SYNTHETIC APERTURE RADAR (SAR)

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Outline

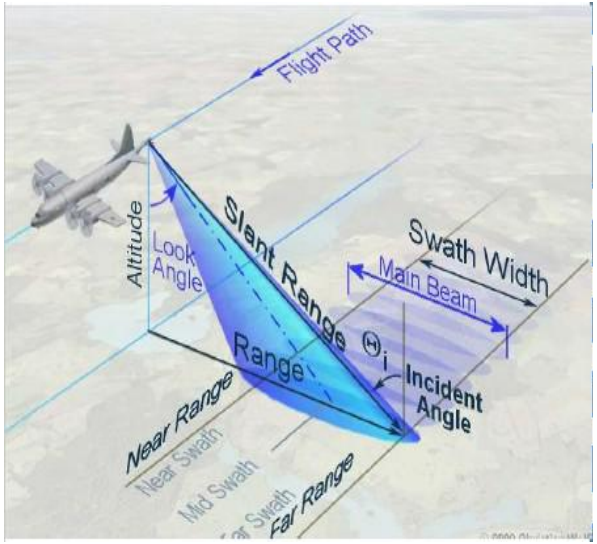
- Why Synthetic Aperture Radar?
- Synthetic Aperture Radar
- How SAR Works?
- SAR Image Formation
- SAR Data Format
- SAR Backscattering
- SAR Imaging Modes
- SAR Applications
- SAR Satellites
- SAR Processing Tools

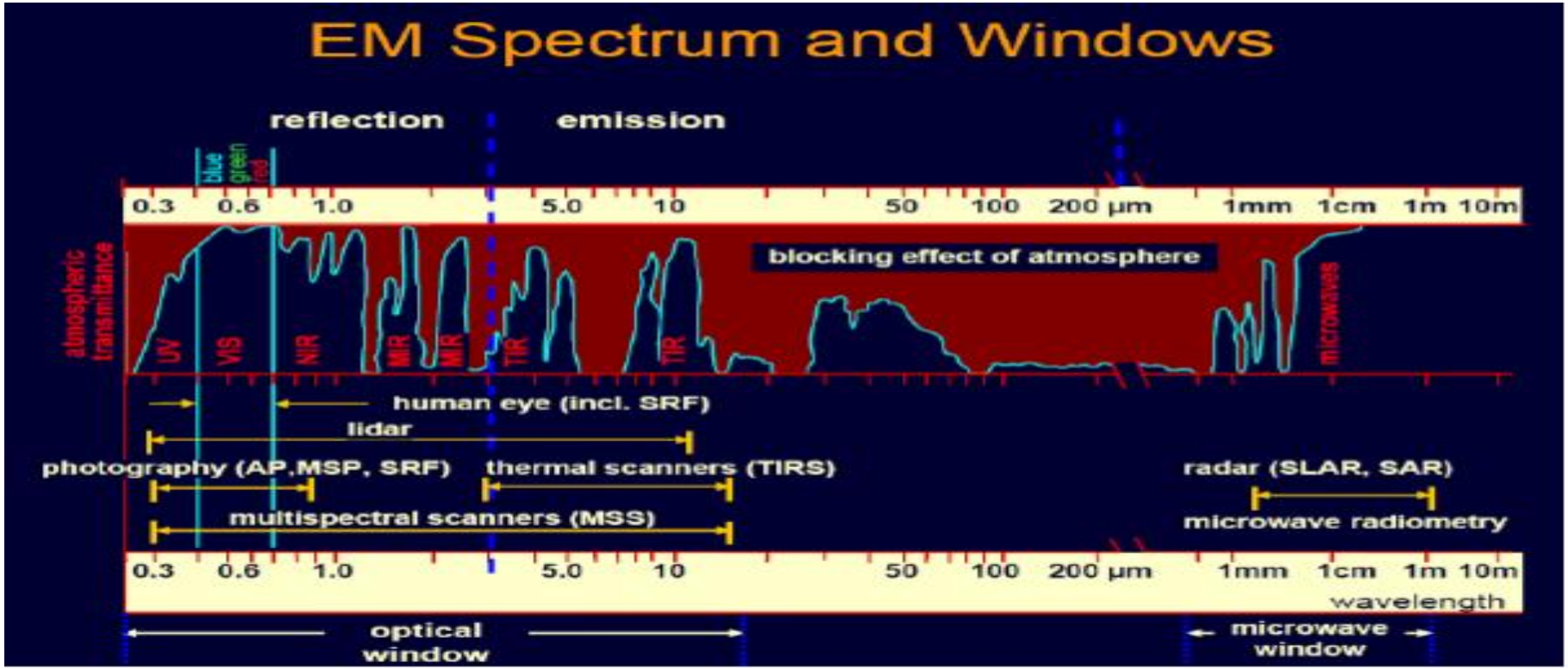
Why Synthetic Aperture Radar (SAR)?

- High resolution capability
- Weather independent
- Day & night imaging capability
- complementary to optical systems
- polarization signature can be exploited (physical structure, dielectric constant)

Synthetic Aperture Radar

- A Synthetic Aperture Radar (SAR), or SAR, is airborne or spaceborne side looking radar system which utilizes the flight path of the platform to generate high-resolution remote sensing image.



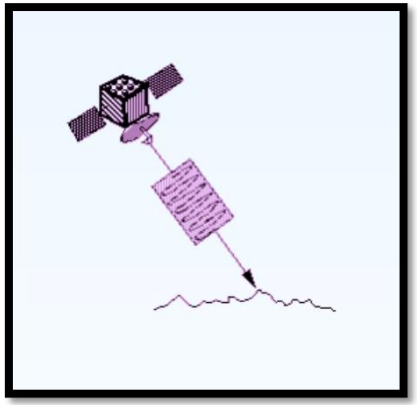


SAR operates in the Microwave section of the EM spectrum.

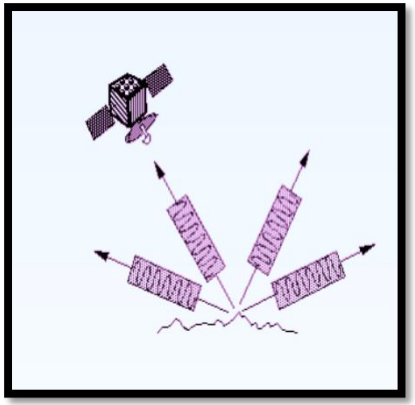
Commonly used frequency Bands

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

How SAR Works?



(Transmit Signal)



(Back Scattering)

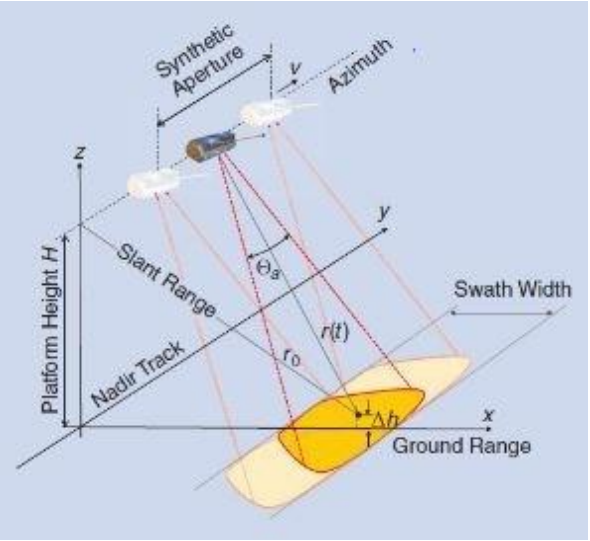
- By measuring the time delay between the transmission of a pulse and the reception of the backscattered "echo" from different targets, their distance from the radar and thus their location can be determined.

