Differential SAR Interferometry

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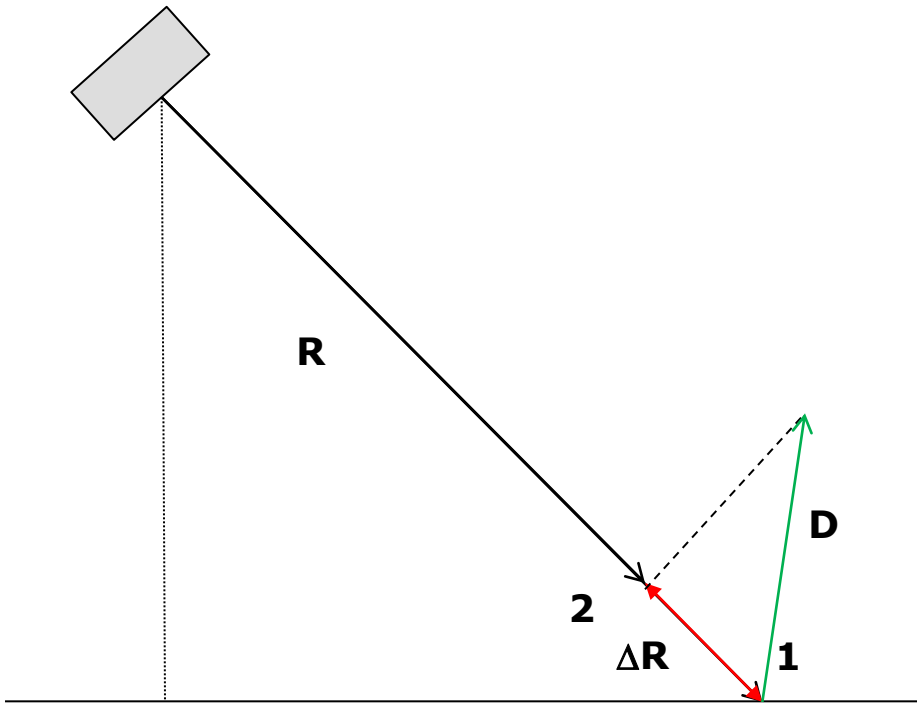
Line-Of-Sight (LOS) Displacement



SAR is measuring range distance (**R_1**, **R_2**) as phase.

InSAR phase is proportional to differences of range distances (**ΔR**), i.e. displacements along LOS direction.

If the full displacement vector **D** is not parallel to the LOS, the projection of the full displacement along the LOS is measured.

The magnitude of the full displacement vector can be reconstructed only if its direction (angle between LOS and full displacement direction) is known. Examples:

- Subsidence (vertical displacement);
- Landslides (direction of the gradient of the local topography).

Differential SAR Interferometry (DInSAR) – Principle

The temporal separation, in repeat-pass interferometry, of days, months, or even years, can be used for long term monitoring of geodynamic phenomena, in which the target has changed position at a relatively slow pace, as in the case of glacial or lava flows movements. However, it is also useful for analysing the results of single events, such as earthquakes.

If two acquisitions are made at different times from the same position, so there is no across-track baseline, then the phase of the interferogram depends only on the change in topography between the acquisition times. Unfortunately, in general, a difference in the across-track position of the satellites also exists; in this case, multiple acquisitions can be done to map the topography, or an external DEM can be used to take rid of its influence.

$$\phi_{Int} = 4\pi \frac{R_1 - R_2}{\lambda} = \phi_{Topography} + \phi_{Change} + \phi_{Movement} + \phi_{Atmosphere}$$

DInSAR phase

$$\phi_{Int} = 4\pi \frac{R_1 - R_2}{\lambda} = \phi_{Topography} + \phi_{Change} + \phi_{Movement} + \phi_{Atmosphere}$$

$$= \frac{4\pi B_n}{\lambda R \sin\theta} h + \phi_{Change} + \frac{4\pi}{\lambda} \Delta R_{Movement} + \phi_{Atmosphere}$$

$$= \frac{4\pi B_n}{\lambda R \sin\theta} h + \frac{4\pi}{\lambda} \Delta R_{Movement} + \phi_{Noise}$$

Phase Ambiguity

$$\phi_{Int} = \frac{4\pi B_n}{\lambda R \sin\theta} h + \frac{4\pi}{\lambda} \Delta R_{Movement} + \phi_{Noise}$$

$$\phi_{Movement} = \frac{4\pi}{\lambda} \Delta R_{Movement}$$

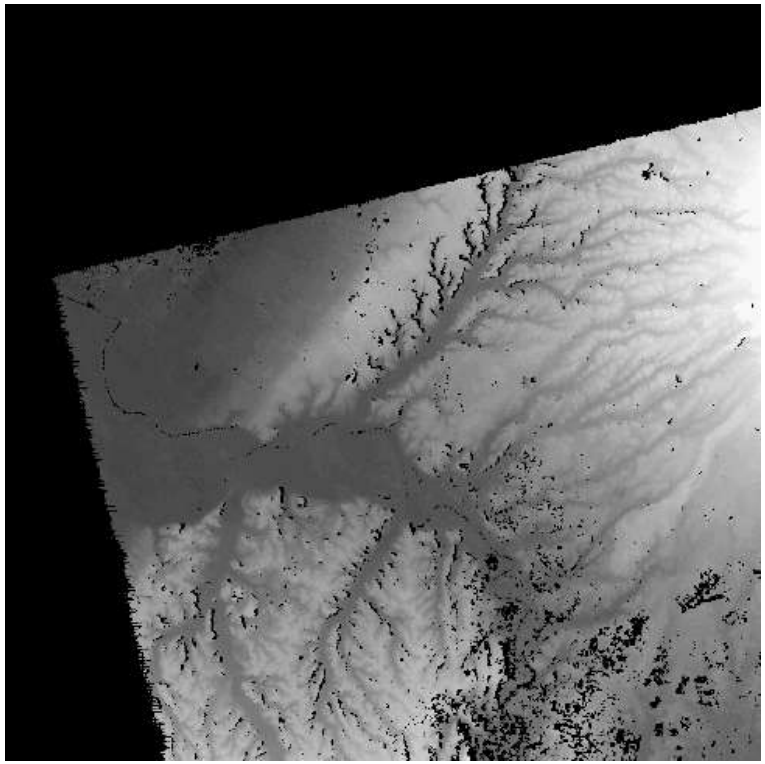
$$DispAmb = \frac{\lambda}{2}$$

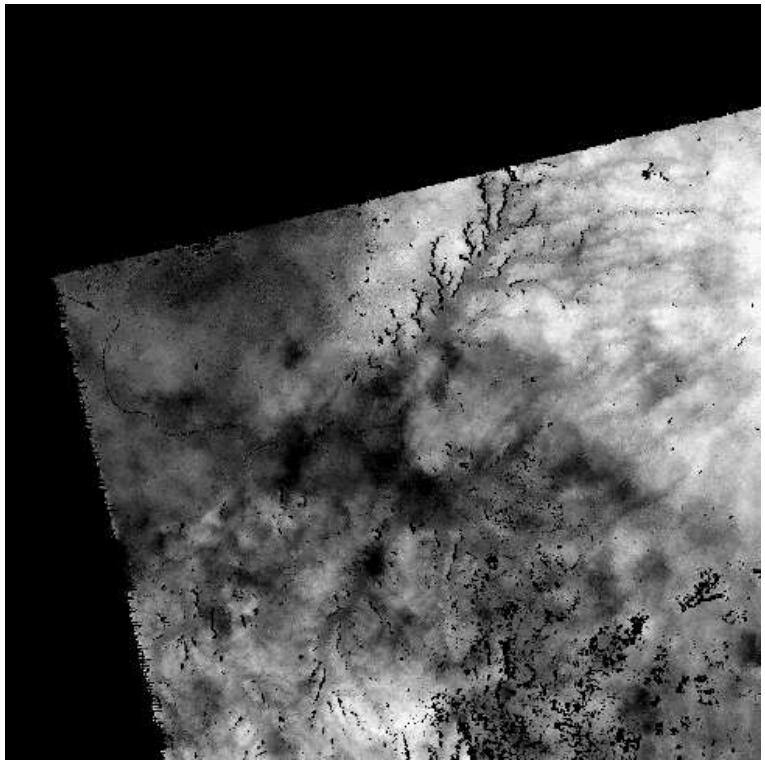
Atmospheric and Ionospheric Effects

InSAR and DInSAR techniques are based on the measurements of two-way path difference $\Delta R = 2(R_1 - R_2)$ in a radar wavelength scale. If microwave pulses pass through locally dense vapor in the troposphere, there appears a time delay caused by the vapor, and the path difference becomes $\Delta R + \Delta R_T$ where ΔR_T is the path difference corresponding to this time delay.

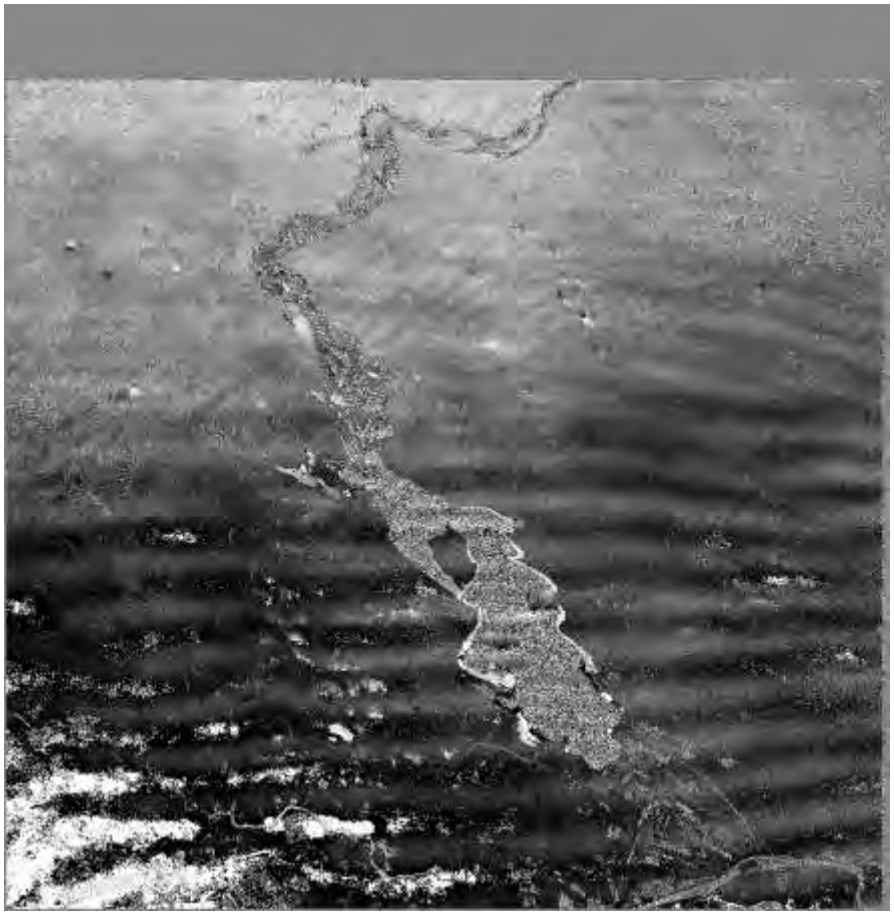
The phase delay can be corrected or mitigated by stacking or averaging a large number of interfetograms (Stacking Interferometry), since the atmosphere has short spatial correlation length with virtually no temporal correlation between data acquisition times.

