RADAR INTERFEROMETRY

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CAMPI ELETTROMAGNETICI, MODULO 2

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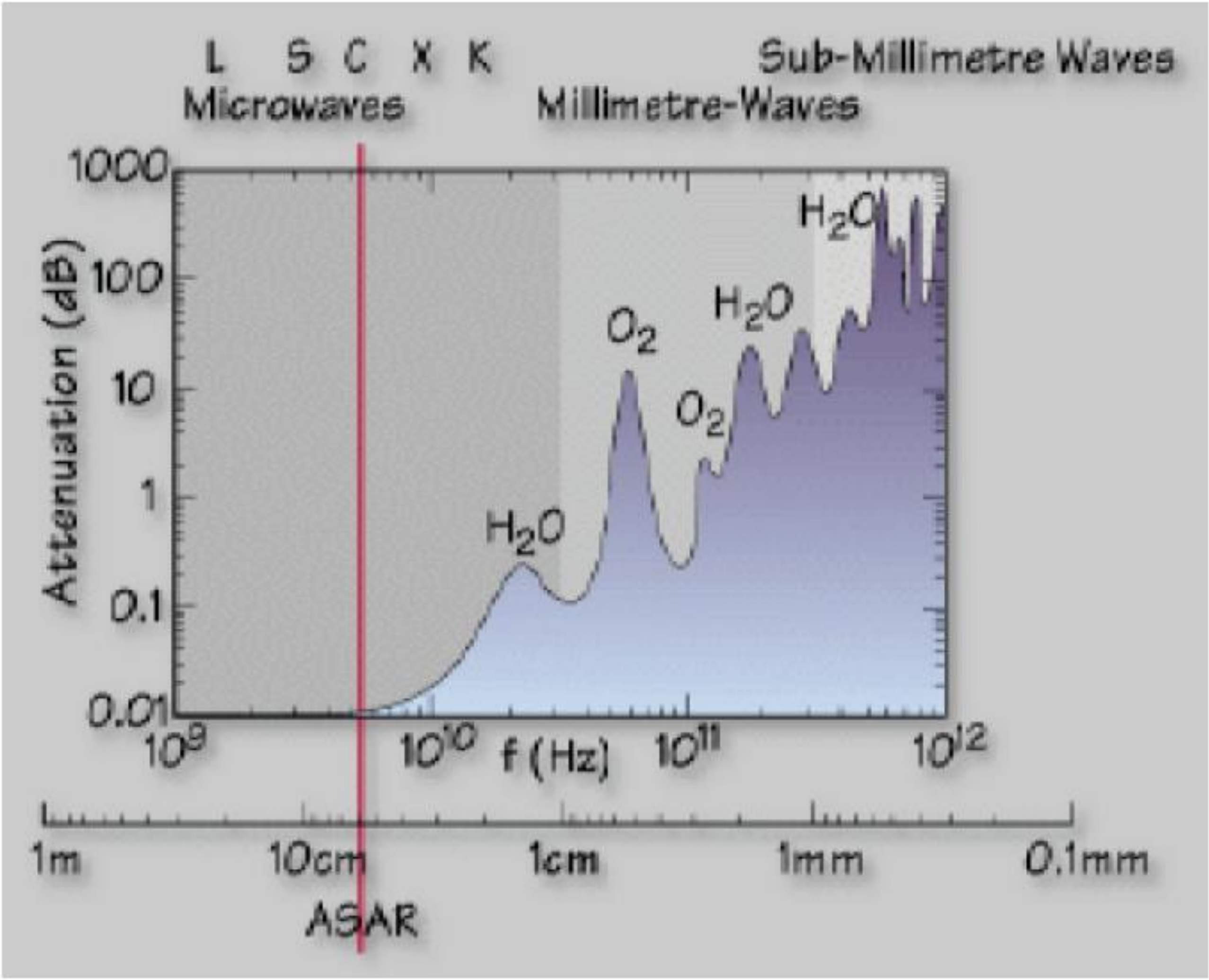
Geoinformazione
Tor Vergata

Introduction

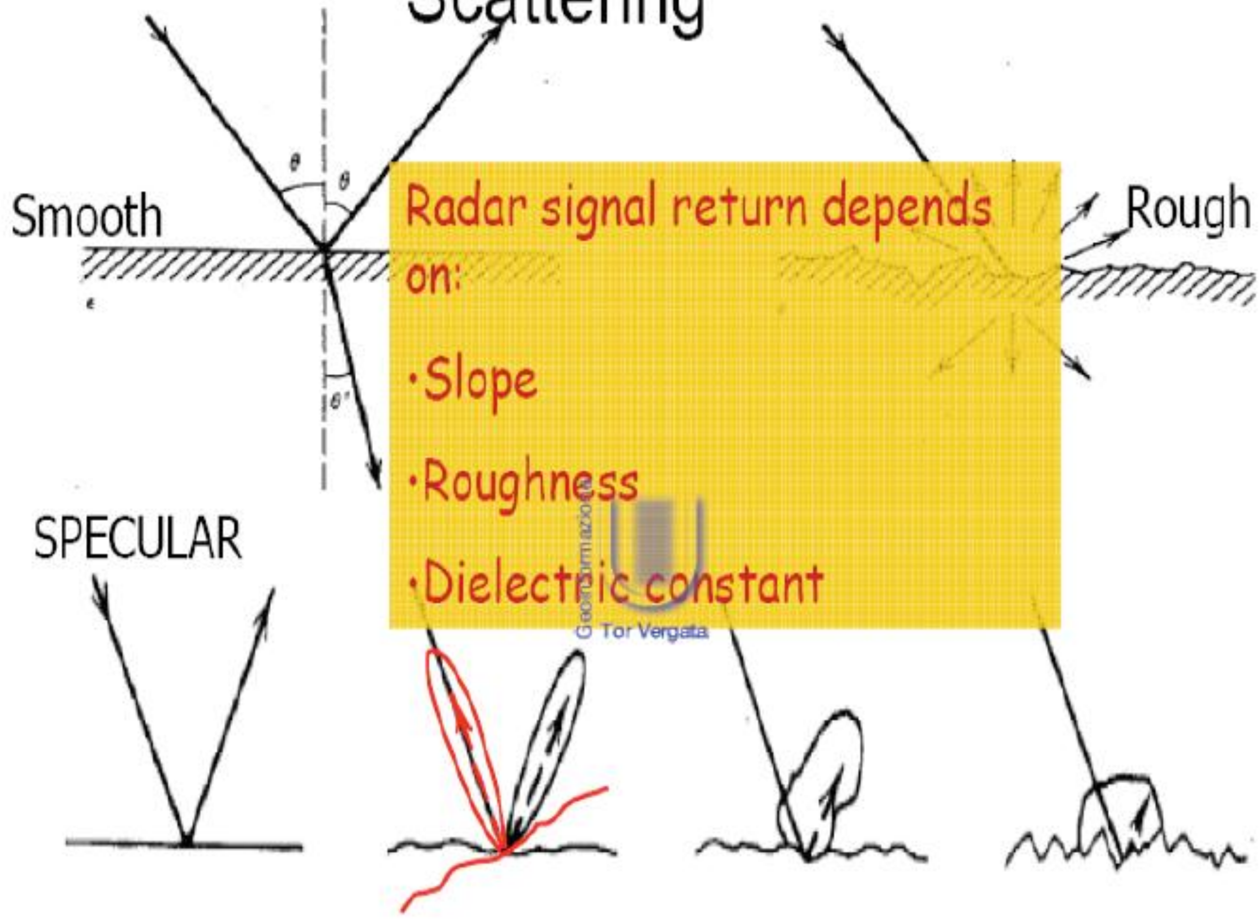
- Radar is an ACTIVE sensor (providing its own illumination) working
- Radar data contain a double information:
  - INTENSITY (or AMPLITUDE), related to the strength of the signal (*backscatter*
  - PHASE, related to the time necessary to the emitted wave to reach the targe

Why radar ?



