HYDROSAR – WEATHER-RELATED HAZARD INFORMATION FROM SAR

Contributors:

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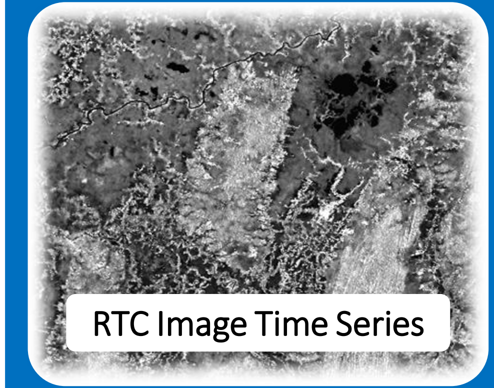
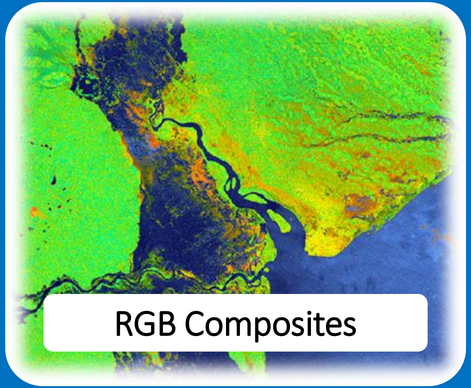
Lecture 1: An intro to Synthetic Aperture Radar (SAR) with a Focus on Its Applications for Flood Mapping

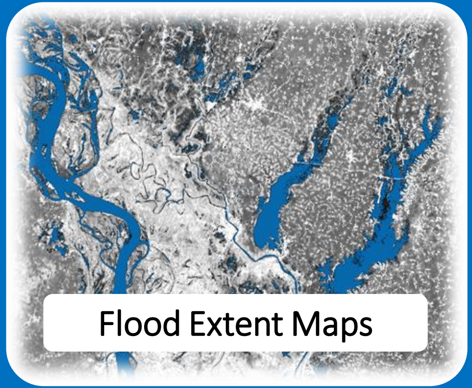
HydroSAR is an SERVIR-AST-Funded Project to Develop Products, Tools & Services to Support Monitoring Hydrological Hazards in the HKH Region

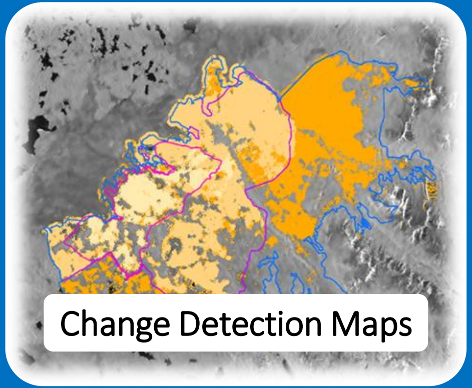
UNIVERSITY OF ALASKA FAIRBANKS

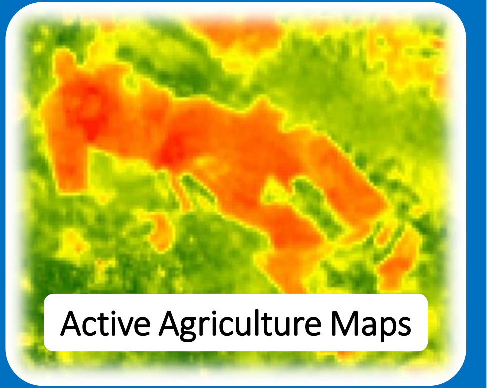
SAR-based value-added products


RTC Image Time Series


RGB Composites


Flood Extent Maps


Change Detection Maps


Active Agriculture Maps

Cloud-based Computational Resources

Automatic Cloud-based Production Pipelines

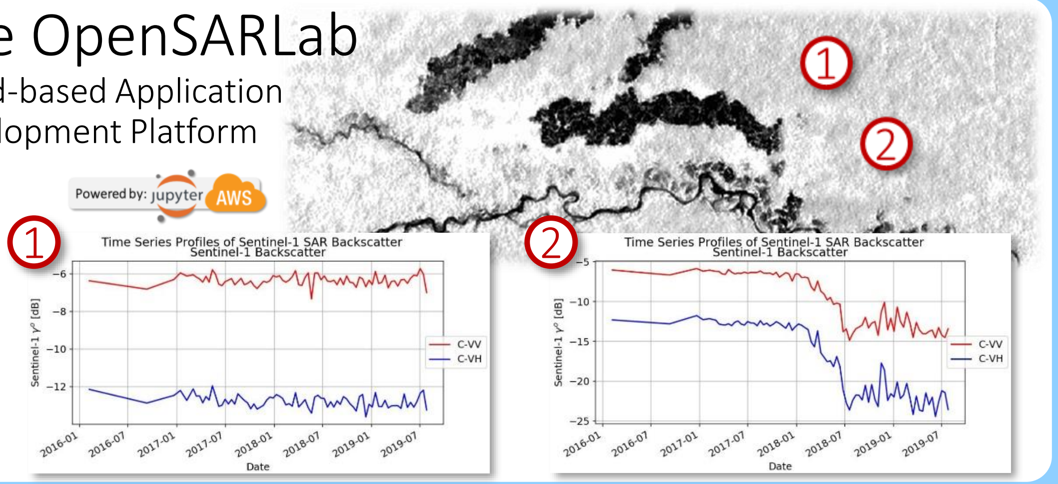
Exercising mature algorithm large scale
using cloud-based workflows

User → AWS Elastic Beanstalk Website → AWS RDS → AWS Lambda → AWS EC2 Instance → AWS S3

The OpenSARLab

Cloud-based Application
Development Platform

Powered by: jupyter AWS



The HydroSAR Team

HydroSAR Development Team

University of Alaska Fairbanks / Alaska Satellite Facility

- Franz J Meyer
- Eric Lundell
- Alex Lewandowski
- Brooke Kubby
- Thomas Meyer

Marshall Space Flight Center

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Jet Propulsion Laboratory

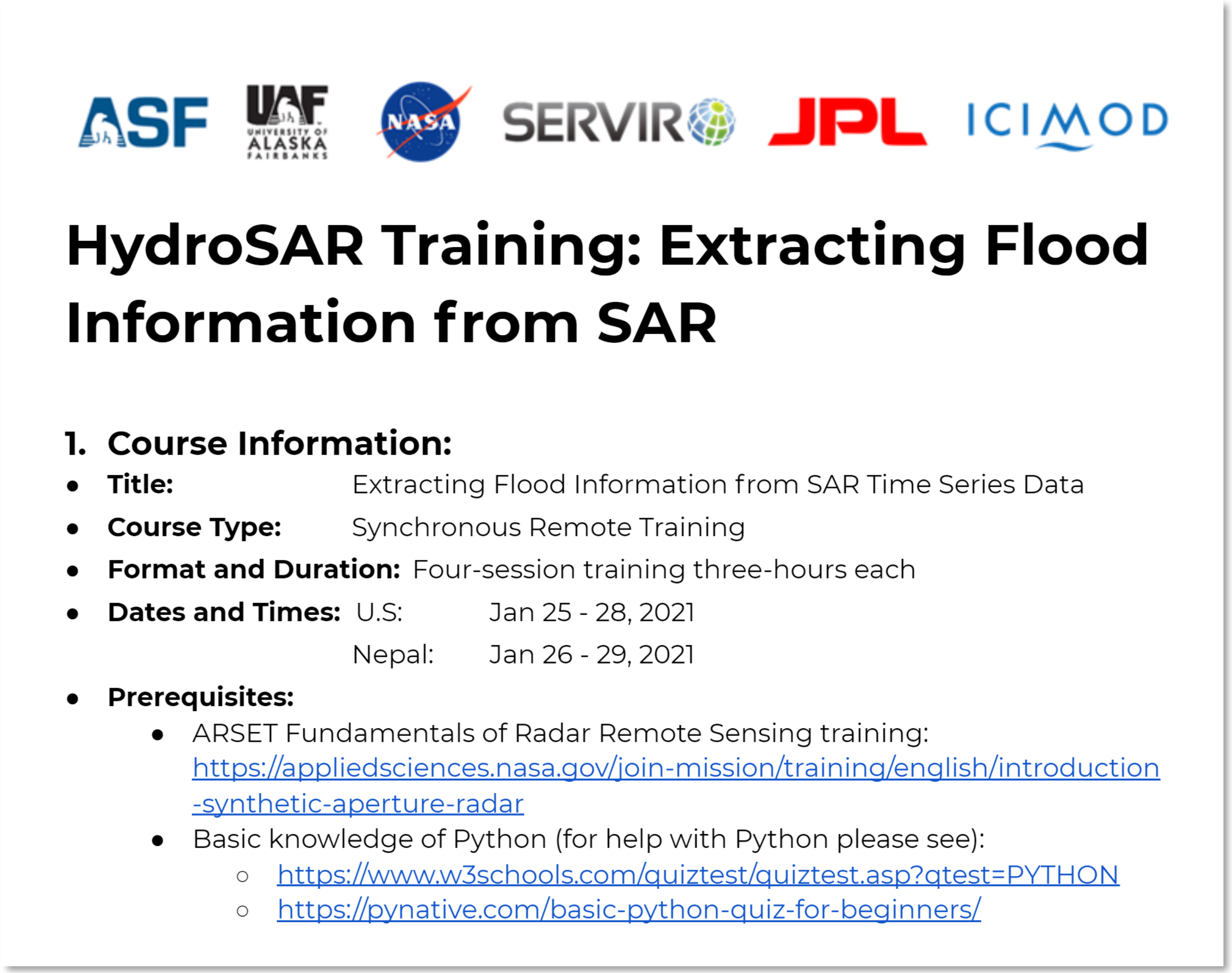
- Bruce Chapman

HydroSAR Partners

ICIMOD

HydroSAR Training Syllabus

- The Syllabus and all lecture materials can be found here:
  – https://drive.google.com/drive/folders/1QOdS5P3kv52pkkjidsY8Jlkil-3lsSBn?usp=sharing



HydroSAR Training: Extracting Flood Information from SAR

1. **Course Information:**

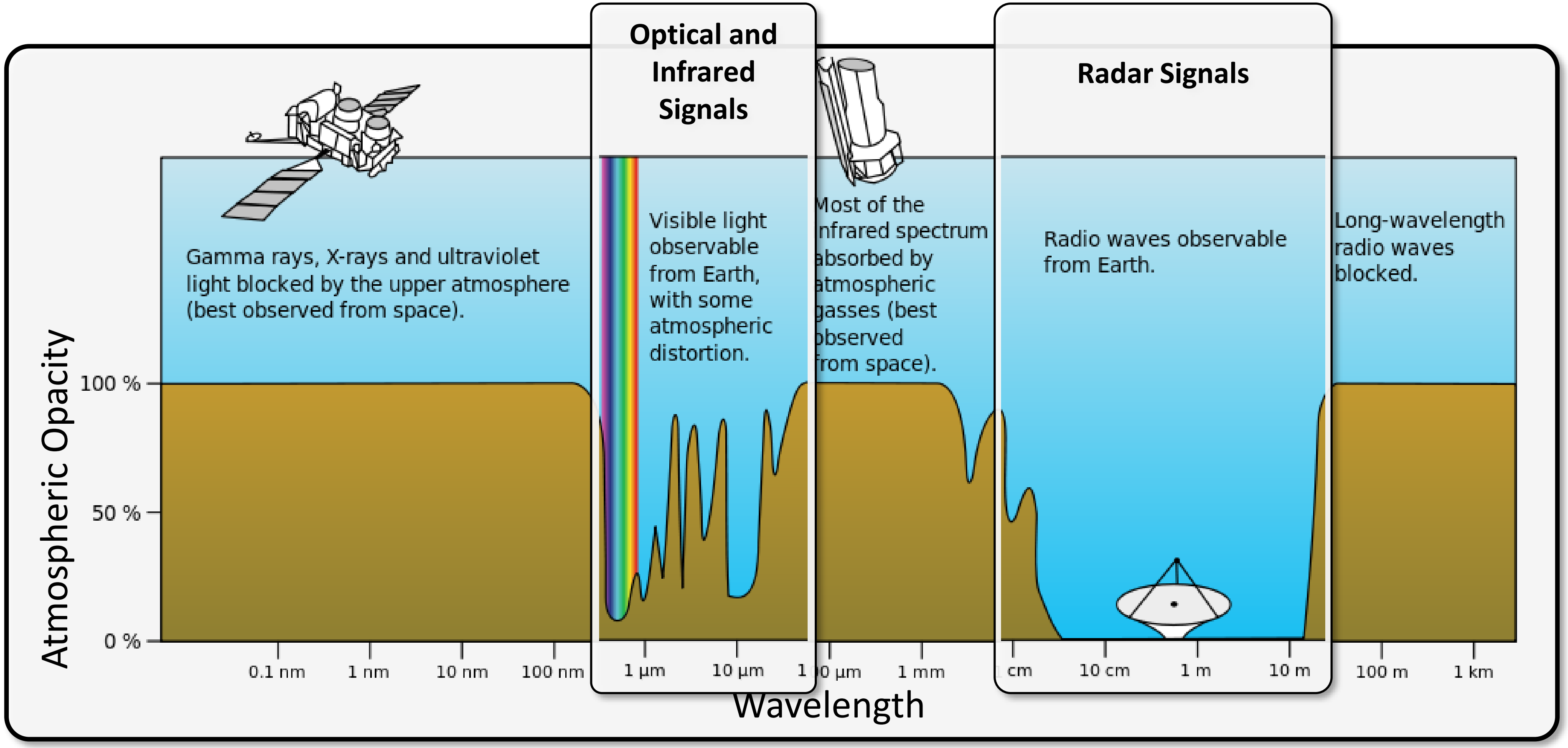
- **Title:** Extracting Flood Information from SAR Time Series Data
- **Course Type:** Synchronous Remote Training
- **Format and Duration:** Four-session training three-hours each
- **Dates and Times:** U.S: Jan 25 - 28, 2021
  Nepal: Jan 26 - 29, 2021
- **Prerequisites:**
  - ARSET Fundamentals of Radar Remote Sensing training: https://appliedsciences.nasa.gov/join-mission/training/english/introduction-synthetic-aperture-radar
  - Basic knowledge of Python (for help with Python please see):
    - https://www.w3schools.com/quiztest/quiztest.asp?qtest=PYTHON
    - https://pynative.com/basic-python-quiz-for-beginners/

BENEFITS OF RADAR REMOTE SENSING

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 Weather-Related Events such as Flooding and Rain-Triggered Landslide Activity

Animation of the use of SAR during Flooding events

(credit: DLR TerraSAR-X team)

Modern SAR Sensors provide regularly-sampled, high-resolution & weather-independent earth observation data from Space

ESA Sentinel-1 SAR

Preparation for NASA-ISRO SAR (NISAR) Radar Earth Observation Satellite Project

LAUNCH SPRING 2023

First spaceborne L- and S-band SAR

Full global coverage in 12 days

150 Petabyte of Earth Observation data / year

ALL DATA FREE AND OPEN!

