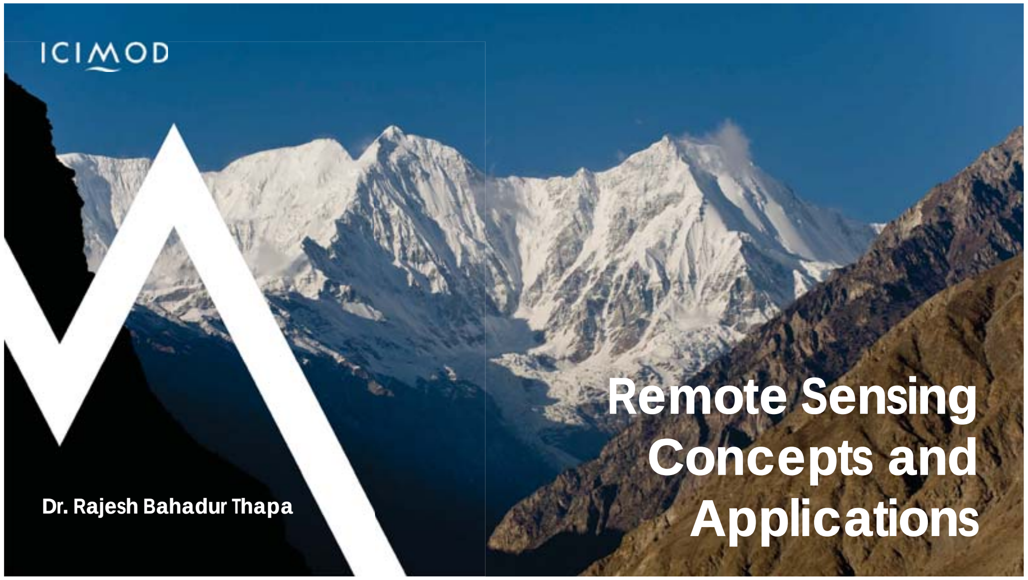

Remote Sensing Concepts and Applications

Dr. Rajesh Bahadur Thapa

BIO Presenter

Dr. Thapa works at ICIMOD and leads the Group on Land Use Land Cover Change and Ecosystem Services, Geospatial Solutions Theme and the Capacity Development Programme of SERVIR-HKH (NASA-USAID) Initiative, MENRIS Regional Programme. His researches focus on monitoring and assessment of terrestrial environments including forest, agriculture, urban, and disasters thematic areas and capacity development. He empowers people to use emerging Earth observation and geospatial technologies for making evidence-based decisions to protect the pulse of the planet.

He is an active member of Group on Earth Observations (GEO) Capacity Development Working Group and has over twenty years work experience across various Asian countries including Japan, Thailand, and the HKH region. Prior to joining ICIMOD, he served at the Japan Aerospace Exploration Agency (JAXA). He was also a visiting professor at the University of Tsukuba, Japan. He holds a PhD in Geoenvironmental Science, MSc in Remote Sensing and GIS, and Master Degree in Geography. Recently, SERVIR Global recognized his remarkable contributions and unwavering commitment to capacity development for connecting space to village mission and awarded prestigious SERVIR Award of Excellence.
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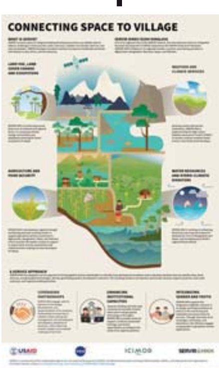
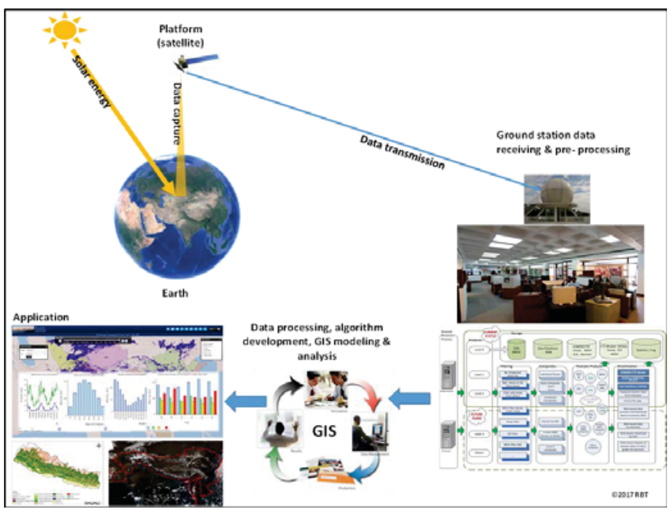
Remote Sensing Concepts





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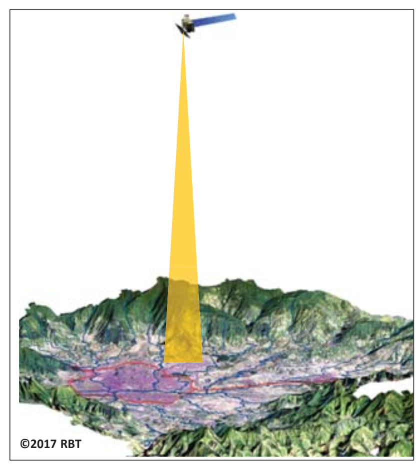
Remote Sensing Concepts



- Remote sensing is the science for collecting and interpreting information on targets (objects or areas) without being in physical contact with them.
- It employs electromagnetic energy in the form of radio waves, light, and heat as a means of detecting and measuring target characteristics.
- Remote sensing gathers information about the Earth from a distance, usually from aircraft or satellites

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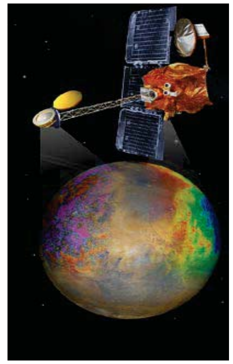
Remote Sensing Platforms

Ground-based

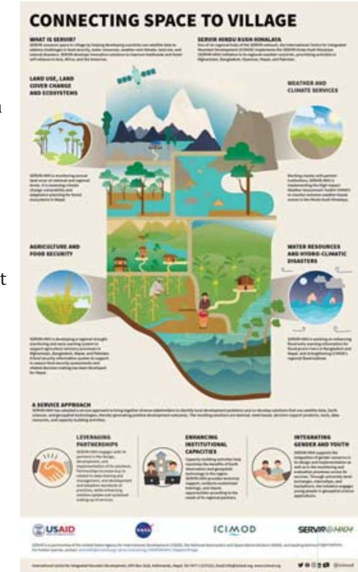
Aerial-based



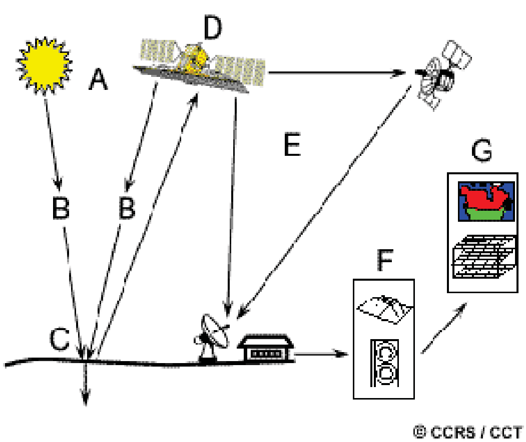
Satellite-based

Components of Remote Sensing

- **Energy source:** Sun, irradiance from earth's materials which is used in passive remote sensing; RADAR, irradiance from artificially-generated energy sources, which is used in active remote sensing)
- **Platforms:** The vehicle which carries a sensor, i.e., balloon, aircraft, space shuttle, satellite, international space station, etc.
- **Sensors:** Device that receives electromagnetic radiation and converts it into a signal that can be recorded and displayed as either numerical data or an image (camera, scanner, radar, etc.).
- **Processing:** Handling remotely sensed signal data, i.e., photographic, digital, etc.
- **Institutionalization:** Organization for executing at all stages of remote-sensing technology to connect space to village.



Remote Sensing Work-flow



A. Energy source
B. Radiation and the atmosphere
C. Interaction with the target
D. Recording of energy by the sensor
E. Transmission, reception, and processing
F. Interpretation and analysis
G. Applications

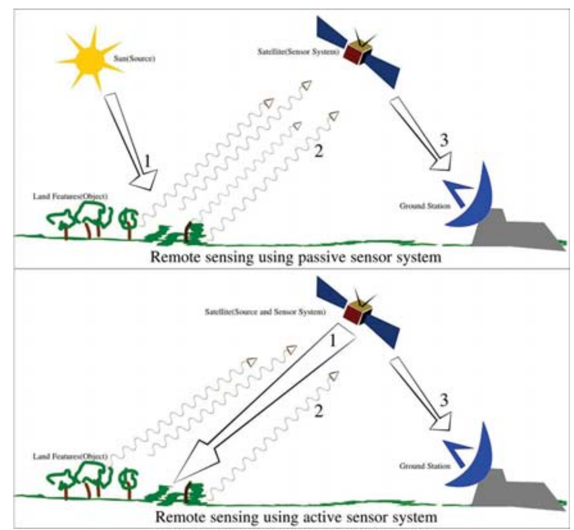
Basics of RS System: PASSIVE/ACTIVE

Passive satellite/sensors (OPTICAL): Sentinel-2, ALOS AVNIR-2, PRISM; Landsat Series; AVHRR, Spot, MODIS, IKONOS, Quickbird, Worldview, etc.

