esa space solutions

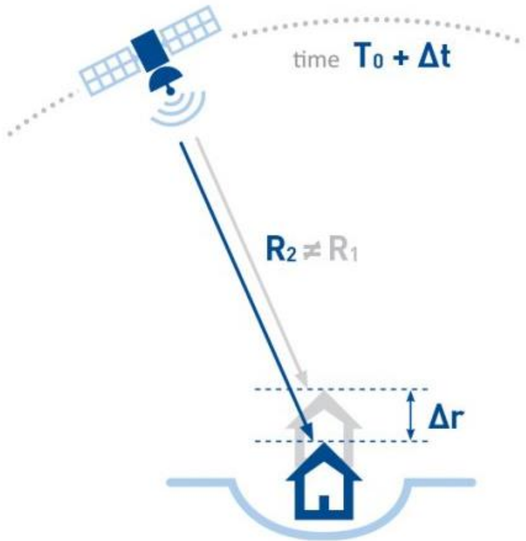
Copernicus Academy

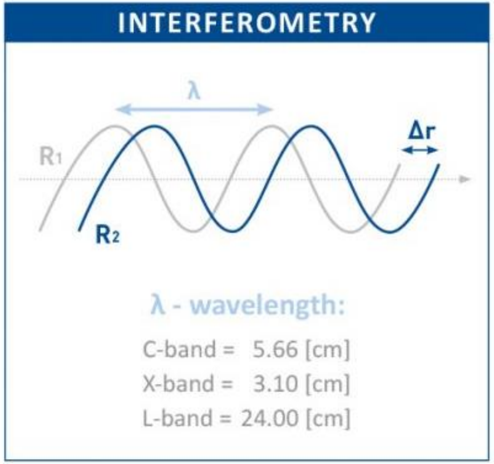
ÚSTAV GEOGRAFIE
Prírodovedecká fakulta UPJŠ v Košiciach

12. SAR for land subsidence

SAR Interferometry (InSAR) – use of phase for change detection

Interferometric Synthetic Aperture Radar (InSAR) also known as SAR Interferometry, is the measurement of signal phase change between two images acquired over the same area at different time. When a point on the ground moves, it alters the distance between the sensor and the point, resulting in a change in the signal phase.





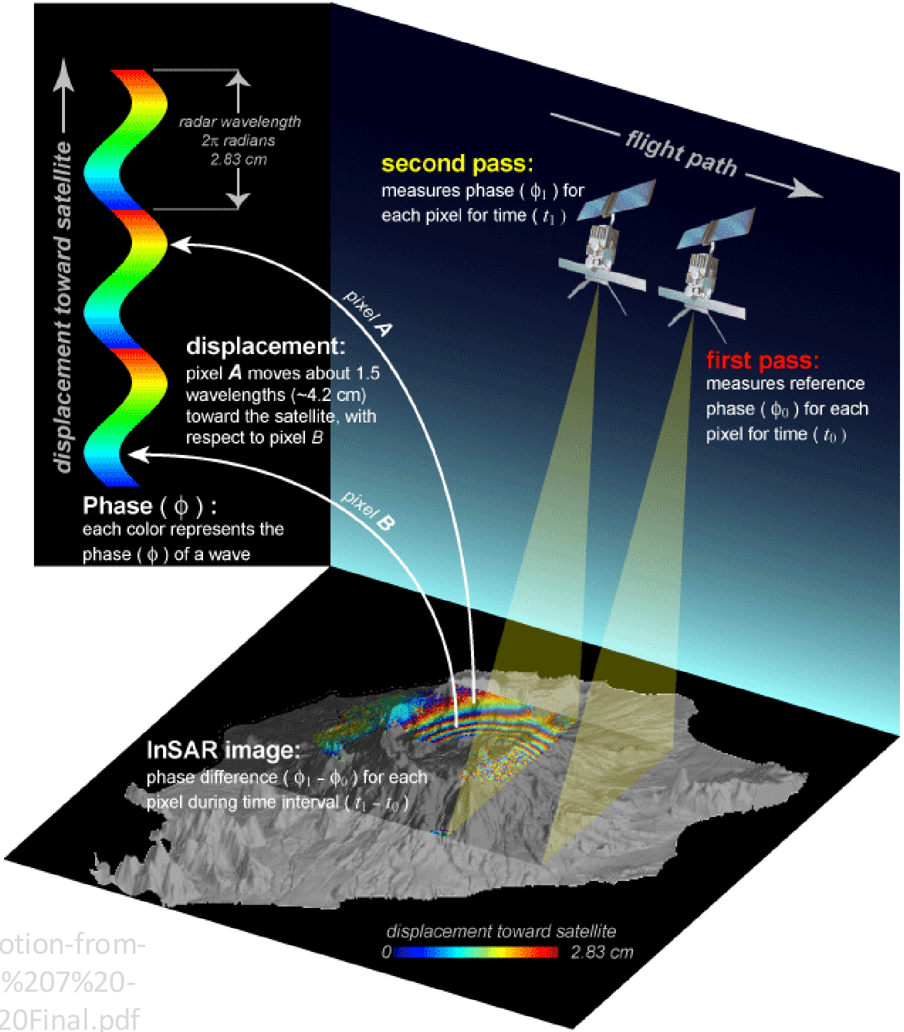
The radar signal's phase represents the number of oscillation cycles the wave completes during its journey from the radar to the surface and back.

Interferometry is the only solution for resolving this issue!

https://site.tre-altamira.com/company/our-technology/

Differential Interferometry

- Differential Interferometry or DInSAR is a intererometric technique in which topographic effects are compensated by using a Digital Elevation Model (DEM)
- Small surface deformations in the Earth's surface, such as subsidence, uplift, or deformation, can be detected with high precision, sometimes down to the millimeter level
- Particularly useful for monitoring ground movements caused by natural phenomena like earthquakes, landslides, or human activities such as mining or groundwater extraction.



