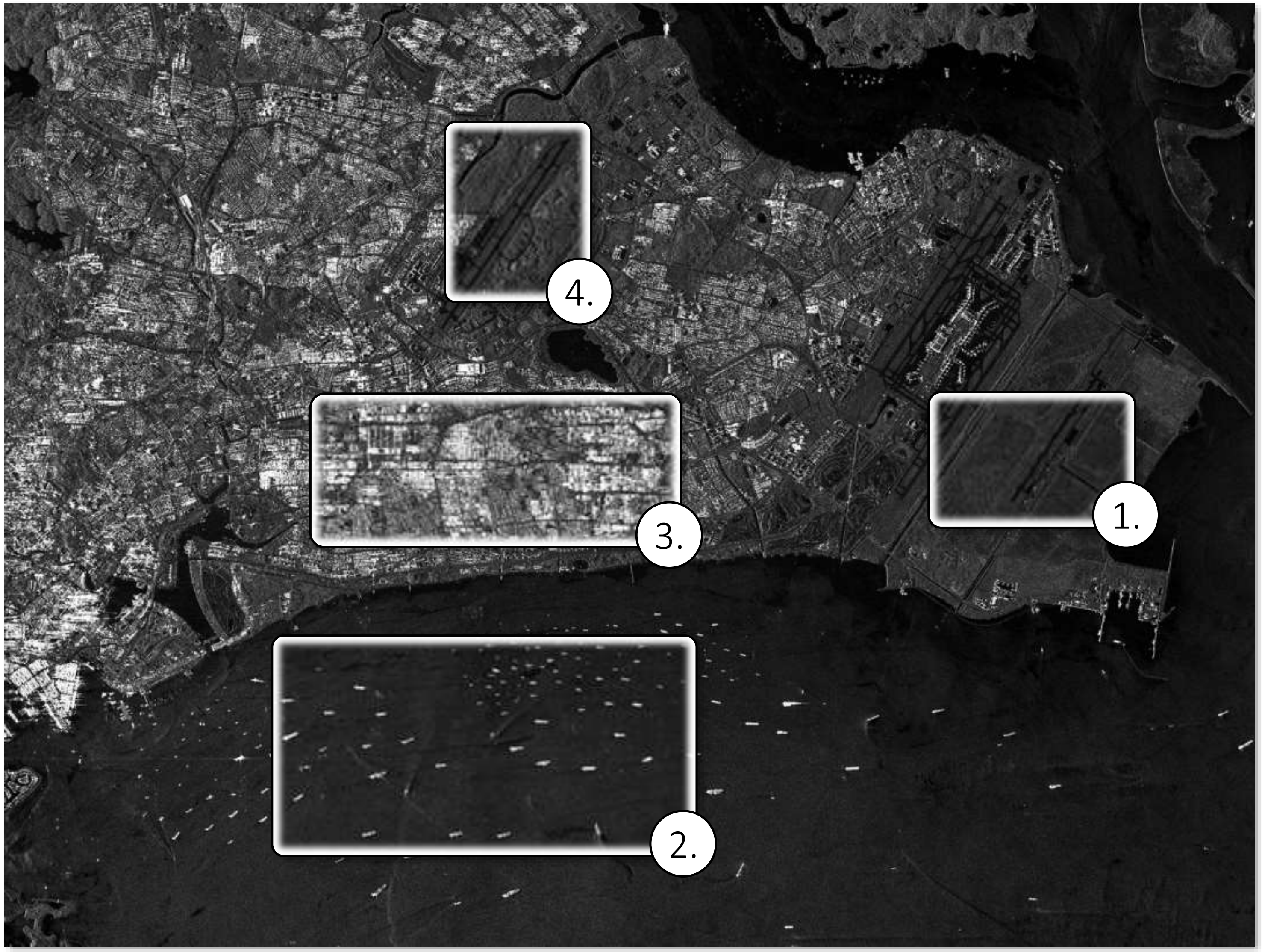
Sensor Types Relevant for this Course

Synthetic Aperture Radar Sensors

Think – Pair – Share

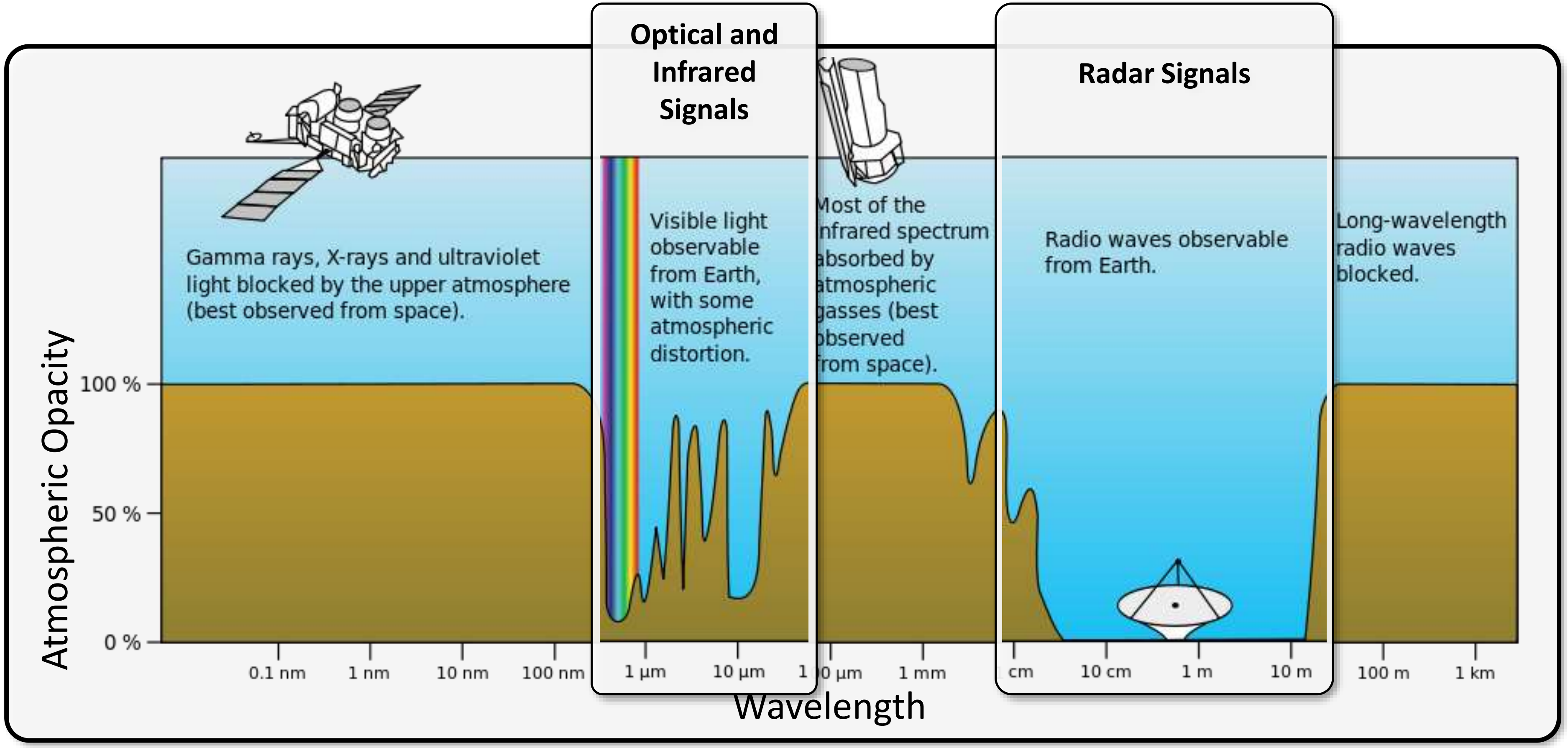
SAR Image Interpretation

- What do these five image areas show?



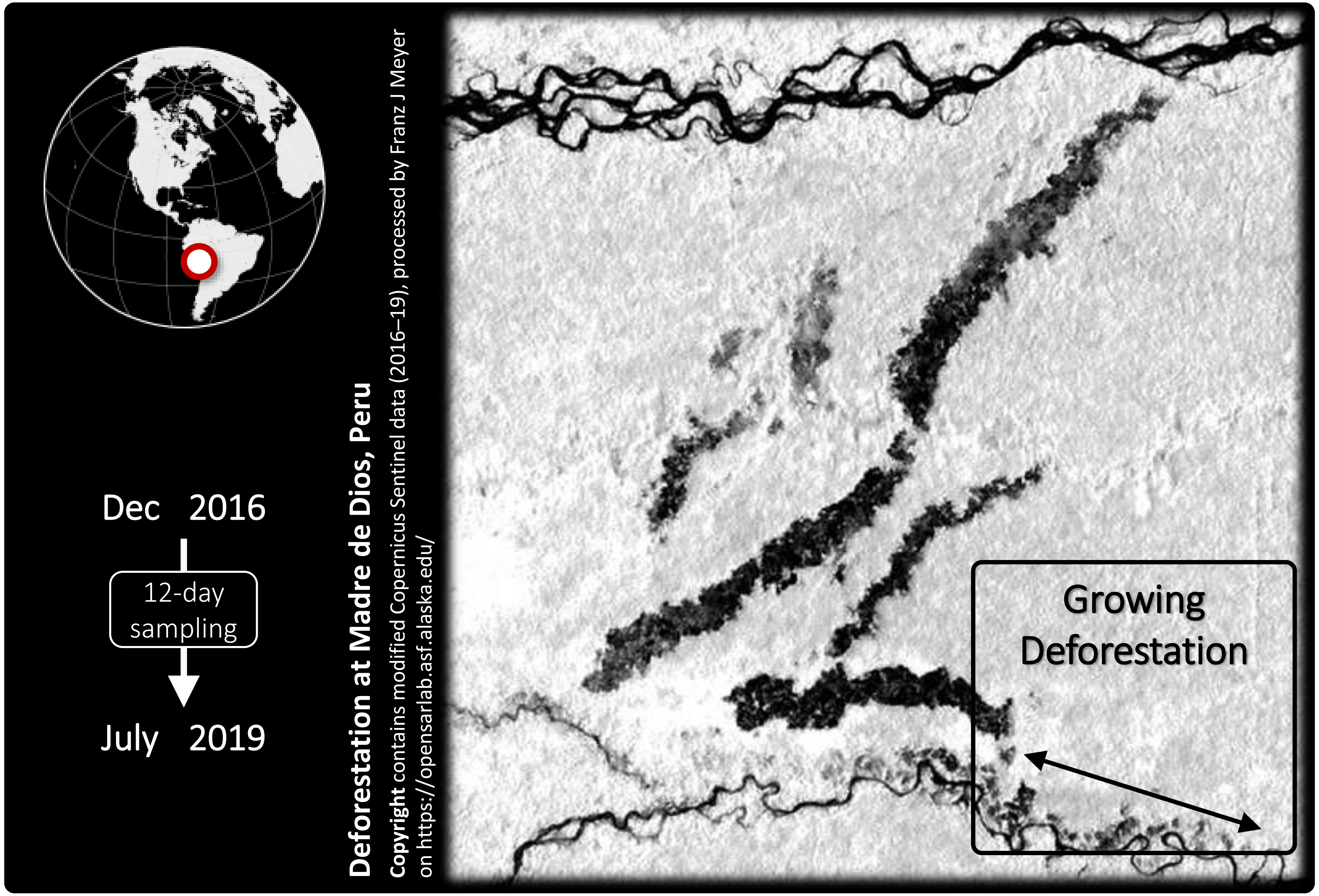
Wavelength Discriminates Radar from Optical Data

- **Radar has excellent capabilities for routine global change monitoring**
  - **24/7 imaging capabilities:** due to weather and illumination independence
  - **Advanced change detection performance**: due to stable image geometry and own signal source
  - **Complementary to optical sensors**: provides independent information about surface



NASA Earth Observatory images by Robert Simmon, using Suomi NPP VIIRS data from Chris Elvidge (NOAA National Geophysical Data Center)

Weather Independence Provides Advantages Especially For Cloud Affected Regions Such as the Rain Forest