NISAR INVOLVEMENT

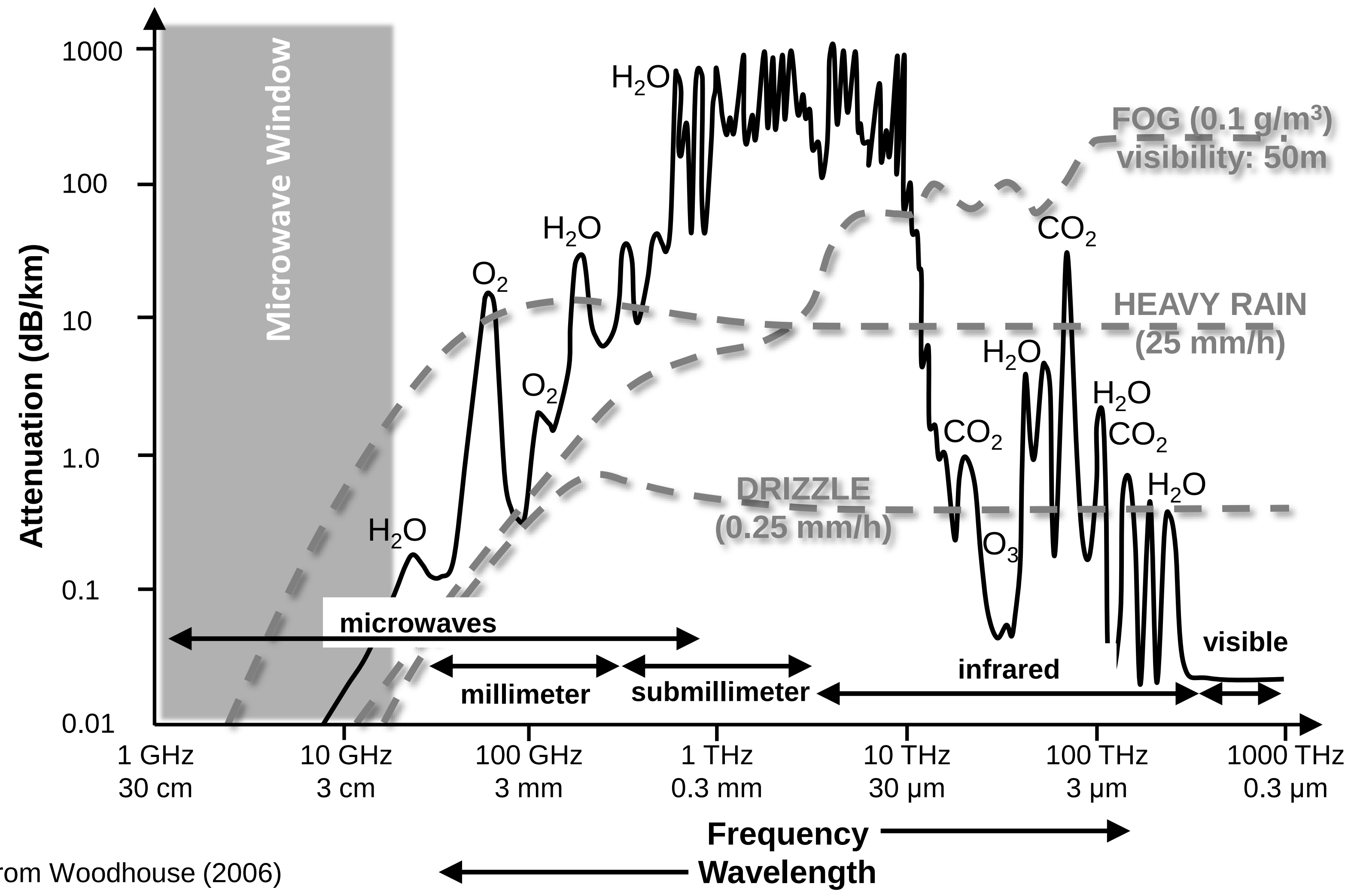
- NISAR Data Center
- NISAR Ground Station
- NISAR Science Team Member
- NISAR L2 Algorithm Development

The Microwave Spectrum

(approximate)

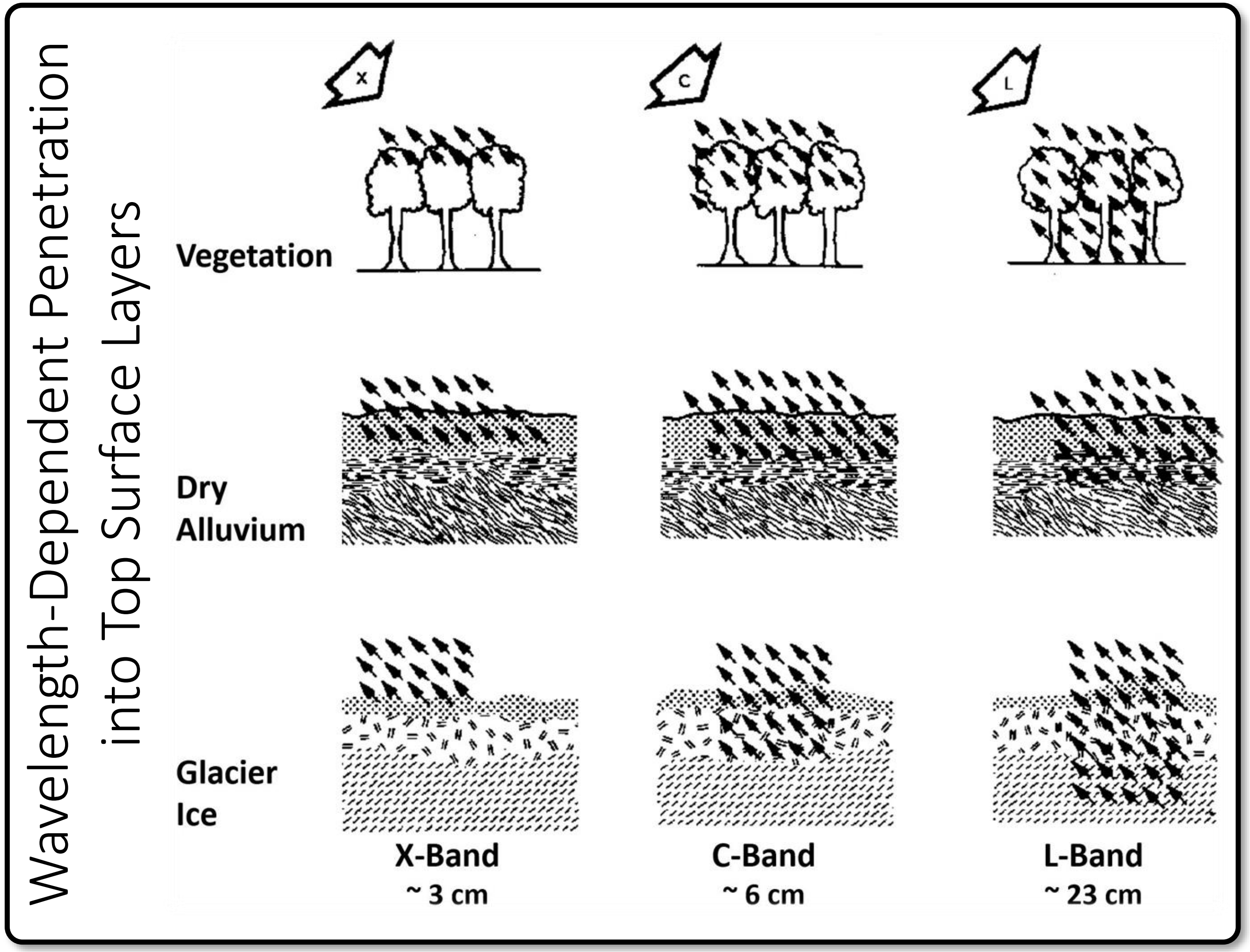
Band	Frequency f_0		Wavelength $\lambda = c/f_0$		Typical Application
Ka	27 – 40	GHz	1.1 – 0.8	cm	Rarely used for SAR (airport surveillance)
K	18 – 27	GHz	1.7 – 1.1	cm	Rarely used for SAR (H_2O absorption)
Ku	12 – 18	GHz	2.4 – 1.7	cm	Rarely used for SAR (satellite altimetry)
X	8 – 12	GHz	3.8 – 2.4	cm	**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

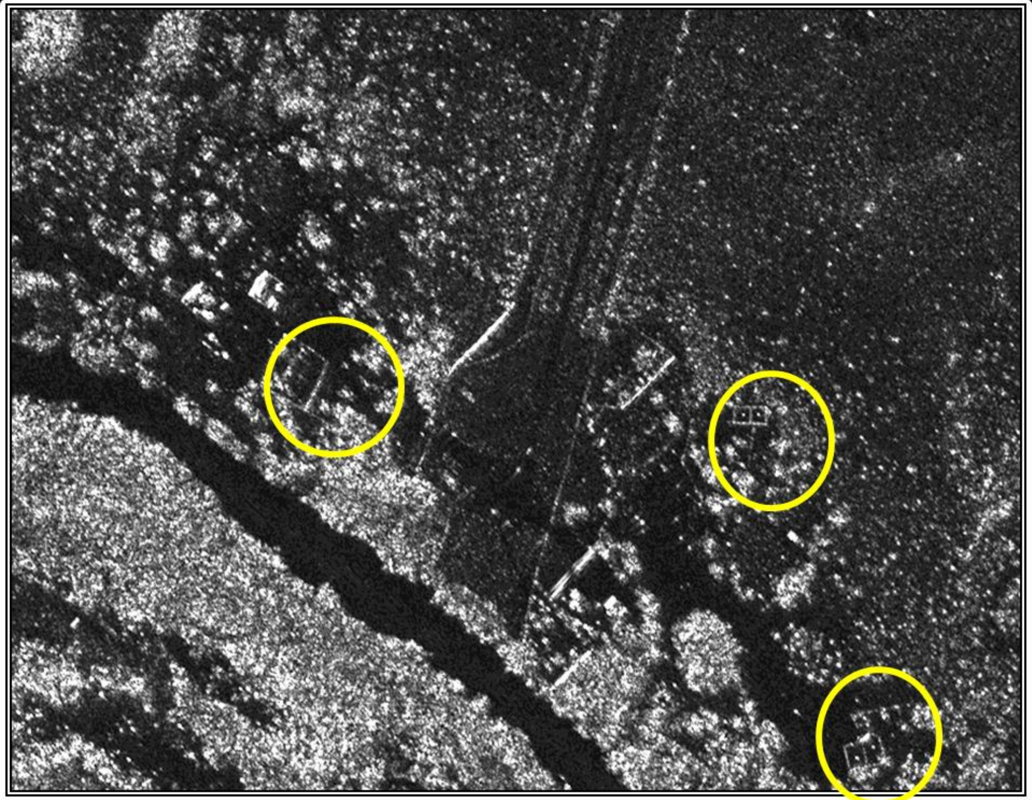


From Woodhouse (2006)

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



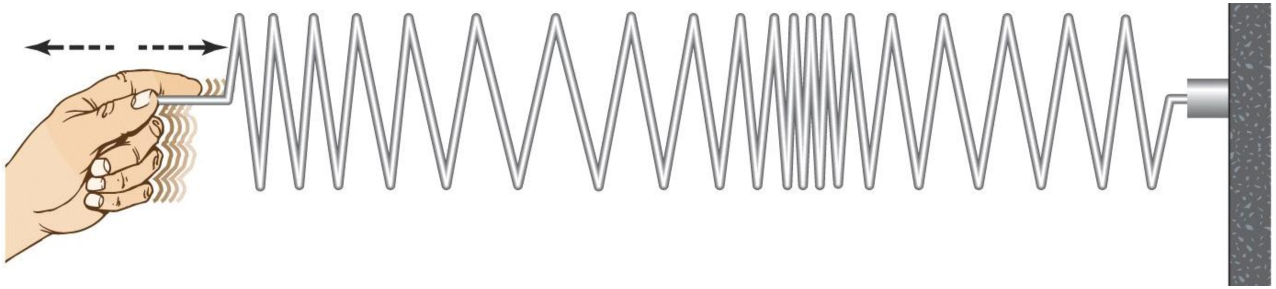
- **Example**: X-band vs P-band penetration into Forest Canopies



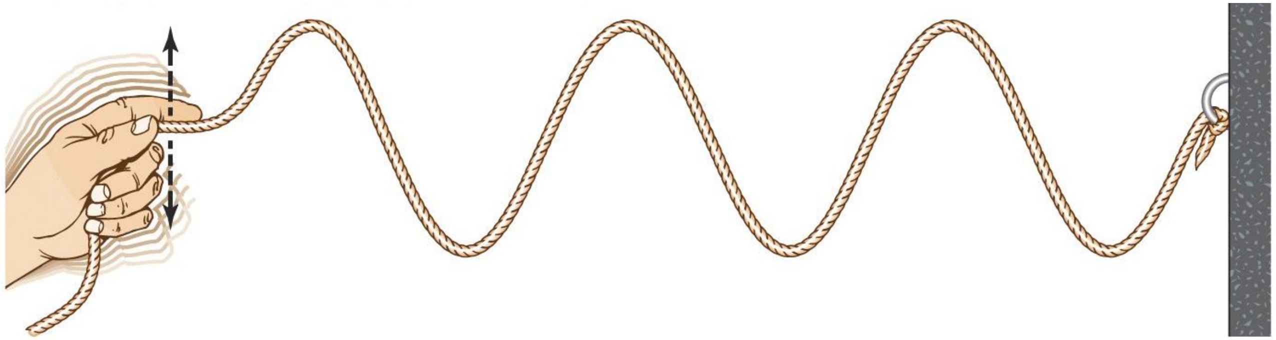
P-band radar image of forested area

Radar like Optical EM Signals are Transverse Oscillating Waves

Longitudinal oscillating waves (sound waves, waves on oceans)

