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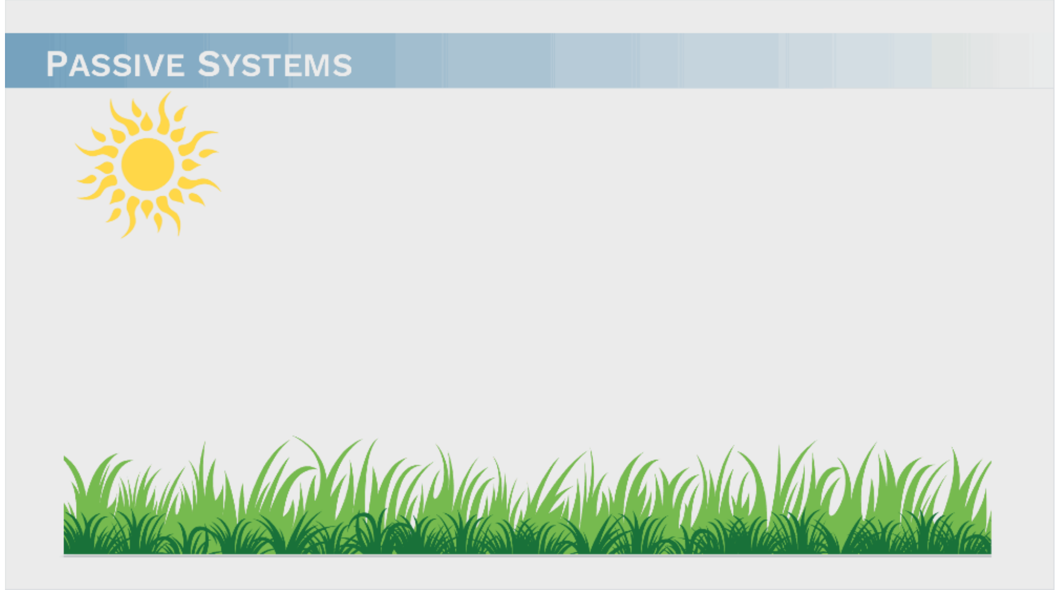
Radar Remote Sensing

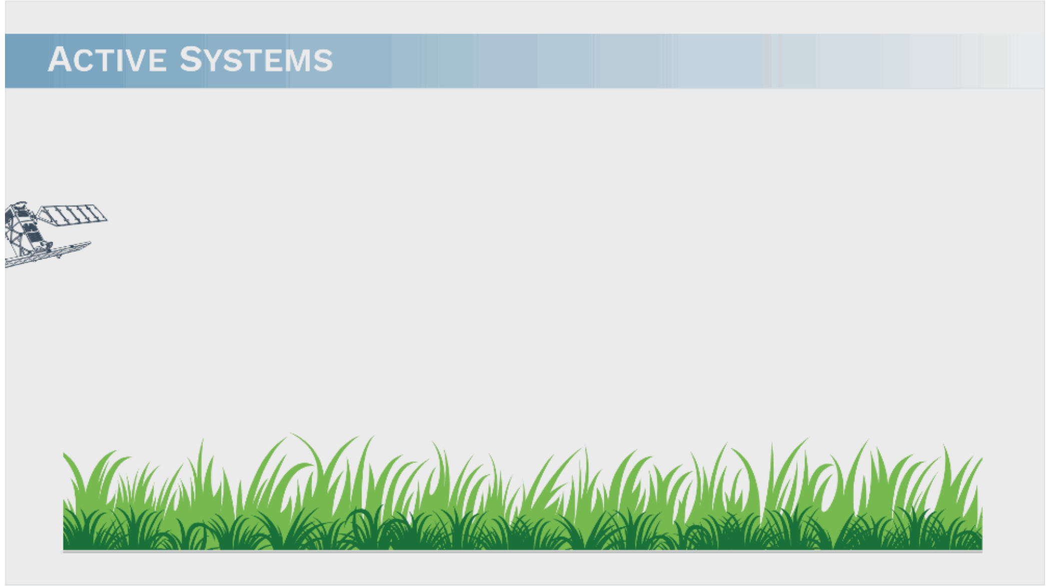
Passive remote sensing

- The sun illuminates the surface in its whole spectrum
- The ground scatters the energy back to the sensor
- The sensor captures the backscattered signal

Active remote sensing

- The satellite generate its own signal, with a certain frequency/polarization, that illuminates the ground
- The ground scatters the energy back to the sensor
- The sensor captures the backscattered signal in a certain polarization





Sources : Echoes In Space – EO College

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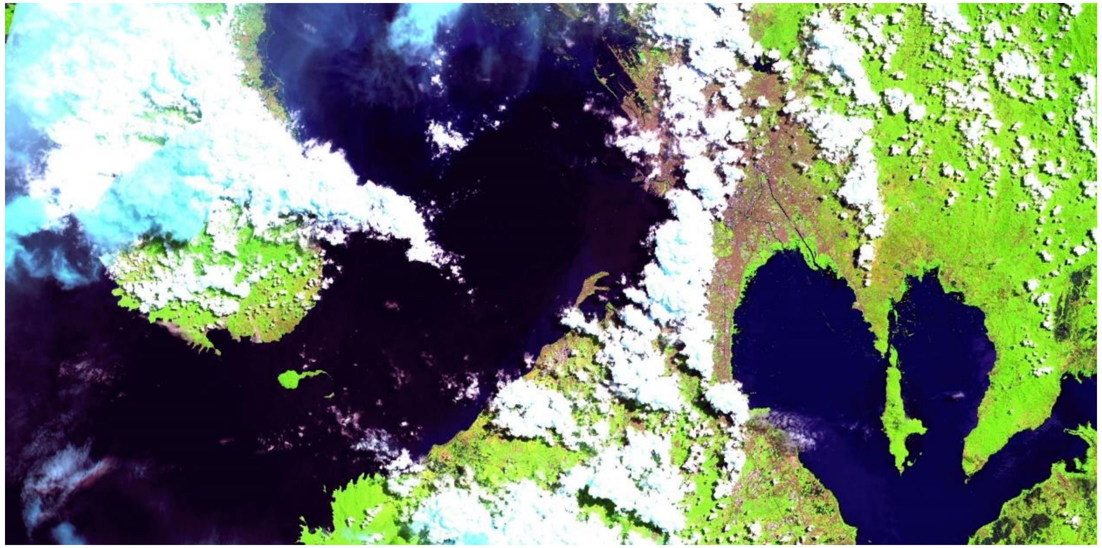
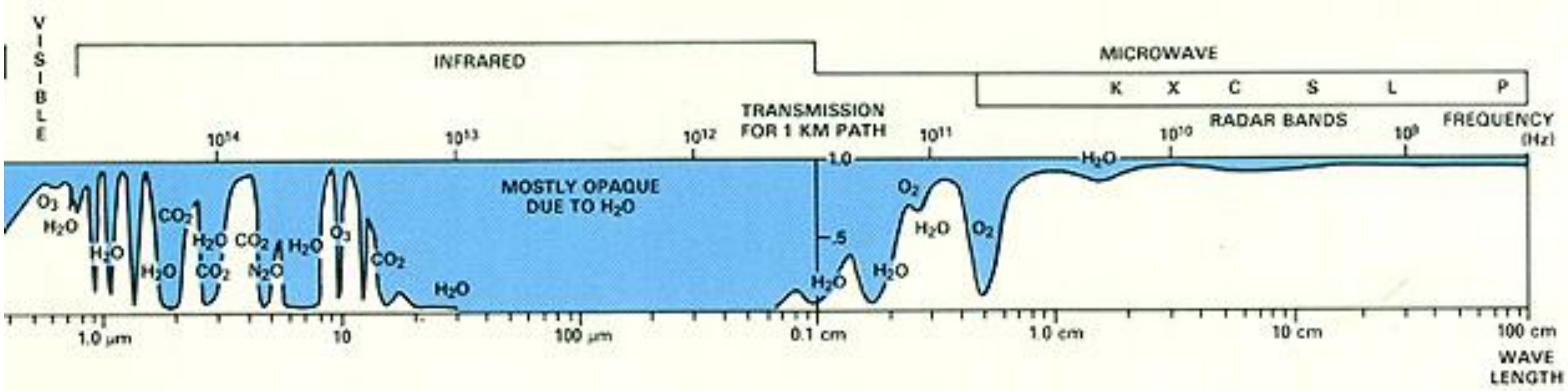
Advantages of Radar imagery

- Day and night observations
- Cloud and atmosphere penetration
- Choice of the frequency and polarization

→ Increase by a 10-factor the number of acquisitions compared to optical data

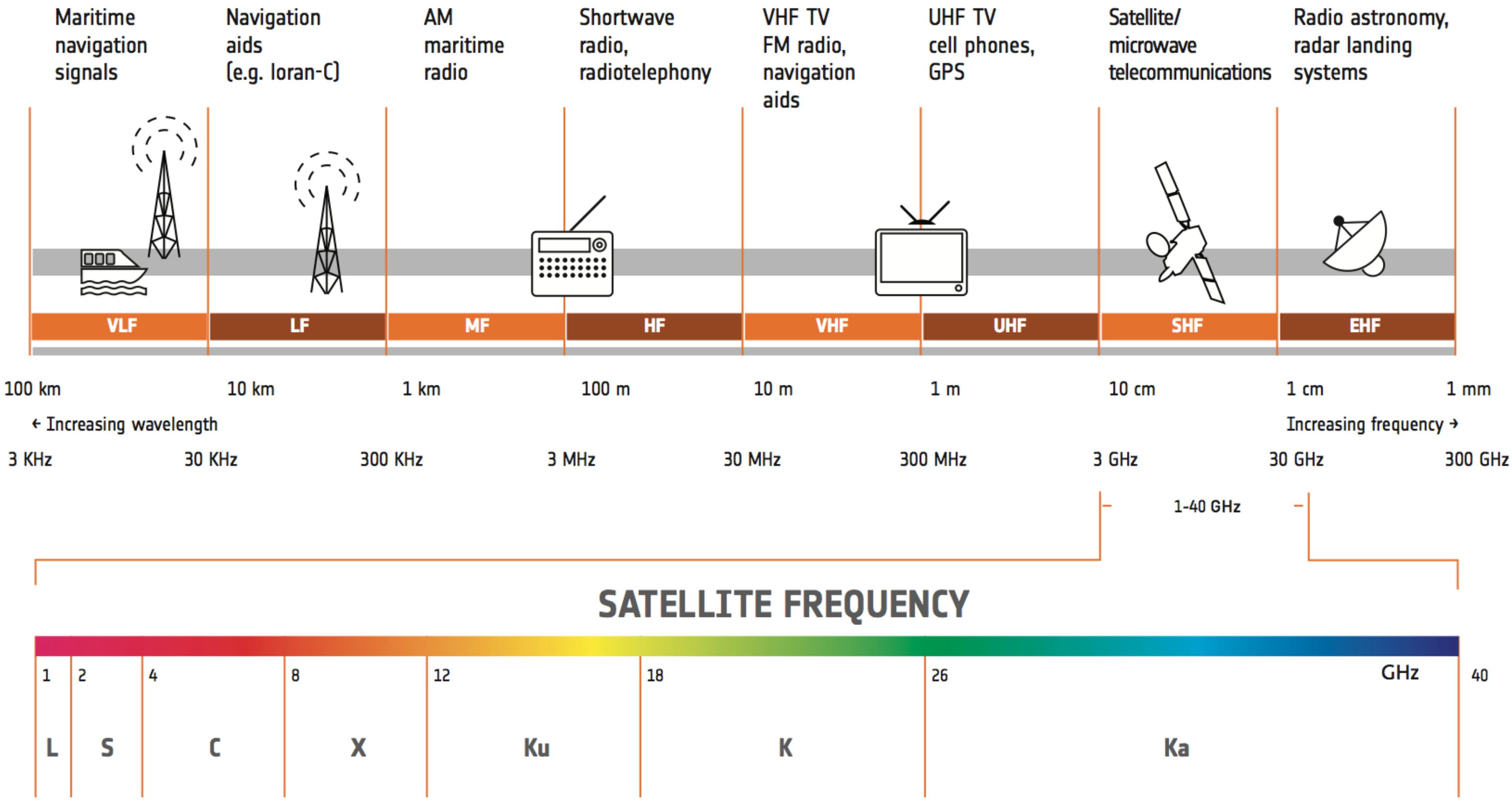




Sources : Remote Sensing – Christian Barbier

Frequency bands in radar remote sensing

- Between 1 and 40 GHz
- Ambiguous naming conventions
- Each band has properties, determining their application (topography, glaciology, ocean, …)
- The signal reacts strongly with elements of size similar to the wavelength employed



Sources : Echoes In Space – EO College

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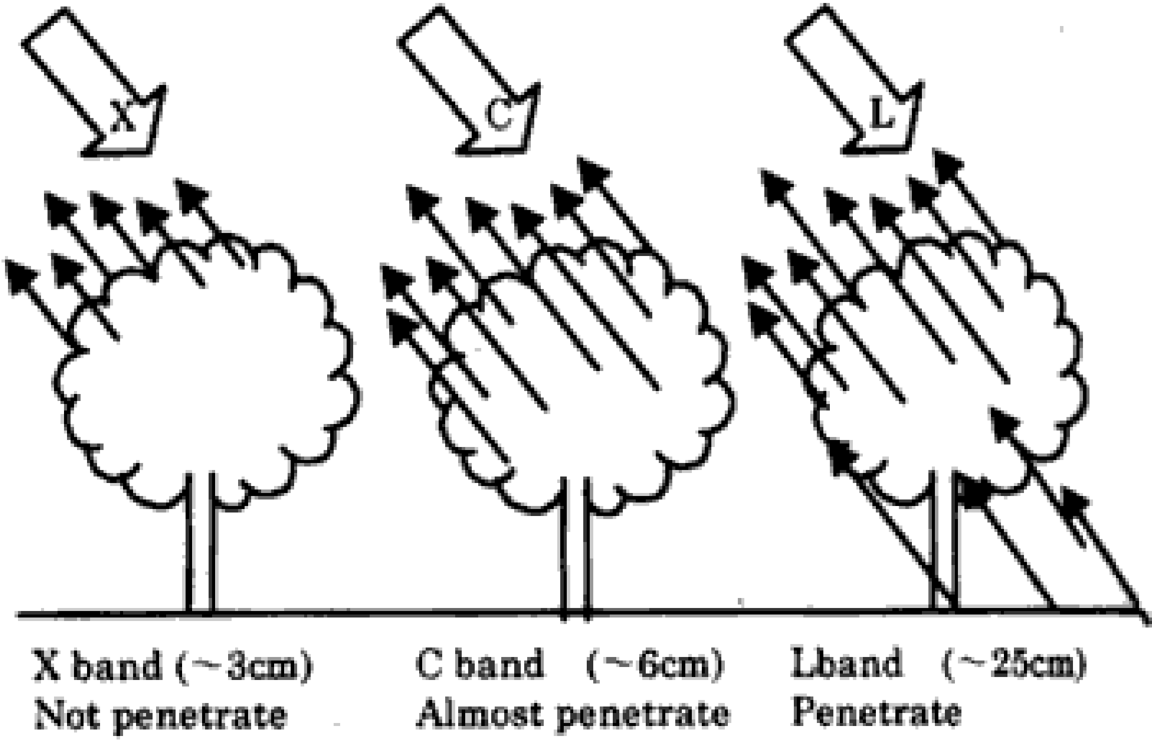
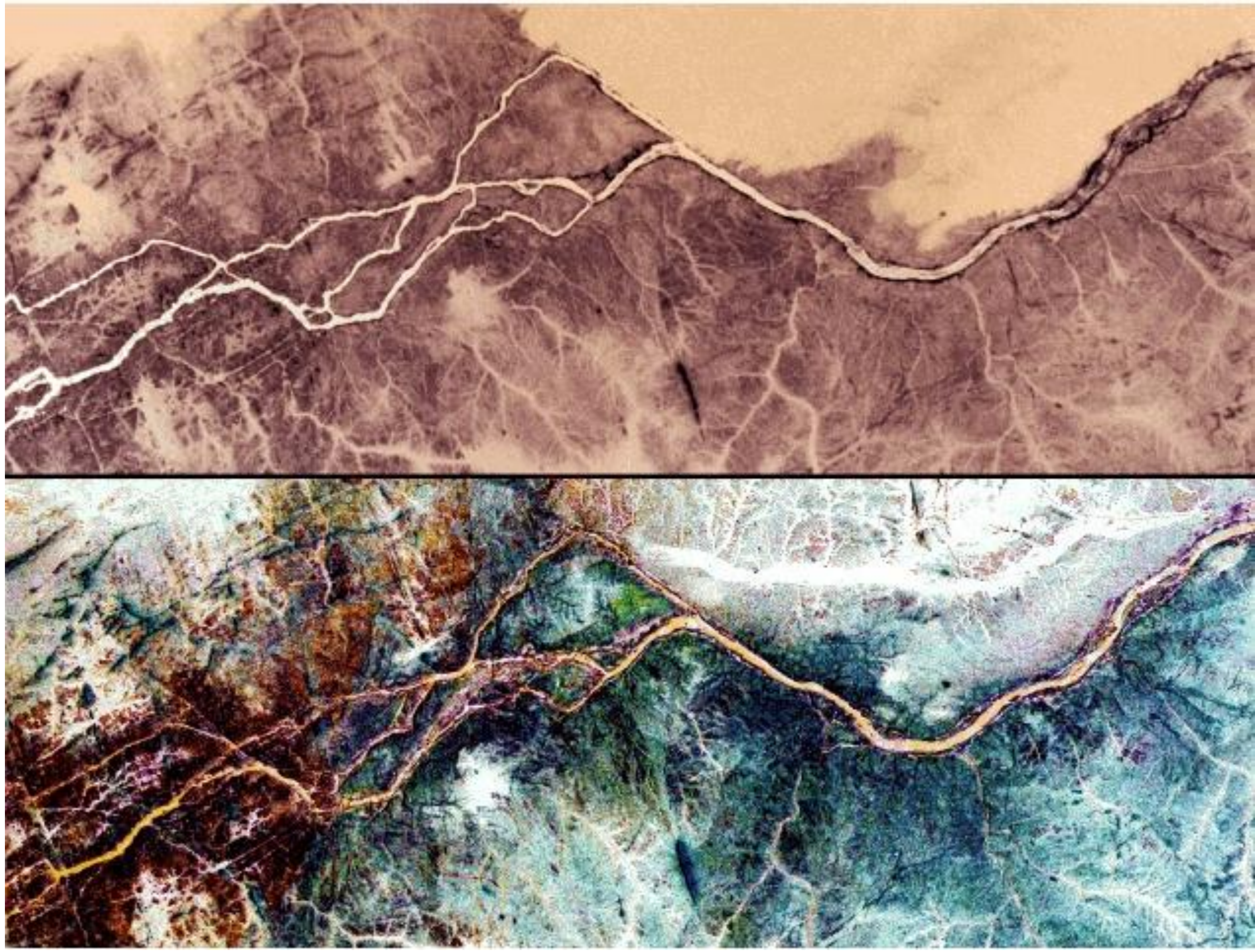
Frequency bands in radar remote sensing (example #1)