Active satellite/sensors (RADAR): Sentinel-1, ALOS PALSAR, ALOS-2, RADARSAT, TanDEM-X, TerraSAR-X, etc.

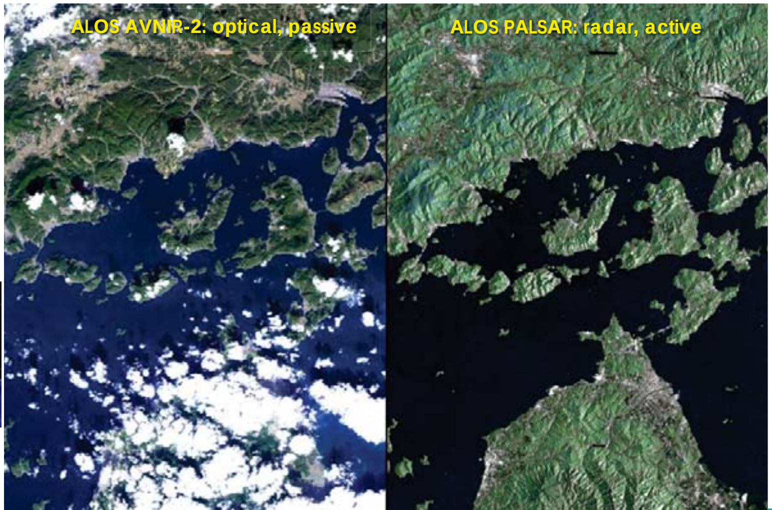
There are also some airborne sensor, such as PiSAR, PiSAR-L2, LiDAR, etc. Recently UAVs based small sensors are also getting popular

Satellite height: 300~36000 km; Airborne: ~12 km



Optical vs Radar: same satellite, time & location but different sensors

JAXA –Advanced Land Observing Satellite (ALOS)



Optical vs Radar: Optical

Optical remote sensing makes use of visible, near infrared and short-wave infrared sensors to form images of the earth's surface by detecting the solar radiation reflected from targets on the ground. Different materials reflect and absorb differently at different wavelengths. Thus, the targets can be differentiated by their spectral reflectance signatures in the remotely sensed images. Optical systems are nadir looking!

- Panchromatic imaging system: this is a single channel detector sensitive to radiation within a broad wavelength range. If the wavelength range coincide with the visible range, then the resulting image resembles a "black-and-white" photograph taken from space.
- Multispectral imaging system: this is a multichannel detector. Each channel is sensitive to radiation within a narrow wavelength band. The resulting image is a multilayer image which contains both the brightness and spectral (colour) information of the targets being observed.
- Hyperspectral imaging systems: This acquires images in about a hundred or more contiguous spectral bands. The precise spectral information contained in a hyperspectral image enables better characterisation and identification of targets.

Optical vs Radar: Radar

Radio detection and ranging (radar) refers to a technique as well as an instrument.

The radar instrument emits electromagnetic pulses in the radio and microwave regime and detects the reflections of these pulses from objects in its line of sight.

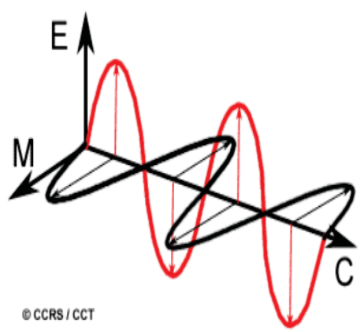
The radar technique uses the two-way travel time of the pulse to determine the range to the detected object and its backscatter intensity to infer physical quantities such as size or surface roughness.

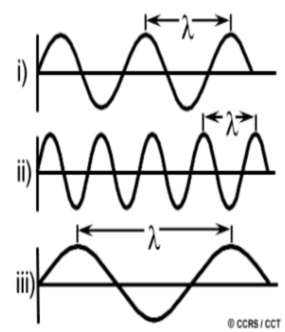
Unlike optical, radar systems consists of all-weather and all-day capabilities allowing regular mapping of areas affected by heavy cloud cover, persistent rain, or extended darkness.

Radar systems are side looking! The signals interact differently with the surface than most other sensing systems, providing interesting new information about the observed environment.

Electromagnetic Radiation

Energy from any sources comes in the form of electromagnetic radiation





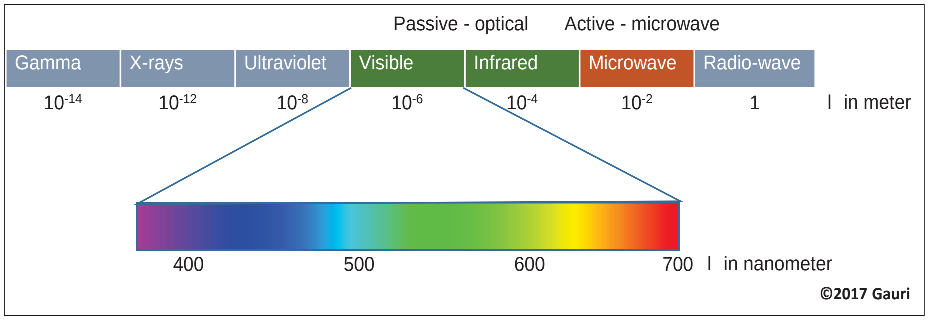
ER consists of Electrical field (E) and Magnetic field (M), travel at the speed of light (C).

Wavelength and Frequency. The wavelength is the length of one wave cycle, which can be measured as the distance (in m, cm, mm, and nm) between successive wave crests.

Frequency refers to the number of cycles of a wave passing a fixed point per unit of time. Frequency is normally measured in hertz (Hz), equivalent to one cycle per second, and various multiples of hertz. These two are inversely related to each other. The shorter the wavelength, the higher the frequency and vice-versa.

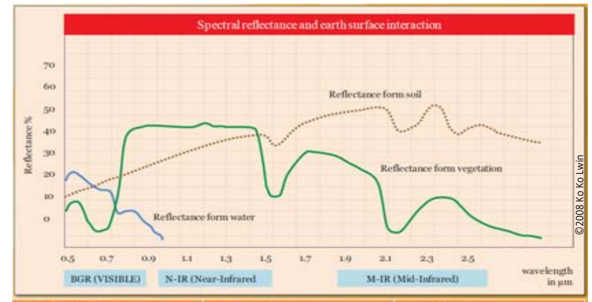
Electromagnetic Spectrum

From very short Gamma rays to very long radio waves

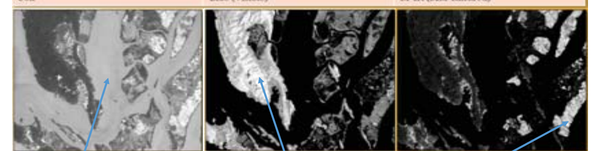


Blue (400 – 500), Green (500 – 600) and Red (600 – 700) bands

Spectral Properties of Objects



Surface category	Low reflectance	High reflectance
Water	N-IR (Near -Infrared)	Blue (Visible)
Vegetation	M-IR (Mid-Infrared)	N-IR (Near-Infrared)
Soil	Blue (Visible)	M-IR (Mid-Infrared)

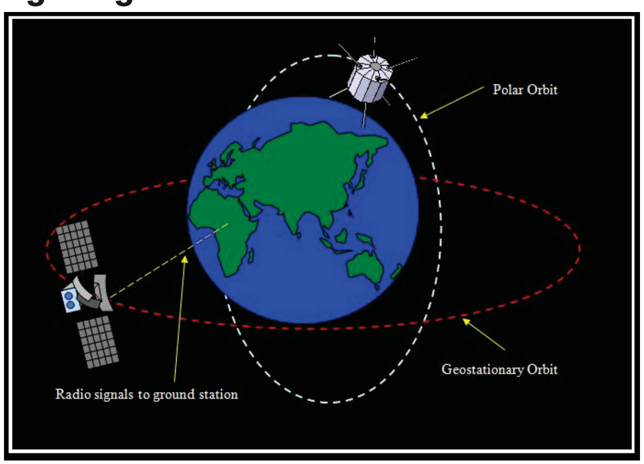


TM B1: High reflectance in water | TM B4: High reflectance in vegetation | TM B7: High reflectance in bare soil

Types of Remote Sensing Images

Polar orbit (sun-synchronous), earth resources satellites, Landsat, SPOT, ALOS, IKONOS, QuickBird, etc.

