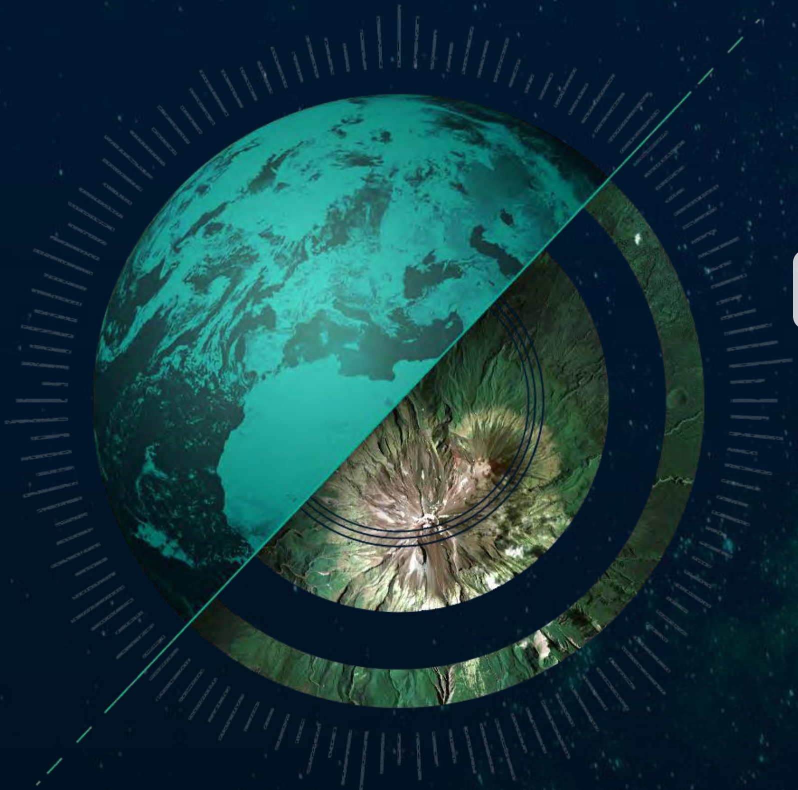
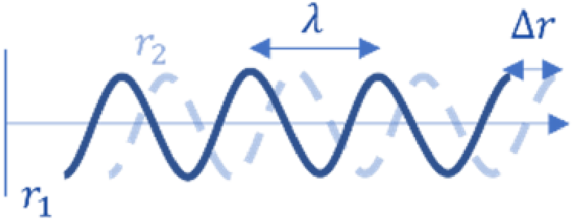


13. SAR for earthquake monitoring

SAR Interferometry (InSAR) – use of phase difference

It is all about the phase of the SAR signal...

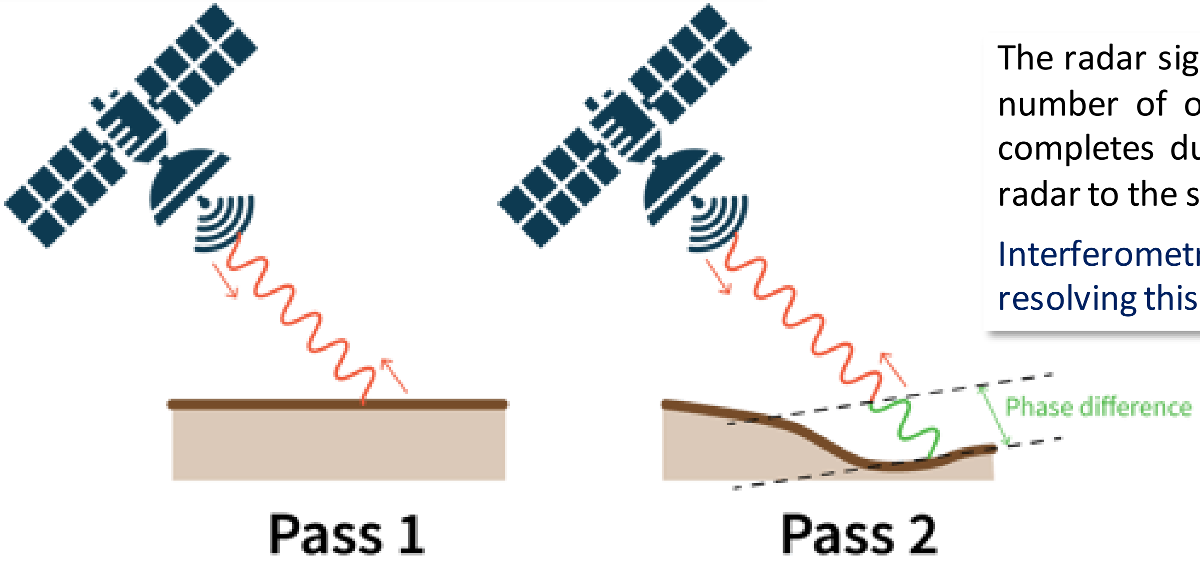
SAR Interferometry (InSAR) makes use of the phase difference between two complex valued images from different view angle, i.e. forming baseline, so that topography of the area can be imaged.