SAR Image Formation
SAR Data Format
SAR Backscattering
SAR Imaging Modes

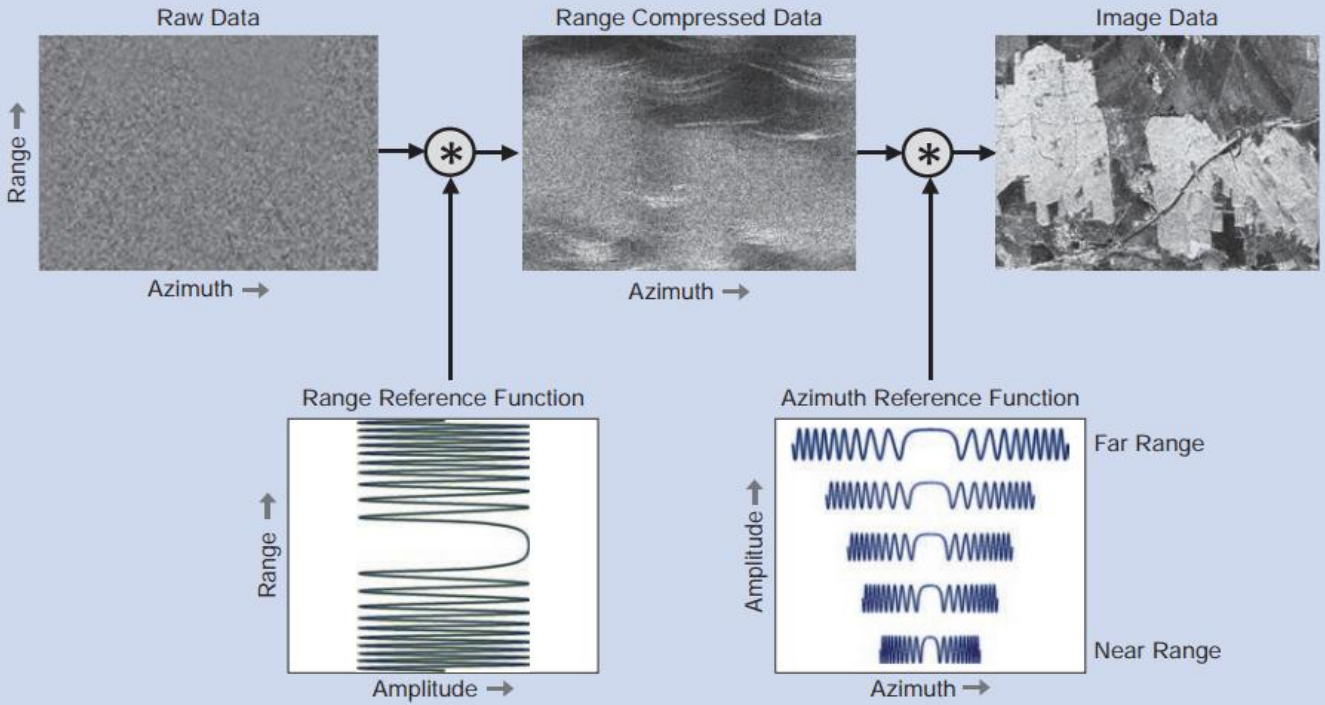
SAR Image Formation

SAR Image Formation

- Typically, Synthetic Aperture Radar (**SAR**) produces a two-dimensional (2-D) **image**. One dimension in the **image** is called range and the other dimension is called azimuth and is perpendicular to range.



SAR Image Formation



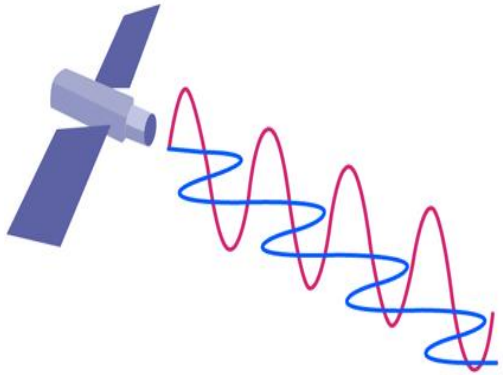
SAR Data Format

SAR Data Format

- **RAW Data:** SAR signal reflected from one single point is spread along both azimuth and range. Signal data cannot be viewed as an image.
- **Single Look Complex (SLC) Data** : Each pixel gives a complex number that carries amplitude and phase information about the microwave field backscattered.
- **Multilook Data:** Due to slant near-range appear compressed relative to far-range. Multilooking is the process in which square pixels are generated.
- **Geocoded Data:** Reference the latitude and longitude
- **Polarimetric Data**

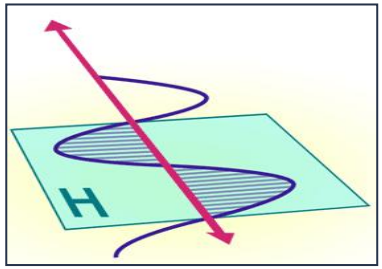
Types of Polarization

- **Single polarization or Co-Polarised :** The radar system operates with the same polarization for transmitting and receiving the signal. **(HH or VV)**
- **Cross polarization :** A different polarization is used to transmit and receive the signal. **(HV or VH)**
- **Dual polarization :** The radar system operates with one polarization to transmit the signal and both polarizations simultaneously to receive the signal.
- **Quad polarization :** H and V polarizations are used for alternate pulses to transmit the signal and with both simultaneously to receive the signal.

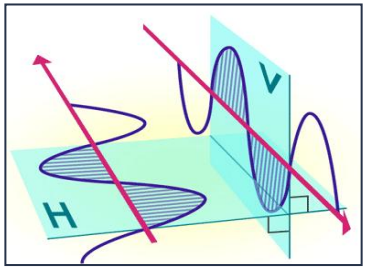


Horizontally (blue) and Vertically (red) polarized waves.

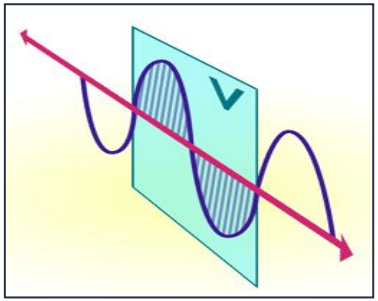
Single & Cross Polarization



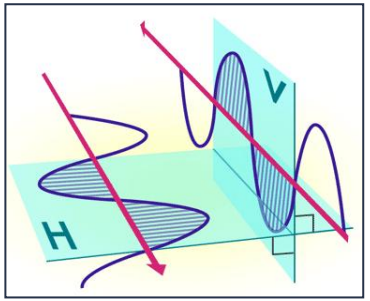
(a)
HH = Horizontal Transmit,
Horizontal Receive



(c)
HV = Horizontal Transmit,
Vertical Receive



(b)
VV = Vertical Transmit,
Vertical Receive



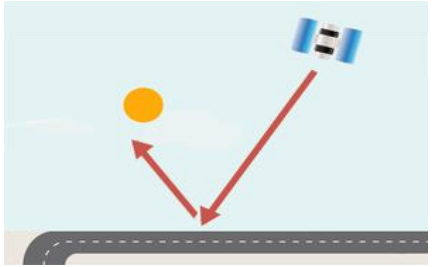
(d)
VH = Vertical Transmit,
Horizontal Receive

SAR Backscattering

SAR Backscattering

- **Single Bounce** or rough surface scattering
- **Double Bounce** or corner reflection
- **Volume Scattering**, which can also be multipath propagation