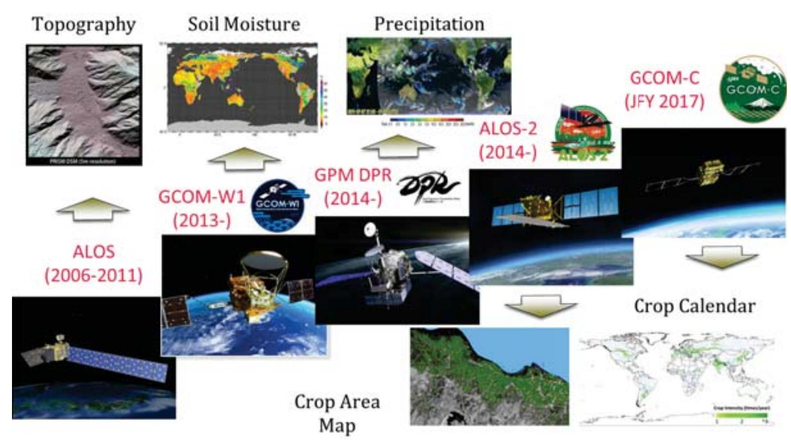
Geostationary orbit, directly over equator at very high altitudes and revolves in the same direction that the earth rotates (west to east), used in metrological, communication and broadcasting applications (e.g., GEOS, Meteosat, EDUSAT, GALAXY-27, KALPANA-1, etc.).



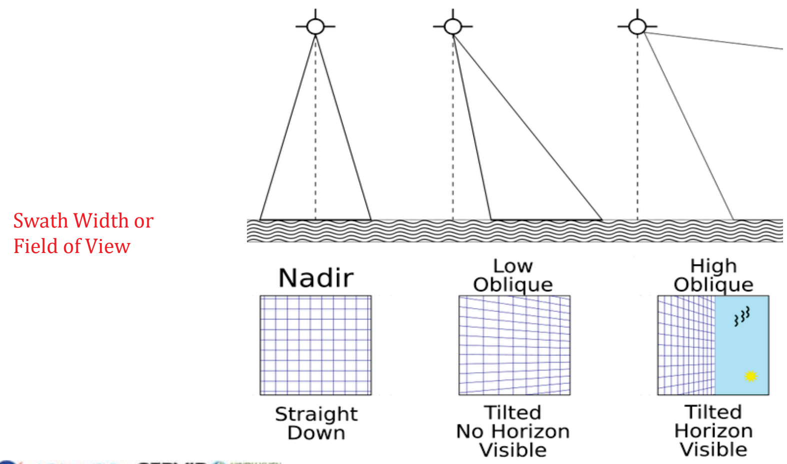
Types of information from remote sensing…

Field sensor, UAV, Airplane, Satellite …

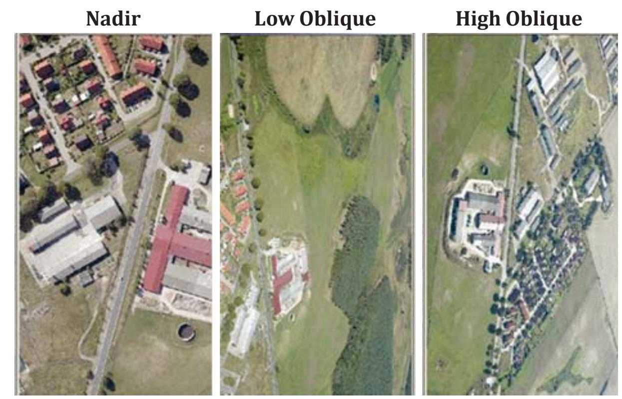
Satellite Sensors: Optical, RADAR, MWR, LiDAR etc.



Nadir vs Oblique viewing



Nadir vs Oblique viewing



Characteristics of Remotely Sensed Imagery

Remote sensing systems differ in the level of detail or resolution they can capture and data are available at a variety of resolutions, we will cover four types of satellite resolution:

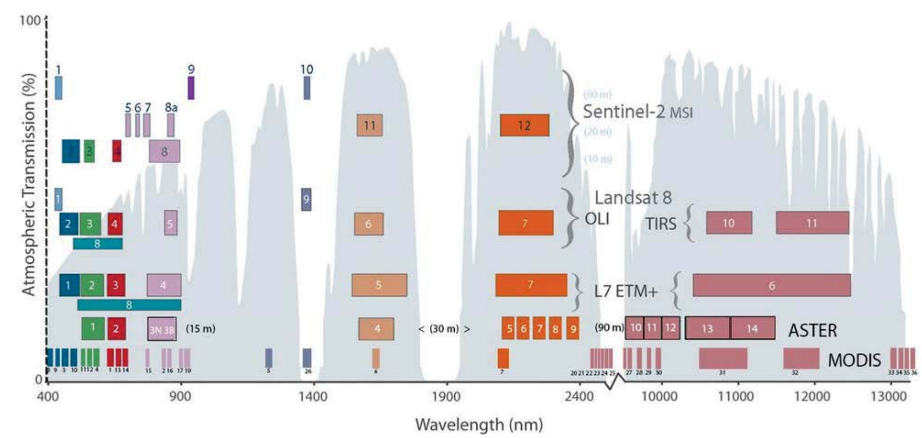
1) **Spectral Resolution** – refers to the degree to which a satellite sensor can distinguish or resolve features of the electromagnetic spectrum

2) **Radiometric Resolution** – refers to the number of quantized bits that are used for recording the reflected electromagnetic energy.

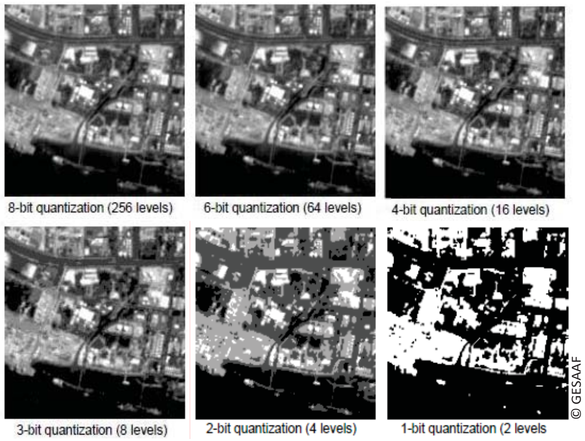
3) **Spatial Resolution** – refers to the number of pixels utilized in construction of a digital image. Images having higher spatial resolution are composed of a greater number of pixels than those of lower resolution.

4) **Temporal Resolution** – refers to the frequency of a measurement with respect to time. Often there is a trade-off between temporal and spatial resolution.

Spectral Resolution



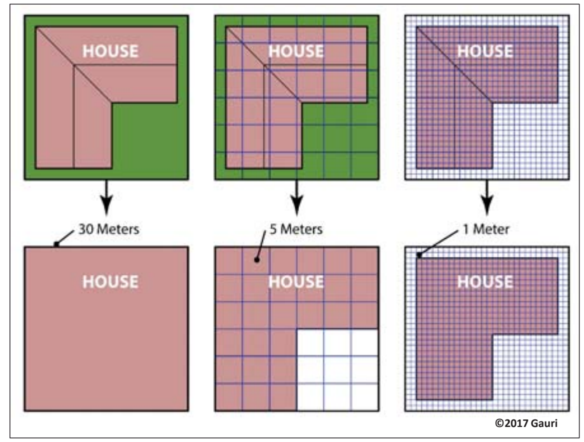
Radiometric Resolution



The radiometric resolution of image data in remote sensing stands for the ability of the sensor to distinguish different grey-scale values. It is measured in bit. The more bit an image has, the more grey-scale values can be stored, and, thus, more differences in the reflection on the land surfaces can be spotted.

A bit is a binary number that is 0 or 1. For computer processing, the byte unit (1 byte = 8bits; covers integer value between 0-255; or 256 grey levels)

Spatial Resolution



Spatial Resolution

Satellite	Resolution	Satellite	Resolution
GeoEye	0.41m	ALOS	2.5m~100m
Worldview 1, 2	0.46m	ALOS 2	3m~100m
Pleiades-1A	0.5m	Sentinel 1	5m~100m
Quickbird	0.61m	Sentinel 2	10m~60m
Ikonos	0.82m	ASTER	15m
SPOT 5, 6	1.5 – 5 m	LANDSAT	15m~60m
Rapid Eye	5m	MODIS	250~1000m

Faisal Masjid, Google Earth Imagery, 18.06.2019

Temporal Resolution

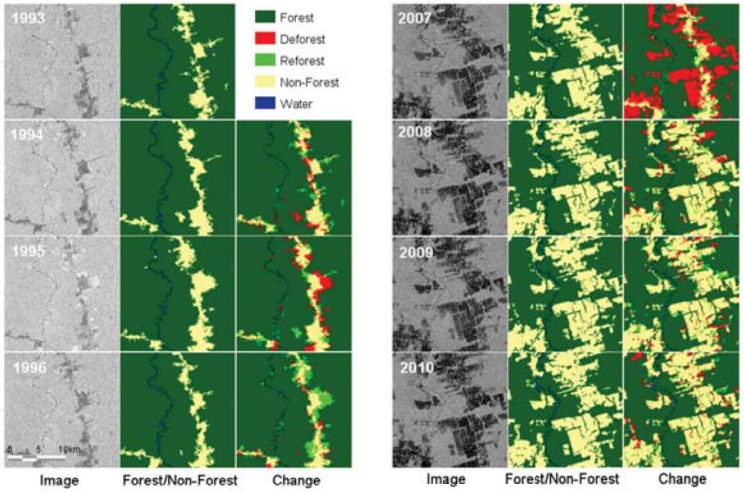
The temporal resolution specifies the revisiting frequency of a satellite sensor for a specific location.

