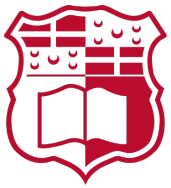
Introduction to Interferometric SAR

Dr Ing Gianluca Valentino
Department of Communications and Computer Engineering
Faculty of ICT, University of Malta

25th March 2021
11th ESA Training Course on Earth Observation



L-Università ta' Malta

The Malta Council for Science & Technology

European Space Agency

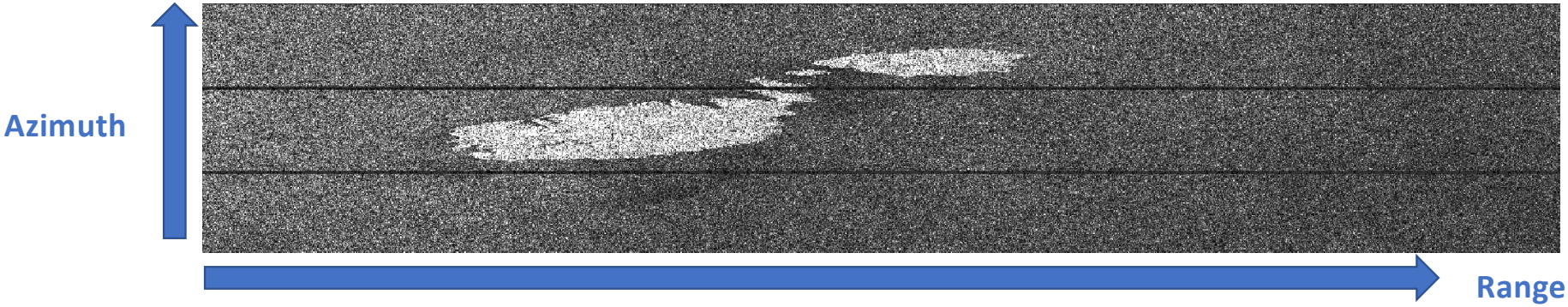
Outline

- InSAR: the basics
- InSAR processing pipeline:
  - Interferogram generation
  - Flat Earth removal
  - Topographic phase removal
  - Denoising
  - Phase unwrapping
  - Displacement estimation
- Applications of InSAR
- The Coastal SAGE project

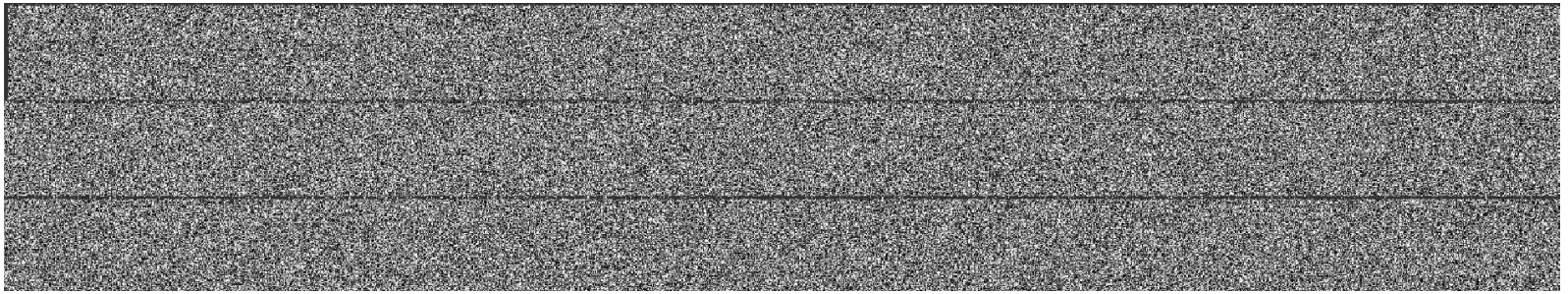
SAR amplitude and phase

- Each pixel value in a SAR acquisition is a complex number $(a + bi)$
- Amplitude: $\sqrt{a^2 + b^2}$

SLC = Single Look Complex

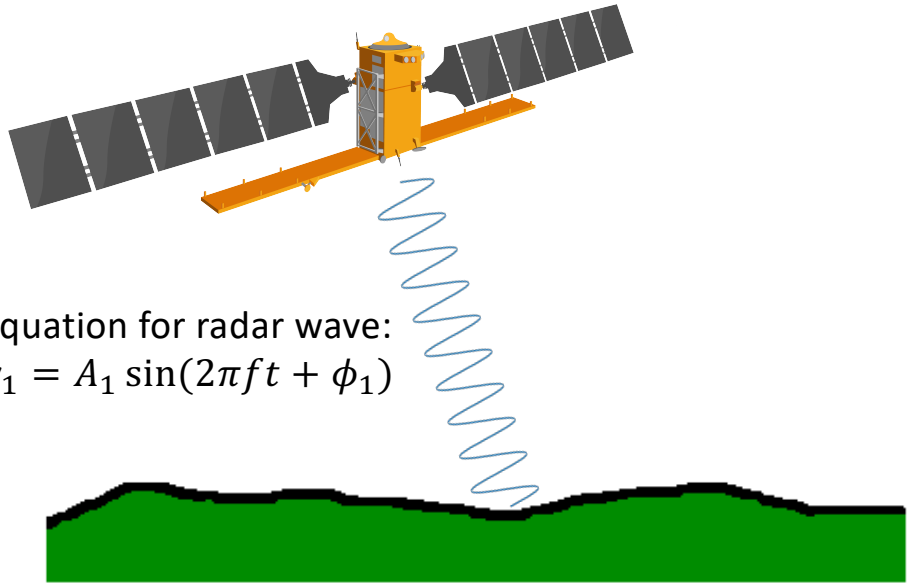


- Phase: $\arctan \frac{b}{a}$



InSAR basics

Acquisition 1 (date X)

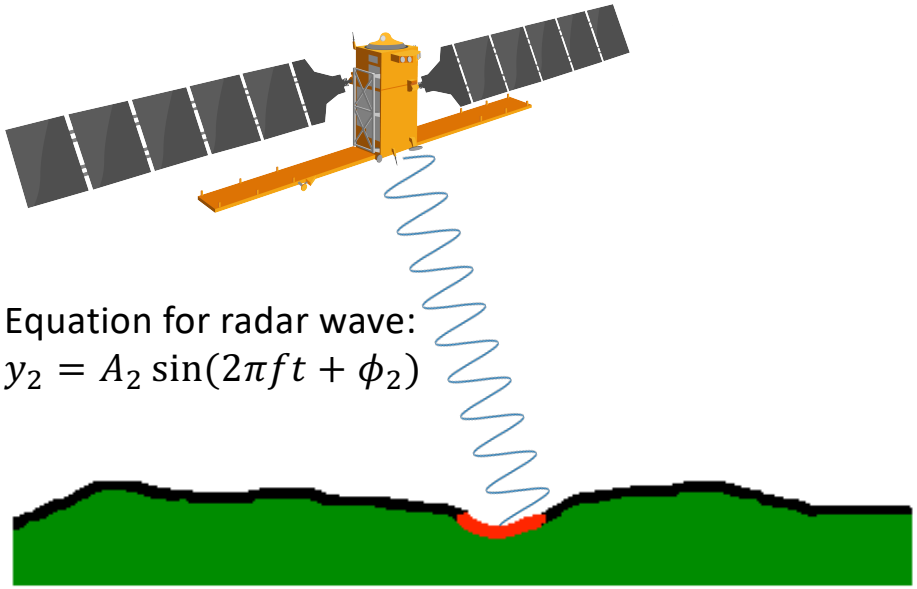


Equation for radar wave:
$y_1 = A_1 \sin(2\pi f t + \phi_1)$

λ = wavelength

For Sentinel-1 (C-band), λ = 6 cm

Acquisition 2 (date X + t)

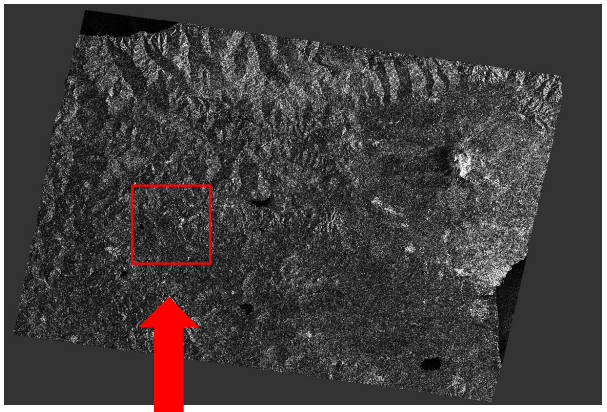


Equation for radar wave:
$y_2 = A_2 \sin(2\pi f t + \phi_2)$

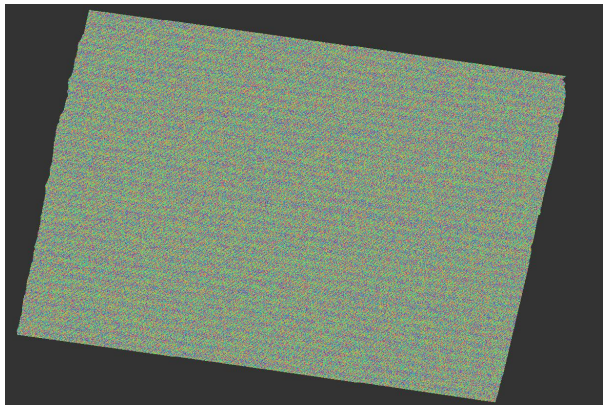
If there is a deformation e.g. subsidence (or uplifting) in the Earth's surface, then the radar wave has to travel more (or less).