- Smaller wavelengths are stopped by the canopy of the trees (leaves)
- Longer wavelengths go through the canopy and interact with the ground



Sources : Remote Sensing – Christian Barbier

Optical Image (top) vs SAR-C image (bottom)



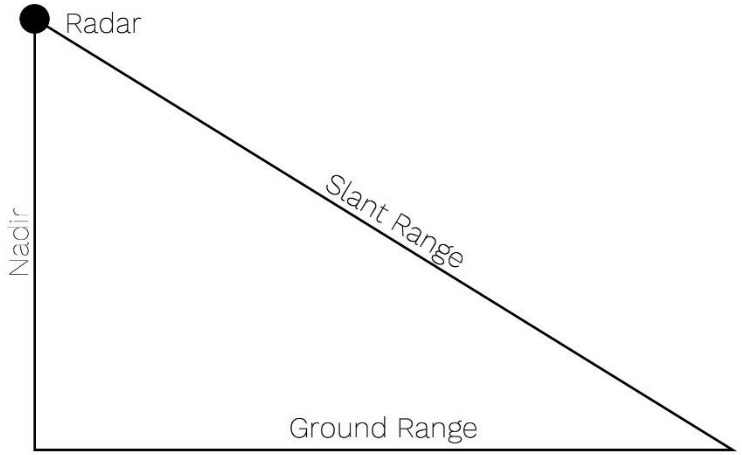
Sources : Introduction to the Physique and Techniques of Remote Sensing – C. Elachi

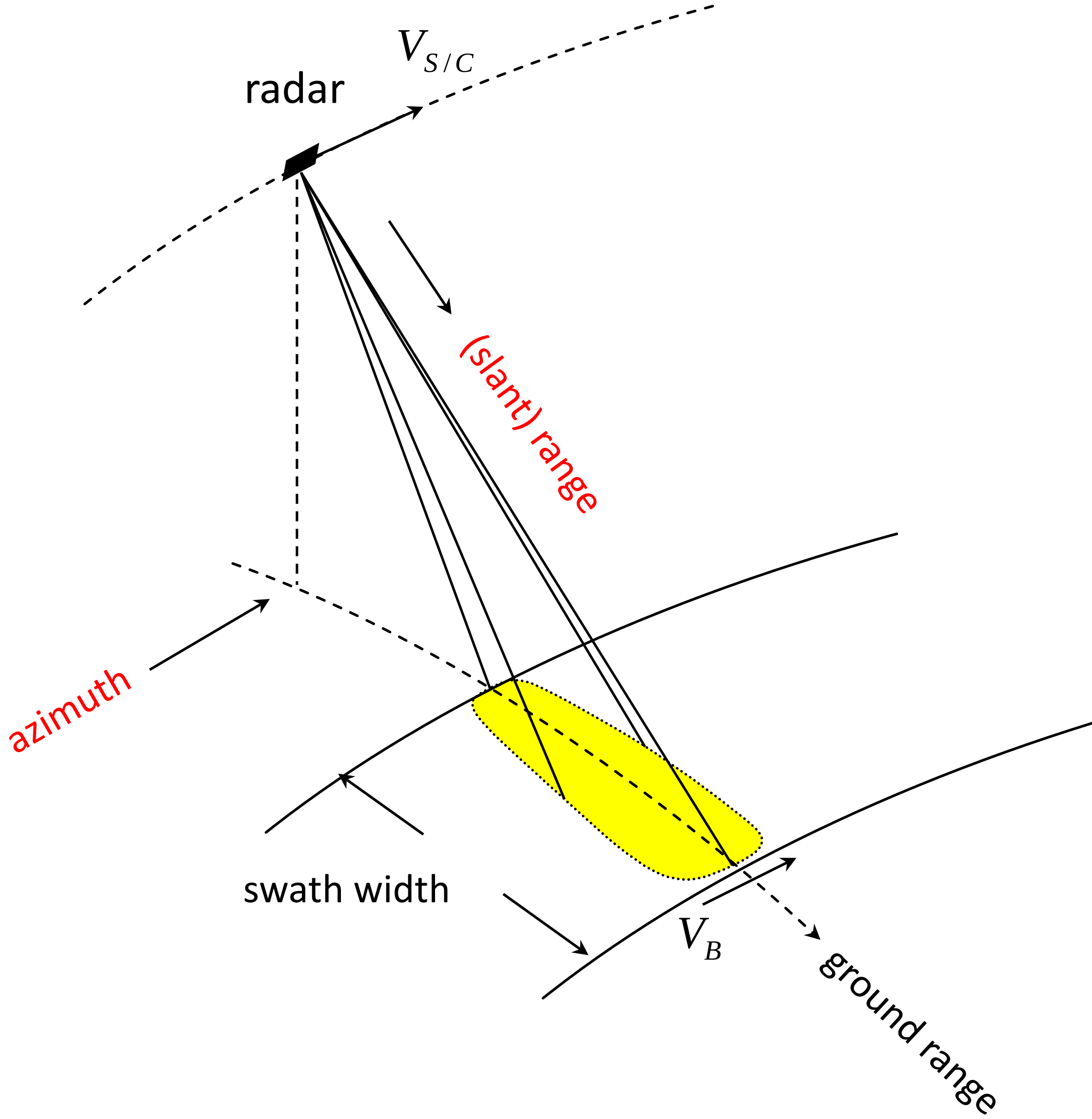
Frequency bands in radar remote sensing (example #2)

- Radar frequencies are able to penetrate into the ground
- Penetration depth are related to the wavelength and the soil humidity
- Using C-band SAR and working in arid environment, we can observe the old Nil river (Soudan)
- Radar brings a new Eye on geophysical elements

Acquisition Geometry

- The satellite sends its signal perpendicular to its orbit, and off-nadir (side-looking)
- Images coordinates corresponds to a geomery called *azimuth / slant-range*
- Slant-range axis corresponds to a distance from the satellite (not a distance projected to the ground)





Sources : SAR Imaging - SAREDU

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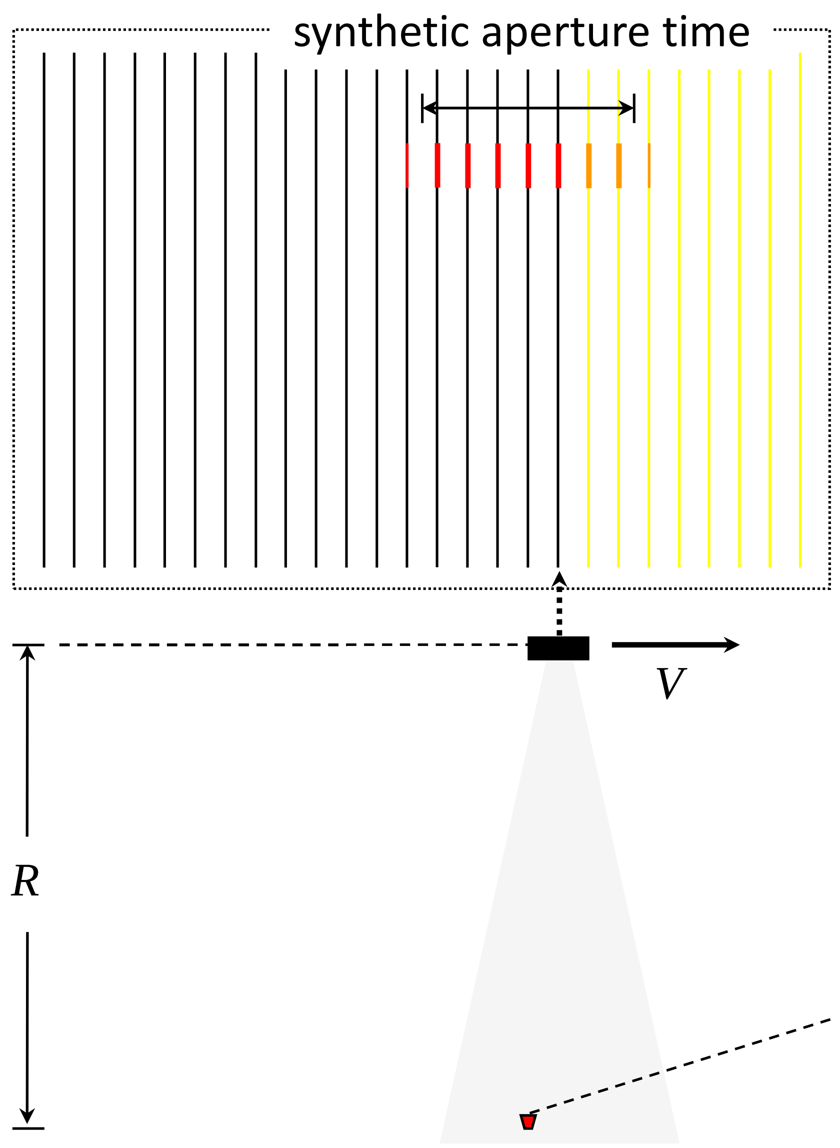
Resolution problem in radar remote sensing

- Spatial resolution is dependant on the wavelength

$$\Delta x = \frac{r\lambda}{L}$$

- For ERS satellite, resolution of ~5km per pixel
- Solution : synthetic aperture
  - ➢ Synthetic Aperture Radar (SAR) (not studied here)
  - ➢ ~decametric resolution and even better



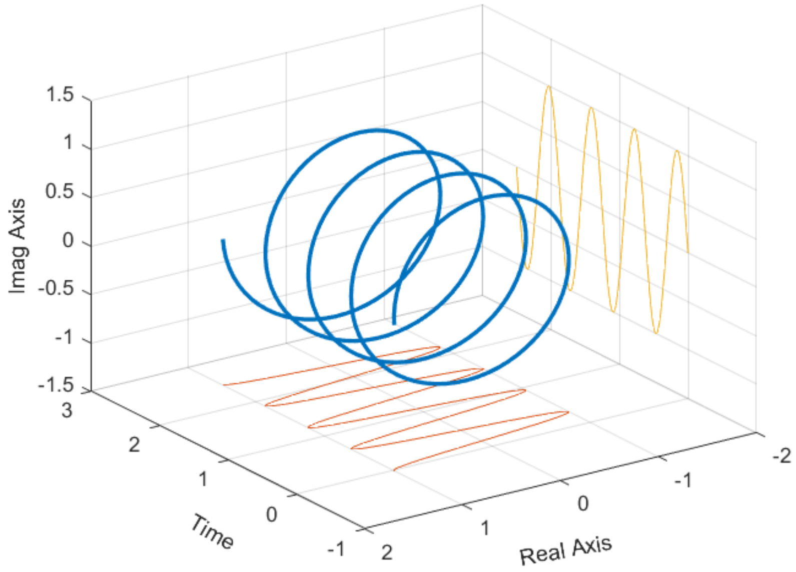
Sources : *SAR Imaging - SAREDU*

SAR Image

- A SAR Image is complex (mathematical sense)
- The image is a bidimensional signal u where each pixel is composed of an amplitude A and a phase theta

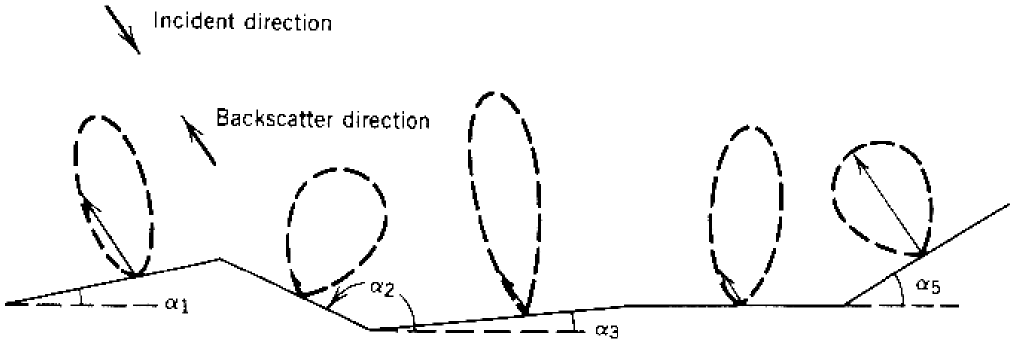
$$u = A\, e^{j\varphi} = A \cos\varphi + j\, A \sin\varphi$$

- In optical remote sensing, we can only use amplitude information
- In SAR remote sensing, we can use amplitude for many applications, but the phase can be extremely useful (cf. SAR interferometry)

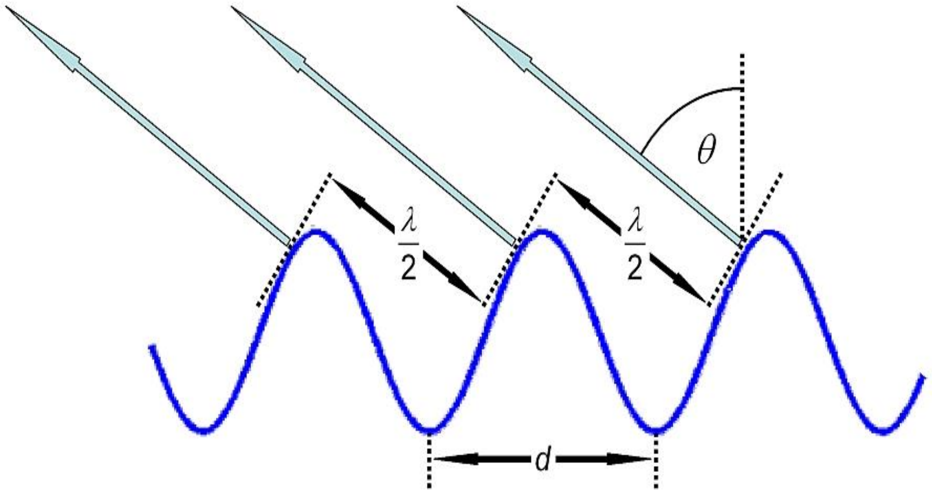


Amplitude

- Amplitude depends on backscatering mechanisms related to the average proporties of the illuminated area
- Typically, you can link the amplitude of the backscattered signal to two distinct parameters:
  - Roughness
  - Moisture
- In addition, it is affected by acquisition geometry, and by local topography. These are influencing the angle between the normal of the slope and the look angle of the sensor