Change in phase allows detection of ground movement

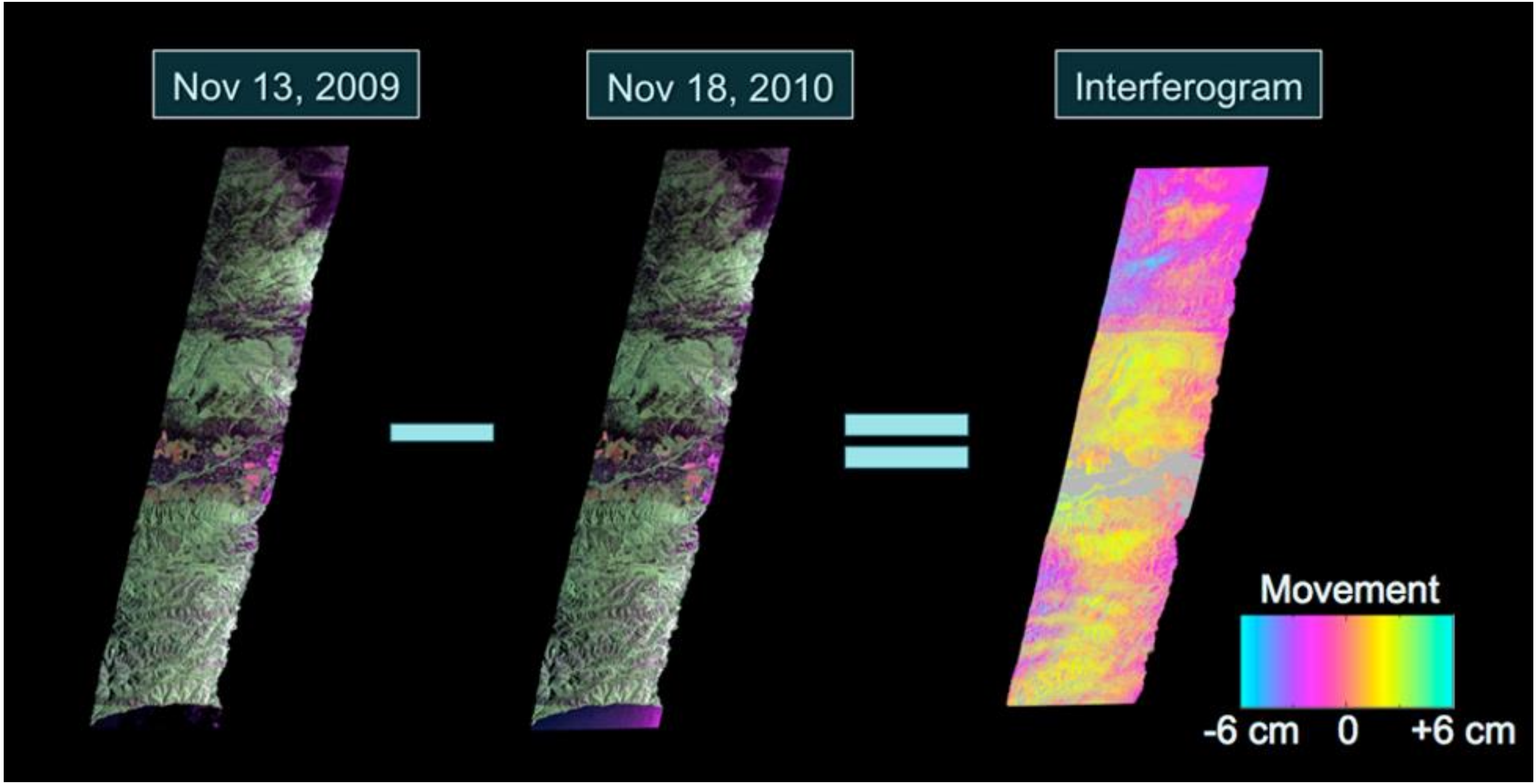
The radar signal's phase represents the number of oscillation cycles the wave completes during its journey from the radar to the surface and back.

Interferometry is the only solution for resolving this issue!



https://blog.descarteslabs.com/hs-fs/hubfs/GDS%20Blog%20series/InSAR-phase.png?width=500&name=InSAR-phase.png

SAR Interferometry (InSAR) – use of phase difference



https://nisar.jpl.nasa.gov/mission/get-to-know-sar/interferometry/

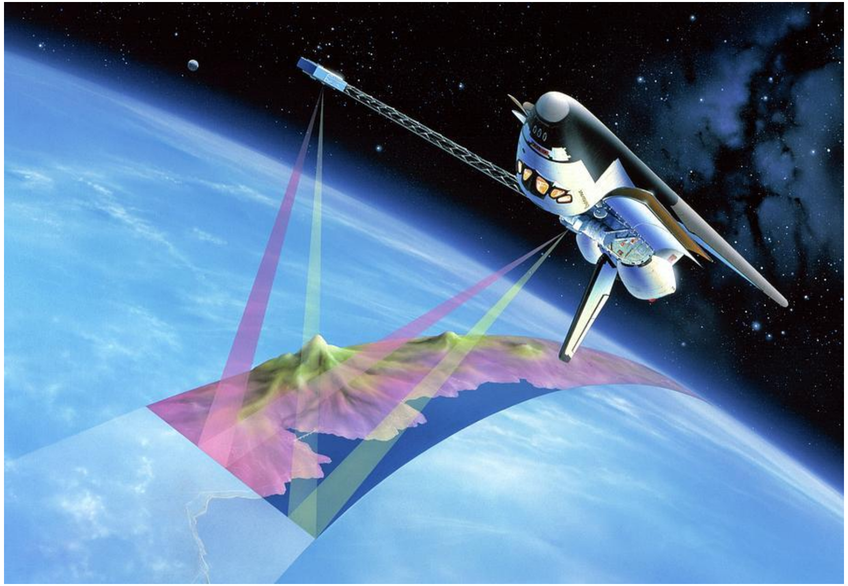
SAR Interferometry (InSAR) – applications

Topographic mapping/Cartography

- SAR interferometry played a crucial role in the 2000 Shuttle Radar Topography Mission (SRTM)

  → Updated in the 2018 release known as NASADEM

- Radar interferometry from airborne platforms is commonly employed to generate topographic maps in the form of digital elevation models (DEMs)

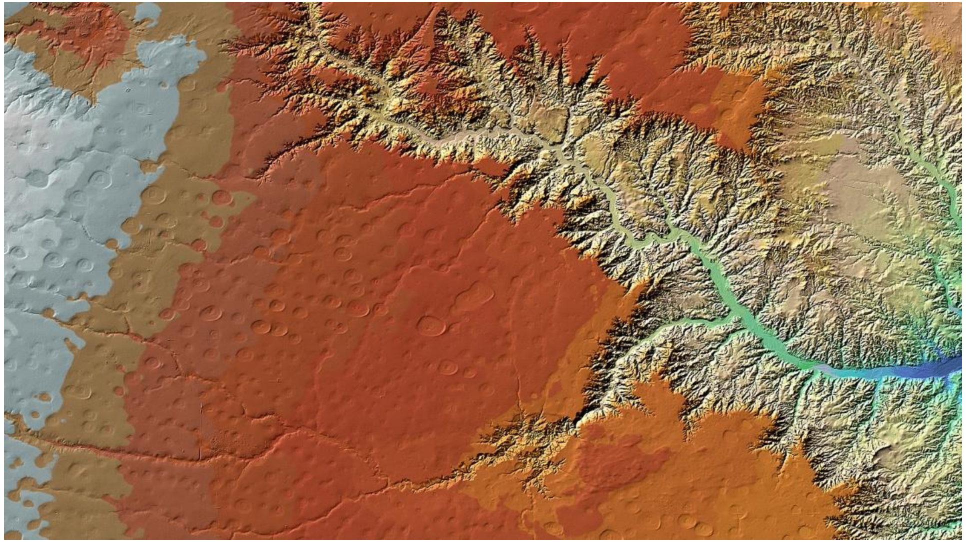


https://sciencephotogallery.com/featured/shuttle-radar-topography-mission-detlev-van-ravenswaay.html

SAR Interferometry (InSAR) – applications

Topographic mapping/Cartography

- Technology facilitates various applications enabled by topography, particularly in rapid mapping scenarios, such as:
  - land use management
  - classification
  - hazard assessment
  - urban planning
  - geology
  - hydrology



Source: https://www.dlr.de/eoc/en/desktopdefault.aspx/tabid-11930/20984_read-23316/

