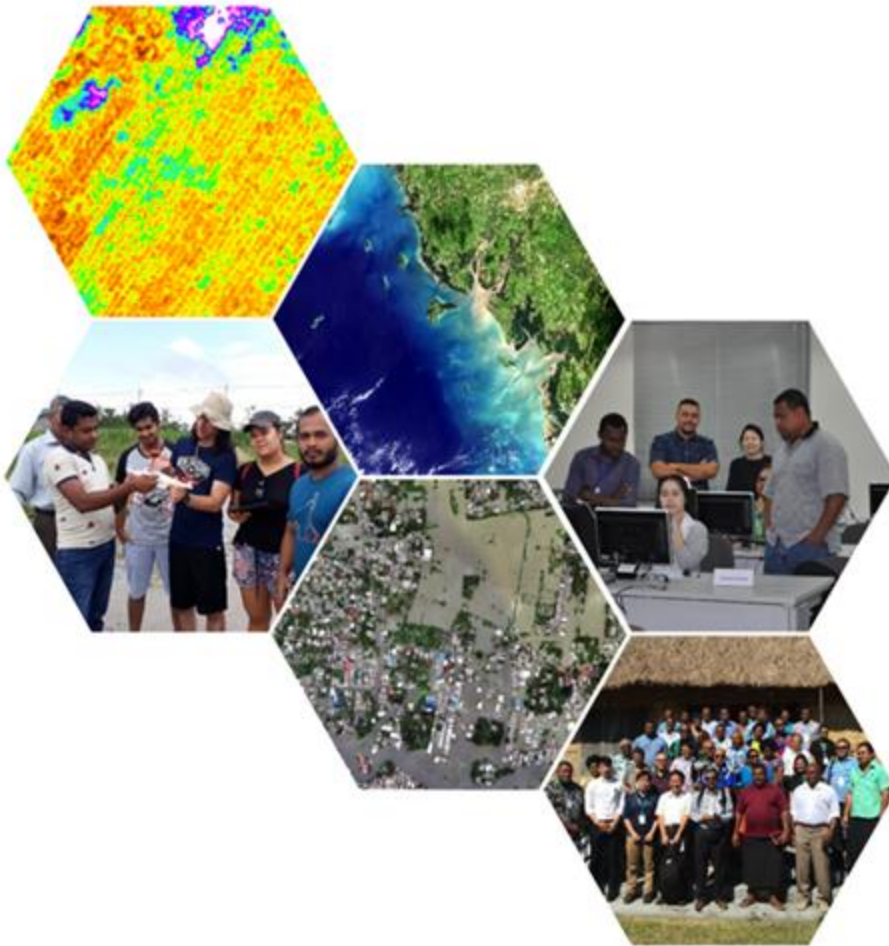


# Introduction to Remote Sensing: Optical to SAR



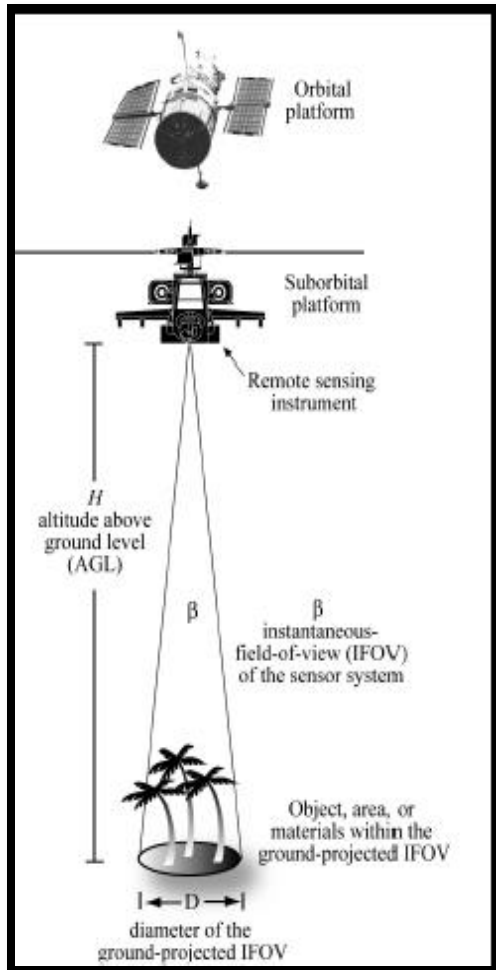
# What is Remote Sensing?

Measurement of a quantity associated with an object by a device not in direct contact with the object

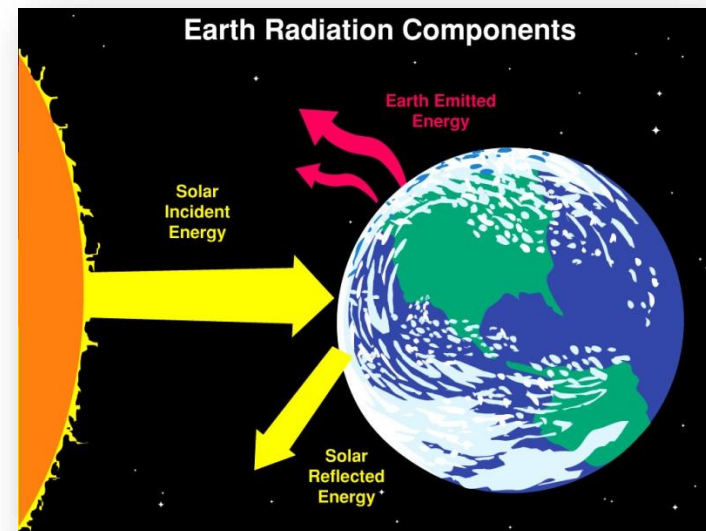


- ❑ Platform depends on application
- ❑ What information? how much detail?
- ❑ How frequent?

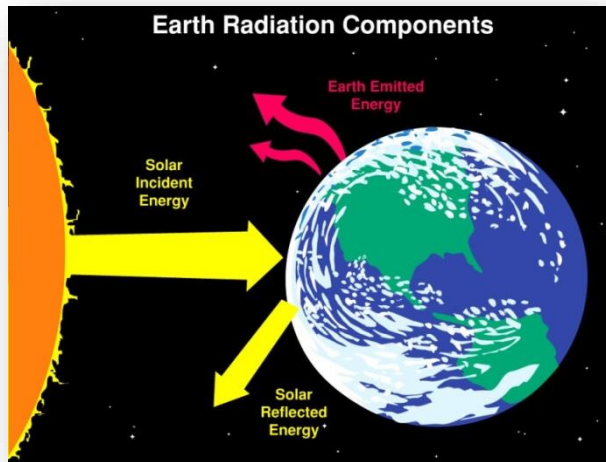
# Measuring properties of the Earth-Atmosphere system from space



Satellites carry instruments or sensors which **measure electromagnetic radiation** coming from the earth-atmosphere system



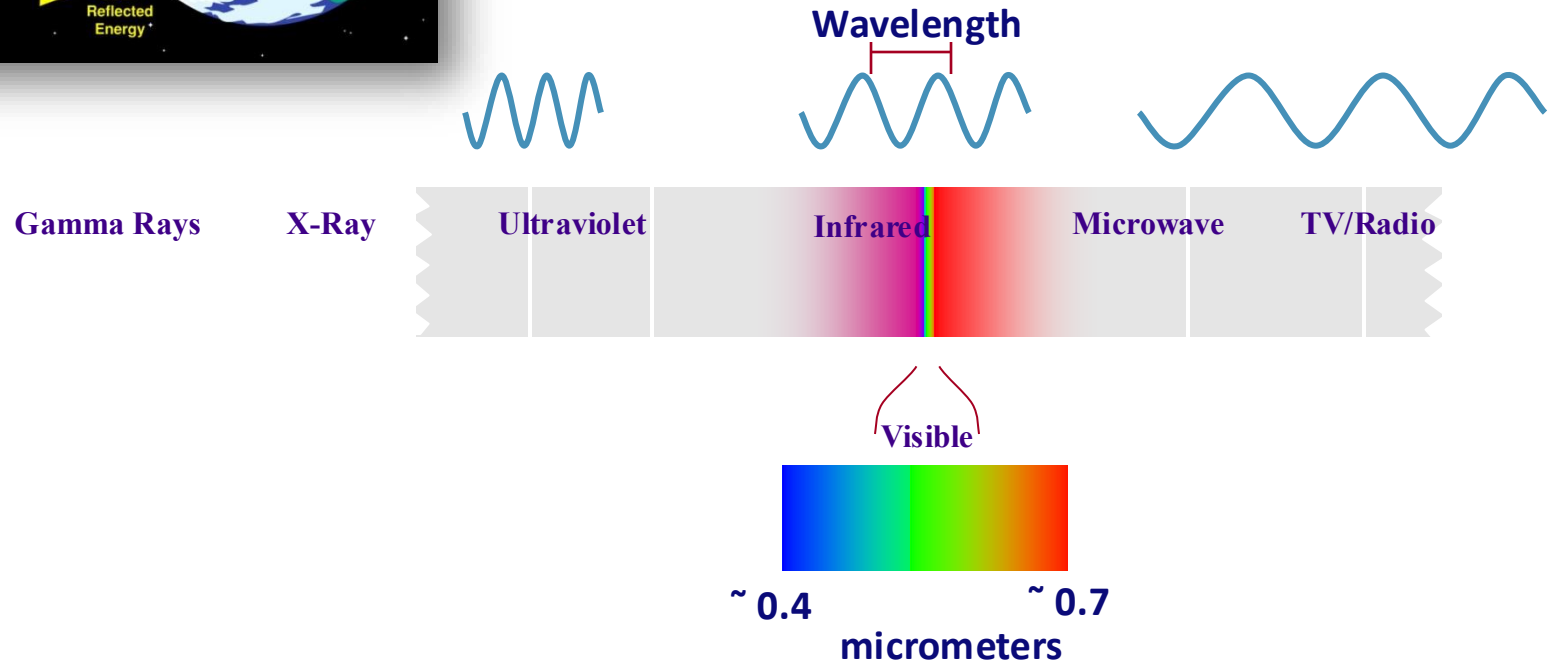
# Electromagnetic Radiation



Earth-Ocean-Land-Atmosphere System :

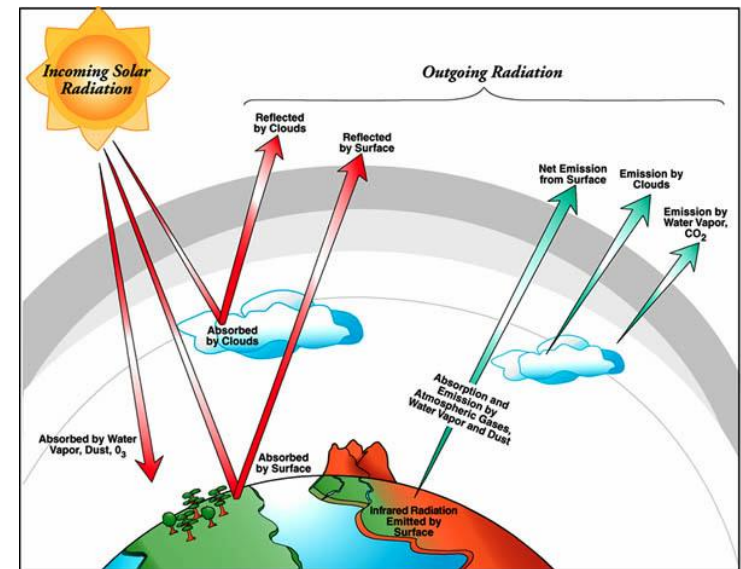
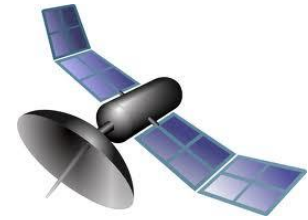
- reflects solar radiation back to space
- emits Infrared radiation and Microwave radiation to space

## Electromagnetic Spectrum

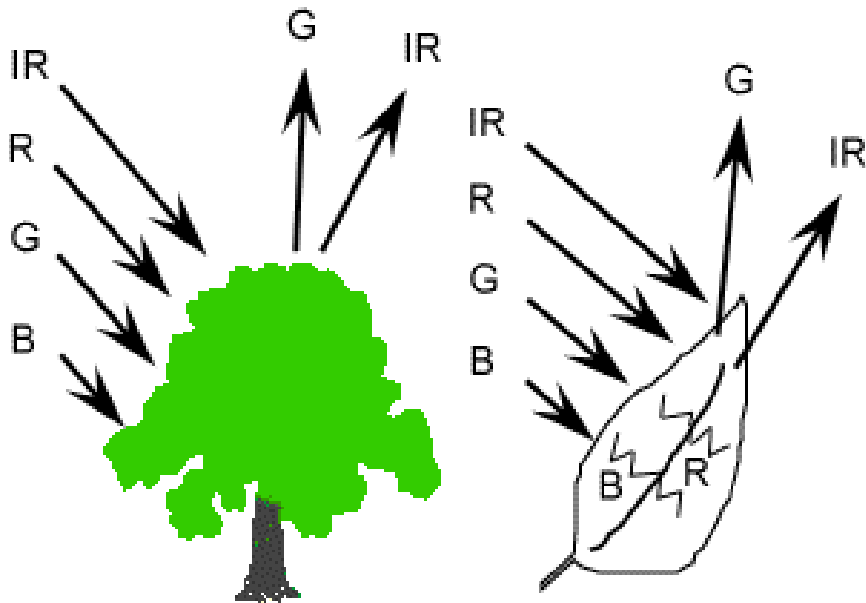


# Measuring Properties of Earth-Atmosphere System from Space

- The intensity of reflected and emitted radiation to space is influenced by the surface and atmospheric conditions
- Thus, satellite measurements contain information about the surface and atmospheric conditions



