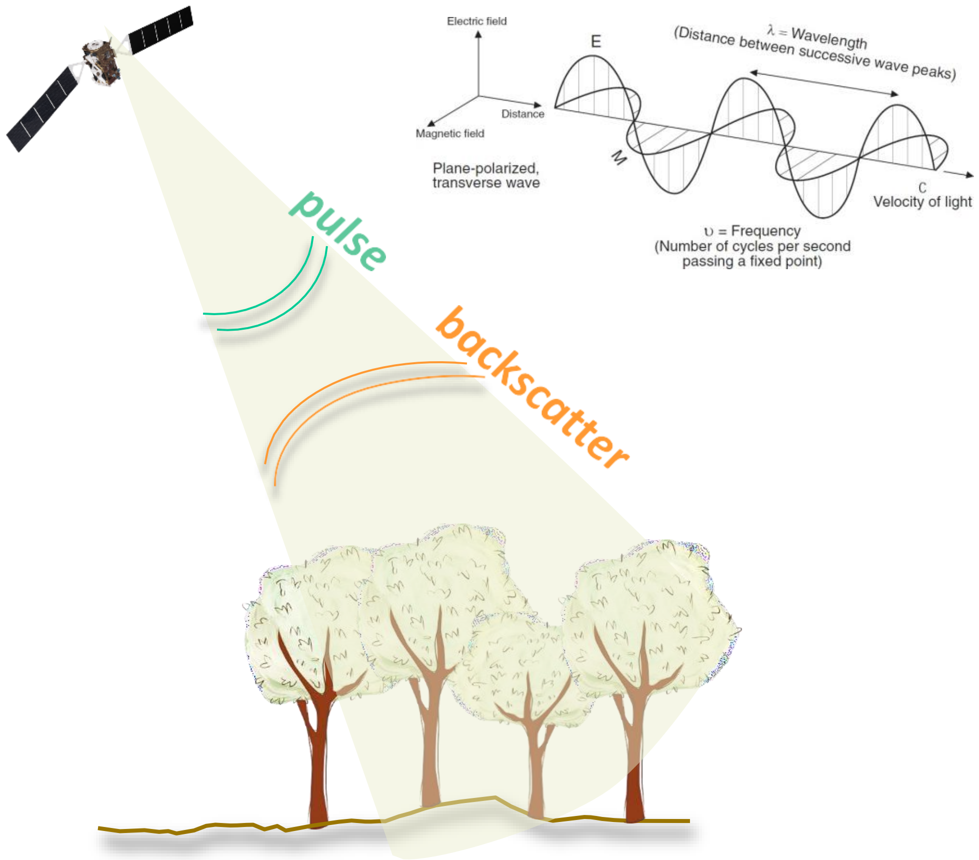
esa space solutions
Copernicus Academy
ÚSTAV GEOGRAFIE
Prírodovedecká fakulta UPJŠ v Košiciach

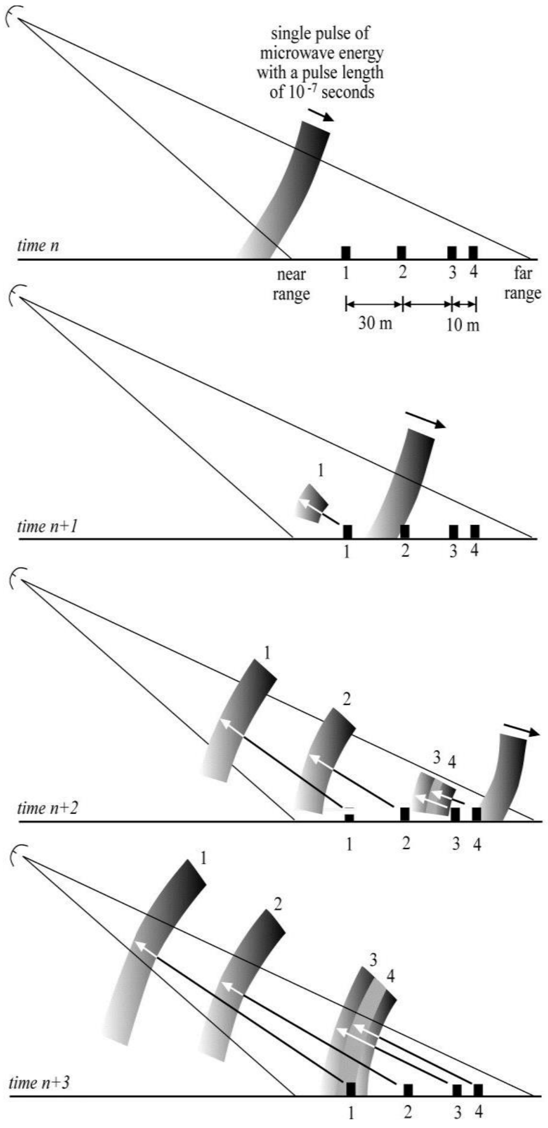
5. Basics of Radar Remote Sensing - principles and applications

Active Radar Remote Sensing

Basic characteristics of radar systems/SAR sensors

Active ⇒ **independent of sun illumination** (generate EM-waves)





Radar principle

EMG transmitted in bursts of energy - pulses (approx. every 0.000 000 1 s)