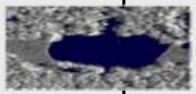
Single Bounce

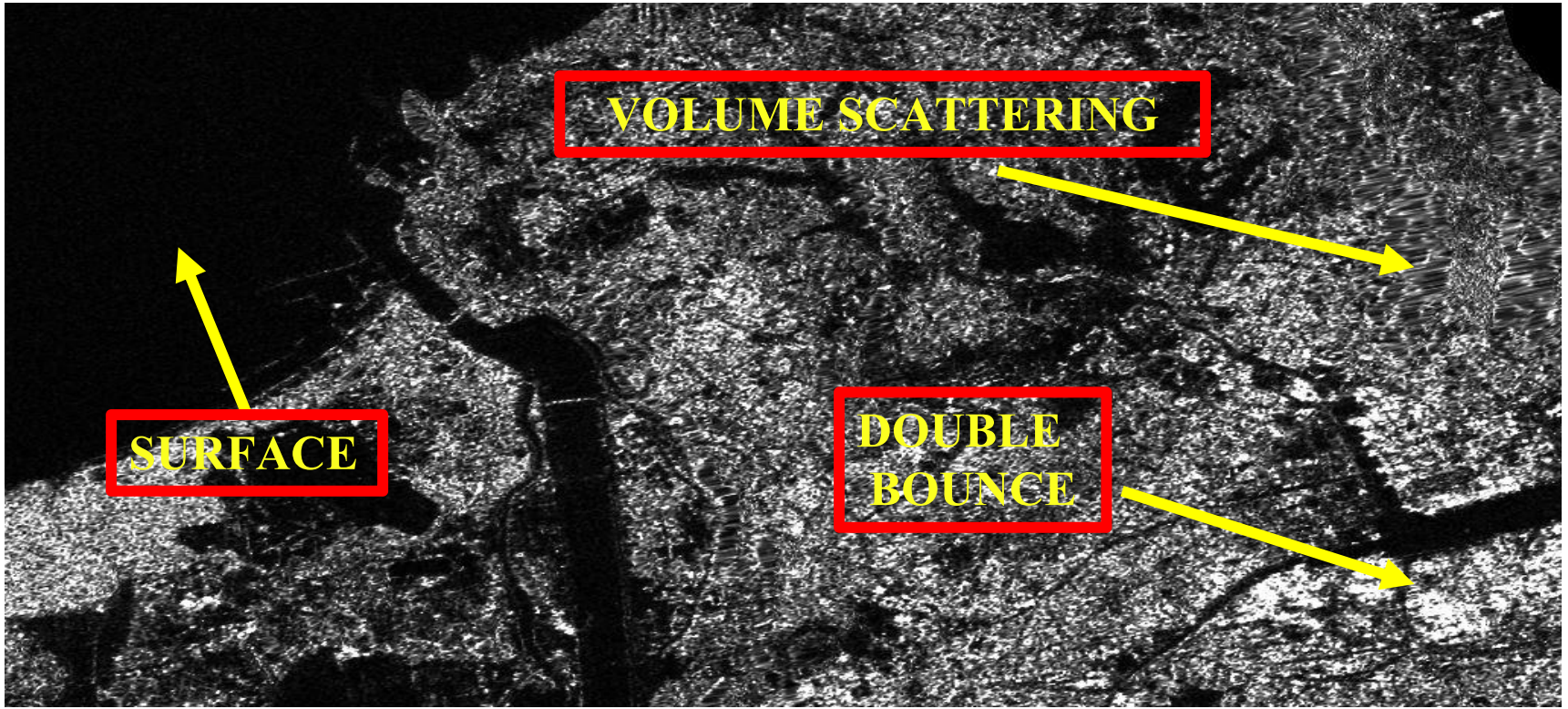


Double Bounce

Volume Scattering

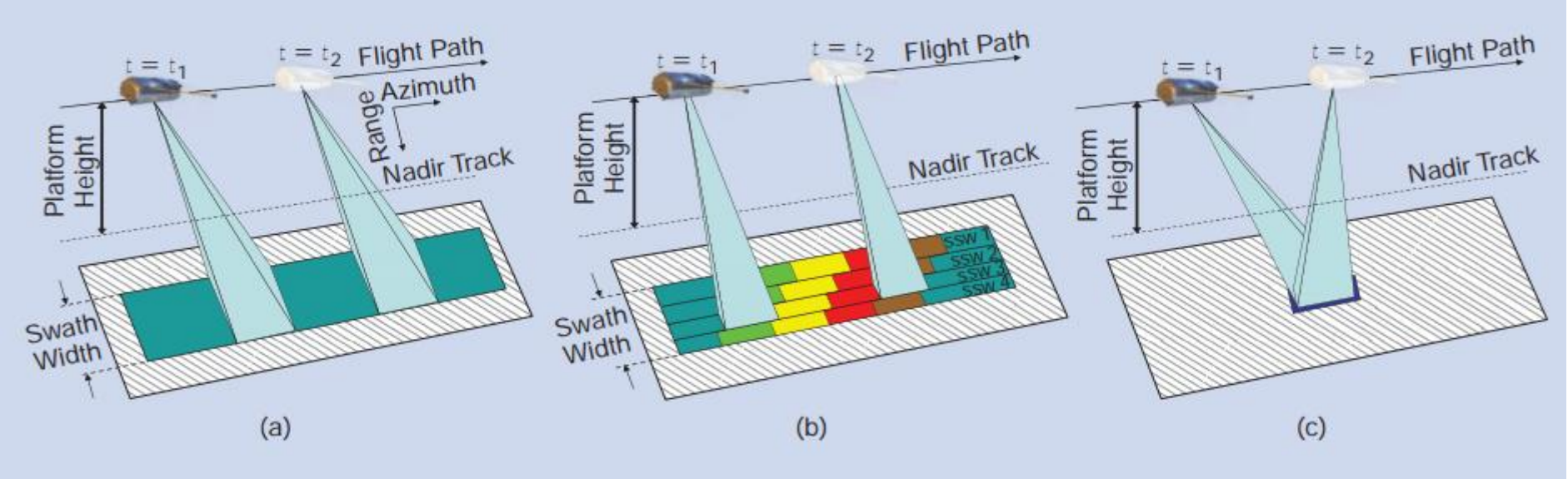
Backscattering Coefficient

Levels of Radar backscatter		Typical scenario
• Very high backscatter (above -5 dB)		Man-Made objects (urban) Terrain Slopes towards radar very rough surface radar looking very steep
• High backscatter (-10 dB to 0 dB)		rough surface dense vegetation (forest)
• Moderate backscatter (-20 to -10 dB)		medium level of vegetation agricultural crops moderately rough surfaces
• Low backscatter (below -20 dB)		smooth surface calm water, road very dry terrain (sand)


VOLUME SCATTERING
SURFACE
DOUBLE BOUNCE

SAR Imaging Modes

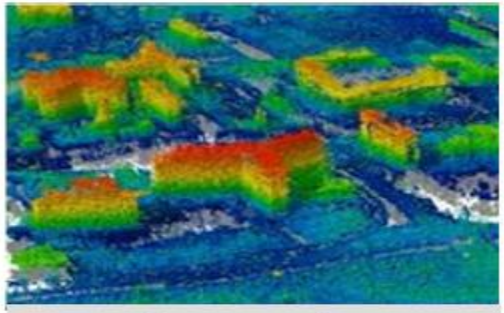
SAR Imaging Modes



(a) Stripmap (b) ScanSAR (c) Spotlight

SAR Applications

3D Mapping
(Digital Elevation Model)



Tomography
(Urban Mapping)

