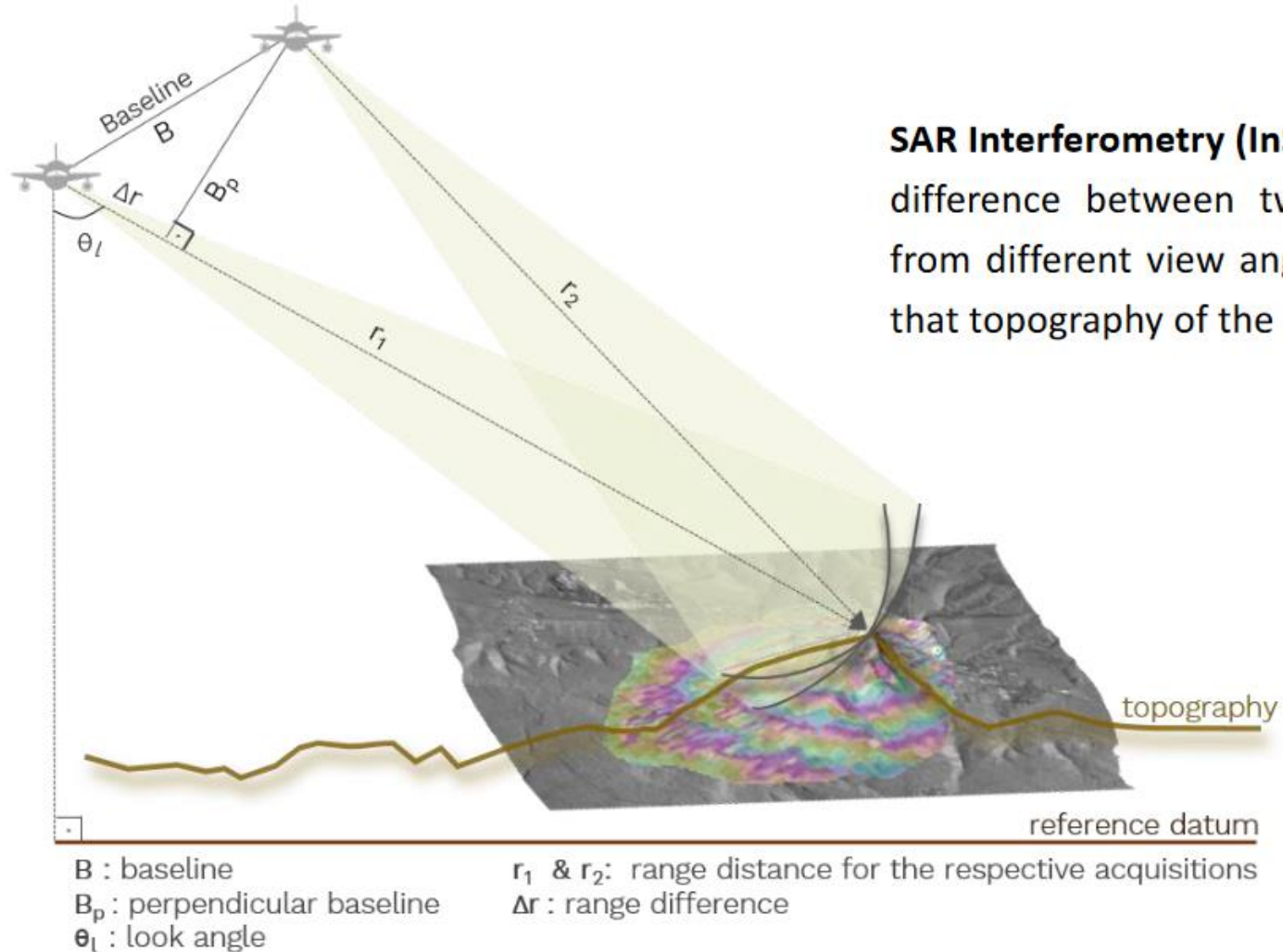# 3. SAR remote sensing for land applications 2 – Introduction to Interferometric SAR
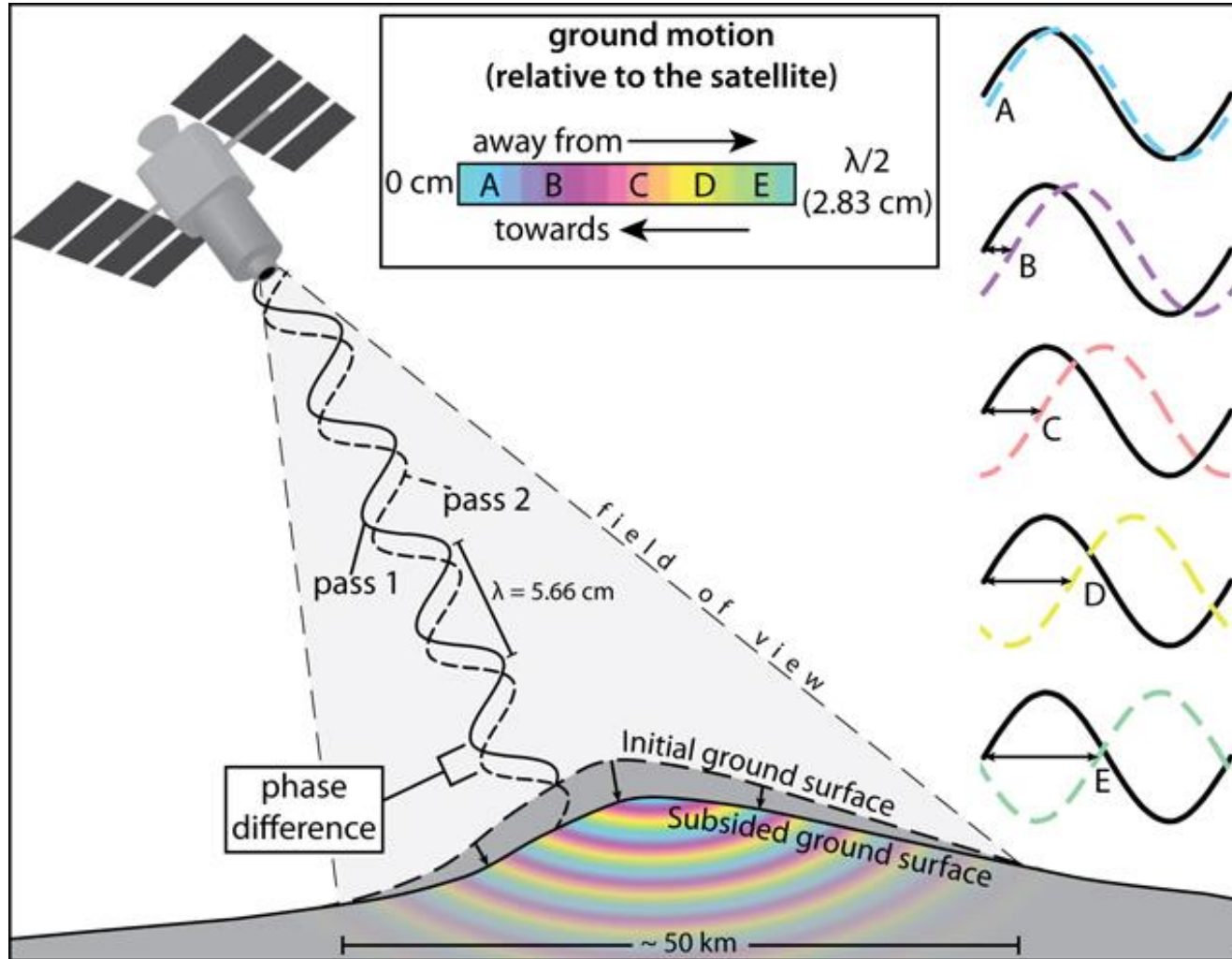
Synthetic Aperture Radar Interferometry (InSAR)

Determining elevation

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.

topography

reference datum

B : baseline
B_p : perpendicular baseline
θ_l : look angle

r_1 & r_2: range distance for the respective acquisitions
Δr : range difference

Synthetic Aperture Radar Interferometry (InSAR)
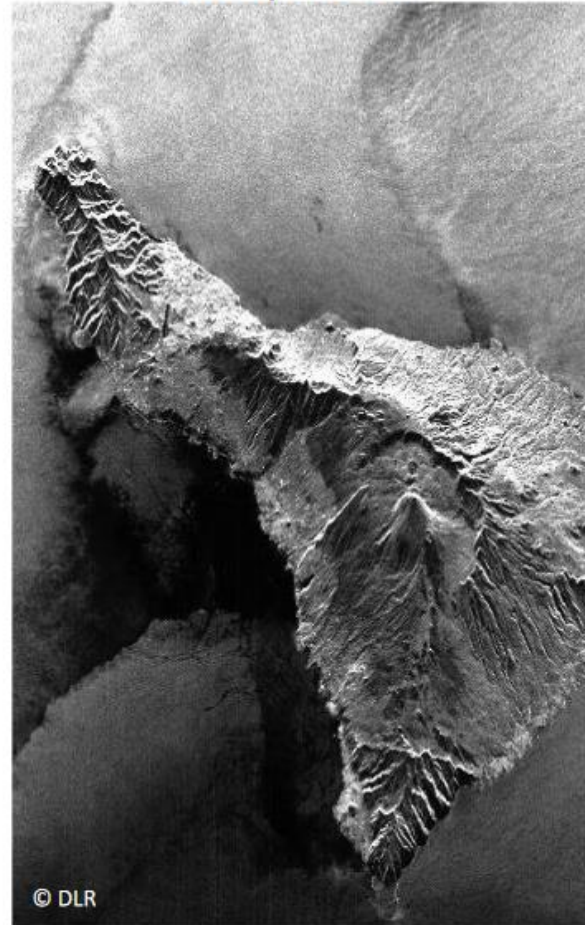
Determining elevation

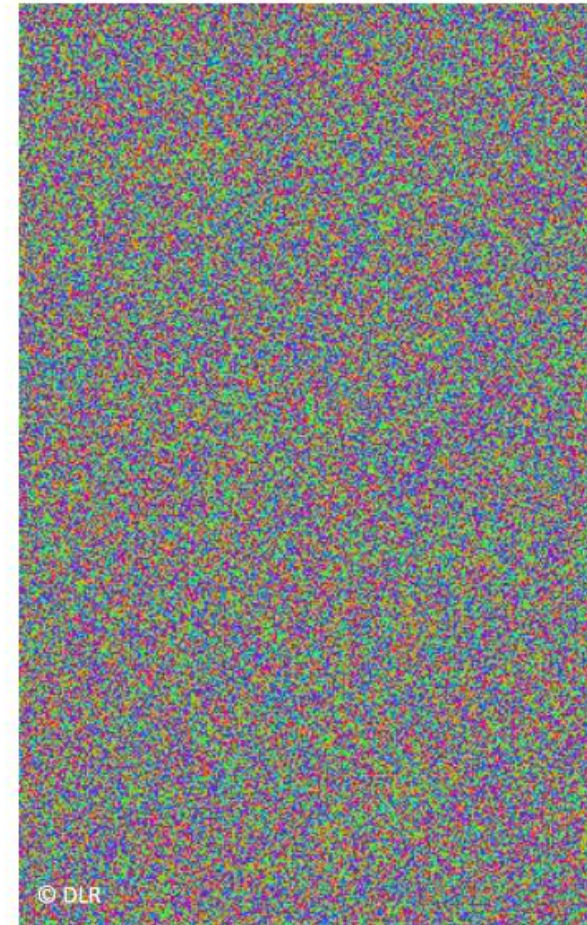# Synthetic Aperture Radar Interferometry (InSAR)

Amplitude and phase

A complex SAR image can be decomposed into ...
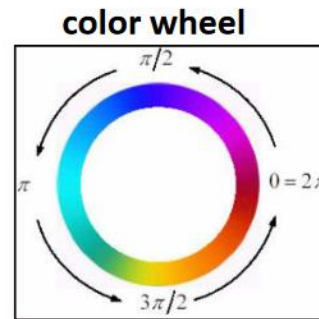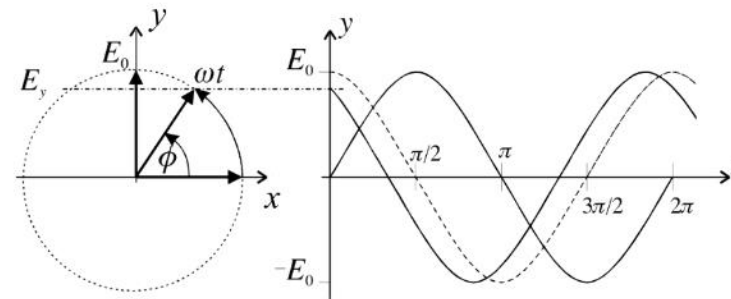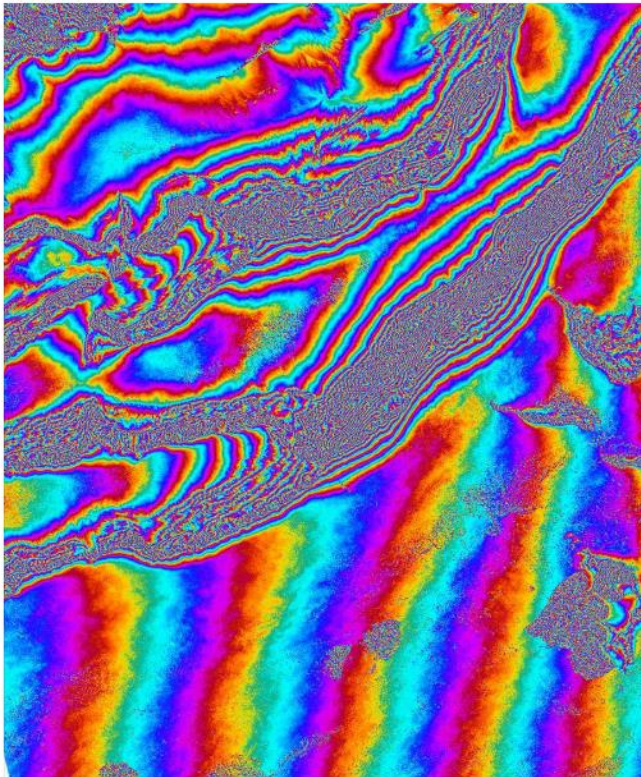
Amplitude & Phase