L S C X K
Microwaves
Millimetre-Waves
Sub-Millimetre Waves
Attenuation (dB)
1000
100
10
1
0.1
0.01
10^9
10^{10}
f (Hz)
10^{11}
10^{12}
H_2O
O_2
O_2
H_2O
H_2O
1m
10cm
1cm
1mm
0.1mm
ASAR

Scattering



Radar signal return depends on:

- Slope
- Roughness
- Dielectric constant

SYNTHETIC APERTURE RADAR

A **S**ynthetic **A**perture **R**adar (**SAR**), or SAR, is a coherent mostly airborne or spaceborne sidelooking radar system which utilizes the flight path of the platform to simulate an extremely large antenna or aperture electronically, and that generates high-resolution remote sensing imagery.

AMPLITUDE

The detected SAR image contains a measurement of the amplitude of the field backscattered toward the radar by the objects (scatterers) contained in each SAR resolution cell. Typically, exposed rocks and urban areas show strong amplitude (bright pixel) whereas smooth flat surface,like quiet water basins show low amplitude (dark pixels) since the scattered field is measured in the backward direction

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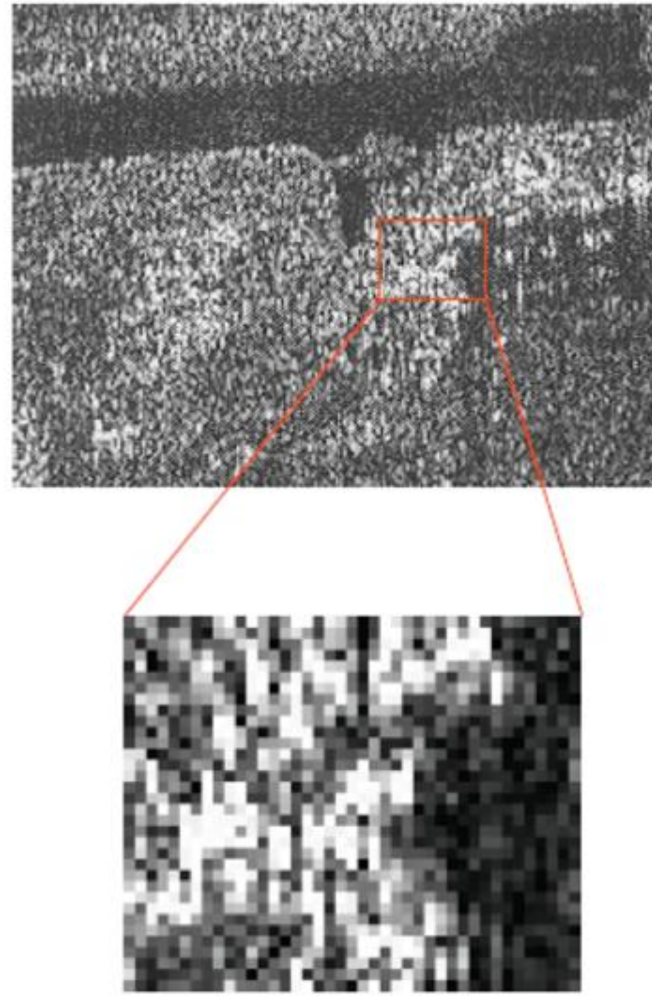
PHASE

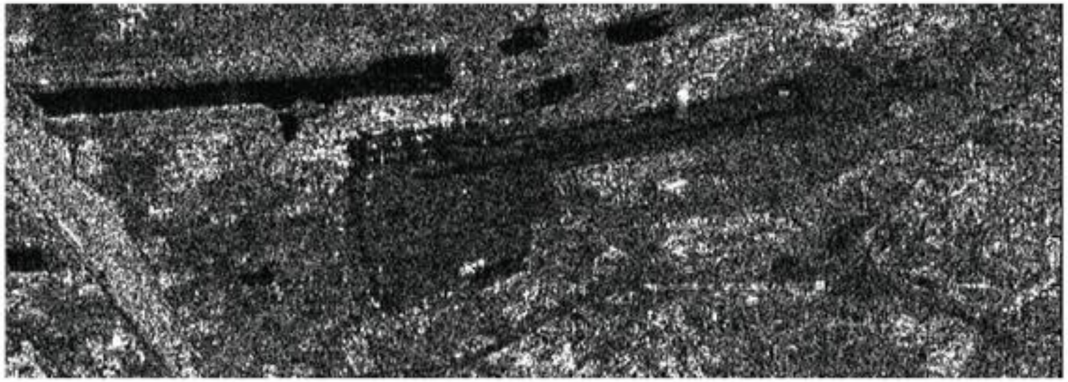
The wave transmitted from the radar has to reach the scatterers on the ground and then to come back to the radar in order to form the SAR image.

Scatterers at different distance from the radar introduce a different delay between transmission and reception of the wave. Due to the almost pure sinusoidal nature of the transmitted signal, this delay is equivalent to a phase change between transmitted and received field.

SPECKLE

The presence of more scatterers within each SAR Resolution Cell, generates the so-called "speckle" effect that is common to all coherent imaging systems. Surfaces of the same type have different backscattered amplitude in the image. This speckle effect is direct consequence of the interference of the fields re-irradiated by many small "elementary" scatterers within the resolution cell.

