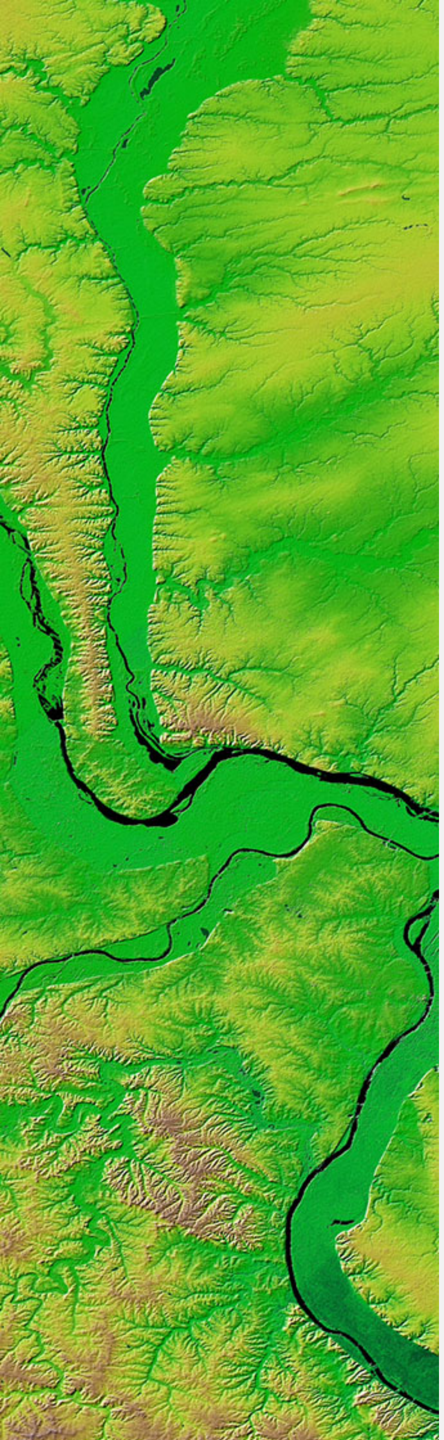


National Aeronautics and
Space Administration

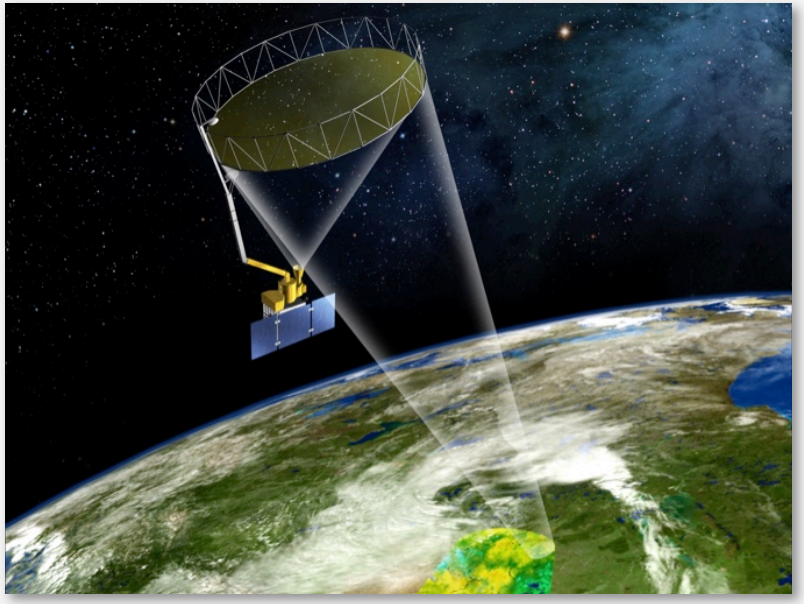
ARSET

Applied Remote Sensing Training

http://arset.gsfc.nasa.gov

@NASAARSET

Introduction to SAR



Erika Podest and Amita Mehta

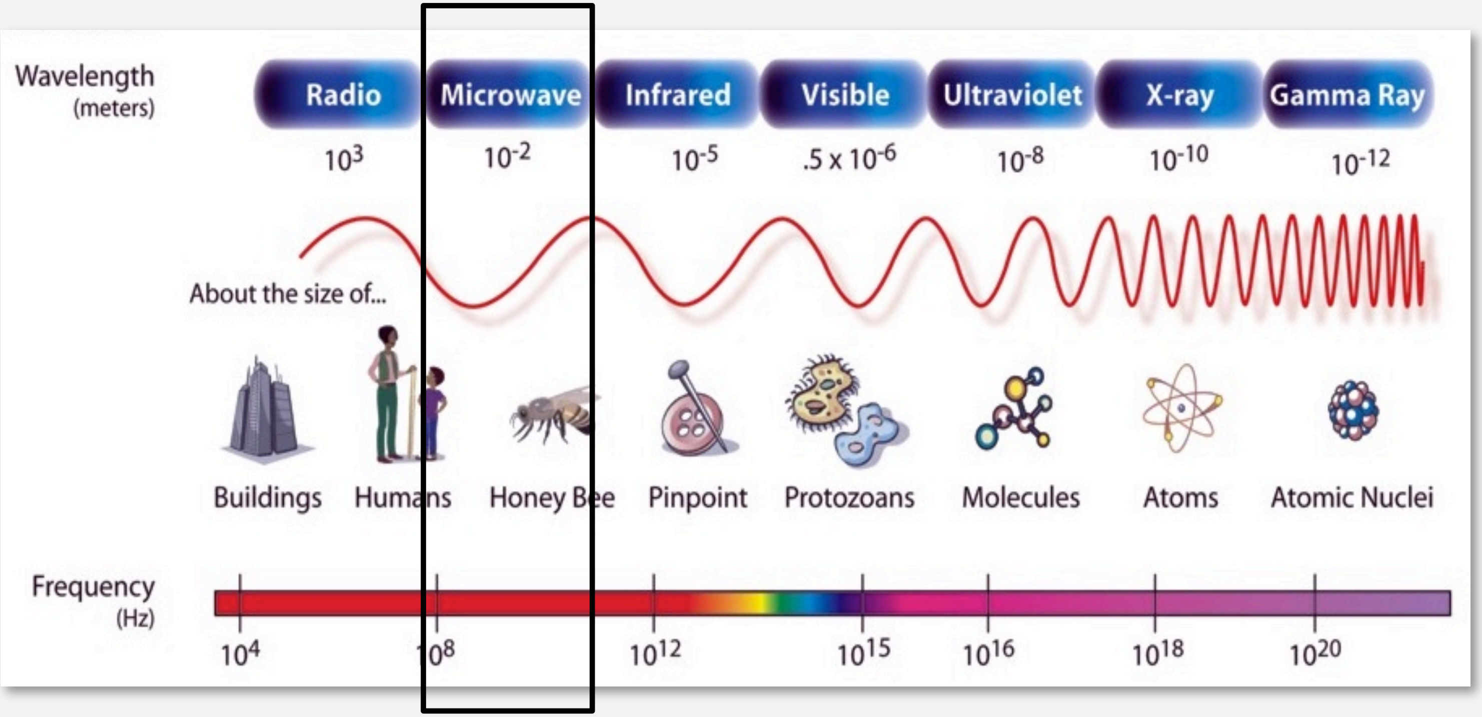
Learning Objectives

By the end of this presentation, you will be able to:

- Understand the physics of SAR image formation
- Describe the interaction of SAR with the land surface
- Describe the necessary data preprocessing
- Explain what information and data are available from SAR

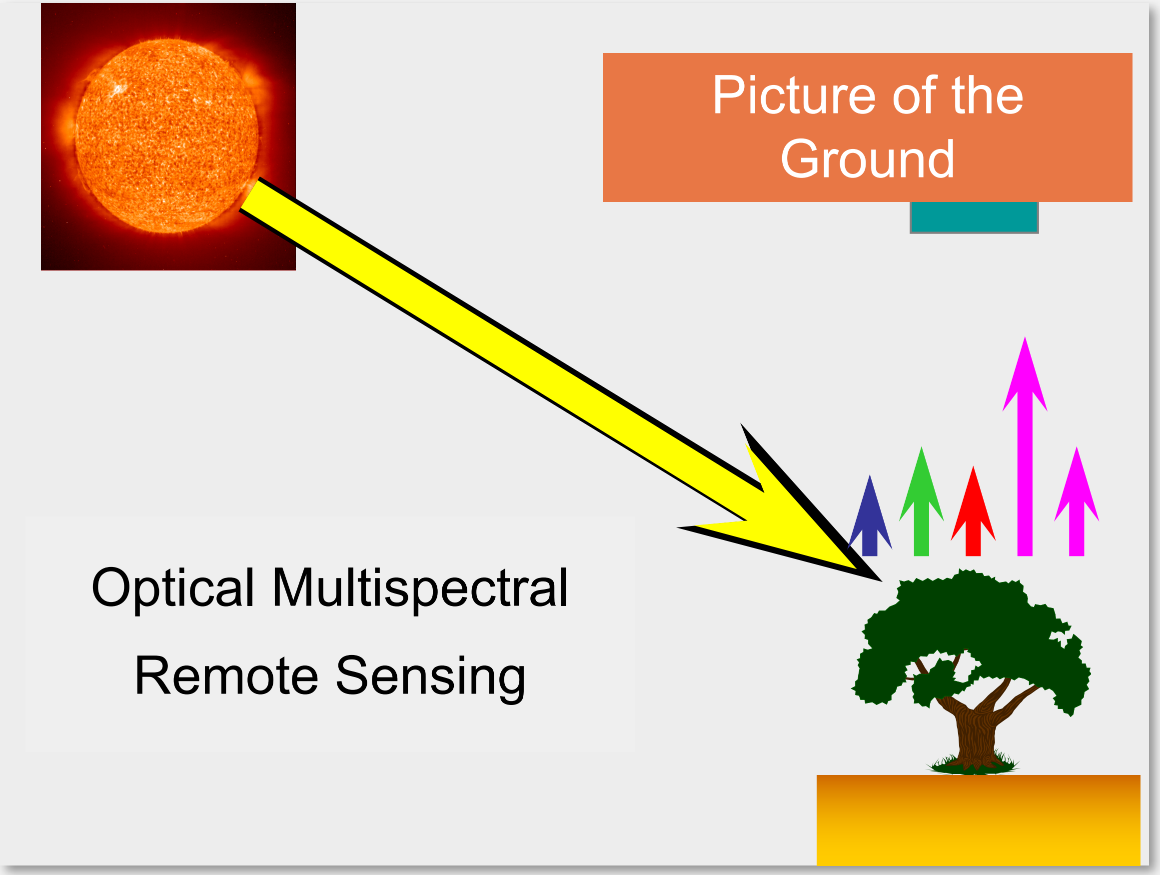
The Electromagnetic Spectrum

- The surface of the Earth cannot be imaged with visible or infrared sensors when there are clouds or dense vegetation
- Optical sensors measure reflected solar light and only function in the daytime
- Microwaves can penetrate clouds and vegetation, and can operate in day or night conditions