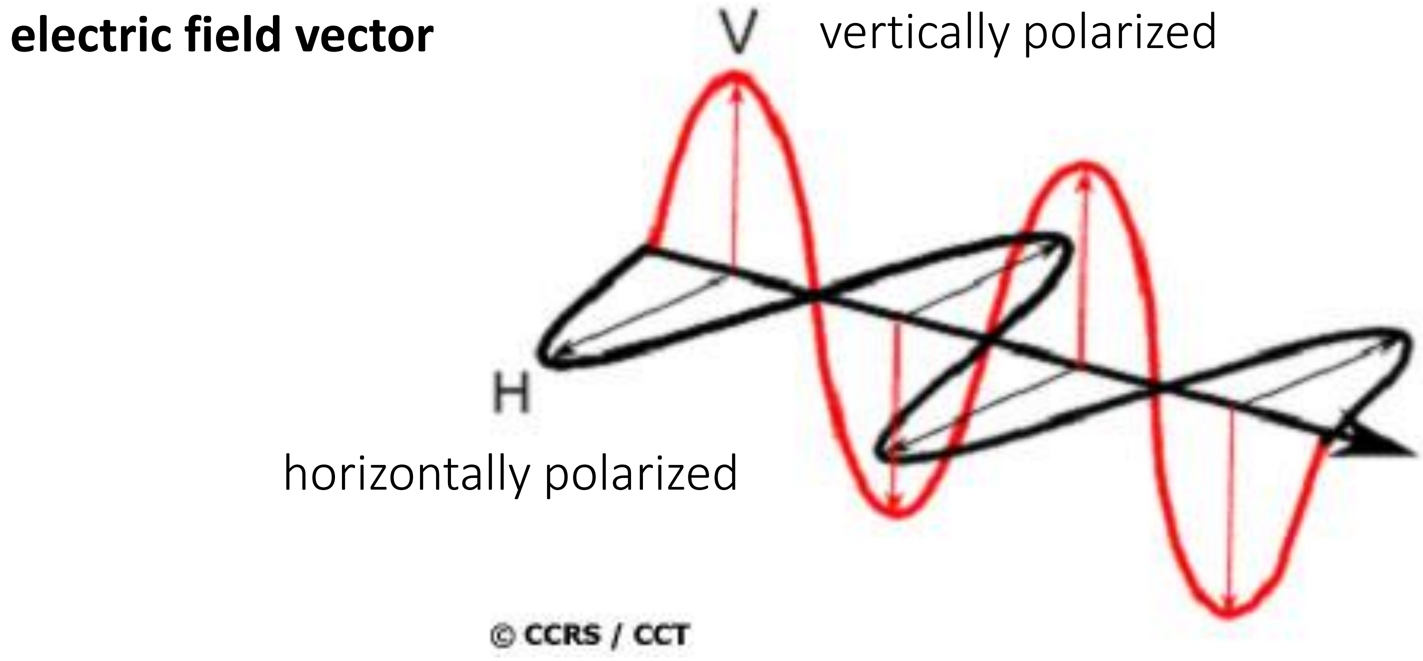


Transverse oscillating waves (e.g., EM waves)



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

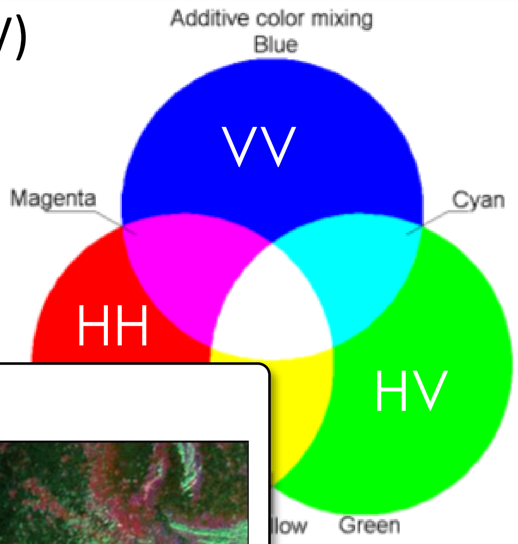
In Radar, we can Control the Polarization of the Transverse Oszillating Signal → Its Polarization



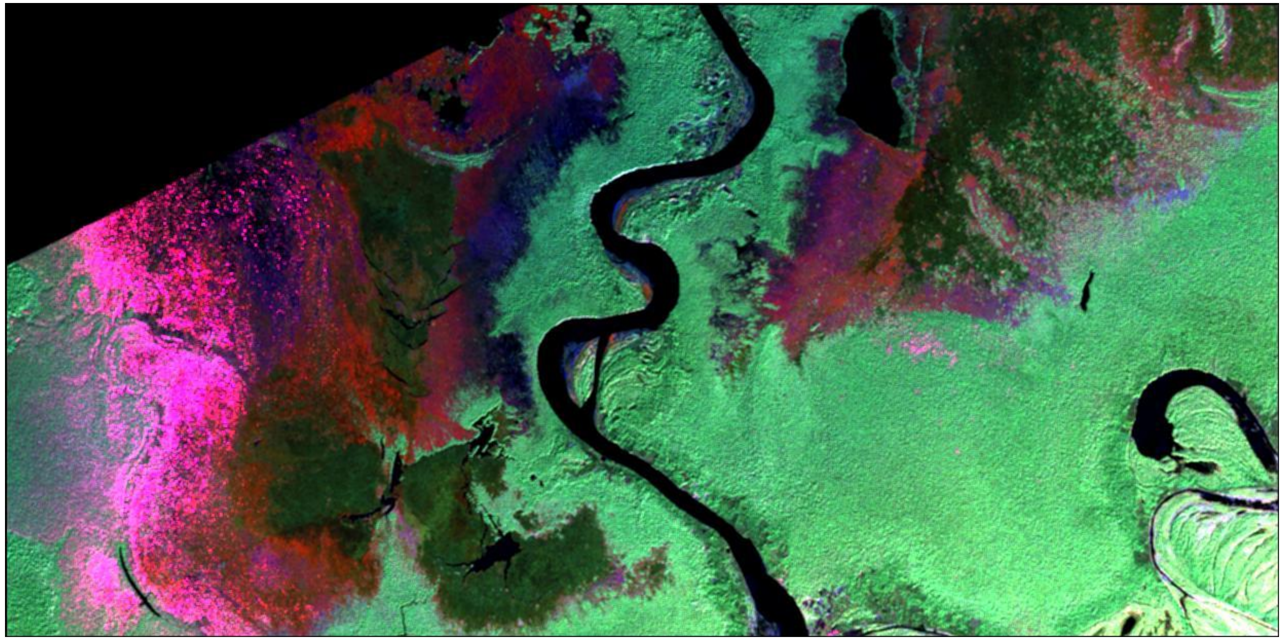
- Polarization planes are perpendicular – orientation technically arbitrary
- Usually, horizontal and vertical planes are chosen
- The terms horizontal and vertical then refer to either the earth or the antenna surface

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

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

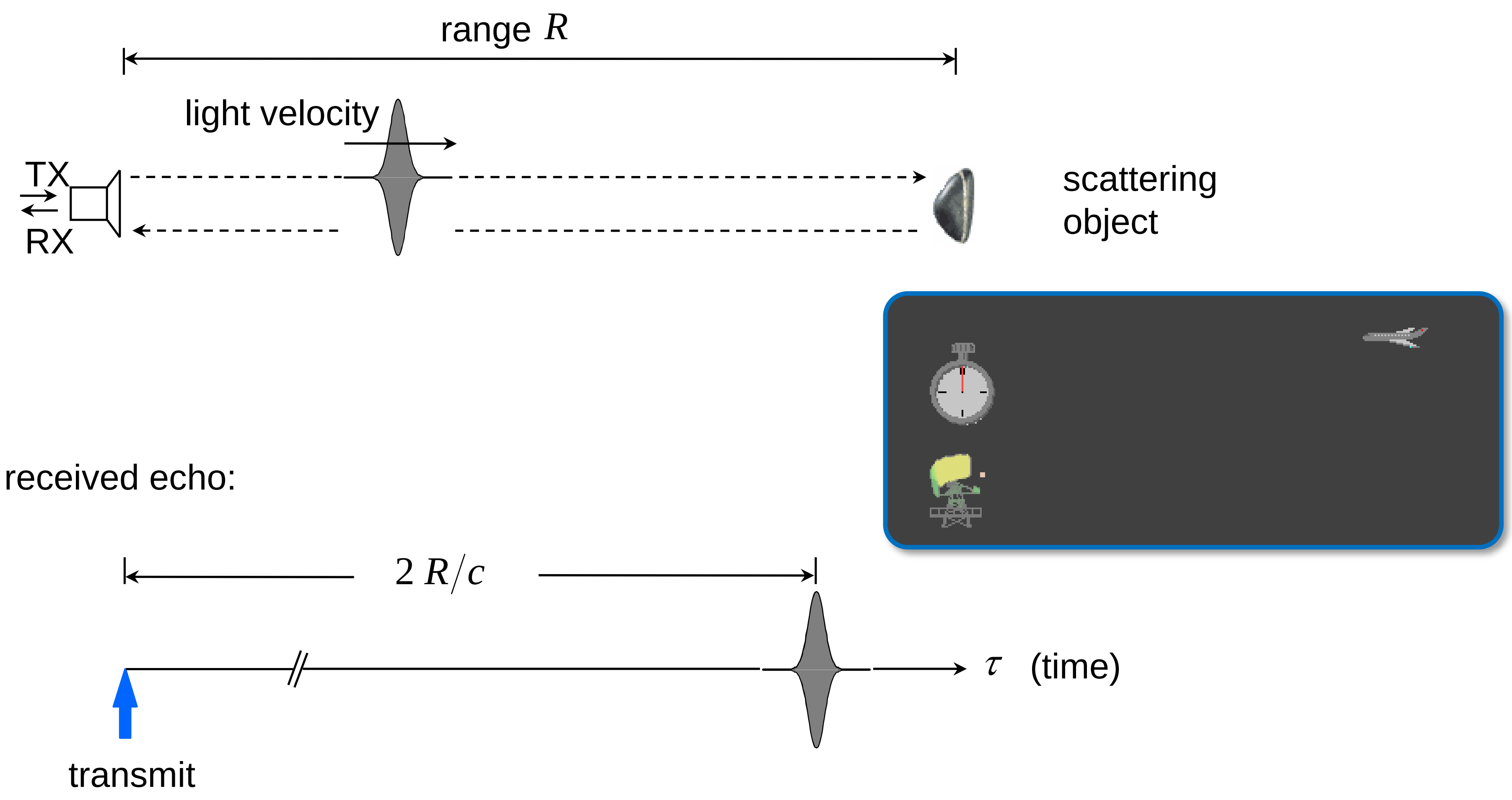


RGB Combination of Polarizations

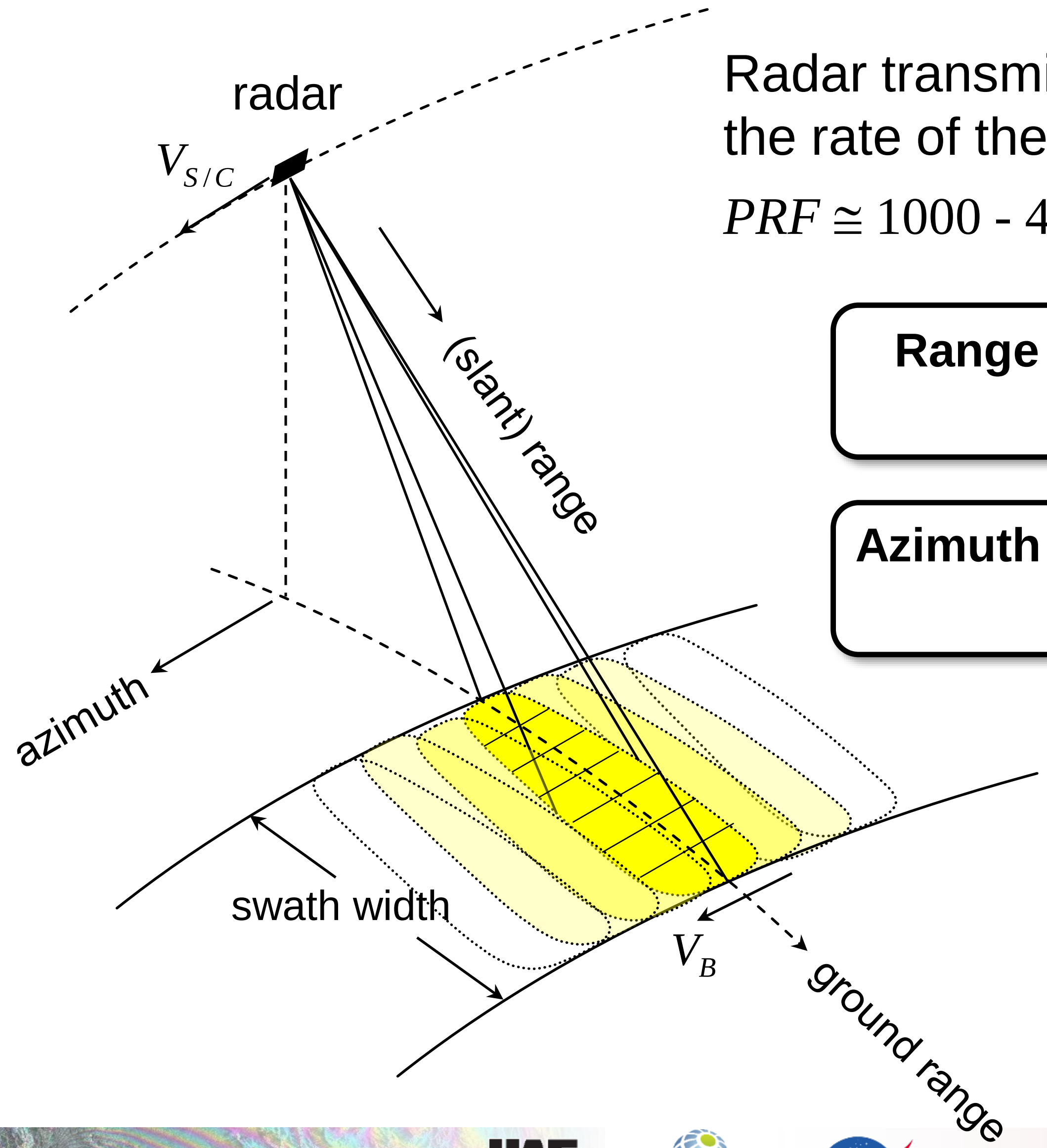


WHAT IS SYNTHETIC APERTURE RADAR (SAR)?