High temporal resolution: < 24hours – 3days
Medium temporal resolution: 4-16 days
Low temporal resolution: > 16 days

Settlement bubbles in Manohara (*Thapa et al. 2008. City Profile: Kathmandu*)

Temporal Resolution - Forest change in Para, Amazon (Radar Data: JERS-1, ALOS/PALSAR)

Forest monitoring! Can any one articulate, what did you see in 2007?

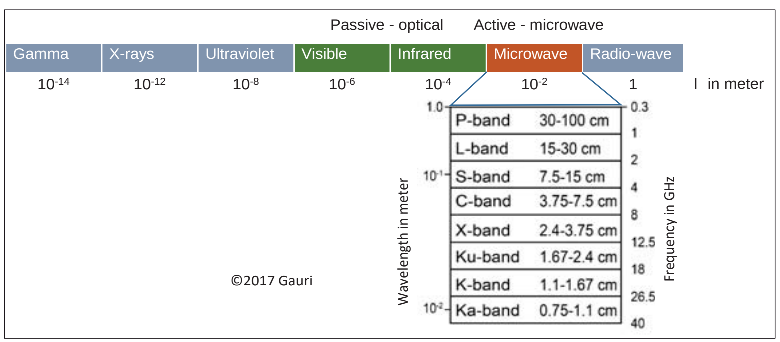


(C)JAXA, METI analyzed by JAXA

Spectral Bands Commonly Used in Remote Sensing

Spectral bands (μm)	Applications
Blue (0.45 – 0.52)	analysis of water characteristics, water depth, and the detection of subsurface features
Green (0.52 – 0.60)	water quality studies measuring sediment and chlorophyll concentration
Red (0.63 – 0.69)	discriminating vegetation types, assessing plant condition, delineating soil and geologic boundaries, and identifying cultural features
Panchromatic (0.50 – 0.90)	digitally combined with two or three of the multispectral bands to produce color images with spatial detail of the panchromatic image and the spectral detail of the multispectral bands
Near Infrared (0.7 – 1.0)	useful for vegetation mapping, crop condition monitoring, biomass estimation, and soil moisture assessment
Shortwave Infrared (1.0 – 3.0)	useful for analyzing moisture levels in soil and for monitoring plant vigor and crop condition, distinguishing clouds from snow and ice
Medium wave (3.0 - 8) and Long Wave Infrared (8 – 14)	useful to measure the temperature of features such as industrial sites, pipelines carrying heated materials, geothermal sites, and thermal pollution, also useful for the analysis of vegetation stress, soil moisture, and geology
Microwave region (radar)	useful for mapping of vegetation structure and biomass, flooding, geological sites, etc.

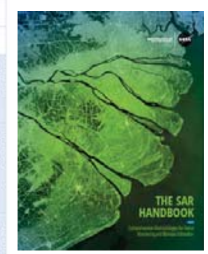
Spectrum of Microwave Region



The microwave region of the spectrum is quite large, relative to the visible and infrared, and there are several wavelength ranges from 0.1cm to 100cm (300GHz to 0.3GHz in frequency) with unique code band. Microwaves with longer wavelengths than Ka-band (7.5mm) are generally used as radar. Currently, X-band, C-band, and L-band are in operation in Earth observation satellites, i.e., TerraSAR-X, Sentinel-1, ALOS-2, respectively

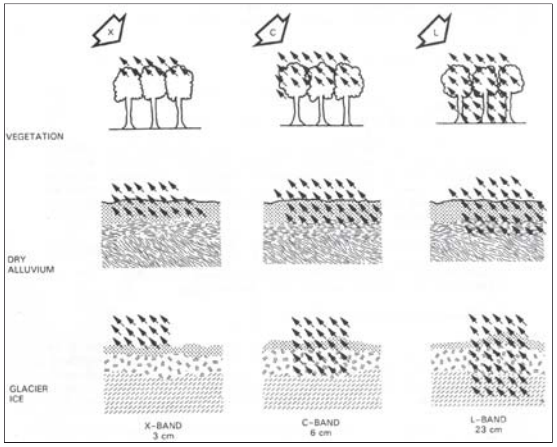
Spectrum of Microwave Region

SAR Band	Frequency	Wavelength	Typical Application
Ka	27 – 40 GHz	1.1 – 0.8 cm	Rarely used for SAR (airport surveillance)
K	18 – 27 GHz	1.7 – 1.1 cm	Rarely used (H_2O absorption)
Ku	12 – 18 GHz	2.4 – 1.7 cm	Rarely used for SAR (satellite altimetry)
X	8 – 12 GHz	3.8 – 2.4 cm	High resolution SAR (urban monitoring; ice and snow, little penetration into vegetation cover; fast coherence decay in vegetated areas)
C	4 – 8 GHz	7.5 – 3.8 cm	SAR workhorse (global mapping; change detection; monitoring of areas with low to moderate vegetation; improved penetration; higher coherence); Ice, ocean, maritime navigation
S	2 – 4 GHz	15 – 7.5 cm	Little but increasing use for SAR-based Earth observation; agriculture monitoring (NISAR will carry an S-band channel; expands C-band applications to higher vegetation density)
L	1 – 2 GHz	30 – 15 cm	Medium resolution SAR (Geophysical monitoring; biomass and vegetation mapping; high penetration; InSAR)
P	0.3 – 1 GHz	100 – 30 Cm	Biomass. First P-band spaceborne SAR will be launched around 2020; vegetation mapping and assessment. Experimental SAR.



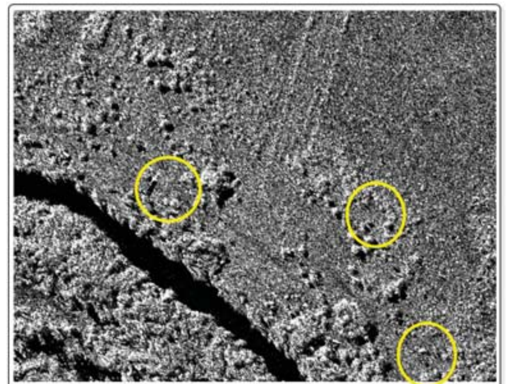
Source: *The SAR Handbook 2019*

Advantages of Microwave Signals



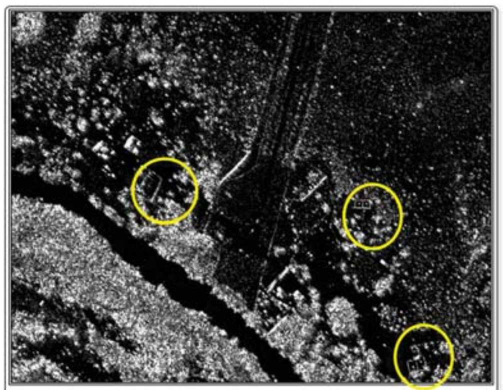
This figure provides a conceptual overview of the influence of sensor wavelength λ on signal penetration into a variety of surface types. The radar signals penetrate deeper as sensor wavelength increases. This is related to the dependence of the dielectric constant ε_r on the incident wavelength, allowing for higher penetration at L-band than at C- or X-band.

Effects of different bands in surface penetration



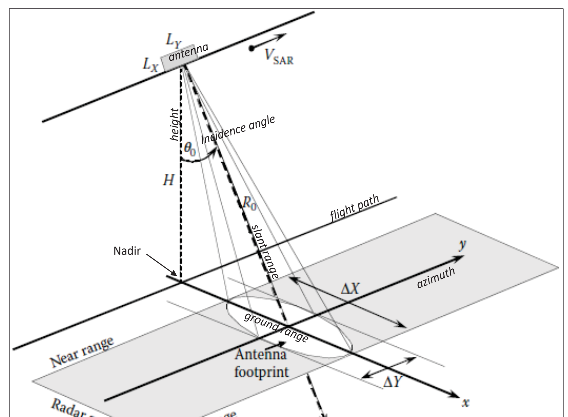
X-band radar image of forested area

Effects of different bands in surface penetration



P-band radar image of forested area

Observation Geometry of Imaging Radars

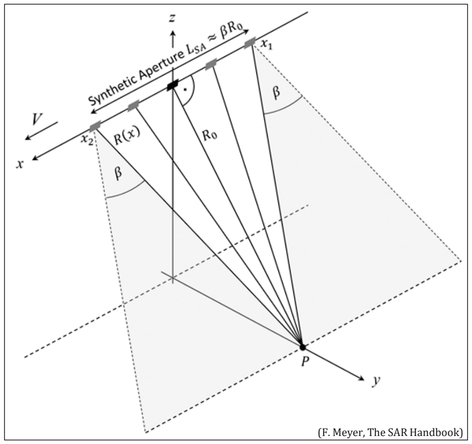


Adapted from: Lee and Pottier, 2009

Side-looking geometry

The figure is a schematic diagram of a radar observation geometry where a platform is moving along a straight path at altitude H. Unlike most optical imaging systems, which point their sensors towards nadir, the antenna of imaging radar is pointed away from nadir by a look angle.