This results in a phase change: $\Delta\phi = \phi_1 - \phi_2$

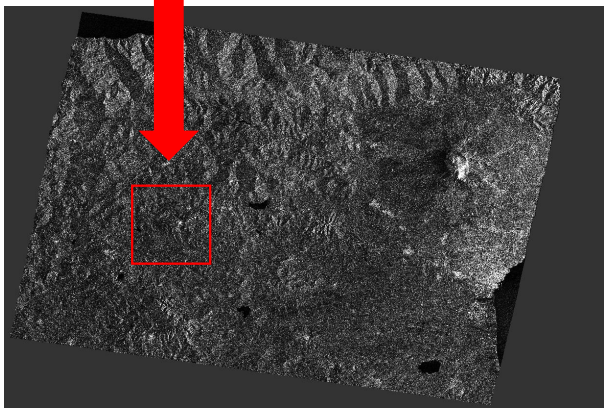
Interferogram generation



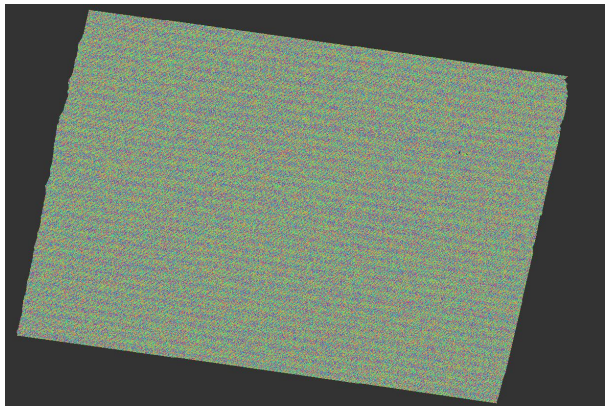
Amplitude A_1



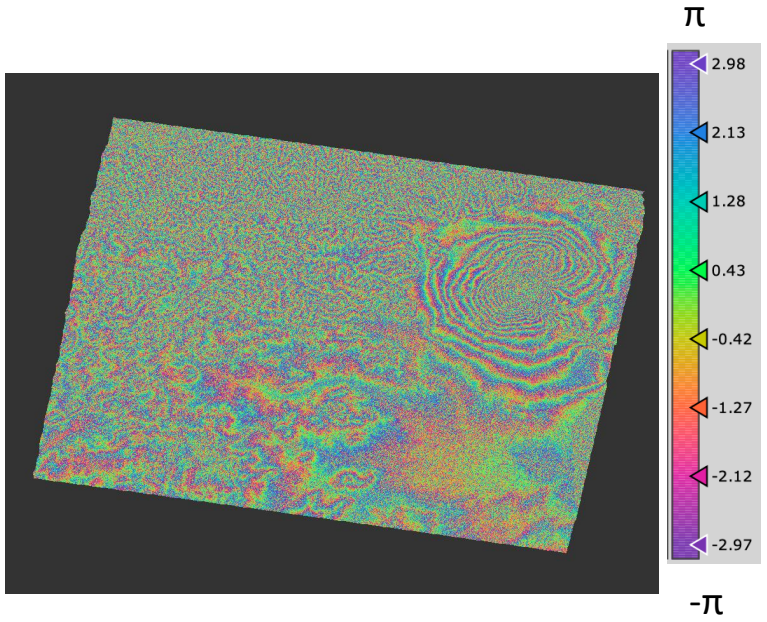
Phase ϕ_1



Amplitude A_2



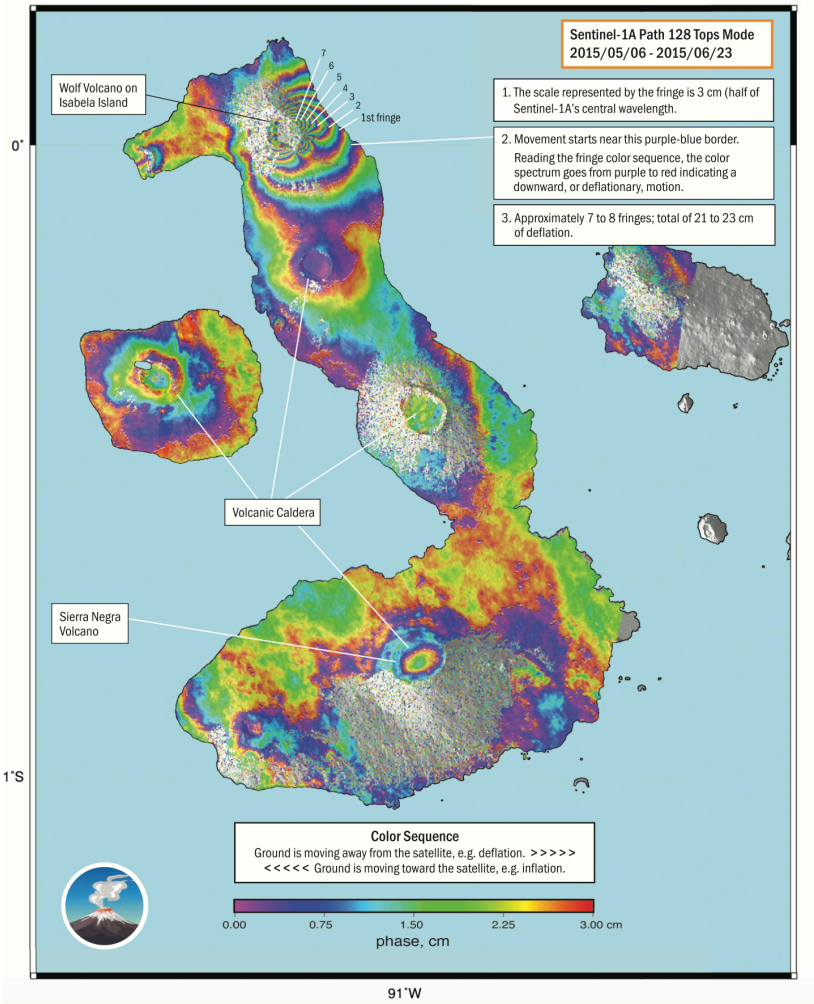
Phase ϕ_2



Interferogram: $\Delta\phi = \phi_1 - \phi_2$

How to interpret an interferogram?

Galapagos Islands, 06/05/2015 – 23/06/2015



The change in phase between the two acquisitions gives rise to colour fringes.

Fringe = one cycle of the spectrum colours from purple to red.
= displacement corresponding to half the wavelength

Total displacement: number of fringes x half wavelength

To determine the sense of motion, we look at the colour sequence:

- If colour sequence = purple to red, then ground has moved away from the satellite (deflation)
- If colour sequence = red to purple, then ground has moved towards the satellite (uplifting)

In this example, colour sequence = purple to red => **deflation**

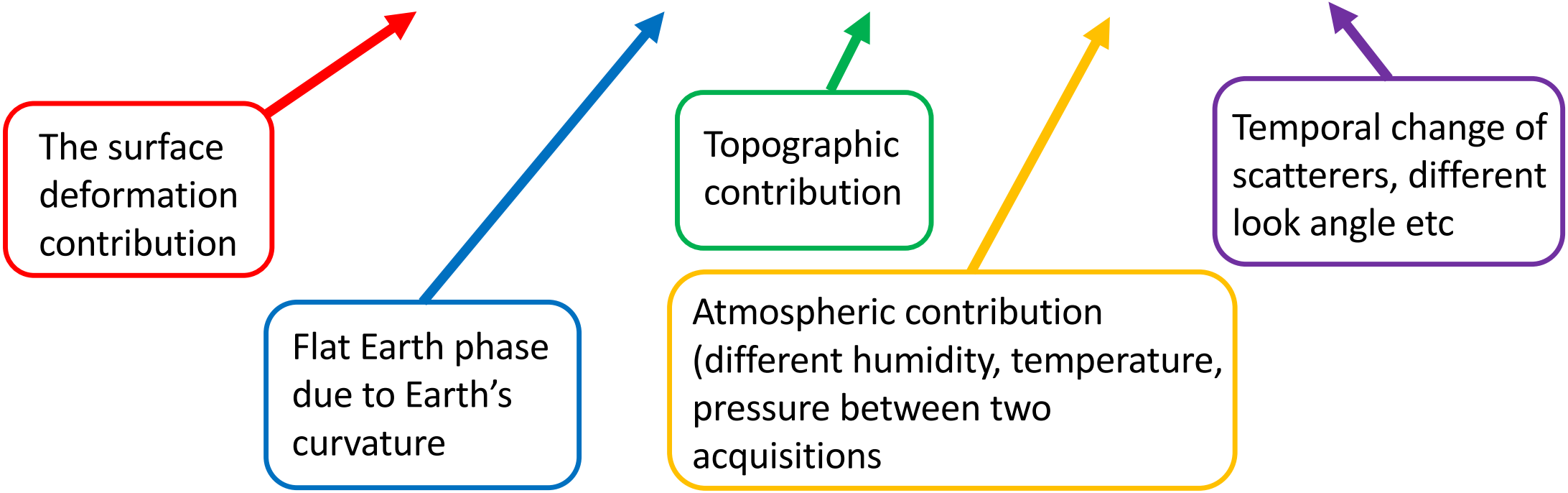
Also, there are 7-8 fringes between start of movement and top of volcano, so total deflation should be around 21-23 cm.