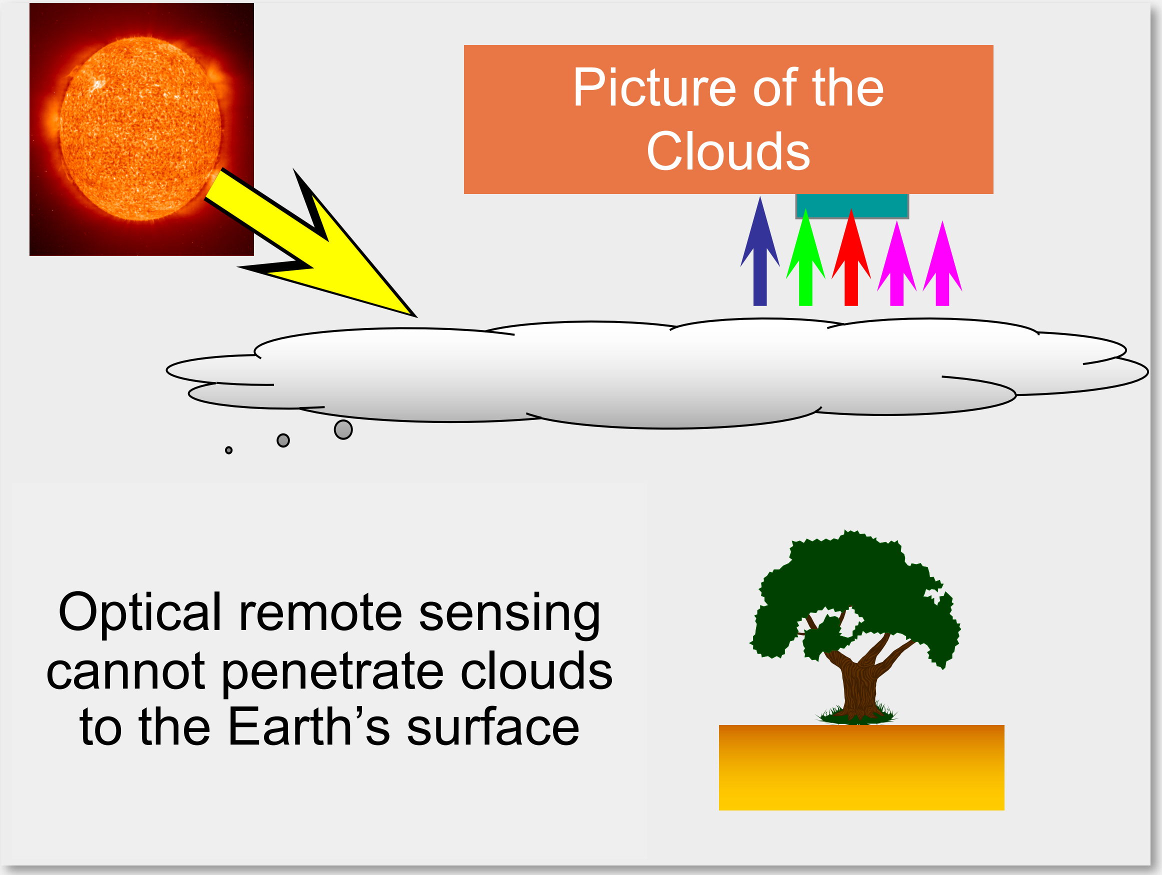


Optical Remote Sensing: Advantages and Disadvantages

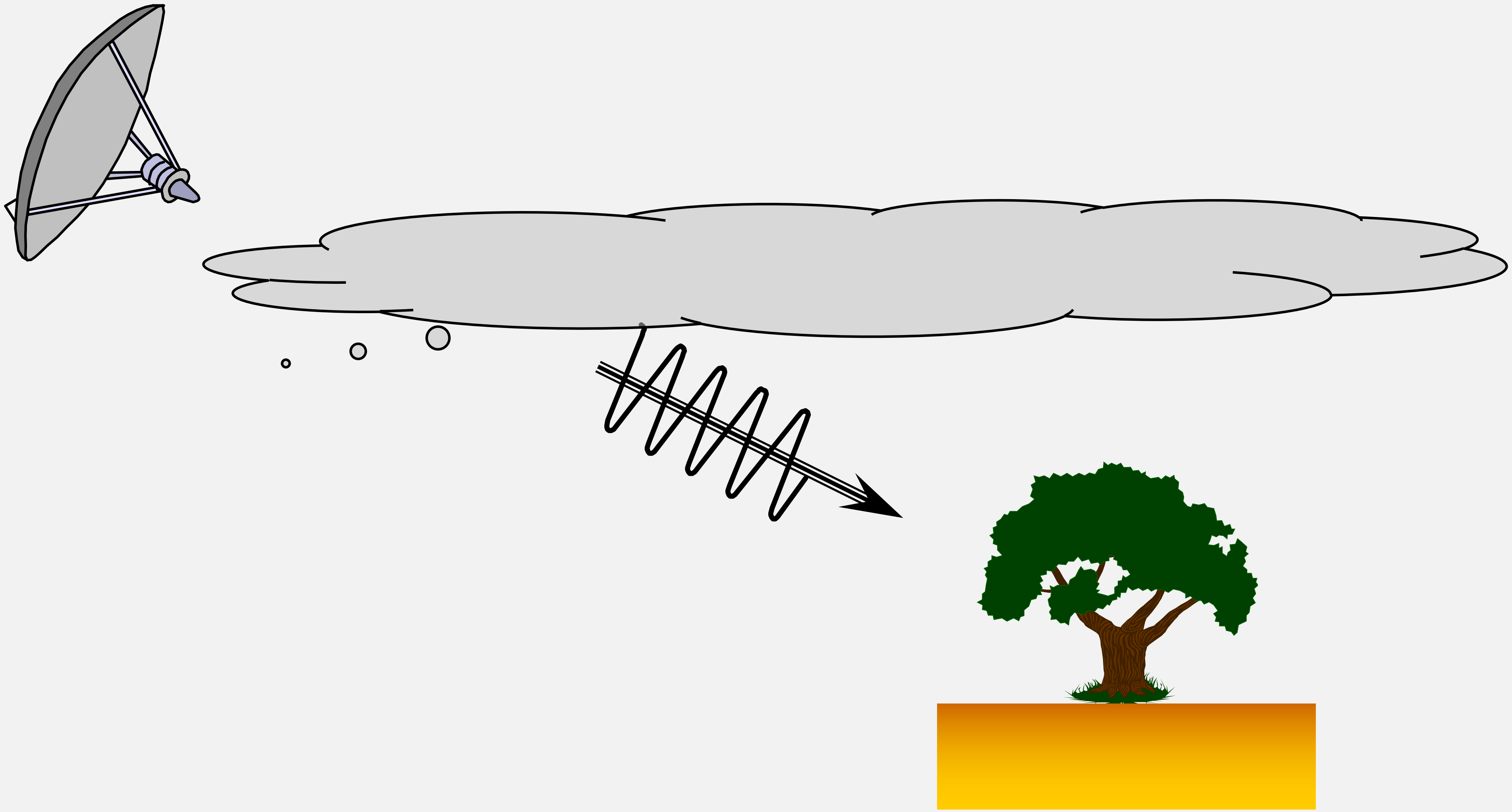
Advantages



Disadvantages



Radar: Advantages



Remote Sensing Example of Optical vs. Radar

Volcano in Kamchatka, Russia, Oct 5, 1994

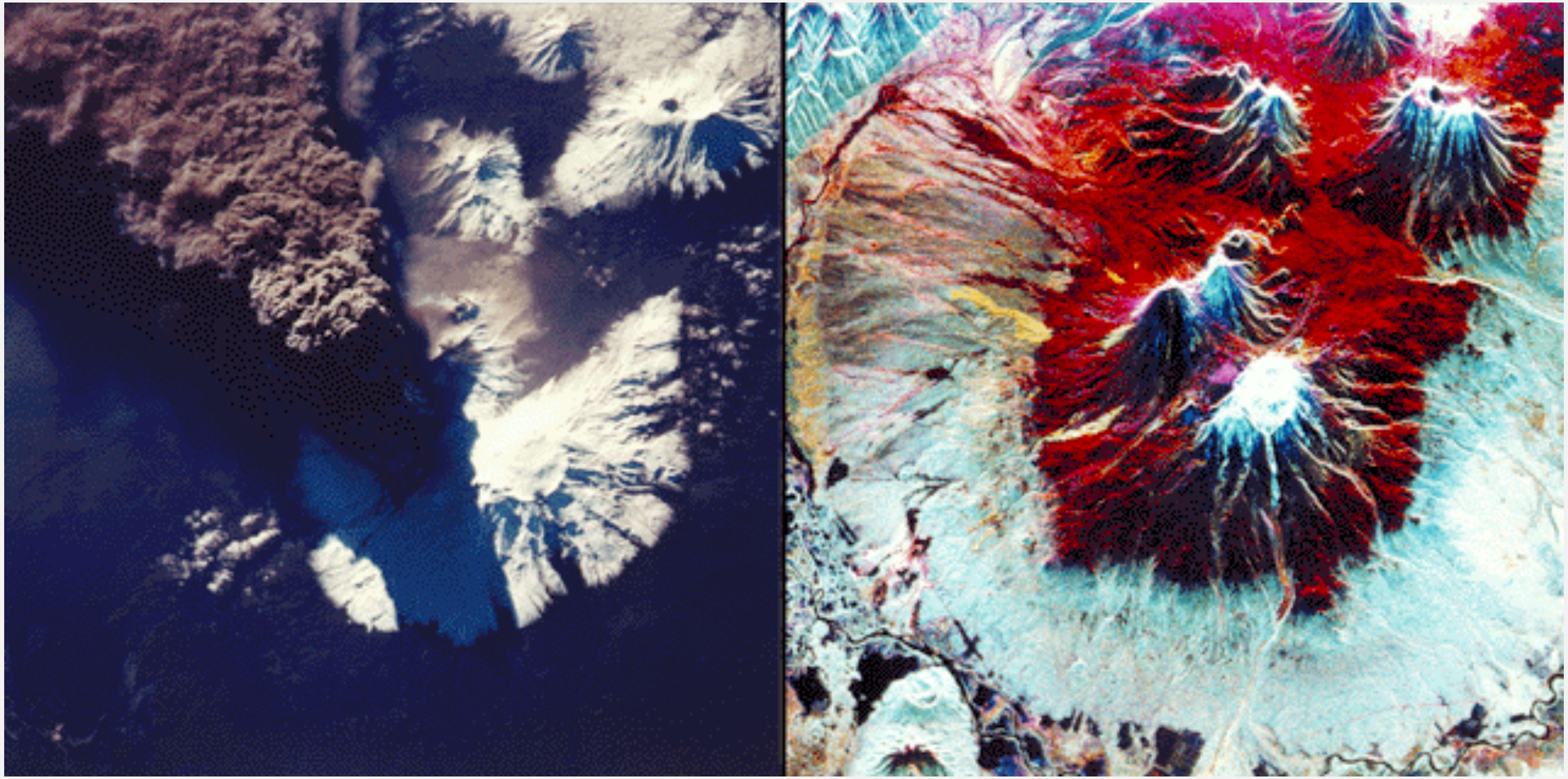
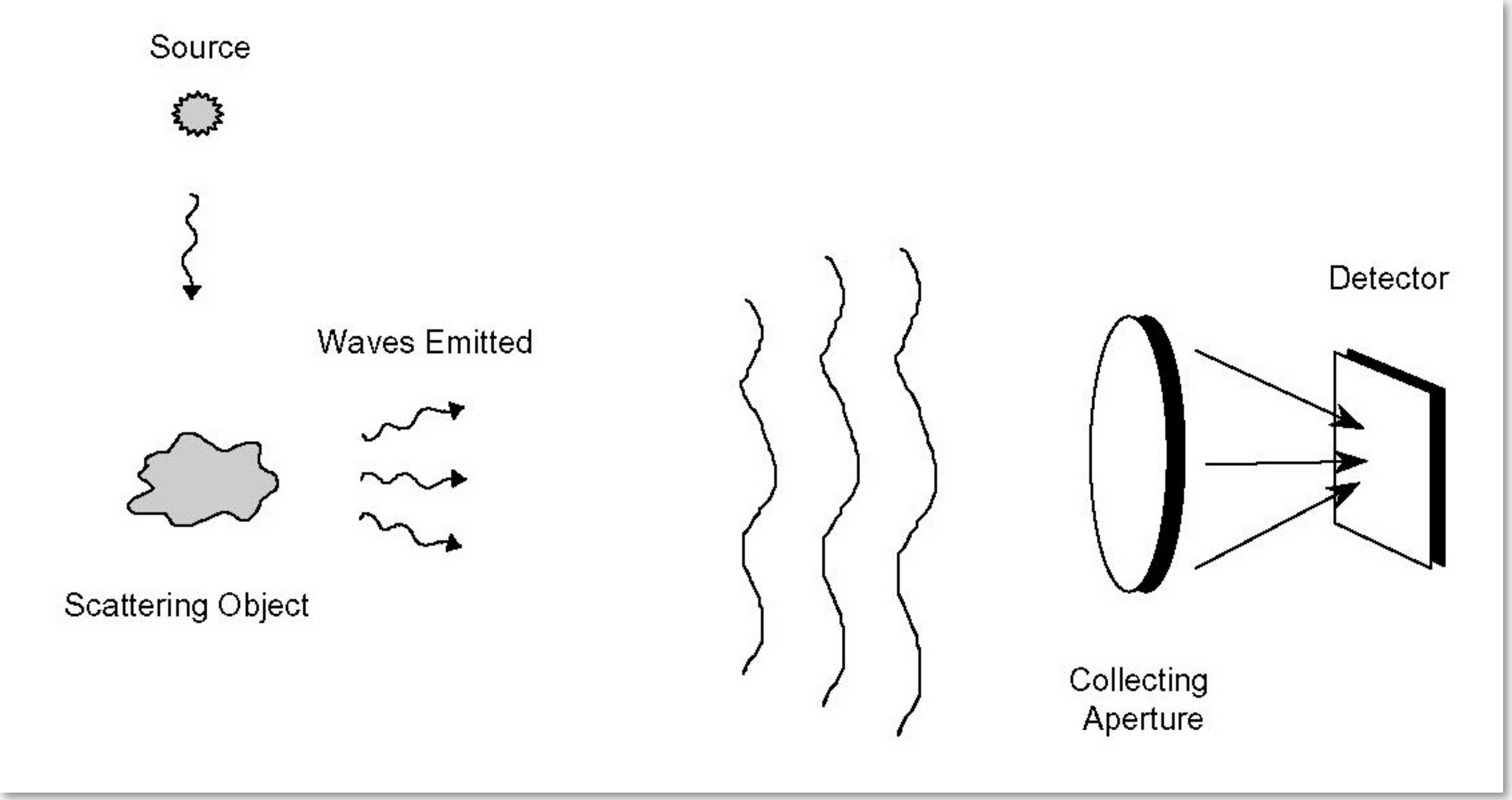
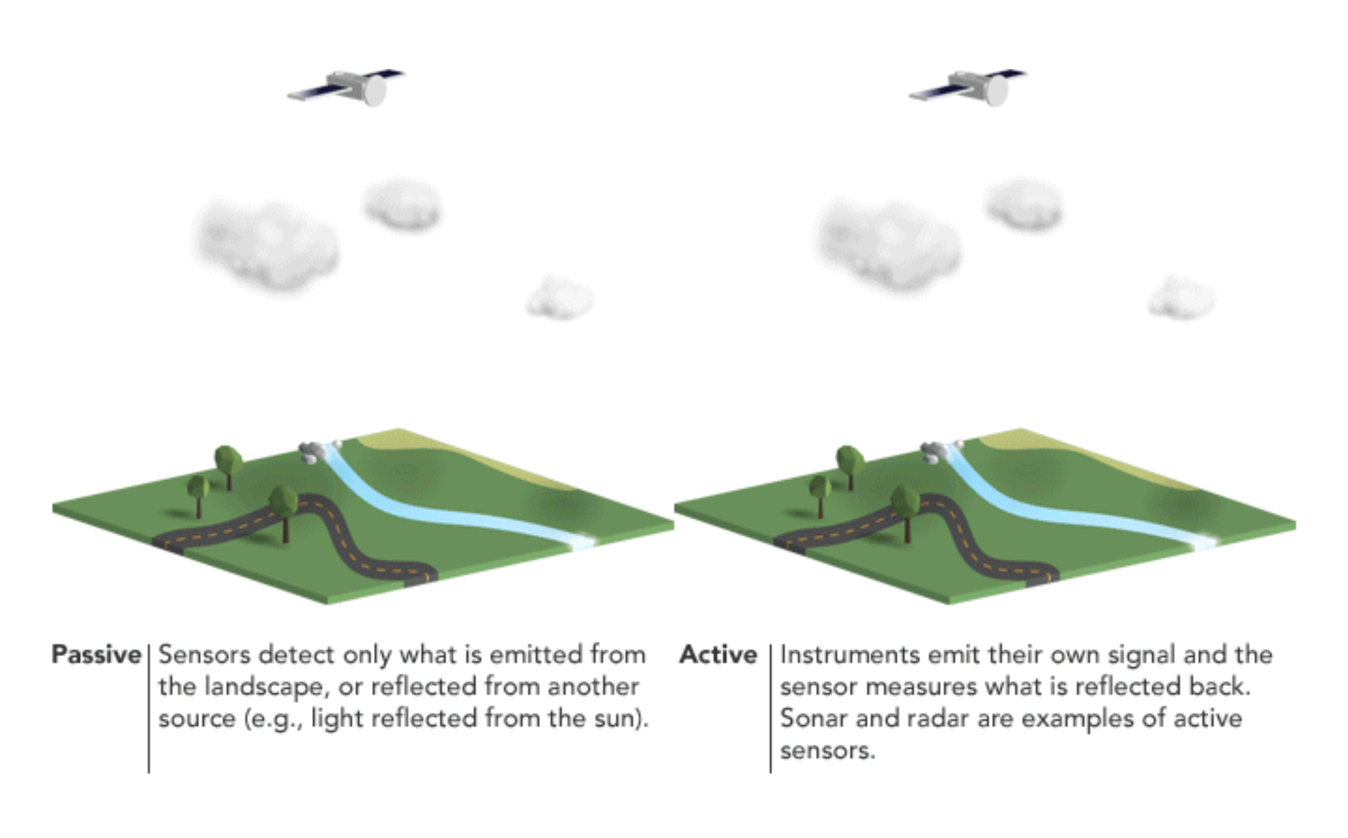


Image Credit: Michigan Tech Volcanology

Basic Remote Sensing System



Remote Sensing Instruments: Active and Passive



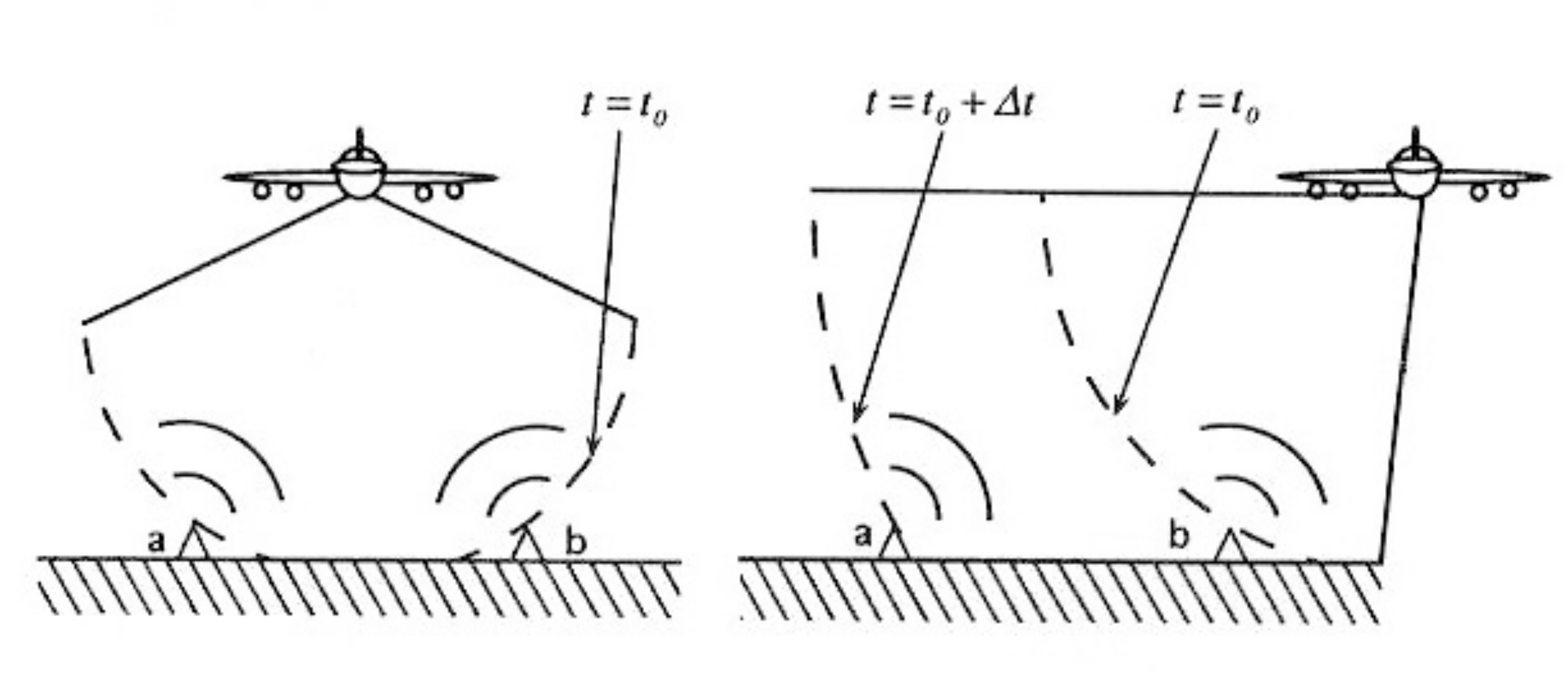
Passive Sensors:

- The source of radiant energy arises form natural sources
- e.g. the sun, Earth, other “hot” bodies

Active Sensors

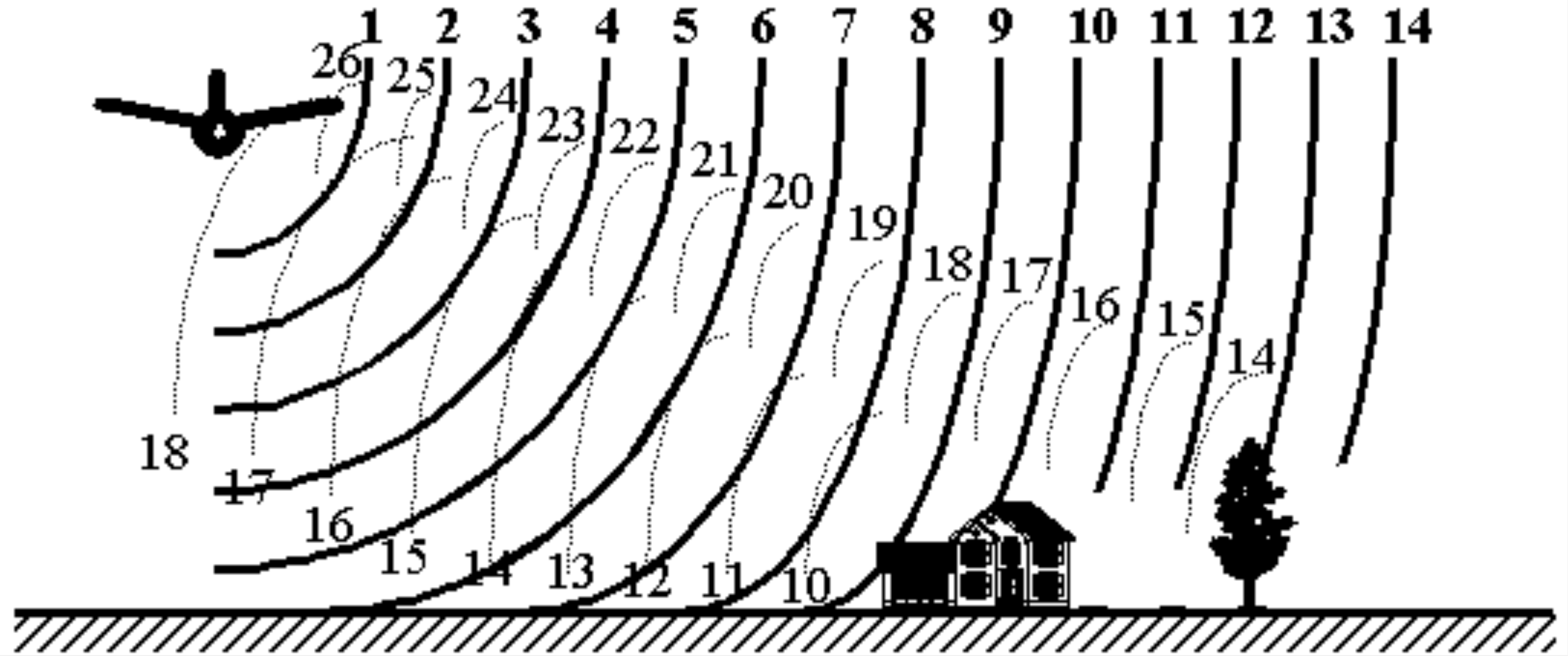
- Provide their own artificial radiant energy source for illumination
- e.g. **radar, synthetic aperture radar (SAR)**, LIDAR