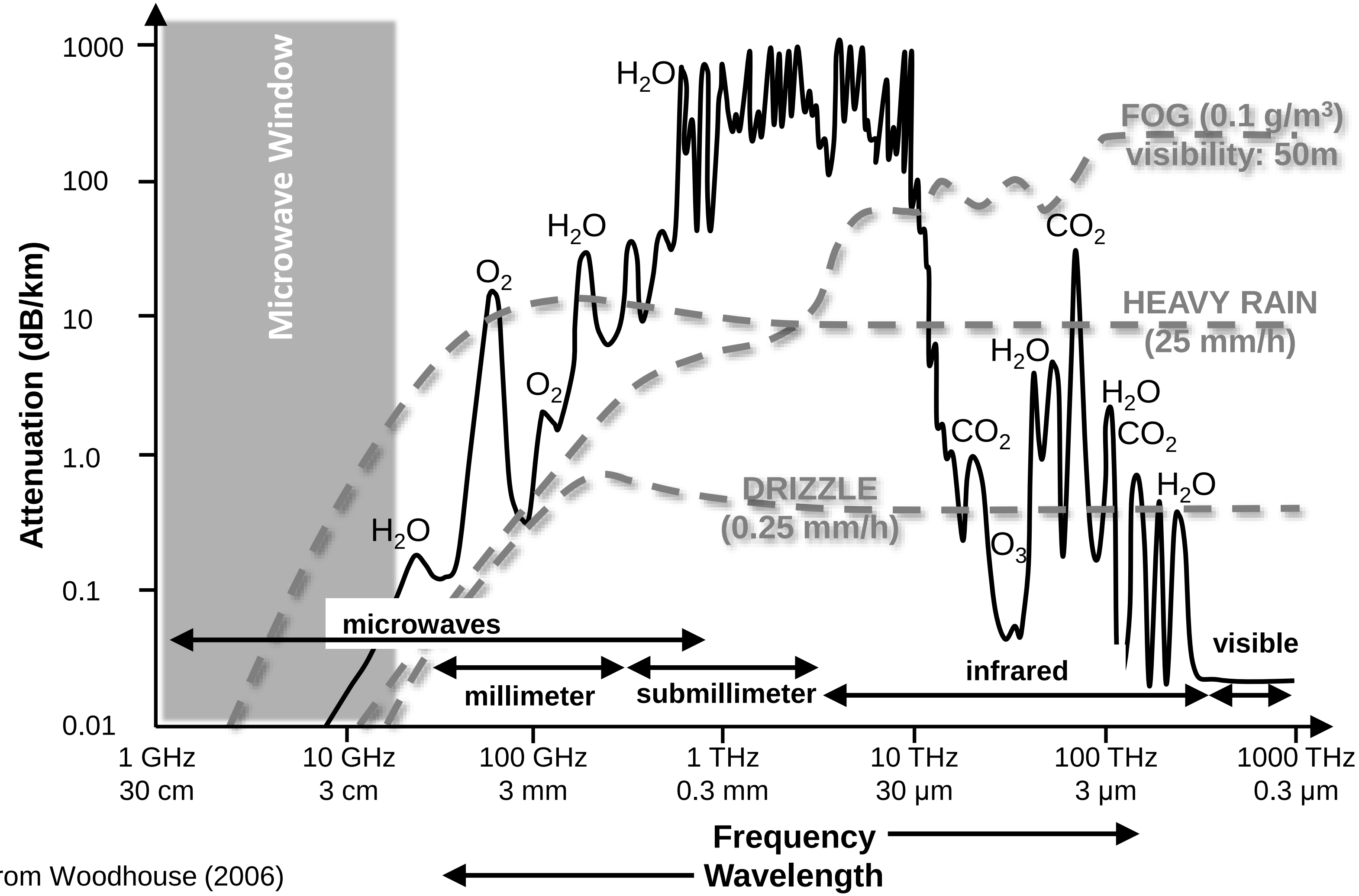


The Microwave Spectrum

(approximate)

Band	Frequency f_0		Wavelength $\lambda = c/f_0$		Typical Application
Ka	27 – 40	GHz	1.1 – 0.8	cm	Rarely used for SAR (airport surveillance)
K	18 – 27	GHz	1.7 – 1.1	cm	Rarely used for SAR (H_2O absorption)
Ku	12 – 18	GHz	2.4 – 1.7	cm	Rarely used for SAR (satellite altimetry)
X	8 – 12	GHz	3.8 – 2.4	cm	**High-resolution SAR** (urban monitoring; ice and snow; little penetration into vegetation cover; fast coherence decay in vegetated areas)
C	4 – 8	GHz	7.5 – 3.8	cm	**SAR workhorse** (global mapping; change detection; monitoring areas with low to moderate vegetation; improved penetration; higher coherence)
S	2 – 4	GHz	15 – 7.5	cm	**Little but increasing use for SAR-based Earth obs.**; agriculture monitoring (NISAR will carry S-band; expands C-band applications to higher vegetation density)
L	1 – 2	GHz	30 – 15	cm	**Medium resolution SAR** (Geophysical monitoring; biomass and vegetation mapping; high penetration; InSAR)
P	0.3 – 1	GHz	100 – 30	cm	**Biomass estimation**. First P-band spaceborne SAR will be launched ~2020; vegetation mapping and assessment. Experimental SAR.

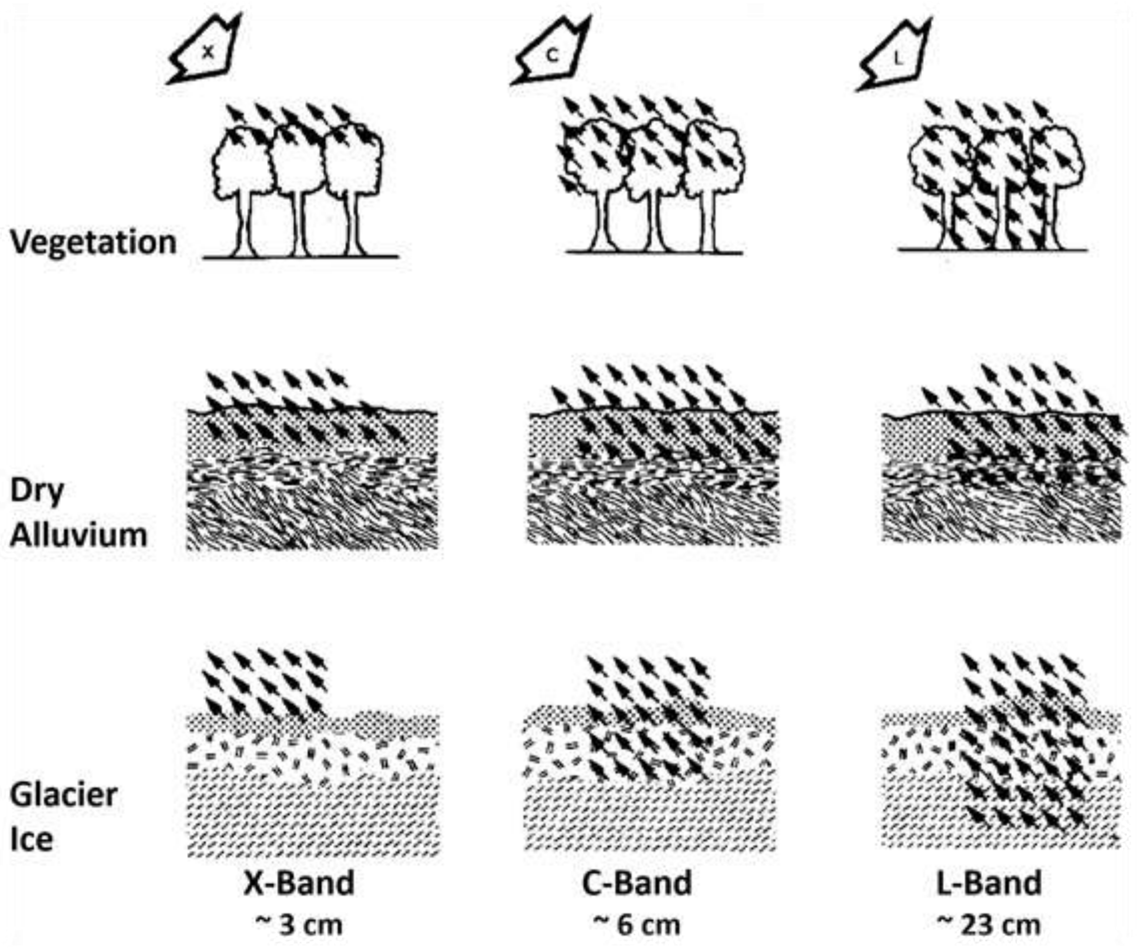
Atmosphere almost Transparent at Microwave Window



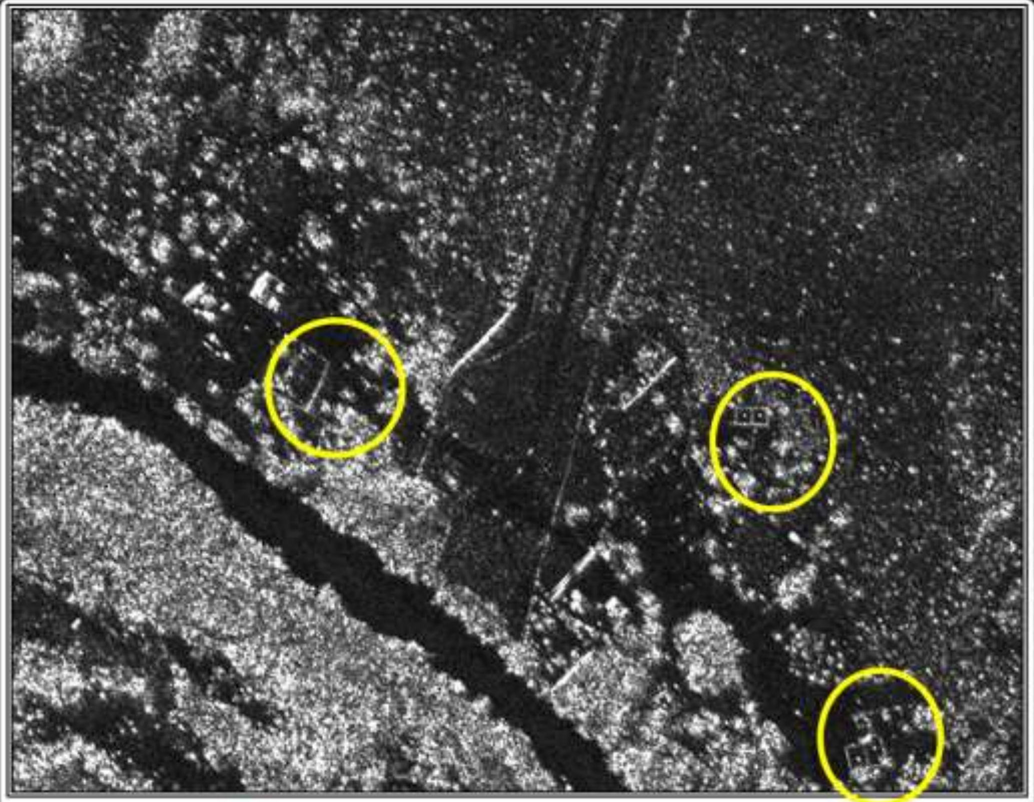
From Woodhouse (2006)

Depending on Signal Wavelength, SAR can Penetrate Into Vegetation and Soils

Wavelength-Dependent Penetration into Top Surface Layers



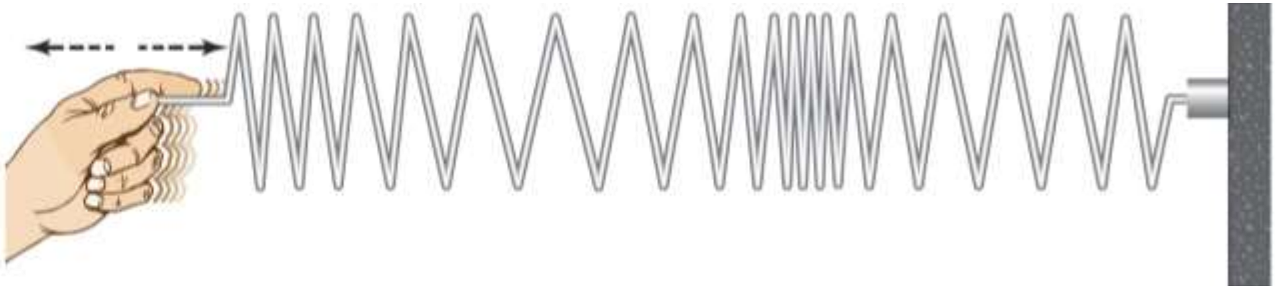
- **Example**: X-band vs P-band penetration into Forest Canopies



P-band radar image of forested area

Radar like Optical EM Signals are Transverse Oscillating Waves

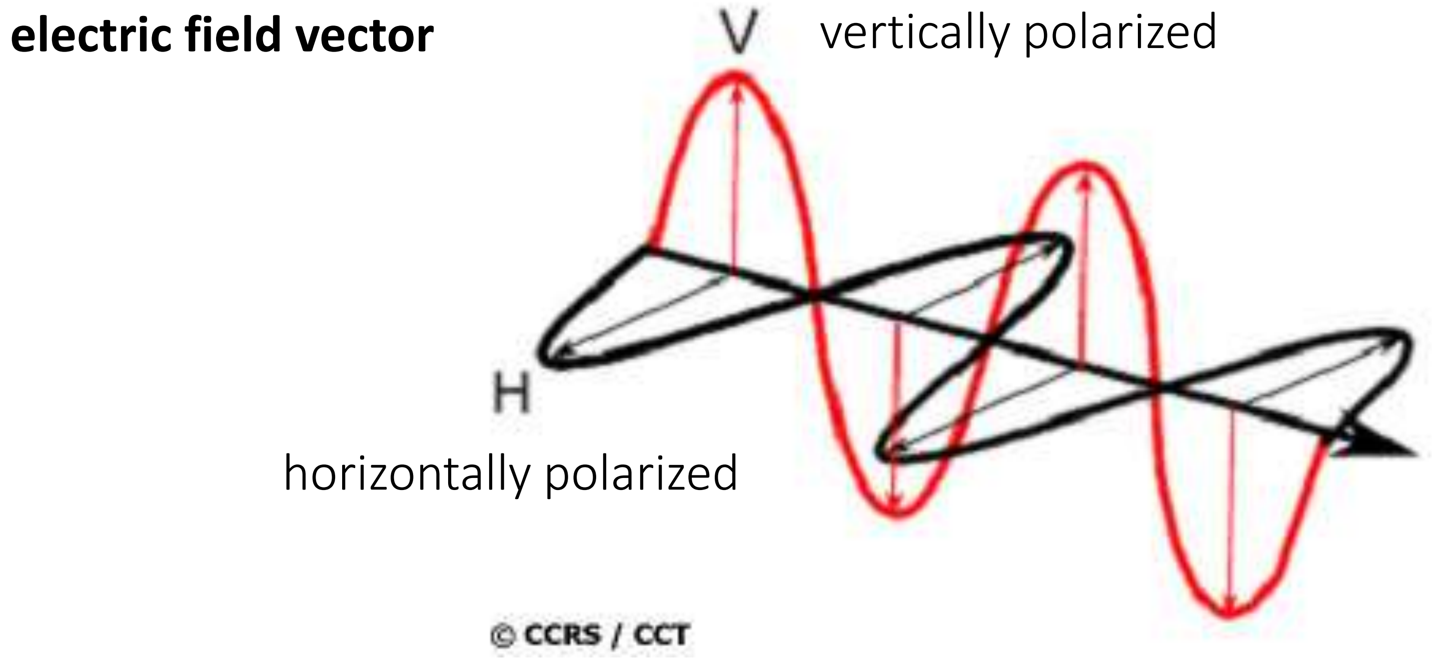
Longitudinal oscillating waves (sound waves, waves on oceans)