Source: www.unavco.org

InSAR processing

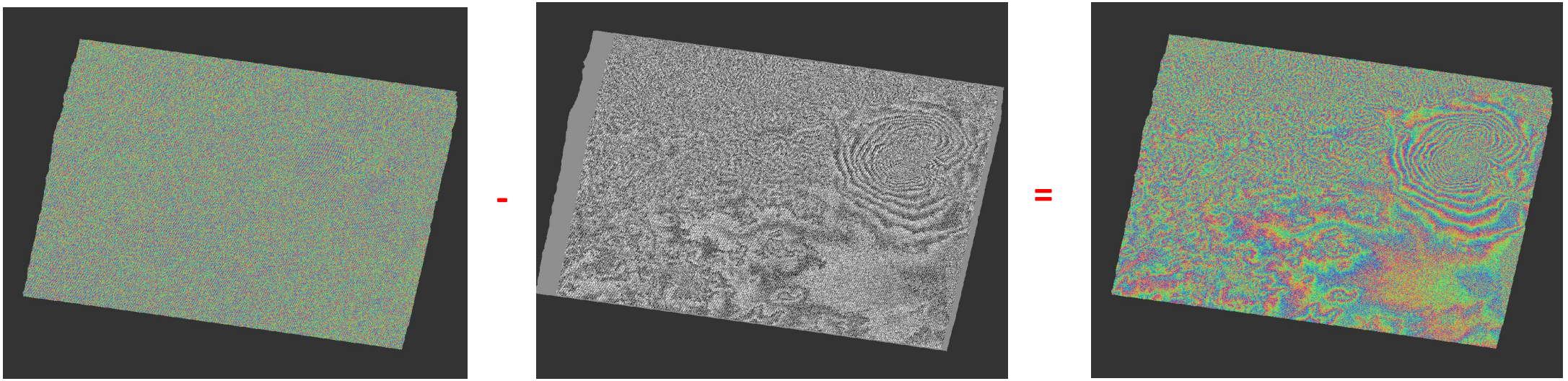
- The interferometric phase is a combination of multiple factors:

$$\Delta\phi_{int} = \Delta\phi_{displacement} + \Delta\phi_{flat} + \Delta\phi_{elevation} + \Delta\phi_{atm} + \Delta\phi_{noise}$$



InSAR processing: Flat Earth removal

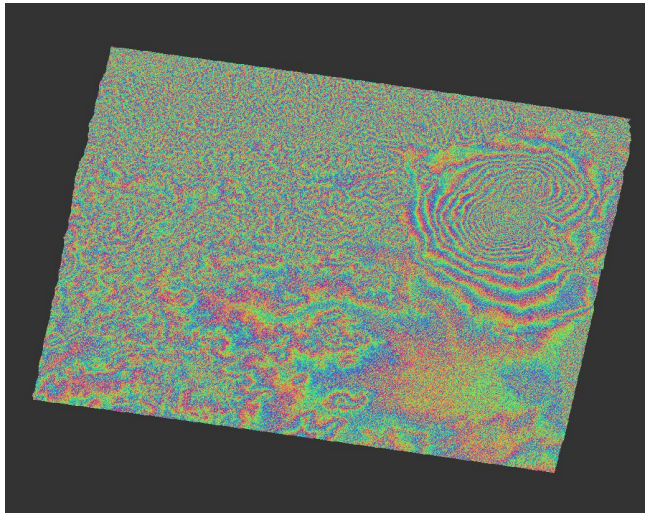
- Next, we need to remove the phase interferogram that would result from a flat-earth.



- After removing the flat-earth effect we are left with an interferogram that contains topography + deformation between the two acquisitions and atmospheric effect.

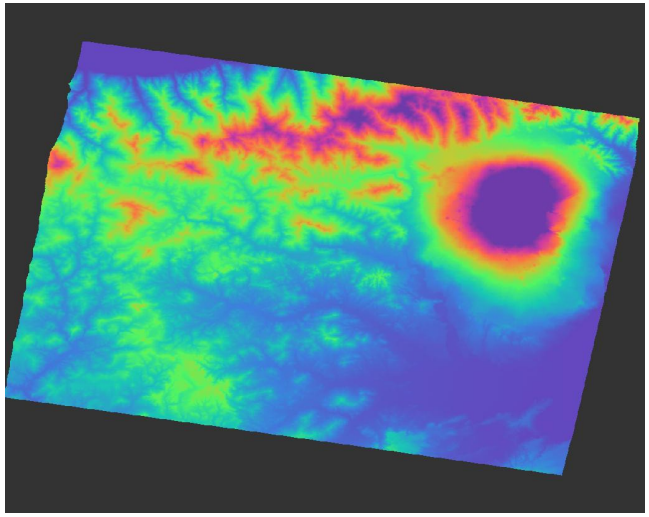
InSAR processing: topographic phase removal

Interferogram



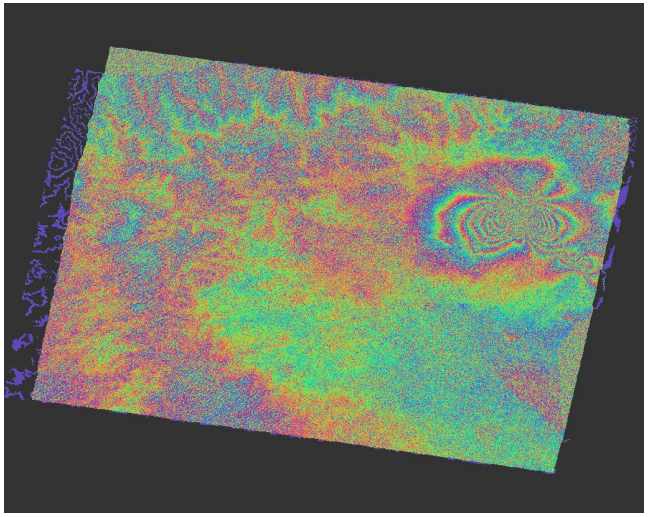
-

Digital Elevation Model (DEM)



=

Differential Interferogram



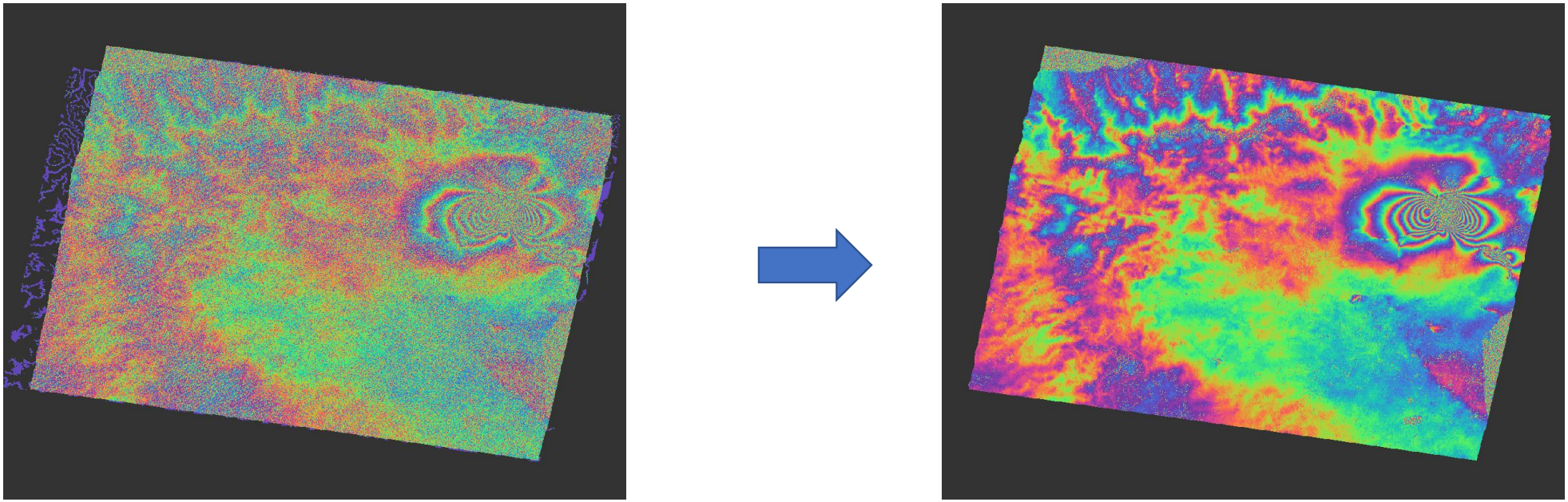
This now gives us Differential InSAR = DInSAR

