

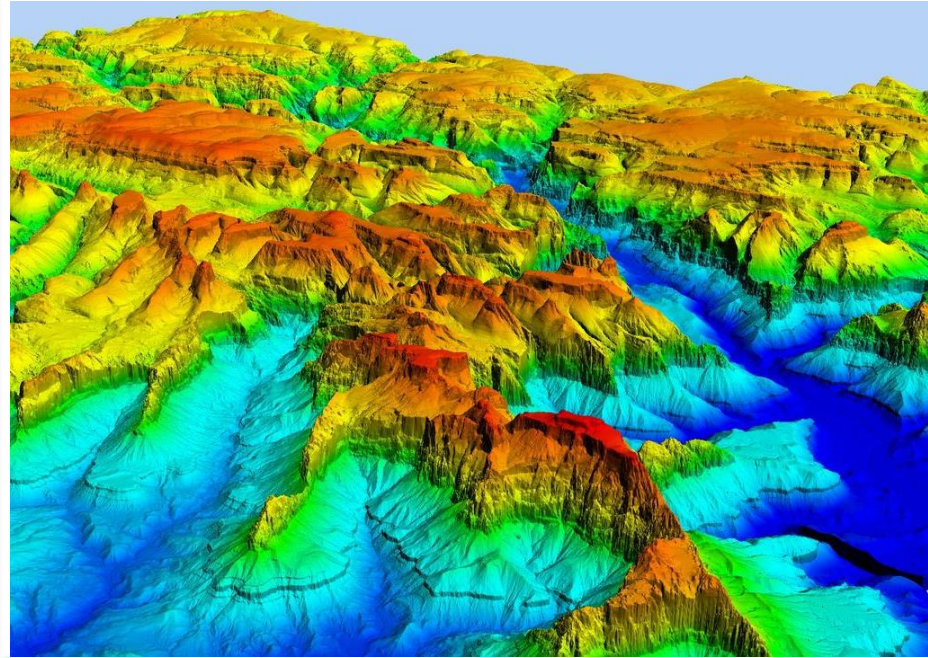


## 12. Retrieval of digital elevation model (DEM) from ESA EO data and comparison with LiDAR outputs

# What is DEM?

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- A Digital Elevation Model (DEM), also referred to as the Digital Terrain Model (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 the surface, free of vegetation, buildings and other non ground objects with reference to a datum such as Mean Sea Level (MSL).

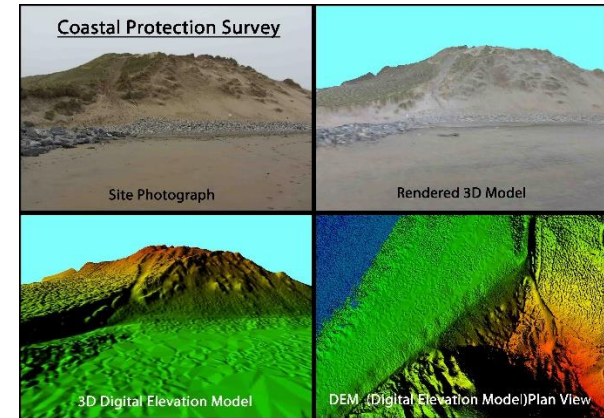
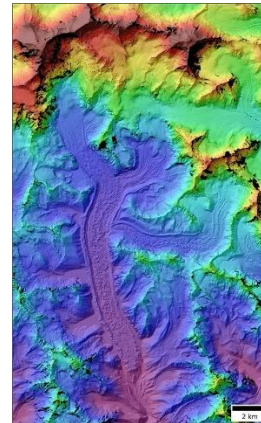
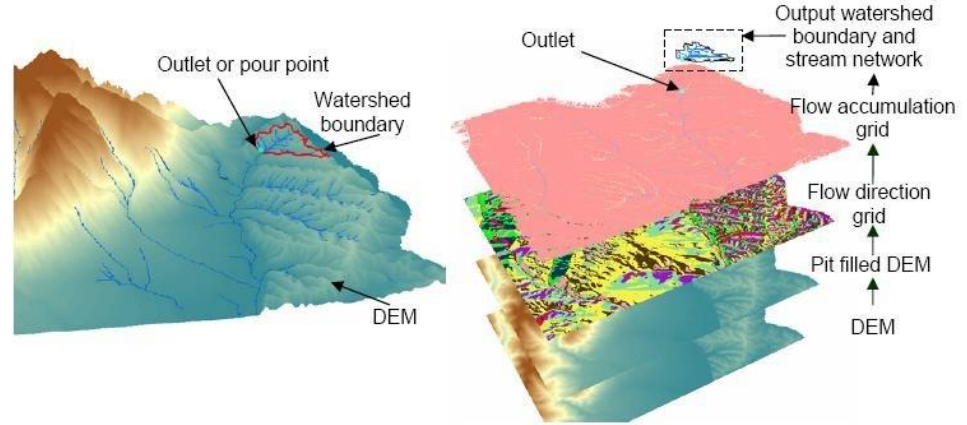


Source: <https://www.surveyinggroup.com/dsm-dem-dtm-elevation-models-in-gis/>

# Use of DEM

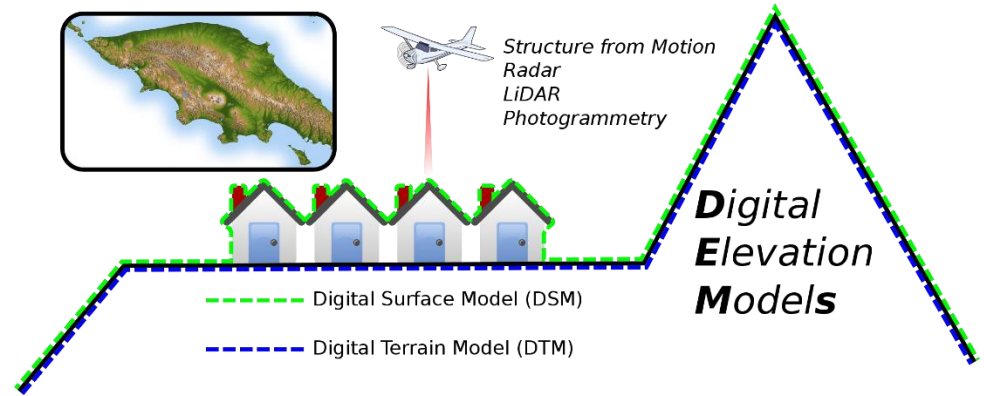
Digital Elevation Models (DEMs) are used in many applications in the context of earth sciences:

- 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 other points
- **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).