Atmospheric Effects

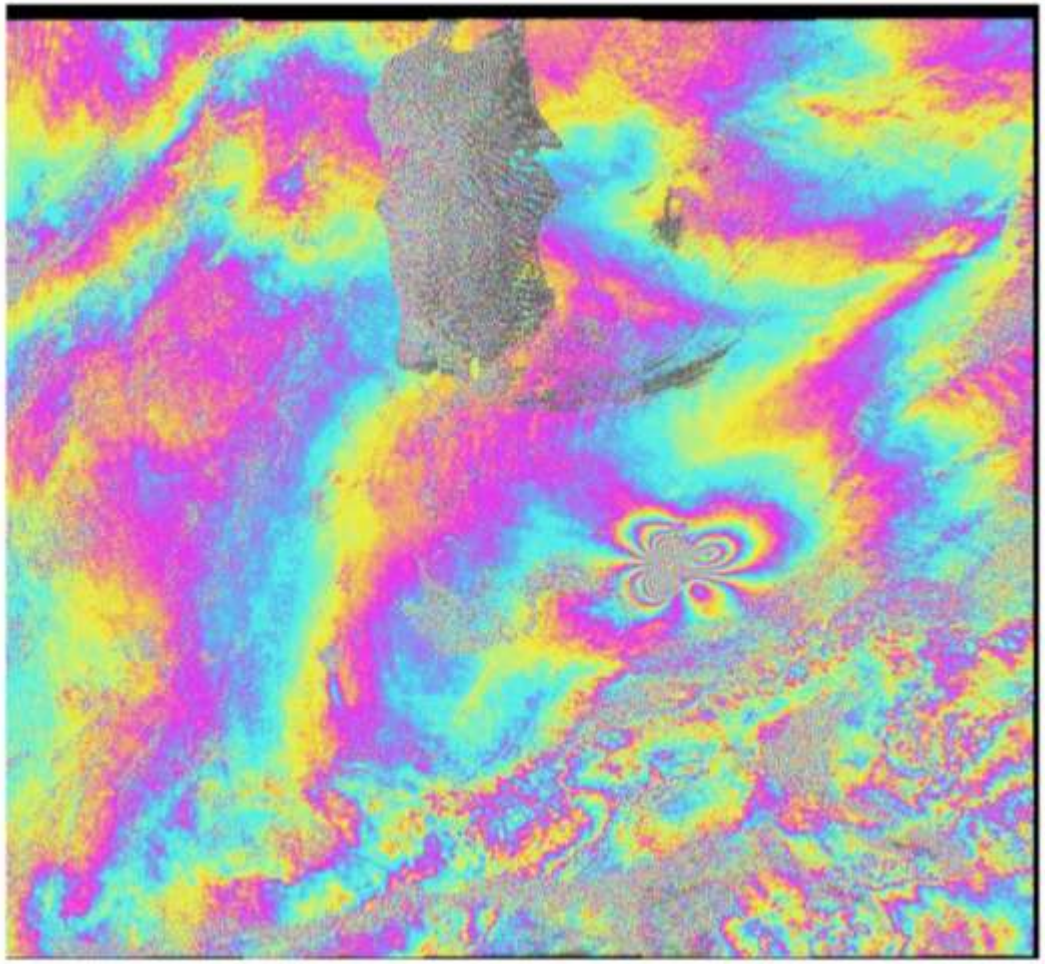




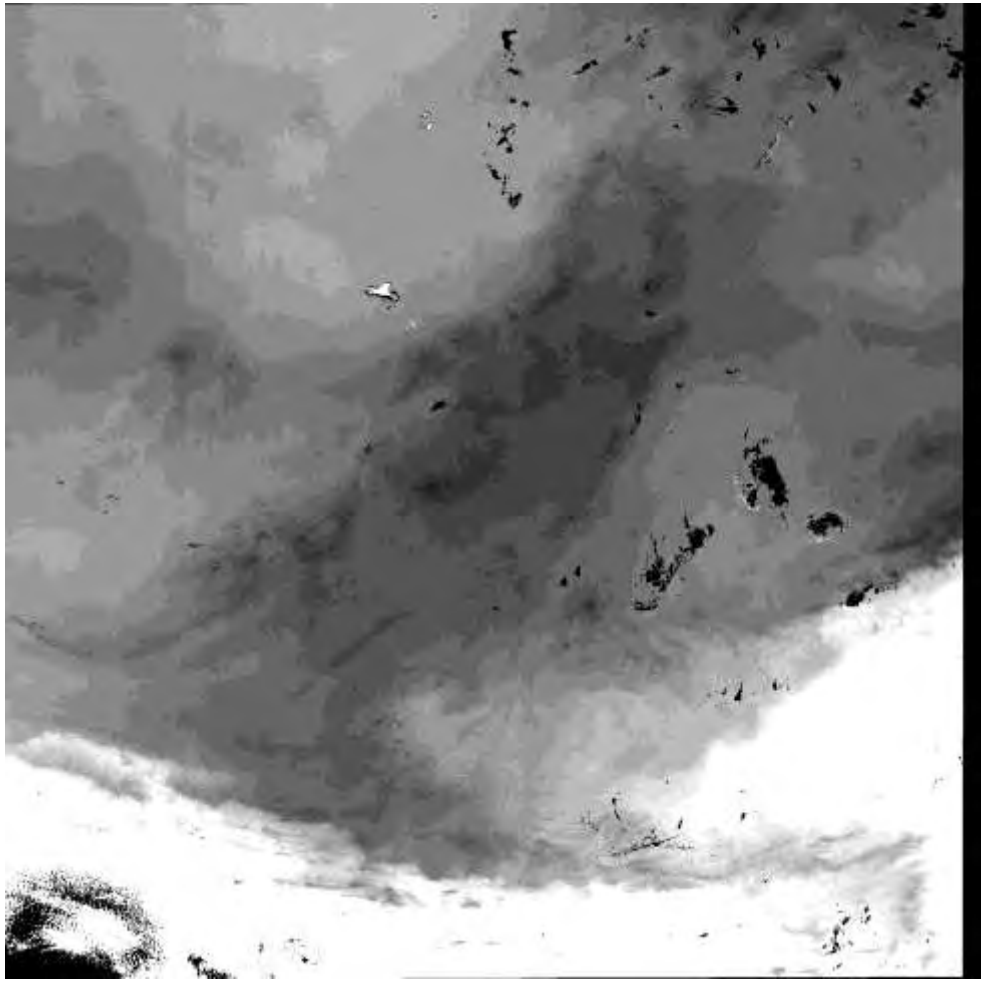
Atmospheric and Ionospheric Effects



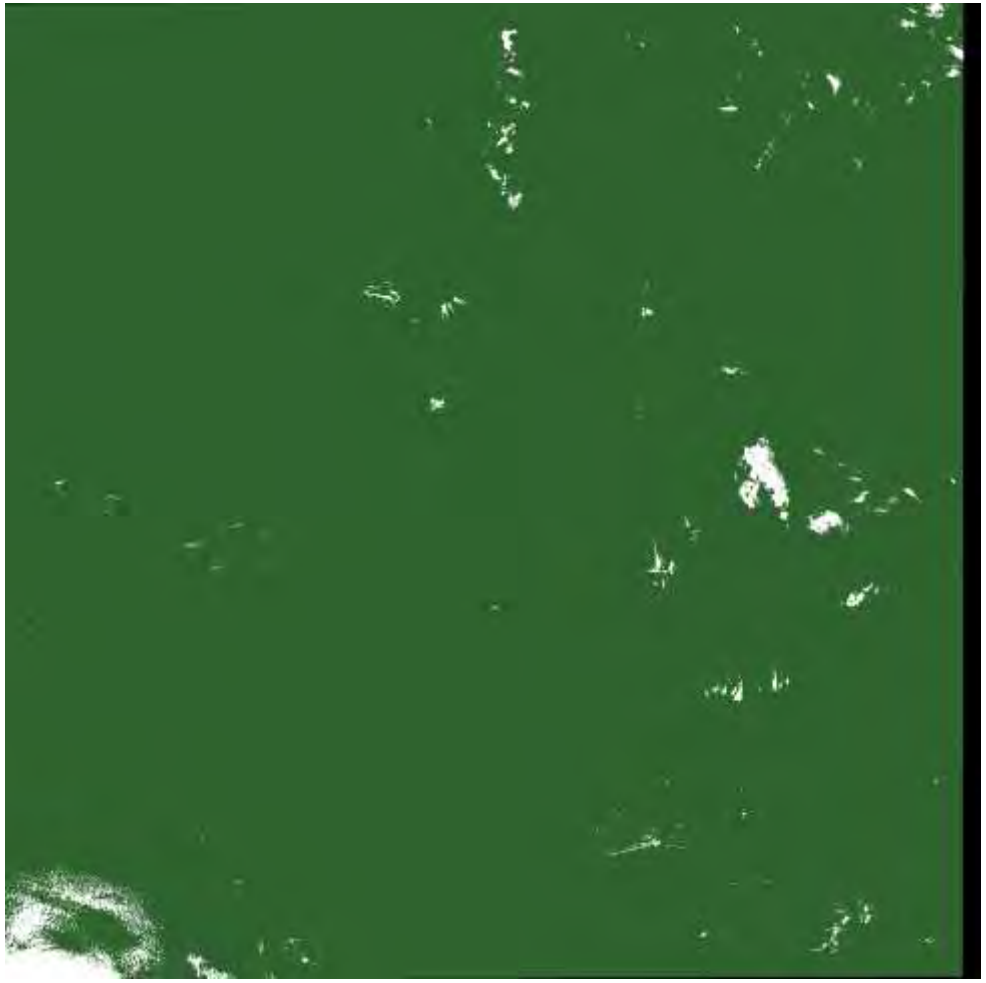
Bam Earthquake (2003) – ASAR WS interferogram