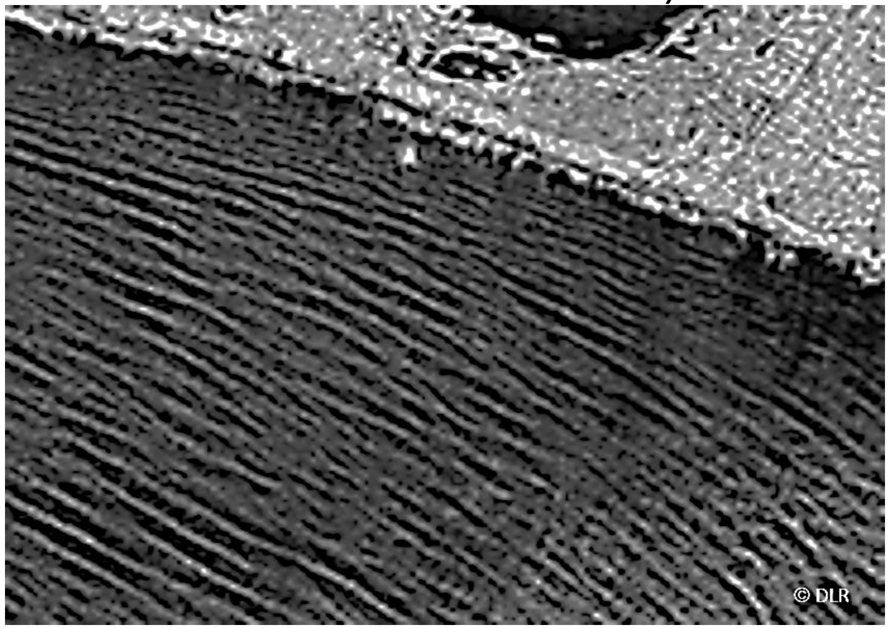
Sources : Spaceborne Radar Remote Sensing– C. Elachi



Direct application of the amplitude

- Ocean surface can be considered as a mirror for radar wavelength (specular reflexion)
- During calm winds, surface appears black because the signal is not sent back toward the sensor
- During moderte winds, waves are periodically creating slopes perpendicular to the line-of-sight of the sensor (bright lines)
- During strong winds, the ocean reacts as a rough surface

Estimated winds : 3.25 m/s



Sources : Echoes In Space – EO College

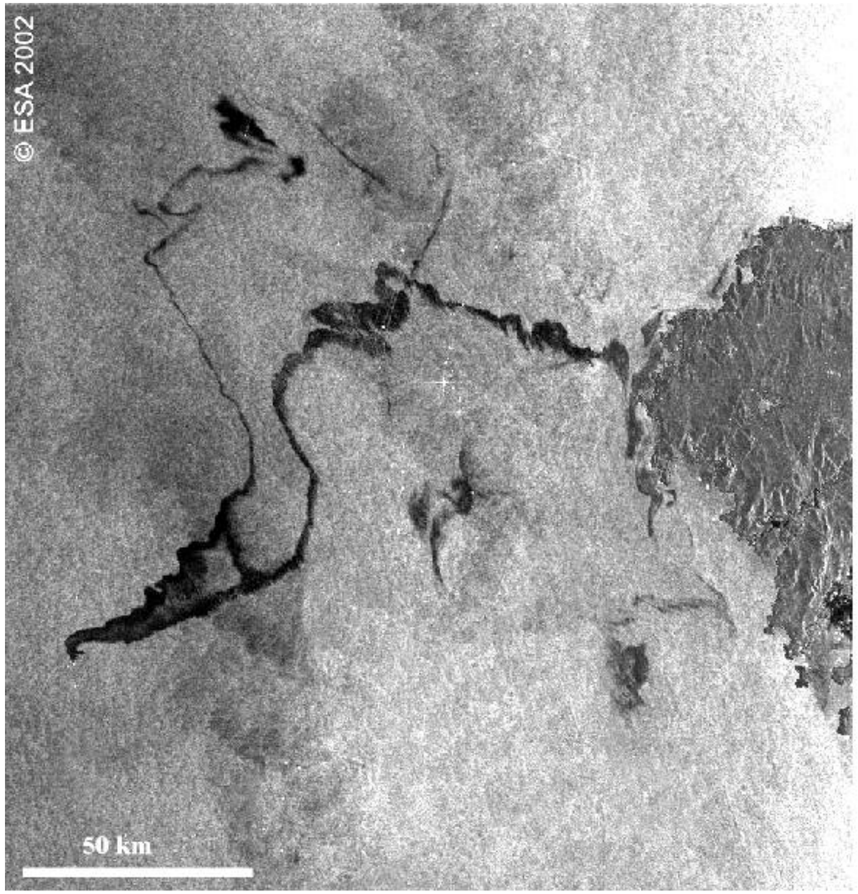
Direct application of the amplitude

- When the radar signal meets two perpendicular smooth surface, the backscattered signal keeps a very strong amplitude
- « Double bounce » effect
- Common in urban areas

Sources : Echoes In Space – EO College

Direct application of the amplitude

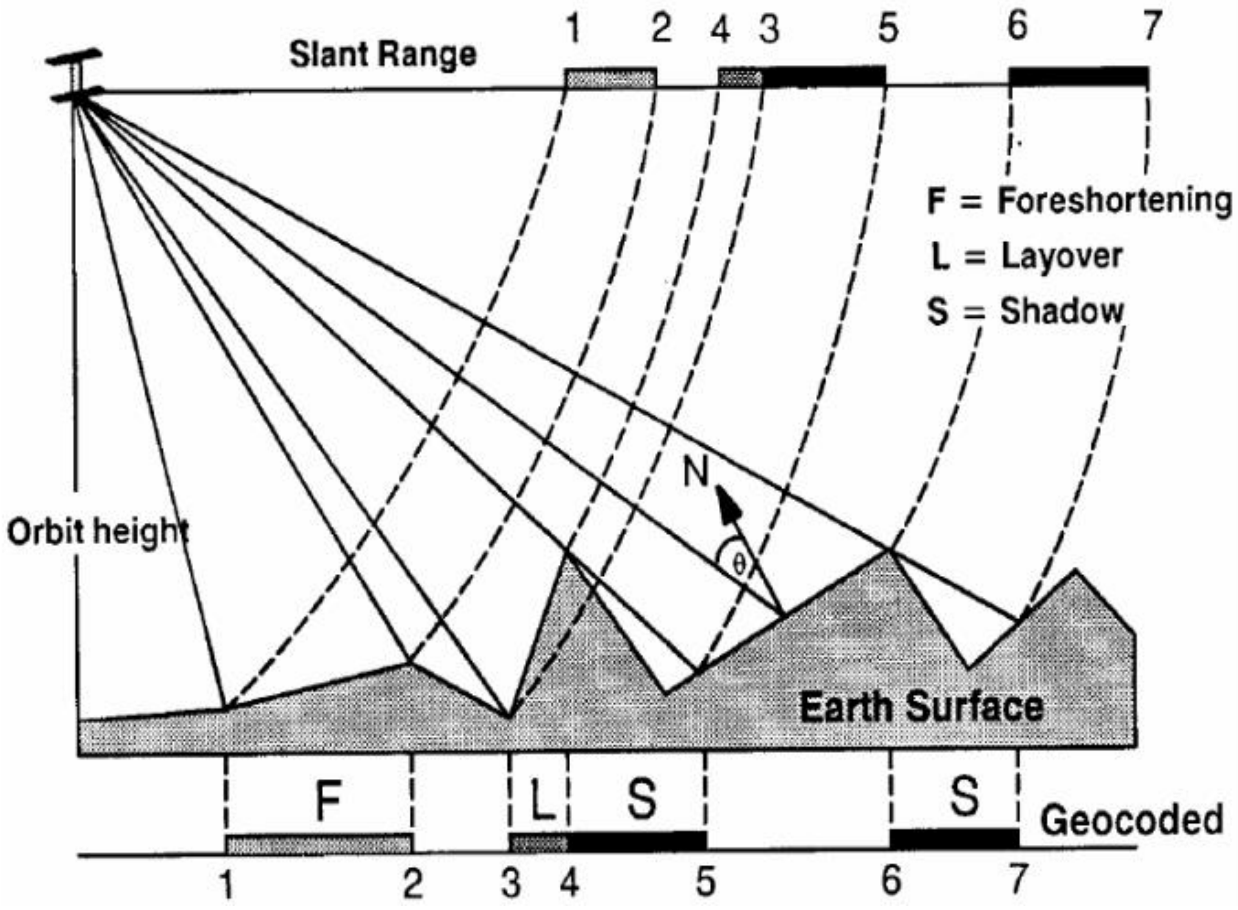
Oil Spill Detection



Ship monitoring

Geometric distorsions (topography)

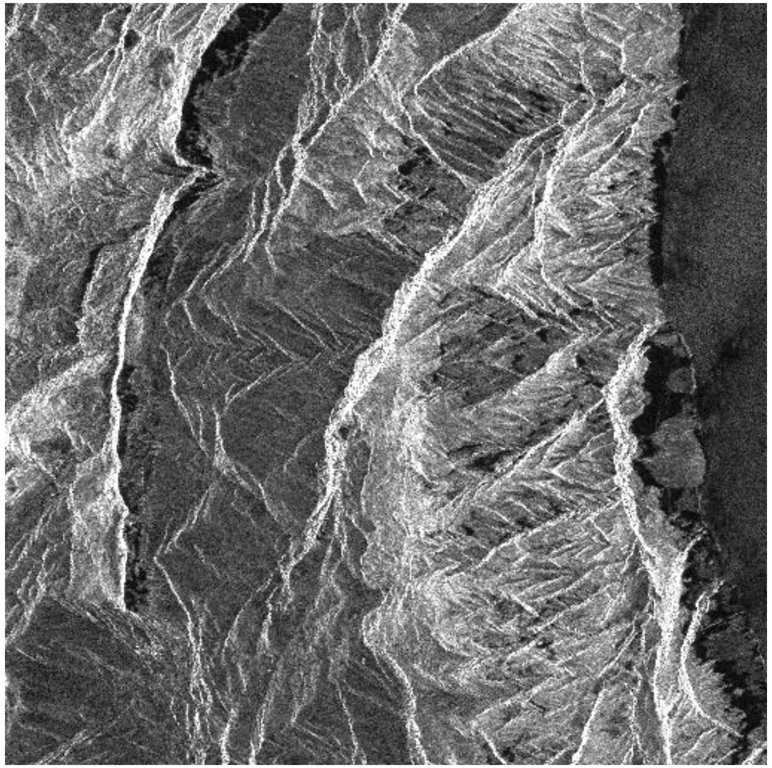
- Radar measures distances, not angles (in contrast with optical images). Acquisition geometry introduces artifacts related to topography
  - Foreshortening
  - Layover
  - Shadowing
- The steeper the topography, the stronger the artifacts
- The bigger the look angle, the stronger the artfacts

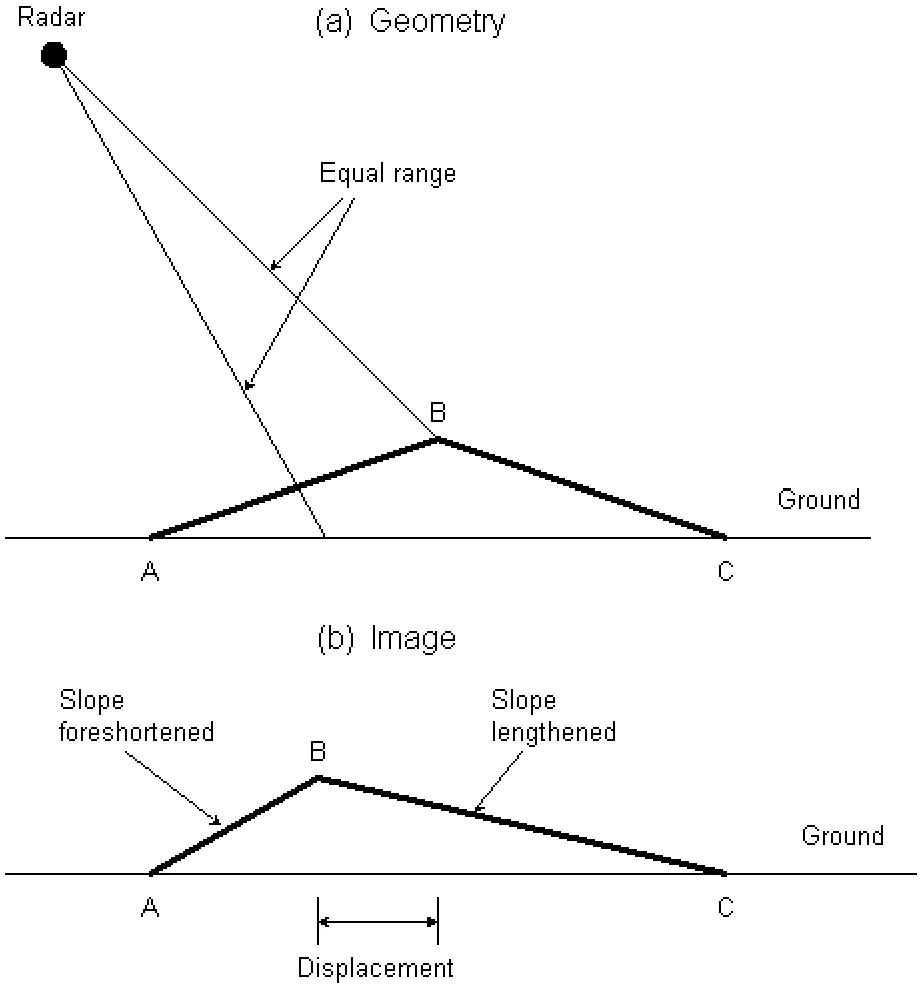


Sources : Spaceborne Radar Remote Sensing– C. Elachi

Foreshortening

- Higher altitudes are closer to the satellite; therefore they appear sooner in the image