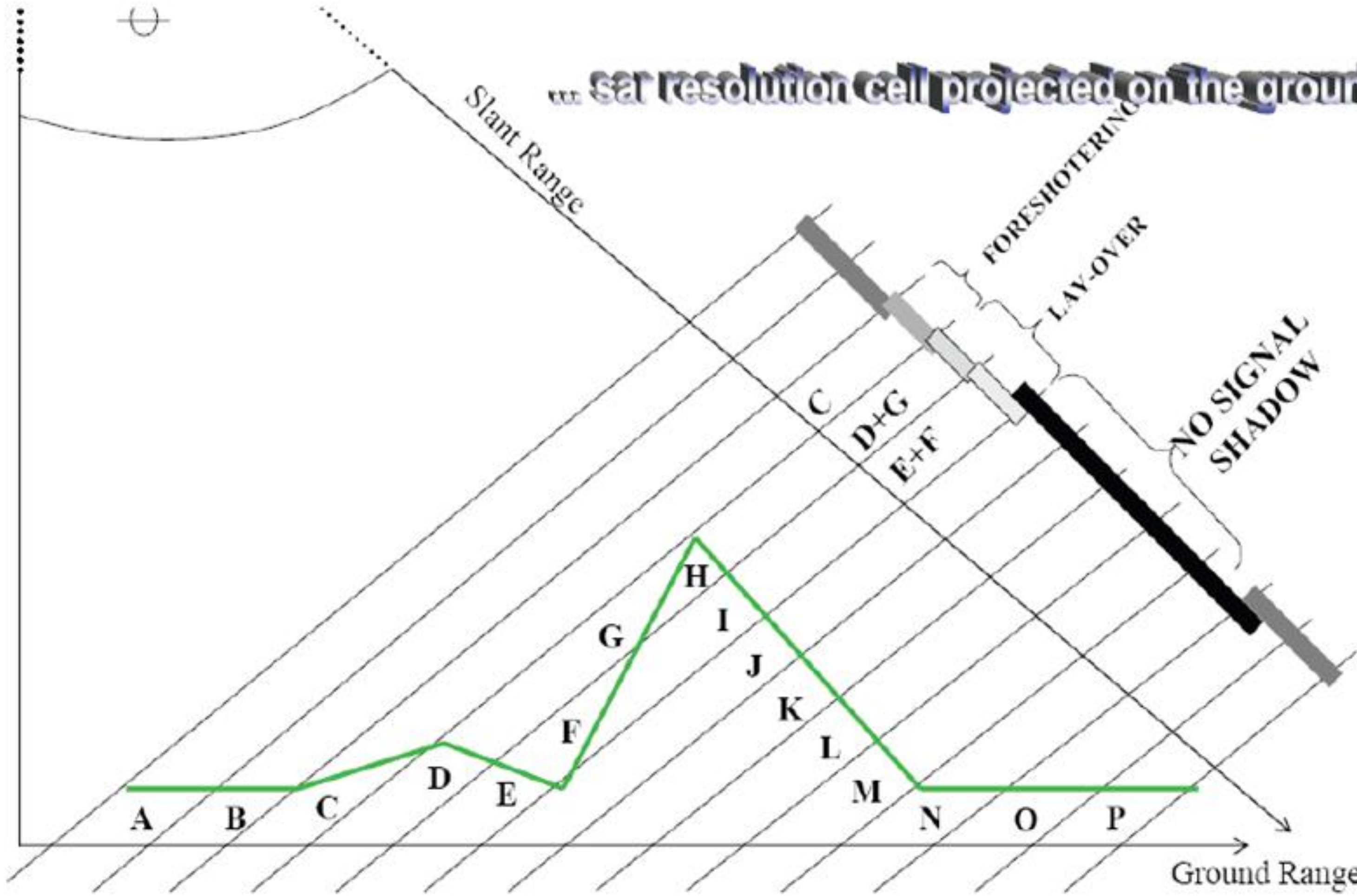


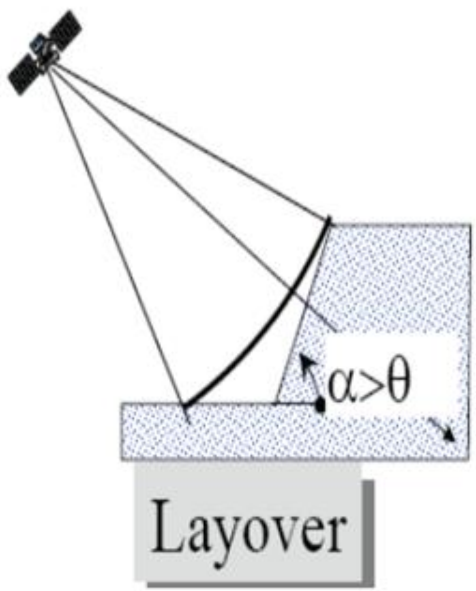


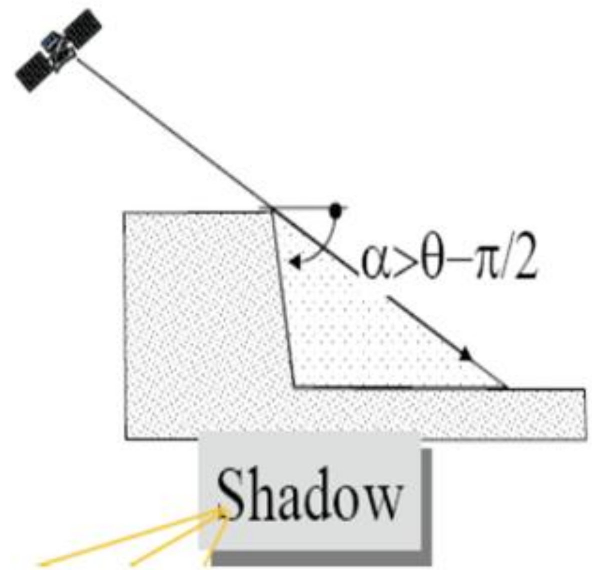
Single SAR image

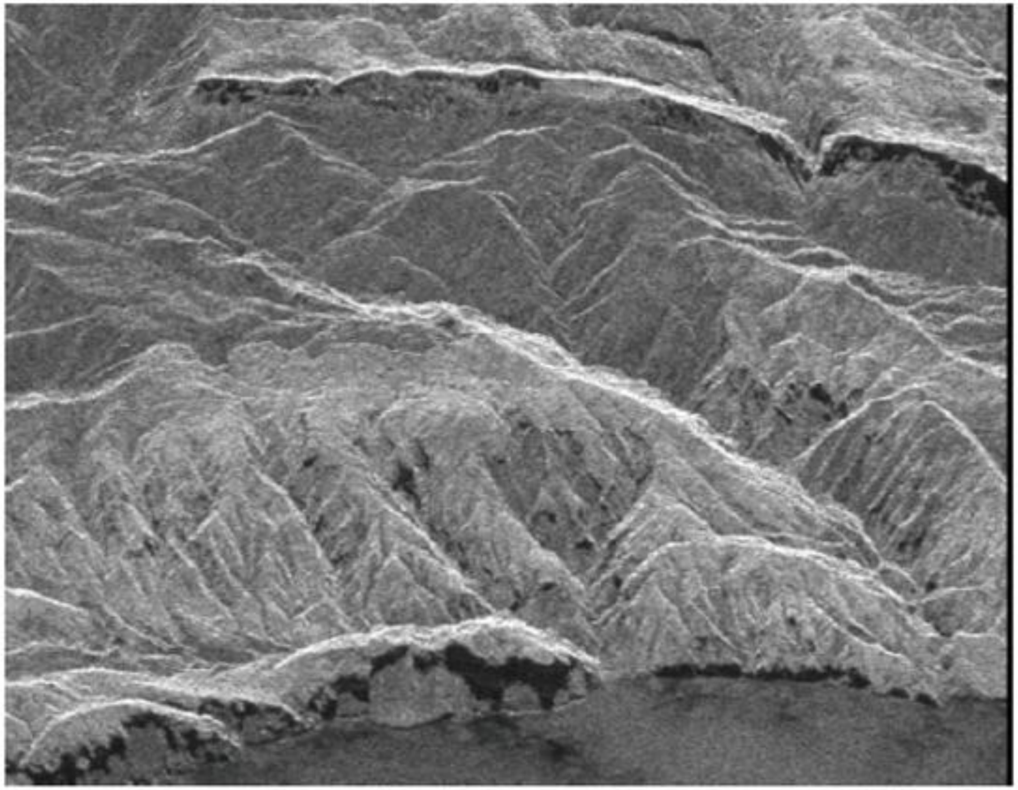
Multiple SAR image

... sar resolution cell projected on the ground