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

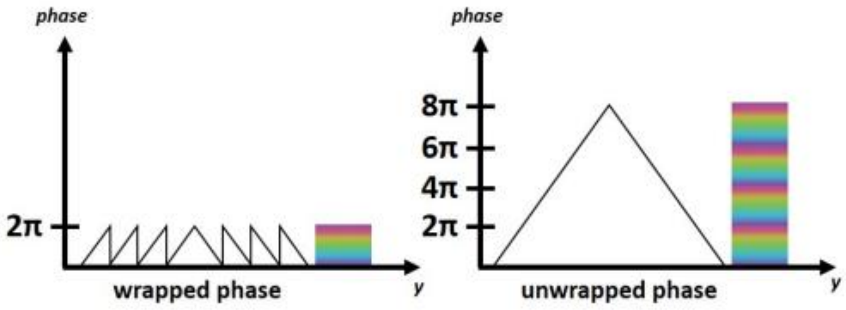
Phase unwrapping

- 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

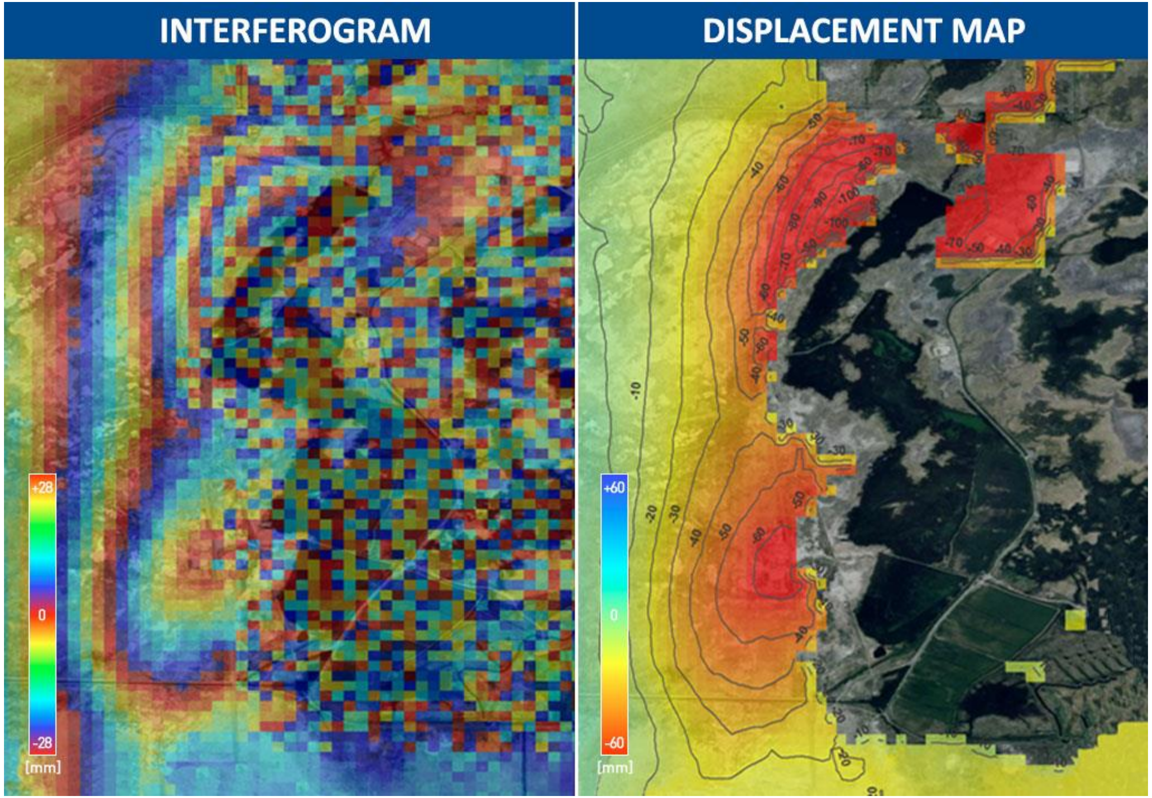
$$\Delta\phi_{topo} = \frac{2\pi p}{\lambda}\left(\rho_1 - \rho_2\right) = \frac{2\pi p}{\lambda}\vec{b} \bullet \vec{l}$$

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

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



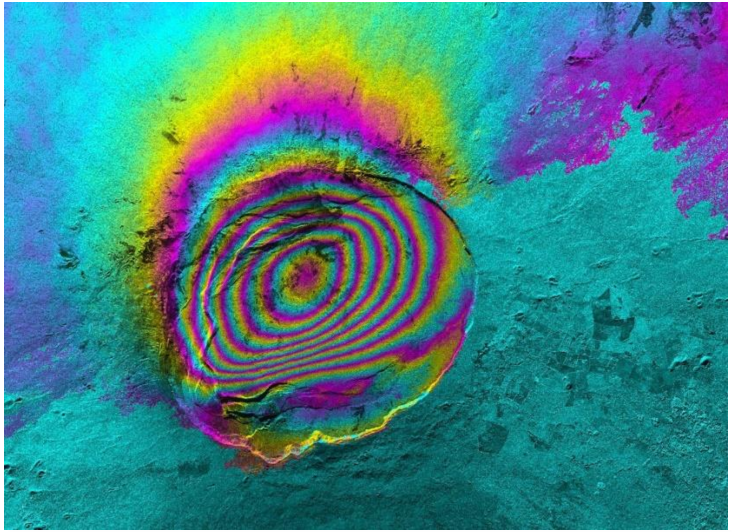
Phase unwrapping



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

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

Interferogram



One cycle of color represents one cycle of relative phase.

