Remote Sensing 1: GEOG 4/585

Lecture 6.2.

Active remote sensing: Radar

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in 165 Condon Hall

Required reading:
Principles of Remote Sensing pp 345-406

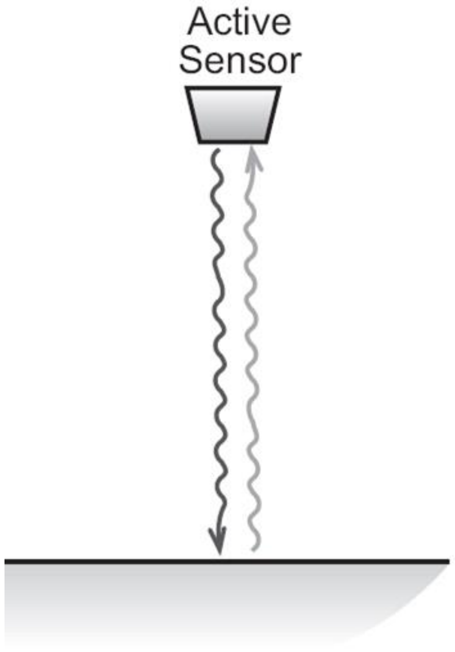
Definitions

- RADAR (RAdio Detection And Ranging)

- Transmit long-wavelength radiowaves (~1 – 100 cm) through the atmosphere and record energy backscattered from the terrain

- Advantages:
  - Can sense the surface through clouds and in darkness
  - Penetrate vegetation, dry sand, and snow
  - Support interferometry for mapping of 3D terrain and cm-scale motion

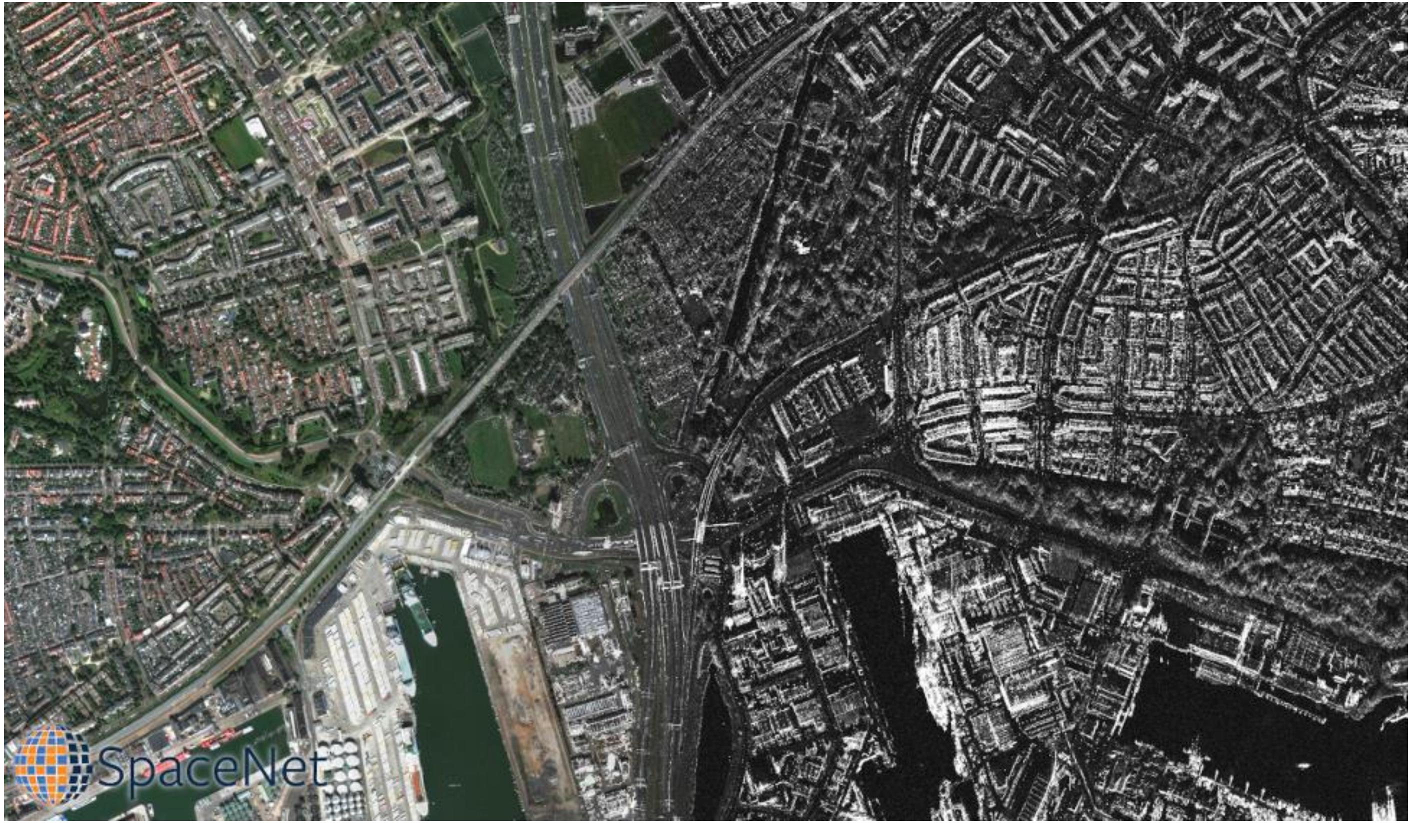
- Disadvantages:
  - Confusing, both in understanding how it works and also image interpretation.



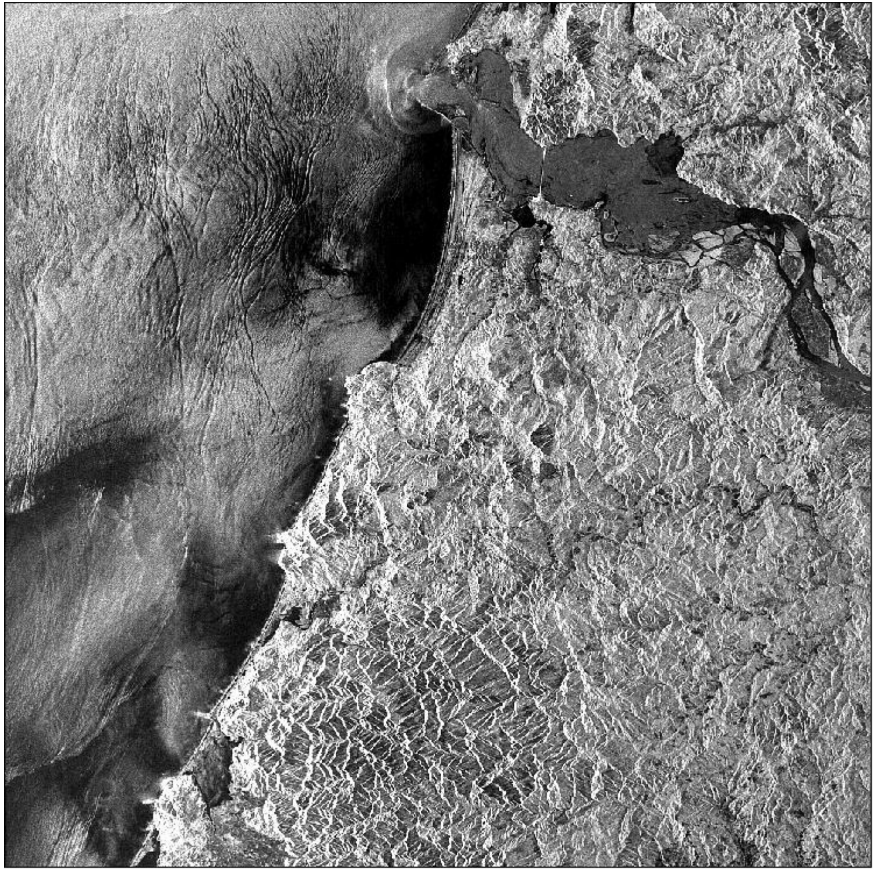
Applications

- The Magellan spacecraft was launched on May 4, 1989 to map the surface of Venus beneath the clouds