# Electromagnetic Energy: Example



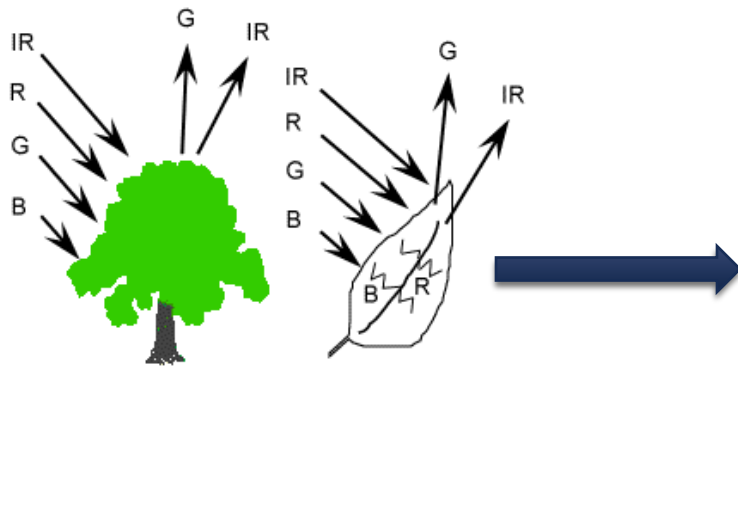
Example: Healthy, green vegetation absorbs **Blue** and **Red** wavelengths and reflects **Green** and Infrared



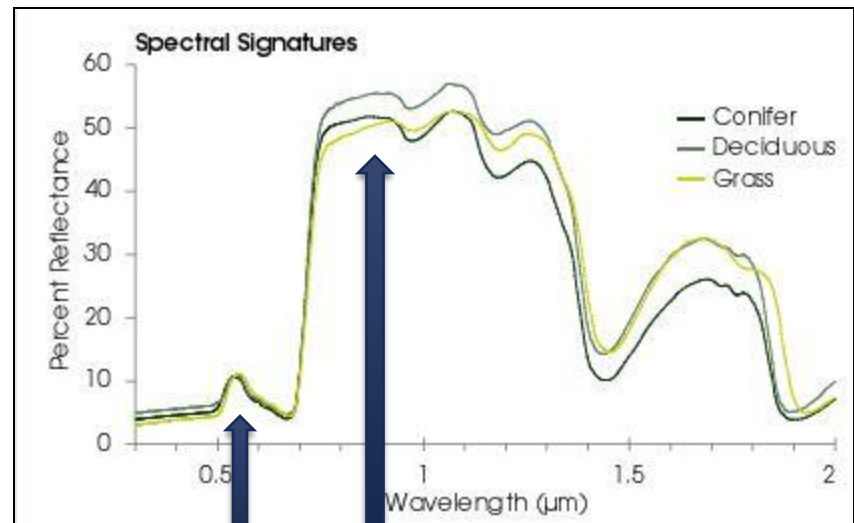
That's why we see healthy vegetation as green

# Spectral Signatures

- Every kind of surface has it's own spectral signature
- Going back to the healthy vegetation example....



## Spectral Signature

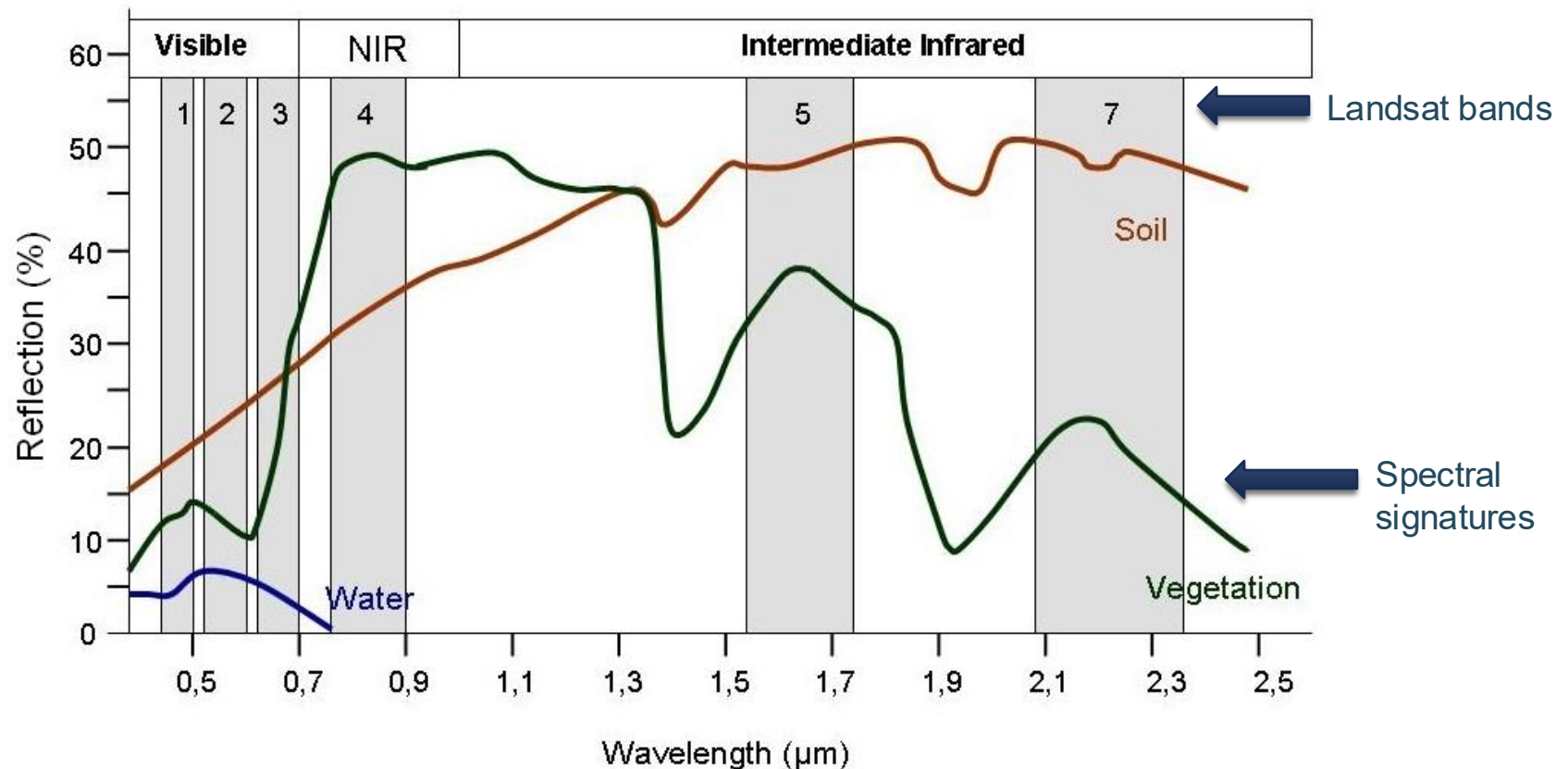


Green Near-Infrared (IR)



## Now to include the imagery....

Remotely sensed imagery acquires information in different wavelengths, representing different parts of the Electromagnetic Spectrum





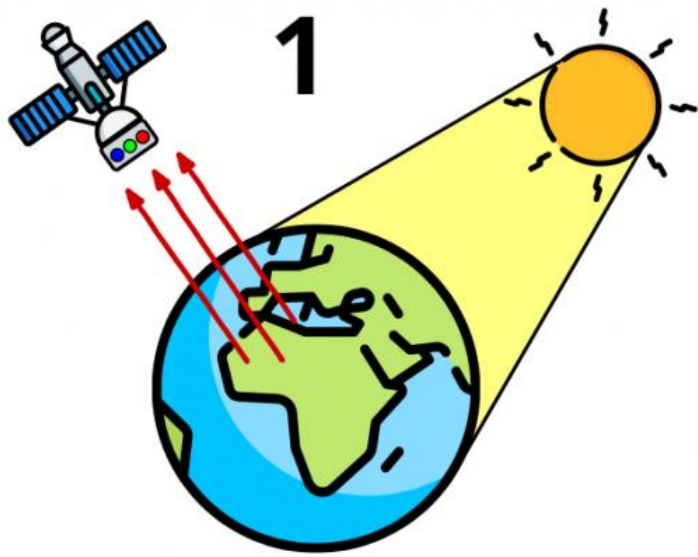
## **Type of Sensors**

**Spectral Resolution**

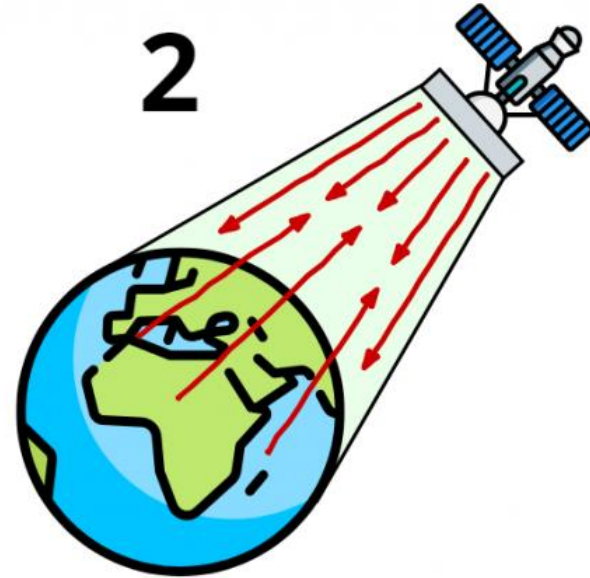
**Radiometric Resolution**

**Spatial Resolution**

# Two Types of Remote Sensing



- Passive  
(Multispectral/Hyperspectral/Optical)
  - Source: sun
  - Receive reflectance from the target to the sensor

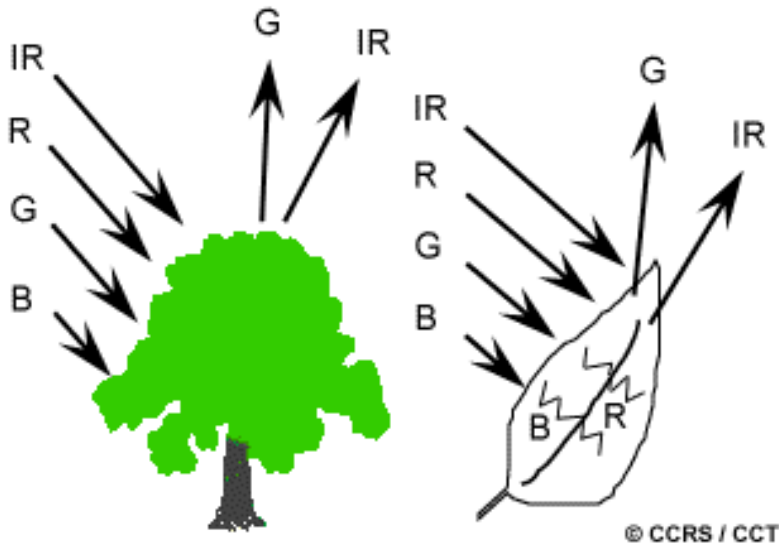


- Active (Microwave or Radar)
  - Source: satellite sensor
  - Receive backscatter from the target to the sensor

# Satellite Sensors

**Passive** remote sensors measure radiant energy reflected or emitted by the Earth-atmosphere system

Examples: Landsat, MODIS



Landsat image of San Francisco Bay Area

# Satellite Sensors

**Active** remote sensors ‘throw’ beams of radiation on the earth-atmosphere system and measure ‘back-scattered’ radiation

The back-scattered radiation is converted to geophysical quantities

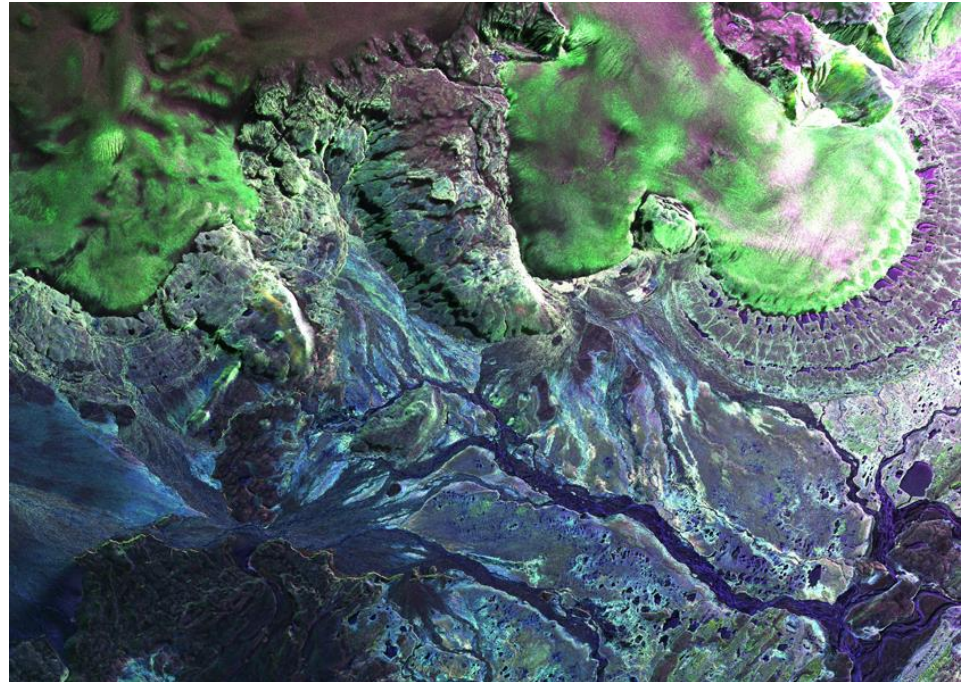
Advantages:

- Can be used day or night
- Can penetrate cloud cover

Disadvantages:

- Challenging to process

Examples: Radar (microwave), LIDAR



*Image courtesy of [uavsar.jpl.nasa.gov](http://uavsar.jpl.nasa.gov)*

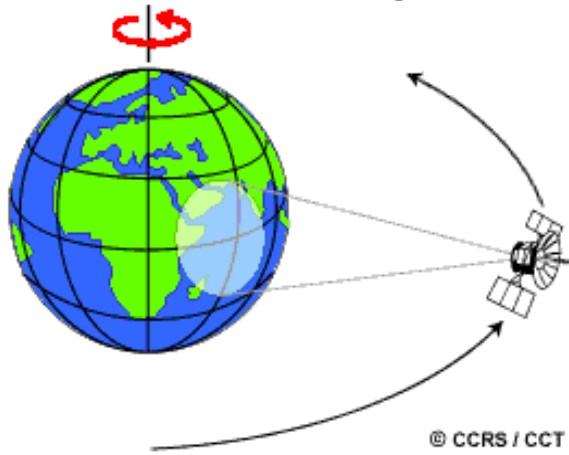
UAV SAR image of a glacier in Hofsjokull, Iceland (June 12, 2009). The blue areas are bare ground surfaces and the green areas are ice.

