Introduction to SAR missions, radar remote sensing techniques and applications to Land, and interferometry principles

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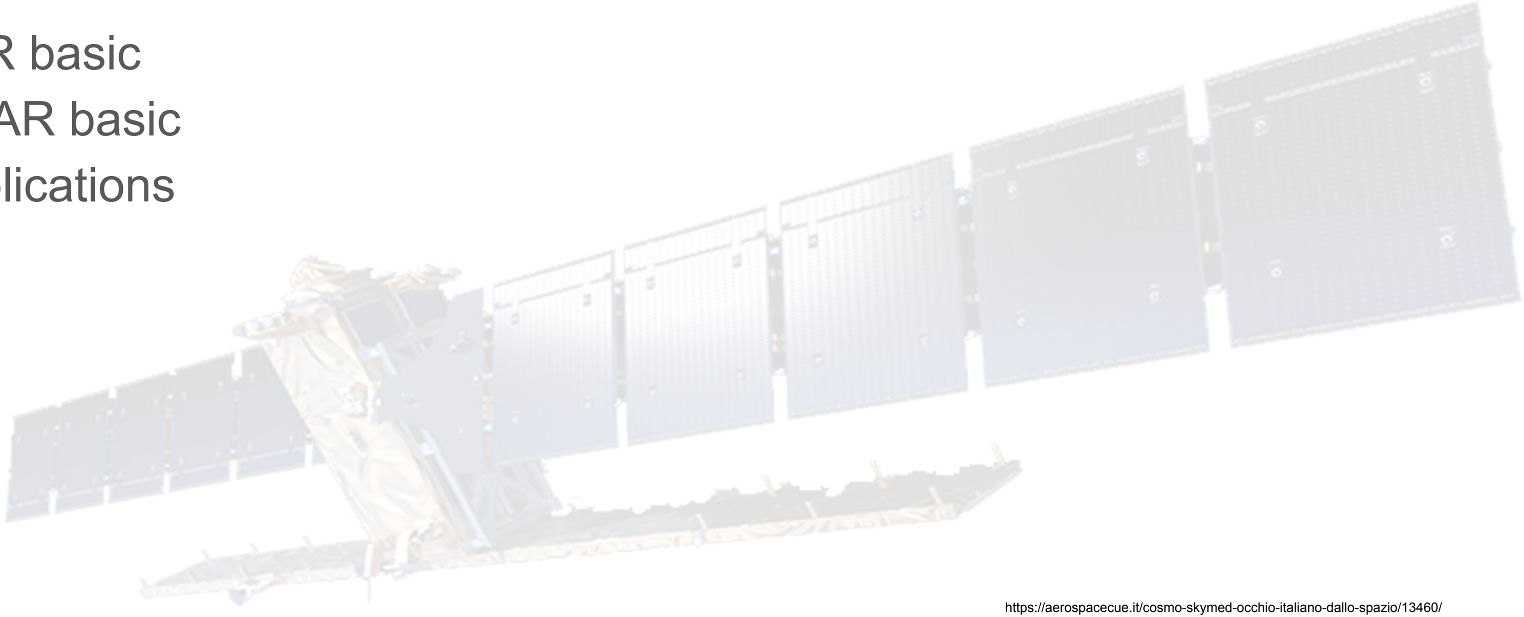
Outline

- SAR basic
- InSAR basic
- Applications



https://aerospacecue.it/cosmo-skymed-occhio-italiano-dallo-spazio/13460/

The lesson was built on

Satellite InSAR Data
Reservoir Monitoring from Space

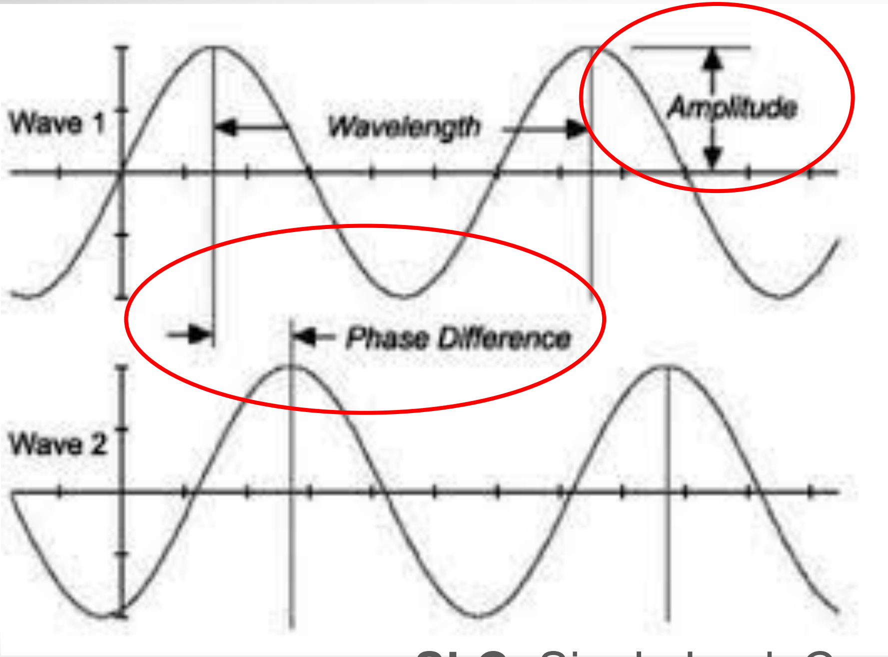
Alessandro Ferretti

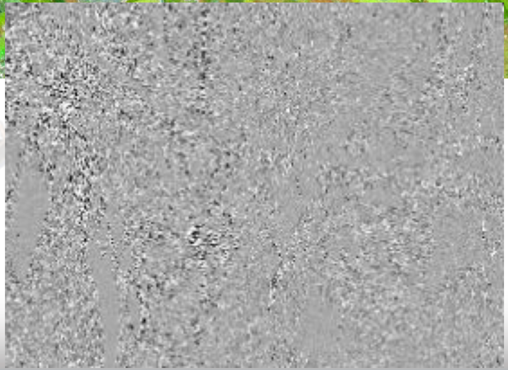
https://www.researchgate.net/publication/260986568_Satellite_InSAR_Data_Reservoir_Monitoring_from_Space