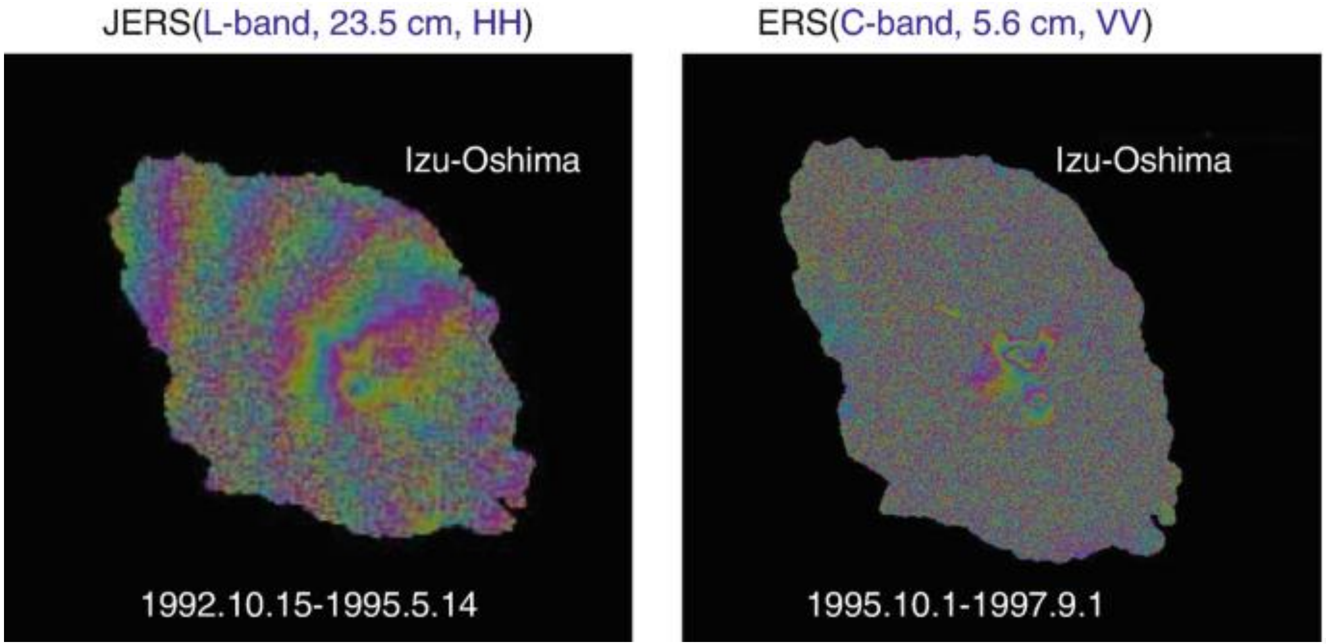
https://nisar.jpl.nasa.gov/mission/get-to-know-sar/interferometry/

- The SAR interferogram is created by multiplying each pixel of the first SAR image with the complex conjugate of the corresponding pixel in the second image
- Consequently, the amplitude of the interferogram is determined by the product of the amplitudes of the two images, while its phase, represents the difference in phase between the two images. This phase difference is caused by variations in path length due to differences in elevation, motion, or deformation.
- The resulting interference pattern, referred to as FRINGE, is represented within the range of [-π , π].

Coherent Change Detection

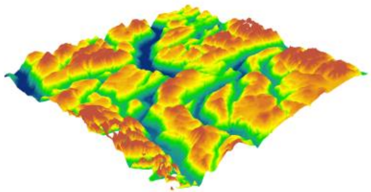
SIR-C L and C-band Interferometry

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

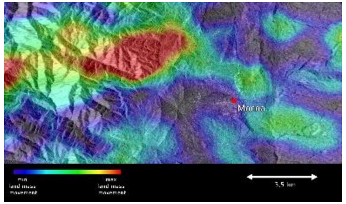


https://media.springernature.com/lw685/springer-static/image/prt%3A978-3-030-58631-7%2F17/MediaObjects/978-3-030-58631-7_17_Part_Fig7-97_HTML.png

