Synthetic Aperture Radar Interferometry (InSAR)

basic concepts

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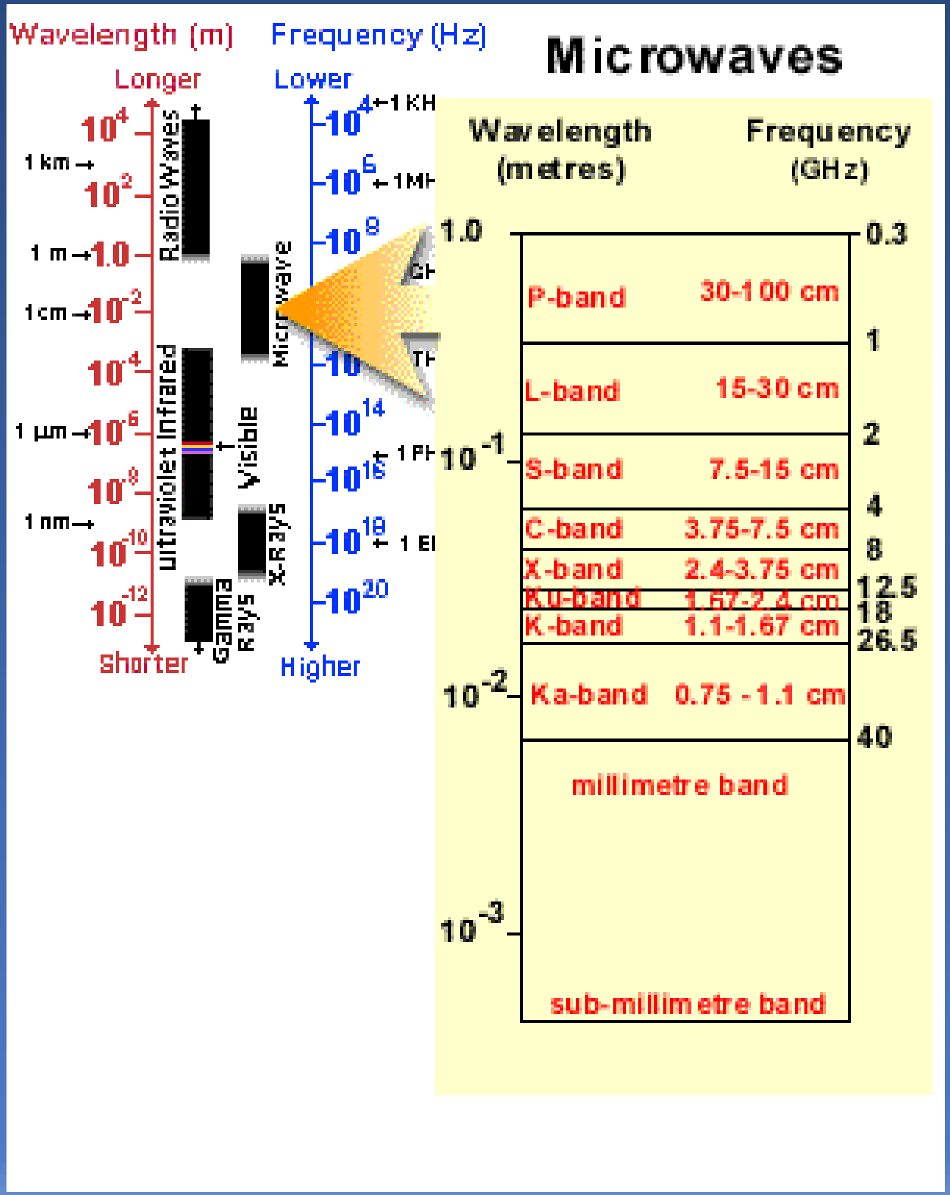
Plan

- What is a radar image (SAR) ?
- Radar interferometry (InSAR)
- Time series (PSI or [M]SBAS)
- Amplitude Time series

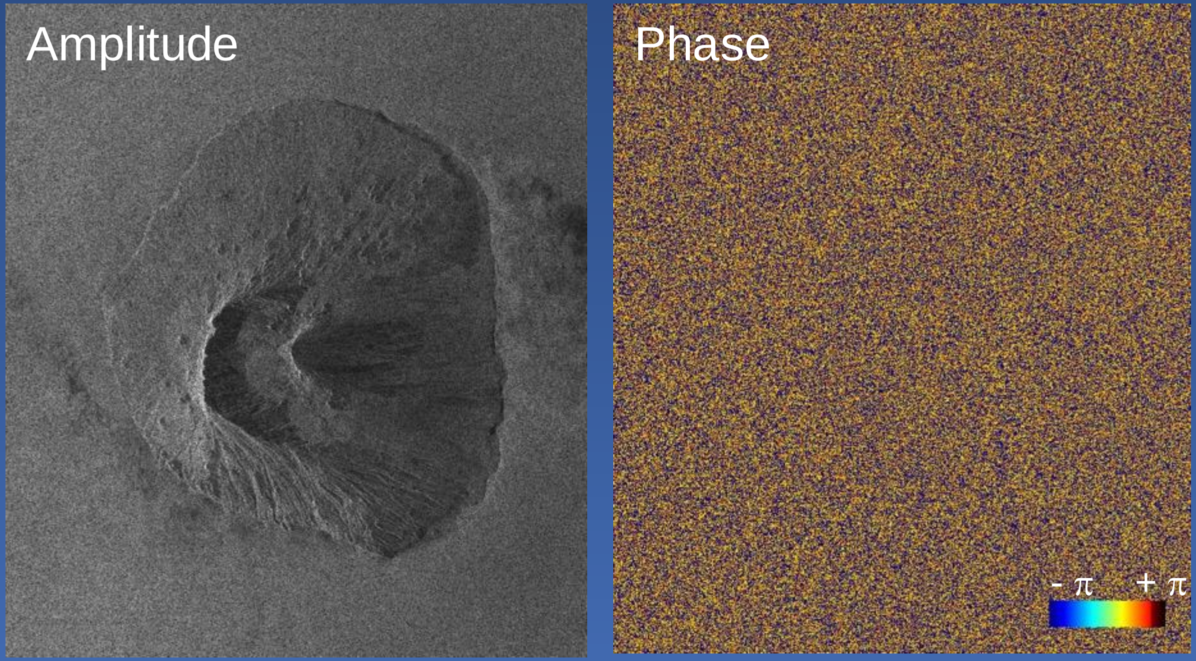
What is a SAR image?

- Hyperspectral (1mm < λ < 1m) => All weather
- Own illumination source => night & day



What is a SAR image?

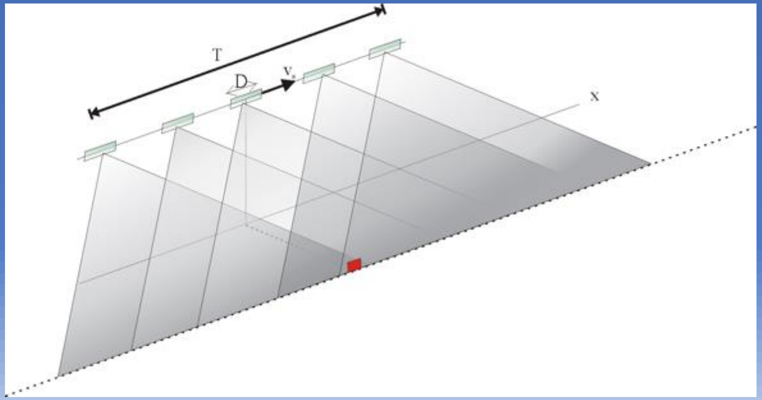
- Hyperspectral (1mm < λ < 1m) => All weather
- Own illumination source => night & day
- Radar image => Amplitude and phase



Fogo Island (Cape Verde), Aug. 9th 2005, Envisat ASAR

- To increase the spatial resolution :

  Simulate larger antenna by taking advantage of satellite displacement (Synthetic Aperture Radar)