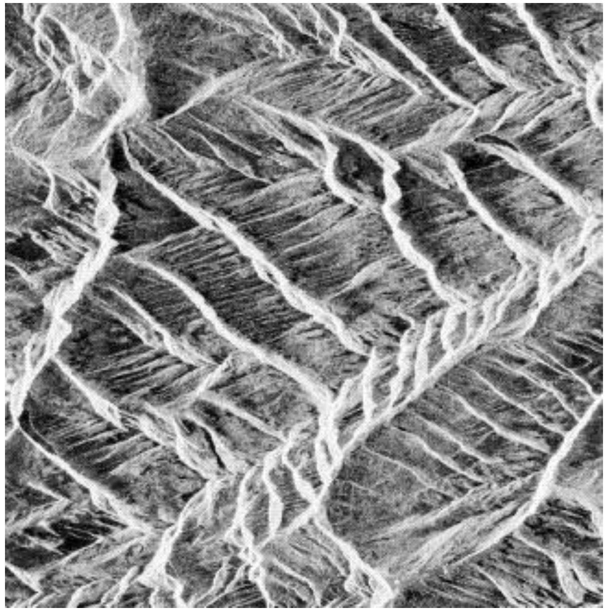


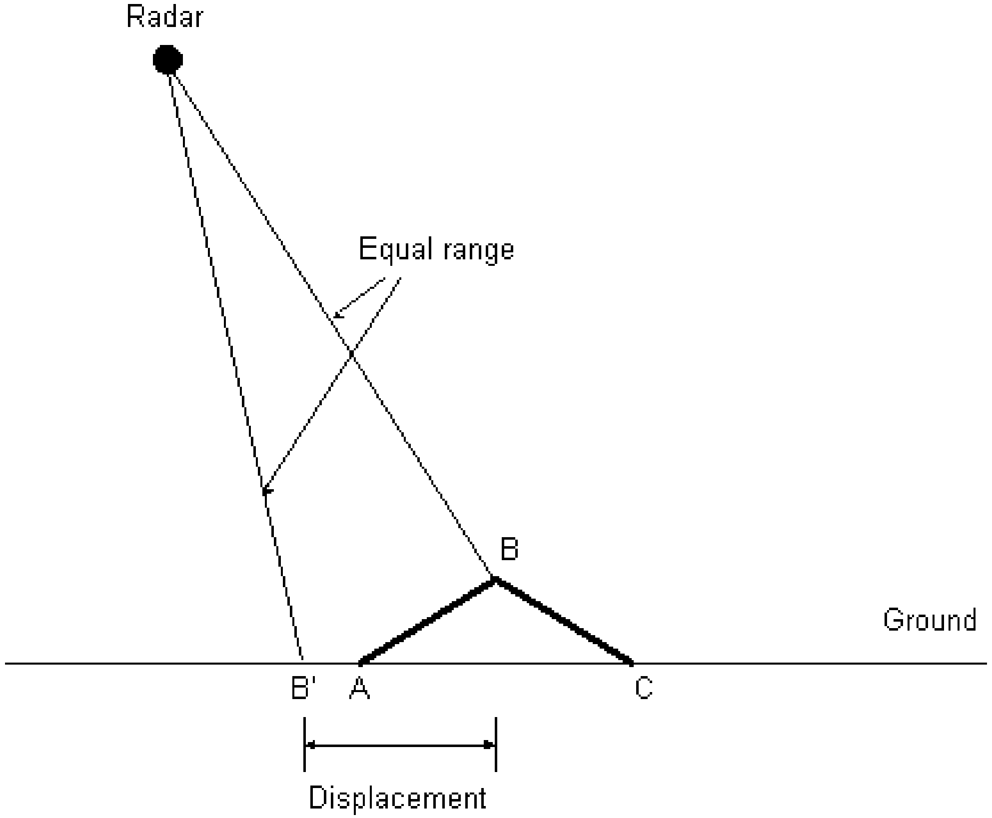


Sources : Echoes In Space – EO College

Layover

- Extreme case of the foreshortening
- The top of the mountain is seen BEFORE its foot. The top appears before in the SAR image
- Mountains are seen « upside-down »

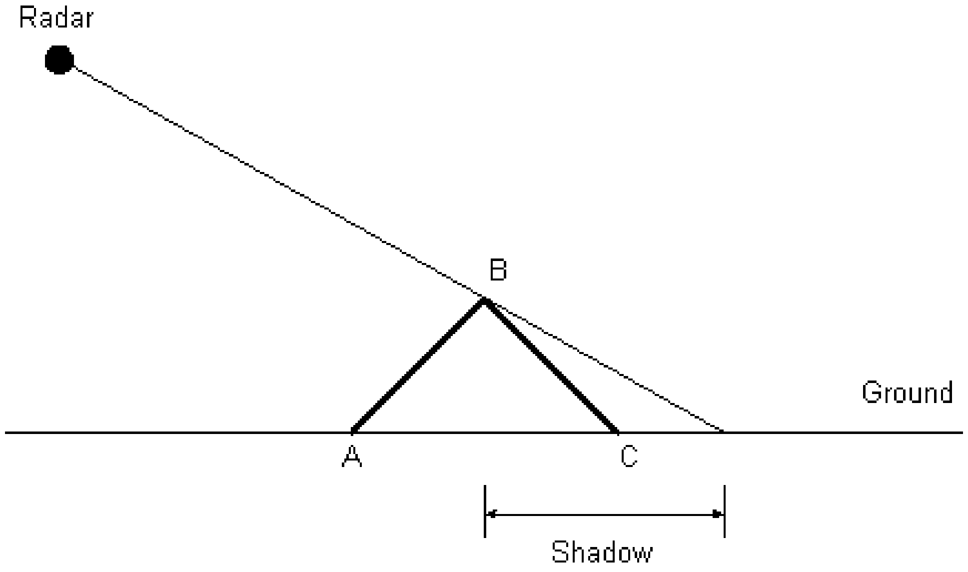


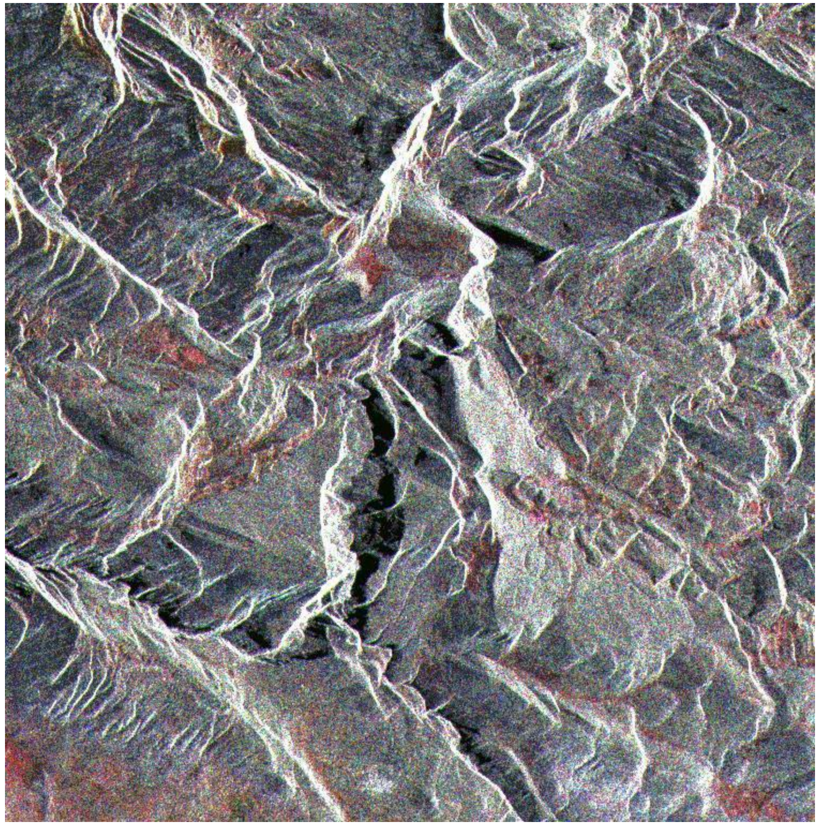


Sources : Echoes In Space – EO College

Shadowing

- Topgraphy is hiding parts of the area
- Pixels appears black. For a given distance, no backscaterred signal is received

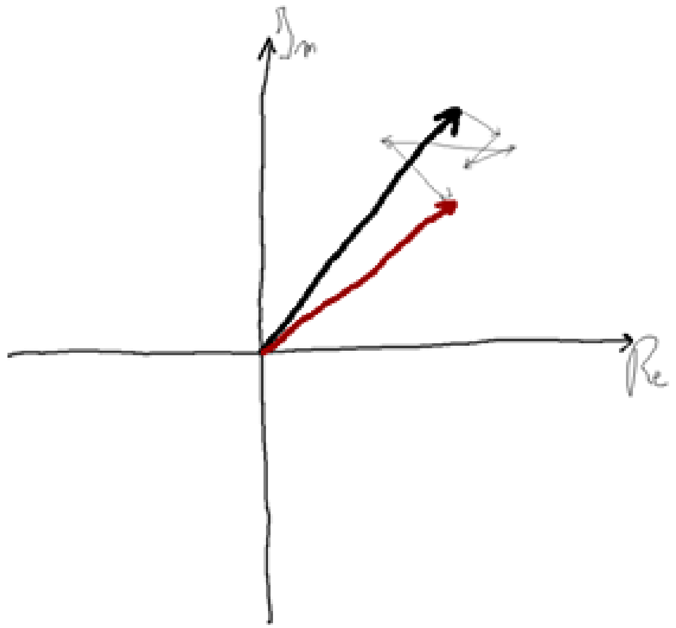




Sources : Echoes In Space – EO College

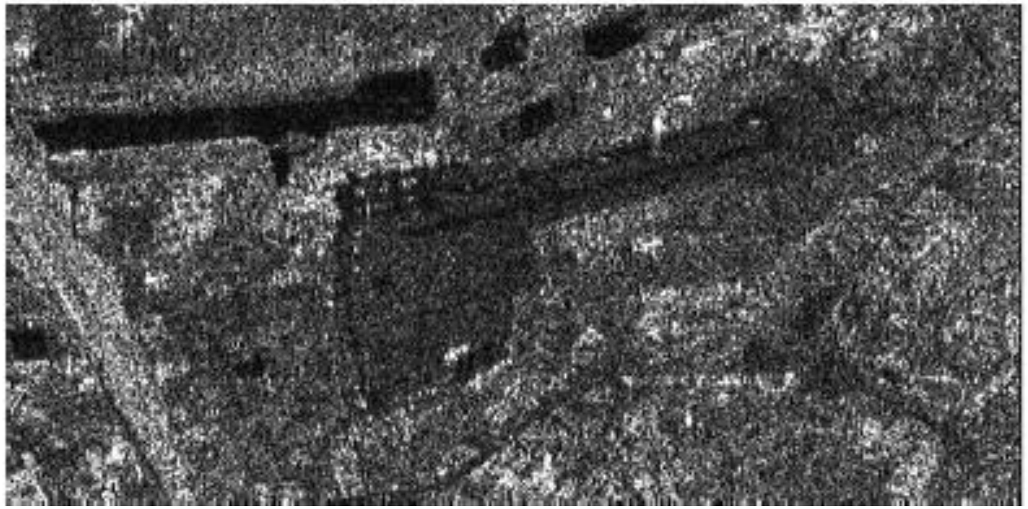
Speckle

- The backscattered signal has an amplitude and a phase information. It can be represented in the complex plane
- But the signal contains a reconstruction term, containing the contributions of all the scaterers inside the pixel
- This reconstruction phase modifies the amplitude and phase. It creates a deterministic noise called « speckle »



Multilooking

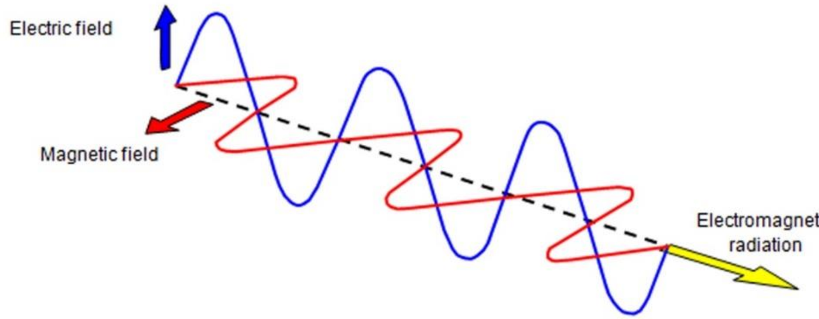
- Statistically, the speckle has a null-expectancy
- Spatial/temporal averaging can reduce this effect
- This technique is called multilooking

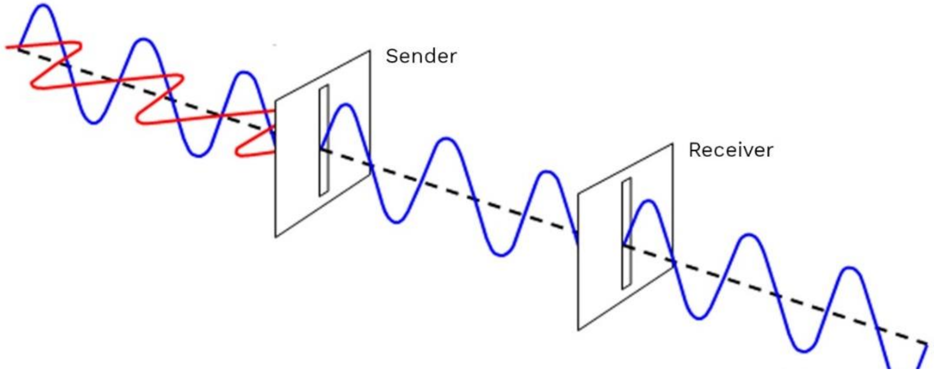


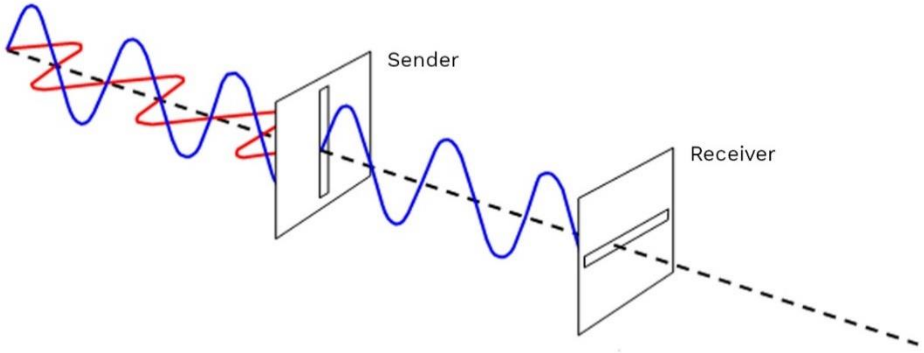
Sources : Spaceborne Radar Remote Sensing– C. Elachi

Polarization

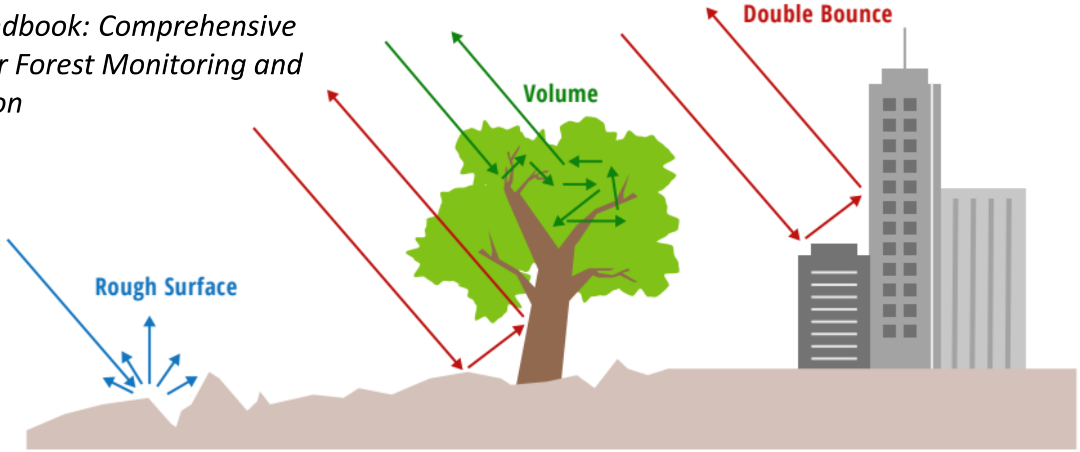
- The satellite sends a pulsed electromagnetic wave
- It is possible to control the polarization of the electromagnetic wave of the sensor
- In SAR, we work with linear polarization
- It also possible to control in which polarization we capture the returned signal
- Example :
    - VV : vertical transmit, vertical receive
    - VH : vertical transmit, horizontal receive