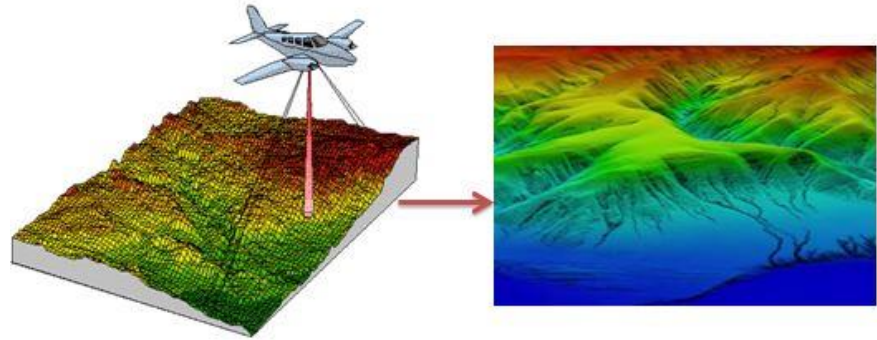


Source: [https://commons.wikimedia.org/wiki/File:The\\_difference\\_between\\_Digital\\_Surface\\_Model\\_%28DSM%29\\_and\\_Digital\\_Terrain\\_Models\\_%28DTM%29\\_when\\_talking\\_about\\_Digital\\_Elevation\\_models\\_%28DEM%29.svg](https://commons.wikimedia.org/wiki/File:The_difference_between_Digital_Surface_Model_%28DSM%29_and_Digital_Terrain_Models_%28DTM%29_when_talking_about_Digital_Elevation_models_%28DEM%29.svg)



# DEM Retrieval

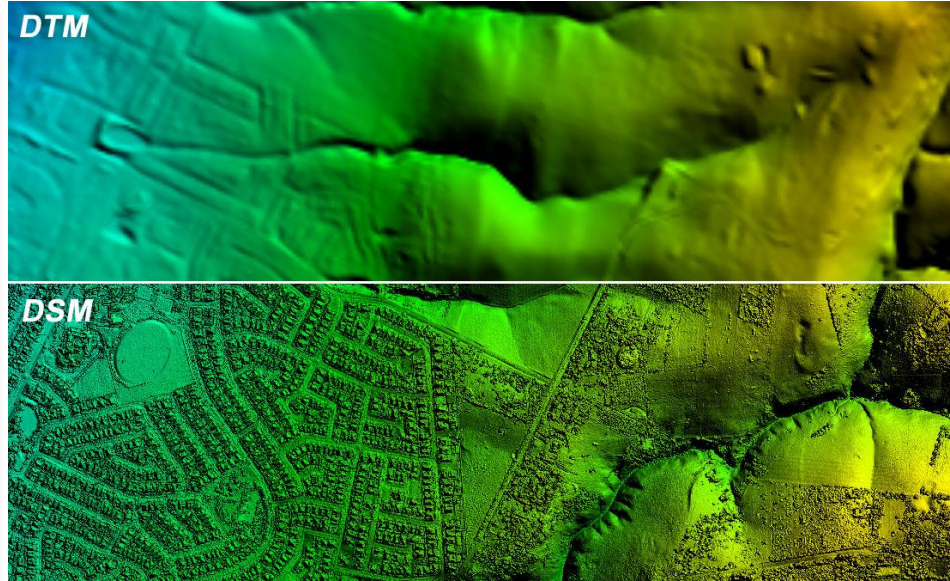
- DEMs are generated by using the elevation information from several points spaced at regular or irregular intervals.
- DEMs are commonly built using data collected using remote sensing techniques such as photogrammetry and LIDAR, but they may also be built from land surveying.



# DEM Retrieval

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- Since the early 21st century, the development of LiDAR technology and point-cloud processing methods has enabled the derivation of both Digital Terrain Models (DTMs) and Digital Surface Models (DSMs) from a single data source.

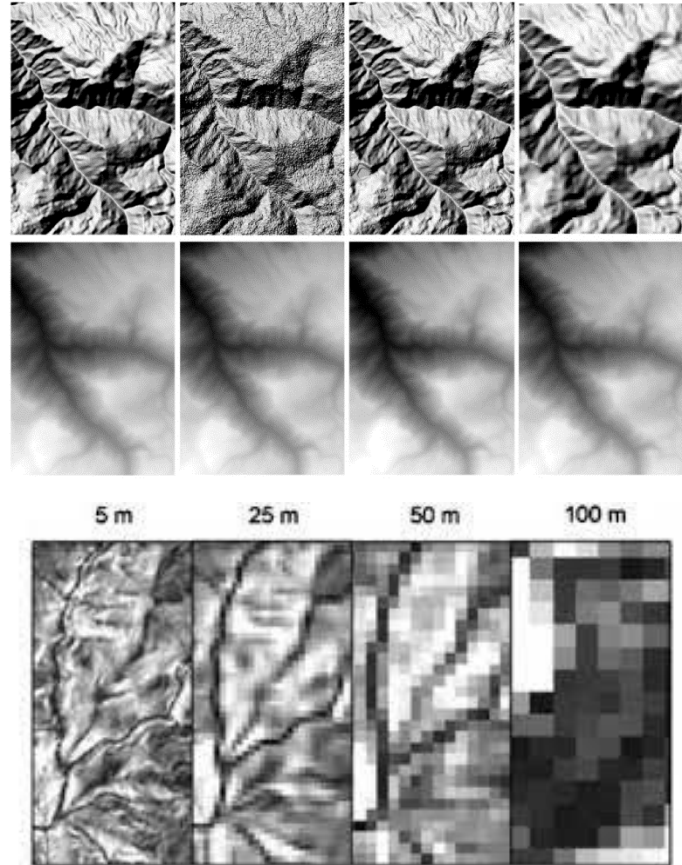


# DEM Quality

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.



# 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

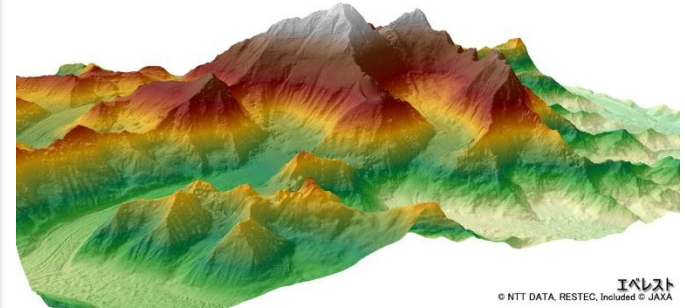
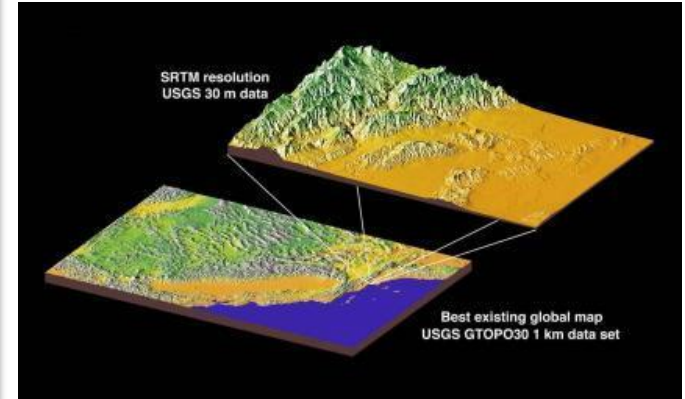
- A joint operation between NASA and Japan was the birth of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
- ASTER GDEM boasted a global resolution of 90 meters with a resolution of 30 meters in the United States
- You can download the ASTER DEM data for free from the USGS EarthExplorer