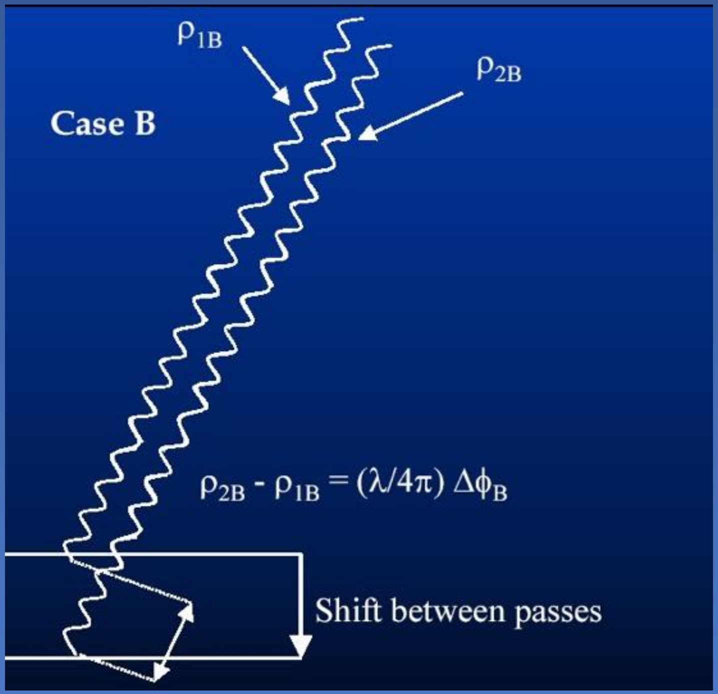


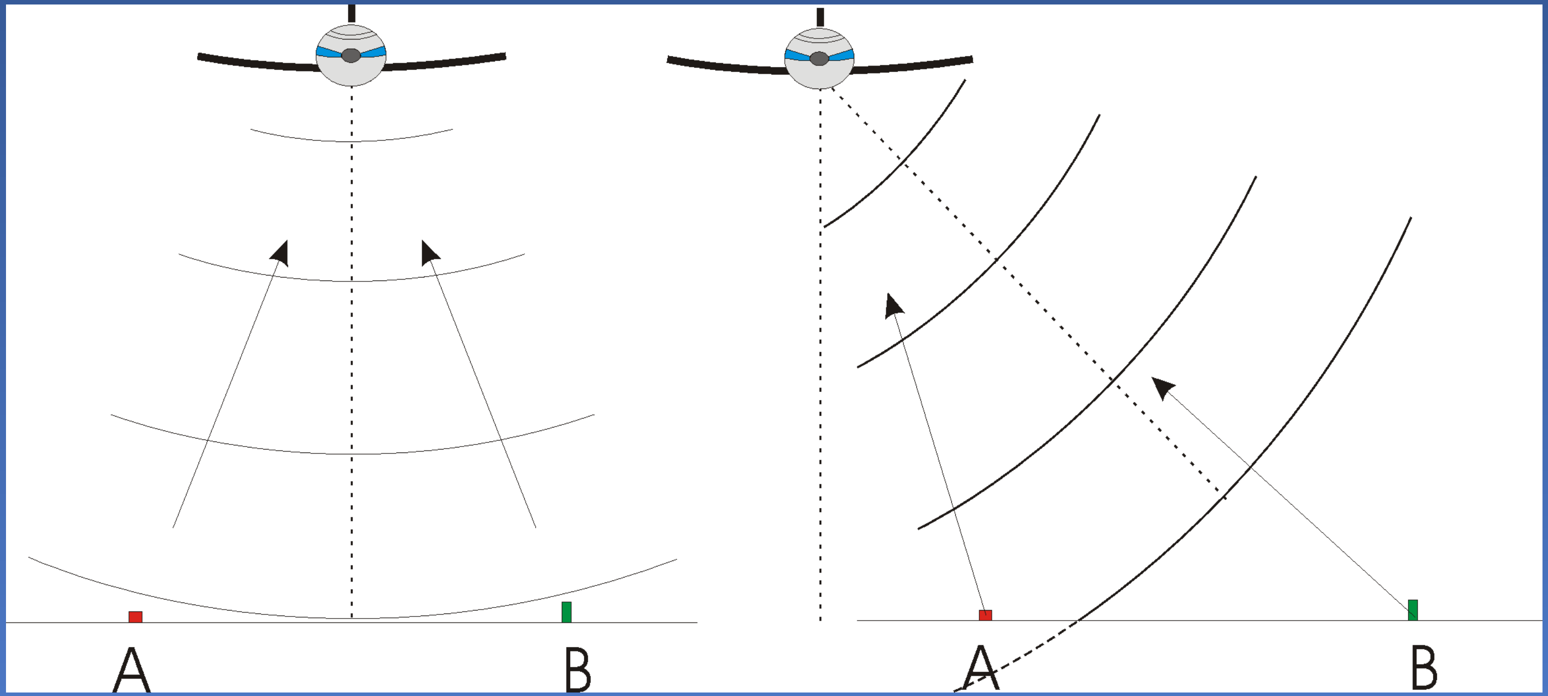
ENVISAT: 1 pixel = 5 x 25m

= resolution of a 2.2 km long antenna !

What is a SAR image?

Phase => information about distance, thought needs oblique viewing geometry

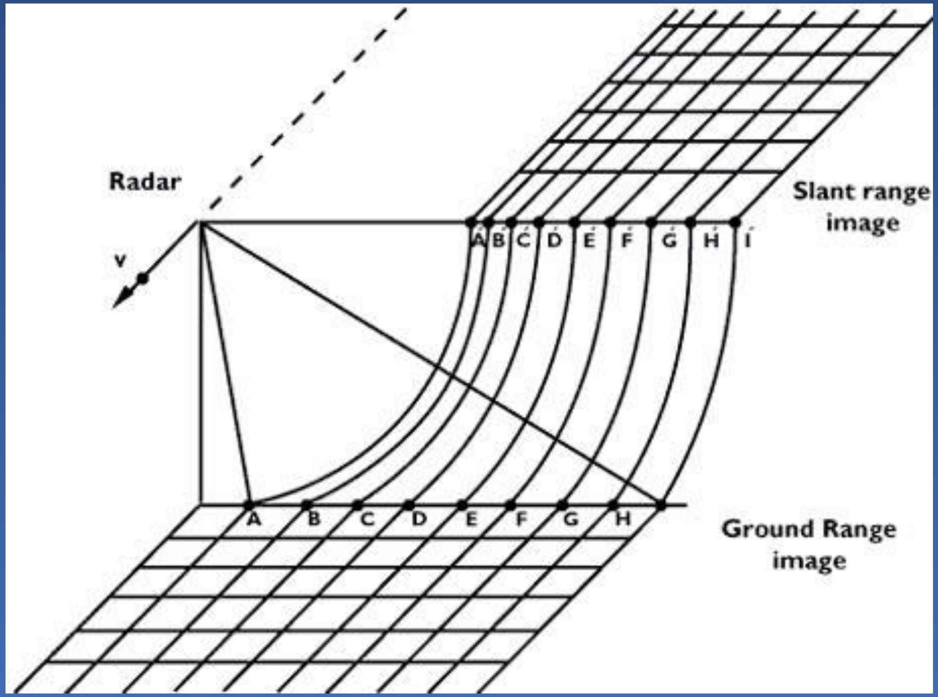


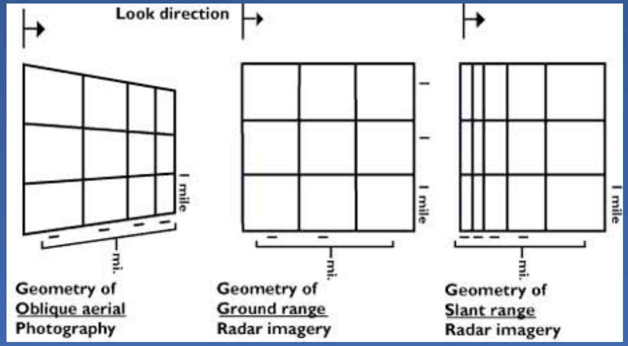


A and B at same distance
from the sensor = same on image

What is a SAR image?

Side view →
image distorsions





Optical imagery: measures angles
Radar: measures distances

Image time-range (or slant-r ange)

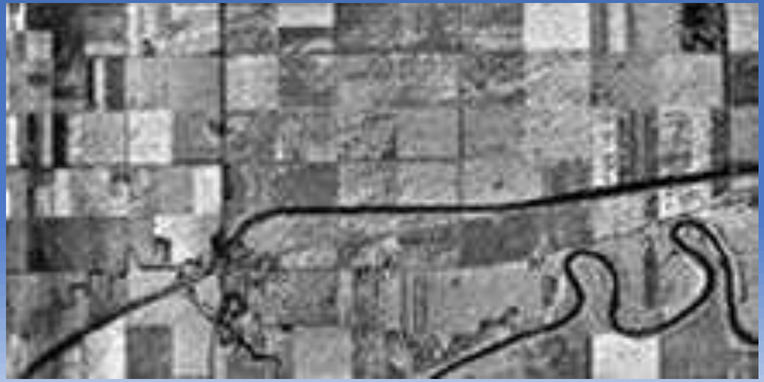
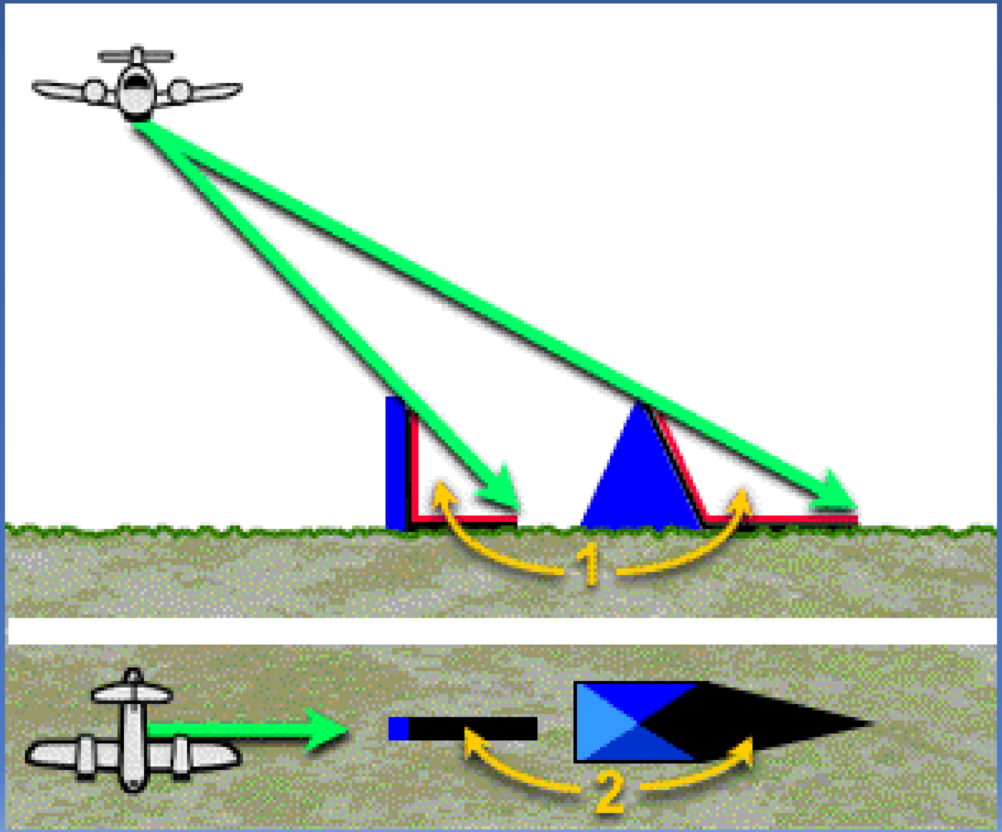


Image ground-range

What is a SAR image?