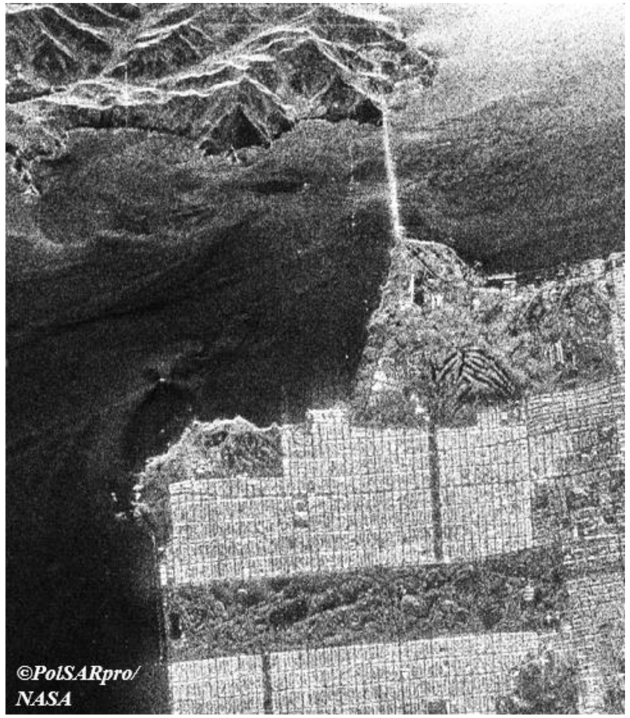


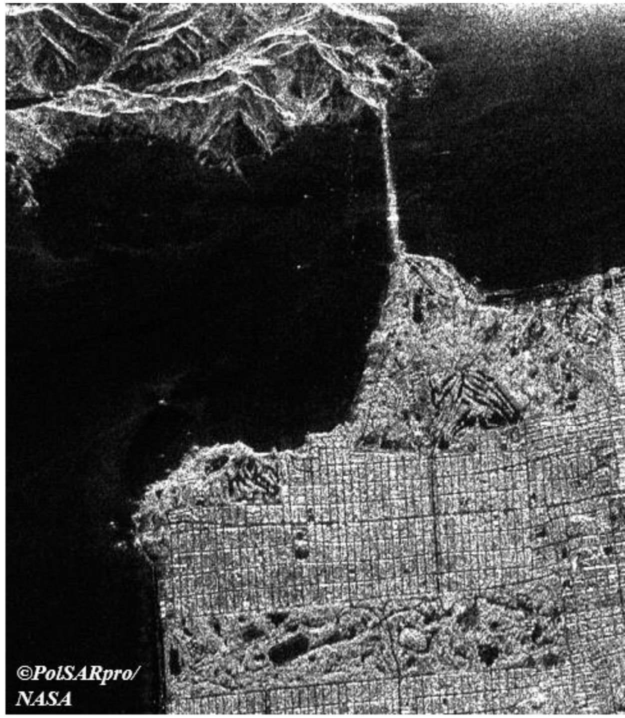
Sources : Echoes In Space – EO College



Polarization (examples)

- Differences of intensity of signals between different polarizations can discriminate land use
- Anthropic elements are used to scatter back the signal without changing its polarization state
- Trees change the polarization of the signal

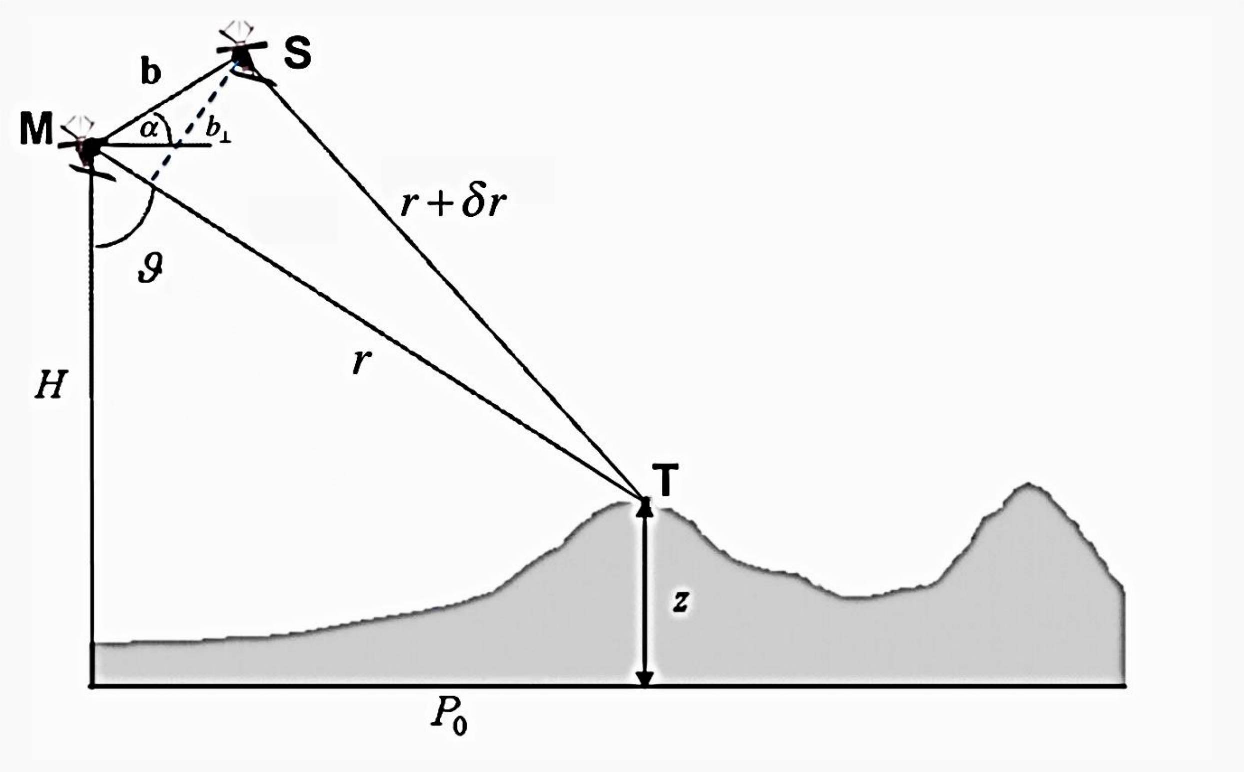




Sources : Echoes In Space – EO College

SAR Interferometry: Principles

- A SAR image contains an amplitude **and** a phase information
- The phase term is proportional to the path from the satellite to the ground (and back)
- Based on two SAR images taken from two similar points of view, with slightly different view angle, it is possible to retrieve the topography
- First image is at a distance *r* from the target
- The second one is at a distance $r + \delta r$



Sources : *A Review of Interferometric Synthetic Aperture RADAR (InSAR) Multi-Track Approaches for the Retrieval of Earth's Surface Displacements*

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SAR Interferometry: Principles

- Image 1 (Master) :

$$M = A_M e^{j\varphi_M}$$

- Image 2 (Slave) :

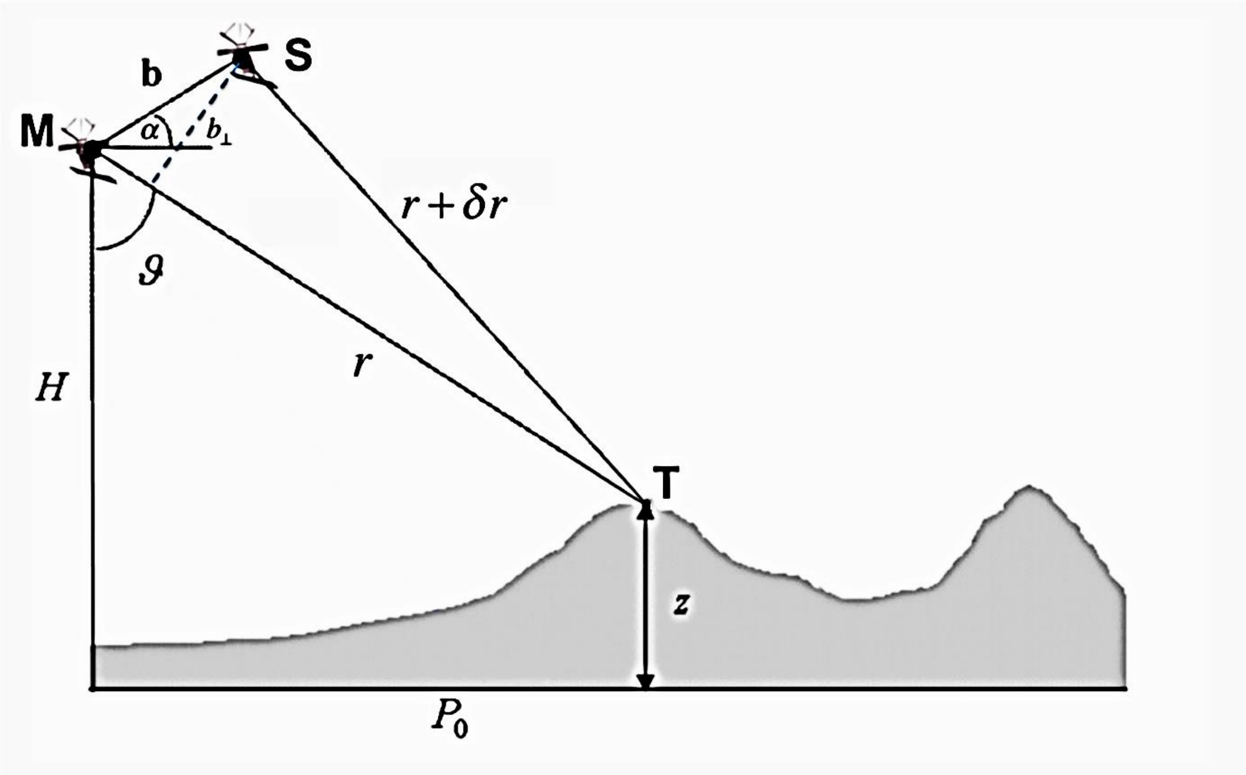
$$S = A_S e^{j\varphi_S}$$

- interferogram :

$$\mathrm{Intf} = M.S^* = A_M A_S e^{j(\varphi_M - \varphi_S)}$$

- This phase difference is called *interferometric phase* and is proportional to the traveled path difference between the 2 images

$$\varphi_{intf} = \varphi_M - \varphi_S = \frac{4\pi}{\lambda}\delta r$$



Sources : A Review of Interferometric Synthetic Aperture RADAR (InSAR) Multi-Track Approaches for the Retrieval of Earth's Surface Displacements

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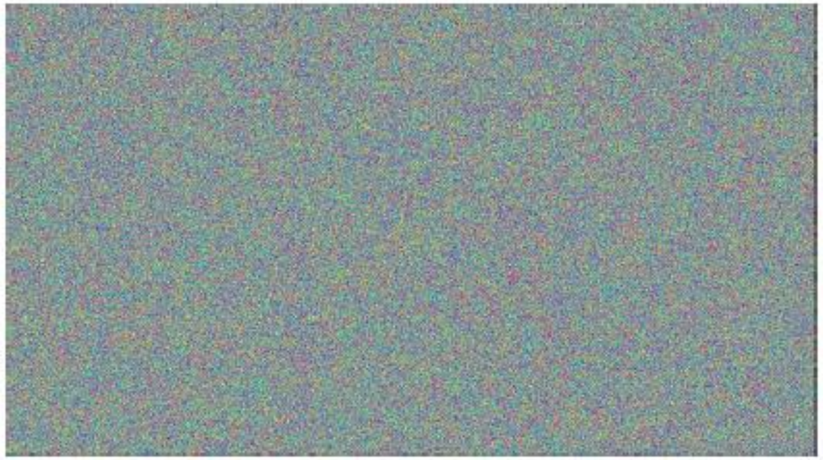
SAR Interferometry: Principles

$$\varphi_{intf} = \varphi_M - \varphi_S$$



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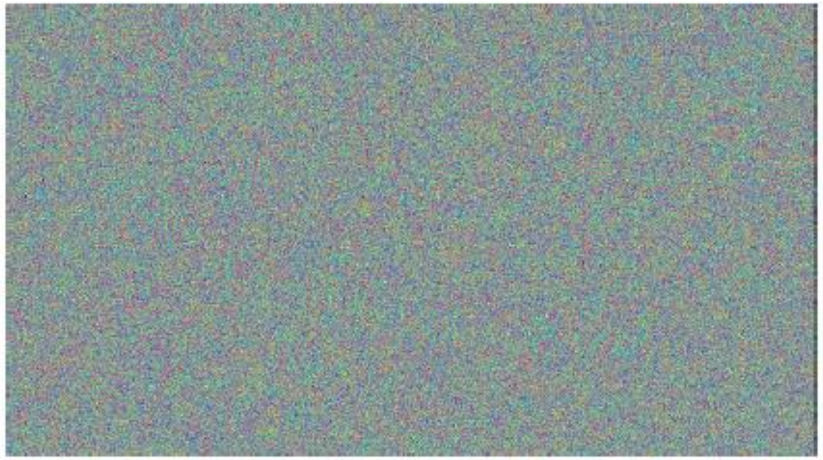

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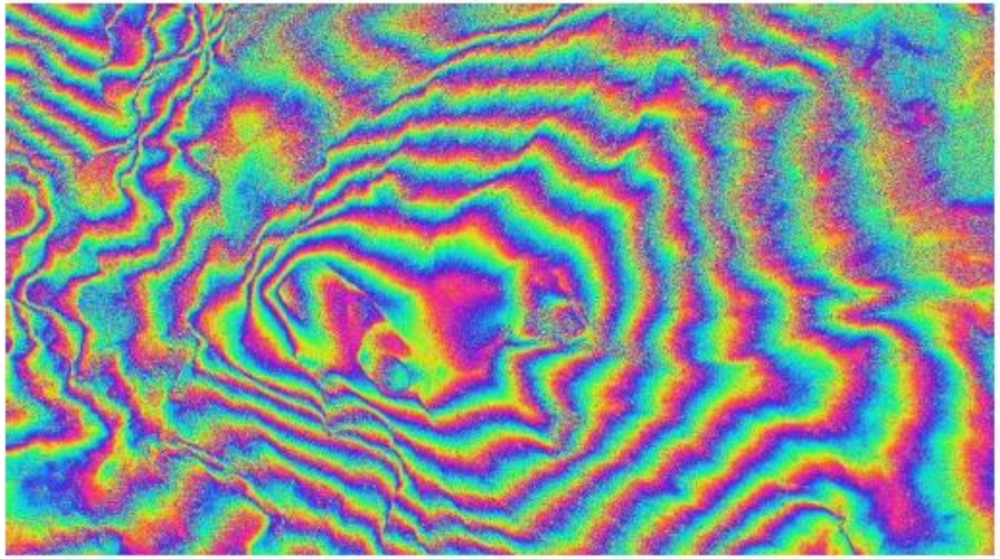
TanDEM-X– Copahue volcano



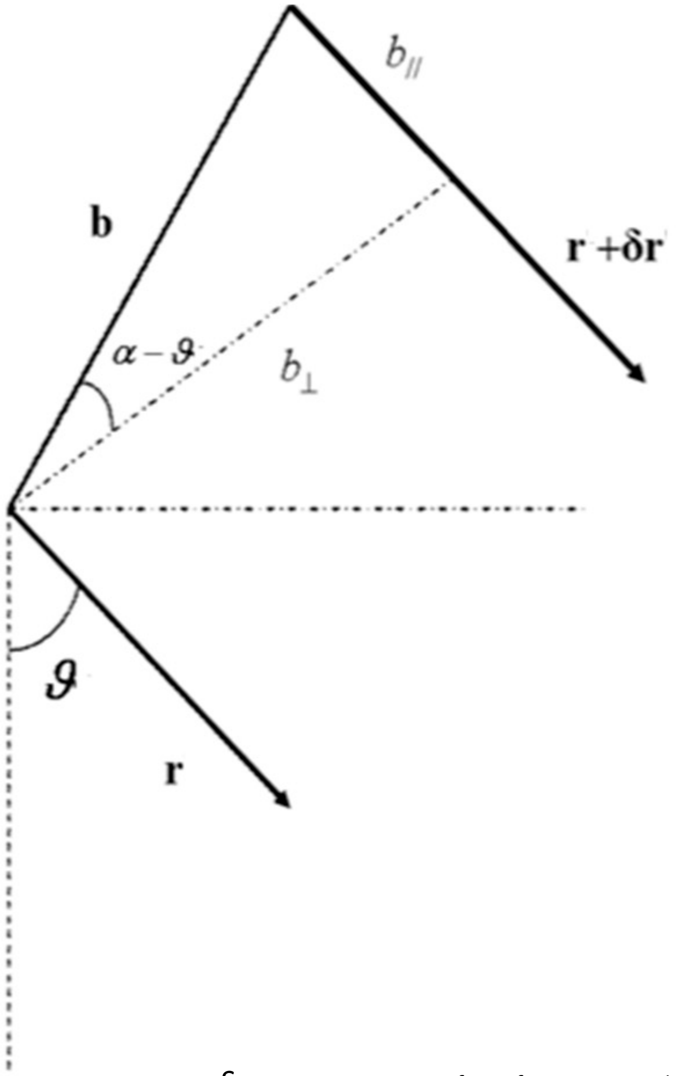
Sources : Fabspace2.0 , Radar Remote Sensing – Ludivine Libert (2018)

SAR Interferometry: Principles

- In Spaceborne SAR remote sensing, we can assume far field hypothesis and write

$$\varphi_{intf} = \frac{4\pi}{\lambda}\delta r \sim -\frac{4\pi}{\lambda}\mathrm{b}\sin(\theta-\alpha) = \frac{4\pi}{\lambda}b_{parallèle}$$

- Since this phase depends on incidence angle, we can observe that the interferometric phase varies even without topography. This is called *orbital phase* component. Its contribution can be modelled and removed.
- Topography also influences the $\boldsymbol{\delta r}$ component and thus the interferometric phase