## 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

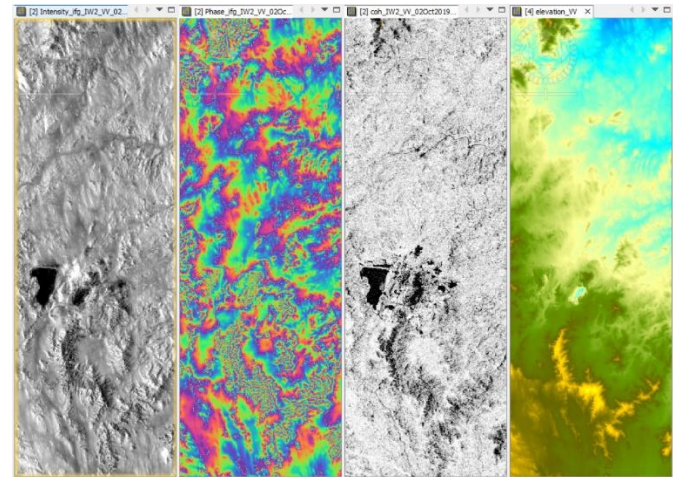
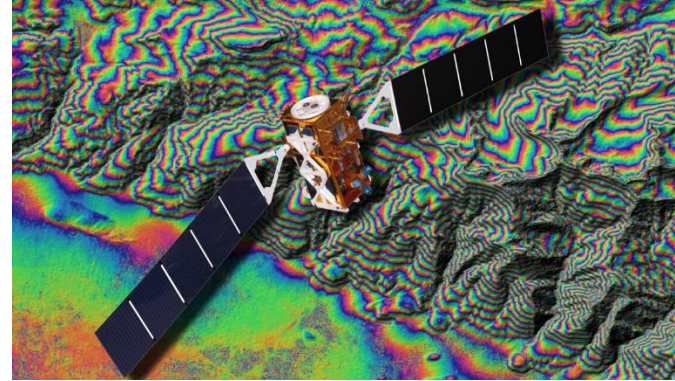
- CARTOSAT 1 and 2 derived stereo DEM, available for entire India freely





# Retrieval of DEM using Sentinel-1 radar data

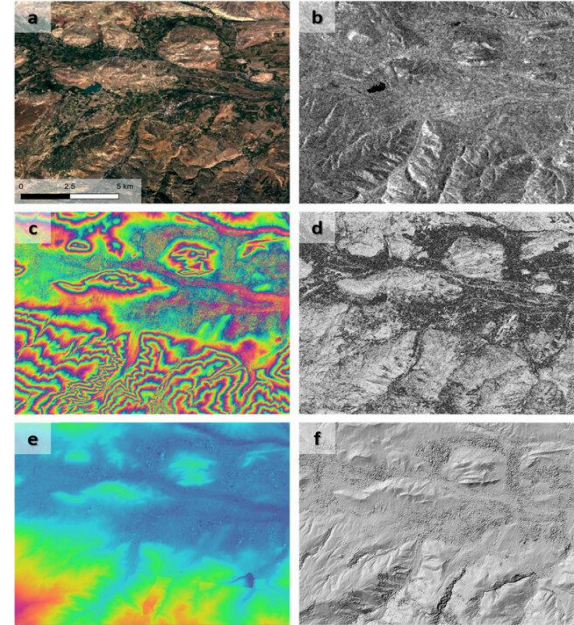
- The launch of Sentinel-1 by the European Space Agency (ESA) in 2014 marked the beginning of a new era in openly available radar data under the Copernicus Programme.
- This C-band radar mission, comprising Sentinel-1A (S1A) and Sentinel-1B (S1B), provides data at a spatial resolution of  $5 \times 20$  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

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## 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.

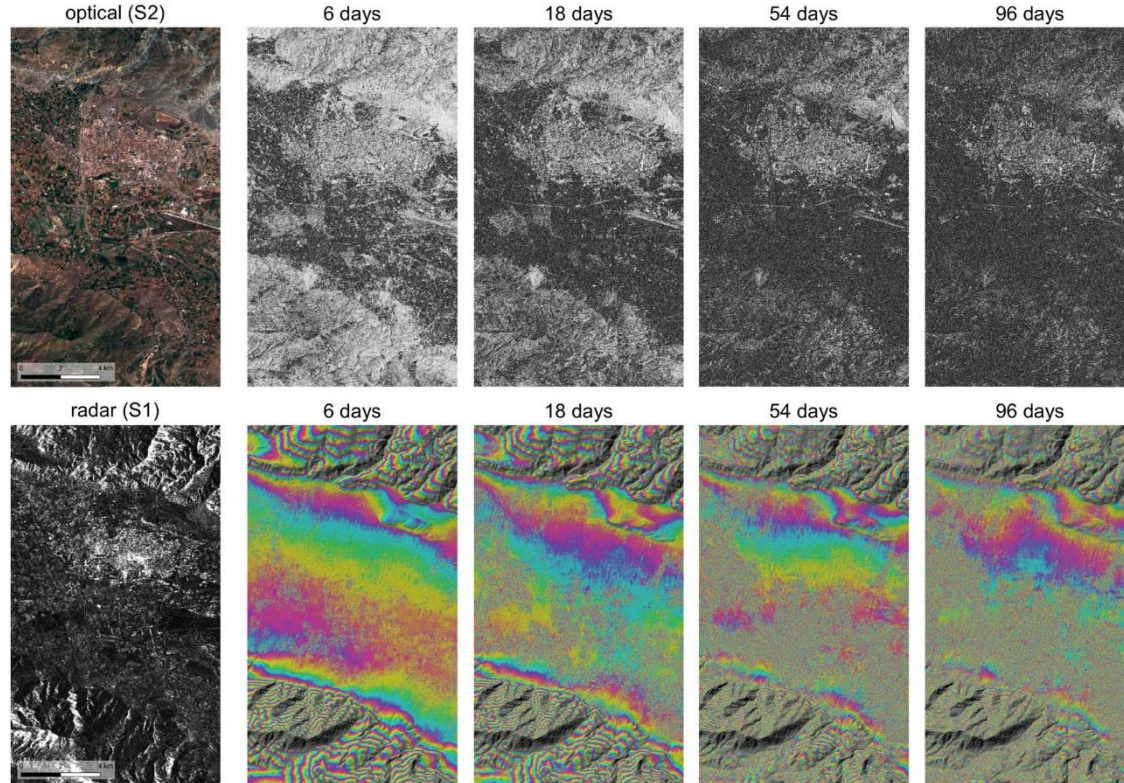
**3.Considerations for Sentinel-1:** Sentinel-1 was primarily designed for deformation retrieval (DInSAR) rather than DEM generation, resulting in predominantly short baselines, often below 30 meters. Finding image pairs with short temporal baselines and large perpendicular baselines can be challenging.

