Basics of Synthetic Aperture Radar Remote Sensing

Synthetic Aperture Radar (SAR) Remote Sensing Training Course

Economic Cooperation Organization (ECO)

Prepared by Dr. Mehrnoosh Omati

Remote Sensing Expert of National Cartographic Center (NCC)

20-22 June, 2022

Tehran, Islamic Republic of Iran

SAR Remote Sensing

Contents:

Introduction of Remote Sensing

Remote sensing applications

Electromagnetic radiation basics

Types of remote sensing sensors

Advantage of microwave over optical systems

Active and passive microwave remote sensing

Sensitivity of return signal to sensor and target parameters

Radar geometry

Geometric distortions

Range/azimuth resolutions

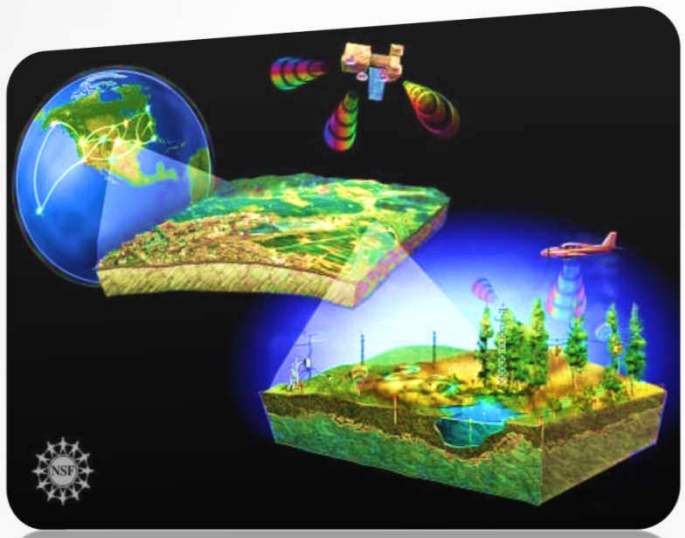
Introduction of synthetic aperture radar (SAR)

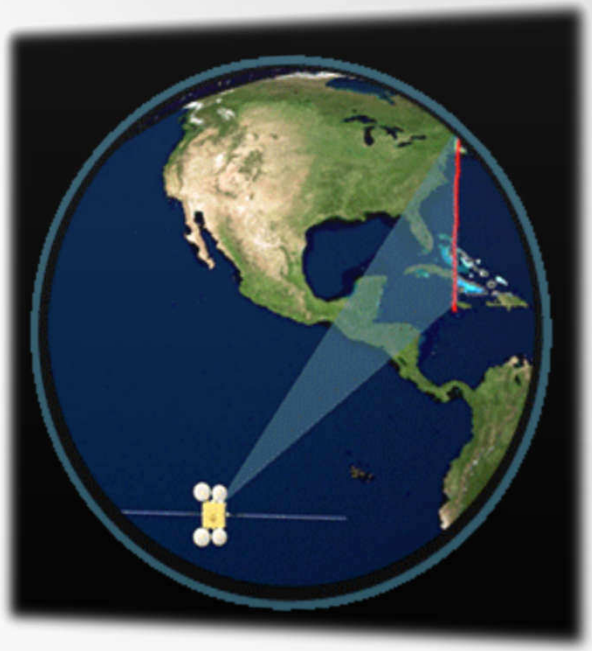
Remote Sensing

Remote Sensing is a method of acquiring information about the properties of an object or phenomenon from a distance

Three main categories of remote sensing platforms:

1. Ground-based
2. Airborne-based
3. Spaceborne-based

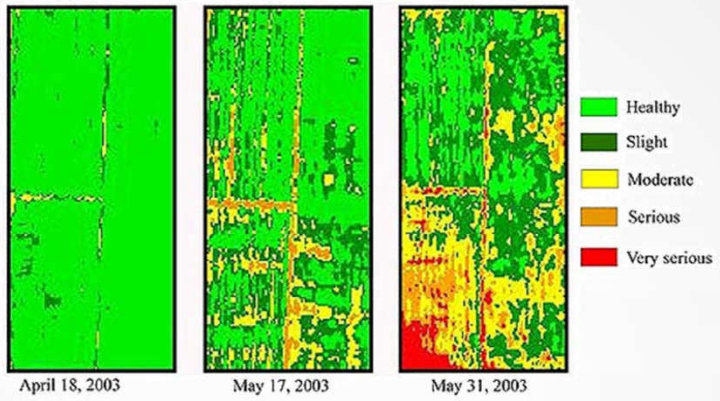




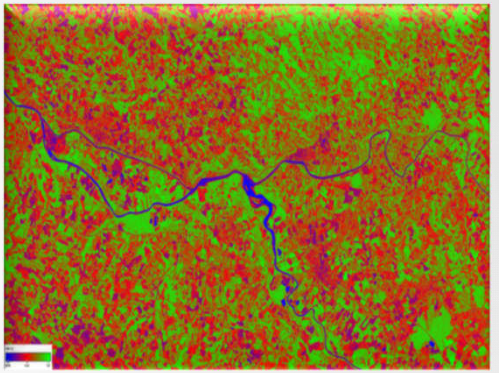
Remote Sensing Applications

Range of remote sensing includes:

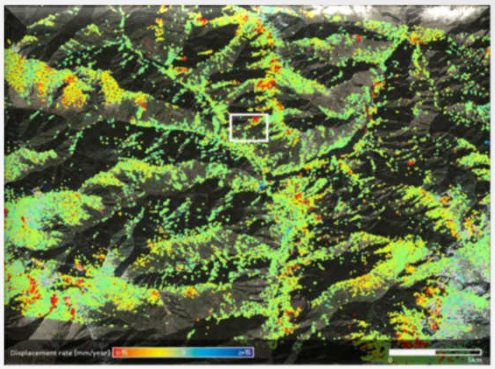
- Water resources
- Soil mapping and degradation
- Agriculture
- Forestry
- Land cover/land use mapping
- Monitoring of land cover/land use changes
- Natural or human-made disaster management
- Urban studies



Crop disease monitoring


Strength of the vegetation


Flood mapping


Landslide monitoring

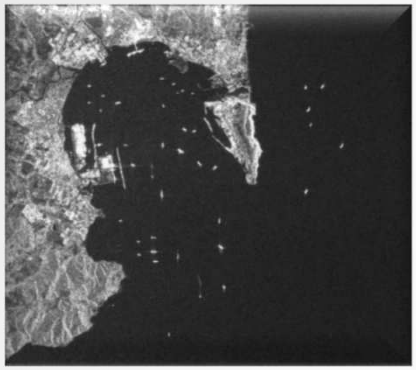
Remote Sensing Applications

Coastal studies

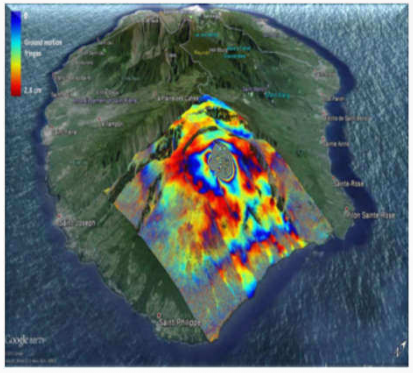
Oceanography

Climatology

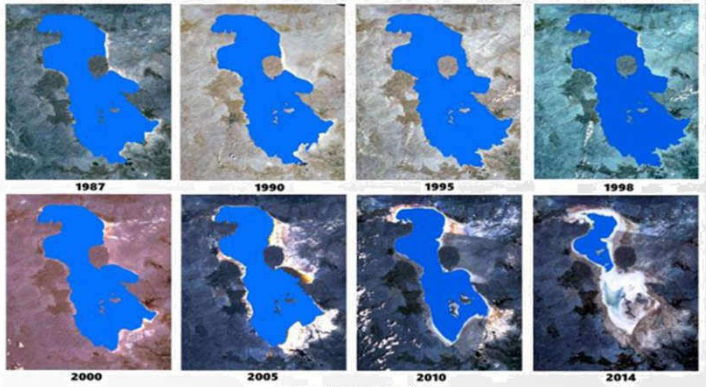
And so on



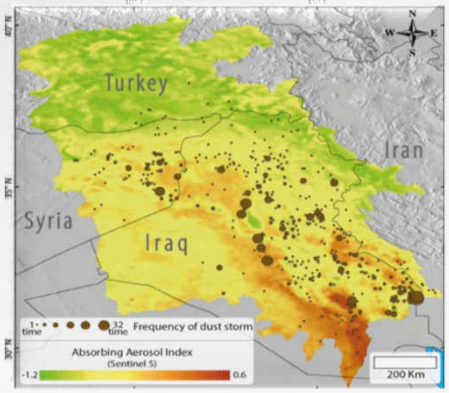
Ship detection & monitoring



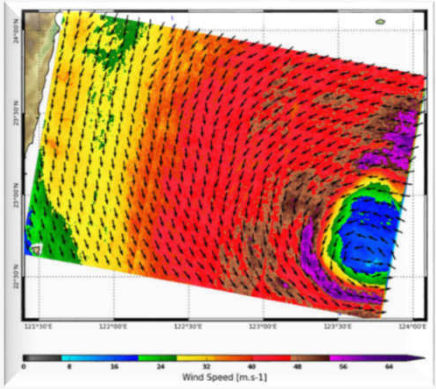
Volcano monitoring



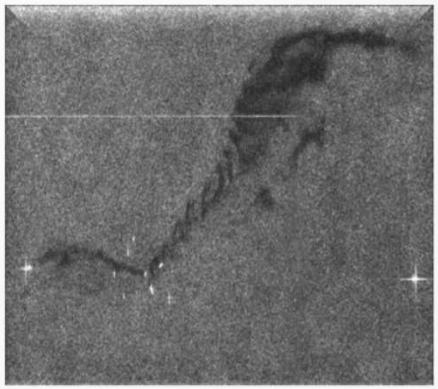
Monitoring Urmia lake area



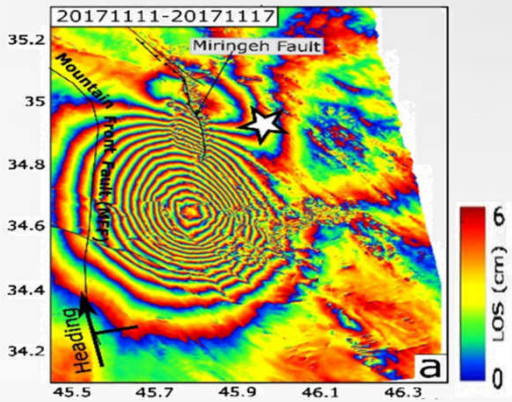
Dust storm



Wind speed on ocean surface



Oil pollution monitoring

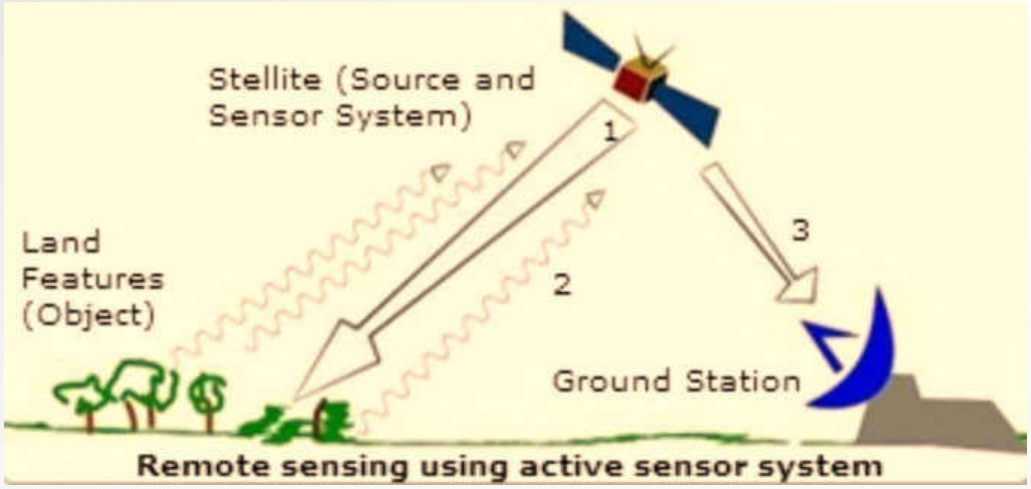


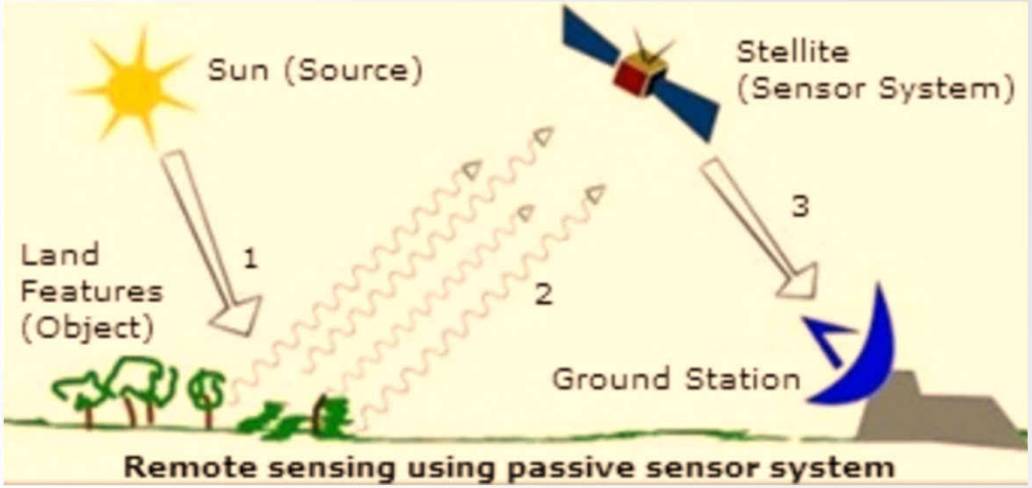
Earthquake Analysis

Remote Sensing Instruments

Two categories of imaging sensors in remote sensing:

1. Passive sensors
2. Active sensors

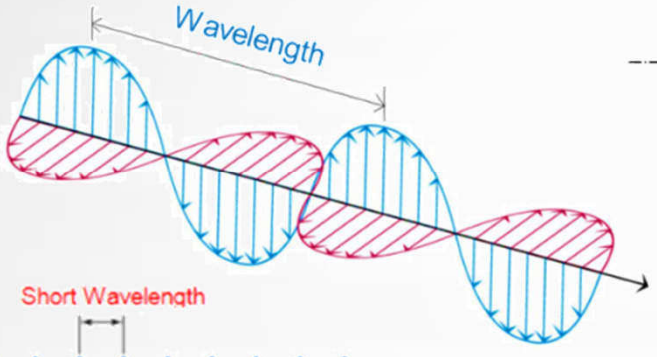


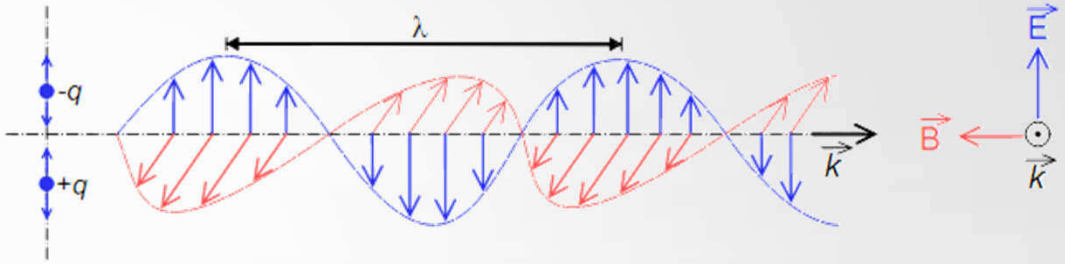


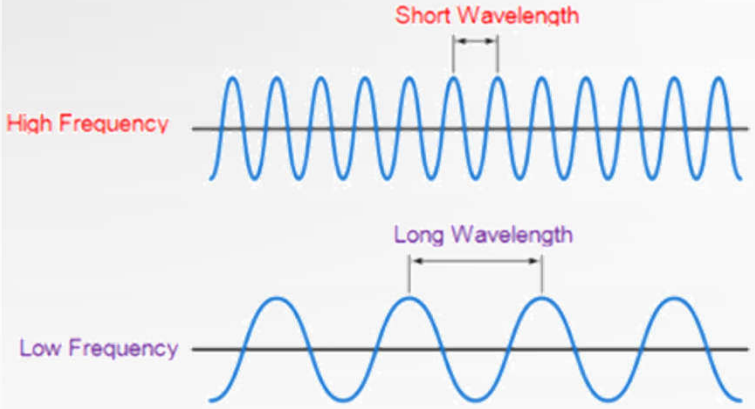
Electromagnetic Wave

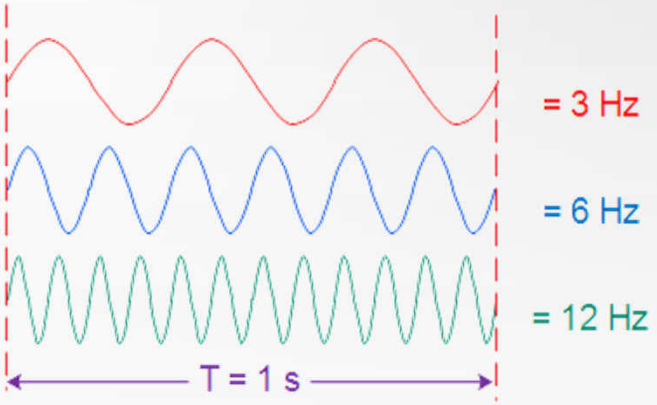
The most important characteristics of an electromagnetic wave:

- ✓ Wavelength (Frequency)
- ✓ Amplitude
- ✓ Phase





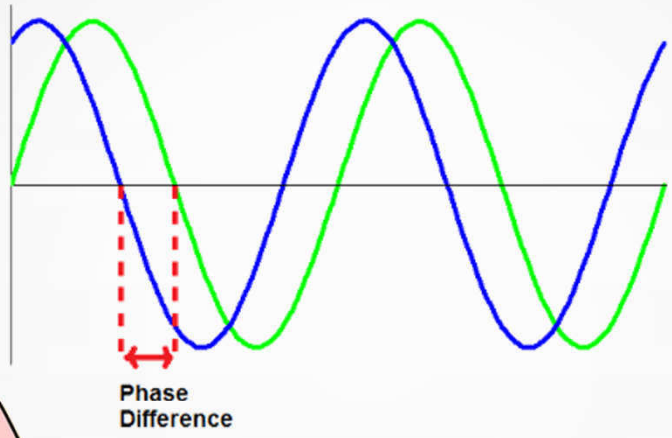


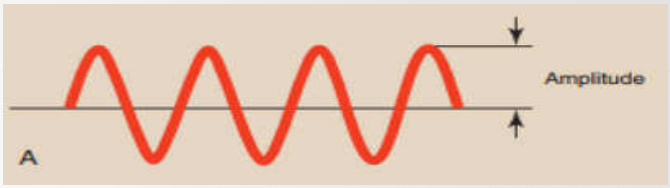


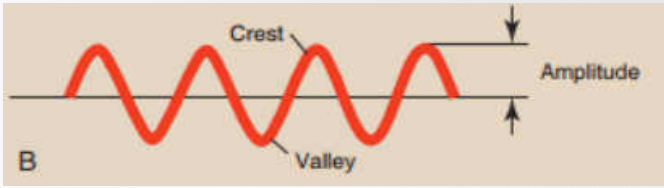
Electromagnetic Wave

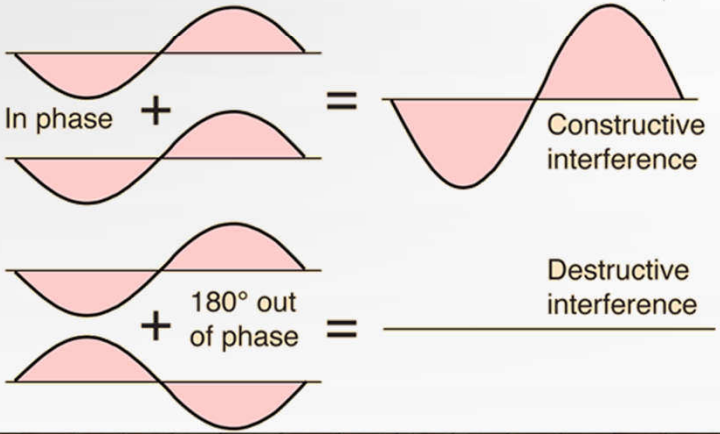
The most important characteristics of an electromagnetic wave:

- ✓ Wavelength (Frequency)
- ✓ Amplitude
- ✓ Phase

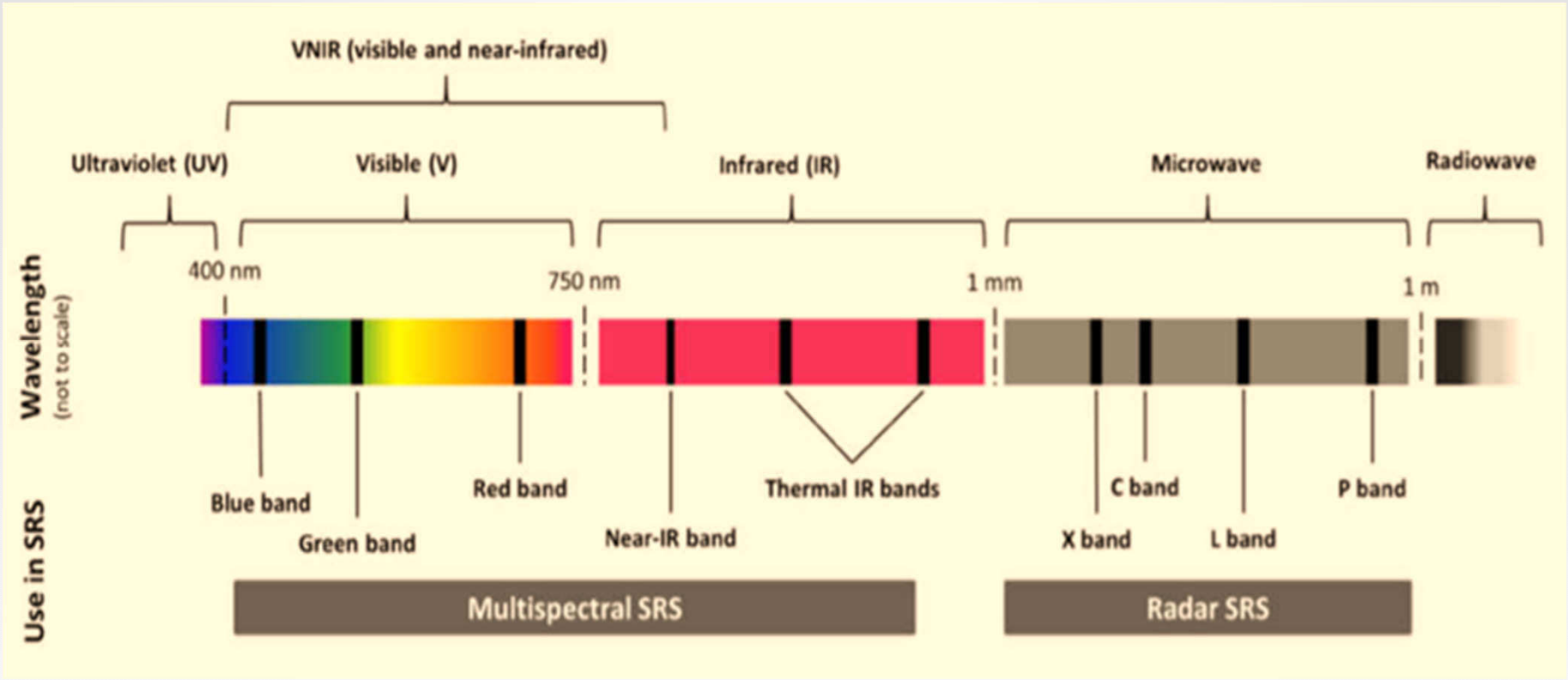




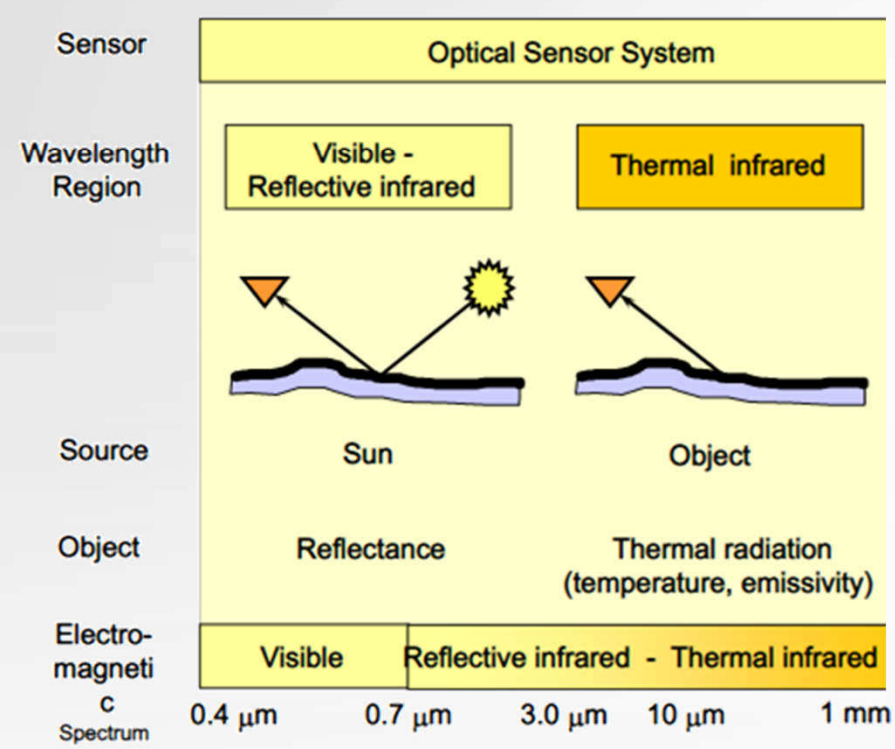


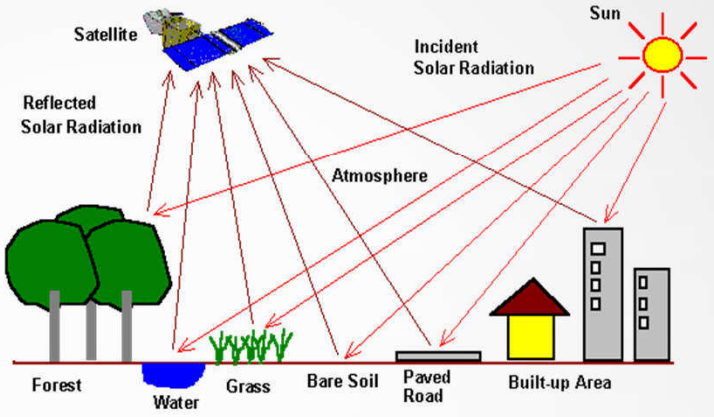


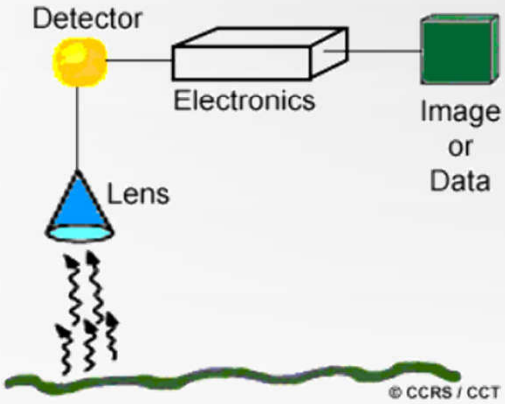
Electromagnetic Spectrum



Types of Remote Sensing

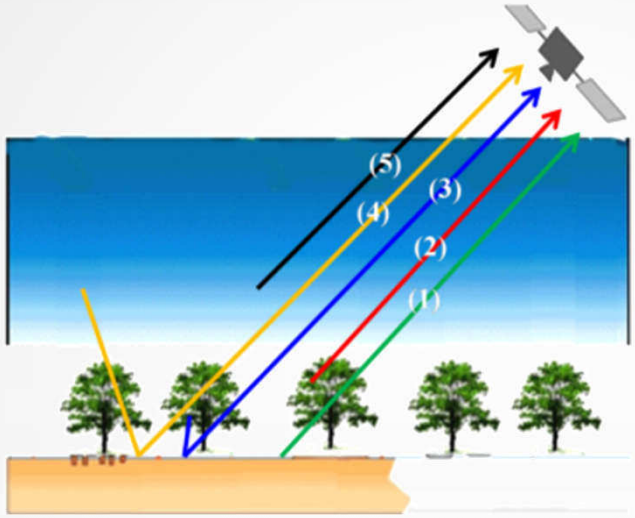




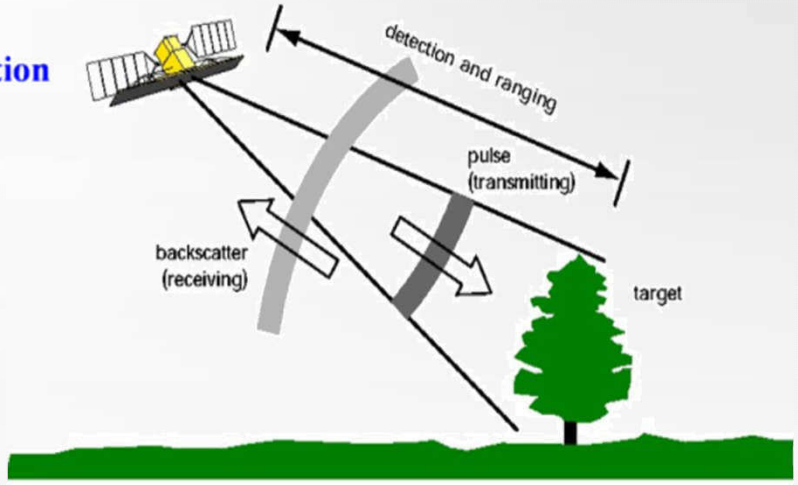


Types of Remote Sensing

Sensor	RADAR System
Wavelength Region	Microwave
	object radar
Source	Transmitted by Remote sensing System
Object	microwave radiation / backscattering coefficient
Electro-magnetic Spectrum	Microwave
	1 mm



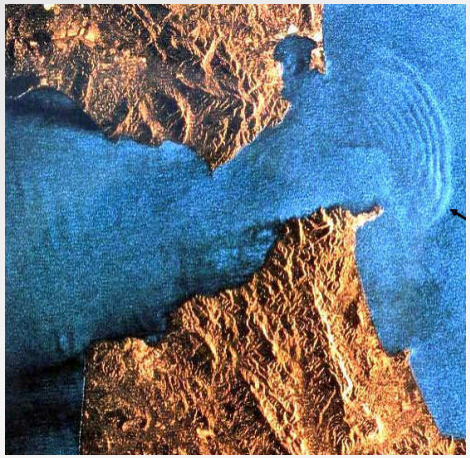
Passive microwave



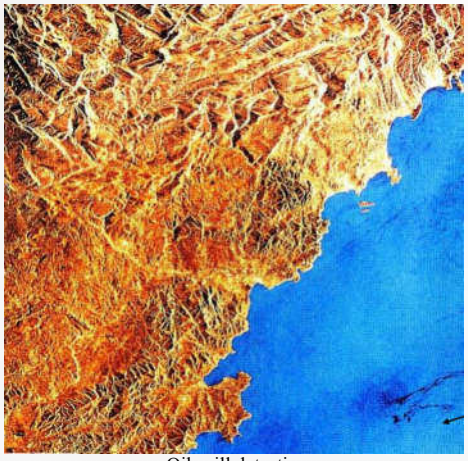
Active microwave

Advantages of Radar

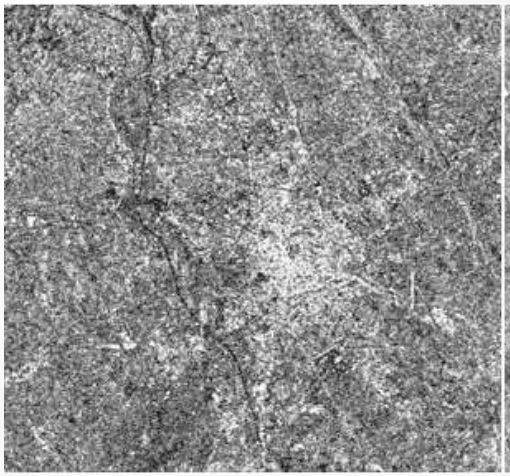
- ✓ Day or night imaging
- ✓ All weather imaging
- ✓ Sensitivity to factors such as roughness and moisture



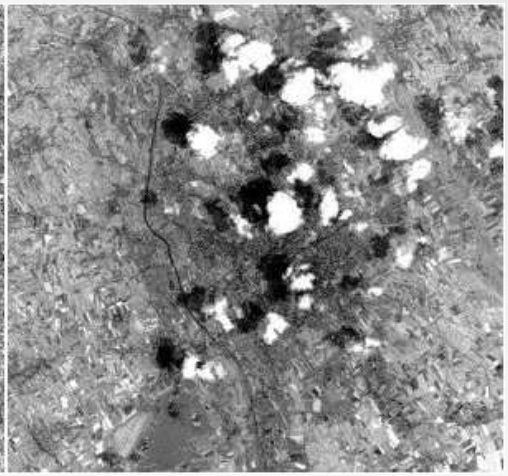
Detection of internal waves



Oil spill detection



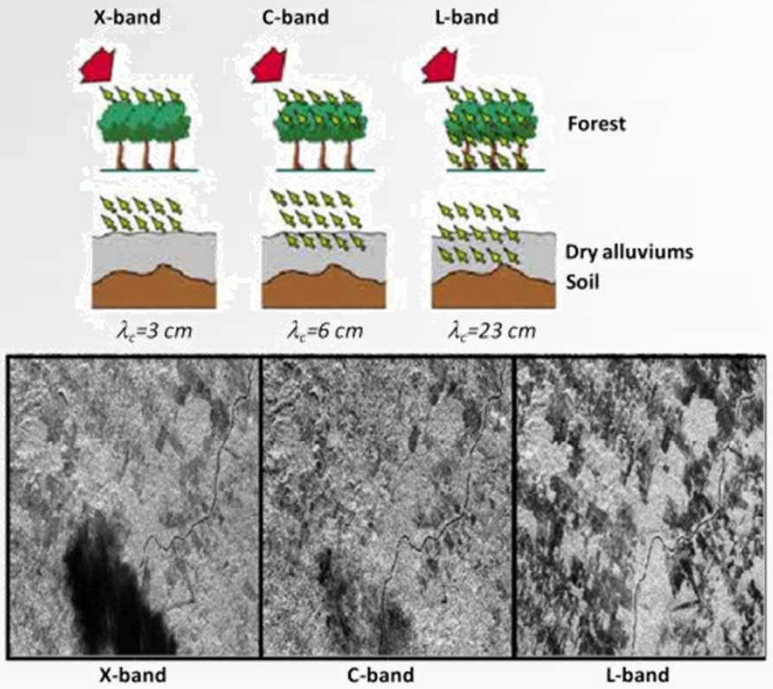
ERS-1 SAR 9:59 AM

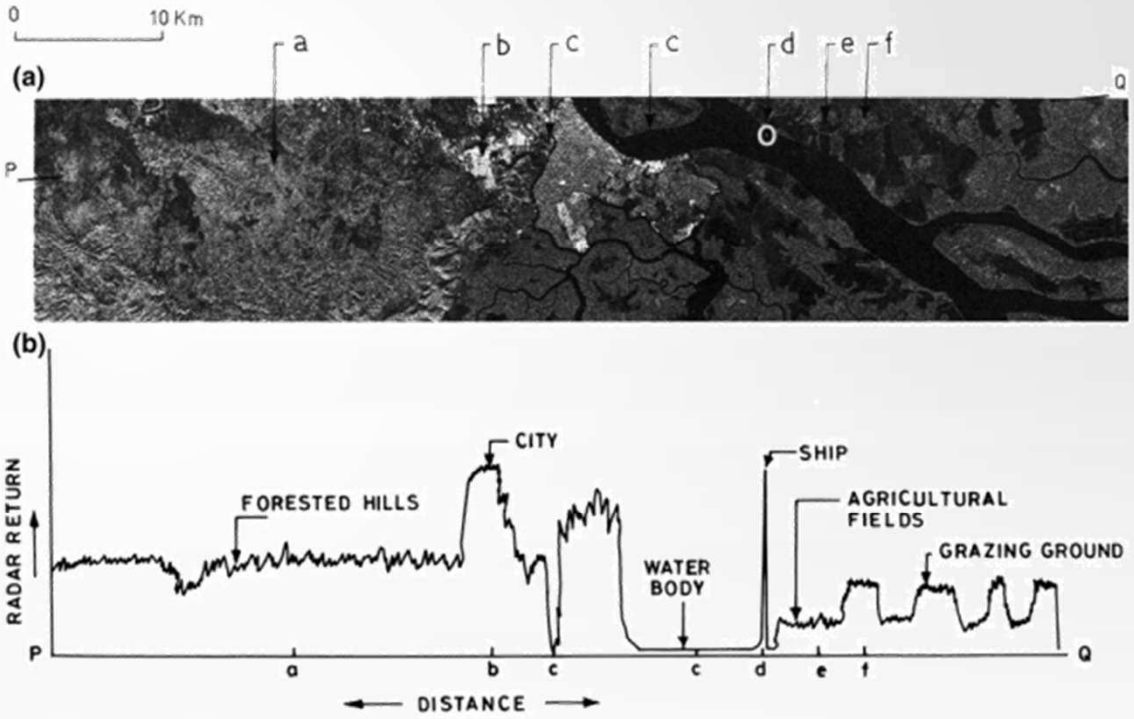


Landsat – 5 9:14 AM

Advantages of Radar

- ✓ Sensitivity to the geometrical structure of the earth's surface
- ✓ Penetration through vegetation and soil





Passive Microwave Applications

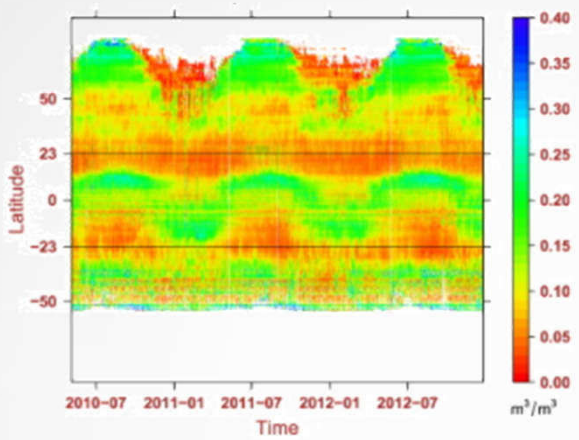
Soil moisture

Sea surface temperature

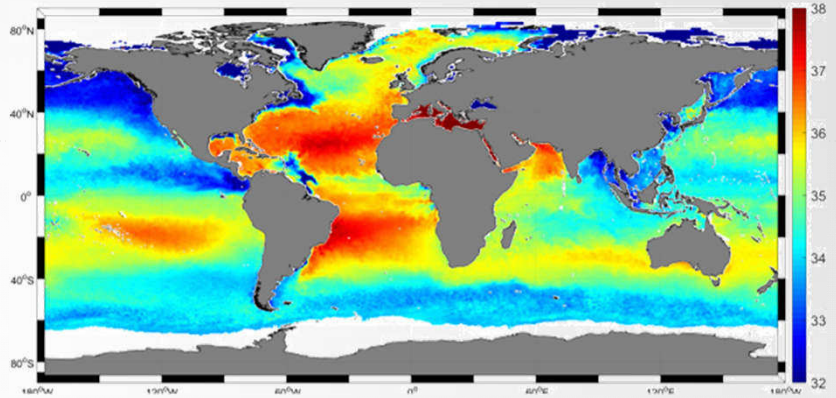
Surface wind speed

Atmospheric water vapor

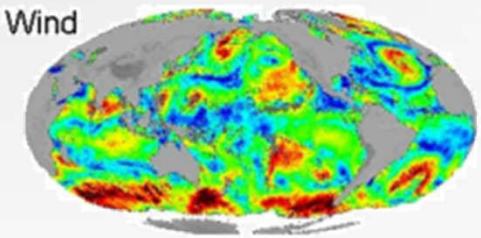
Sea/lake ice extent, concentration and type