© DLR

© DLR

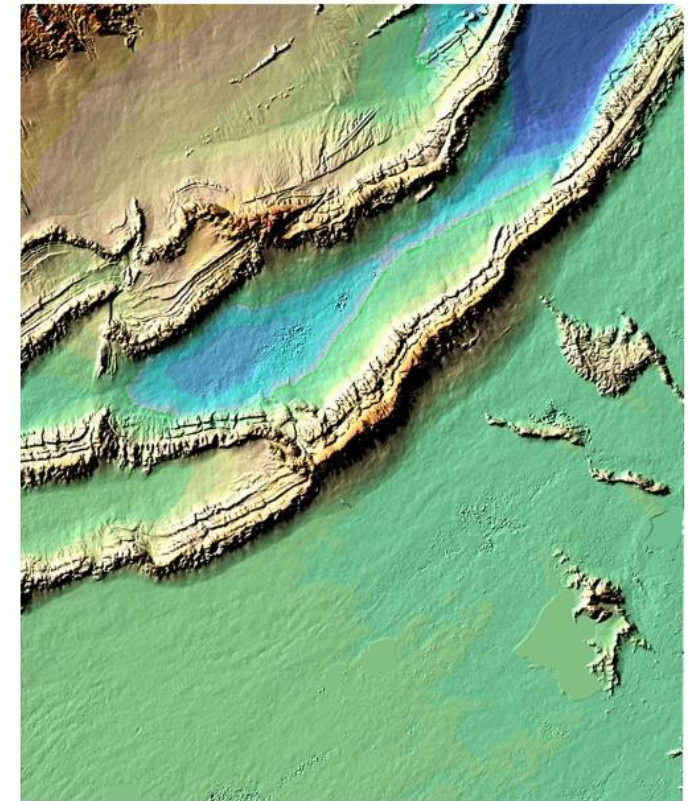# Synthetic Aperture Radar Interferometry (InSAR)

Phase to elevation (DEM)

Interferometric phase
Bachu, China
approx. 100 km × 80 km

color wheel

Phase is always ambiguous w.r.t. integer multiples of 2π
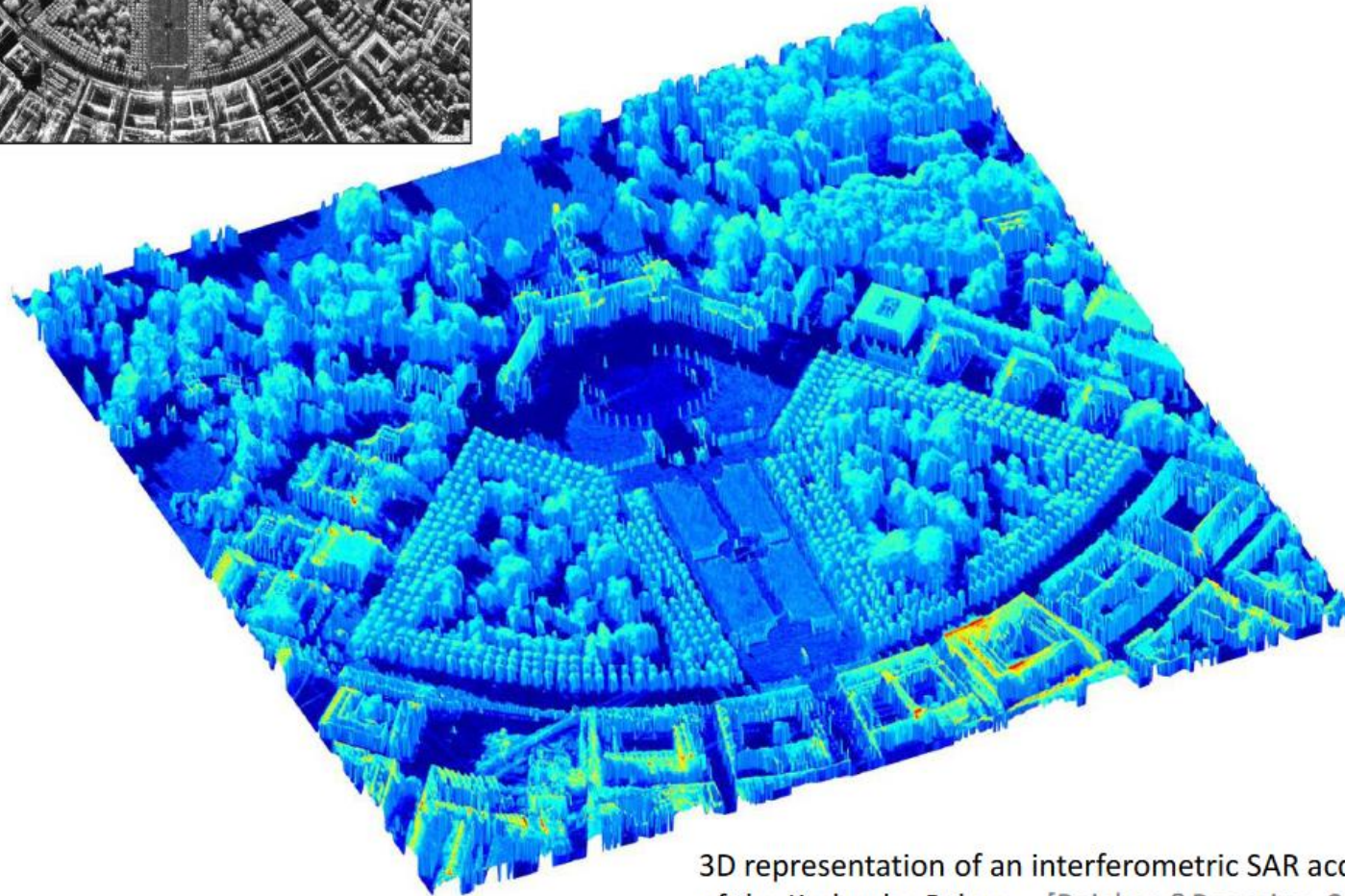→ phase unwrapping required!

Final DEM

Synthetic Aperture Radar Interferometry (InSAR)

Trees acquired at superhigh resolution (X-band)
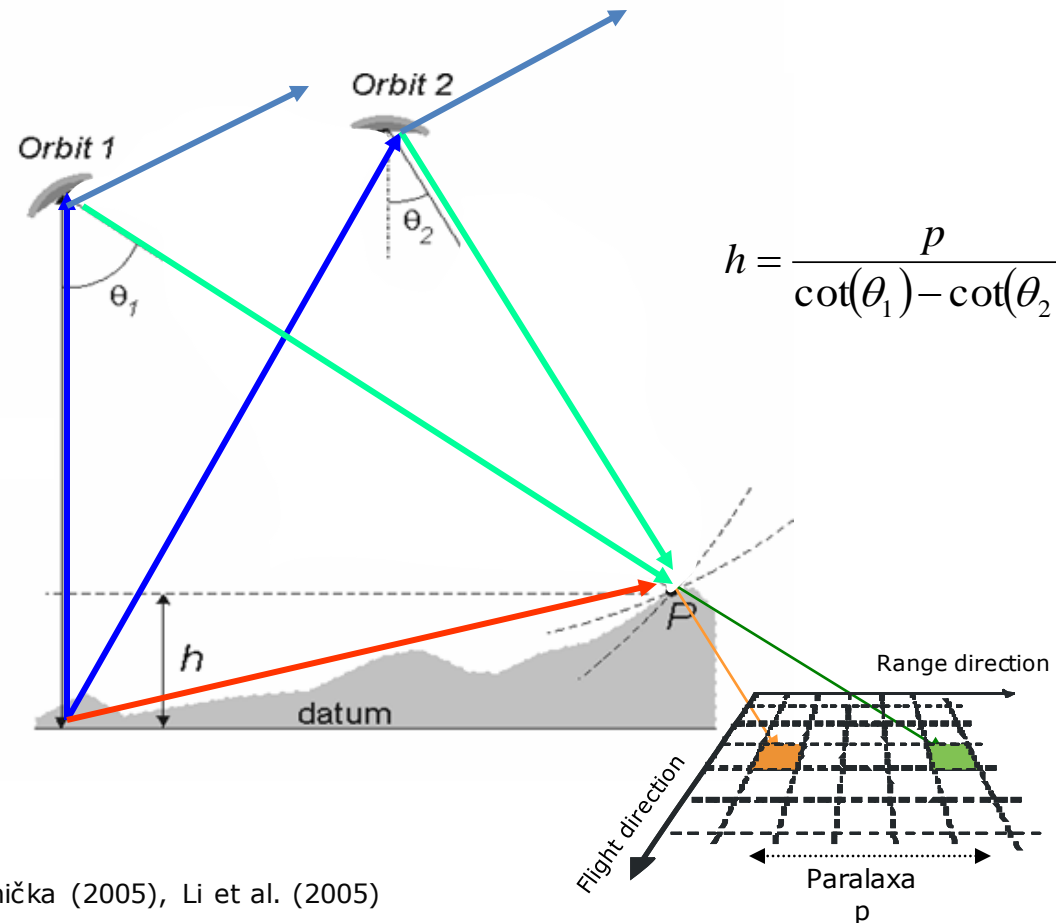
3D representation of an interferometric SAR acquisition of the Karlsruhe Palace   [Reigber &Roessing, 2008]

Synthetic Aperture Radar Interferometry (InSAR)

Methods of image analysis

Radargrametry

The principle of **measuring the parallax** of point P using SAR stereo images.

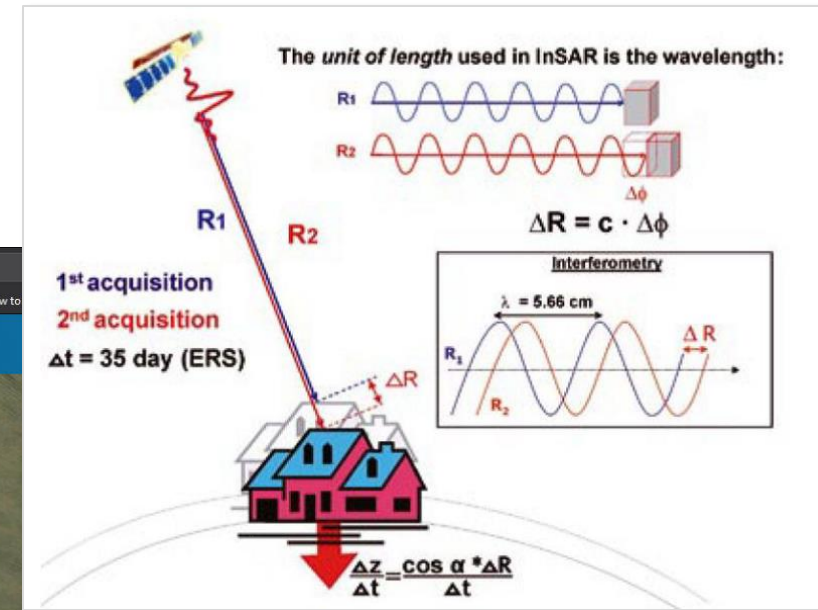$$h = \frac{p}{\cot(\theta_1) - \cot(\theta_2)}$$

Kianička (2005), Li et al. (2005)

Synthetic Aperture Radar Interferometry (InSAR)

Methods of image analysis

Persistent scatter SAR interferometry


https://portal.remotio.space/#/insar

Persistent scatter SAR interferometry PSInSAR

- Measurement of movement on points with intense radar signal reflection does not involve using all pixels of the radar record, as in D-InSAR. Many pixels in D-InSAR may have unstable coherence of reflected radiation over time (reflectivity changes over time) due to variations in moisture and vegetation growth.

- Objects that consistently reflect microwaves well are found naturally (rock outcrops, rocky walls) or artificially (roofs, buildings, building corners, antennas, pipes).

- This method determines the phase change of waves due to slight movement of the signal reflector

- It enables the determination of surface deformation/object movement with millimeter precision.

- Compared to GNSS measurements, PSInSAR offers the advantage of monitoring a large number of points over a larger area at a lower cost.

InSAR for high-resolution DEM generation

- A Digital Elevation Model (DEM), also referred to as the Digital TerrainModel (DTM) is a digital model or three dimensional (3D) representation of the land surface elevation with respect to any reference datum.