http://www.intechopen.com/books/land-applications-of-radar-remote-sensing

https://www.sarmap.ch/pdf/SAR-Guidebook.pdf

COHERENT microwave radiation



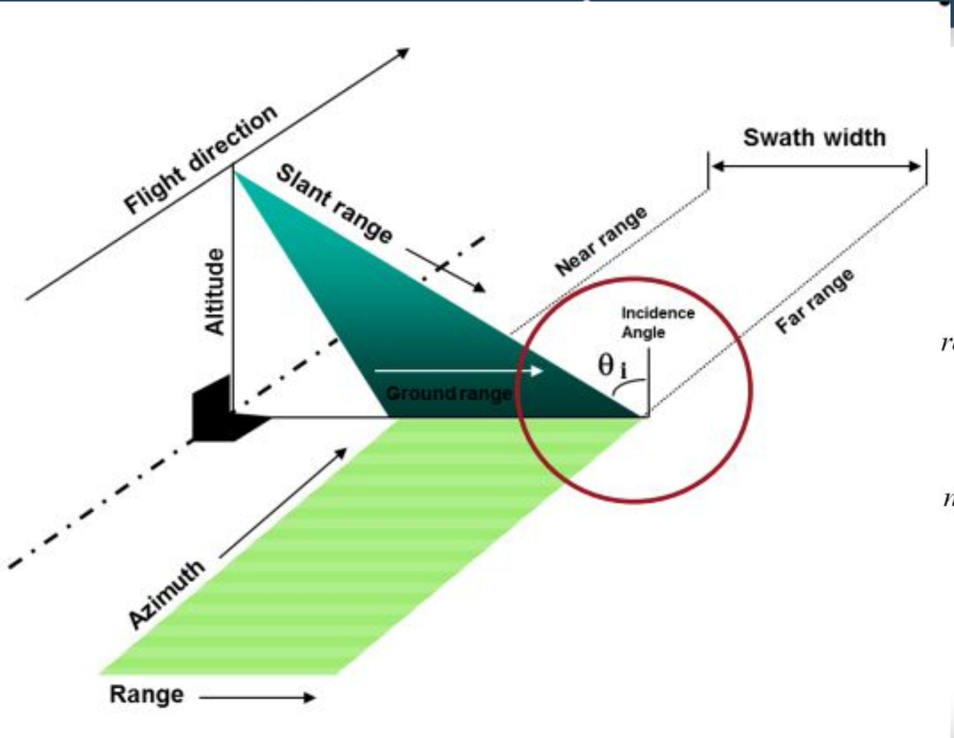


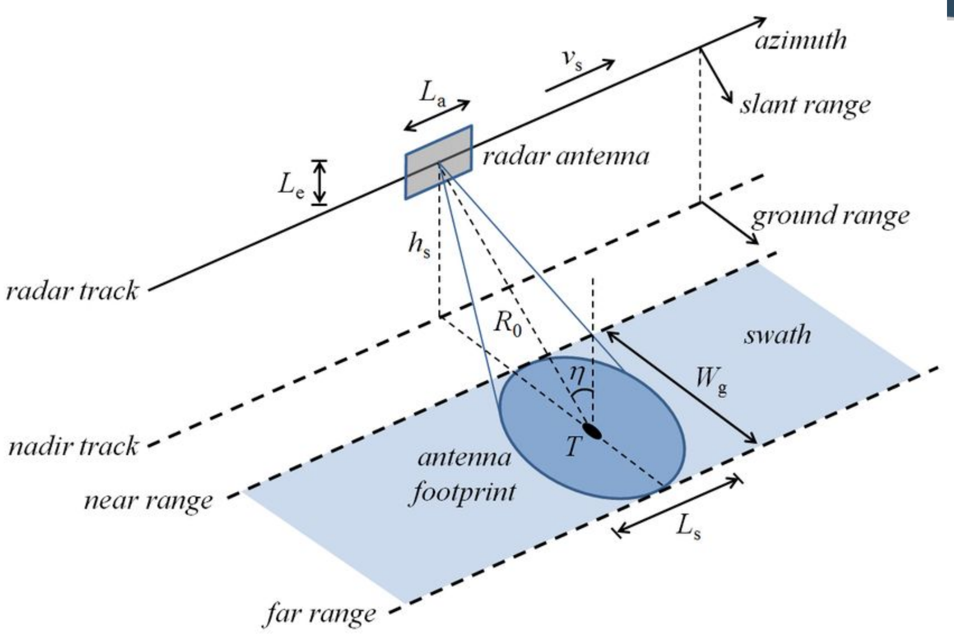
SLC=Single Look Complex

Sentinel-1 - The game changer (2014)

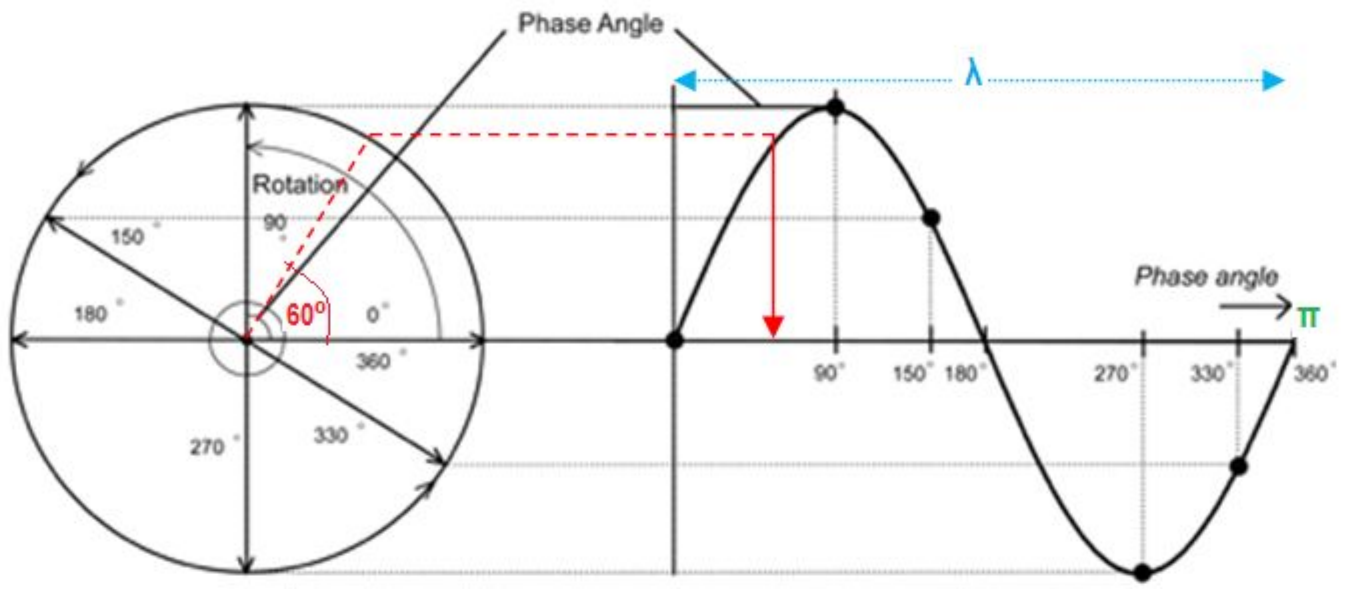
RGB - R=2015.01.13 G=2014.10.09 B=2015.05.01

Acquisition geometry





Phase basic



$4\pi r/\lambda$

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modulo-2π

The sensor-to-target distance can always be expressed as an integer number of wavelengths, plus a segment equal to a fraction of λ.

More precisely, taking into account the two-way travel path of the radar pulse, the "effective wavelength" of the system is λ/2, since the "phase signature" of a point-wise object doesn't change if its distance from the radar is changed by multiples of λ/2.

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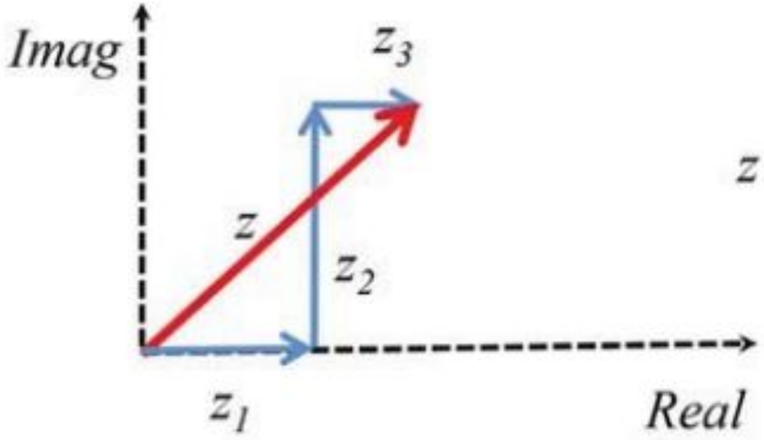
Scatterers



$$z = z_1 + z_2 + z_3$$

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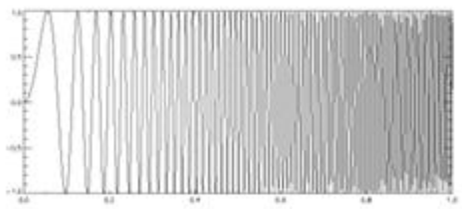
Range resolution

The range resolution of a pulsed radar system is limited fundamentally by the bandwidth of the transmitted pulse. A wide bandwidth can be achieved by a short duration pulse. However, the shorter the pulse, the lower the transmitted energy and the poorer the radiometric resolution. To preserve the radiometric resolution, SAR systems generate a long pulse with a linear frequency modulation (or chirp).



Chirp, real part

After the received signal has been compressed, the range resolution is optimised without loss of radiometric resolution.