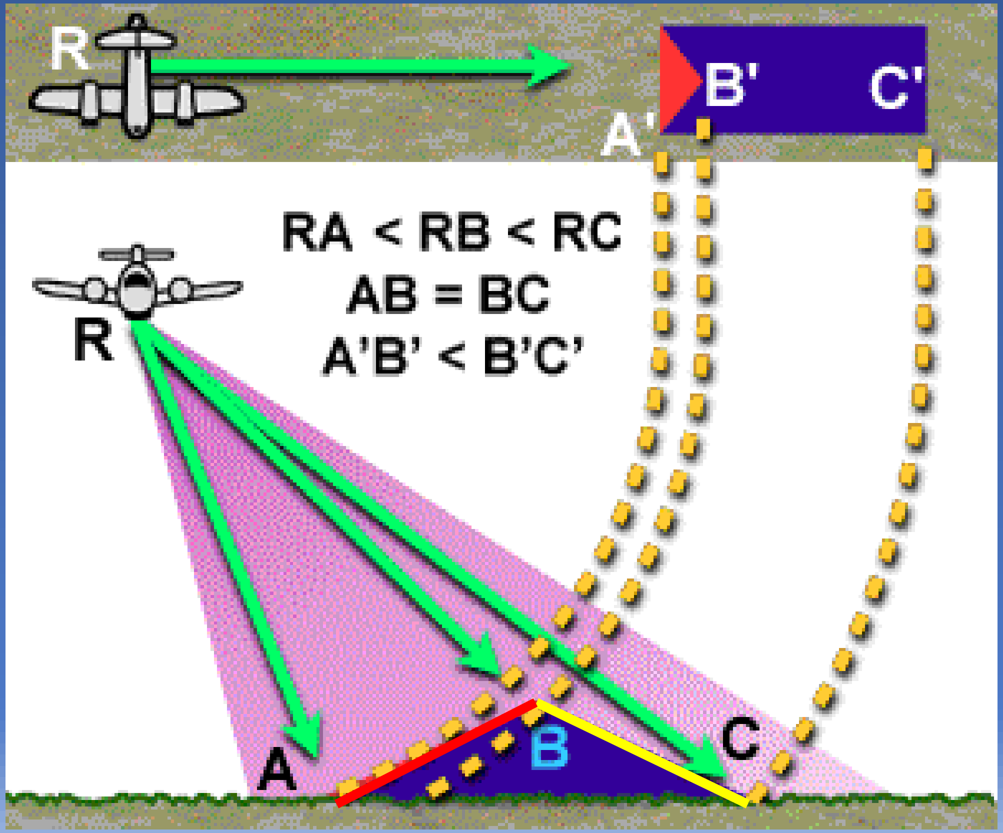
Side view➔
shadowing

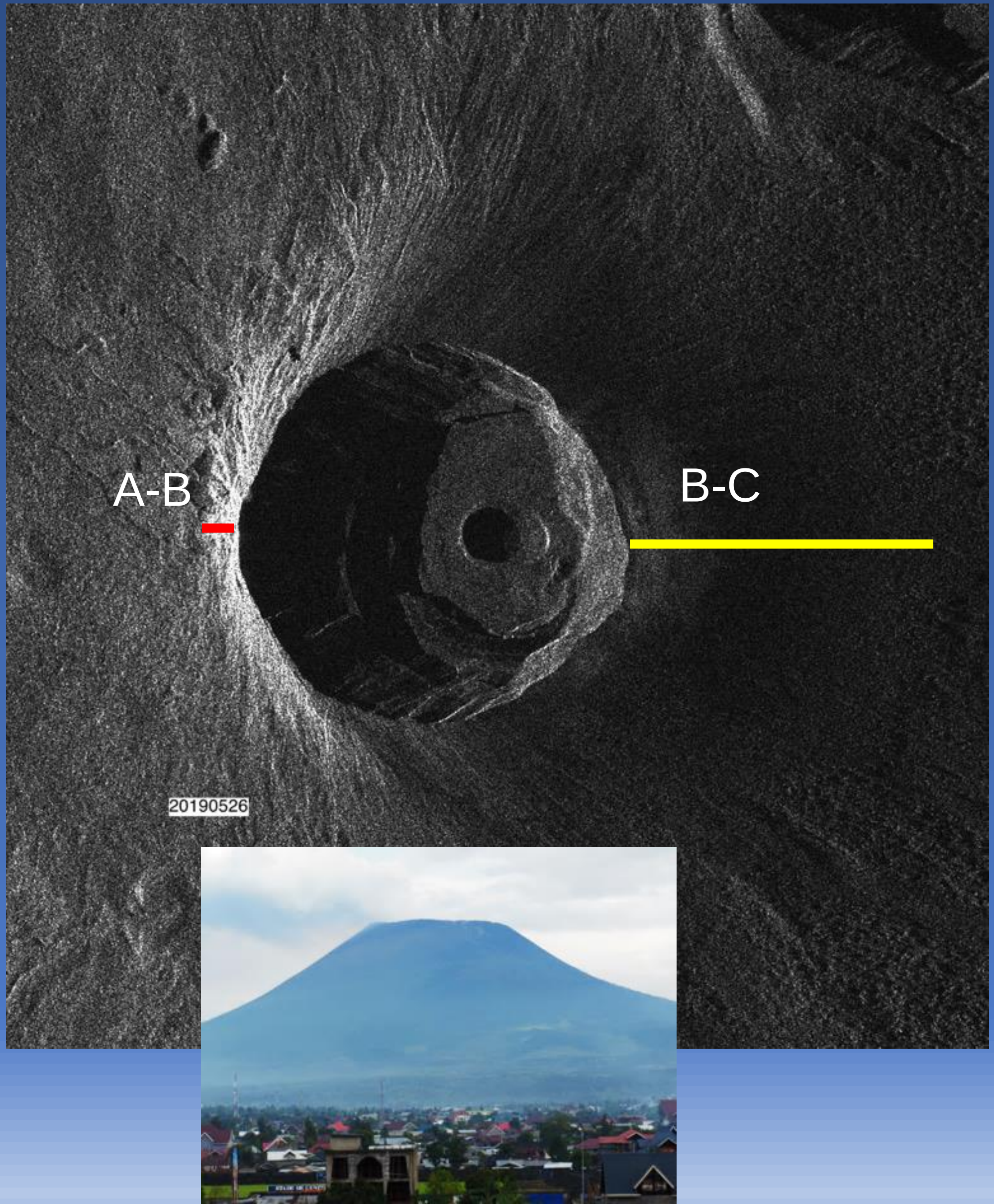


Area invisible
from satellite

What is a SAR image?

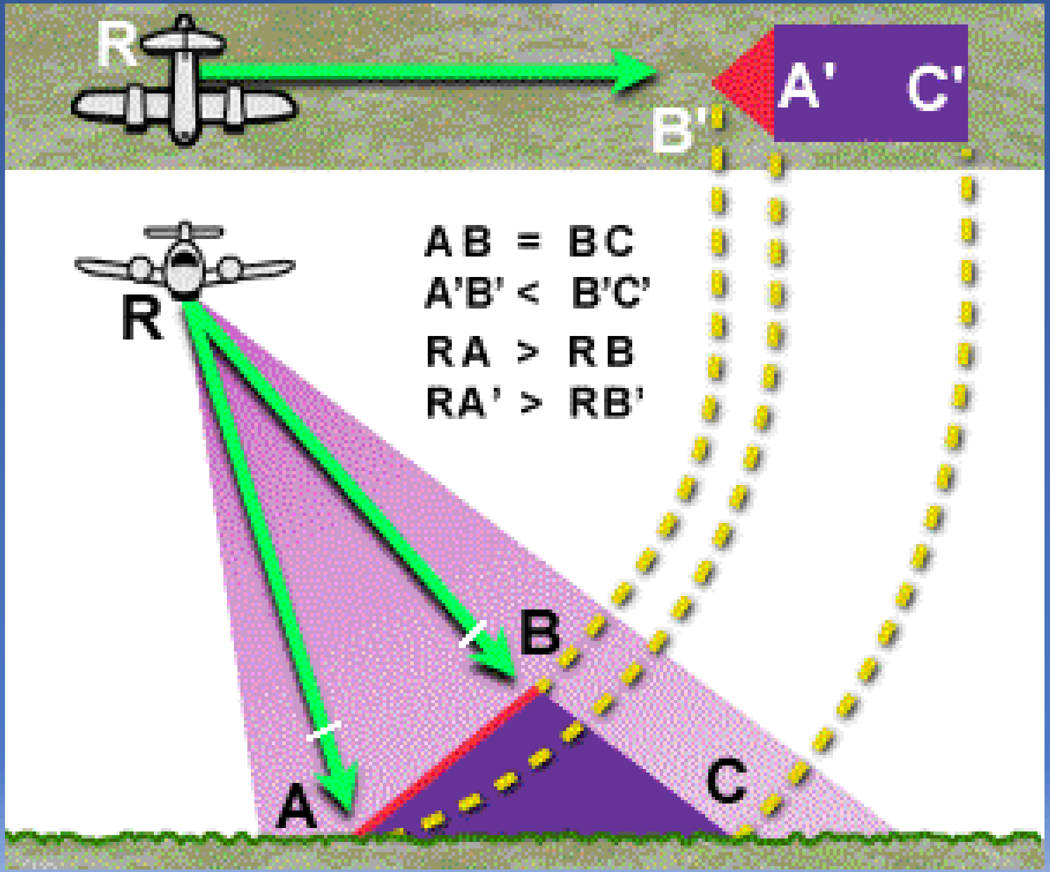
Topography => Shortening

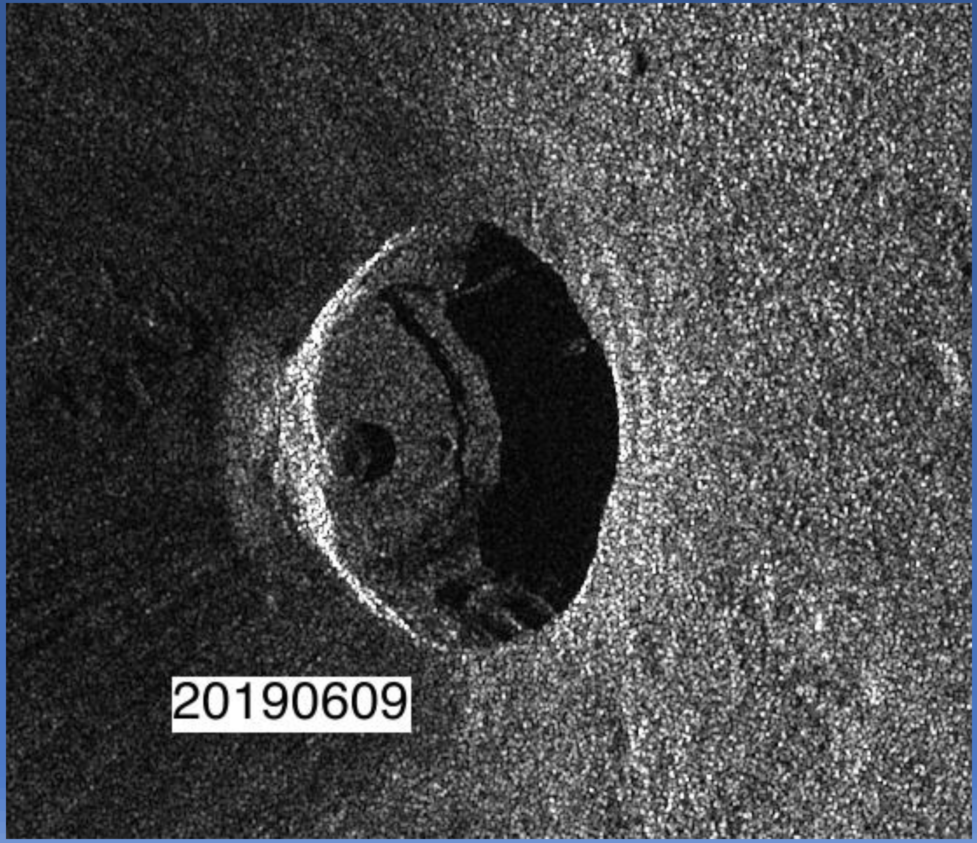




What is a SAR image?