Basic Concepts: Down Looking vs. Side Looking Radar



Basic Concepts: Side Looking Radar

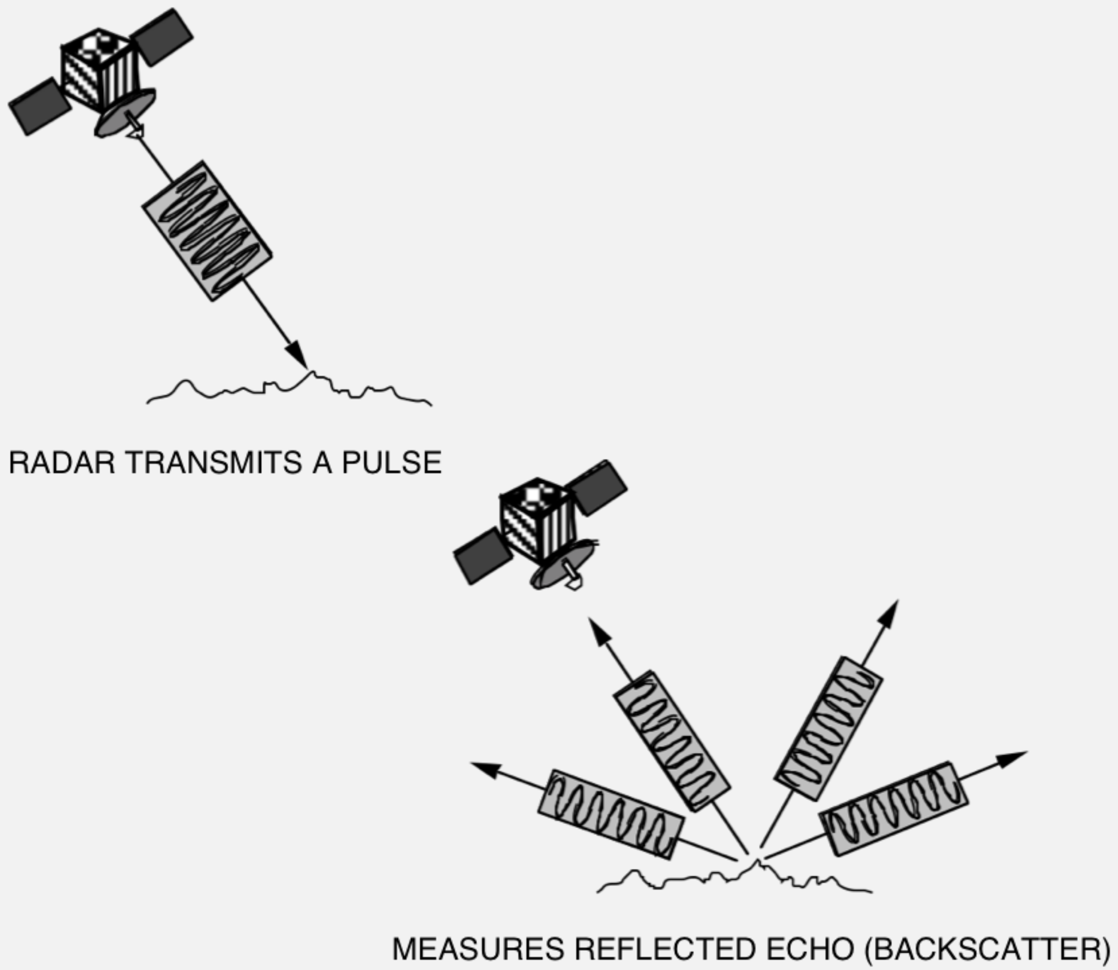
- Each pixel in the radar image represents a complex quantity of the energy that was reflected back to the satellite
- The magnitude of each pixel represents the intensity of the reflected echo



Credit: [Paul Messina, CUNY NY](), after Drury 1990, Lillesand and Kiefer, 1994

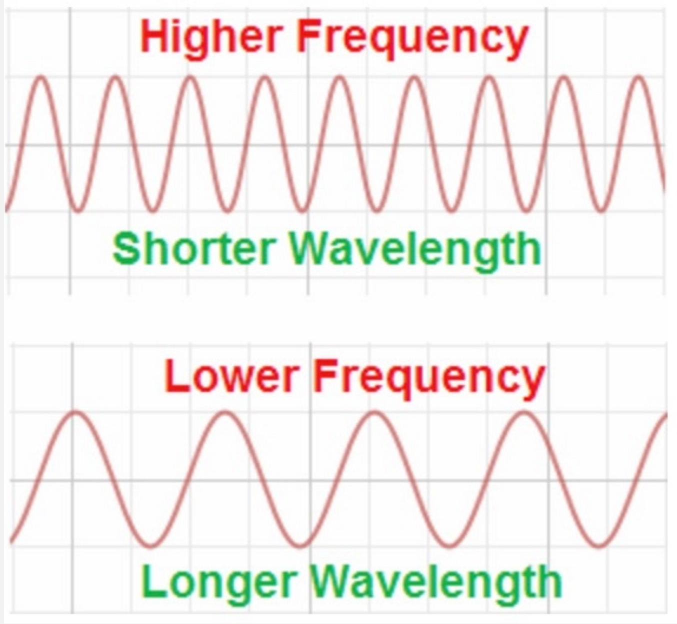
Review of Radar Image Formation

1. Radar can measure time delay and strength of reflected echo (amplitude and phase measurements)
2. Radar can only measure part of an echo reflected back towards the antenna (backscatter)
3. Radar pulses travel at the speed of light
4. Time delay → ability to image objects at different ranges from radar (range resolution)
5. Strength (amplitude) of reflected echo is called radar backscatter



Radar Parameters: Wavelength

$$\text{Wavelength} = \frac{\text{Speed of light}}{\text{frequency}}$$



Band designation*	Wavelength (λ), cm	Frequency (ν), GH_z (10^9 cycles · sec^{-1})
Ka (0.86 cm)	0.8 to 1.1	40.0 to 26.5
K	1.1 to 1.7	26.5 to 18.0
Ku	1.7 to 2.4	18.0 to 12.5
X (3.0 cm, 3.2 cm)	2.4 to 3.8	12.5 to 8.0
C (6.0)	3.8 to 7.5	8.0 to 4.0
S	7.5 to 15.0	4.0 to 2.0
L (23.5 cm, 25 cm)	15.0 to 30.0	2.0 to 1.0
P (68 cm)	30.0 to 100.0	1.0 to 0.3

* Wavelengths most frequently used in radar are in parenthesis

Radar Parameters: Wavelength

- Penetration is the **primary factor** in wavelength selection
- Penetration through the forest canopy or into the soil is greater with longer wavelengths

Commonly Used Frequency Bands

Frequency band	*Frequency range*	*Application Example*
• VHF	300 KHz - 300 MHz	Foliage/Ground penetration, biomass
• P-Band	300 MHz - 1 GHz	biomass, soil moisture, penetration
• L-Band	1 GHz - 2 GHz	agriculture, forestry, soil moisture
• C-Band	4 GHz - 8 GHz	ocean, agriculture
• X-Band	8 GHz - 12 GHz	agriculture, ocean, high resolution radar
• Ku-Band	14 GHz - 18 GHz	glaciology (snow cover mapping)
• Ka-Band	27 GHz - 47 GHz	high resolution radars

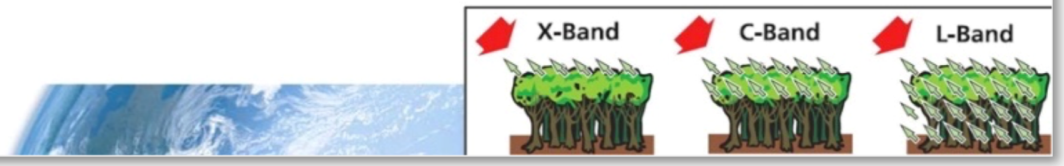
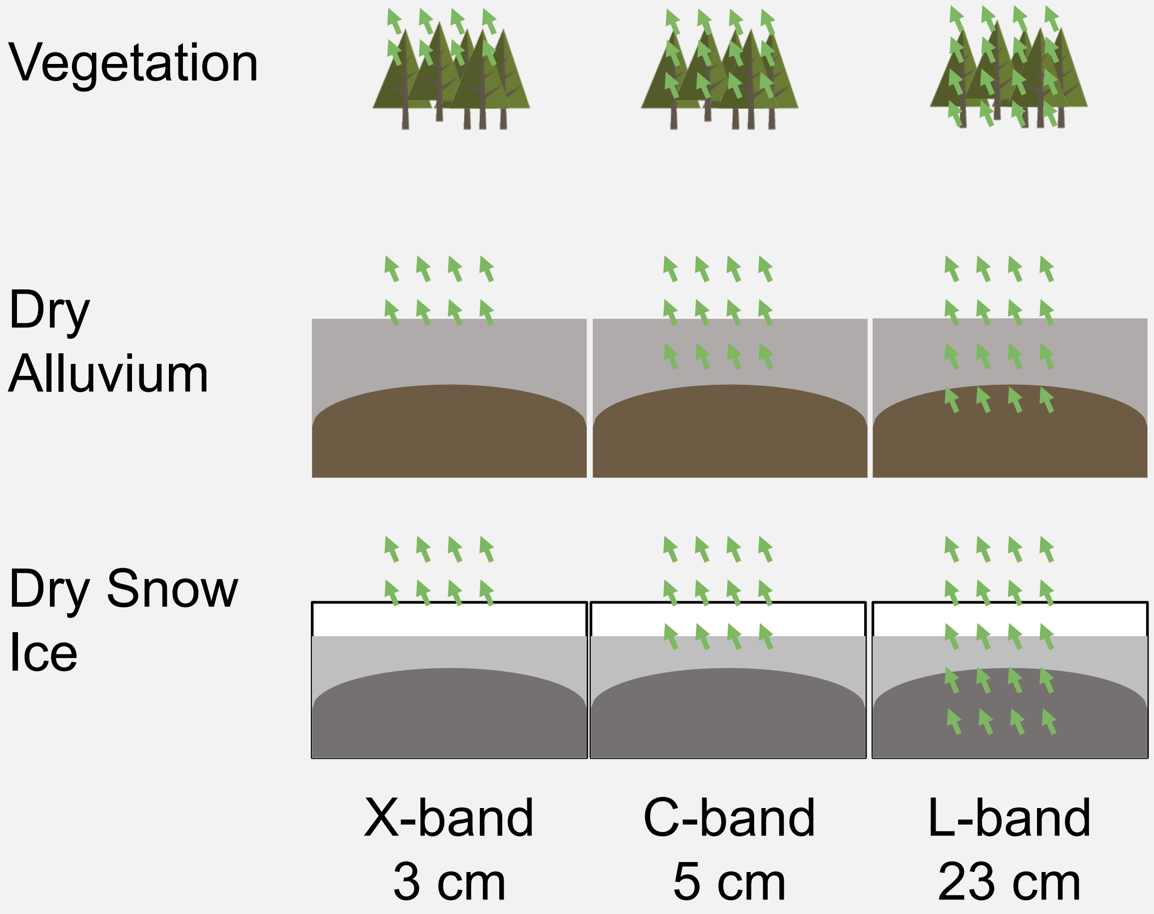


Image Credit: DLR

Penetration as a Function of Wavelength



- Waves can penetrate into vegetation and (in dry conditions) soil
- Generally, the longer the wavelength, the stronger the penetration into the target

Image based on ESA [Radar Course 2]

Example: Radar Signal Penetration into Dry Soils

- Different satellite images over southwest Libya
- The arrows indicate possible fluvial systems

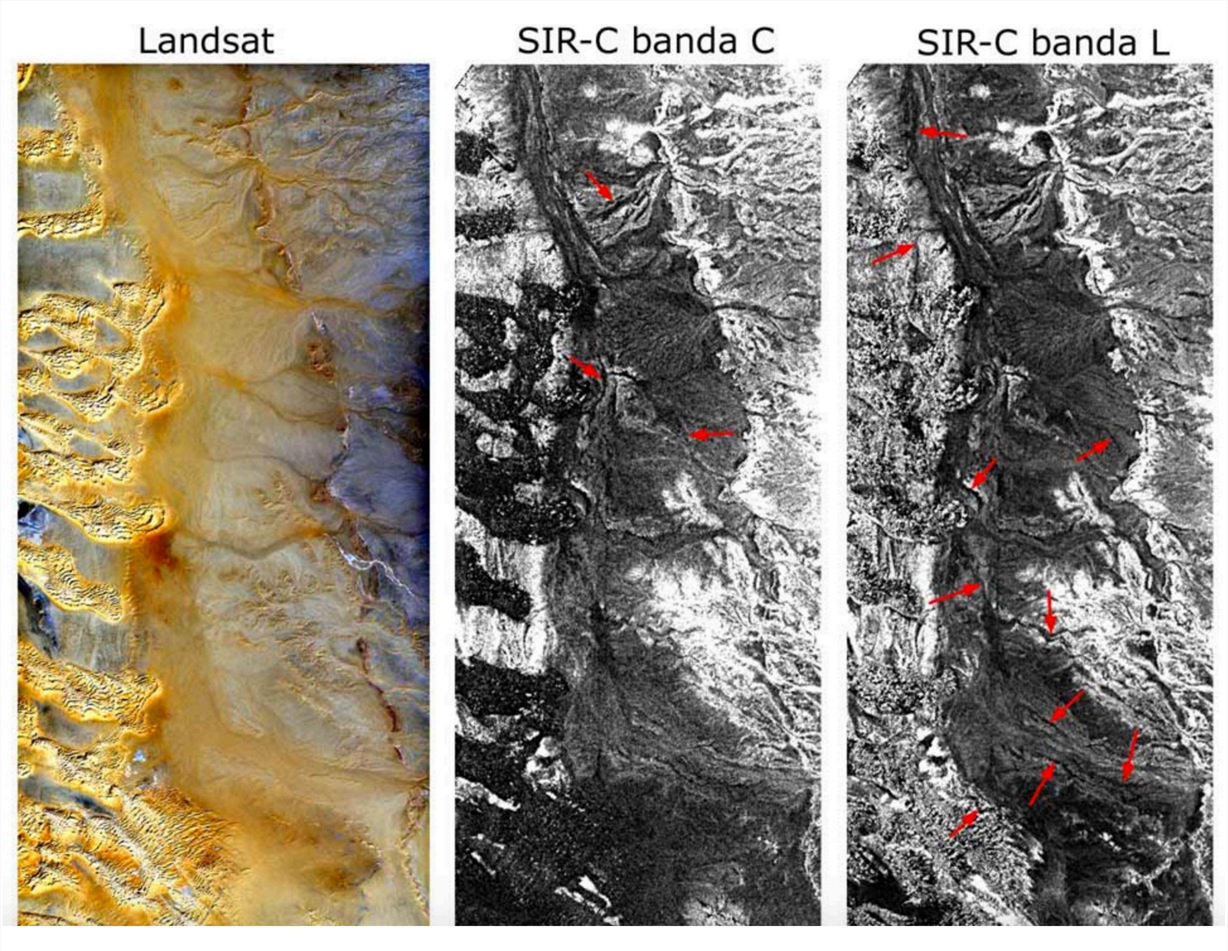
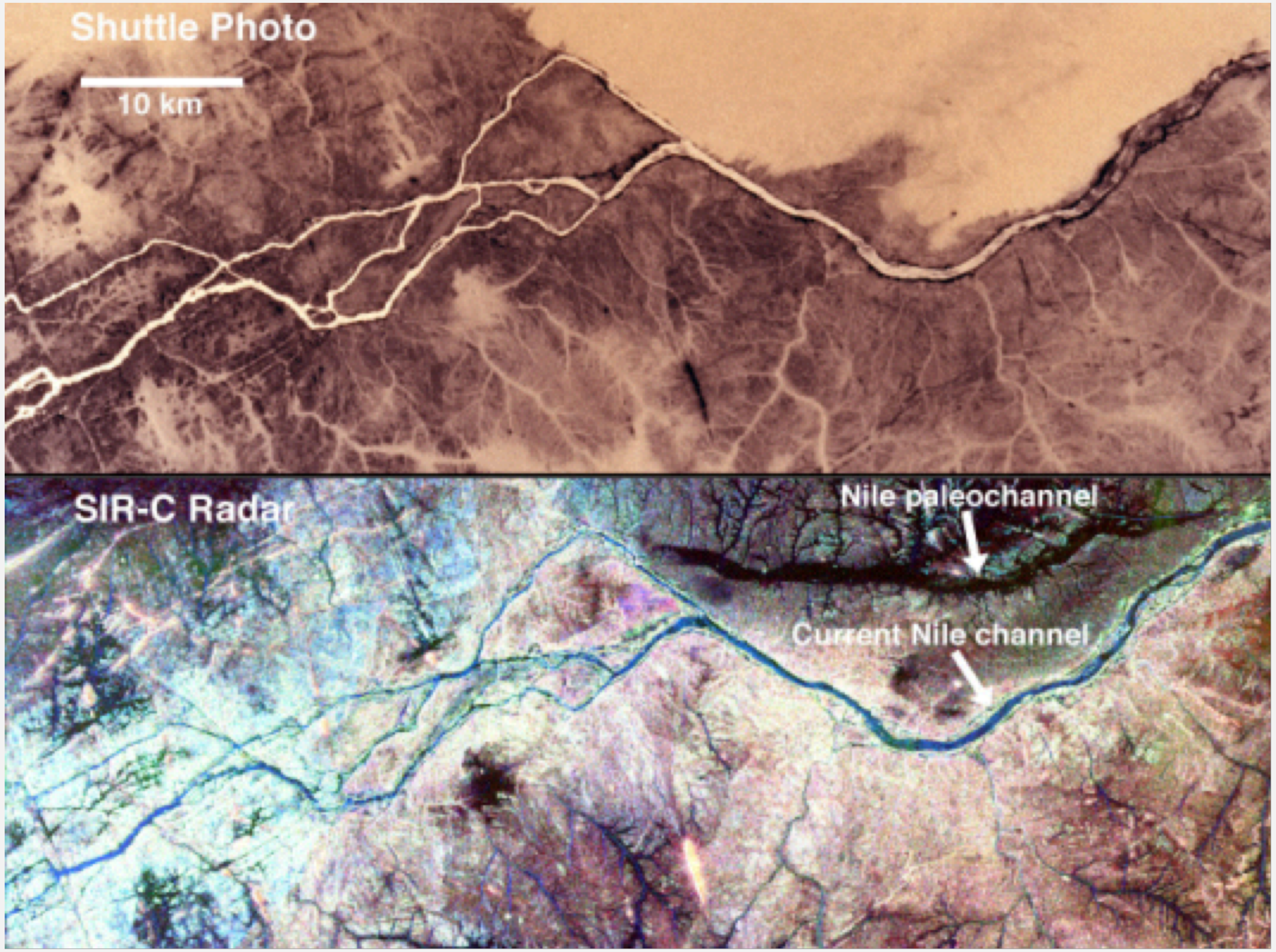
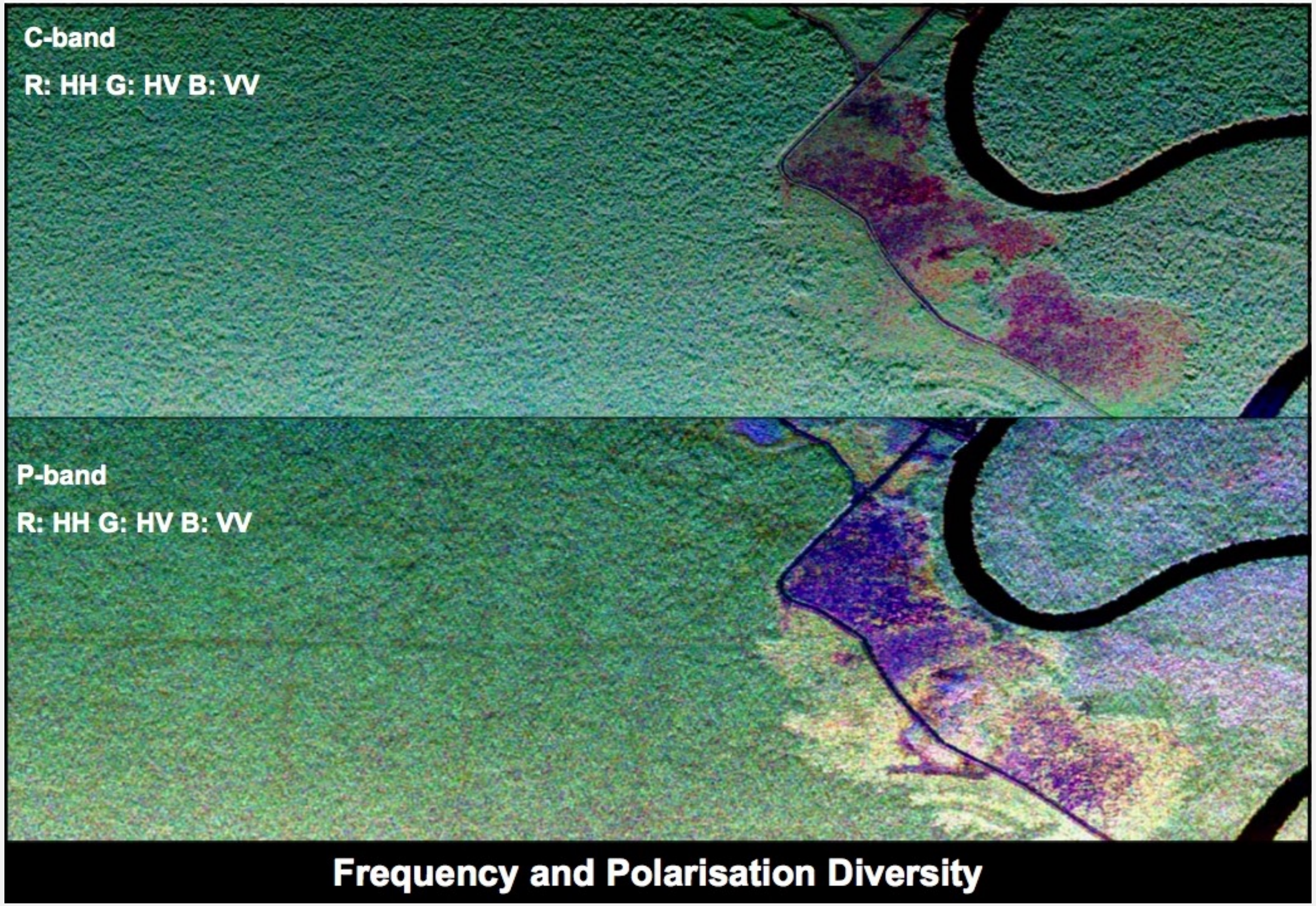