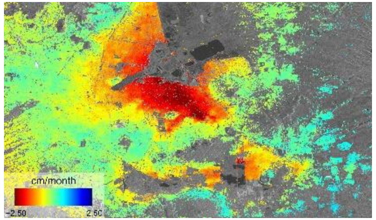
Applications of InSAR



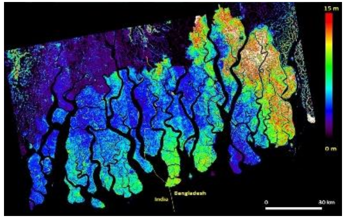
DEM generation



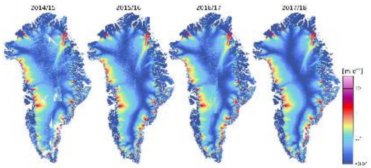
Land surface



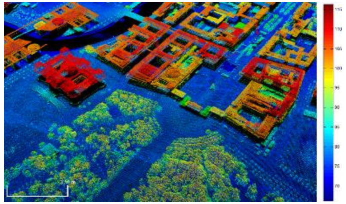
Crustal deformation



Forest monitoring



Cryosphere

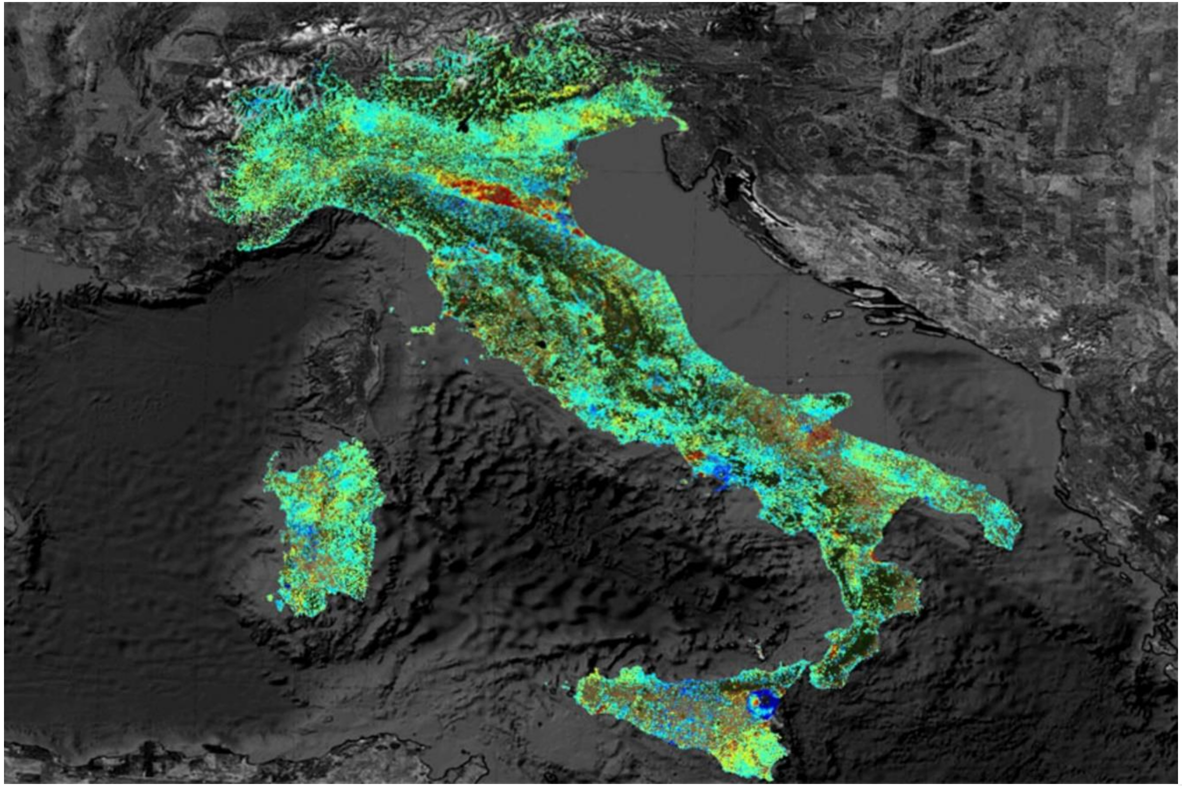


SAR Tomography

https://gisgeography.com/free-global-dem-data-sources/, https://www.esa.int/ESA_Multimedia/Images/2014/12/Mexico_City_subsidence, https://www.esa.int/ESA_Multimedia/Images/2019/07/Ice_velocity_maps_of_Greenland, https://www.esa.int/ESA_Multimedia/Images/2017/04/Sentinel-1_sees_Mocoa_landslide, https://www.esa.int/Applications/Observing_the_Earth/Mapping_forest_structure_from_space

Applications of InSAR

Subsidence of Italy

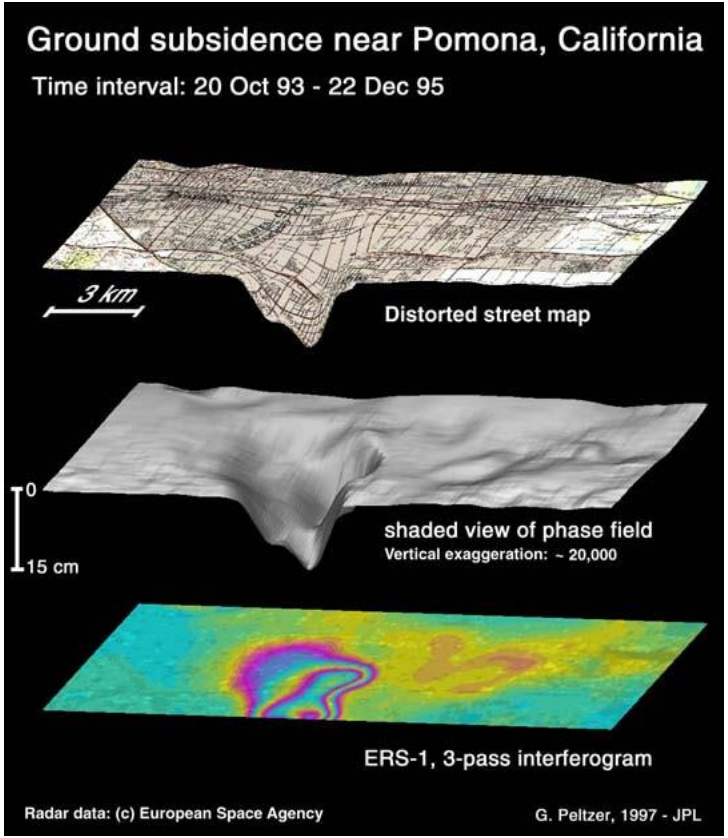


With advances in the methods of interferometry, subsidence of entire countries can now be mapped. This image shows the average displacement rates over millions of permanent scatterers identified over Italy using data from ESA's ERS missions (1992–2001). The project was financed by the Italian Ministry of the Environment and carried out by e-GEOS, TRE and Compulab.

CREDIT: Tele-Rilevamento Europa (TRE)

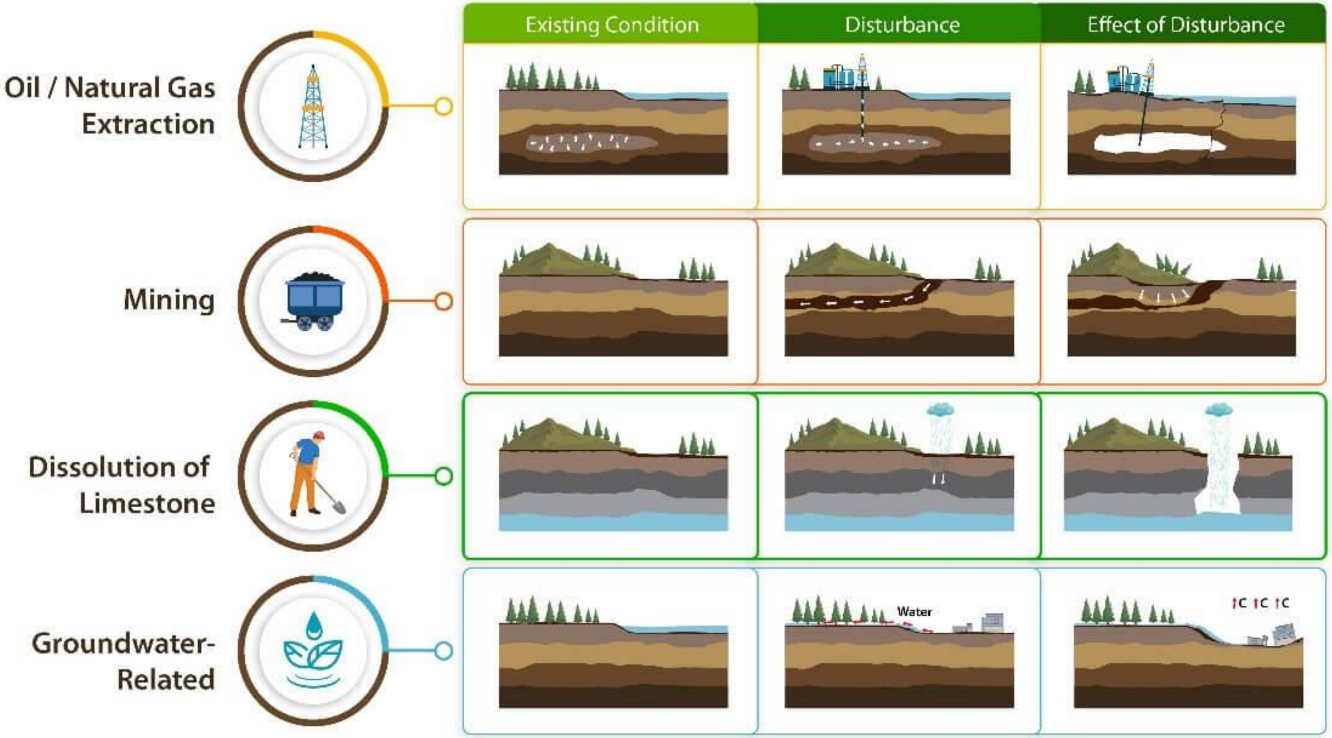
Crustal deformation

- Gradual changes in the Earth's crust over time, typically caused by:
  - natural processes - tectonic plate movements, earthquakes, volcanic activity
  - human-induced activities: mining or groundwater extraction
- Displacements of the Earth's surface: including uplift, subsidence, faulting, folding, or other
- Key indicator to understand the dynamic processes occurring beneath the Earth's surface and to assess the potential for seismic hazards