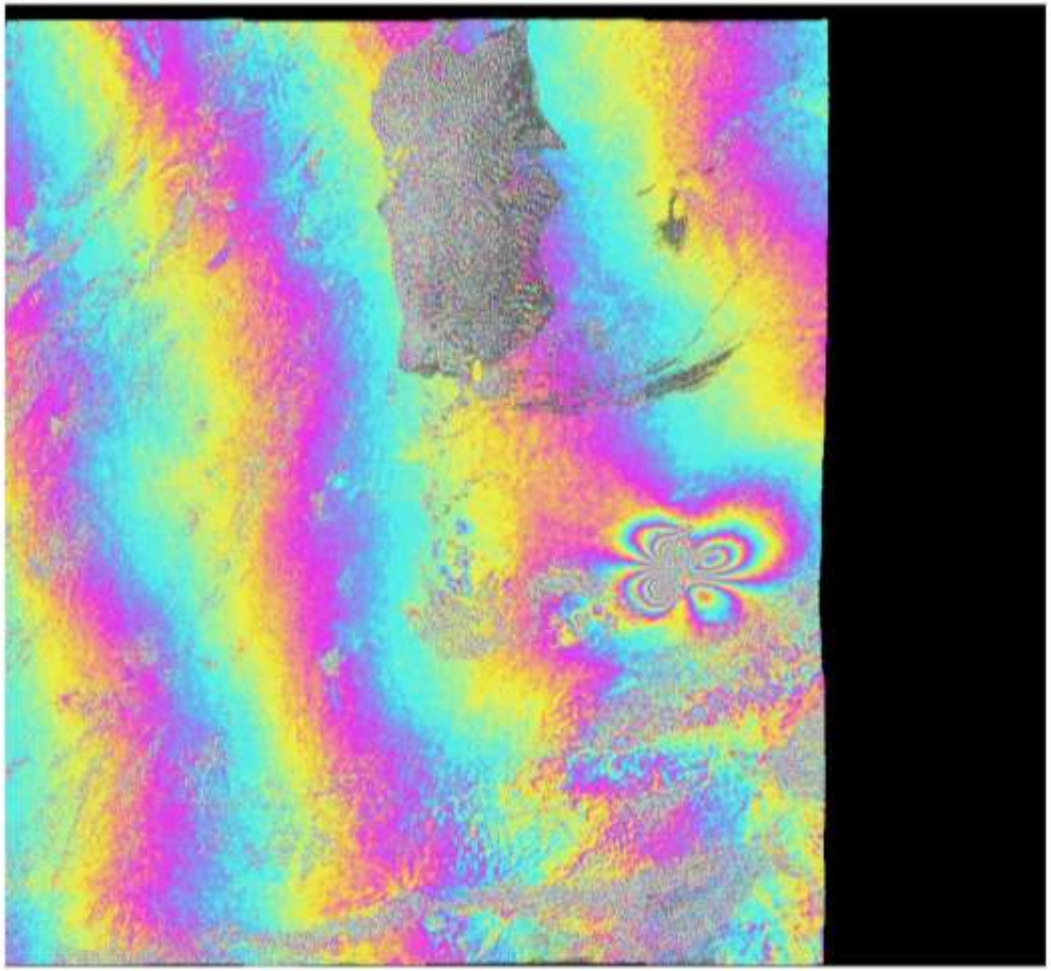
Bam – MERIS Water vapour for master



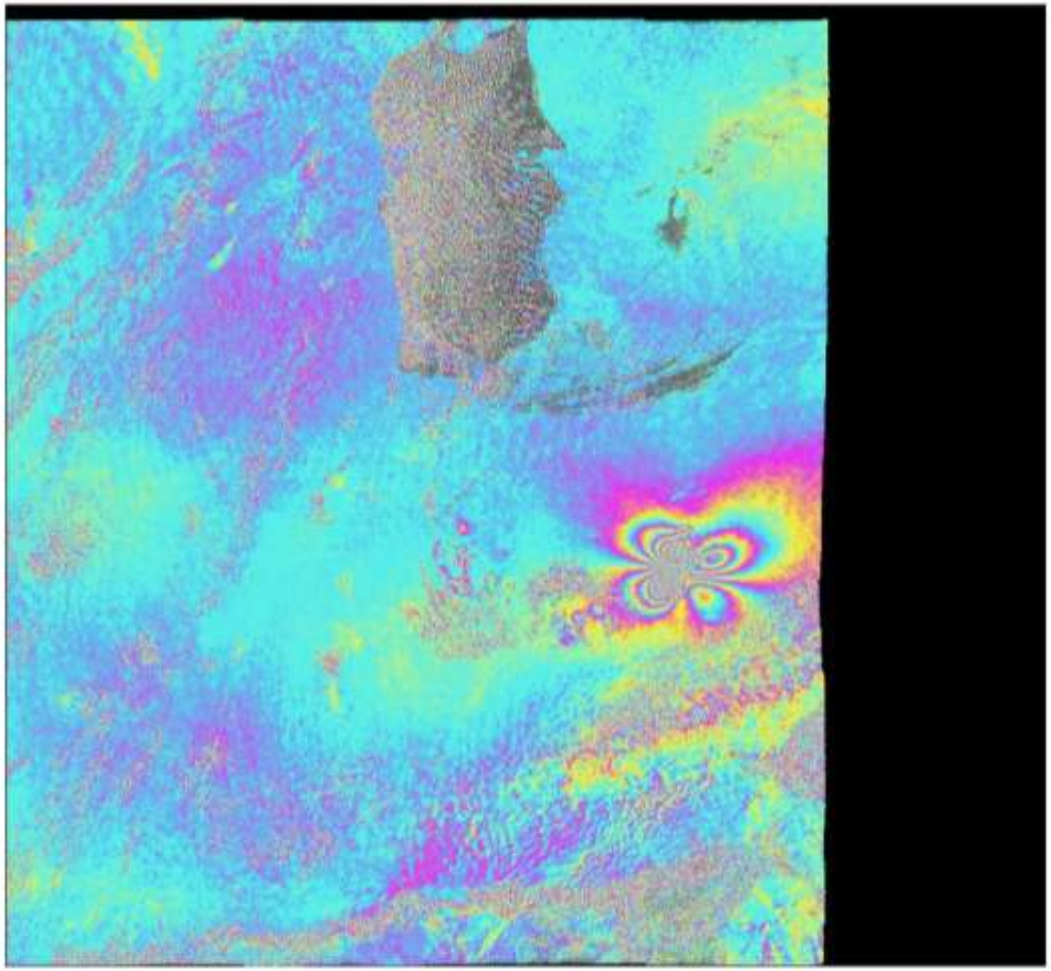
Bam – MERIS cloud mask



Bam – MERIS corrected interferogram



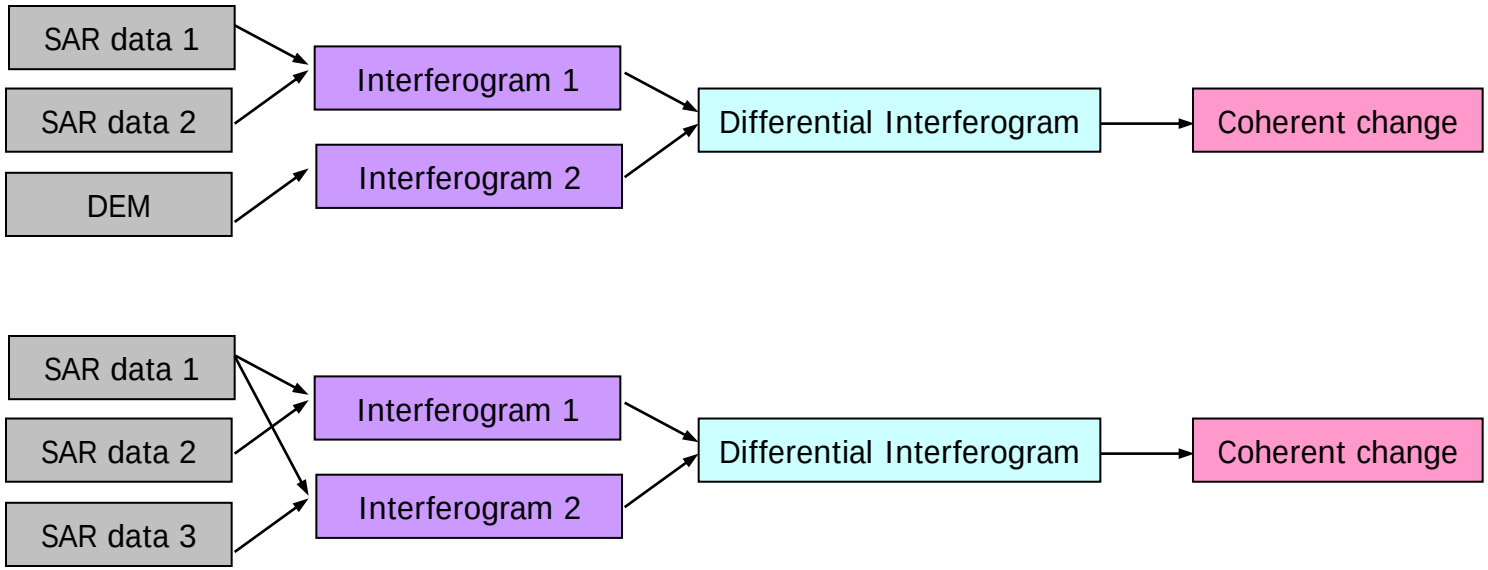
Bam – MERIS and orbital corrected interferogram



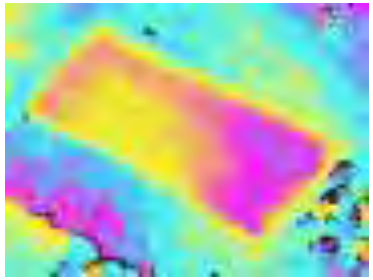
Differential Interferograms

Differential interferograms can be generated in different ways:

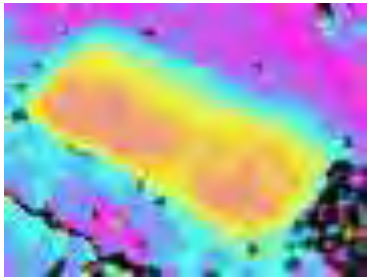
1. Passes 1 (pre event) and 2 (after event), in combination with an external DEM (used for subtracting the topography induced fringes), are considered.
2. In order to isolate fringes related to the displacement (i.e. deformation event happened between date 2 and date 3), the interferogram generated from passes 1 and 2 is combined with the interferogram generated from passes 1 and 3.



