Basics of Synthetic Aperture Radar (SAR) Remote Sensing

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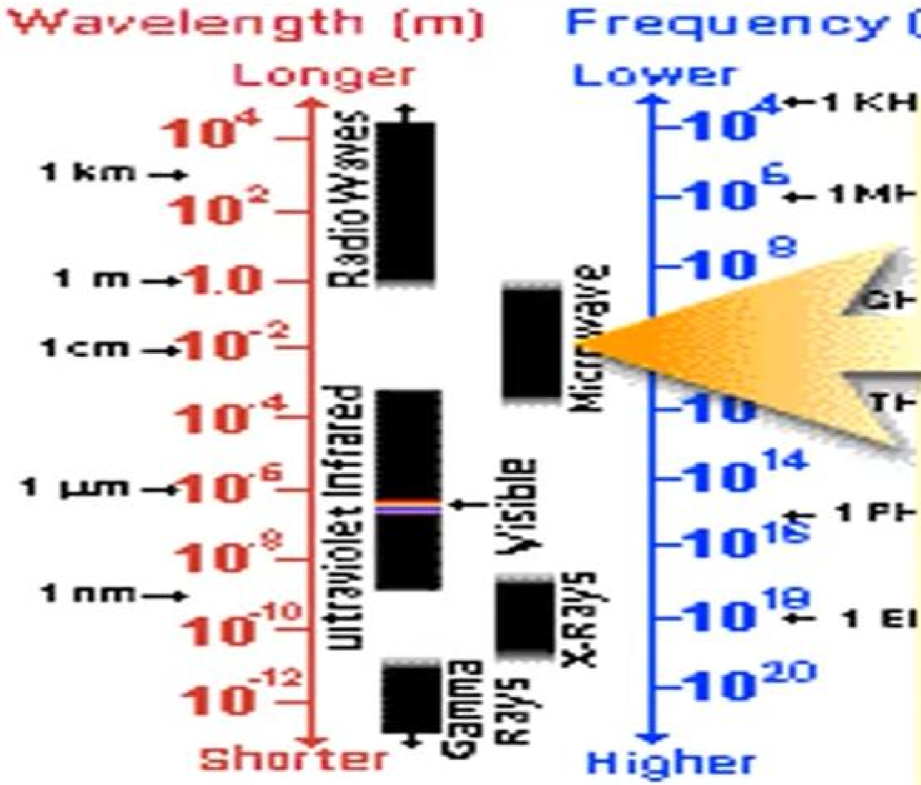
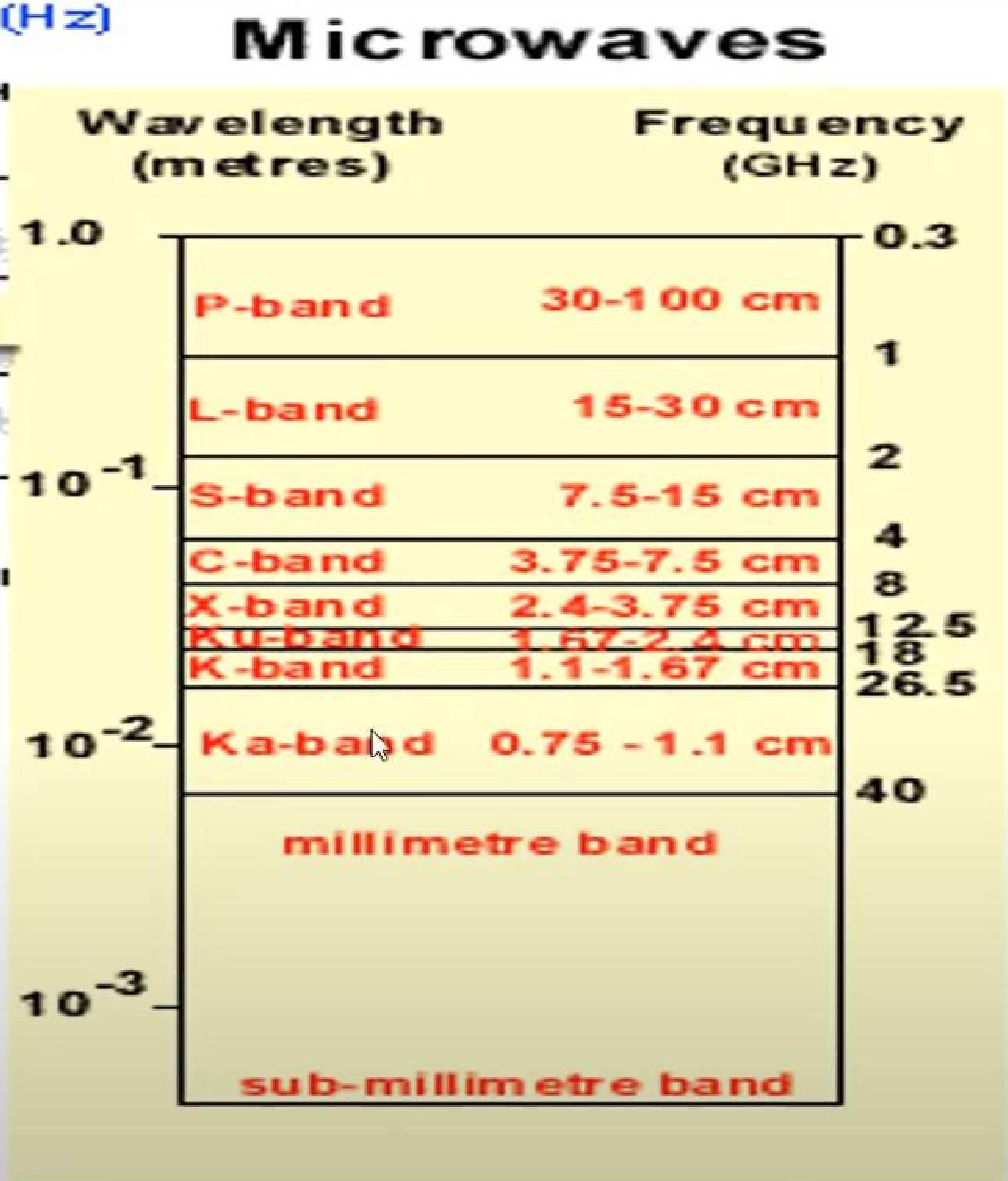
Microwave Remote Sensing

The remote sensing which is carried in the Microwave region of electromagnetic spectrum is known as microwave remote sensing technique. 1 mm to 100 cm range of electromagnetic spectrum is generally used for spaceborne microwave remote sensing.

Microwave Bands





Microwave bands are divided in K-, X- C-,S-, L- and P- bands. There will be increase in wavelength of the electromagnetic waves if one will move from K-band to P –band.

http://www.nrcan.gc.ca/node/14623

Introduction

Synthetic aperture radar (SAR) is a form of radar that is used to create images of objects, such as landscapes – these images can be either two or three dimensional representations of the object.

- The Remote Sensing which is carried out in the microwave region of electromagnetic spectrum is known as microwave remote sensing.
- SAR remote sensing is an imaging active microwave remote sensing technique which provides higher spatial resolution data.

Synthetic Aperture Radar

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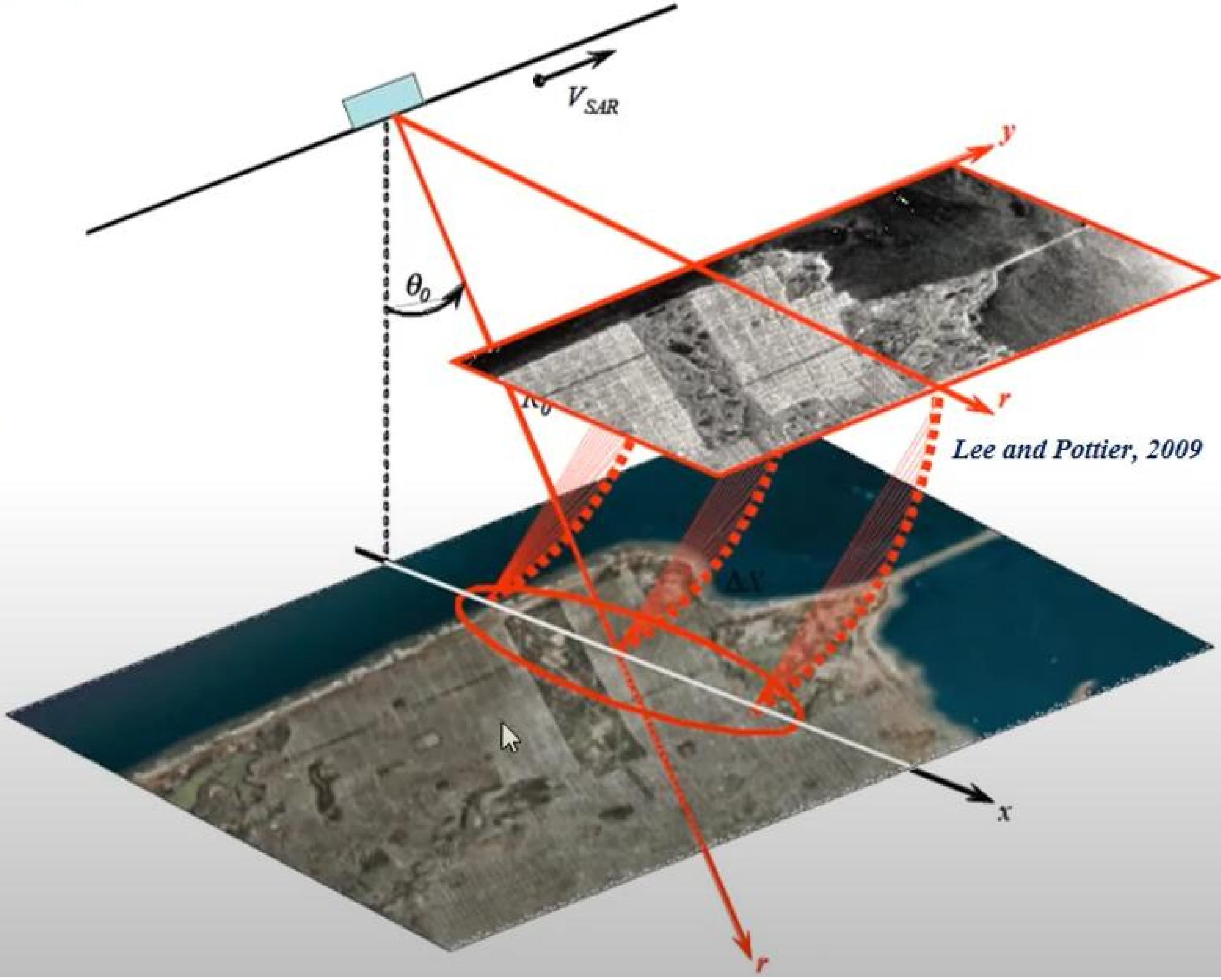
SAR remote sensing is an imaging active microwave remote sensing technique which provides higher spatial resolution data.