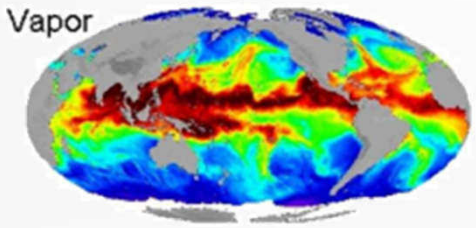
Soil moisture



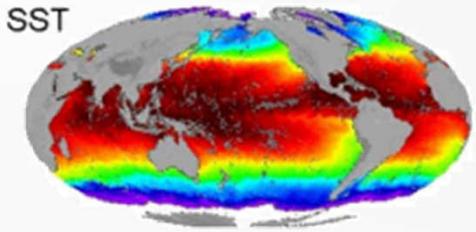
Sea surface salinity



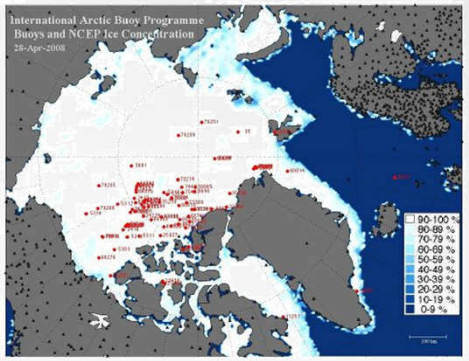
Wind speed over the ocean



Atmospheric water vapor over the ocean



Sea surface temperature over the ocean



Sea ice concentration

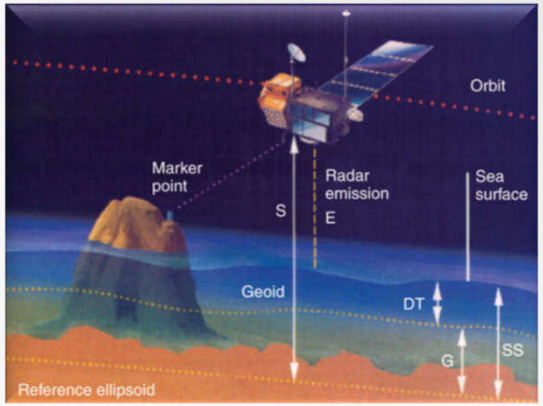
Active Microwave

Non-Imaging

- ✓ Altimeter
  - ✓ Electromagnetic frequency between 13.5 and 14 GHz (Ku-band)
  - ✓ Nadir-looking pulse radars
  - ✓ Determination of the distance from the satellite to a target surface by:
    - ✓ Measuring the round trip time delay to a target

$$t_0 = \frac{2 \cdot h}{c_0}$$

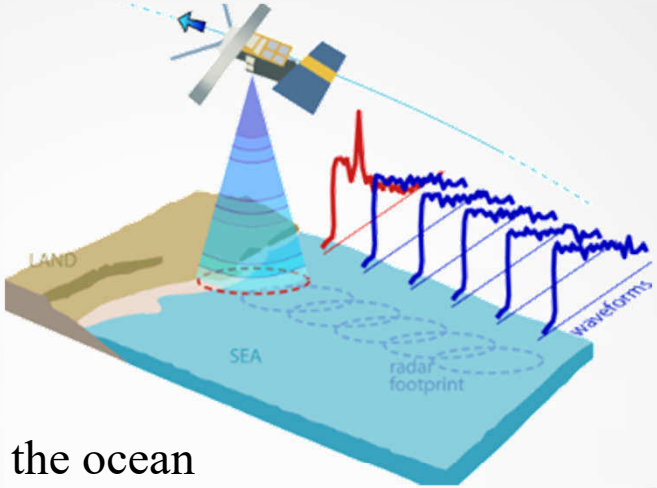
  - ✓ Used on:
    - ✓ Aircraft for altitude determination
    - ✓ Aircraft and Satellites for topographic mapping
    - ✓ Sea surface height measurements

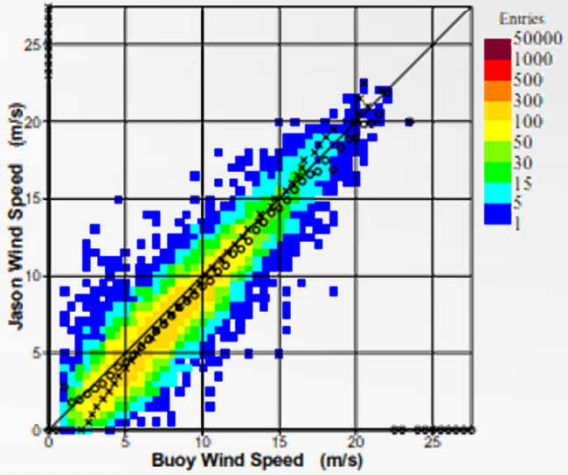


Active Microwave

Non-Imaging

- ✓ Altimeter
  - ✓ Nadir-looking pulse radars
  - ✓ Return signal's amplitude
    - ✓ Measurement of wave height over the ocean
  - ✓ Return signal's waveform
    - ✓ Measurement of wave speed over the ocean
  - ✓ Envisat
  - ✓ ERS-1-2
  - ✓Jason-1,Jason-2
  - ✓TOPEX

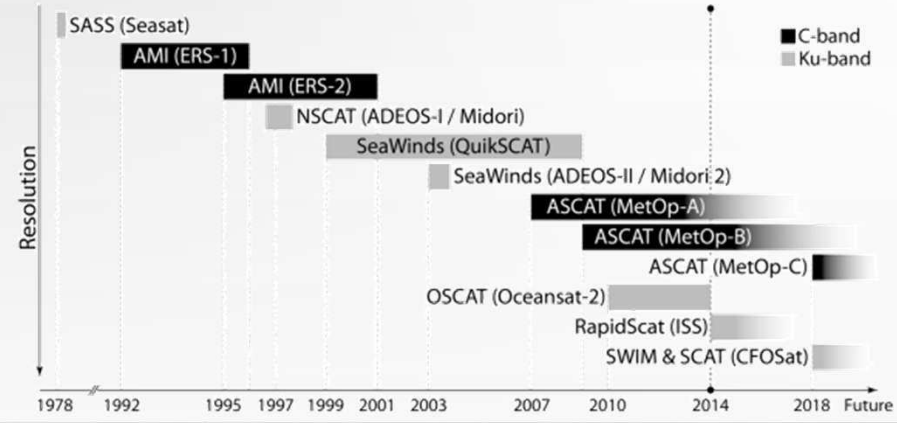


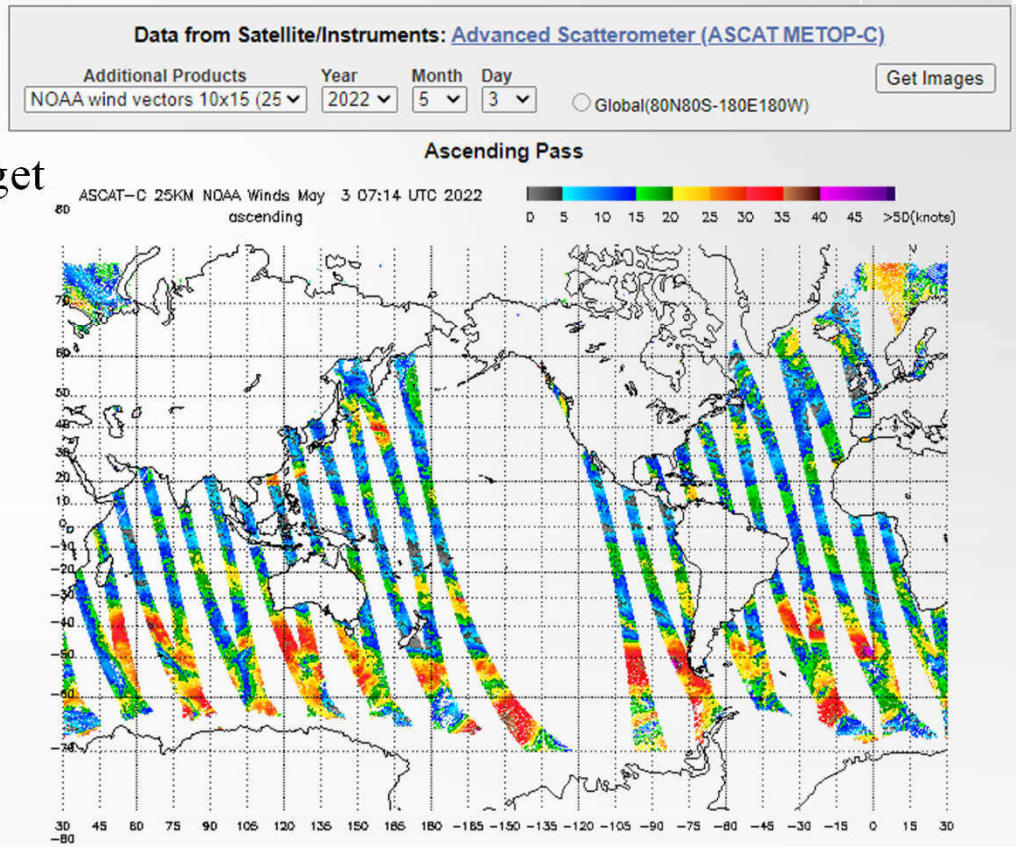


Active Microwave

Non-Imaging

- ✓ Scatterometer
  - ✓ Measures the scattering of radar energy by a target
  - ✓ Used to derive both the:
    - ✓ Wind speed over the sea
    - ✓ Direction of the Wind

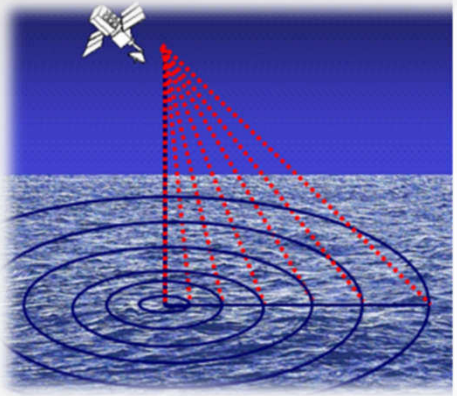


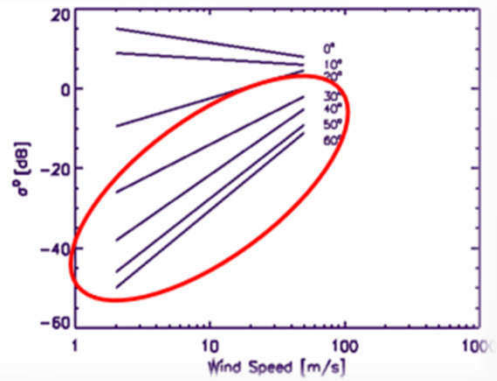


Active Microwave

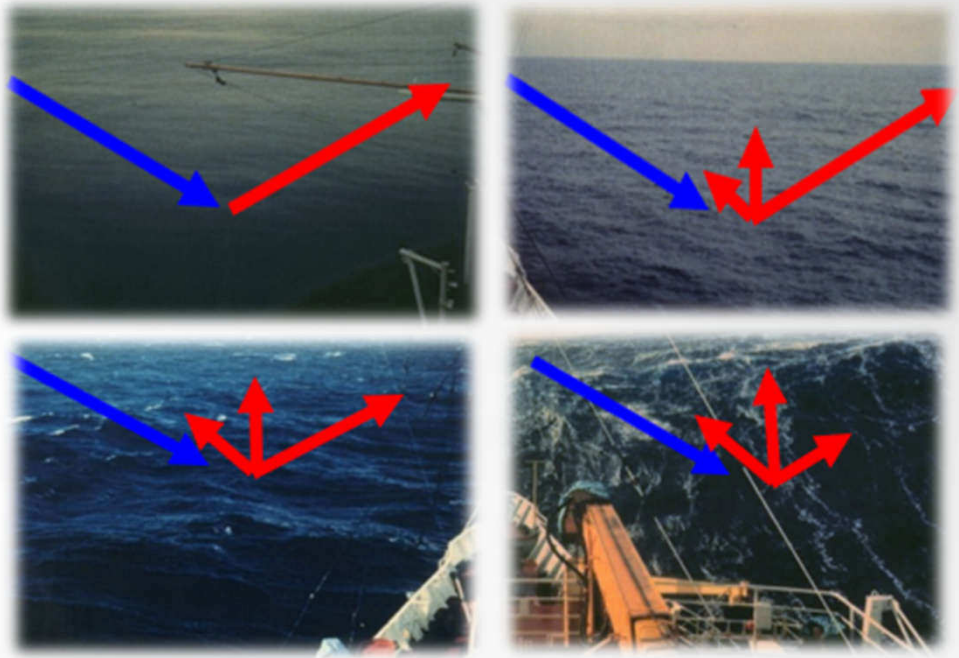
Non-Imaging

- ✓ Scatterometer
  - ✓ Backscatter depends on:
    - ✓ Surface roughness
    - ✓ Incidence angle of the incoming microwave





Backscatter as a function of wind speed and incidence angle

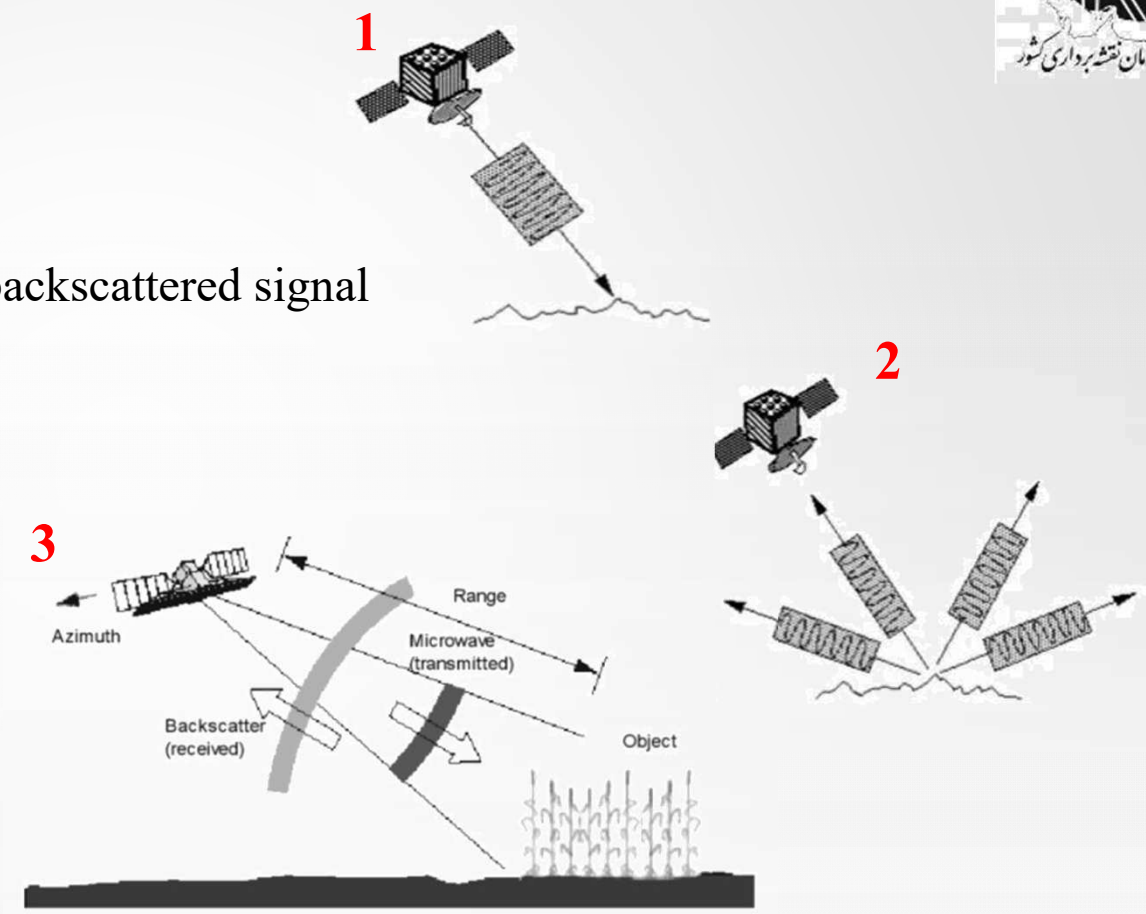


Backscatter modulation by surface roughness

Active Microwave

Imaging

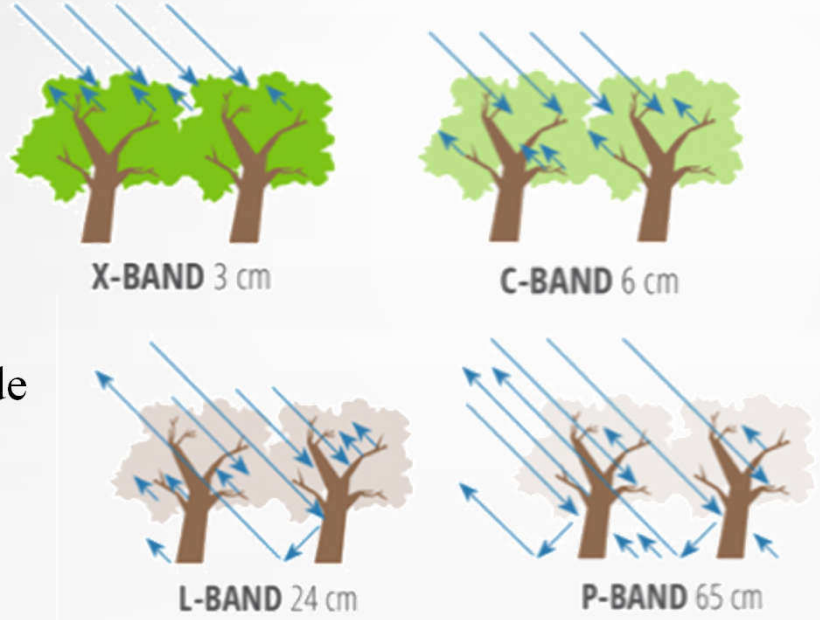
- ✓ Radio detection and Ranging (Radar)
- ✓ Time delay between the transmitted and backscattered signal
- ✓ Discrimination between different targets
- ✓ Strength of the backscattered signal
- ✓ Determination the distance to the target
- ✓ Two types of imaging radars:
- ✓ Real Aperture Radar (RAR)
- ✓ Synthetic Aperture Radar (SAR)



Radar Backscattering

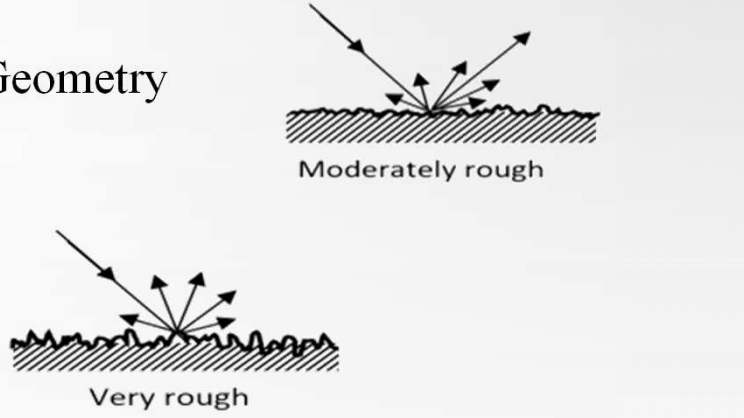
Radar backscattering behavior depends upon the:

- ✓ Sensor parameters:
  - ✓ Frequency
  - ✓ Polarization
  - ✓ Incidence angle
  - ✓ Acquisition mode



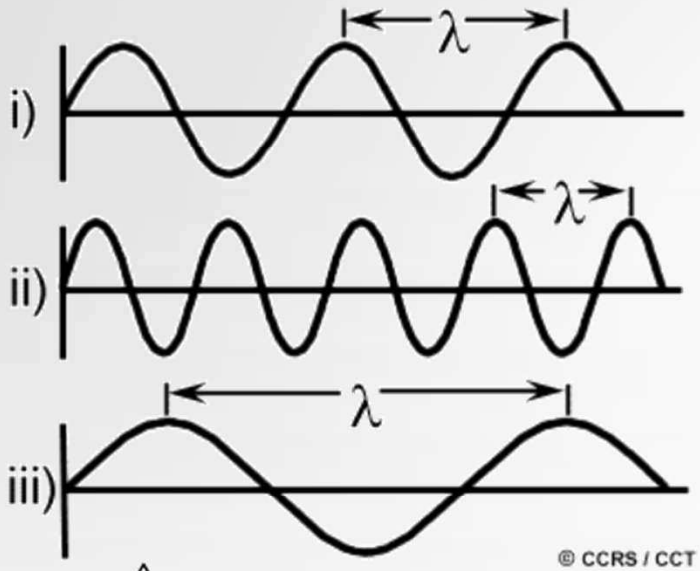
Penetration into the canopy at different wavelengths

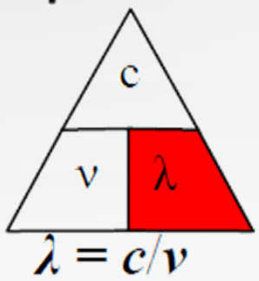
- ✓ Target parameters:
  - ✓ Roughness
  - ✓ Dielectric constant
  - ✓ Geometry



Reflection from surfaces with different roughness

Frequency



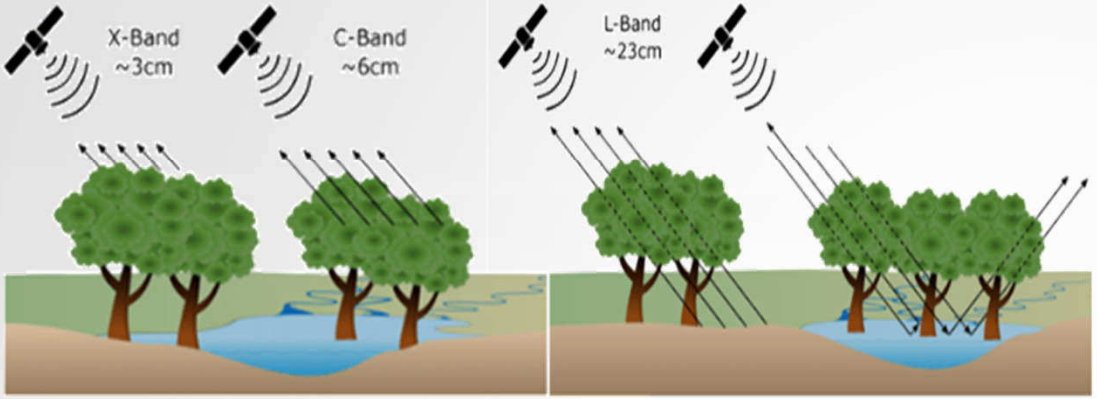


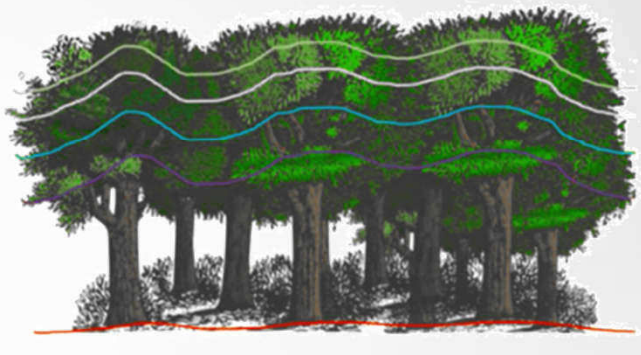
$\lambda = c/\nu$

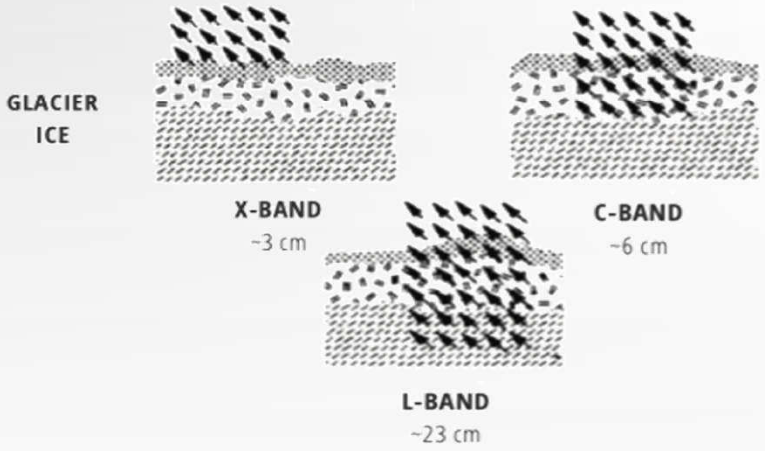
$C=3.10^8$ m
λ =wavelength in m

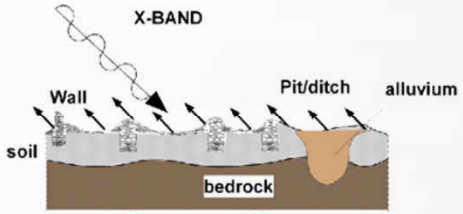
Frequency band	Wavelength (cm)	Frequency (GHz)
Ka	0.8-1.1	40 -26.5
K	1.1-1.7	26.5 -18
Ku	1.7-2.4	18 -12.5
X	2.4-3.8	12.5 -8
C	3.8-7.5	8 -4
S	7.5-15	4 -2
L	15 -30	2 -1
P	30 -100	1 -0.3

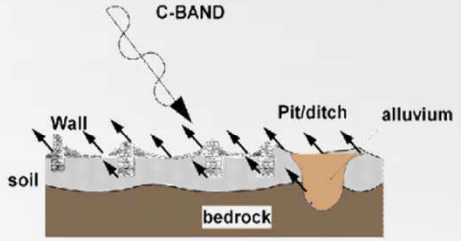
Frequency

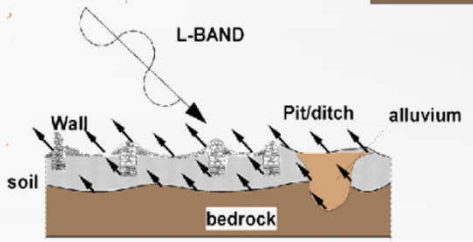

X-Band
~3cm
C-Band
~6cm
L-Band
~23cm


Legend:
True Surface
Ku Band Surface
X Band Surface
C Band Surface
L Band Surface
P Band Surface

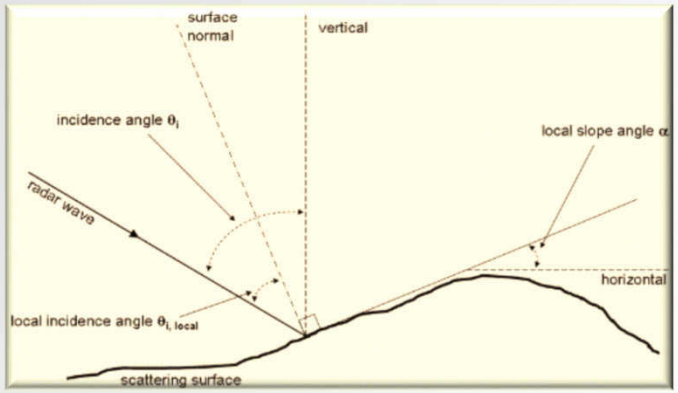

GLACIER
ICE
X-BAND
~3 cm
C-BAND
~6 cm
L-BAND
~23 cm

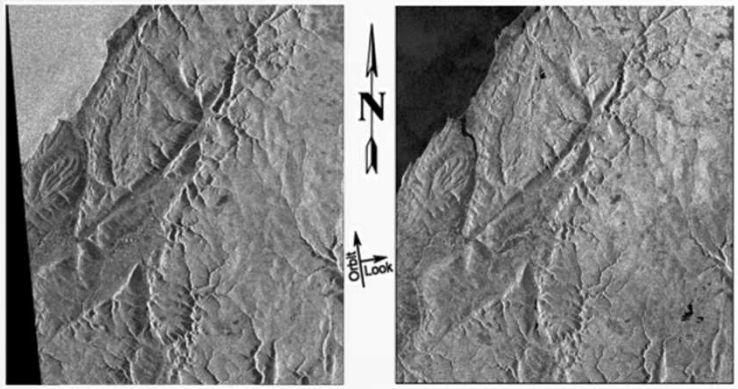

X-BAND
Wall
Pit/ditch
alluvium
soil
bedrock

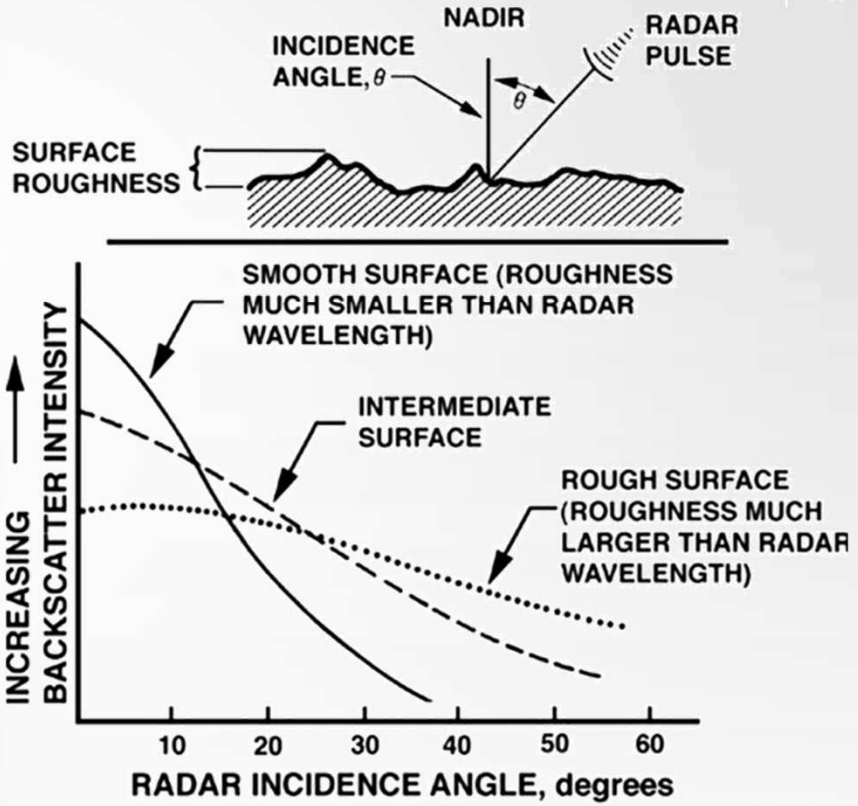

C-BAND
Wall
Pit/ditch
alluvium
soil
bedrock


L-BAND
Wall
Pit/ditch
alluvium
soil
bedrock

Incidence Angle



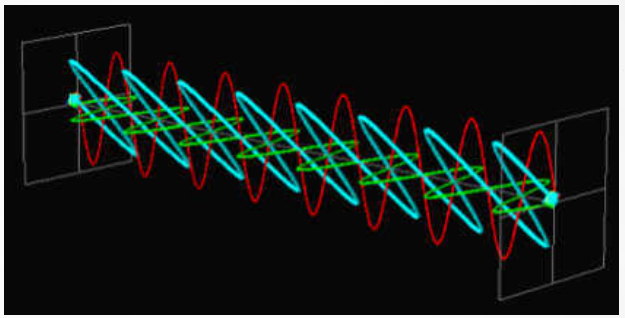




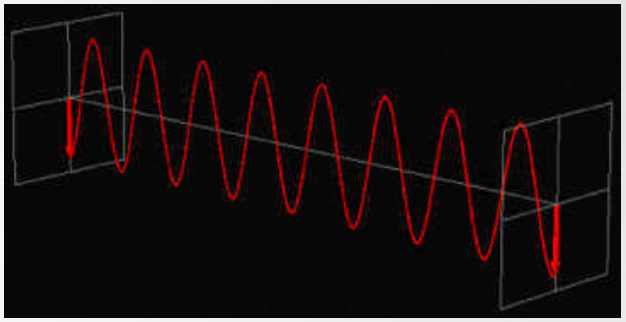
Polarization

Polarization refers to the orientation of the electric field of the EM wave

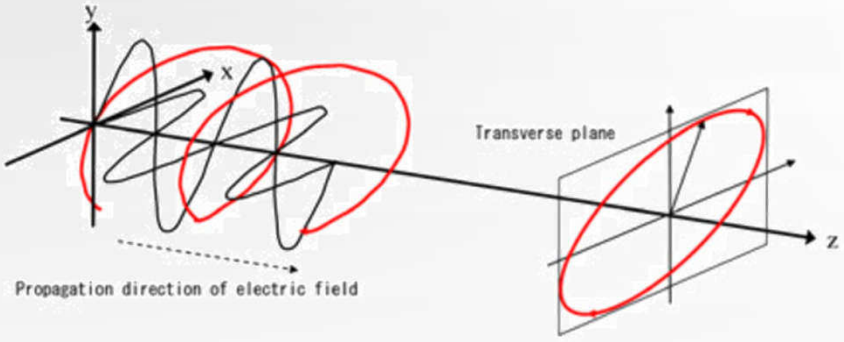
- ✓ Three basic types of polarization:
  - ✓ Linear
  - ✓ Circular
  - ✓ Elliptical



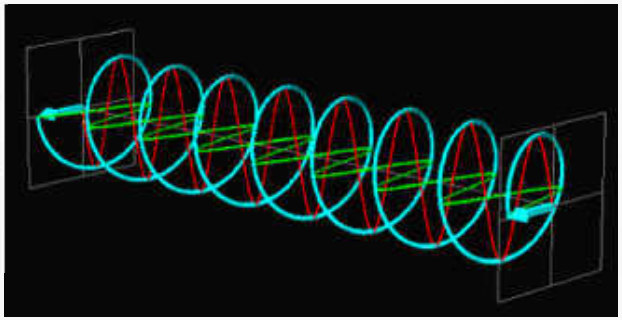
Linear 45 degree polarization



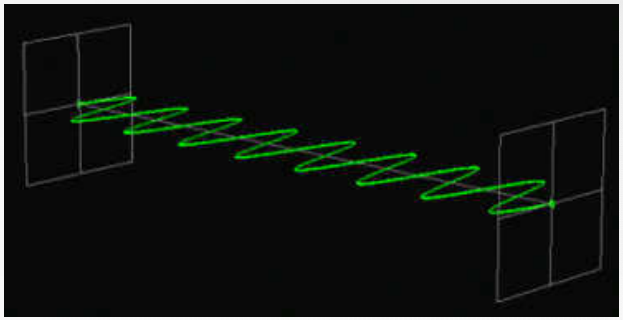
Vertical polarization



Elliptical polarization



Left/right circular polarization

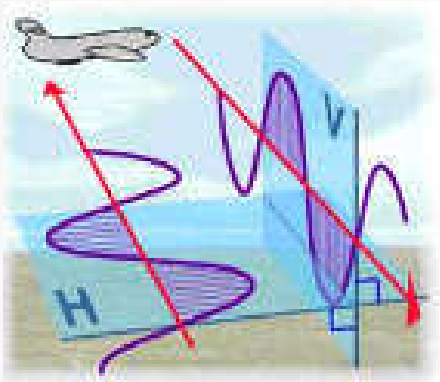


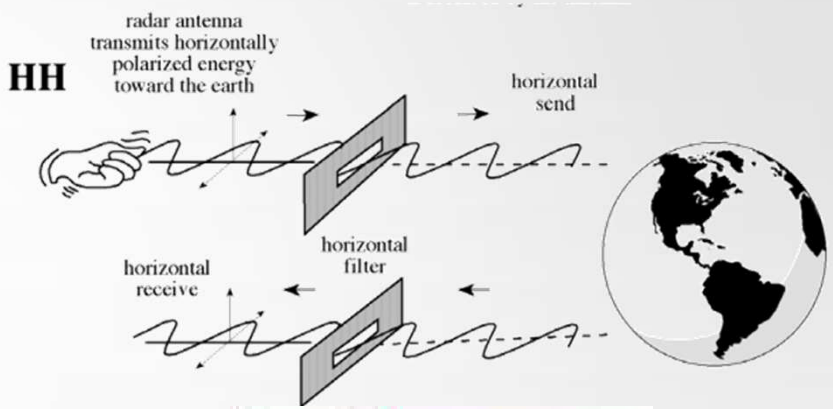
Horizontal polarization

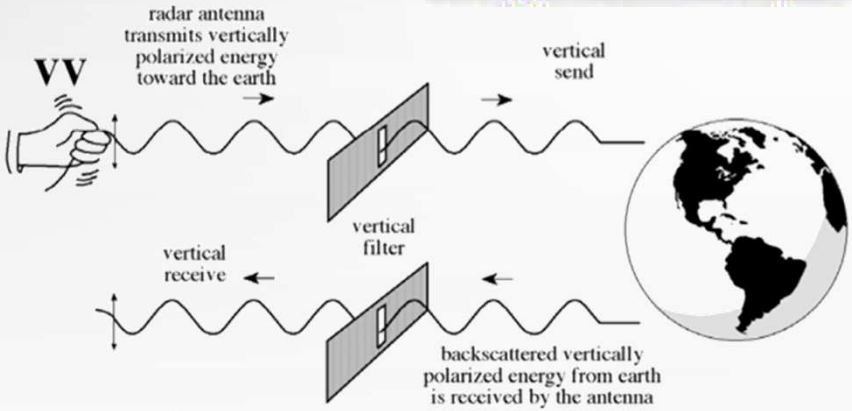
Polarization in Radar System

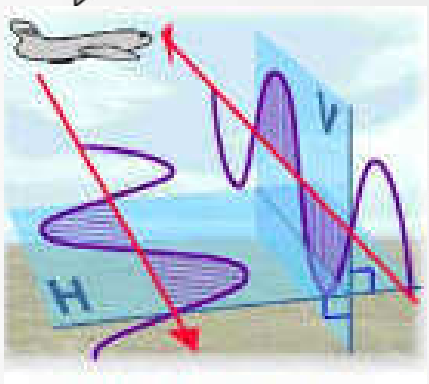
Radar systems using H and V linear polarizations can have the following channels:

- ✓ HH
- ✓ VV → **Co-Polarized**
- ✓ HV
- ✓ VH → **Cross-Polarized**





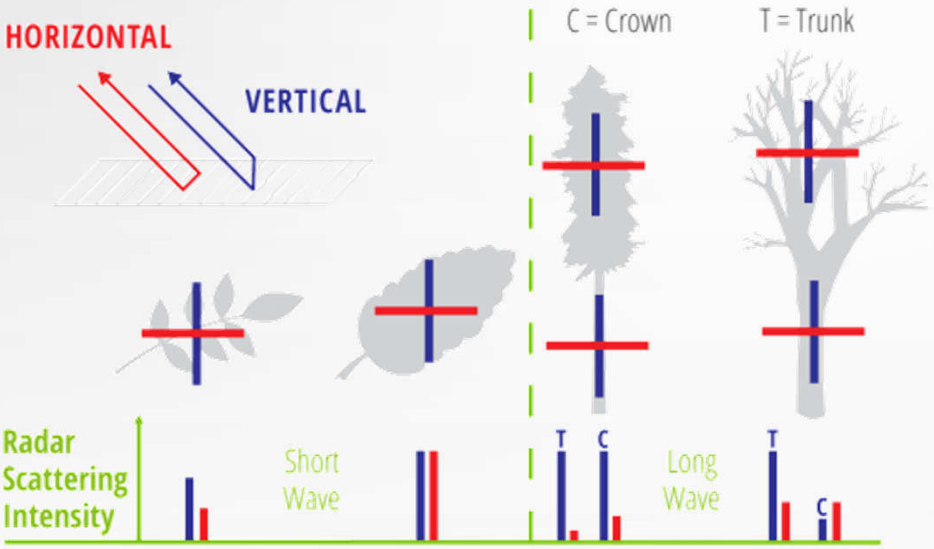


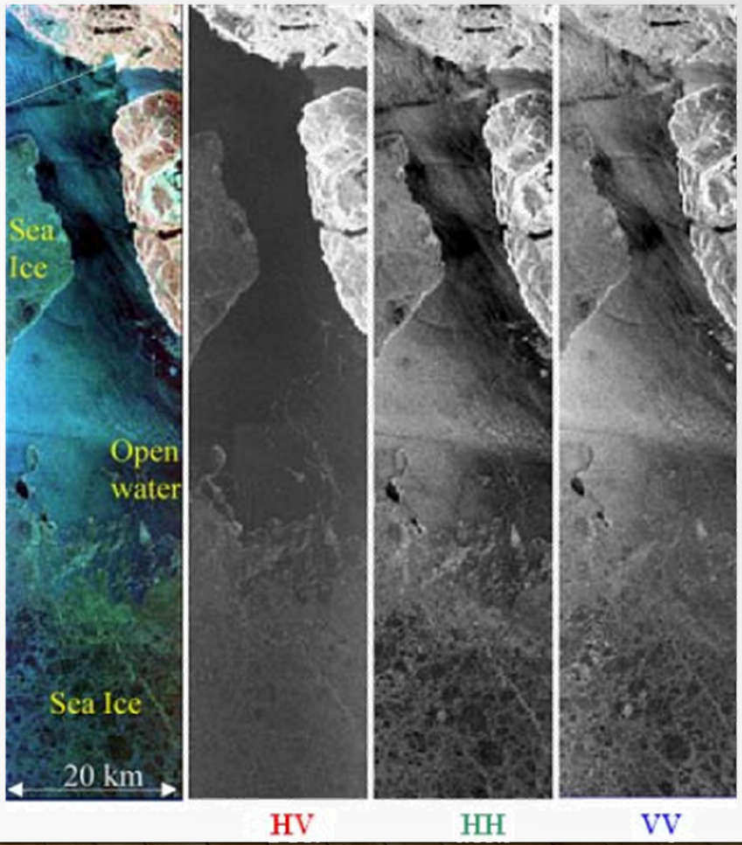


Polarization in Radar System

Radar systems can have different levels of polarization complexity:

- ✓ Single polarized – HH or VV or HV or VH
- ✓ Dual polarized – HH and HV, VV and VH, or HH and VV
- ✓ Four polarizations (Polarimetric) – HH, VV, HV, and VH

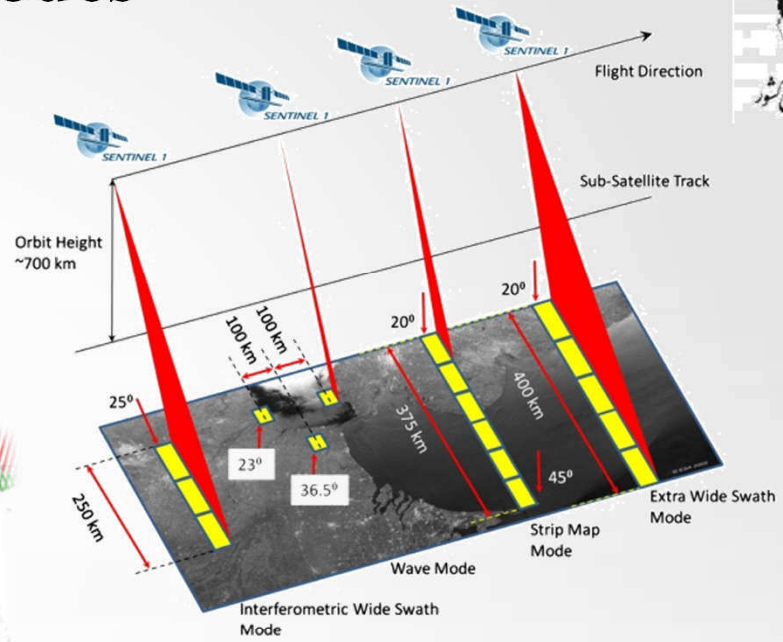


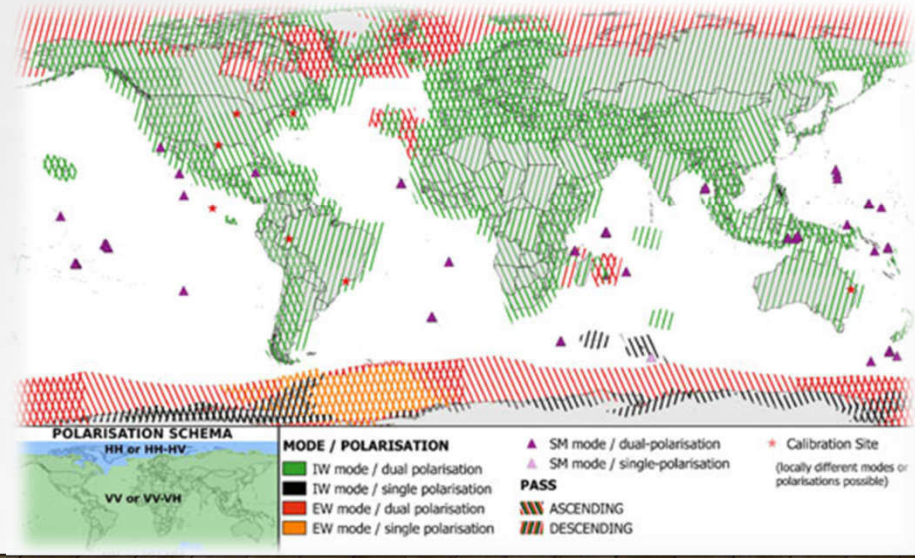


Acquisition Modes

Sentinel – 1A & 1B operate in four acquisition modes:

- ✓ Stripmap
- ✓ Interferometric Wide (IW) Swath
- ✓ Extra Wide (EW) Swath
- ✓ Wave

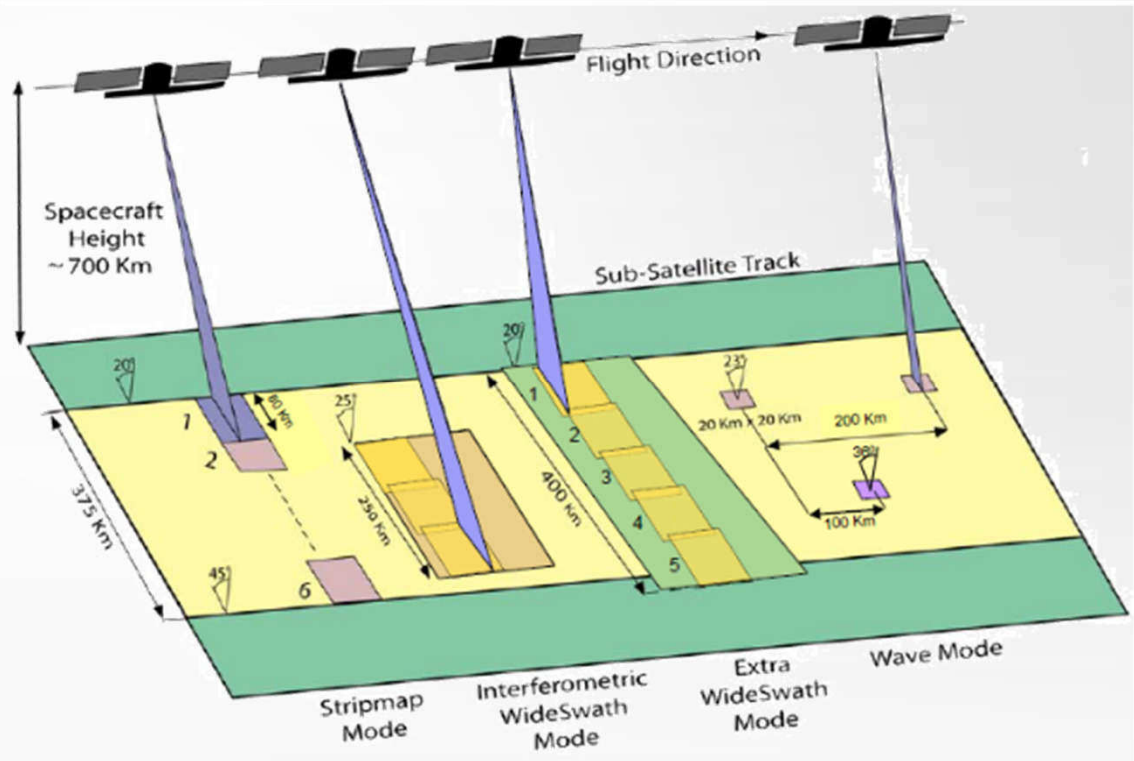




Acquisition Modes

Sentinel – 1A & 1B operate in four acquisition modes:

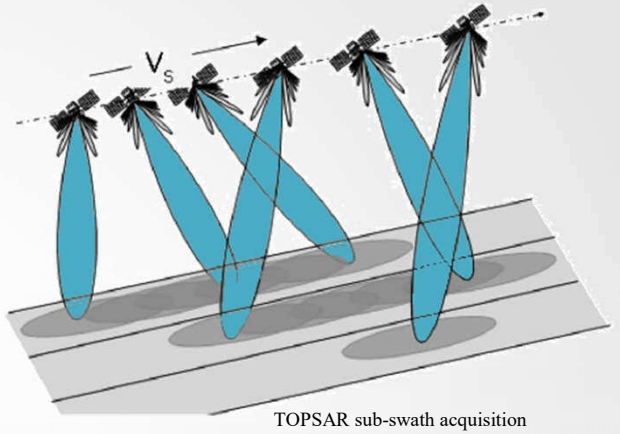
- ✓ Stripmap
  - ✓ Swath width : 80 km
  - ✓ Resolution : 5m 5 m
  - ✓ Polarization options:
    - ✓ Dual: HH+HV, VV+VH
    - ✓ Single: HH, VV
  - ✓ Incidence angle : 18.3 – 46.8 degree



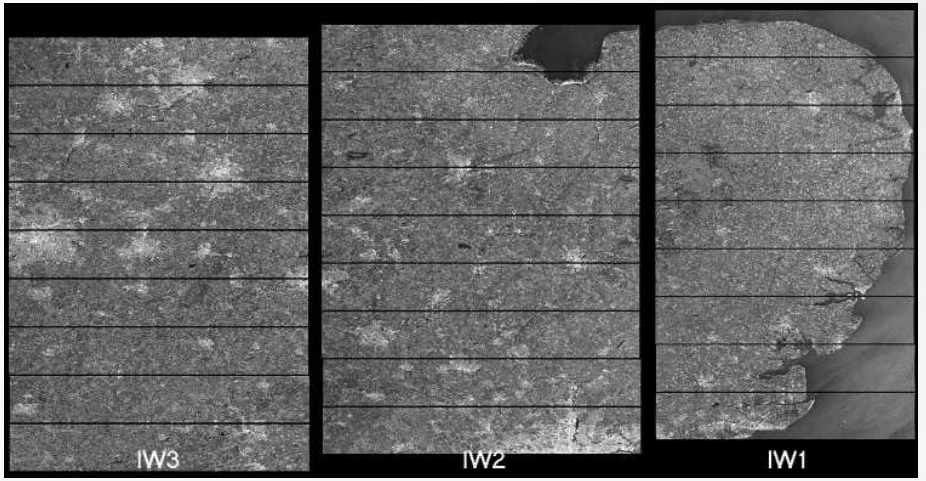
Acquisition Modes

Sentinel – 1A & 1B operate in four acquisition modes:

- ✓ Interferometric Wide (IW) Swath
  - ✓ Swath width : 250 km
  - ✓ Resolution : 5m × 20 m
  - ✓ Polarization options:
    - ✓ Dual: HH+HV, VV+VH
    - ✓ Single: HH, VV
  - ✓ Incidence angle : 29.1 – 46.0 degree



TOPSAR sub-swath acquisition

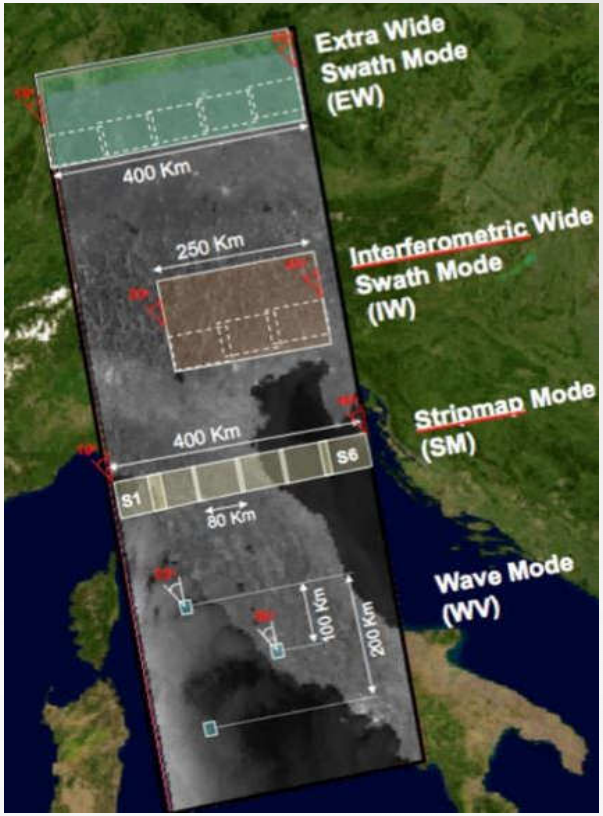


IW bursts and sub-swaths

Acquisition Modes

Sentinel – 1A & 1B operate in four acquisition modes:

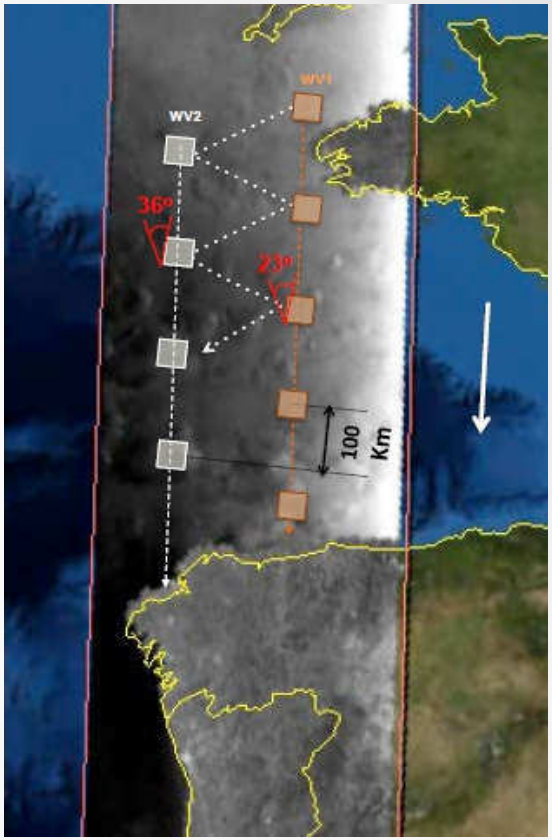
- ✓ Extra Wide (EW) Swath
  - ✓ Swath width : 410 km
  - ✓ Resolution : 20m ‹40 m
  - ✓ Polarization options:
    - ✓ Dual: HH+HV, VV+VH
    - ✓ Single: HH, VV
  - ✓ Incidence angle : 18.9 – 47.0 degree



Acquisition Modes

Sentinel – 1A & 1B operate in four acquisition modes:

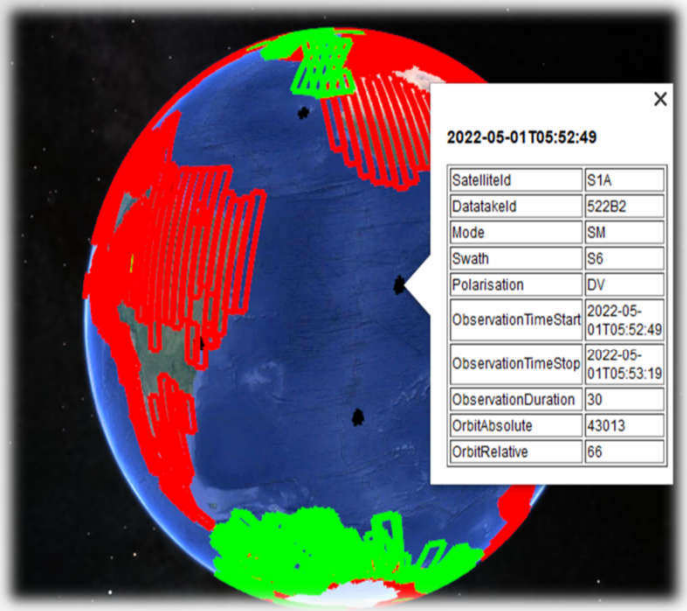
- ✓ Wave
  - ✓ Vignette ground coverage : 20 km ×20 km
  - ✓ Resolution : 5m ×5 m
  - ✓ Polarization options:
    - ✓ Single: HH, VV
  - ✓ Incidence angle ranges :
    - ✓ 21.6 – 25.1 degree
    - ✓ 34.8 – 38.0 degree

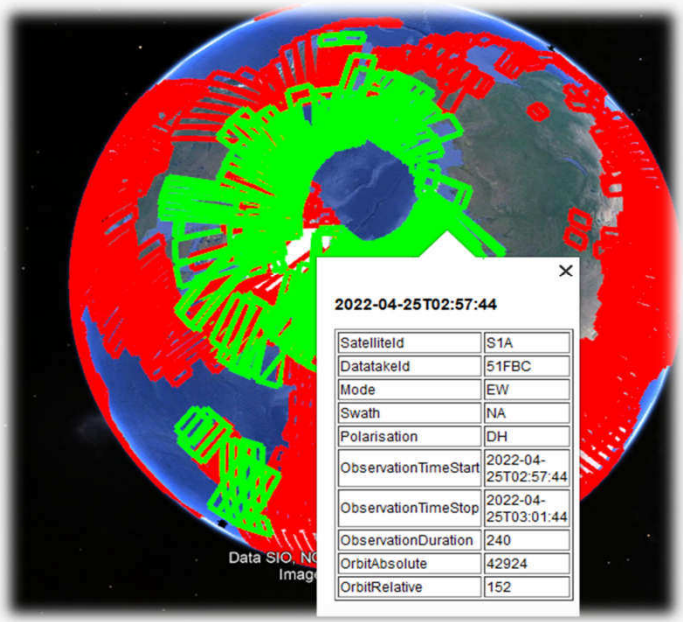


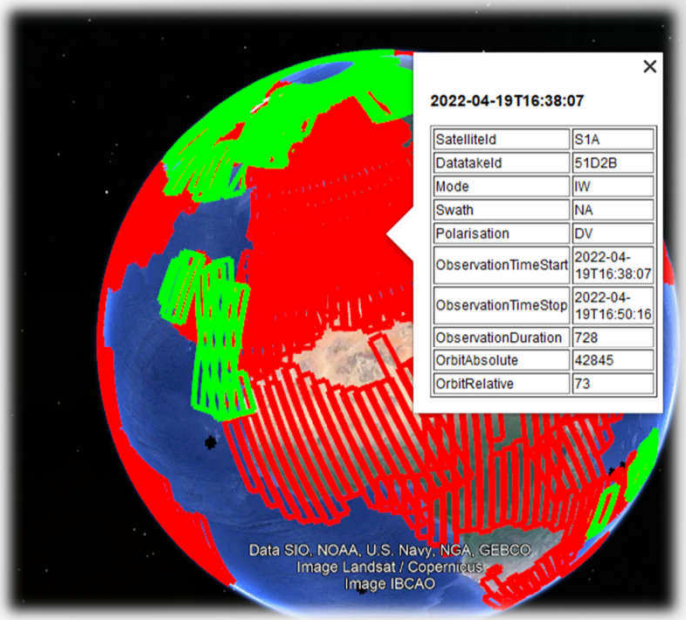
Acquisition Modes

Acquisition segments archive:

https://sentinel.esa.int/web/sentinel/missions/sentinel-1/observation-scenario/acquisition-segments/archive