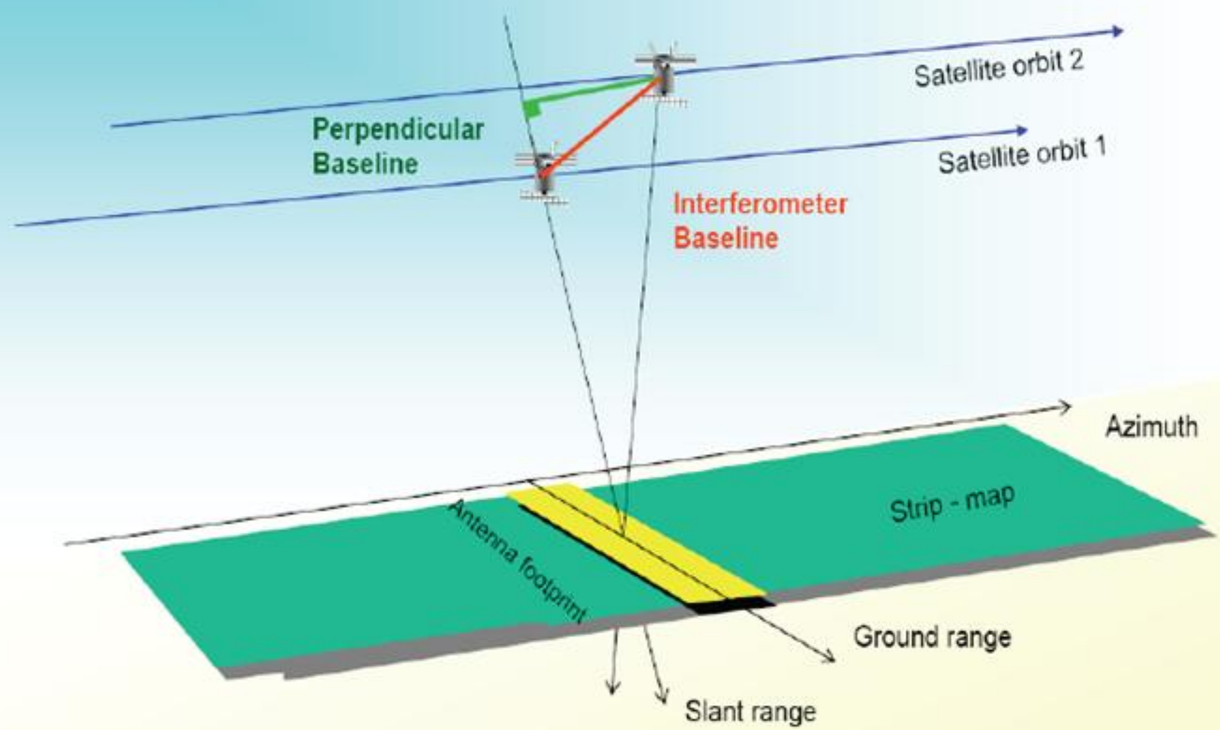

α>θ
Layover


α>θ−π/2
Shadow



Foreshortening and lay-over

INSAR GEOMETRY



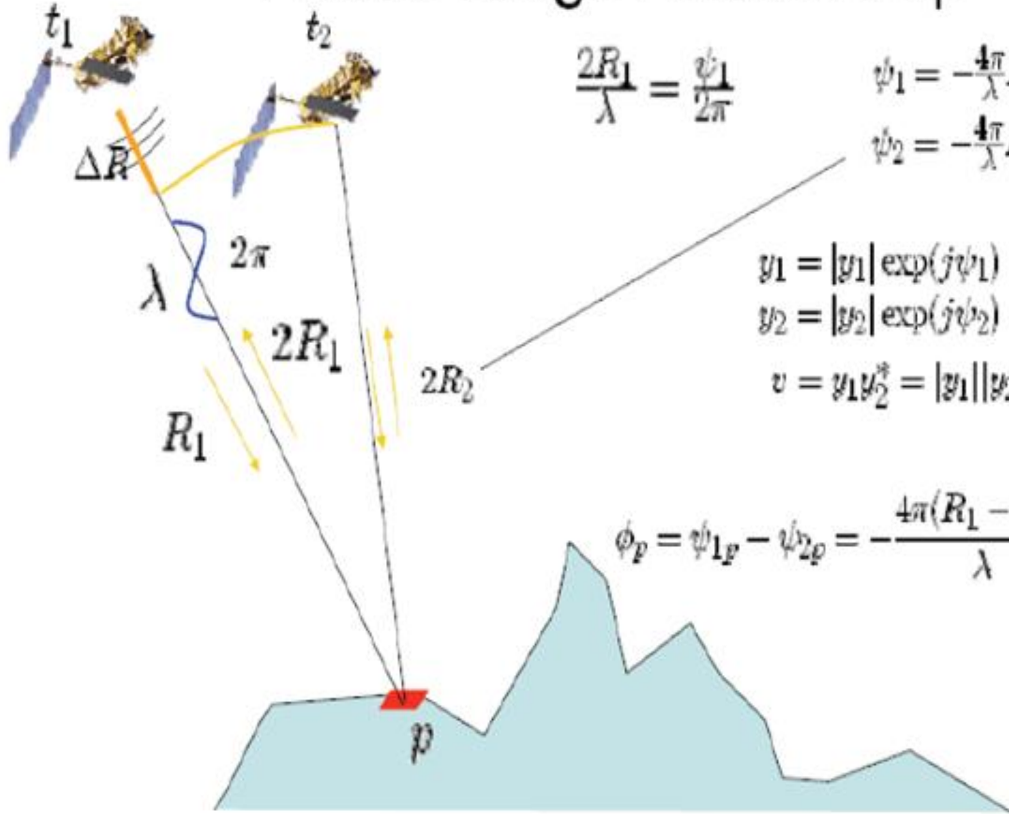
SAR INTERFEROGRAM

Cross - multiplying pixel by pixel the complex field of the first SAR image times the second one complex conjugated.