InSAR processing: atmospheric effects

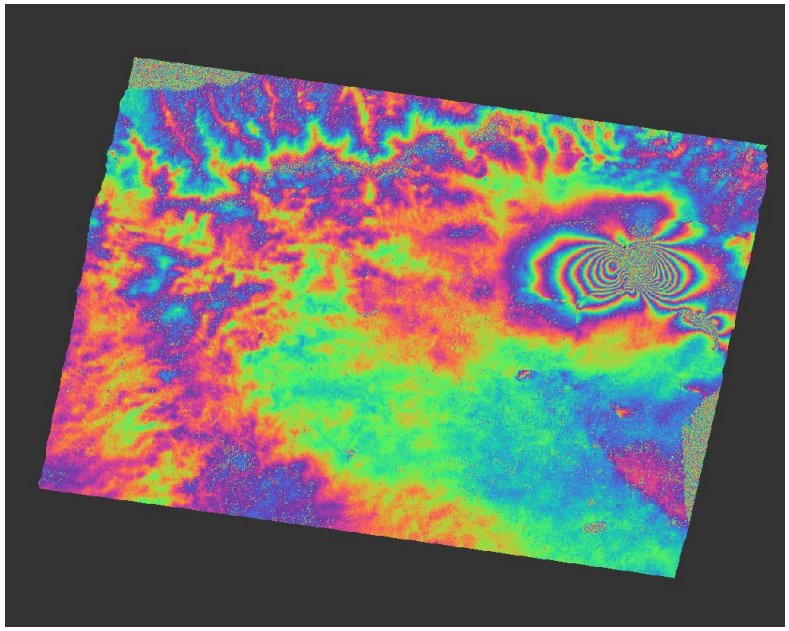
- Moisture in the atmosphere may distort the wavelength of the radar waves.
- Atmospheric effects are typically negligible, in particular when the expected displacement is high (e.g. earthquake, volcanic eruption)
- A number of correction techniques exist, e.g. https://github.com/dbekaert/TRAIN

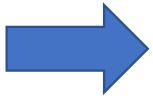
InSAR processing: noise

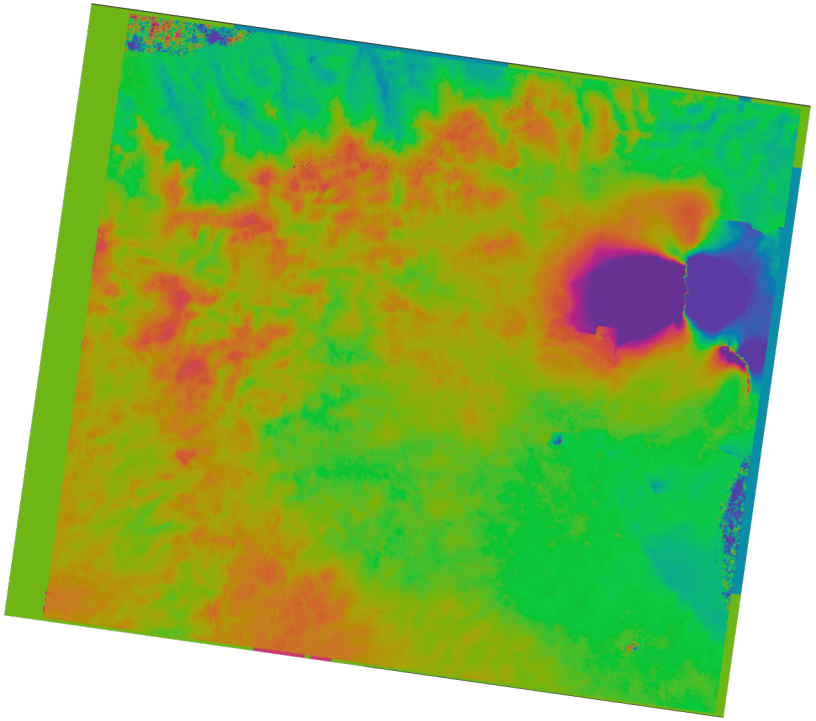
- Phase multilooking and filtering

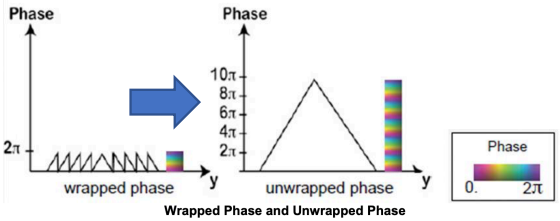


Phase unwrapping





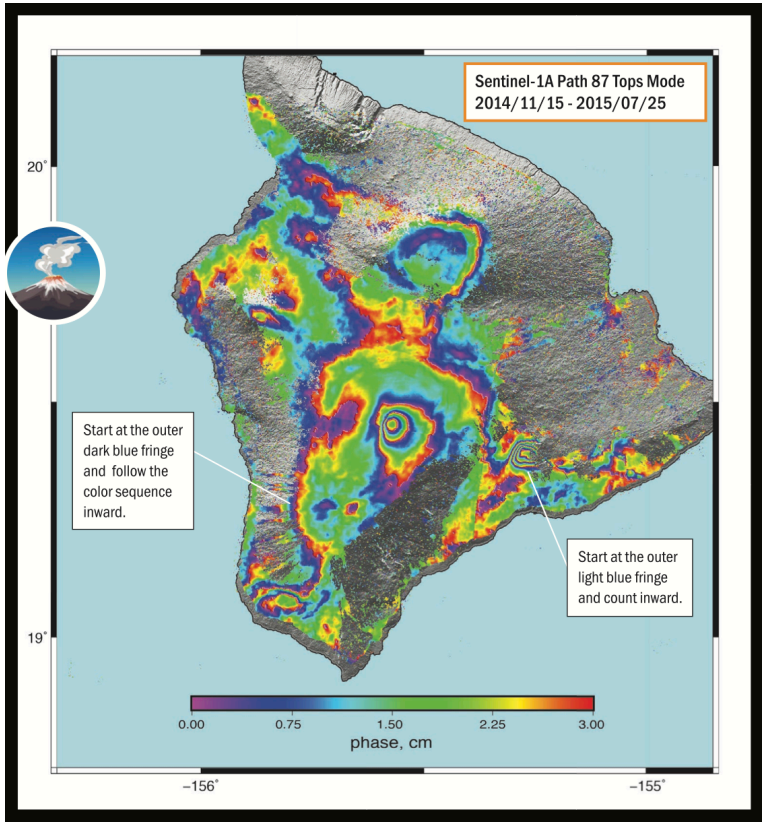




Wrapped Phase and Unwrapped Phase

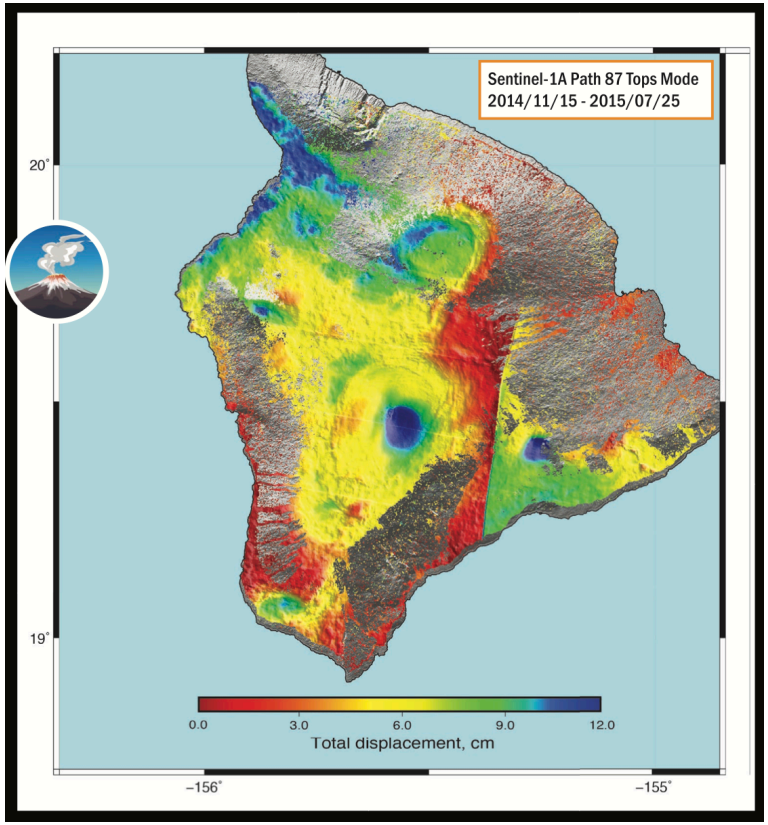
Hawaii inflation event, 15/11/2014– 25/07/2015

Wrapped phase



Wrapped interferograms show deformation as multiple colour sequences. For both volcanoes in this image, the spectrum of colours goes from red to purple, indicating the ground is moving towards the satellite (inflation). The central volcano inflated approximately 12 cm.