Image Credit: A Perego

Example: Radar Signal Penetration into Dry Soils



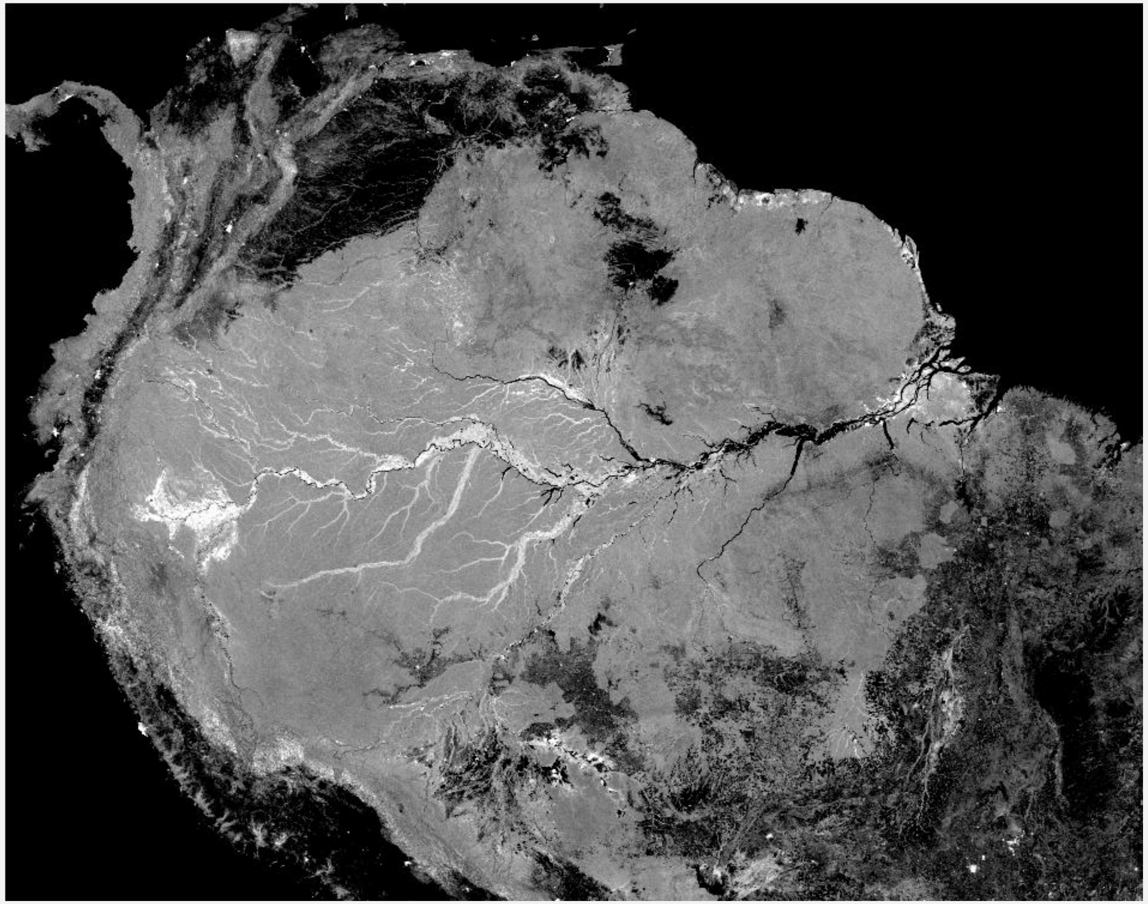
Example: Radar Signal Penetration into Vegetation



Example: Radar Signal Penetration into Wetlands

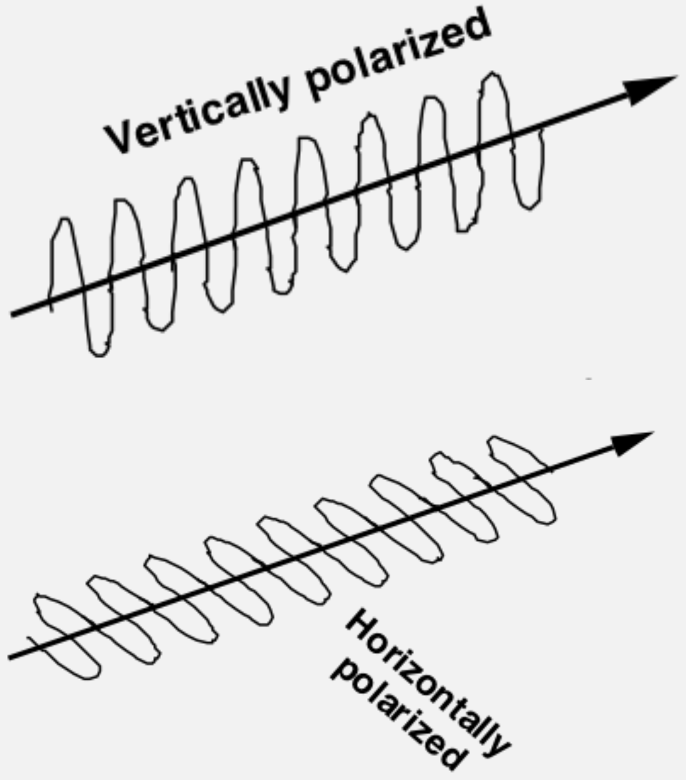
- L-band is ideal for the study of wetlands because the signal penetrates through the canopy and can sense if there is standing water underneath
- Inundated areas appear white in the image to the right

SMAP Radar Mosaic of the Amazon



Radar Parameters: Polarization

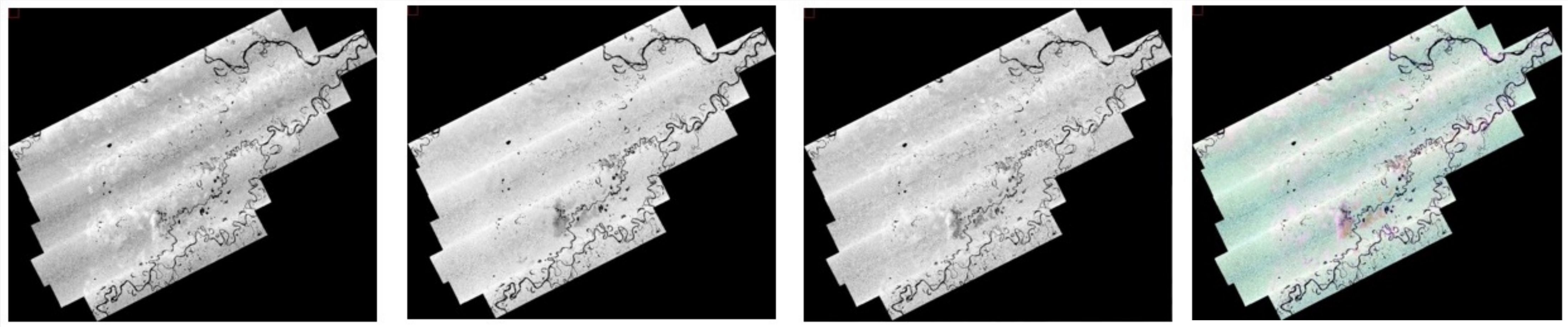
- The radar signal is polarized
- The polarizations are usually controlled between H and V:
  - HH: Horizontal Transmit, Horizontal Receive
  - HV: Horizontal Transmit, Vertical Receive
  - VH: Vertical Transmit, Horizontal Receive
  - VV: Vertical Transmit, Vertical Receive
- Quad-Pol Mode: when all four polarizations are measured
- Different polarizations can determine physical properties of the object observed



Example of Multiple Polarizations for Vegetation Studies

Pacaya-Samiria Forest Reserve in Peru

Images from UAVSAR (HH, HV, VV)



Radar Parameters: Incidence Angle

- The angle between the direction of illumination of the radar and the Earth's surface plane
- Depending on the height of the sensor, the incidence angle will change direction
- This is why the geometry of an image is different from point to point in the range direction
- Local Incidence Angle:
  – accounts for local inclination of the surface
  – incidence angle influences image brightness

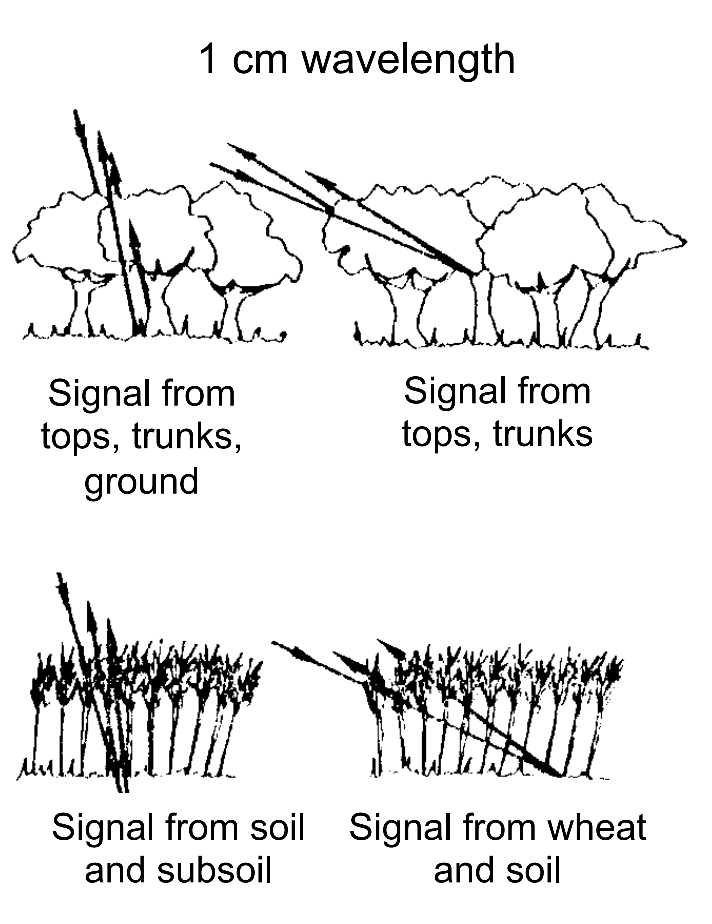


Image Credit: Ulaby et al. (1981a)

Questions

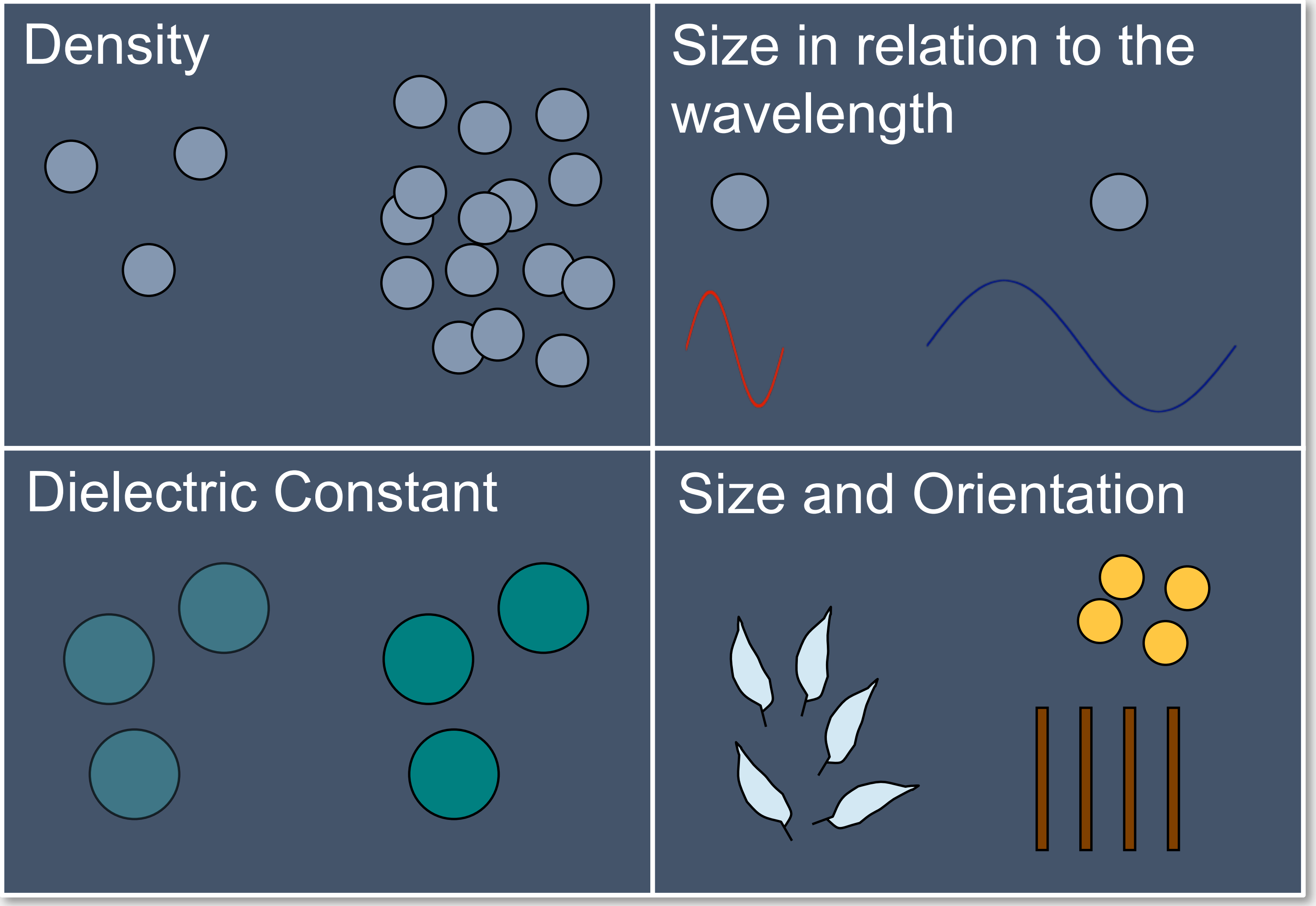
1. What are the advantages of radar sensors?
2. What are three main radar parameters that need to be considered for a specific study?
3. What is the relationship between wavelength and penetration?
4. What’s the usefulness of having different polarizations?
5. What’s the effect of varying incidence angles?