Optical vs. radar imagery



Radar imagery from Seasat in 1978

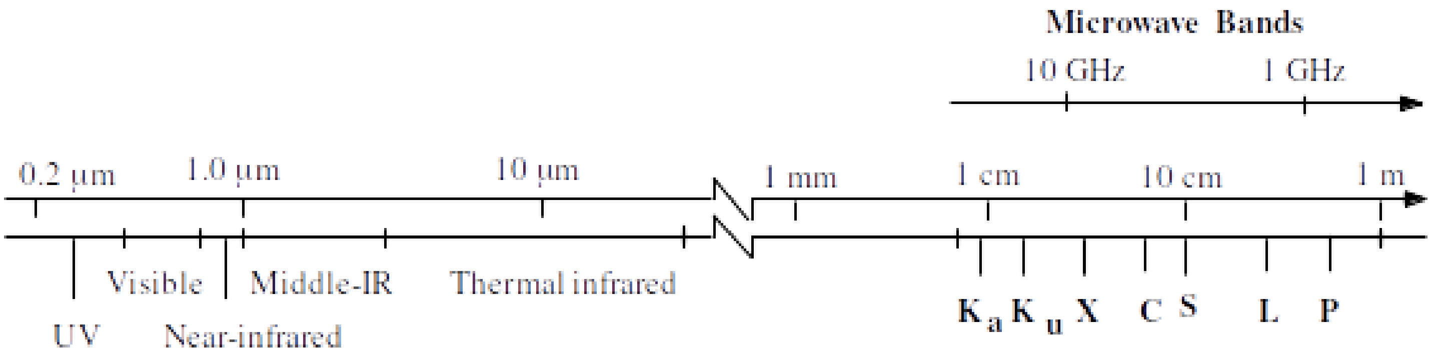


Radar wavelengths

- Radar wavelengths are much longer than visible/NIR energy used in other remote sensing systems.

- Radiowave energy is measured in *centimeters* rather than micrometers/nanometers.

- Radiowaves (or microwaves) have a frequency of between 30 Hz and 300 GHz



Radar wavelengths

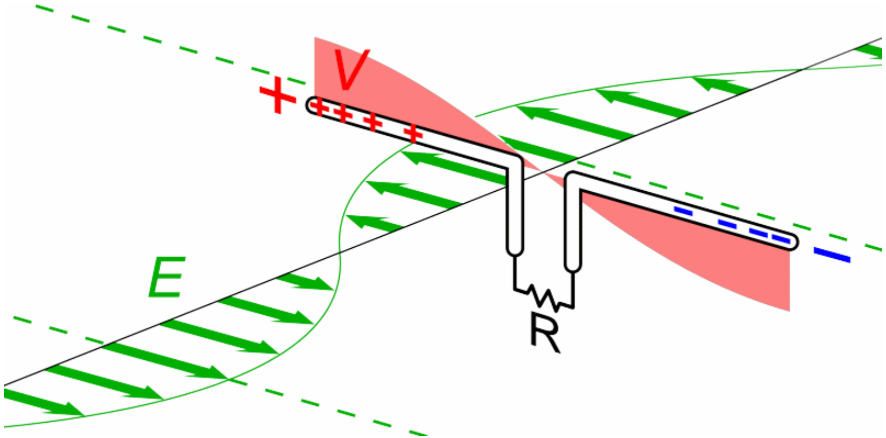
- Radar bands have unusual names (e.g., K, Ka, Ku, X, C, S, L, and P)

Frequency band	Frequency range (GHz)	Wavelength range (cm)
L band	1–2	15–30
S band	2–4	7.5–15
C band	4–8	3.75–7.5
X band	8–12	2.5–3.75
Ku band	12–18	1.67–2.5
K band	18–27	1.11–1.67
Ka band	27–40	0.75–1.11
V band	40–75	0.4–0.75
W band	75–110	0.27–0.4

Sending and receiving a radar pulse

- We use *antennas* to transmit radiowave signals to the Earth's surface where they are backscattered

- Antenna can be customized so that the signal characteristics (e.g., wavelength, polarization, incidence angle) can be adjusted according to the desired application

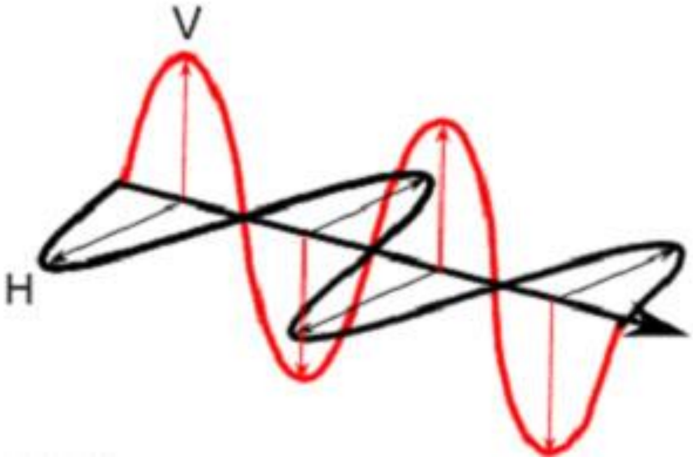


Polarization of radiowaves

- Radar antennas send and receive *polarized* energy meaning electromagnetic wave vibrations are only in a single plane that is perpendicular to the direction of travel.

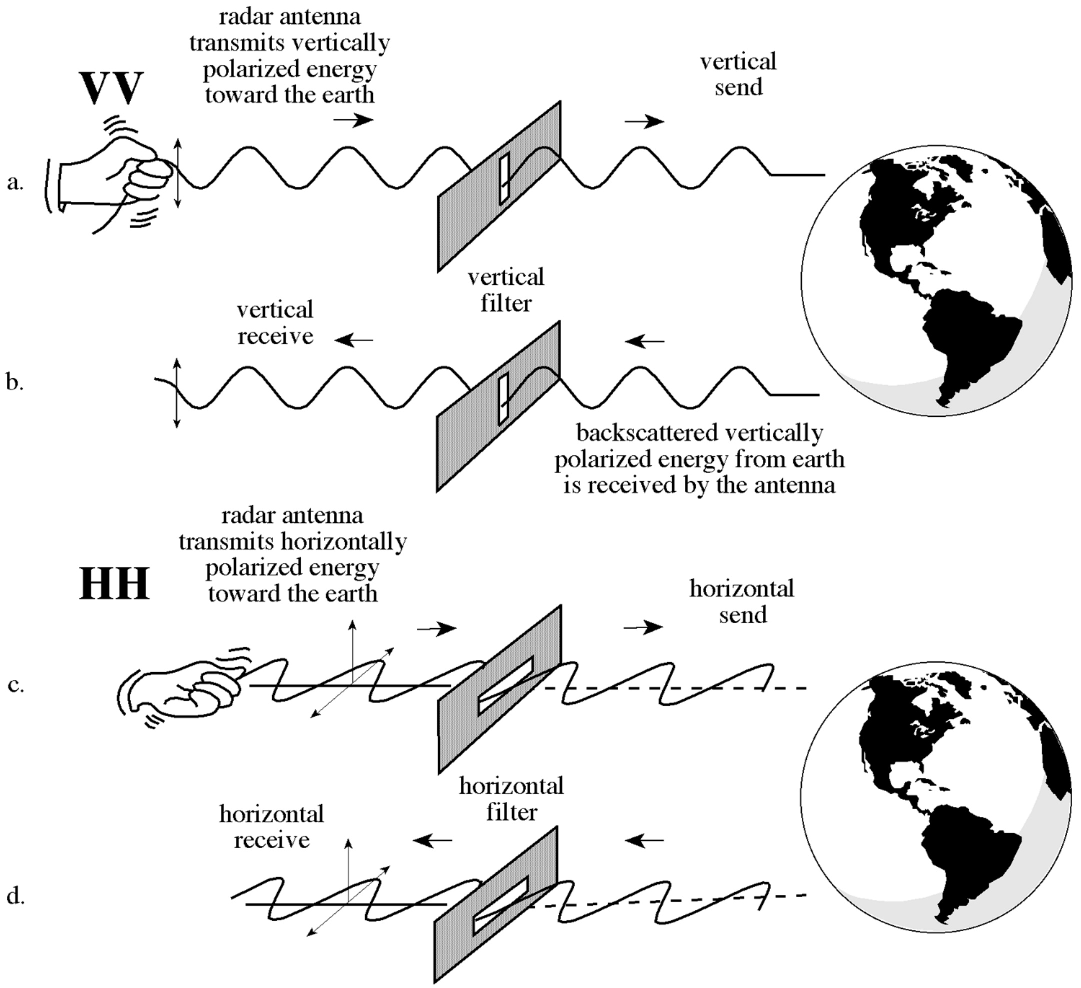
- The pulse of electromagnetic energy sent out by the antenna may be vertically or horizontally polarized.