Transverse oscillating waves (e.g., EM waves)

Traverse oscillating waves (like EM waves) have one additional degree of freedom: Direction in which oscillation takes place, **called Polarization**

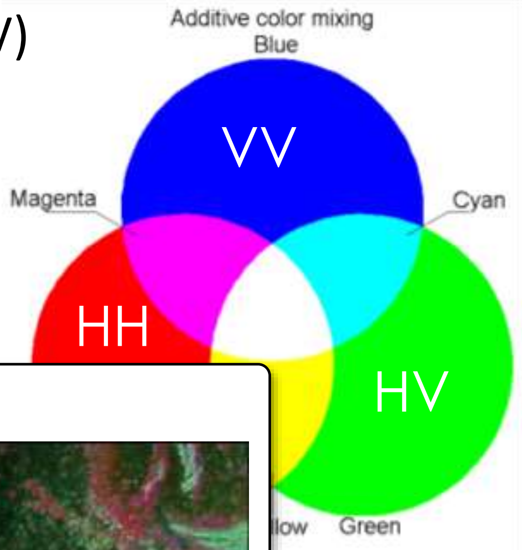
In Radar, we can Control the Polarization of the Transverse Oszillating Signal → Its Polarization



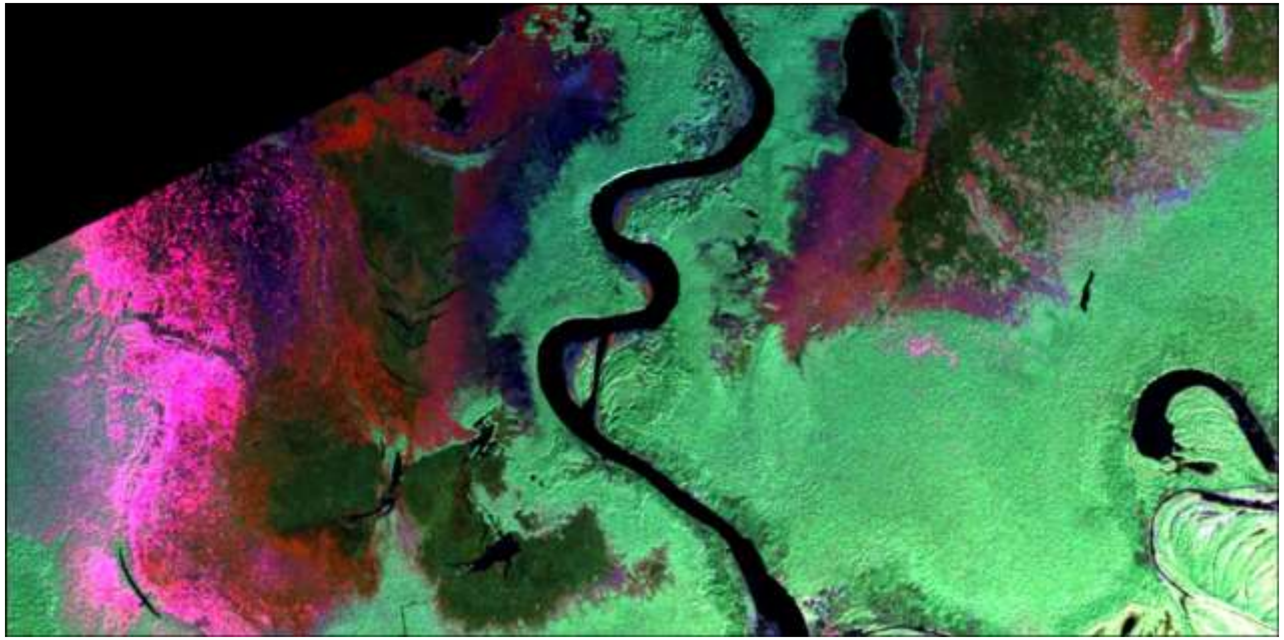
- Polarization planes are perpendicular – orientation technically arbitrary
- Usually, horizontal and vertical planes are chosen
- The terms horizontal and vertical then refer to either the earth or the antenna surface

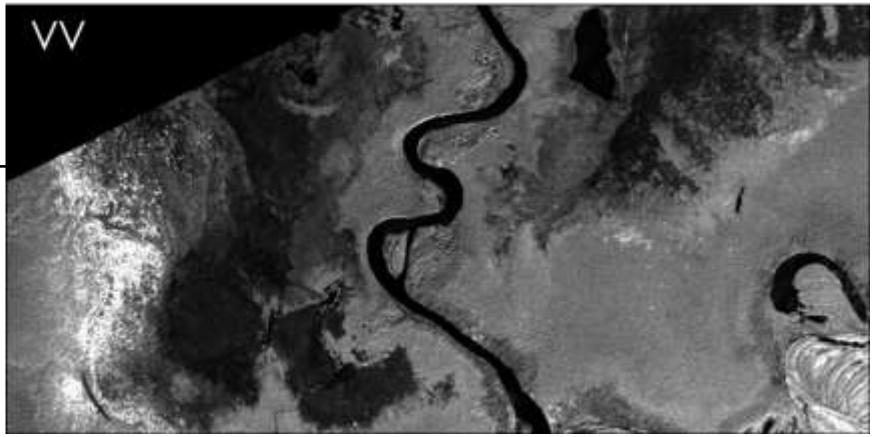
Example of Multiple Polarizations for Vegetation Studies - Pacaya-Samiria Forest Reserve in Peru

- L-band SAR images from UAVSAR (HH, HV, VV)



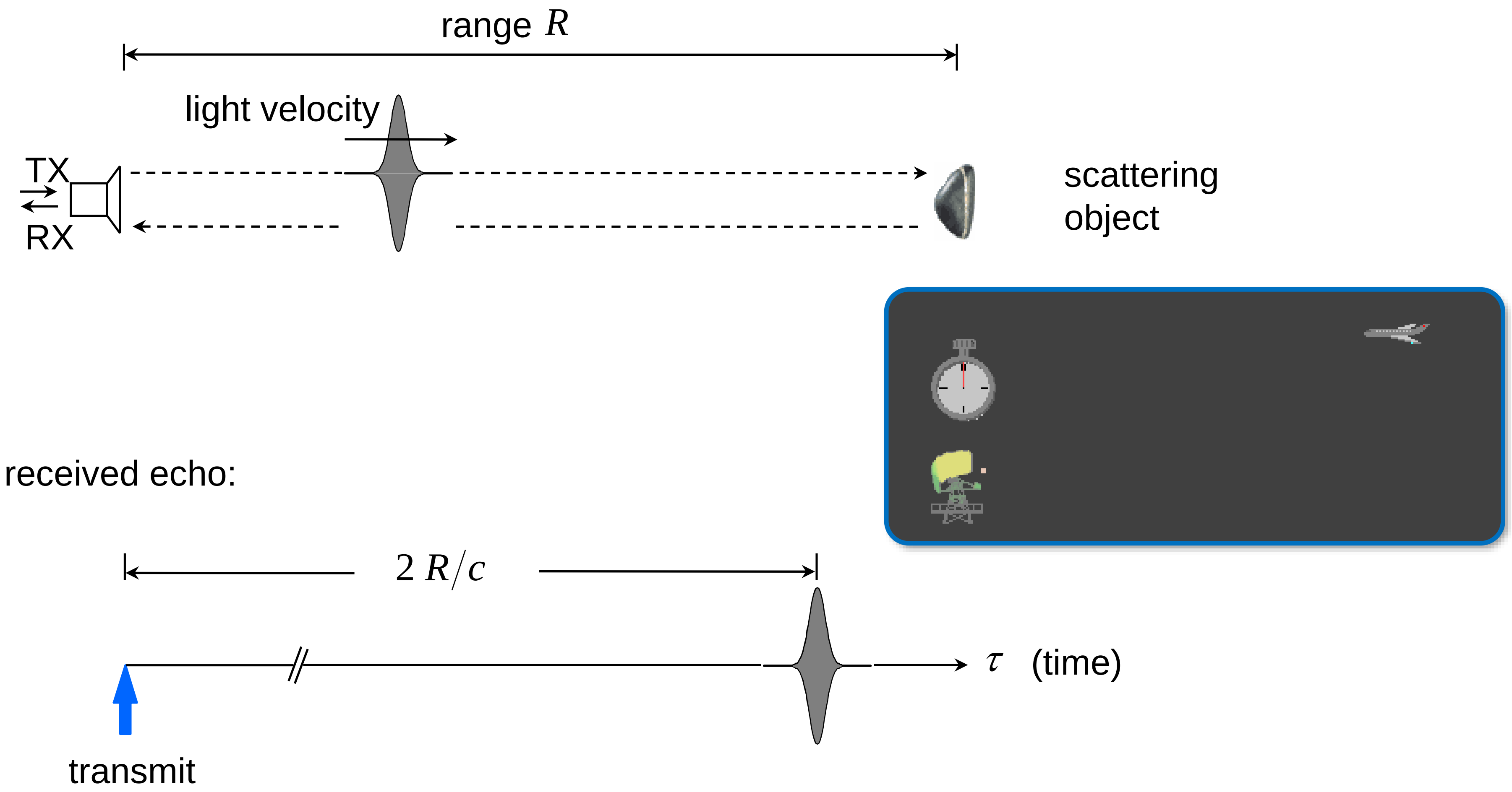
RGB Combination of Polarizations



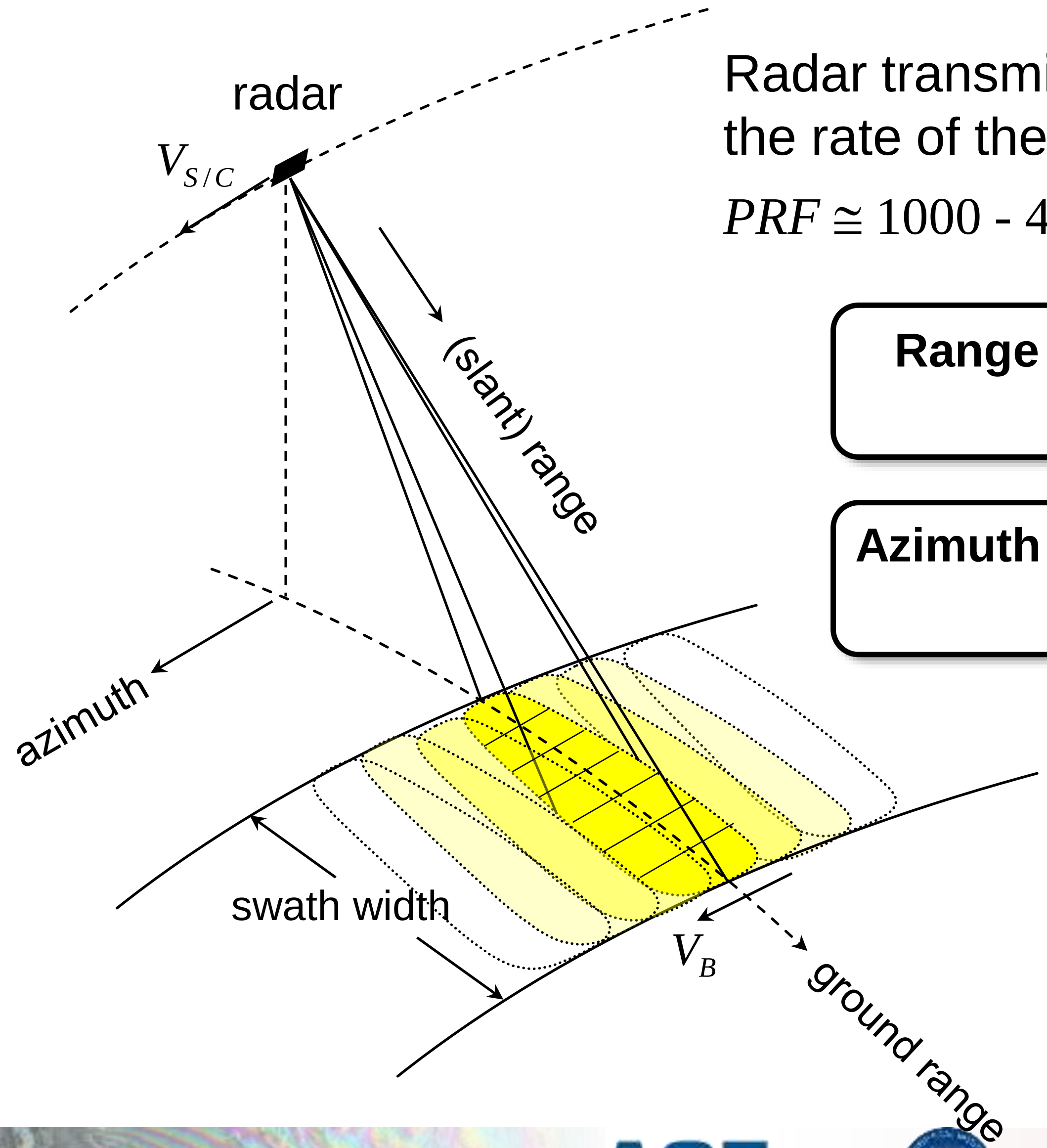


WHAT IS SYNTHETIC APERTURE RADAR (SAR)?