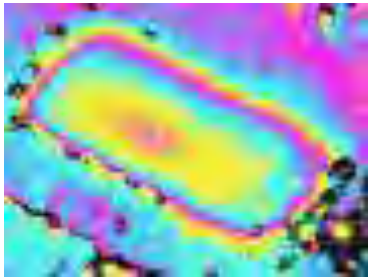
Peri-urban



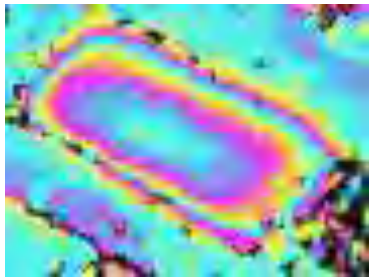
11 days



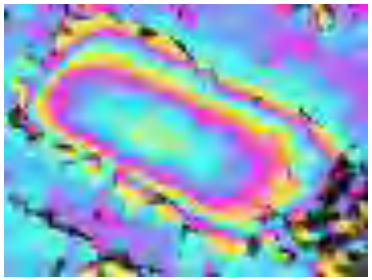
22 days



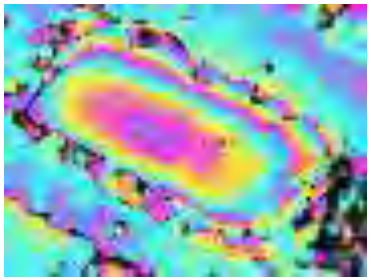
33 days



44 days



55 days

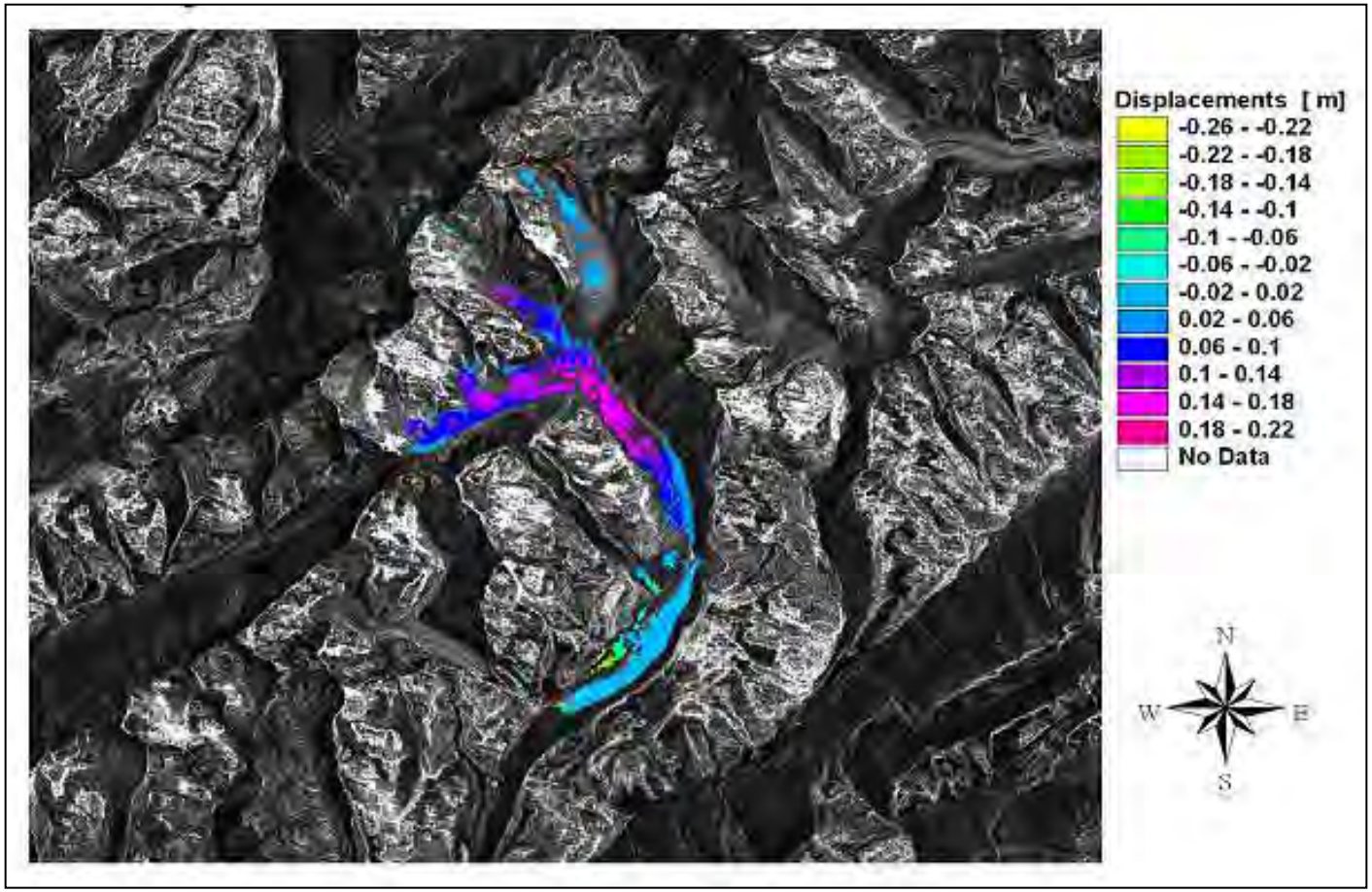


66 days

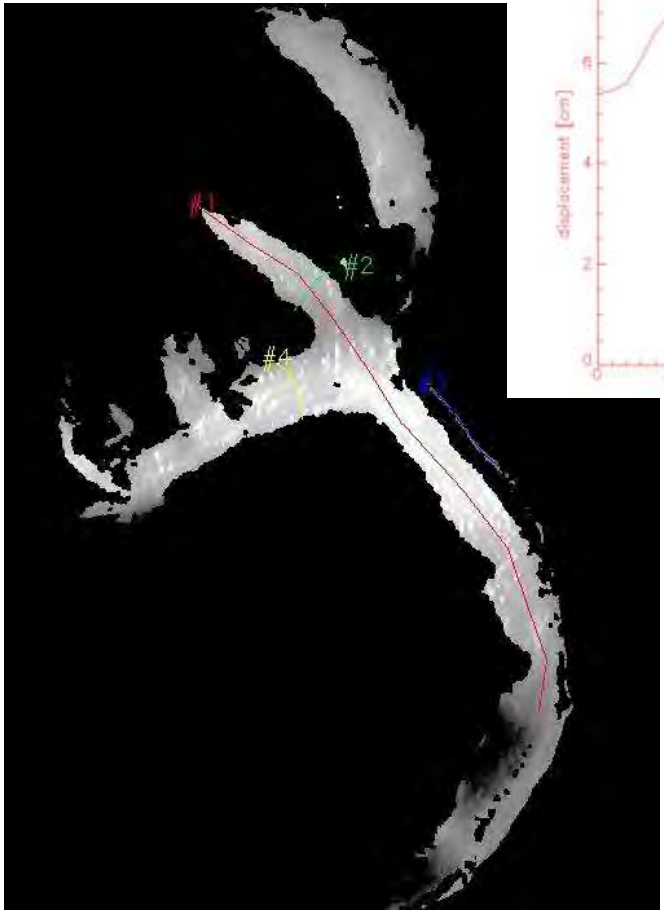
1 colour cycle ~= 1.55 cm of displacement
1 pixel = 3m

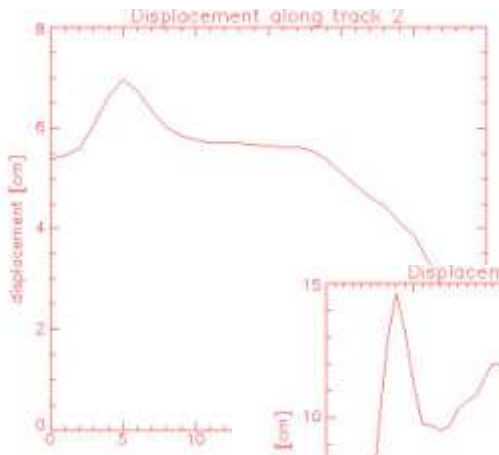
TerraSAR-X Data © Infoterra

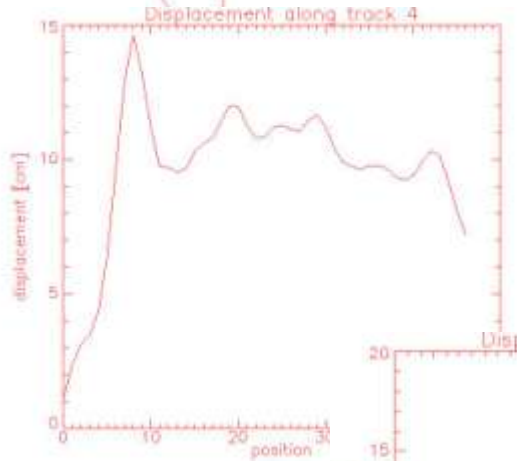
Glacier movements



Glacier movements







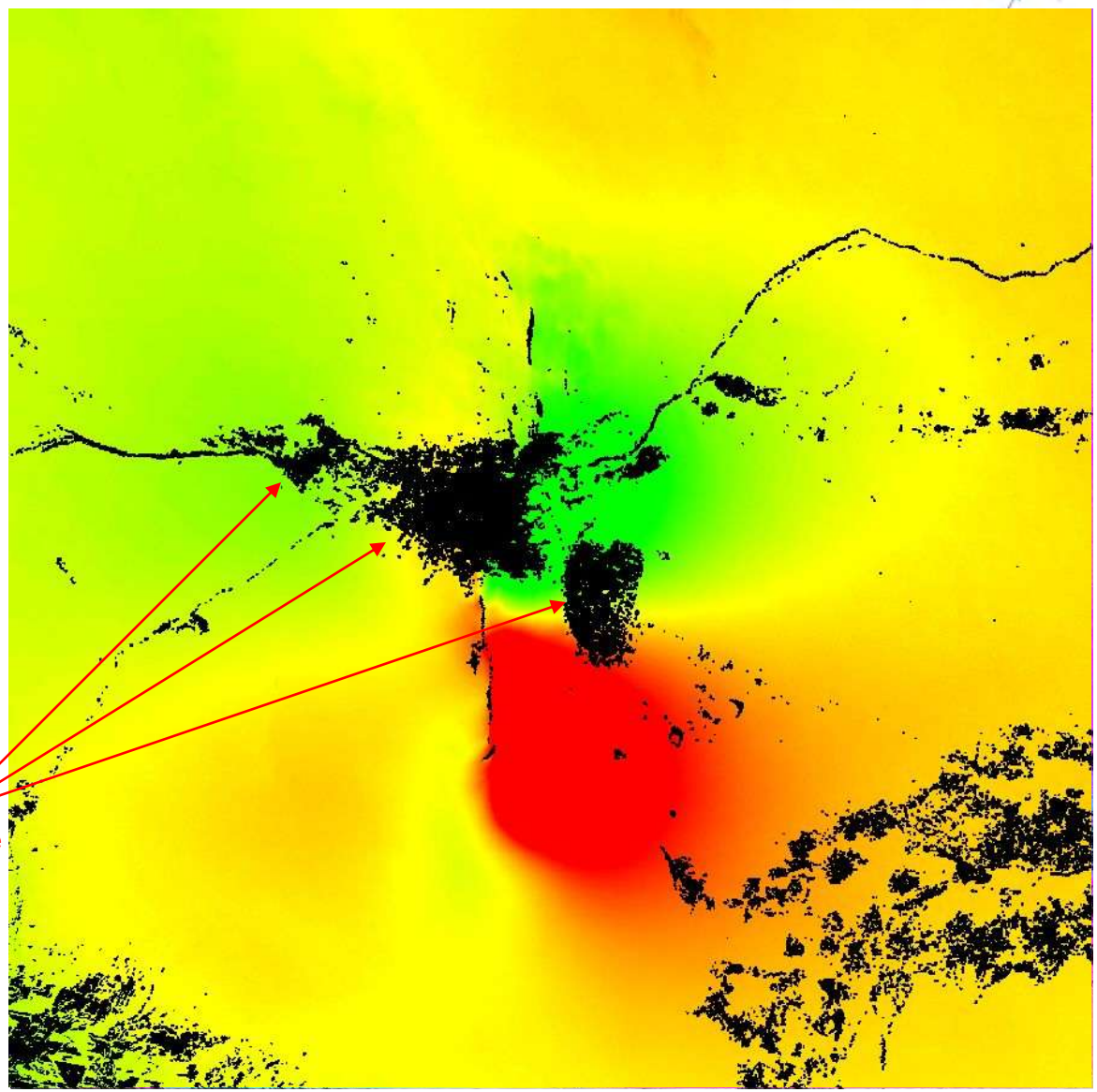
Bam earthquake

Land deformation map

[illegible]