**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

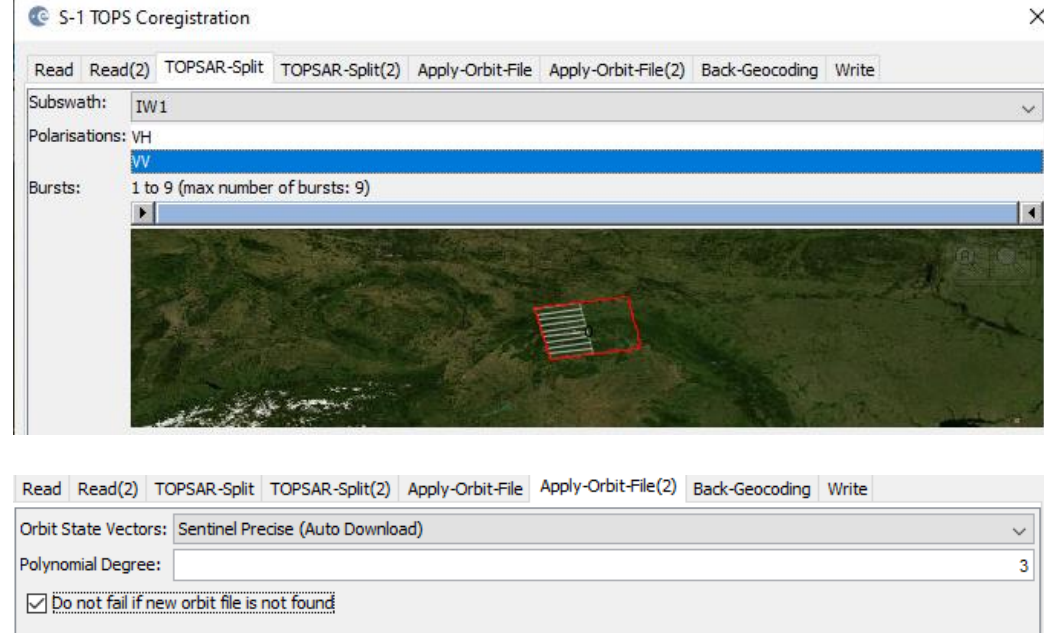
In order to utilize the phase difference between the acquisitions, it is necessary to first create a stack containing both products. Coregistration involves aligning both products with sub-pixel accuracy using image statistics.

## 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 Spectral Diversity (ESD) operator is utilized. It implements range and azimuth shift corrections to the secondary image.

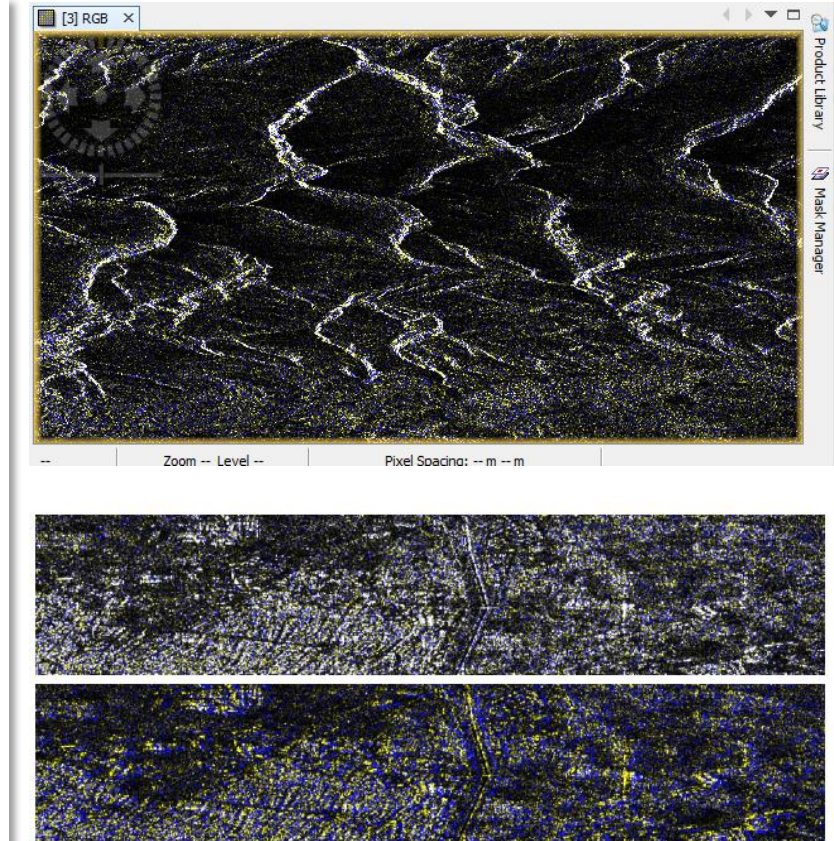


Figure 15: Successful (top) vs. failed (bottom) coregistration in an RGB image

# 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.

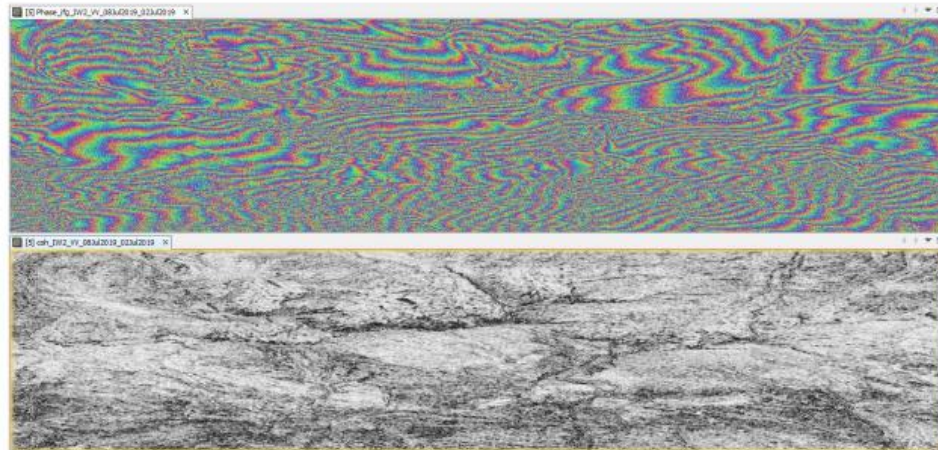


Figure 18: Interferogram (top) and coherence (bottom)