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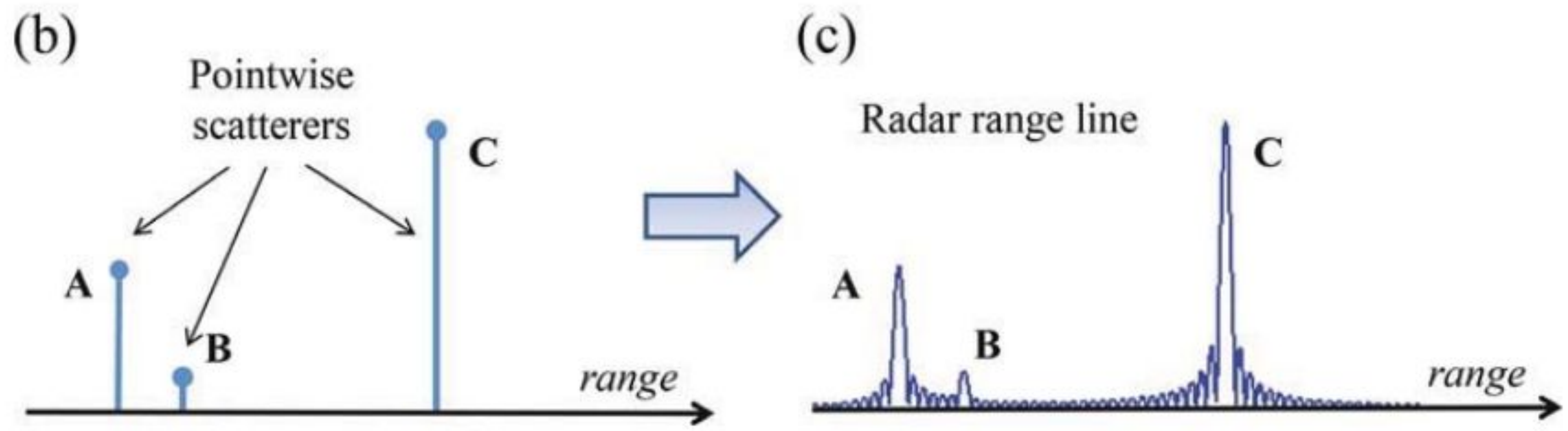
Separation



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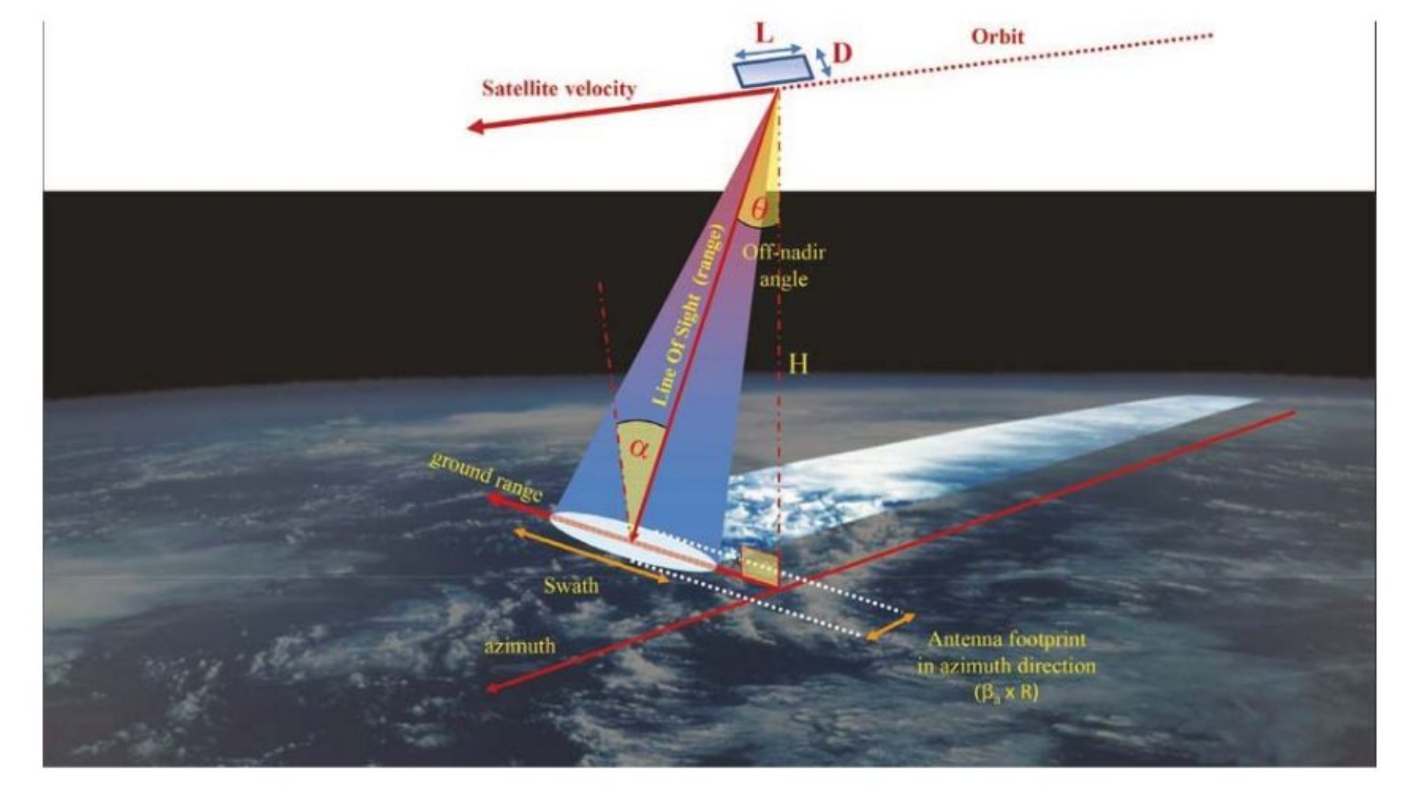
Acquisition geometry



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SAR system

install the radar on a moving carrier, pointing the antenna in the direction **orthogonal to that of motion**, an object can be illuminated on the ground several times by different radar pulses; at least whenever the target distance is large enough. Therefore, the radar return of the object will be present in several range lines.

simulate large antenna, while physically not existing, appropriately combining the reflected signal from the target. This processing technique was given the name Synthetic Aperture Radar (SAR).

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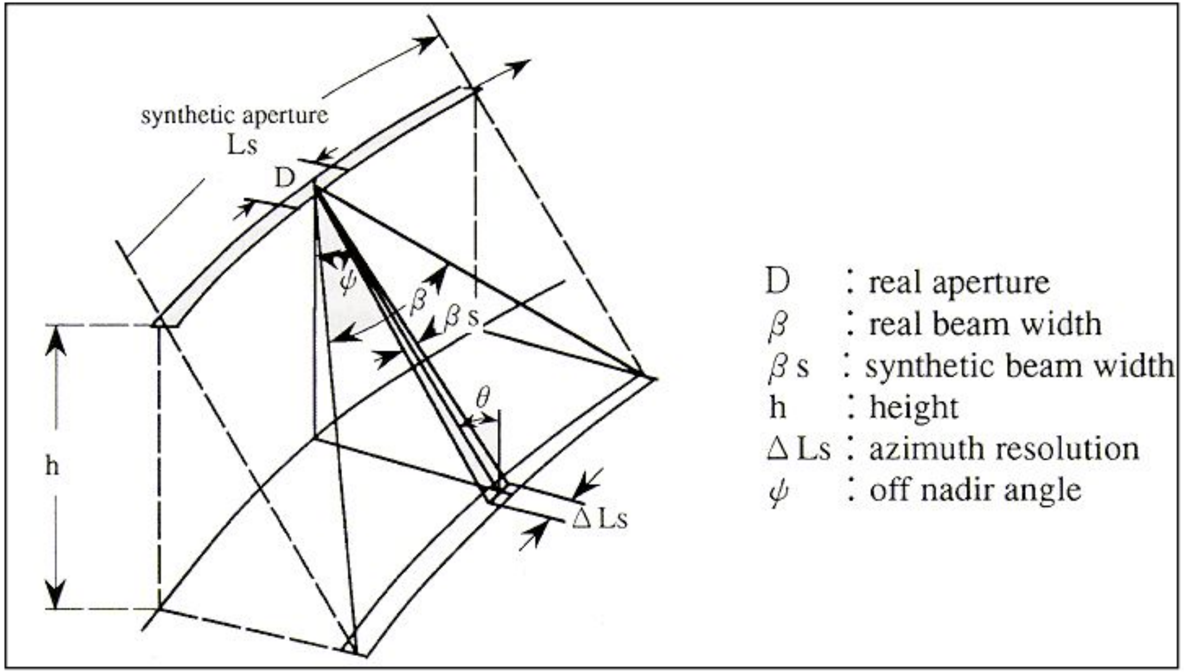
Azimuth Resolution