# Spatial and Temporal Resolution of Satellite Measurements

- Depends on the satellite orbit configuration and sensor design
- Temporal resolution:
  - How **frequently** a satellite observes the same area of the earth?
- Spatial Resolution:
  - How much **detail** can we see on the ground?
  - Decided by its **pixel** size -- **pixel is the smallest unit measured by a sensor**

# Types of Satellite Orbits

## Geostationary orbit

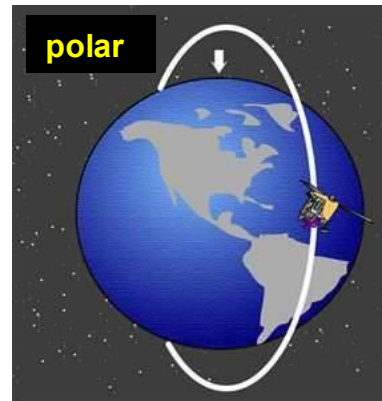


Satellite is at ~36,000 km above earth at equator. Same rotation period as earth's. Appears 'fixed' in space.

- Frequent measurements
- Large (global) spatial coverage
- Low spatial resolution

Examples: weather or communications satellites

## Low Earth Orbit (LEO)



Circular orbit constantly moving relative to the Earth at 160-2000 km. Can be in Polar or non-polar orbit

- Less frequent measurements
- Limited spatial coverage
- Large spatial resolution

Polar orbit examples: Landsat or Terra satellites

# Spatial Resolution

Spatial resolution refers to the detail discernable in an image by a pixel

Sensor	Spatial Resolution
Digital Globe (and others)	0.5 cm - 4 m
Landsat	30 m
Sentinel-2	10 m
MODIS	250 m-1km

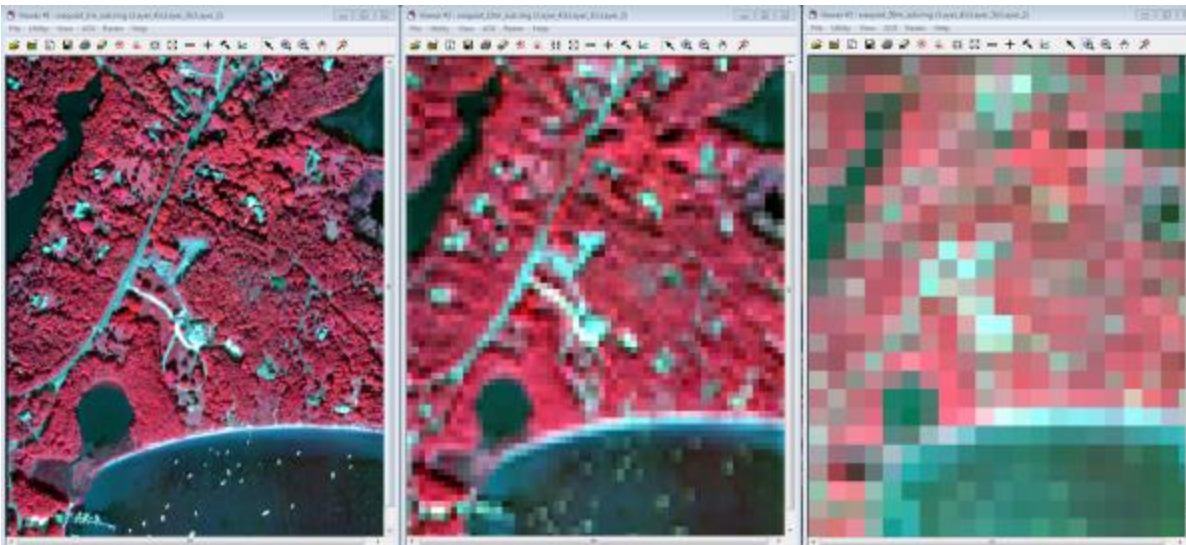


# Spatial Resolution

1 meter

10 meter

30 meter



*Image courtesy of [www.csc.noaa.gov](http://www.csc.noaa.gov)*

BUT....there is a tradeoff between spatial resolution and spatial extent!



**SRI LANKA**  
(Image Source-MODIS)



**MODIS**

*Pixel Size : 250m*



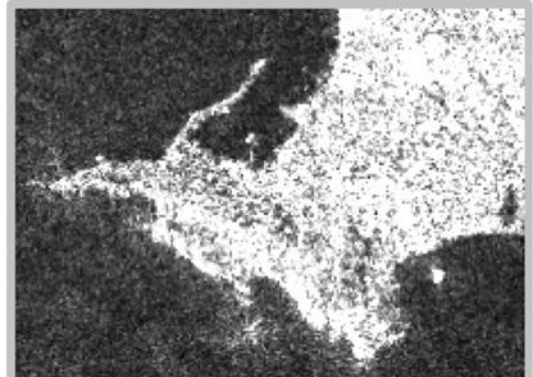
**Landsat 7 ETM+**

*Pixel Size : 30m*



**ALOS AVNIR-2**

*Pixel Size : 10m*



**ALOS PALSAR**

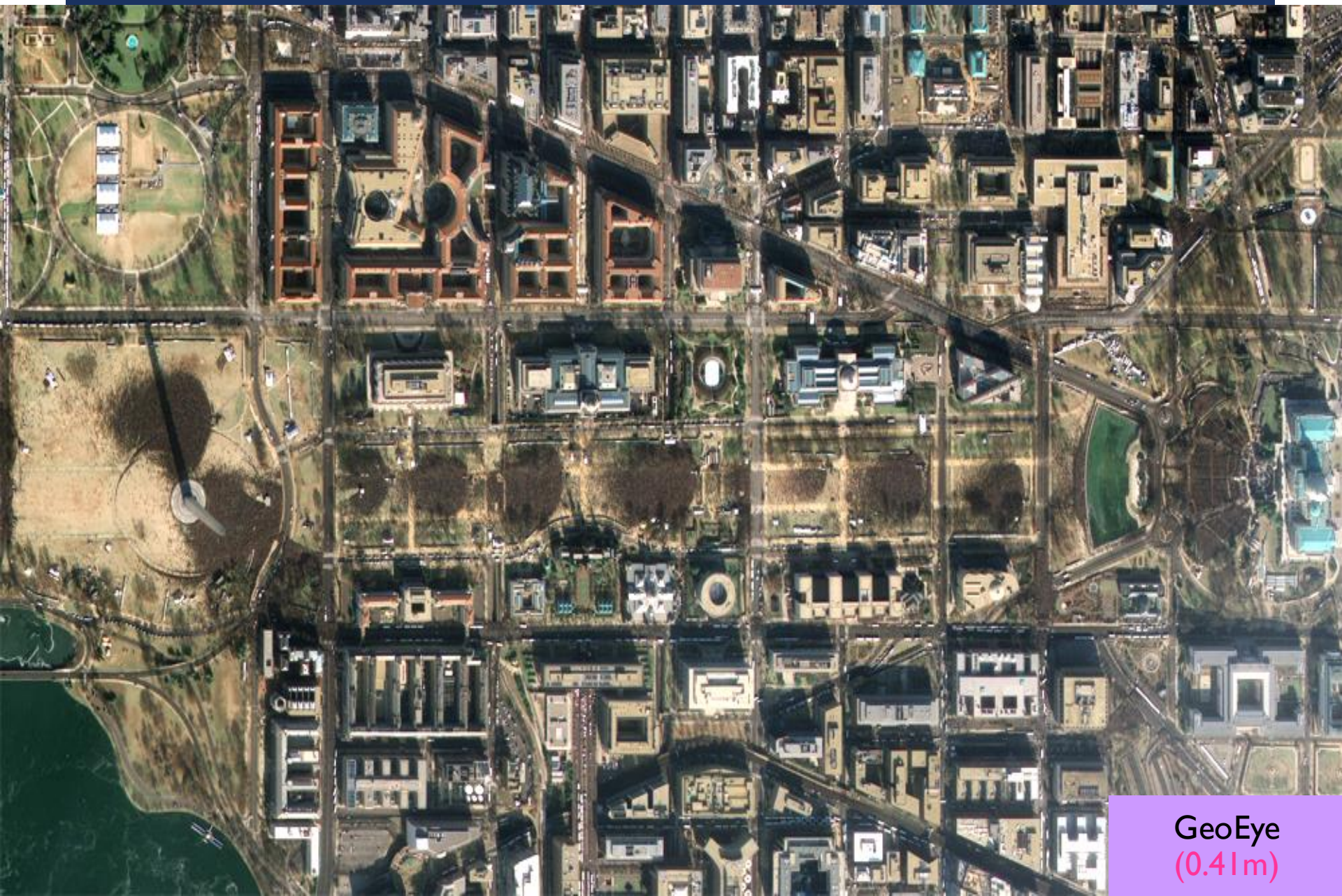
*Pixel Size : 6.25m*



**GeoEye-1 (Pan Sharpened)** *Pixel Size : 0.41m*

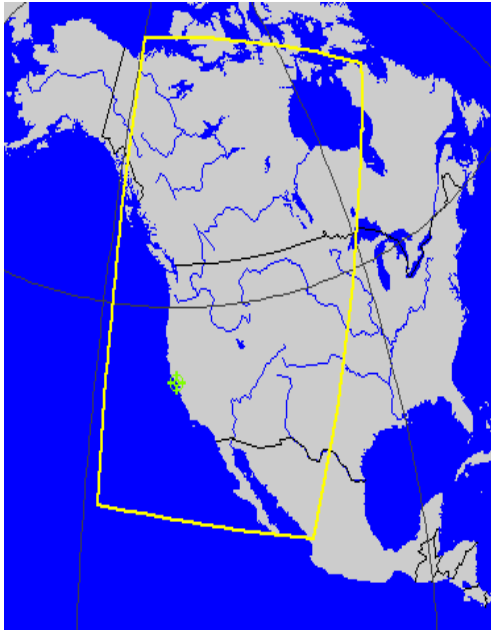


# GeoEye 1 Image at Obama's Presidential Speech, 20-1-2009

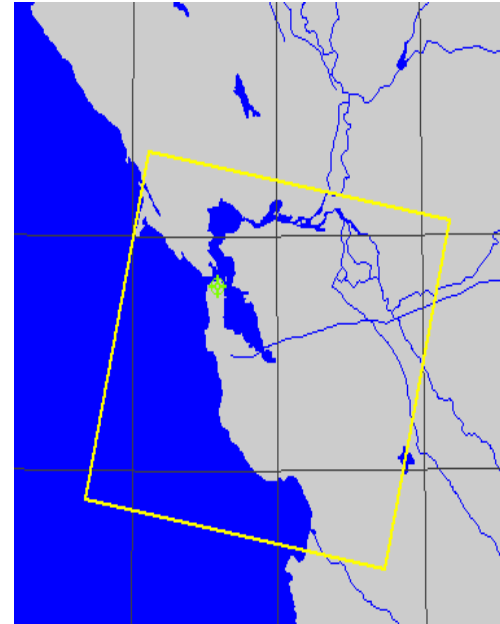


GeoEye  
(0.41m)

# Spatial Extent



**MODIS (1 km)**



**Landsat (30 m)**

Generally, the higher the spatial resolution the less area is covered by a single image



# NASA Satellite Measurements with Different Spatial Resolution

## Landsat Image of Philadelphia

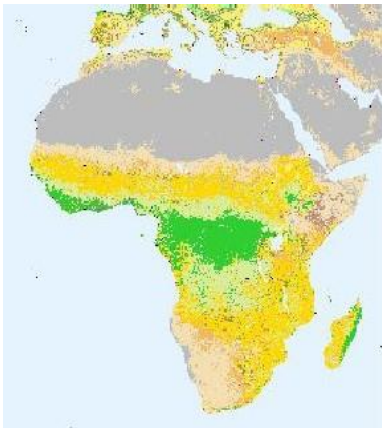
Spatial resolution: 30 m



## Land Cover from Terra/MODIS:

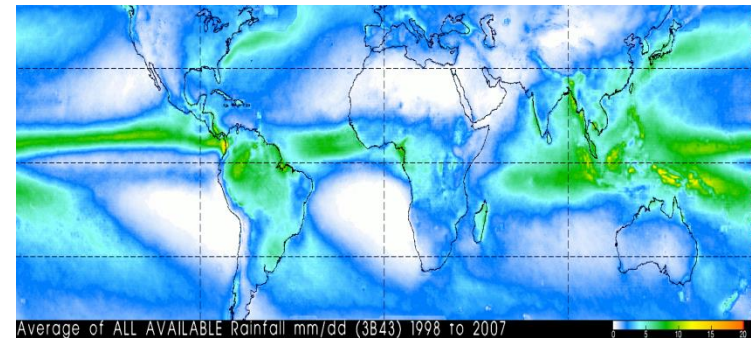
Spatial resolution: 1 km<sup>2</sup>

(From: <http://gislab.jhsph.edu/>)