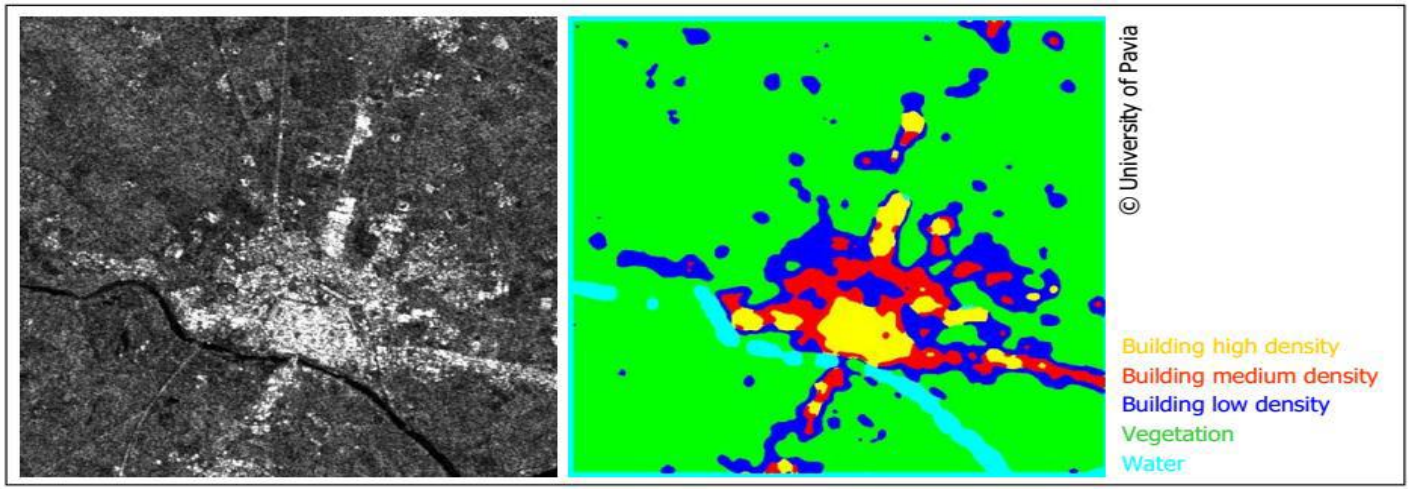
- Topography (DEM generation with interferometry)
- Oceanography (wave spectra, wind speed, ocean currents)
- Glaciology (snow wetness, snow water equivalent, glacier monitoring)
- Agriculture (crop classification and monitoring, soil moisture)
- Geology (terrain discrimination, subsurface imaging)
- Forestry (forest height, biomass, deforestation)
- Moving Target Indication (MTI)
- Volcano and earthquake monitoring (differential interferometry)
- Environment monitoring (oil spills, flooding, urban growth, global change)
- Military surveillance and reconnaissance (strategic policy, tactical assessment)

Applications of SAR in Urban Studies

- Urban Mapping / Urban Sprawl /Urban Land Cover Mapping
- Urban Regional Plan /Development/ Implementation Plan
- Urban Infrastructure
- Urban DEM
- Urban Surface Water Bodies / Parks /Urban Forest
- Urban Change Detection
- Urban Disasters: Flood; Earth Quake; Subsidence; Land Slides

Urban Mapping / Urban Sprawl /Urban Land Cover Mapping

- Urban areas are difficult to analyse, primarily due to many different land cover type(e.g streets, buildings, parks, etc.),each of which have their own shape, geometry and dimension characteristics.

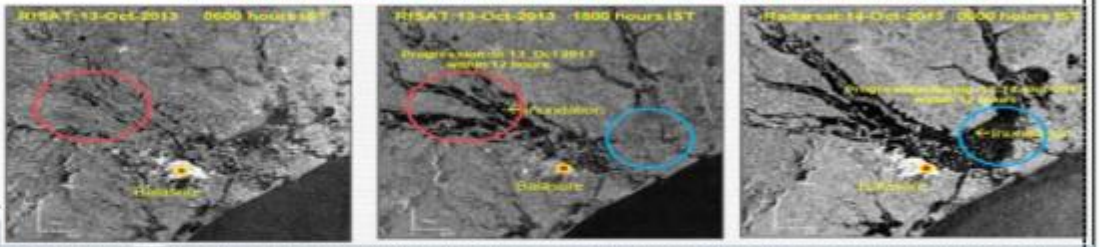


Urban/Non-urban: texture analysis approach (i.e. A technique that take into account of the spatial relationship between neighbouring pixels.)The extracted features are finally classified using supervised non-parametric classifiers, such as the Fuzzy Artmap

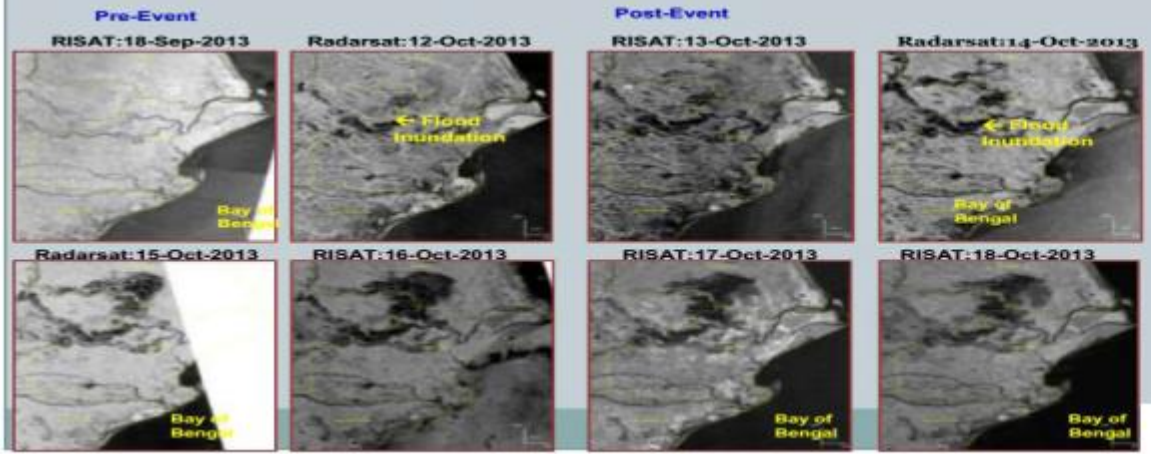
Urban Disasters

- A cyclonic storm "Phailin" made landfall at around 9 pm on 12th October 2013 near the coast of Gopalpur in Ganjam district inundating vast stretches.
- DSC kept a close watch and RISAT-1 data was planned over the affected areas.
- Combination of RISAT-1 data along with other satellite data helped in continuous monitoring of the flood event.

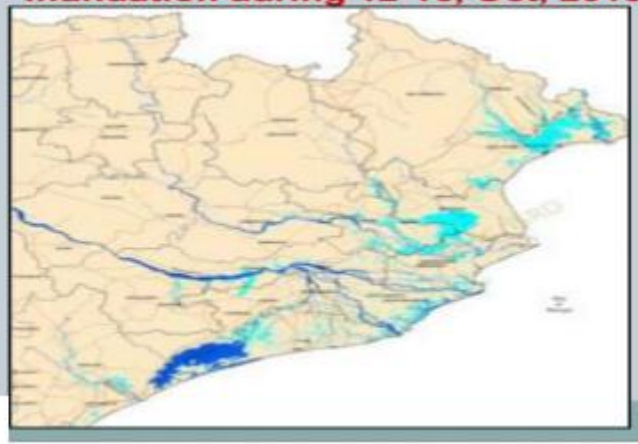
Flood progression within 12 hrs as captured by RISAT & RADARSAT



Monitoring of the event



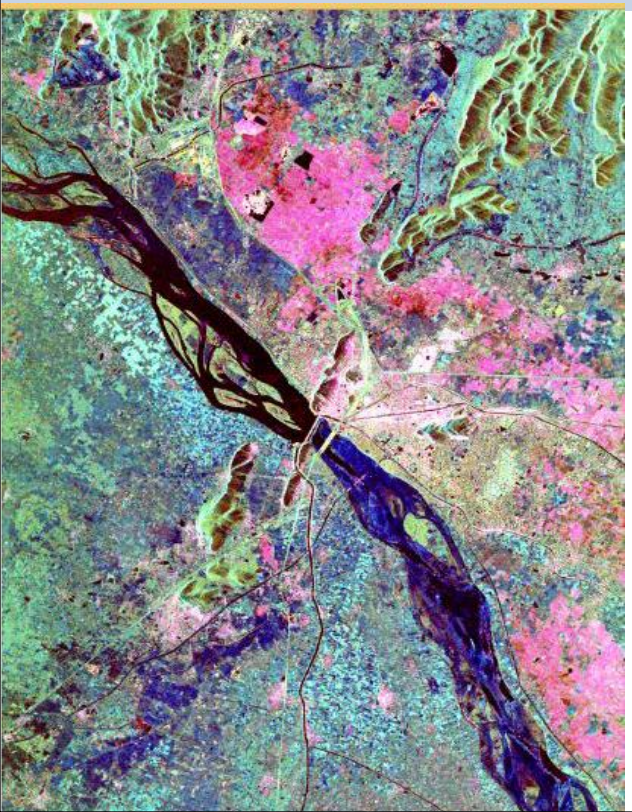
Cumulative Flood Map
Inundation during 12-16, Oct, 2013