Crustal deformation

Landslip and land subsidence

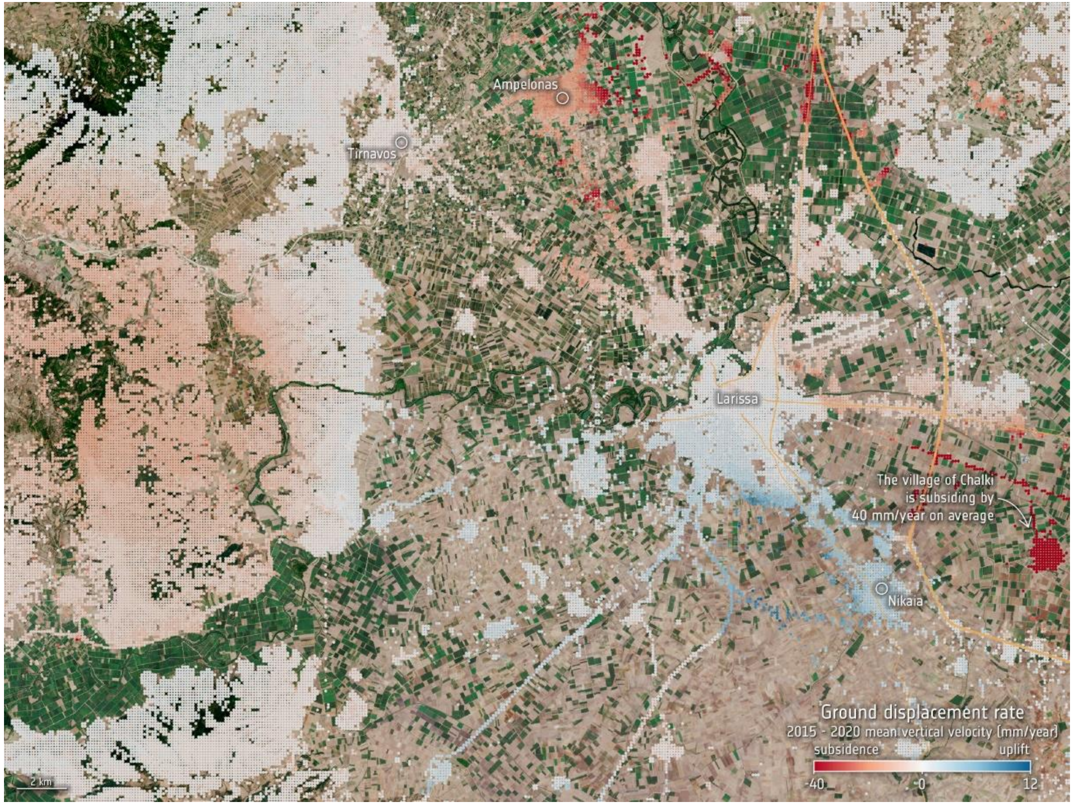


Downward movement of soil or sinking of the land from its previous level

https://spacegen.guru/landslip-and-land-subsidence/

SAR for Land Subsidence - Applications

Monitoring of groundwater extraction



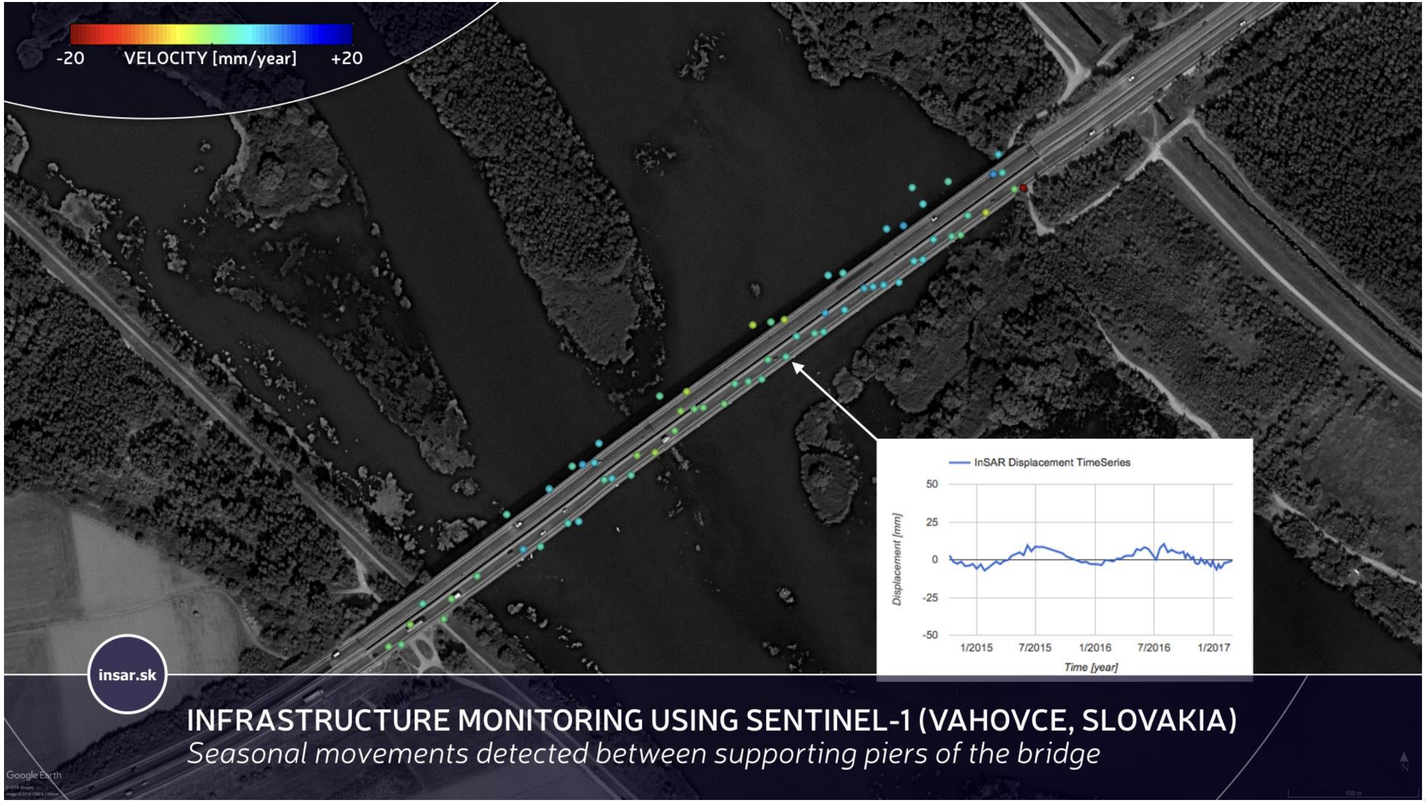
Larissa's ups and downs

For example, this image shows the rate of ground displacement between 2015 and 2020 in and around Larissa, the capital of the Thessaly region in Greece. While the southern outskirts of Larissa experience some uplift, the village