Synthetic Aperture Radar (SAR)



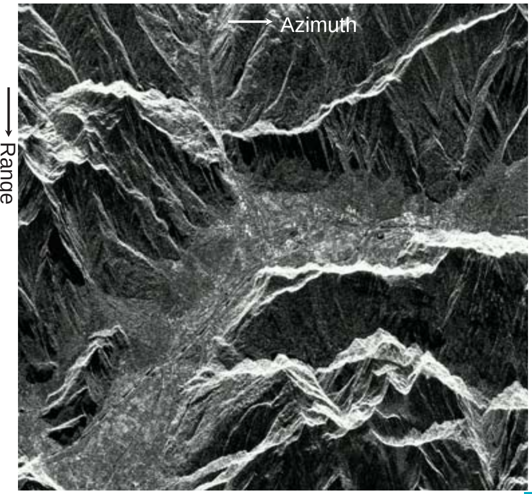
A radar antenna (indicated by a gray rectangle) of reasonably short length is moving at a velocity V along its flight path from the right to the left. While moving, it is constantly transmitting short radar pulses and is receiving echoes returned from objects on the ground. Each radar pulse illuminates an instantaneous footprint of size S on the Earth surface.

SAR is an active sensor transmitting a microwave signal towards a target and receive a reflection called backscatter

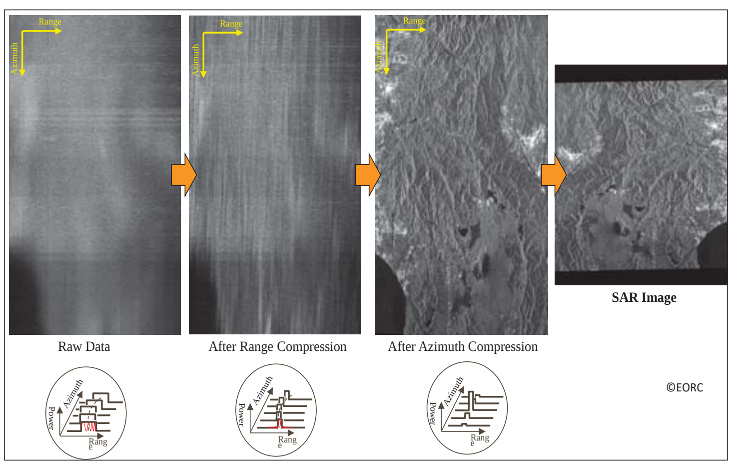
How imaging radar works?

Identify the directions for Azimuth and Range

Tips:
Imaging radars are side-looking!

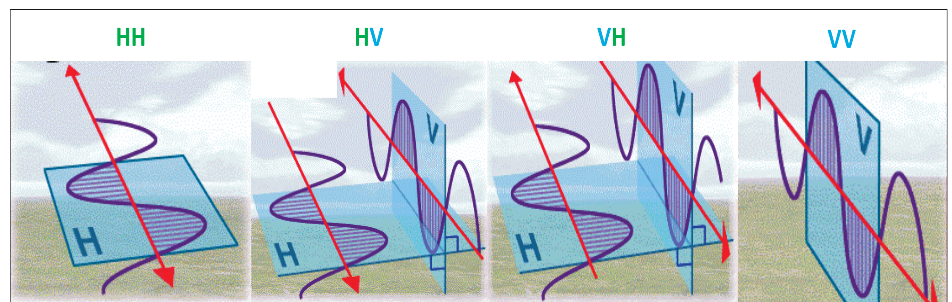


SAR image processing flow



SAR image is constructed from the many pulses reflected by each single target and received by the antenna and registered at all position along the flight path. Then image processing algorithm performs range and azimuth compressions to create 2-D SAR image

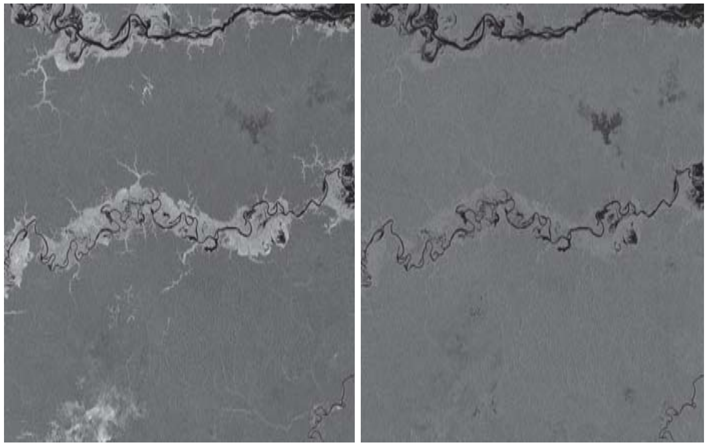
Radar polarizations



Adapted from ESA

Most radars are designed to transmit microwave radiation either horizontally polarized (H) or vertically polarized (V)

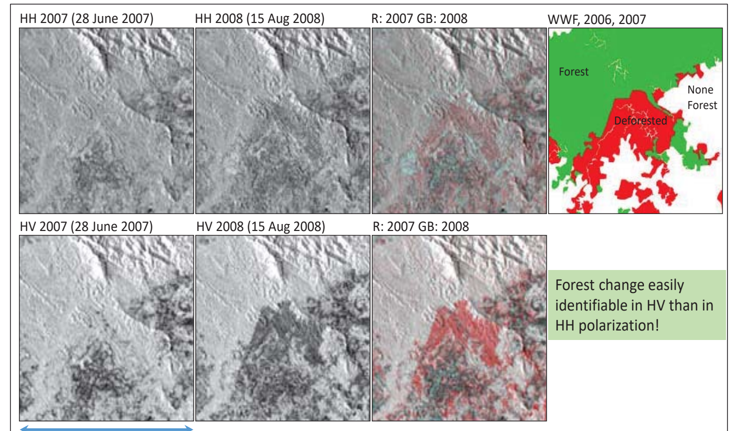
Polarizations and applications



HH polarization (left) and HV polarization (right). Image source: ALOS PALSAR

HH is sensitive to flooded forest, logged with trunks remaining, mangrove degradation while HV is sensitive to forest/non-forest contrast, vegetation structure, and biomass.

Polarizations and applications

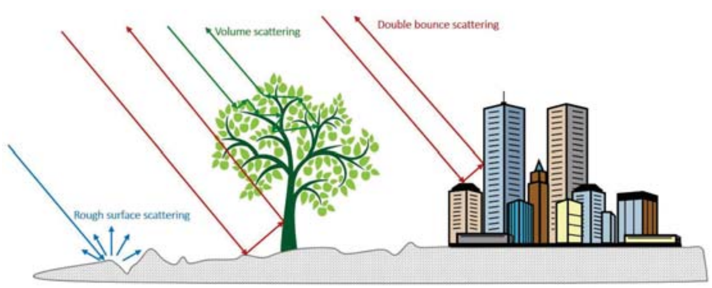


Change detection - impact of polarization

Depending on the transmitting and receiving polarizations, the radiation interacts with object and get backscatters differently. Both wavelength and polarization affect how a radar images the surface

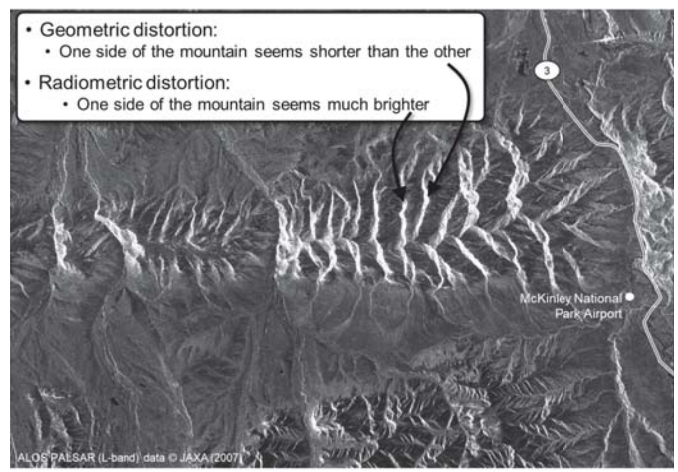
Scattering mechanisms

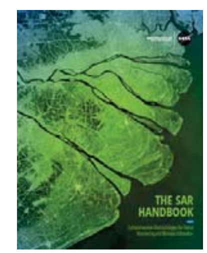
- Three main scattering mechanisms dominate:
  - Surface scattering: Water, bare soils, roads – scattering strongly dependent on surface roughness and sensor wavelength
  - Double-bounce scattering: Buildings, tree trunks, light poles – little wavelength dependence
  - Volume Scattering: Vegetation; dry soils with high penetration – strongly dependent on sensor wavelength and dielectric properties of medium