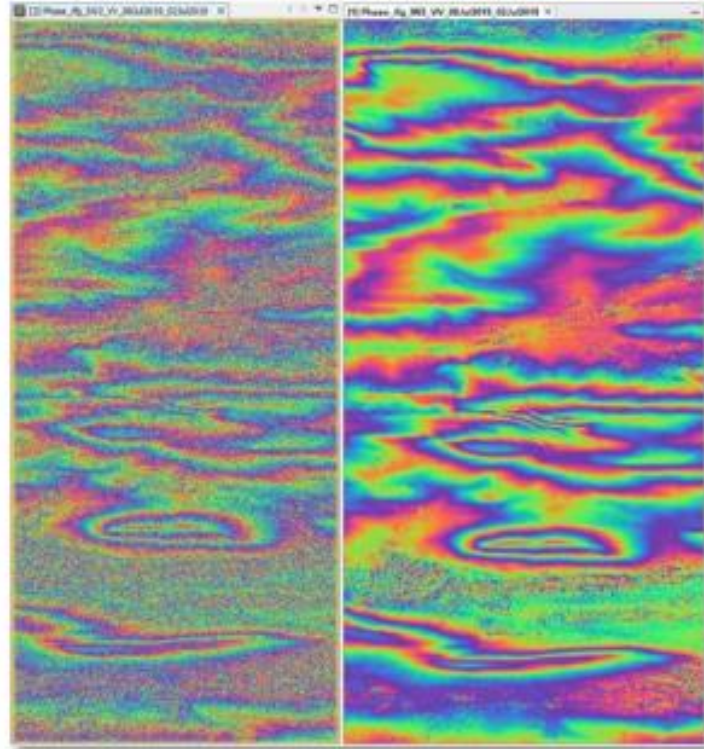
# Create a DEM using Sentinel-1 radar data