Red and green tones represent the areas of largest deformation (in opposite direction).
Yellowish areas correspond to smaller deformation zones.
The deformation field is calculated as generated from a N-S oriented strike-slip fault

Urban areas mostly affected by the quake
- incoherent behaviour -



Analytical models

Geophysical source of displacement
Shape / type
Parameters

→

Model
Equations

→

Modeled quantities
(X,Y,Z) Surface deformations

Measuring system
(DIn)SAR
GPS

→

Observed quantities
(LOS) deformations

<u>Inversion</u>

Find the parameters of the source that provide modeled deformations as close as possible (in an LMSE sense) to the observed deformations

Analytical models

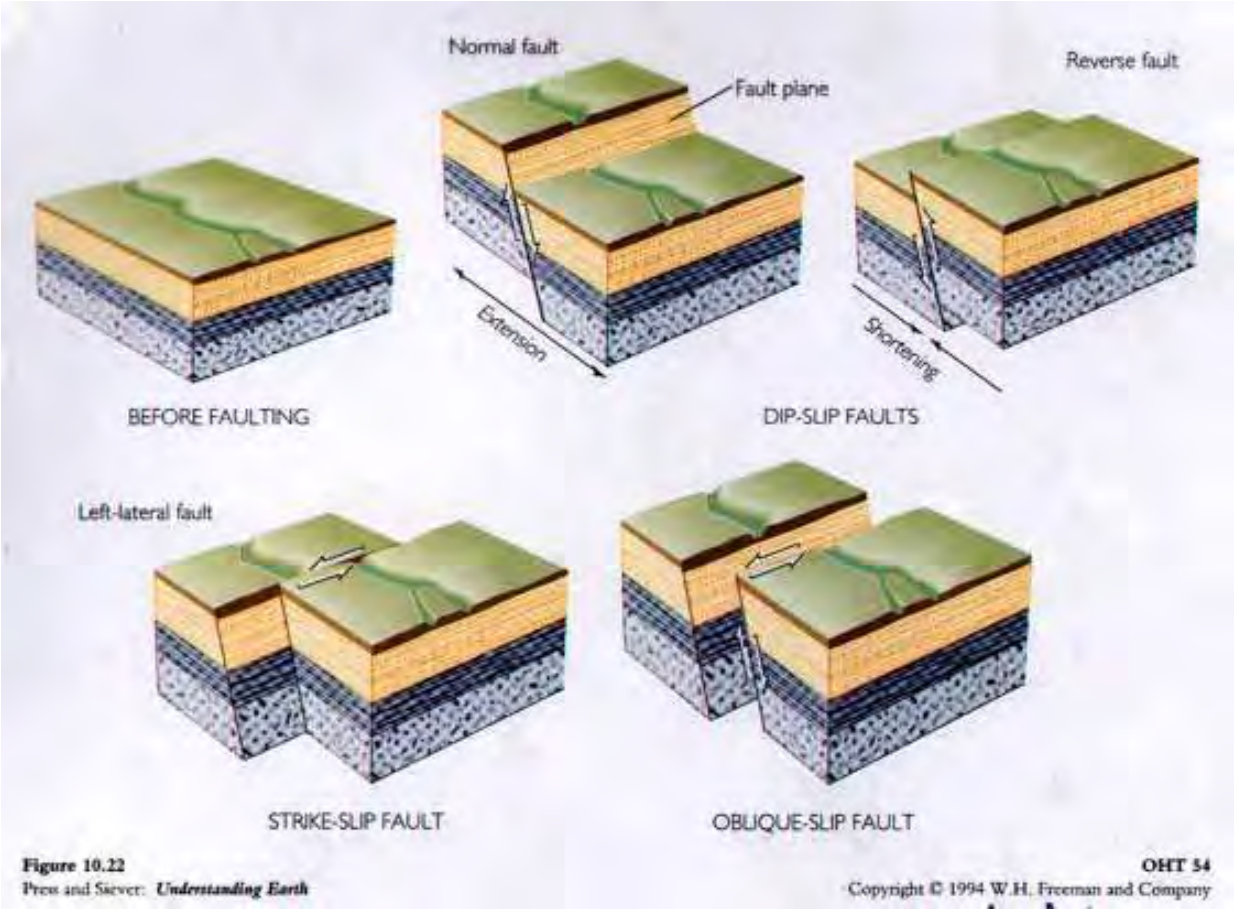
Okada

- Earthquakes
- Landslides
- Subsidence
- Sinkholes

Mogi

- Volcanoes

Fault types


Normal fault
Fault plane
Reverse fault
Extension
Shortening
BEFORE FAULTING
DIP-SLIP FAULTS
Left-lateral fault
STRIKE-SLIP FAULT
OBLIQUE-SLIP FAULT
Figure 10.22
Press and Siever: Understanding Earth
OHT 54
Copyright © 1994 W.H. Freeman and Company

Okada Elastic Dislocation Model

Input

Position (E, N)

Depth (d)

Dimension (L, W)

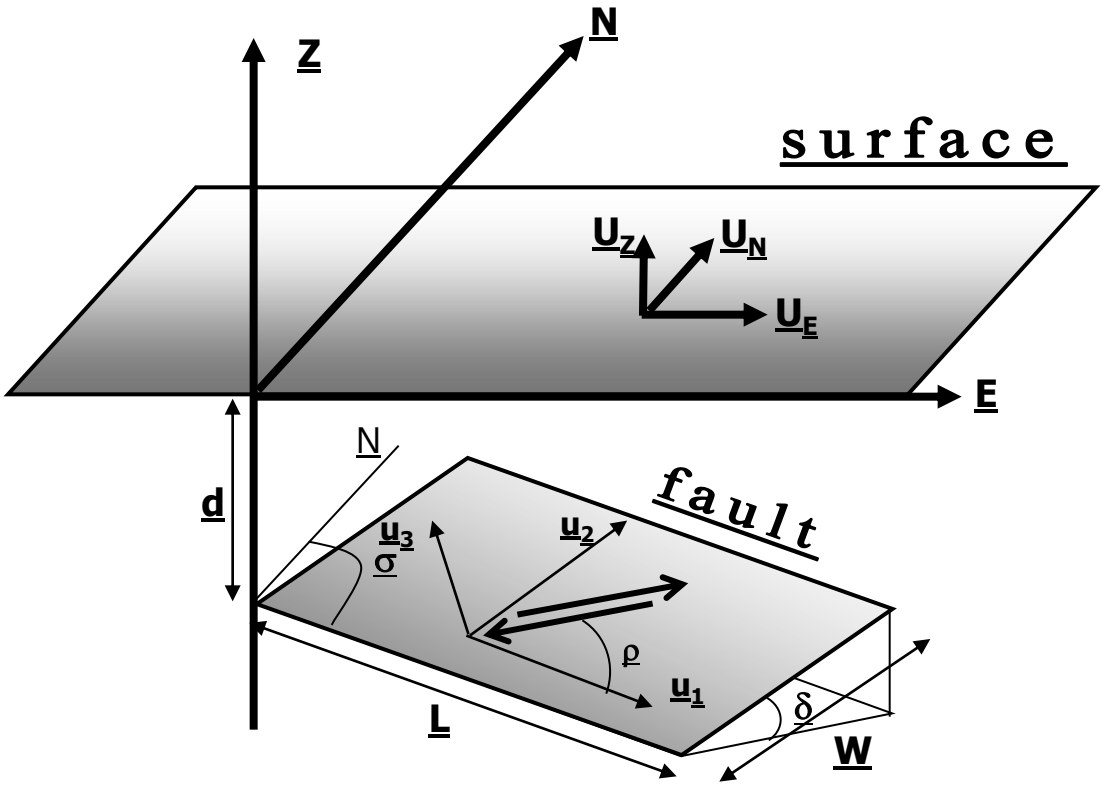
Strike (s)

Dip (d)

Shear Dislocation (u_1+u_2)

Opening (u_3)

Rake (r)



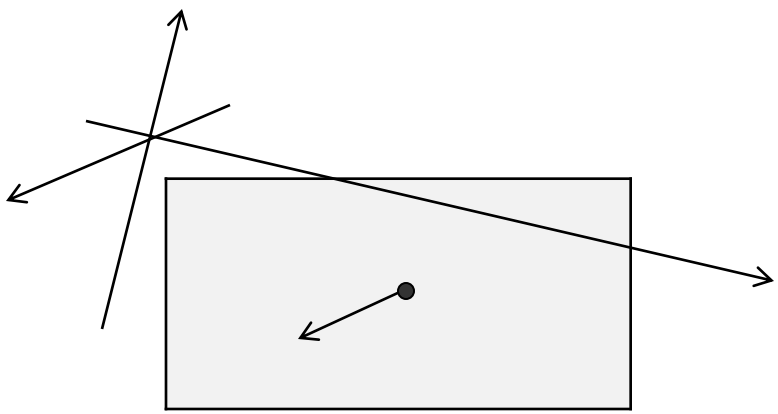
Output

Surface Displacement (U_E,U_N,U_Z)

Two steps inversion model

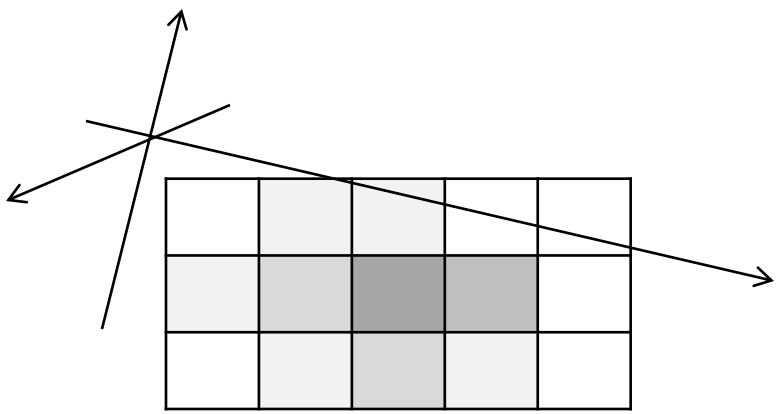
1. Non-linear inversion

Estimate the overall parameters (location, orientation, dimension, dislocation amount etc. of an homogeneous source)