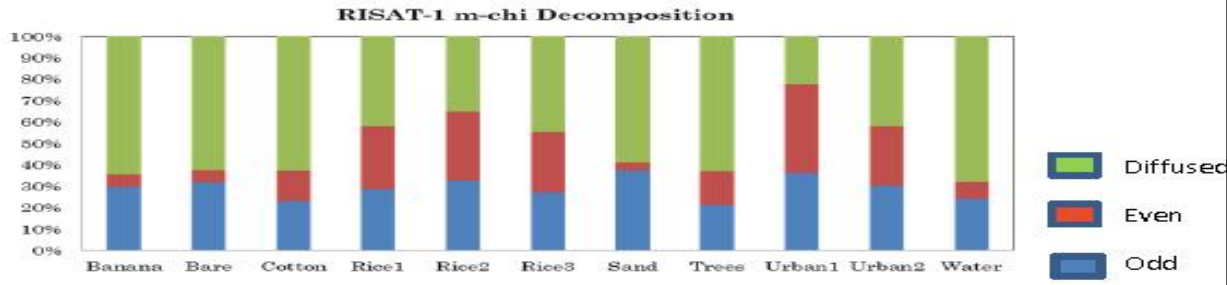
Applications of SAR in Agriculture

- Monitoring of Agricultural Land Use Change (Cropland expansion, intensification, abandonment, change in crop type and practices)
- Retrieval of bio-physical parameters for use in classification
- Suggest alternative cropping
- Mapping of field tillage and crop residue
- Early warning of harvest shortfalls or abundance
- Provide inputs for crop insurance Provide inputs for crop insurance
- Accurate assessment of current season crop dynamics

RISAT-1 Hybrid Pol Data for Crop Classification



- m-chi Decomposition Image RISAT Decomposition Image RISAT-1 FRS hybrid 1 –pol (RH pol (RH-RV) data RV) data over Godavari Delta
- Red: even ; Green: diffused ; Blue: odd scattering contributions
- Pink colored areas signify paddy areas,cyan colored areas signify denser vegetation and blue colored areas show more of surface scattering(water bodies of fallow areas)
- Scattering contribution of different targets enables an understanding of the the SAR-target interactions and gives an idea of nature of target. Based on this a classification can be done the image.



Scattering contribution of different targets

Applications of SAR in Soil Moisture

- Yields repeatable measurement and area extensive
- Possibility of acquiring global soil moisture
- To compensate for lack of in-situ soil moisture measurement networks
- To better understand climate and climate change
- To cope with consequences of climate change
- To support sustainable water resources management

Dielectric Properties

- Penetration depth depending on
  - Dielectric constant/soil moisture content
  - Wavelength

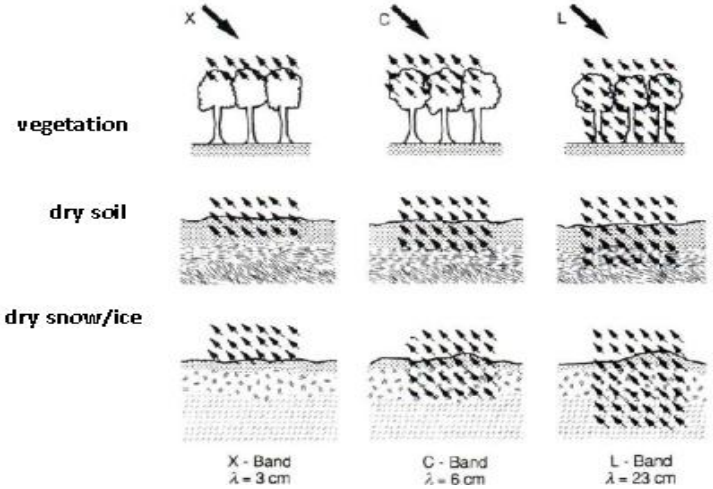
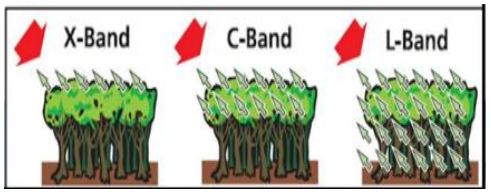


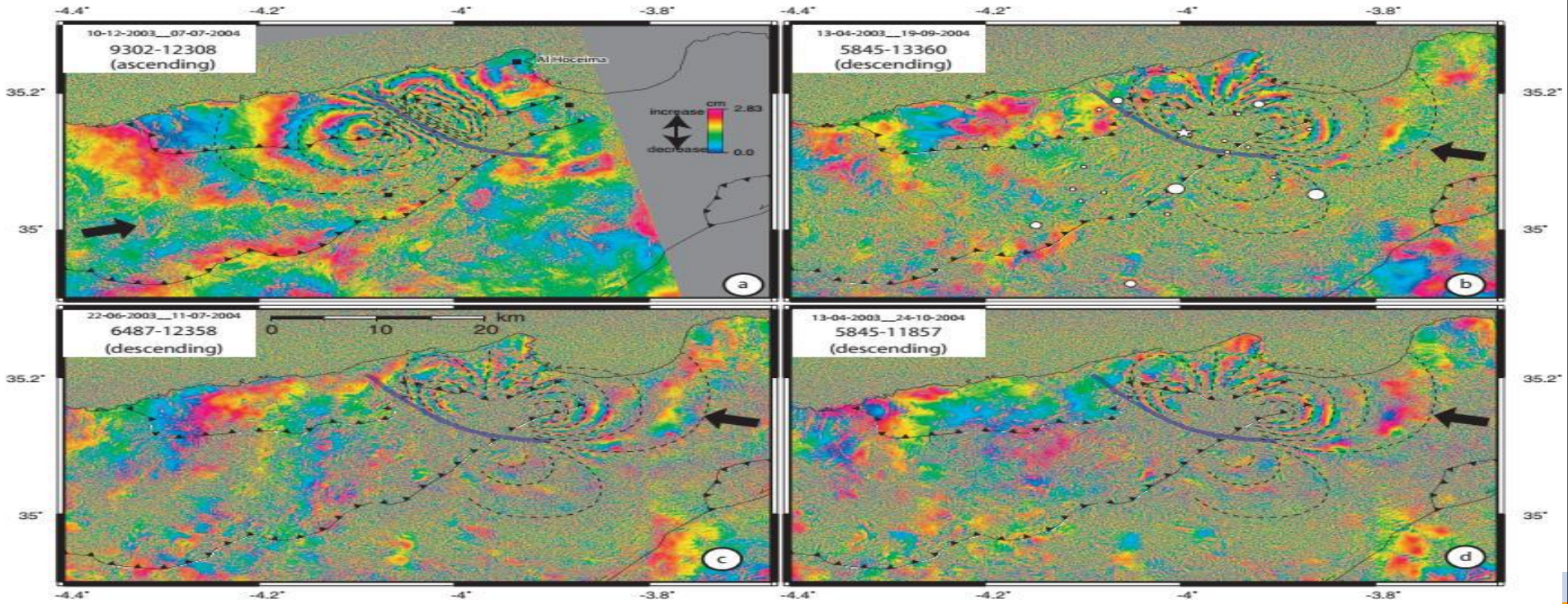
Fig.: Relationship between penetration depth and wavelength (Albertz, 1991)