Unwrapped phase



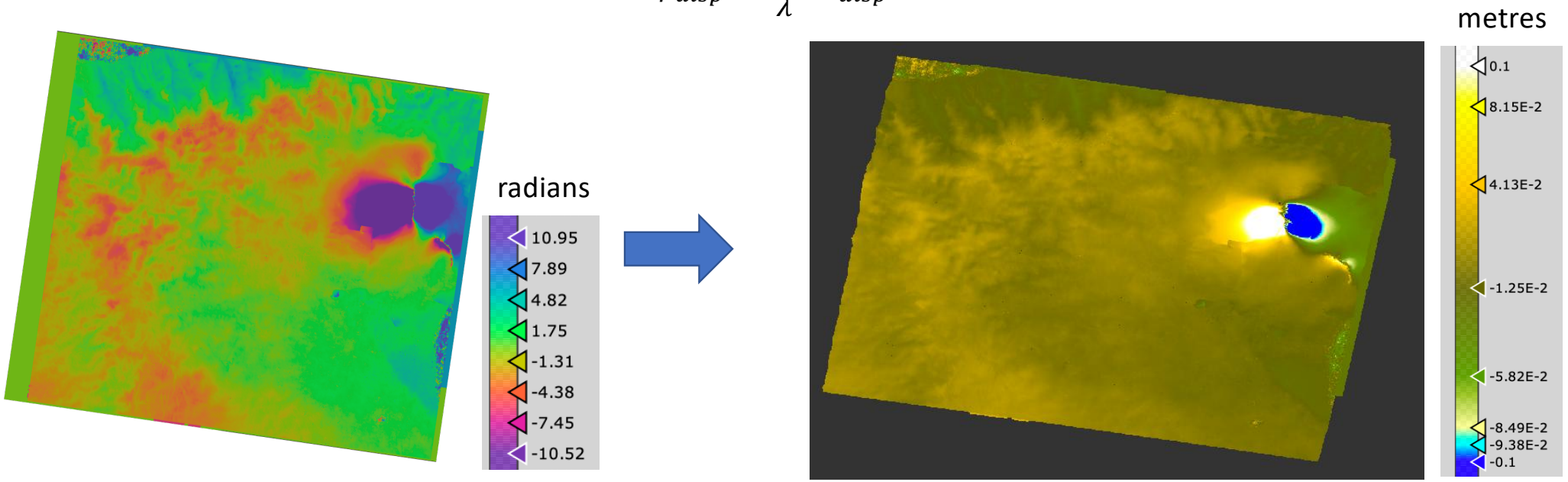
Unwrapped interferograms show total displacement of deformation. An unwrapped interferogram is created by adding the fringes together from the wrapped interferogram. The total inflation of the central volcano is ~12 cm, agreeing with the wrapped interferogram.

Source: www.unavco.org

Phase to displacement conversion

- The final step is to convert the unwrapped phase to a displacement in metres.
- This can be done via the following formula:

$$\phi_{disp} = \frac{4\pi}{\lambda}\Delta r_{disp}$$



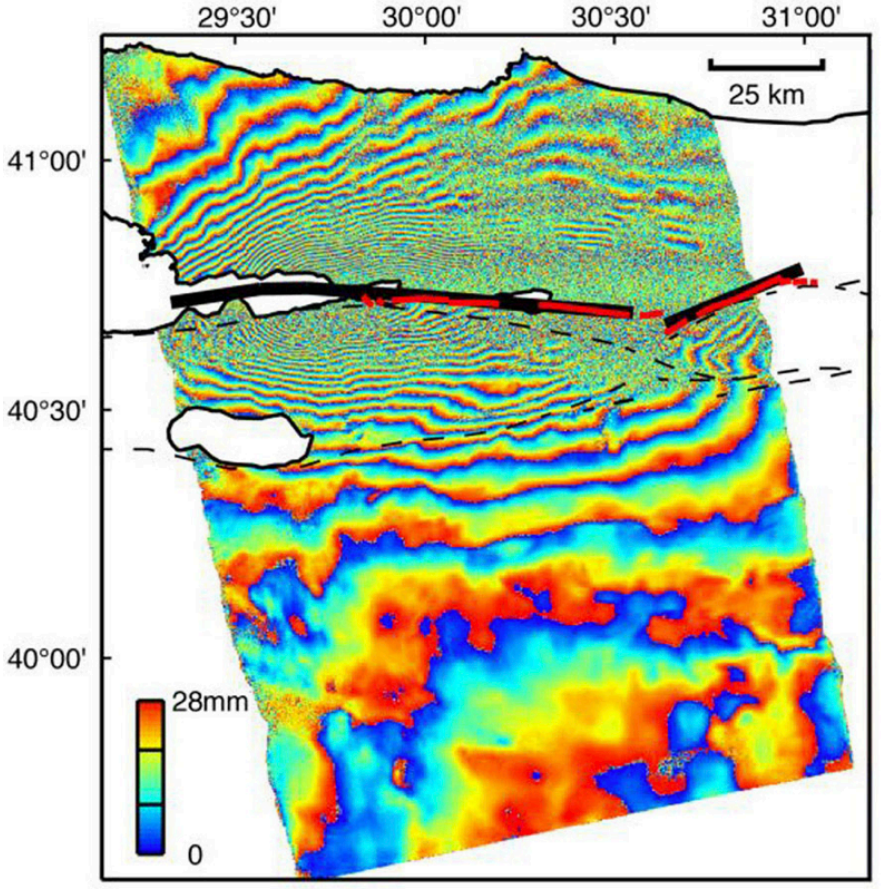
Applications: earthquakes

InSAR analysis of Landers earthquake, 1993

D. Massonnet et al., Nature 364, 138-142 (1993)

Red lines = mapped surface rupture

Black lines = fault rupture inferred from SAR

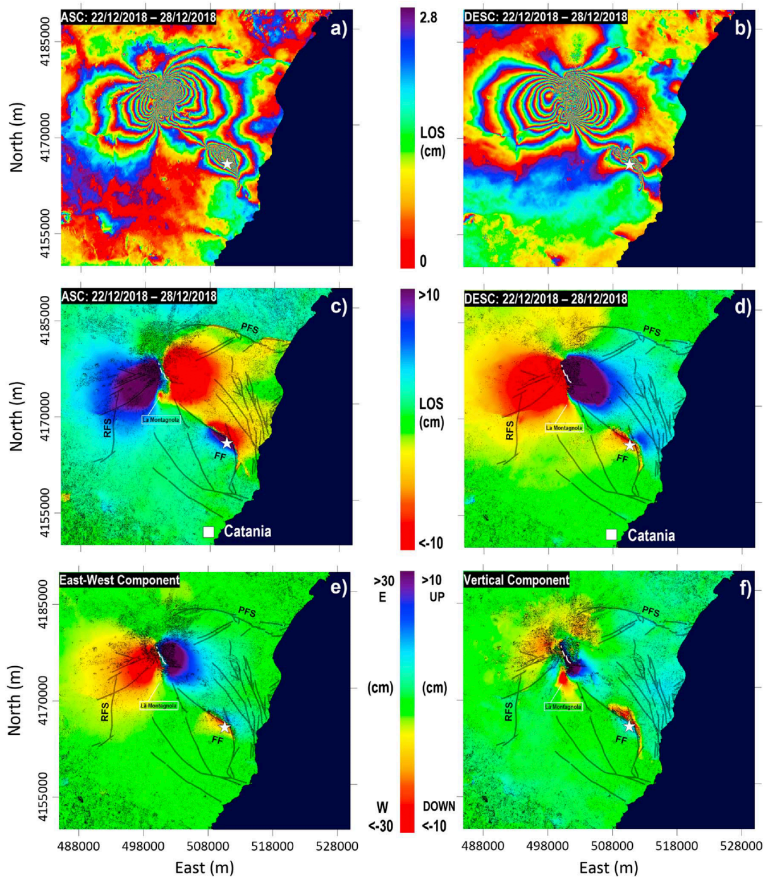


Interferogram of Izmir earthquake, 1999.

T. Wright, E. Fielding, B. Parsons., Geophysical Research Letters, vol. 28 no.6, 2001

Applications: Volcanic activity

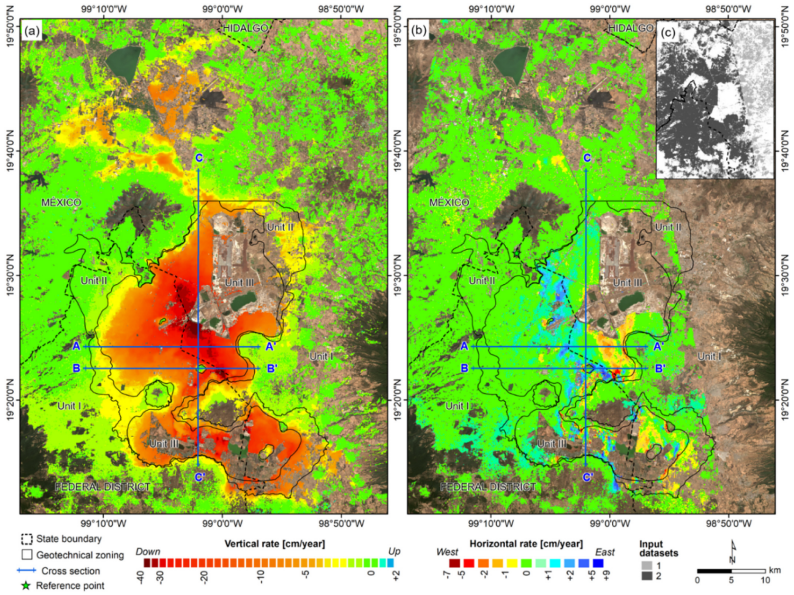
- Mount Etna displacements (December 2018)



V. De Novellis et al, Geophysical Research Letters, 2019

Applications: Land Subsidence

- Land subsidence in Mexico City:

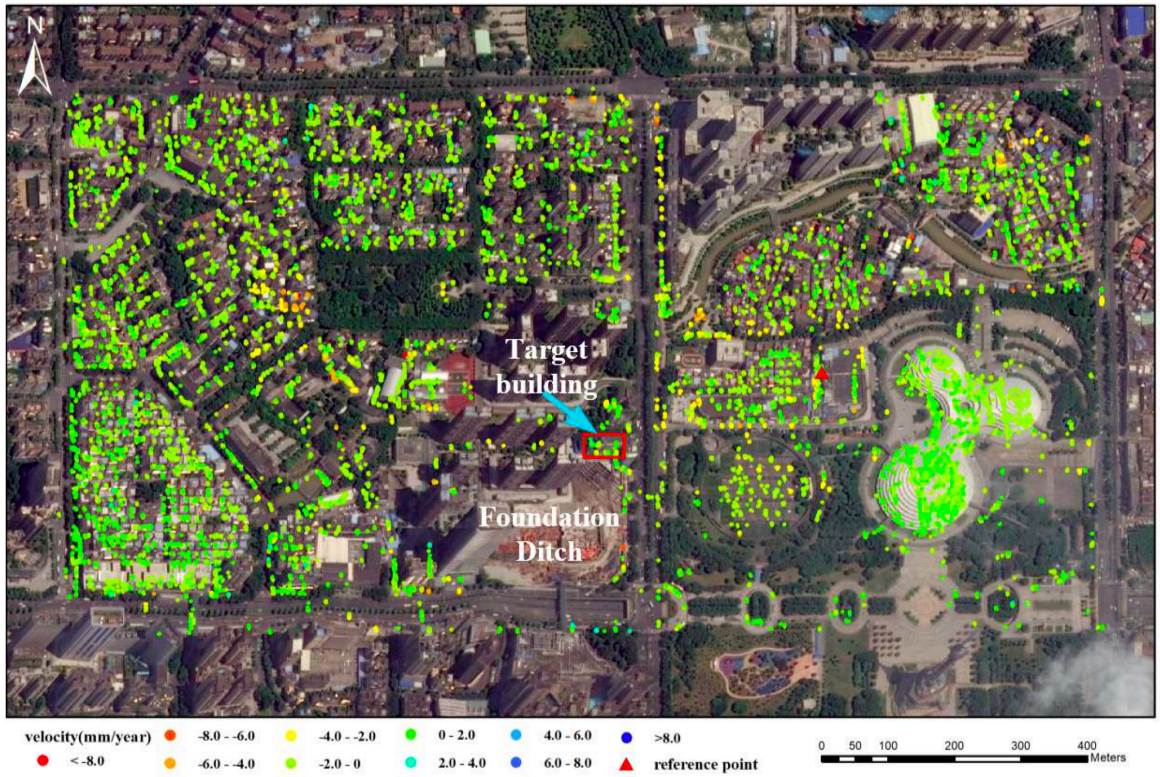


F. Cigna, D. Tapete, Remote Sensing of Environment, vol 253, 2021

Sources: http://geodesy.fiu.edu/MexSubsidence/index.html
https://www.structuremag.org/?p=13964

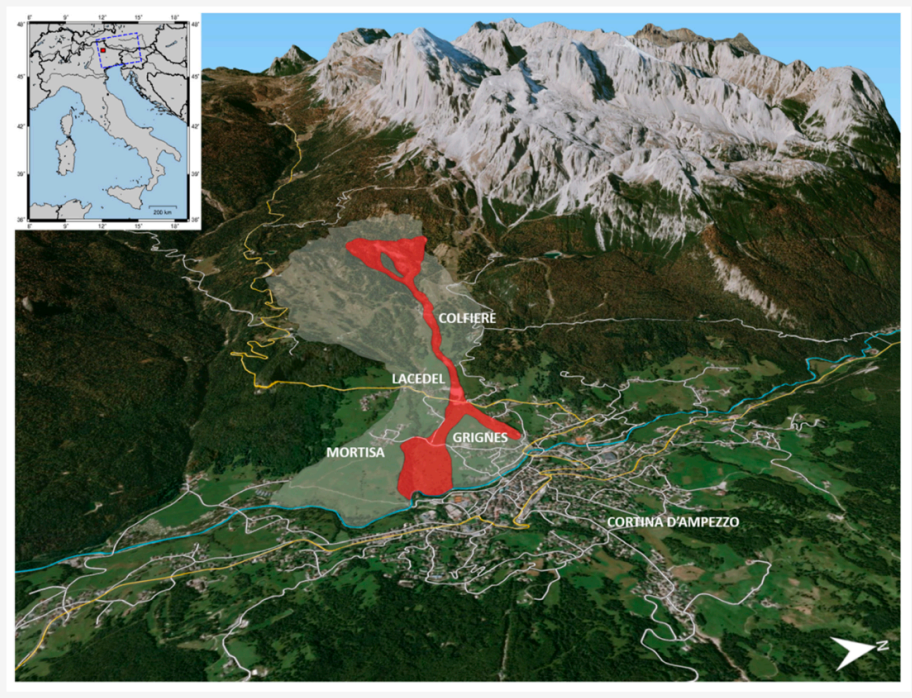
Applications: Building and infrastructure monitoring

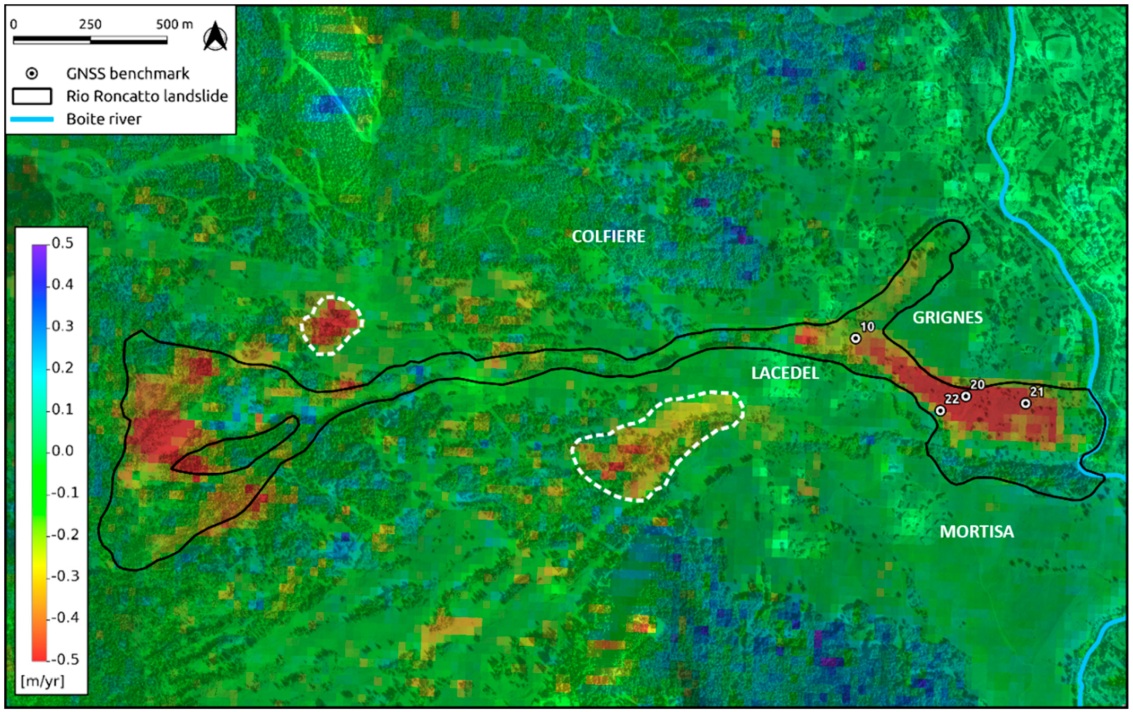
- Instabilities and deformations may also be man-made, e.g. due to nearby construction activities.
- Persistent Scatterer Interferometry may be used to detect slow movement with mm precision



M. Zhu et al, Remote Sens. (2018) 10, 1816.

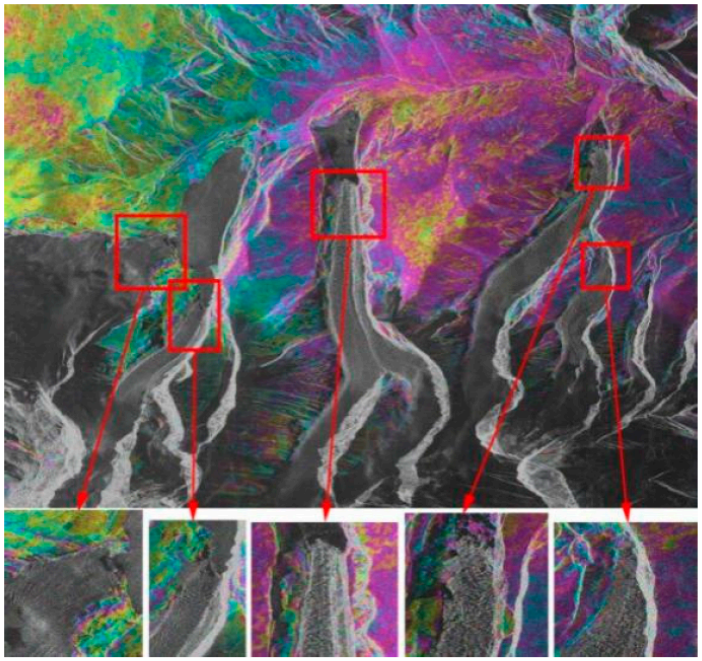
Appliations: Landslides





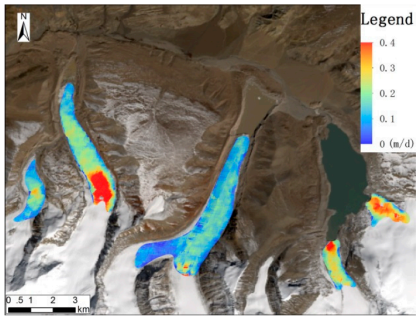
M. Mantovani et al, Remote Sens. (2019) 11(18)