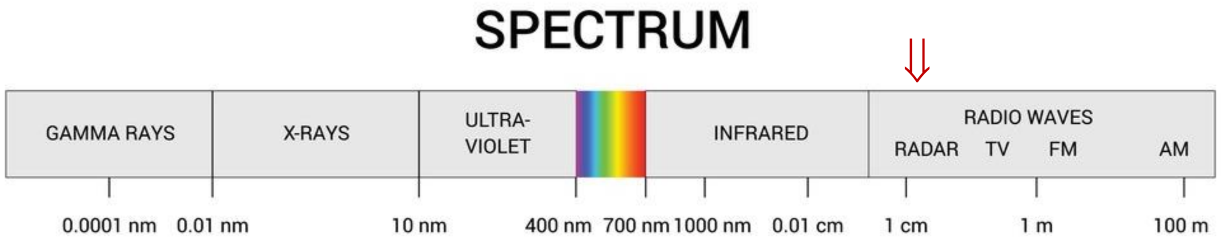
The energy of a single pulse is reflected from objects on the surface in order of distance from source/ transmitter on board

The intensity of the reflected energy and the time it takes for a given pulse to return are recorded

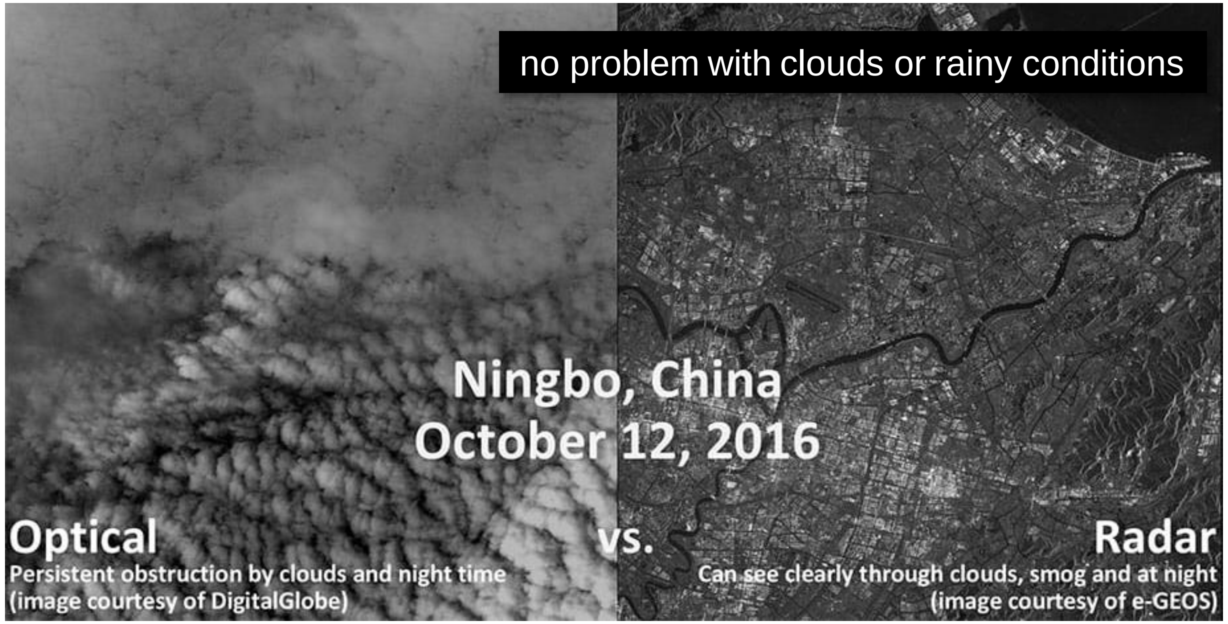
Source: https://www.researchgate.net/publication/349395724_Spaceborne_SAR_Remote_Sensing_for_Monitoring_of_Vegetation_Dynamics_in_Arid_and_Semi-arid_Environment/figures?lo=1&utm_source=google&utm_medium=organic/
Jensen (2008)