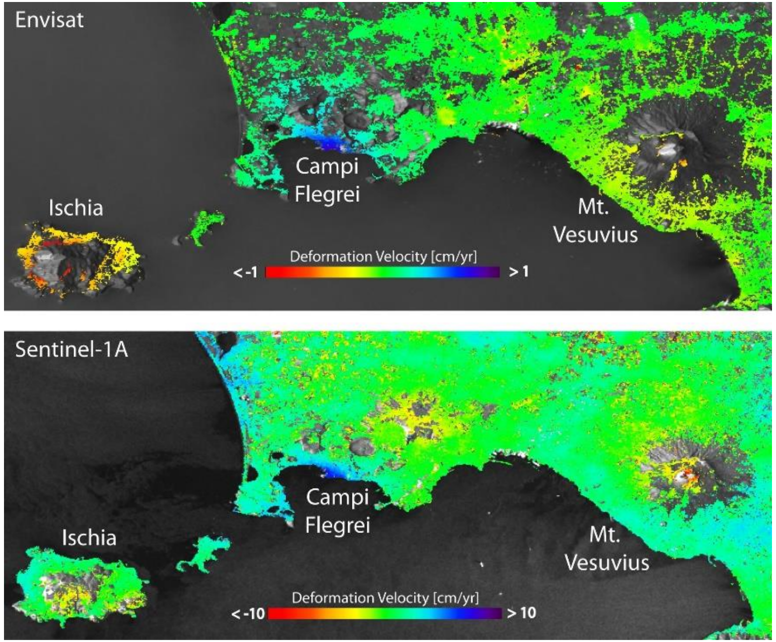
SAR Interferometry (InSAR) – applications

Deformation Mapping and Change Detection

- Repeat Pass Radar Interferometry is commonly employed to generate topographic change maps - digital displacement models (DDMs).
- Relative displacement accuracy: 0.1-1 cm
- Post spacing and resolution ranging: 10-100 m
- DDMs widths: 10-350 km

Common applications:

- Monitoring and modeling of earthquakes, volcanoes, landslides, land subsidence
- Detecting deforestation, change detection, disaster monitoring, glacier dynamics

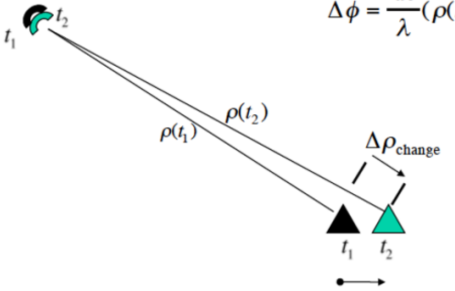


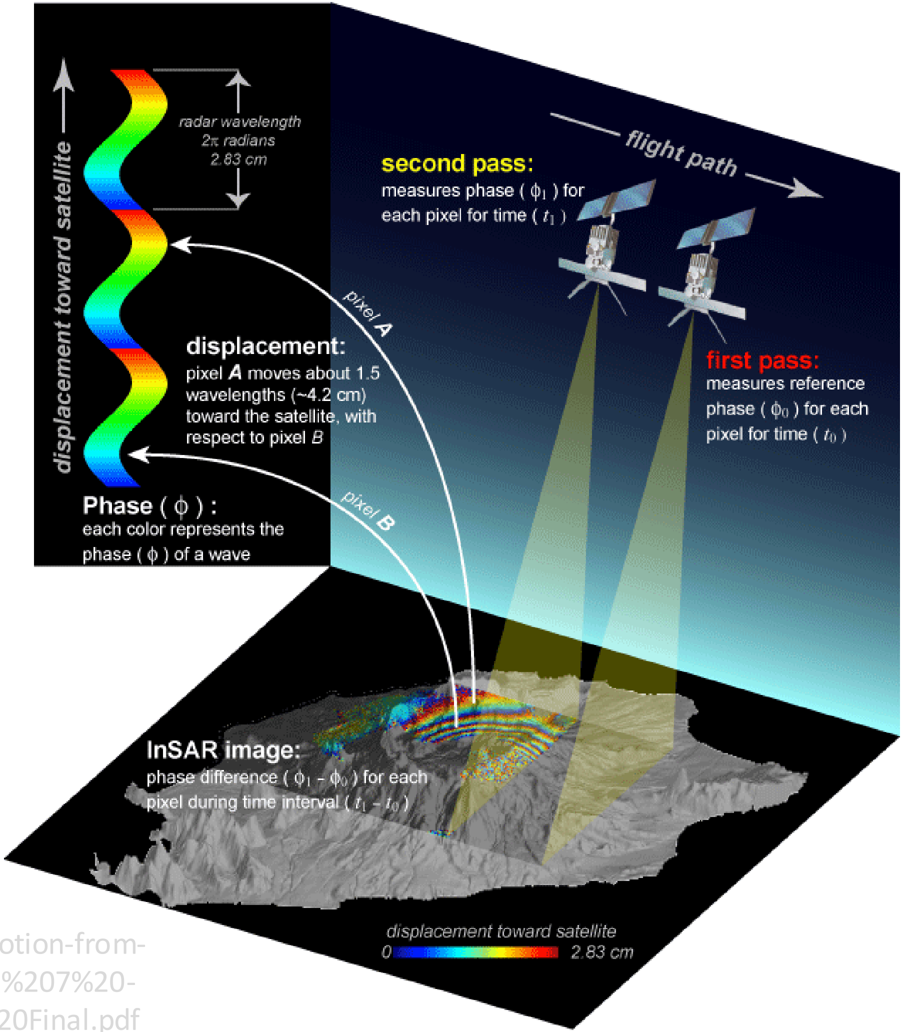
https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-1/Sentinel-1_brings_radar_remote_sensing_to_new_level

Differential Interferometry

When two observations are conducted from identical positions in space but at separate times, any alteration in the range of a surface feature is directly proportional to the interferometric phase.

$$\Delta\phi = \frac{4\pi}{\lambda}(\rho(t_1) - \rho(t_2)) = \frac{4\pi}{\lambda}\Delta\rho_{\mathrm{change}}$$

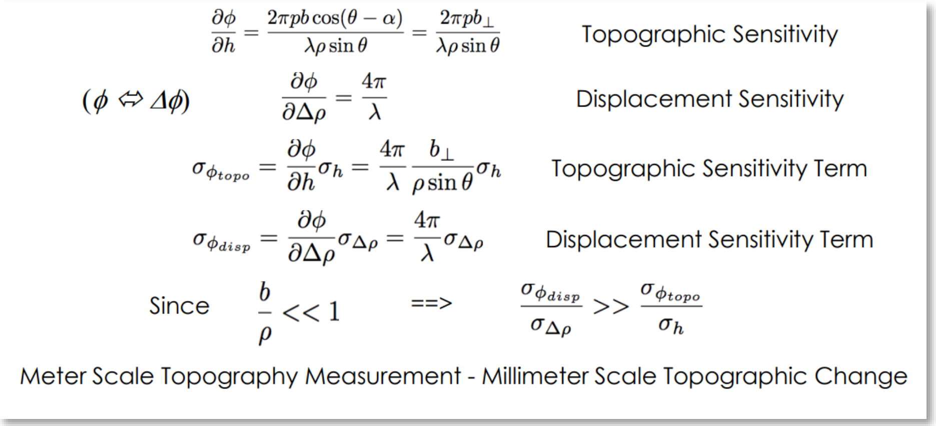




https://britgeopeople.blogspot.com/2017/01/assessing-ground-motion-from-spaceby.html, https://dges.carleton.ca/courses/IntroSAR/SECTION%207%20-%20Carleton%20SAR%20Training%20-%20InSAR%20Theory%20-%20Final.pdf