Backscattering Mechanisms of the Radar Signal

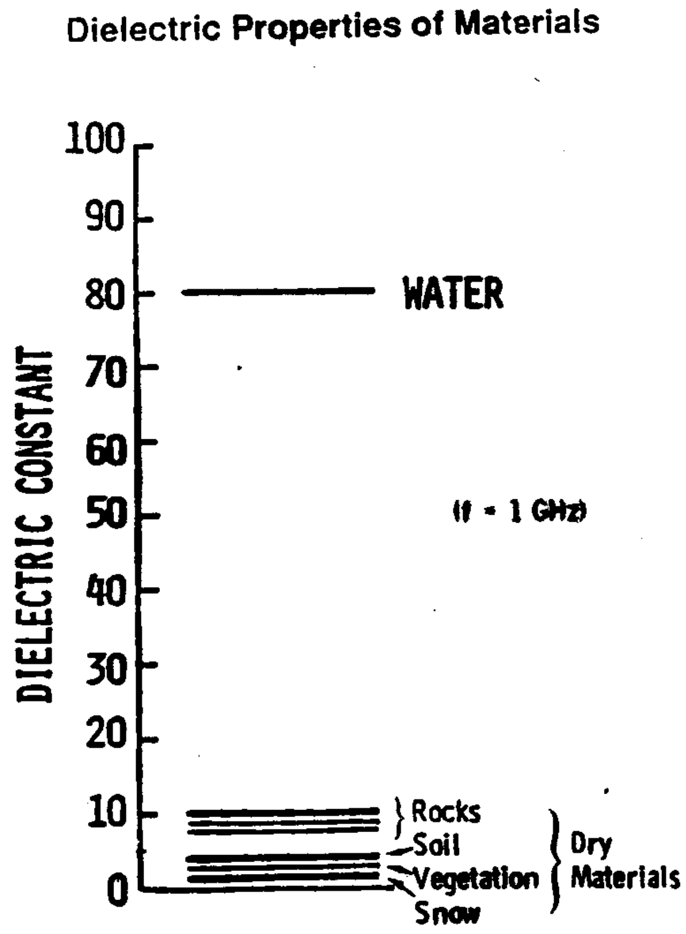
Radar Backscatter

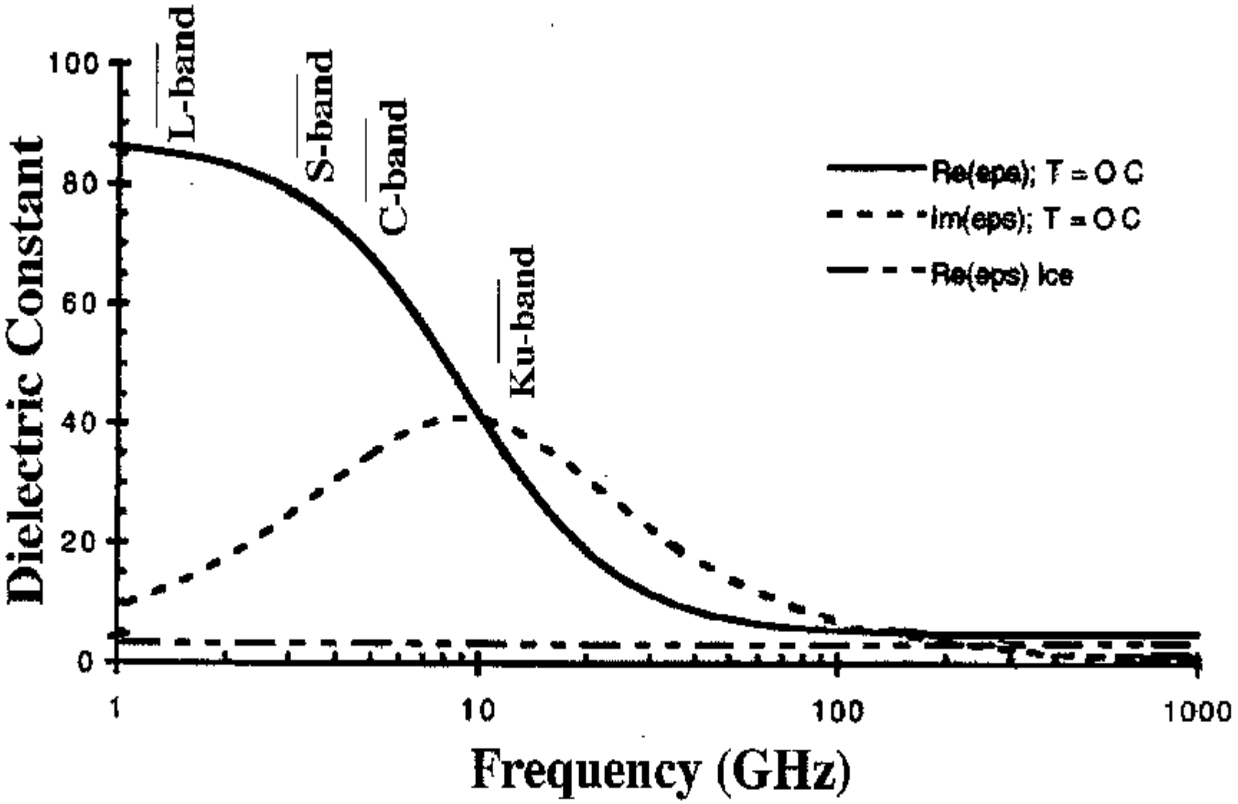
- The radar echo contains information about the Earth’s surface, which drives the reflection of the radar signal
- This reflection is driven by:
  – The frequency or wavelength: radar parameter
  – Polarization: radar parameter
  – Incidence angle: radar parameter
  – Dielectric constant: surface parameter
  – Surface roughness relative to the wavelength: surface parameter
  – Structure and orientation of objects on the surface: surface parameter

Backscattering Mechanisms



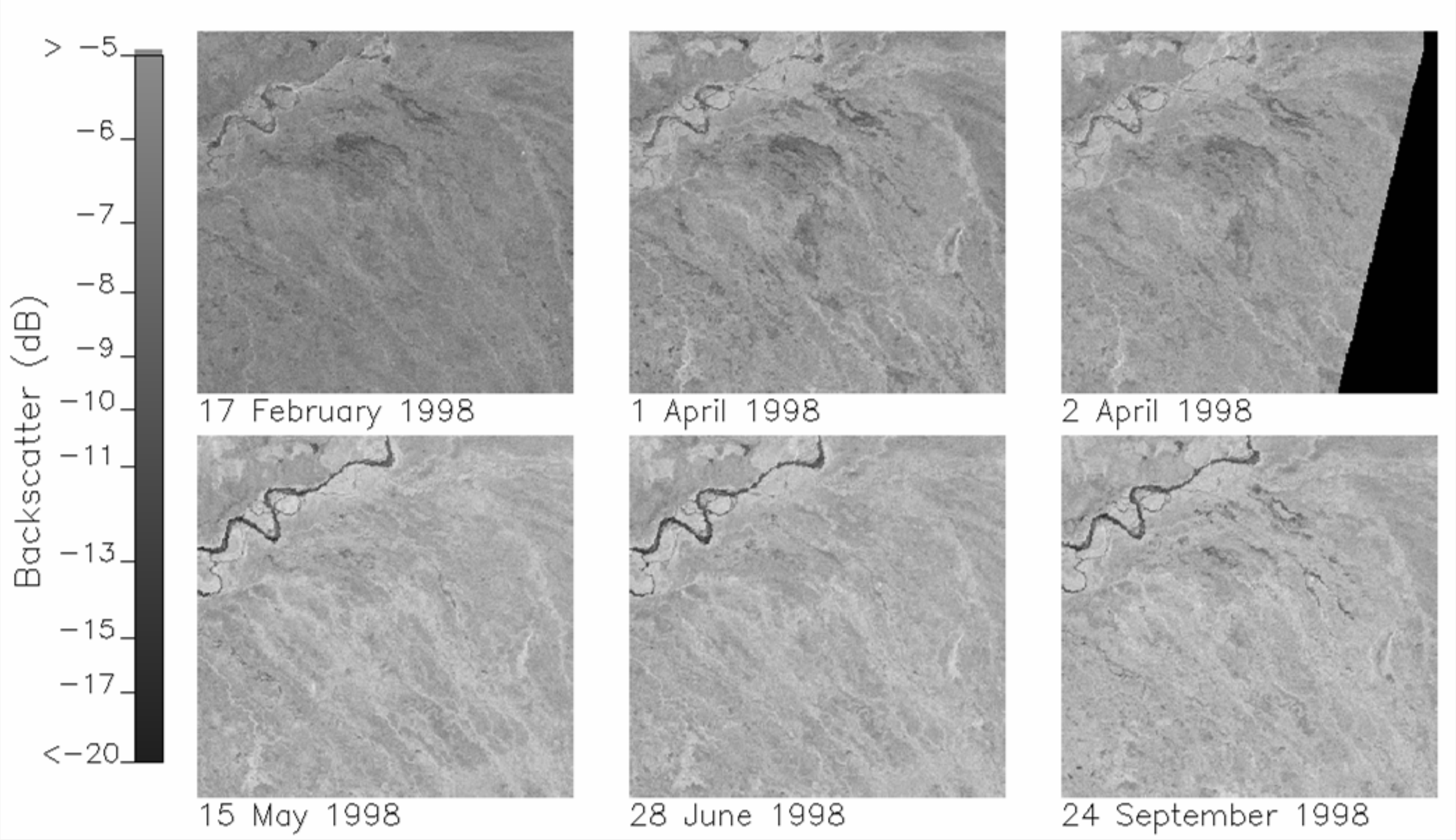
Surface Parameters: Dielectric Constant





Dielectric Properties of the Surface and its Frozen or Thawed State

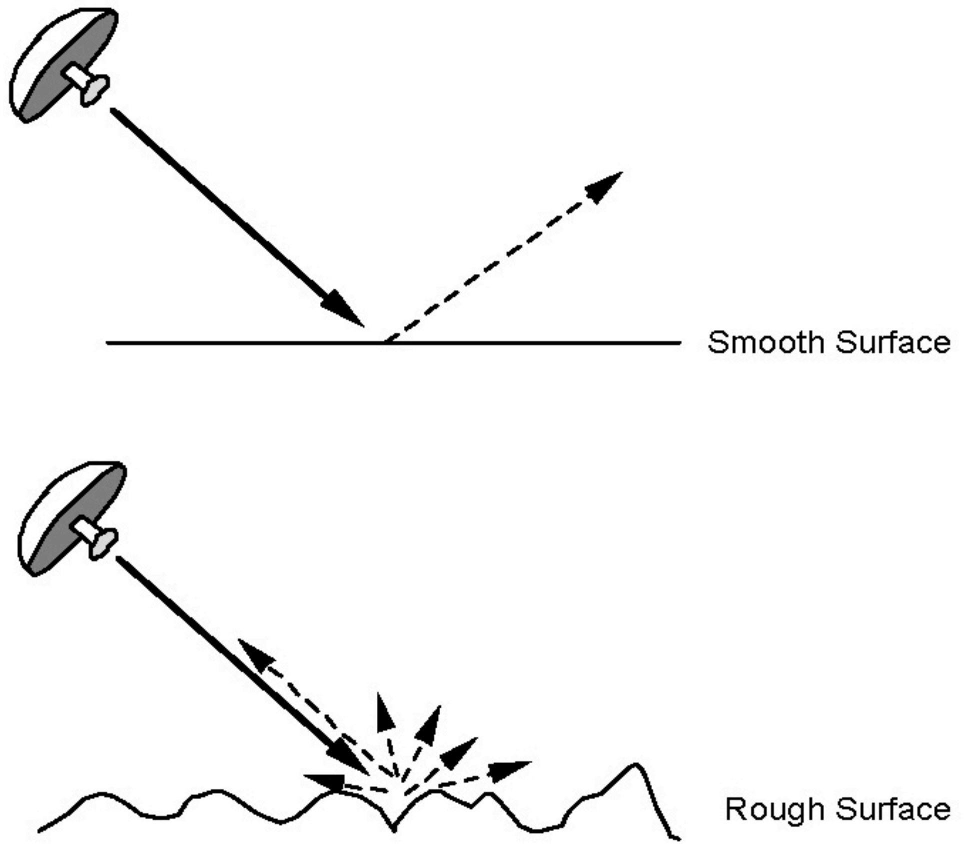
- During the land surface freeze/thaw transition there is a change in dielectric properties of the surface
- This causes a notable increase in backscatter



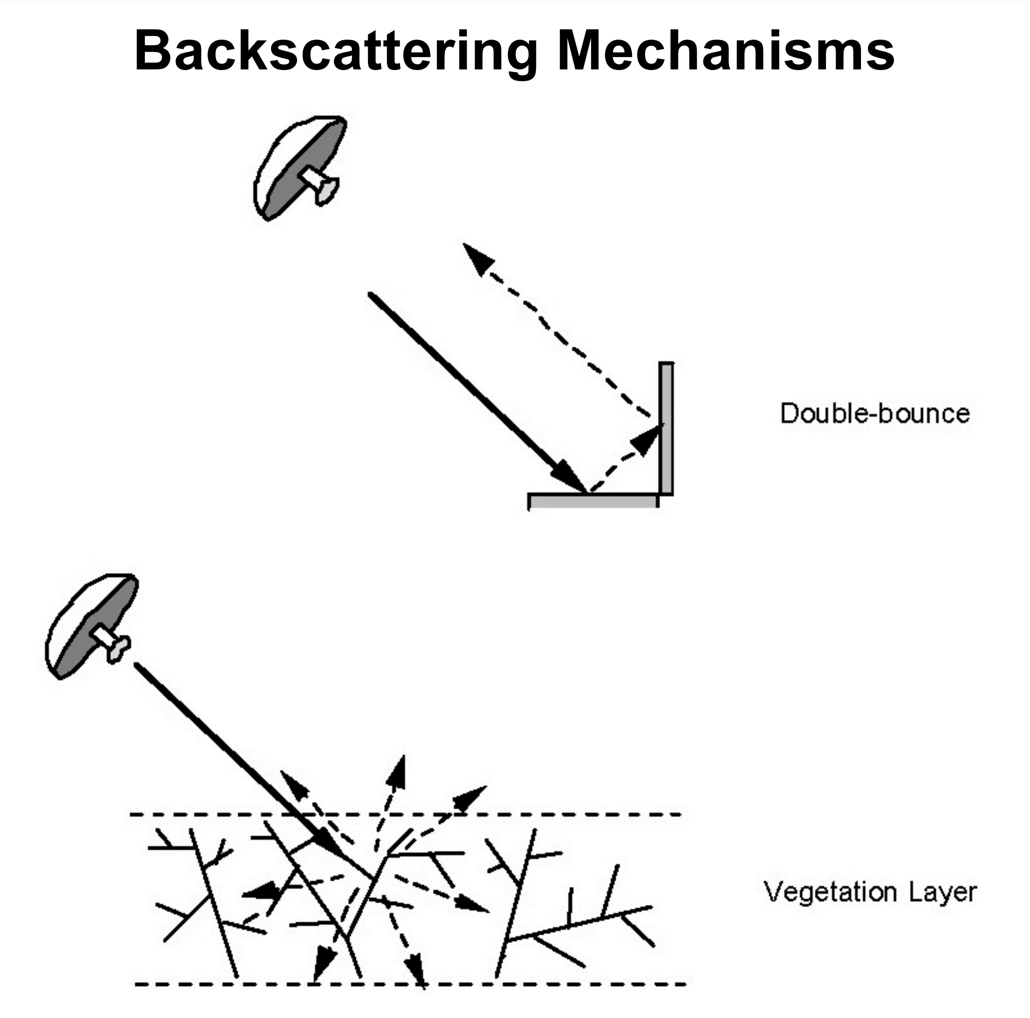
Radar Backscatter Sources: Part 1

- The radar signal is primarily sensitive to surface structure
- The scale of the objects on the surface relative to the wavelength determine how rough or smooth they appear to the radar signal and how bright or dark they will appear on the image