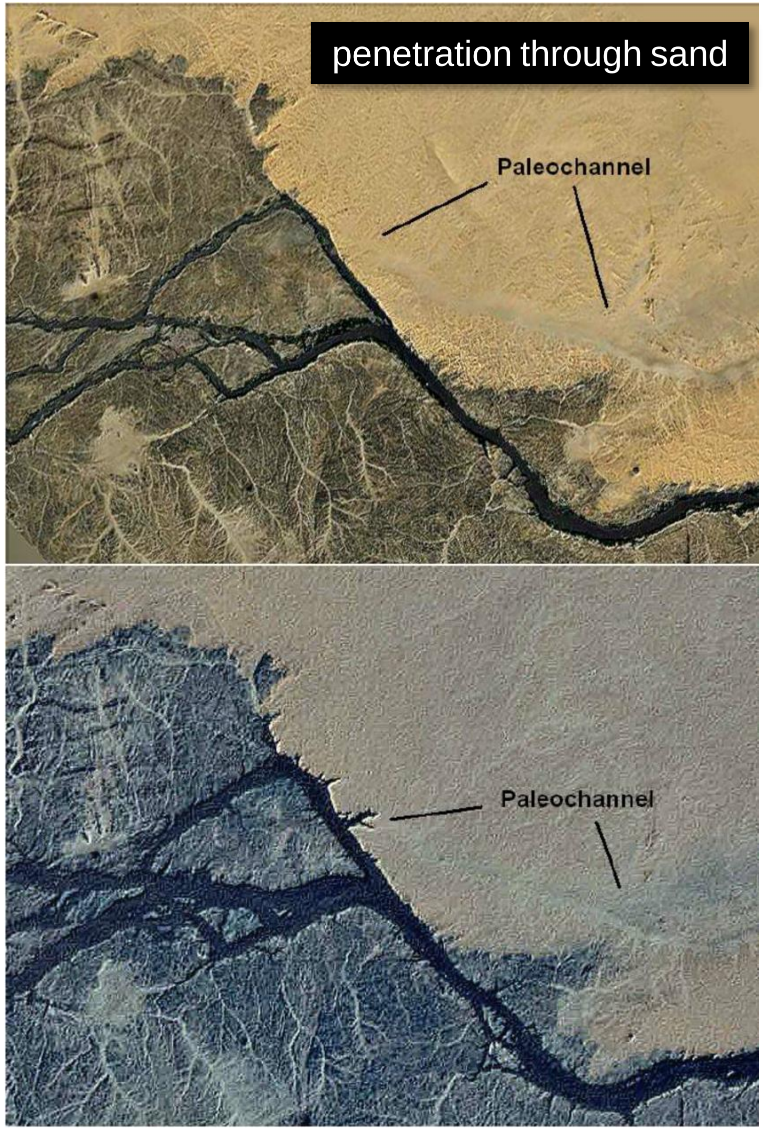
Active Radar Remote Sensing

Basic characteristics of radar systems/SAR sensors



Microwave $\Rightarrow$ penetrates into/through objects



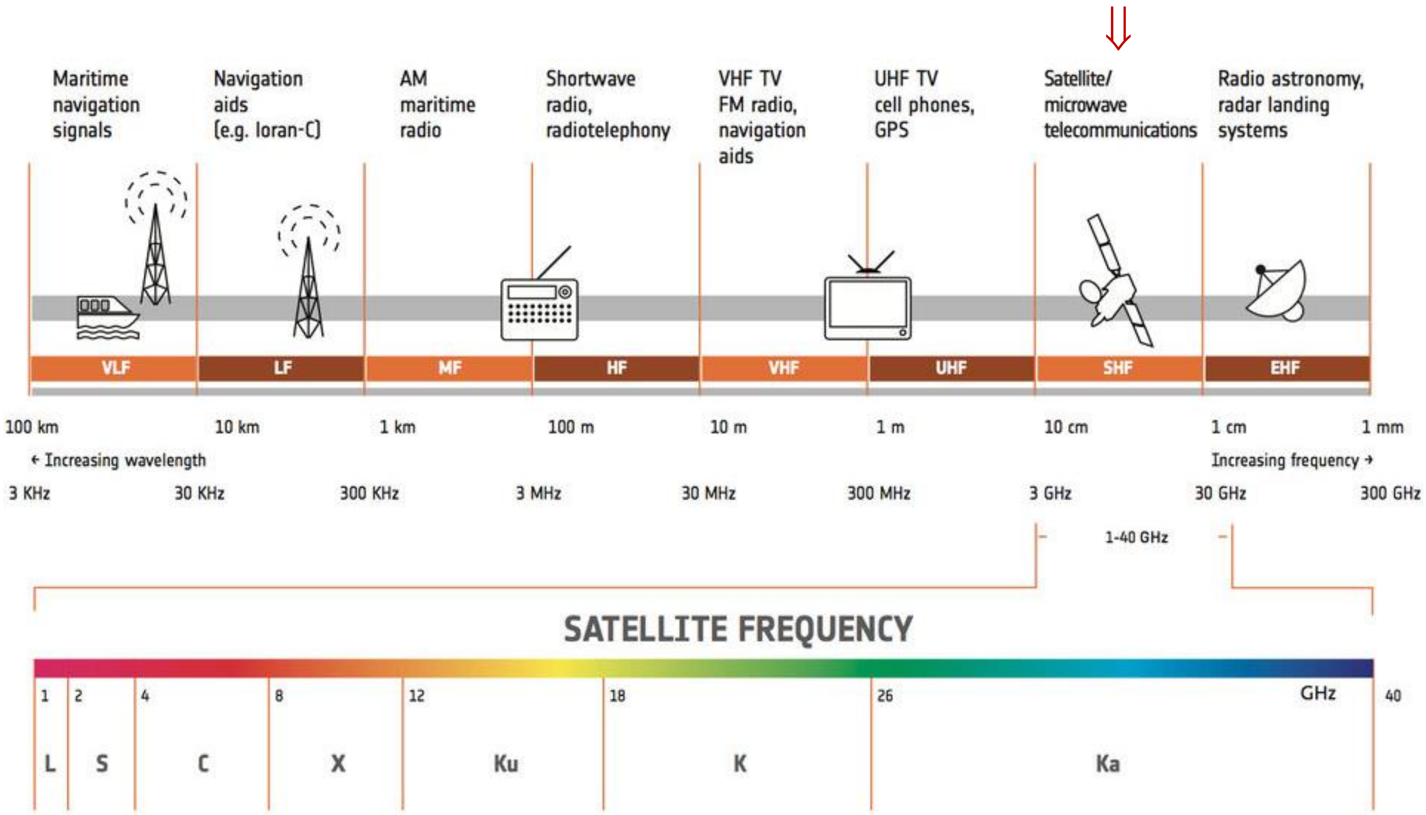


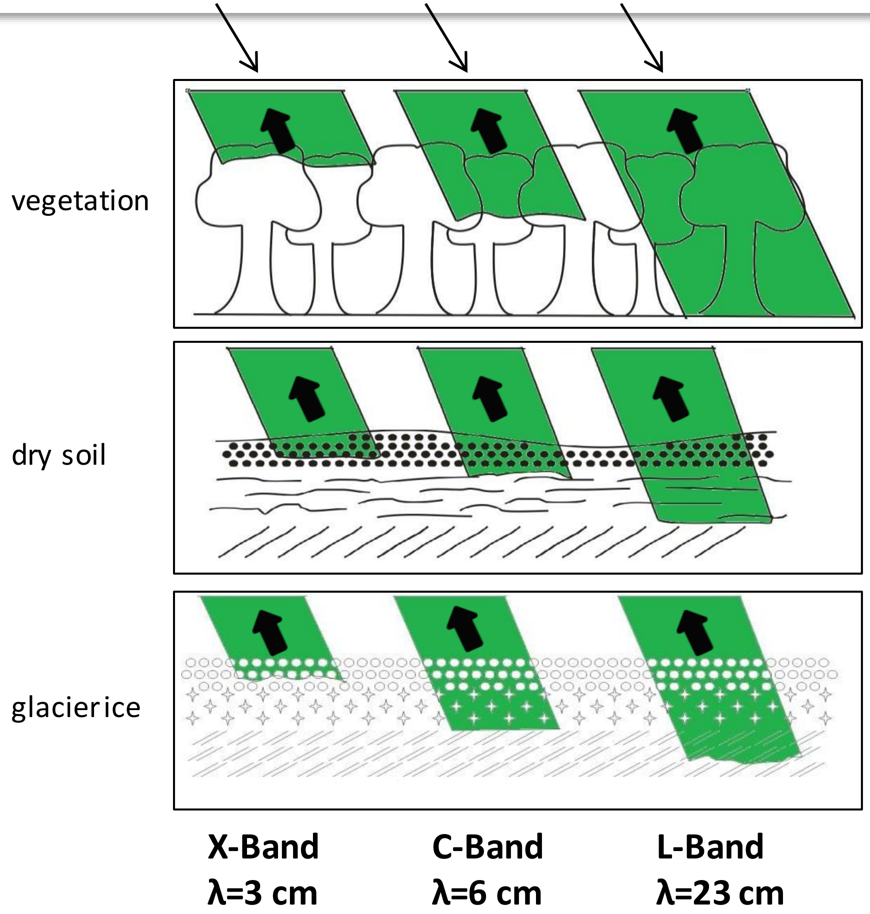
Source: https://resources.pcb.cadence.com/blog/2023-using-the-x-band-and-ka-band-frequencies-for-radar-applications, https://apogeospatial.com/a-killer-app-for-sats/, https://arxiv.org/abs/1011.4911,

Active Radar Remote Sensing

RADAR band designations, wavelenghts and frequencies

- The penetration depth is depending on **wavelength** and **dielectric characteristics** of objects