SAR Versus Other Earth Observation Instruments

	Lidar	Optical Multi-Spectral	SAR
Platform	airborne/spaceborne	airborne/spaceborne	airborne/spaceborne
Radiation	own radiation	reflected sunlight	own radiation
Spectrum	infrared	visible/infrared	microwave
Frequency	single frequency	multi-frequency	multi-frequency
Polarimetry	N.A.	N.A.	polarimetric phase
Interferometry	N.A.	N.A.	interferometric phase
Acquisition time	day/night	day time	day/night
Weather	blocked by clouds	blocked by clouds	see through clouds

http://www.sarmap.ch/pdf/SAR-Guidebook.pdf

SAR Satellites

RISAT-1: April 2012: C-band

Radarsat 1: 1995: C-band

Radarsat 2: 2007: C-band (Quad-pol)

ERS 1: 1991-2000 :C-band

ERS 2: 1995 :C-band

JERS : 1992-98 : L-band

ENVISAT: 2002: C-band

ALOS: 2006: L-band (Quad-pol)

TerraSAR-X: 2007: X-band (Quad-pol)

TanDEM-X: 2010: X-band (Quad-pol)

ALOS-2: 2014: L-band (Quad-pol)

Sentinel-1A: 2014: C-band

Sentinel-1B: 2016: C-band

RADARSAT Constellation Mission (RCM): 2019: C-band

Comparison of the various SAR bands

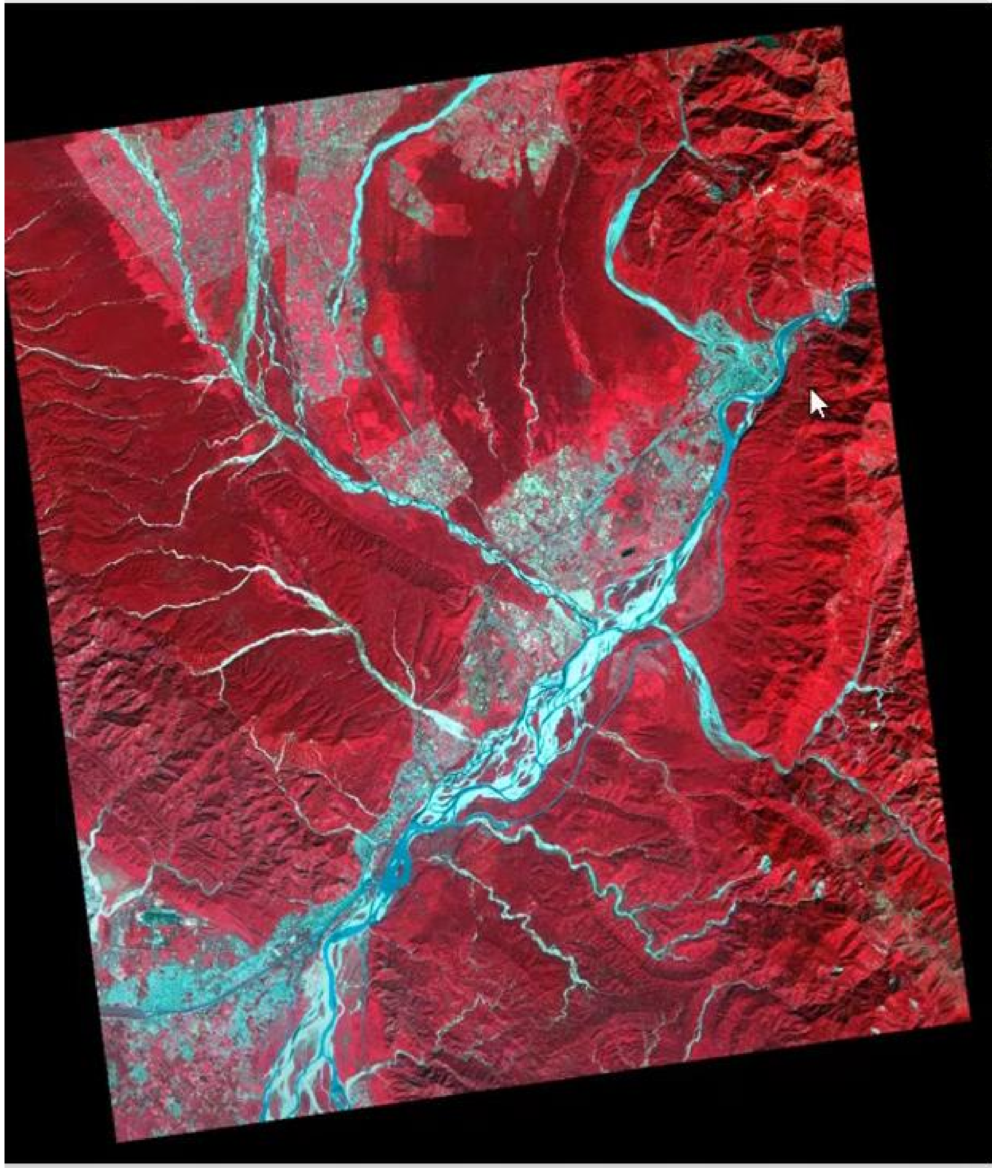
Band	Frequency	Wavelength (cm)	Spaceborne SAR Systems	Typical Applications/Strengths
P-band	43.2-438 MHz	68.5-69.4	BIOMASS	High penetration, detection of targets concealed by foliage or camouflage, buried object, archaeological, estimates of biomass, map forest disturbances.
L-band	1215-1300 MHz	23.1-24.7	SEASAT, JERS-1, ALOS PALSAR, ALOS-2 PALSAR-2, SAOCOM-1A/1B, NISAR-L, Tandem-L	Good penetration, land applications – forestry, environmental monitoring, agriculture, geology, hydrology.
S-band	3.1-3.3 GHz	9.1-9.7	ALMAZ-1, HJ-1c, KONDOR-E, NovaSAR-1, NISAR-S	Ship detection, ice mapping, oil spill detection, flood mapping, forestry mapping, crop classification.
C-band	5.25-5.57 GHz	5.4-5.7	ERS-1/2, Envisat ASAR, Radarsat-1/2, RCM, RISAT-1/1-A, Sentinel 1A/B	Sensitive to ocean features, ship detection sea ice surveillance, oil spill monitoring.
X-band	9.5-9.8 GHz	3.1-3.2	TerraSAR-X/TanDEM-X, COSMO-SkyMed, IGS-1B/3B, TecSAR, RISAT-2, PAZ, KOMPSAT-5, SAR-Lupe, ICEYE constellation	Sensitive to surface roughness, high resolution applications, topographic mapping, flood mapping.

Source: https://research.csiro.au/cceo/novasar/novasar-introduction/satellite-specifications-capabilities/sar-overview/

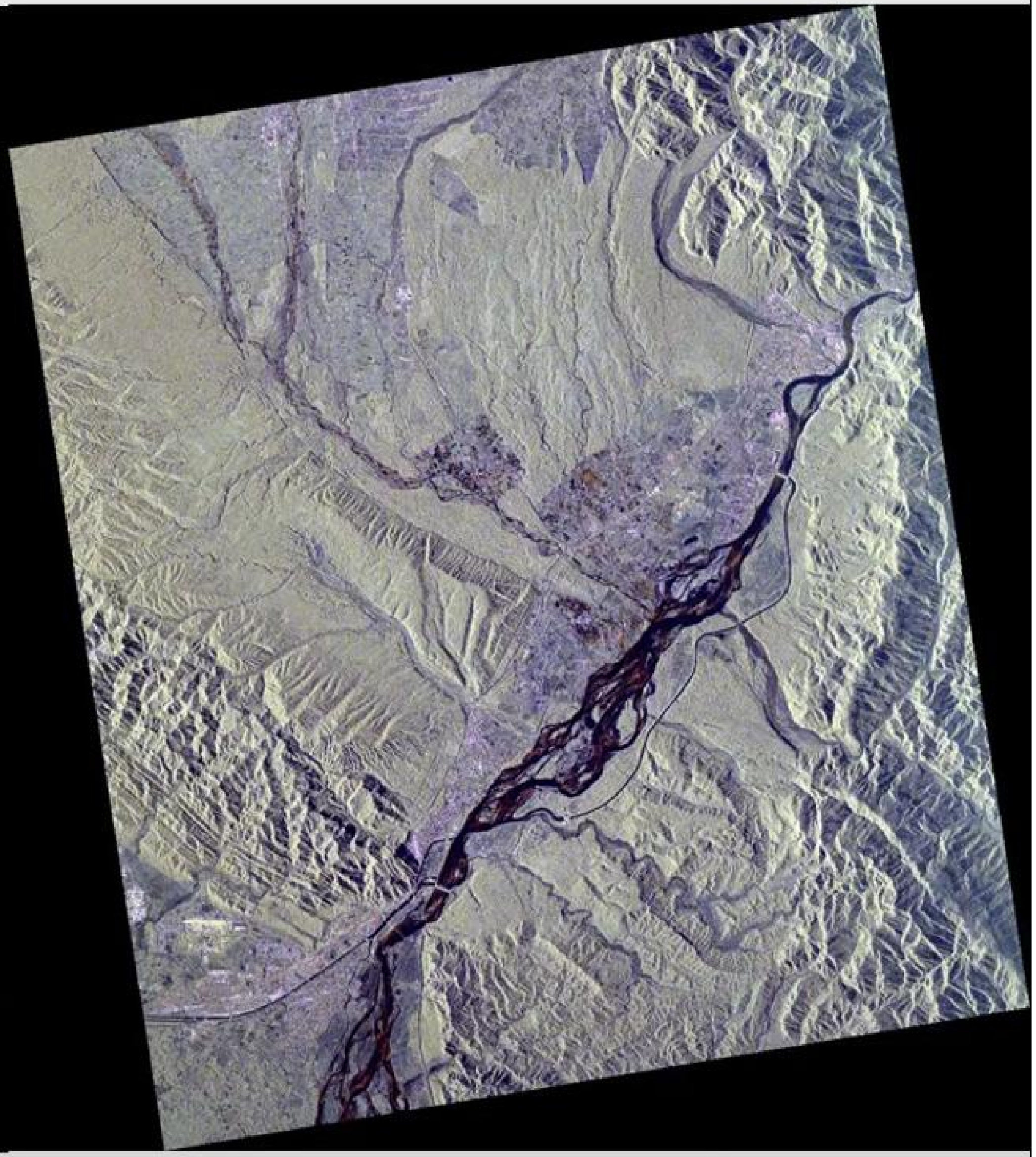
Indian SAR Earth Observation Satellites

Sensor	Operation	Band
RISAT-2	April 20, 2009	X-Band,
RISAT-1	April 26, 2012	C-Band, Hybrid/Dual
RISAT-2B	May 22, 2019	X-Band
RISAT-2BR1	Dec 11, 2019	X-Band
RISAT-1A	Feb 14 2022	C-Band, Hybrid Polarimetry
NISAR NASA-ISRO SAR Mission	Launch scheduled in 2023*	L-band & S-band (*Source:http://database.eohandbook.com/database/missionsummary.aspx?missionID=642, Date: 23.01.2020, The CEOS Database)