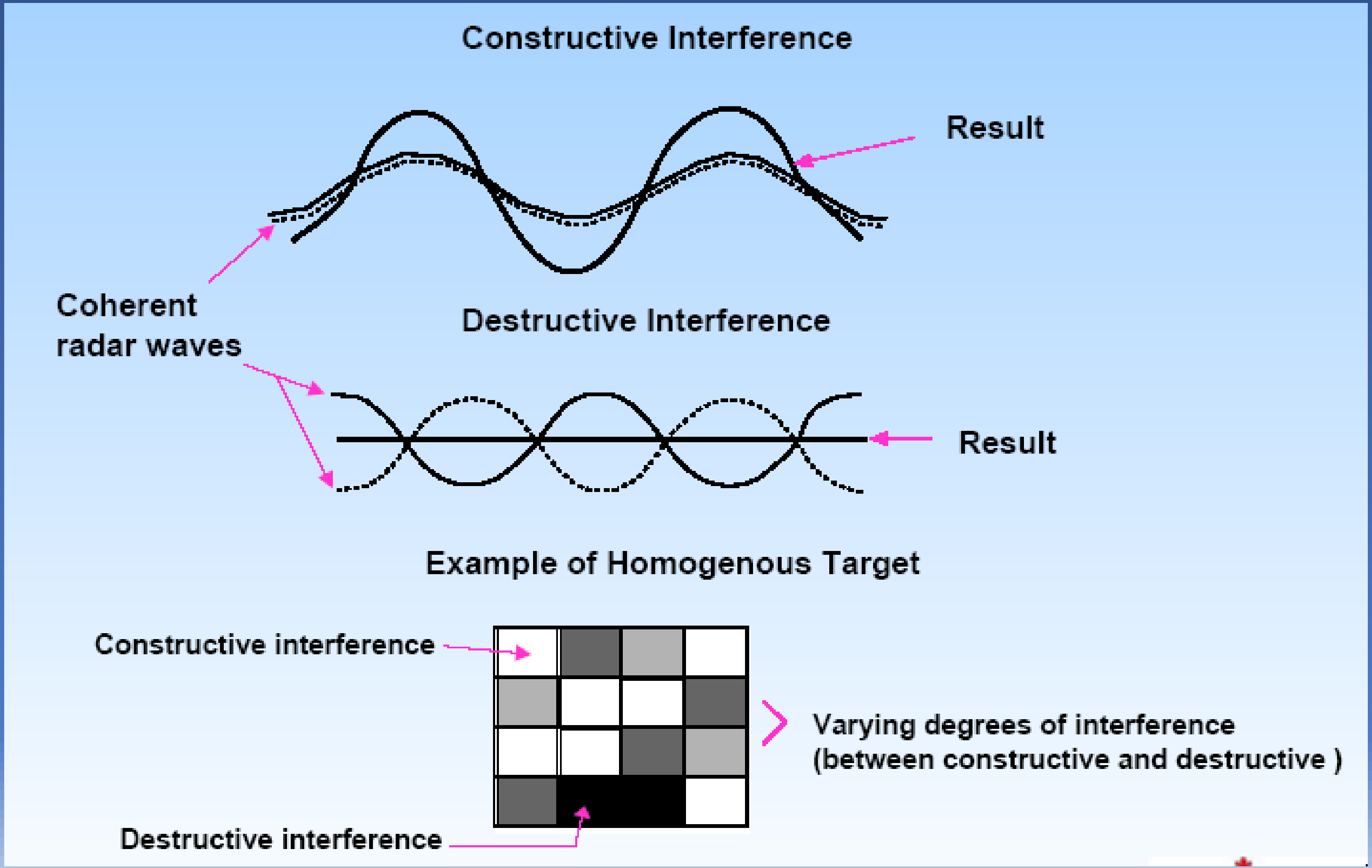
Topography => Layover





The *speckle* in radar images

The signal backscattered by a pixel is formed by the ensemble of the elementary and random reflectors



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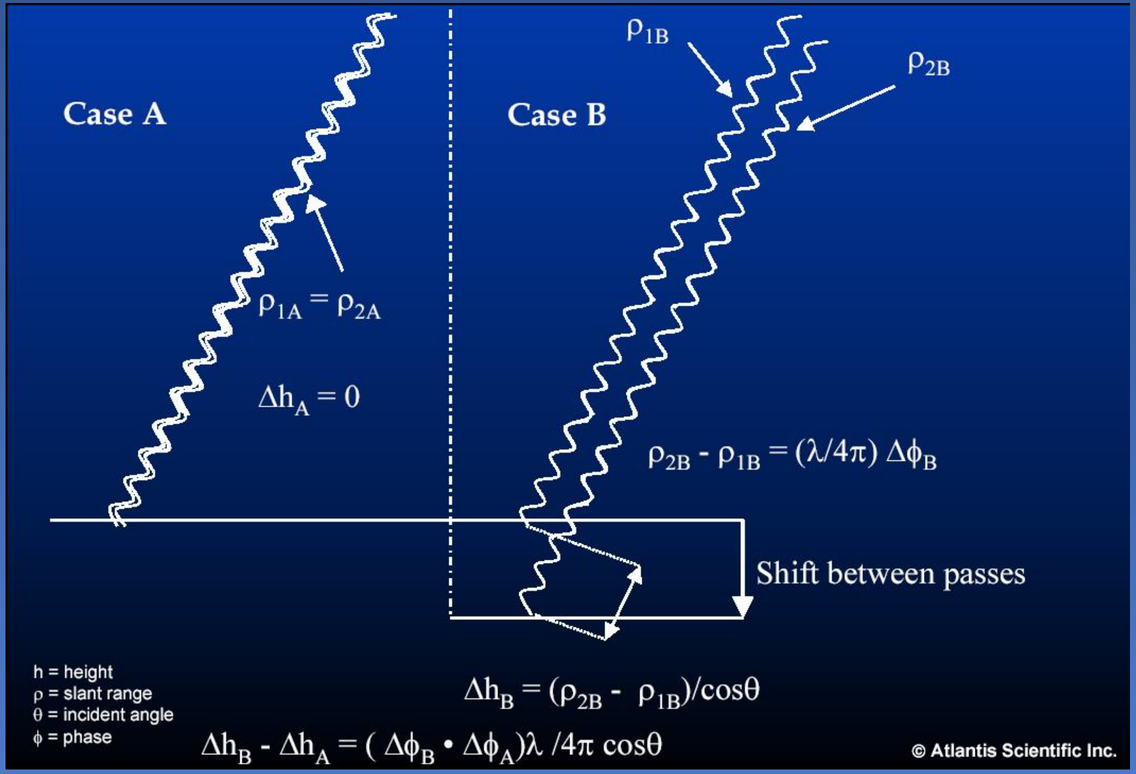
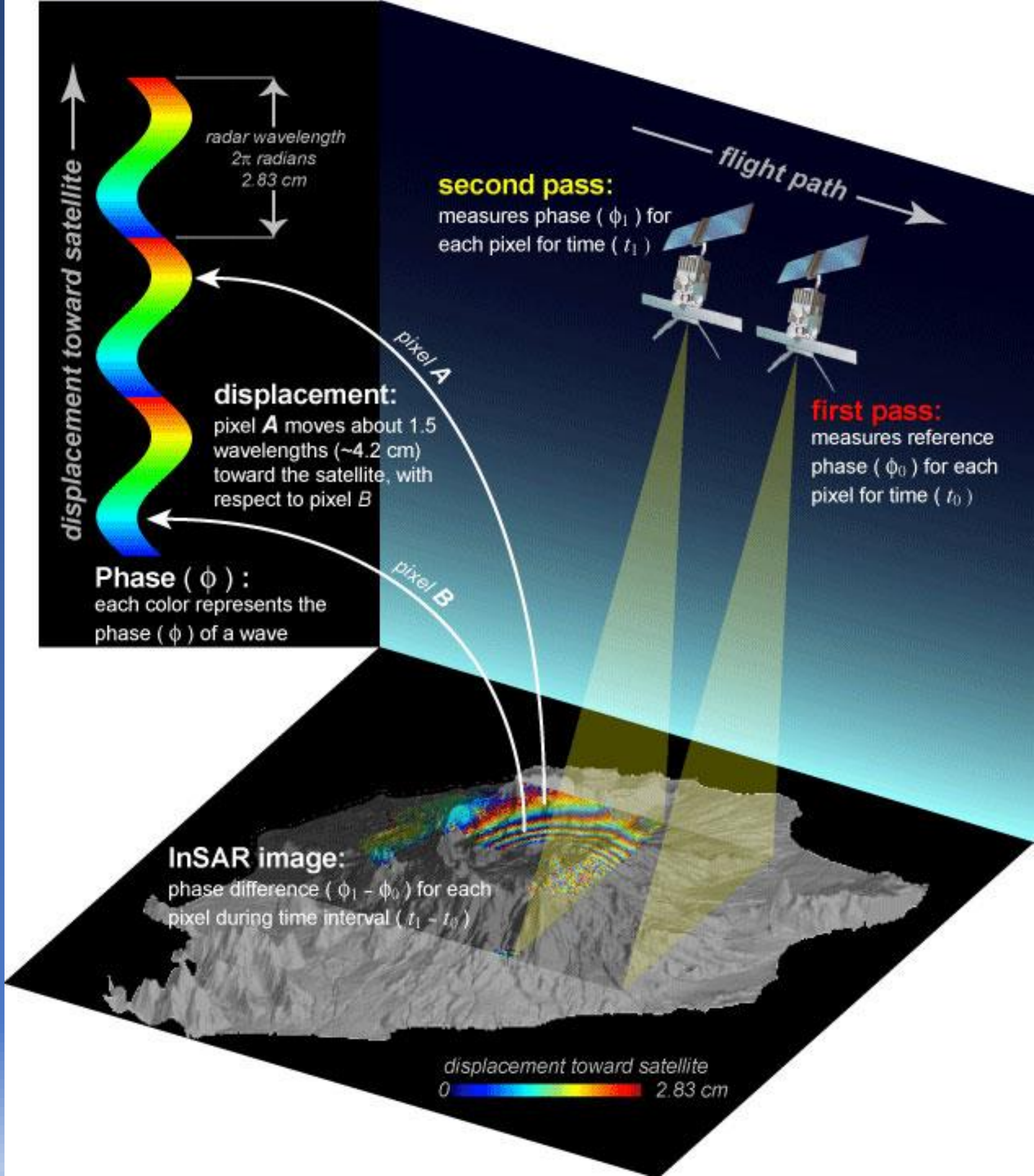
InSAR method

Interferometry between 2 RADAR signals

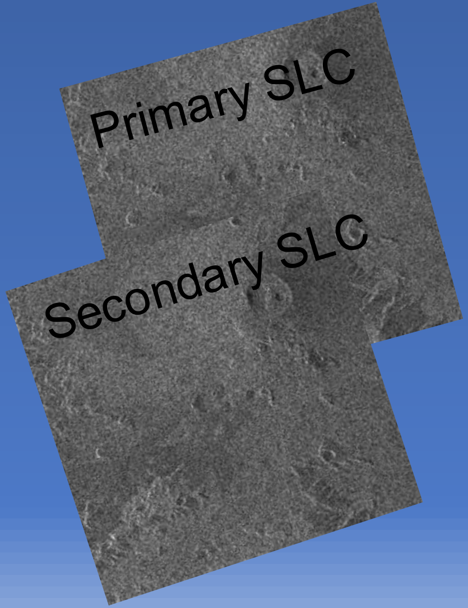


1 fringe = λ / 2 ~ 3cm (in C-band)