Appliations: Glacier motion

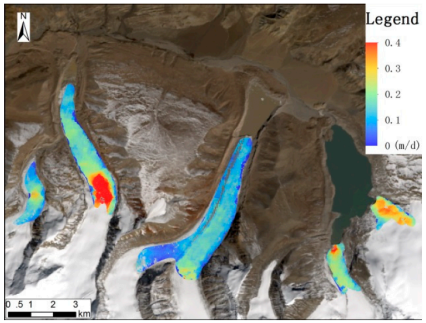


$-\pi$ Interferometric Phase (Radians) π

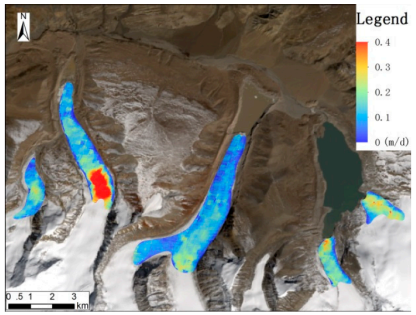
J. Fan et al, Remote Sens. (2019) 11, 625



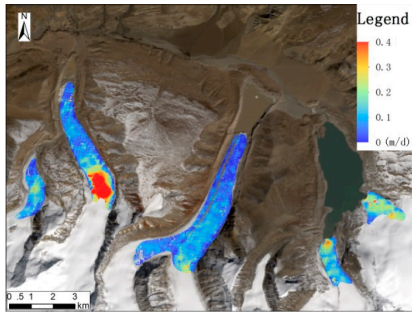
(a) 2016/07/31–2016/08/16



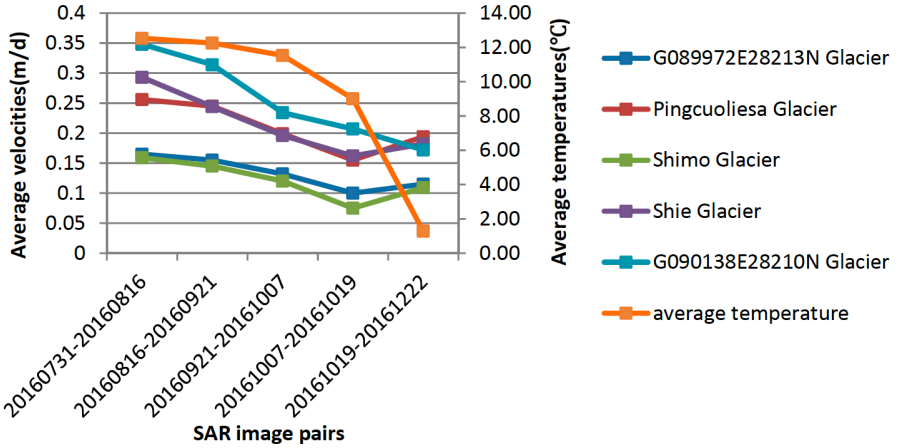
(b) 2016/08/16–2016/09/21



(c) 2016/09/21–2016/10/07



(d) 2016/10/07–2016/10/19

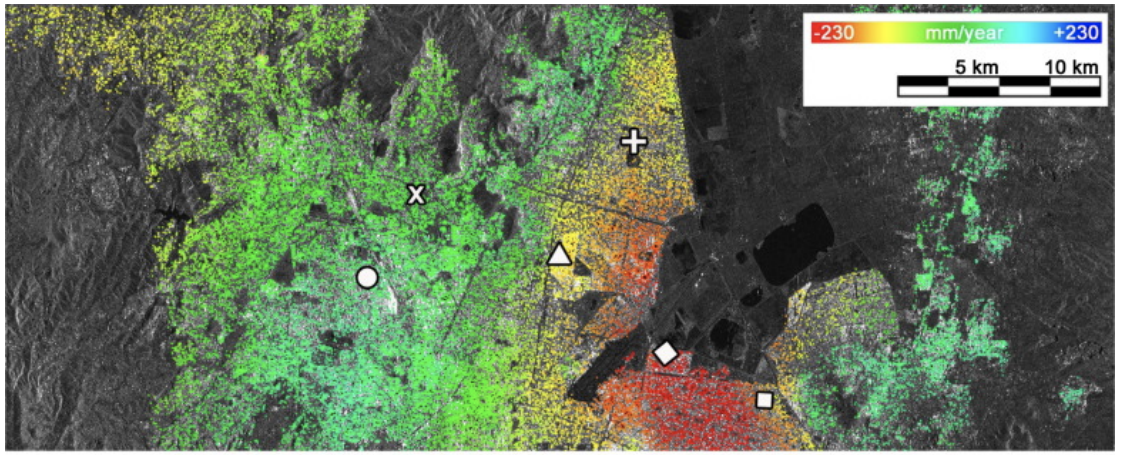


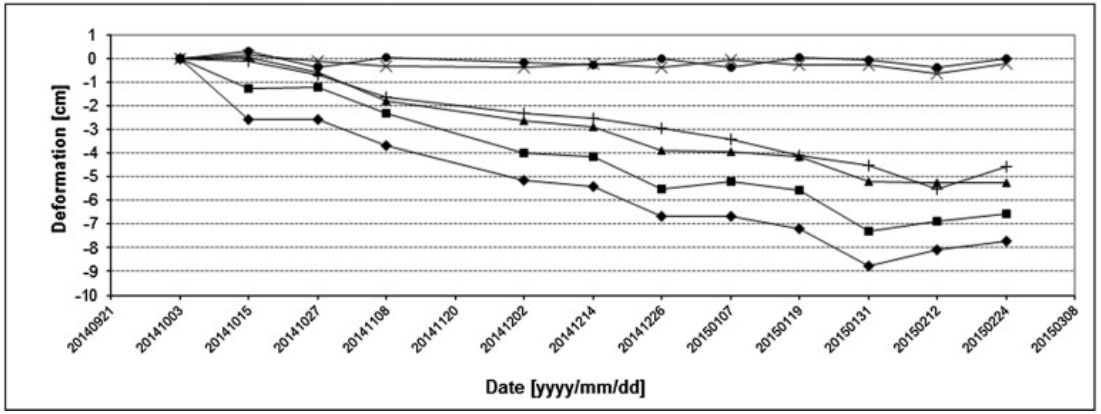
Coastal SAGE project

- Coastal erosion is of importance to the Maltese Islands as the coast is one of the most intensely-used and visited areas.
- Erosion along the rocky shoreline poses hazards to life, infrastructure and cultural heritage.
- Current response to this issue is mostly reactive and driven by visual site inspections.
- The Coastal SAGE project will use AI techniques to improve the InSAR processing pipeline to better monitor the phenomenon of erosion.
- It is led by the University of Malta with the Ministry for Transport, Infrastructure and Capital Projects as partner.
- Funding: €150,000 through MCST Space Research Fund.

Persistent Scatterer Interferometry

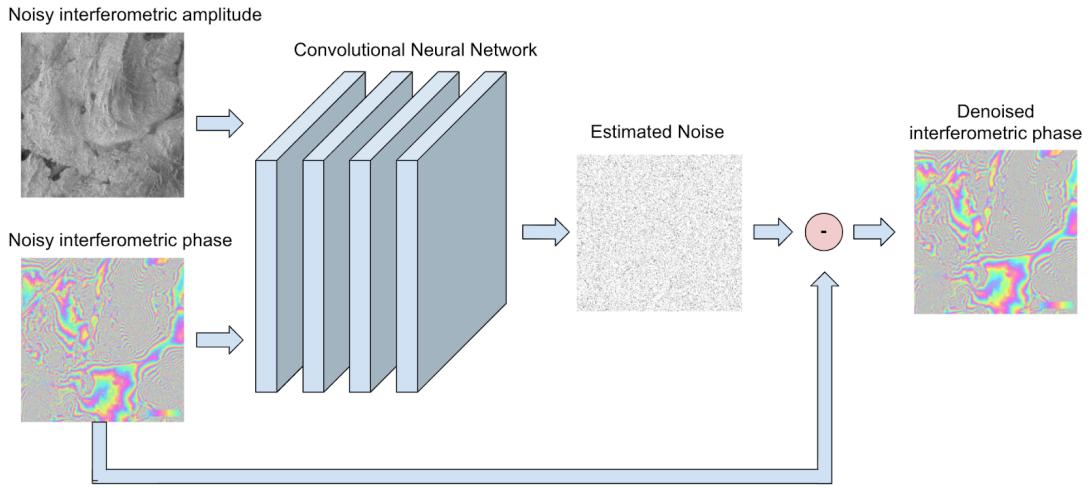
- Certain pixels in a scene may be coherent over a sequence of interferograms.
    - i.e. they reflect the signal roughly in the same way each time the satellite passes over.
- These pixels are known as **persistent scatterers.**
- Therefore, they are very useful in estimating slow deformation over time with high precision (mm).