Radar Principle



How to Form a Radar Image



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

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

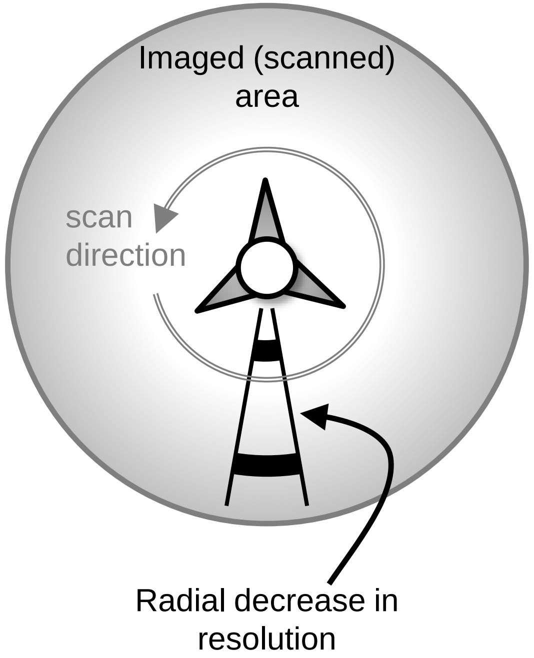
Range pixels:	pixel size defined by pulse width (radar principle)

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

Imaging the Surface with SLARs

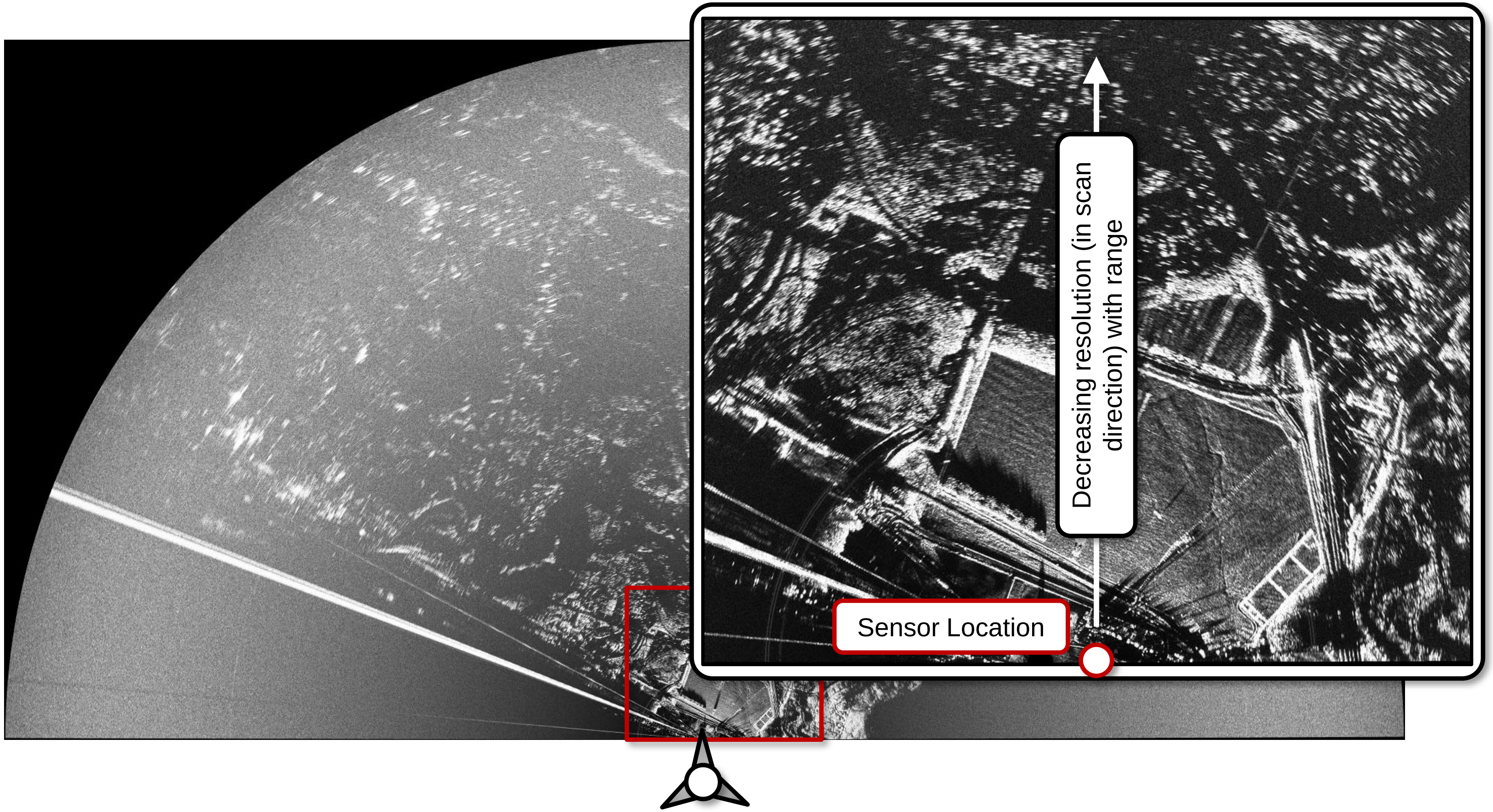
Scanning Ground-based Radar System as a SLAR Example

- Resolution defined by pulse length & length of antenna



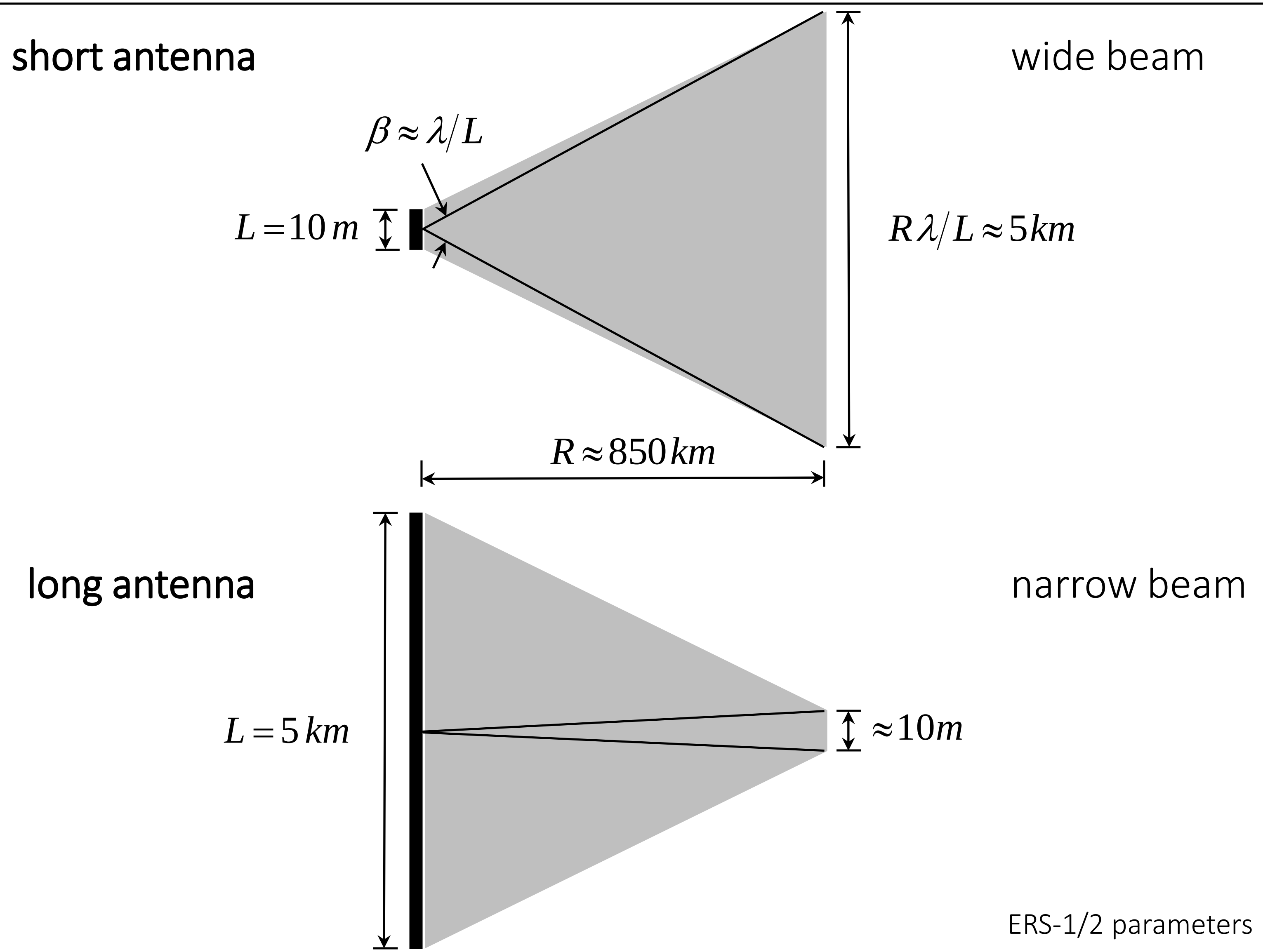
Example of Scanning Ground-Based Radar Acquisition

- 180 degrees scan angle – location: Fairbanks, Alaska



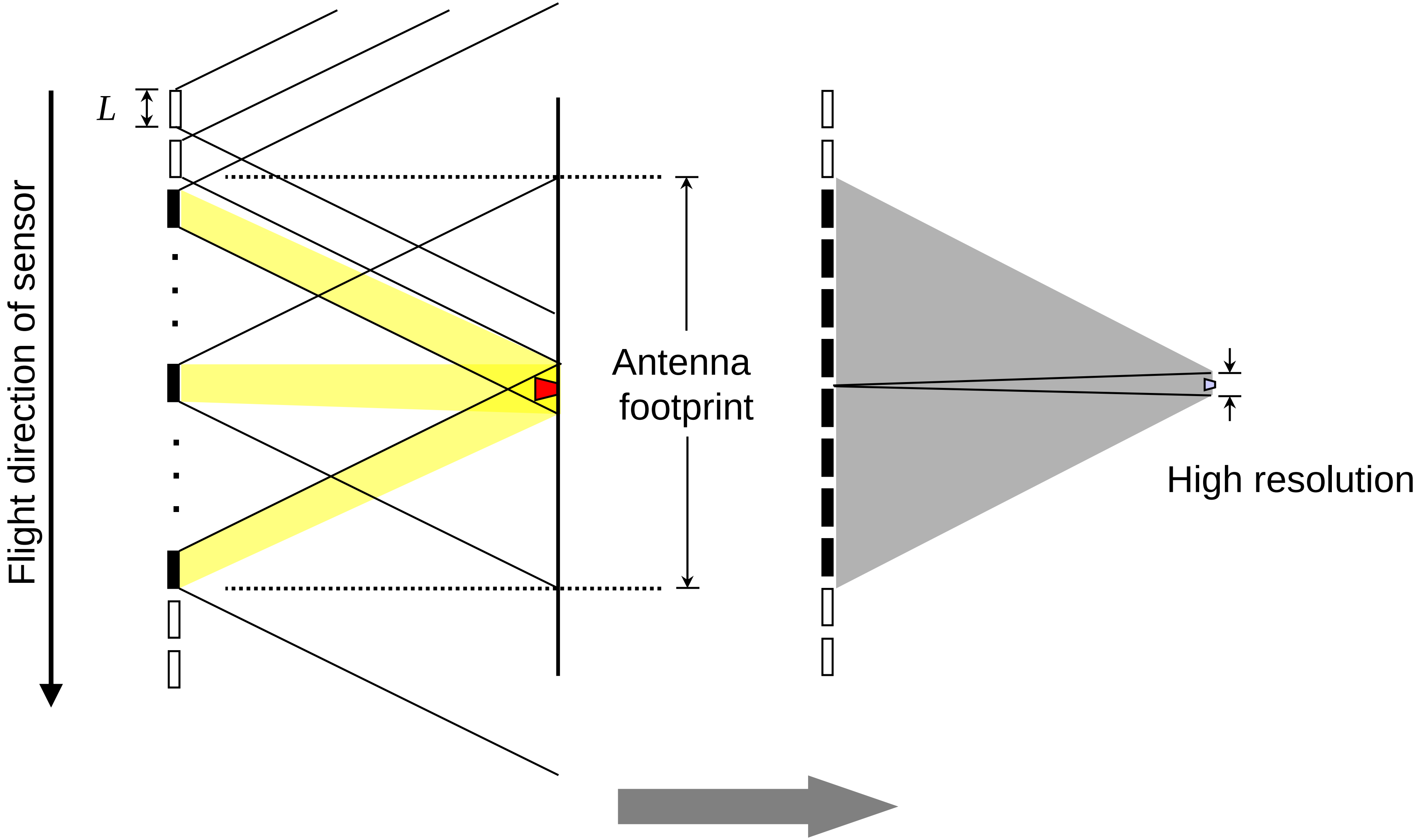
The Problem of SLARs – Azimuth Resolution Degrades with Distance

Antenna Size vs. Beam Width



ERS-1/2 parameters

Formation of a Synthetic Aperture — SAR Principle



Combination of overlapping acquisitions

Modern Radars (so called **SAR**’s) Enable Meter-Resolution Imaging from Space

Guelb er Richat, Mauritania

Shallow ring structures of limestone, dolomites, and brecchias (TerraSAR-X image, July 8, 2007, courtesy: DLR)

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

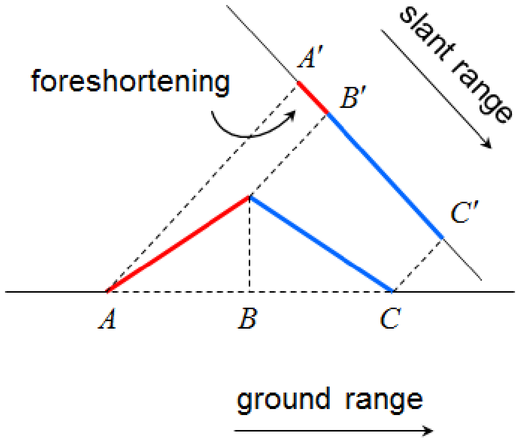
	ESA Biomass Mission Europe	NISAR USA/India
Operation Date	2018	2020
Frequency Band	P	S
Polarization	Polarimetric Interferometric	Polarimetric Interferometric
Spatial Resolution [m]	50-200	~3
Repeat Cycle [days]	25	12