Need of SAR Data



LISS-4 FCC



RISAT-1 Hybrid-pol FCC

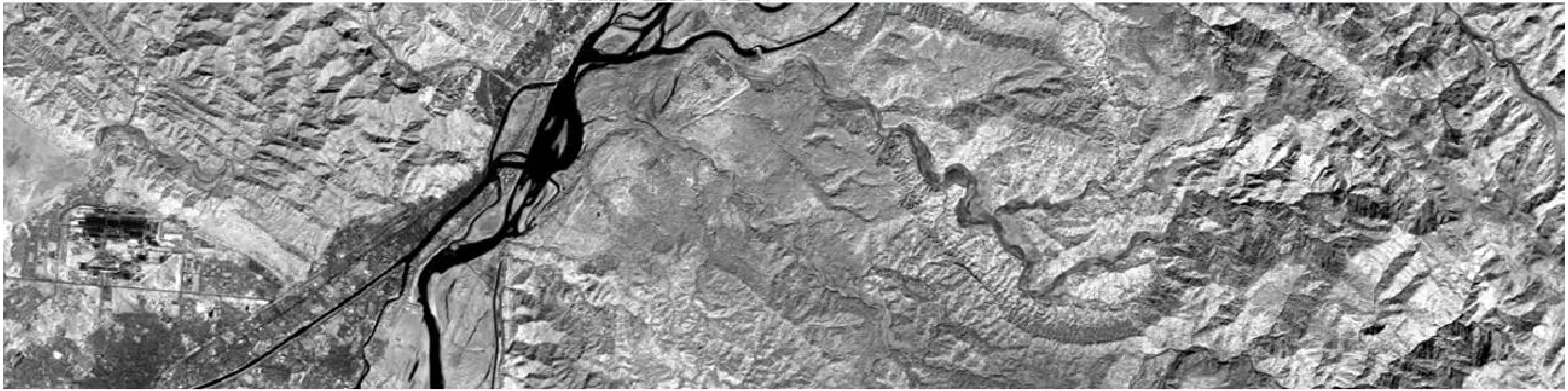
LISS-4

Microwaves and optical data are fundamentally different

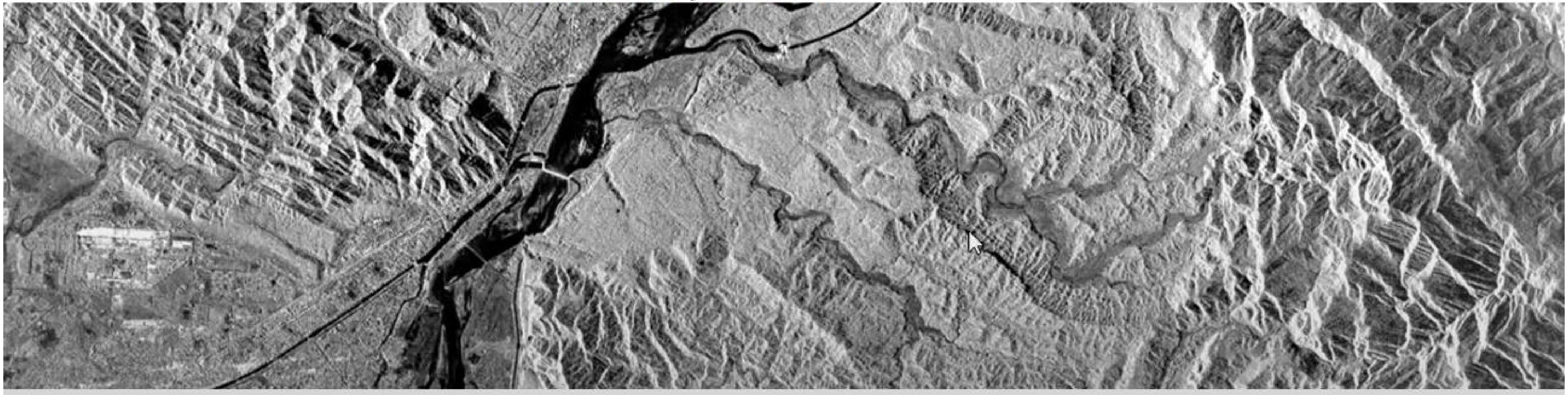
- Microwaves are primarily sensitive to structure and water content
- Optical data are reflectance spectra obtained from sunlight and is primarily sensitive to the illumination characteristics and molecular components of the region being imaged.

RISAT-1

IRS-R2 LISSIV



RISAT-1, FRS-1



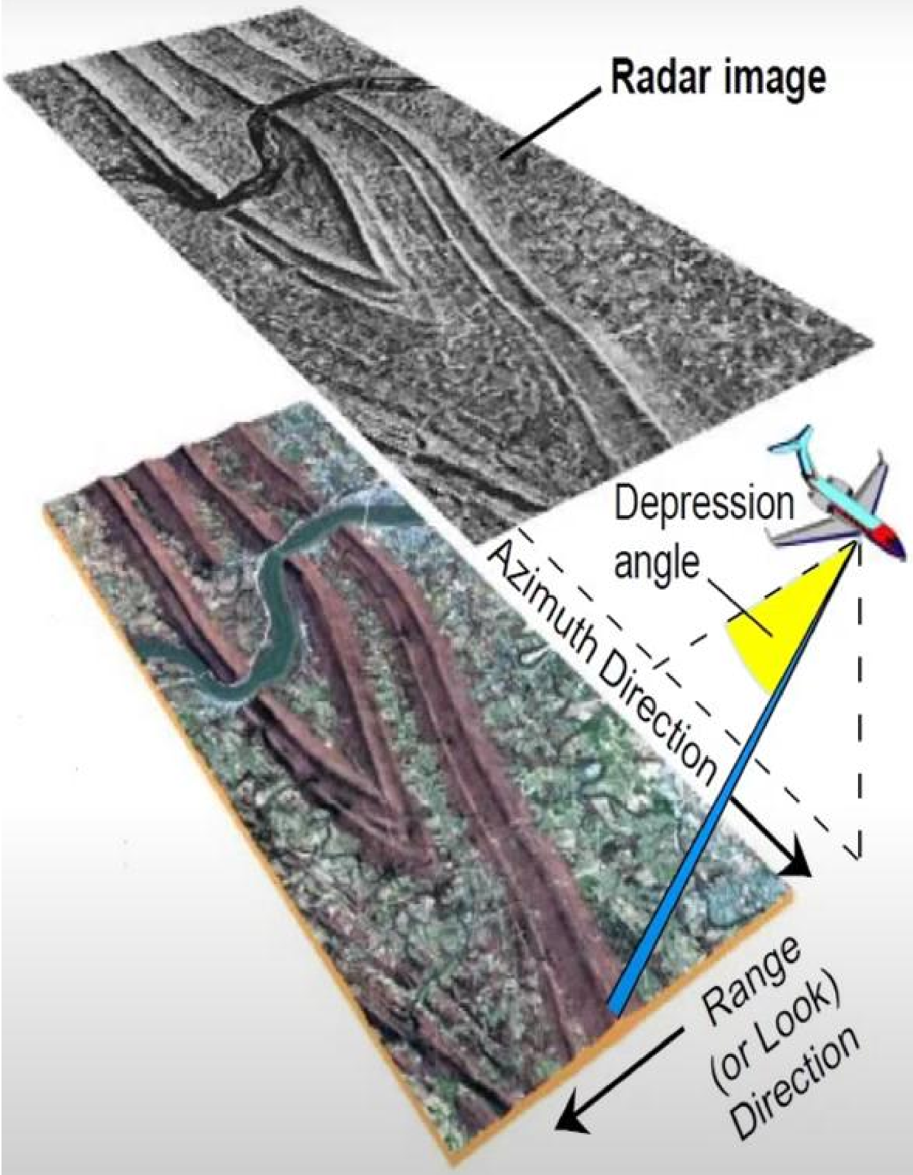
Sahara region was not always the dry desert it is today