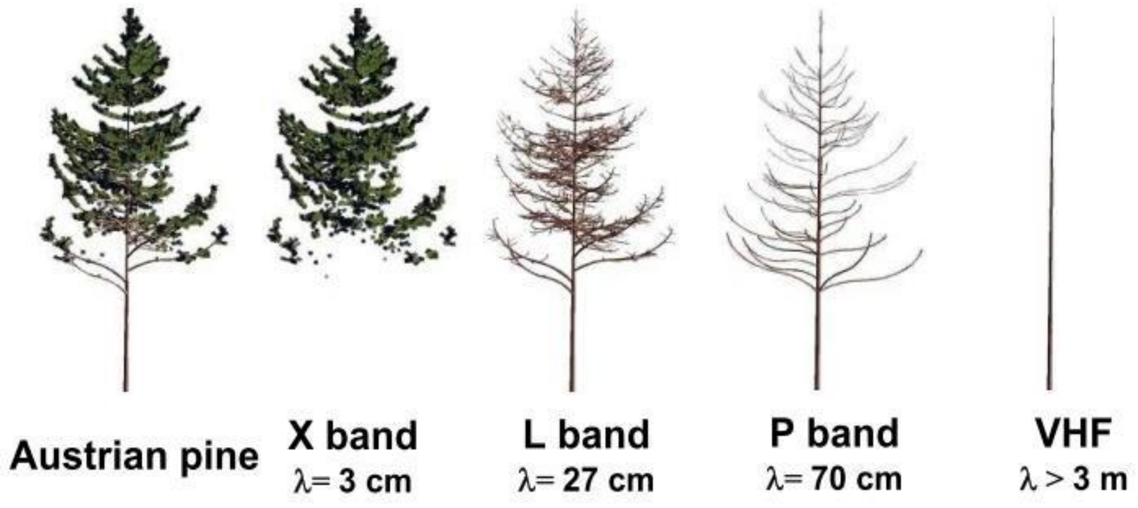


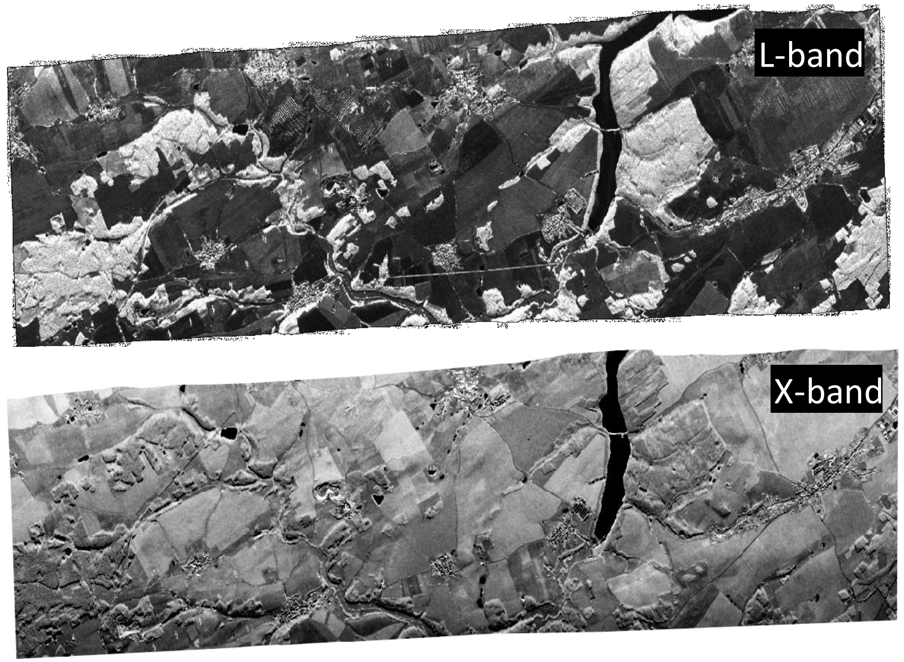
Source: https://www.esa.int/ESA_Multimedia/Images/2013/11/Satellite_frequency_bands, https://dges.carleton.ca/courses/IntroSAR/Winter2019/SECTION%202%20-%20Carleton%20SAR%20Training%20-%20Radar%20Basics%20-%20FINAL.pdf

Active Radar Remote Sensing

RADAR band designations, wavelenghts and frequencies

- The penetration depth is depending on **wavelength** and **dielectric characteristics** of objects





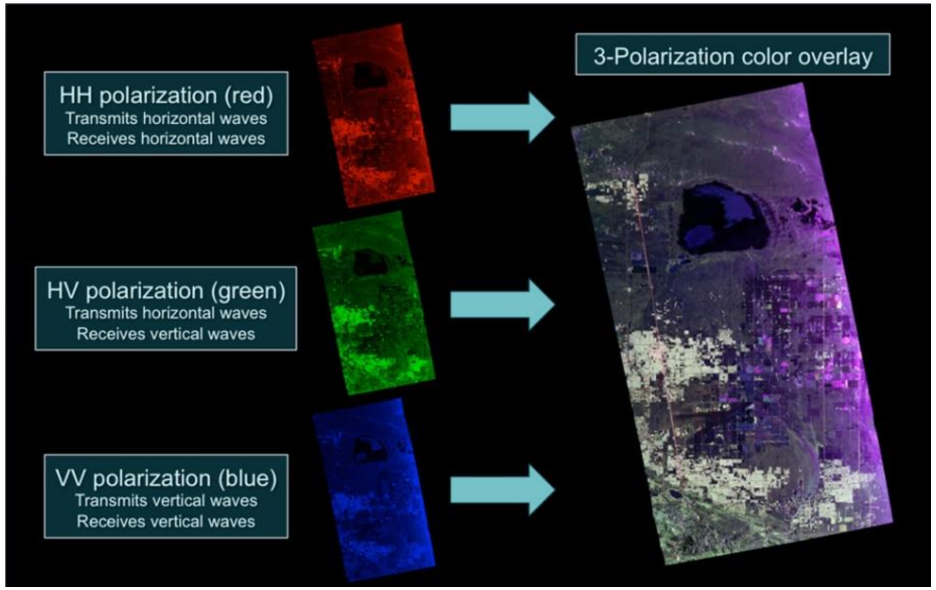
Source: https://eo-college.org/topic/forest/

Active Radar Remote Sensing

SAR IMAGING, POLARIMETRY

- SAR (Synthetic Aperture Radar) polarimetry is a technique that uses the polarization properties of radio waves for Earth observation. In the context of forestry, polarimetry has several significant applications. Here are some ways SAR polarimetry is employed in forestry:
- **Vegetation Characterization**:
  - Different types of vegetation have distinct backscatter characteristics depending on the signal's polarization.
- **Forest Structure**:
  - Polarimetric data can reveal information about tree heights, tree trunk thickness, or forest age. For instance, vertical polarization is often more strongly reflected by taller trees compared to shorter ones.
- **Biomass Estimation**:
  - Biomass is a key indicator of forest health and its carbon storage capability. Through polarimetry, the amount of biomass in a forest can be estimated.
- **Change Detection**:
  - By comparing polarimetric images from different time periods, areas of deforestation, forest damage, or regeneration can be identified.
- **Soil Moisture Determination**:
  - Beneath vegetation, there might be backscatter related to soil moisture. Polarimetry can help isolate these signals from the vegetation backscatter, allowing for a more accurate estimate of soil moisture.
- **Forest Damage Identification**:
  - Whether due to pests, diseases, natural disasters, or human activities, polarimetry can help pinpoint areas where the forest is damaged or stressed.

- Thus, SAR polarimetry offers a comprehensive view of forest ecosystems and their dynamics. With this technology, scientists, foresters, and natural resource managers can better understand the state of forests, monitor changes over time, and make informed decisions about the management and protection of these vital ecosystems.