GEOMETRIC PROPERTIES OF SAR

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

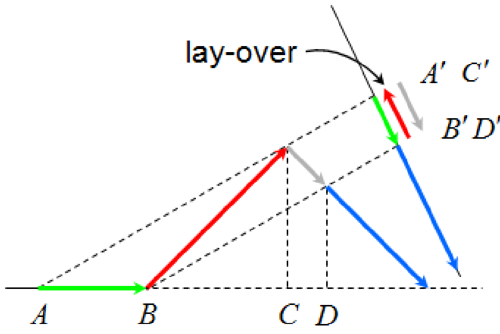
Foreshortening

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



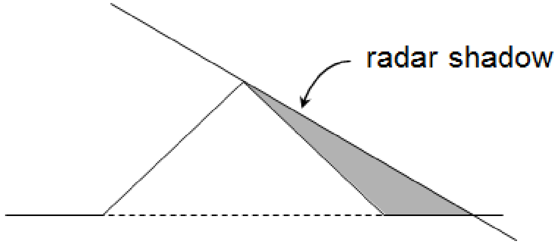
Layover

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



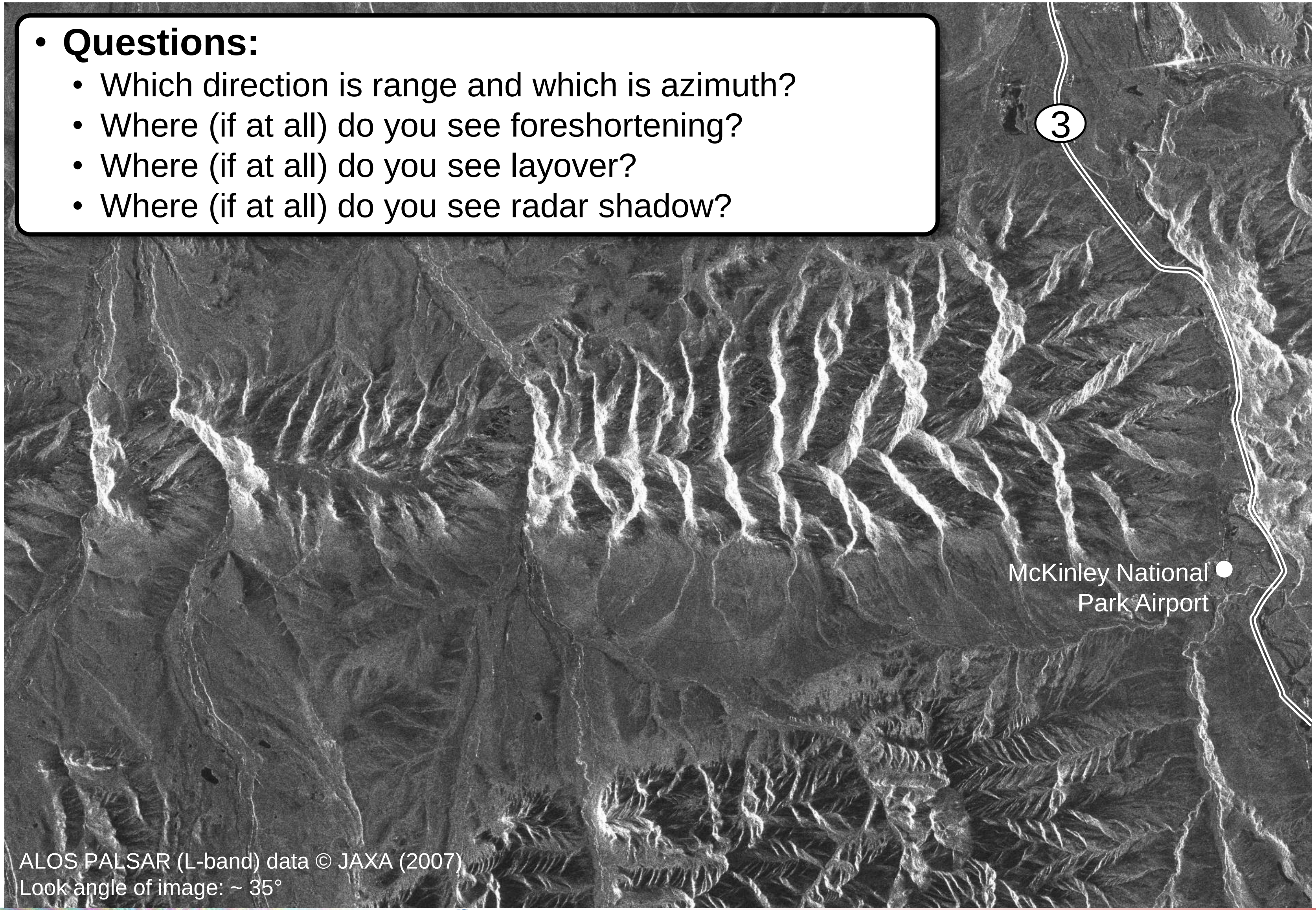
Shadow

- 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

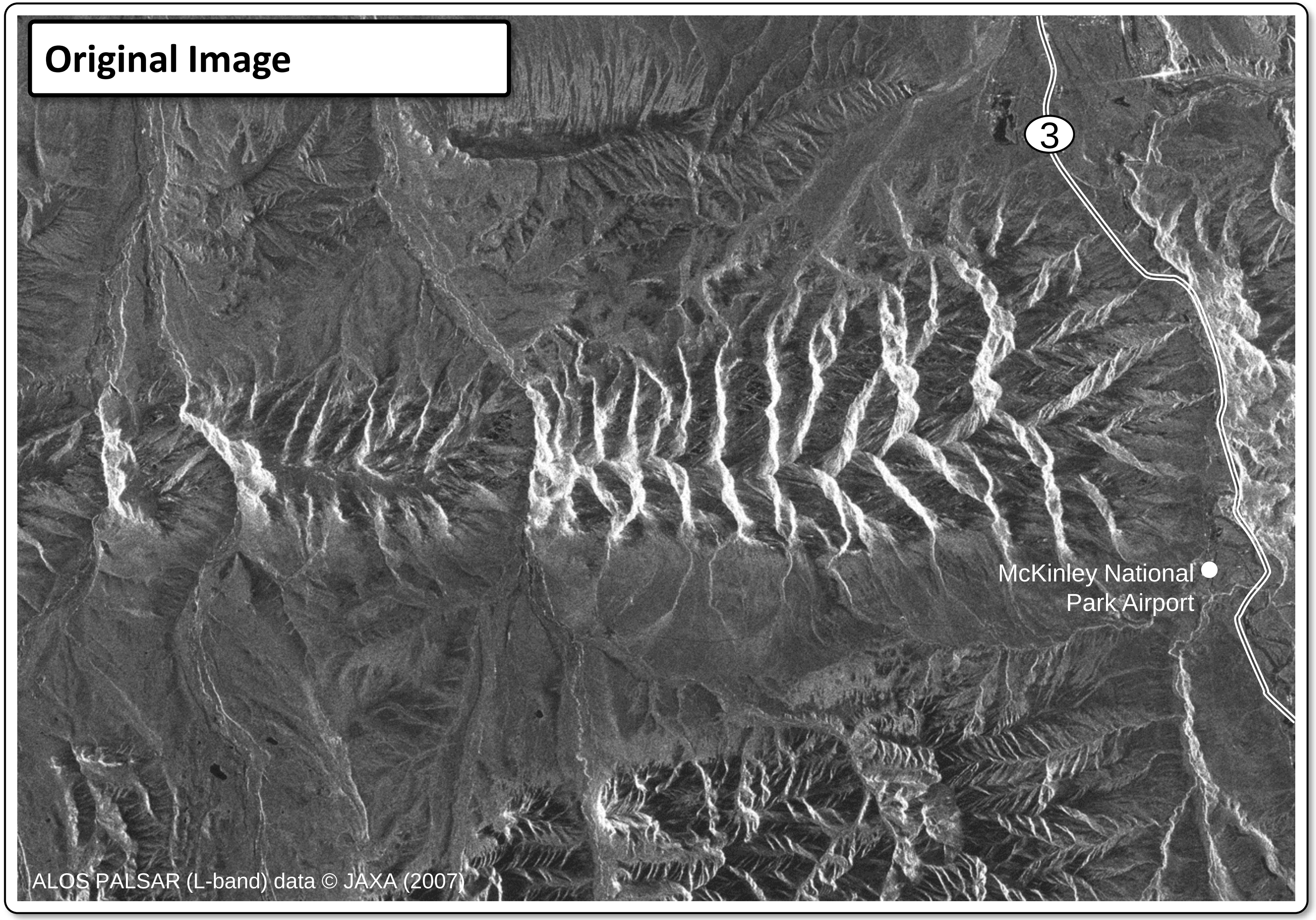
Geometric Terrain Correction

- **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

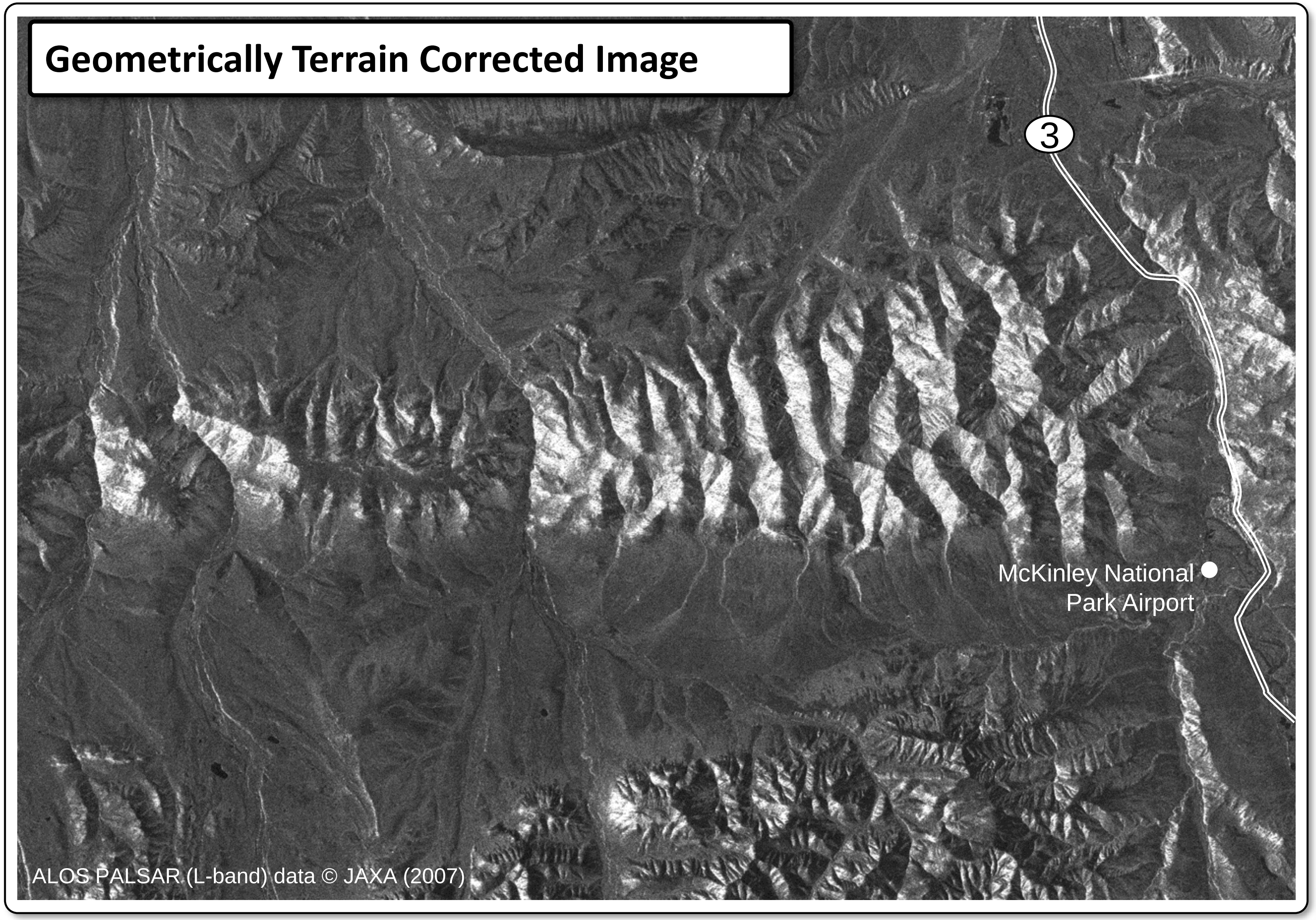
- **GTC problem:** What are the image gray values in every pixel of the output (geocoded) image given the input image and the DEM?

- **Geocoding *including GTC* uses a Digital Elevation Model to project every image pixel onto its right location on the earth surface**

Geometric Terrain Correction Example (I)



Geometric Terrain Correction Example (II)