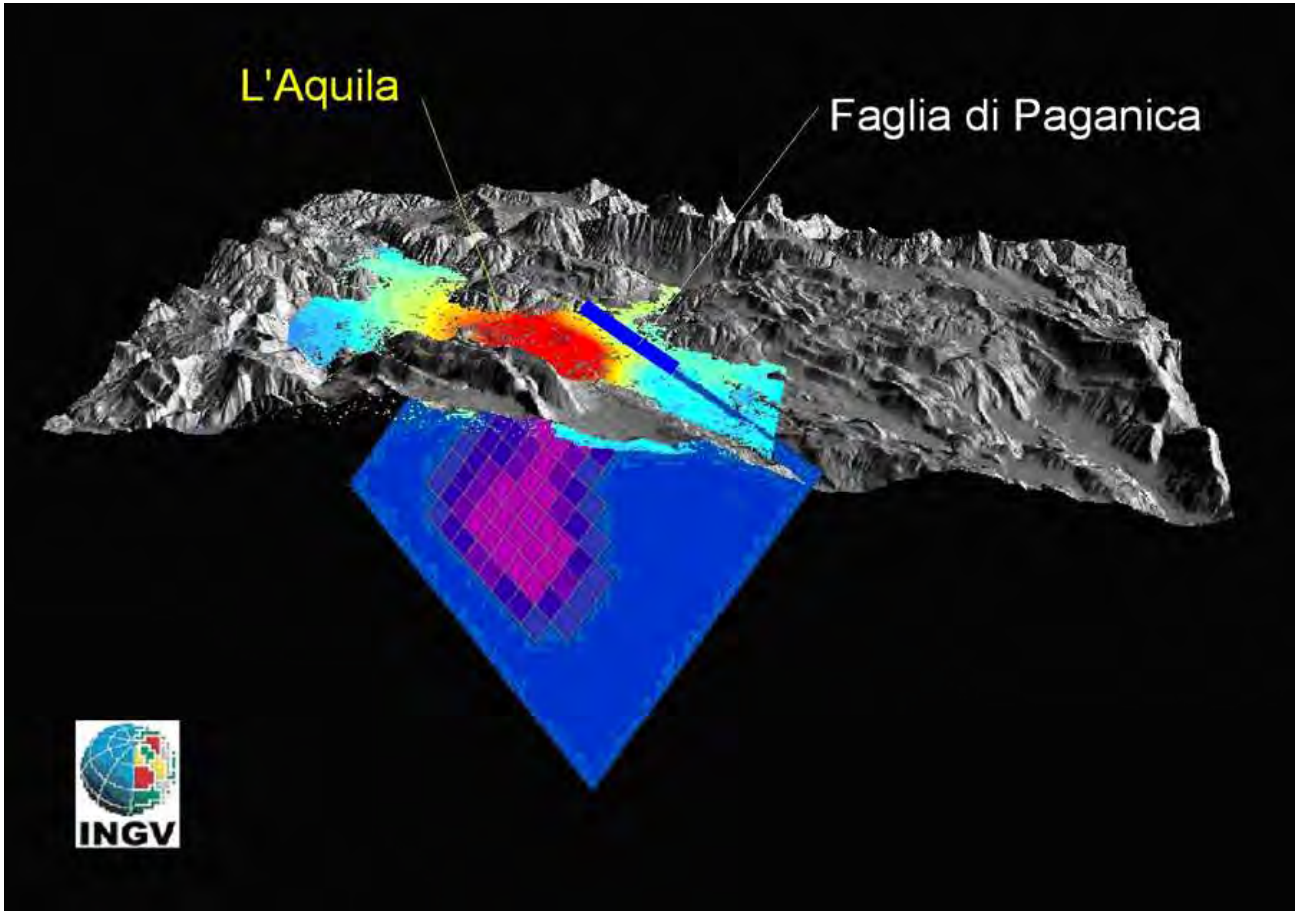


2. Linear inversion

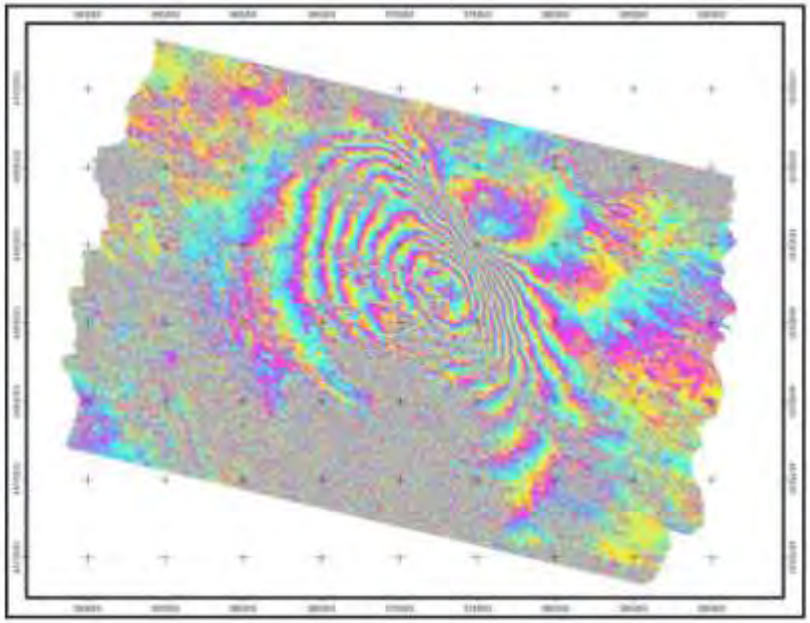
Subdivide the homogeneous source in several elementary patches with same geometry and estimate for each a own (distributed) amount of dislocation