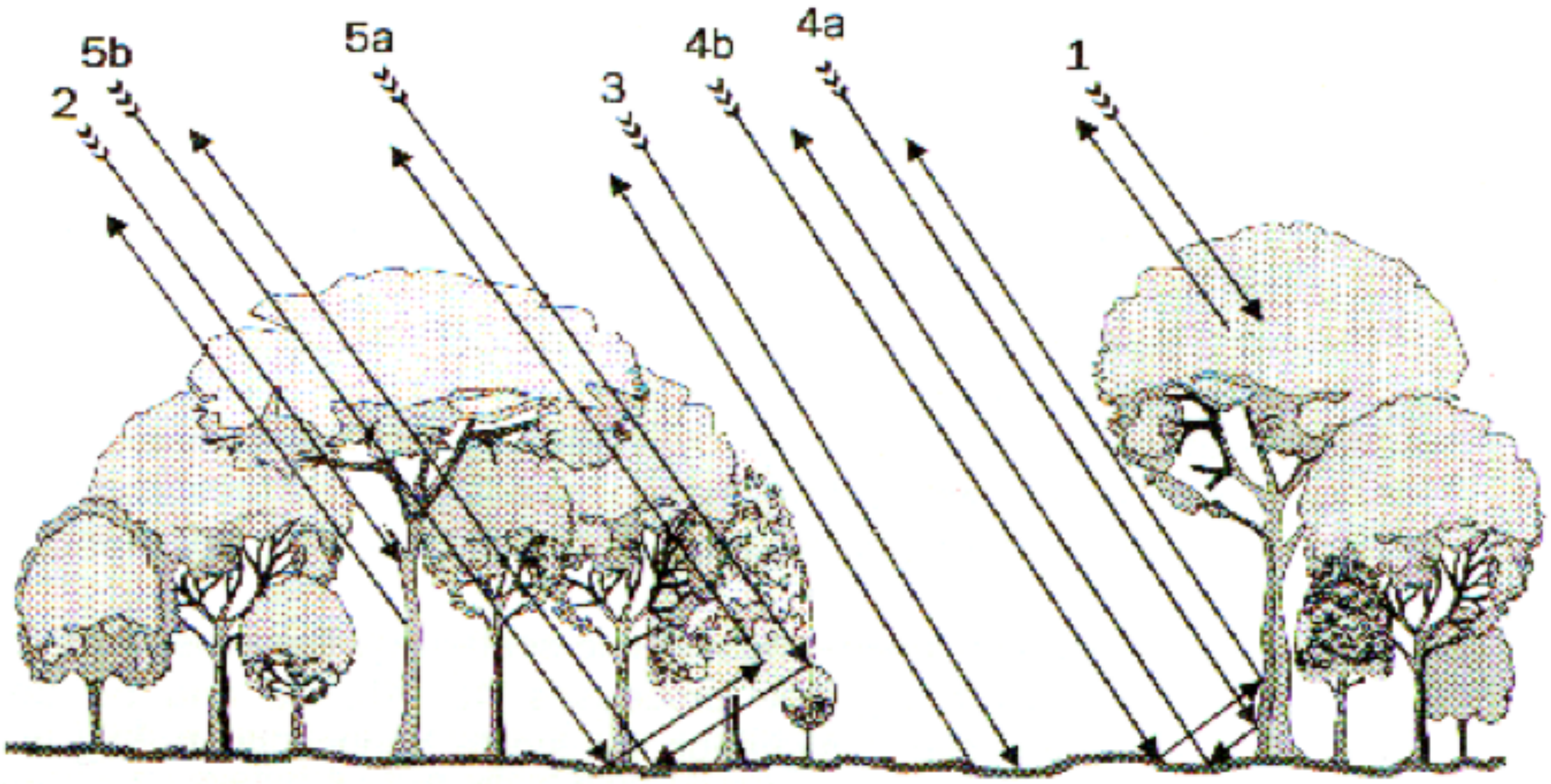
Backscattering Mechanisms



Radar Backscatter Sources: Part 2



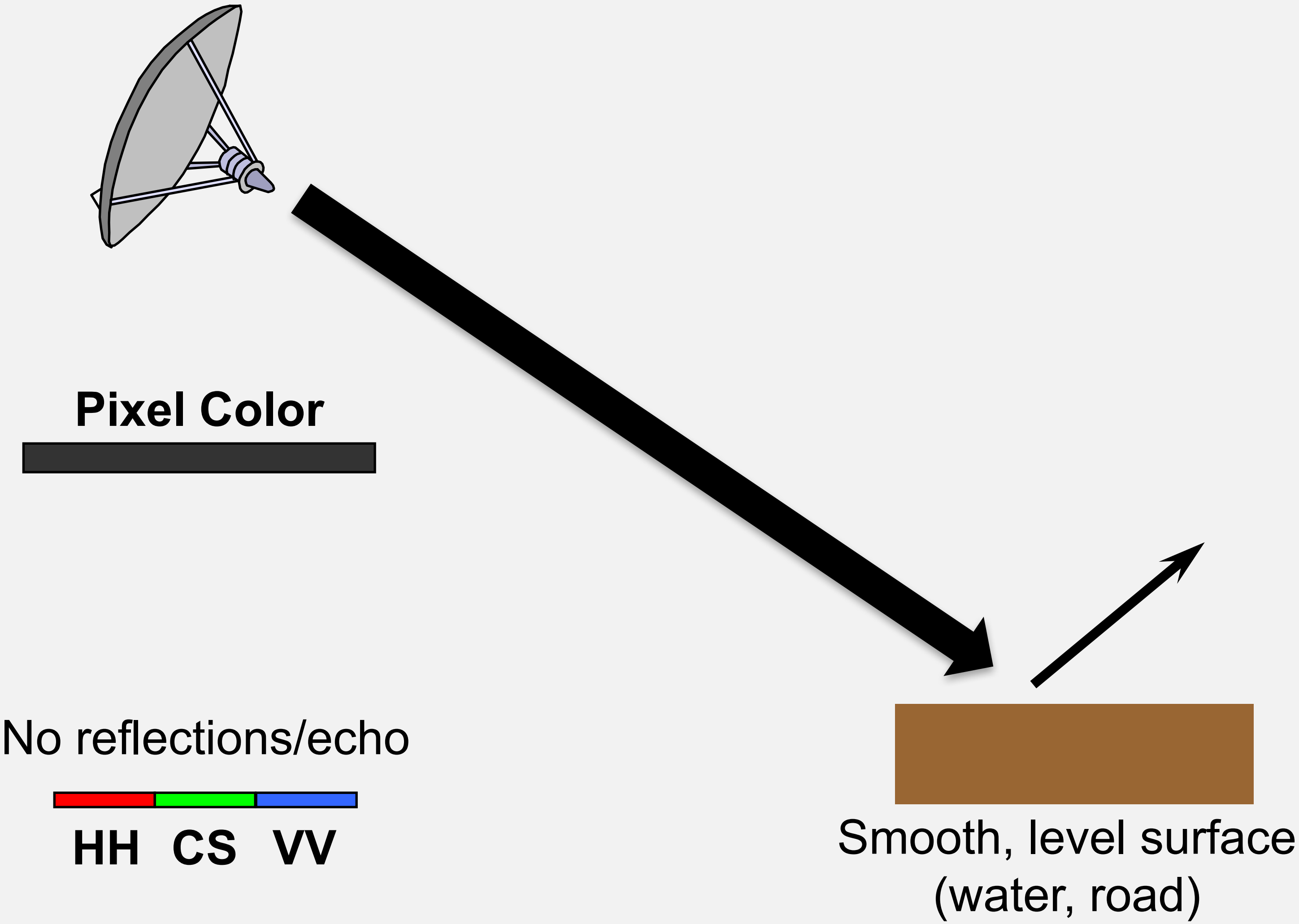
Radar Backscatter Sources: Part 3

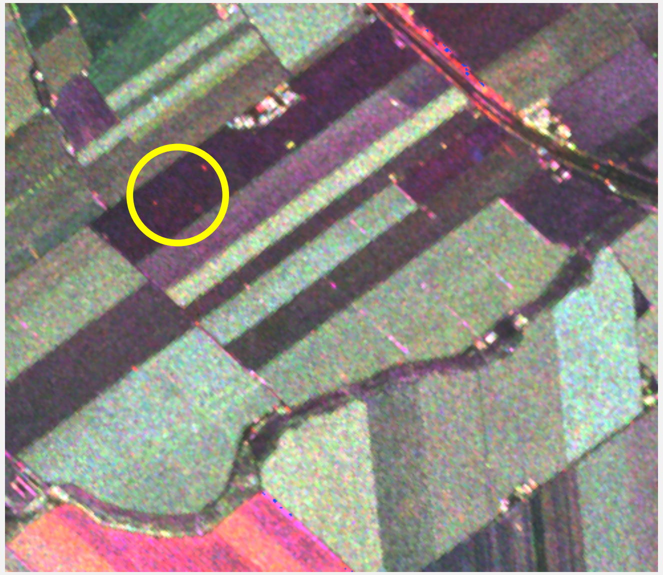


Dominant backscattering sources in forests: (1) crown volume scattering, (2) direct scattering from tree trunks, (3) direct scattering from the soil surface, (4a) trunk - ground scattering, (4b) ground - trunk scattering, (5a) crown - ground scattering, (5b) ground - crown scattering.

Radar Interaction Types

Mirror-Like Reflection (Specular Reflection)



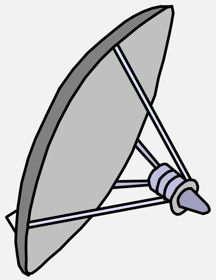


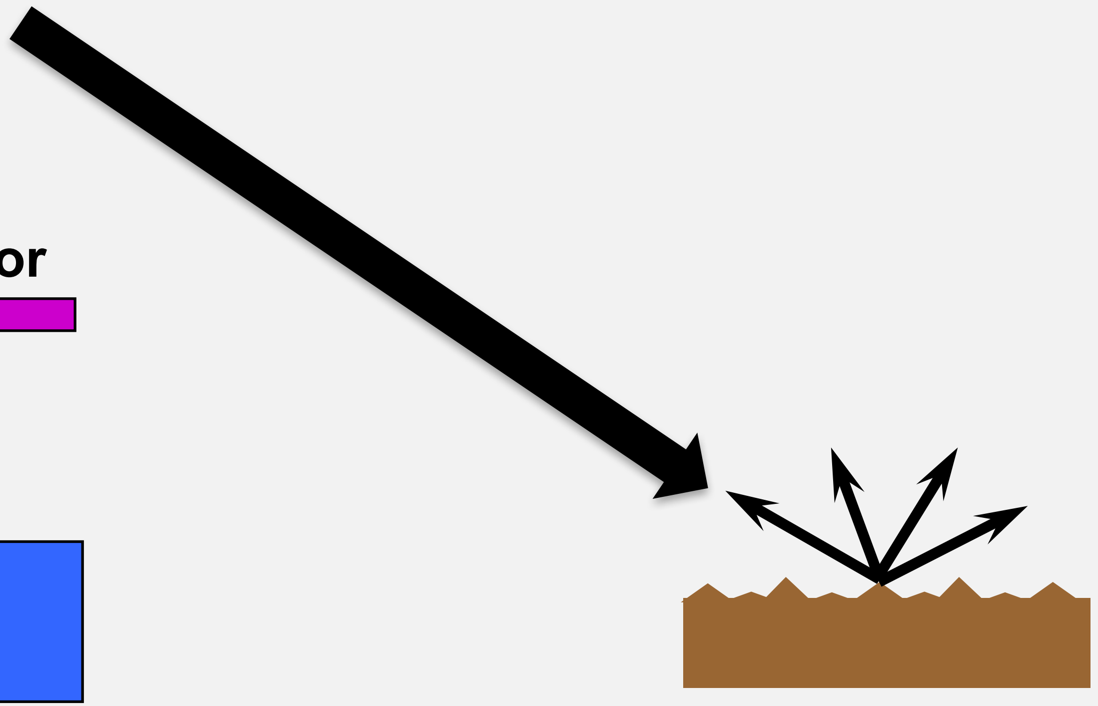
Salinas Valley, California
October 24, 1998
L-Band Image

Source: Natural Resources Canada

Radar Interaction Types

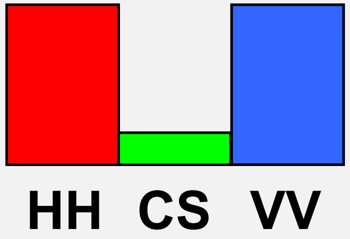
Rough Surface Reflection

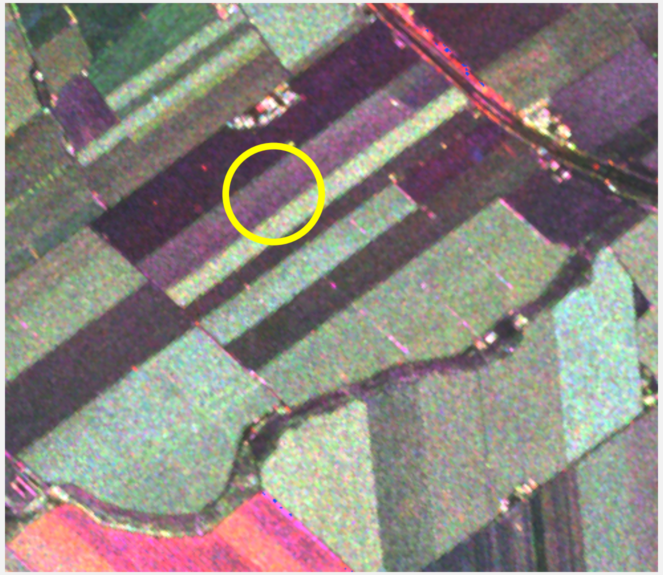




Rough, bare surface

Pixel Color



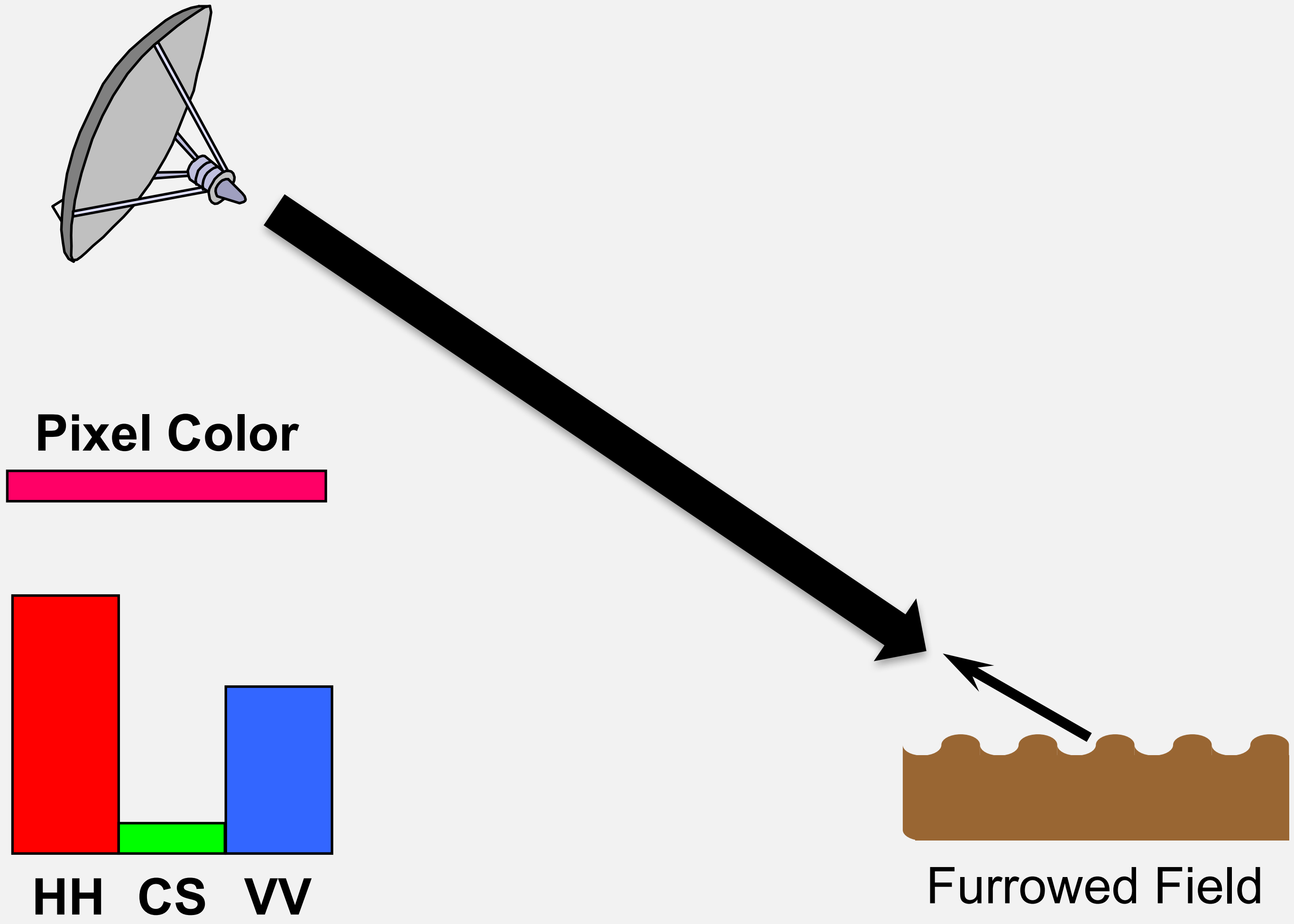


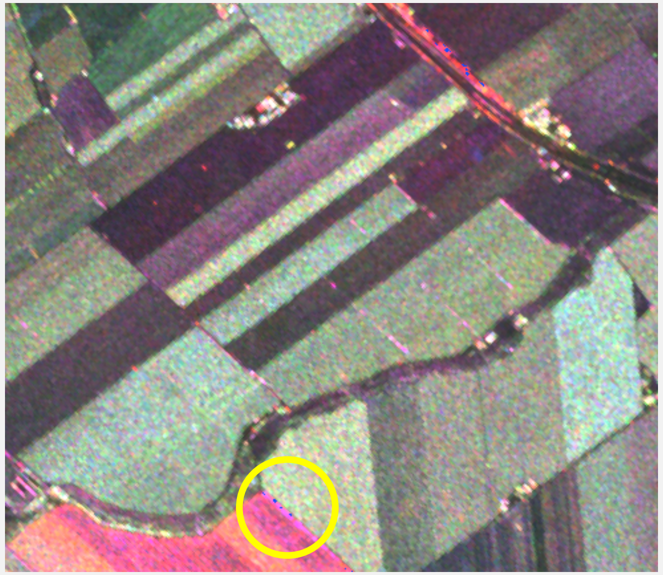
Salinas Valley, California
October 24, 1998
L-Band Image

Source: Natural Resources Canada

Radar Interaction Types

Furrowed Surface Reflection



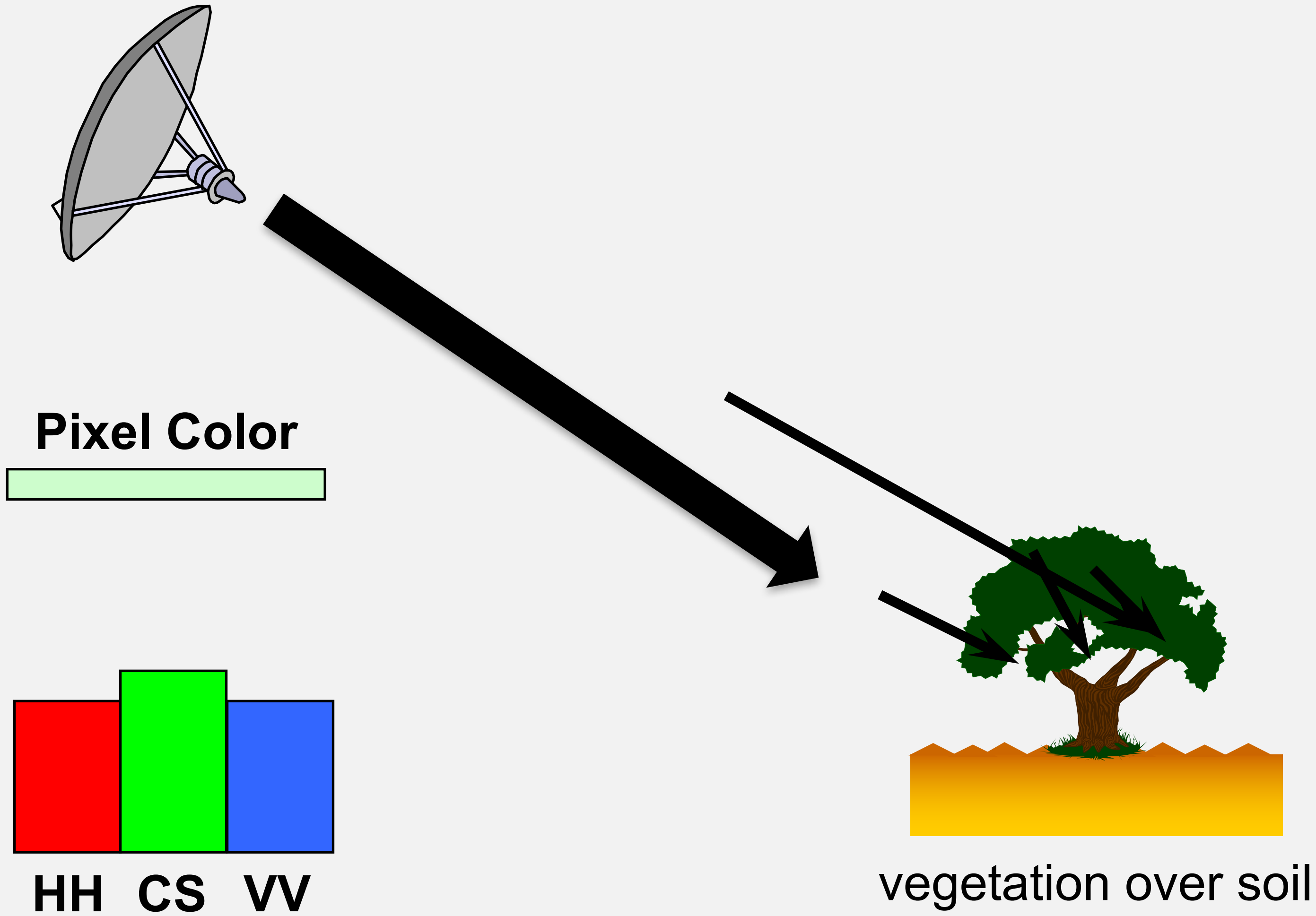


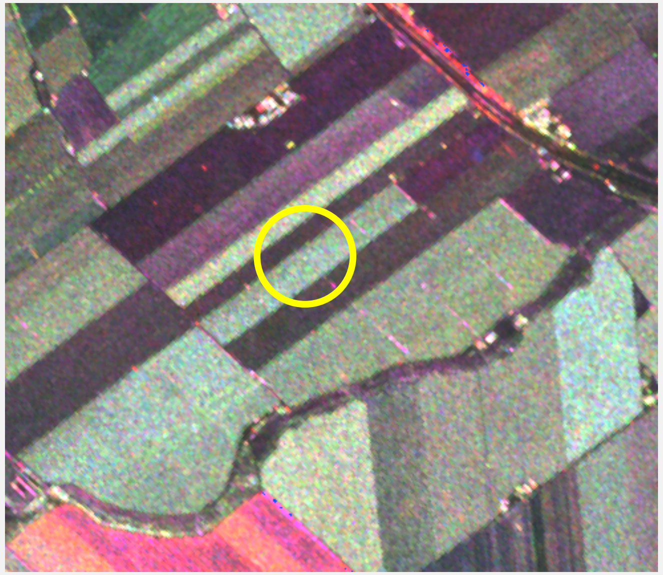
Salinas Valley, California
October 24, 1998
L-Band Image