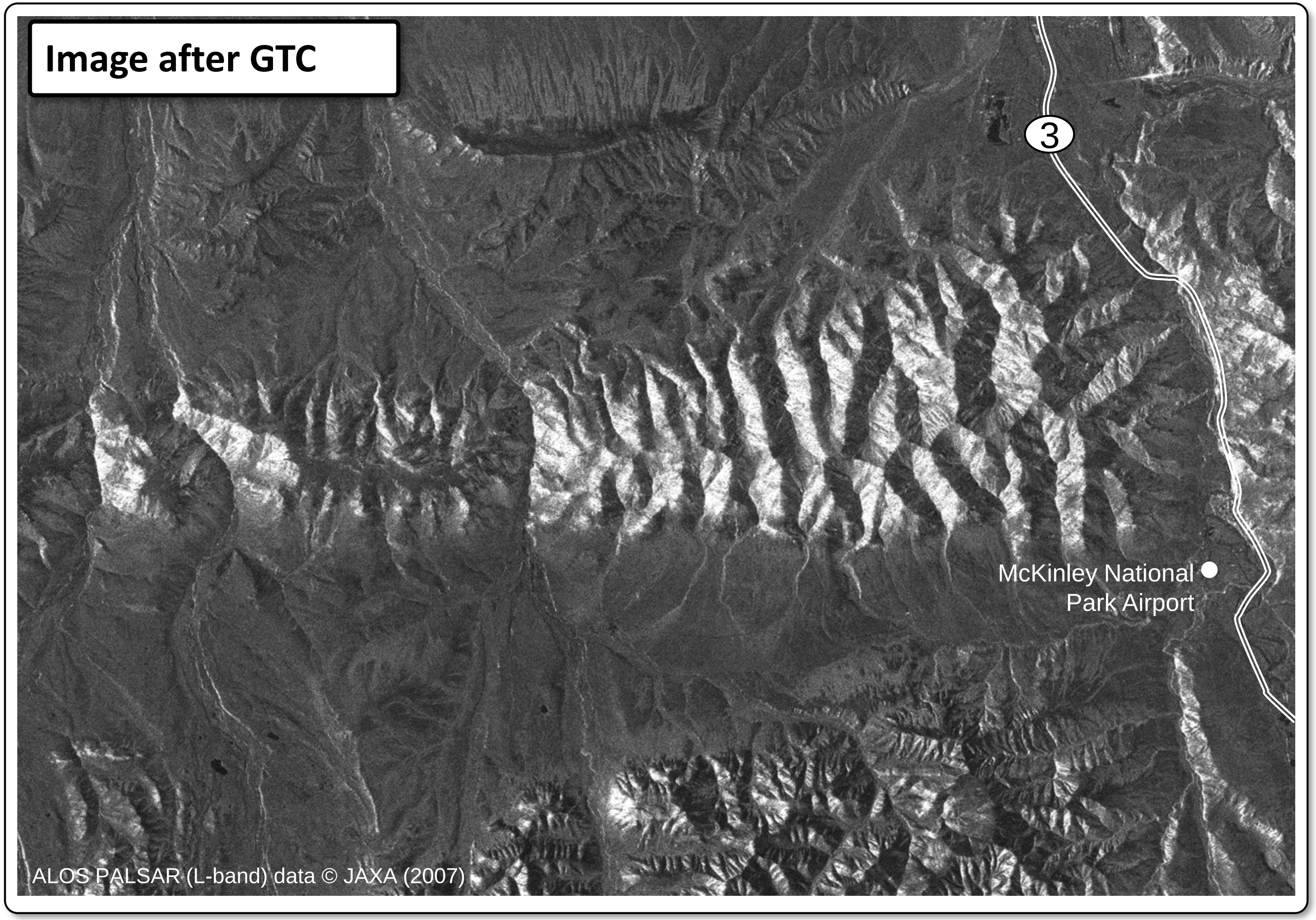


Radiometric Terrain Correction

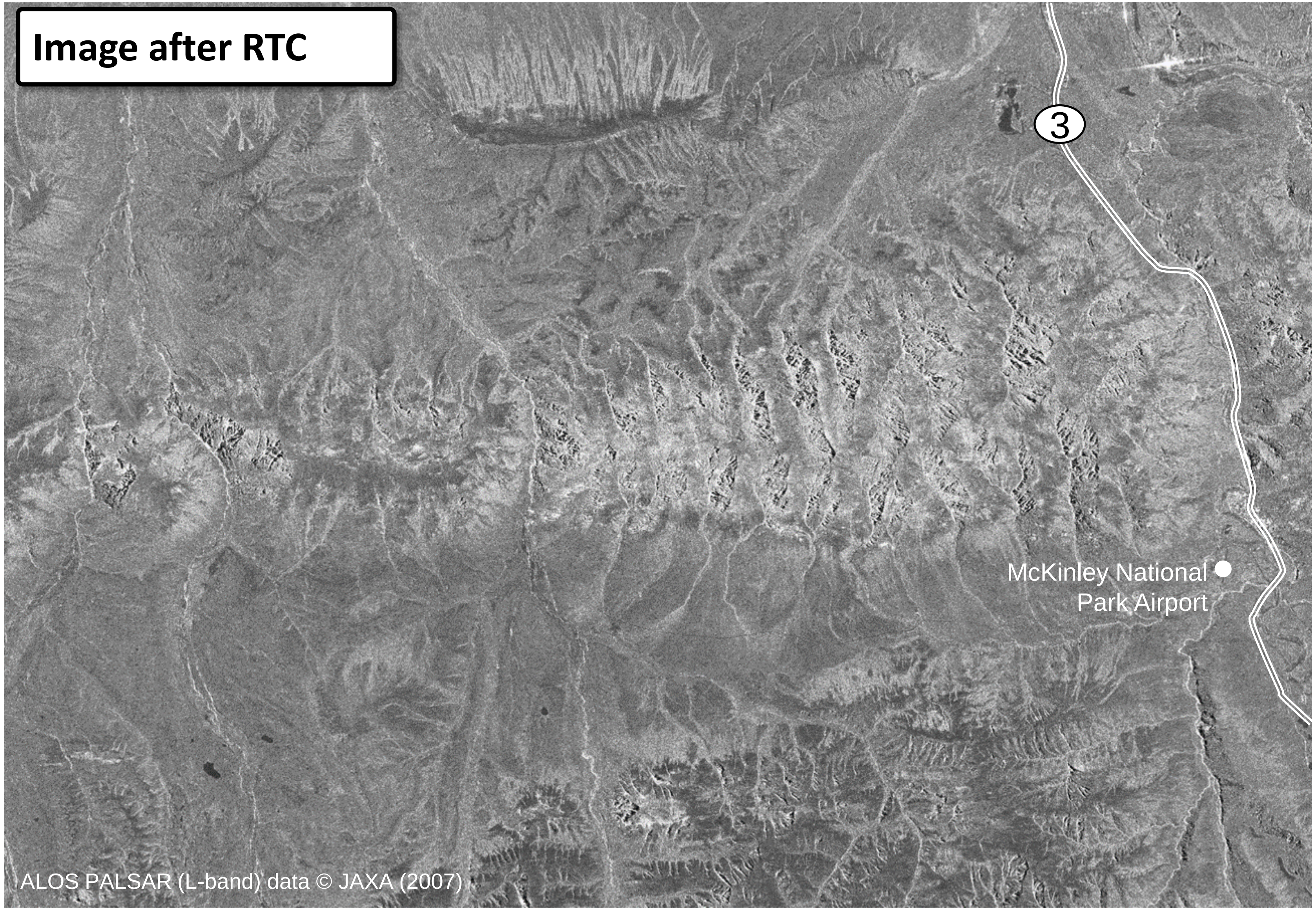
- **Problem:** Sensor facing slopes appear overly bright in radar images.
- **Cause:** Pixel Size on sensor-facing slopes is larger → more ground is integrated into pixel → brightness goes up

- **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

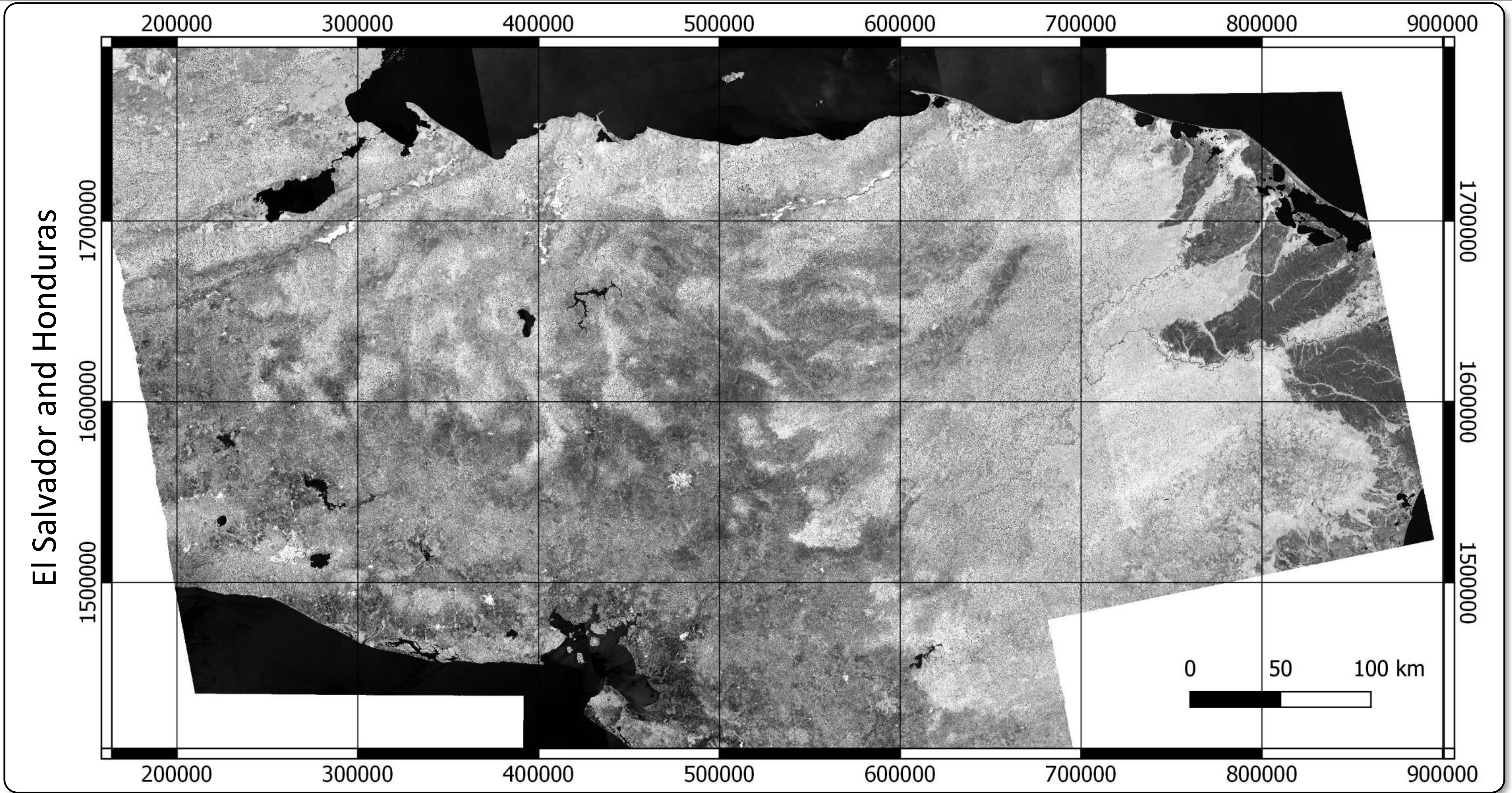
Radiometric Terrain Correction Example (I)



Radiometric Terrain Correction Example (II)



Sentinel-1 RTC images over El Salvador and Honduras



HOW SAR SEES THE WORLD

SAR Characteristics Relevant for Ecosystems Monitoring

- **SAR backscatter values are determined by both sensor and target characteristics**

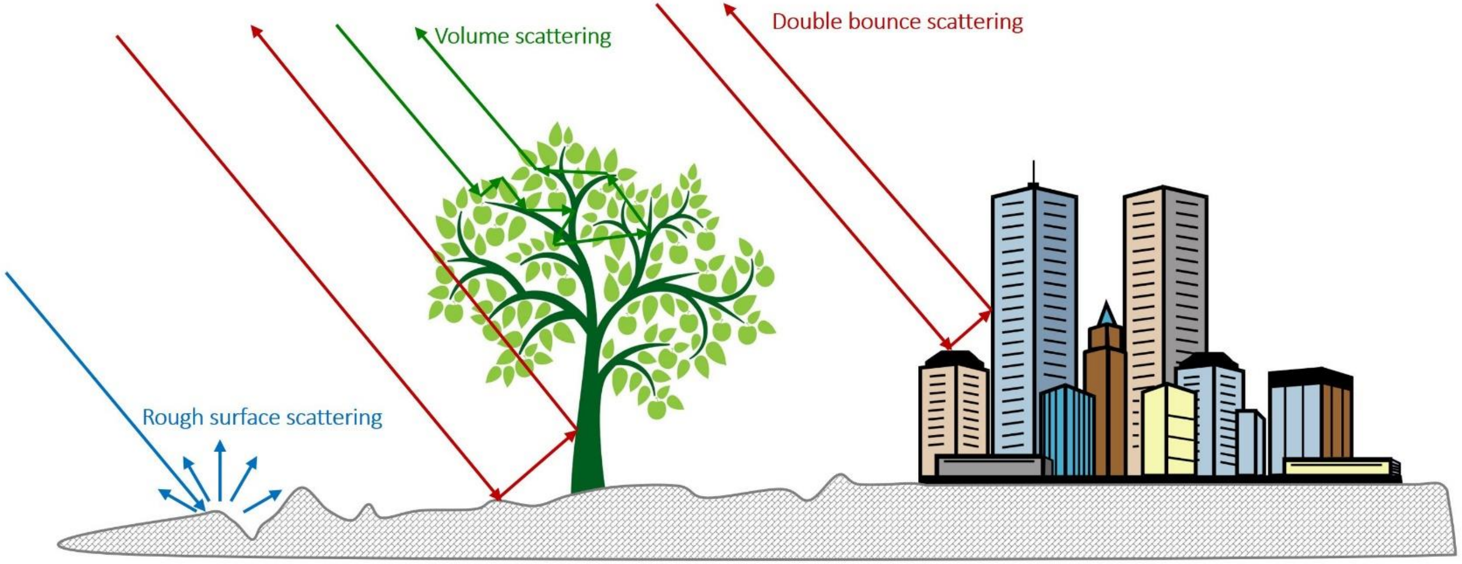
- **Sensor Characteristics:**
  - frequency/wavelength of the SAR,
  - polarization of the transmitted and received SAR signal,
  - incidence angle of the radar beam interacting with the ground,
  - and look direction of the sensor

Especially for time series analysis:
Use data with same sensor characteristics
→ avoid misinterpretation of sensor characteristics as change

- **Target Characteristics:**
  - **Surface roughness and vegetation structure** → more roughness and more structure increase SAR backscatter
  - **Increased moisture in soils and vegetation** → increase SAR backscatter
  - Standing open water → typically very dark - However, wind and currents can rough up water and increase brightness especially for short wavelength (X- and C-band) observations
  - At longer wavelengths, double-bounce effect under canopies can have strong backscatter signal (see Slide 9)

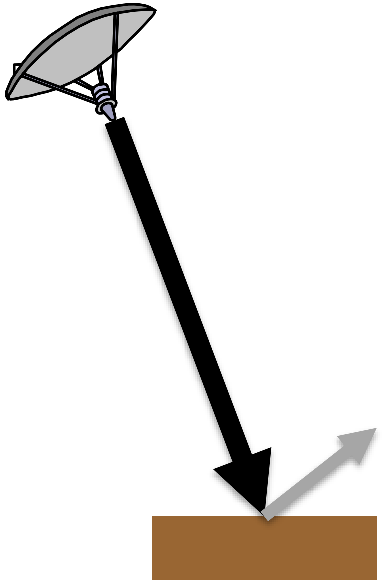
Radar Interaction with Objects on the Surface

- **At Radar wavelength, scattering is very physical and can be described as a series of bounces on scattering interfaces**
- **Three main scattering mechanisms dominate**:
  - **Scattering on (rough) surfaces**: **Water**, bare soils, roads – Scattering strongly dependent on surface roughness and sensor wavelength (see Slide #6)
  - **Double-bounce scattering**: Buildings, tree trunks, light poles – little wavelength dependence
  - **Volume Scattering**: Vegetation; dry soils with high penetration – strongly dependent on sensor wavelength and dielectric properties of medium



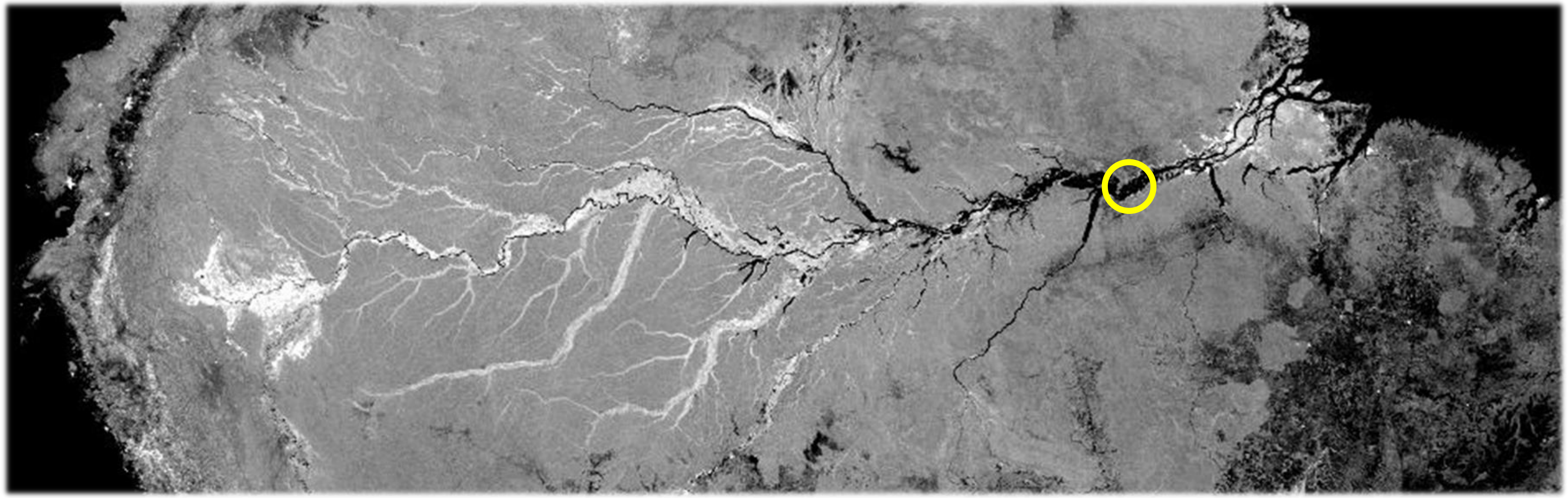
Examples of Radar Interaction

Smooth Surface Reflection (Specular Reflection)



Smooth, level surface
(open water, road)

SMAP Radar Mosaic of the Amazon Basin
April 2015 (L-band, HH, 3 km)