Radar Principle



How to Form a Radar Image



Radar transmits pulses and receives echoes at the rate of the pulse-repetition frequency (PRF):

$PRF \cong 1000 \text{ - } 4000 \text{ Hz}$

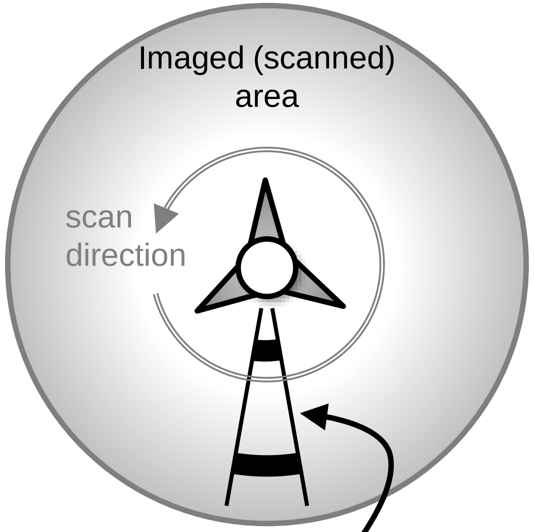
Range pixels: pixel size defined by pulse width (radar principle)

Azimuth pixels: scanning in flight direction at $V_{S/C}$

Imaging the Surface with SLARs

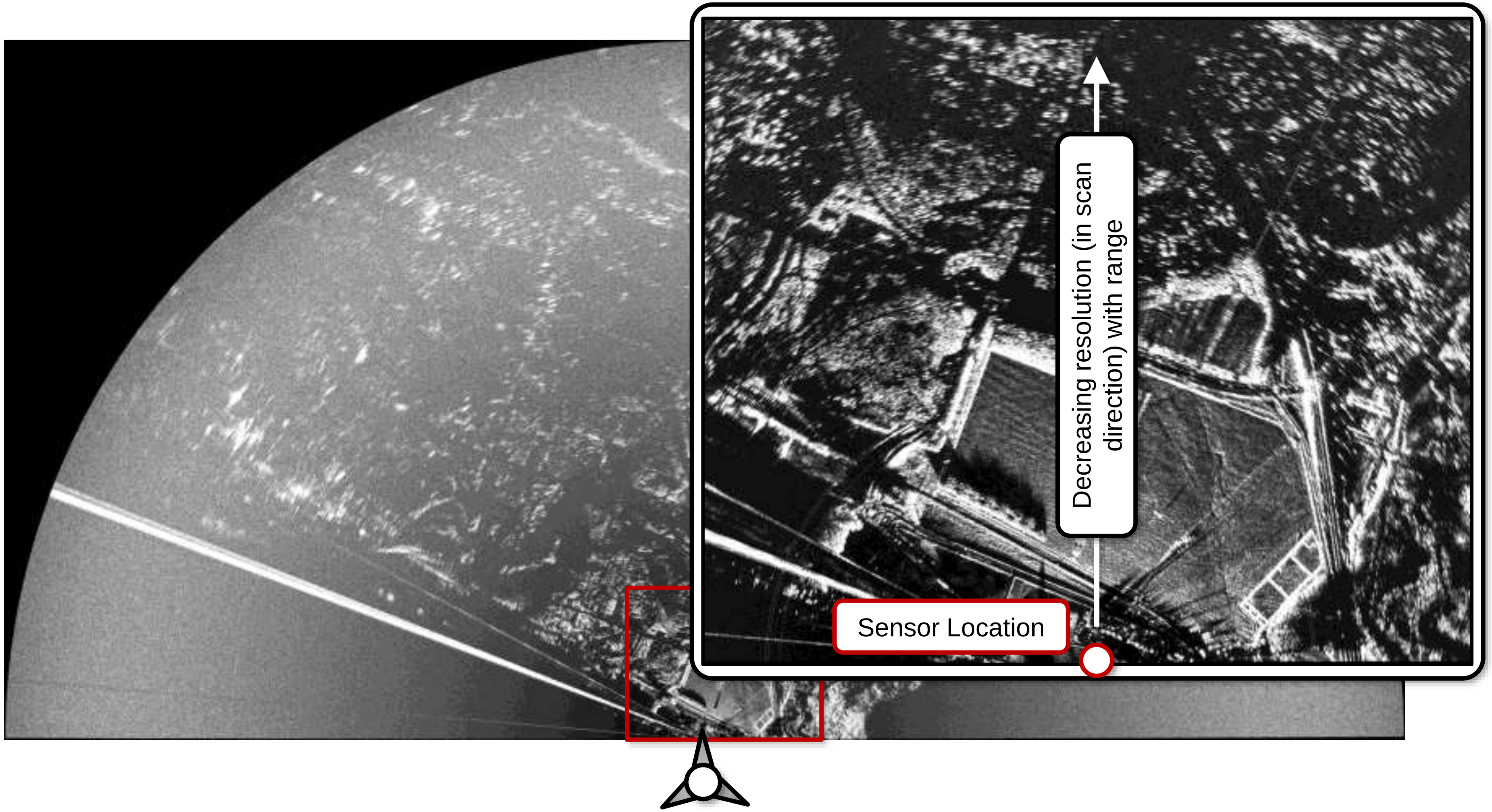
Scanning Ground-based Radar System as a SLAR Example