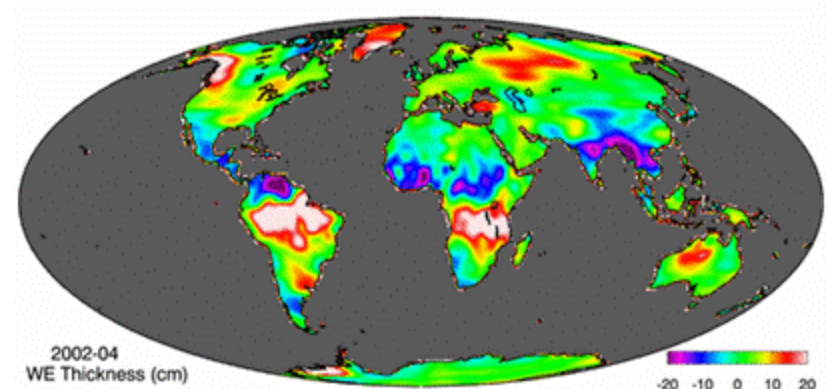
## Rain Rate from TRMM

Spatial resolution: 25 km<sup>2</sup>



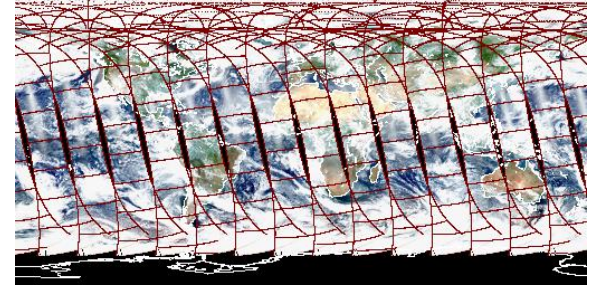
## Terrestrial Water Storage Variations from

**GRACE:** Spatial resolution: 150,000 km<sup>2</sup> or coarser  
(Courtesy: Matt Rodell, NASA-GSFC)



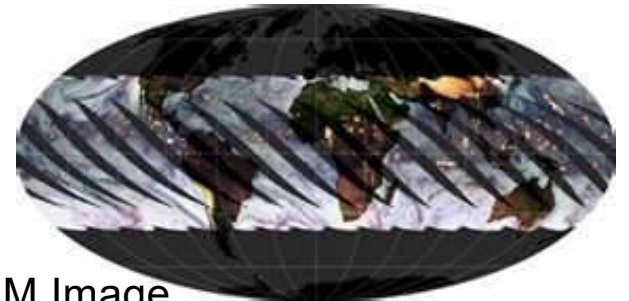
# Spatial Coverage and Temporal Resolution

**Polar orbiting satellites:** global coverage - but one to two or less measurements per day per sensor. Orbital gaps present. Larger Swath size, higher the temporal resolution.



Aqua ( “ascending” orbit) day time

**Non-Polar orbiting satellites:** Less than one per day. Non-global coverage. Orbital gaps present. Larger Swath size, higher the temporal resolution.



TRMM Image

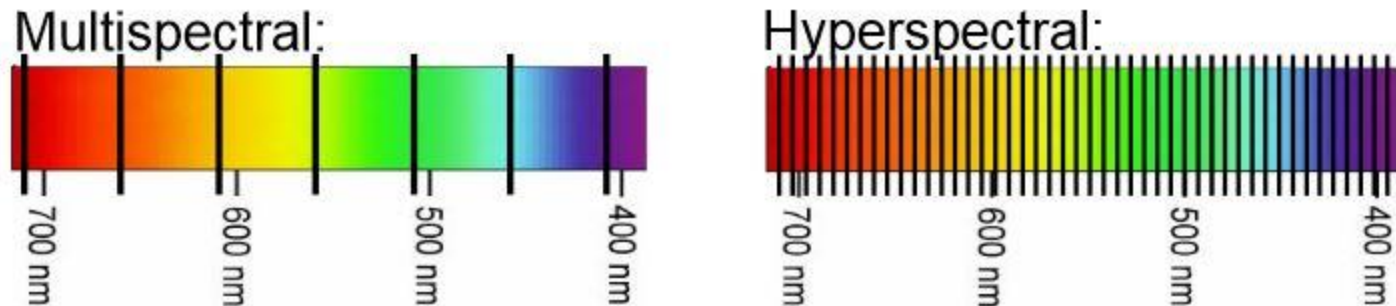
**Geostationary satellites:** multiple observations per day, but limited spatial coverage, more than one satellite needed for global coverage.



GOES Image

# Spectral and Radiometric Resolution

**Spectral Resolution:** The number and width of spectral channels. More and finer spectral channels enable remote sensing of different parts of the atmosphere



**Radiometric Resolution:** Remote sensing measurements represented as a series of digital numbers – the larger this number, the higher the radiometric resolution, and the sharper the imagery. © NASA



# Examples of Optical Sensors and Satellites

Sensors	Satellite	Bands	Spatial Resolution	Revisit Period
MSI	Sentinel-2	VIS, SWIR	10, 20, 60 m	10 / 5 days (with combined constellation)
OLCI, SLSTR	Sentinel-3	VIS, SWIR, TIR	300, 500, 1000 m	27 days
AVHRR	NOAA	VIS, SWIR, TIR	1000 m	Daily
MODIS	TERRA, AQUA	VIS, SWIR, TIR	1000 m	Daily, 2, 8, 16 days
ASTER	TERRA	VIS, SWIR, TIR, Stereo	15, 30, 90 m	16 days
ETM+	Landsat 5, 7	VIS, SWIR, TIR	15, 30, 60 m	8 days
OLI, TIRS	Landsat 8, 9	VIS, SWIR, TIR	15, 30, 100 m	8 days
HRV	SPOT 5	VIS, SWIR	2.5, 5, 10 m	1 – 3 days
Dig-Camera	IKONOS	VIS<, NIR (4 Chan.)	1, 4 m	1-3 days
Dig-Camera	QuickBird	VIS, NIR (4 Chan.)	0.7, 2.5 m	3 days
Dig-Camera	Pleiades	VIS, NIR	0.5, 2 m	Daily

# Remote Sensing Observations : Trade Offs

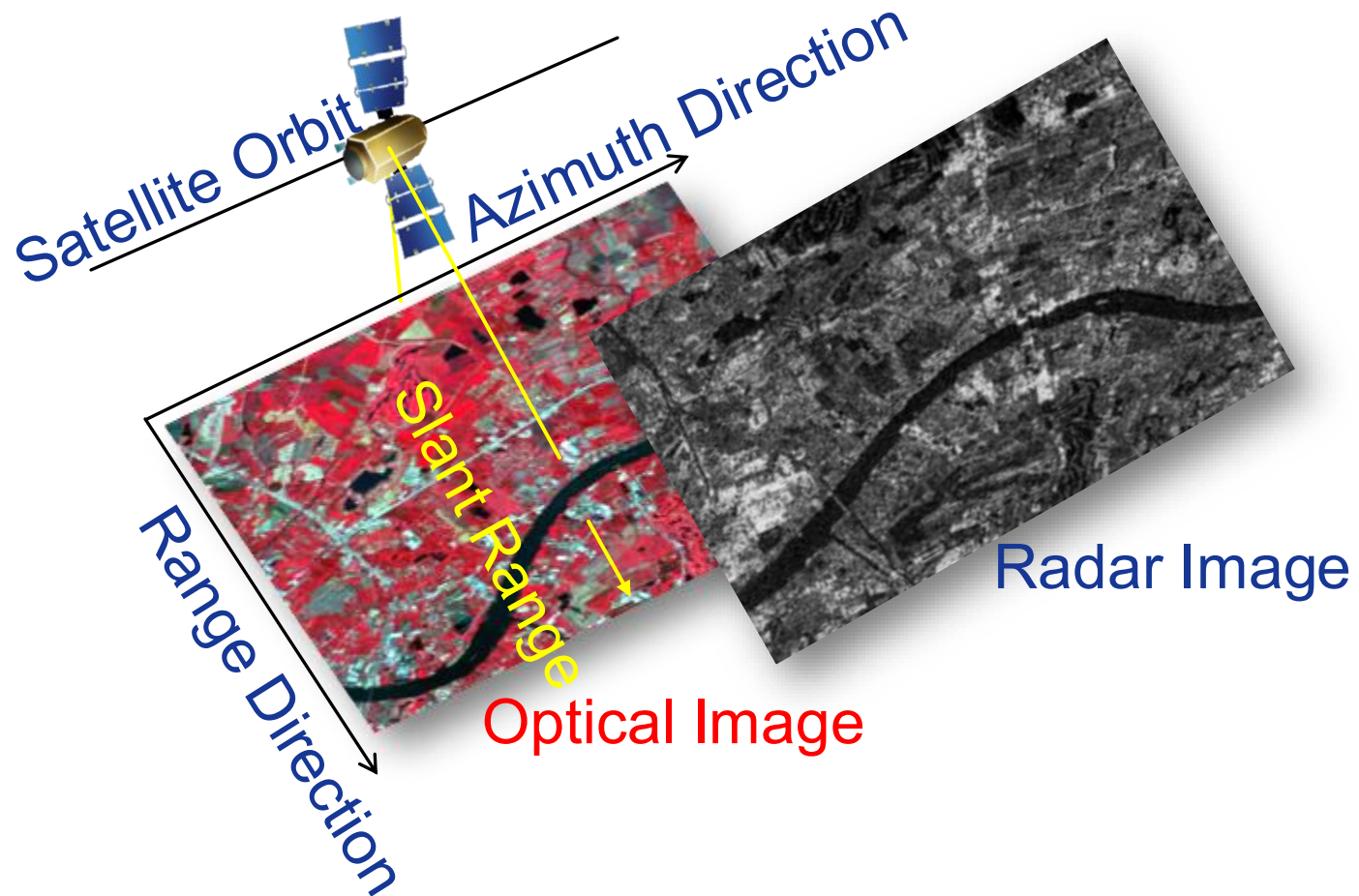
- It is very difficult to obtain extremely high spectral, spatial, temporal and radiometric resolution at the same time
- Several sensors can obtain global coverage every one – two days because of their wide swath width
- Higher spatial resolution polar/non-polar orbiting satellites may take 8 – 16 days to attain global coverage
- Geostationary satellites obtain much more frequent observations but at lower resolution due to the much greater orbital distance
- Large amount of data with varying formats
- Data applications may require additional processing, visualization and other tools



# Microwave Remote Sensing



# SAR Image Vs Optical

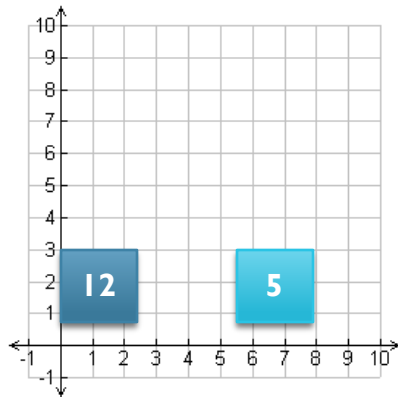


The radar "sees" the scene in a very different way from the human eye or from an optical sensor.