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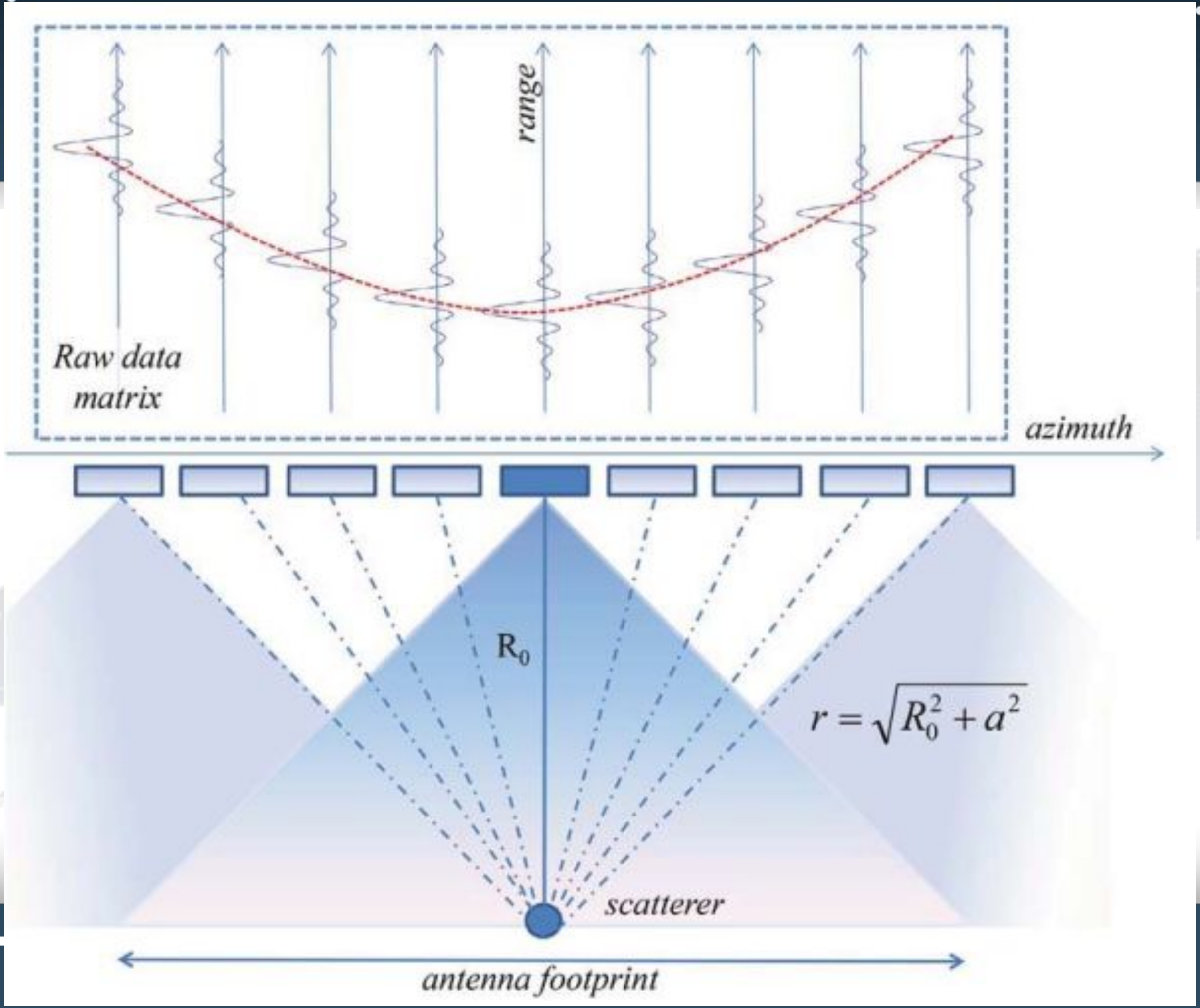

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RCS

Radar specialists refer to the **Radar Cross Section (RCS)** to define the degree of visibility of an object, i.e. its capacity to be detected by scattering enough energy back to the radar antenna.

RCS values are independent of the sensor-to-target distance.

sigma naught:in order to obtain measurements independent of the image resolution or pixel size, the concept of a normalized radar cross section is often used in radar remote sensing.

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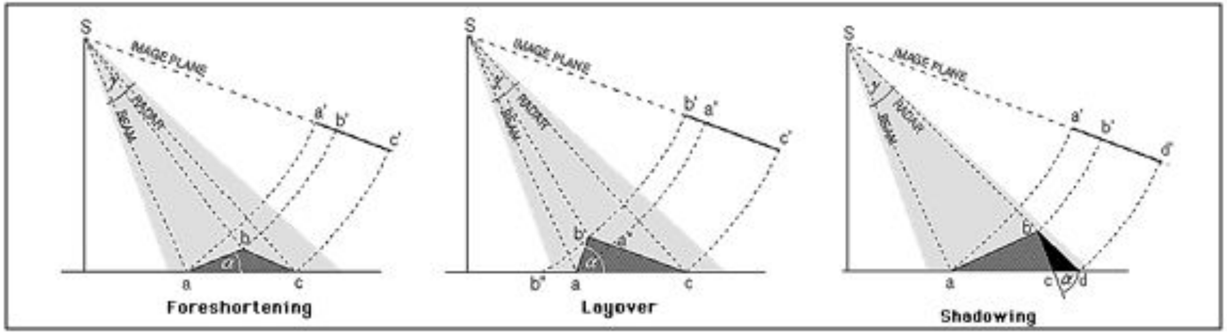
Geometric distortions

The points *a*,*b*, and *c* are imaged as *a′*,*b′*, and *c′* in the slant range plane (see figure). This shows how minor differences in elevation can cause considerable range distortions. These relief induced effects are called foreshortening, layover and shadow.



Layover is an extreme case of foreshortening, where the slope α is bigger than the incidence angle (θ). With an increasing (horizontal) distance, the slant range between sensor and target decreases.

Shadow is caused by objects, which cover part of the terrain behind them.

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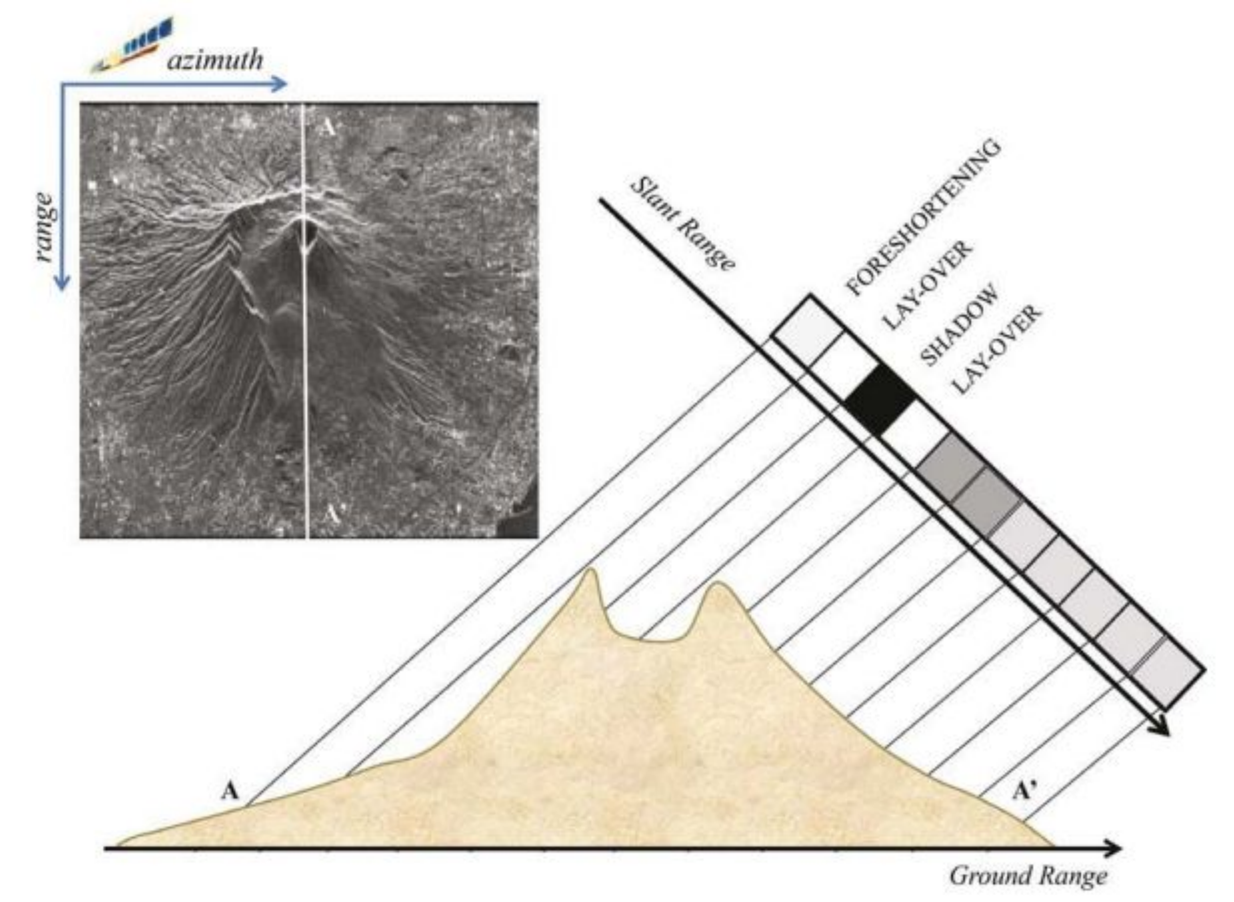