- Resolution defined by pulse length & length of antenna



Example of Scanning Ground-Based Radar Acquisition

- 180 degrees scan angle – location: Fairbanks, Alaska

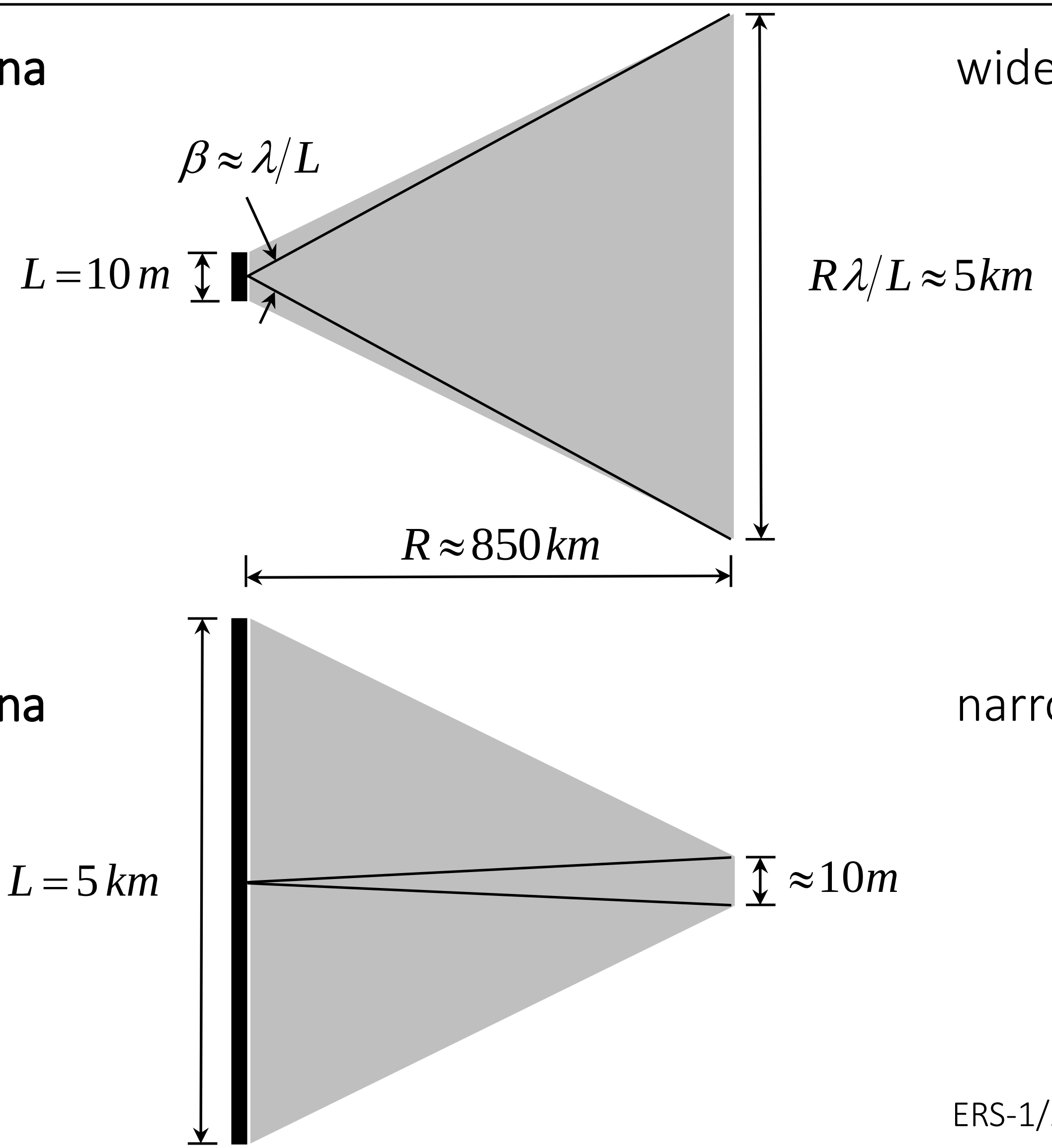


The Problem of SLARs – Azimuth Resolution Degrades with Distance

Antenna Size vs. Beam Width

short antenna

wide beam

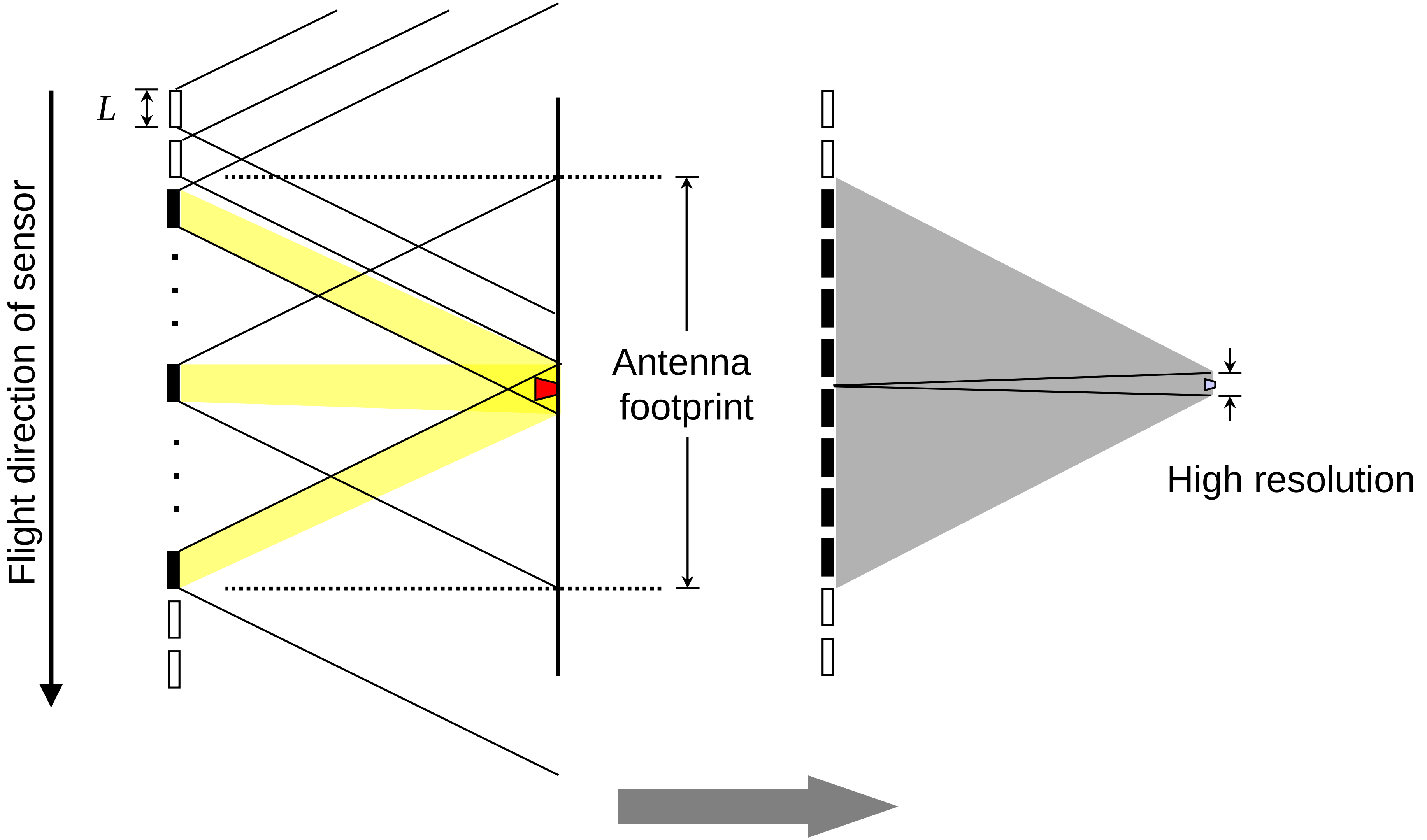


long antenna

narrow beam

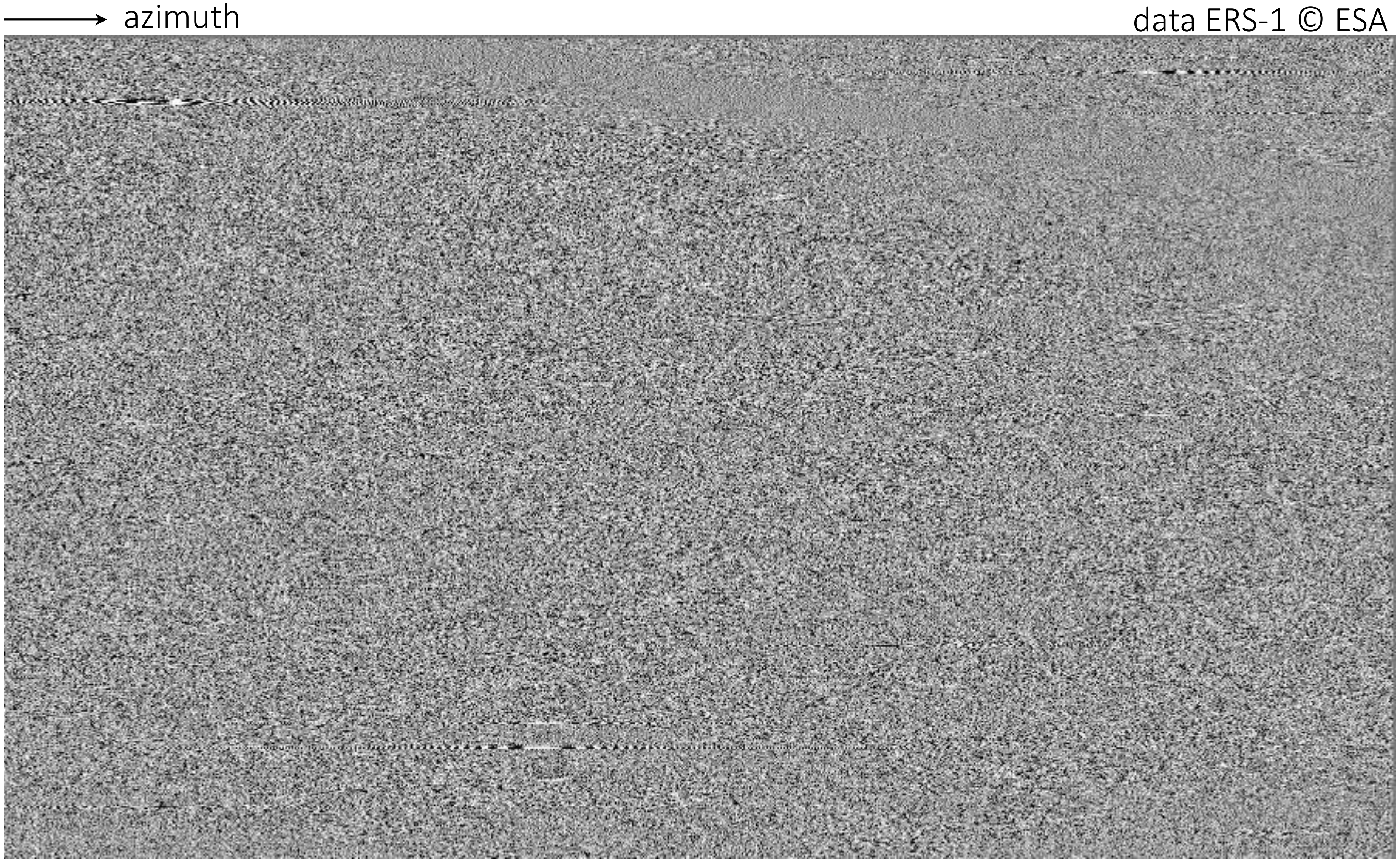
ERS-1/2 parameters

Formation of a Synthetic Aperture — SAR Principle

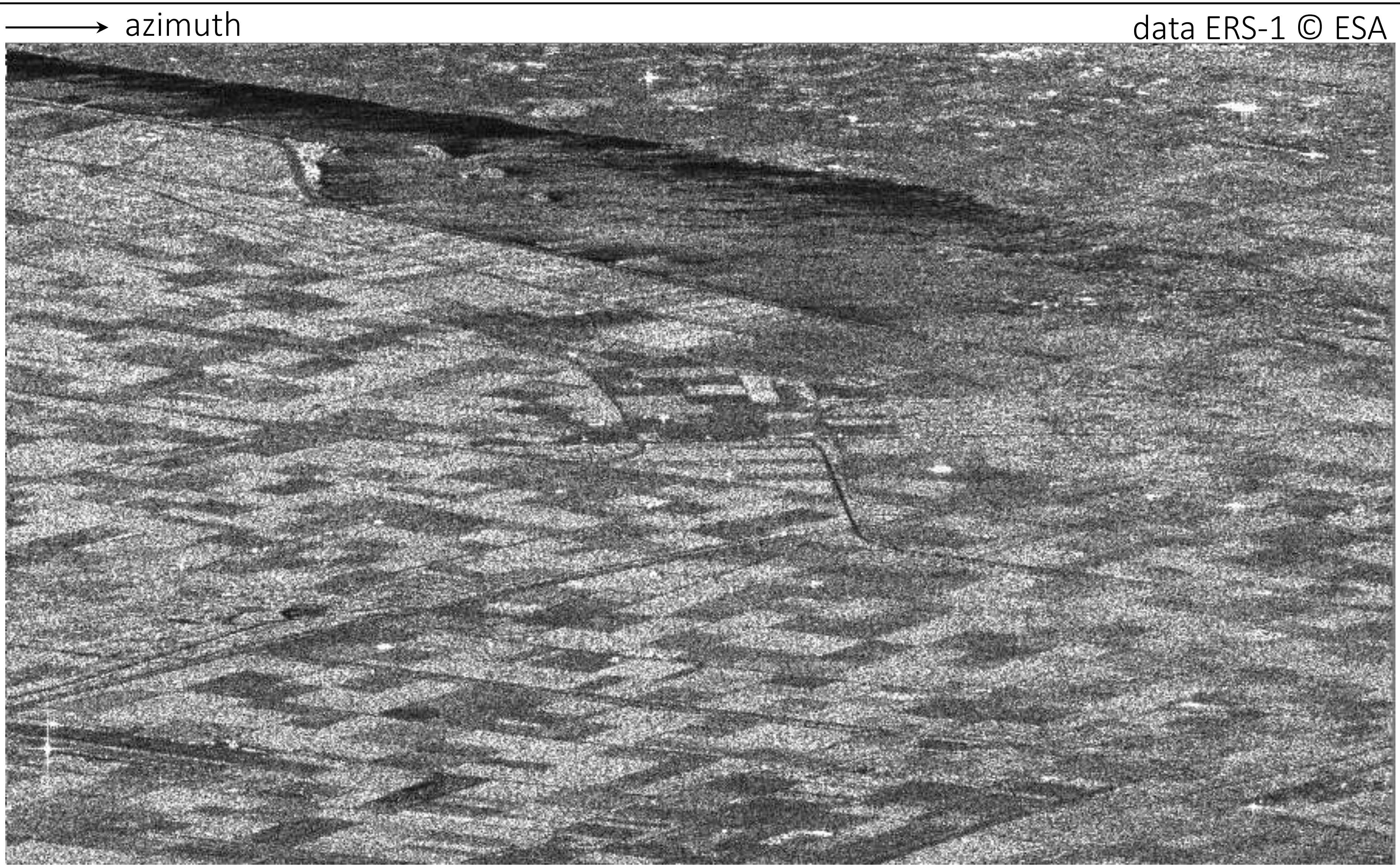


Combination of overlapping acquisitions

Original SAR Observations



SAR Data After Image Formation



SAR Data After Image Formation and Multi-Looking to Reduce Noise

After azimuth pixel averaging by 4 to achieve approximately square pixels

Satellite SAR Sensors: L-Band

	SEASAT	JERS-1 Japan	ALOS PALSAR Japan	ALOS-2 PALSAR-2 Japan	ALOS-4 PALSAR-3 Japan	SAOCOM, 1A / 1B Argentina	NISAR USA/India
Operation Date	1978 (105 days)	1992-1998	1/2006 4/2011	2014	2020	2018/2019	2022
Frequency Band	L	L	L	L	L	L	L
Polarization	HH	HH	Polarimetric	Polarimetric	Polarimetric	Dual	Dual
Spatial Resolution [m]	20	18	10, 20, 100	3 - 100	3 - 100	10-100	10
Repeat Cycle [days]	17	44	46	14	14	16/8	12

Satellite SAR Sensors: C-Band

	RADARSAT-1 Canada	RADARSAT-2 Canada	RADARSAT Constellation Mission Canada	ERS-1/2 Europe	Envisat Europe	Sentinel-1 ESA
Launch/ Operation Date	1995	2007	2018	1991-2011	2002-2012	2014 (A) 2016 (B)
Frequency Band	C	C	C	C	C	C
Polarization	HH	Quad-pol	Quad-pol	VV	HH, VV, HV	Dual-Pol Interferometric
Spatial Resolution [m]	10-100	3-100	3-100	30	10-100	5-100
Repeat Cycle [days]	24	24	1	3/75/176	35	12/6

Sentinel-1 C/D approved for operations until 2030

Satellite SAR Sensors: X-Band

	TerraSAR-X Tandem-X DLR/InfoTerra	Cosmo SKYMED Constallation, ASI, eGeos
Operation Date	4/2007 2009 Tandem-X	2007
Frequency Band	X	X
Polarization	Polarimetric Interferometric	Polarimetric Interferometric
Spatial Resolution [m]	Up to 1	Up to 1
Repeat Cycle [days]	11	16

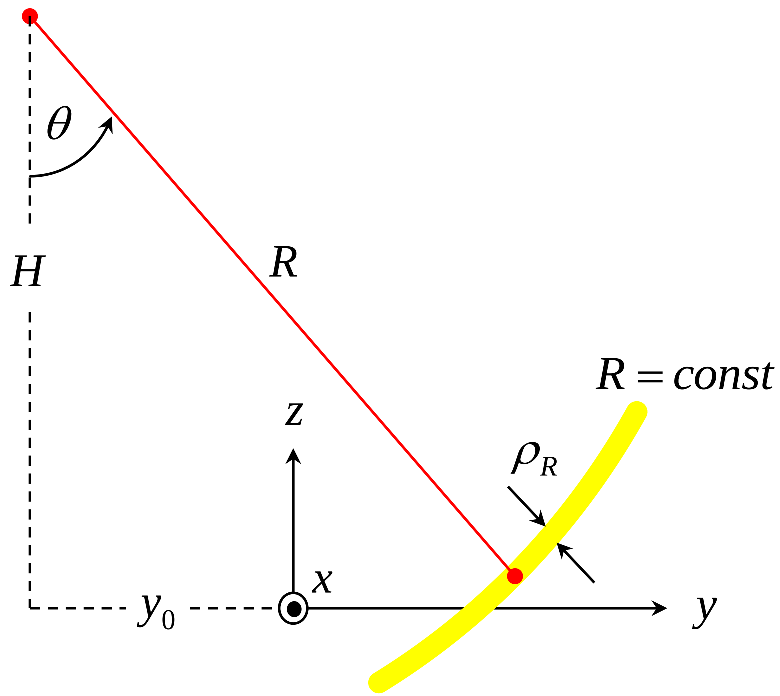
Satellite SAR Sensors: Other Bands

	ESA Biomass Mission Europe	NISAR USA/India
Operation Date	2018	2020
Frequency Band	P	S
Polarization	Polarimetric Interferometric	Polarimetric Interferometric
Spatial Resolution [m]	50-200	~3
Repeat Cycle [days]	25	12