Differential Interferometry - Sensitivities

- Differential interferometry detects millimeter-level surface deformation by comparing the phase difference between two radar images acquired at different times
- Changes in the surface elevation cause a shift in the interference pattern, which is reflected in the phase of the radar signal
- By analyzing these phase differences, even subtle surface deformations on the order of millimeters can be detected and measured.



$$\frac{\partial \phi}{\partial h} = \frac{2\pi p b \cos(\theta - \alpha)}{\lambda \rho \sin\theta} = \frac{2\pi p b_\perp}{\lambda \rho \sin\theta}$$ Topographic Sensitivity

$(\phi \Leftrightarrow \Delta\phi)$ $$\frac{\partial \phi}{\partial \Delta\rho} = \frac{4\pi}{\lambda}$$ Displacement Sensitivity

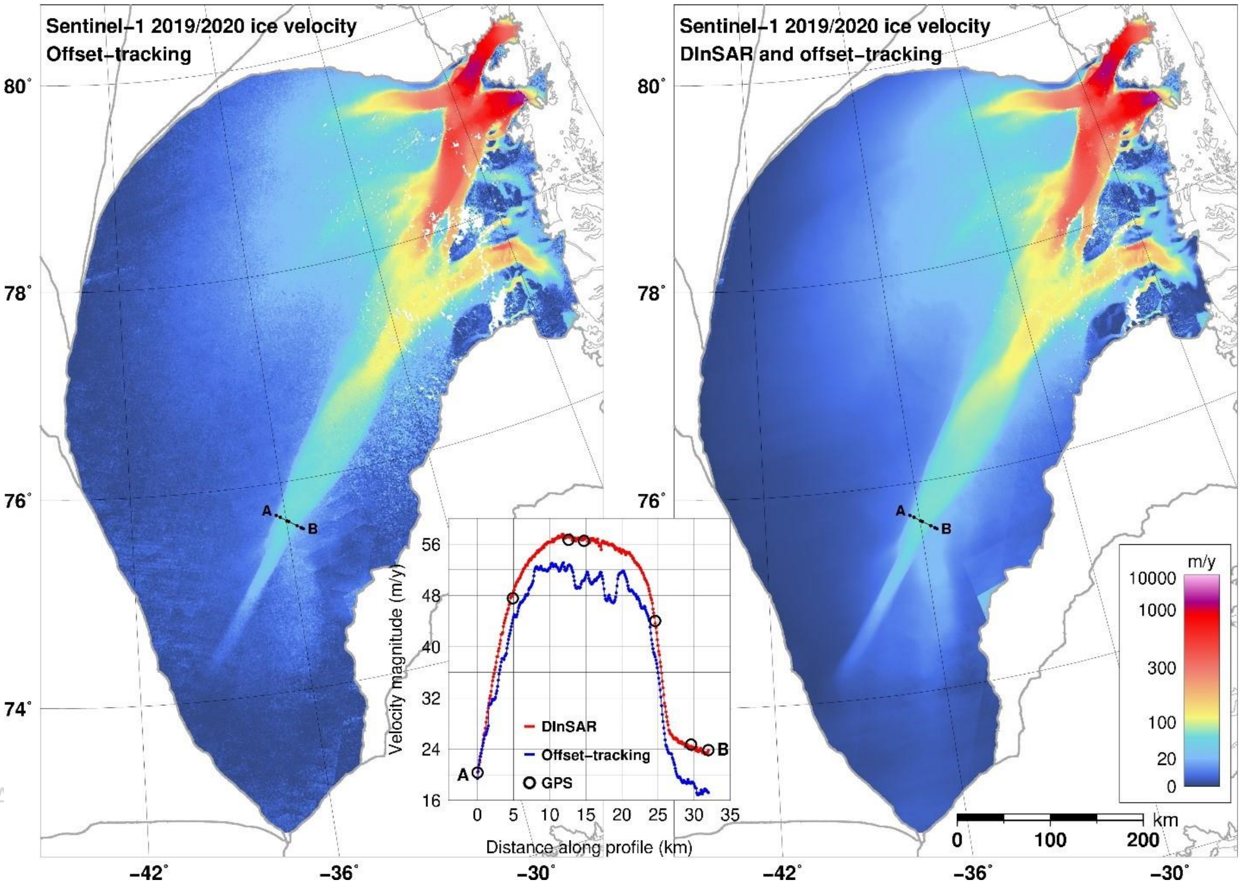
$$\sigma_{\phi_{topo}} = \frac{\partial \phi}{\partial h}\sigma_h = \frac{4\pi}{\lambda}\frac{b_\perp}{\rho \sin\theta}\sigma_h$$ Topographic Sensitivity Term

$$\sigma_{\phi_{disp}} = \frac{\partial \phi}{\partial \Delta\rho}\sigma_{\Delta\rho} = \frac{4\pi}{\lambda}\sigma_{\Delta\rho}$$ Displacement Sensitivity Term

Since $\frac{b}{\rho} << 1$ ==> $\frac{\sigma_{\phi_{disp}}}{\sigma_{\Delta\rho}} >> \frac{\sigma_{\phi_{topo}}}{\sigma_h}$

Meter Scale Topography Measurement - Millimeter Scale Topographic Change

Differential Interferometry - Sensitivities



https://eo4society.esa.int/wp-content/uploads/2021/05/icevelocity1.jpg

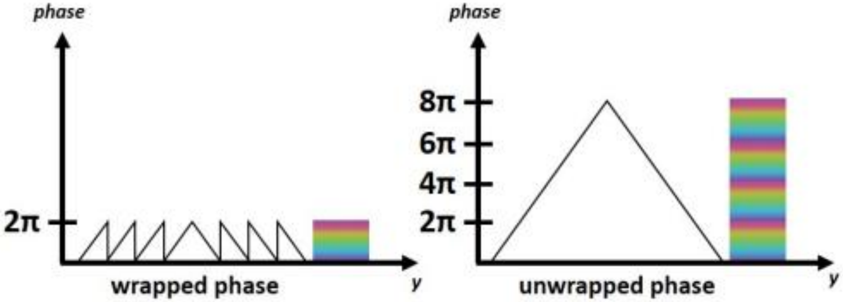
Phase unwrapping

- In order to correlate the interferometric phase with topographic height, the phase must undergo an unwrapping process
- Then, the proper 2p phase “ambiguity” must be determined
- The altitude of ambiguity refers to the altitude difference that causes a change in the interferometric phase
- Phase unwrapping resolves this ambiguity by integrating the phase difference between adjacent pixels