- At Radar wavelength, scattering is very physical and can be described as a series of bounces on scattering interfaces

Distortions

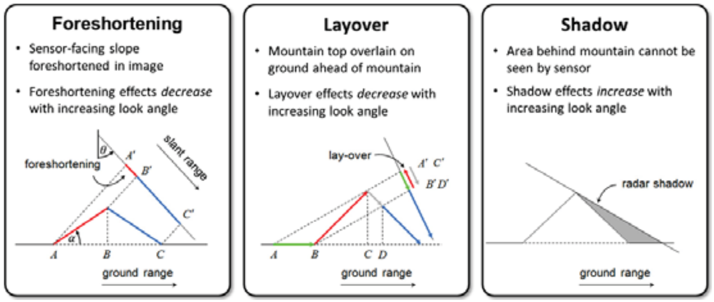




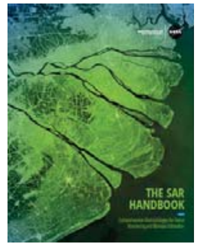
Source: ***The SAR Handbook 2019***

Distortions – Geometric

Main geometric distortions on SAR images with their dependence on acquisition geometry.



(Chapter 2. F. Meyer)



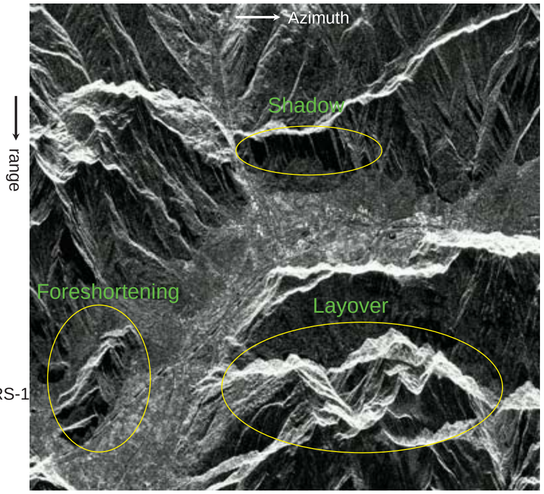
Source: ***The SAR Handbook 2019***

Distortions – Geometric

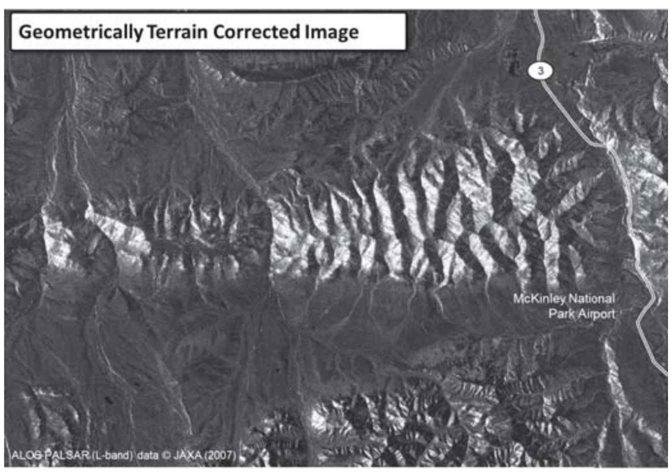
Foreshortening occurs when the radar beam reaches the base of a tall feature tilted away from the radar before it reaches the top. Small incidence angle produces large influence from this distortion. The foreshortened slopes appear as bright features on the image.

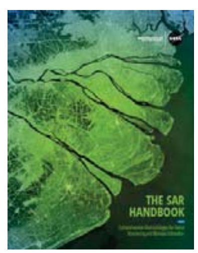
Layover occurs when the radar beam reaches the top of a tall feature before it reaches the base. This effect on a radar image looks similar to that due to the foreshortening. Small incidence angle also produces large influence from this distortion.

Shadow occurs when the radar beam is not able to illuminate the ground surface behind tall features or slopes. Large incidence angle produces large shadowed area.



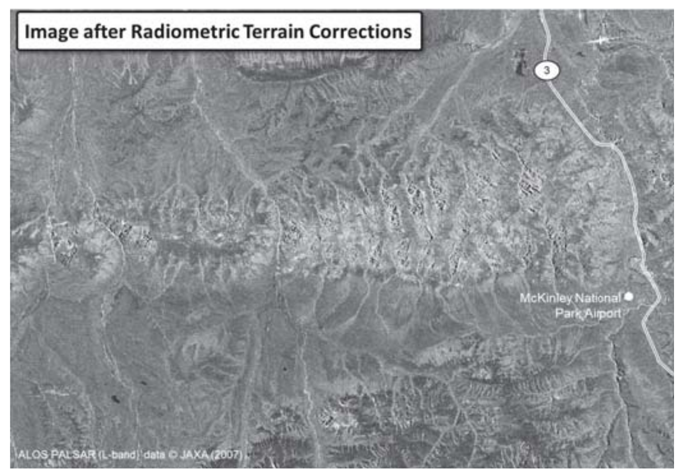
Distortions

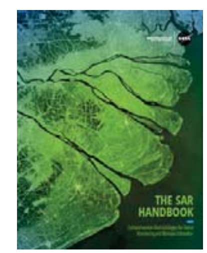




Source: ***The SAR Handbook 2019***

Distortions

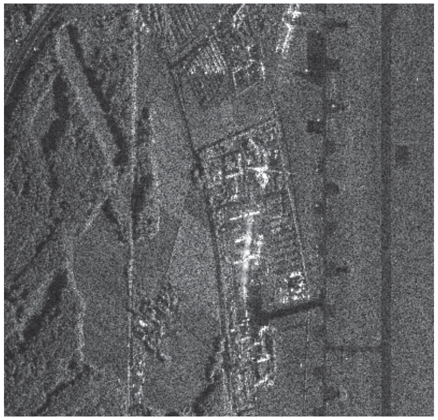




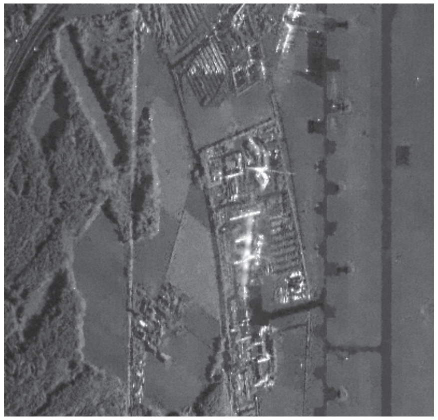
Source: ***The SAR Handbook 2019***

Distortions – Radiometric

Speckle reduction



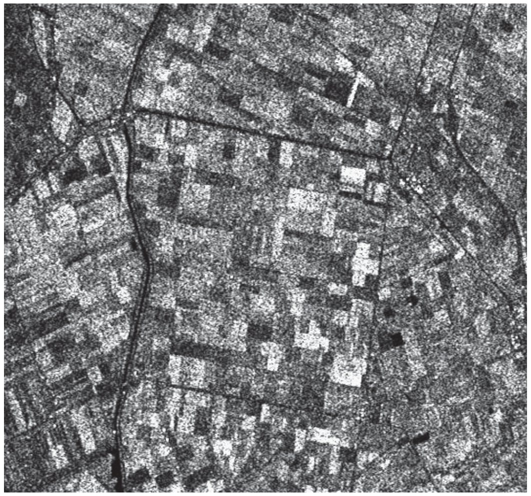
Original SAR Image
SAR data © AeroSensing GmbH



Speckle Filtered
Bayesian Algorithm

Distortions – Radiometric

- Noise caused "Speckle" which is an inherent property of all coherent imaging systems
- Technically, it looks noise but it is not, it is an interference pattern



(The SAR Handbook, Chapter 2. F. Meyer)

Remote Sensing Applications

There are so many applications of remote sensing…

- Water resources
- Weather and climate services
- Agriculture and food security
- Land use land cover, and ecosystem
- Disaster monitoring, emergency response, and management
- Topographic mapping
- Forest monitoring
- Measuring motion of the Earth's surface to understand earthquakes and volcanoes and support emergency management efforts.
- Studying the movements and changing size of glaciers and icecaps to explain long-term climate variability.
- Assessing geology, geophysical structure, and terrain for the likelihood of finding oil, gas or other natural resources.
- Monitoring of oil spills. Etc.