- Images can be produced using different polarizations (HH, HV, VV, VH)



Polarized radar

- send and receive vertically polarized energy (VV)
- send and receive horizontally polarized energy (HH)
- send horizontal and receive vertically polarized energy (HV)
- send vertical and receive horizontally polarized energy (VH)



Polarization

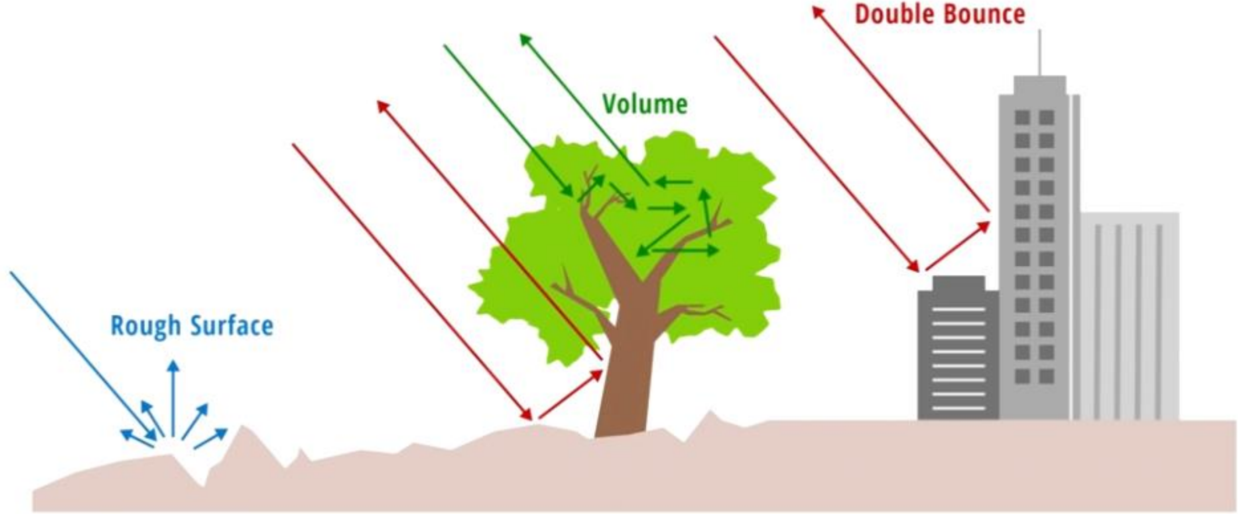


Figure 2.9 Schematic sketch of the three main scattering types considered for SAR data.

RELATIVE SCATTERING STRENGTH BY POLARIZATION:

Rough Surface Scattering	$\lvert S_{VV} \rvert > \lvert S_{HH} \rvert > \lvert S_{HV} \rvert$ or $\lvert S_{VH} \rvert$
Double Bounce Scattering	$\lvert S_{HH} \rvert > \lvert S_{VV} \rvert > \lvert S_{HV} \rvert$ or $\lvert S_{VH} \rvert$
Volume Scattering	Main source of $\lvert S_{HV} \rvert$ and $\lvert S_{VH} \rvert$

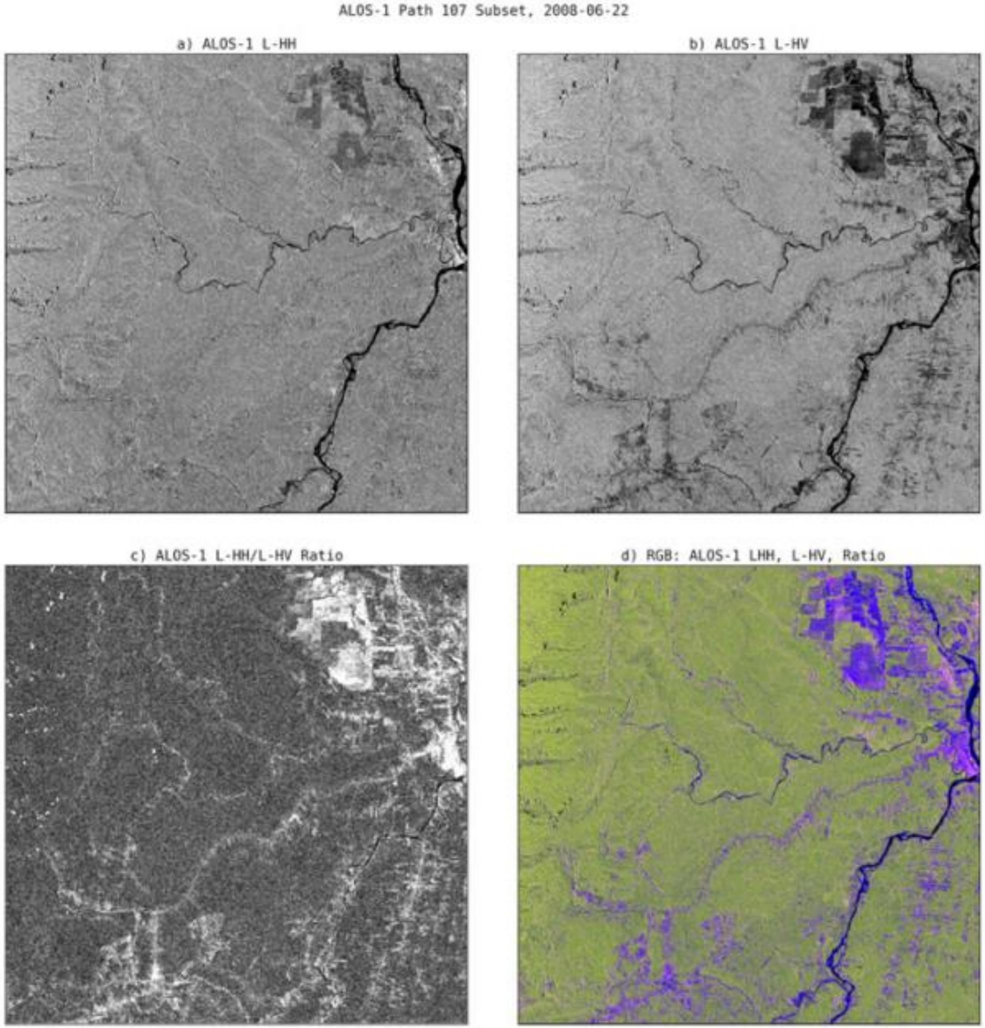
VV = Vertical Transmit, Vertical Receive
HH = Horizontal Transmit, Horizontal Receive
VH = Vertical Transmit, Horizontal Receive
HV = Horizontal Transmit, Vertical Receive

Polarization

- Cross-polarized images using L-band radar on ALOS-1

- Red channel = HH
- Green channel = HV
- Blue channel = HH/HV ratio

- Cross-polarized reflections make the fishbone logging pattern more visible because there is less randomization of polarized radiowaves (less volume scattering)



Radar backscatter coefficient, σ°

- It is the effects of terrain on the radar signal that we are usually most interested in, i.e. the amount of *radar cross-section*, σ, reflected back to the receiver, per unit area *a* on the ground. This is called the *radar backscatter coefficient* (σ°) and is computed as :

$$\sigma^\circ = \sigma / a$$

- The radar backscatter coefficient (“radar backscatter”) determines the percentage of electromagnetic energy reflected back to the radar from within a resolution cell, e.g. 10 x 10 m.

- The actual σ° for a surface depends on a number of terrain parameters like geometry, surface roughness, moisture content, and the radar system parameters (wavelength, depression angle, polarization, etc.).