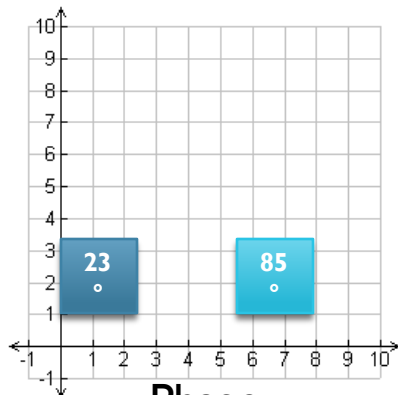
# SAR Image



00.15



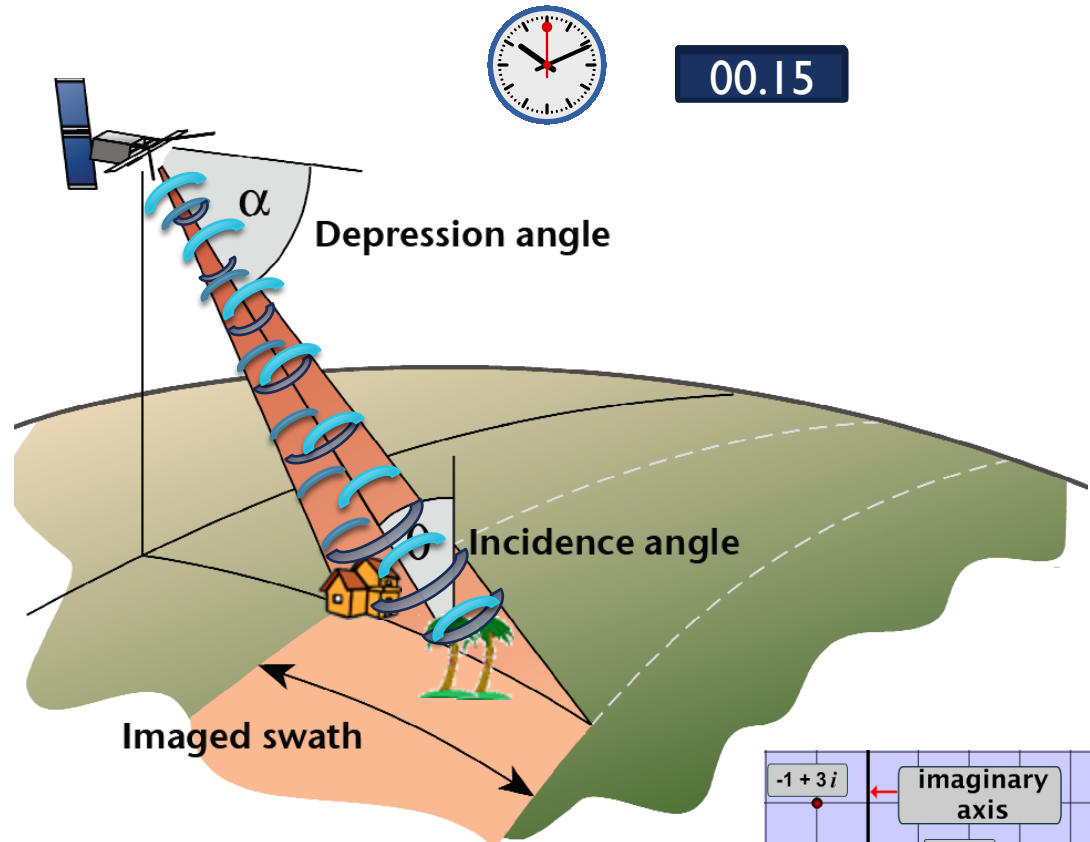
Amplitude



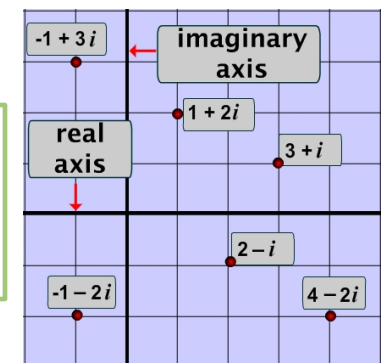
Phase

Single SAR image

Single Polarization

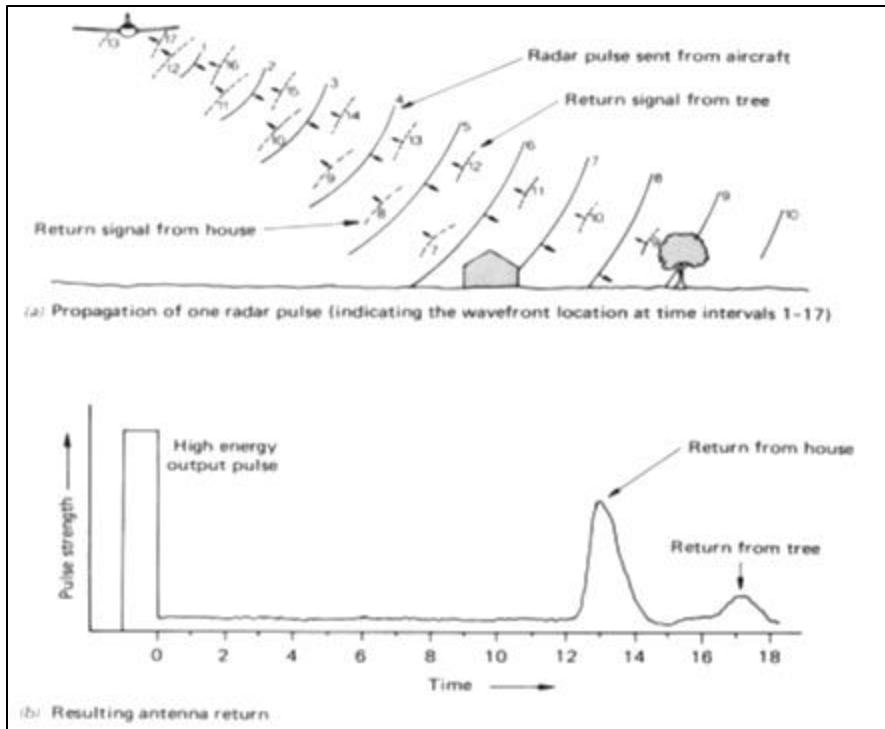


The data is stored as complex numbers (real and imaginary)



# Radar Signal to Imaging

## Amplitude and Phase (SAR Signal Characteristics)



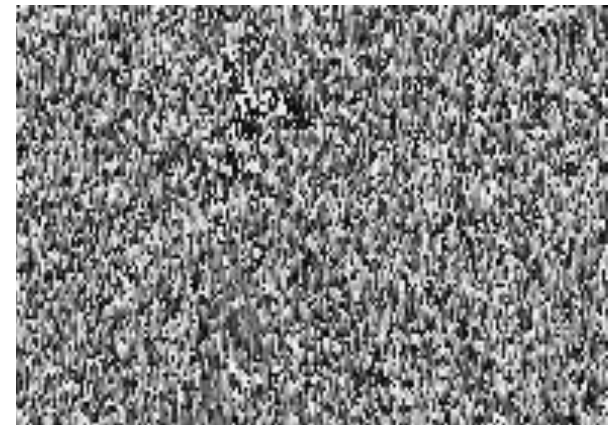
**Amplitude (A):** Strength of the radar response (Height of EM wave)

**Intensity ( $I = A^2$ )** = proportion of microwave backscattered from target to sensor

**Phase ( $\Phi$ )** : Fraction of one complete sine wave (determined by the distance between the satellite antenna and the ground targets.



**Amplitude (A)**



**Phase ( $\Phi$ )**

# Radar Wavelengths

Band	Frequency (GHz)	Wavelength (cm)	Type Application
<b>Ka</b>	27 – 40 GHz	1.1 – 0.8	Rarely used for SAR (airport surveillance)
<b>K</b>	18 – 27 GHz	1.7 – 1.1	rarely used (H <sub>2</sub> O absorption)
<b>Ku</b>	12 – 18 GHz	2.4 – 1.7	rarely used for SAR (satellite altimetry)
<b>X</b>	8 – 12 GHz	3.8 – 2.4	High resolution SAR (urban monitoring; ice and snow, little penetration into vegetation cover; fast coherence decay in vegetated areas)
<b>C</b>	4 – 8 GHz	7.5 – 3.8	SAR Workhorse (global mapping; change detection; monitoring of areas with low to moderate penetration; higher coherence); ice, ocean maritime navigation
<b>S</b>	2 – 4 GHz	15 – 7.5	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)
<b>L</b>	1 – 2 GHz	30 – 15	Medium resolution SAR (geophysical monitoring; biomass and vegetation mapping; high penetration, InSAR)
<b>P</b>	0.3 – 1 GHz	100 - 30	Biomass. First p-band spaceborne SAR will be launched ~2020; vegetation mapping and assessment. Experimental SAR.

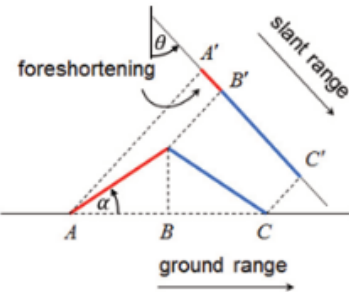
Source: <https://www.earthdata.nasa.gov/learn/backgrounders/what-is-sar>



# Geometric distortions on SAR images

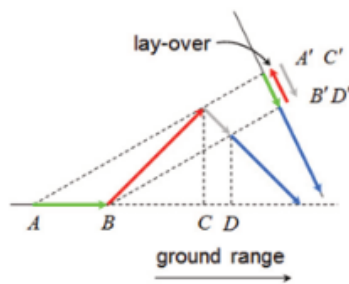
## FORESHORTENING

- Sensor-facing slope foreshortened in image
- Foreshortening effects *decrease* with increasing look angle



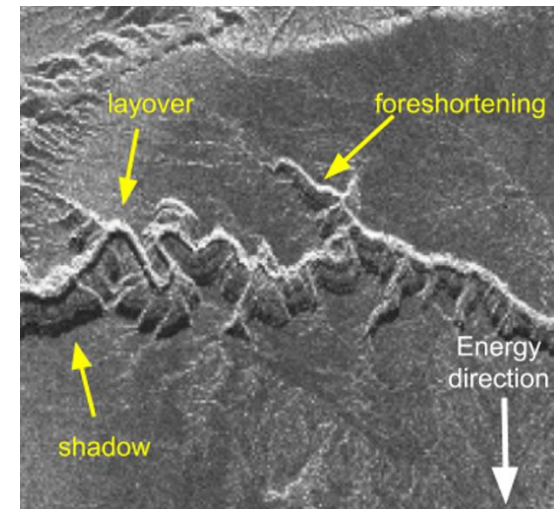
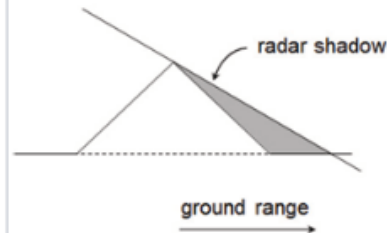
## LAYOVER

- Mountain top overlain on ground ahead of mountain
- Layover effects *decrease* with increasing look angle



## SHADOW

- Area behind mountain cannot be seen by sensor
- Shadow effects *increase* with increasing look angle



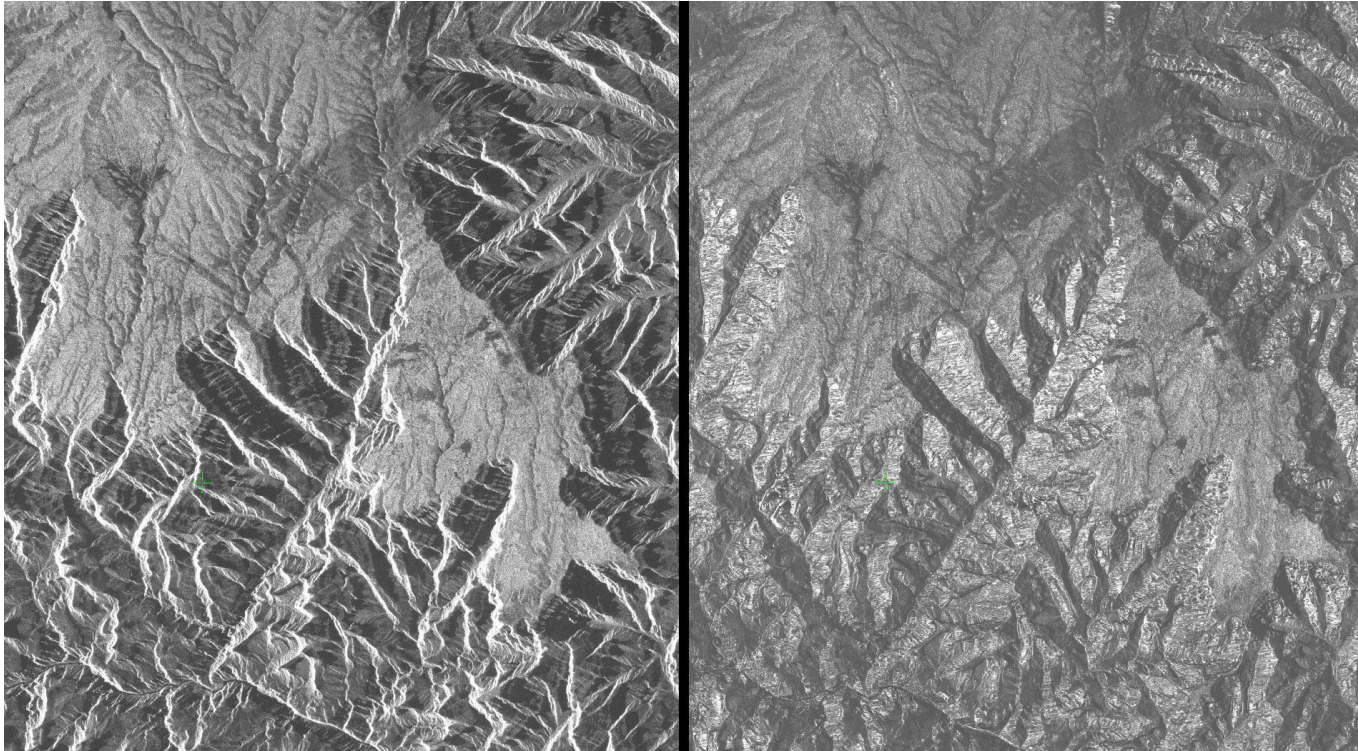
Examples of Geometric Effects in SAR Imagery (Image Credit: ERS, ESA 2011. Retrieved from ASF DAAC 20 January 2020.

Source: Flores, Anderson., Herndon, K. E., Thapa, R. B., & Cherrington, E. (2019). *THE SAR Comprehensive Methodologies for Forest*. 307.

<https://doi.org/10.25966/nr2c-s697>

<https://www.capellaspace.com/sar-101-an-introduction-to-synthetic-aperture-radar/>

# Terrain Correction SAR images



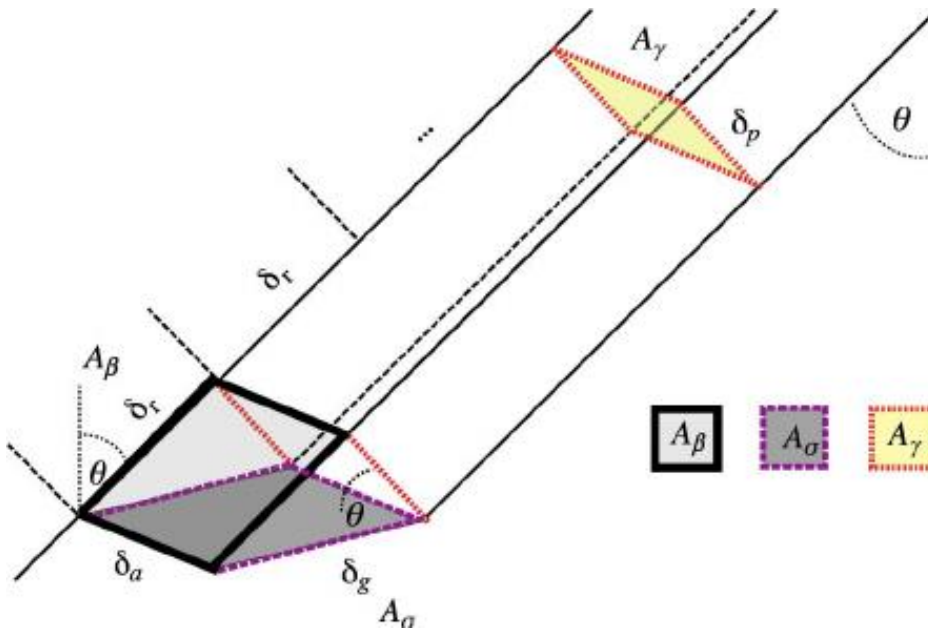
These two images of part of the Grand Canyon are processed from the same PALSAR data. The image on the left is uncorrected. The image on the right is terrain-corrected. In the uncorrected image, the sides of the canyon appear to be stretched on one side and compressed on the other side.