- Technically a DEM contains only the elevation information of thesurface, free of vegetation, buildings and other non ground objects with reference to a datum such as Mean Sea Level (MSL).
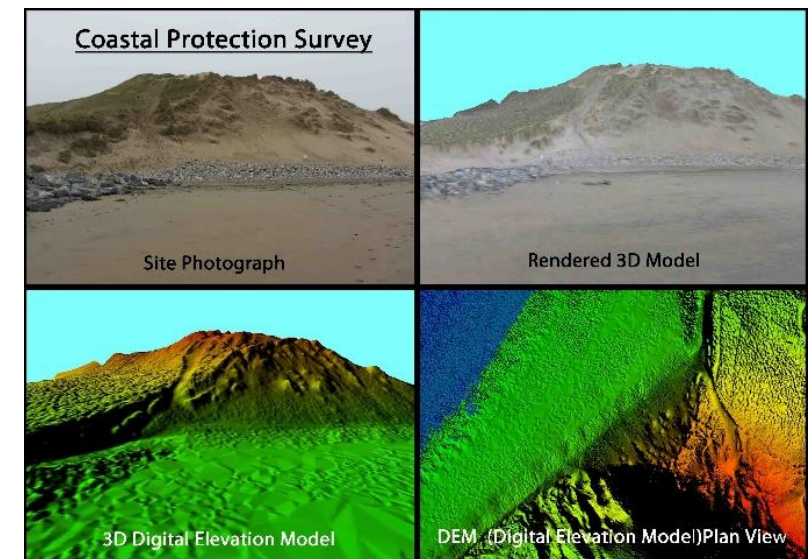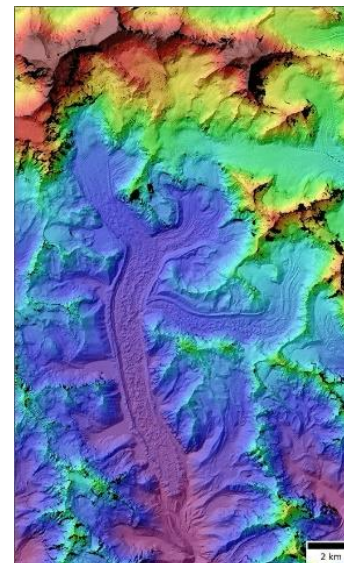

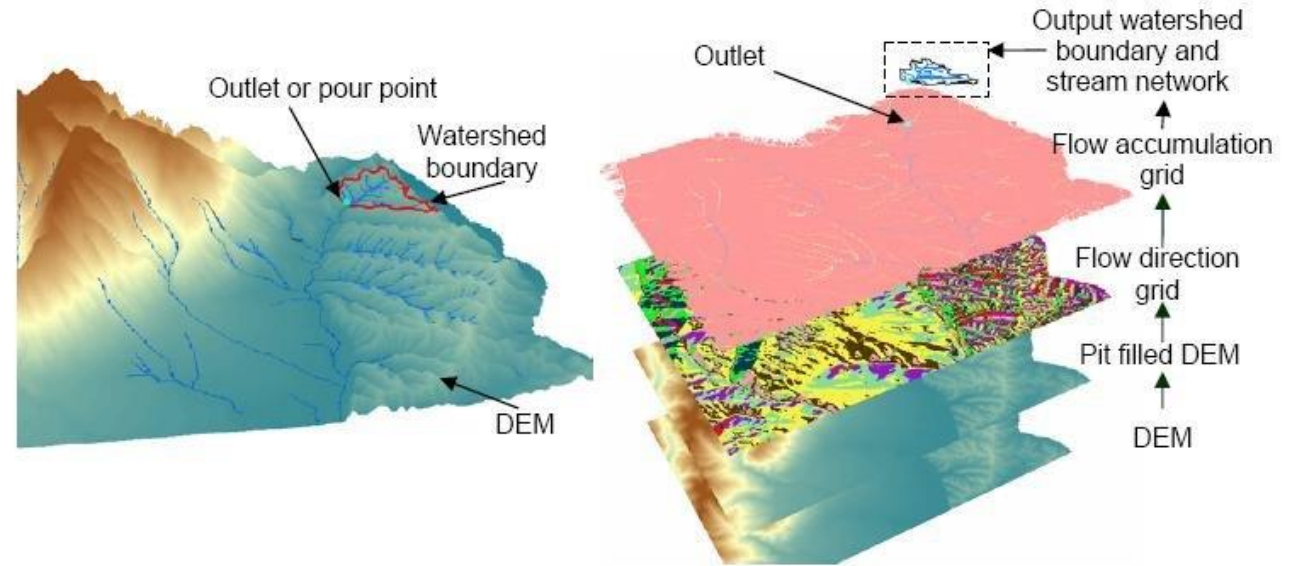Source: https://www.surveyinggroup.com/dsm-dem-dtm-elevation-models-in-gis/
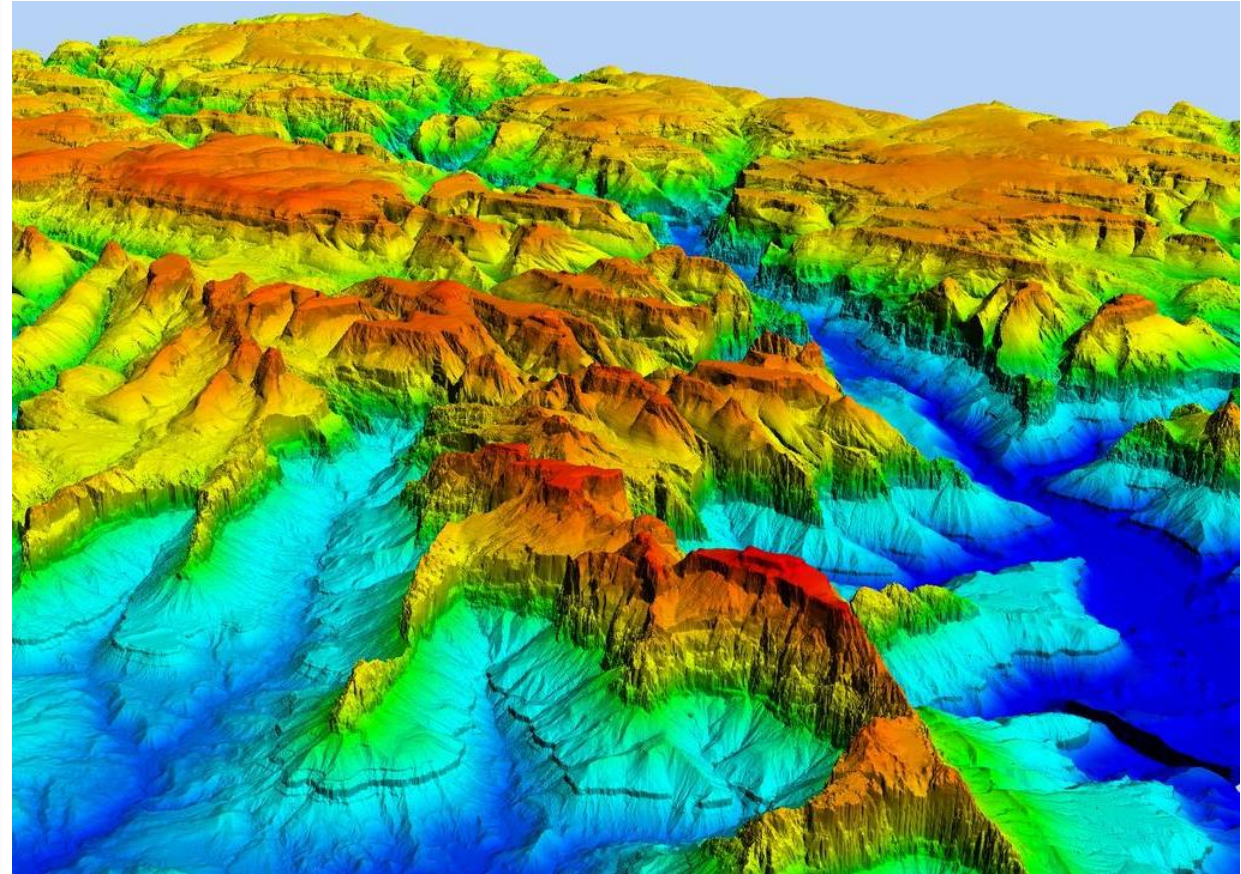
Use of DEM

Digital Elevation Models (DEMs) are used in many applications in the context of earth sciences:

- Topographic mapping

- Environmental modelling

- Rainfall-runoff studies

- Watershed management

- Coastal management

- Landslide hazard zonation

- Seismic source modelling

- etc. ...

Types of DEM

- **Digital Terrain Models (DTM)** - the height of the earth's surface in relation to otherpoints

- **Digital Elevation Models (DEM)** - the height of the earth's surface specifically in relation to a standard global/regional elevation (normally sea level).

- **Digital Surface Models (DSMs)** - the height of the surface including objects (buildings, vegetation, etc).
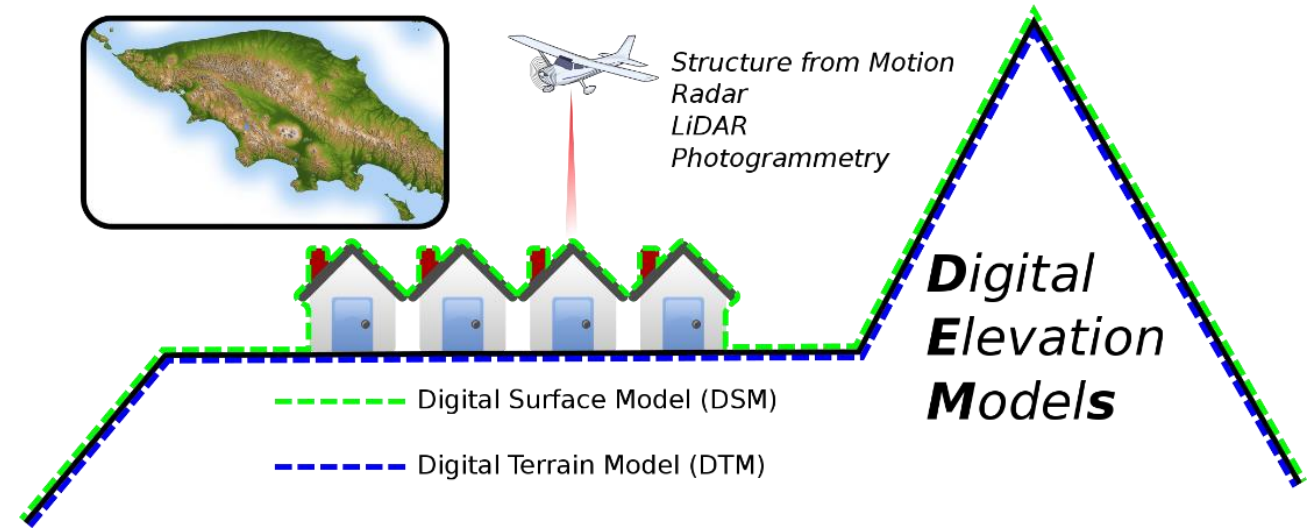
Structure from Motion
Radar
LiDAR
Photogrammetry

Digital Surface Model (DSM)

Digital Terrain Model (DTM)

Digital Elevation Models

DEM Retrieval

- DEMs are generated by using the elevation information from several points spaced at regular or irregular intervals.

- DEMs are commonly built using data collected using remote sensing techniques such as SAR, photogrammetry and LIDAR, but they may also be built from land surveying.
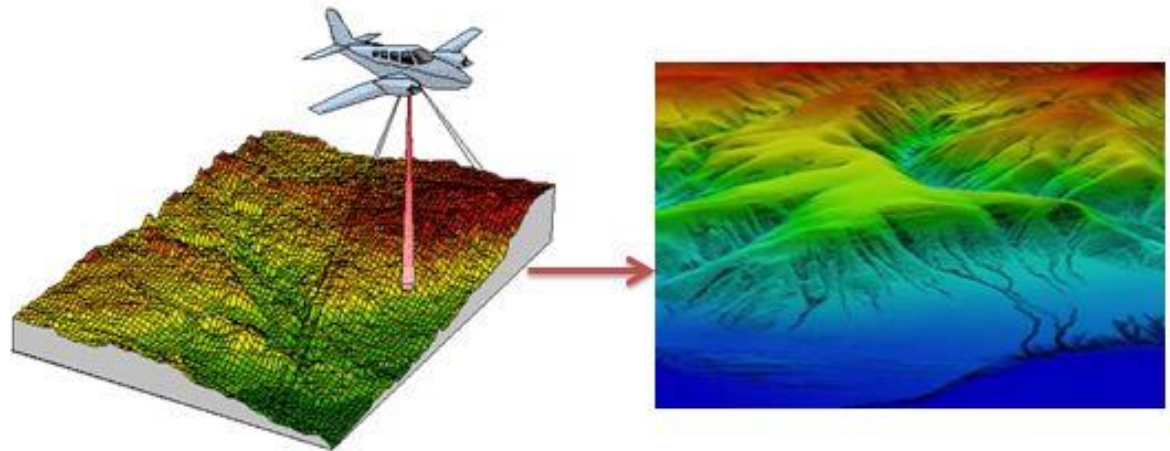
DEM Quality

The quality of a DEM is a measure of how accurate elevation is at each pixel (absolute accuracy) and how accurately is the morphology presented (relative accuracy).

Several factors play an important role for quality of DEM-derived products:

- terrain roughness
- sampling density
- grid resolution or pixel size
- Interpolation algorithm
- vertical resolution
- terrain analysis algorithm
- reference 3D products include quality masks that give information on the coastline, snow, etc.