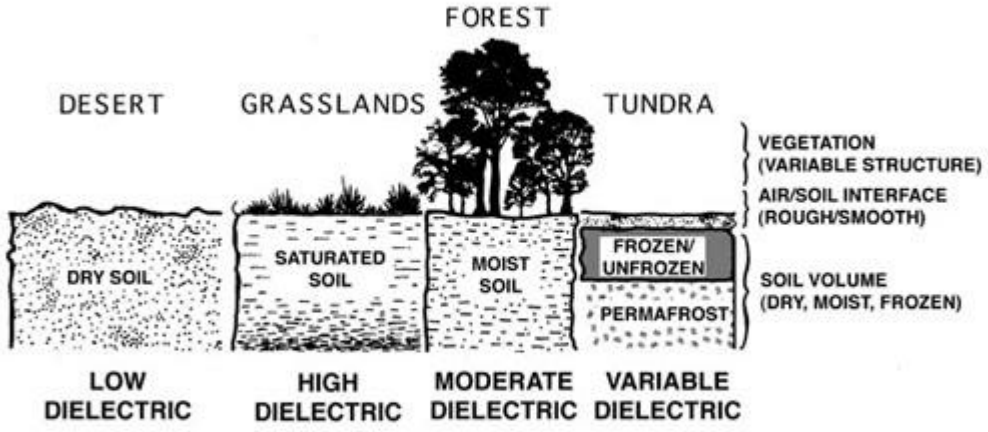
- σ° is logarithmic and has units of decibels (dB)

Factors influencing backscatter, σ°

- Dielectric constant
- Surface roughness (micro-roughness)
- Incidence angle
  - Sensor viewing geometry (fixed)
  - Local surface topography (variable)
- Radar system

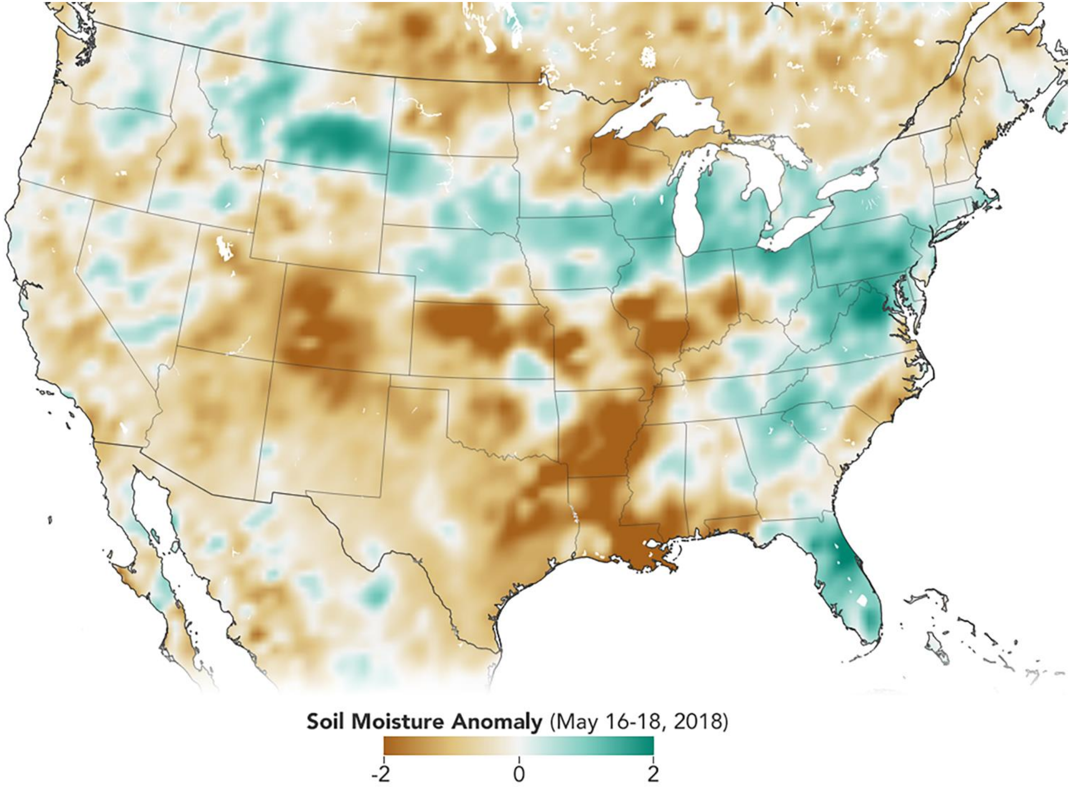
Dielectric constant

- Electric permeability of a material, where higher means better at reflecting radiowaves
- Most earth materials have a dielectric constant in the range of 1 to 4 (air = 1, vegetation = 3, ice = 3.2), dielectric constant of liquid water is 80
- Moisture content therefore strongly affects radar reflectivity

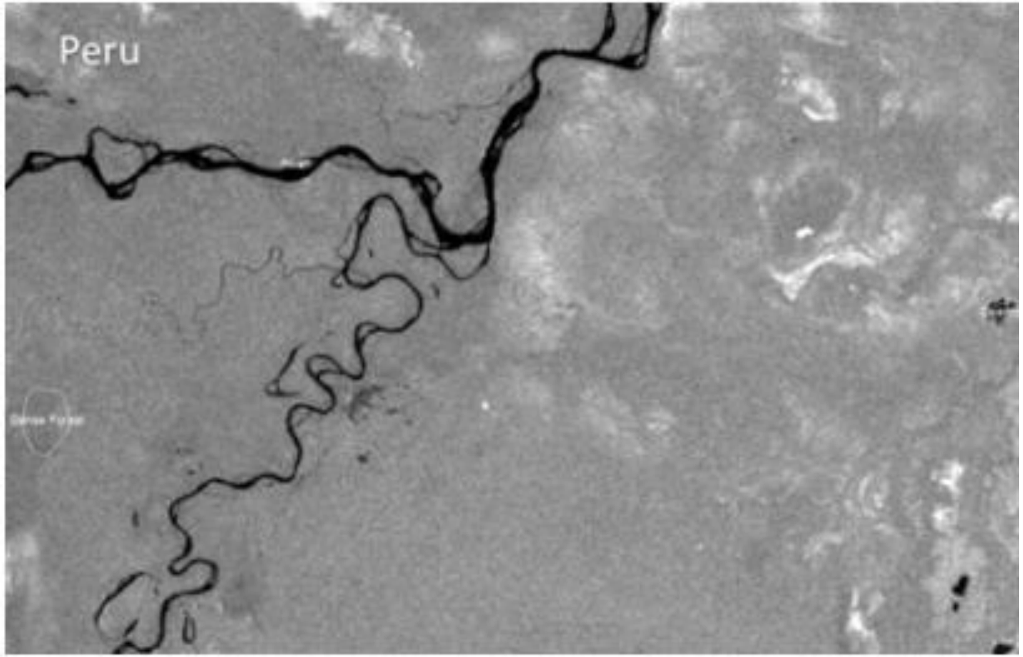


Soil moisture from radar

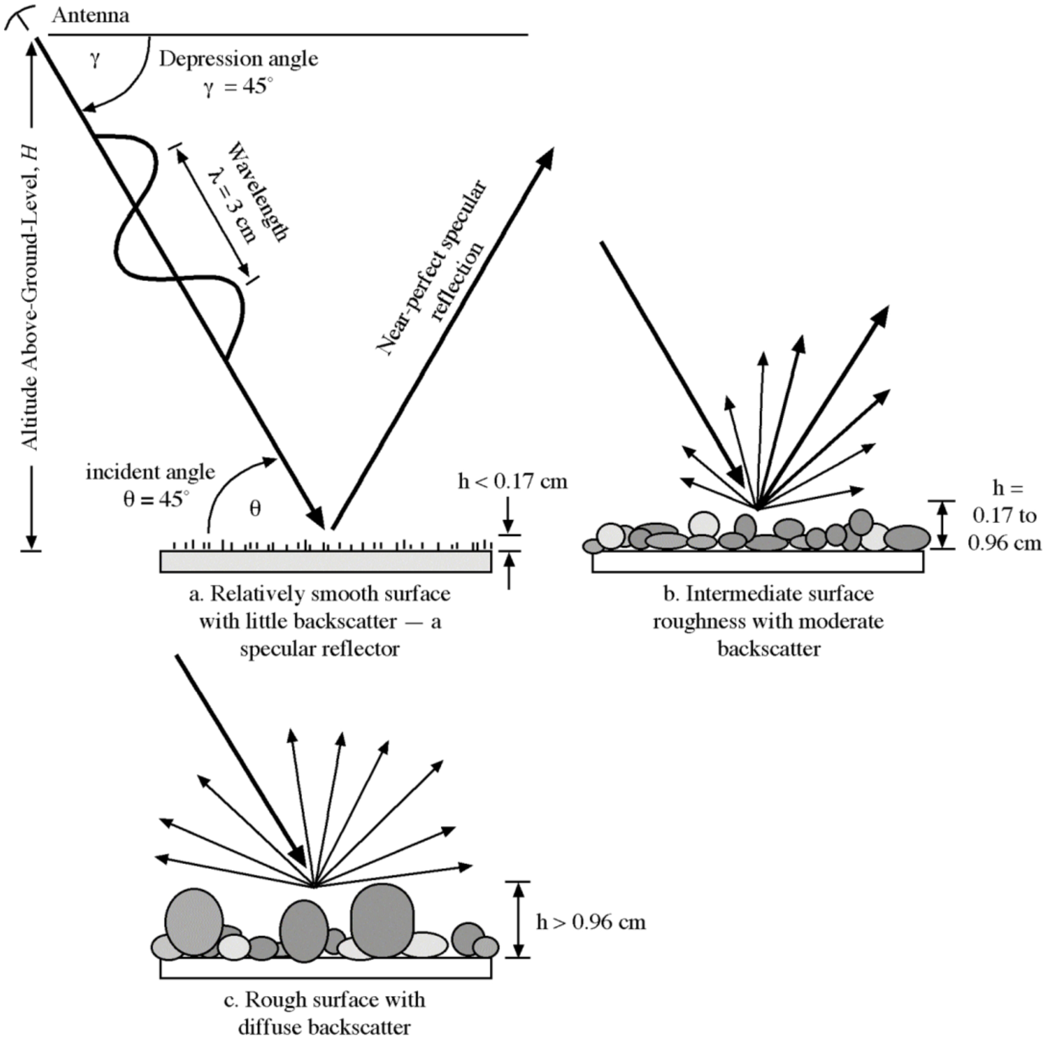
- NASA's Soil Moisture Active Passive (SMAP) mission launched in Jan 2015
- Soil with a higher moisture content appears "brighter" when illuminated by microwave frequencies (1.2 GHz)
- Operational forecasting of flooding and droughts