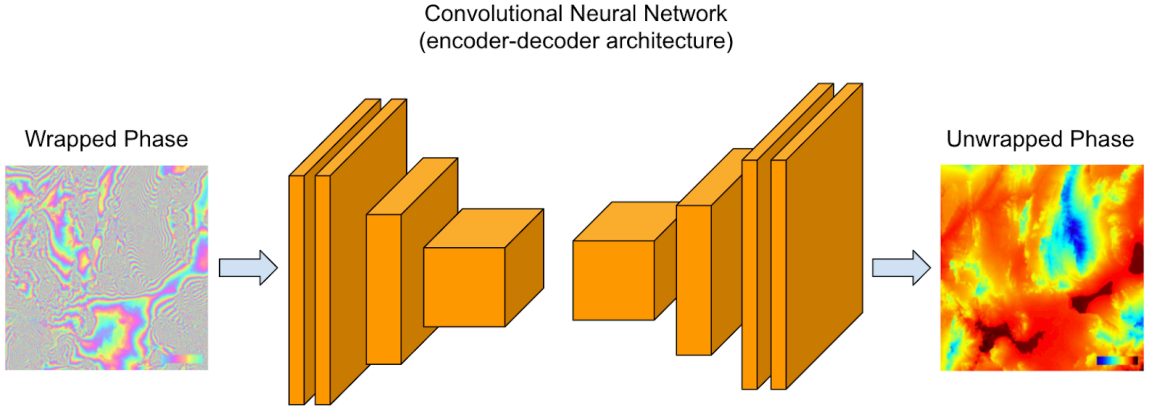




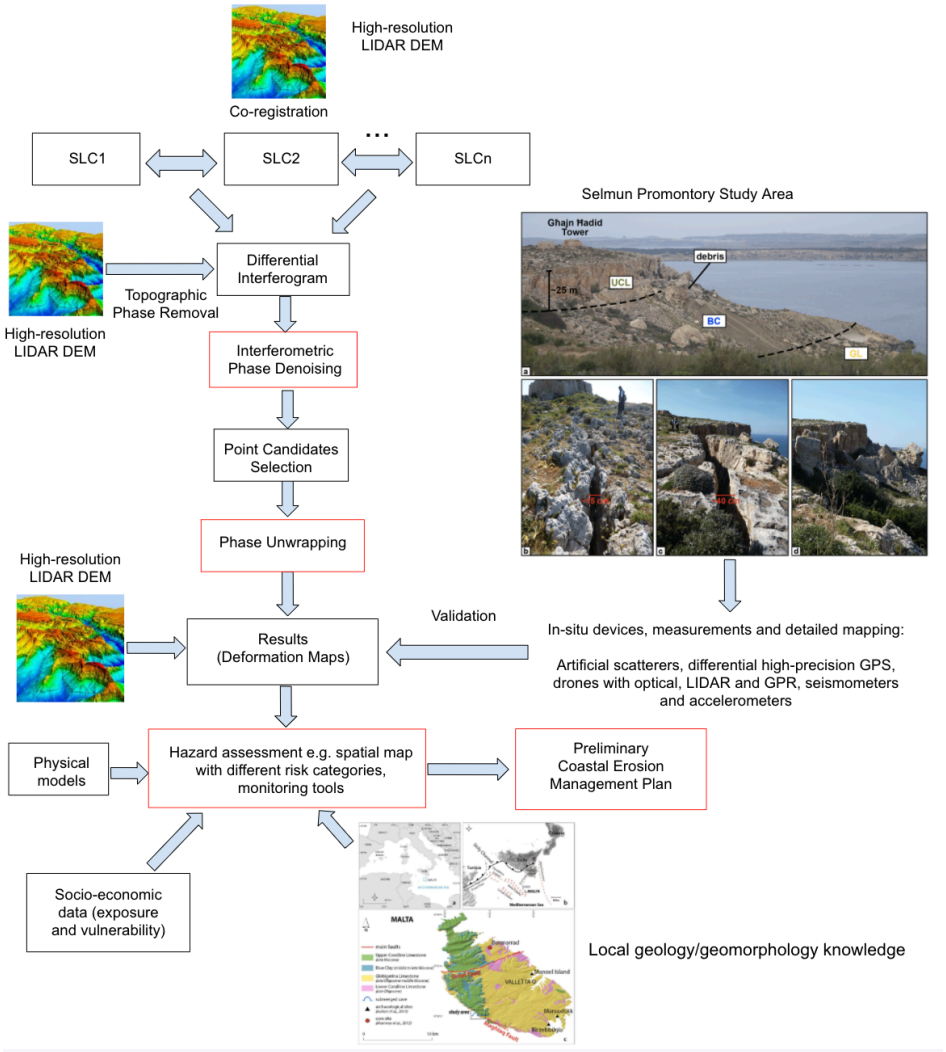
Planned research contribution

- Our planned research contribution is to use **Artificial Intelligence (AI)** techniques to improve the PSI pipeline:
  - Improved SAR interferometric phase denoising
  - Improved phase unwrapping

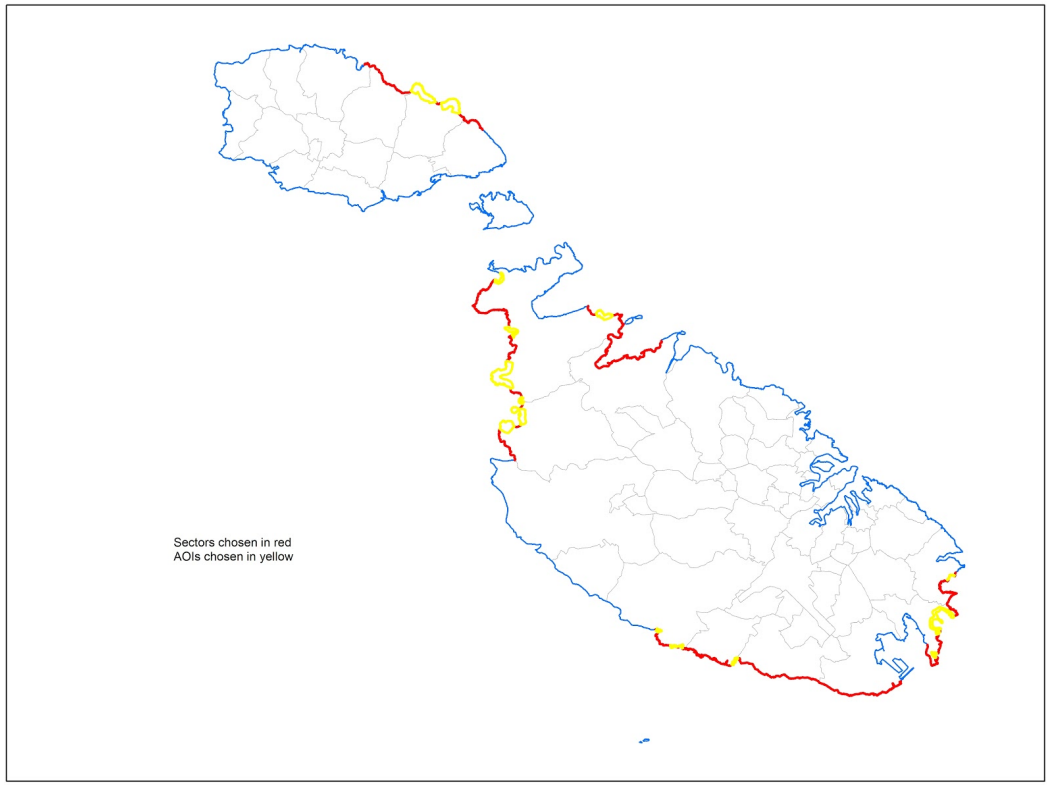


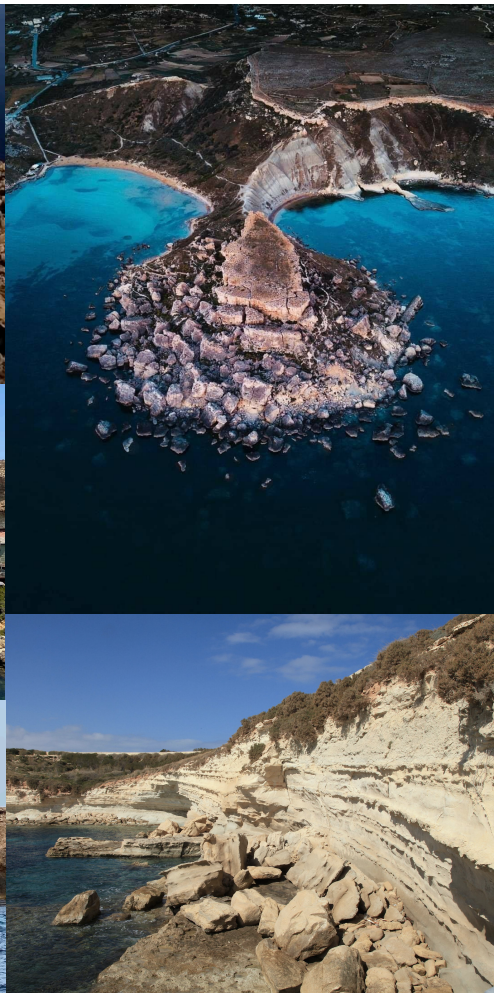


Planned research contribution



Study Areas in the Maltese Islands





Acknowledgements

Project Coastal SAGE financed by the Malta Council for Science and Technology, for and on behalf of the Foundation for Science and Technology, through the Space Research Fund.

Xjenza

The Malta Council for
Science & Technology