of Chalki to the southeast subsided by an average of 40 mm a year, largely as a result of groundwater extraction. Ampelonas to the northwest also experienced subsidence.

CREDIT: contains modified Copernicus Sentinel data (2015–2020), processed by EGMS/ESA

SAR for Land Subsidence - Applications

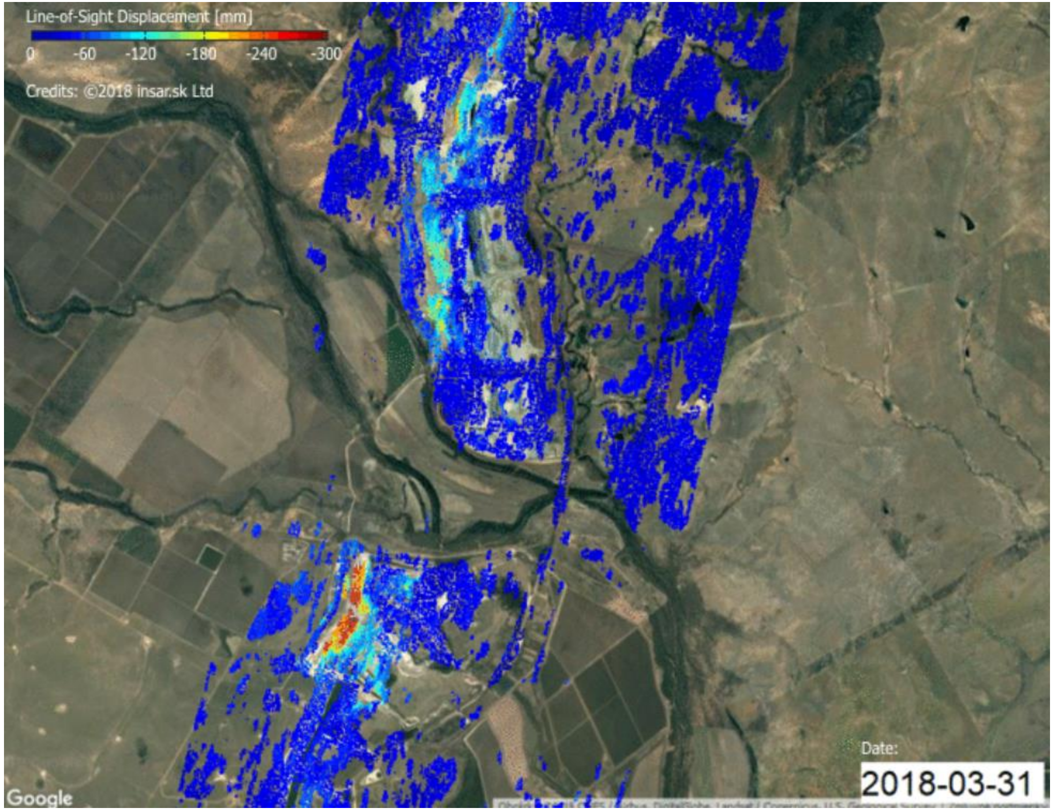
Infrastructure monitoring



https://insar.space/projects/

SAR for Land Subsidence - Applications

Monitoring of coal mining activity



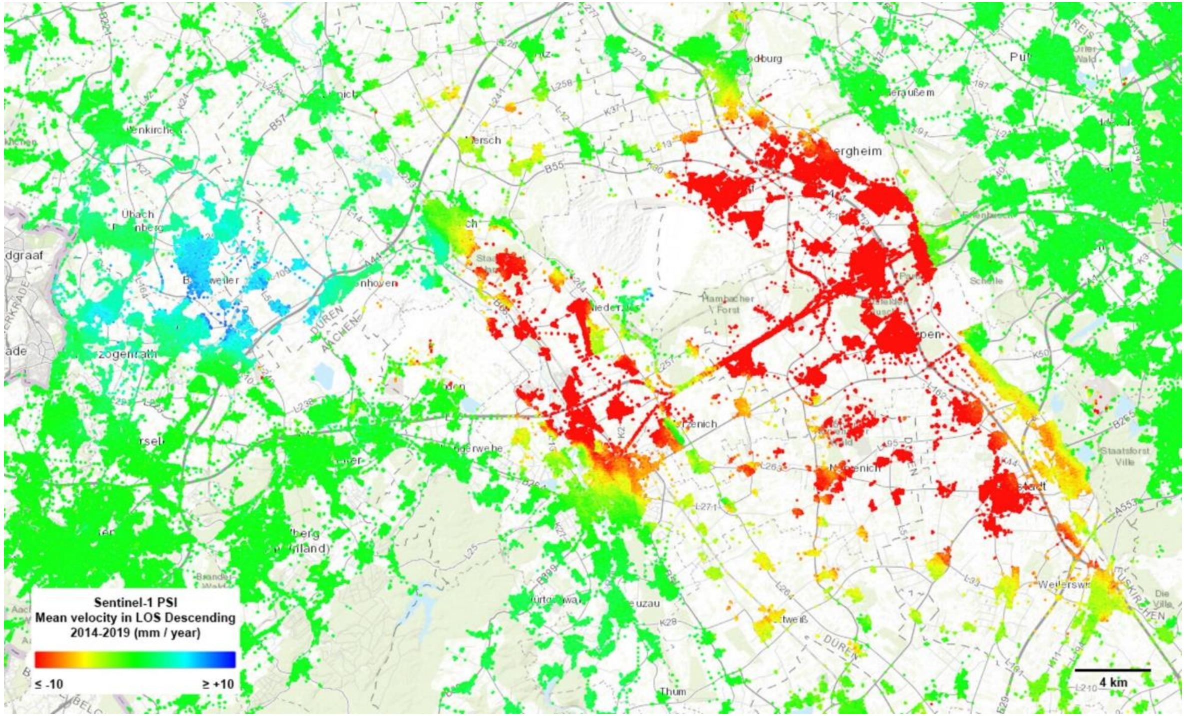
Downward movement of soil or sinking of the land from its previous level