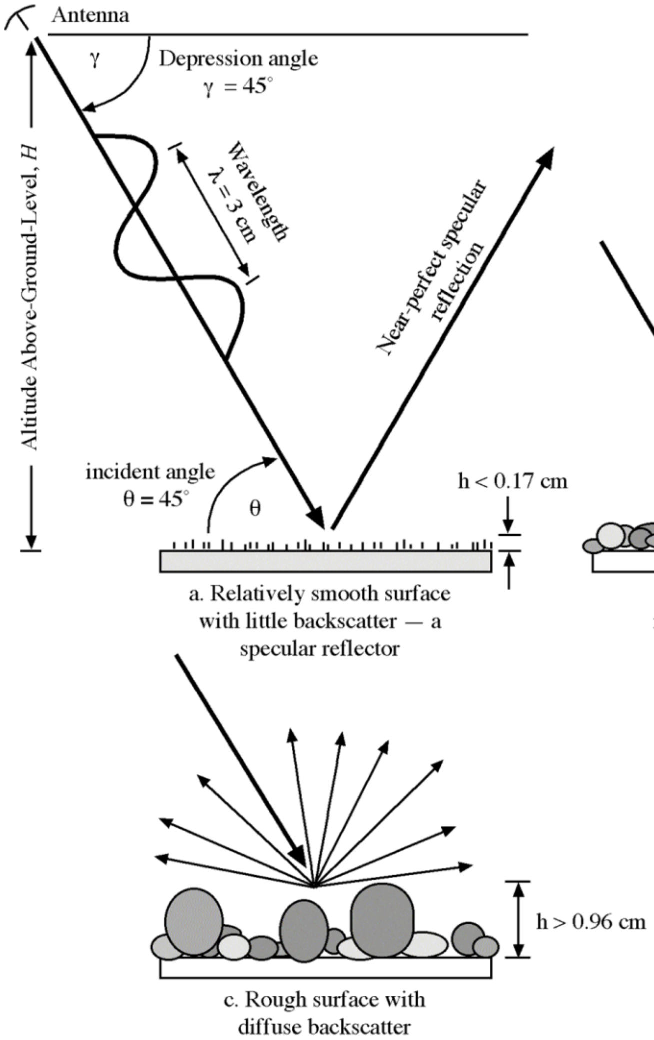
Water in radar image?



Surface roughness



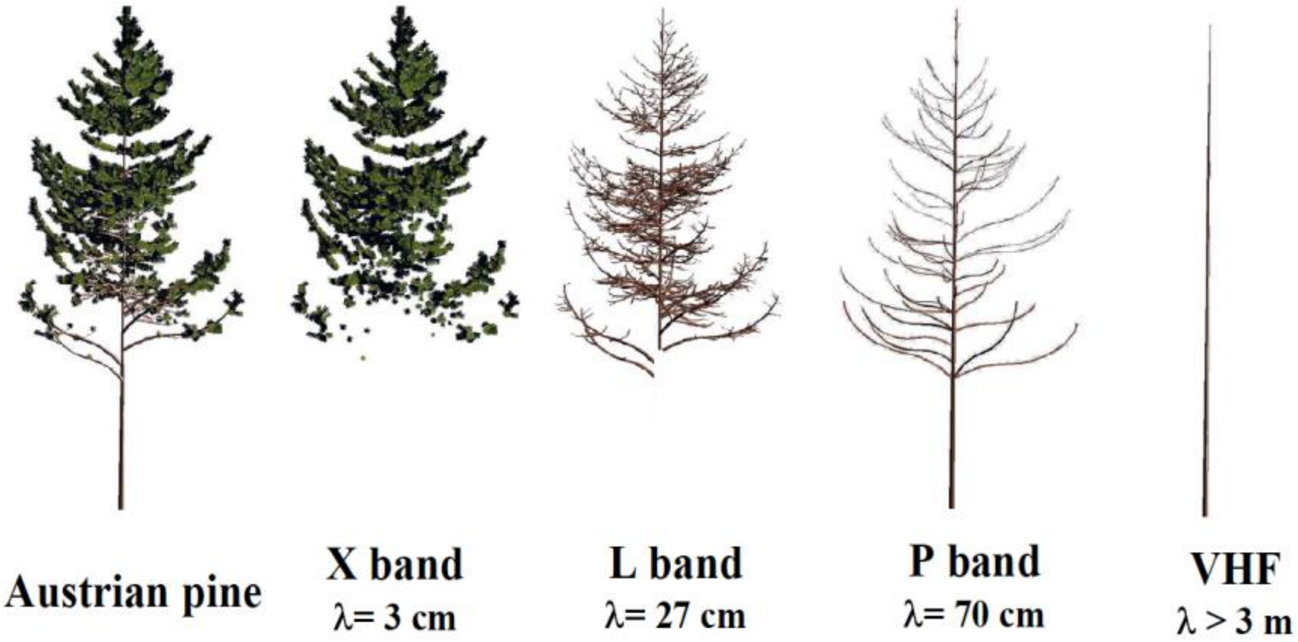
Surface roughness



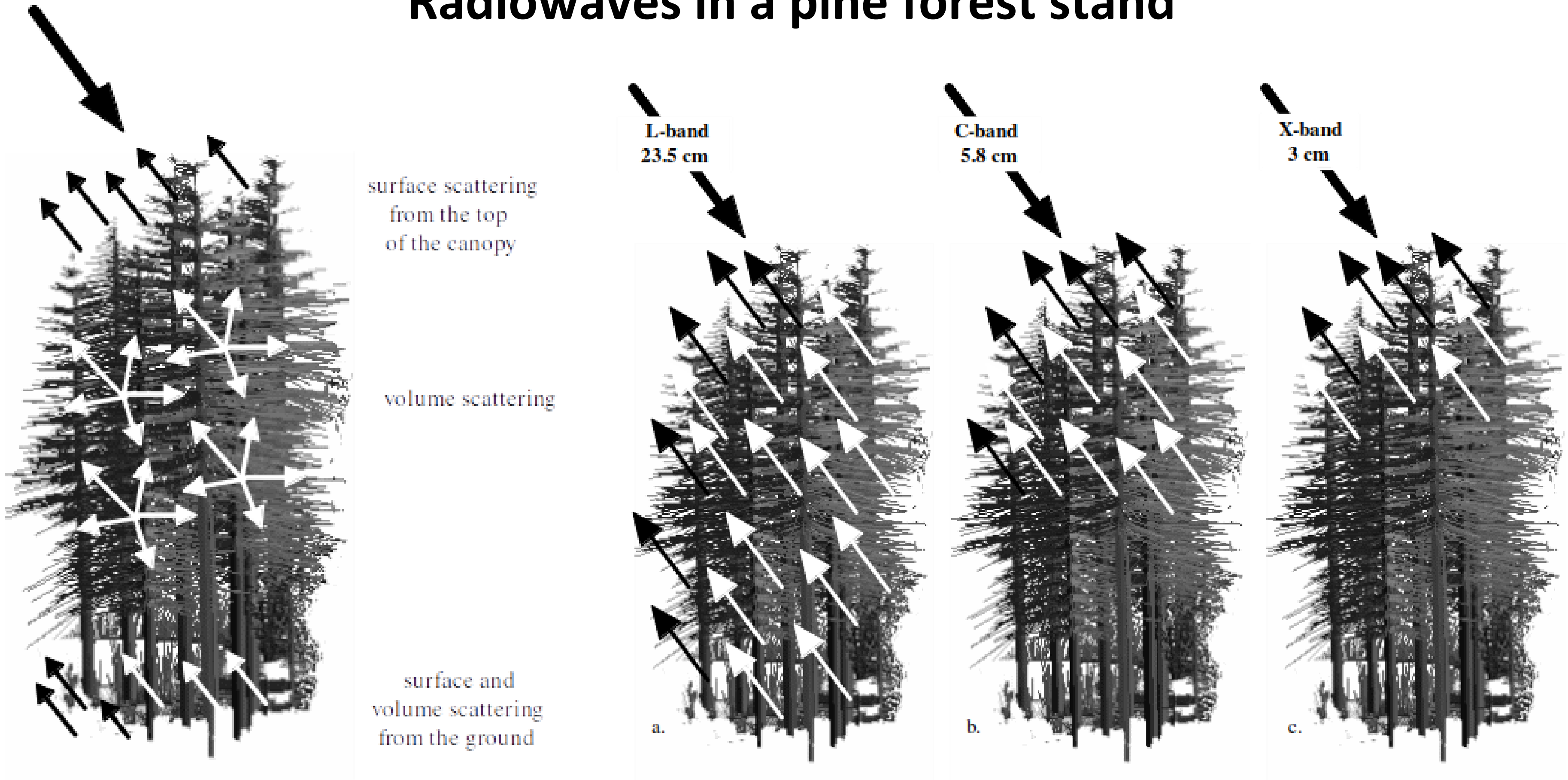
Lockheed F-117 Nighthawk is a specular reflector of radiowaves