Sources : A Review of Interferometric Synthetic Aperture RADAR (InSAR) Multi-Track Approaches for the Retrieval of Earth's Surface Displacements

Interferometric phase content

- In the end, the interferometric phase is composed of a multitude of terms

$$\varphi_{intf} = \varphi_{orb} + \varphi_{topo} + \varphi_{mvt} + \varphi_{atm} + (\varphi_{noise})$$

- The first three can be determined geometrically by

$$\varphi_{orb} = -\frac{4\pi}{\lambda}\frac{B_n s}{R\tan\theta}$$

$$\varphi_{topo} = -\frac{h}{\sin\theta}\frac{B_n}{R_0}\frac{4\pi}{\lambda}$$

$$\varphi_{mvt} = \frac{4\pi}{\lambda} displ$$

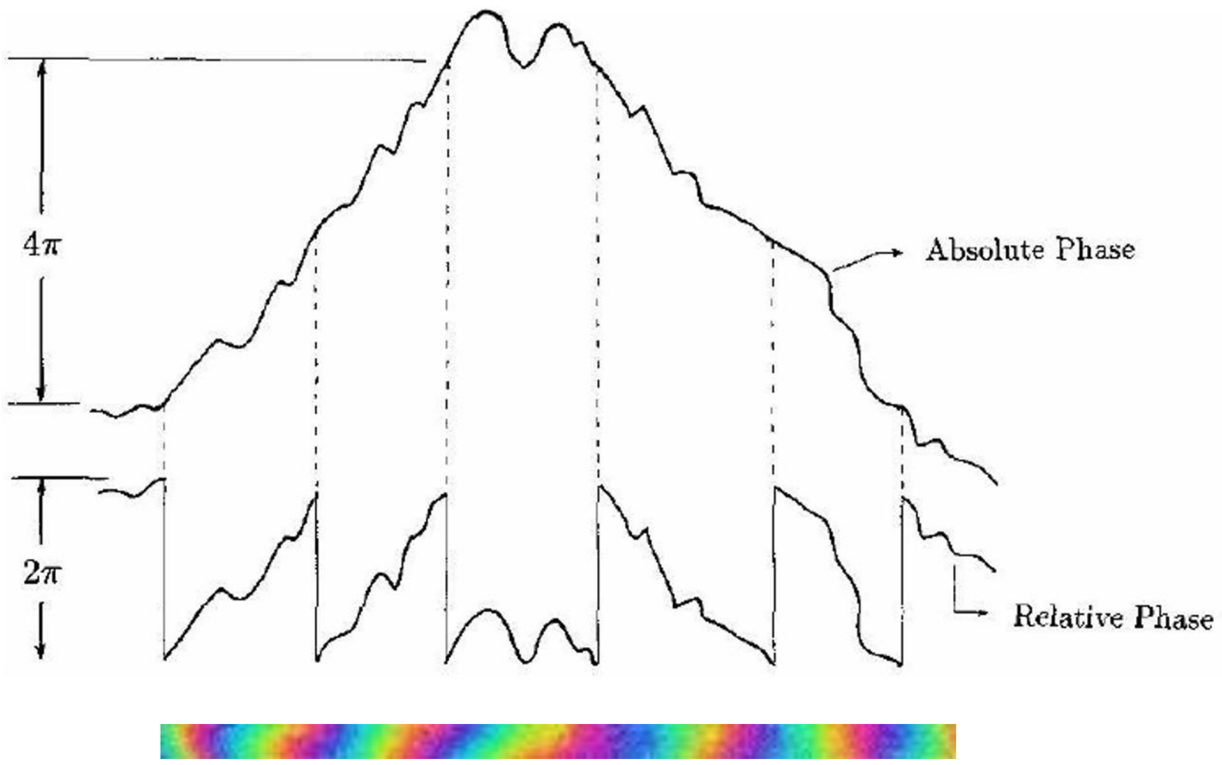
- The atmosphere is either neglected (not always possible) or corrected (stacking, split band, etc)

Phase Unwrapping

- The interferometric phase is ambiguous. It is only known mod 2π. The absolute phase is given by

$$\Phi = N * 2\pi + \varphi$$

- We need to determine an algorithm able to retrieve this integer *N* in order to get the absolute interferometric phase



Sources : Remote Sensing – Christian Barbier

Height Ambiguity

- Interferometric phase is comprised between - π and +π.
- Height ambiguity is the height that produces a 2π shift in the interferogram
- It is given by

$$h_a = -\frac{\lambda\, r \sin\theta}{2b_{perp}}$$

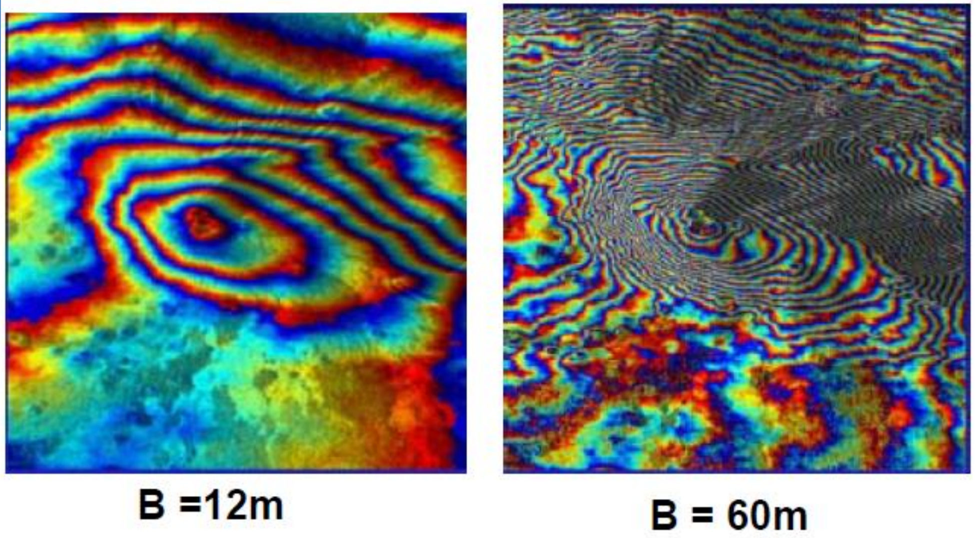
Height Ambiguity

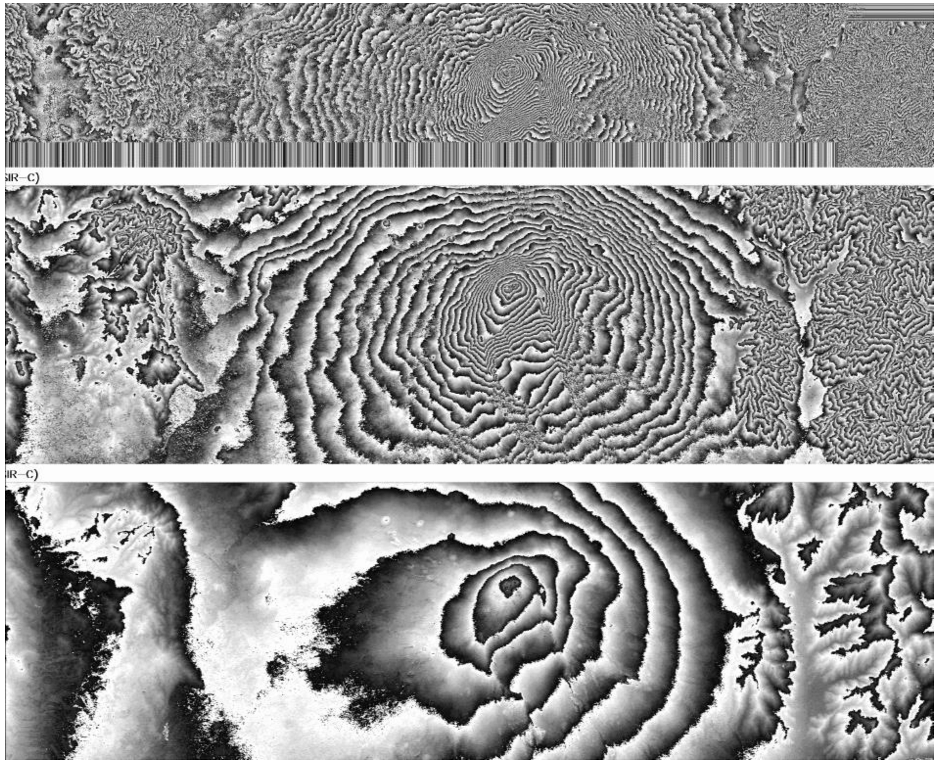
- Height Ambiguity is given by

$$h_a = -\frac{\lambda\, r \sin\theta}{2\, b_{perp}}$$

  - A Higher baseline between acquisition increase topographic sensitivity

  - The smaller the wavelength, the higher the fringe rate (illustrations showing X, C and L-band resp.)





Sources : Remote Sensing – Christian Barbier

Phase unwrapping (example)

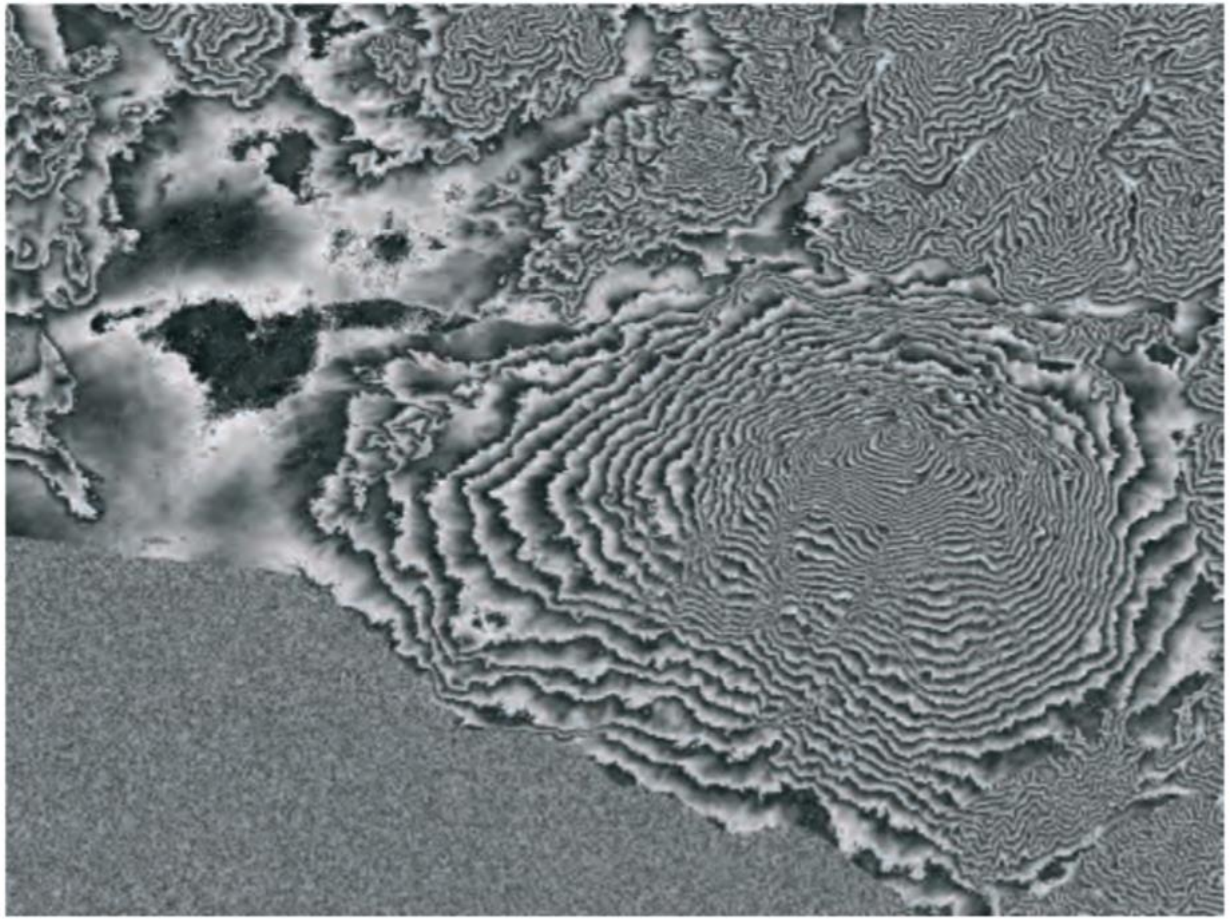


Figure 2-5: Flattened interferogram of Mount Etna generated from ERS tandem pairs. The perpendicular baseline of 115 metres generates an altitude of ambiguity of about 82 metres.

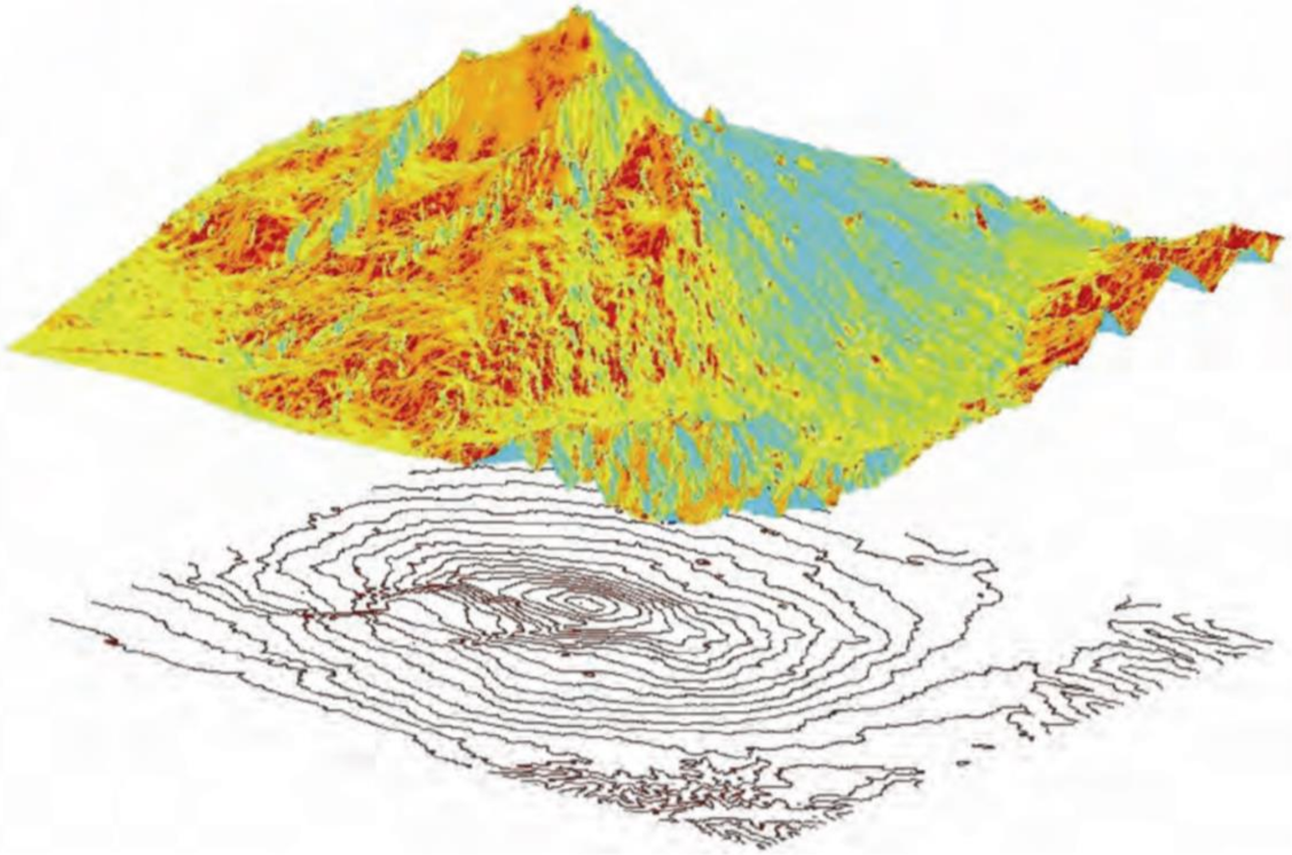


Figure 2-6: Perspective view of Mount Etna as seen from the Northeast. The DEM of Mount Etna has been generated by unwrapping and re-sampling the flattened interferogram of Figure 2-5: The estimated vertical accuracy is better than 10 metres. Contour lines are shown below the DEM.