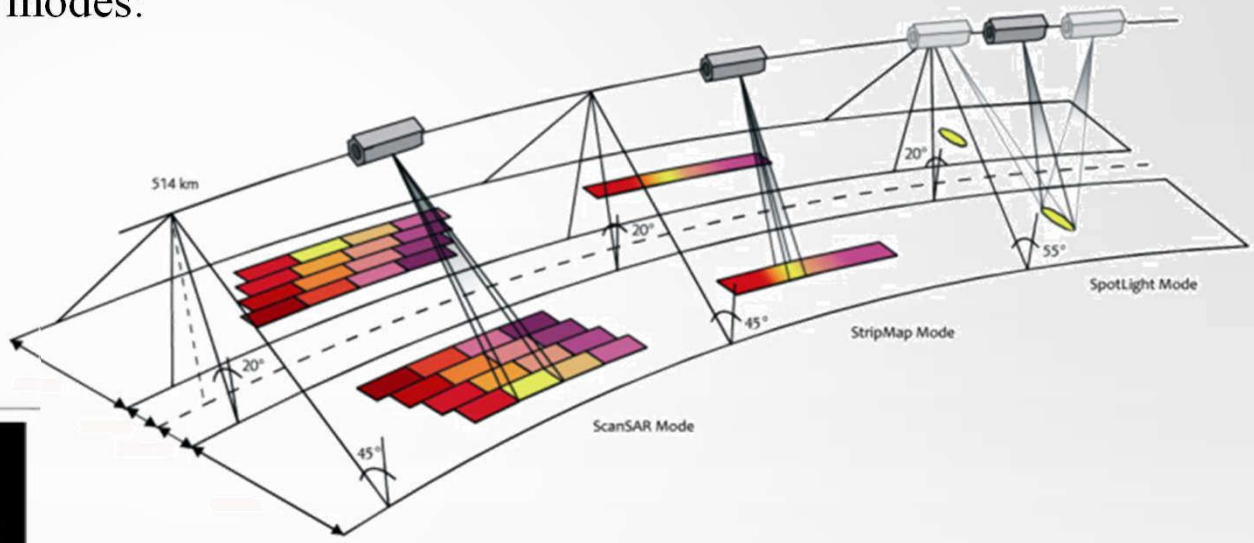


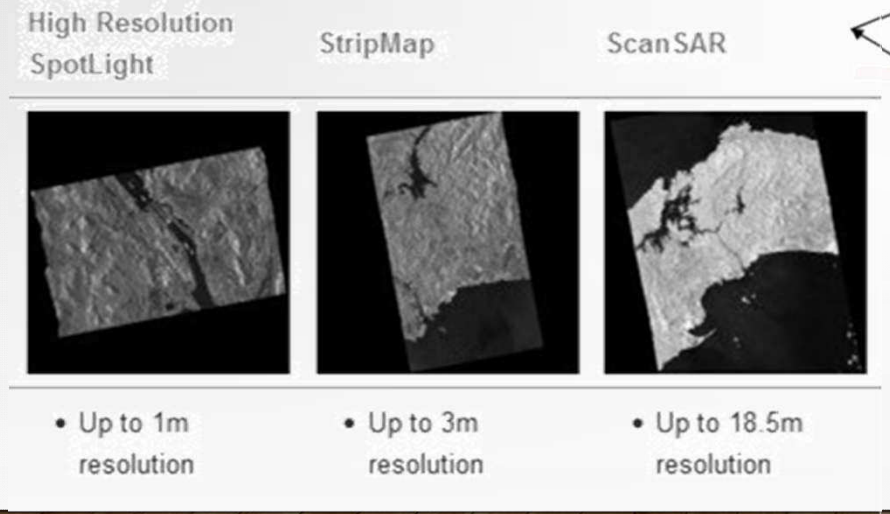


Acquisition Modes

TerraSAR-X can operate in three resolution modes:

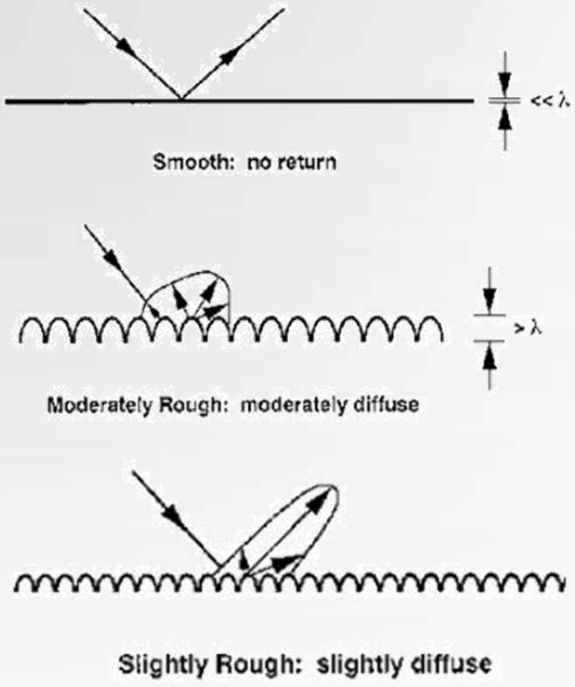
- ✓ Spotlight
- ✓ Stripmap
- ✓ ScanSAR

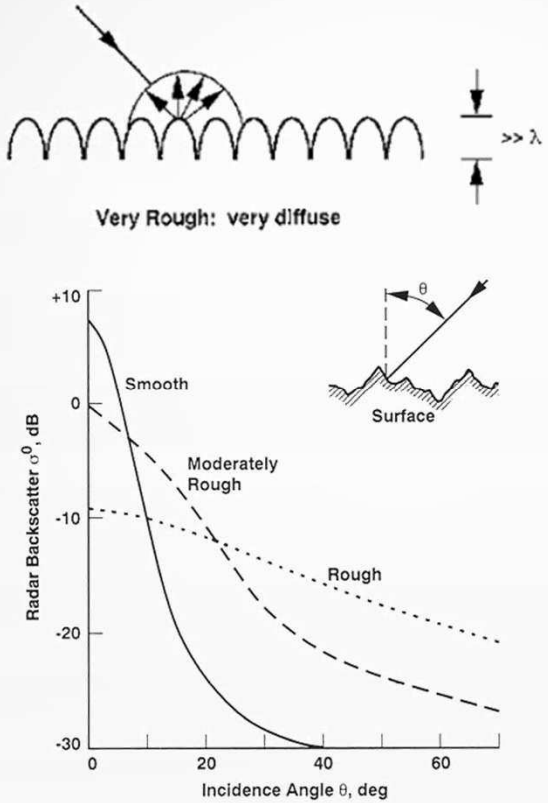


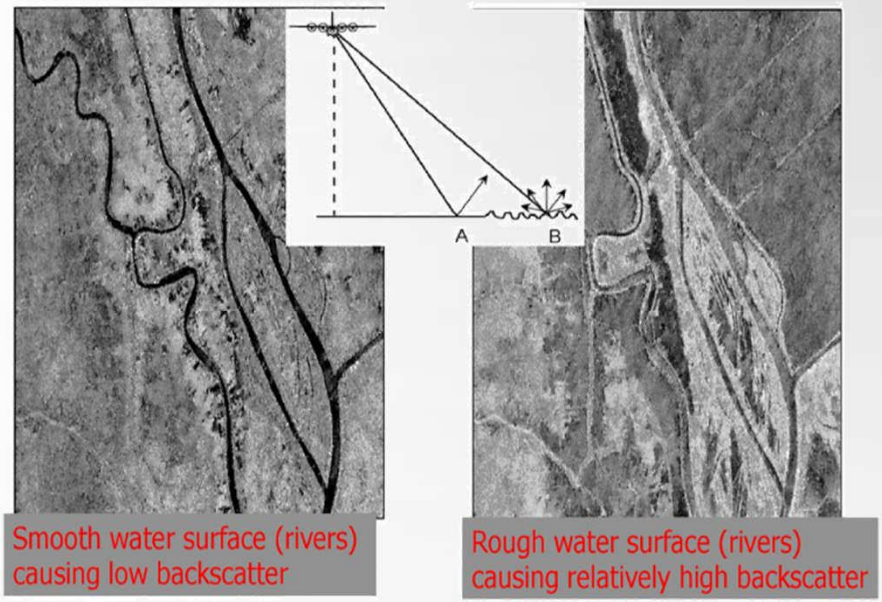


Target Parameters

Surface roughness





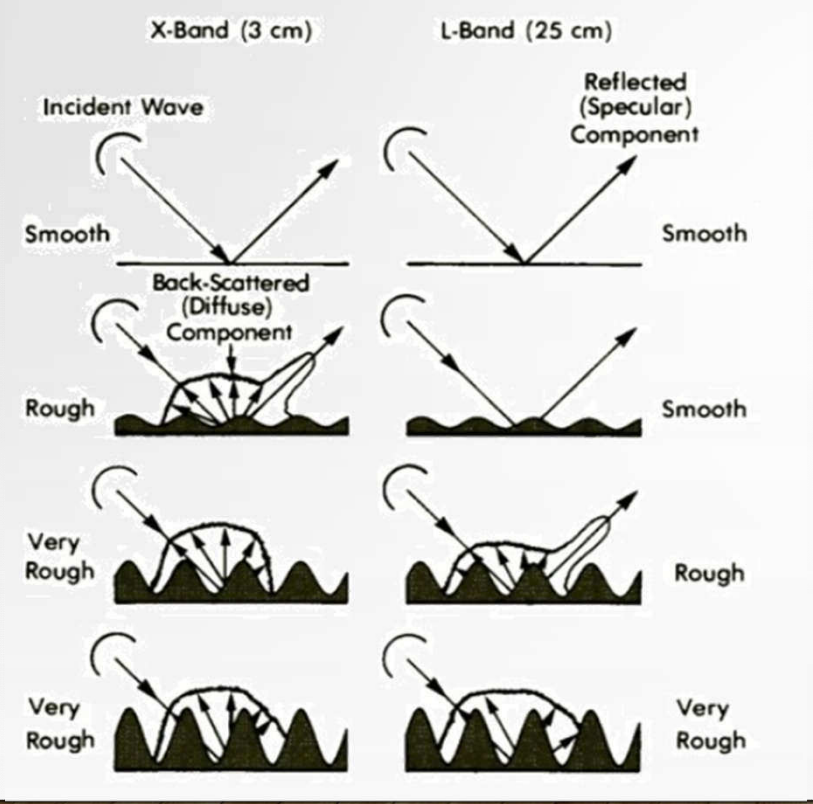


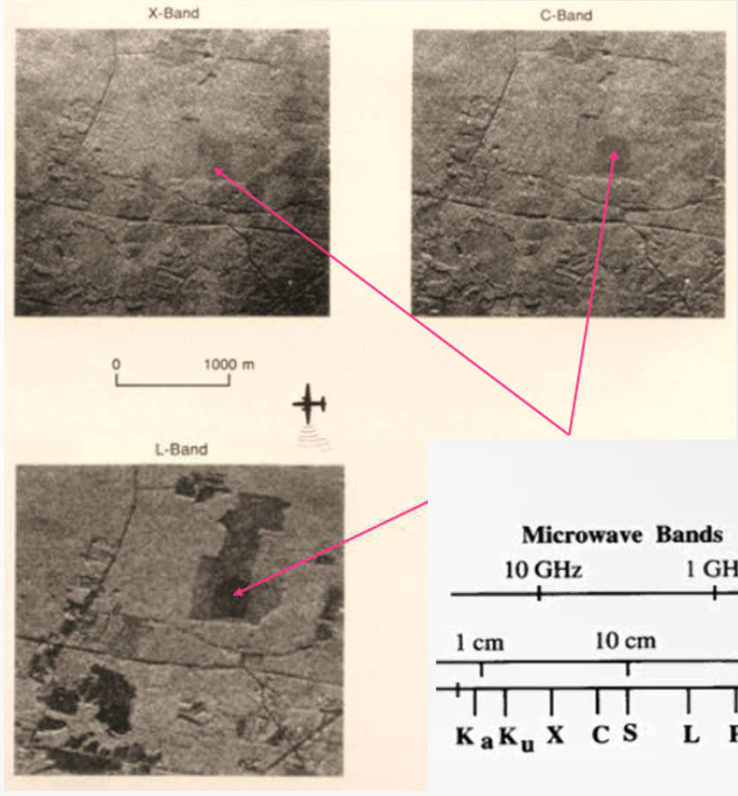
Smooth water surface (rivers) causing low backscatter

Rough water surface (rivers) causing relatively high backscatter

Target Parameters

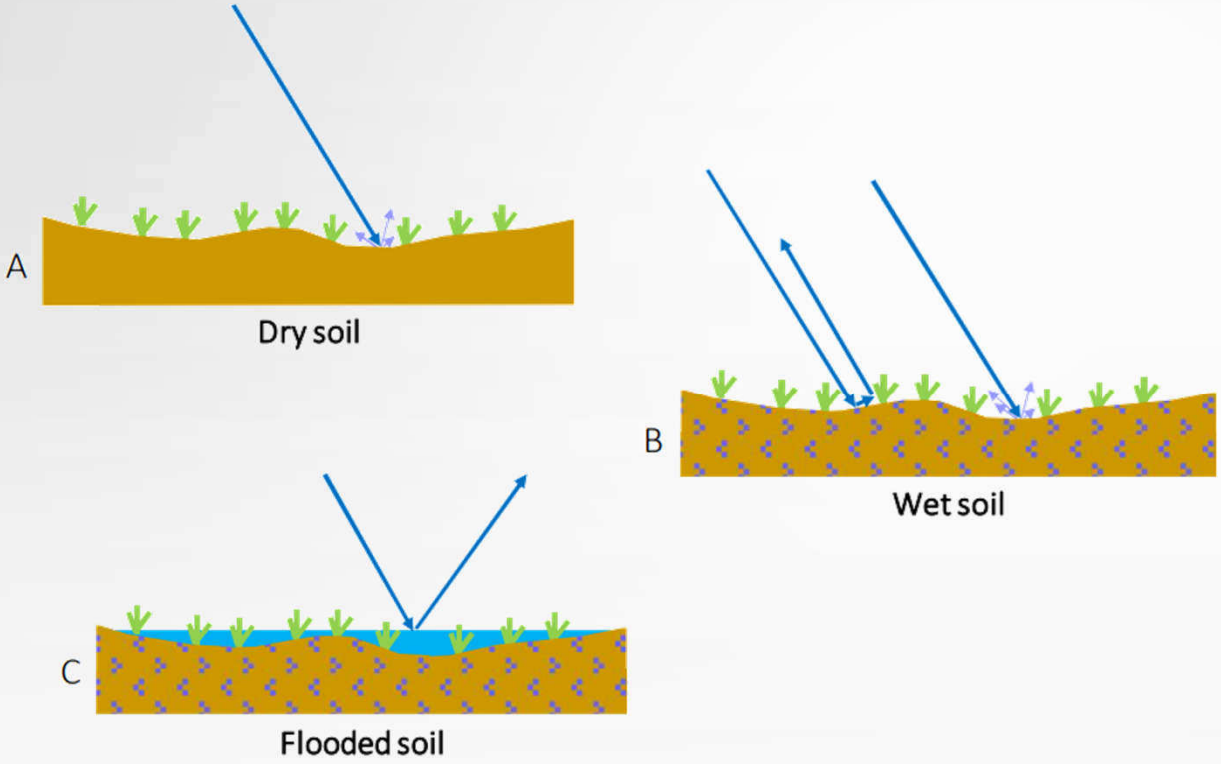
Surface roughness

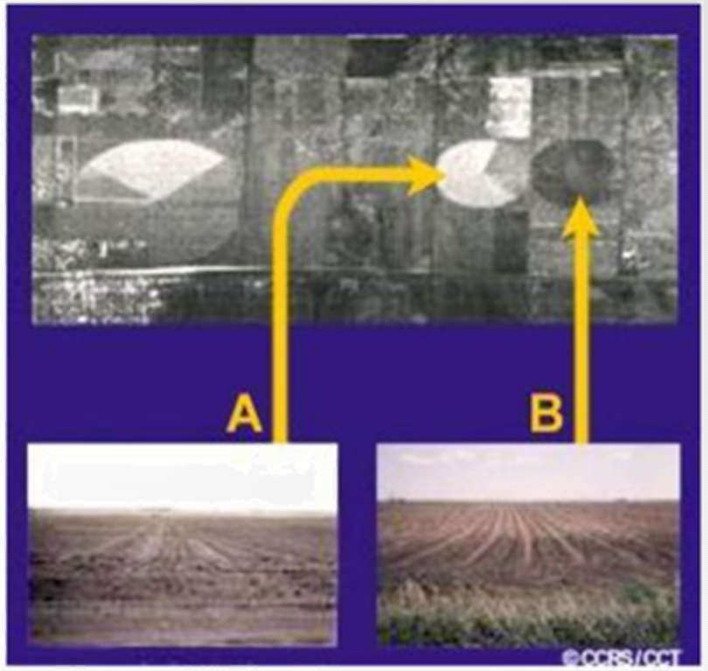




Target Parameters

Moisture content





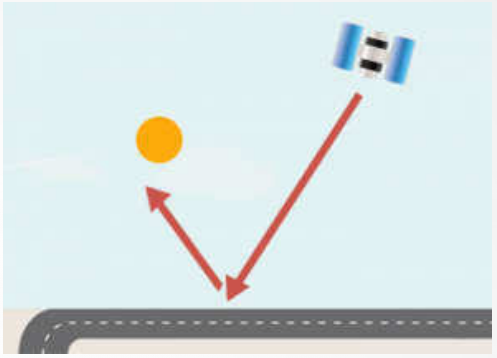
A = Irrigated field

B = Non-irrigated field

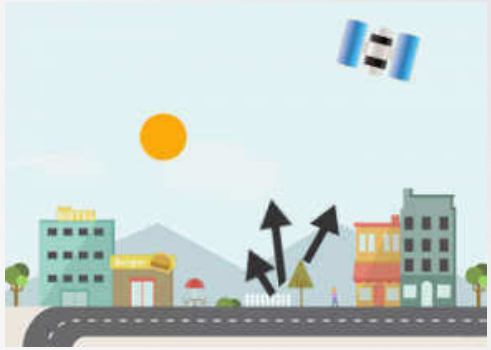
Target Parameters

Surface geometry

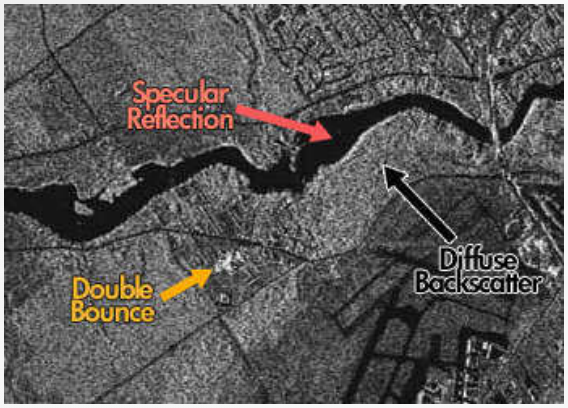
- ✓ There are three types of radar interactions:
  - ✓ Specular reflection
  - ✓ Double-bounce scattering
  - ✓ Diffuse scattering