Applications of SAR in Geoscience

- Structural mapping
- Lithological mapping
- Mapping geomorphological features
- Mineral exploration
- Active fault mapping
- Study of geological disasters: Earthquakes , Volcanoes ,Land Subsidence

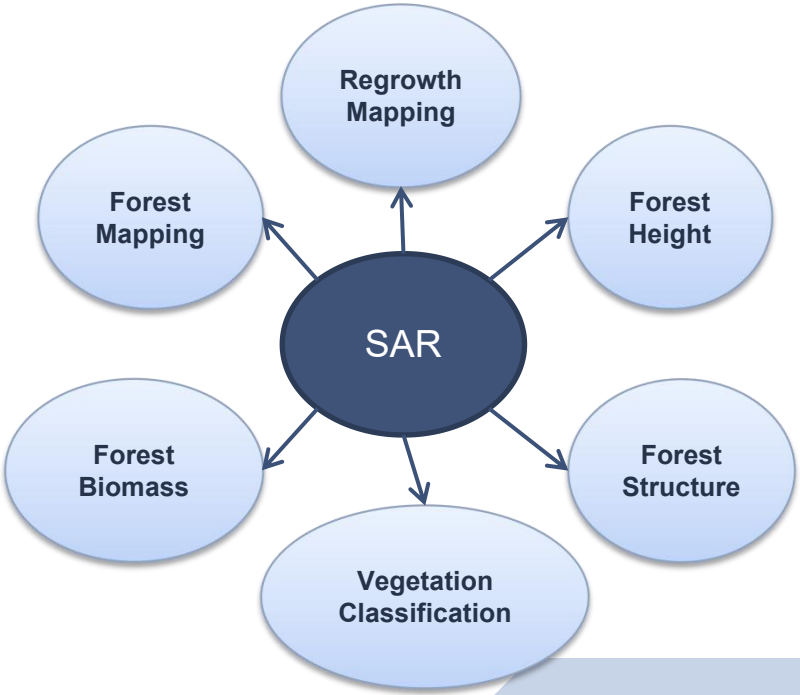
InSAR for fault modelling studies



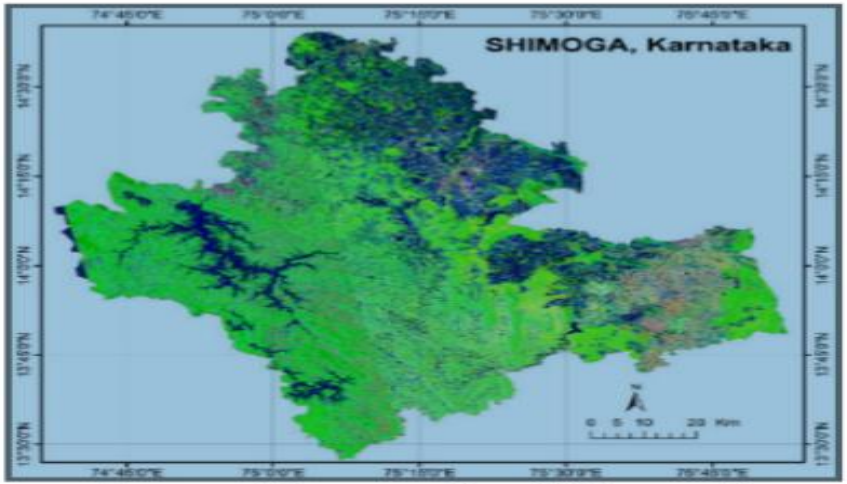
Surface deformation associated with 24 February 2004 Al Hoceima earthquake. Blue line is best model fault and barbed lines are inactive thrust.(Cakir et al.,2006,BSSA)

Applications of SAR in Forestry

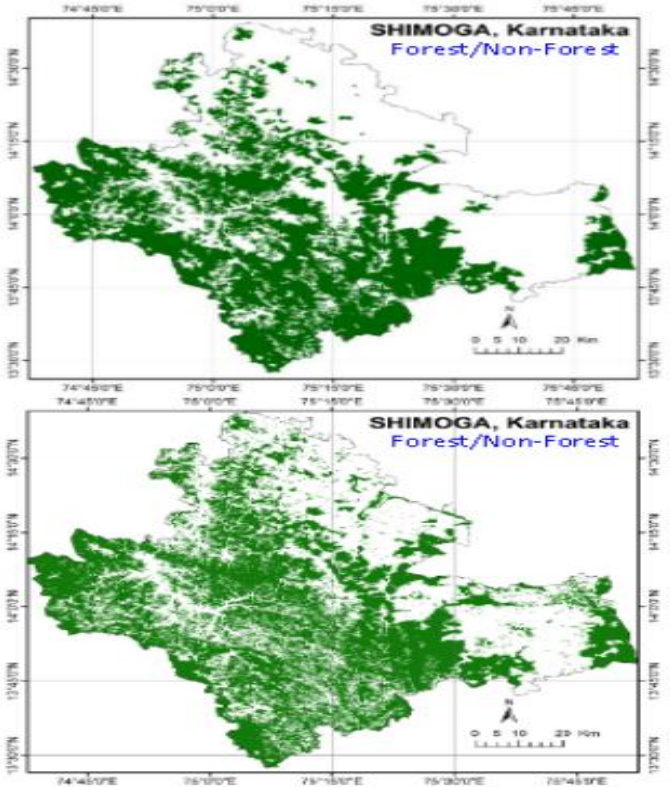
- Amplitude data
  - Forest cover mapping
  - Secondary Forests / Vegetation
- Polarimetric data
  - Vegetation categories within forest
  - Forest Biomass
- Interferometric data
  - Forest Stand height
  - Land cover classification
- Pol-InSAR
  - Forest structure / physiognomy



Extraction of forest cover from Polarimetric SAR Data



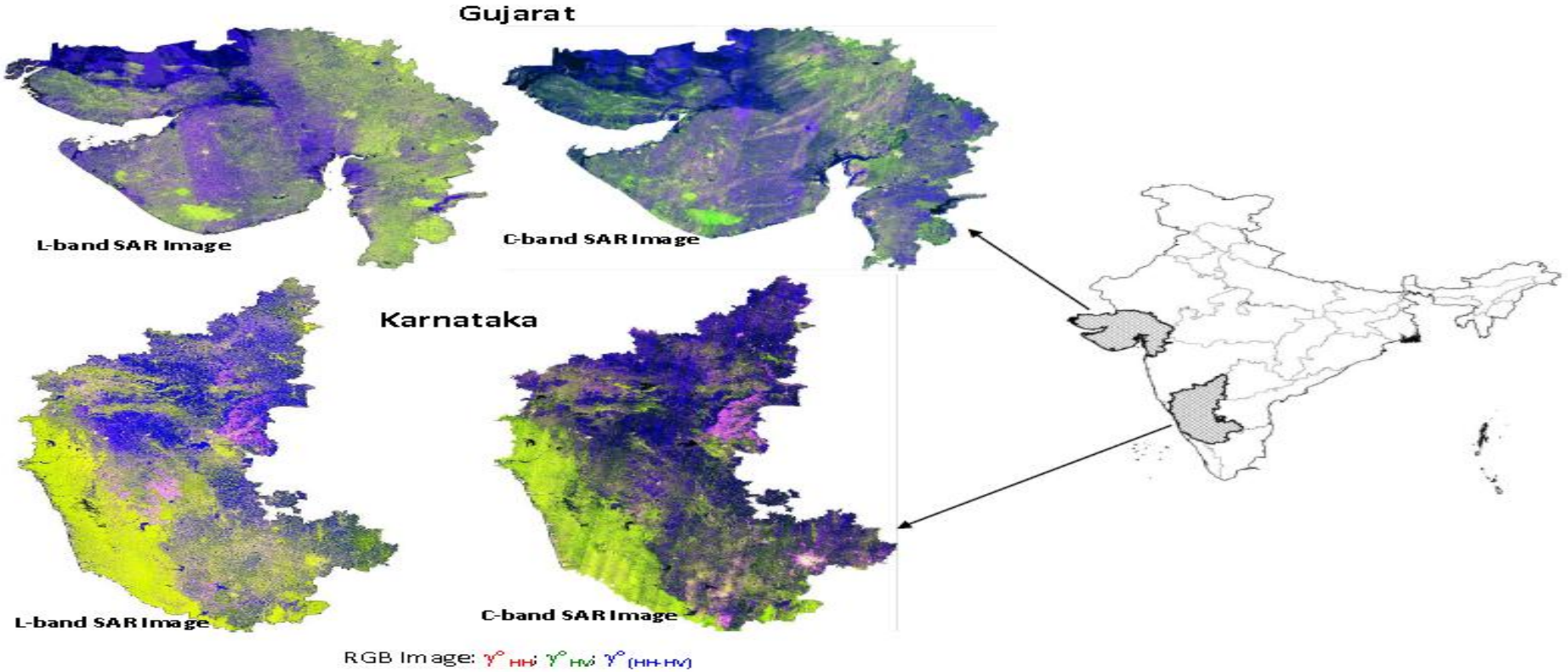
Yamaguchi Decomposition RGB image of ALOS PALSAR-2 Polarimetric data, 2016