5 m   25 m   50 m   100 m
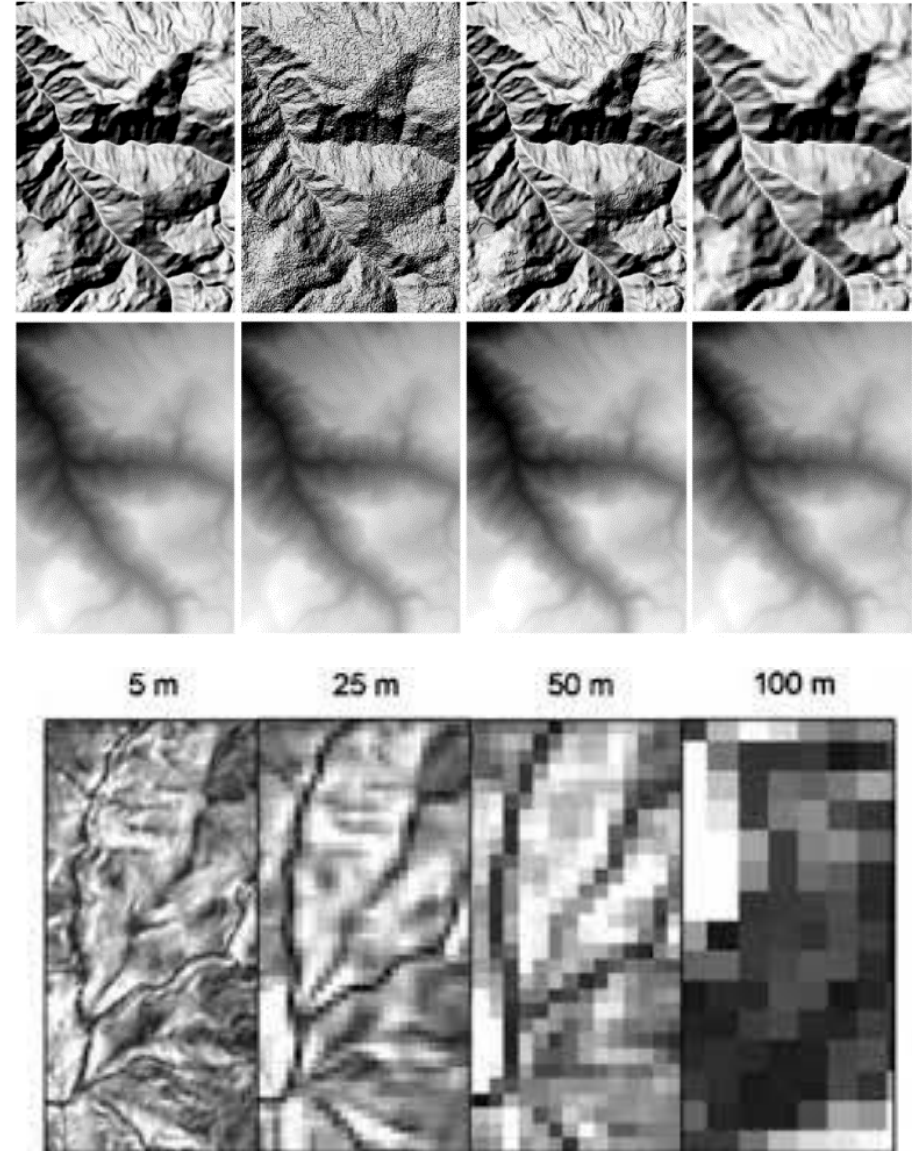
Free DEM data sources

1. Space Shuttle Radar Topography Mission (SRTM)
- 1-arc second global digital elevation model with a spatial resolution of about 30 meters covering most of the world with absolute vertical height accuracy of less than 16m
- SRTM DEM data is being howsed on the USGS EarthExplorer server

**2. ASTER Global Digital Elevation Modal**
- A joint operation between NASA and Japan was the birth of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
- ASTER GDEM boasted a global resolution of 90 meters with a resolution of 30 meters in the United States
- You can download the ASTER DEM data for free from the USGS EarthExplorer

3. JAXA's Global ALOS 3D World
- 30-meter spatial resolution digital surface model (DSM) constructed by the Japan Aerospace Exploration Agency's (JAXA)
- The most precise global-scale elevation data at this time using the Advanced Land Observing Satellite "DAICHI" (ALOS)
- The DSM was generated using stereo mapping (PRISM) for worldwide topographic data with its optical stereoscopic observation
- In order to obtain this highly accurate DSM, you have to register online through the "JAXA Global ALOS portal"

4. Indian Portal Bhuvan
- CARTOSAT 1 and 2 derived stereo DEM, available for entire India freely
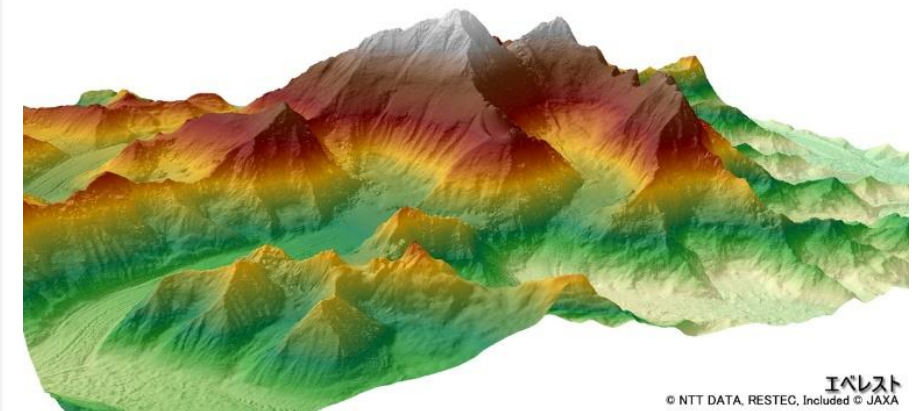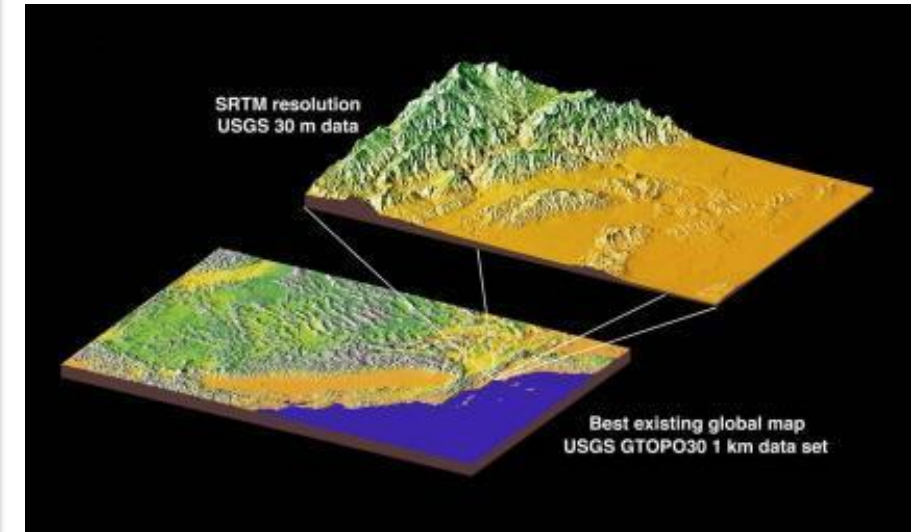
Retrieval of DEM using Sentinel-1 radar data

- The launch of Sentinel-1 by the European Space Agency (ESA) in 2014 marked the beginning of a new era in openly available radar data under the Copernicus Programme.

- This C-band radar mission, comprising Sentinel-1A (S1A) and Sentinel-1B (S1B), provides data at a spatial resolution of 5 × 20 m (single look complex).

- While primarily designed for differential radar interferometry (DInSAR) to measure surface deformations, its capability to derive Digital Elevation Models (DEMs) is limited. Despite this, studies on absolute elevations or object heights are scarce and often associated with exaggerated expectations.
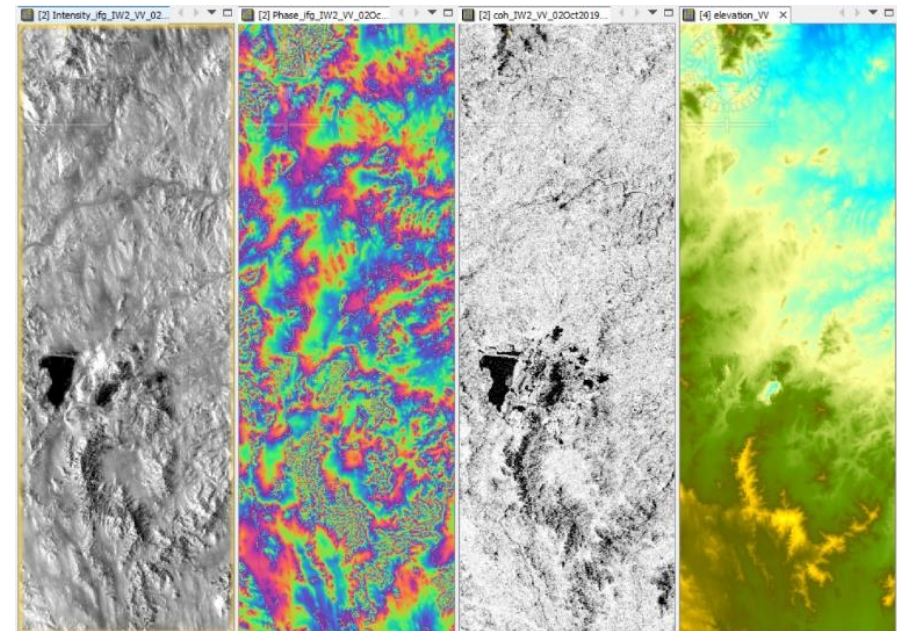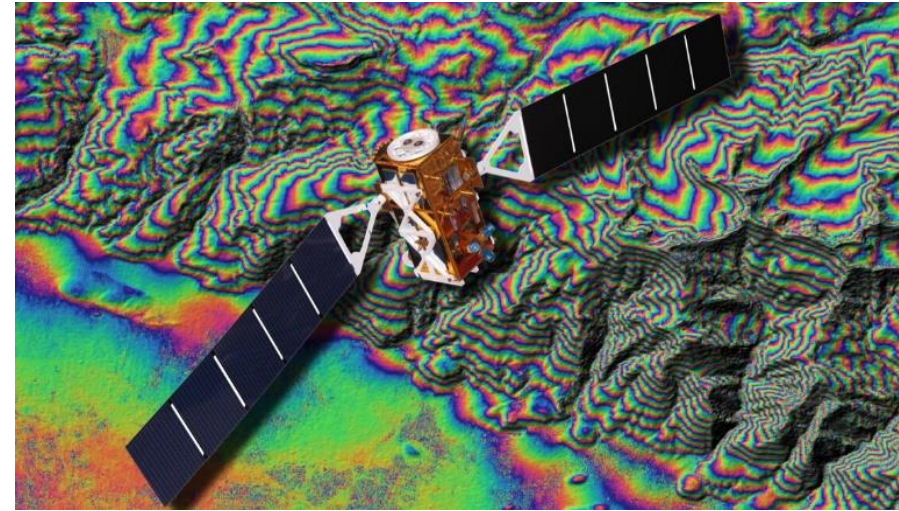
Create a DEM using Sentinel-1 radar data

This steps allow the user to create a DEM product from two Sentinel-1 SLC scenes:

- Data Pre-processing
- Coregistration
- Interferogram Formation and Coherence Estimation
- Visualize Interferometric Phase — TOPS Deburst
- Multi-looking and Phase Filtering
- Phase unwrapping and import
- Create the DEM – Convert Phase to Elevation
- Geocode the DEM
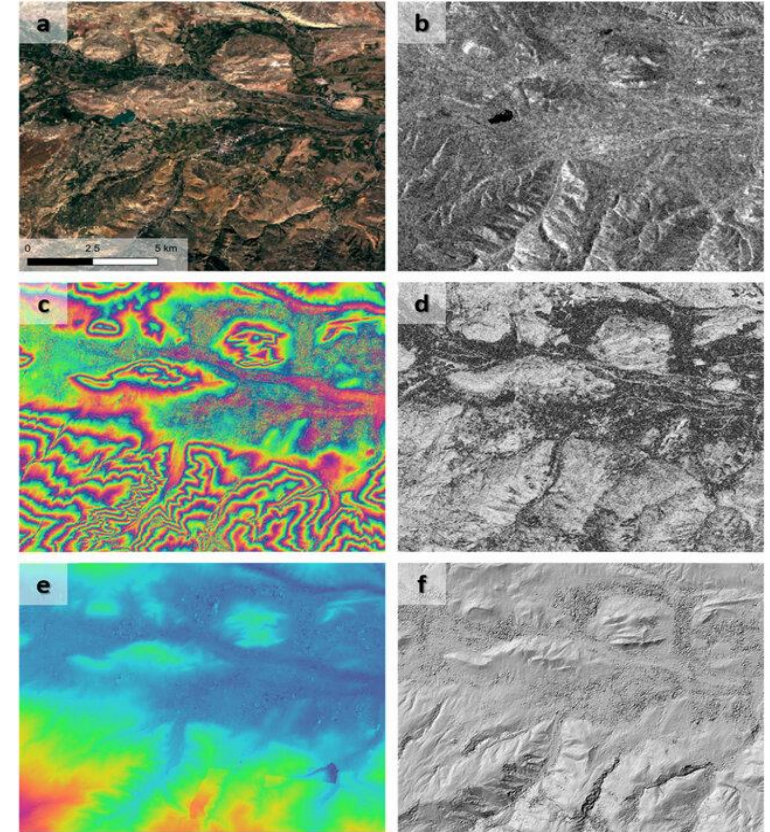
Steps of DEM generation with Sentinel-1: (a) Sentinel 2 image from 02.07.2019 (for visual reference), (b) Sentinel-1 image from 02.07.2019, (c) interferogram from 26.06.19 and 02.07.2019, (d) coherence image, (e) unwrapped interferogram, and (f) hillshade of the derived DEM.

Create a DEM using Sentinel-1 radar data

Preparation

Choosing appropriate image pairs is essential for successful DEM generation. Key considerations include:

1.Minimizing Temporal Decorrelation: Select image pairs with a short temporal baseline to reduce the risk of phase decorrelation. Longer time gaps between acquisitions can lead to out-of-phase signals, particularly over vegetation, water, or areas with changing moisture conditions.