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

Active Radar Remote Sensing

- Radar altimetry
- Radar imaging
  - SLAR – side look-angle radar
  - INSAR – interferommetric synthetic aperture radar
    - D-insar
    - PS-insar

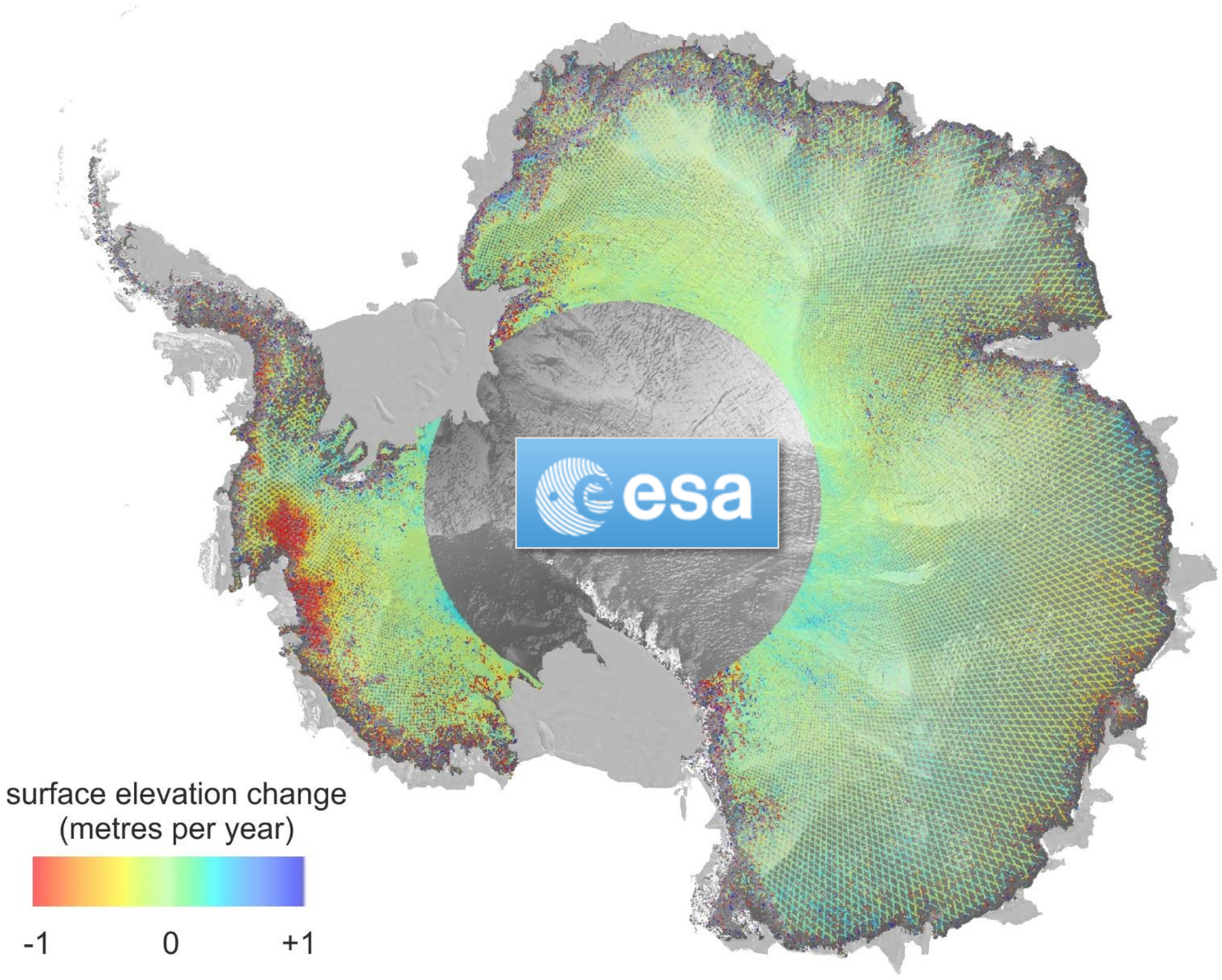
Radar Altimetry = measuring altitude / vertical height

[ESA](#) article

[video](#)

[video 2](#)