https://spacegen.guru/landslip-and-land-subsidence/

https://insar.space/projects/

SAR for Land Subsidence - Applications

Monitoring of coal mining activity

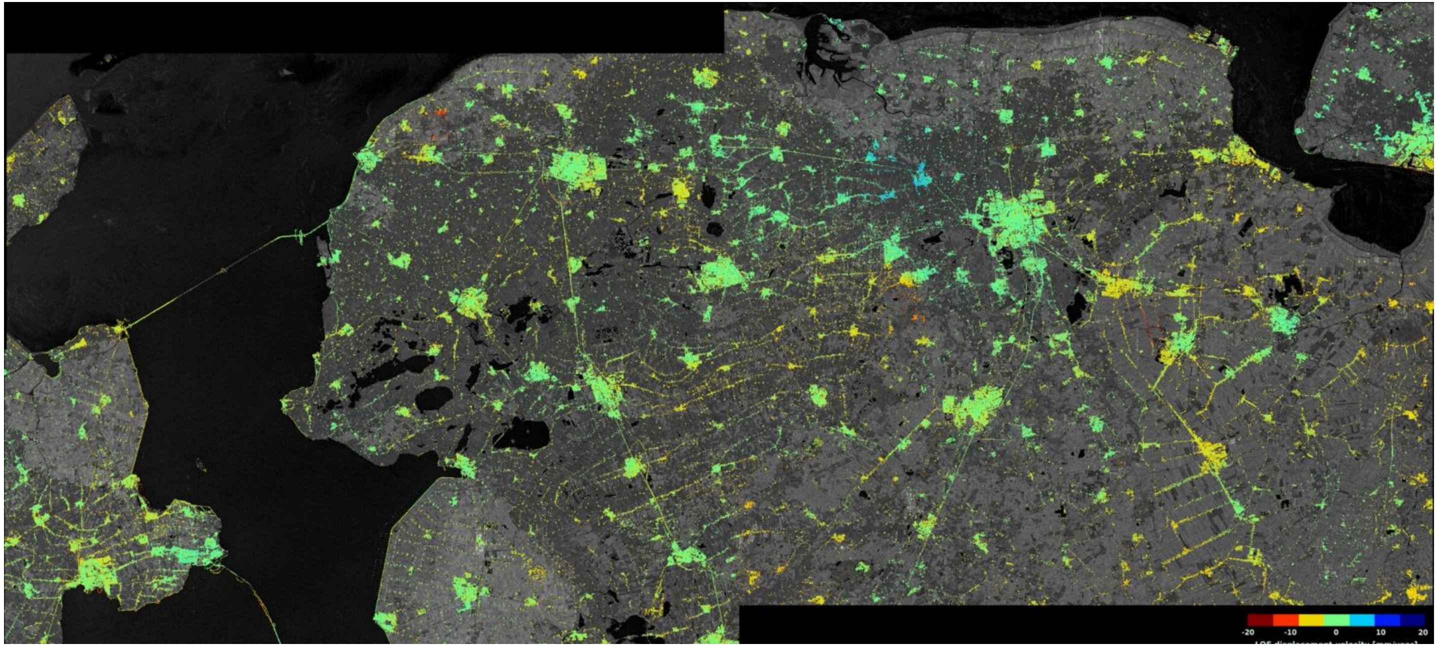


Based on ‘Persistent Scatterer Interferometry’ radar data from the Copernicus Sentinel-1 mission, the map shows how the land surface shifted in millimetres a year between 2014 and 2019 in the Ruhr in Germany. The subsidence shown in red is because of open pit lignite mining accompanied by groundwater lowering. Blue patches in the adjacent area are likely to be related to the rise of groundwater after mining activities ceased.

CREDIT: contains modified Copernicus Sentinel data (2014–19), processed by BGR (2020)

SAR for Land Subsidence - Applications

Monitoring the sinking

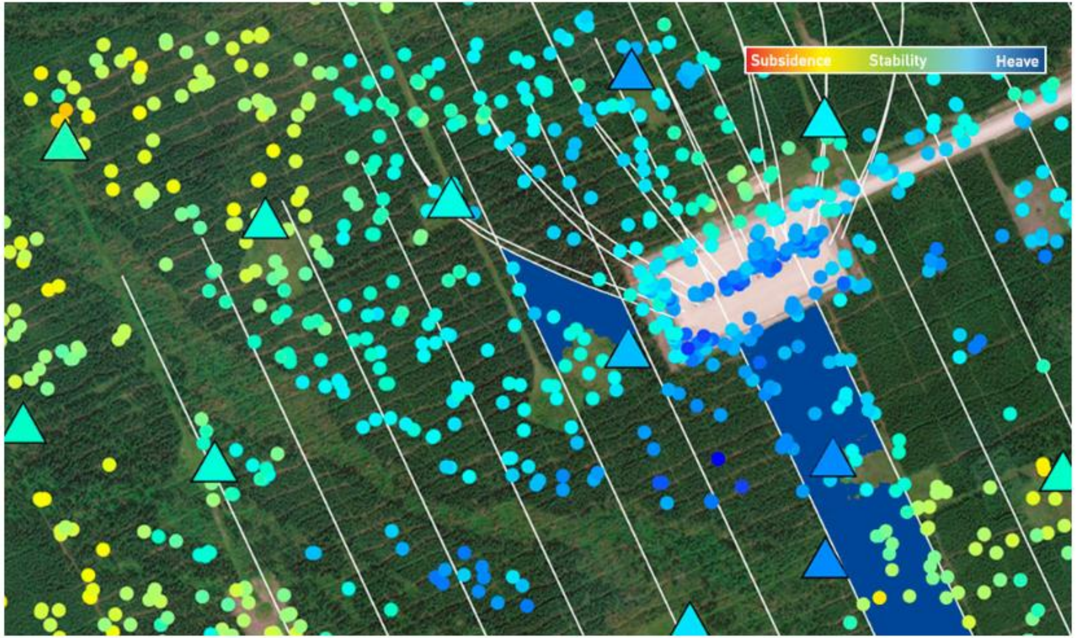


Using images that Sentinel-1A acquired between November 2014 and April 2016, this map shows subsidence (red) and uplift (blue) in the northeast of the Netherlands.