ASFDAAC 2014; Includes Material ©JAXA/METI 2008. <https://www.asf.alaska.edu/sar-data/palsar/terrain-corrected-rtc/>

Source: G.P Salvatore Virdis (2019): AT 76.9037 Principles and Applications of InSAR; Satellite radar images.

# Radiometric Calibration

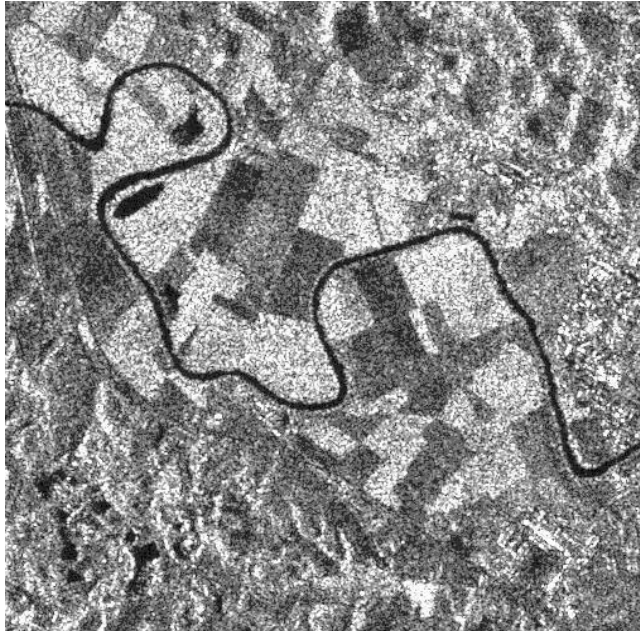
- Normalized Backscatter



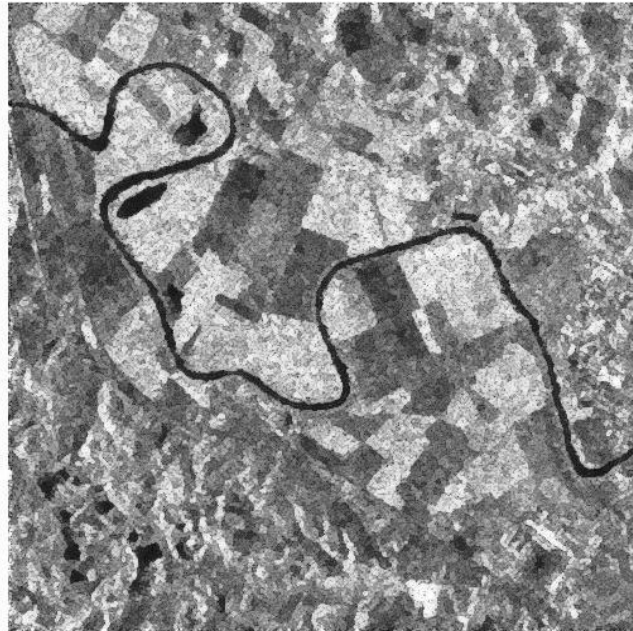
- Gamma ( $\gamma^\circ$ ) :  
normalized to an area perpendicular to the line of sight.
- Beta ( $\beta^\circ$ ): normalized to an area defined in slant range plane
- Sigma ( $\sigma^\circ$ ): normalizes the radar signal by the actual area on the ground.



# Speckle Effect



Original

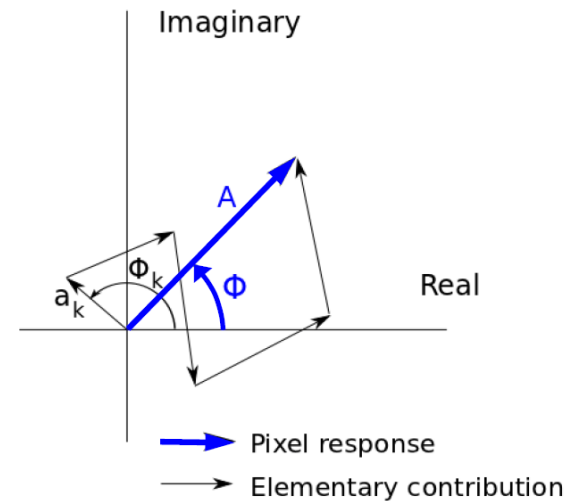
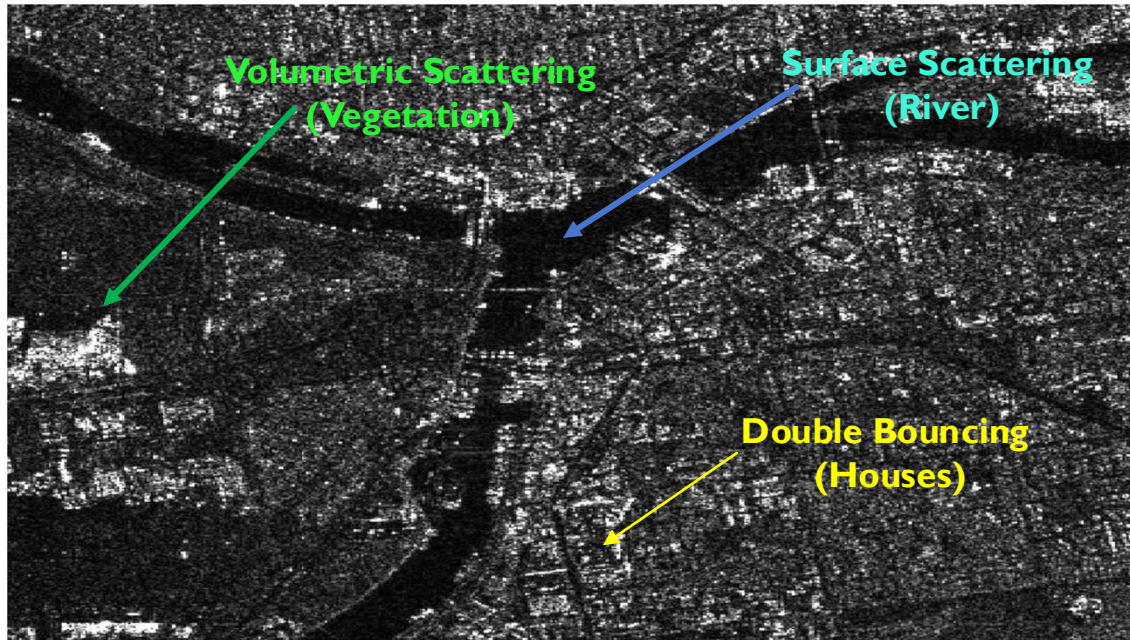


Removing Speckle Effects

Speckle occurs due to occurrence of individual scatters in each pixels combining positive and negative interferences (salt-and-pepper) effect.

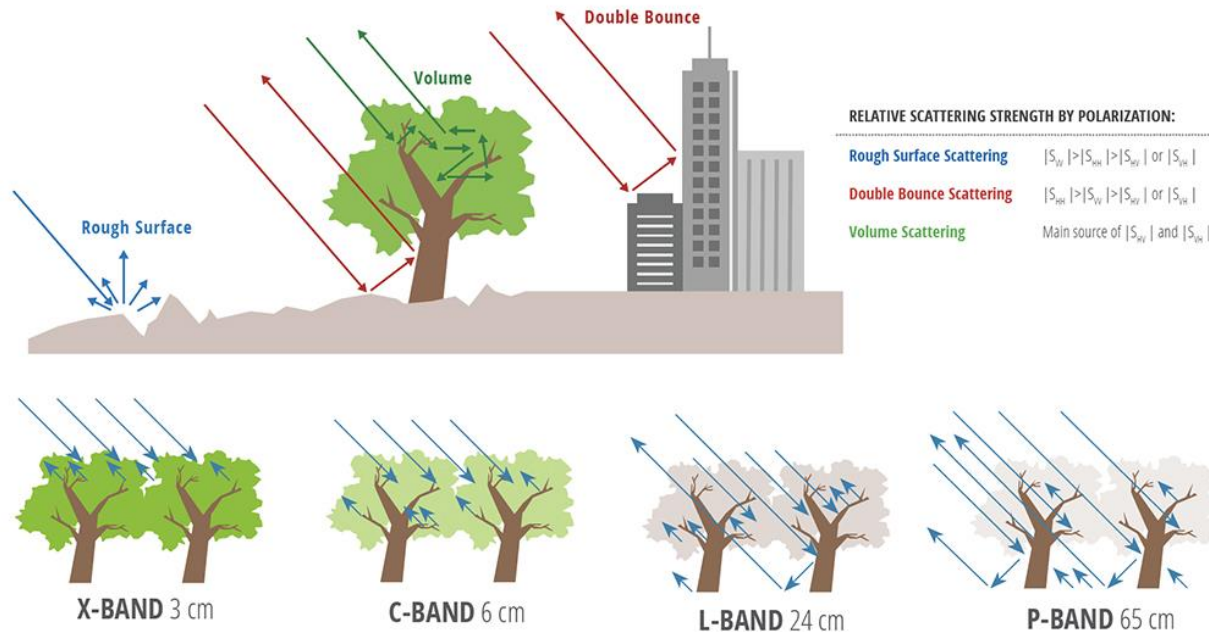
This causes otherwise uneven backscatter return, because generally SAR is a coherent imaging method.

# Scattering Mechanism of SAR Data



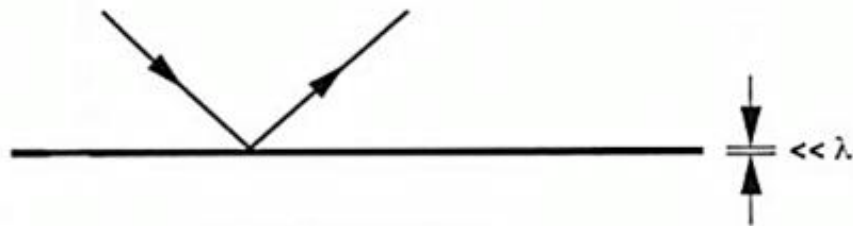
single look image detected by the Sentinel-1 mission.

# Radar Scattering and Radar Wavelength



- Depending on the wavelength of radar wave, the backscatter signal mechanism back to sensor will have different influences.
- But then, the type of the Earth's object also plays some role in backscatter.
- Penetration is controlled by wavelength type and object type.

# Surface Roughness can influence backscatter values



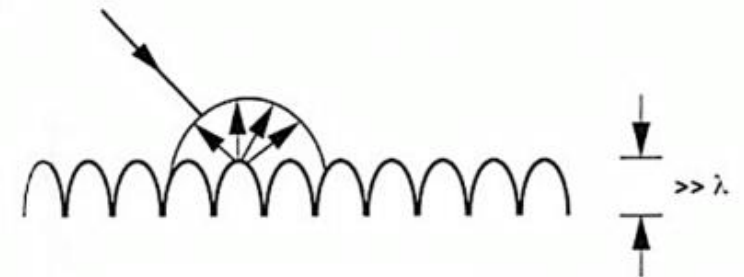
Smooth: no return



Moderately Rough: moderately diffuse



Slightly Rough: slightly diffuse

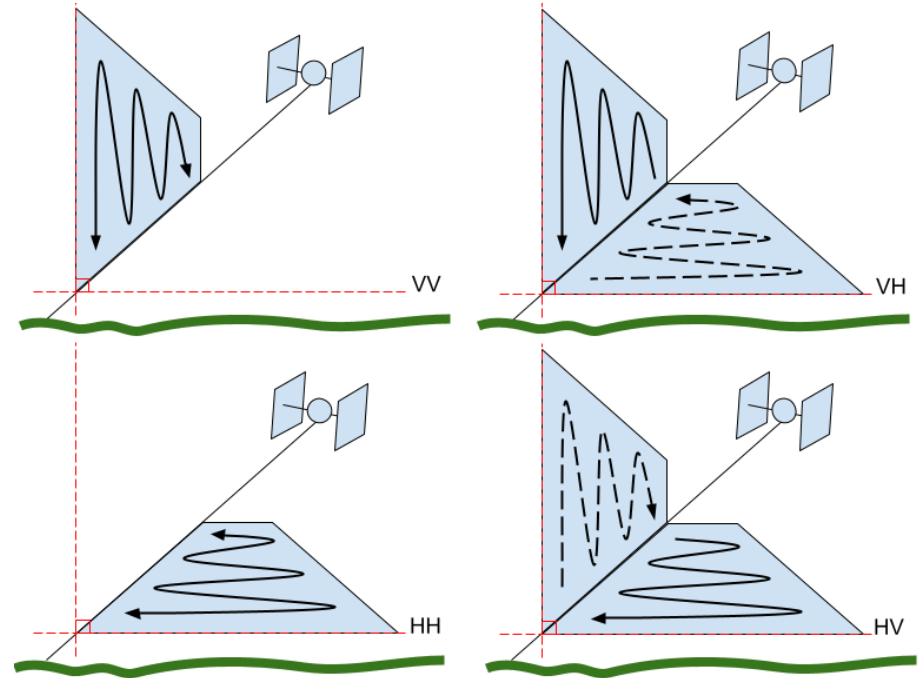


Very Rough: very diffuse



# Radar Polarization

- Polarization = orientation of the plane in which the transmitted electromagnetic wave oscillates.
- Four types:
  - VV
  - VH
  - HV
  - HH