ALOS PALSAR-2 Forest / Non-Forest Map, 2016

Forest cover map generated from ALOS PALSAR-2 Polarimetric data, 2016

Estimation of forest above-ground biomass over Gujarat & Karnataka



Estimation of forest above-ground biomass over Gujarat

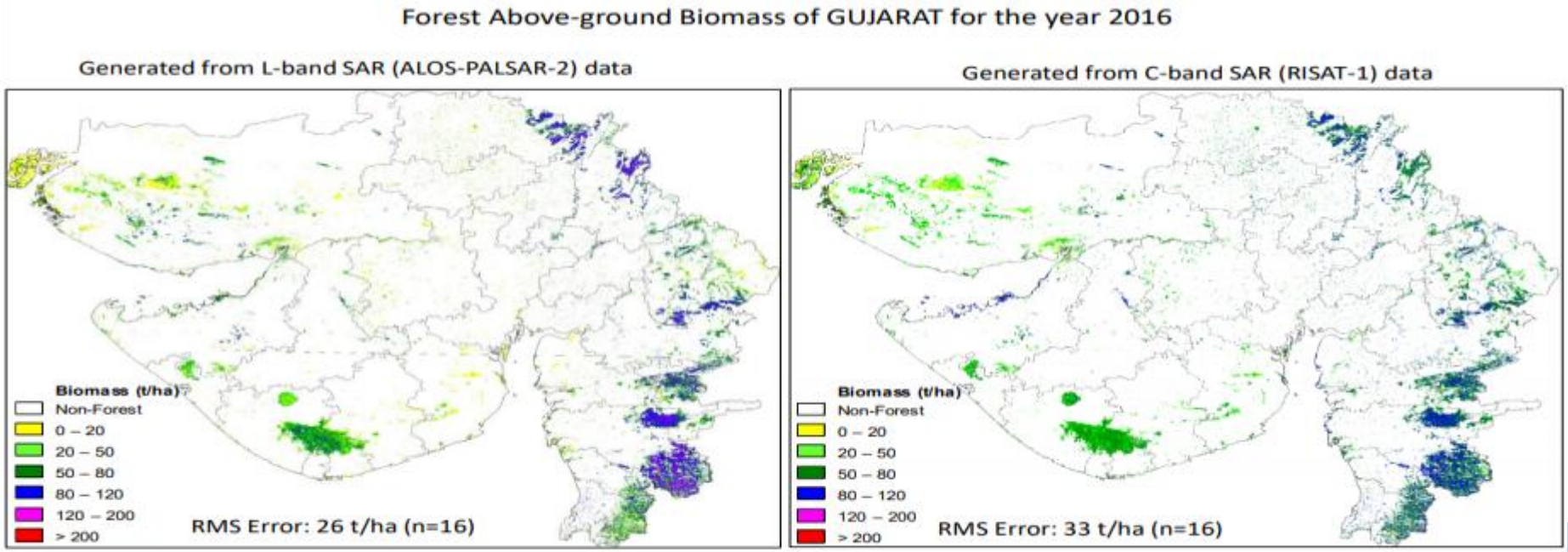
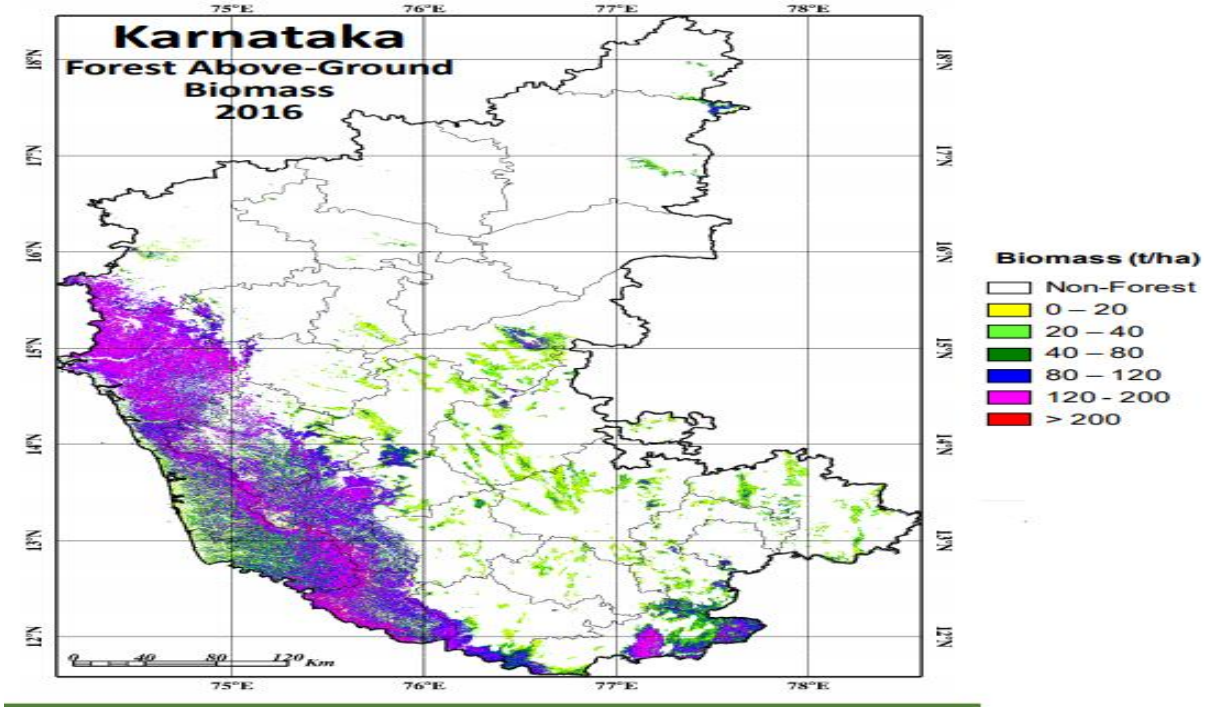


Fig.: Forest aboveground biomass maps (expressed in tons per hectare)of Gujarat generated from (left) L-band (ALOS-PALSAR) and (right) C-band (RISAT-1) SAR data