GEOMETRIC PROPERTIES OF SAR

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

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

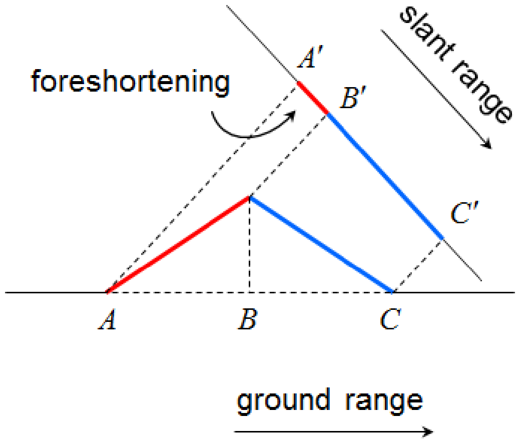


where $R = \sqrt{(y_0 + y)^2 + (H - z)^2}$

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

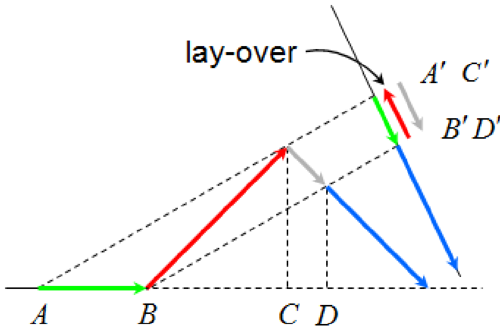
Foreshortening

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



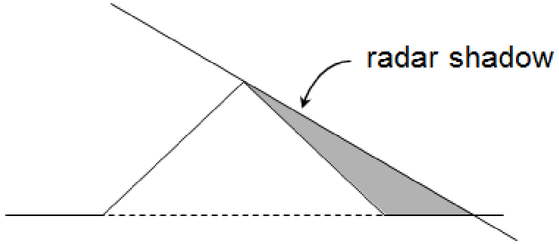
Layover

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



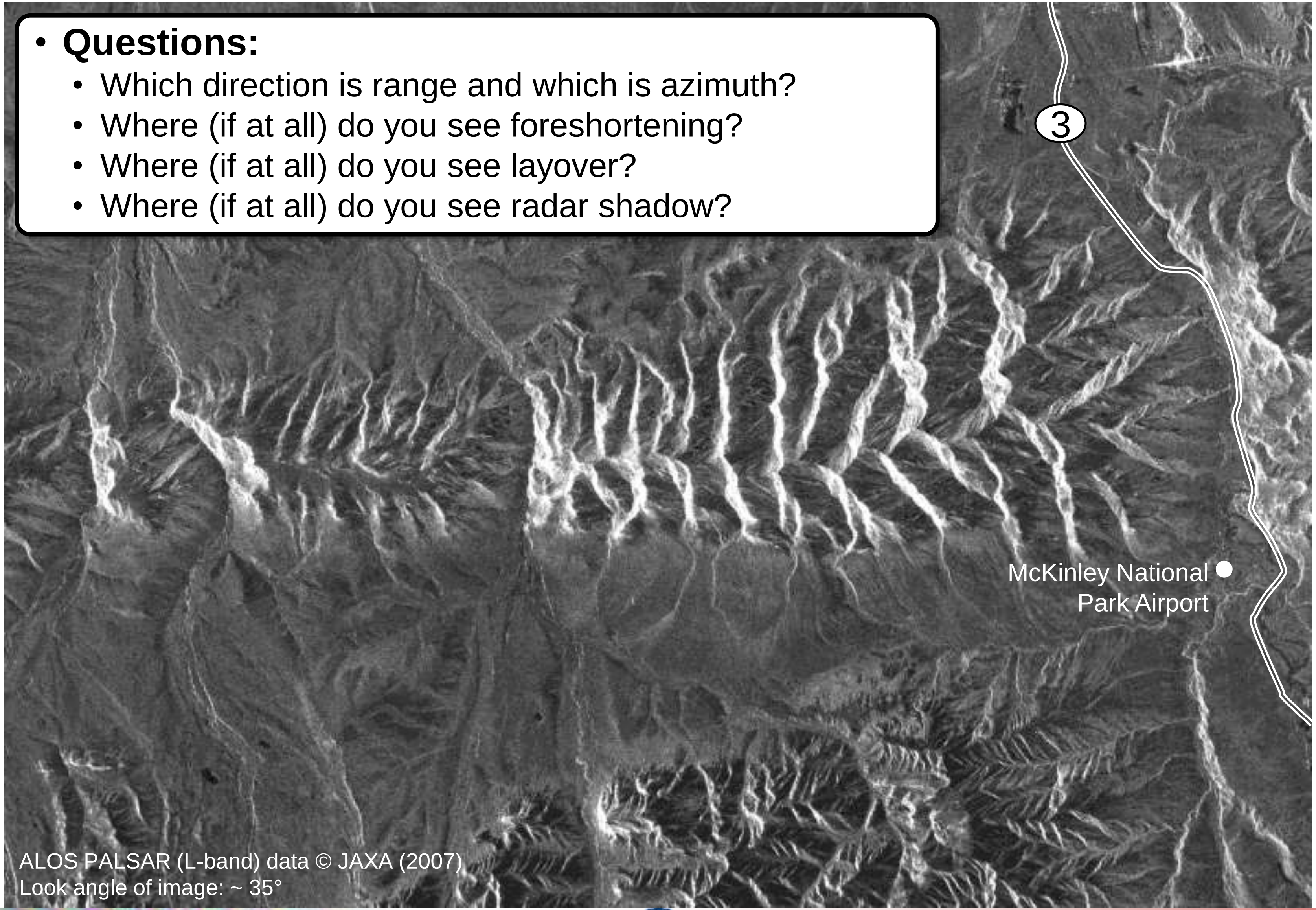
Shadow

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



Examples of 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?



ALOS PALSAR (L-band) data © JAXA (2007)
Look angle of image: ~ 35°

CORRECTING GEOMETRIC PROPERTIES OF SAR

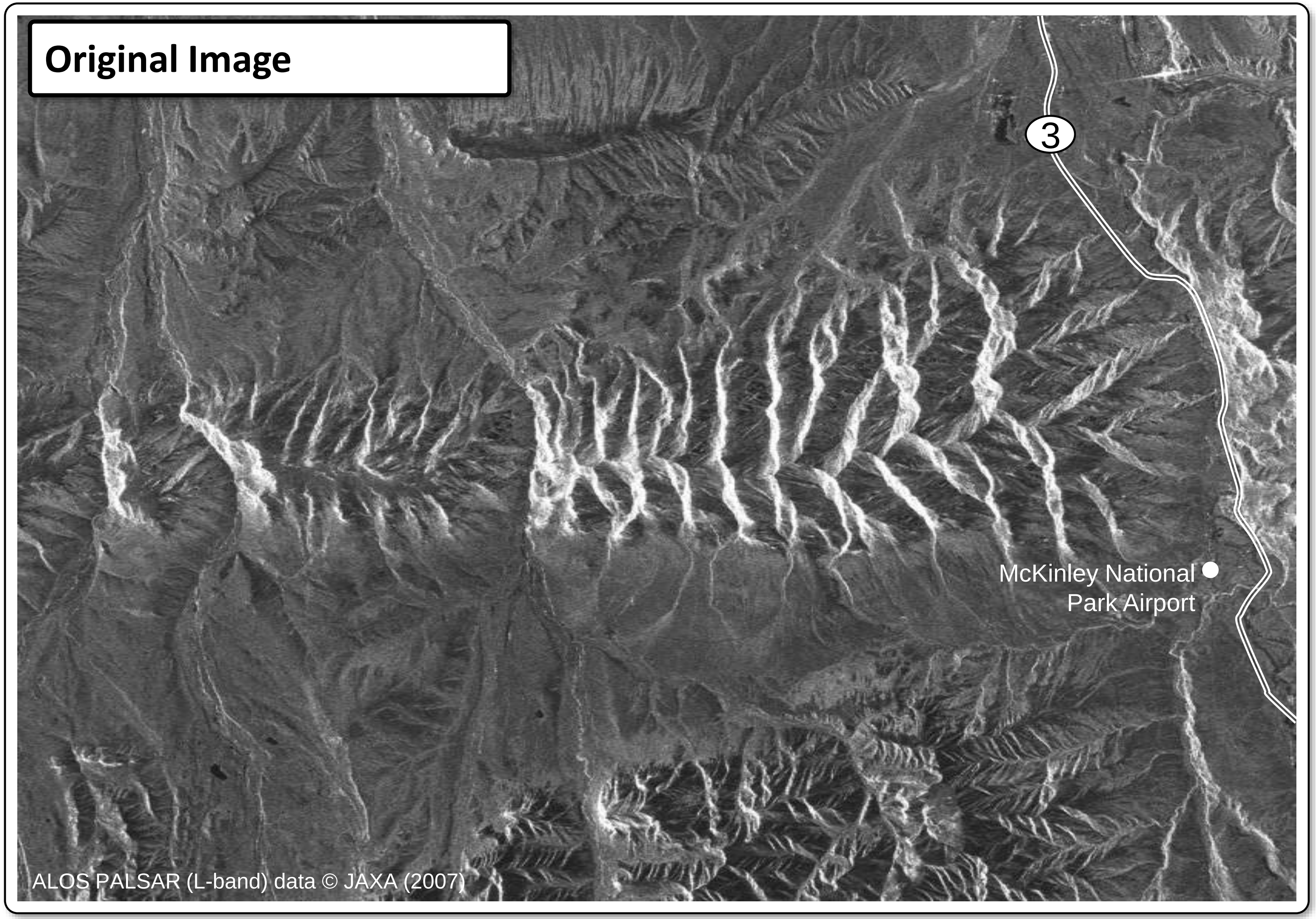
Geometric Terrain Correction

- **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

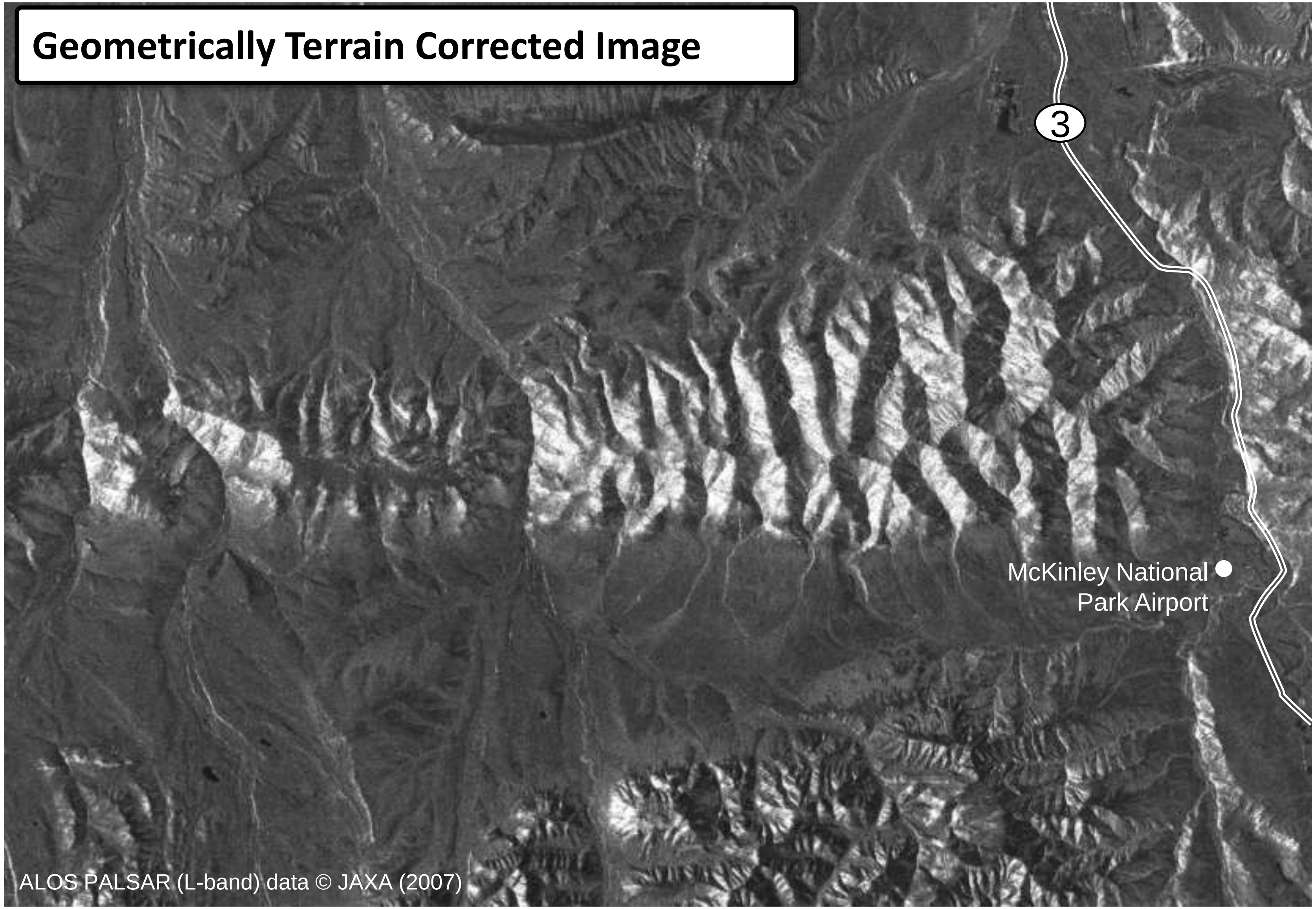
- **GTC problem:** What are the image gray values in every pixel of the output (geocoded) image given the input image and the DEM?

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

Geometric Terrain Correction Example (I)



Geometric Terrain Correction Example (II)