*Note: V = Vertical, H = Horizontal.*

*1<sup>st</sup> element of pair = Transmit;*

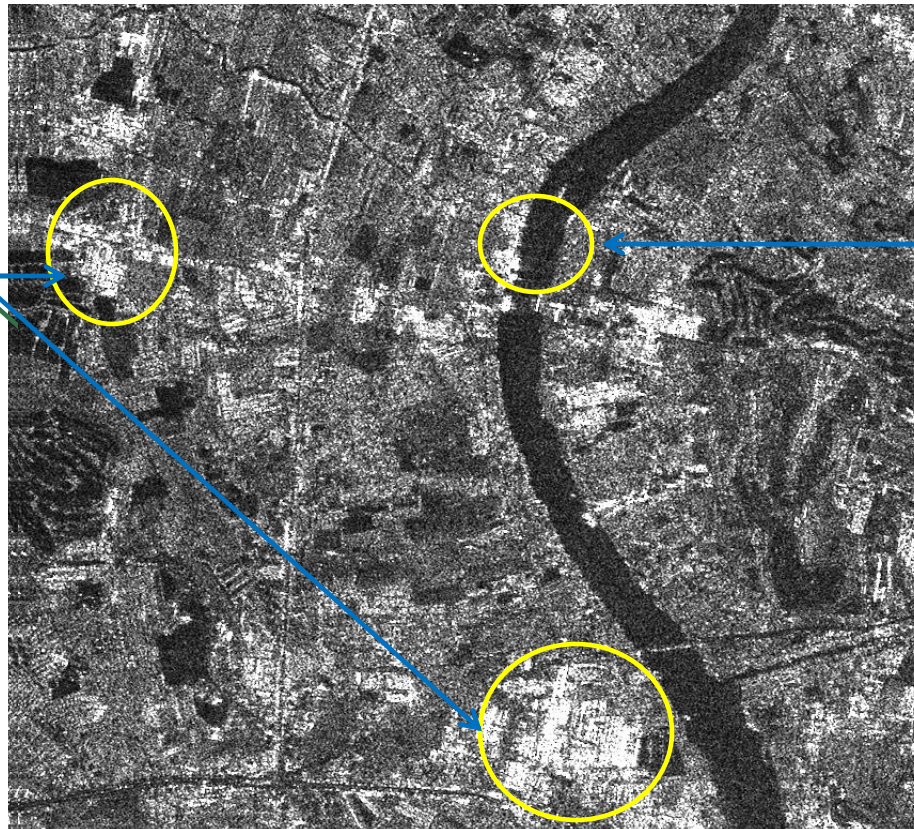
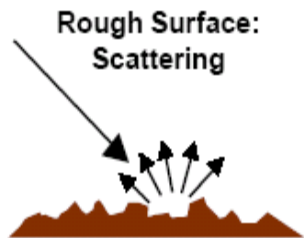
*2<sup>nd</sup> element of pair = Receive*

# Interpretation of SAR image

Each pixel in a SAR image contains a measurement of the amplitude of the radiation backscattered toward the radar by the object.

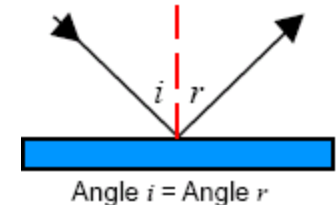
correspond to area of strong backscattered radiation and **dark pixels** correspond to low backscattered radiation.

Urban areas  
with strong  
backscattered  
radiation



Water body  
with low  
backscattered  
radiation

Smooth Surface:  
Specular Reflection  
(no radar return)



ALOS/PALSAR FBD image over Bangkok ,Thailand

# Interferometric SAR (InSAR)

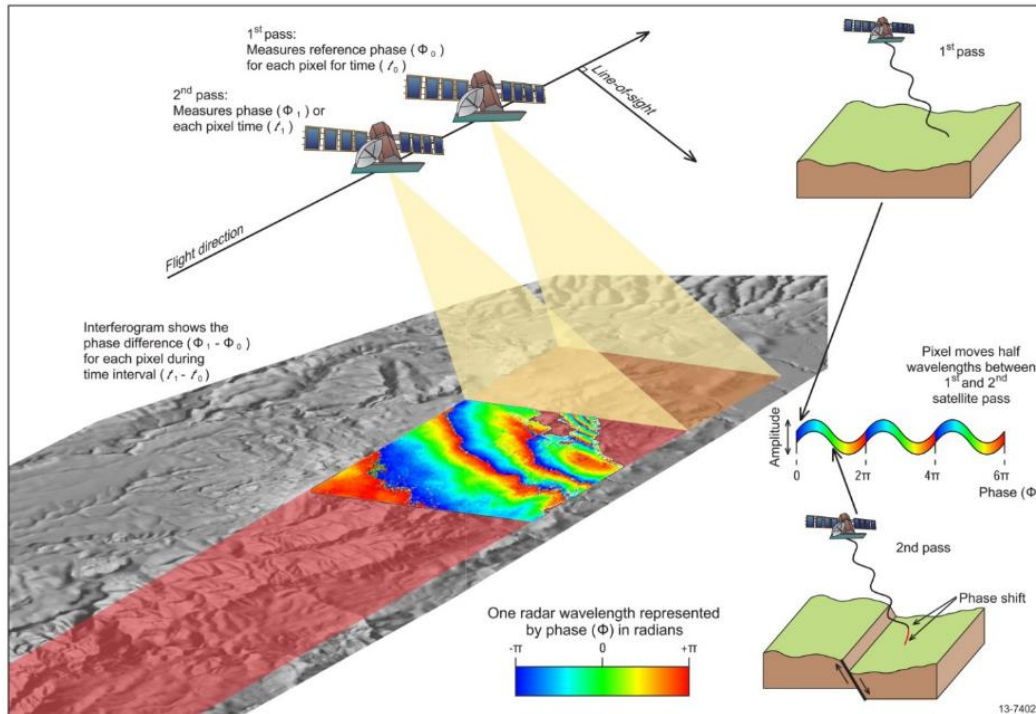


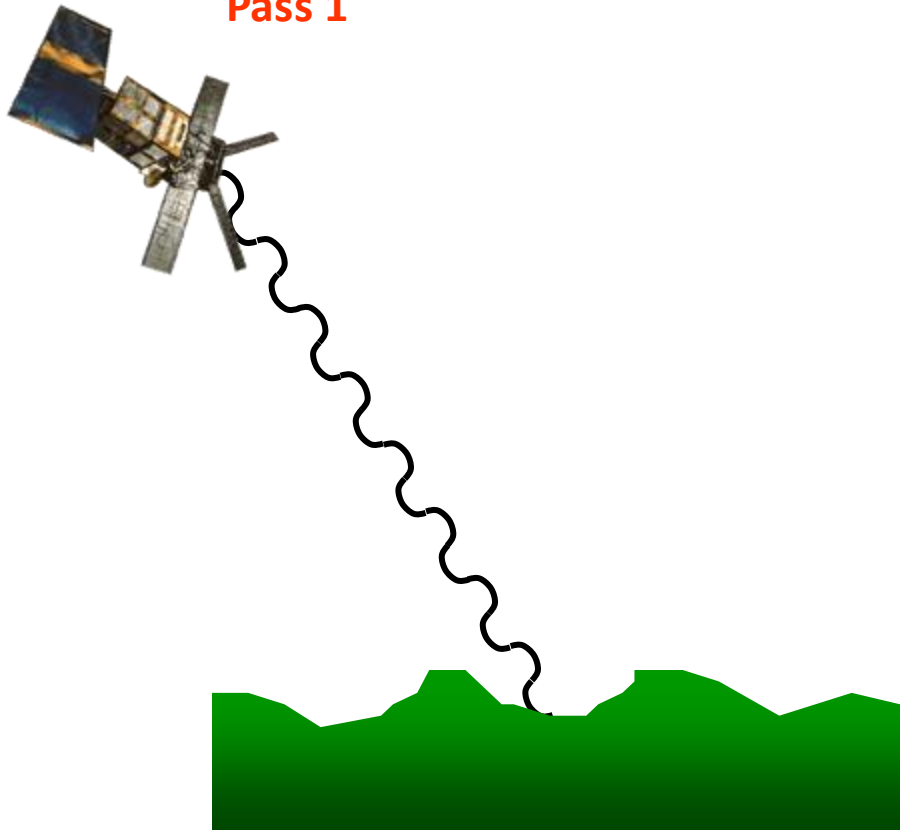
Figure 1.1: Cartoon depiction of the InSAR methodology. Two SAR images of the same area are acquired at different times. If the surface moves between the two acquisitions a phase shift occurs and an interferogram maps this phase difference.

- InSAR uses the phase information recorded by the sensor to measure the distance from the sensor to the target.
- When at least two observations of the same target are made, the distance, with additional geometric information from the sensor, can be used to measure changes in land surface topography. These measurements are very accurate (up to the centimeter level!)

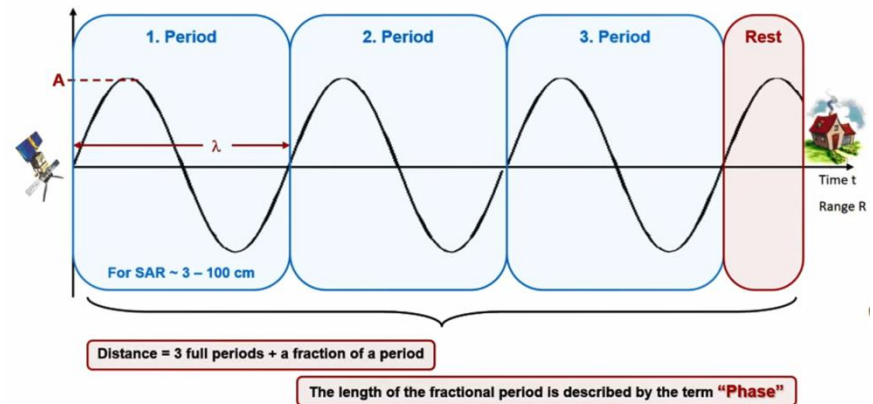
Source: Garthwaite, M. C., Nancarrow, S., Hislop, A., Thankappan, M., Dawson, J. H., & Lawrie, S. (2015). The Design of Radar Corner Reflectors for the Australian Geophysical Observing System: a single design suitable for InSAR deformation monitoring and SAR calibration at multiple microwave frequency bands. In Australian Gov Report (Issue April). <https://doi.org/10.11636/Record.2015.003>