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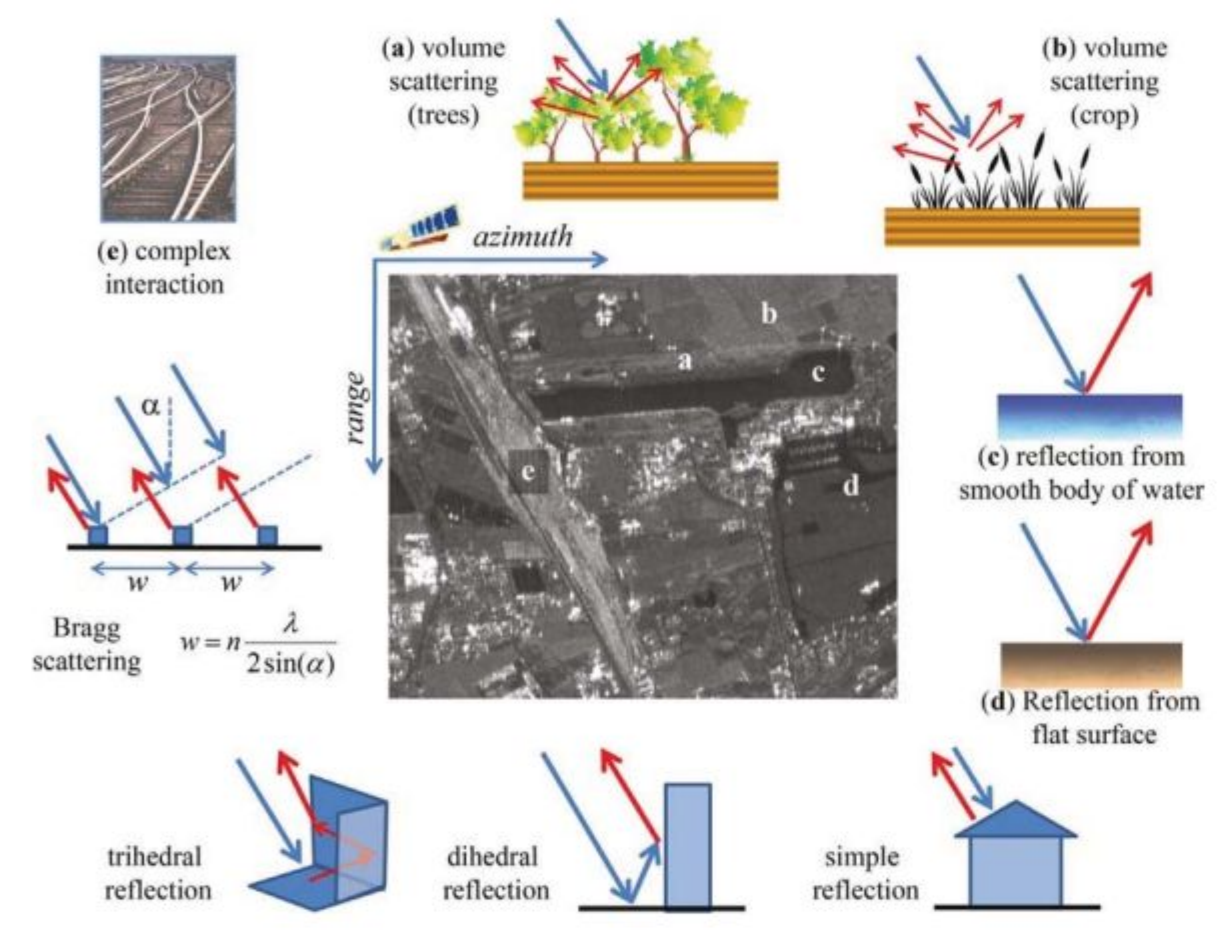
Scattering mechanisms



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Measuring phase variations

The phase value ϕ of a pixel P of a radar image can be modelled as a mixture of four different contributions:

$$\phi(P) = \varphi + \frac{4\pi}{\lambda} r + \alpha + \nu \qquad (3.1)$$

φ

$\frac{4\pi}{\lambda} r$

α the ionosphere and clouds, water vapour, rain, fog in the troposphere, affect the speed of propagation

ν noise

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SAR interferometry

The difference of the phase values of pixel P of two SAR images,

(they have been properly re-sampled (co-registered), so that homologous pixels correspond to the same resolution cell.)

$$\Delta\phi(P) = \Delta\varphi + \frac{4\pi}{\lambda}\Delta r + \Delta\alpha + \Delta v$$

By computing the phase difference of two SAR images on a pixel-by-pixel basis, we generate an interferogram (master and slave).

Frozen scenario> $\Delta\phi(P) = \frac{4\pi}{\lambda}\Delta r$

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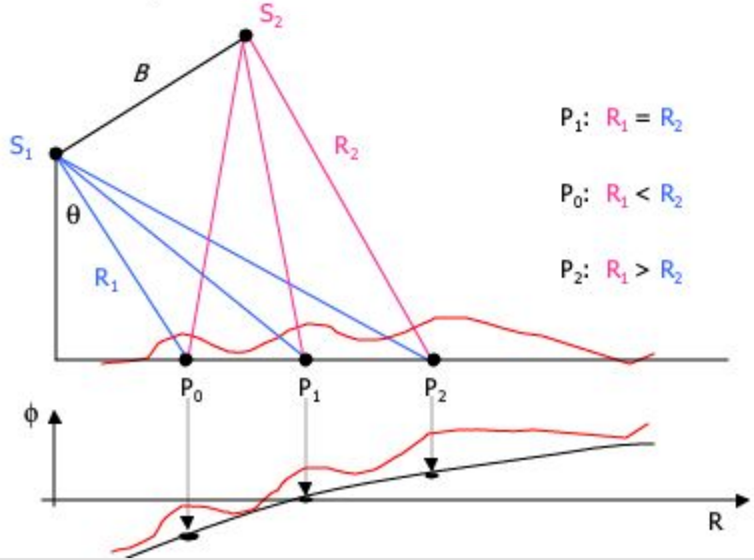
Interferogram Generation

After image co-registration an interferometric phase (ϕ) is generated by multiplying one image by the complex conjugate of the second one. A complex interferogram (*Int*) is formed as schematically shown in the illustration below.