Estimation of forest above-ground biomass over Karnataka

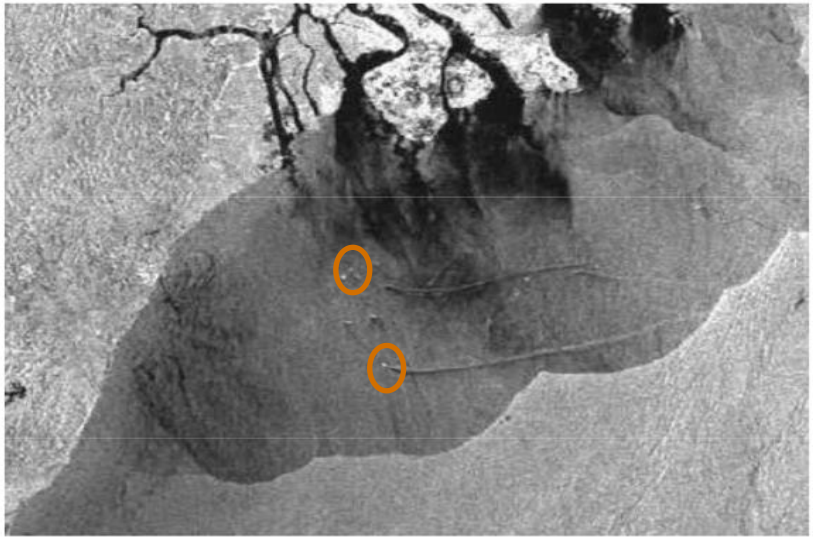


Applications of SAR in Coastal Studies

- Ocean Wave Parameters
- Coastal Bathymetry
- Internal Waves
- Oil Spills
- Ship Detection
- Ocean Currents
- Coastal Inundations

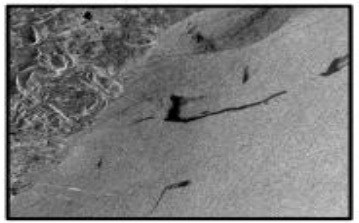
Oil Spill & Ship Detection

Ship Detection

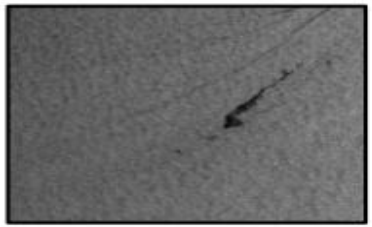


ERS-2 SAR image covers the estuary of the river Kutai in Borneo with its fresh water plume.Inside the plume area are visible several ships (bright spots) together with their turbulent wakes.

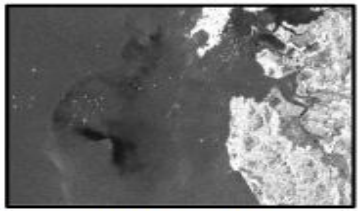
Oil Spill Detection



ERS-1



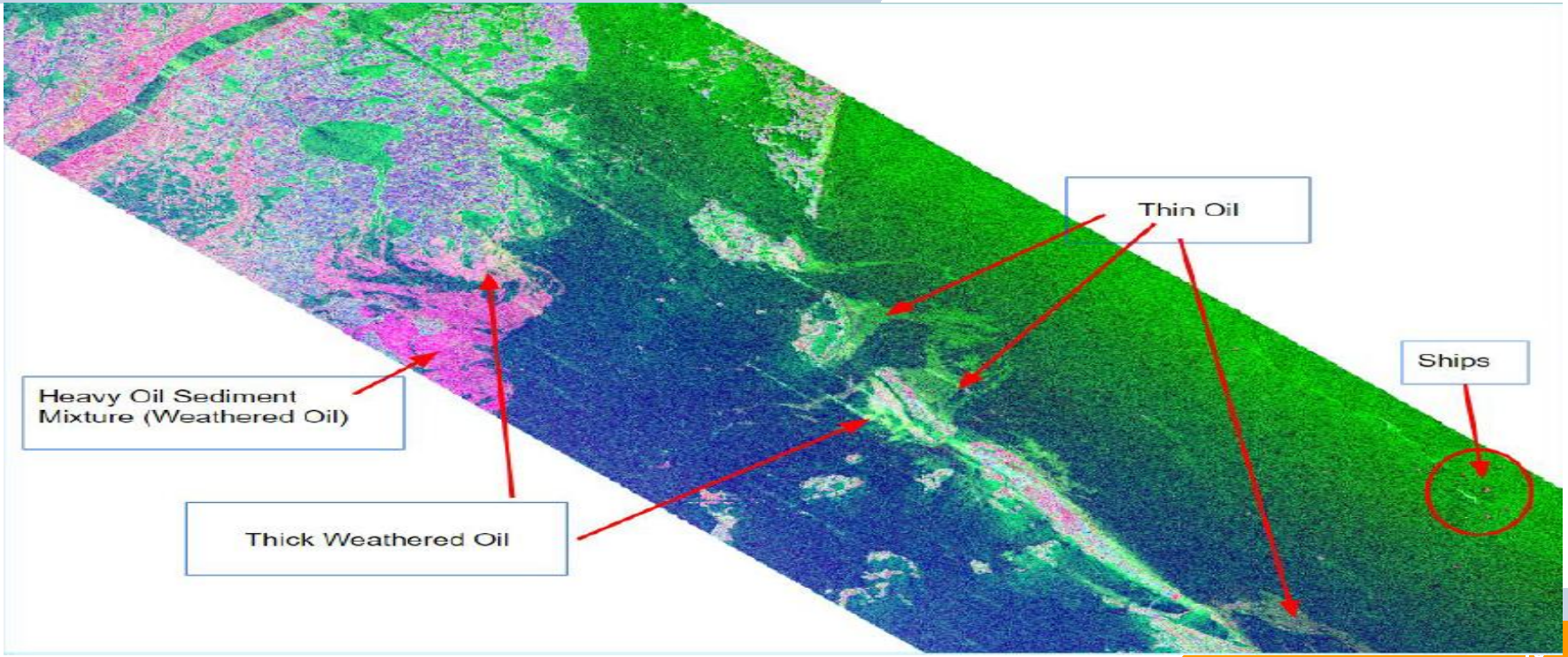
ENVISAT ASAR



ALOS PALSAR

RISAT

Oil Spill & Ship Detection



H/A/Alpha Decomposition, UAVSAR, Full Polarimetric L band (Gulf of Mexico)

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 :June 15, 2007: X-band (Quad-pol)
Tandem-X: June 21, 2010: X-band (Quad-pol)
KOMPSAT-5:August 22, 2013: X-band
Sentinel-1:April 3, 2014:C-Band
ALOS-2:May 24, 2014: L-band (Quad-pol)

Indian SAR Earth Observation Satellites

Radar Imaging Satellite Missions

Sensor	Operation	Band
RISAT-2	April 20, 2009	X-Band
RISAT-1	April 26, 2012	C-Band Hybrid/Dual
NISAR NASA-ISRO SAR Mission	2019-2020	Dual Frequency L-band & S-band
RISAT-1A	----------	C-Band Hybrid Polarimetry
RISAT-3	----------	L-Band Fully /Hybrid Polarimetry

SAR Processing tools

- Envi
- SNAP
- POLSARPro
- Microwave Data Analysis Software (MIDAS): In-house software for MW Data Analysis & Processing (ISRO)

References

[1] P. Mishra, D. Singh, and Y. Yamaguchi, “Land cover classification of palsar images by knowledge based decision tree classier and supervised classifiers based on sar observables," Progress In Electromagnetics Research B, vol. 30, pp. 47-70, 2011.

[2] Xie, Saining, and Zhuowen Tu, "Holistically-nested edge detection," In Proceedings of the IEEE international conference on computer vision, pp. 1395-1403. 2015.

[3] http://www2.geog.ucl.ac.uk/~mdisney/teaching/PPRS/PPRS_7/esa_sar_tutorial.pdf

[4] http://learningzone.rspsoc.org.uk/index.php/Learning-Materials/Radar-Imaging/Image-Interpretation-Polarisation

[5] https://vedas.sac.gov.in/vedas/downloads/ertd/SAR.pdf

[6] https://earth.esa.int/documents/10174/642943/6-LTC2013-SAR-Moreira.pdf

[7] http://www.ijaconline.com/classification-crop-types-using-c-band-sar-data/

THANK YOU