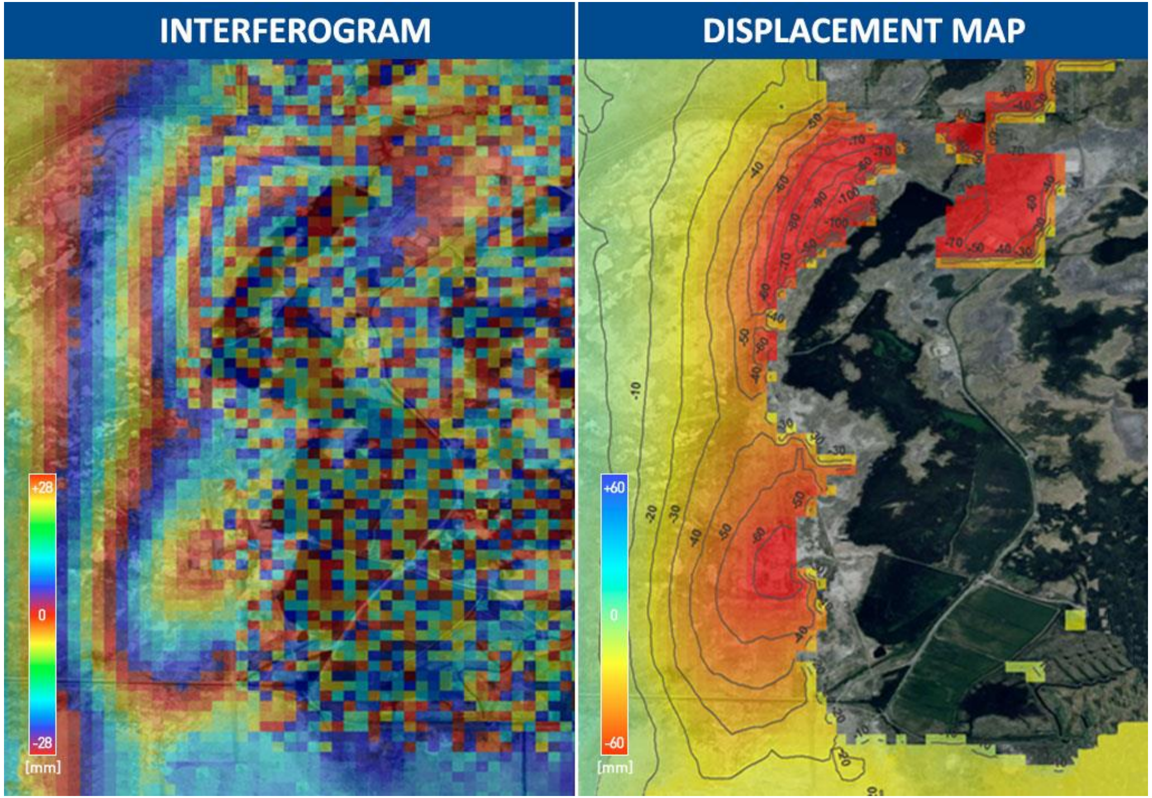
$$\Delta\phi_{topo} = \frac{2\pi p}{\lambda}\left(\rho_1 - \rho_2\right) = \frac{2\pi p}{\lambda}\vec{b} \bullet \vec{l}$$

$$\Delta\phi_{meas} = \mathrm{mod}\left(\Delta\phi_{topo}, 2\pi\right)$$

$$\Delta\phi_{unwrap}(s,\rho) = \Delta\phi_{topo}(s,\rho) + \Delta\phi_{const}$$



Phase unwrapping



https://site.tre-altamira.com/insar/

- Consequently, unwrapped results should be interpreted as relative height or displacement between pixels in two images.

Correlation Theory

Decorrelation

- InSAR signals decorrelate = become incoherent due to noise, scattering, rotation of viewing geometry, random motions over time
- Relates to the local phase standard deviation of the interferogram phase and affects:

  - height and displacement accuracy
  - ability to unwrap phase
- Correlation effects are multiplicative, unlike phase effects, which are additive
- When there is low coherence or decorrelation for any reason, it leads to a loss of information in that area.

$\gamma = \gamma_v \gamma_g \gamma_t \gamma_c$

where

γ_v is volumetric (trees)

γ_g is geometric (steep slopes)

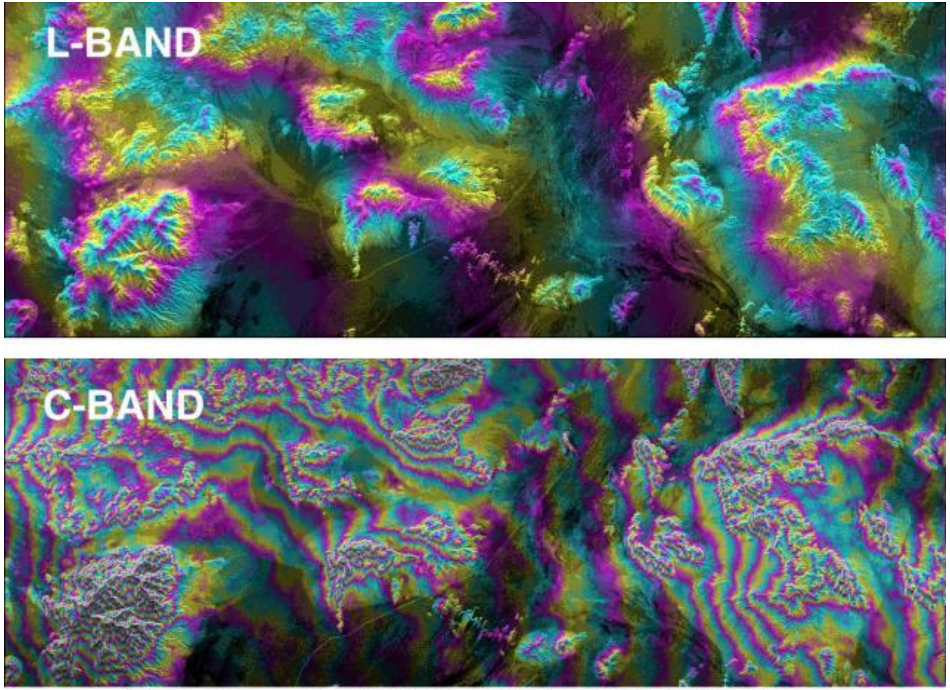
γ_t is temporal (gradual changes)

γ_c is sudden changes

Coherent Change Detection

SIR-C L and C-band Interferometry

- Simultaneous C and L band
- InSAR experiments have shown good correlation at L-band