$Int = S_1 \,.\, S_2^*$

$\phi = 4\pi\,(R_1 - R_2)\,/\,\lambda$

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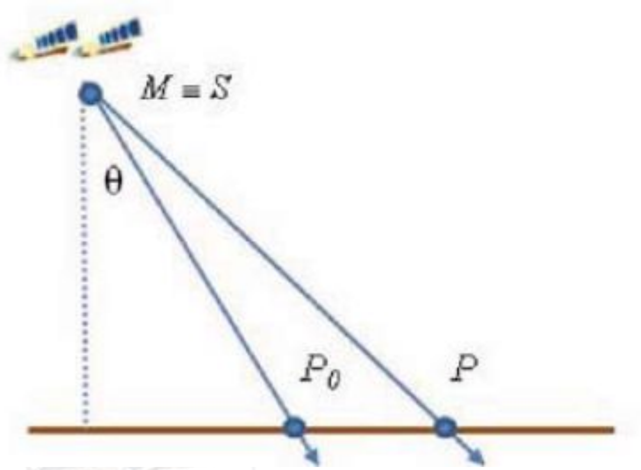
Zero baseline/ No deformation



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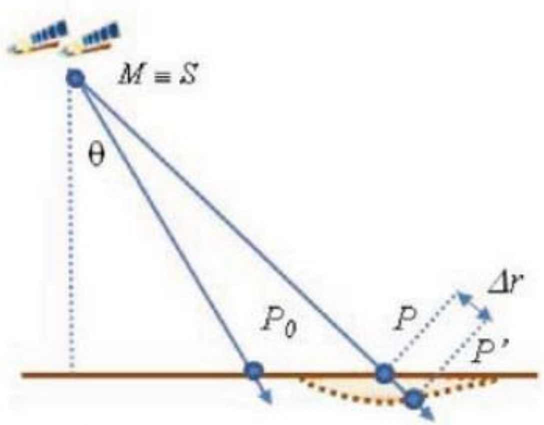
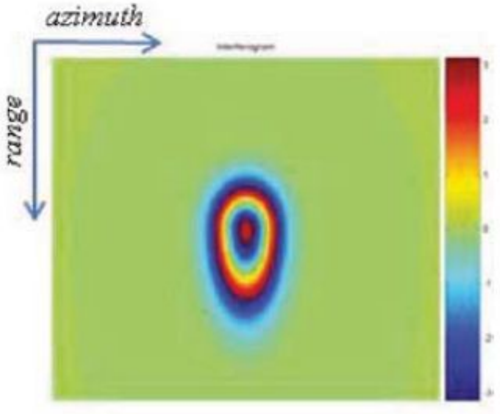
Zero baseline/ No zero deformation





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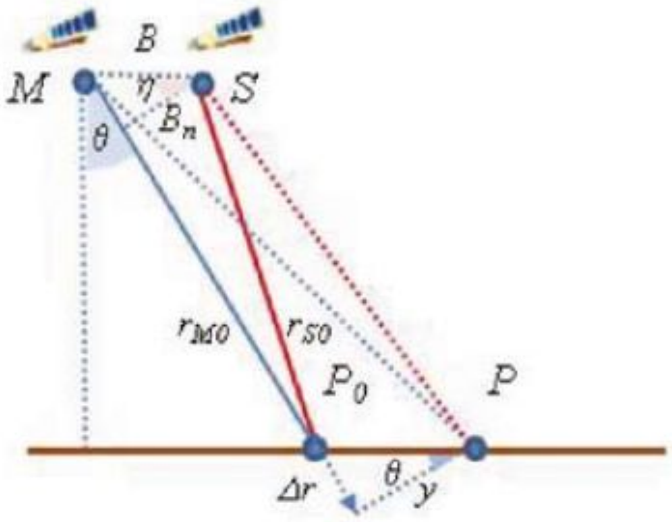
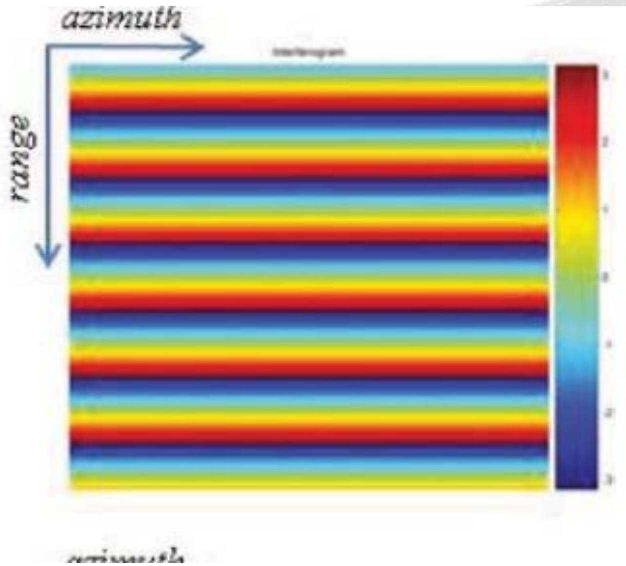
No surface deformation. No topography.Non zero baseline





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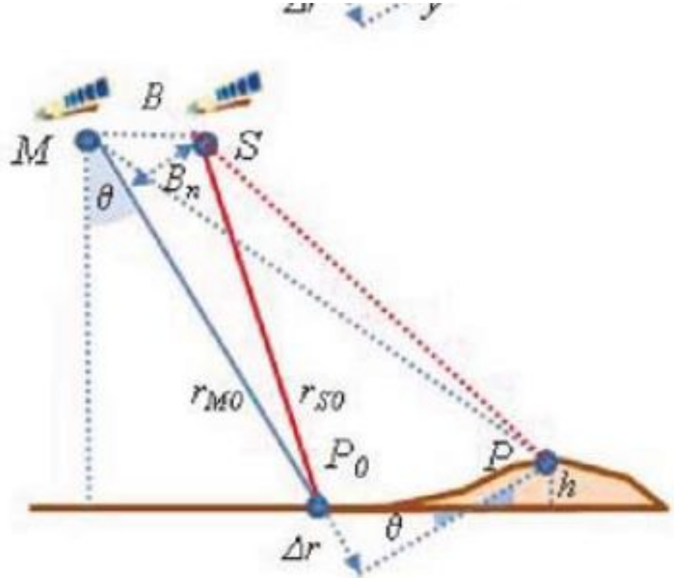
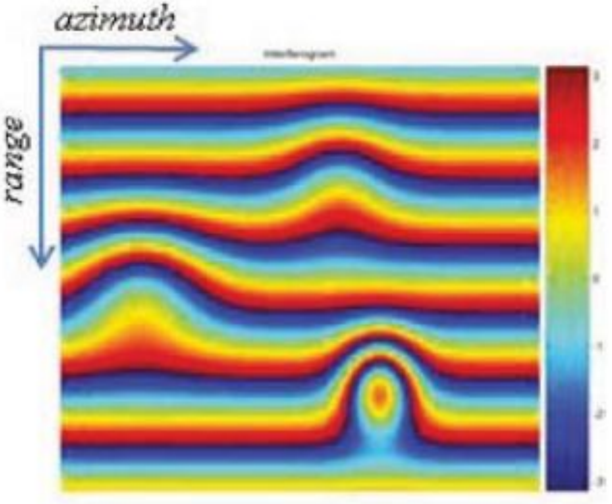
No surface deformation. No flat topography. Non zero baseline





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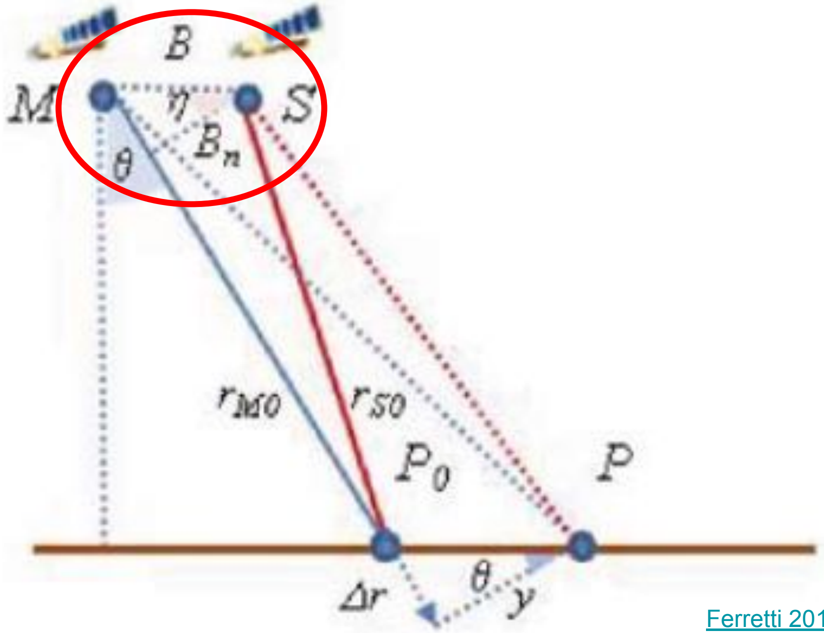
Baseline has a linear approximation of the interferometric phase

$$\phi(P_0) = \frac{4\pi}{\lambda}(r_{M0} - r_{S0}) \approx \frac{4\pi}{\lambda} B \sin\eta$$