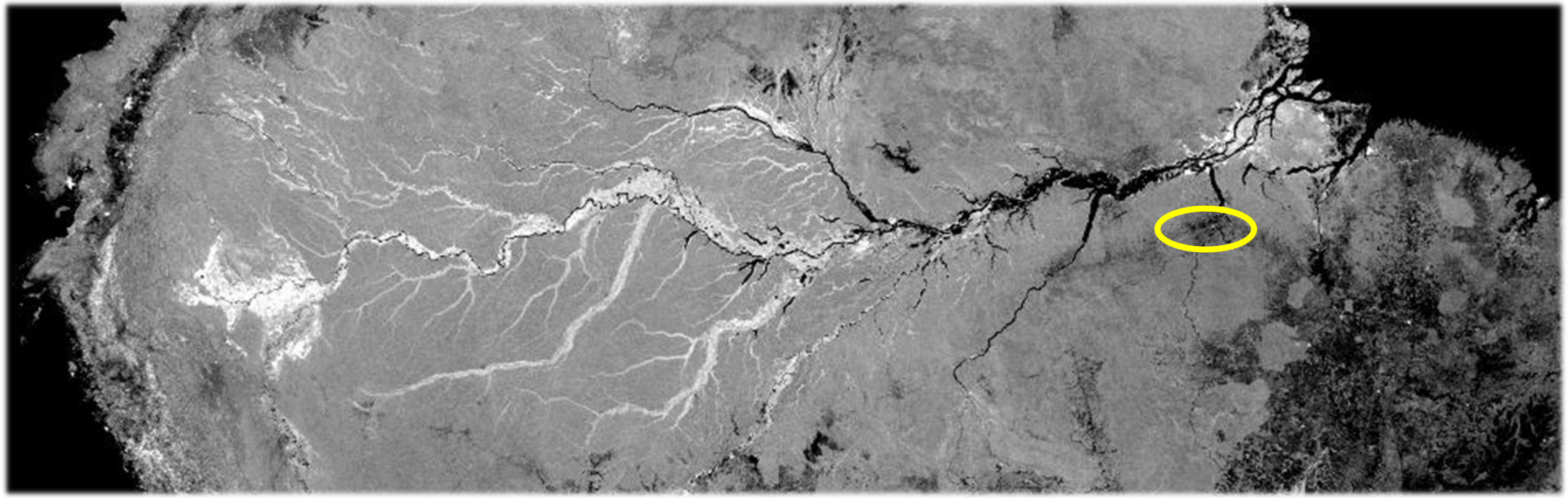
Pixel Color

Examples of Radar Interaction

Rough Surface Scattering

rough bare surface
(deforested areas, tilled agricultural fields)

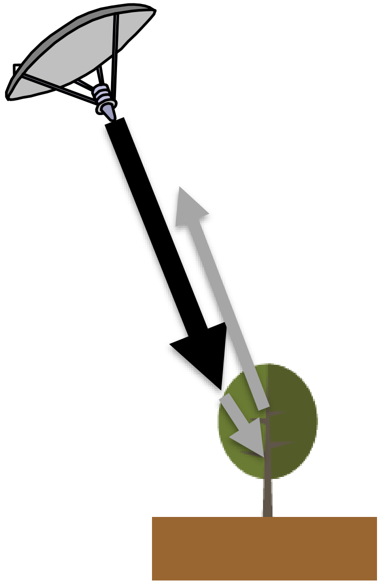
SMAP Radar Mosaic of the Amazon Basin
April 2015 (L-band, HH, 3 km)



Pixel Color

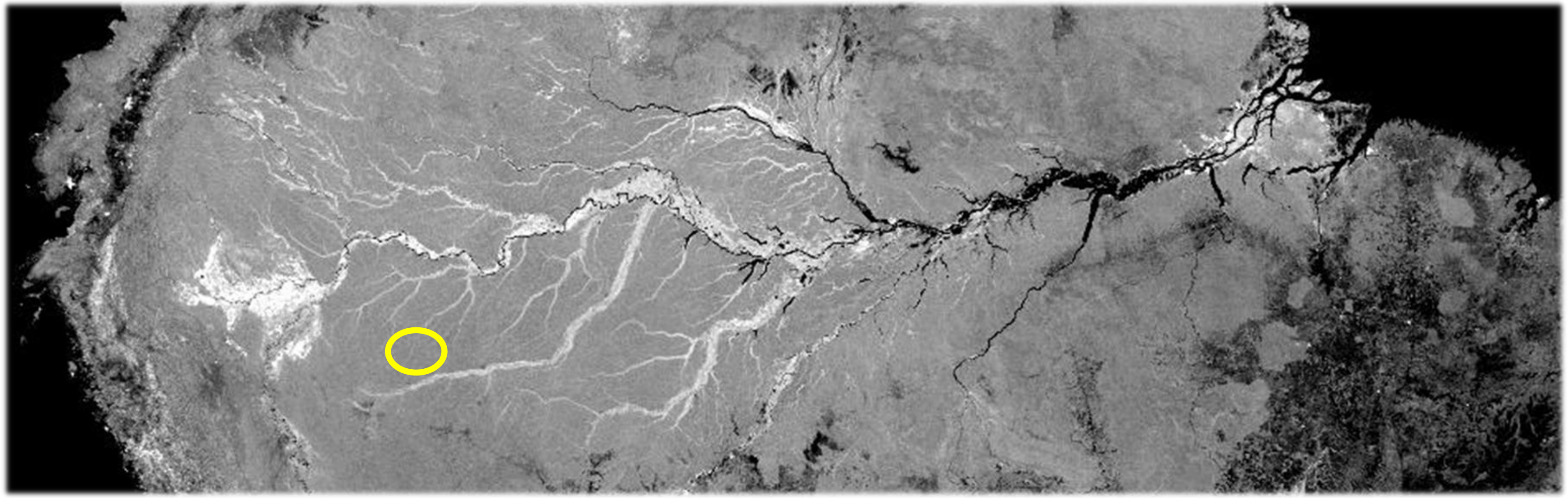
Examples of Radar Interaction

Volume Scattering by Vegetation



Vegetation

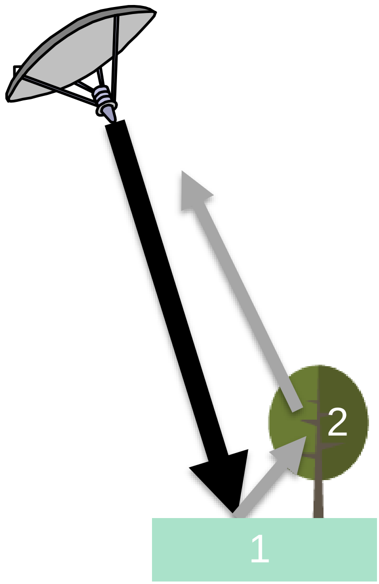
SMAP Radar Mosaic of the Amazon Basin
April 2015 (L-band, HH, 3 km)



Pixel Color

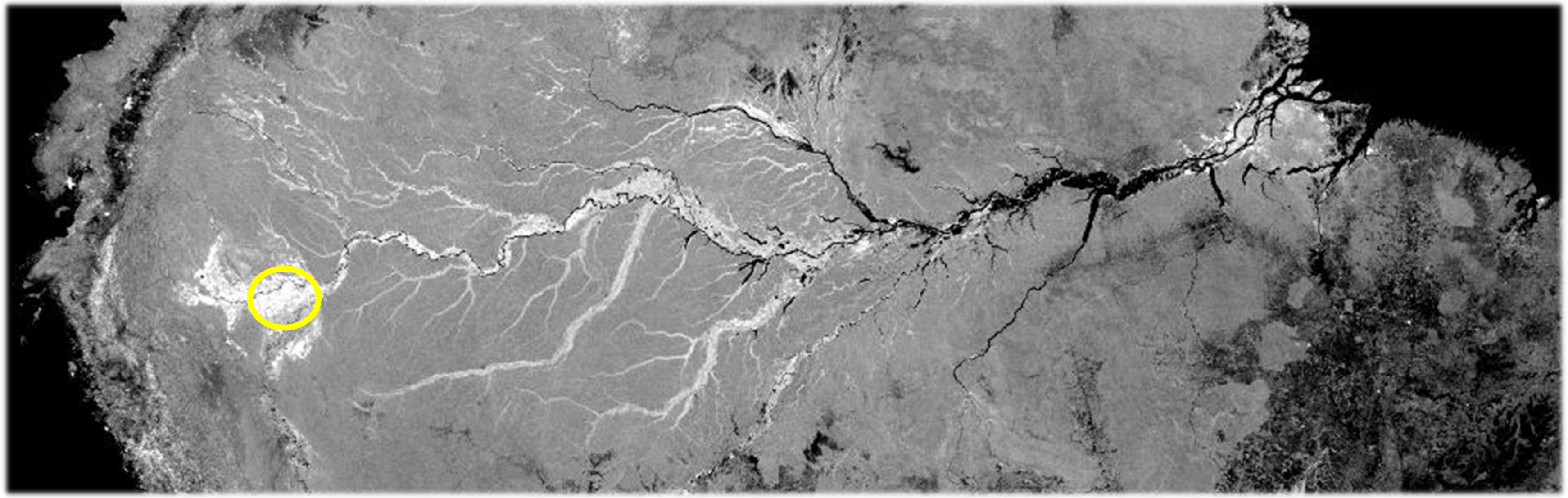
Examples of Radar Interaction

Double Bounce Scattering



Inundated Vegetation

SMAP Radar Mosaic of the Amazon Basin
April 2015 (L-band, HH, 3 km)



Pixel Color

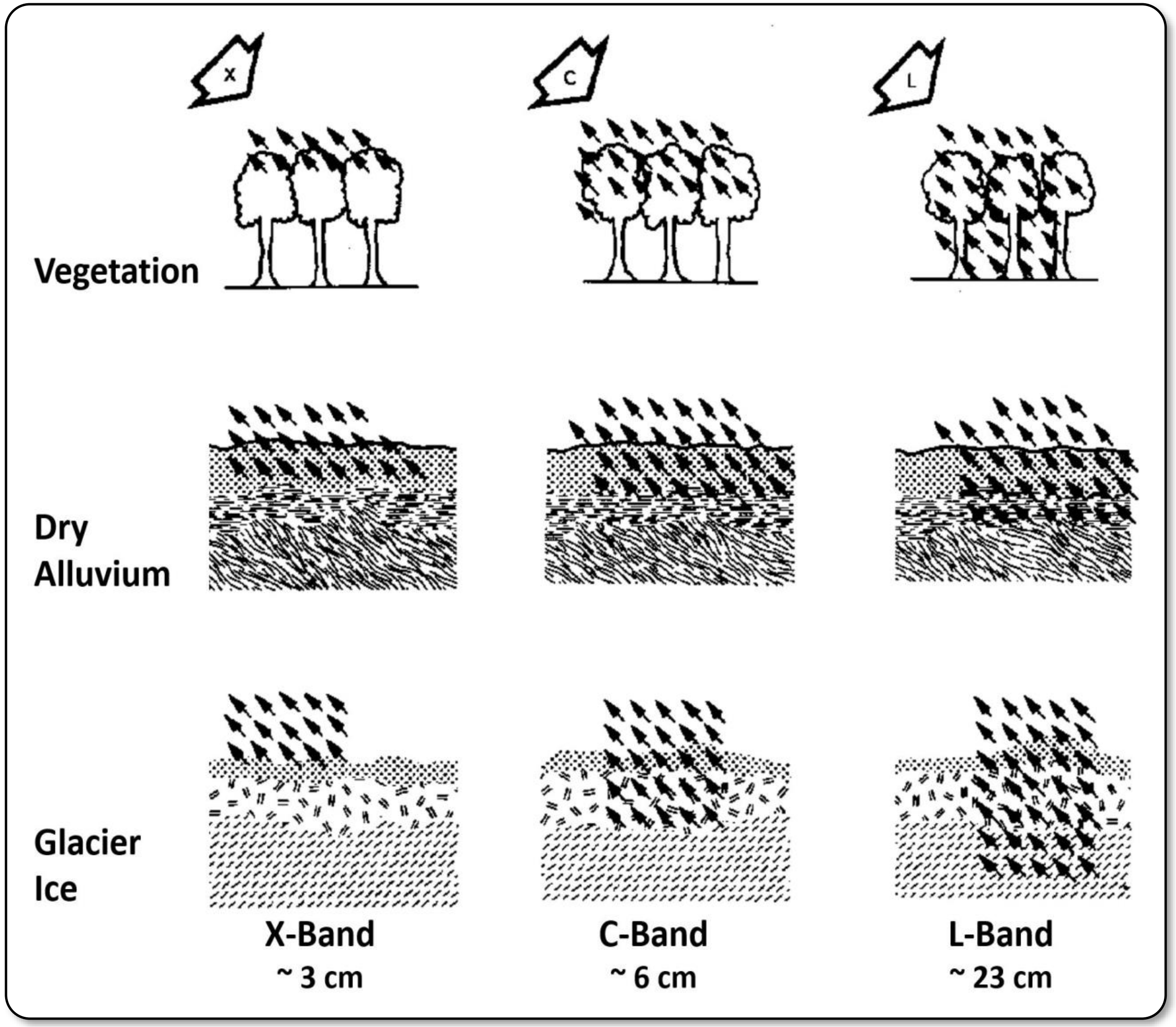
Influence of Wavelength on Signal Penetration

- **Penetration into vegetation and soils increases with sensor wavelength**

L-band penetration > C-band > X-band

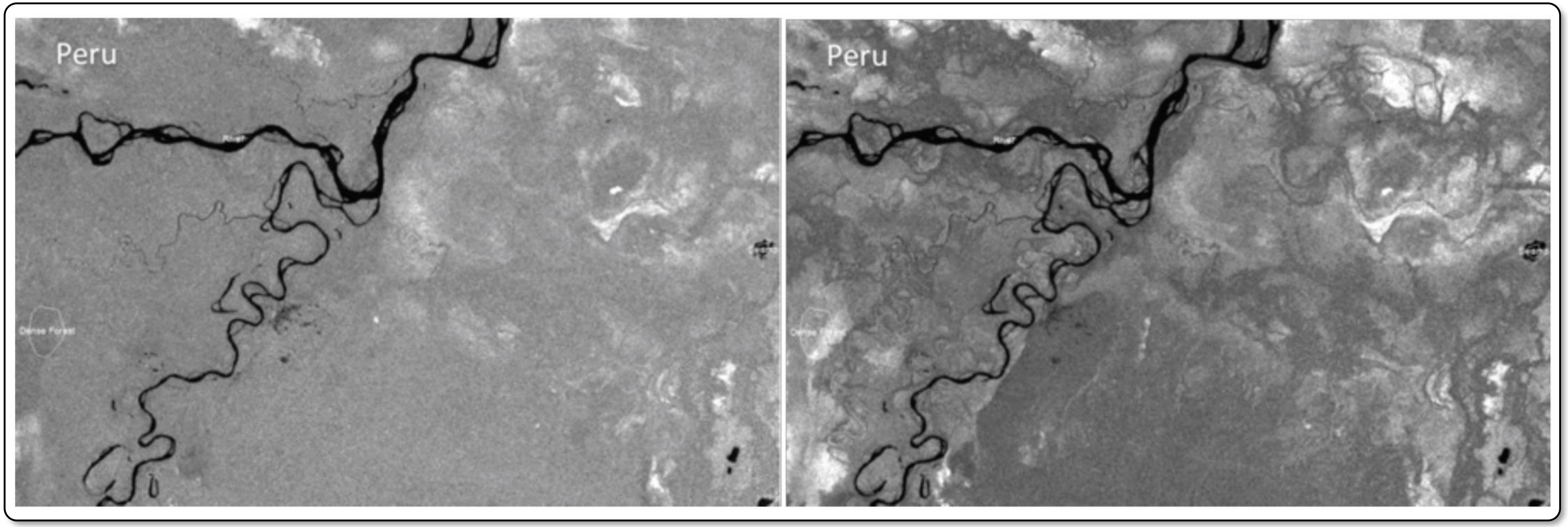
- **For vegetated areas:**
  - X-band SAR mostly scatters at the tops of tree canopies
  - C- and L-band signals penetrate increasingly → more volume scattering & better for vegetation characterization
  - Longer wavelength → improved mapping of inundation under forest canopies