Penetration of radiowaves

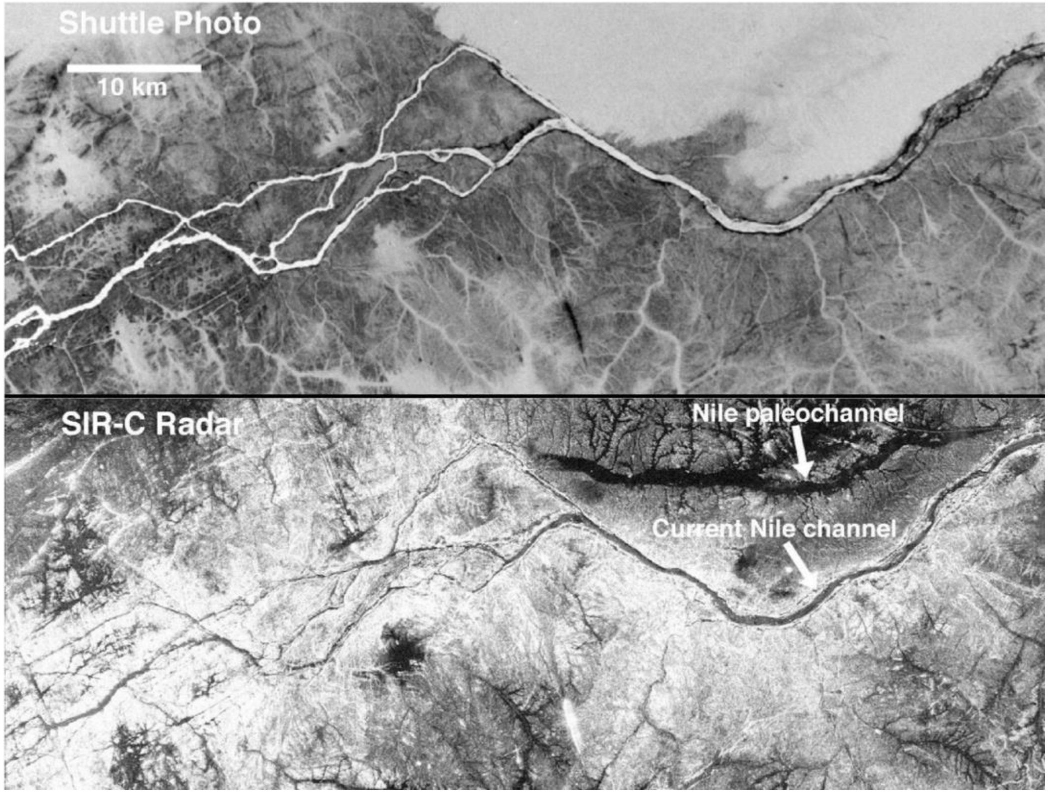
- Radiowaves can travel through objects that have small dielectric constants (e.g snow, sand, foliage)
- Longer wavelengths penetrate more than shorter wavelengths



Radiowaves in a pine forest stand



Paleochannels of the River Nile

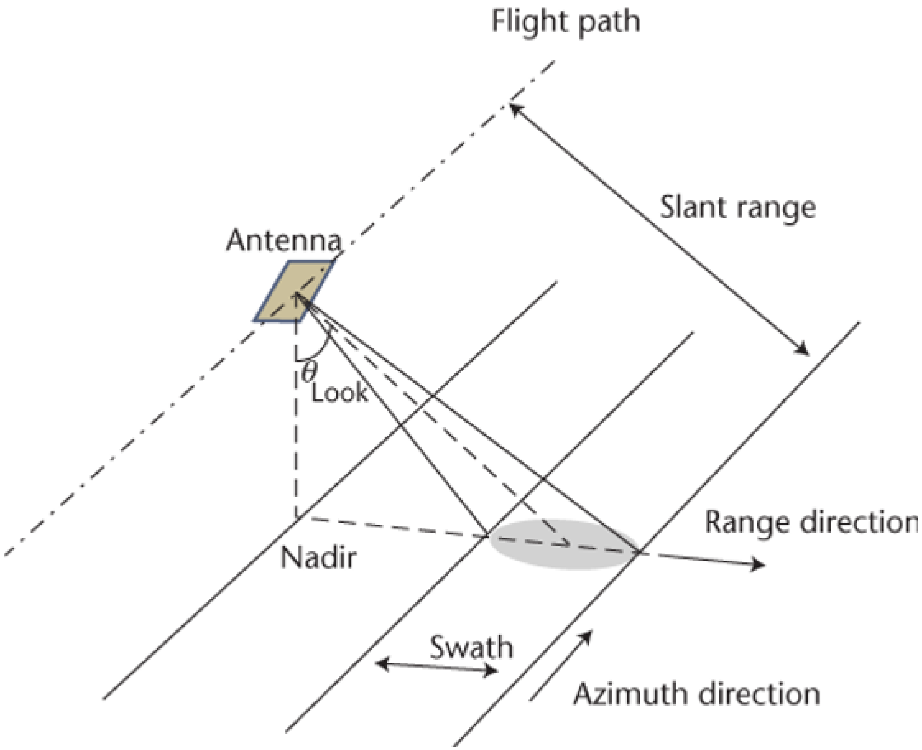


- The top photograph from *color infrared film* from Space Shuttle Columbia in November 1995.
- The *radar image* at the bottom was acquired by Spaceborne Imaging Radar C/X-Band Synthetic Aperture Radar (SIR-C/X-SAR) aboard Space Shuttle Endeavour in April 1994.