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Differential displacement

If we want to estimate the local topography from our interferogram, we should focus on the first one, while for detecting surface deformation phenomena we need to single out the second.

$$d\phi \approx \frac{4\pi}{\lambda}\frac{B_n}{r_{M0}}\frac{h}{\sin\theta} + \frac{4\pi}{\lambda}d$$

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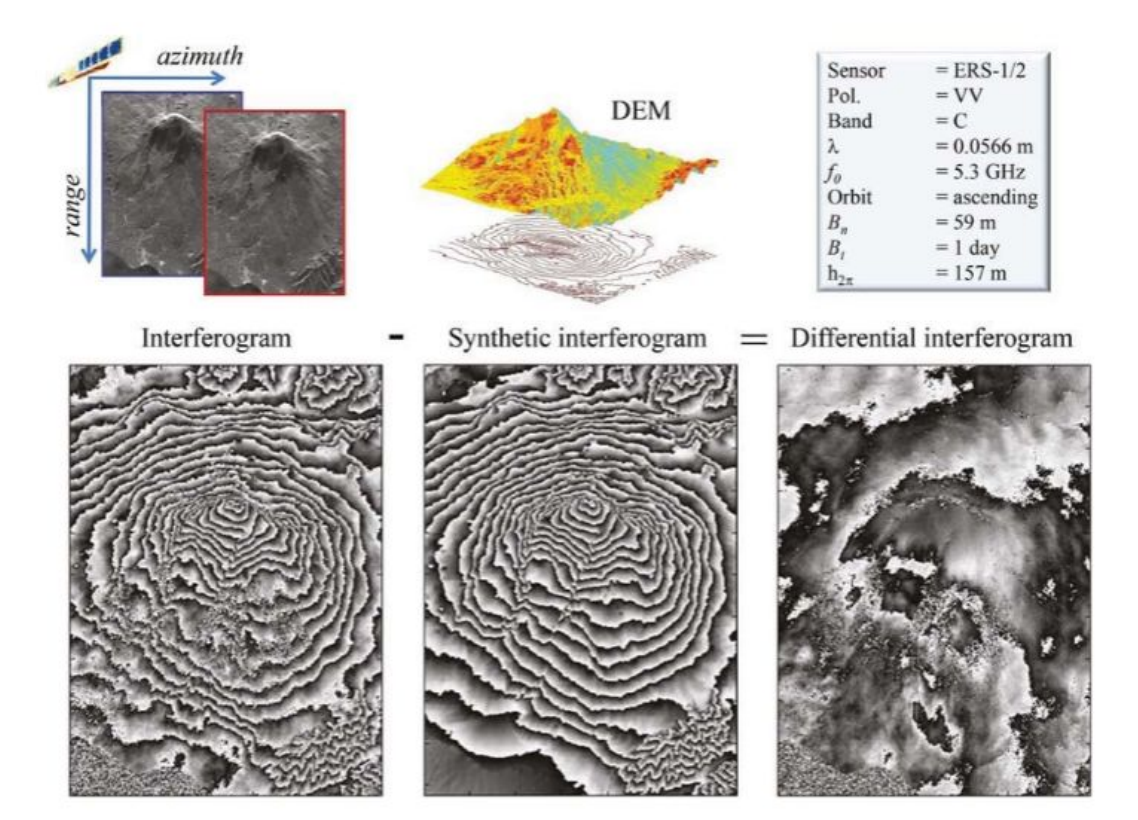
Differential interferogram generation



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Coherence

$$\gamma_c = \frac{E[(a+n_M)(a+n_S)^*]}{\sqrt{E[|a+n_M|^2]E[|a+n_S|^2]}} = \frac{\sigma_a^2}{\sigma_a^2+\sigma_n^2} = \frac{1}{1+SNR^{-1}} = \gamma$$

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Other impacts on interferogram

Geometrical decorrelation

Volume decorrelation

Temporal decorrelation:

Coherence values change significantly: wet snow, wind, as well as volume decorrelation phenomena (stronger in particular months) and human activities can cause a drop of coherence values.

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Atmospheric effects

Sometimes, particularly in areas characterized by rough topography, atmospheric effects create phase artefacts that can compromise the detection of surface deformation signals, at least when using single interferograms.

Atmospheric Phase Screen (APS)

Phase anomalies can be caused by inhomogeneities in temperature, pressure and water content in the troposphere (and variations of electron density in the ionosphere.

Atmospheric stratification

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Phase Unwrapping

Phase values are wrapped, as they are known modulo-2π: the proper number of phase cycles has to be estimated by means of a phase unwrapping algorithm.

The aim of phase unwrapping is to recover the integer number of cycles k to be added to the wrapped phase ψ so that the unambiguous phase value φ can be finally obtained for each image pixel.

Almost all the phase unwrapping algorithms are based on the assumption that the true unwrapped phase field is "smooth" and varies "slowly". More precisely, neighbouring phase values are supposed to be within one-half cycle (π radians) of one another.

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$$\phi = \psi + 2\pi \cdot k$$

Phase Unwrapping

The phase of the interferogram can only be modulo 2π. Phase Unwrapping is the process that resolves this 2π ambiguity. Several algorithms (such as the branch-cuts, region growing, minimum cost flow, minimum least squares, multi-baseline, etc.) have been developed. In essence, none of these are perfect, and depending on the applied technique some phase editing should be carried out in order to correct the wrong unwrapped phases. The most reliable techniques are those in which different algorithms are combined.

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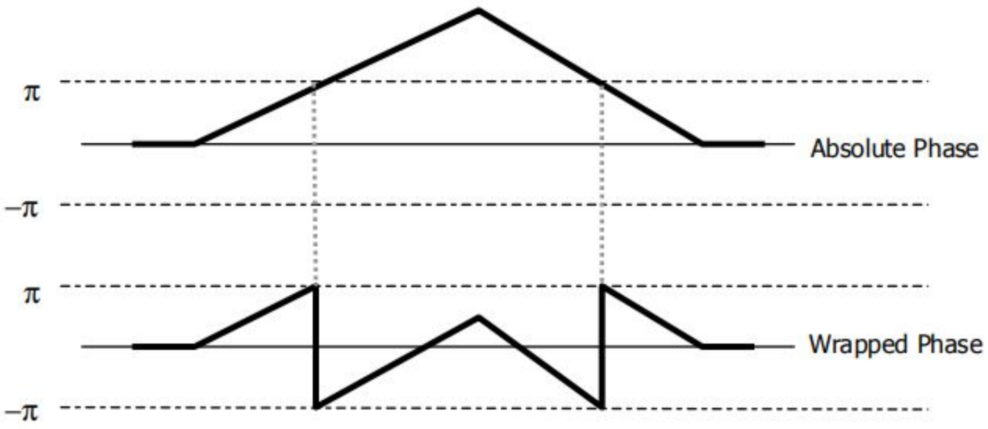
Interferogram Generation - Wrapped Phase

The interferometric phase (ϕ) is expressed as ϕ = tan(Imaginary(*Int*) / Real(*Int*)), modulo 2π.



In order to resolve this inherent ambiguity, phase unwrapping must be performed.