Source: Natural Resources Canada

Radar Interaction Types

Volume Scattering by Biomass



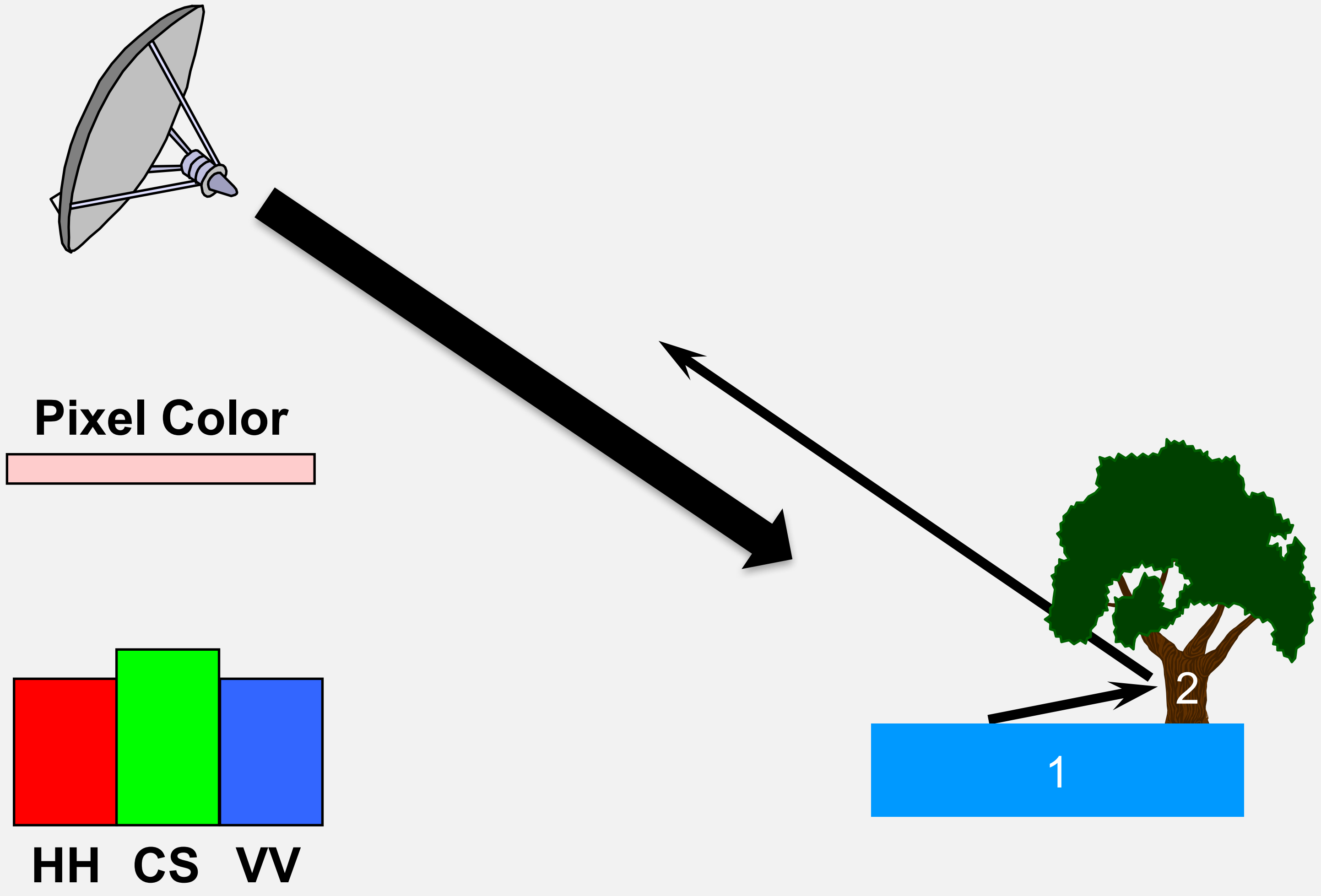


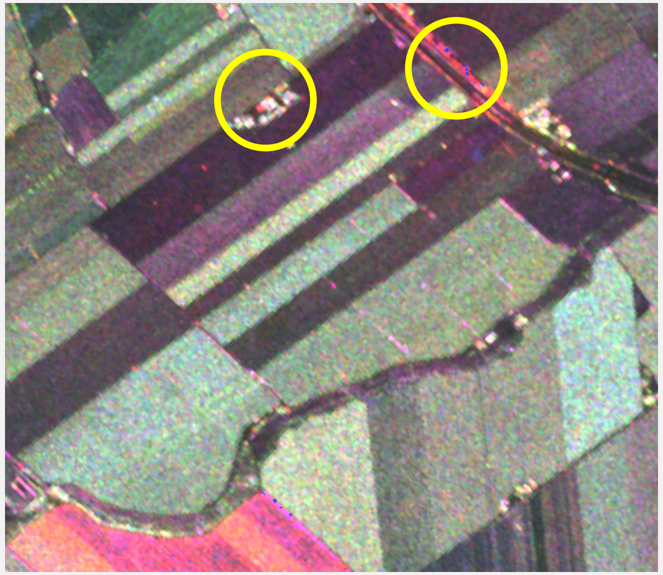
Salinas Valley, California
October 24, 1998
L-Band Image