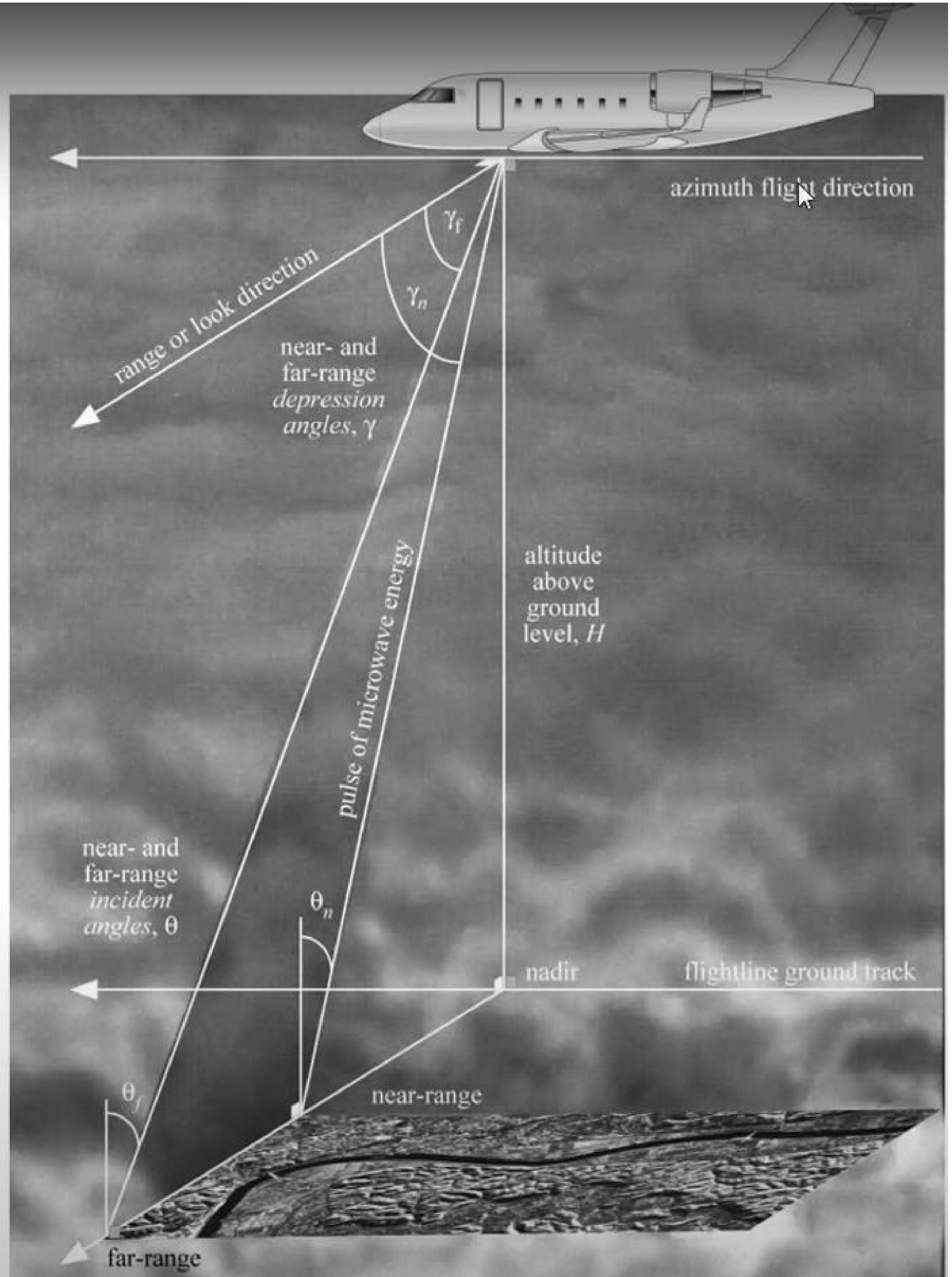
Figure shows a rather dramatic case of how the early SIR-A radar, operating at the L-band, was able to peer underneath the sand of the Sahara to reveal previously unmapped drainage channels from an earlier, wetter geologic era. This vegetation and surface penetration capability has been applied in the field of archeology as well.

https://www.nap.edu/read/21729/chapter/6#86

NASA/JPL; "Shuttle Imaging Radar-A," November 12, 1981, http://www.jpl.nasa.gov/history/index_timeline.htm.

SAR Geometry





http://www.microimages.com/documentation/Tutorials/radar.pdf

John R. Jensen- Remote Sensing of the Environment: An Earth Resource Perspective

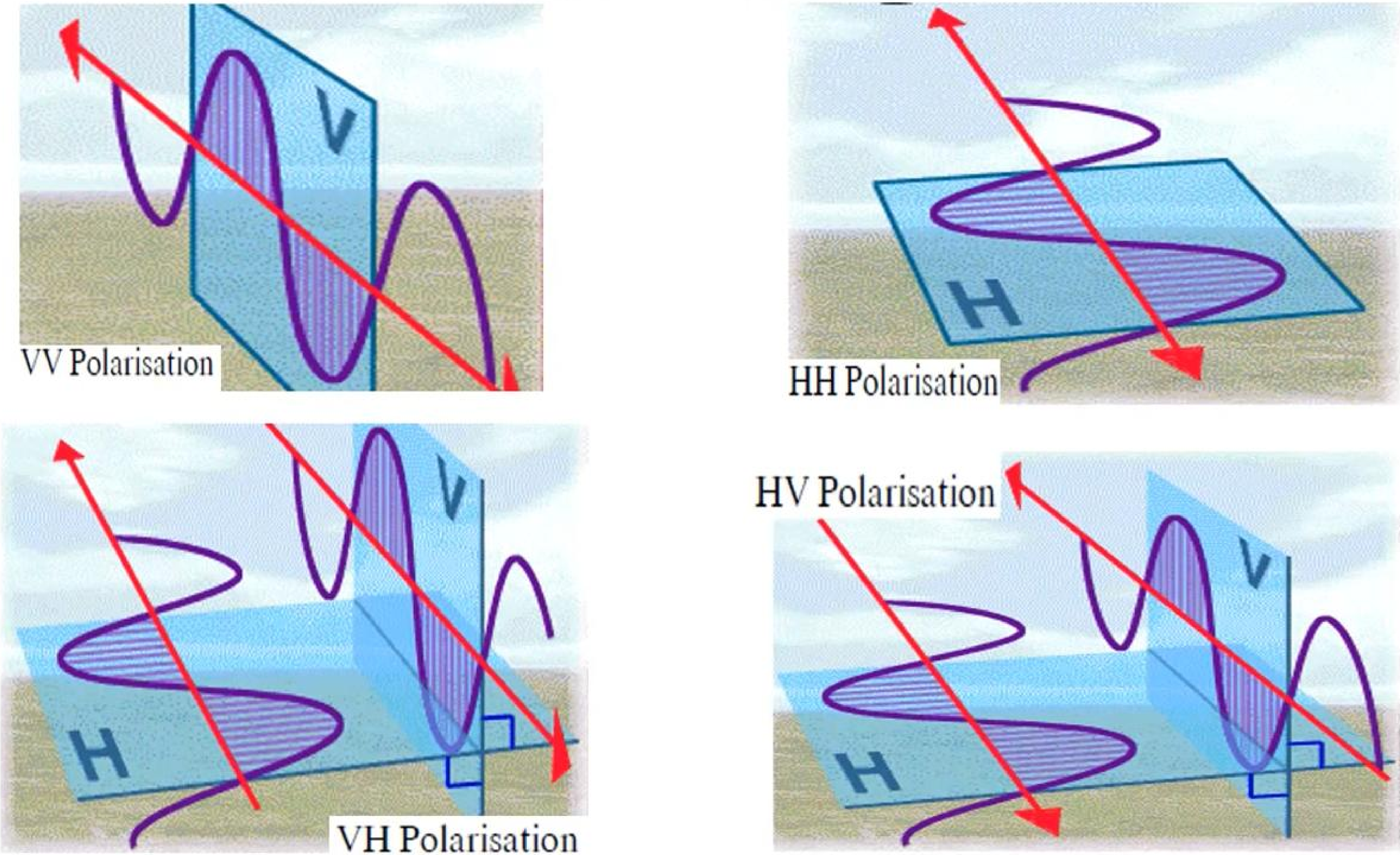
SAR Resolution

- **Azimuth Resolution-** Azimuth resolution describes the ability of an imaging radar to separate two closely spaced scatterers in the direction parallel to the motion vector of the sensor.
- **Range Resolution-** For the radar to be able to distinguish two closely spaced elements, their echoes must necessarily be received at different times.

Radar Polarization

- ***Un-polarized*** **energy vibrates in all possible directions perpendicular to the direction of travel.**
- **Radar antennas send and receive *polarized energy*. *This* means that the pulse of energy is filtered so that its electrical 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.***