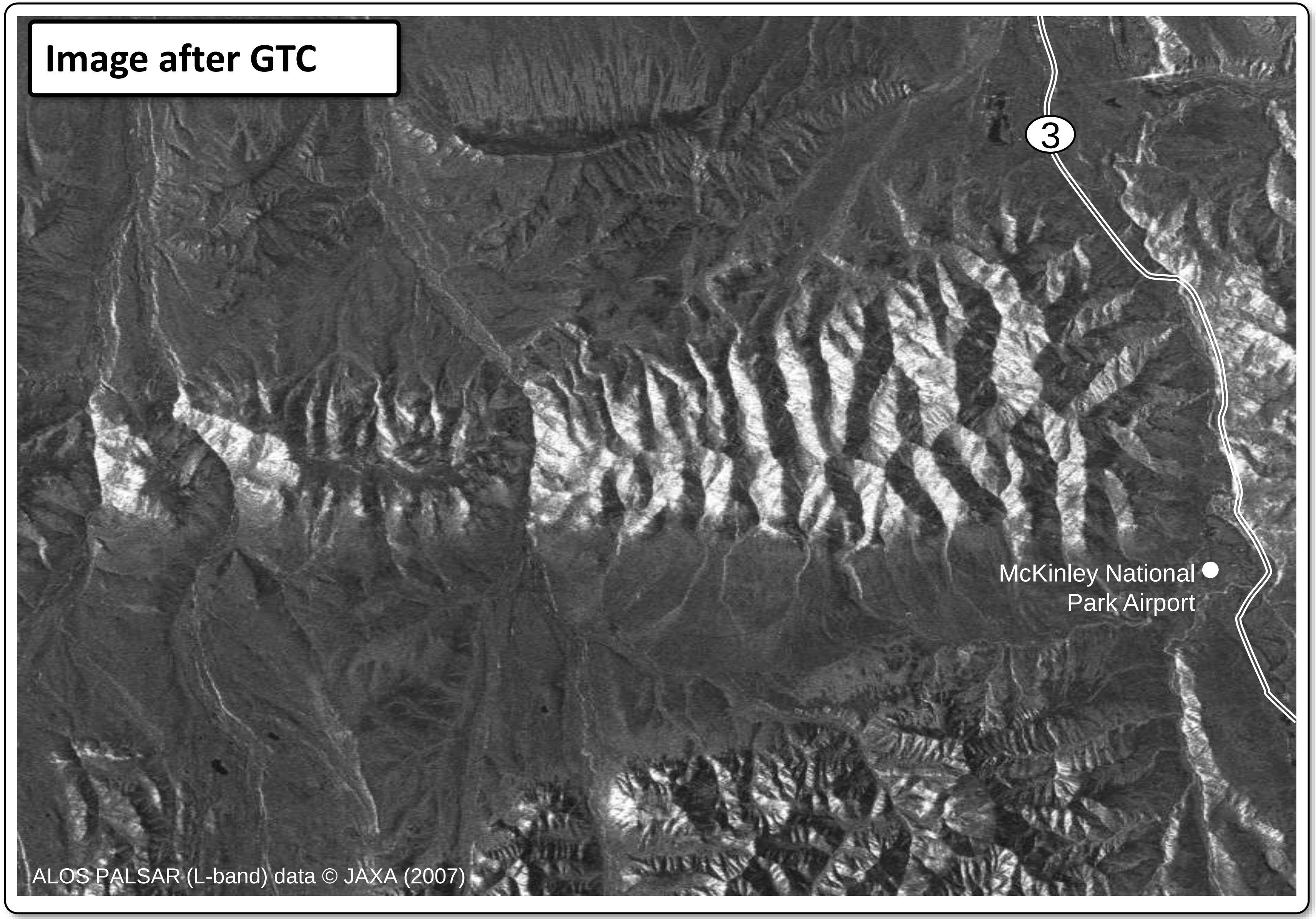


Radiometric Terrain Correction

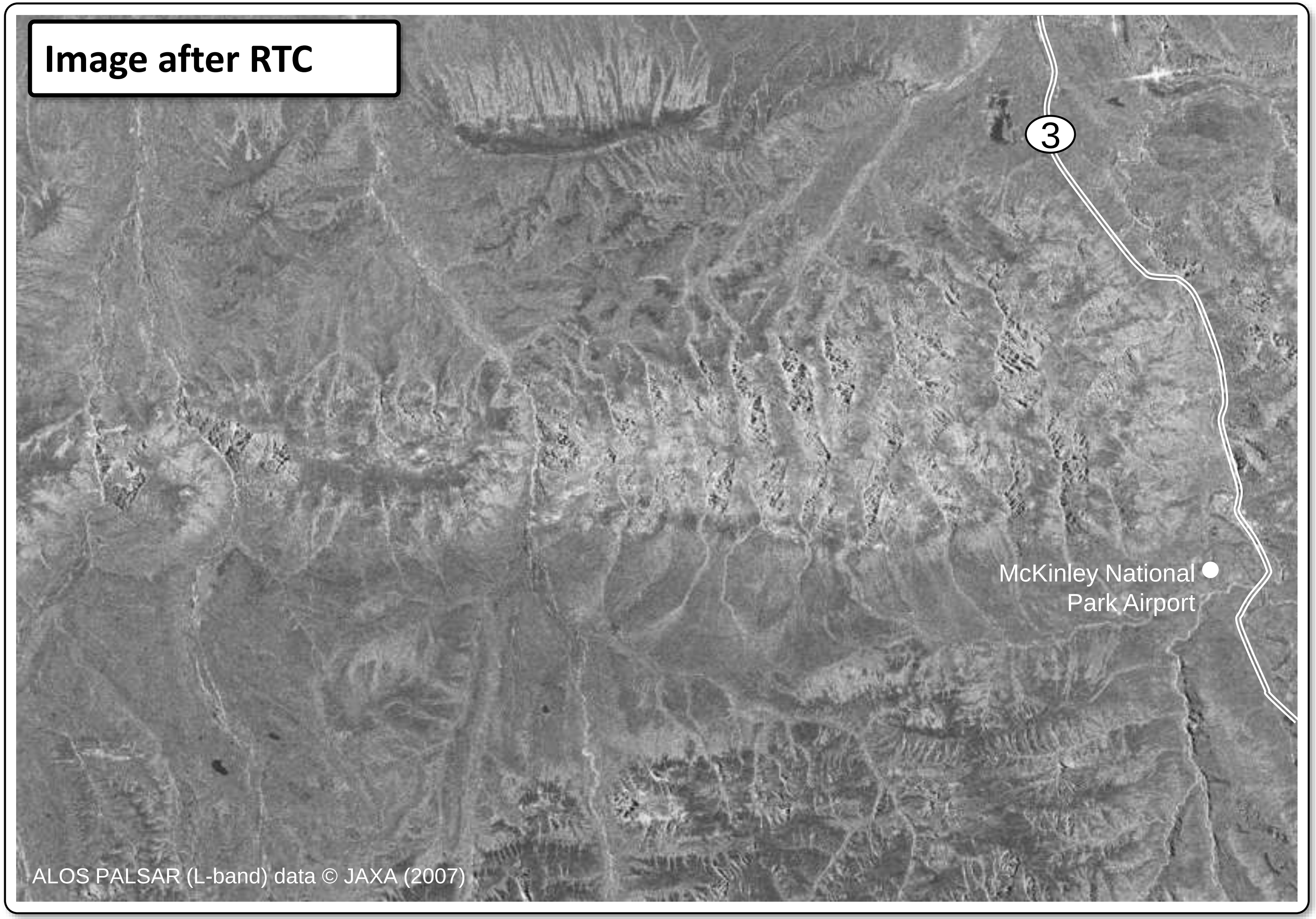
- **Problem:** Sensor facing slopes appear overly bright in radar images.
- **Cause:** Pixel Size on sensor-facing slopes is larger → more ground is integrated into pixel → brightness goes up

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

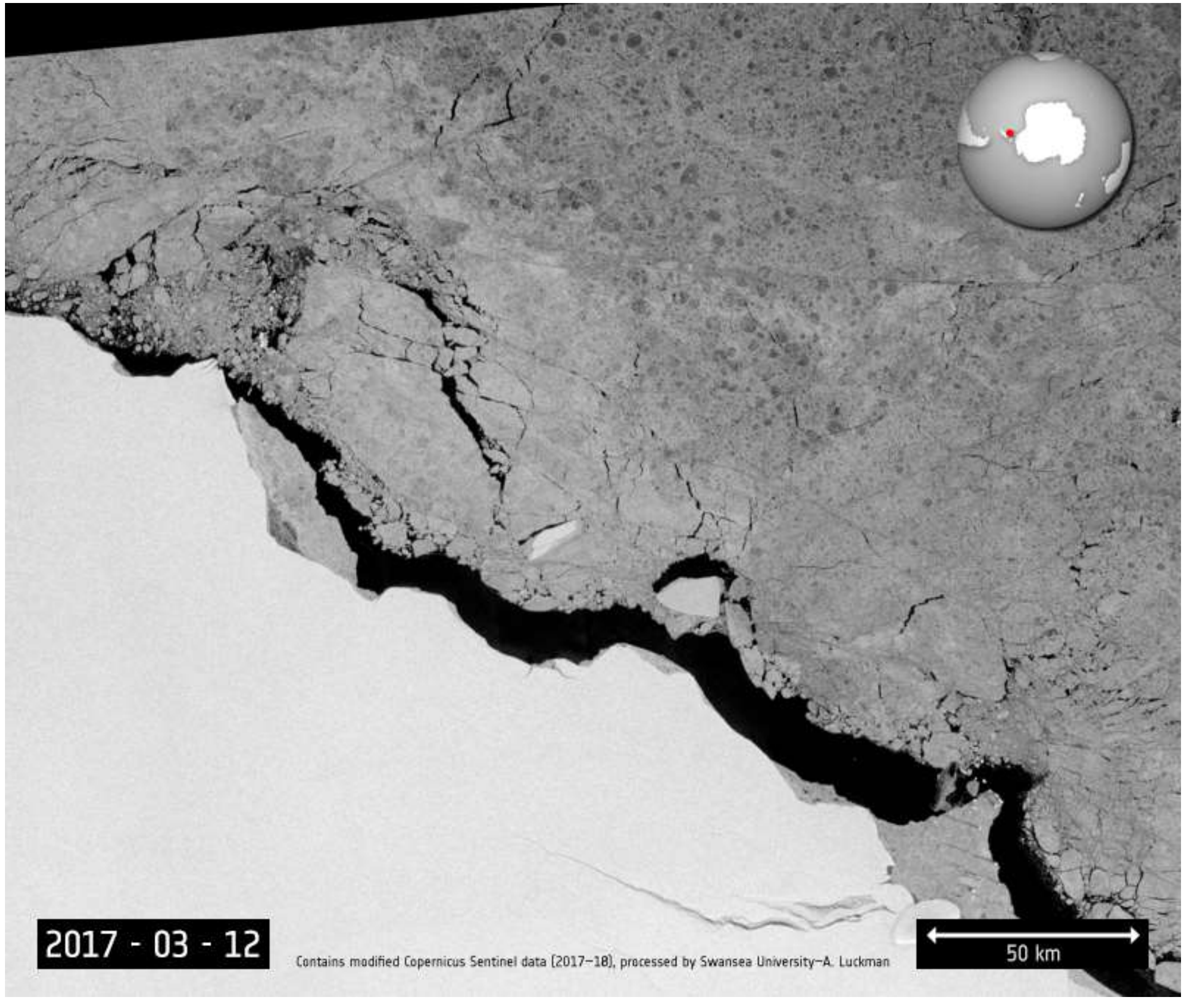
Radiometric Terrain Correction Example (I)



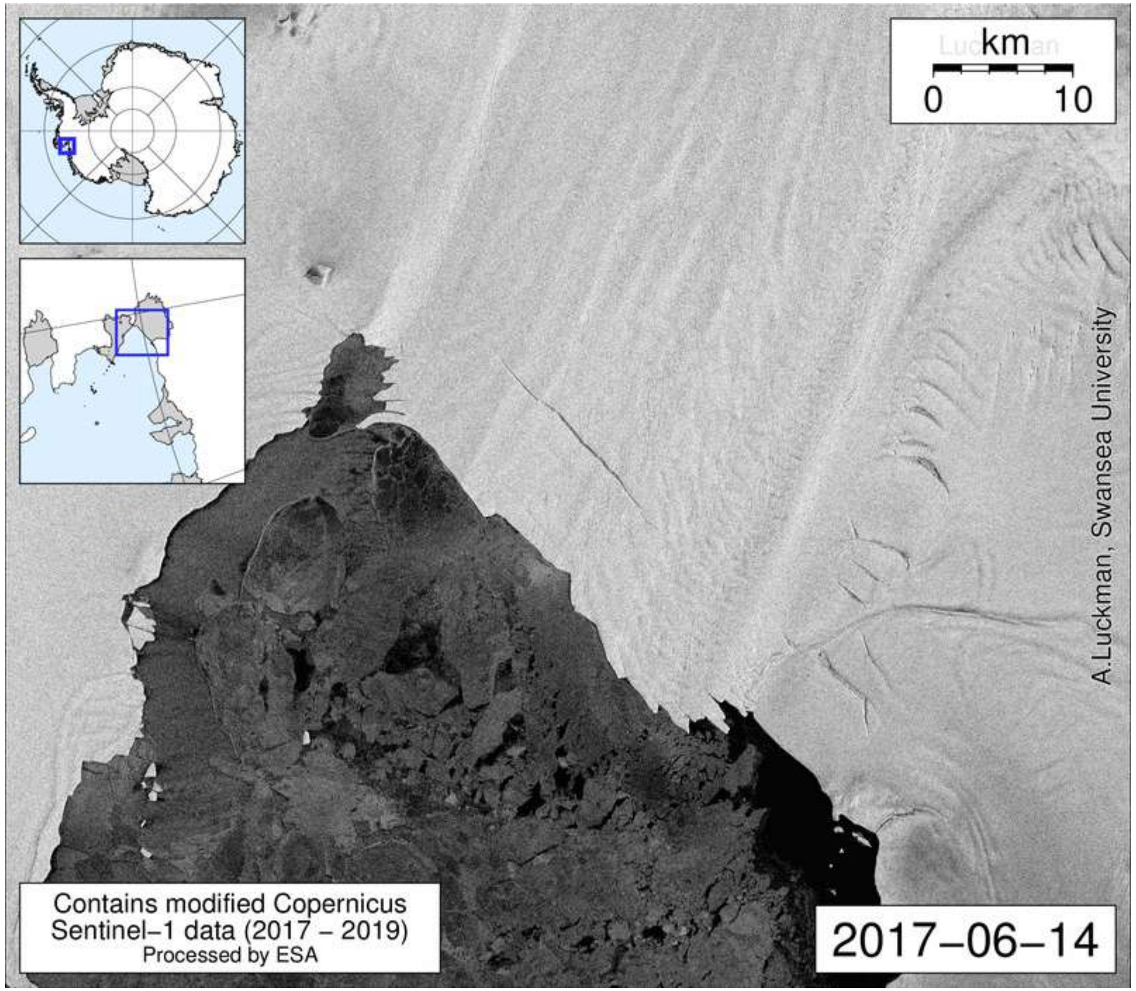
Radiometric Terrain Correction Example (II)