Sources : InSAR Principles – ESA

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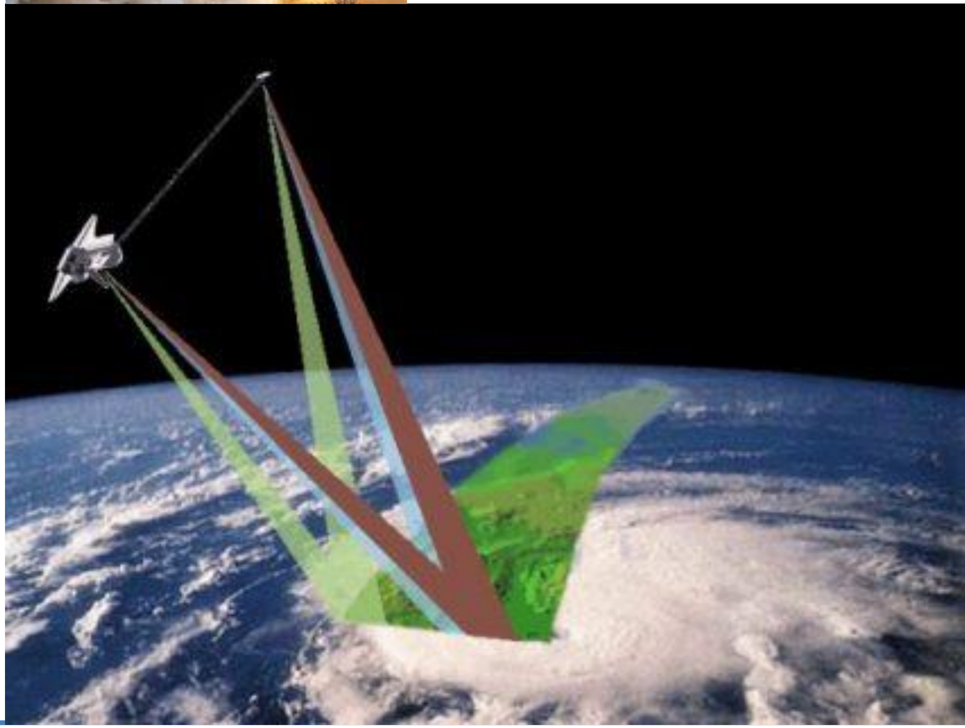
Example : Shuttle Radar Topography Mission (SRTM)

- SAR Interferometry by taking instantaneously 2 acquisitions from 2 sensors separated using a mechanical arm of 60 meters

- This enables to neglect the displacement and atmospheric phase components

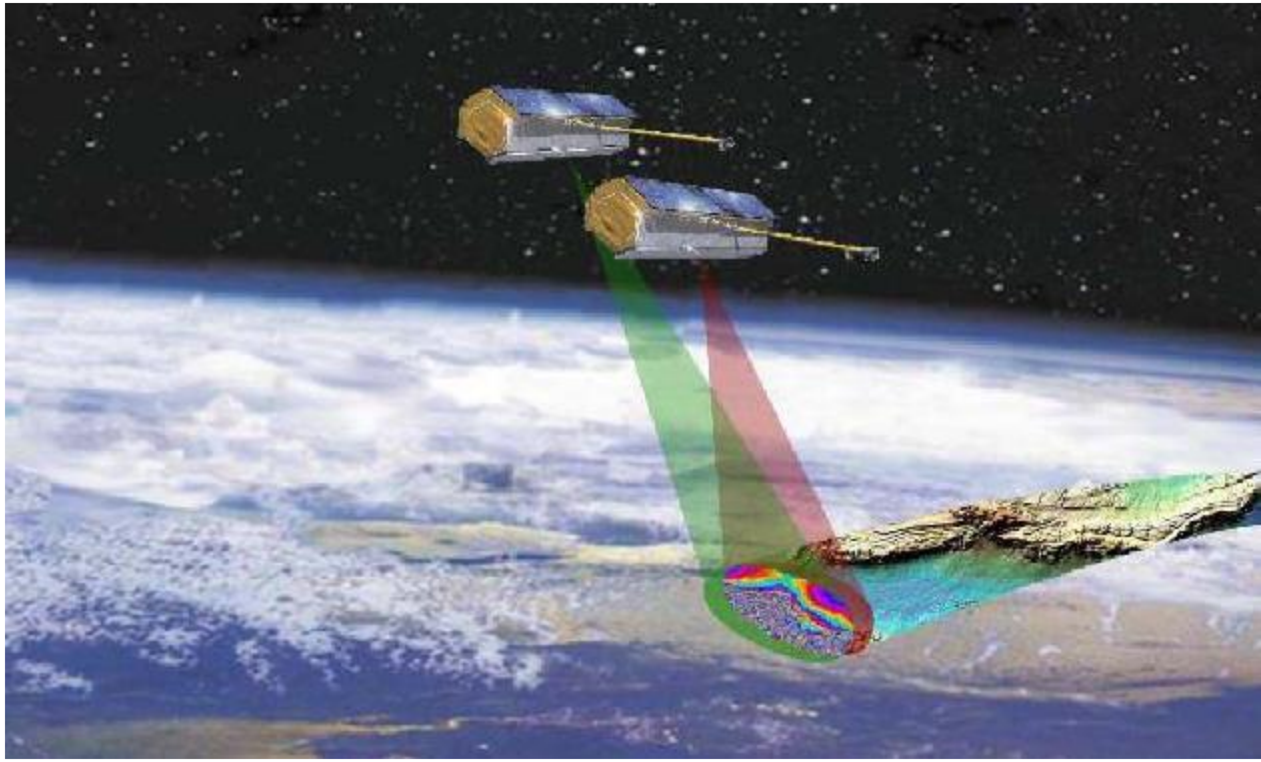
- It allowed to produce a worldwide digital elevation model (from -60 to +60 degrees latitude)

Sources : Digital Geography



Example 2 : TanDEM-X

- 2 TerraSAR-X satellites constellation
- Same advantages as SRTM
- Allow to cover any area at any time to create DEMs



Sources : The TanDEM-X Mission Concept – Zink (2006)

Coherence

- Coherence can be considered as a quality index of the interferogram
- It is the local complex correlation between the master and the slave image

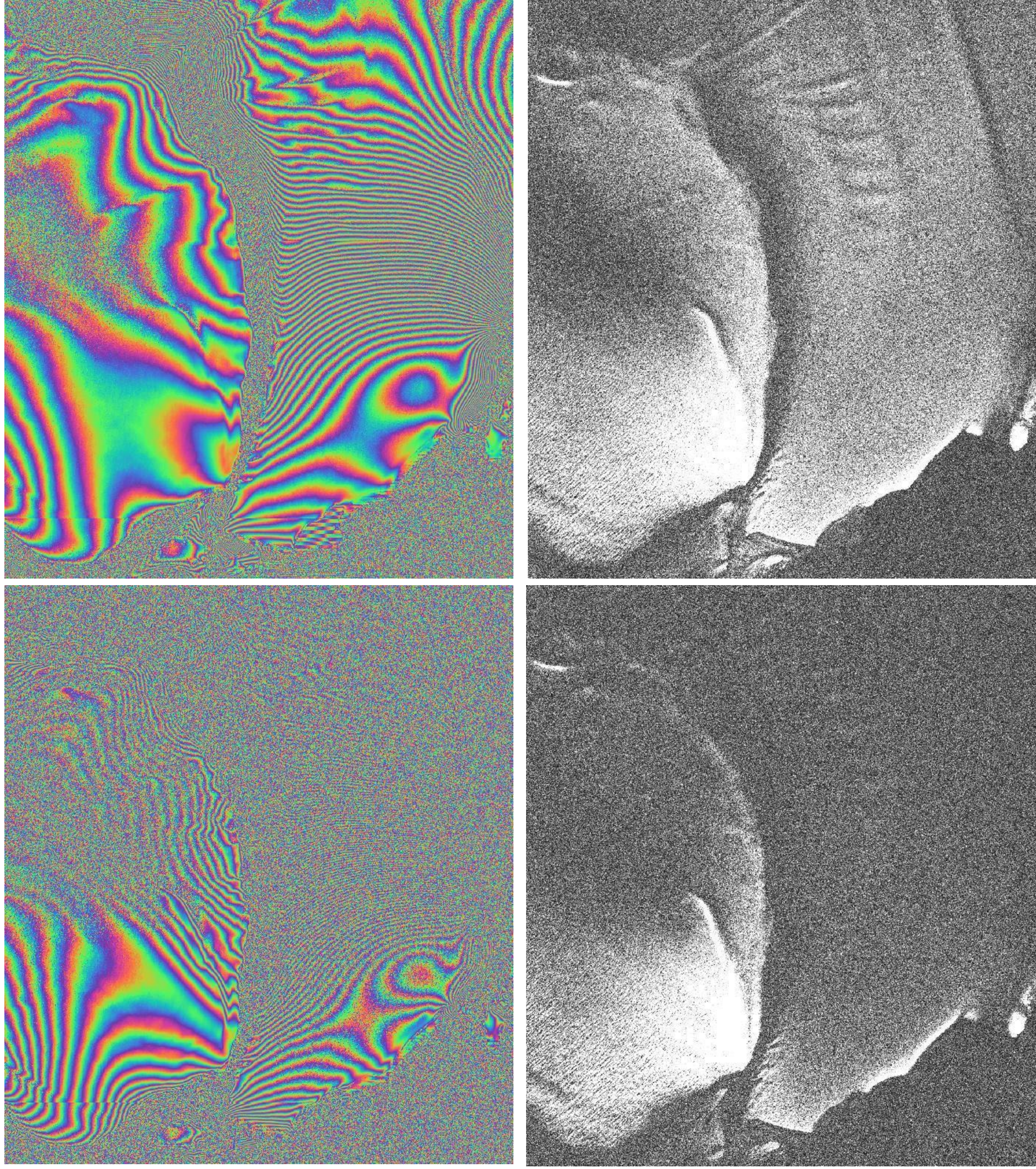
$$\gamma = \frac{|\sum_W M.S^*|}{\sqrt{\sum_W |M|^2 * \sum_W |S|^2}}, \in [0,1]$$

Where W is a window around the pixel (for example 5x5)

- A correlation value of 1 means perfect correlation between the SAR pair, with beautiful fringes in the interferogram and easy to unwrap
- A null coherence means a coherence loss between the two acquisition. This can be caused by land use change for example. The interferometric signal cannot be used nor unwrapped.

Coherence – Interferogram Relationship

- Here is displayed the effect of increasing the time period between two acquisition (temporal decorrelation)
- Slave image taken 12 days after the master image (top) and 24 days after (bottom)
- Depends on the research field



Decorrelation sources

- There are many decorrelation factors in SAR interferometry
  1. Temporal decorrelation. The longer the time interval between acquisition, the bigger the changes within the area of interest
  2. Thermal noise of the sensor
  3. Geometrical geometry. The more separated the satellites, the more different the scatterers appear
  4. Coregistration issues
- These decorrelations sources are multiplicative

$$\gamma = \gamma_{temp} * \gamma_{therm} * \gamma_{geom} * \gamma_{coreg}$$

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Coherence as a variable

- Coherence is a correlation measurement between images
- Low coherence can be witness of changes
- In some case, one can use coherence as a change detection measurement

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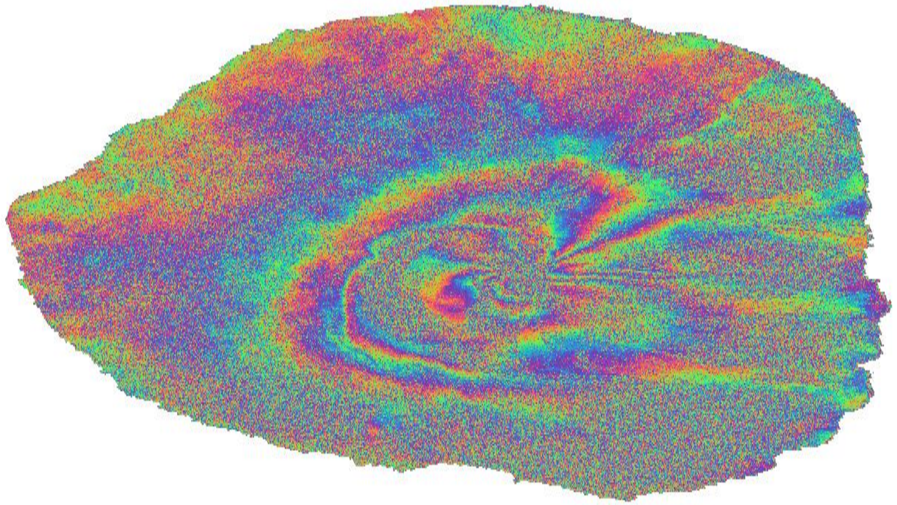
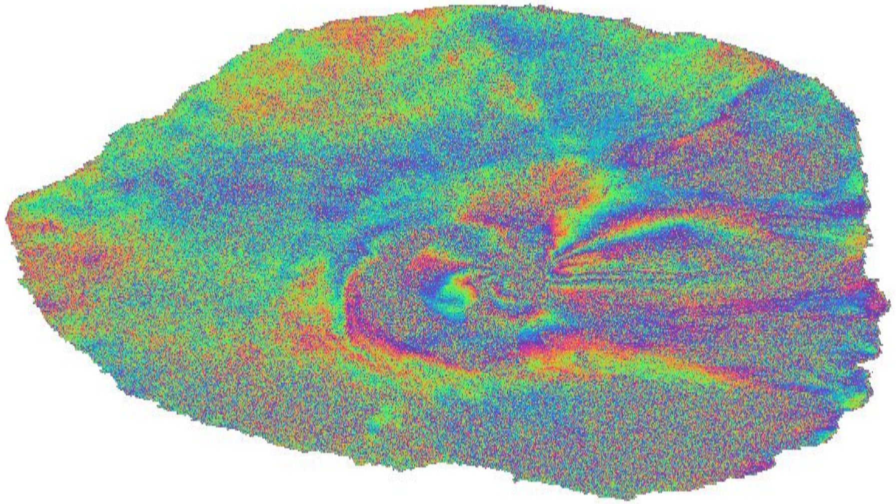
Differential SAR Interferometry

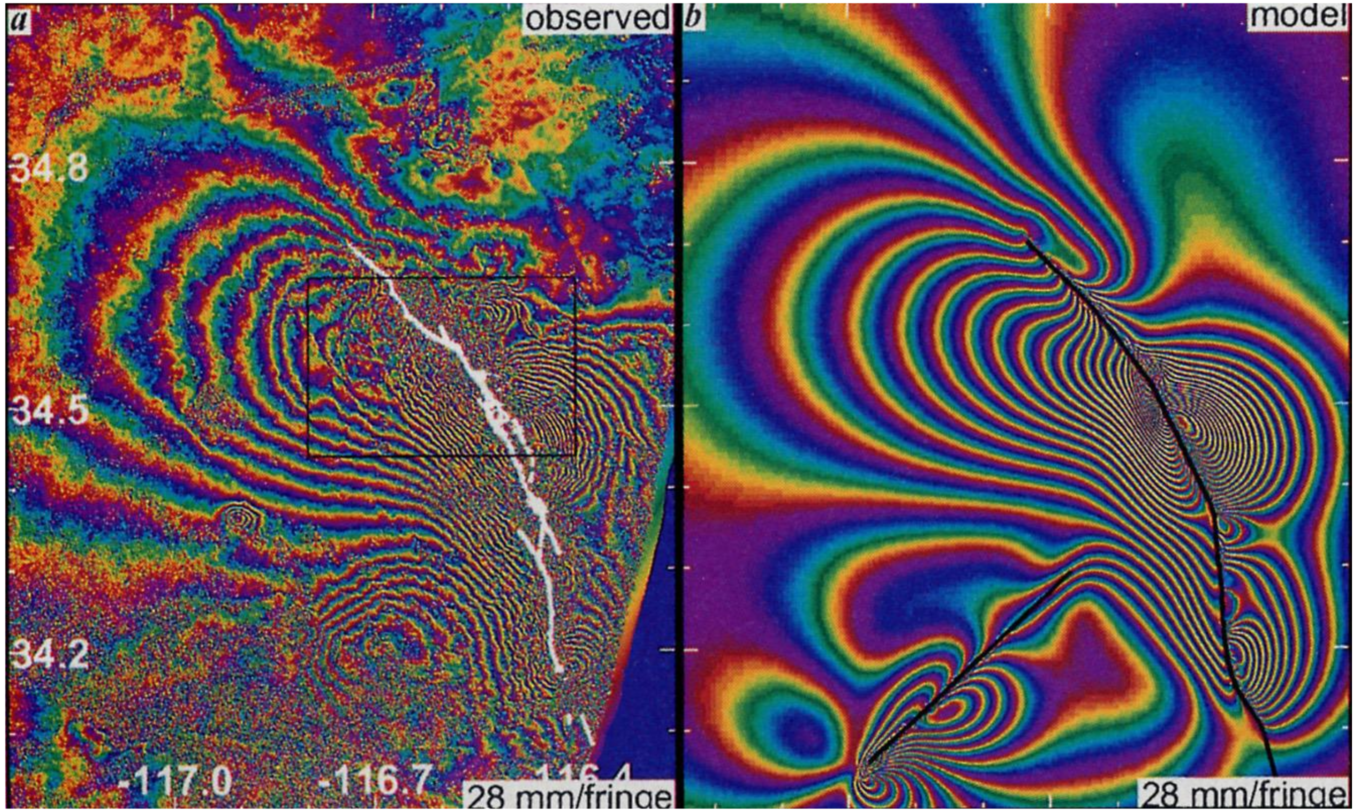
- Topography can be obtained from SAR Interferometry
- If we know the topography, we can compute the topographic phase component and remove it
- If the revisit time is long enough, what remains in the interferogram is a displacement phasae component (if atmospheric phase negligeable)