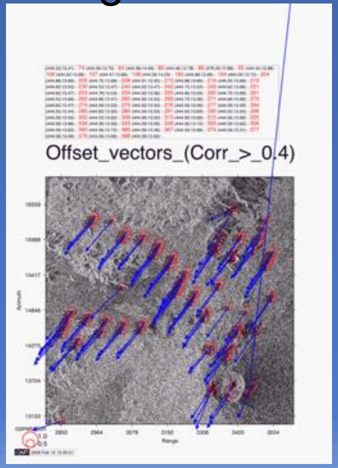


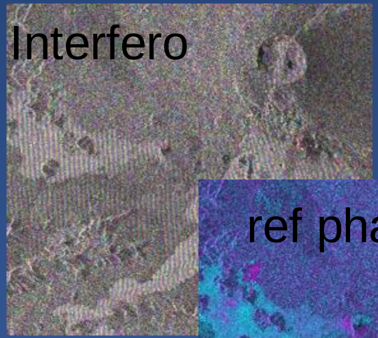
InSAR method

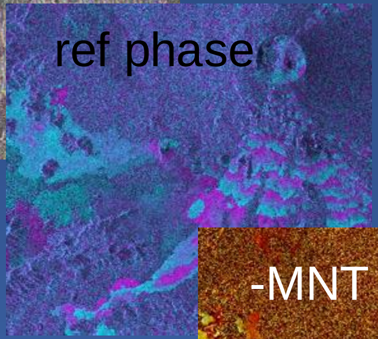
2 RADAR images => deformations

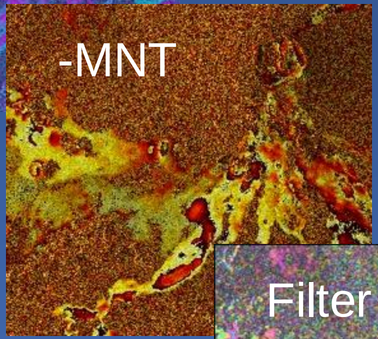


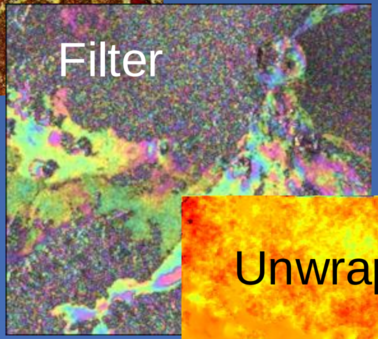
Coregistration

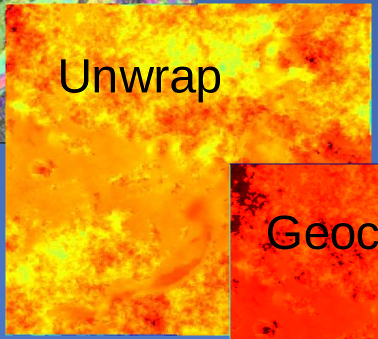


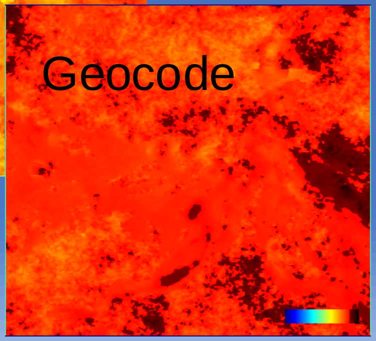


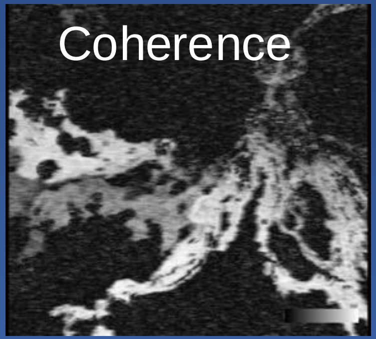


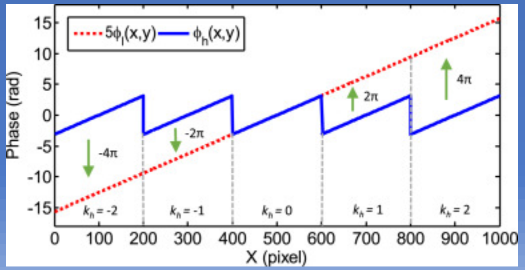










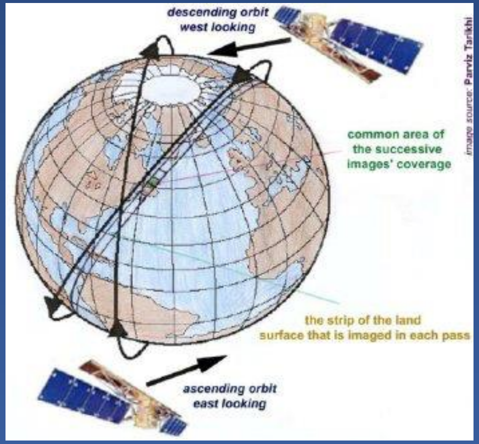


Unwrapping

Coherence

Interferometry :

Mandatory to compare « similar » images, i.e. same geometry (Ascending/Descending, incidence angle, wavelength etc…).



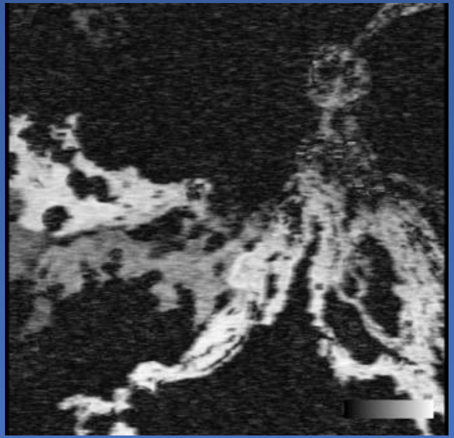
Not only !

⇒ InSAR does not work if:

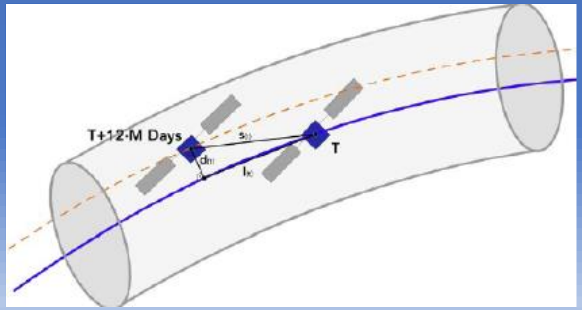
- The signal is not backscattered toward the satellite (specular reflexion on water)

- The backscattering surfaces/properties have changed (vegetation, snow, anthropogenic activities…)
  => Max temporal Baseline (Bt)

0 < Coherence < 1



- If the point of view has changed
  => Max spatial Baseline (Bp). Cfr orbital tube.



Plan

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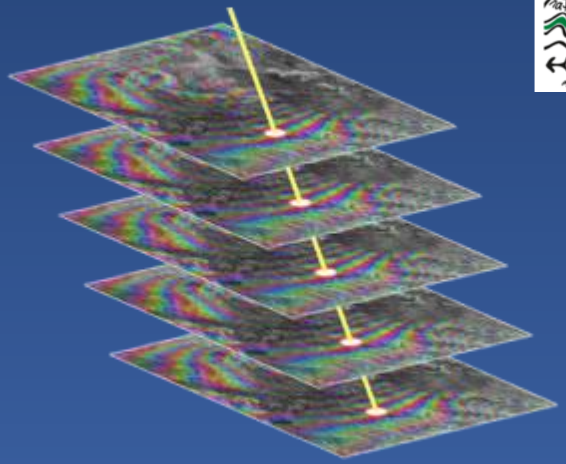
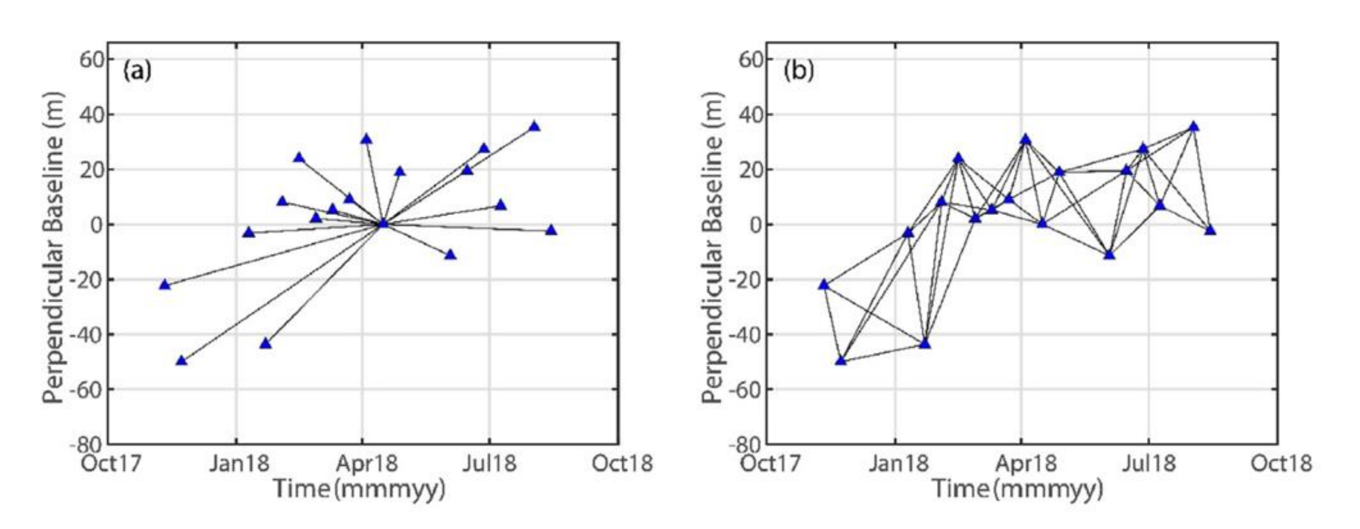
InSAR Times series:



Track displacement through « all » compatible pairs, i.e.
same satellite, same geometry, same polarisation...