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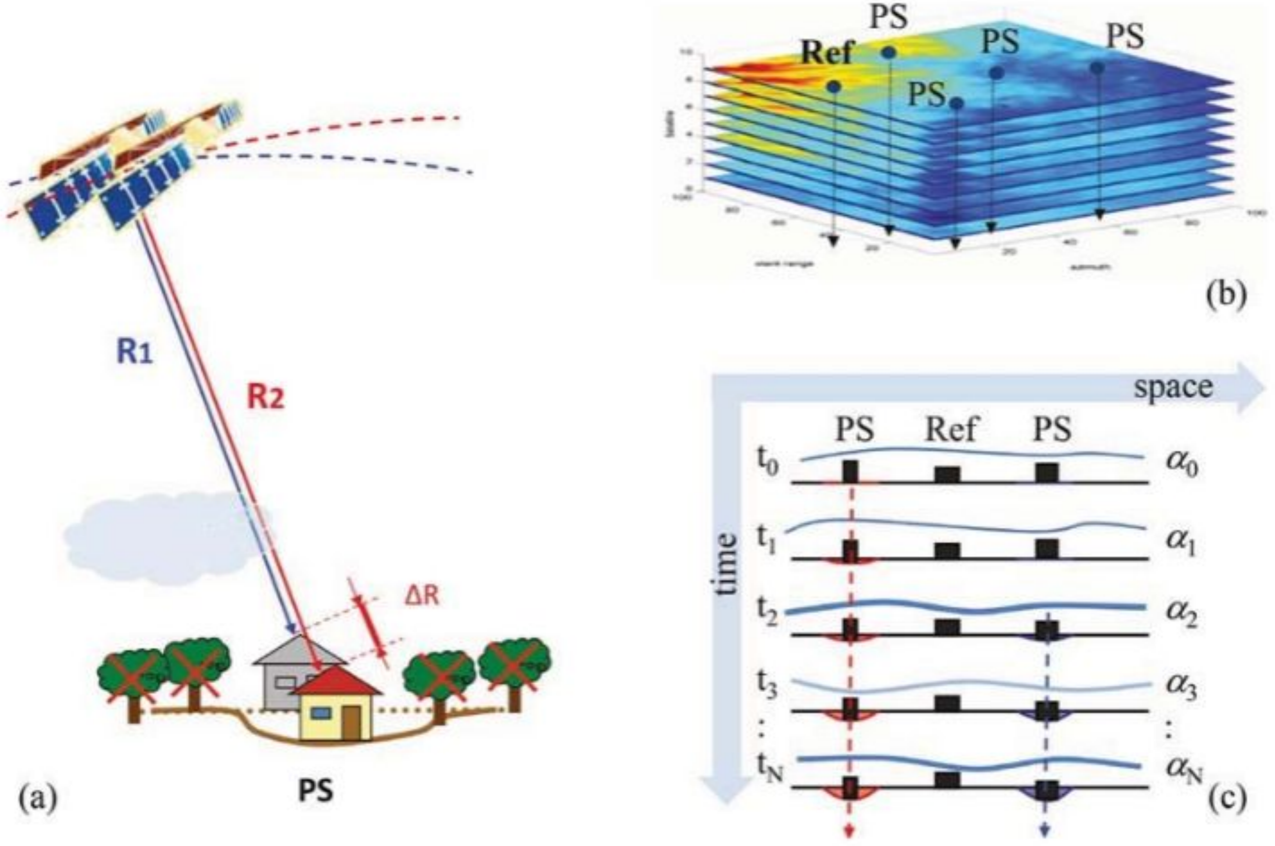
Stacking



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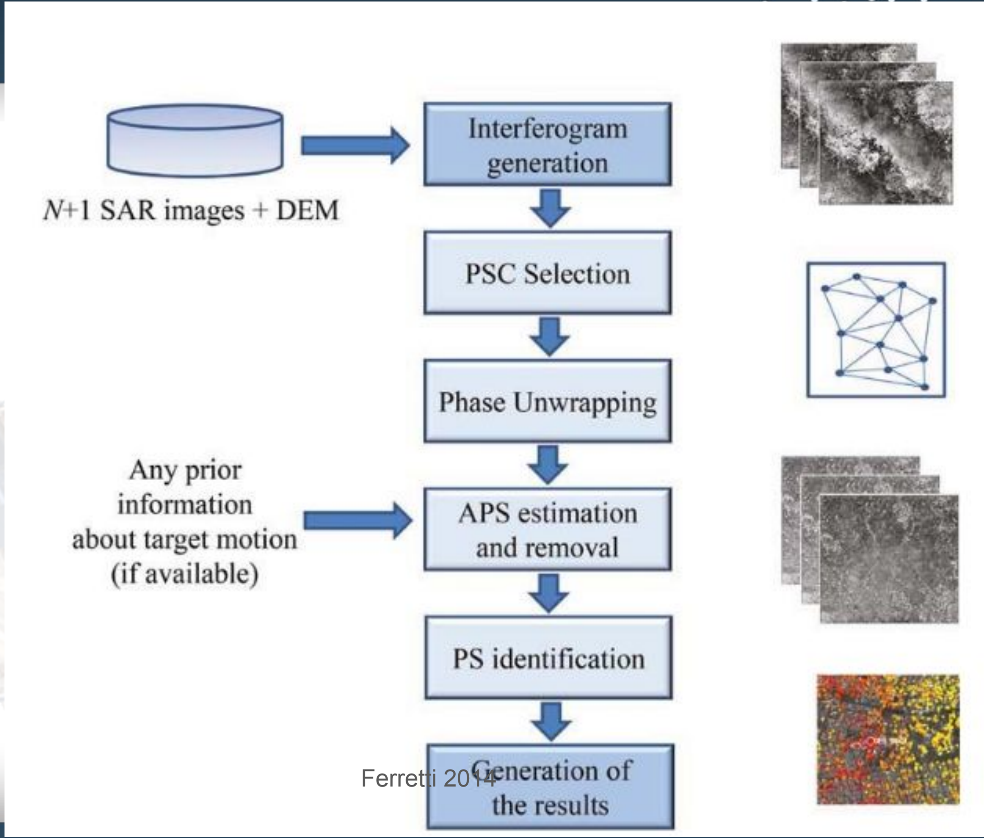
Persistent Scatterers



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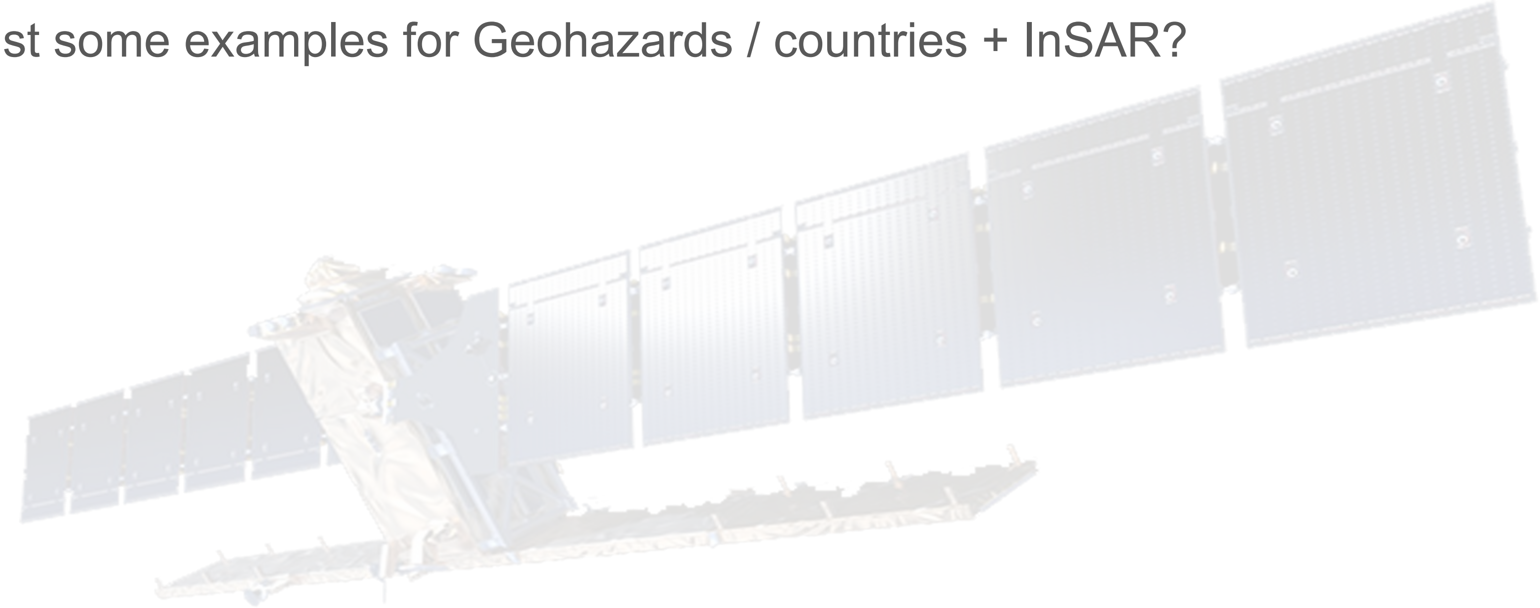
Let's repeat!

Pls list some examples for Geohazards / countries + InSAR?



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