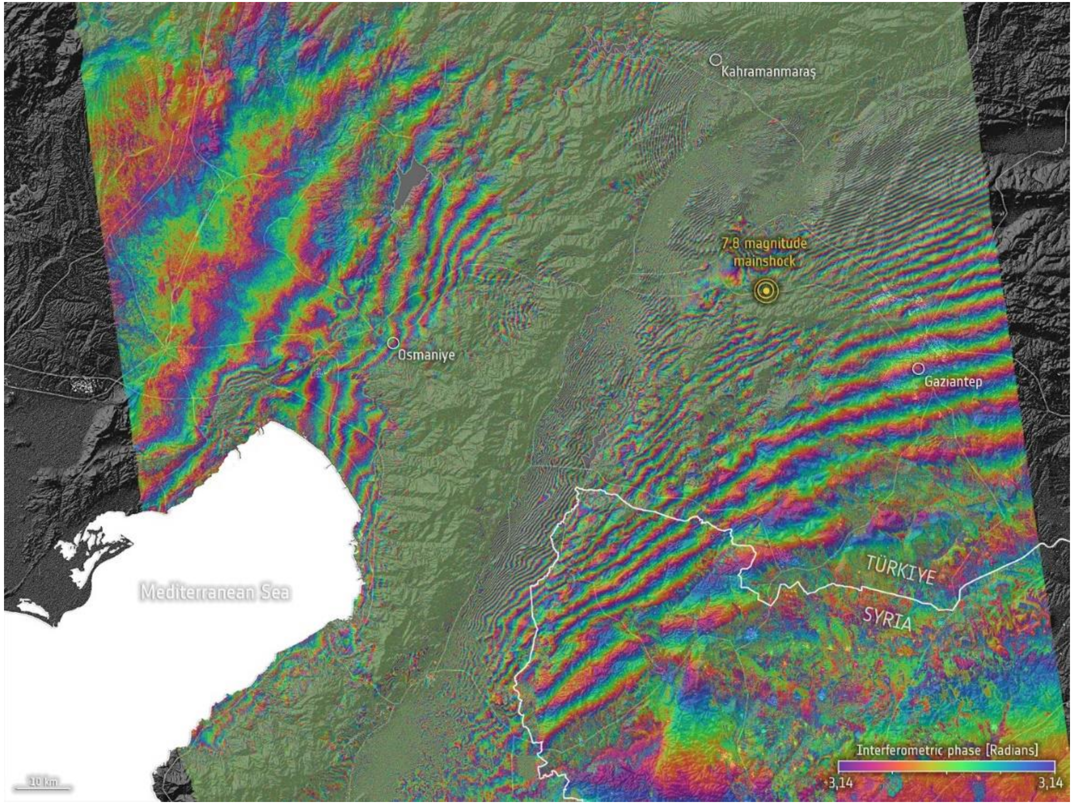


SIR-C L, C BAND INTERFEROGRAMS
FT. IRWIN, CALIFORNIA

https://upload.wikimedia.org/wikipedia/commons/3/32/L_C_band_topo_interferograms.jpg

Applications

Türkiye–Syria interferogram

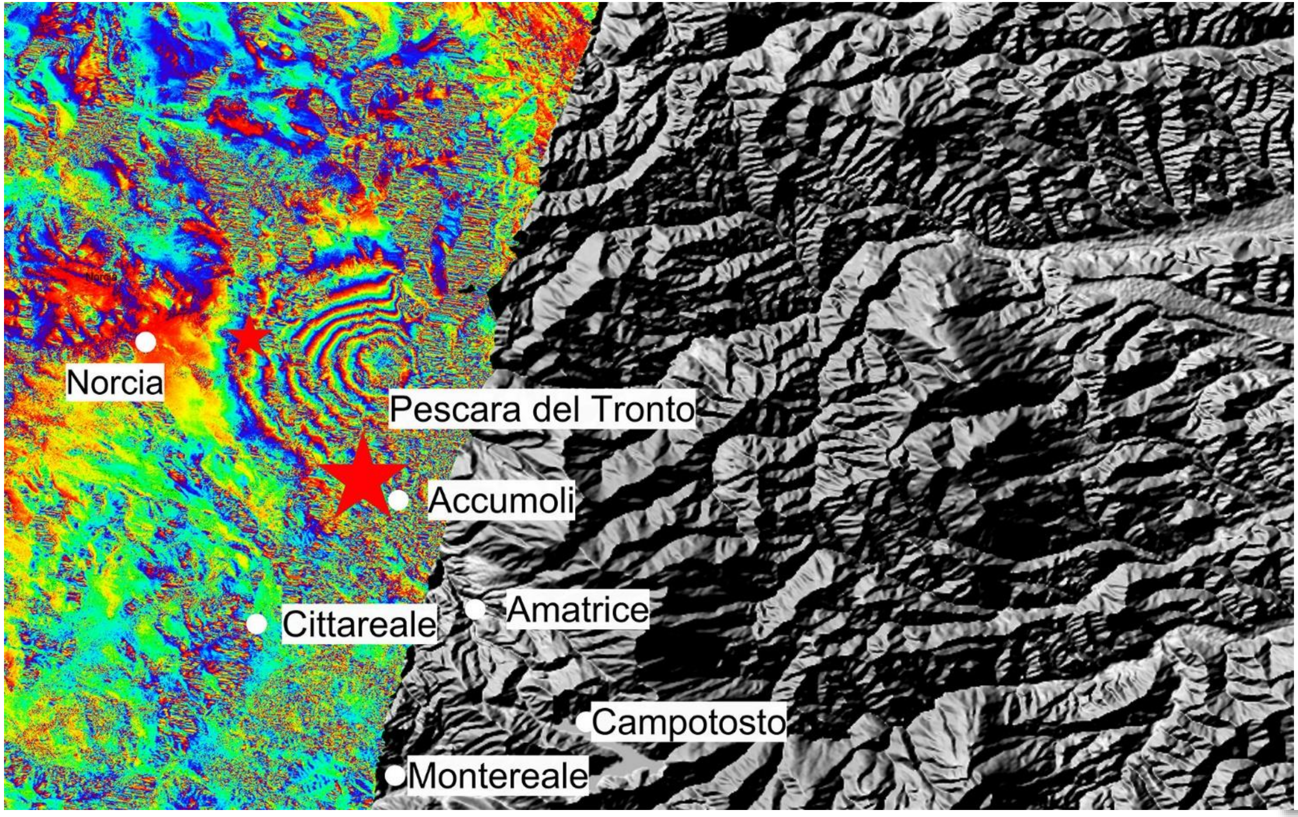


Interferogram showing the coseismic surface displacement in the area near Gaziantep, generated from multiple Copernicus Sentinel-1 scans – before and after the earthquakes.