Radar Altimetry = measuring altitude / vertical height

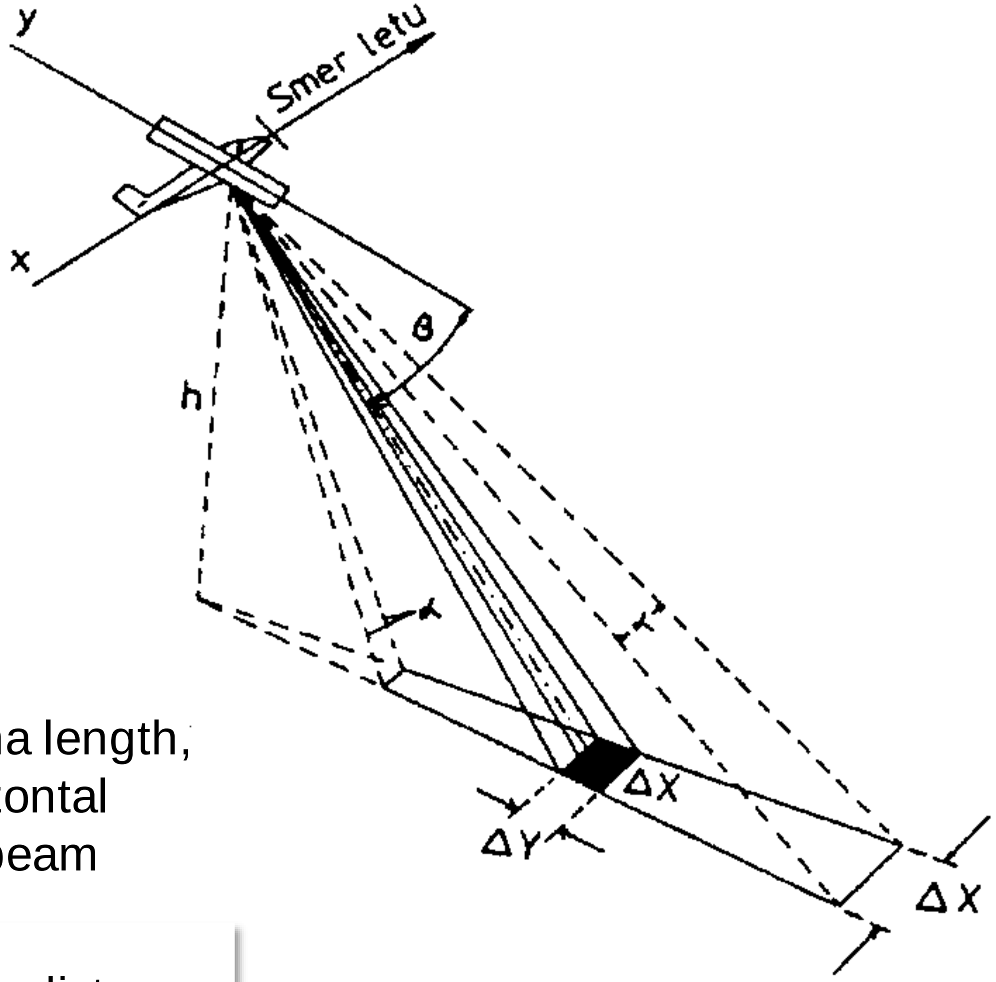


[Copernicus Sentinel-3 provides new measurements of Antarctic Ice Sheet 08 March 2019]

Side looking radar (SLAR)

$$\Delta x = \frac{h.\lambda}{L.\sin\beta}$$

$$\Delta y = \frac{c.\Delta t}{2.\cos\beta}$$



h - flight altitude, L - antenna length,
β - angle between the horizontal plane and the transmitted beam

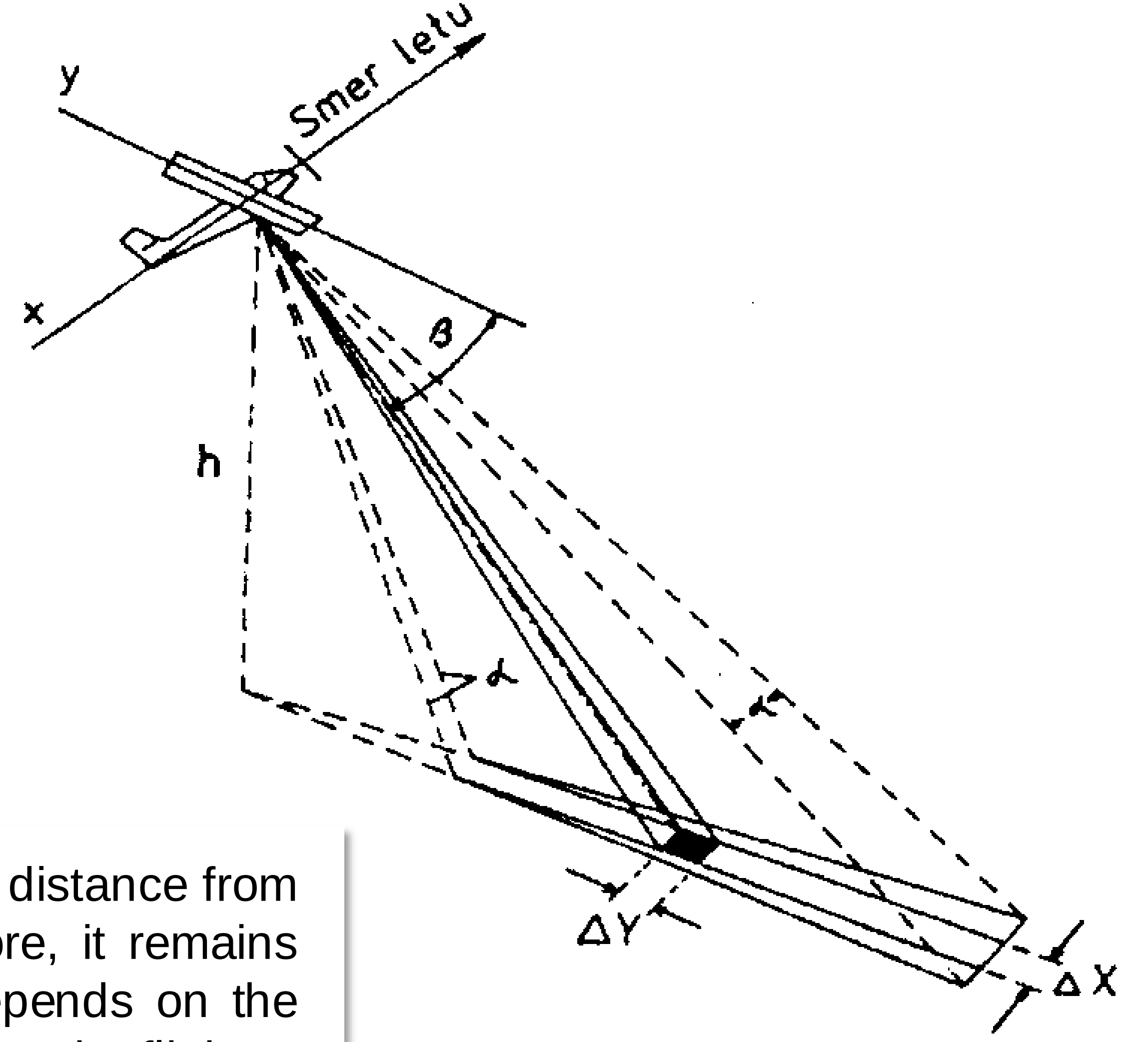
Spatial resolution deteriorates as the distance between the object and the antenna increases.