Thus, the interferogram amplitude is the amplitude of the first image times that of the second one.

Whereas its phase (called interferometric phase) is the phase difference between the two images.

Phase-range relationship



$$\frac{2R_1}{\lambda} = \frac{\psi_1}{2\pi}$$

$$\psi_1 = -\frac{4\pi}{\lambda} R_1$$

$$\psi_2 = -\frac{4\pi}{\lambda} R_2$$

$$y_1 = |y_1| \exp(j\psi_1)$$

$$y_2 = |y_2| \exp(j\psi_2)$$

$$v = y_1 y_2^* = |y_1||y_2| \exp(j(\psi_1 - \psi_2))$$

$$\phi_p = \psi_{1p} - \psi_{2p} = -\frac{4\pi(R_1 - R_2)}{\lambda} = -\frac{4\pi \Delta R}{\lambda}$$

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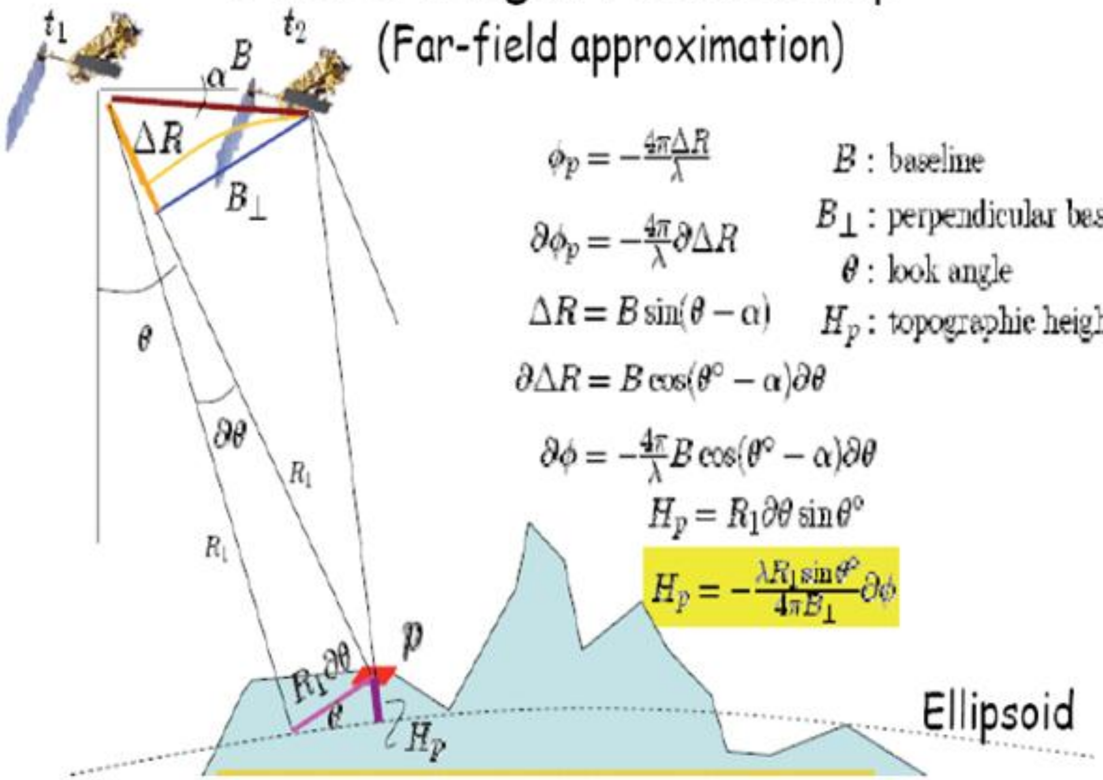
Phase-height relationship

(Far-field approximation)



$$\phi_p = -\frac{4\pi\Delta R}{\lambda}$$

$$\partial\phi_p = -\frac{4\pi}{\lambda}\partial\Delta R$$

$$\Delta R = B\sin(\theta - \alpha)$$

$$\partial\Delta R = B\cos(\theta^\circ - \alpha)\partial\theta$$

$$\partial\phi = -\frac{4\pi}{\lambda}B\cos(\theta^\circ - \alpha)\partial\theta$$

$$H_p = R_1\partial\theta\sin\theta^\circ$$

$$H_p = -\frac{\lambda R_1\sin\theta^\circ}{4\pi B_\perp}\partial\phi$$

B : baseline

$B_\perp$: perpendicular baseline

θ : look angle

H_p : topographic height

Summary of the SAR interferometric phase contributions

$$\Delta\varphi = \Delta\varphi_{flat} + \Delta\varphi_{elevation} + \Delta\varphi_{displacement} + \Delta\varphi_{atmosphere} + \Delta\varphi_{noise}$$

$\Delta\varphi_{flat}$:

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

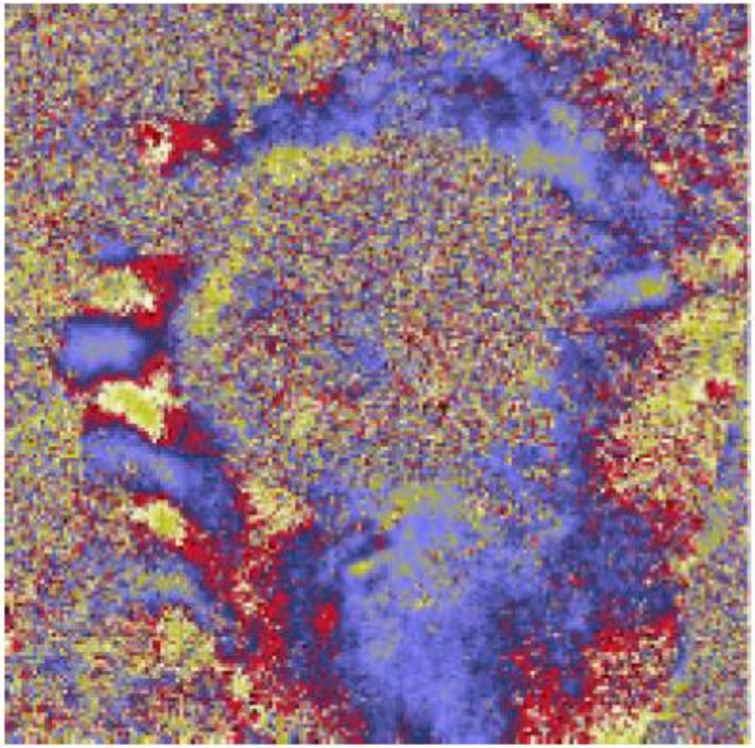
$\Delta\varphi_{elevation}$:

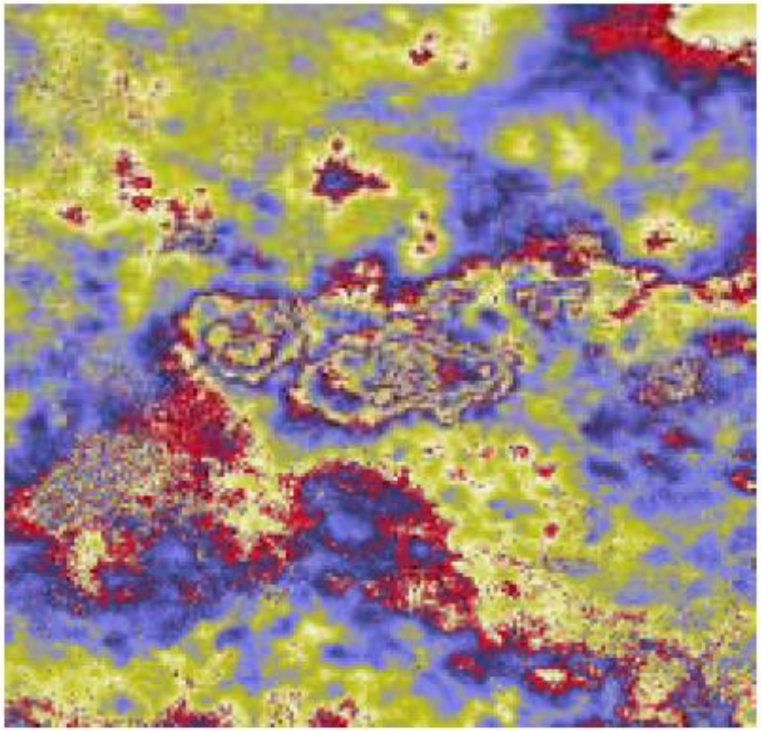
$$-\frac{\Delta q}{sin\theta}\cdot\frac{B_n}{R_0}\cdot\frac{4\pi}{\lambda}$$

$\Delta\varphi_{displacement}$:

$$+\frac{4\pi}{\lambda}d$$

- Atmospheric artifacts

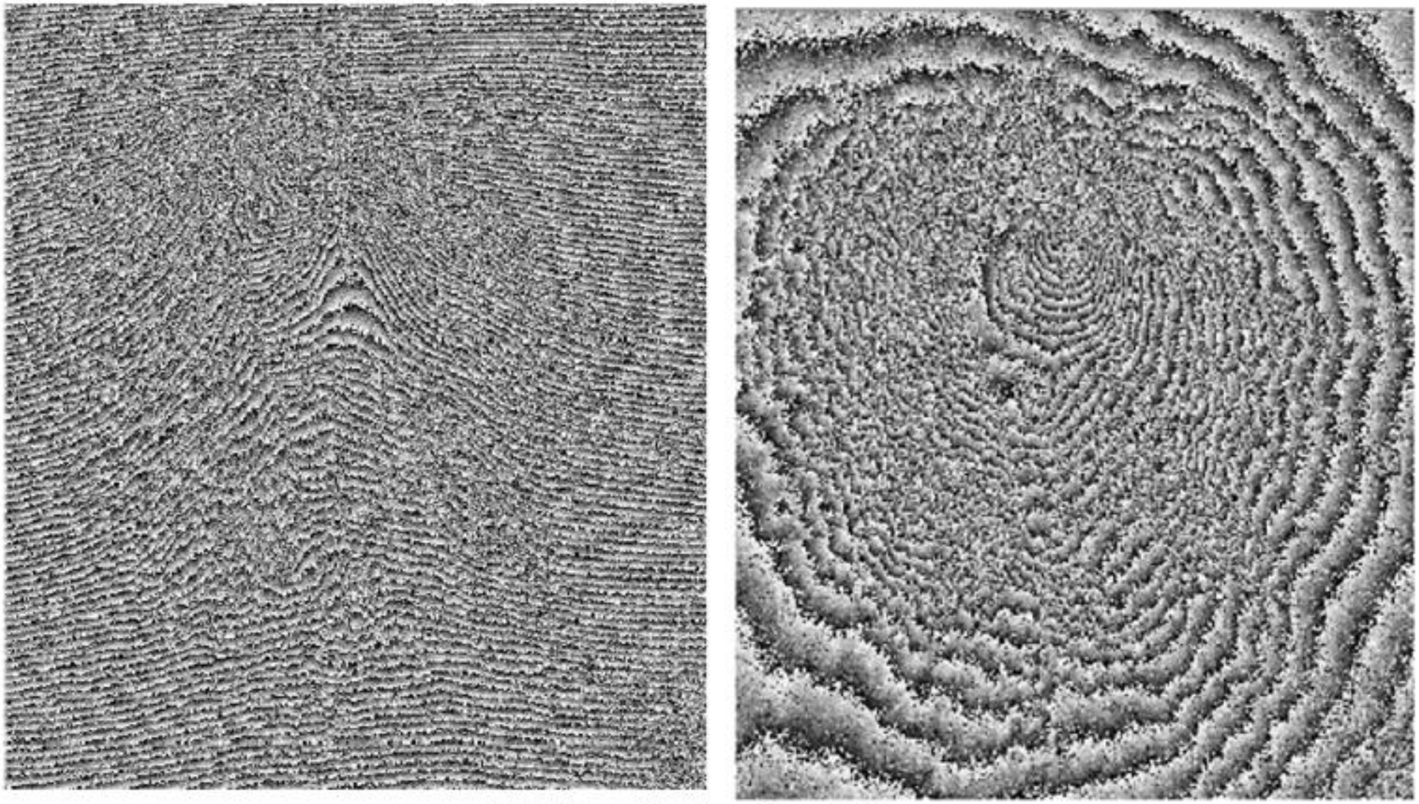




- Fig. Clouds over Etna

Fig. Cloud over Landers (CA)

Interferogram flattening



Mt. Vesuvius, baseline 250 m.

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Calculation of the altitude of ambiguity

$$\Delta\phi = -\frac{\Delta q}{\sin\theta}\cdot\frac{B_n}{R_0}\cdot\frac{4\pi}{\lambda}$$

If

$$\Delta\phi = 2\pi$$

then

$$\frac{\Delta q}{\sin\theta}\cdot\frac{B_n}{R_0}\cdot\frac{4\pi}{\lambda} = 2\pi$$