Land development monitoring (Sector G13, Islamabad)

2007.09.07

8 Months

2008.05.05

Google Earth Imagery

Land development monitoring (Sector G13, Islamabad)

6 Years

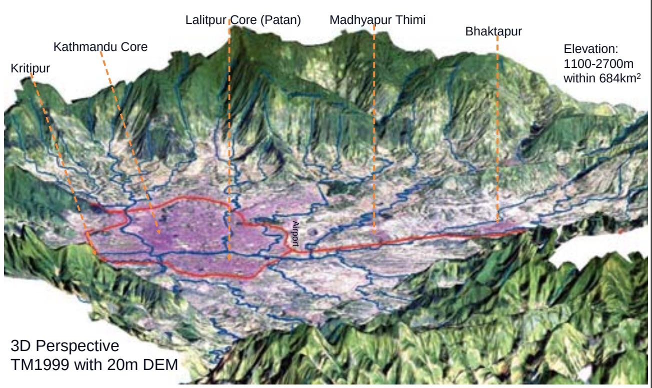
2014.09.01

6 Years

2020.04.22

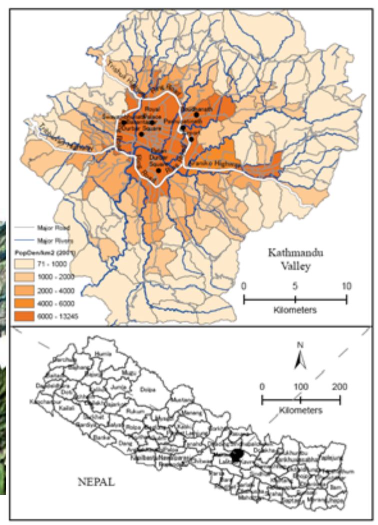
Google Earth Imagery

3D Visualization – Kathmandu Valley

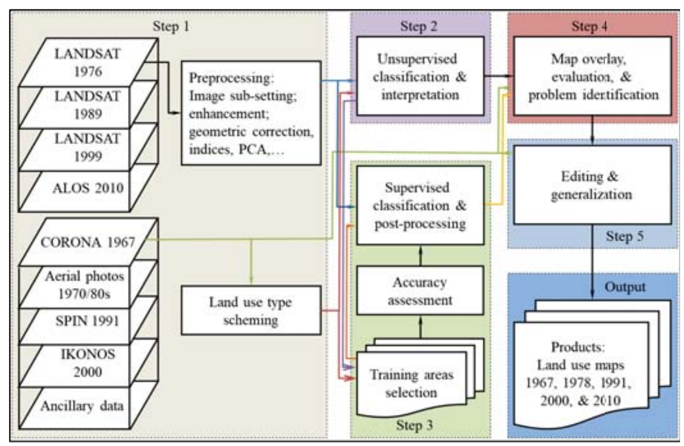


Elevation: 1100-2700m within 684km²

3D Perspective
TM1999 with 20m DEM

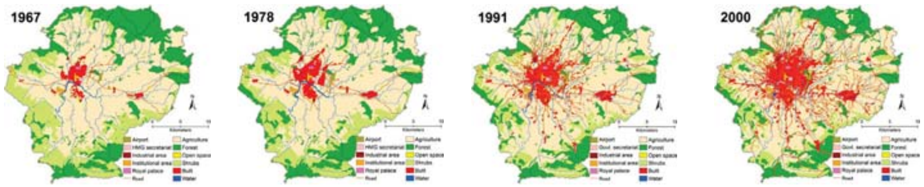


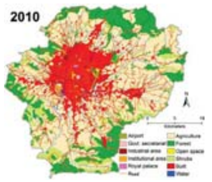
Land use land cover mapping



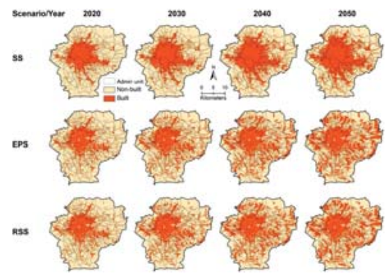
Thapa et al. (2009), Remote Sensing
Thapa 2012, SPIE Proceedings

Land use land cover mapping

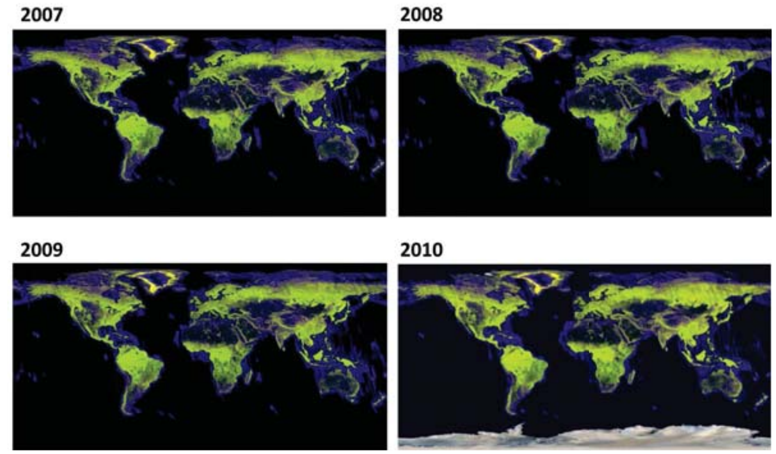




Thapa et al. (2009), Remote Sensing; Thapa (2012), SPIE Proceedings; Thapa et al. (2012), Landscape and Urban Planning

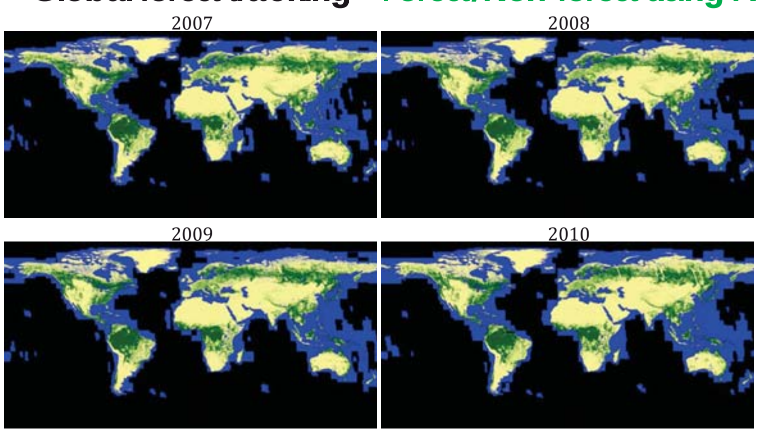


Global forest tracking – JAXA PALSAR Mosaic 25m



PALSAR Mosaic 25m data are available up to 2015, 2016, 2017, 2018 in google cloud and through JAXA data distribution website

Global forest tracking – Forest/Non-forest using PALSAR 25m

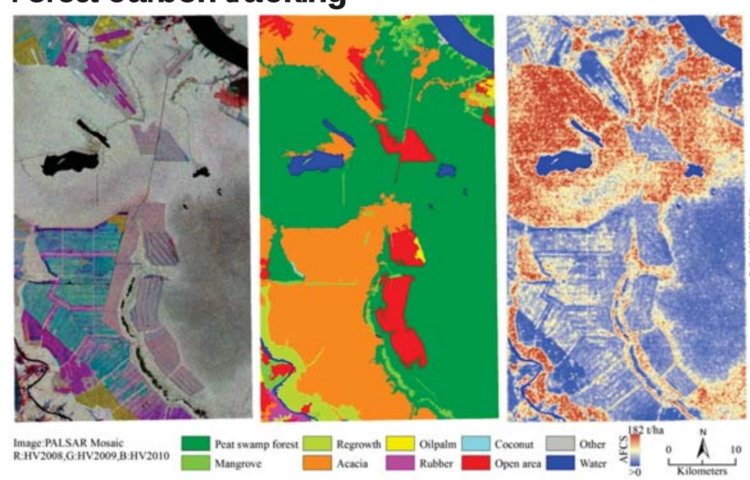


Methods: Shimada, M., ..., **Thapa, R.** et al. (2014), New Global Forest/Non–Forest Maps from ALOS PALSAR data (2007–2010). ***Remote Sensing of Environment***, 155, 13-31.