Radar viewing geometry

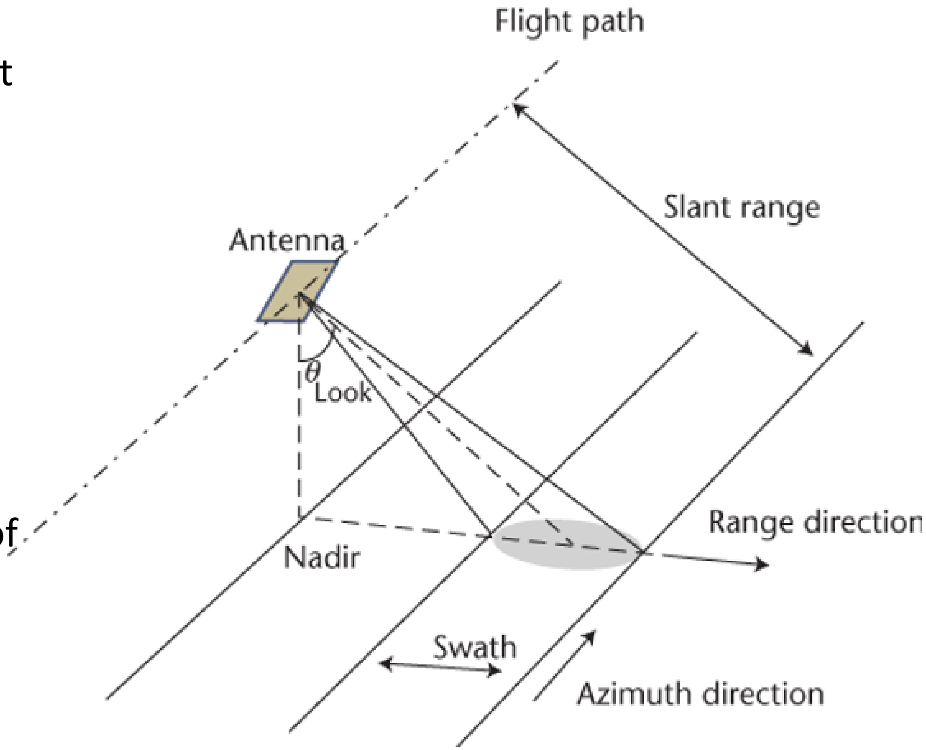
Simple case: Real-Aperture Radar (RAR)

- Nadir
- Azimuth (flight) direction
- Range direction
- Range (near and far)
- Look angle (ϕ)
- Altitude above-ground-level



Azimuth (flight) direction

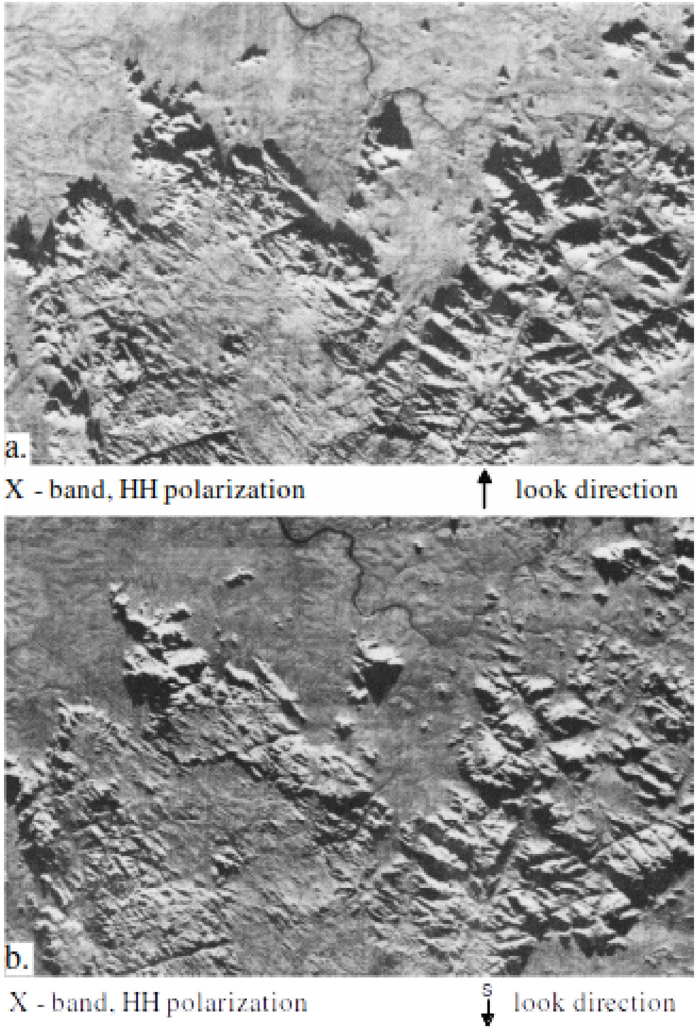
- The aircraft (or spacecraft) travels in a straight line that is called the *azimuth flight direction*
- Radiowave pulses illuminate strips of terrain at right angles (orthogonal) to the azimuth flight direction which is called the *range (or look) direction*
- Terrain illuminated nearest the antenna is called the *near-range* and the farthest point of terrain is called the *far-range*



Range (or look) direction

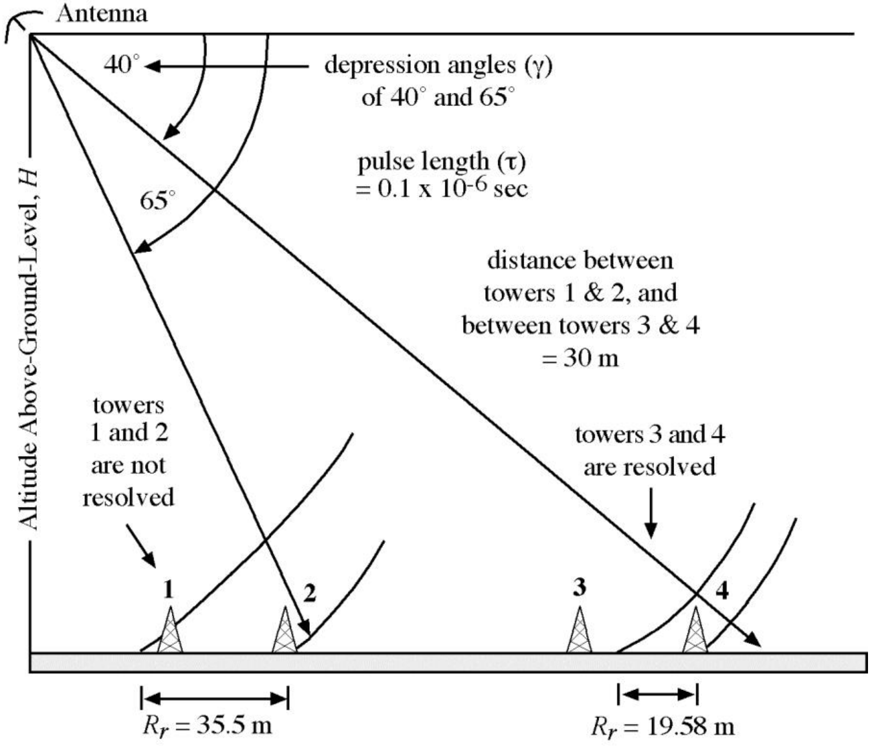
- Generally, objects that are perpendicular to the range direction backscatter *more* than objects in aligned parallel to the range direction.

- Consequently, linear features that appear dark or are imperceptible in a radar image using one look direction may appear bright in another radar image with a different look direction.



Radar spatial resolution

- The spatial resolution of a radar image is a combination of the *range* and *azimuth* resolutions.
- The *range resolution* in the across-track direction (i.e. near- to far-range) is proportional to the length of the microwave pulse and the incident angle
- Pulse length is a function of the speed of light multiplied by the duration of the transmission.
- Objects at different ranges can be distinguished if their range separation is larger than half the transmitted pulse length.



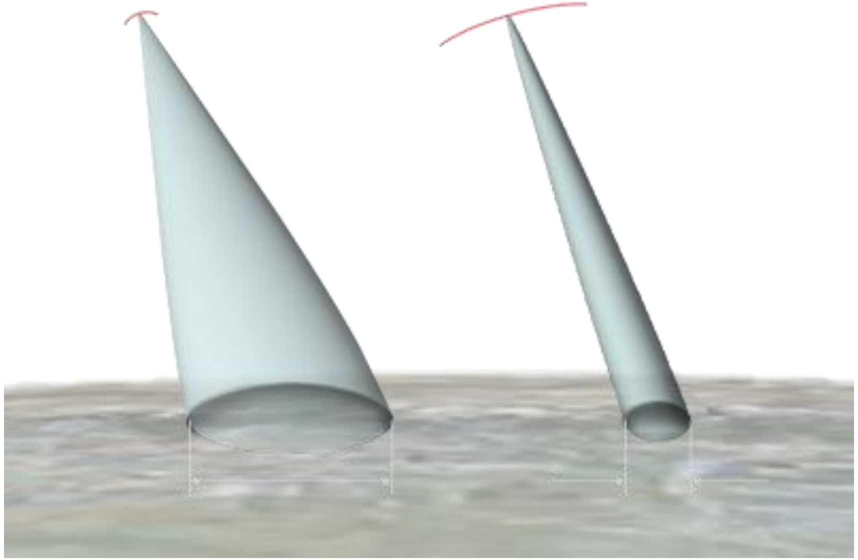
Azimuth resolution

- The *azimuth resolution* is determined by the width of the beam's footprint on the ground