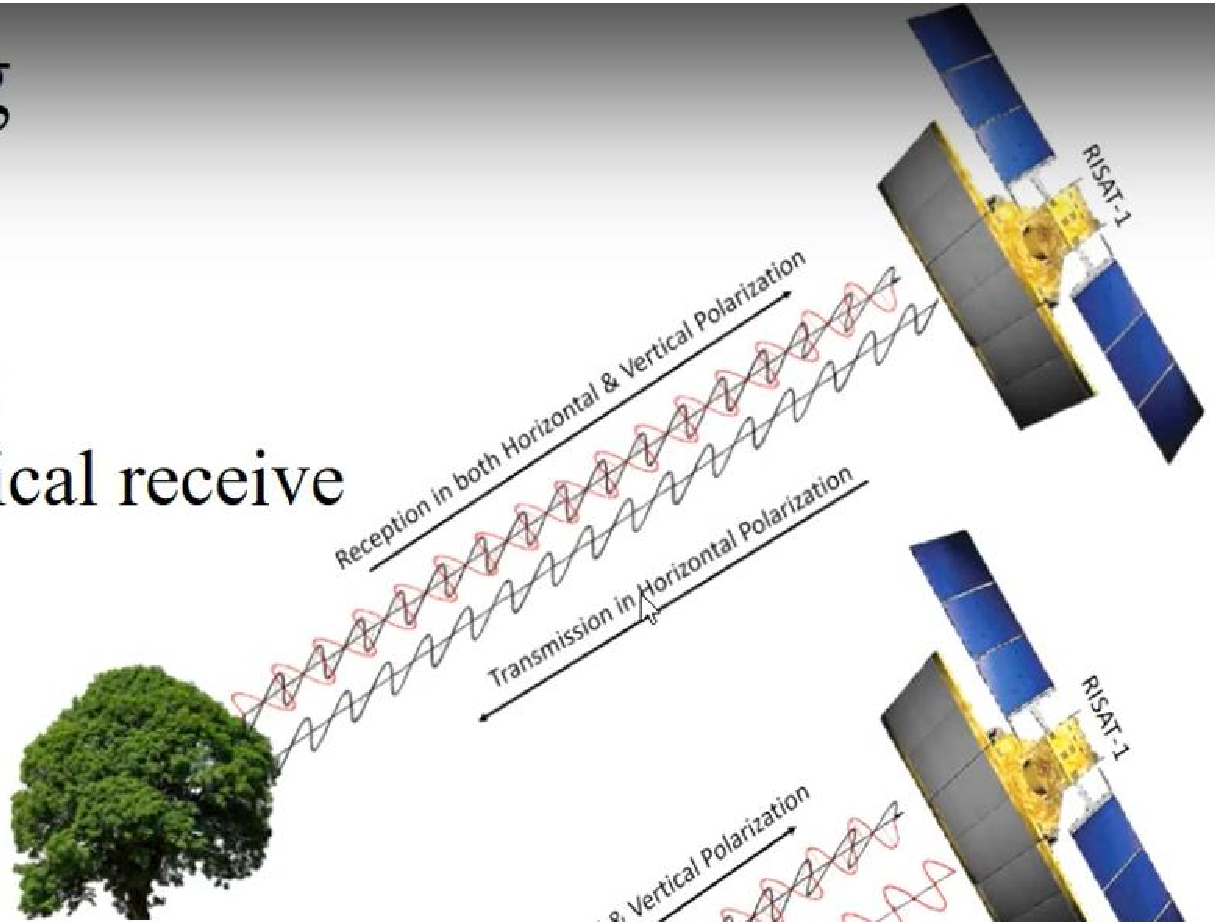
Polarisations



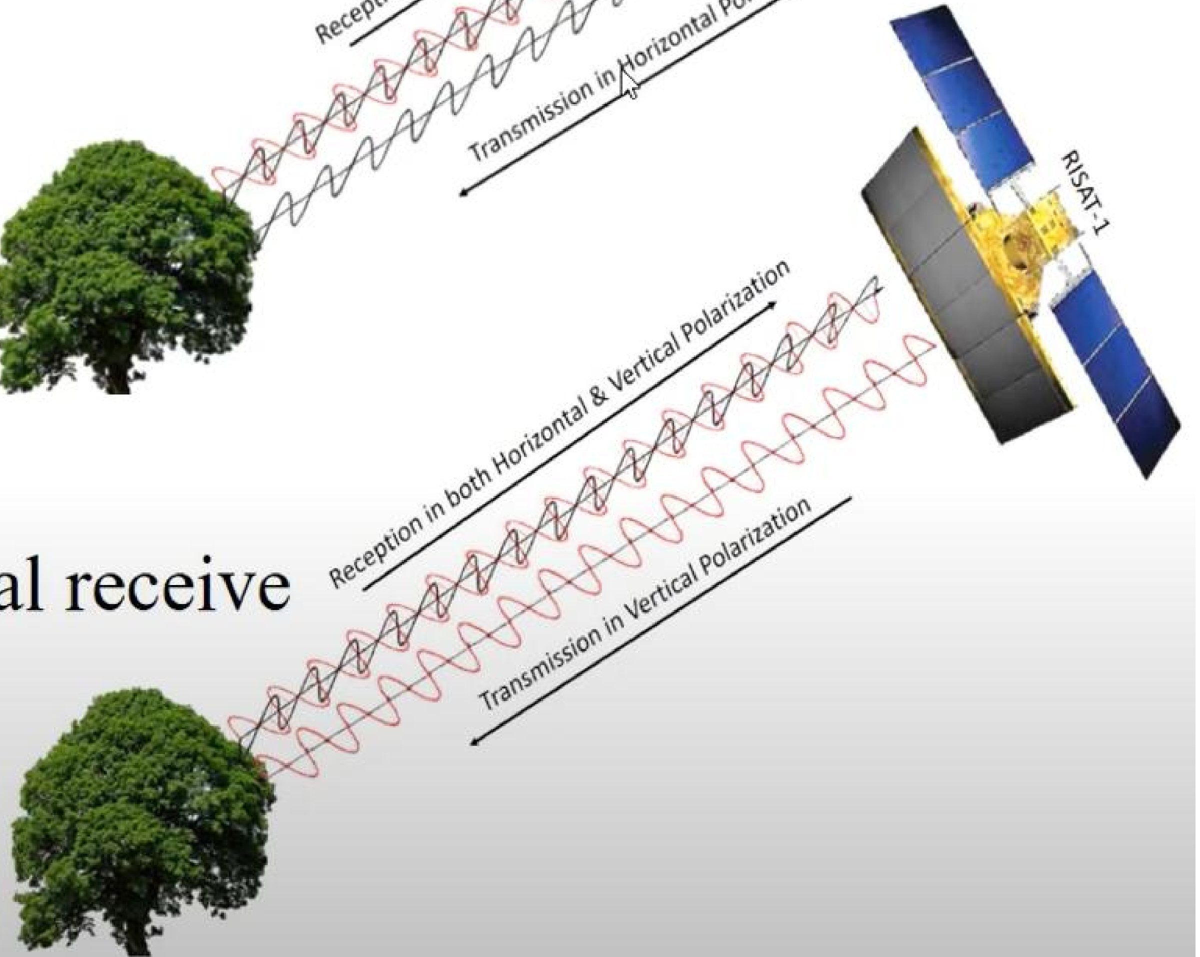
http://envisat.esa.int/handbooks/asar/CNTR1-1-5.html

SAR Imaging

Horizontal transmit:
Horizontal and Vertical receive



Vertical transmit:
Horizontal and Vertical receive



SAR Data

SAR data consist of high-resolution reflected returns of radar-frequency energy from terrain that has been illuminated by a directed beam of pulses generated by the sensor. The radar returns from the terrain are mainly determined by the physical characteristics of the surface features (such as surface roughness, geometric structure, and orientation), the electrical characteristics (dielectric constant, moisture content, and conductivity), and the radar frequency of the sensor.

TerraSAR-X Vishakhapattanam

Surface roughness

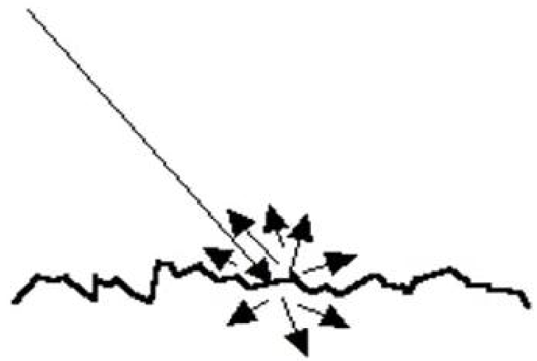
There is a relationship between the wavelength of the radar (λ), the depression angle (γ), and the local height of objects (*h in cm*) *found within the resolution cell being illuminated* by microwave energy. It is called the *modified Rayleigh criteria and can be used to predict what the earth's surface* will look like in a radar image if we know the surface roughness characteristics and the radar system parameters (λ, γ, *h*) mentioned.

Peake and Oliver's modified Rayleigh criterion

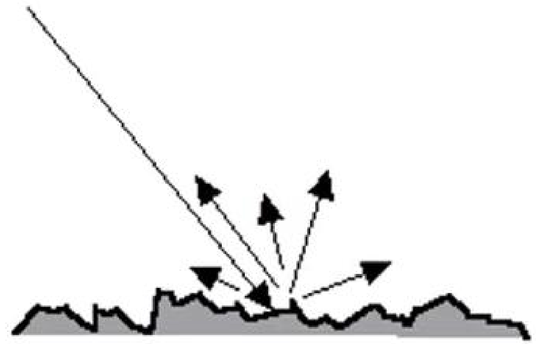
Surface roughness category	Aircraft K_a band $\lambda = 0.86$ cm, $\gamma = 45°$	Aircraft X band $\lambda = 3$ cm, $\gamma = 45°$	Seasat L band $\lambda = 23.5$ cm, $\gamma = 70°$
Smooth, cm	$h < 0.048$	$h < 0.17$	$h < 1$
Intermediate, cm	$h = 0.048$ to 0.276	$h = 0.17$ to 0.96	$h = 1$ to 5.68
Rough, cm	$h > 0.276$	$h > 0.96$	$h > 5.68$

Interaction of EM Wave with Soil

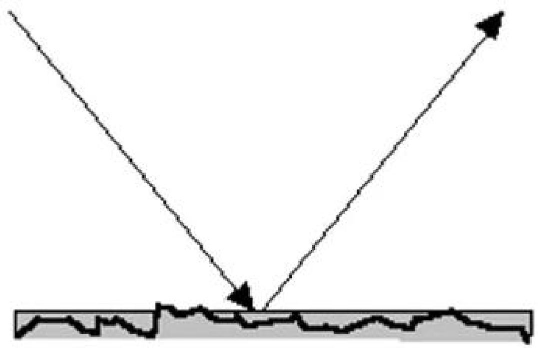
- **Dry Soil: Some of the incident radar energy is able to penetrate into the soil surface, resulting in less backscattered intensity.**



- **Wet Soil: The large difference in electrical properties between water and air results in higher backscattered radar intensity.**

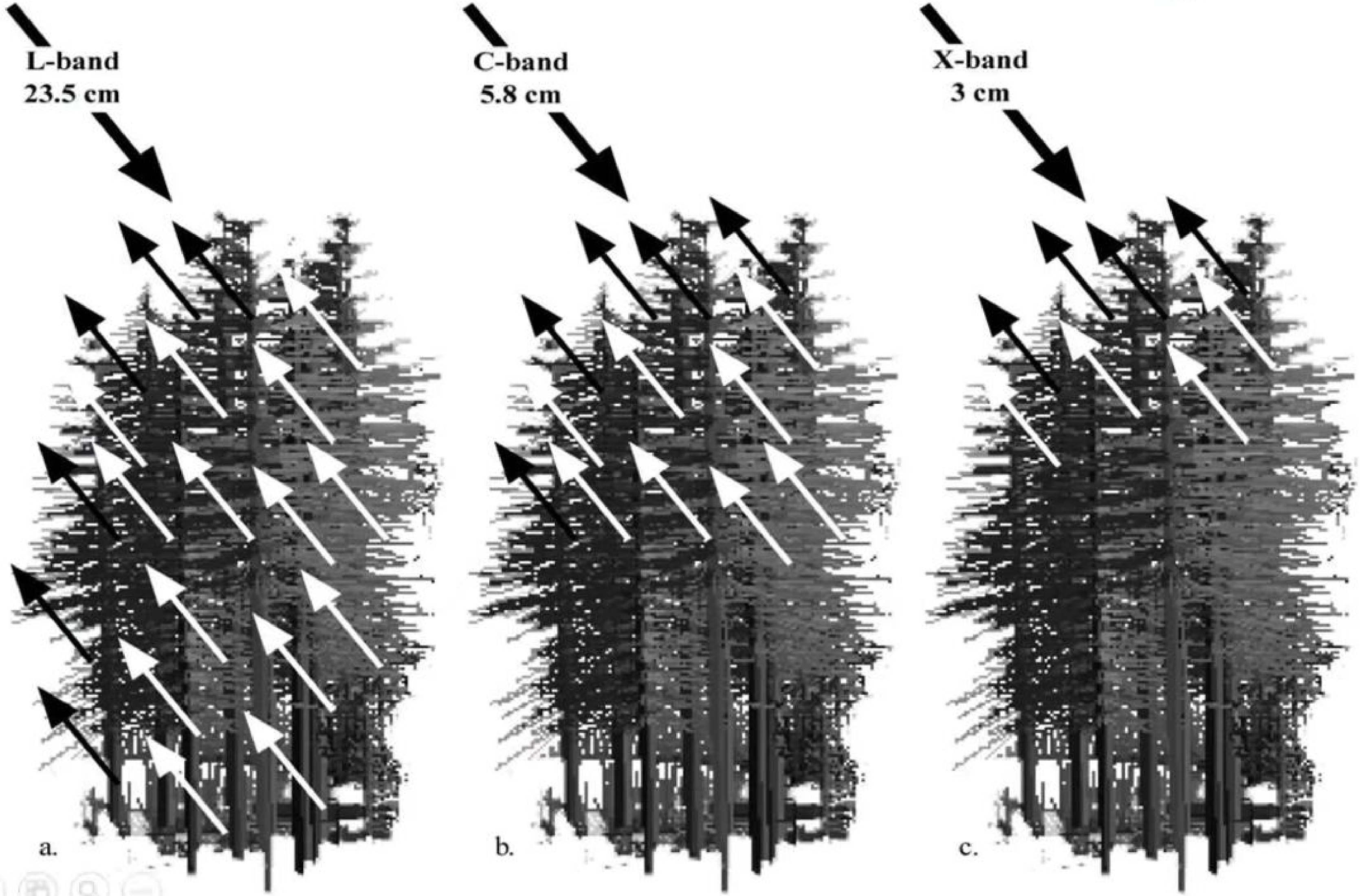


- **Flooded Soil: Radar is specularly reflected off the water surface, resulting in low backscattered intensity. The flooded area appears dark in the SAR image.**