Sentinel-1 RTC Image Time Series In Antarctica



Iceberg A68 Breaking off the Larsen C Ice Shelf



Pine Island Glacier: Satellite animation mid-2017 to Feb-2020

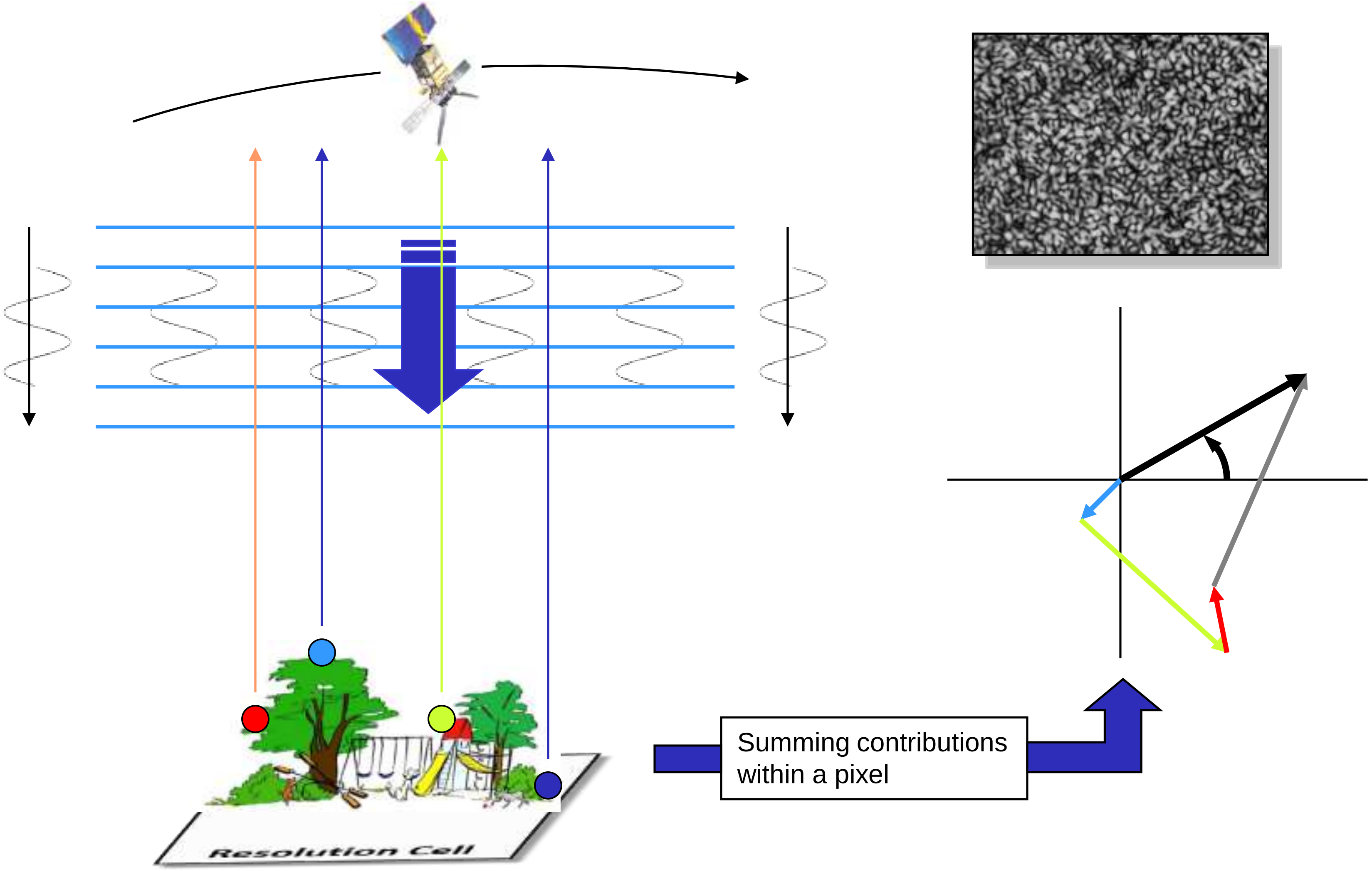
RADIOMETRIC DISTORTIONS – THE SPECKLE NOISE

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

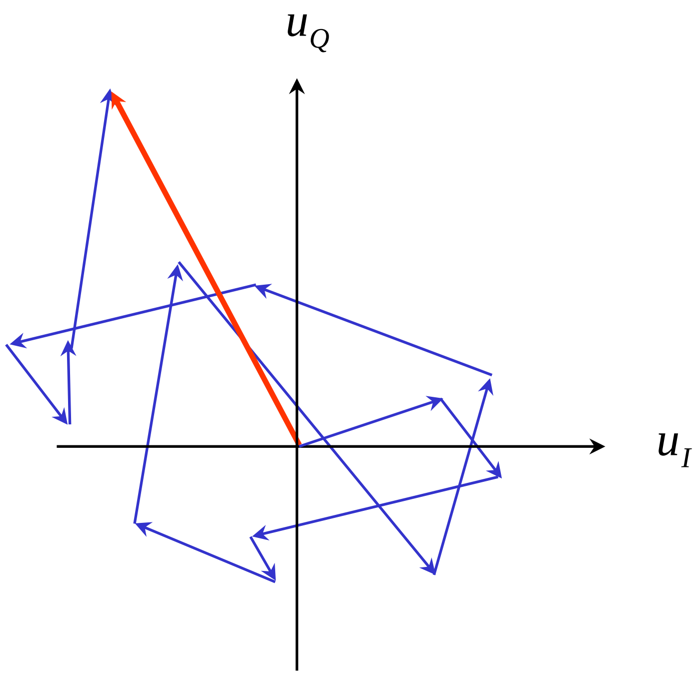


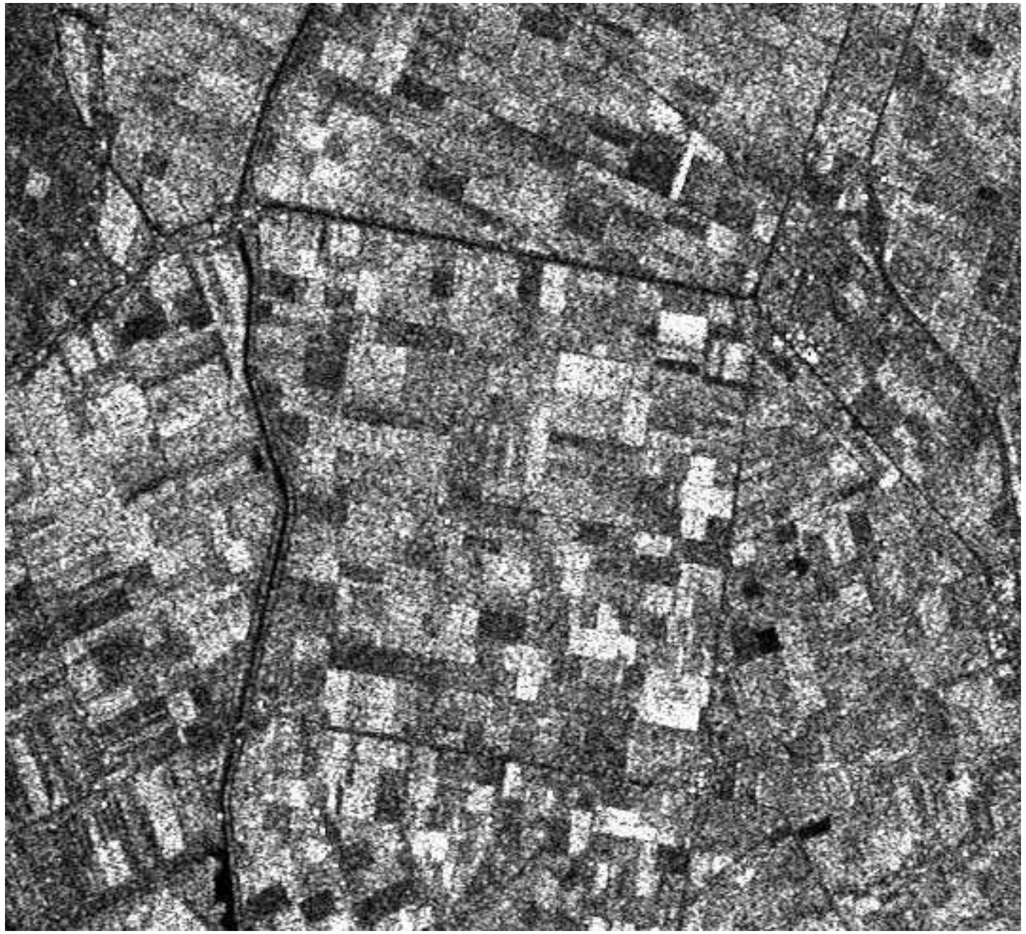
Speckle

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

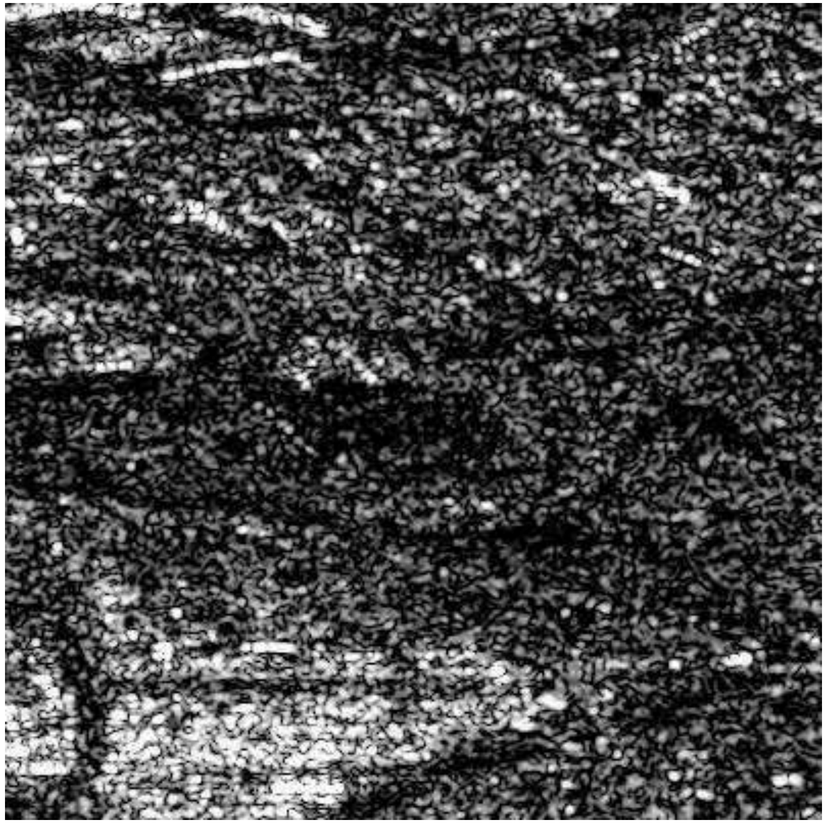




Speckle Example

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)

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

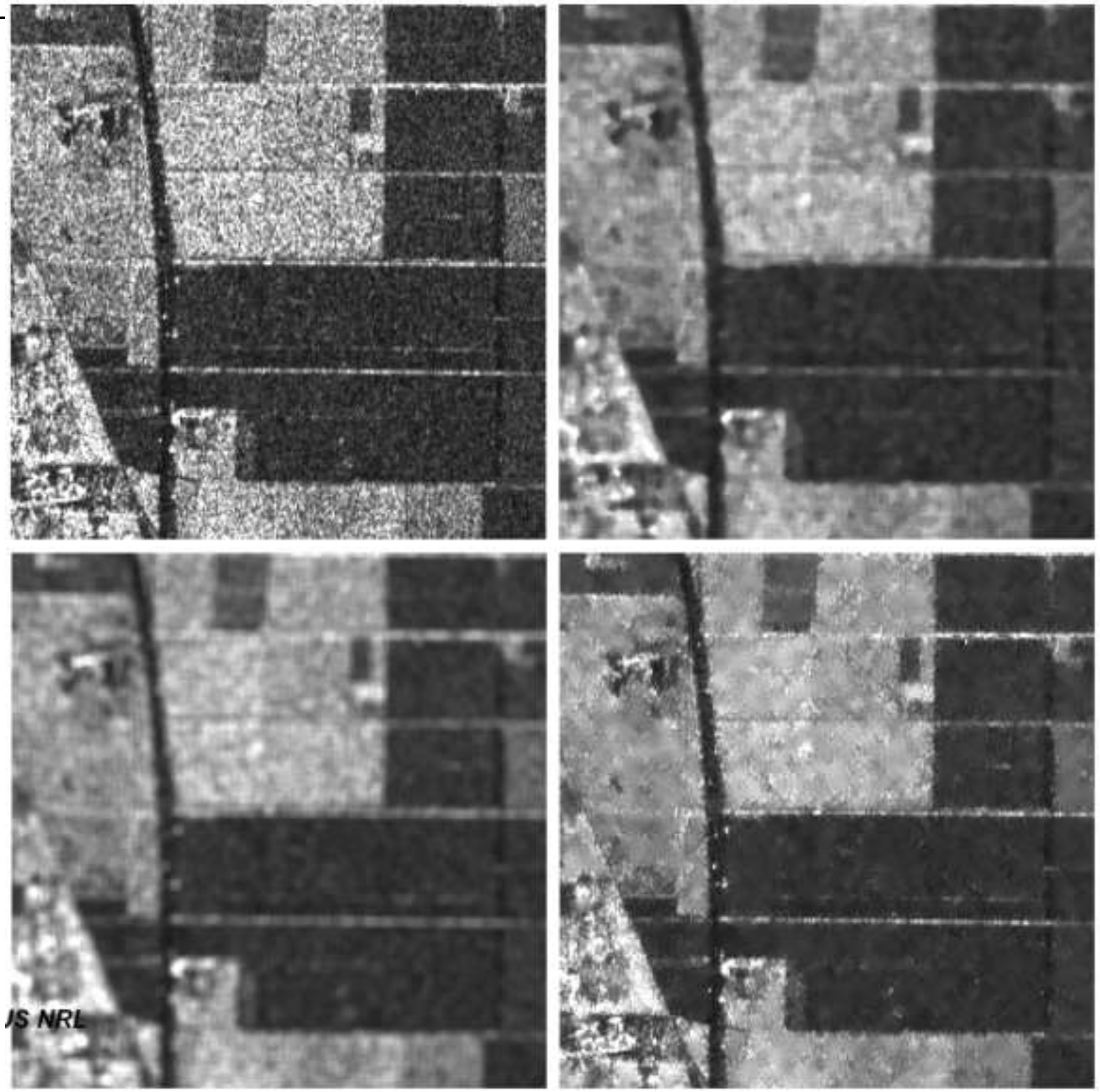
SAR Handbook: Comprehensive Methodologies for Forest Monitoring and Biomass Estimation. Eds. Flores, A., Herndon, K., Thapa, R., Cherrington, E. NASA. 2019. DOI: 10.25966/hbm1-ej07

Speckle Reduction

Example

Original 4-look amplitude

5x5 Median



5x5 Boxcar

Lee refined (7x7)

What's Next?

- **Next Session**: Lab 1: Comparison of Optical and SAR Imagery

- **Preparatory Reading for Upcoming Lectures on InSAR:**
  - For this lecture, please continue to read (or re-read) up to the start of Section 3.3.1 in the following document (10 pages): [FerrettiBook_Chapter3.pdfDownload FerrettiBook_Chapter3.pdf]

QUESTIONS?