- Longer wavelengths have wider beam footprint than shorter wavelengths

- But shorter wavelengths have poorer atmospheric and vegetation penetration capability

- Fortunately, the width of the beam is inversely proportional to the antenna length



Azimuth resolution example

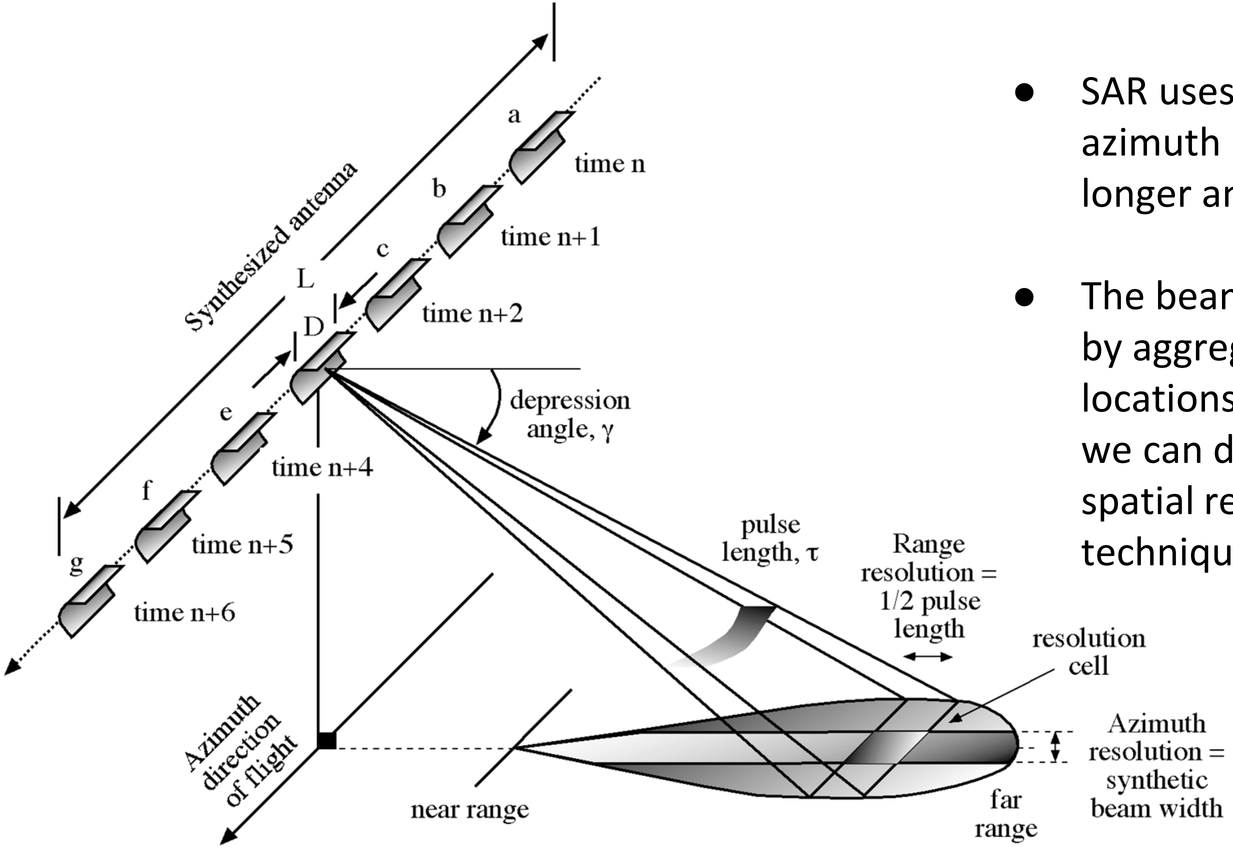
- C-band radar system operating at $\lambda = 0.03$ m and utilizing an antenna of $L = 3$ m length operating at 3000 m altitude with a look angle of 30°

- This system will achieve an acceptable azimuth resolution of 60 m
  - (0.03 / 3) * 3000 * 2

- However, if the same system is operated from a spaceborne platform at 800 km altitude, the azimuth resolution will degrade to 16 km, which is below the required system performance for most Earth observation applications

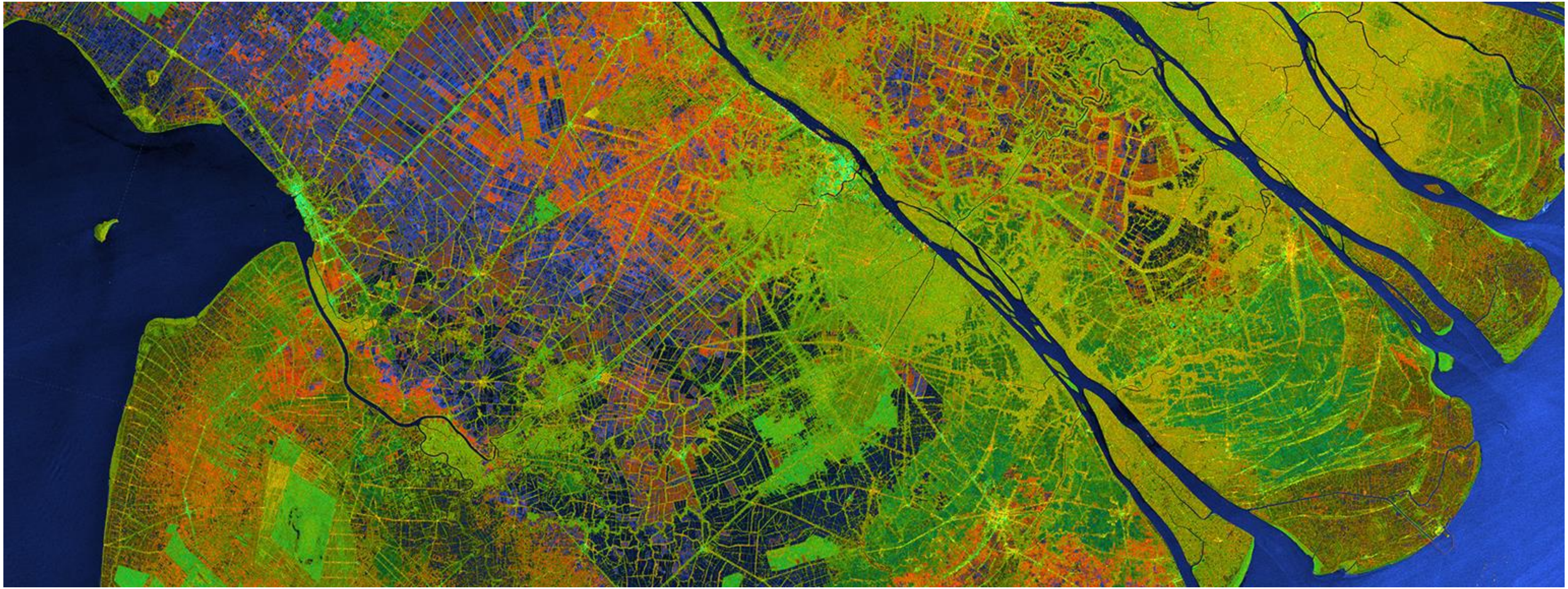
- Antenna length of about 800 m would be needed to achieve a 60 m resolution from space which is not practical

Synthetic aperture radar (SAR)



- SAR uses motion of the antenna along the azimuth (flight) direction to “synthetize” a longer antenna
- The beam footprint is large (several km) but by aggregating returns from many different locations in the azimuth (flight) direction, we can derive a single image with high spatial resolution using postprocessing techniques
- Modern spaceborne SAR sensors can achieve ground resolutions of between 0.5 and 20 m

SAR imagery



Summary

- Penetrates clouds and rain (C-band and longer) making it an all-weather remote sensing system

- May penetrate vegetation, sand, and surface layers of snow.

- Senses in wavelengths outside the visible and infrared regions of the electromagnetic spectrum, providing information on surface roughness, dielectric properties, and moisture content.

- Enables spatial resolution to be independent of distance to the object, with the size of a resolution cell being as small as 1 x 1 m

- Can make digital elevation models and motion maps from radar interferometry

Today's lab

Lab Assignment #6: Canopy height measurement using LiDAR

Objectives:

- We will make a canopy height model in QGIS using LiDAR data.

Deadline: November 9 Tuesday 11:59 pm