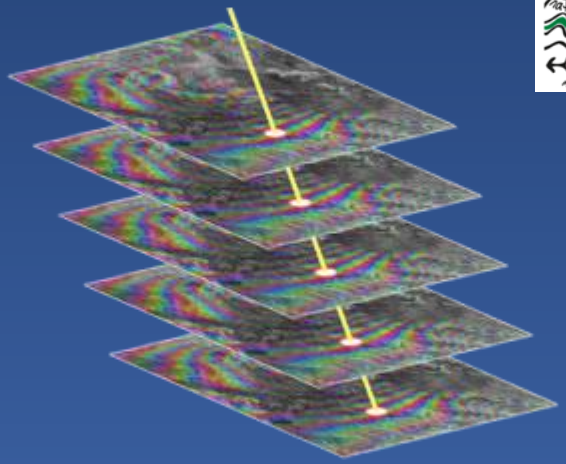
Two type of methods
- Permanent Scatterer Interferometry (PSI):
  - Search for “worst” Bp to keep only good scatterers (usually man-made structures)
  - Better for urban regions

- Small Baseline Subsets (SBAS)
  - Keep only the most favourable (shortests) Bt and Bp to ensure the best coherence
  - Appropriate for natural targets



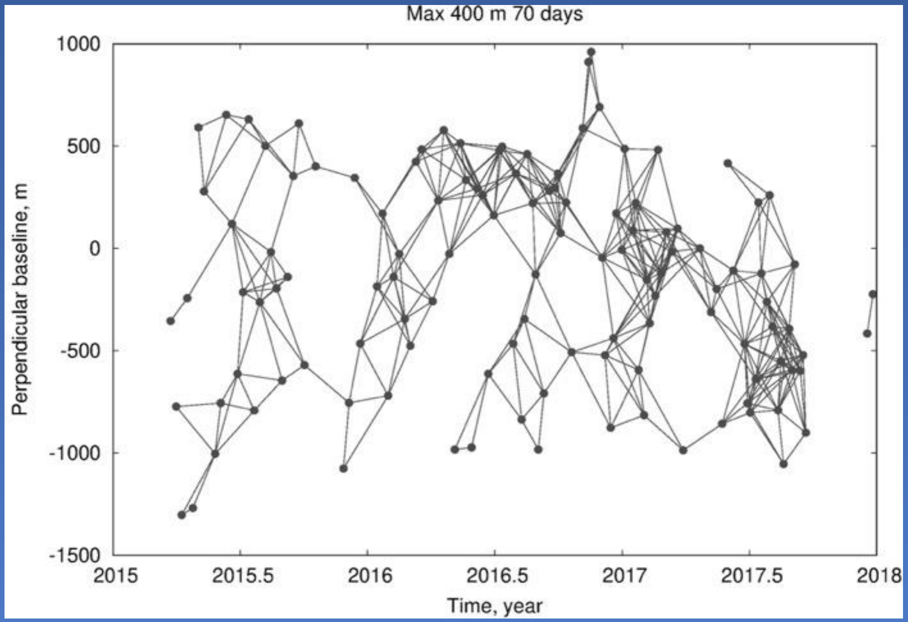
Example baseline plot for (a) the PSI and (b) SBAS method (Li et al. 2022).

InSAR Times series:



SBAS :
- < Max Bt (eg. max 70 days)
- < Max Bp (eg. max 400 m)

Bp

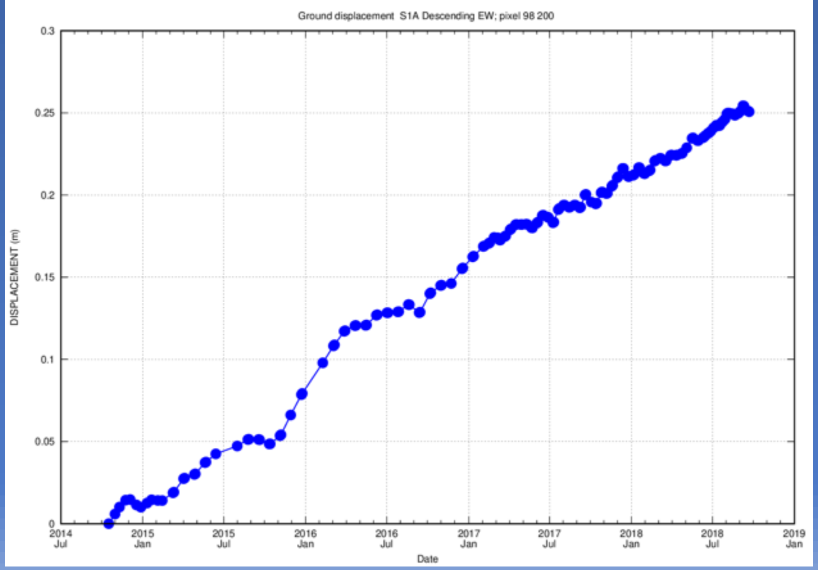


Bt

n images => m interferograms (maximum $(n-n^2)/2$)

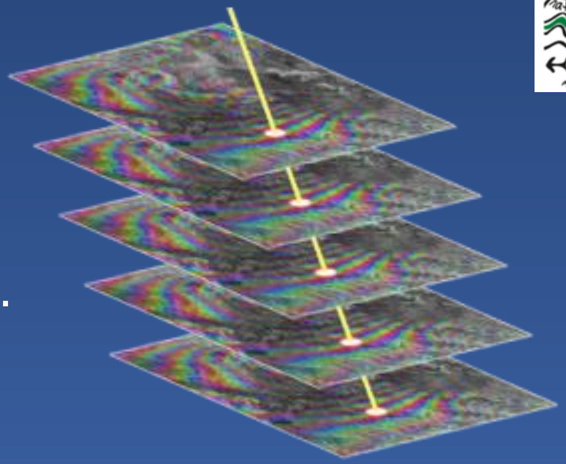
Provides with mean linear velocity map and time series of ground displacements in satellite Line Of Sight

Displacement (m)



Date

InSAR Times series:



For a given geometry (look angle, wave length, polarity…): The Small Baseline Subset (SBAS) method

(Berardino et al. 2002; Usai, 2003).

m interferograms

n images => m interferograms

$$A V_{\text{los}} = \Phi_{\text{obs}}$$

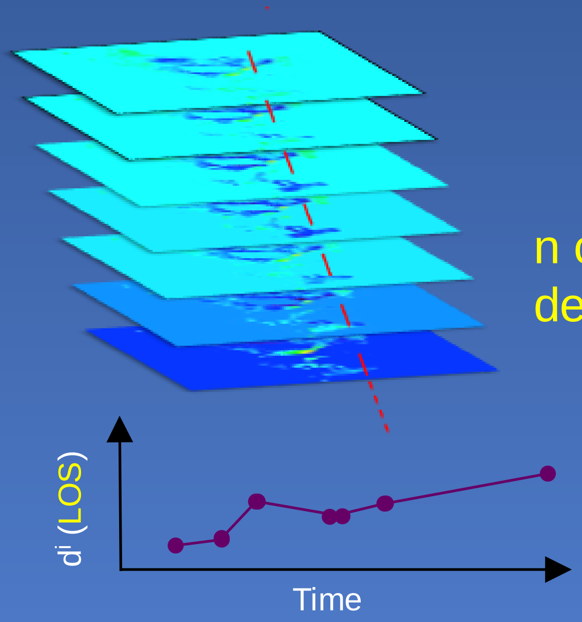
A: time matrix
V: Unknown velocities
Φ: Observed interferograms

$$V_{\text{los}} = A^{+} \Phi_{\text{obs}}$$

Singular Value Decompos. is used for finding a solution of under-/over-determined problem (A^+).

$$d_{\text{los}}^{i+1} = d_{\text{los}}^{i} + V_{\text{los}}^{i+1} \Delta t^{i+1}$$

d : LOS displacements



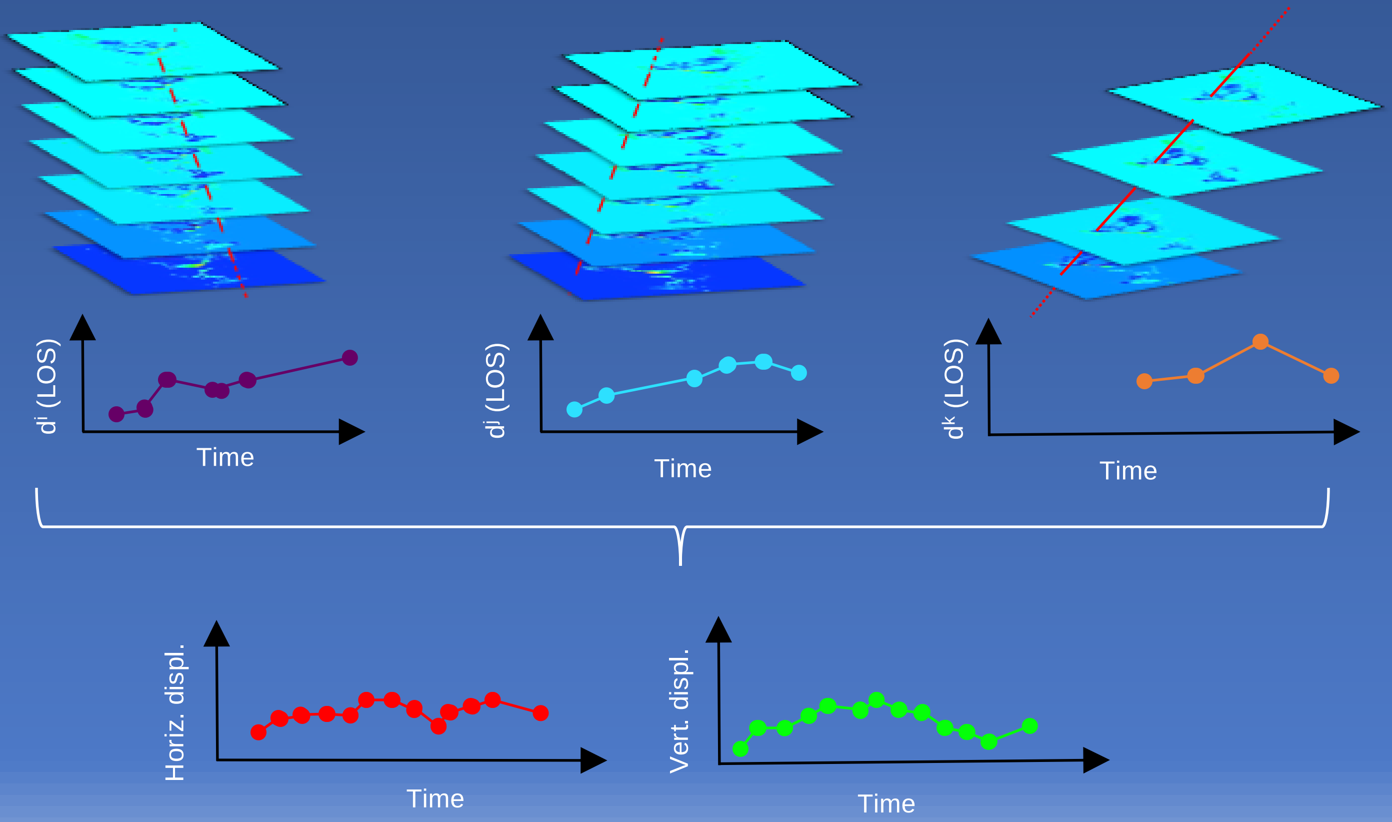
n cumulated deformation maps

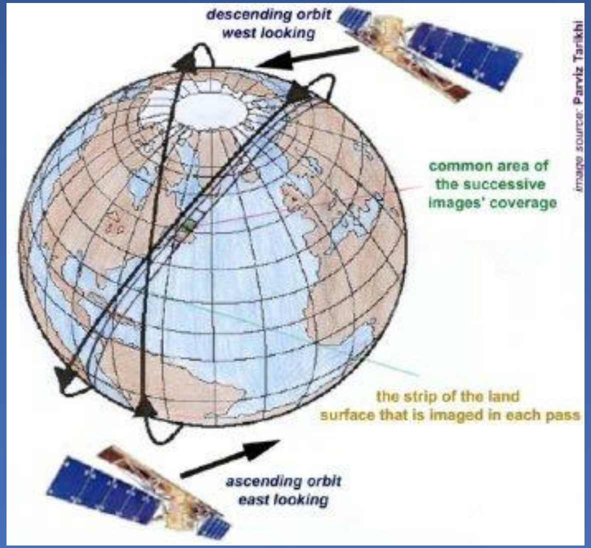
n points

InSAR Times series:

Combining all geometries : The Multidimensional Small Baseline Subset (MSBAS) method.