2.Optimal Perpendicular Baseline: The distance between satellite positions during image acquisition should ideally be between 150 and 300 meters. This ensures sufficient angle between acquisitions, allowing for the retrieval of topographic variations through parallax-like effects.

3.Considerations for Sentinel-1: Sentinel-1 was primarily designed for deformation retrieval (DInSAR) rather than DEM generation, resulting in predominantly short baselines, often below 30 meters. Finding image pairs with short temporal baselines and large perpendicular baselines can be challenging.

4.Monitoring Atmospheric Conditions: Select images acquired during dry periods to minimize phase delays caused by atmospheric water vapor. Avoid selecting images acquired during rainfall events, as they may decrease measurement quality.

Create a DEM using Sentinel-1 radar data

Preparation
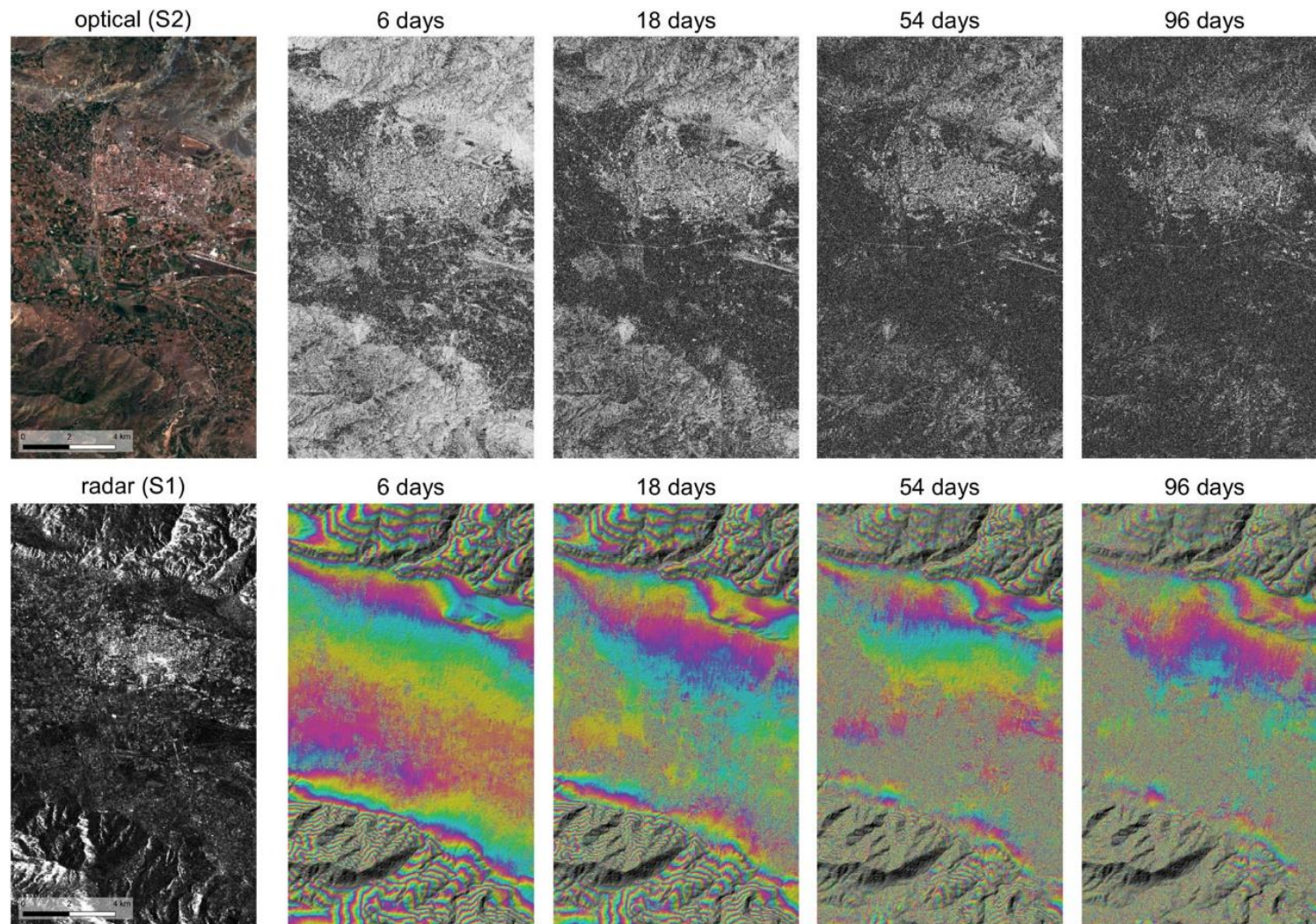
Coherence (top) and interferograms (bottom) for selected temporal baselines. For reasons of visualization, the interferograms are combined with a hillshade representation retrieved from the SRTM data.

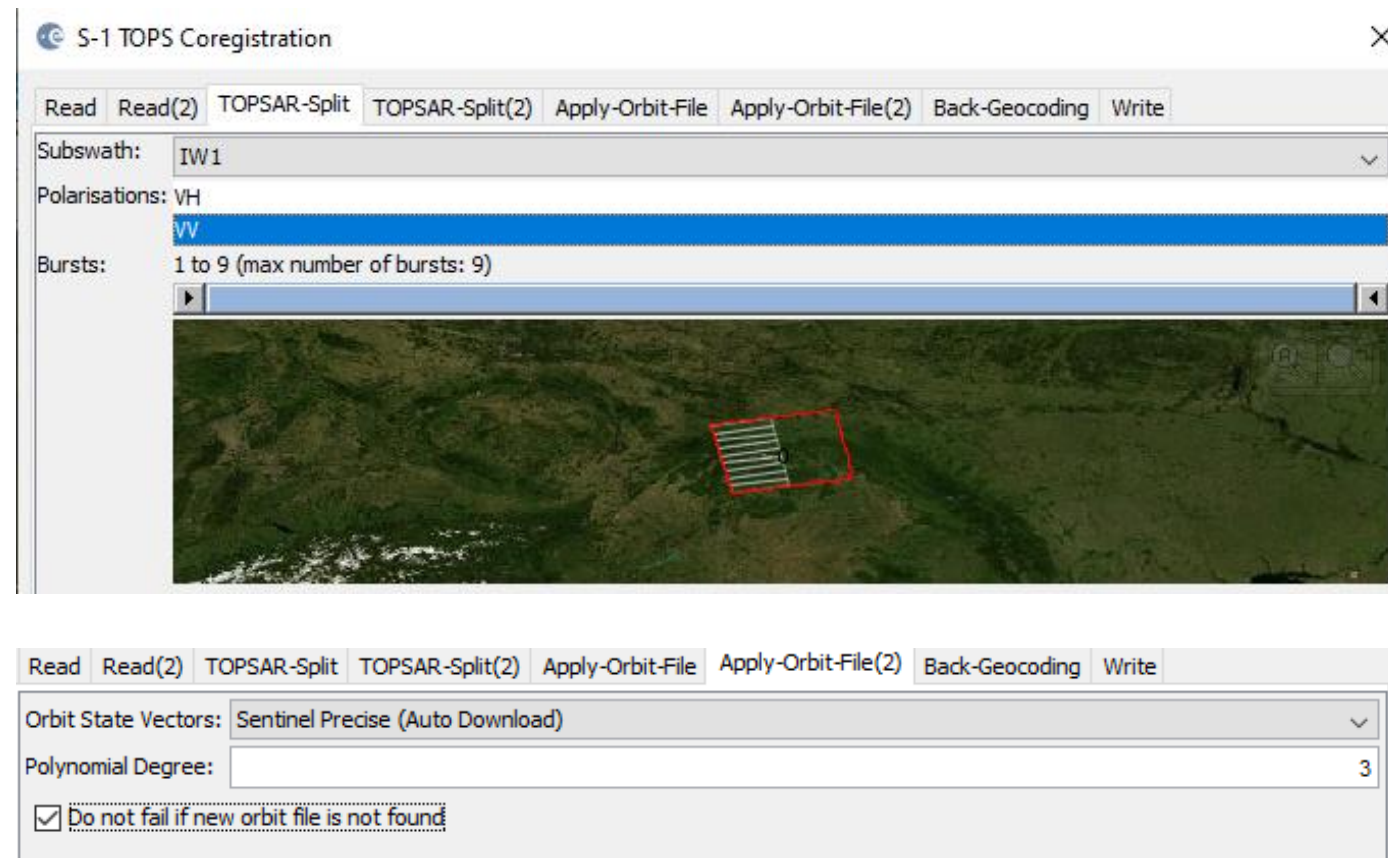# Create a DEM using Sentinel-1 radar data

Coregistration

In order to utilize the phase difference between the acquisitions, it is necessary to first create a stack containing both products. Coregistration involves aligning both products with sub-pixel accuracy using image statistics.

TOPS Split

The S-1 TOPS Split function is utilized to filter and select specific bursts required for analysis.

Applying Orbit Information

Orbit auxiliary data comprises details regarding the satellite's position at the time of data acquisition. SNAP automatically incorporates it into the metadata using the Apply Orbit File operator.

Create a DEM using Sentinel-1 radar data

Coregistration

Back Geocoding and Enhanced Spectral Diversity

- The S-1 Back Geocoding operator, aligns the two split products utilizing orbit details included in the preceding step and data from a digital elevation model (DEM) obtained through SNAP.

- To enhance the coregistration quality, the S-1 Enhanced Spectal Diversity (ESD) operator is utilized. It implements range and azimuth shift corrections to the secondary image.
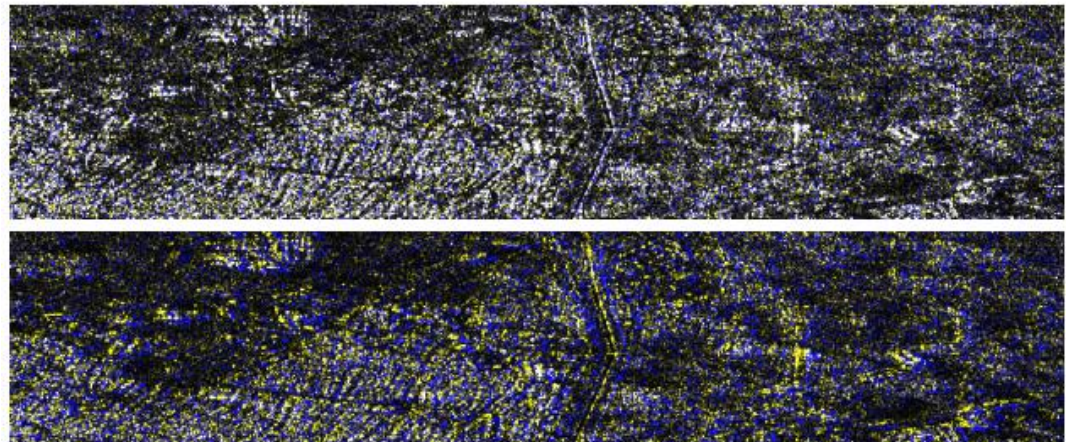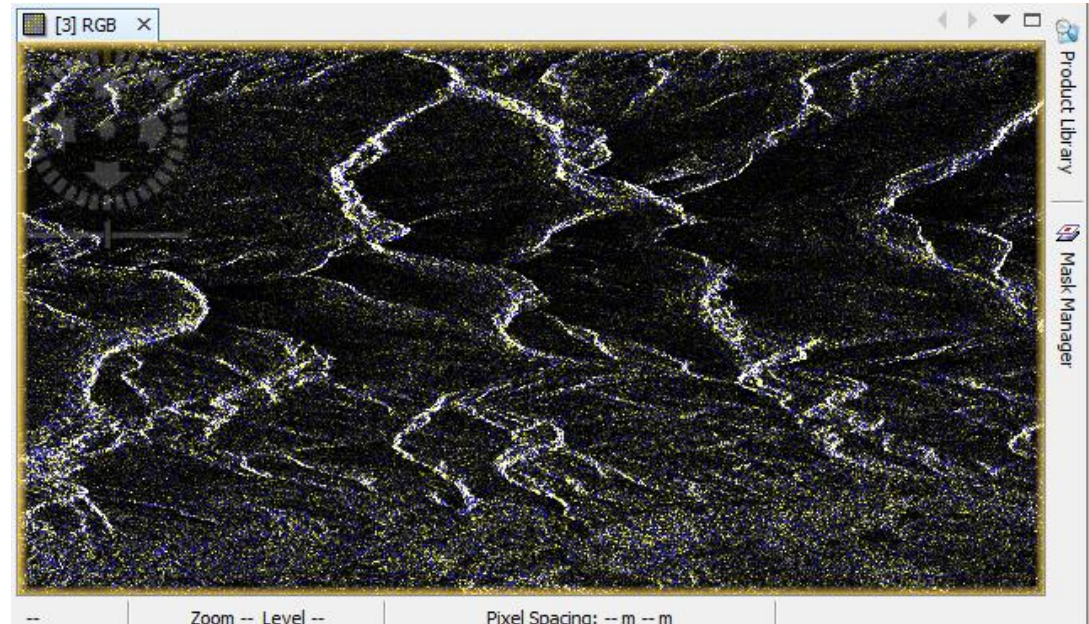