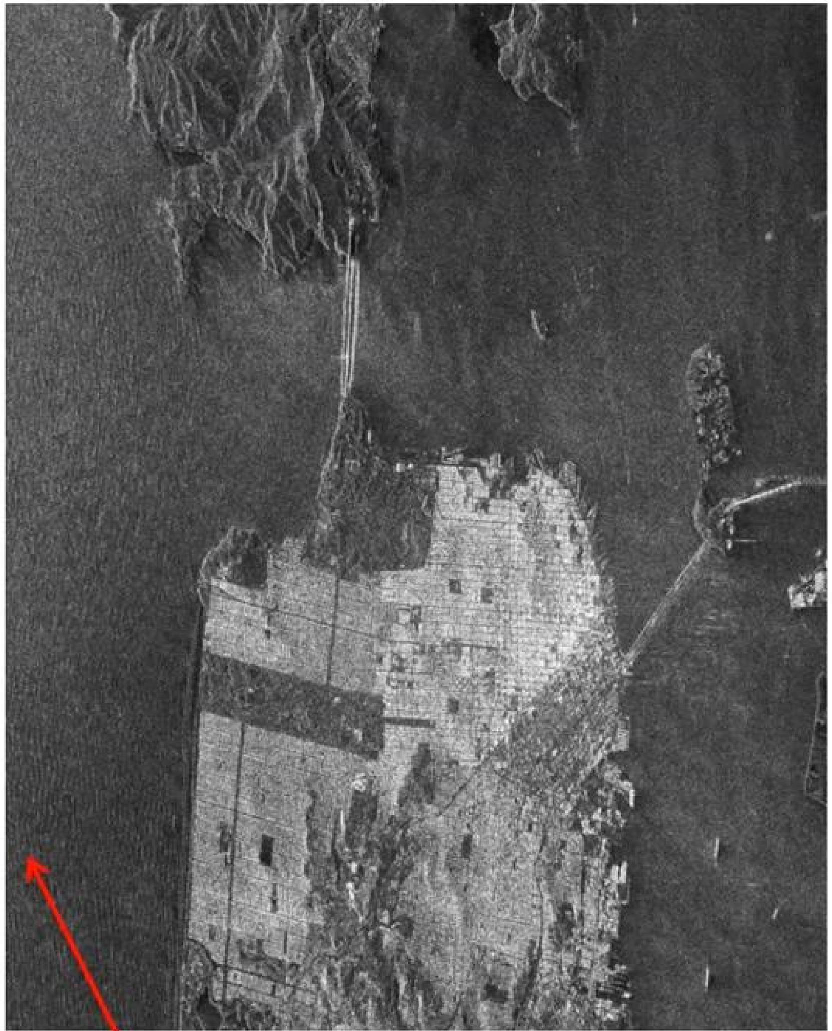
http://www.crisp.nus.edu.sg/~research/tutorial/sar_int.htm

Response of a Pine Forest Stand To X-, C- and L-band Microwave Energy



Complex SAR Image

SAR image pixel is associated with a small area of the Earth's surface (called a resolution cell). Each pixel gives a complex number that carries amplitude and phase information about the microwave field backscattered by all the scatterers (rocks, vegetation, buildings etc.) within the corresponding resolution cell projected on the ground.



(0.587161,-0.356258)

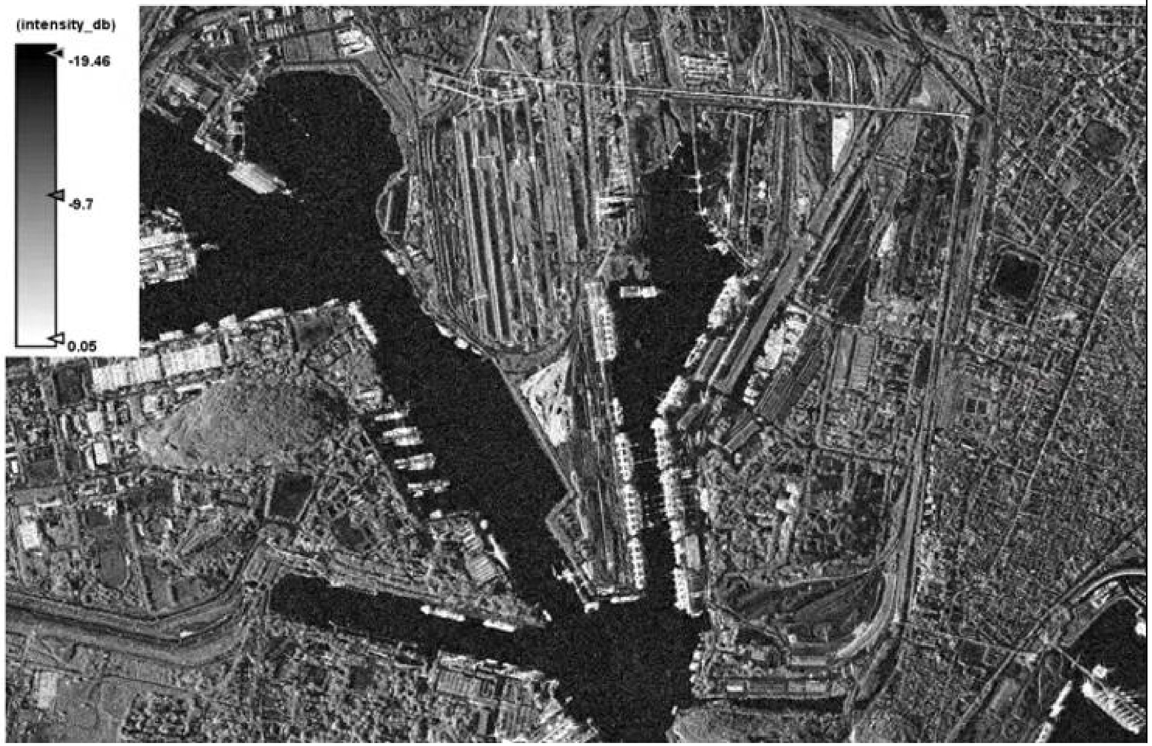
RADARSAT-2 SLC data for San Francisco area (HH Channel)

Speckle

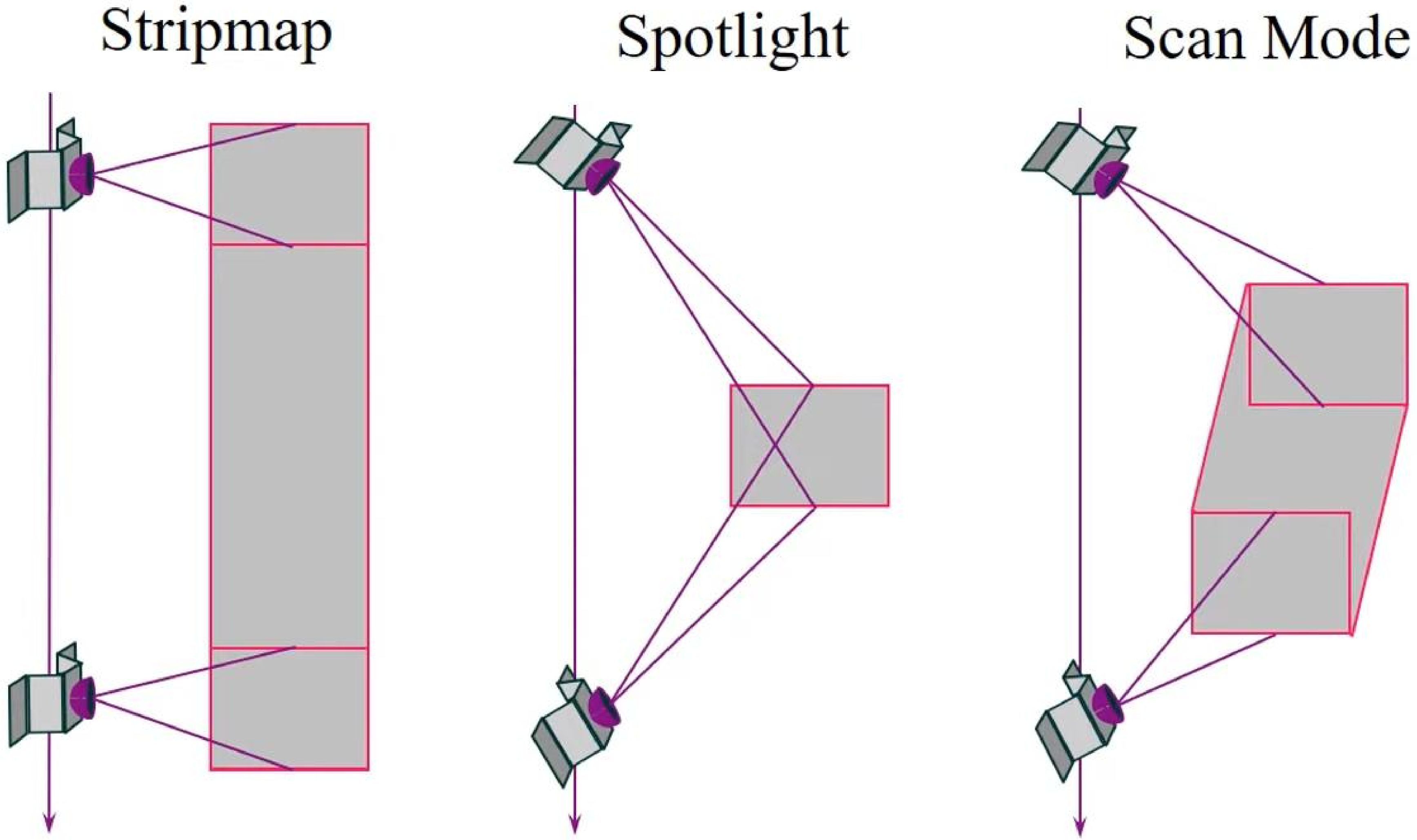
A SAR resolution cell generally contains a large number of scatterers and in comparison to the wavelength this resolution cell appears very large. The returned echo from scatterers is coherently summed to obtain the phase and brightness of the resolution cell. Sometimes due to a very strong reflector at a particular alignment or due to the coherent sum of all the various responses (due to large number of scattereres), the resolution cell shows a brightness value which is much higher than the actual brightness caused by the object. This unexpected bright value of resolution cell appears as speckle on SAR image.