- **Penetration into soils also strongly dependent on soil moisture content** (see slide 21)

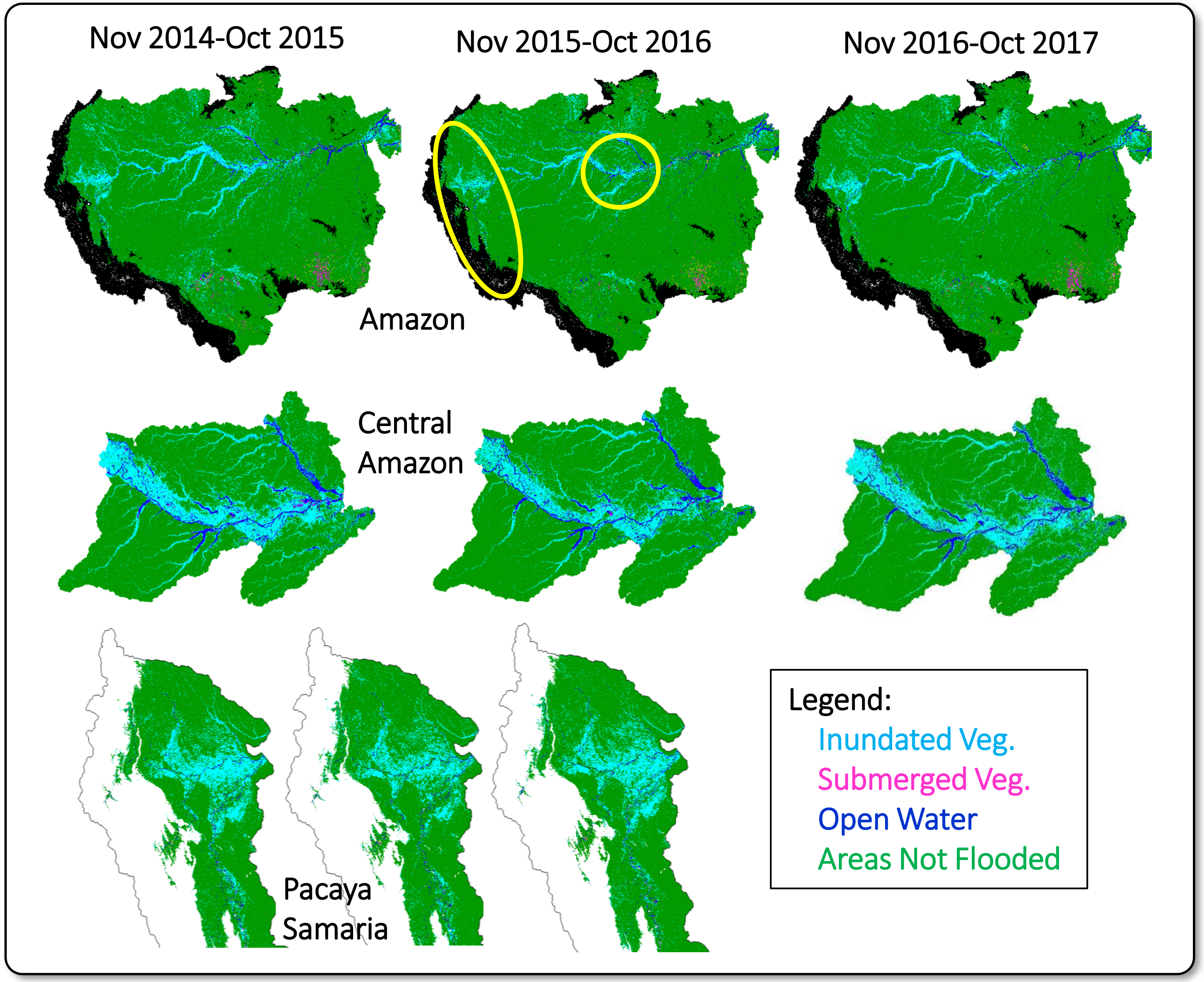


Inundation under Vegetation at L-band Frequencies

- **Increased double-bounce effect from bellow-canopy flooding at L-HH polarization from ALOS-1:**
  - **Left**: Low-water season and
  - **Right**: High-water season
  - Note the brightening of the forests during inundation

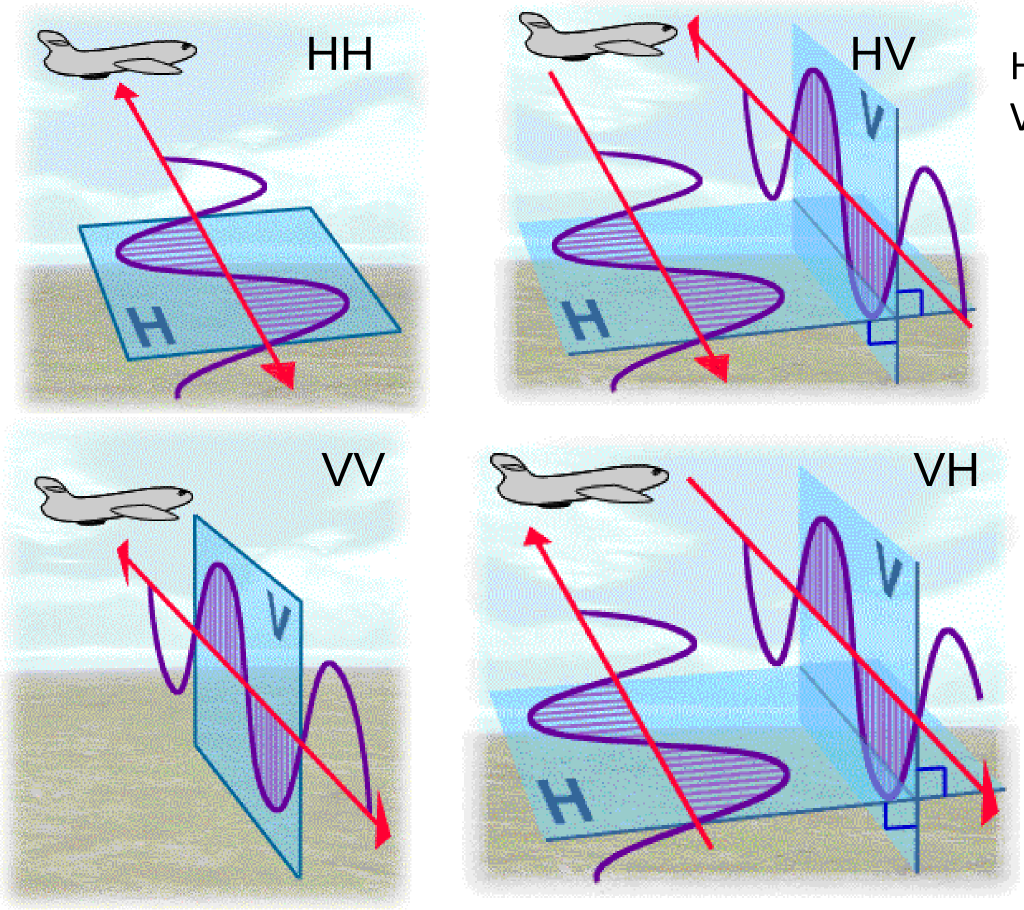


Annual Maximum Inundation in the Amazon derived from L-band HH and HV ALOS PALSAR-2 Data



Different SAR Polarizations See Different Things

Horizontal Transmit
Horizontal Receive



Horizontal Transmit
Vertical Receive

Vertical Transmit
Vertical Receive

Vertical Transmit
Horizontal Receive

Polarimetric Dependence of Scattering Principles

Relative scattering strength by polarization:

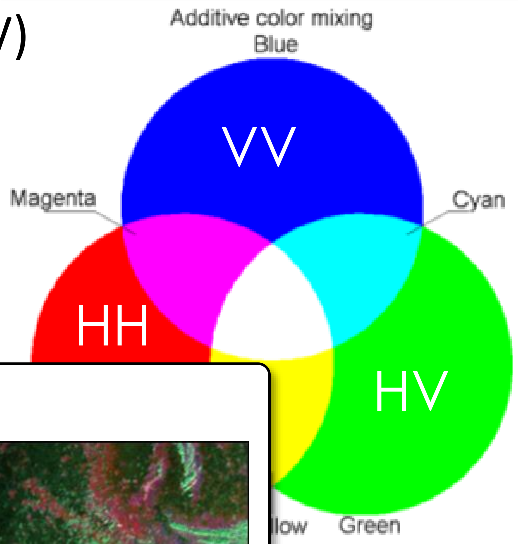
- **Pure Surface Scattering:** $|S_{VV}| > |S_{HH}| > |S_{HV}|\ or\ |S_{VH}|$
- **Double Bounce Scattering:** $|S_{HH}| > |S_{VV}| > |S_{HV}|\ or\ |S_{VH}|$
- **Volume Scattering:** main source of $|S_{HV}|\ and\ |S_{VH}|$

Legend

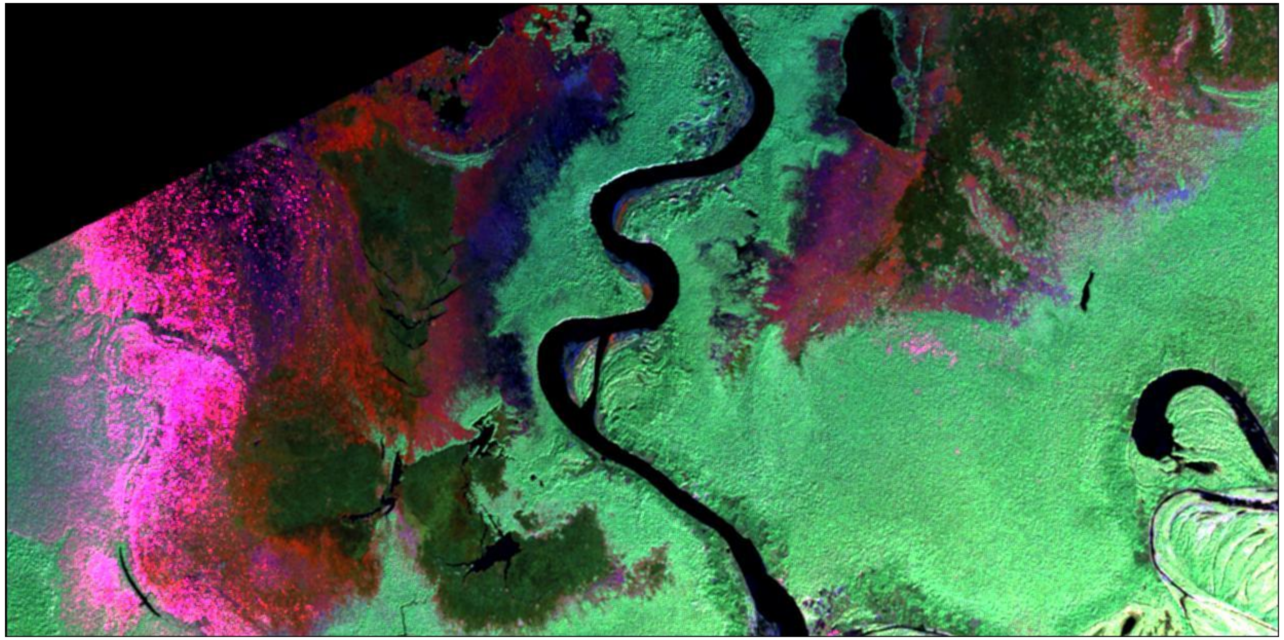
Low Radar Brightness ($|S|$) — High Radar Brightness ($|S|$)

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

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

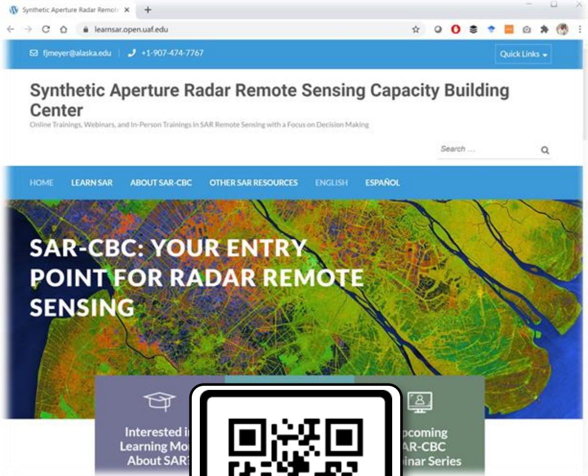


RGB Combination of Polarizations



Selected Additional SAR Training Resources

SAR-CBC is Funded by NASA Applied Sciences



SCAN ME

Information on project partners and activities

Online SAR Course on "Synthetic Aperture Radar: Hazards" on edX

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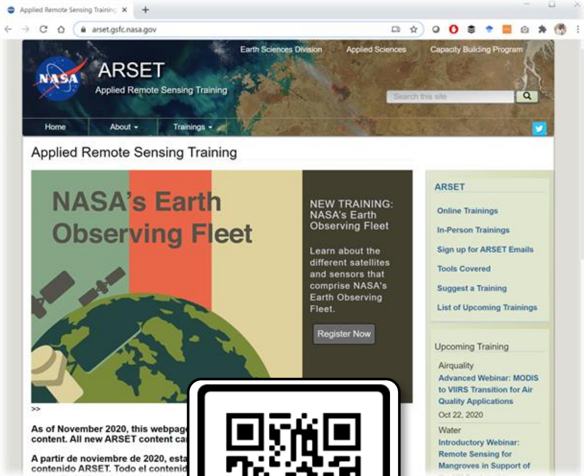
Fully remote accessible

NASA Applied Remote Sensing Training



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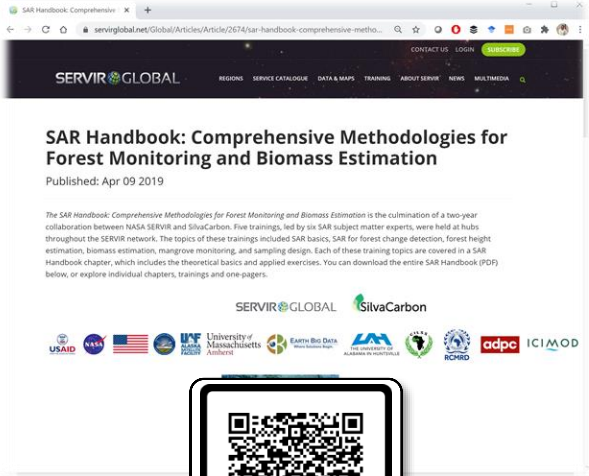
Virtual trainings on all things remote sensing

The SAR Handbook



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Free-and-open book on SAR Remote Sensing

QUESTIONS?

UP NEXT: INTRODUCTION TO THE OPENSARLAB