Figure 15: Successful (top) vs. failed (bottom) coregistration in an RGB image

Create a DEM using Sentinel-1 radar data

Forming an Interferogram

Forming a raw interferogram

An interferogram is created by multiplying the reference image by the complex conjugate of the secondary image. The amplitude of both images is multiplied, while the phase indicates the phase difference between them. The interferometric phase of each SAR image pixel is determined solely by the variance in travel paths from the two SARs to the resolution cell being considered. Thus, the resulting interferogram displays phase fluctuations.
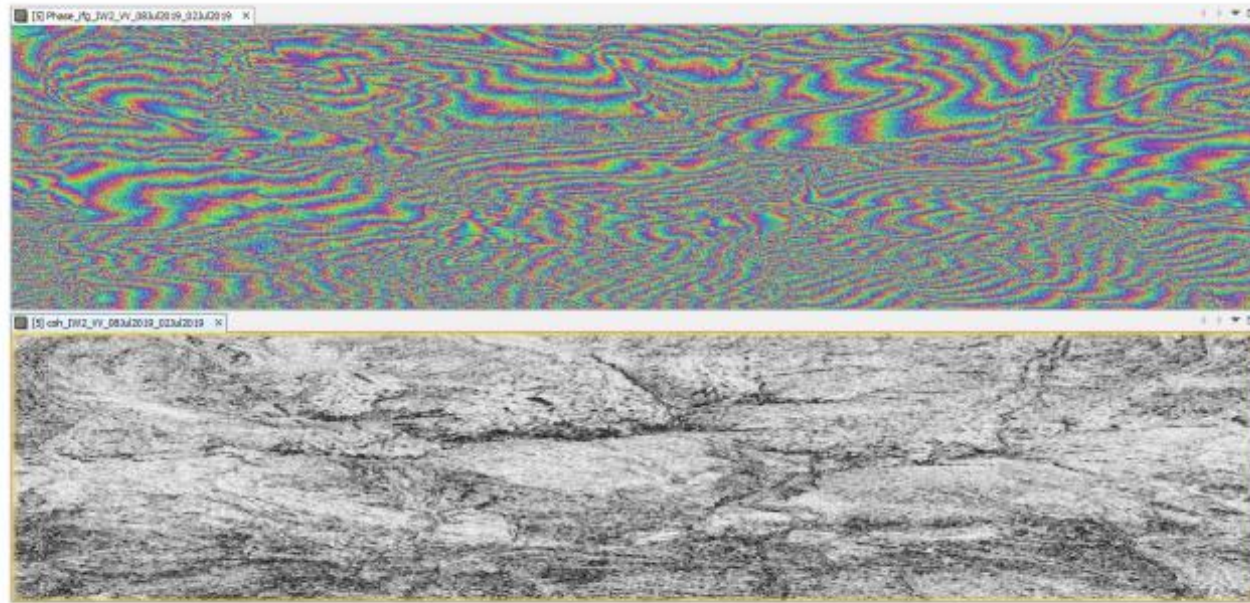

Figure 18: Interferogram (top) and coherence (bottom)

Create a DEM using Sentinel-1 radar data

Tops Debursting

The next stage in interferometry using Sentinel-1 TOPS mode (IWS) data involves "debursting" or merging the bursts to remove the seamlines, a step not required with Sentinel-1 or other stripmap SAR data.

Goldstein Phase Filtering

Interferometric phase can be corrupted by various sources - noise from temporal and geometric decorrelation, volume scattering, processing errors, etc. However, the quality of fringes present in the interferogram can be improved by employing specialized phase filters like the Goldstein filter. This filter utilizes Fast Fourier Transformation (FFT) to enhance the signal-to-noise ratio of the image.
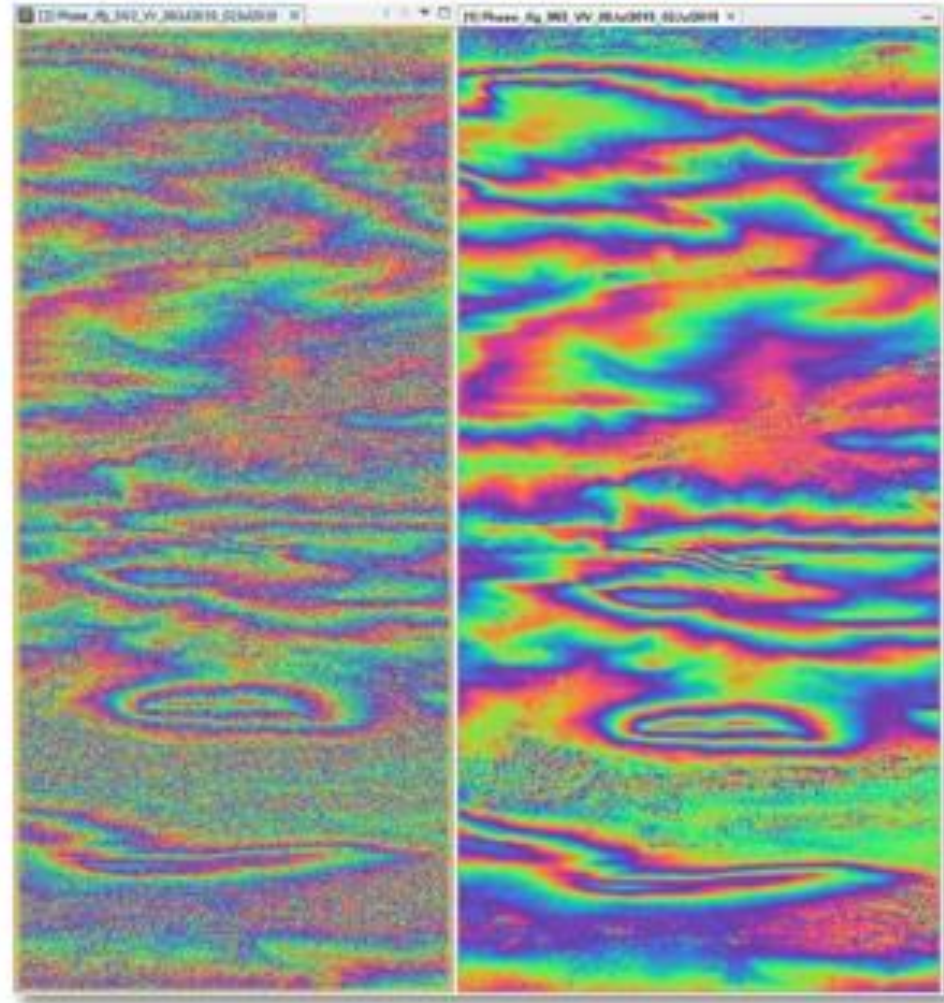

Figure 21: Interferogram before (left) and after (right) Goldstein phase filtering

Create a DEM using Sentinel-1 radar data

Create subset

In the earlier stages of processing, empty pixels along the interferogram's perimeter may have been created, particularly in regions not overlapped by both input images. To remove these sections, employ the Subset function found under Raster. This approach will also decrease processing time in subsequent stages, especially when the analysis is concentrated on a specific area rather than the entire scene.
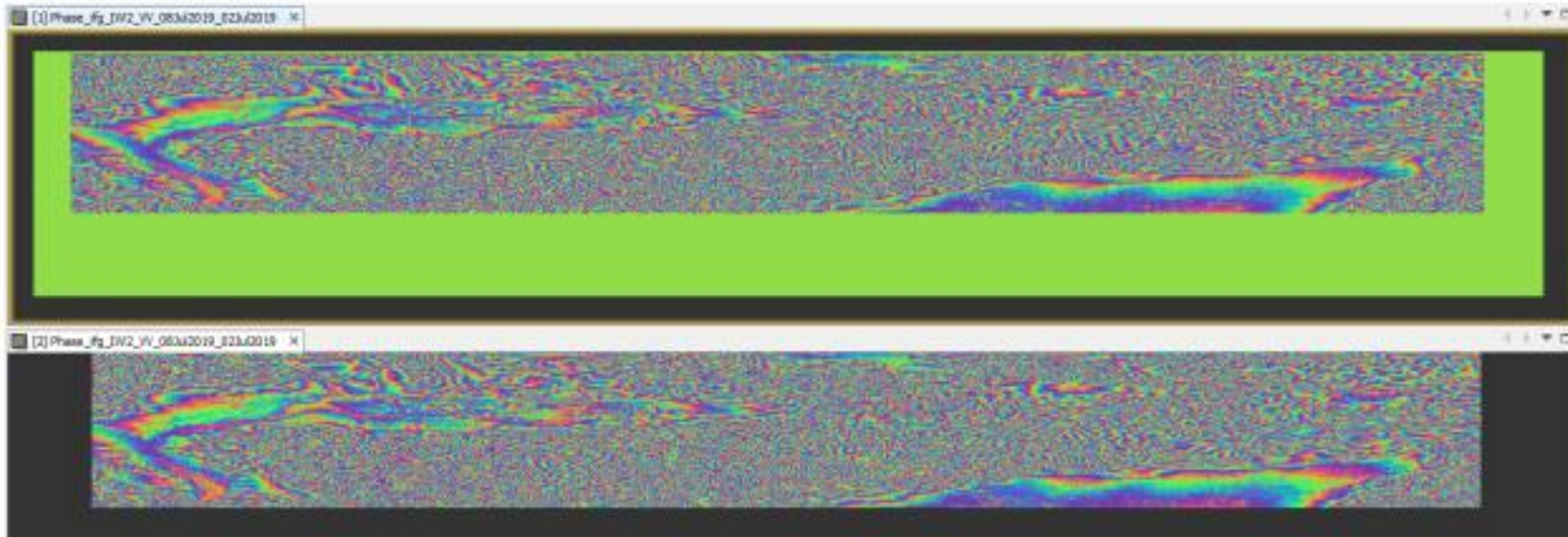

Figure 23: Interferogram before (top) and after (bottom) creating the subset

Create a DEM using Sentinel-1 radar data

Phase unwrapping

- In order to correlate the interferometric phase with topographic height, the phase must undergo an unwrapping process.

- 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

- Once unwrapped, the phase variation between two points on the flattened interferogram provides a measurement of the actual altitude variation

- Consequently, unwrapped results should be interpreted as relative height or displacement between pixels in two images.
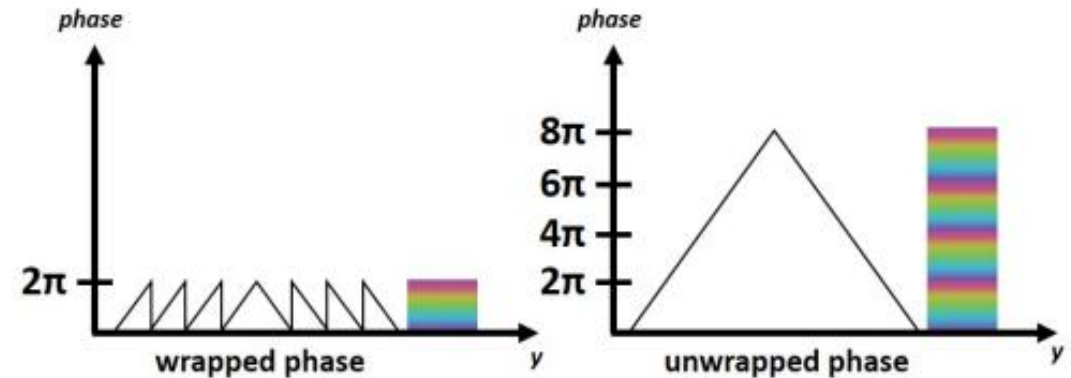
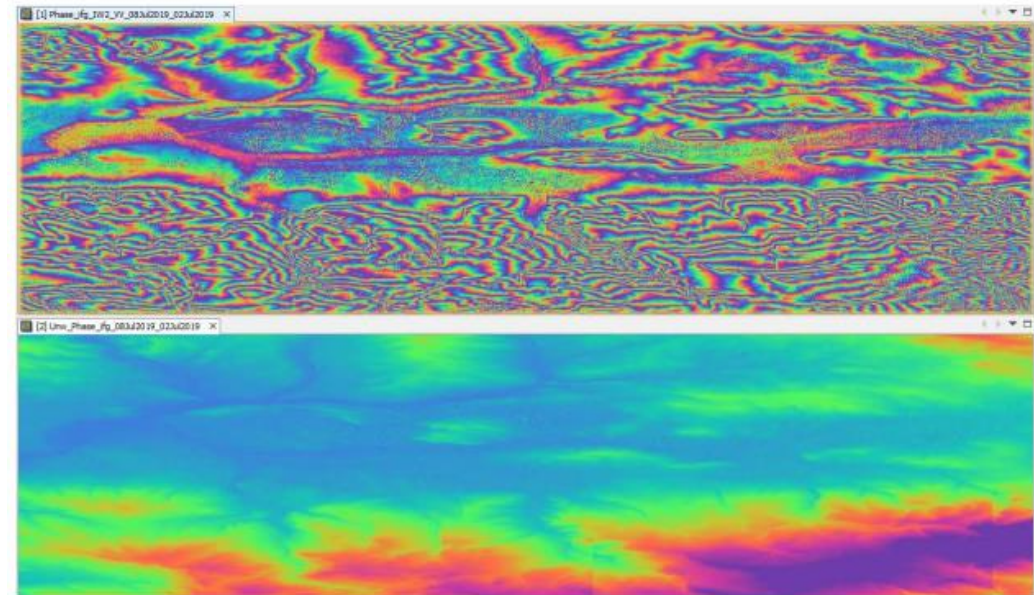Figure 24: Principle of phase unwrapping

Figure 28: Phase before (top) and after (bottom) unwrapping

Create a DEM using Sentinel-1 radar data

Phase to elevation

- The unwrapped phase data is now a continuous raster that has to be converted into a metric measure - to achieve this conversion from radian units to absolute heights is employed