Before speckle filtering

After speckle filtering



SAR Modes

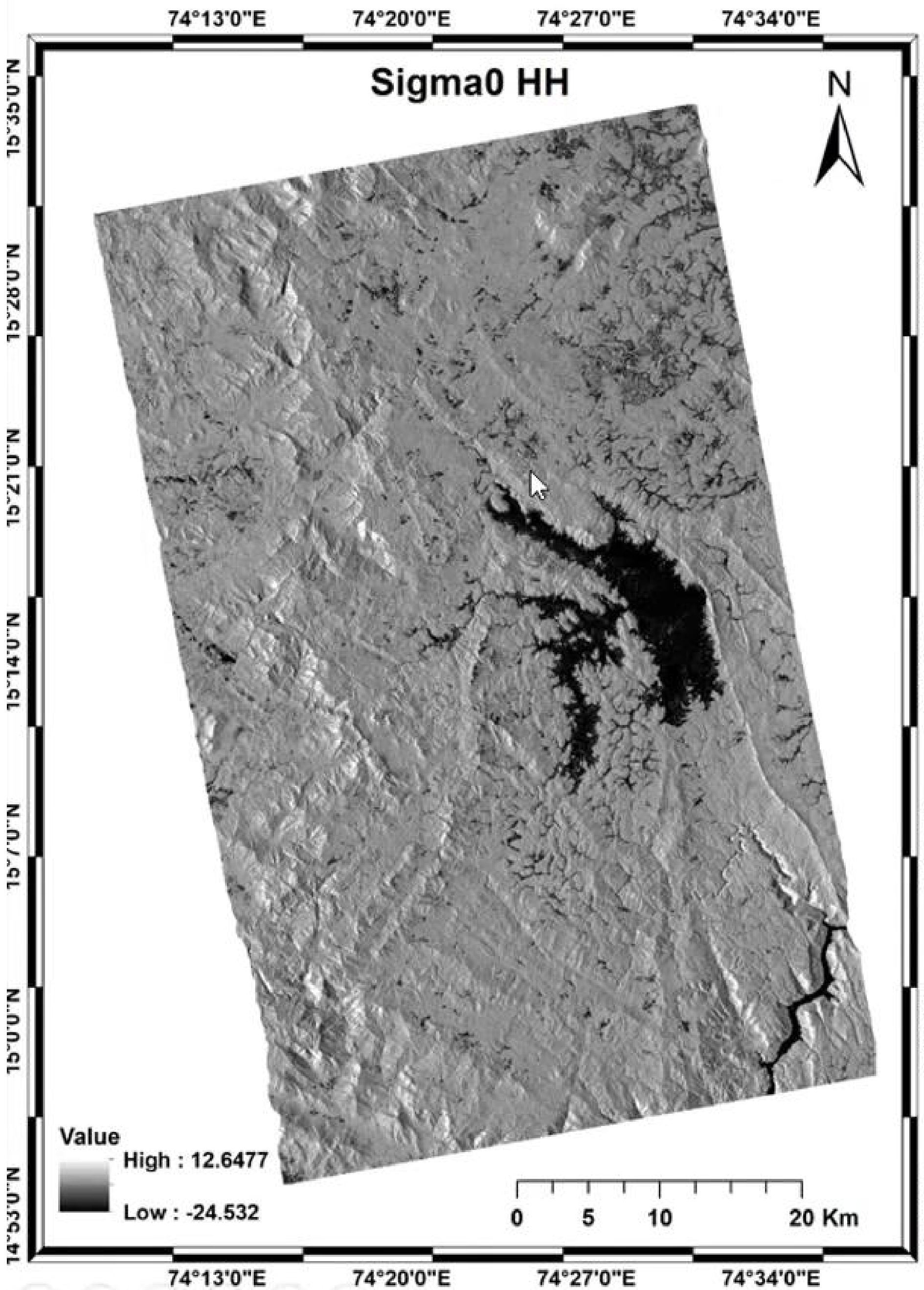


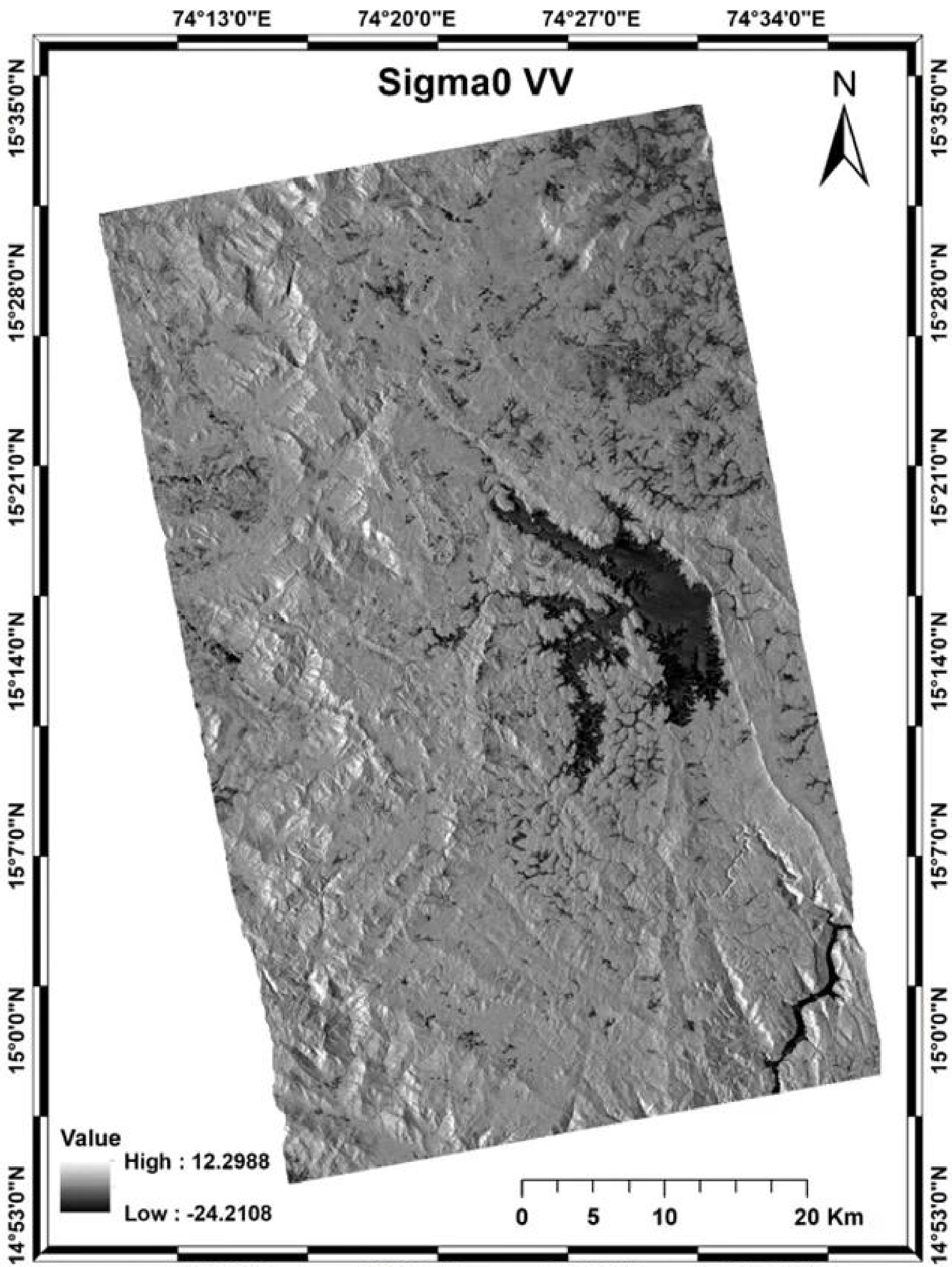
SAR Data Format

- Raw Data
- SLC Data
- Multi-look Data
- Geocoded Data
- Polarimetric Data

Quad-pol SAR

ALOS-2 PALSAR-2 data for the Yellapur Forest





Quad-pol SAR

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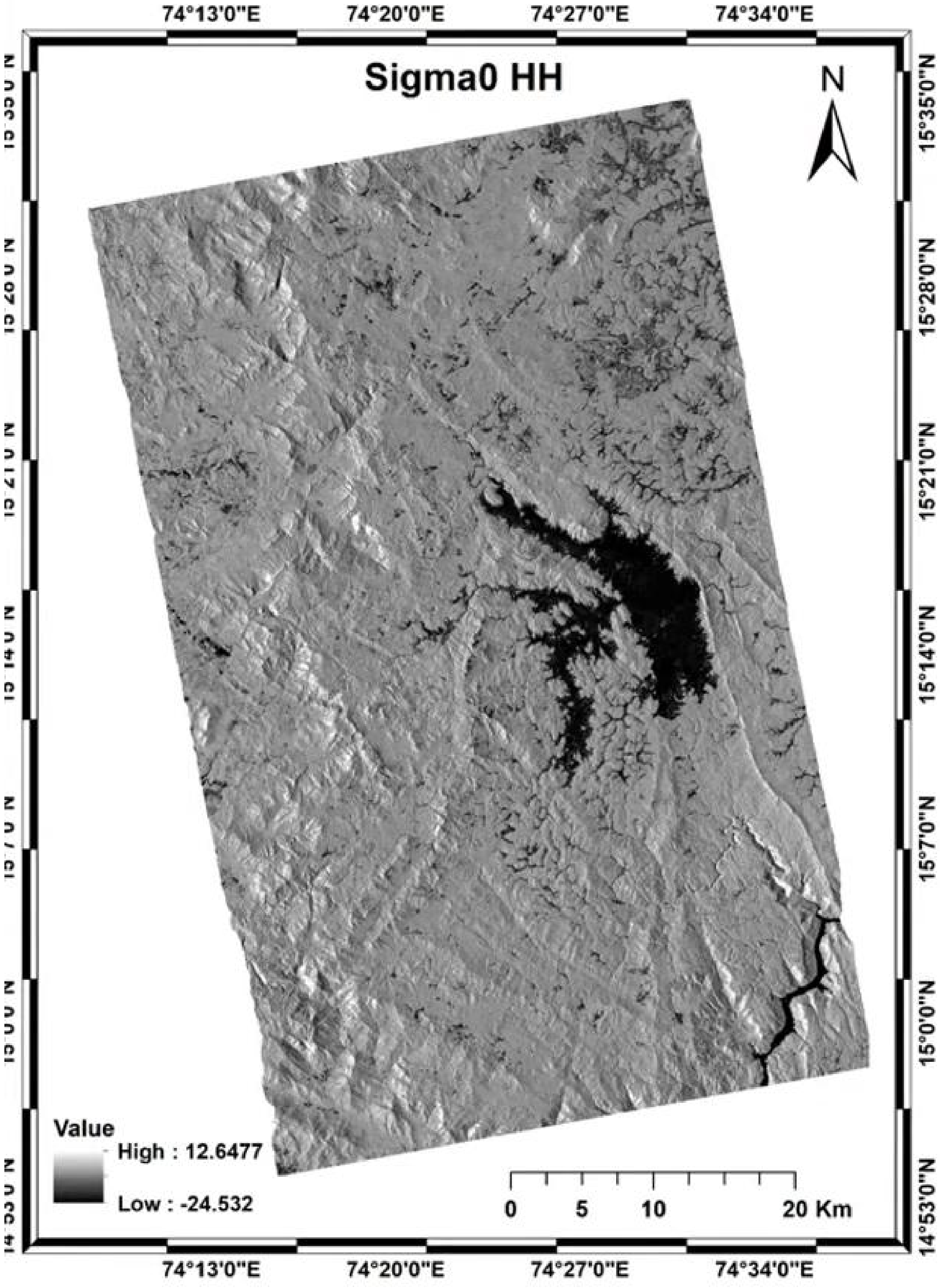

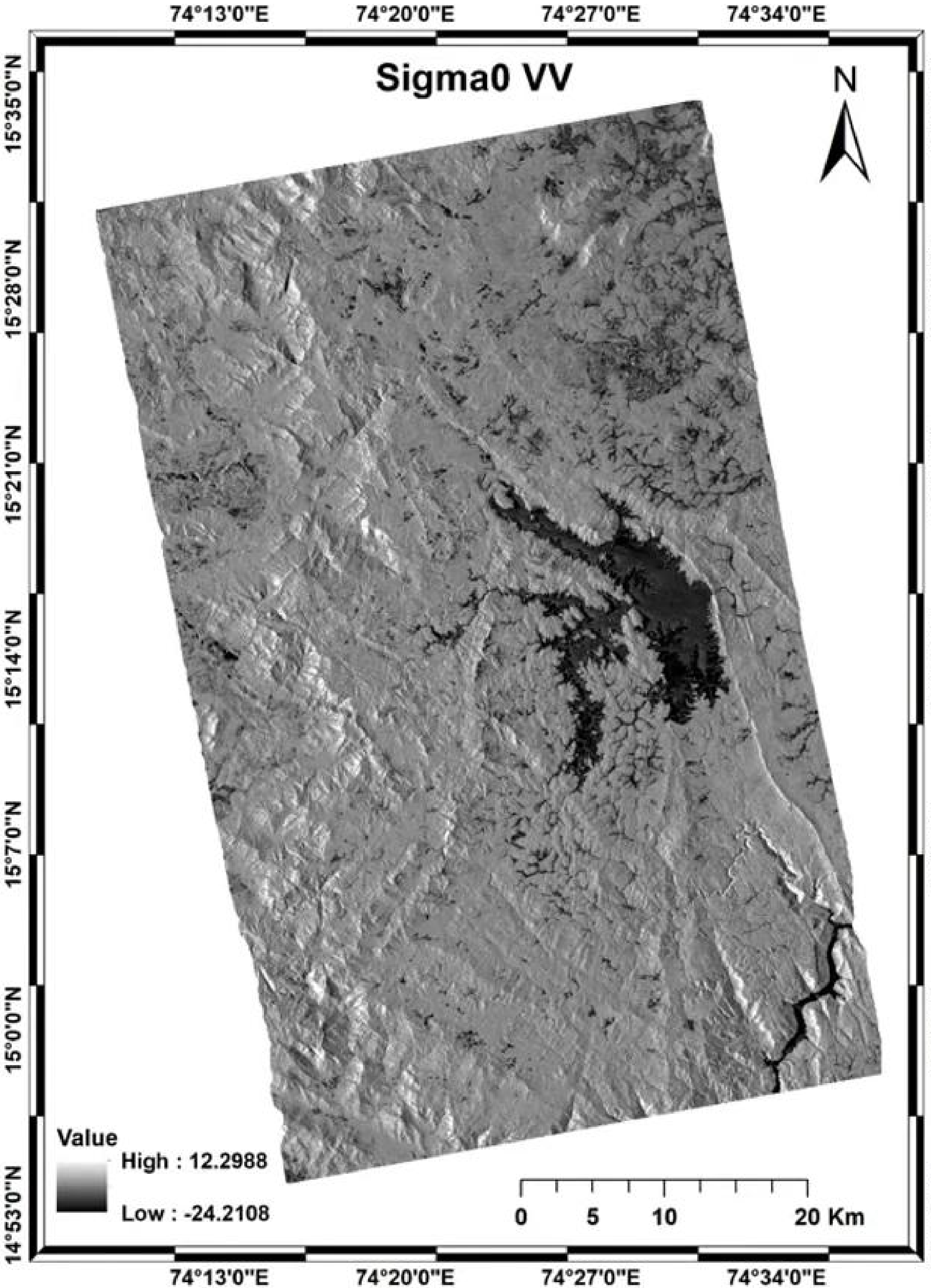

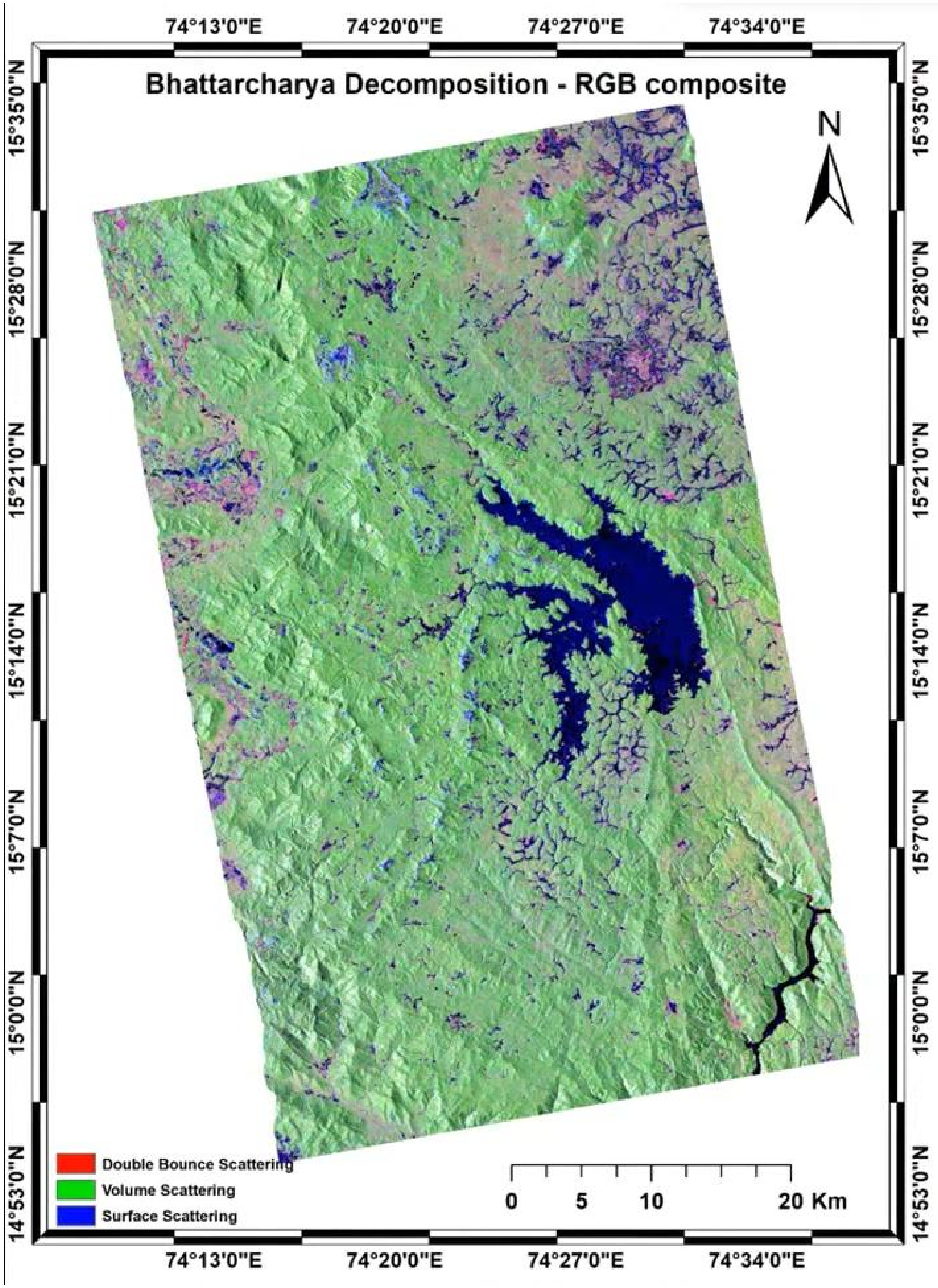

Polarimetric Decomposition Model

Advantages of SAR Remote Sensing

- Cloud penetration capability to provide all weather data
- Night vision capability due to active radar sensor
- Sensitivity of SAR signals to structural and dielectric properties of the Earth's objects.
- Polarimetric and interferometric phase to provide precise target information for different applications.

Applications of SAR Remote Sensing

- SAR interferometry for DEM generation;
- SAR interferometry for subsidence monitoring;
- SAR for Cryospheric/glaciological applications;
- SAR for soil moisture content;
- SAR for structural and bio-physical parameters of forest;
- SAR for crop mapping and monitoring;
- SAR for flood control;
- SAR for oil spills monitoring and ship detection.