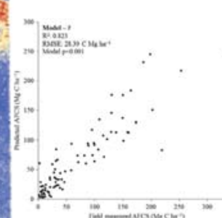
Available up to 2015, 2016, 2017, 2018

● : Forest ● : Non-Forest ● : Water

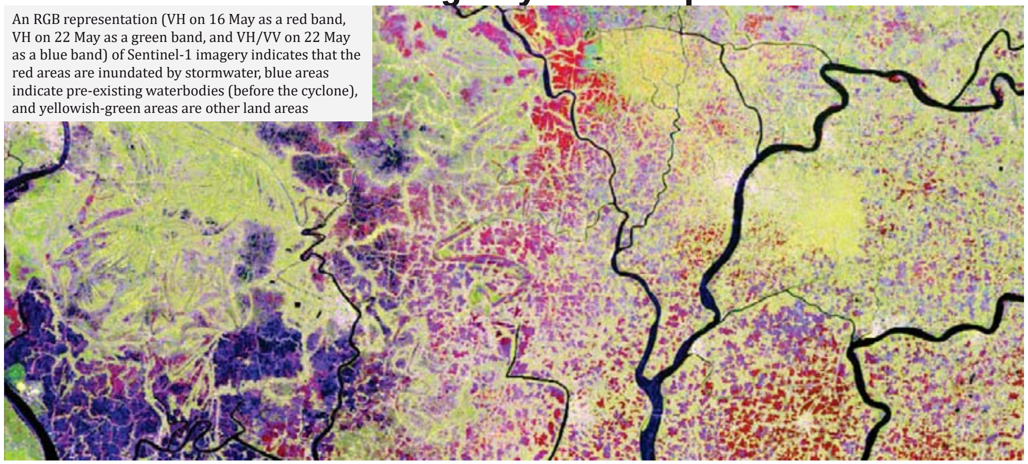
Forest carbon tracking



Thapa et al. (2015), *Remote Sensing of Environment*, 160, 122-133



Water resources monitoring – Cyclone Amphan



An RGB representation (VH on 16 May as a red band, VH on 22 May as a green band, and VH/VV on 22 May as a blue band) of Sentinel-1 imagery indicates that the red areas are inundated by stormwater, blue areas indicate pre-existing waterbodies (before the cyclone), and yellowish-green areas are other land areas

Uddin & Matin (2020) https://tinyurl.com/y8hmysyj

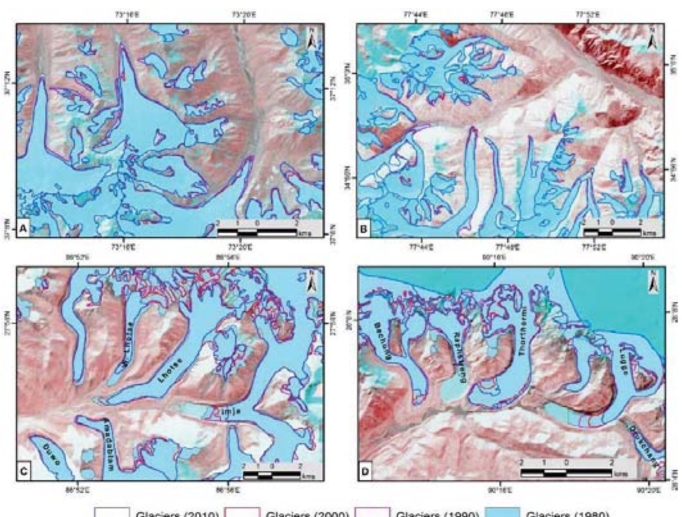
Water resources monitoring

Flooding in Bangladesh

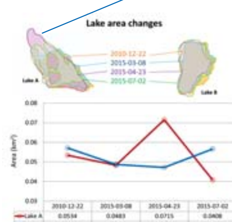
Flooding in Bangladesh observed from Sentinel 1 SAR data processed by Kabir Uddin, ICIMOD

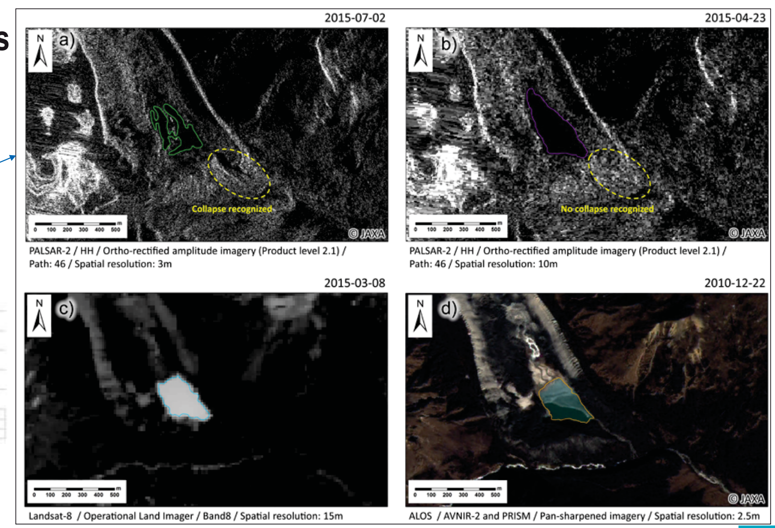
Glacier monitoring

- A - Wakhan Corr., Afgh.
- B - Shyok basin, Pakistan
- C - Imja Valley, Nepal
- D - Lunana area, Bhutan



Glacial lakes monitoring (Bhutan - Lake A)





PALSAR-2 / HH / Ortho-rectified amplitude imagery (Product level 2.1) / Path: 46 / Spatial resolution: 3m

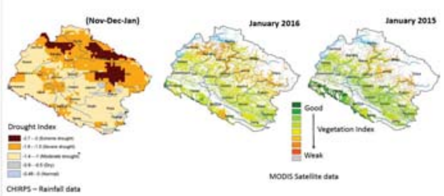
PALSAR-2 / HH / Ortho-rectified amplitude imagery (Product level 2.1) / Path: 46 / Spatial resolution: 10m

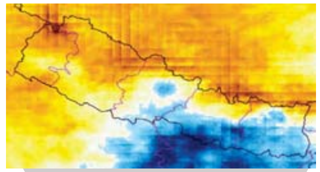
Landsat-8 / Operational Land Imager / Band8 / Spatial resolution: 15m

ALOS / AVNIR-2 and PRISM / Pan-sharpened imagery / Spatial resolution: 2.5m

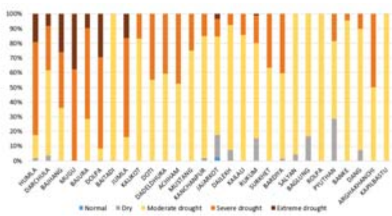
http://www.eorc.jaxa.jp/ALOS-2/en/img_up/dis_pal2_btn-glof_20150702.htm

Drought monitoring

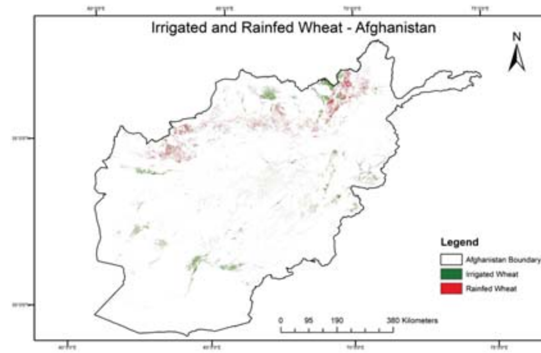


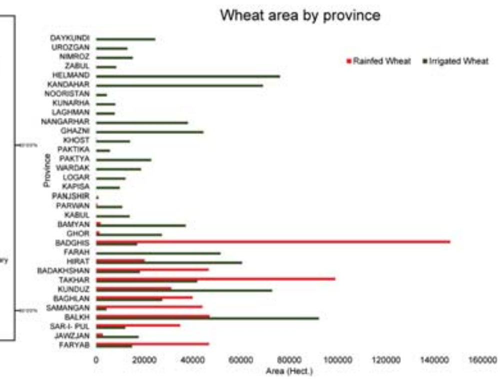


Drought SPI – Sep., 2016



Wheat area mapping in Afghanistan





Distribution of Irrigated and Rainfed Wheat area of Afghanistan in 2017 (Tiwari et al., 2020, Frontiers)

There are many applications …our recent book on applications…

SAR Handbook: Comprehensive Methodologies for Forest Monitoring and Biomass Estimation

Editors: Africa F. Anderson, Kelsey E. Herndon, Rajesh B. Thapa, Emil Cherrington

- **Freely-available** eBook, interactive pdfs, and training modules; result of a 2-year joint collaboration between **NASA SERVIR** & **SilvaCarbon**
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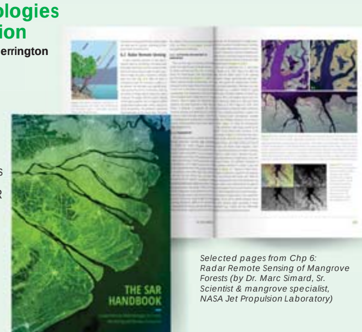
- Reviewed and tested by the SERVIR-Global network
- **Downloadable open-source scripts** and sample datasets for a variety of forestry applications; useful for **beginners to experts**



Selected pages from Chp 6: Radar Remote Sensing of Mangrove Forests (by Dr. Marc Simard, Sr. Scientist & mangrove specialist, NASA Jet Propulsion Laboratory)

Download the SAR Handbook here: https://bit.ly/2UHZtaw
SAR Handbook training modules and more: https://bit.ly/2GeKvAN
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