Source:https://www.esa.int/ESA_Multimedia/Images/2023/02/Tuerkiye_Syria_interferogram

Applications

Italy earthquake displacement



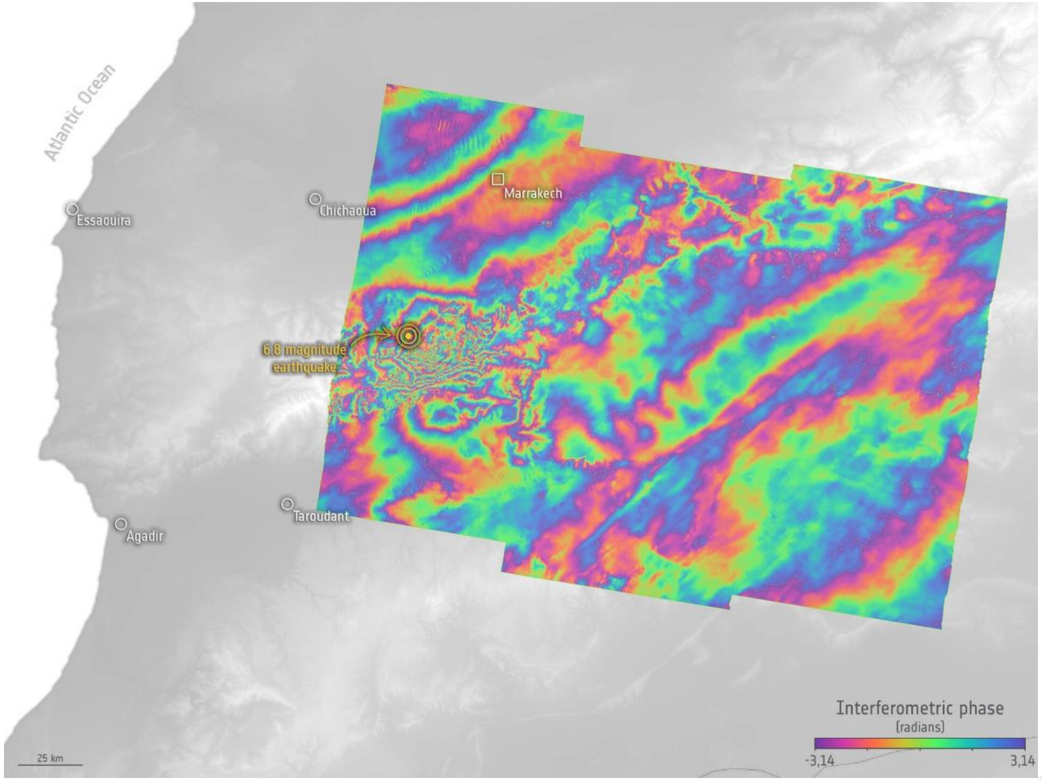
Combining two Sentinel-1 radar scans from 20 August (Sentinel-1B) and 26 August 2016 (Sentinel-1A), this interferogram shows changes that occurred during the 24 August earthquake that struck central Italy.

The seven interferometric ‘fringes’ correspond to about 20 cm of surface deformation in the radar sensor line of sight. Each fringe (which is associated to a colour cycle) corresponds to approximately 2.8 cm of displacement.

CREDIT: Contains modified Copernicus Sentinel data (2016)/ESA/ CNR-IREA

Applications

Morocco earthquake fringes

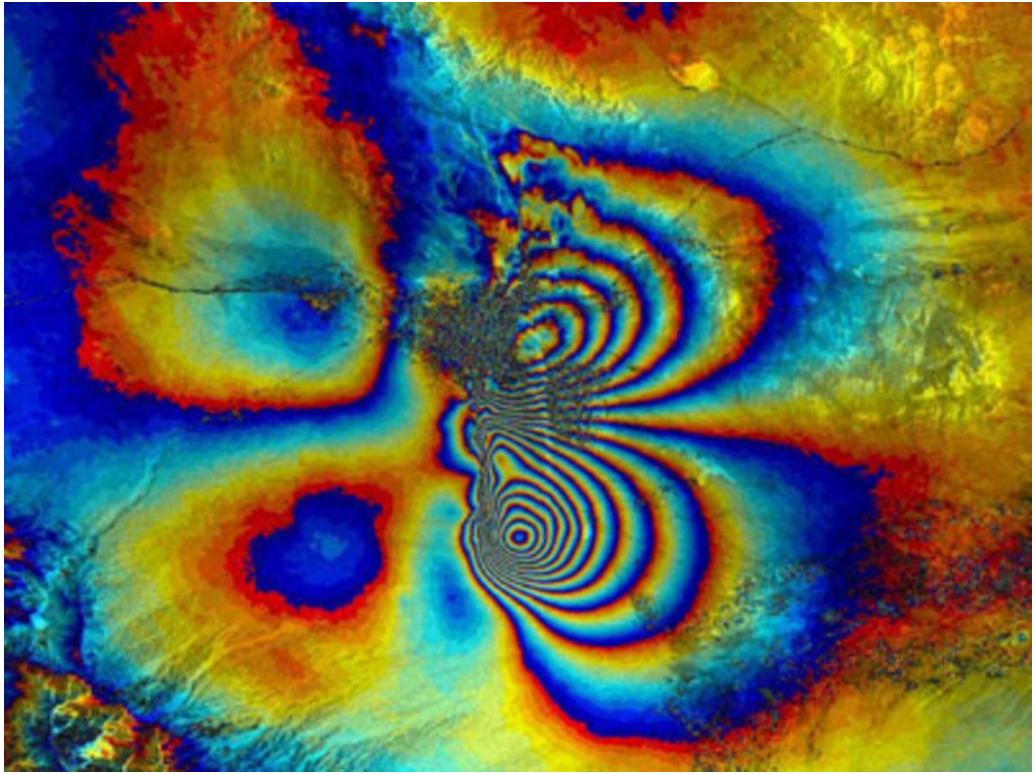


Following the devastating earthquake that struck Morocco on 8 September 2023, radar measurements from Europe's Copernicus Sentinel-1 satellite mission are being used to analyse how the ground has shifted as a result of the quake. This will not only help in planning the eventual reconstruction but will also further scientific research into the effects of earthquakes. Sentinel-1 acquisitions from 30 August 2023 and 11 September were combined to produce this interferogram, the coloured fringe pattern shows surface displacement.

•**CREDIT**: contains modified Copernicus Sentinel data (2023), processed by Aristotle University of Thessaloniki and the DIAPASON InSAR service of CNES integrated by TRE Altamira on the Geohazard Exploitation Platform GEP/ESA