## 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.

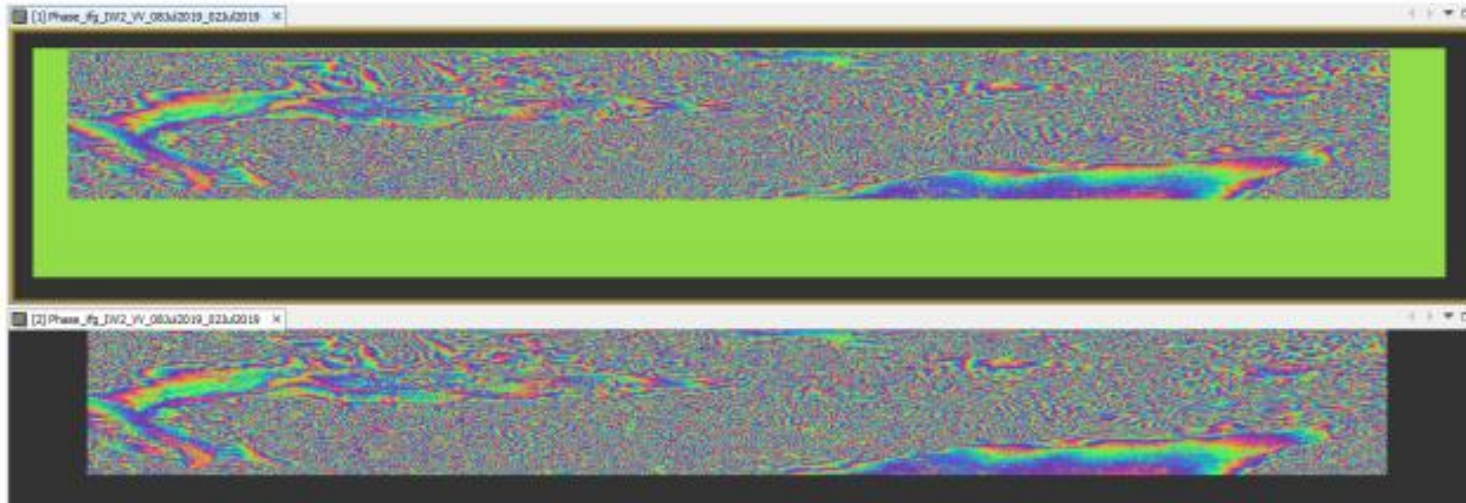


Figure 23: Interferogram before (top) and after (bottom) creating the subset

# 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.

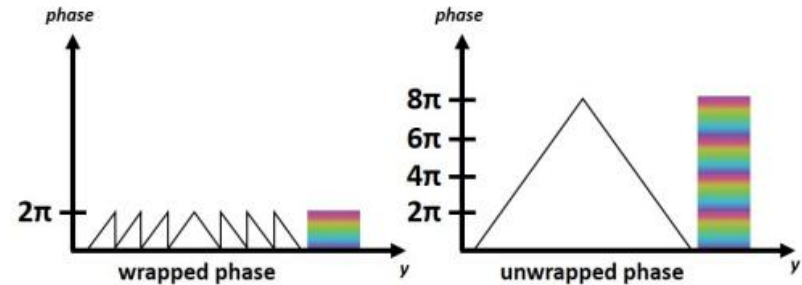


Figure 24: Principle of phase unwrapping

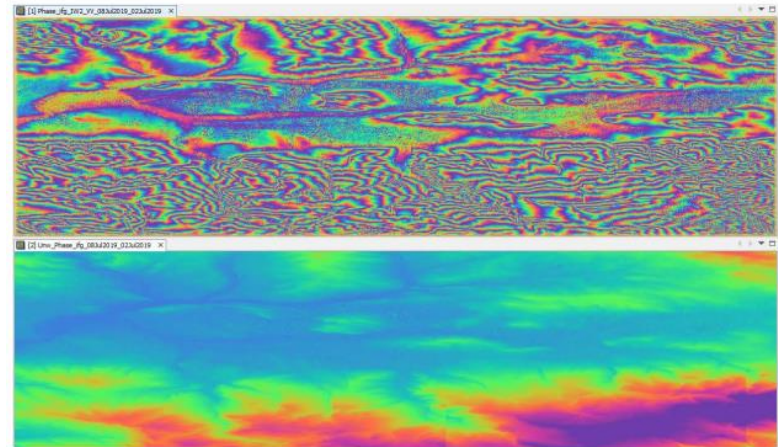
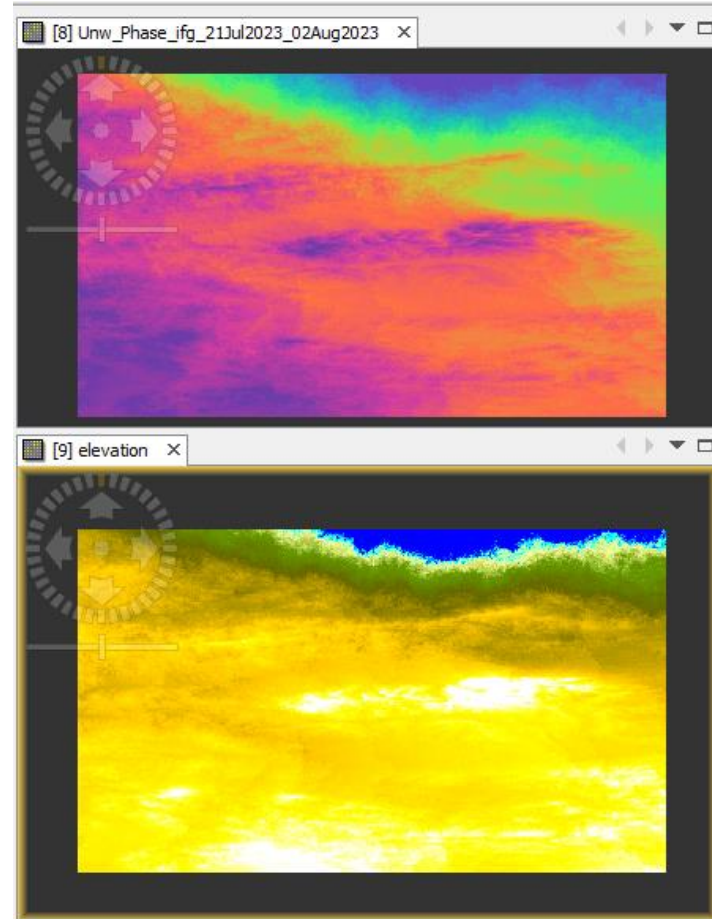
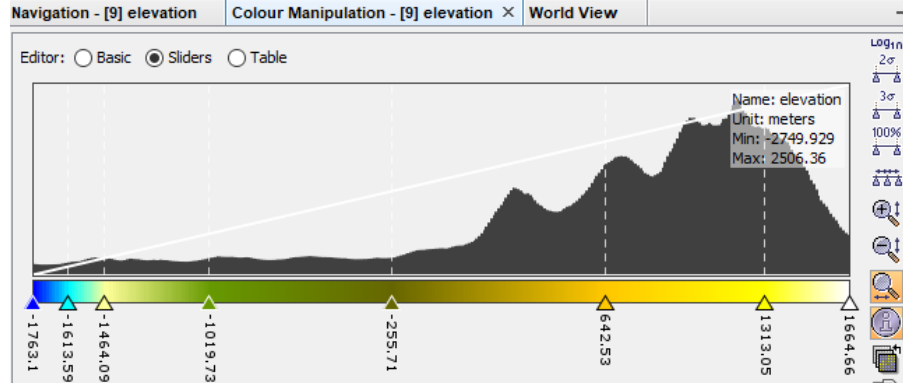


Figure 28: Phase before (top) and after (bottom) unwrapping

# 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

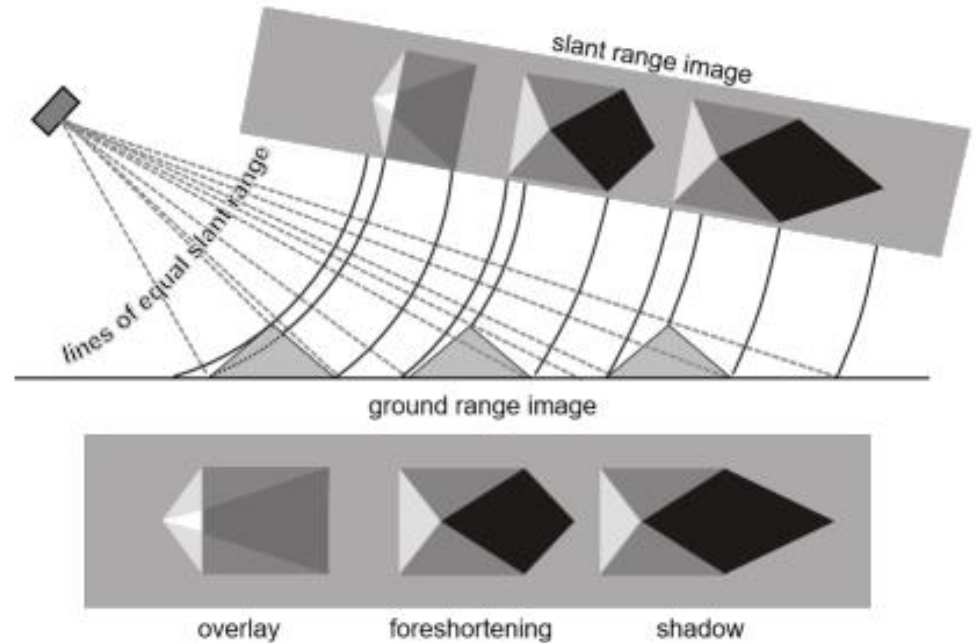


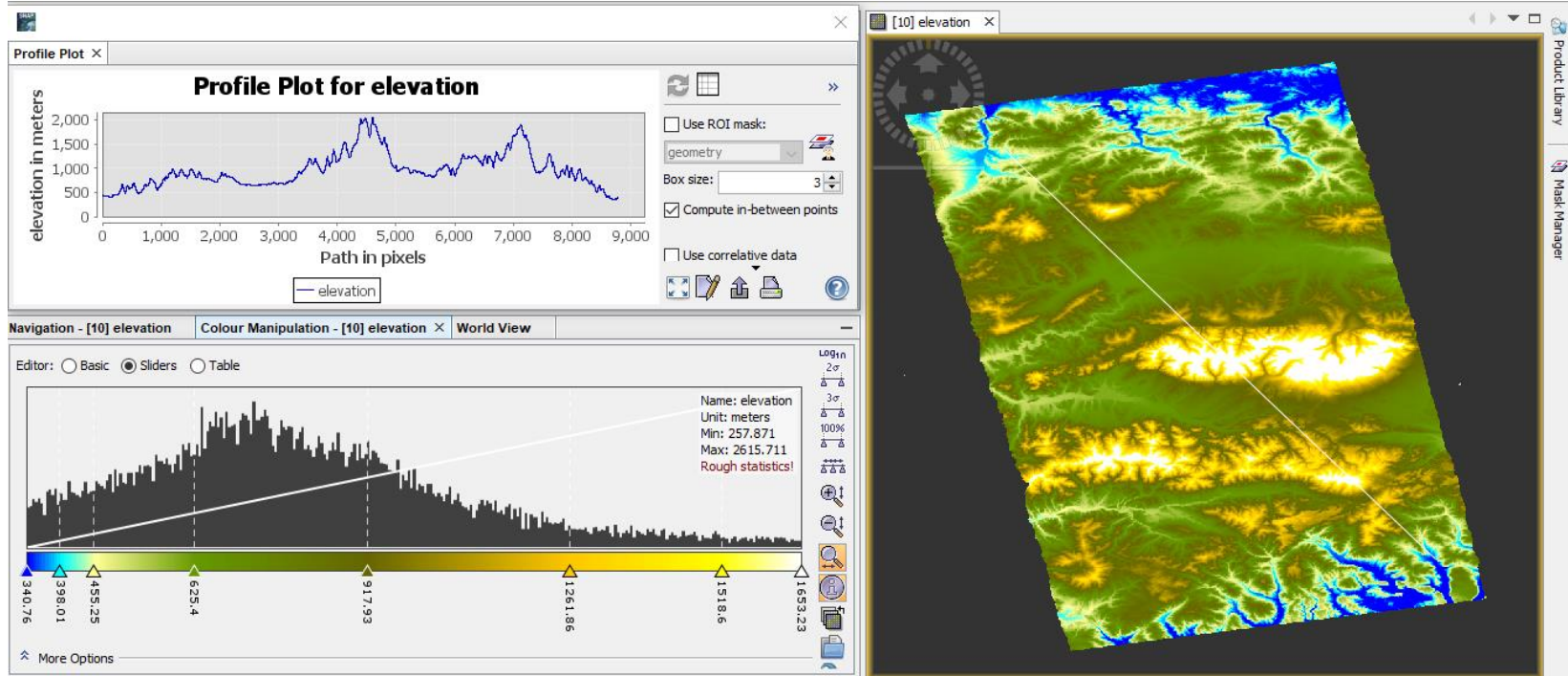
Figure 33: Geometric distortions in radar images ([Braun 2019](#))