Specular reflection



Diffuse scattering



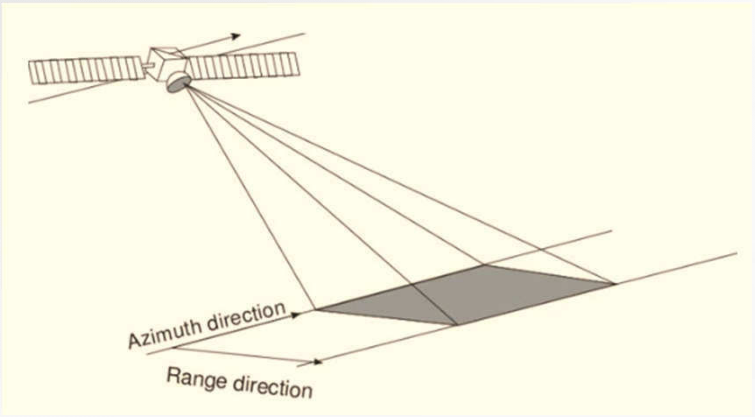
Radarsat-2 image

Double bounce backscatter

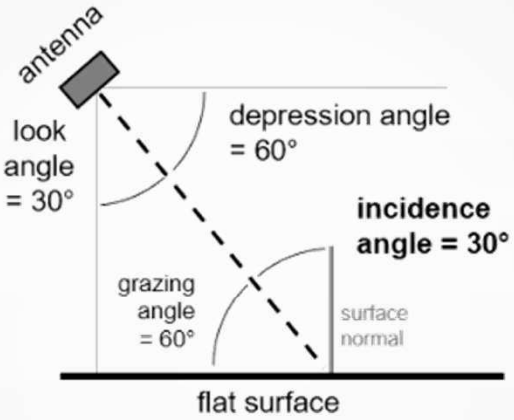
Radar Geometry

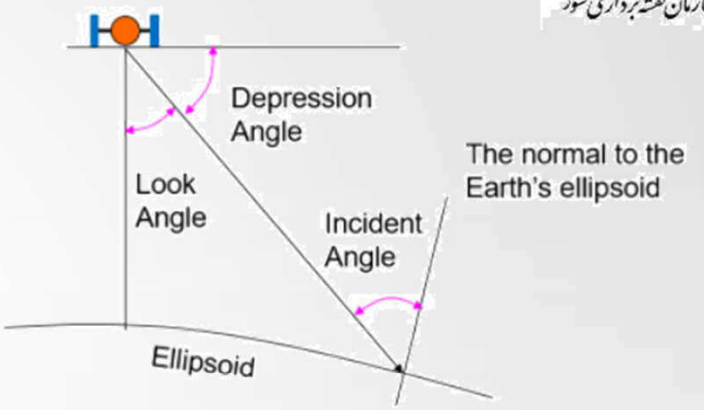
Three angles in side-looking radar imaging:

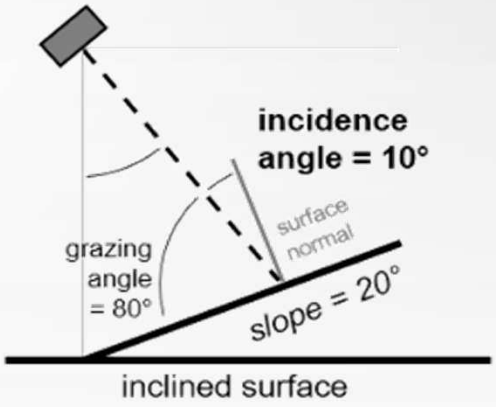
- ✓ Look angle
- ✓ Depression angle
- ✓ Incidence angle



Side-looking radar system



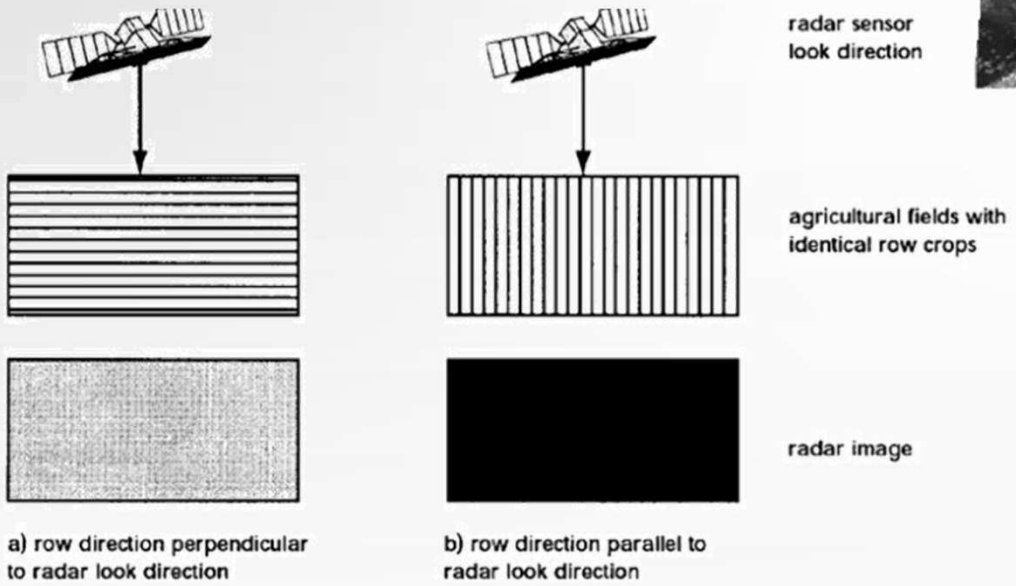


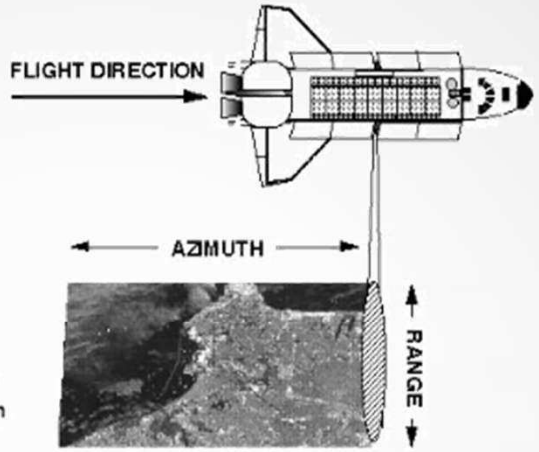


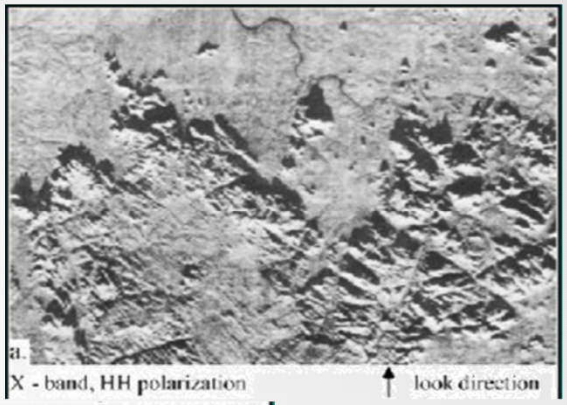
Radar Geometry

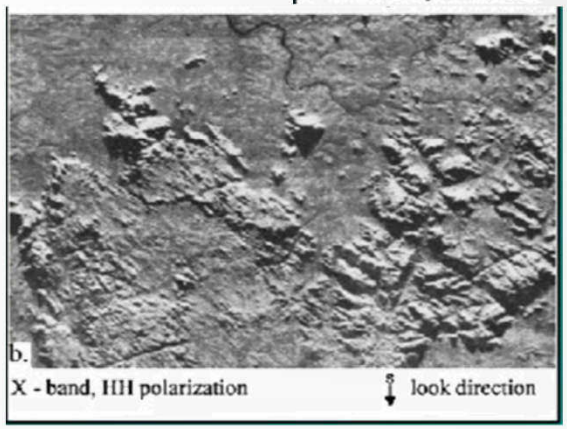
Directions

- ✓ Azimuth direction
- ✓ Range (look) direction





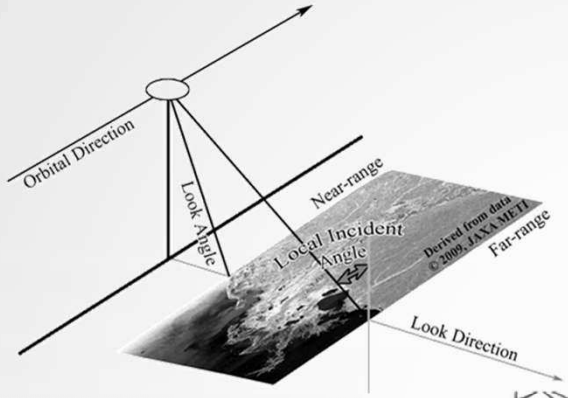


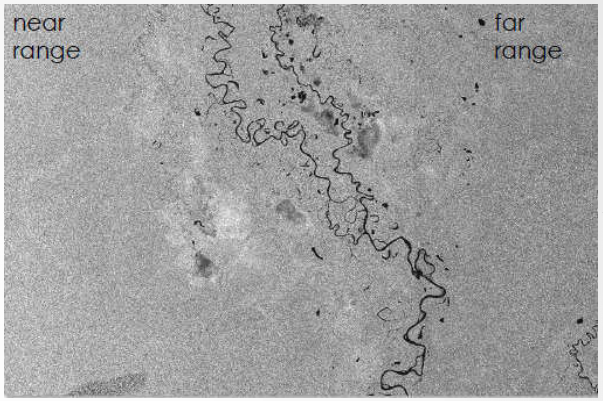


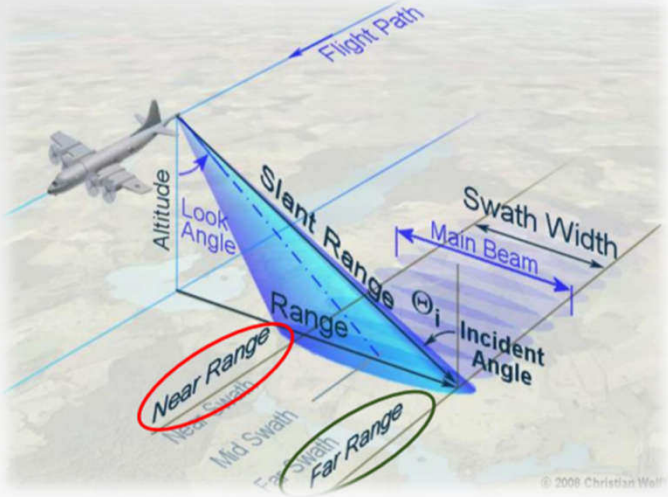
Radar Geometry

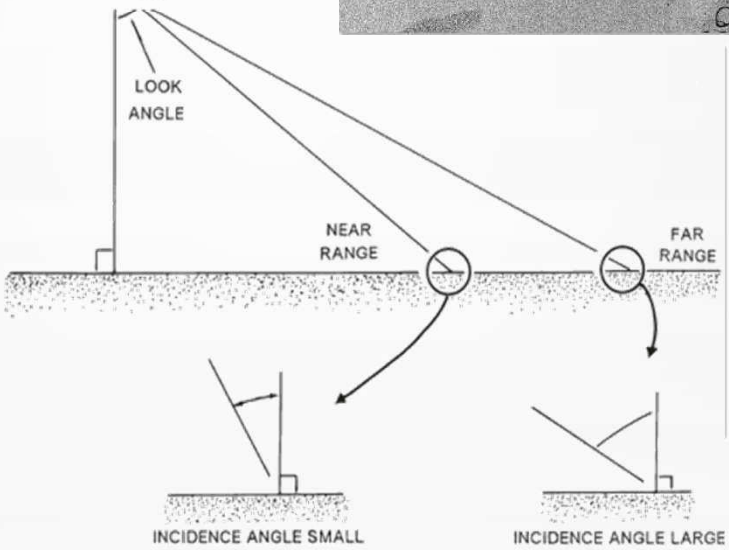
Swath width

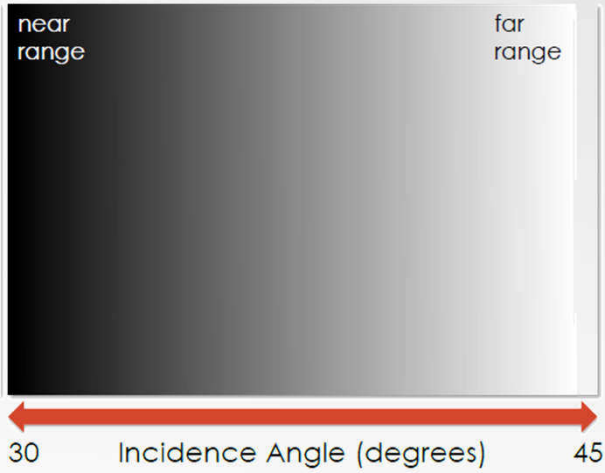
- ✓ Near range
- ✓ Far range







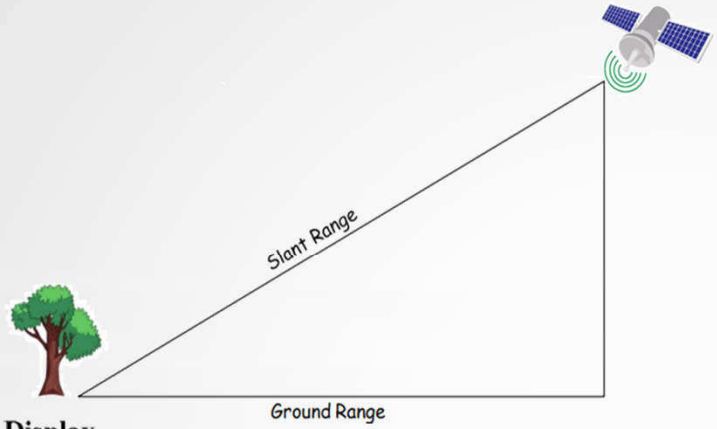




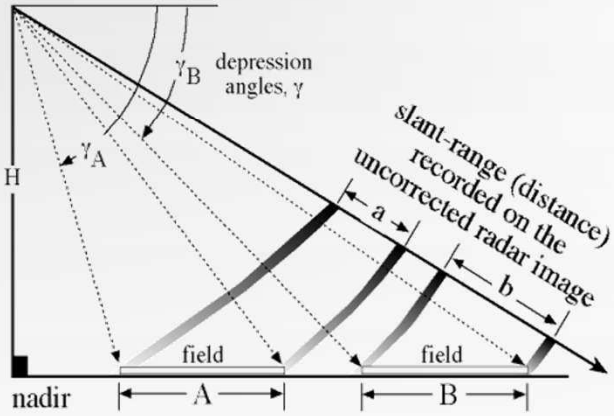
Radar Geometry

Distance

- ✓ Slant range
- ✓ Ground range

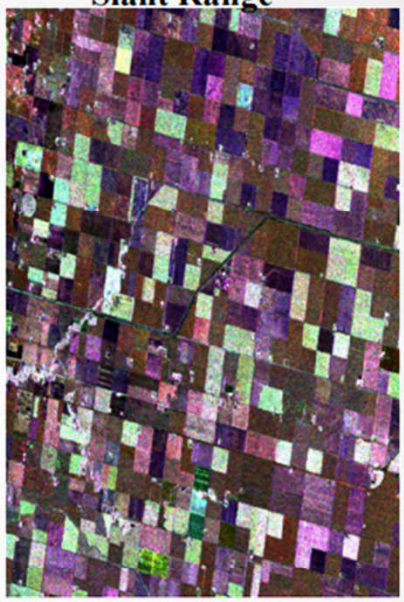


Slant-range Display versus Ground-range Display

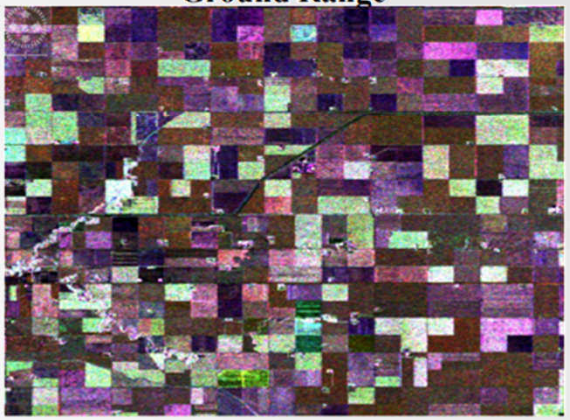


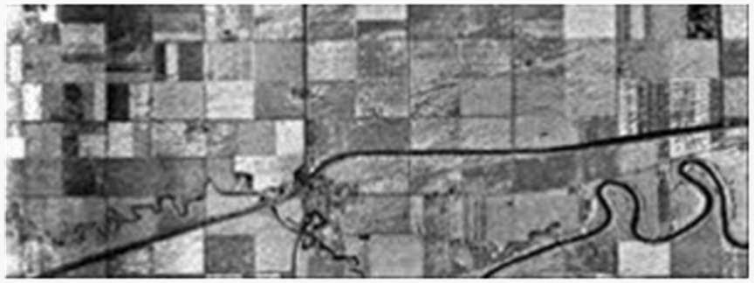
True Ground-range (distance) Display Plane

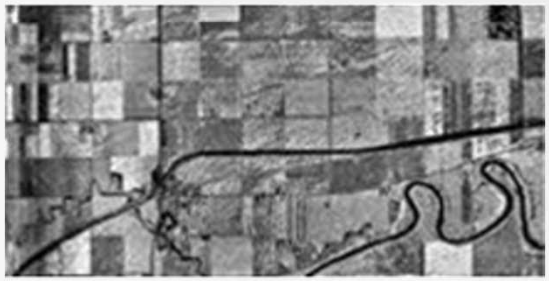
Slant Range



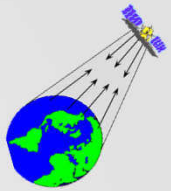
Ground Range





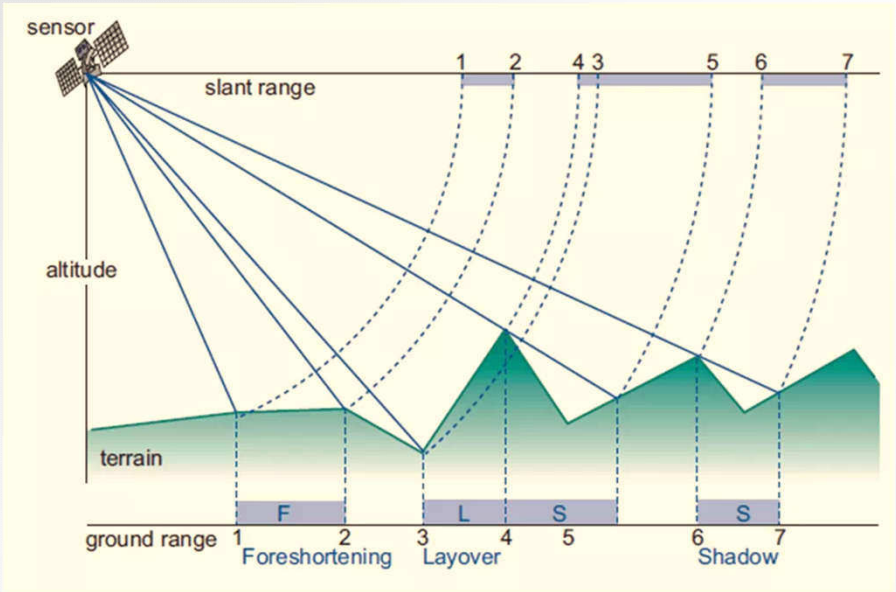


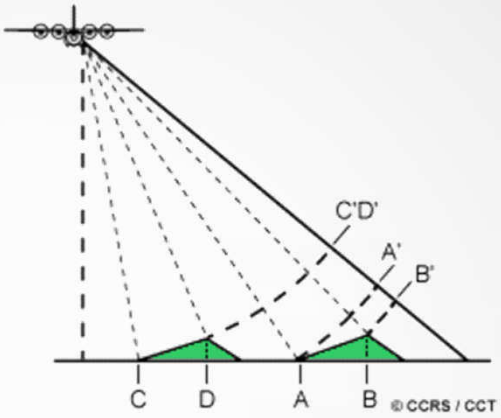
Radar Geometric Distortion

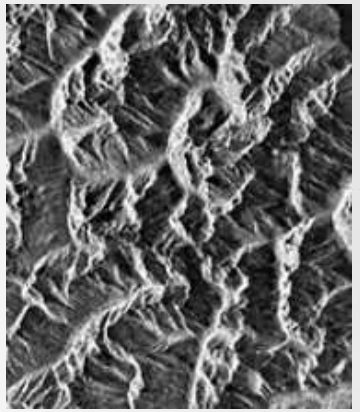


Geometric distortions in radar images including:

- ✓ Foreshortening
- ✓ Layover
- ✓ Shadow







a. **C-band ERS-1**
depression angle 67°
incident angle 23°

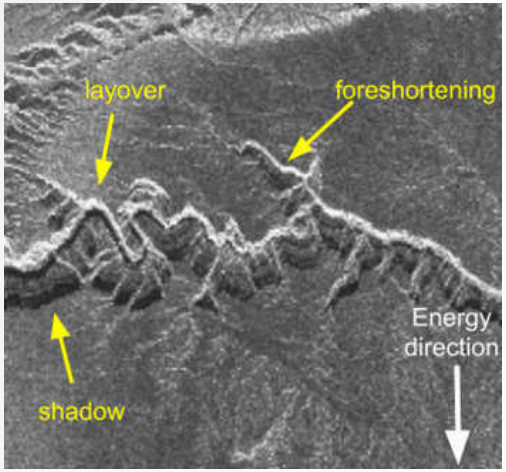
b. **L-band JERS-1**
depression angle 51°
incident angle 39°

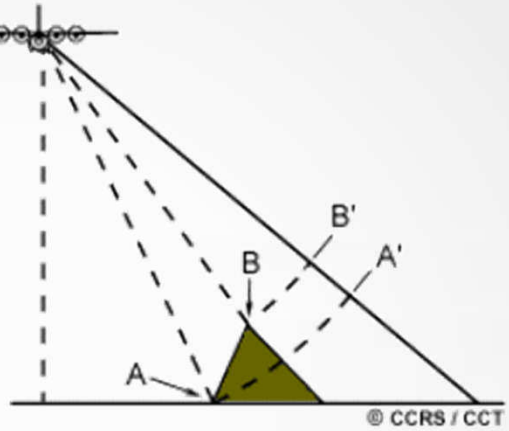
look direction

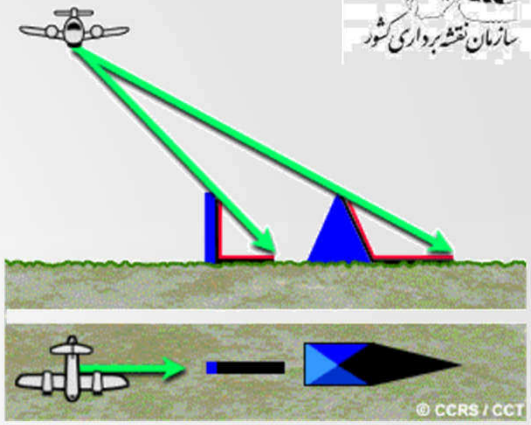
Radar Geometric Distortion

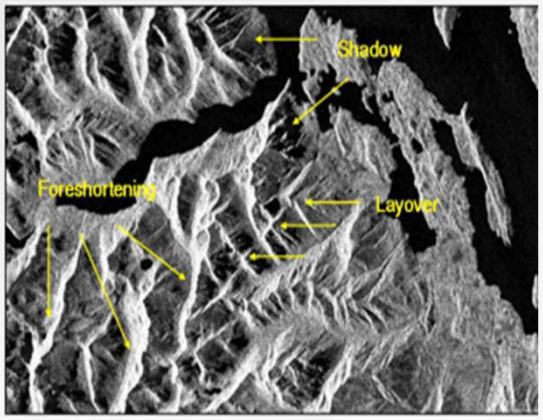
Geometric distortions in radar images including:

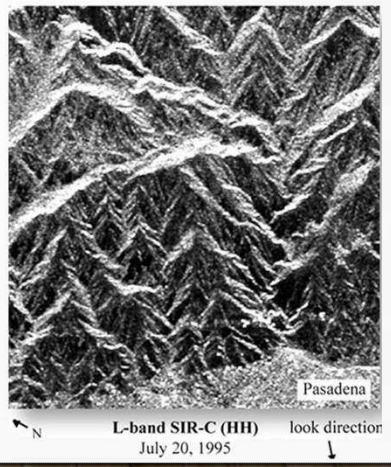
- ✓ Foreshortening
- ✓ Layover
- ✓ Shadow







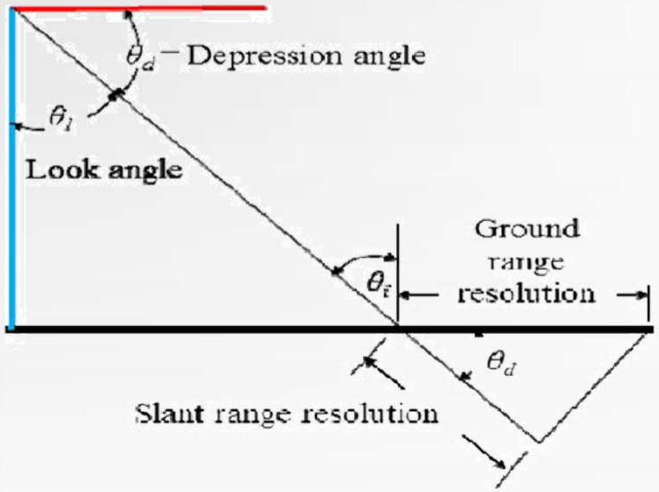


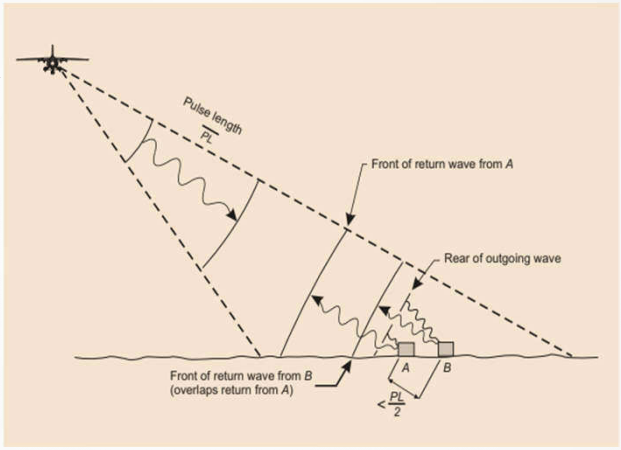


Radar Resolutions

In a radar image, spatial resolution is computed in two directions:

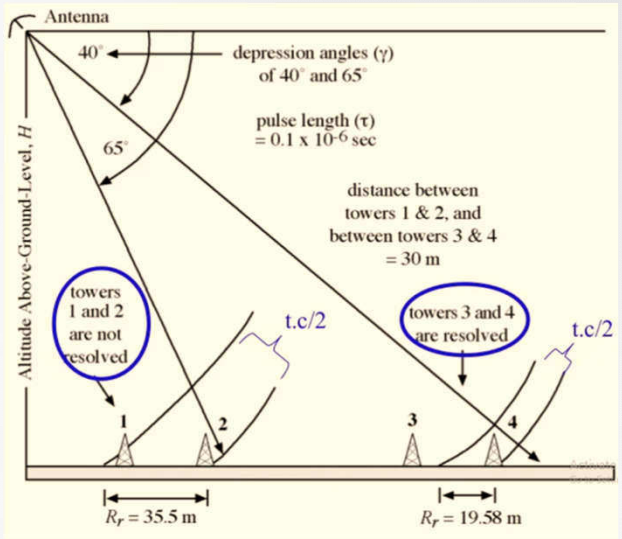
- ✓ Range
  - ✓ Slant range resolution
  - ✓ Ground range resolution
- ✓ Azimuth





$$R_{sr} = \frac{c\tau}{2}$$

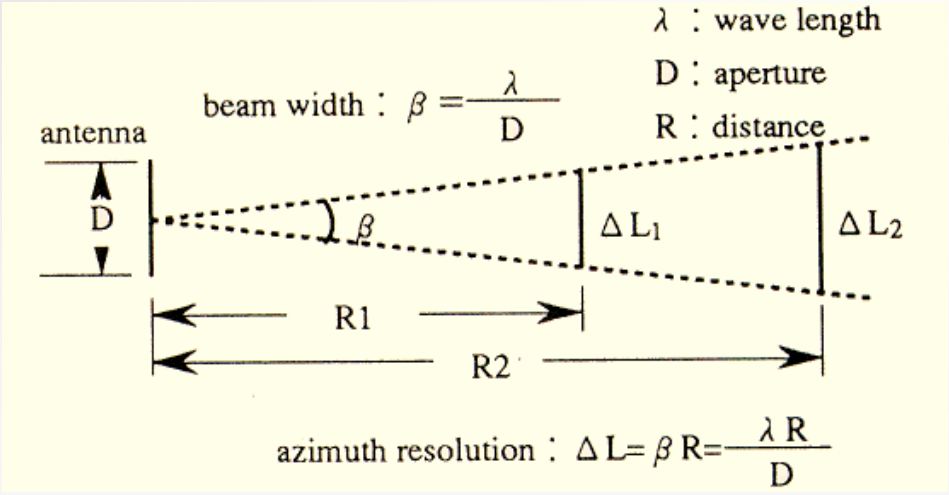
$$R_{gr} = \frac{c\tau}{2\cos\theta_d}$$

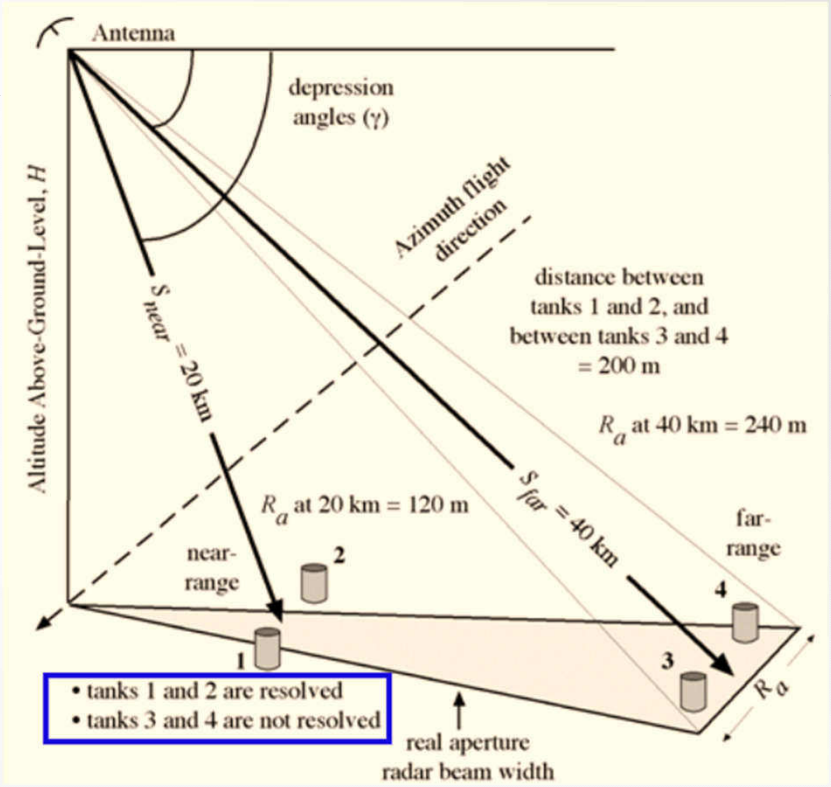


Radar Resolutions

In a radar image, spatial resolution is computed in two directions:

- ✓ Range
  - ✓ Slant range resolution
  - ✓ Ground range resolution
- ✓ Azimuth

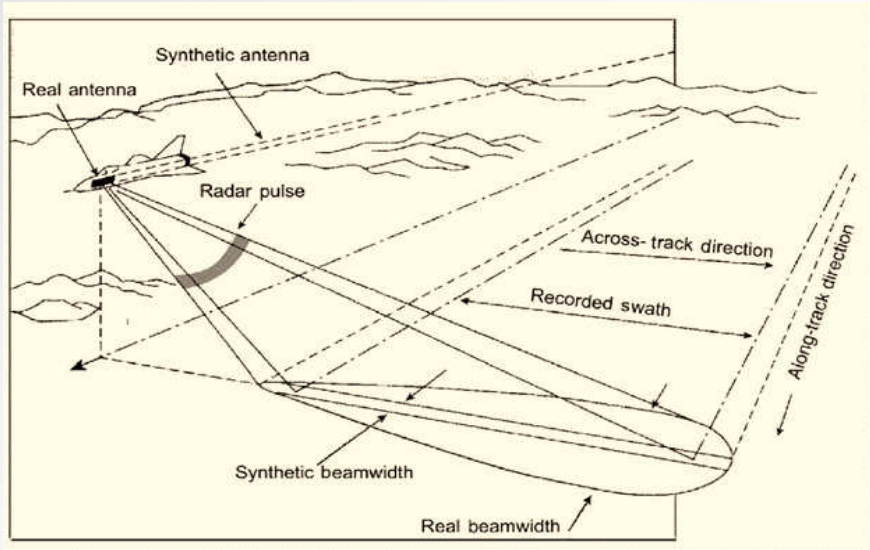


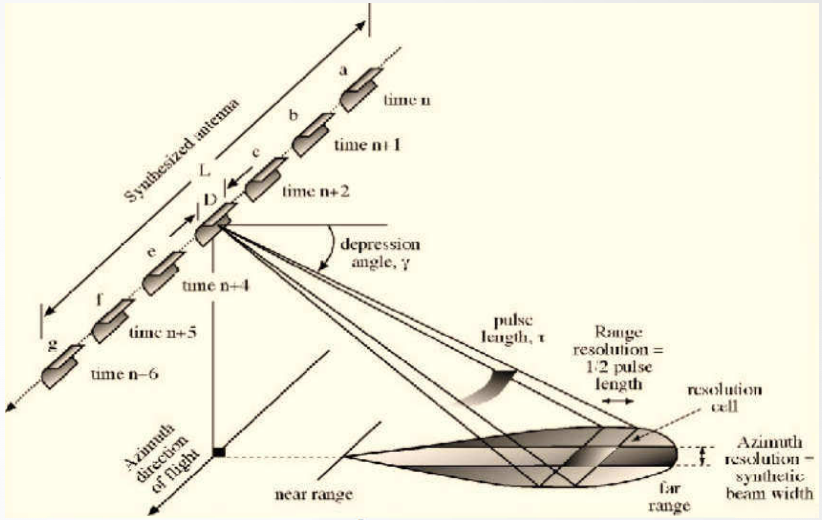


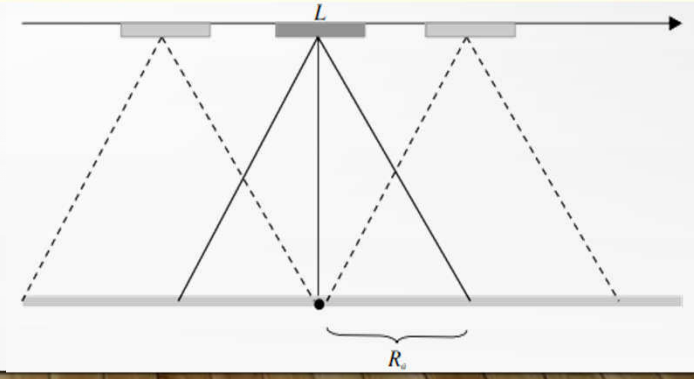
Synthetic Aperture Radar

Imaging radar can be classified into:

- ✓ Real aperture radar (RAR)
- ✓ Synthetic aperture radar (SAR)



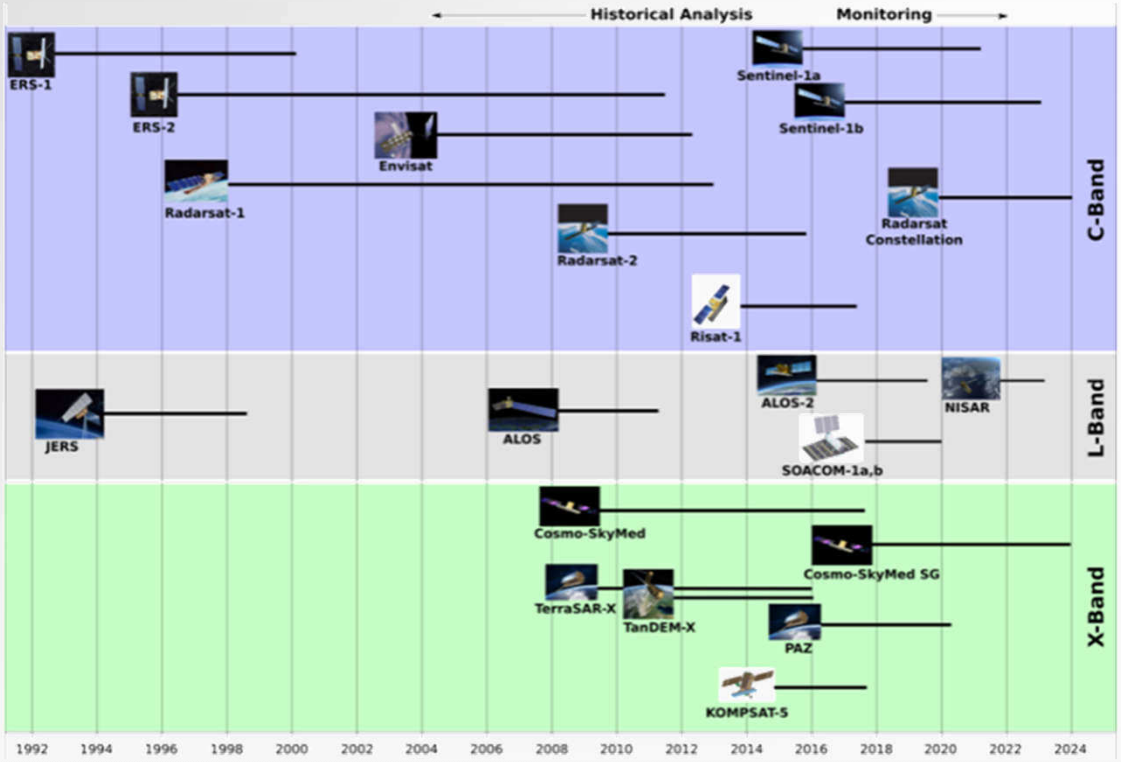




$$R_{aSAR} = \frac{L}{2}$$

Synthetic Aperture Radar

Most airborne and spaceborne radars employ this type of radar



European Space Agency (ESA): ERS-1, ERS-2, Envisat, Sentinel-1

Japan Aerospace Exploration Agency (JAXA): JERS-1, ALOS-1, ALOS-2

Canadian Space Agency (CSA): Radarsat-1, Radarsat-2, Radarsat constellation

Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR): TerraSAR-X, TanDEM-X

Indian Space Research Organization (ISRO): RISAT-1, NISAR (w/ NASA)

Comision Nacional de Actividades Espaciales: SAOCOM

Italian Space Agency (ASI): COSMO-Skymed

Instituto National de Técnica Aeroespacial (INTA): PAZ

Korea Areospace Research Institute (KARI): KOMPSat-5

National Aeronautics and Space Administration (NASA): NISAR (w/ ISRO)