Source: Natural Resources Canada

Radar Interaction Types

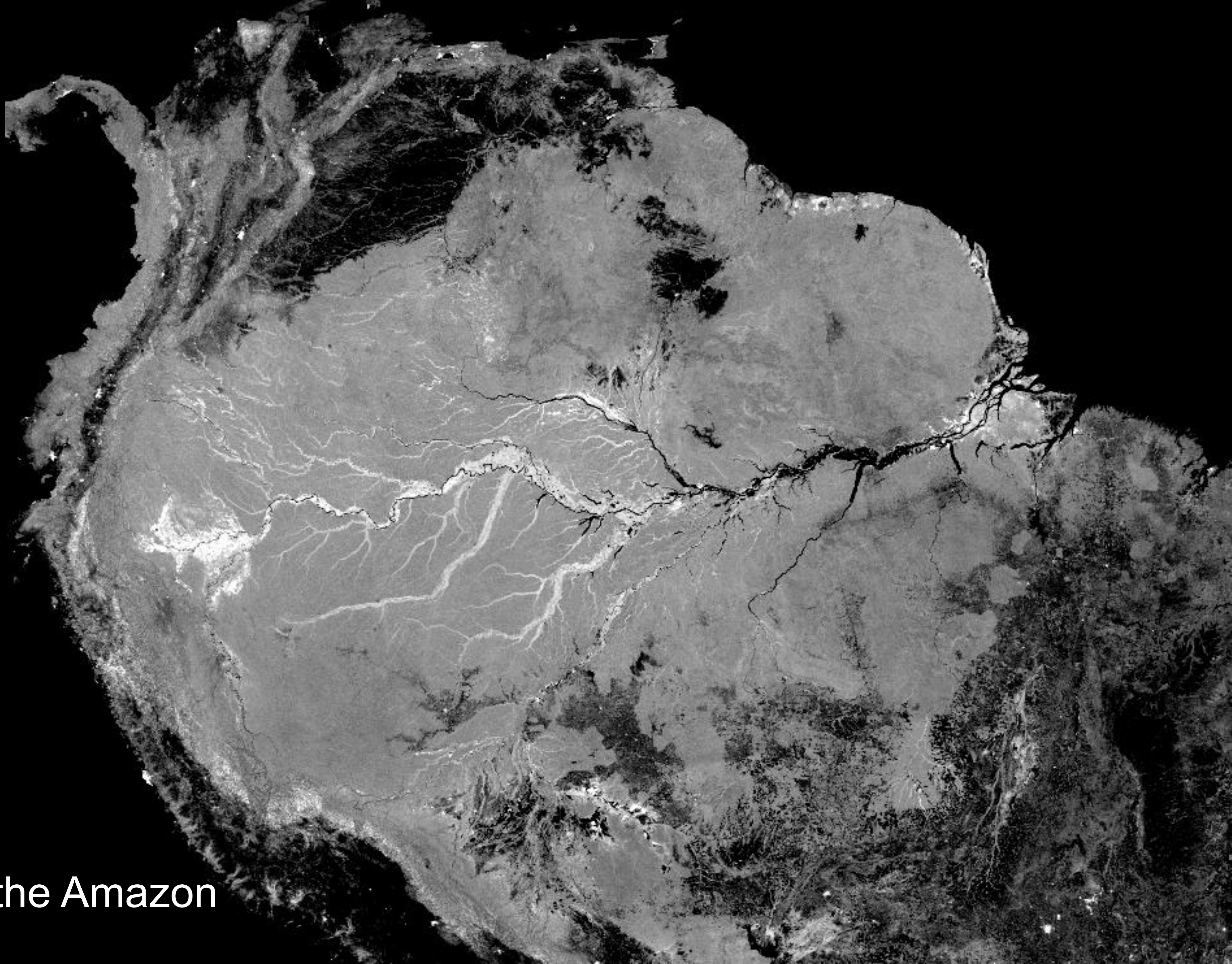
Double Bounce Reflection





Salinas Valley, California
October 24, 1998
L-Band Image

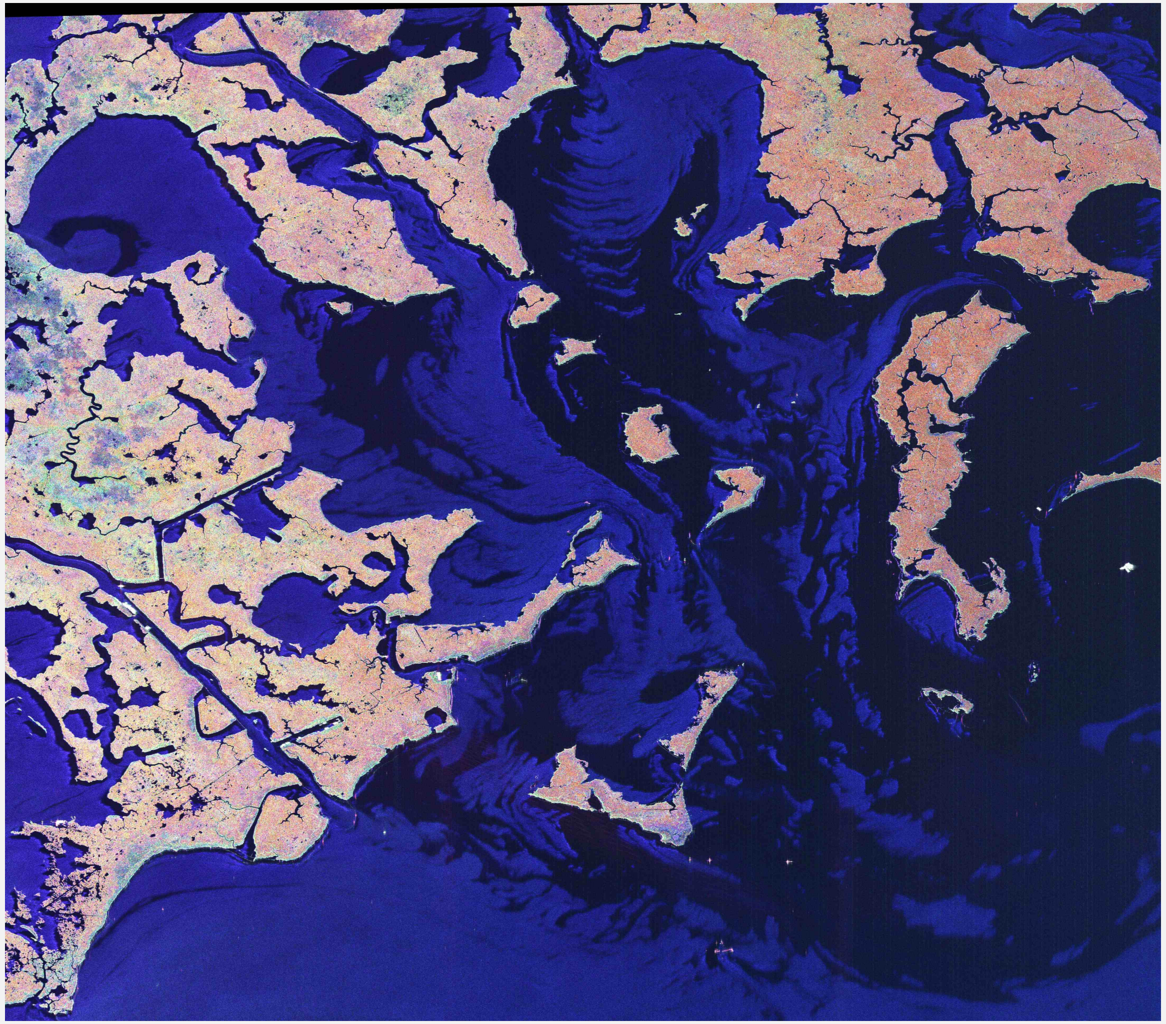
Source: Natural Resources Canada



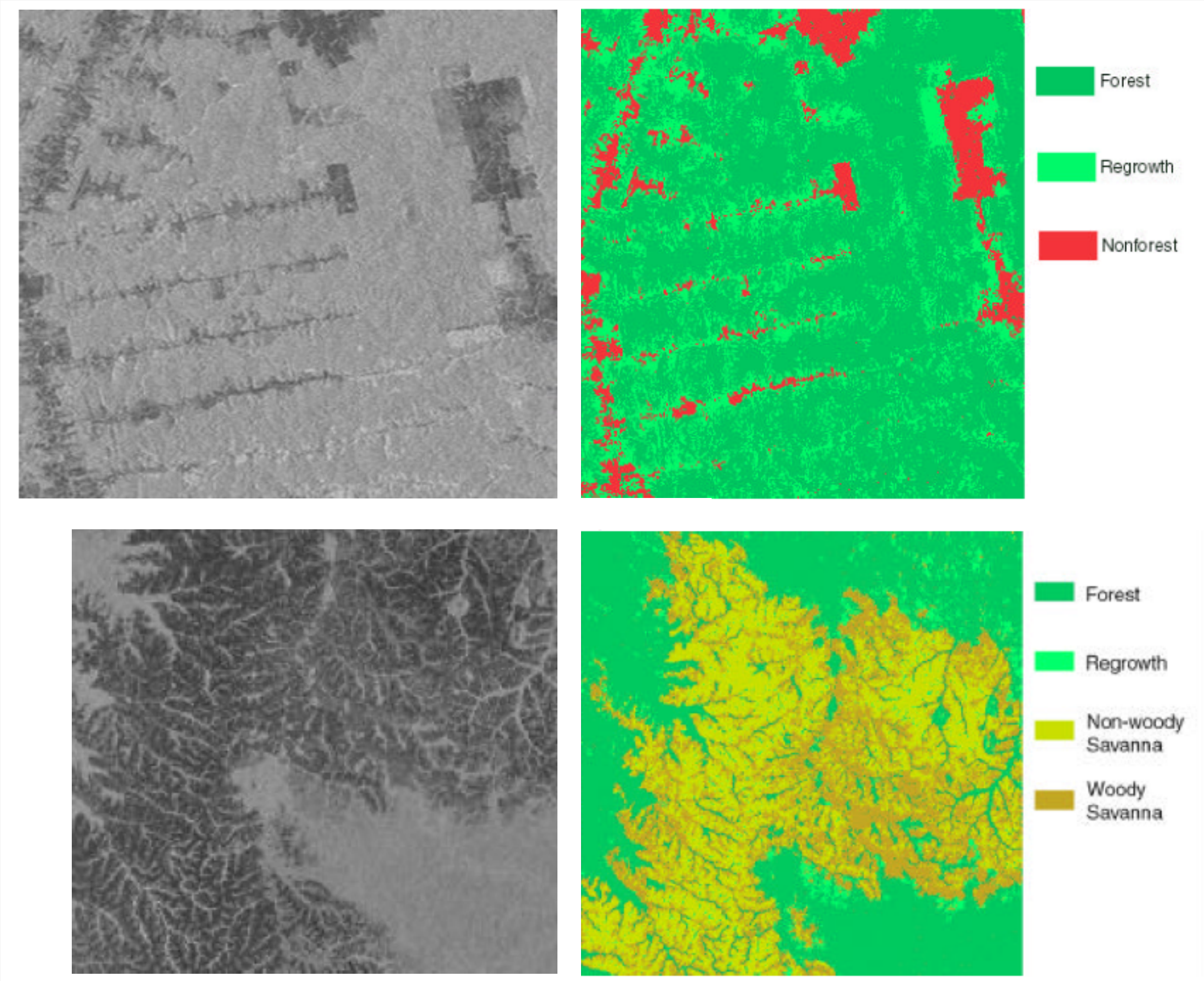
SMAP Radar Mosaic of the Amazon

Example: Detection of Oil Spills on Water

UAVSAR (2 meters):
HH, HV, VV



Example: Land Cover Classification



Brazil

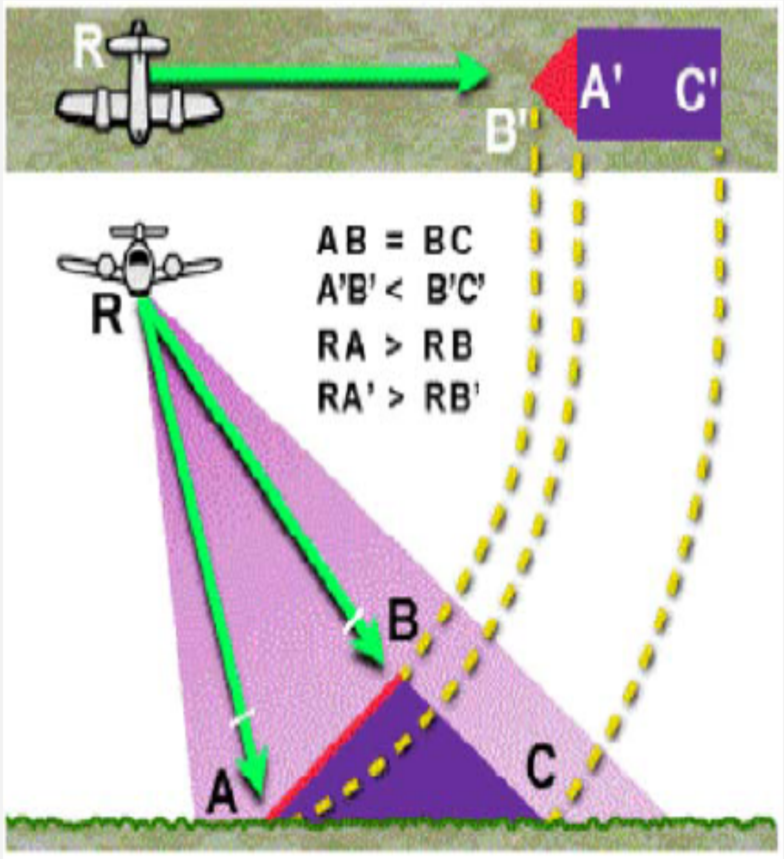
JERS-1 L-band

100 meter resolution

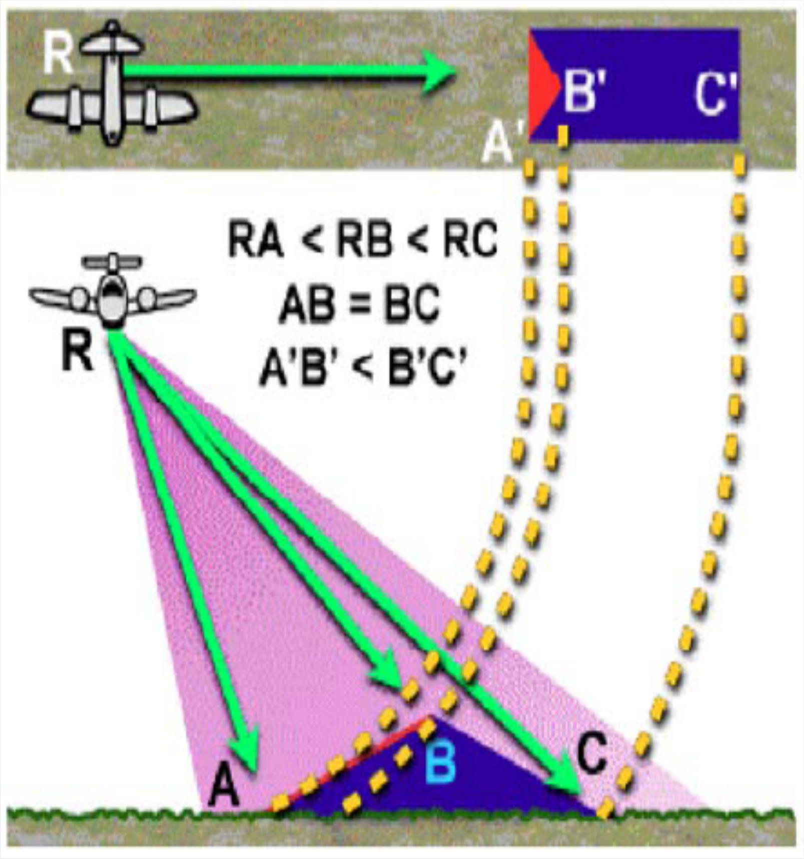
Geometric and Radiometric Distortion of the Radar Signal

Geometric Distortion

Layover



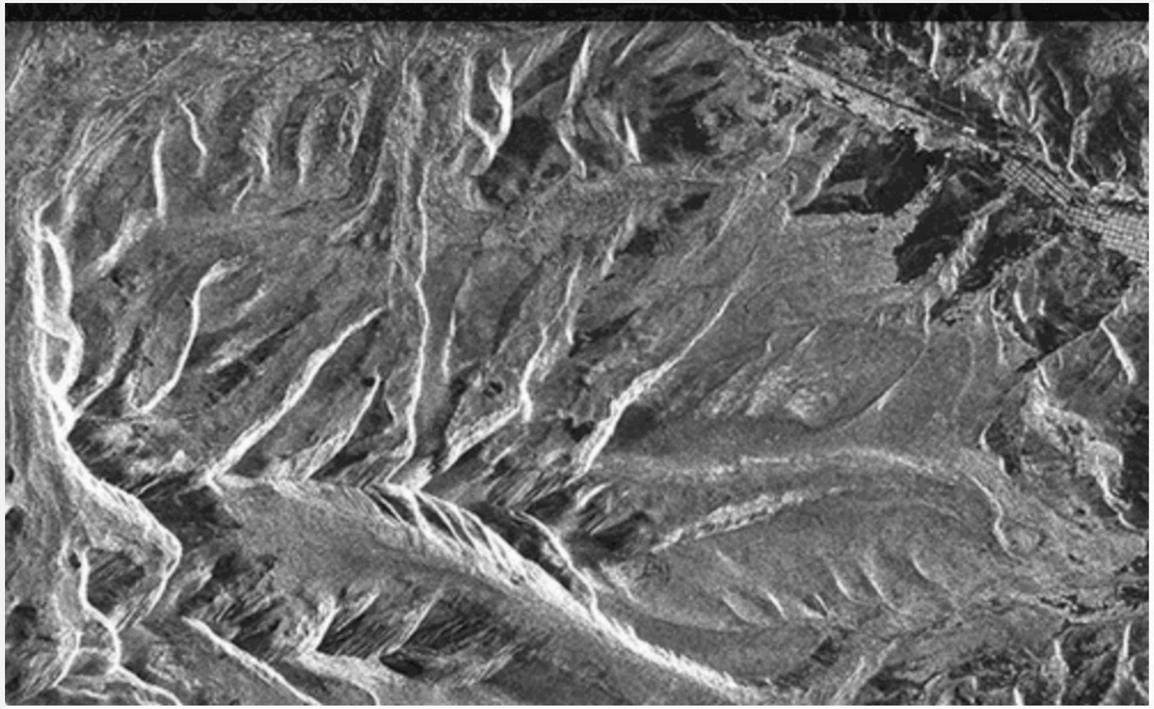
Foreshortening



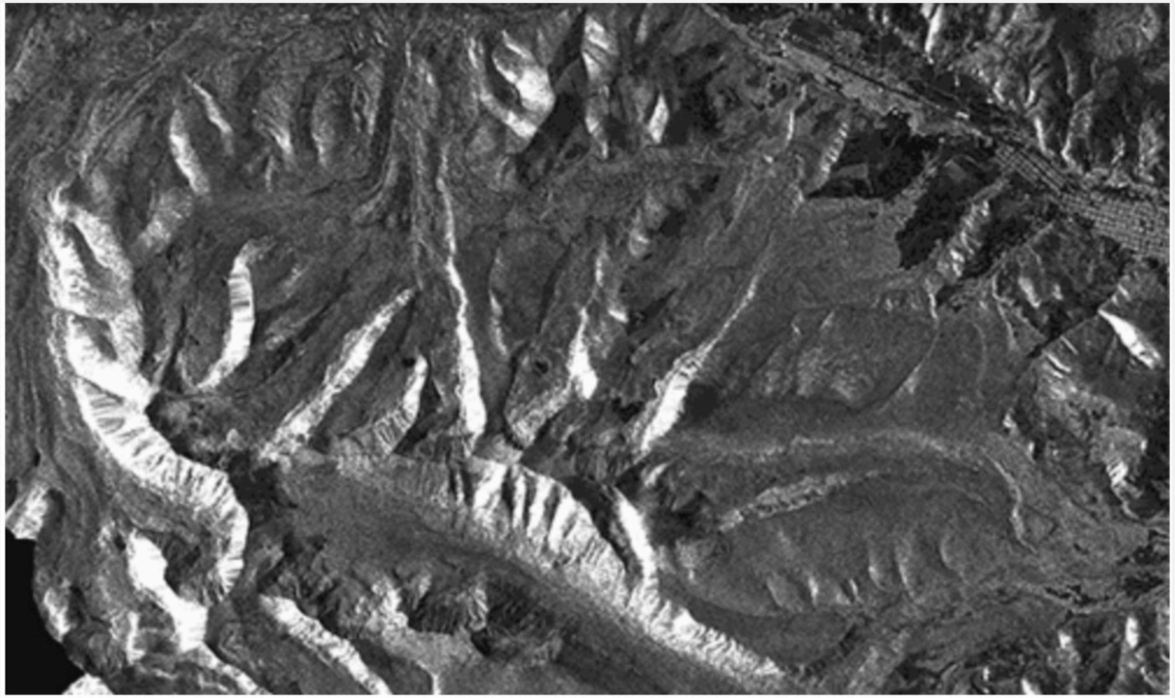
Source: Natural Resources Canada

Foreshortening

Before Correction

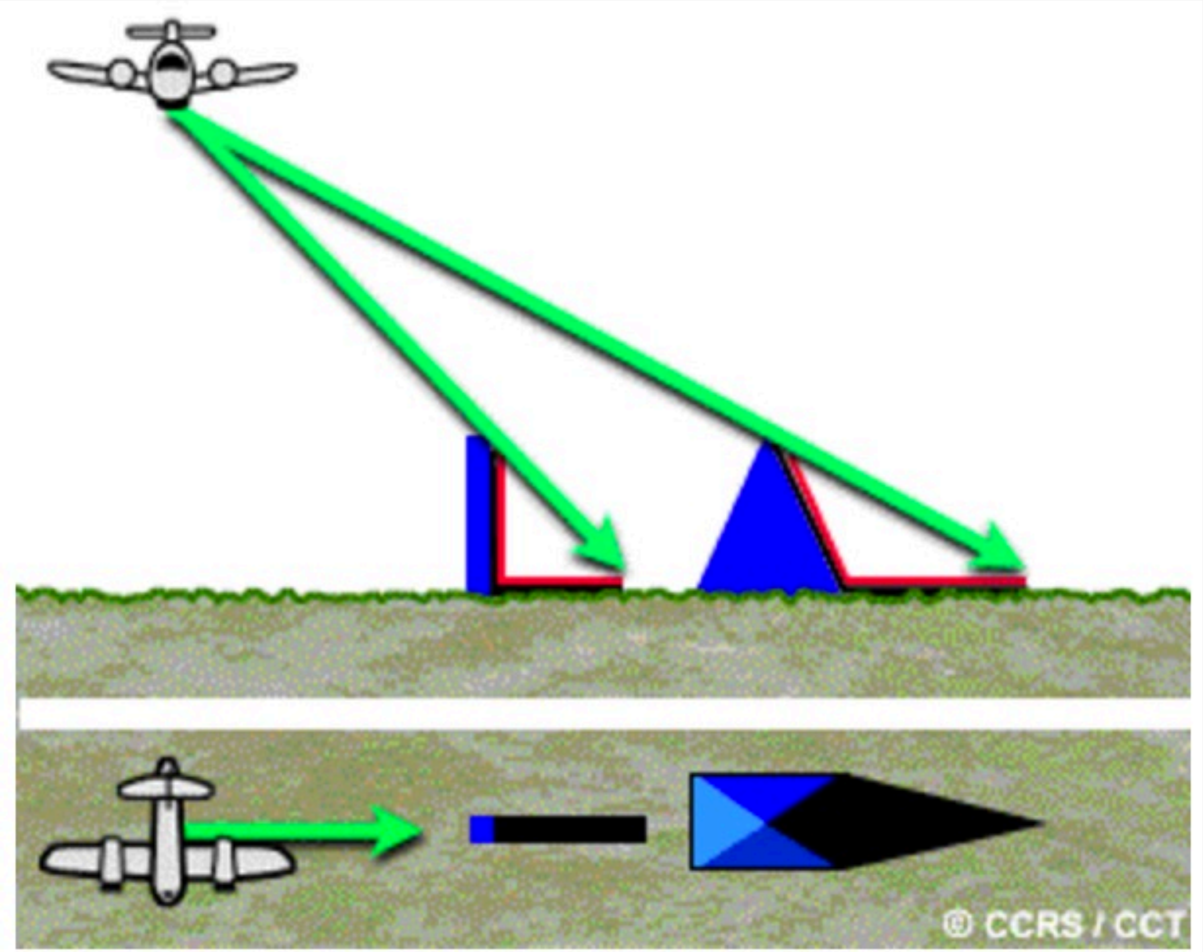


After Correction



Source: ASF

Shadow

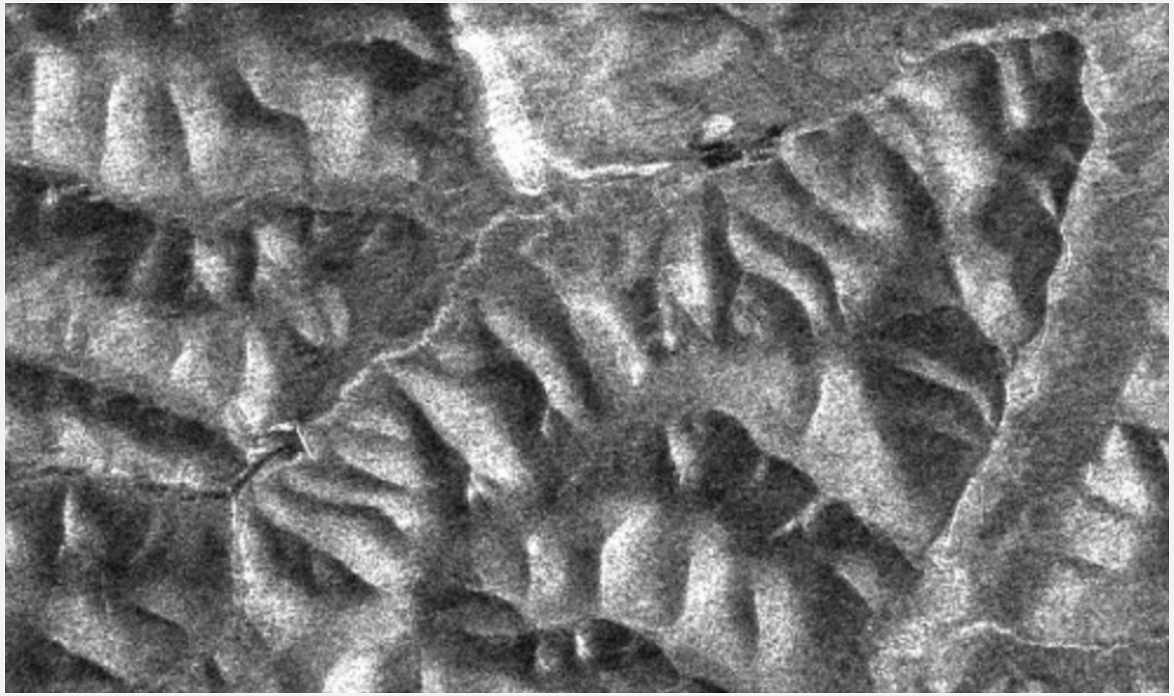


Source: Natural Resources Canada

Radiometric Distortion

- The user must correct for the influence of topography on backscatter
- This correction eliminates high values in areas of complex topography

Before Correction



After Correction

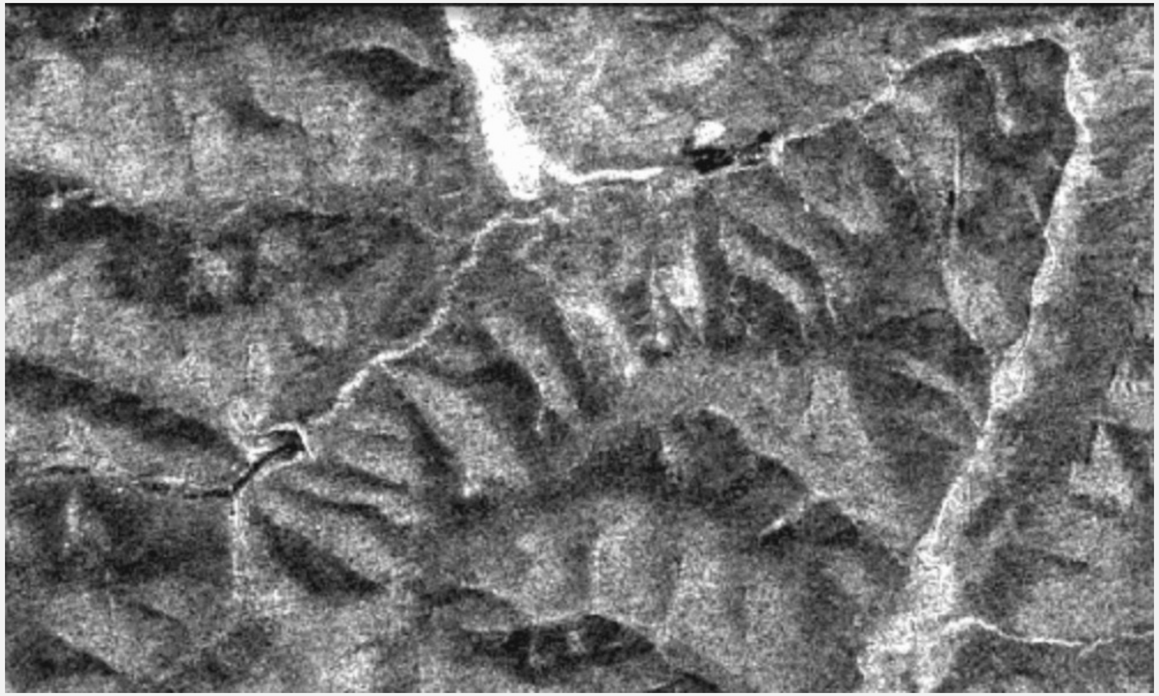


Image Credits: ASF

Radar Data from Different Satellite Sensors

Sensor Name	RADARSAT-2	Sentinel-1A	RISAT-1
Agency	Canadian Space Program (CSP)	European Space Agency (ESA)	Indian Space Research Organization (ISRO)
Instrument	C-band SAR (5.4 GHz)	C-band SAR (5.4 GHz)	C-band SAR (5.35 GHz)
Incidence Angle	Side-looking, 15-45° off-nadir	Side-looking, 15-45° off-nadir	36.85°
Polarization	HH, HV, VV, & VH	(VV & VH) or (HH & HV)	HH & HV
Sensor Height at Equator	798 km	693 km	542 km
Orbit	Sun Synchronous (dusk/dawn)	Sun Synchronous (dusk/dawn)	Sun Synchronous (dusk/dawn)
Revisit Time (Orbit Repeat Cycle)	24 days	12 days	25 days

Radar Data from Different Satellites

Sensor Name	RADARSAT-2	Sentinel-1A	RISAT-1
Resolution	100 m	5 m x 20 m	~25 m
Swath Width	500 km (ScanSAR mode)	250 km (IWS mode)	115 km (MRS)
Mean Local Time	6:00 a.m. descending	6:00 a.m. descending	6:00 a.m.
Launch	14 Dec 2007	3 April 2014	26 Apr 2012
Planned Lifetime	7 years minimum	7 years	5 years

Questions

1. What are the two surface parameters radar is sensitive to?
2. What are the three main backscattering mechanisms?
3. What type of distortions do radar images have?
4. What are the geometric distortions?
5. What type of products can you generate from radar images?
6. How can you use radar images for your specific application?