(Samsonov and d'Oreye, 2012, 2017)





Subpolar Orbits
=> Usually not sensitive to motion in NS direction
(OK if V_N not >> V_E)

InSAR Times series:

Combining all geometries : The Multidimensional Small Baseline (MSBAS) method.

(Samsonov and d'Oreye, 2012, 2017)

For each of the k=1,2,… K datasets:

$$A^k V^k_{\mathrm{los}} = \Phi^k_{\mathrm{obs}}$$

A: time matrix

V: Unknown velocities

Φ: Observed interferograms

$$\left| S^k_N A, S^k_E A, S^k_U A \right| \cdot \left| V_N, V_E, V_U \right|^T = \Phi^k_{obs}$$

V_{los} = **VS** = $S_N V_N + S_E V_E + S_U V_U$,

where V_{los} = line-of-sight scalar velocity

V = velocity vector **V** (V_N, V_E, V_U)

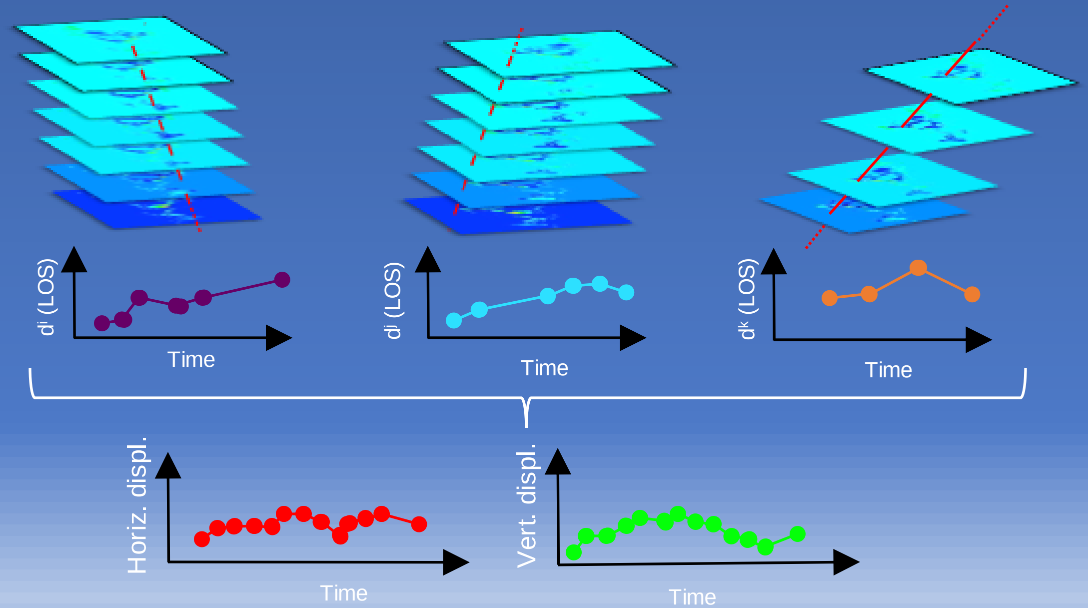
S = unit vector **S** (S_N, S_E, S_U) pointing to the satellite

For all K datasets:

$$\begin{pmatrix} A^1 \\ A^2 \\ \cdots \\ A^K \end{pmatrix} \begin{pmatrix} V_{\mathrm{N}} \\ V_{\mathrm{E}} \\ V_{\mathrm{U}} \end{pmatrix} = \begin{pmatrix} \Phi^1 \\ \Phi^2 \\ \cdots \\ \Phi^K \end{pmatrix}$$

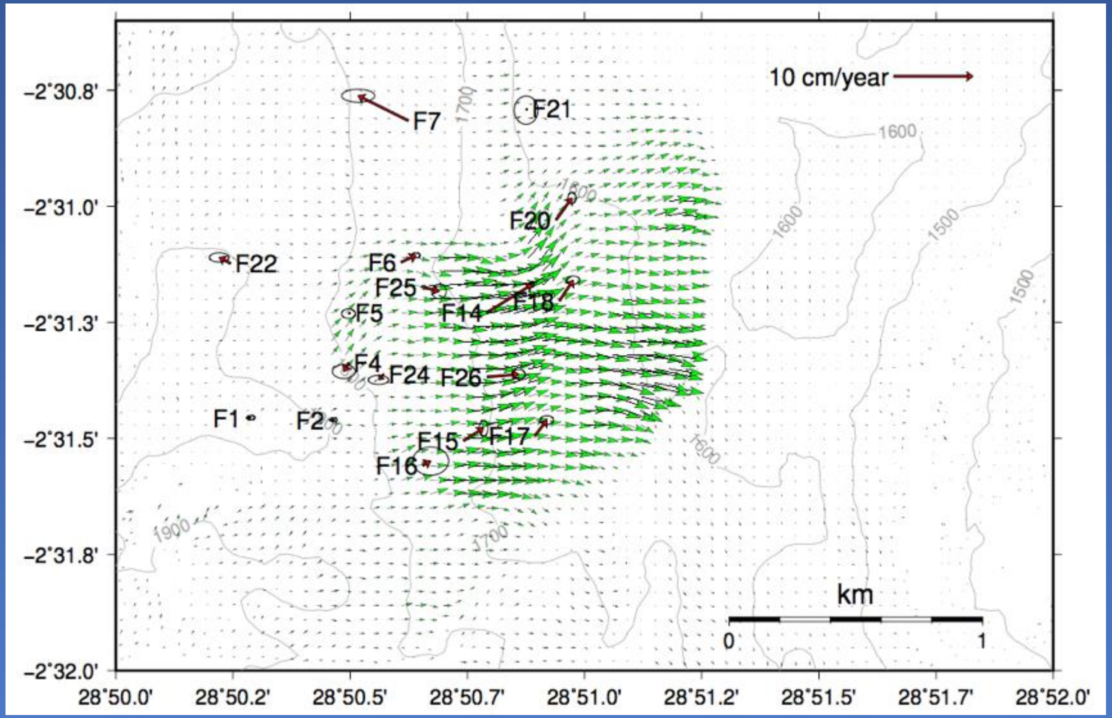
or

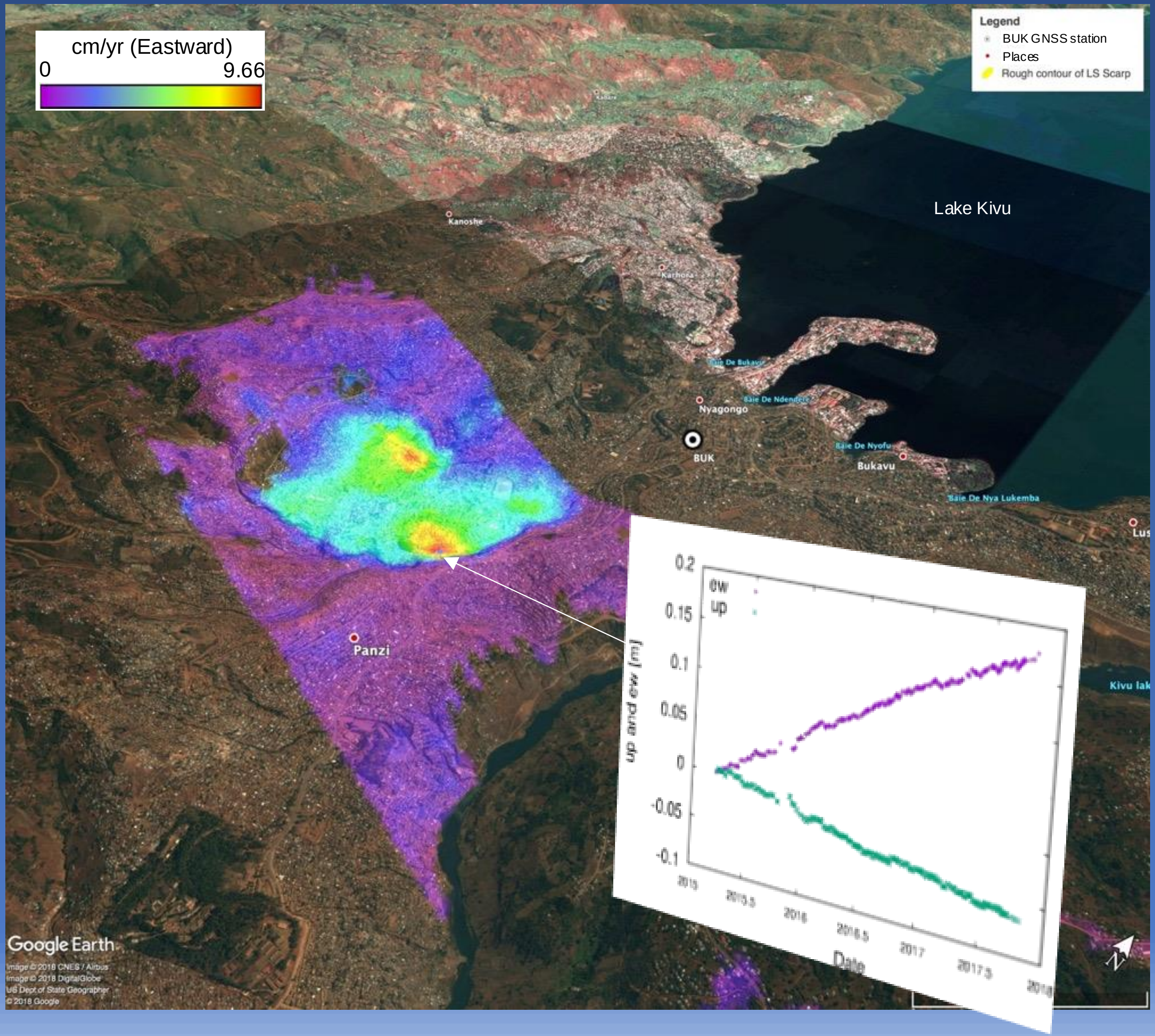
$$\hat{A}\hat{V}_{\mathrm{los}} = \hat{\Phi}_{\mathrm{obs}}$$