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

SAR for Land Subsidence - Applications

Monitoring of ground displacements over the drainage pots

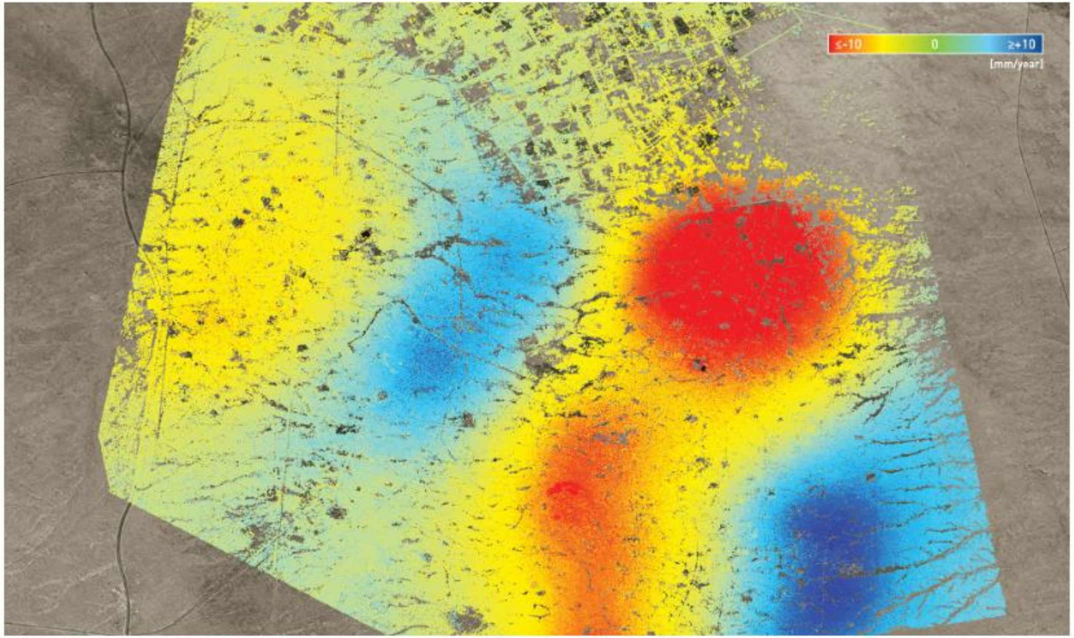


SAGD field in Alberta. SqueeSAR® analysis provided measurements of ground displacement over the drainage pads.

https://site.tre-altamira.com/oil-gas-operations/

SAR for Land Subsidence - Applications

Monitoring displacements over active oil operations

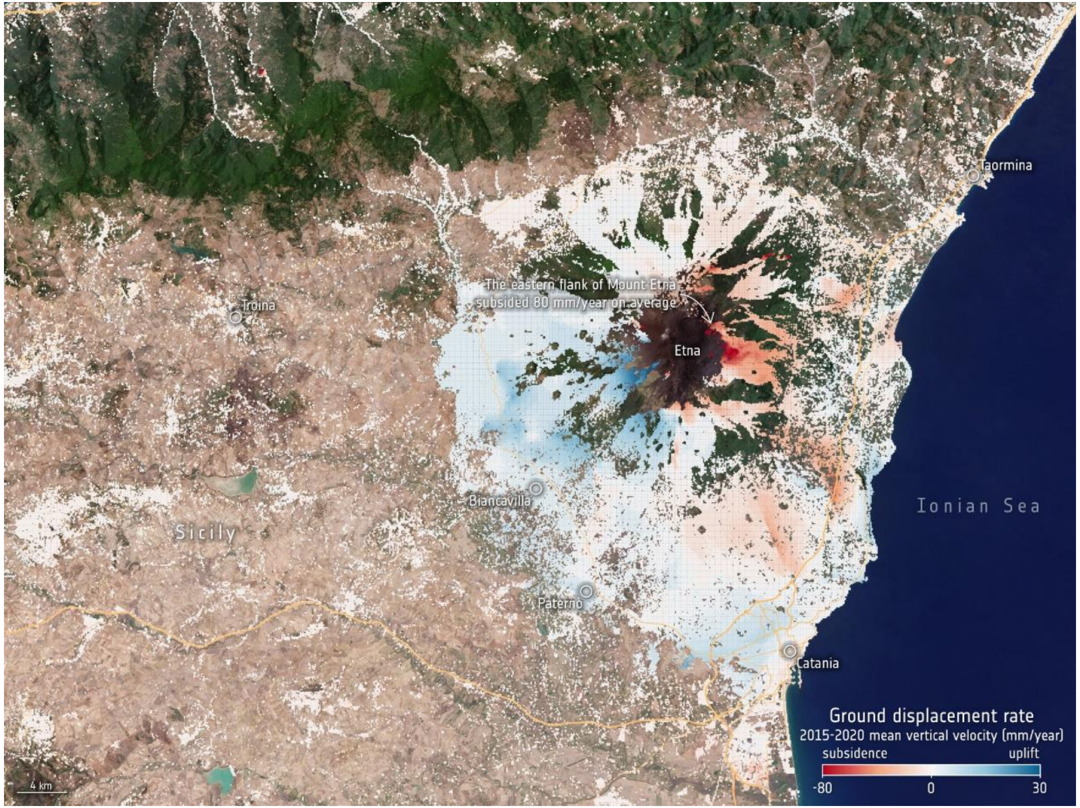


Displacement over active oil operations. Red and blue indicate areas of rapid subsidence and heave detected by SAR satellites. © DLR e.V. 2009-2013 and © Airbus Defense and Space GmbH

https://site.tre-altamira.com/oil-gas-operations/

SAR for Land Subsidence - Applications

Volcano uplift and subsidence



Etna's uplift and subsidence

This image shows the rate of ground displacement between 2015 and 2020 around Mount Etna and surroundings on the Italian island of Sicily. While the volcano's western flank experienced some uplift, its eastern flank subsided, on average, 80 mm a year.

CREDIT: contains modified Copernicus Sentinel data (2015–2020), processed by EGMS/ESA

Thank you for the attention