Applications

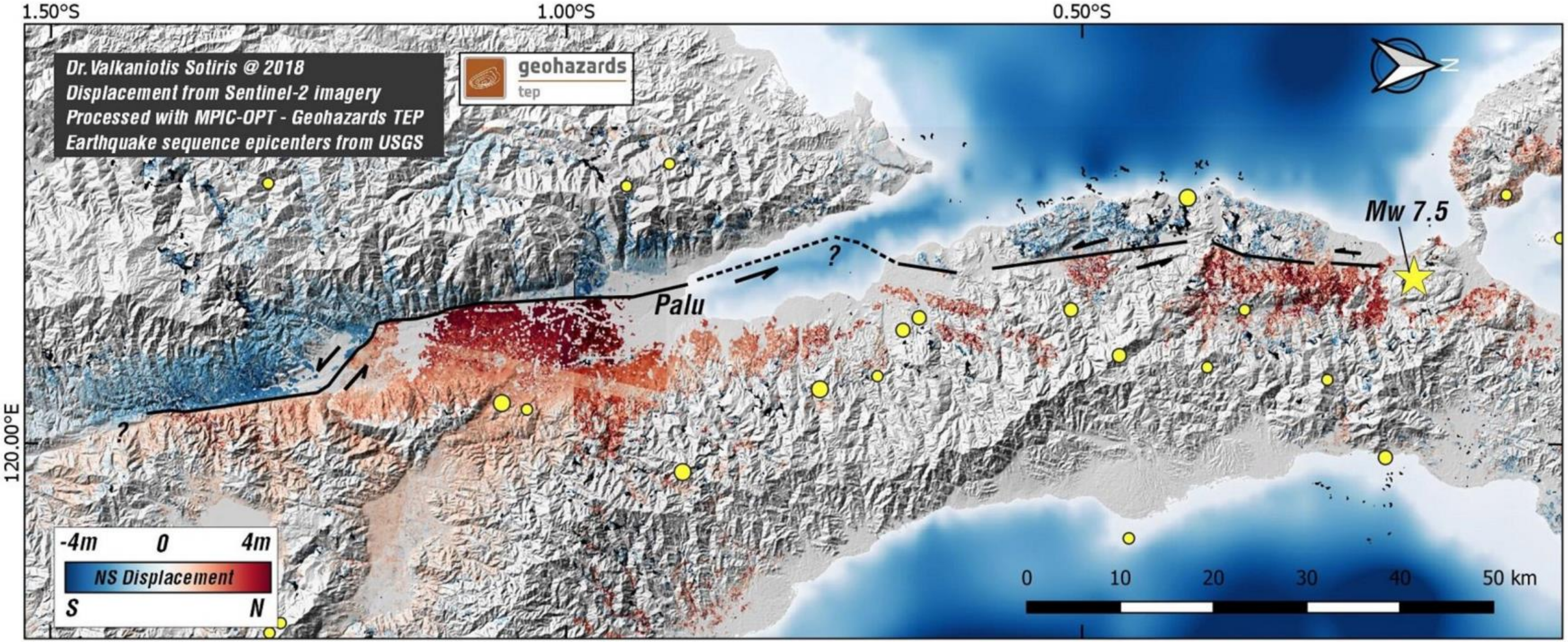
Interferogram of Bam earthquake



This interferogram, created by using Envisat's Advanced Synthetic Aperture Radar (ASAR) data, shows ground motion associated with the 26 December 2003 earthquake at Bam in Iran. CREDIT: Polimi/Poliba

Applications

Indonesia earthquake displacement map

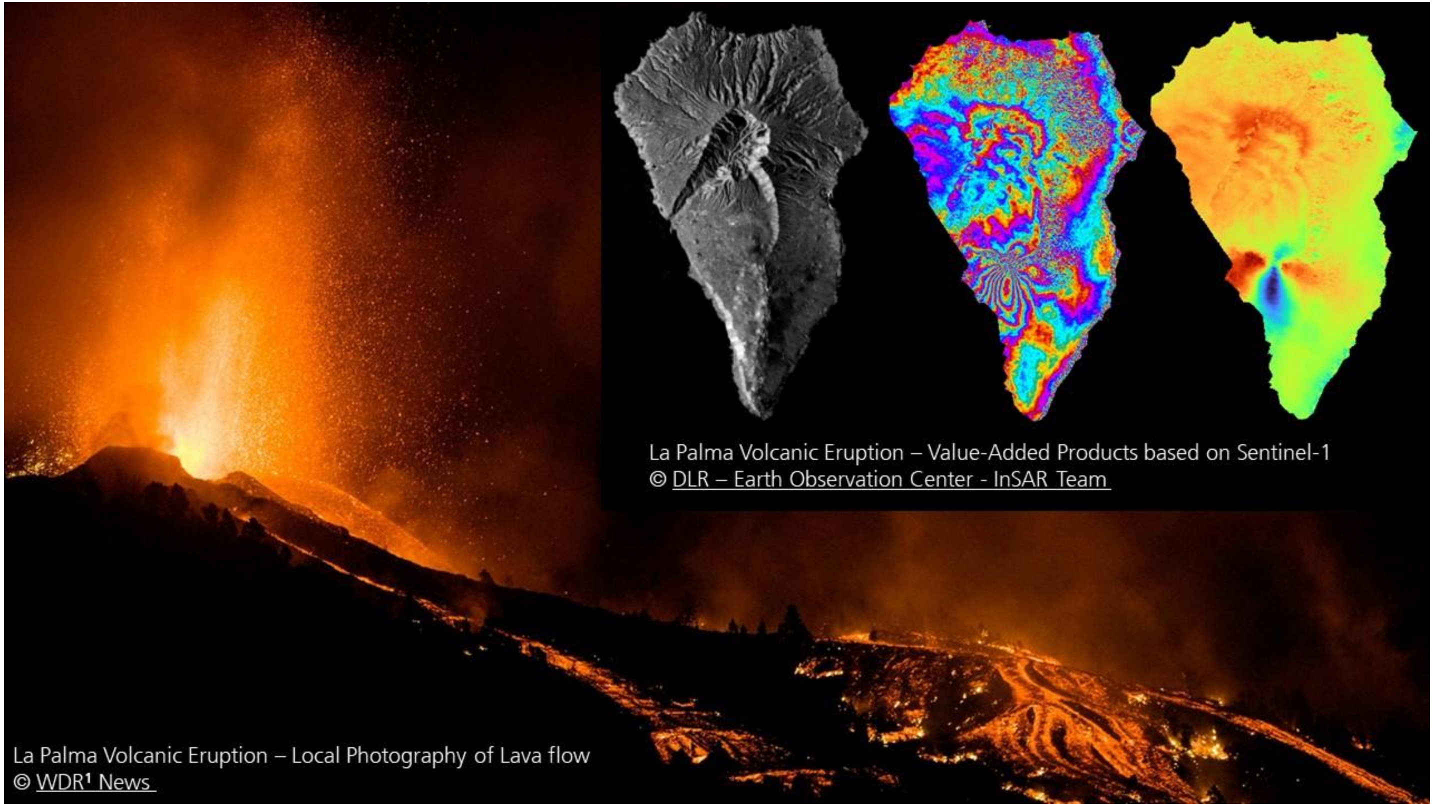


Thematic experts from the Corinth Rift Laboratory in Greece have generated a displacement map using Copernicus Sentinel-2 acquisitions from 17 September and 2 October, showing the impact of the 7.5-magnitude earthquake that hit Indonesia on 28 September 2018. The earthquake and subsequent tsunami have destroyed homes and are thought to have claimed at least 1400 lives according to the most recent reports. It has been estimated that up to 1.5 million people will be affected by these events.

CREDIT: Contains modified Copernicus Sentinel data (2018), processed by the Corinth Rift Laboratory

Applications

Volcano monitoring



La Palma Volcanic Eruption – Value-Added Products based on Sentinel-1
© DLR – Earth Observation Center - InSAR Team

La Palma Volcanic Eruption – Local Photography of Lava flow
© WDR¹ News

https://www.esa.int/gsp/ACT/images/coffee/SCAnsari.jpg

Thank you for the attention