InSAR Times series:

3D Capabilities

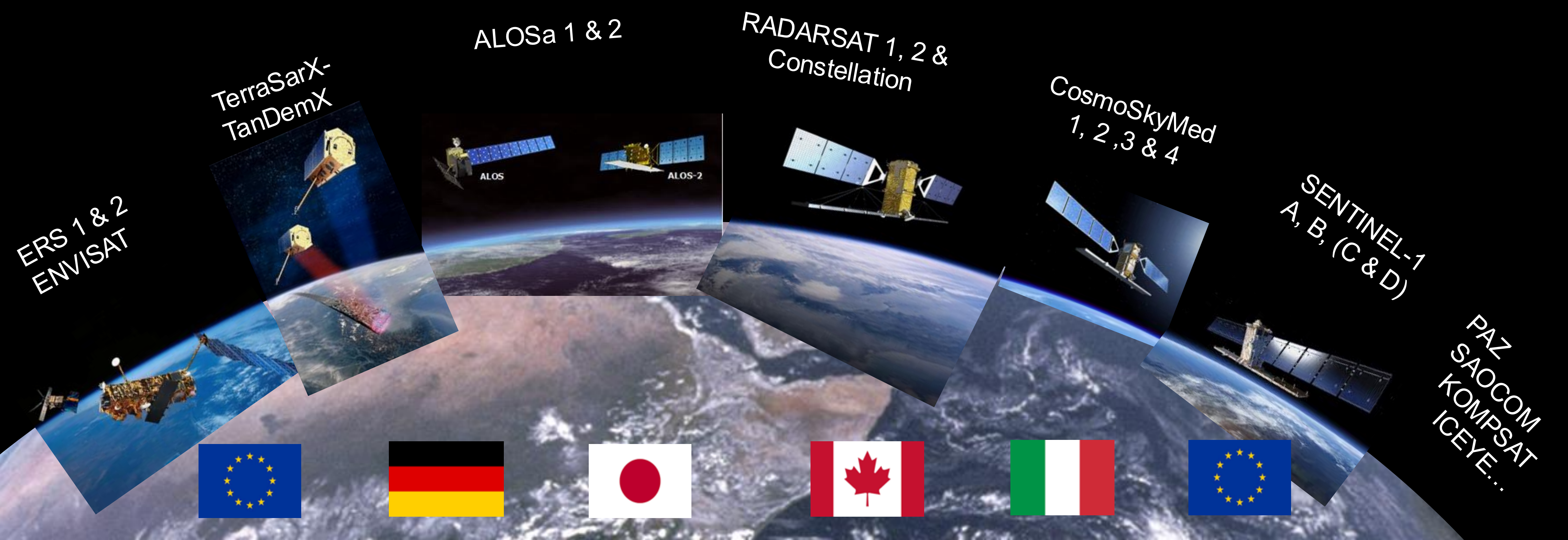




(Samsonov et al., Eng. Geol. 2020)

MSBAS operates with all type of SAR

Several existing SAR satellites and constellations of satellites (and more to come !)
Several type of geometries (Ascending, Descending, incidence angle, λ, polarisation, resolution etc..)



Limitations:

Mandatory conditions:

- Coherence:
  ➔ limited vegetation, same ground conditions
- Diversity of looking angle for 2D/3D decomposition
  ➔ Ascending and Descending
- Appropriate selection of processing parameters, reference points for MSBAS inversion…
- Appropriate pair selection (no gaps, balanced use of images as Primary and Secondary…)
-

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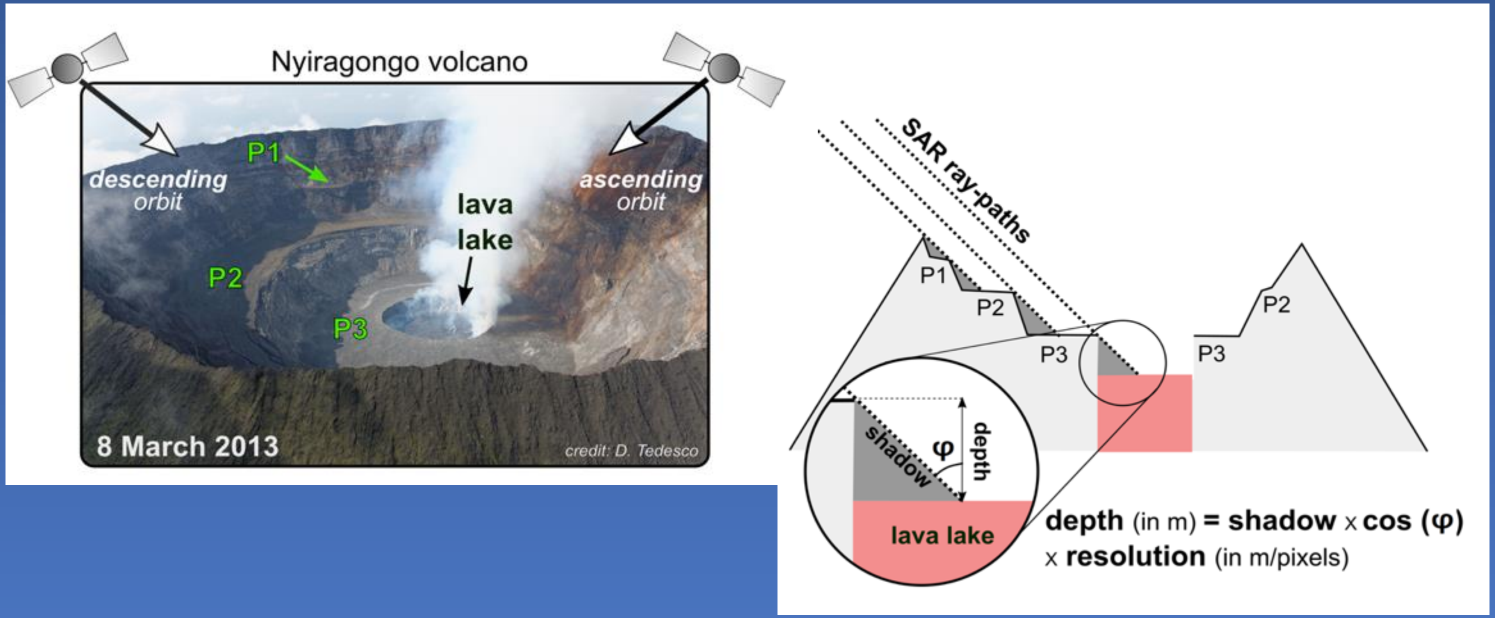
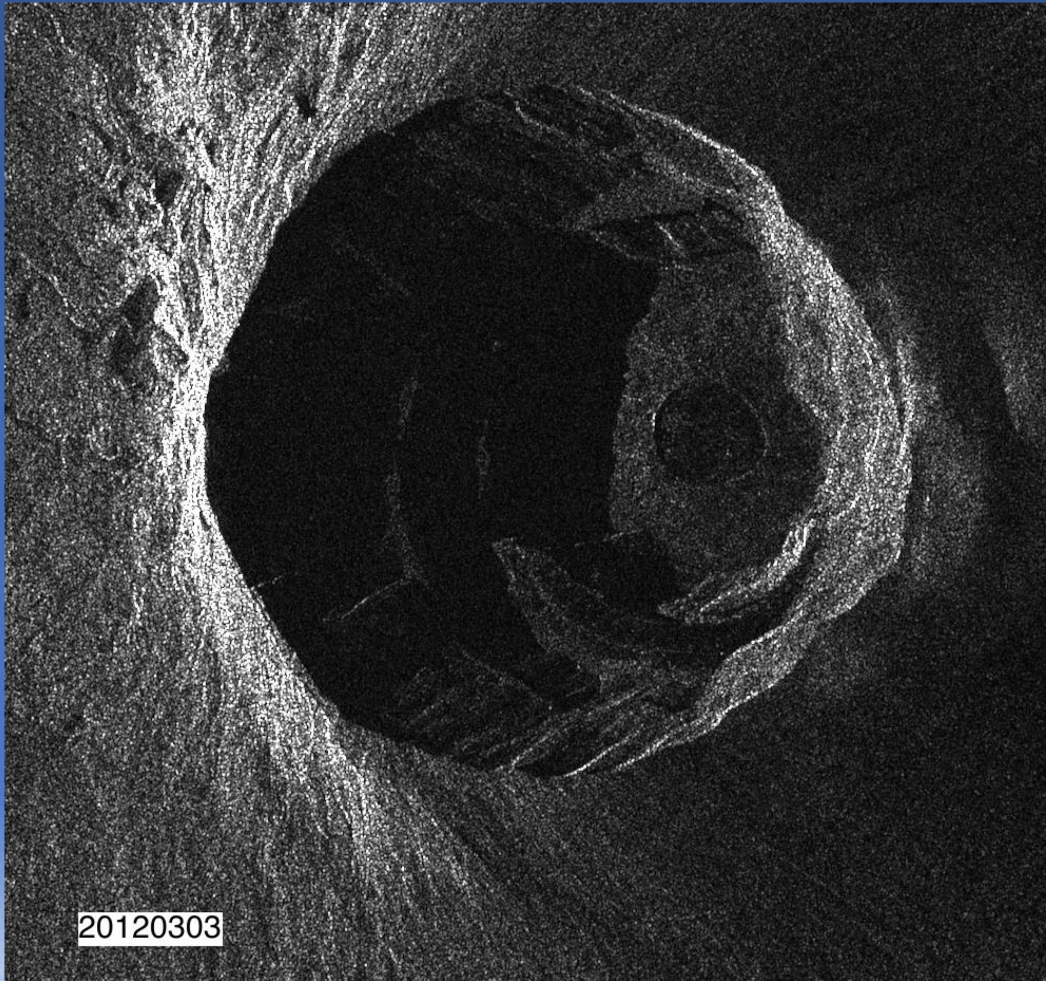
Information from the amplitude images



(Barrière et al. 2018, 2019)

Nyiragongo crater – RS2 UF (2012-2019)



Nyiragongo

- Lava lake depth
- Crater depth

=> Accumulated volume, pressure changes…