Differential SAR Interferometry

- Interferometric phase is extremely sensitive to displacements. We can measure subcentimeter displacement from space
- Example : Landers Earthquake



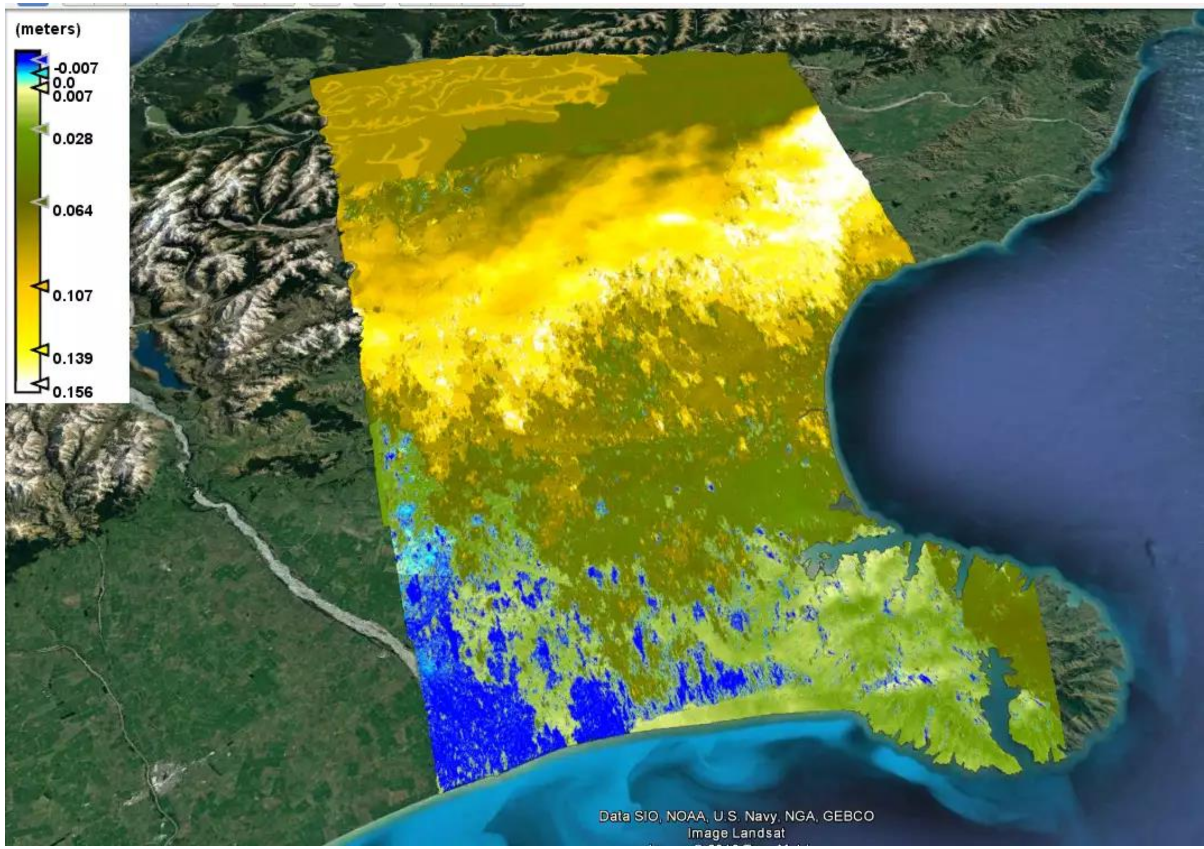
Sources : Fabspace2.0 , Radar Remote Sensing – Ludivine Libert (2018)

Differential SAR Interferometry

- Once unwrapped, the phase can be converted in metric displacement using

$$\varphi_{mvt} = 2\frac{2\pi}{\lambda}displ$$

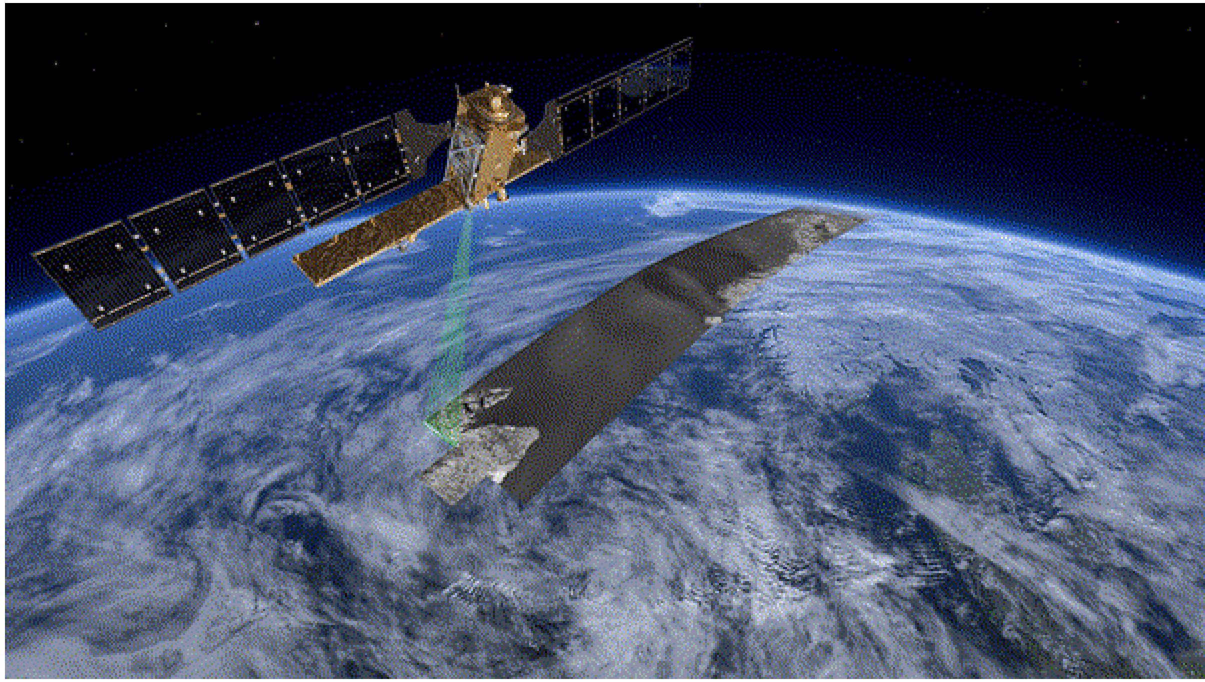
- These results can be projected in any reference coordinates system



Sources : STEP forum - ESA

Current SAR Satellites SA

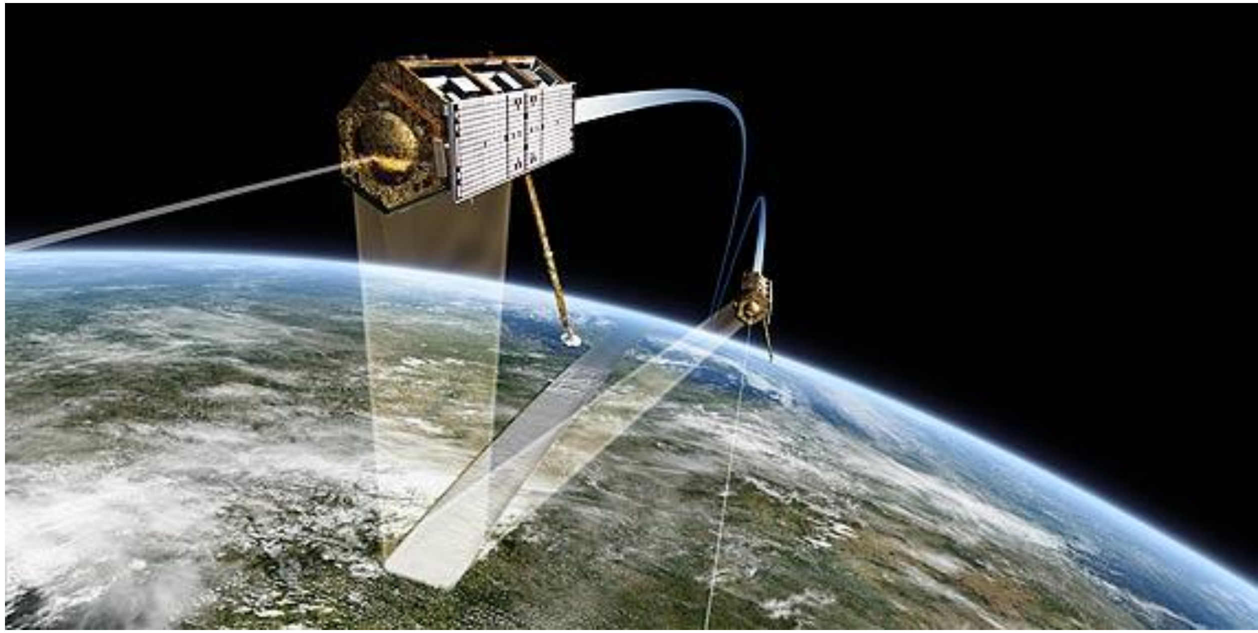
- Sentinel-1 A/B
  - 2014 (S1-A) et 2016 (S1-B)
  - C-Band: 5.56cm
  - Dual polarization HH, HH+HV, VV, VV+VH
  - Repeat pass of 12 days (6 using S1-A and S1-B)
  - Resolution : 5x20 m²



Sources : eoPortal

- Goal : Earth monitoring (broad sense) in radar wavelengths, integrated to the Copernicus program
- Fully open images access with open sources tools to process them (SNAP)

Quentin GLAUDE
Ph.D Student



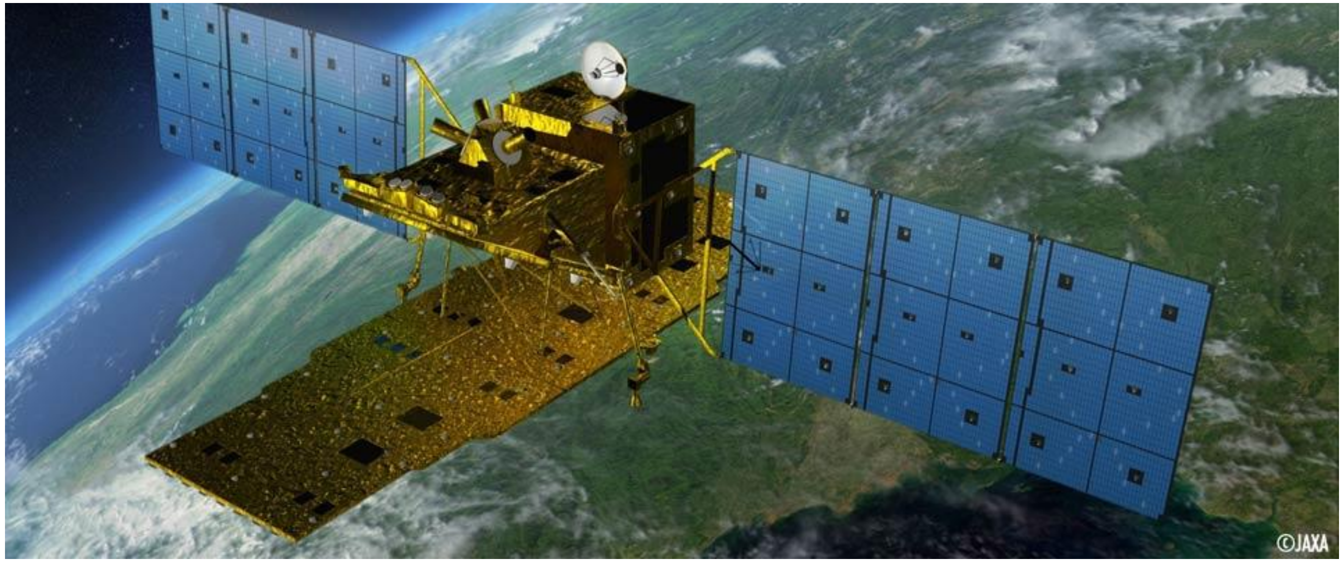
Sources : eoPortal

Current SAR satellites

- TerraSAR / TanDEM-X
    - 2007 and 2010
    - X-Band : 3.1cm
    - Polarization HH/VV/HV/VH (single/dual)
    - Repeat pass of 11 days (0 with TanDEM-X)
    - Resolution : 3x3 m²
- Goal : Digital Elevation Model production on-demand. Atmospheric and displacements phase are minimized with the tandem flight geometry
- $$$
- SNAP can process them too

Current SAR Satellites

- ALOS-2
  - 2014
  - L-Band : 22.9cm
  - Polarization (single/dual/full)
  - Repeat pass of 14 days
  - Resolution : 3x3 m²

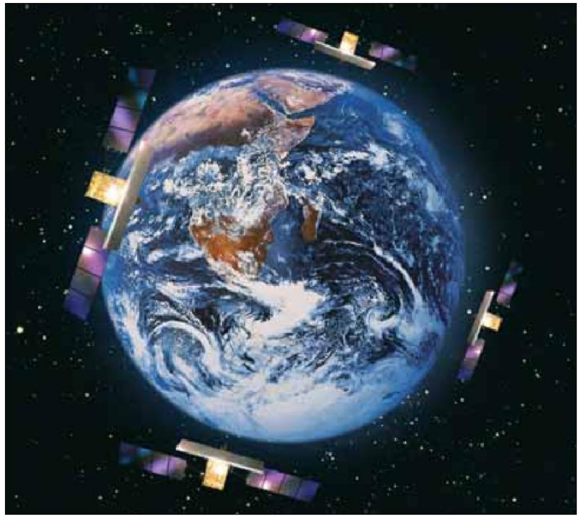


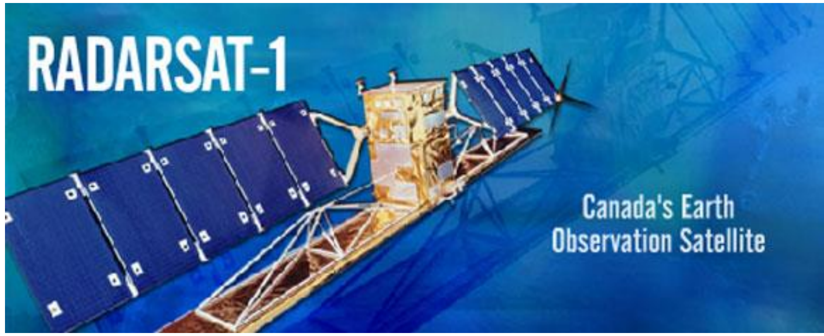
Sources : eoPortal

- But : continuity of ALOS-1, environmental monitoring and risk management
- SNAP handles ALOS-2 data

Current SAR Satellites

- But also …
    - Cosmo-Skymed (X-Band)
    - RadarSat (C-Band)
    - Saocom (L-Band)
    - KompSAT-5 (X-Band)
    - …





Sources : eoPortal