- This operation translates the phase values into surface elevations along the line-of-sight (LOS) in meters. To ensure accuracy, a Digital Elevation Model (DEM) is utilized to align the elevation values correctly.
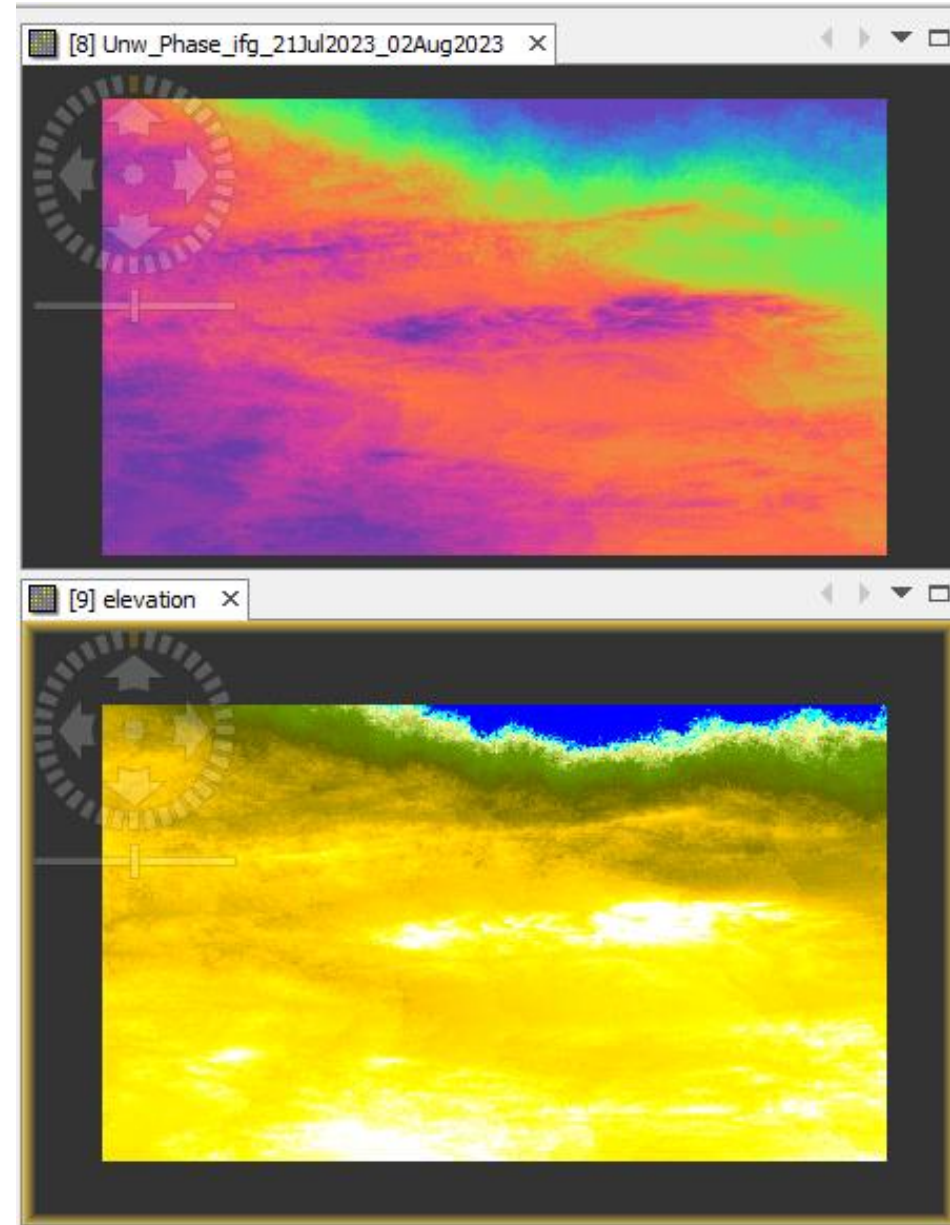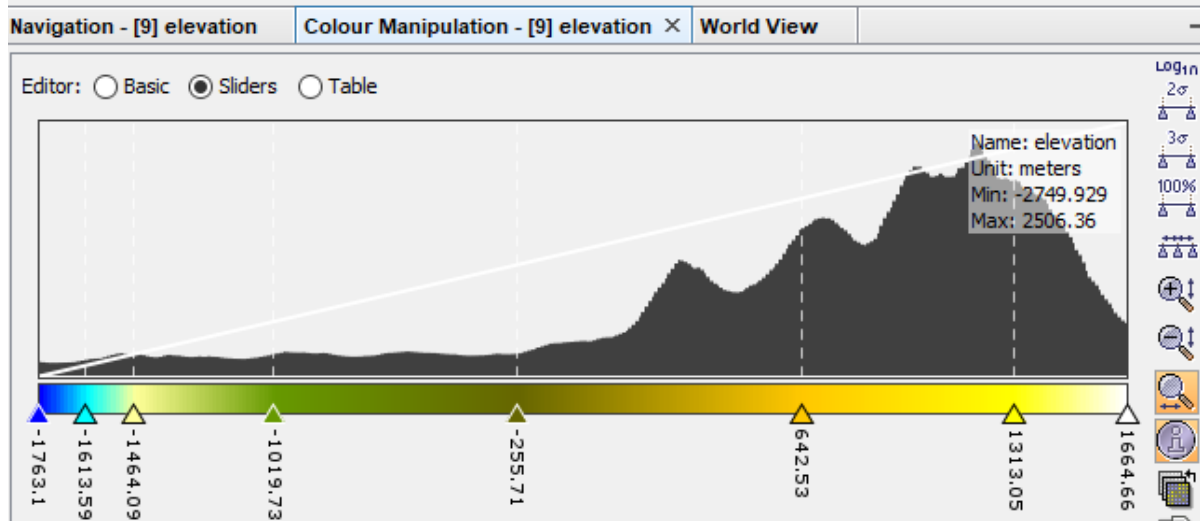
Create a DEM using Sentinel-1 radar data

Terrain correction

- Involves geocoding the image by rectifying SAR geometric distortions, such as foreshortening, layover, and shadow, with the aid of a digital elevation model (DEM), resulting in a map-projected product
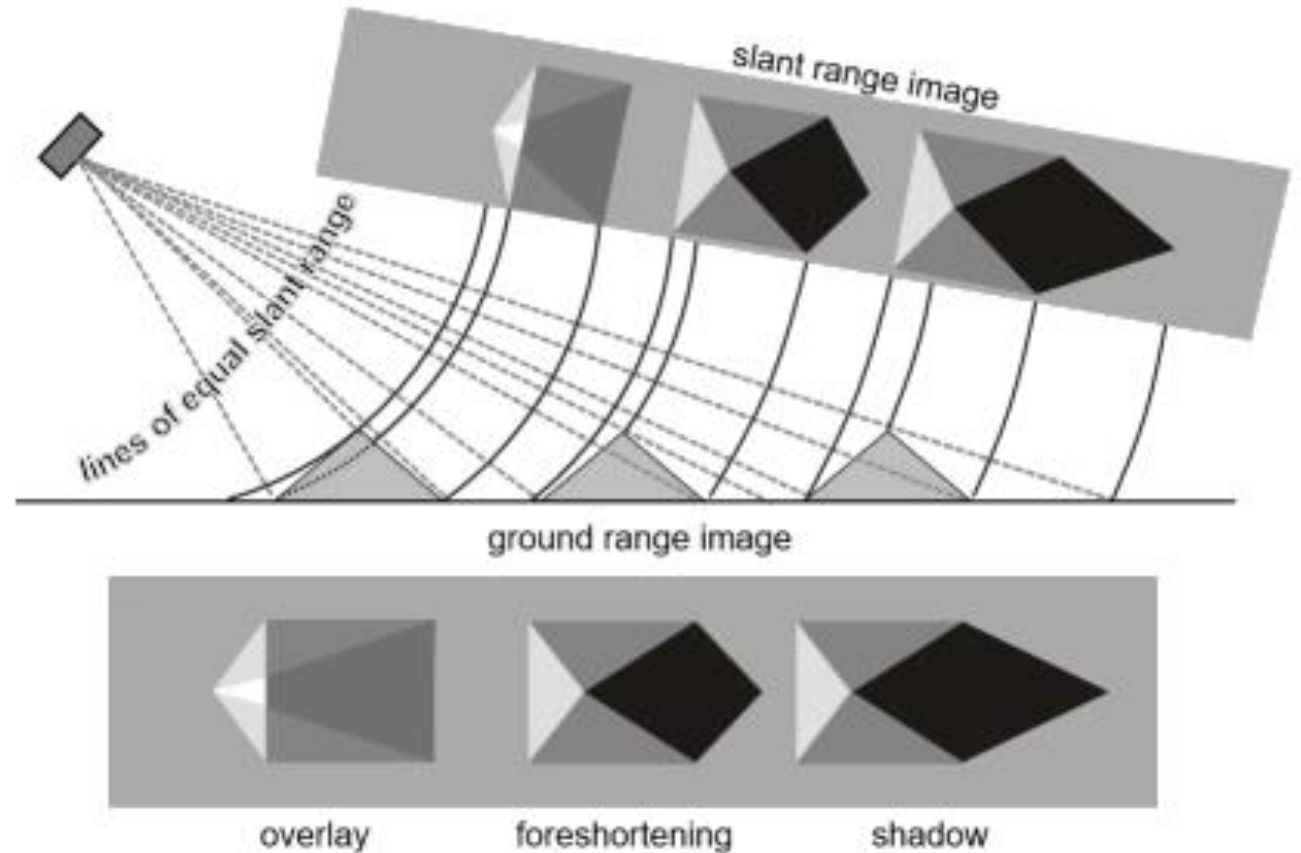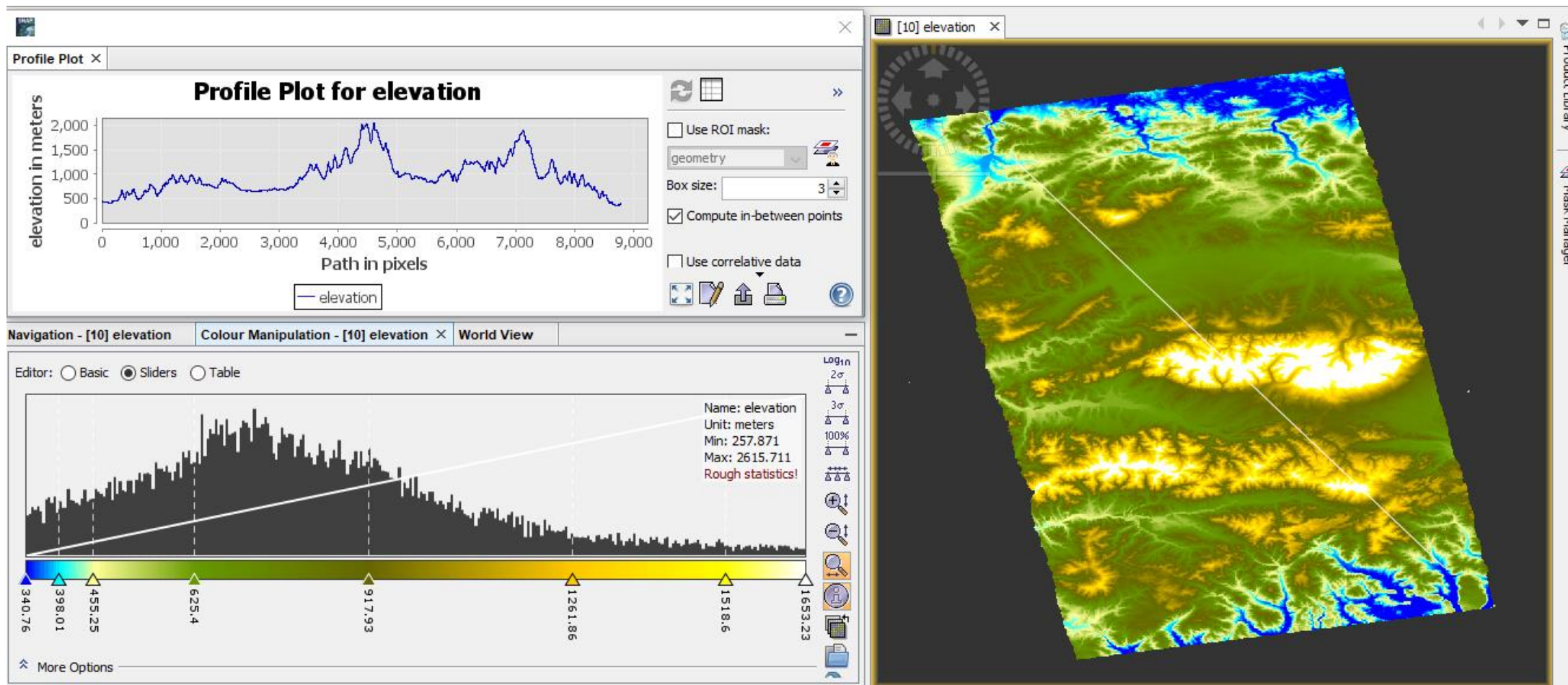

Figure 33: Geometric distortions in radar images (Braun 2019)

# Create a DEM using Sentinel-1 radar data

Final DEM

- A digital elevation model (DEM) that can be exported to other GIS softwares

Tradeoffs of DEMs created with Sentinel-1 C-band

- Unfortunately, the C-band used by Sentinel-1 doesn't penetrate through vegetation. Consequently, DEMs derived from C-band radar don't directly measure the Earth's surface but instead depict the top of the canopy. However, Sentinel-1 offers excellent temporal coverage, resulting in lower temporal decorrelation compared to previous sensors.

- L-band radar exhibits higher coherence compared to C-band radar due to less decorrelation from vegetation. Consequently, creating accurate DEMs from Sentinel-1's C-band radar is more challenging than from ALOS's L-band radar.