# Create a DEM using Sentinel-1 radar data

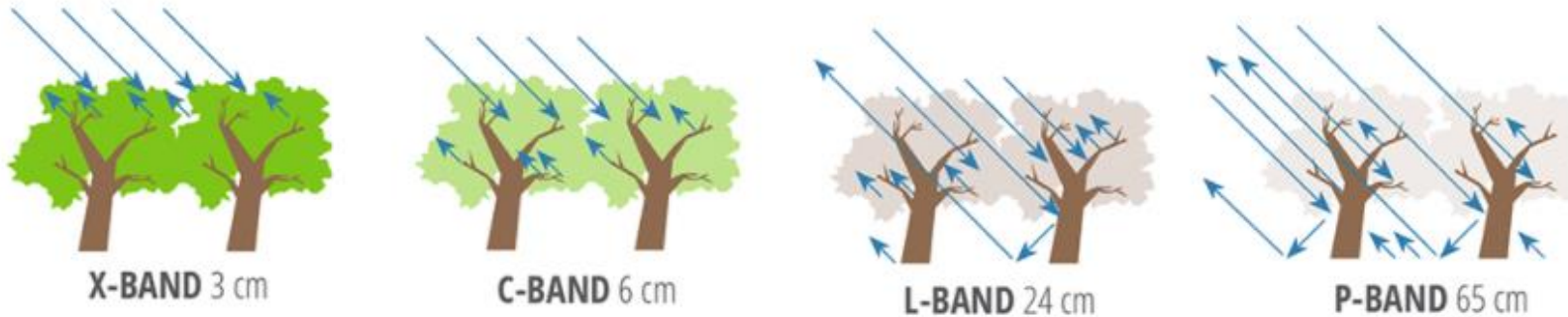
## Final DEM

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



# Tradeoffs of DEMs created with Sentinel-1 C-band

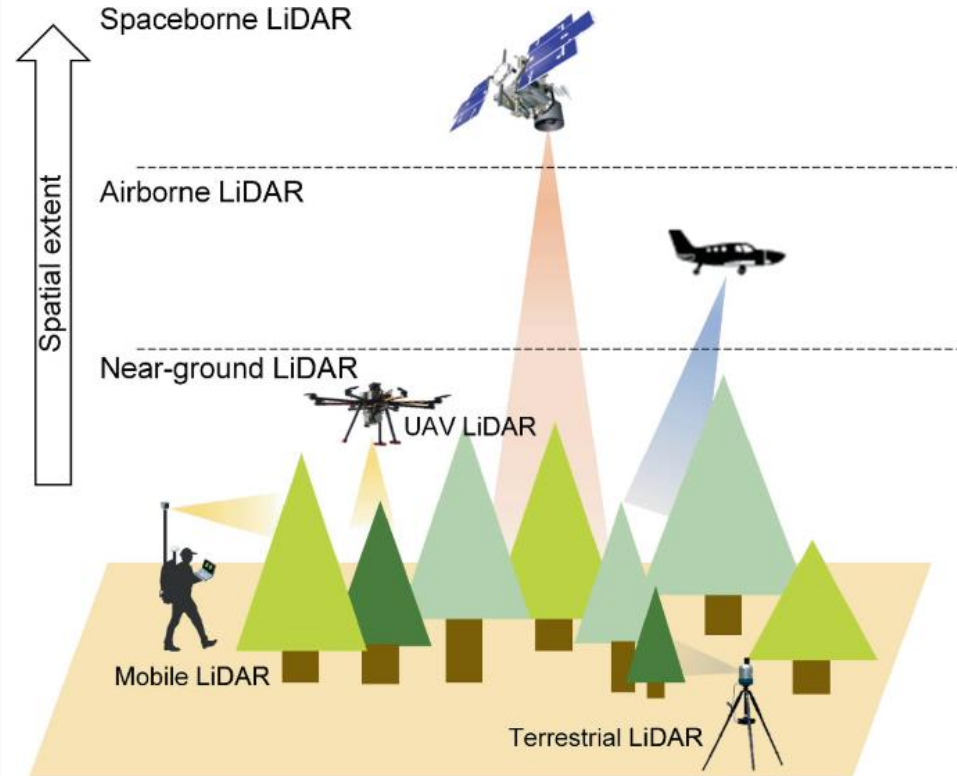
- Unfortunately, the C-band used by Sentinel-1 doesn't penetrate through vegetation. Consequently, DEMs derived from C-band radar don't directly measure the Earth's surface but instead depict the top of the canopy. However, Sentinel-1 offers excellent temporal coverage, resulting in lower temporal decorrelation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



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.