$$\Delta q \times B_n = \frac{\lambda}{2}\sin\theta\ R_0$$

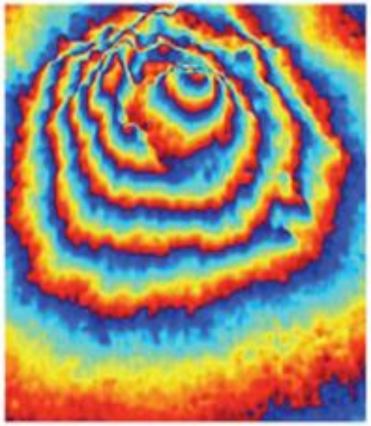
$$\approx 97 \times 97 = 9400$$

The Interferometric phase has 2π periodicity

Altitude of ambiguity: height difference generating a 2π phase change

Bn =50 m

$\Delta q_a \approx 188\, m$

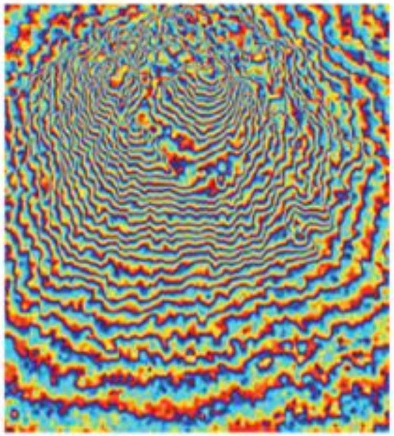


Bn =250 m

$\Delta q_a \approx 37 m$

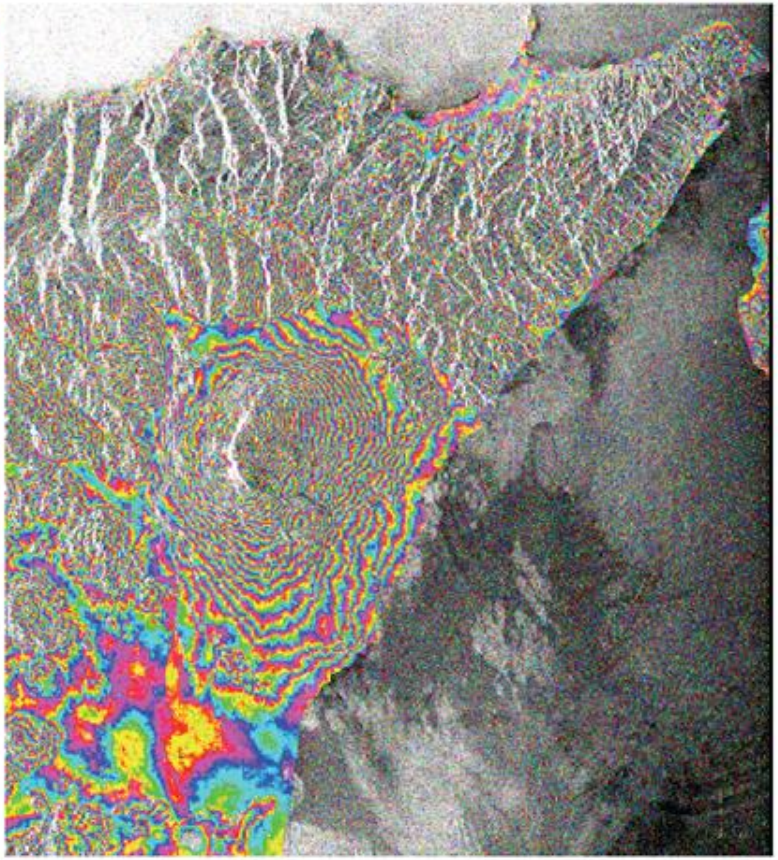
$$\Delta q_a = \frac{\lambda}{2B_n} \sin\theta\, R$$

$$\Delta q_a \times B_n = \frac{\lambda}{2} \sin\theta\, R$$



The greater the baseline, the greater the height accuracy

Mt. Vesuvio and Mt. Etna from ERS SAR interferometry



Noisy Interferograms

Simulated interferogram with no noise

Real ERS interferogram

The interferometric phase is corrupted by noise due to many causes:

1 - *temporal decorrelation*
2 - *geometric decorrelation*
3 - *volume scattering*
4 - *processing errors*

The coherence of the interferometric pair is used to estimate the interferometric phase dispersion with respect to its noiseless value.

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Definition of coherence

Given two SAR images $v_1(r,a)$ and $v_2(r,a)$ forming an interferometric pair, the **complex coherence** of the interferometric pair is defined as follows:

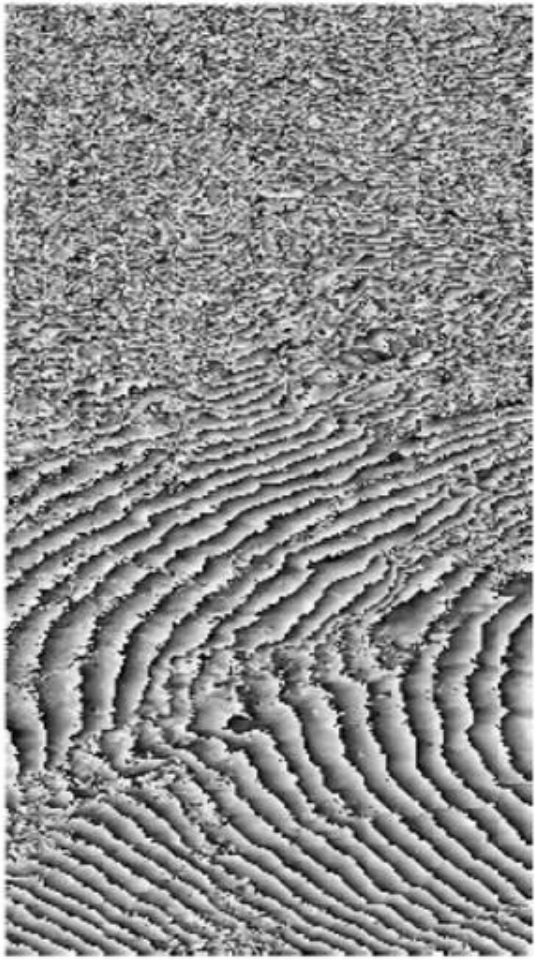
$$\gamma = \frac{E[v_1 v_2^*]}{\sqrt{E[v_1 v_1^*]}\sqrt{E[v_2 v_2^*]}}$$

v_1 *complex pixels of the first SAR image (master)*

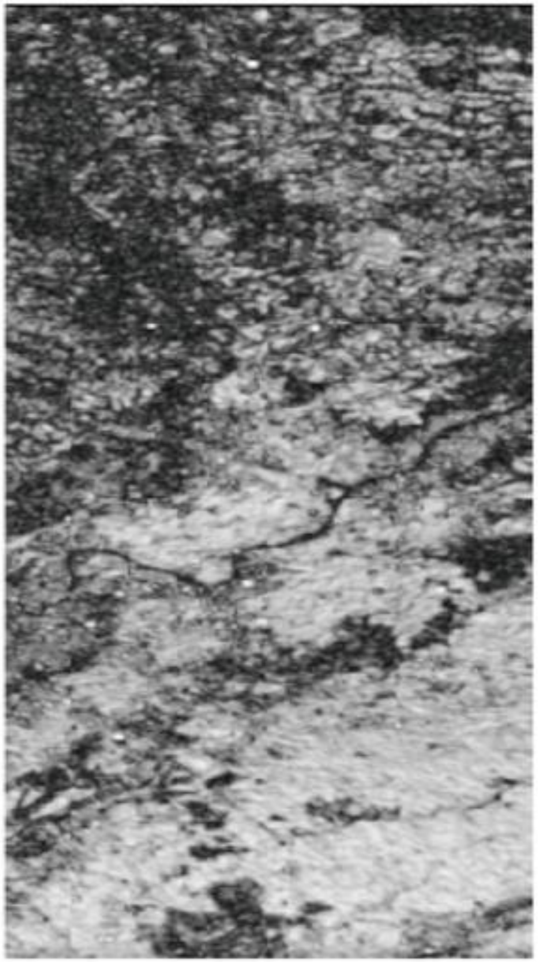
v_2 *complex pixels of the second SAR image (slave)*