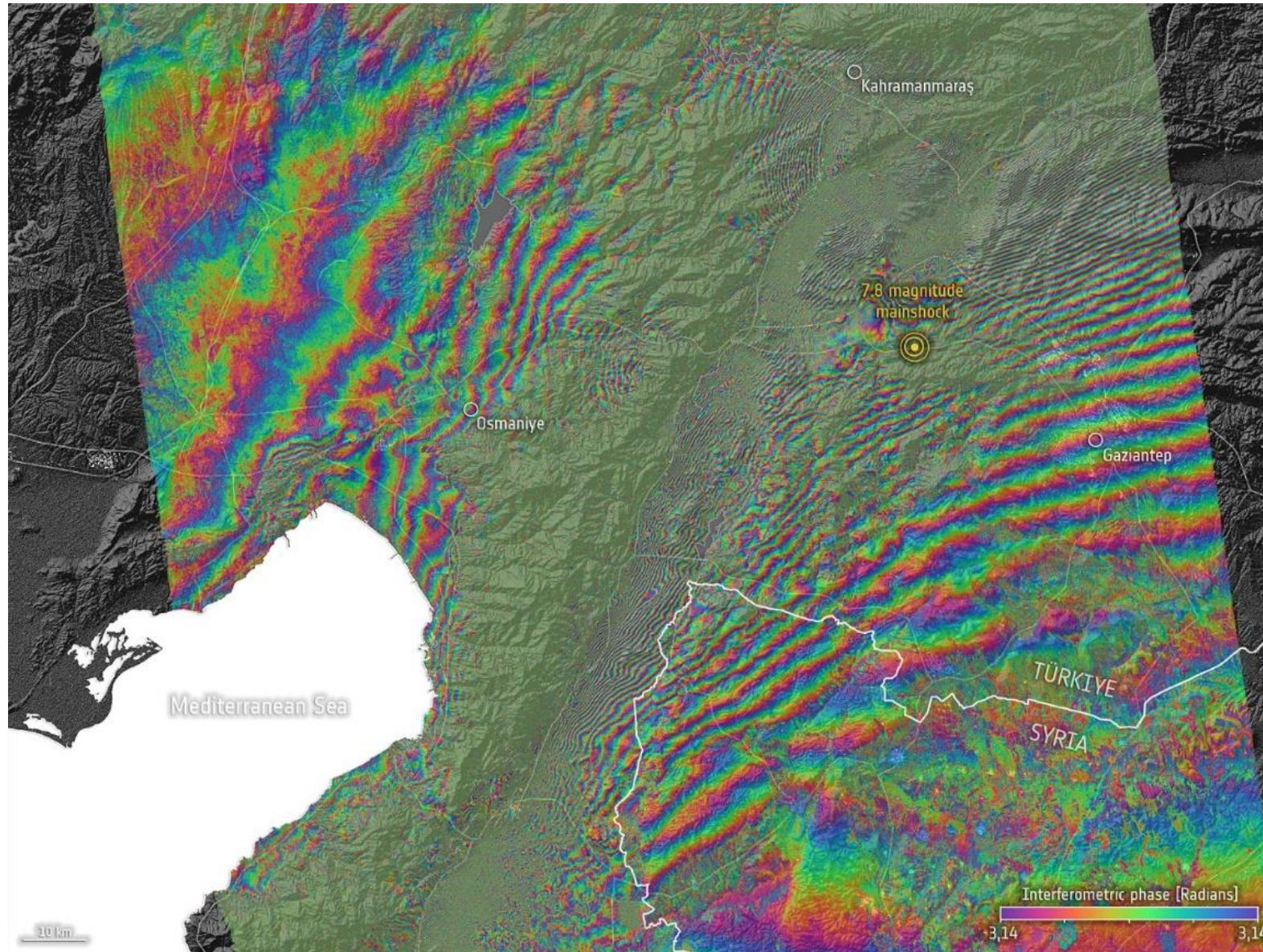**X-BAND** 3 cm   **C-BAND** 6 cm   **L-BAND** 24 cm   **P-BAND** 65 cm
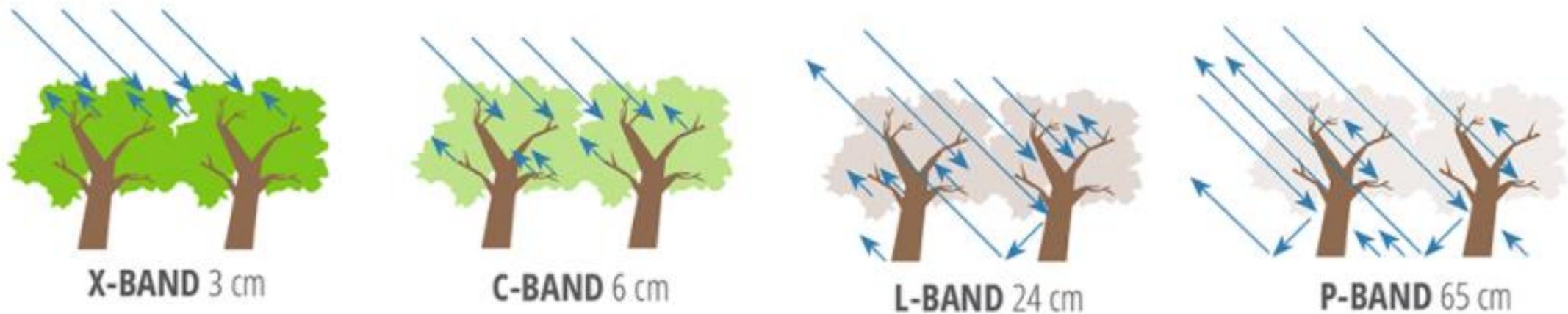
Sensitivity of SAR measurements to forest structure and penetration into the canopy at different wavelengths used for airborne or spaceborne remote sensing observations of the land surface. Credit: NASA SAR Handbook.

InSAR Applications

Source:https://www.esa.int/content
/view/embedjw/428482
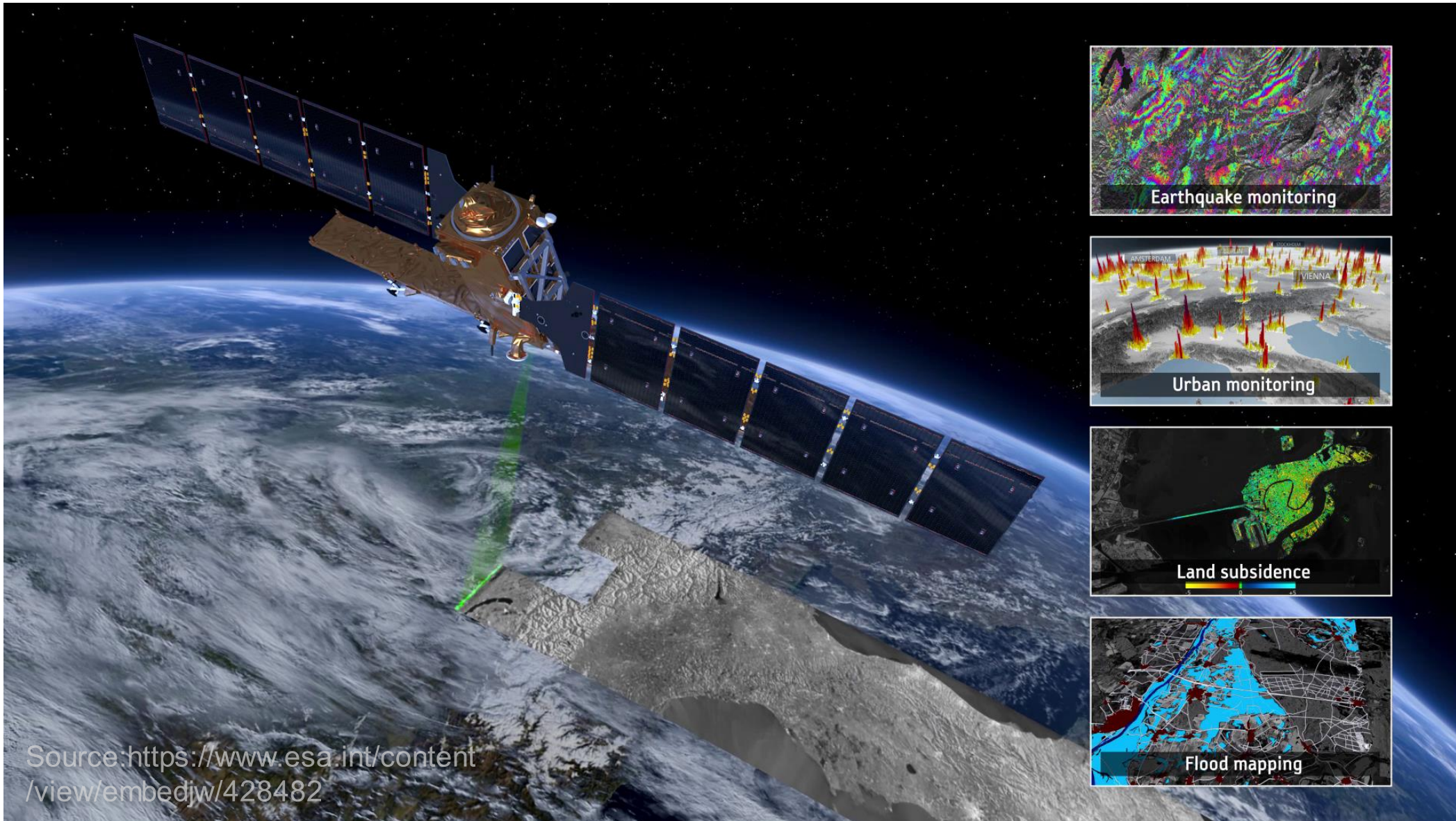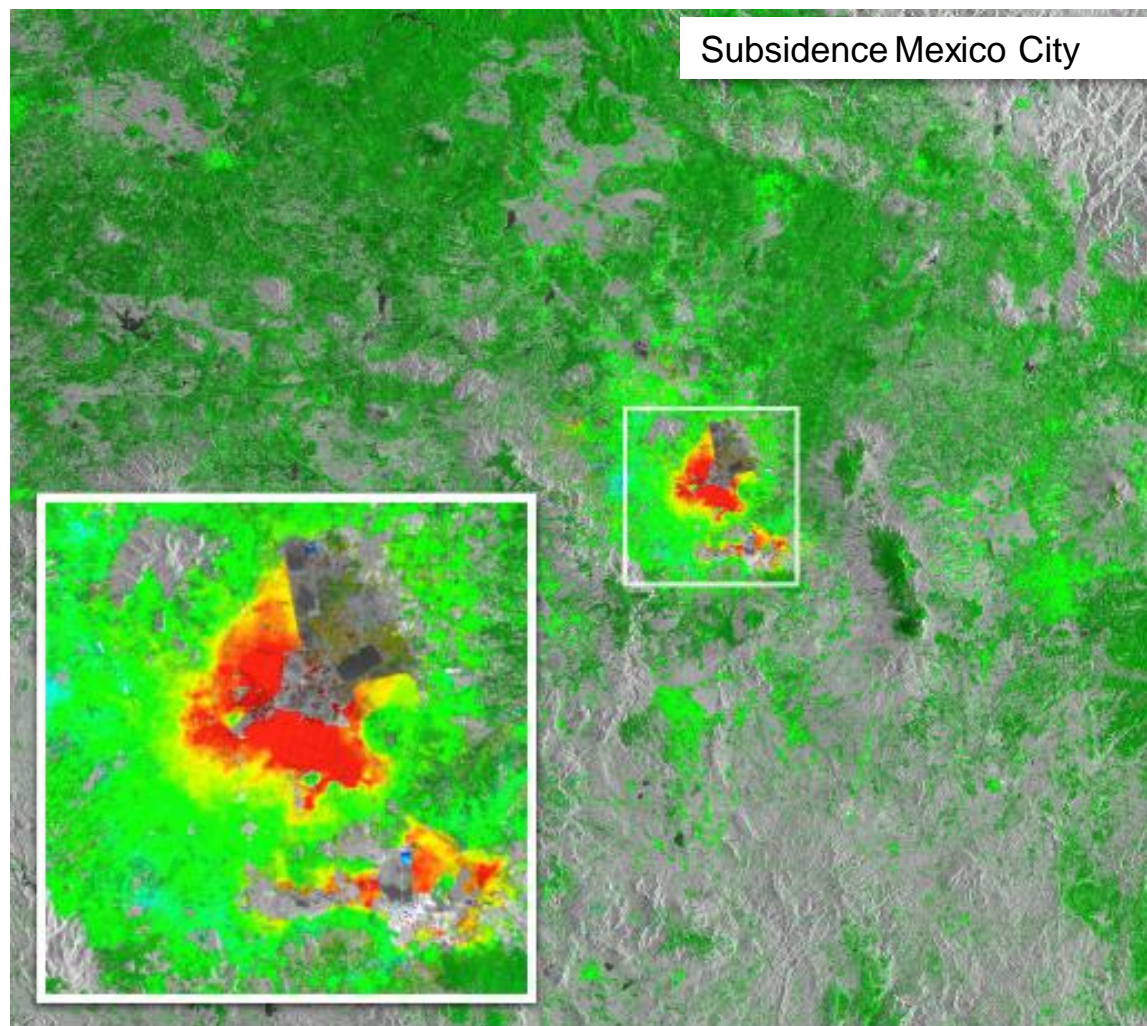
InSAR Applications

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

InSAR Applications

Subsidence Mexico City

-20 cm/yr ▬▬▬ +20 cm/yr

Subsidence Mexico City
This image, showing surface deformation in Mexico City, was generated using a 'stack' of 11 images aquired between 4 April and 30 November 2013. The images are from Radarsat-2, which was programmed to work in an experimental imaging mode called Terrain Observation by Progressive Scans in azimuth (TOPS) to mimic Sentinel-1A's interferometric wide-swath mode. Images such as this are helping users prepare for Sentinel-1A.
Source:https://www.esa.int/ESA_Multimedia/Images/2014/03/Subsidence_Mexico_City

Thank you for the attention