# Retrieval of DEM using LiDAR

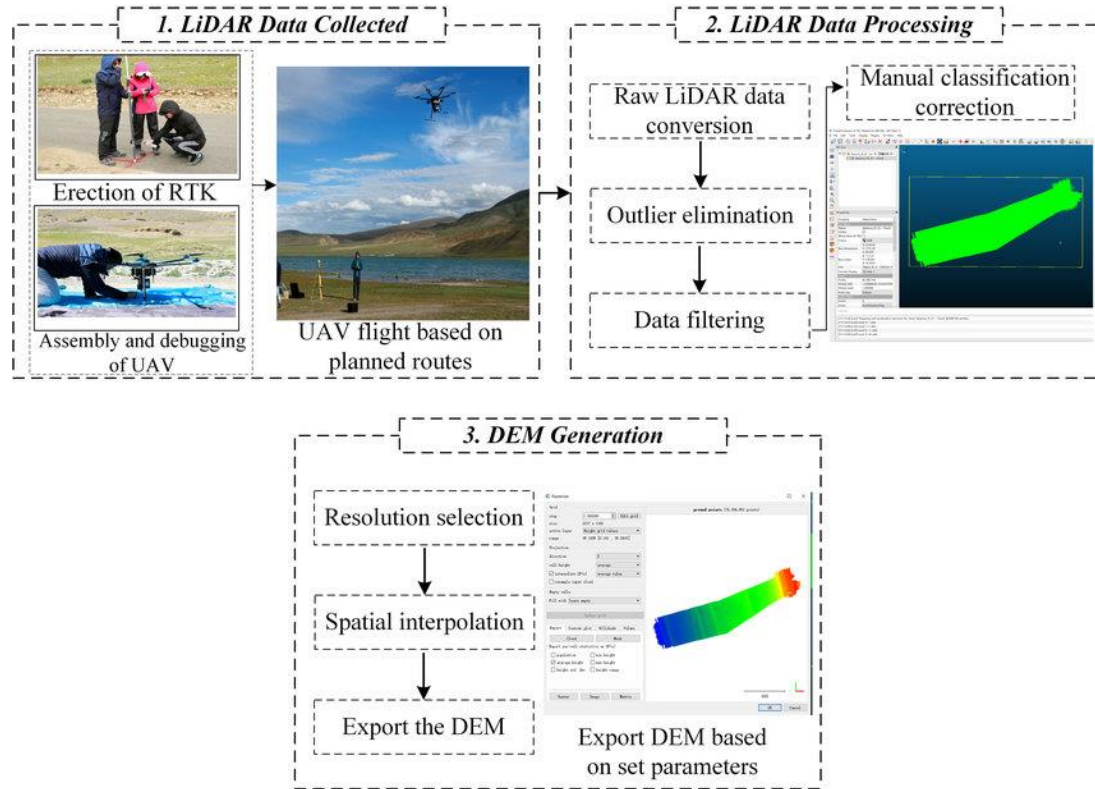
- **Lidar — Light Detection and Ranging — is a remote sensing method used to examine the surface of the Earth.**
- LiDAR employs pulsed laser light to measure distances to the Earth's surface, generating precise three-dimensional data about its shape and surface features.
- A typical LiDAR setup includes a laser, scanner, and specialized GPS receiver. Aircraft are commonly used to collect LiDAR data over large areas. There are two main types of LiDAR: topographic, which uses near-infrared lasers to map land features, and bathymetric, which uses green light to measure water depth and seafloor elevations.



# Retrieval of DEM using LiDAR

Retrieval of DEM using LiDAR involves:

- **Data Acquisition:** LiDAR systems measure surface elevation by emitting laser pulses.
- **Point Cloud Generation:** LiDAR data creates a dense point cloud representing terrain features.
- **Filtering and Classification:** Algorithms remove noise and classify ground points.
- **Surface Interpolation:** Interpolation methods generate a continuous surface from ground points.
- **DEM Generation:** The interpolated surface forms the basis for creating a Digital Elevation Model.
- **Validation:** The accuracy of the LiDAR-derived DEM is assessed for quality assurance.





# Comparison of Optical, SAR and LiDAR parameters

Characteristics/ Properties	Optical	SAR	LiDAR
<b>Electromagnetic range</b>	0.4 $\mu$ m to 1mm	1mm to 1m	250 nm to 10 $\mu$ m Mostly monochromatic wavelength is used. Recently some systems like Optech Titan started the use of multiband data
<b>Sensor direction for the receiving of electromagnetic radiation</b>	Near vertical	Oblique	Near vertical
<b>Information in pixel</b>	Spectral reflection of the particular band.	Amplitude and phase	Not applicable because 3D point cloud is formed that contains the planimetric, altitude and intensity data.
<b>Range Resolution</b> (Weijie and Xiaojie, 2016)	Ground range is used.	Slant range is used.	3D point cloud is formed.
<b>Dielectric constant</b>	Independent	Highly dependent	Independent
<b>Coverage Area</b>	Large	Large	Small
<b>Type of errors</b> (Devapal et al., 2019)	Skew distortion, panoramic distortion, haze, error due to varying solar illumination conditions and error due to unstable platform.	Speckle, layover and foreshortening.	Error due to unstable platform, multipath error, calibration errors of GPS and inertial measurement unit.
<b>Classification error due to self and cast shadow</b> (Lin et al., 2019)	It is affected by the shadow that leads to the misclassification of pixel into low reflectance objects like water.	It is affected from the shadow that leads to the misclassification.	Its integration with other data helps to identify the shadow that improves the classification.

Source: <https://isprs-archives.copernicus.org/articles/XLII-5-W3/1/2019/isprs-archives-XLII-5-W3-1-2019.pdf>

# Comparison of Optical, SAR and LiDAR parameters

<b>Weather dependence</b> (Liu et al., 2019)	Cannot penetrate through clouds; therefore, image is acquired only in clear weather.	Microwaves can penetrate through clouds; therefore, image is acquired in any weather.	Scanning should be performed in cloud free condition.
<b>Cost</b>	Free to expensive. Prize varies according to images resolution. Most of the high resolution images are not free of cost.	Free to expensive Prize varies according to images resolution	High cost Very small amount of data is freely available.
<b>Survey Customization</b>	Only aerial photography can be customized.	Not possible	Airborne and terrestrial scanning can be customized.
<b>Terrain mapping continuity</b>	Provides a continuous mapping of terrain.	Provides a continuous mapping of terrain.	Does not provide a continuous mapping of terrain. Sampling is done at a certain interval through laser pulses.
<b>Displacement detection</b>	Horizontal	Horizontal and vertical	Horizontal and vertical
<b>Bathymetry</b>	Visible and IR waves cannot transmit through water	Microwaves can transmit through water.	Green light is used that can transmit through water.
<b>DEM</b> (Joyce et al., 2009; Polat et al., 2015)	It can be generated by using photogrammetry on stereo pair. Terrain slope effects the DEM generation.	The interferogram is generated by using two complex SAR images and then by using phase unwrapping technique DEM is generated.	Raw data contains the elevation information. Filtering is applied on it to remove the non-ground points. Interpolation is then applied to generate the DEM.
<b>Parallax measurement</b>	Parallax measurement accuracy is usually from centimeters to meters, in the order of the resolution of the imagery.	The accuracy of InSAR parallax measurement is typically ranges from several millimeters to centimeters, in the fraction of SAR wavelength	Not applicable.
<b>Maturity</b>	High. Instruments and algorithms are available and well tested	Medium	Low, it is still in the conception stage.

Source: <https://isprs-archives.copernicus.org/articles/XLII-5-W3/1/2019/isprs-archives-XLII-5-W3-1-2019.pdf>



Thank you for the attention