# ■ Measuring Ground Deformation using InSAR

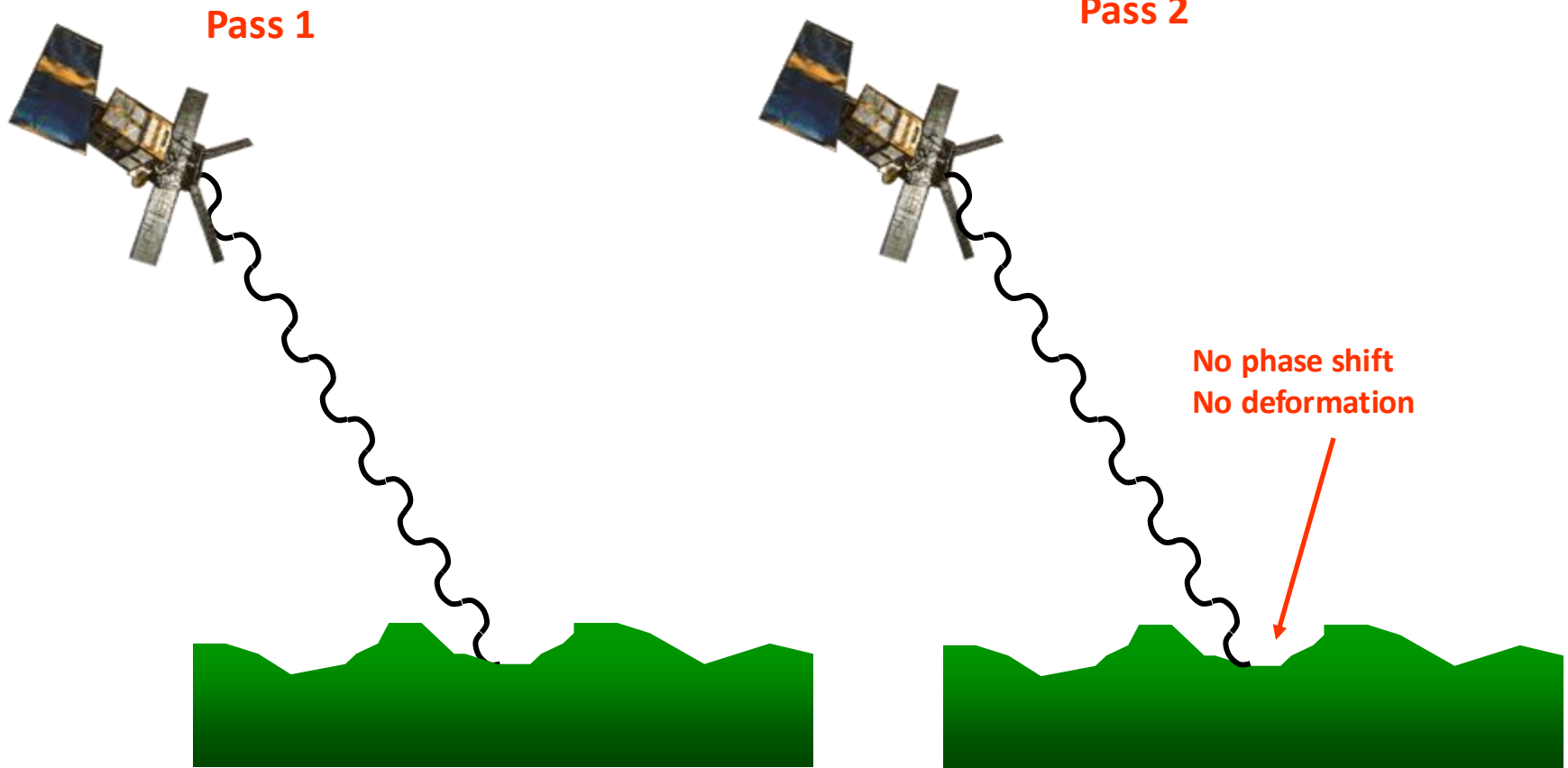
Pass 1



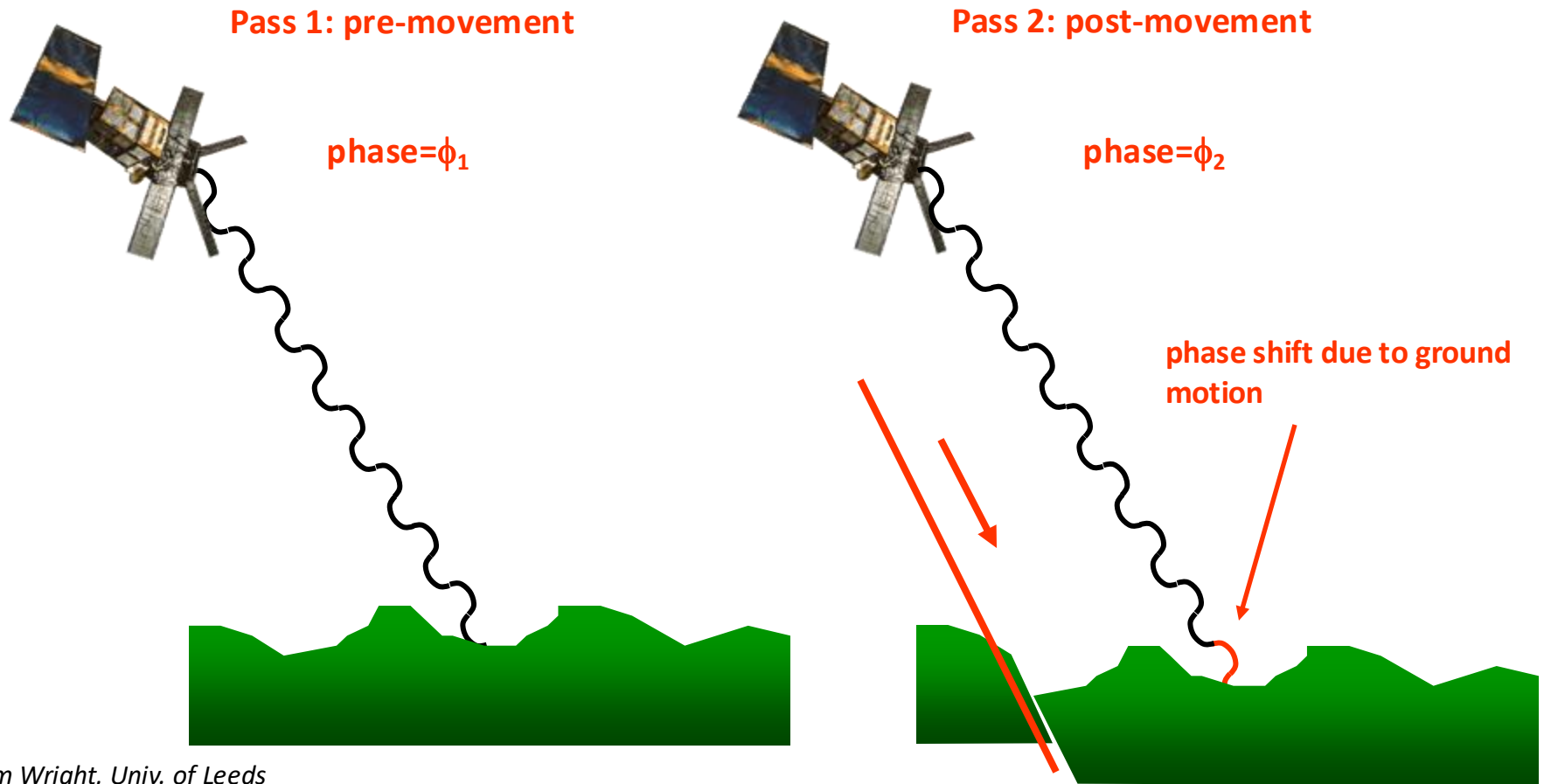
- A radar transmits electromagnetic waves in the radar spectrum
- Phase is a function of the distance from the satellite to the ground (range).



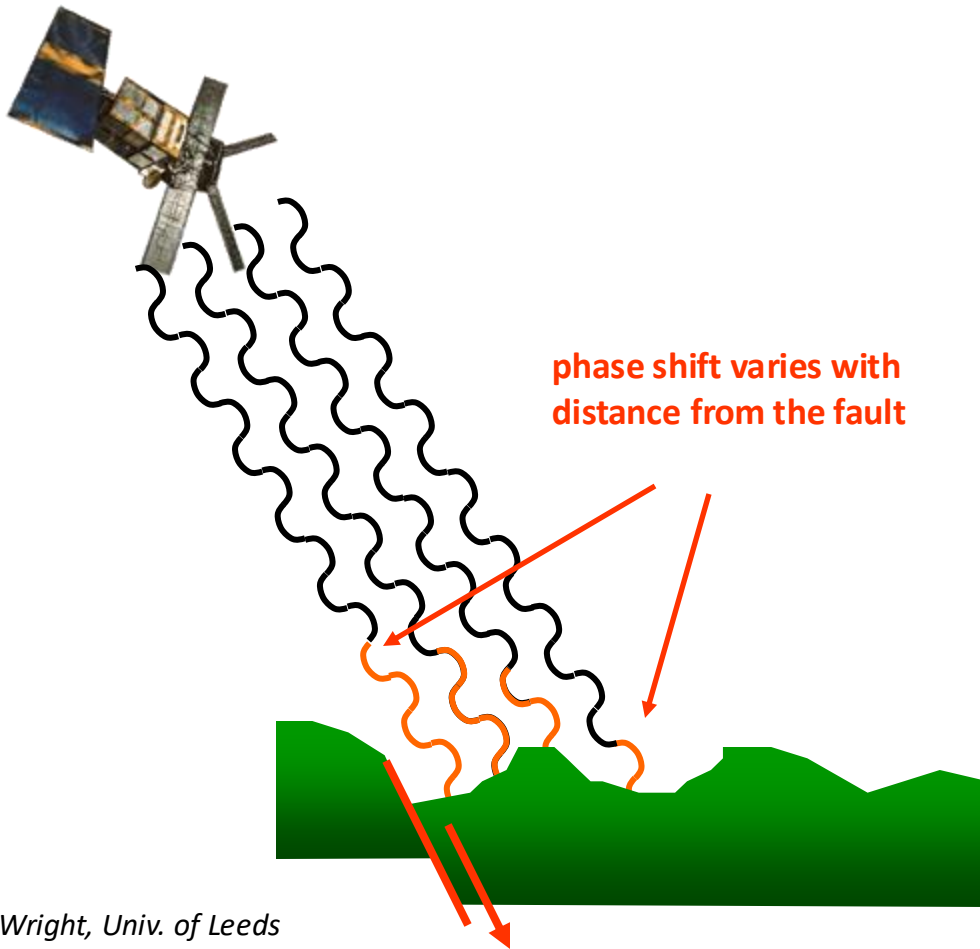
## ■ Measuring Ground Deformation using InSAR



## ■ Measuring Ground Deformation using InSAR

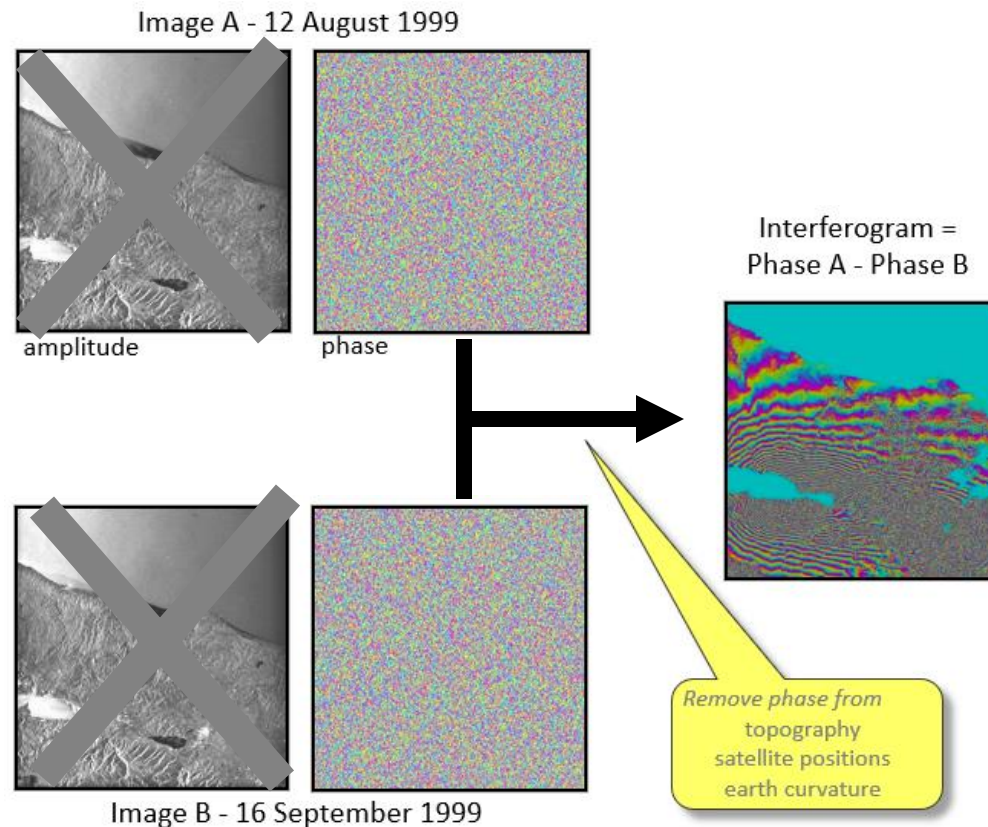


## ■ Measuring Ground Deformation using InSAR





## ■ Measuring Ground Deformation using InSAR



To form interferogram, we calculate:

$$I = u_1 \cdot u_2^*,$$

where  $^*$  is complex conjugate.

InSAR measurements are especially sensitive to topography, ground motion, atmospheric conditions, spatial separation between satellites, and the electrical properties of the ground.

$$\Delta\varphi = \varphi_{\text{flat}} + \varphi_{\text{topo}} + \varphi_{\text{orbit}} + \varphi_{\text{defo}} \\ + \varphi_{\text{tropo}} + \varphi_{\text{iono}} + \varphi_{\text{scat}} + \varphi_{\text{noise}}$$

# Available SAR satellites

**Table 8**  
SAR satellite systems.

Name	Launch	Country	Tandem option	Band	Polarization	Resolution range (m)	Swath width (km)	Orbit repeat cycle (day)
ERS-1	1991	EU	ERS-2	C	VV	30–26	102–84	35
ERS-2	1995	EU	ERS-1 and EnviSat	C	VV	30–26	102–84	35
EnviSat	2002	EU	ERS-2	C	VV, HH, VV + HH, HH + HV, VV + VH	28 × 28 950 × 980	5–400	35
RADARSAT-1	1995	Canada	RADARSAT-2	C	HH	8–100	45–500	24
RADARSAT-2	2007	Canada	RADARSAT-1	C	HH, VV, HV, VH (single, dual or quad)	3 × 1 100 × 100	18–500	24
ALOS	2006	Japan	No	L	HH, VV, HH + HV, VV + VH, HH + HV + VV + VH	7–100	30–450	46
ALOS-2	2014	Japan	No	L	HH, VV, HV, HH + HV, VV + VH, HH + HV + VV + VH	3 × 1 100 × 100	25–350	14
TerraSAR-X	2007	Germany	TanDEM-X	X	HH, VV, HV, VH (single or dual)	1 × 1 16 × 16	5 × 10–1500 × 100	11
TanDEM-X	2010	Germany	TerraSAR-X	X	HH, VV, HV, VH (single or dual)	1 × 1 16 × 16	5 × 10–1500 × 100	11
KOMPSAT-5	2013	South Korea	No	X	HH, HV, VH, VV	1–20	5–100	28
Sentinel-1	2014	EU	Twin sat in 2016	C	HH, VV, HH + HV, VV + VH	5 × 5 25 × 40	20–400	12

HH: Horizontal transmit and Horizontal receive, VV: Vertical transmit and Vertical receive, HV: Horizontal transmit and Vertical receive, VH: Vertical transmit and Horizontal receive.

# Multispectral vs Microwave

- **MapReady:** Developed by the Alaska Satellite Facility. More information and download: <https://asf.alaska.edu/how-to/data-tools/asf-mapready/>
- Sentinel Application Platform (**SNAP**): Developed by ESA. More information and download: <http://step.esa.int/main/download/>
- **PolSARpro**—Developed by ESA. More information and download: <https://earth.esa.int/web/polsarpro/home>.
- **GMTSAR:** <https://topex.ucsd.edu/gmtsar/>
- **ISCE2:** <https://github.com/isce-framework/isce2>

# Radar Signal to Imaging

Type of Remote Sensing	Advantages	Disadvantages
Multispectral	<ul style="list-style-type: none"><li>• A variety of temporal revisit (from daily to 16 days)</li><li>• Snow visible within spectral range</li><li>• Physics behind is quite well-studied.</li></ul>	<ul style="list-style-type: none"><li>• Coarser spatial resolution (Not for commercial satellites)</li><li>• Atmosphere correction required.</li><li>• Cloud, shadow cover.</li><li>• Limited for snow grain size researches.</li><li>• Confusion between snow, ice and cloud</li></ul>
Microwave	<ul style="list-style-type: none"><li>• Cloud penetration/ no effect by weather condition</li><li>• Day or night</li><li>• Finer spatial resolution</li><li>• Substantial ground penetration</li><li>• Polarization (V and H component)</li><li>• Interferometry possible.</li></ul>	<ul style="list-style-type: none"><li>• Image geometry</li><li>• <b>Low</b> temporal resolution</li><li>• Speckle effect</li><li>• Sensitive to moisture, water content in the ground.</li><li>• Required detailed understanding of radar system.</li></ul>

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# THANK YOU

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