$E[\ ]$ *Expected value*

interferogram



Coherence



Summary of the coherence contributions

$$\gamma = \gamma_T \cdot \gamma_G \cdot \gamma_V \cdot \gamma_P$$

Temporal

It cannot be avoided

Geometric

It can be partially eliminated

Volumetric

It cannot be avoided

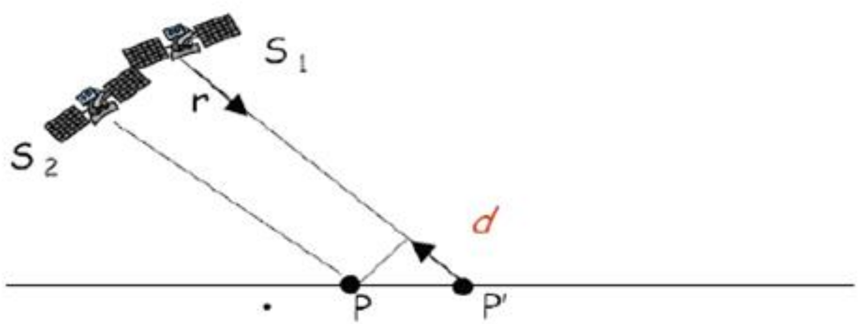
Processing

It should be avoided

DINSAR:
Differential SAR Interferometry

SAR interferometric phase: ground motion contribution

If a scatterer on the ground slightly changes its relative position in the time interval between two SAR acquisitions (e.g. subsidence, landslide,
earthquake …), an additive phase term, independent of the baseline, appears.



$$\Delta\varphi_{displacement} = \frac{4\pi}{\lambda} d$$

SAR interferometric phase: ground motion contribution

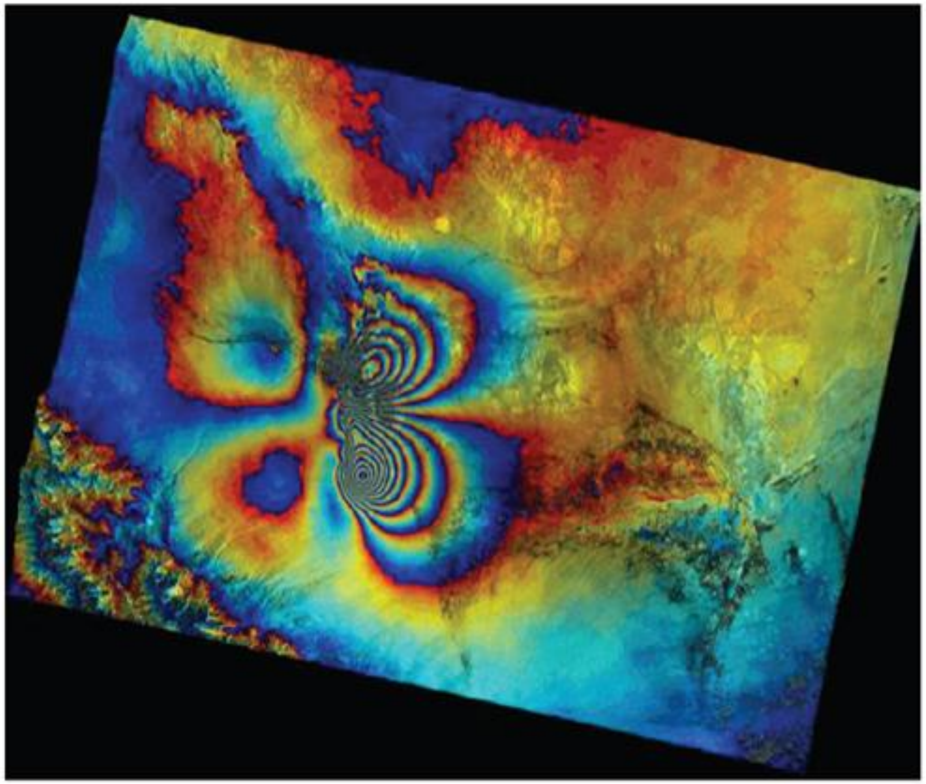
The sensitivity of the interferometric phase to the ground motion is much larger than that to the elevation difference.

In the ERS case assuming a perpendicular baseline of 150m the following expression of the interferometric phase (after interferogram flattening) holds:

$$\Delta\varphi = \Delta\varphi_{elevation} + \Delta\varphi_{displacement} =$$

$$= -\frac{q}{10} + 225\ d$$

Bam earthquake (Iran, 2003)



- ENVISAT data, geocoded.
- Topographic fringes do not hide the

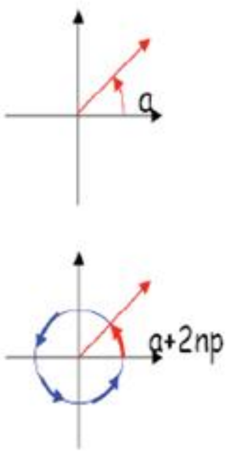
  ground motion

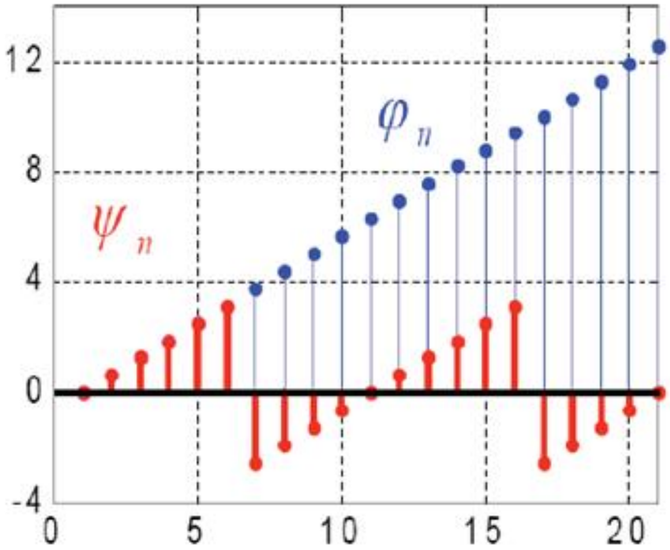
1D Phase unwrapping (1)

Problem: Wrapped phase value of sample *n* are represented as angles within the range -p ~ +p.

$$\psi_n = W(\varphi_n) = angle\ \{\exp(j\varphi_n)\}$$

Given a sequence of wrapped phase values ψ_n we want to recover the unwrapped phase values φ_n





Processing flowchart

Basic procedure