Abruzzi earthquake

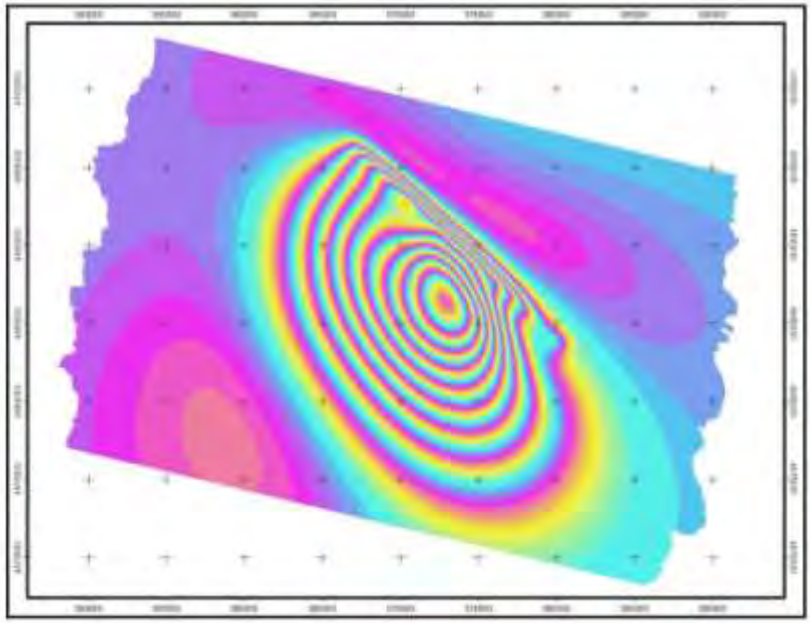


Geological modeling based on DInSAR displacements

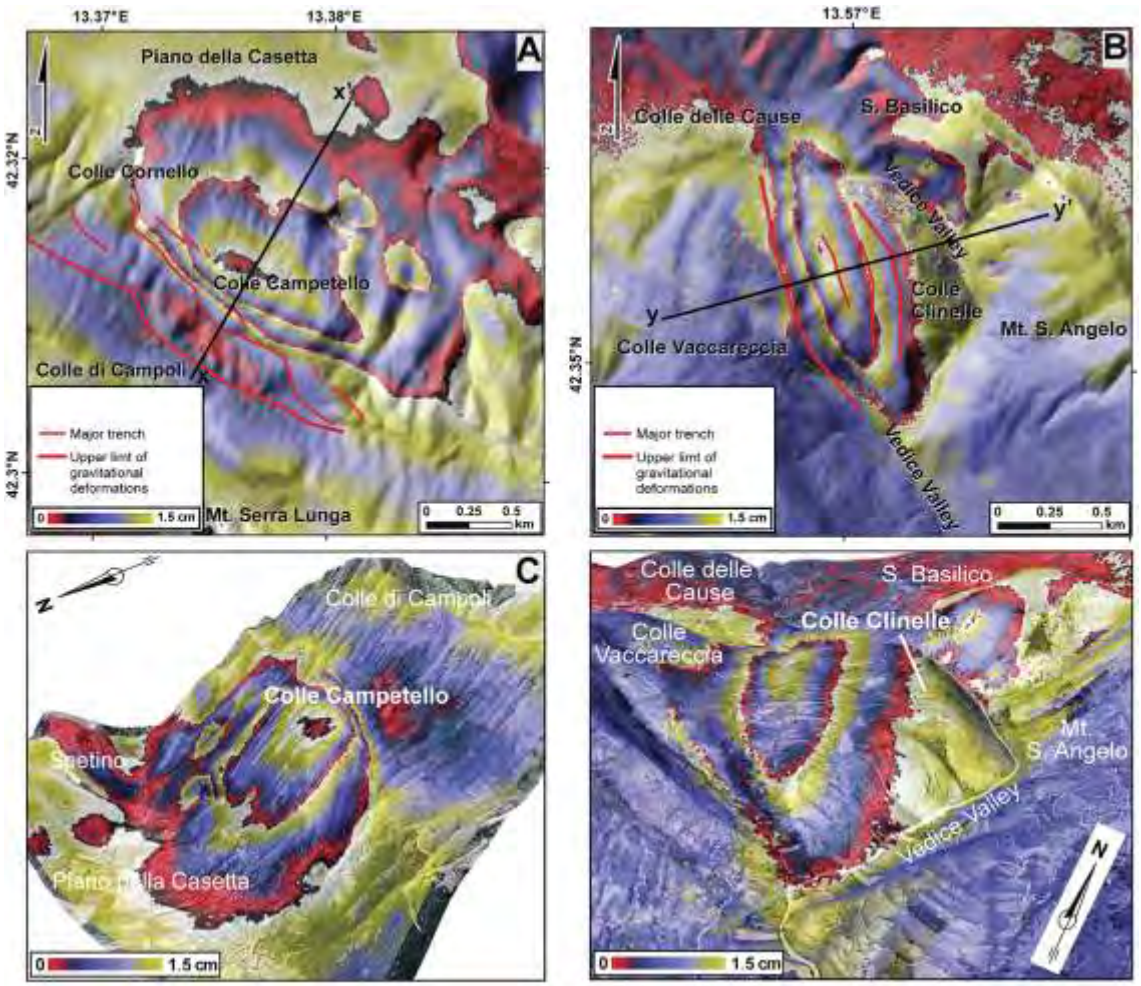


ASAR differential phase

Synthetic interferogram based on Okada model

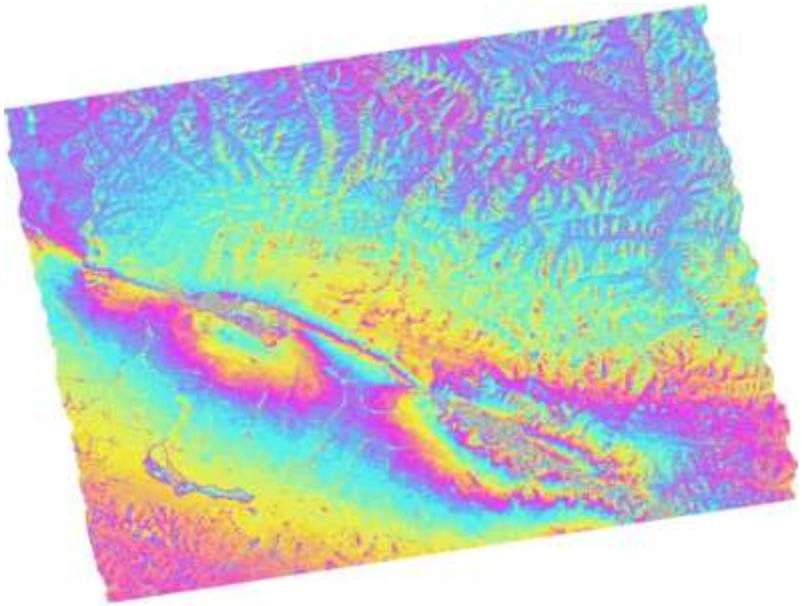


Residual effects after removing the modeled phase: landslides

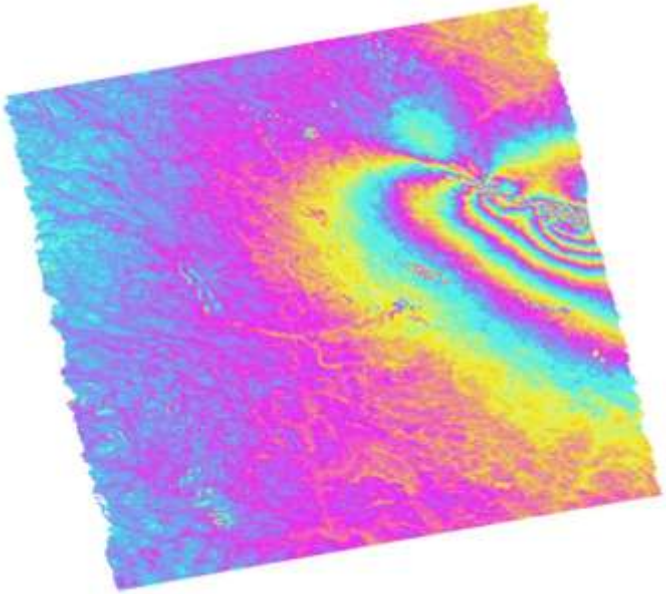


INGV

Yushu earthquake

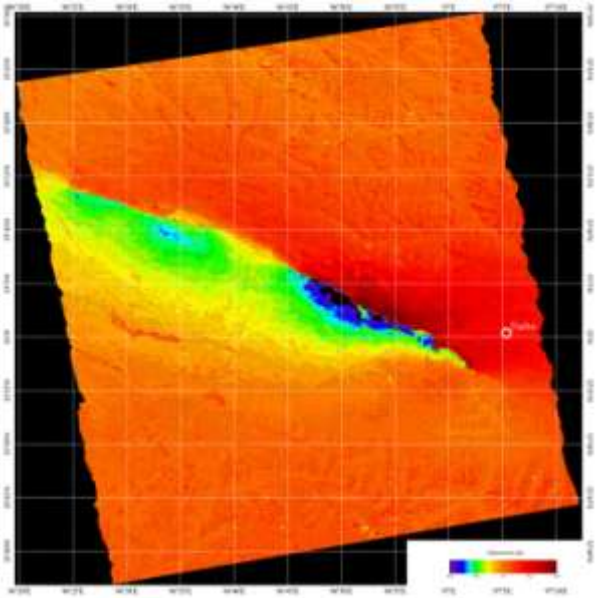


PALSAR-1 co-seismic interferogram

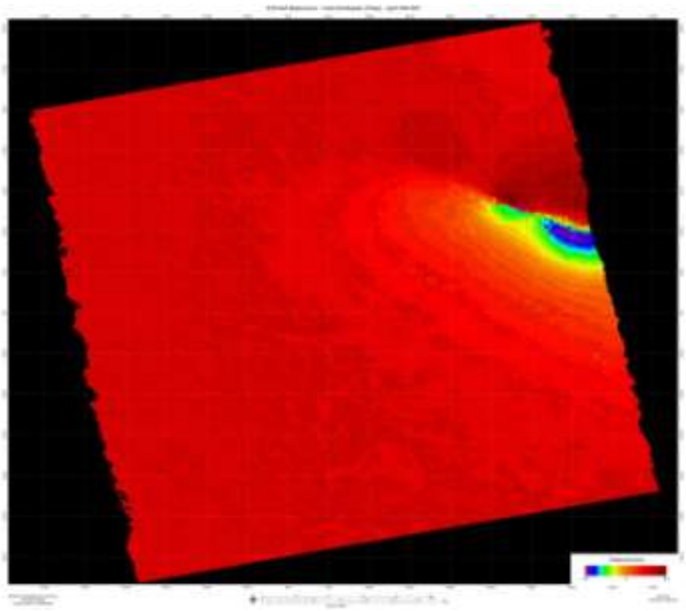


ASAR co-seismic interferogram

Yushu earthquake



PALSAR-1 displacements map

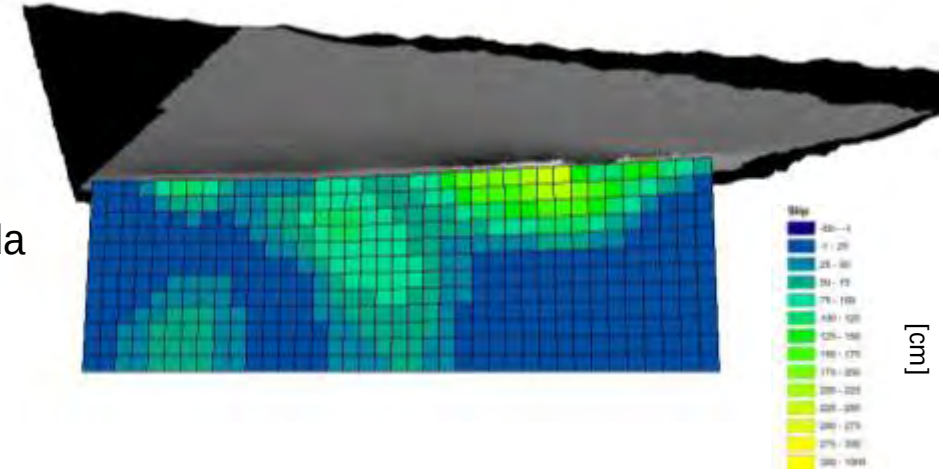


ASAR displacements map

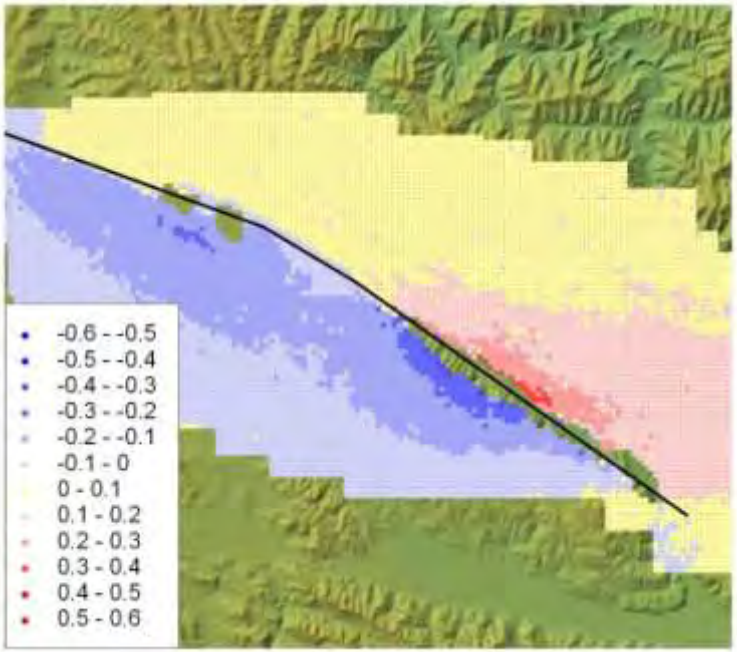
Yushu earthquake

Location of the modeled faults

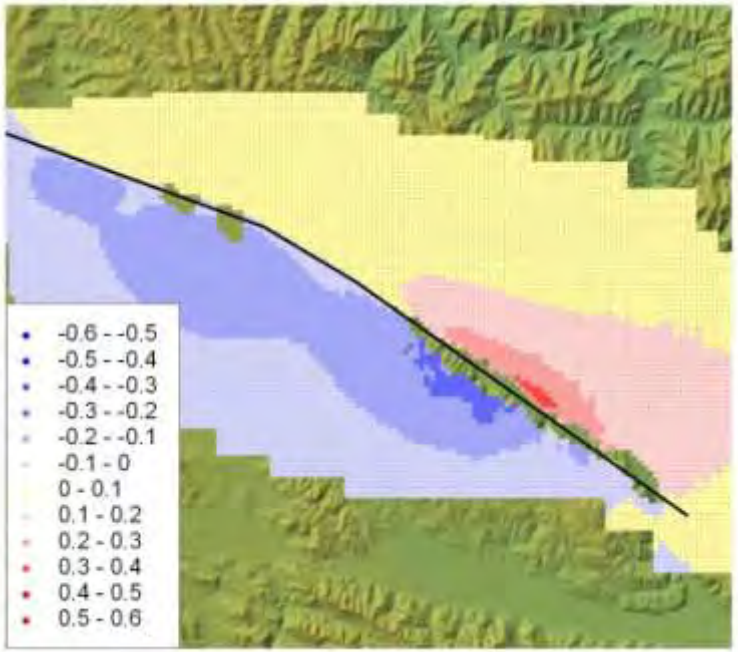
Slip distribution according to Okada



Yushu earthquake

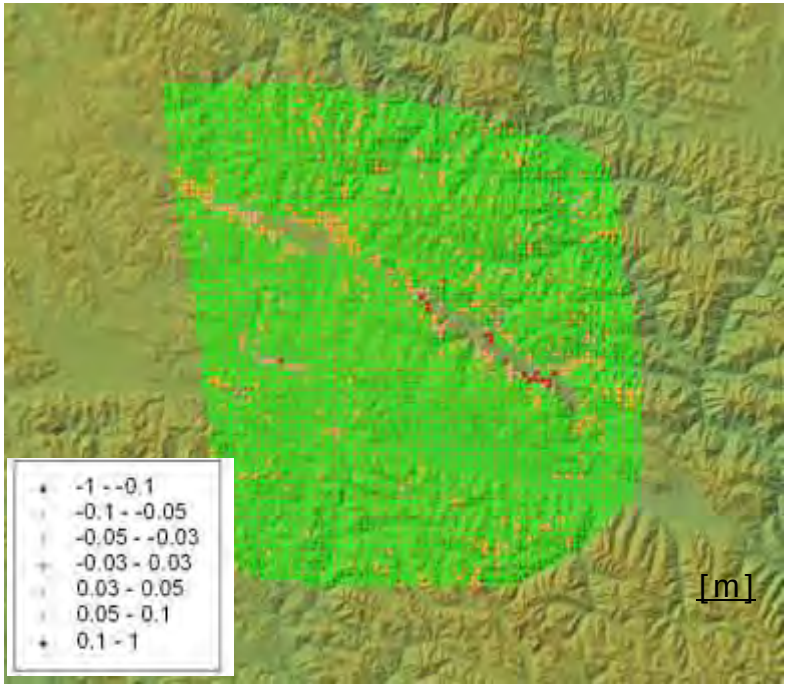


Observed displacement, PALSAR-1

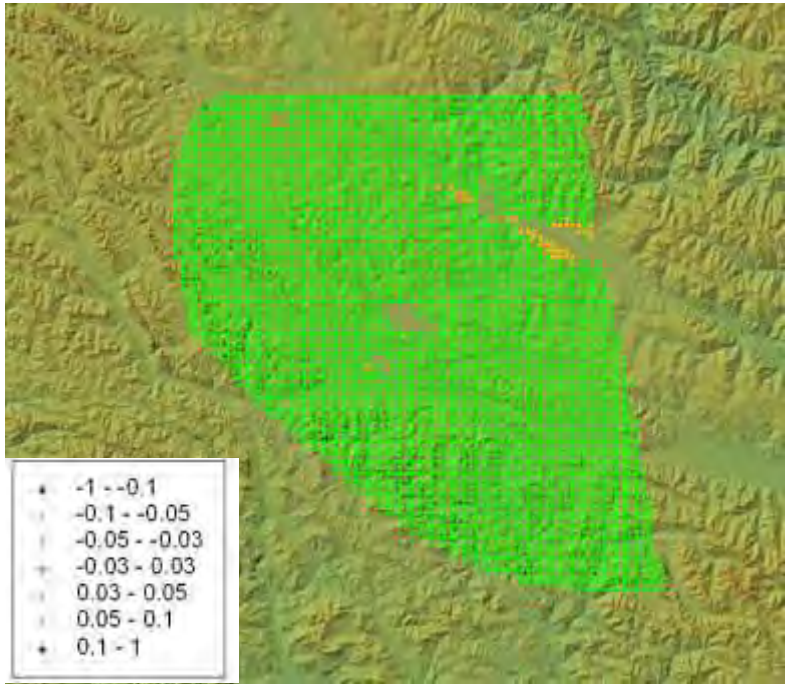


Modeled displacement, PALSAR-1

Yushu earthquake



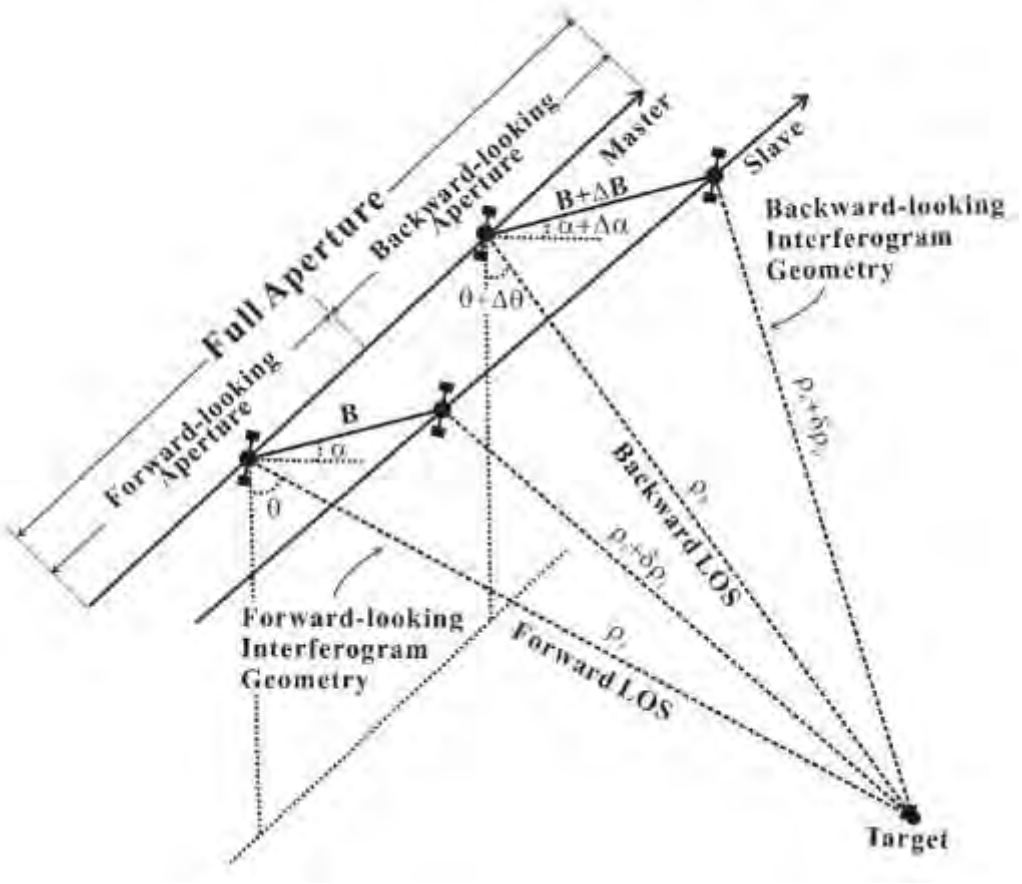
PALSAR-1 Residuals



[m]

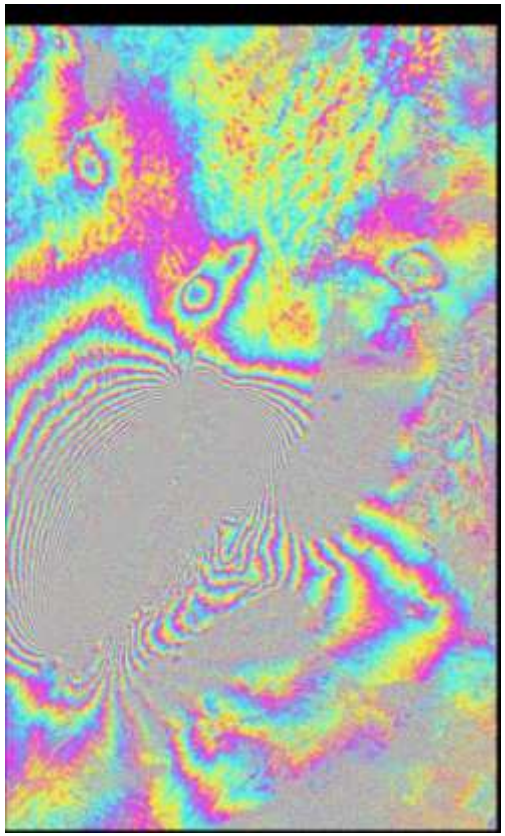
ASAR Residuals

Multiple Aperture Interferometry (MAI) – Principle

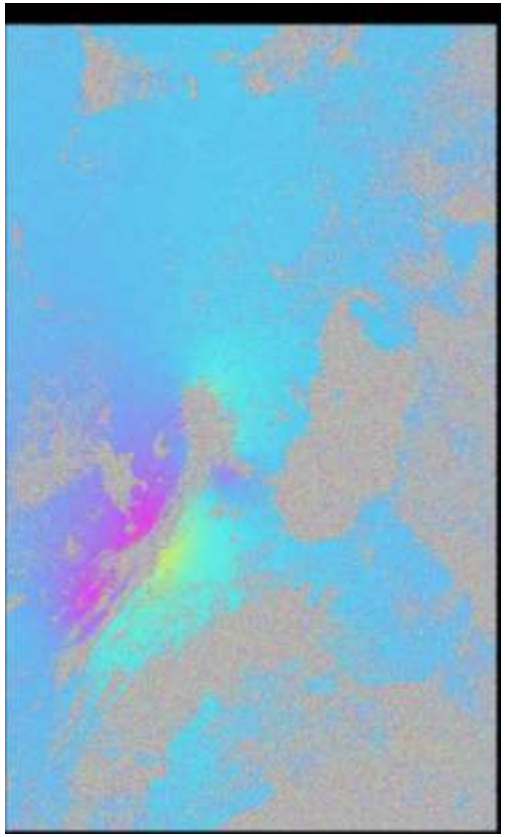


Estimating the along-track displacement component as difference from forward- and backward-looking interferograms.

Extending the displacement measurement to the azimuth direction



DInSAR
Each 2π cycle ~= 2.8 cm



MAI
Each 2π cycle ~= 5 m

Afar earthquake Ethiopia

All data have been processed using

SARscape®
The Earth Observation information gateway

SARscape - Modules

- **Basic**

  It includes a set of processing steps for the generation of SAR products based on intensity. This module is complemented by a multi-purpose tool.

  This module is complemented by:

  - **Focusing**

    It supports the focusing of ERS-1/2 SAR, JERS-1 SAR, ENVISAT ASAR and ALOS PALSAR-1 data.

  - **Gamma & Gaussian Filter**

    It includes a whole family of SAR specific filters. They are particularly efficient to reduce speckle, while preserving the radar reflectivity, the textural properties and the spatial resolution, especially in strongly textured SAR images. Developed in collaboration with Privateers.

SARscape® - Modules

- **Interferometry**
  It supports the processing of Interferometric SAR (2-pass interferometry, InSAR) and Differential Interferometric SAR (n-pass interfereometry, DInSAR) data for the generation of Digital Elevation Model, Coherence, and Land Displacement/ Deformation maps.

  This module is complemented by:
  - **ScanSAR Interferometry**
    It offers the capabilities to process InSAR and DInSAR data over large areas (400 by 400 km). Developed in collaboration with Aresys.
  - **Interferometric Stacking**
    Based on Small Baseline Subset (SBAS) and Persistent Scatterers (PS) techniques this module enables to determine displacements of individual features on the ground.
  - **Radargrammetry**
    It offers the capabilities to generate Digital Elevation Model from Stereo-SAR data.
  - **SAR Polarimetry / Polarimetric Interferometry**
    The PolSAR/PolInSAR module supports the processing of polarimetric and polarimetric interferometric SAR data.

SARscape - Modules

- **Quality Assessment Tool**

  In order to quantitatively assess the geometric, radiometric, and polarimetric quality of SAR products, a Quality Assessment Tool (QAT) based on a solid methodology is proposed. The overall architecture of the QAT system supports the quality assessment for ENVISAT ASAR (IM,AP,WS) and RADARSAT-1 and -2 (FB,SB,WB,EB,ScanSAR) data.