Synthetic aperture radar (SAR)

$$\Delta x = \frac{L}{2}$$

$$\Delta y = \frac{c.\Delta t}{2.\cos\beta}$$

h - flight altitude, L - antenna length, β - angle between the horizontal plane and the transmitted beam



The spatial resolution is independent of the distance from the antenna in the flight direction. Therefore, it remains constant in the flight direction, while it depends on the viewing angle in the direction perpendicular to the flight.

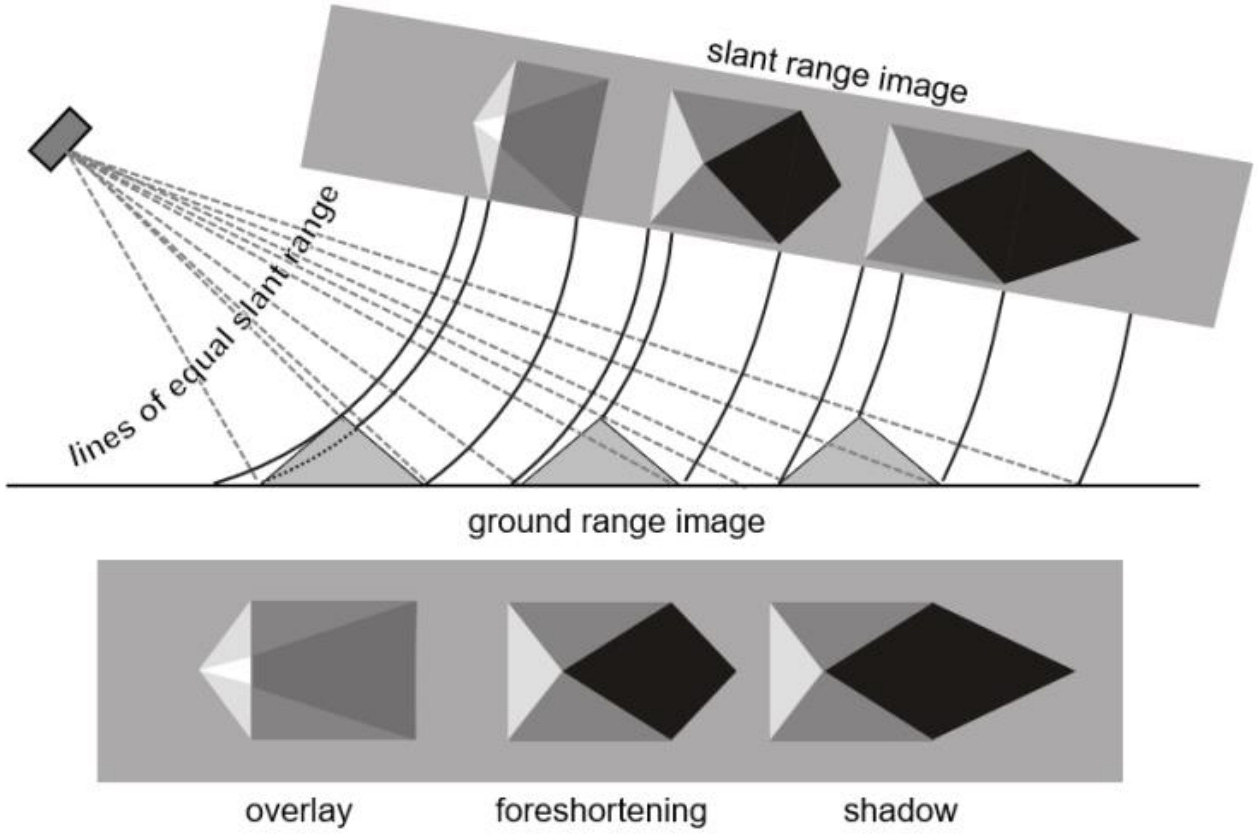
Geometric Effects in SAR images

Effects of side-looking geometry

→ Side looking geometry of SAR systems cause some typical geometric effects

- The effects are:
  - ❖ Foreshortening
  - ❖ Layover
  - ❖ Radar shadow

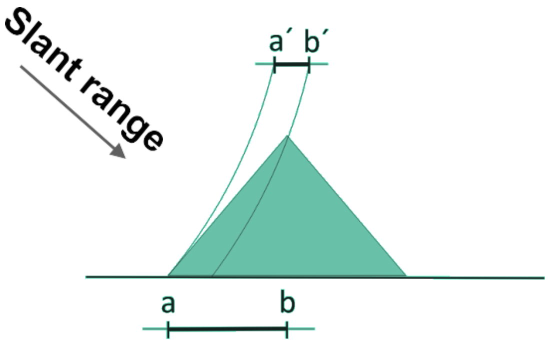
- Controlled by:
  - ❖ Incidence angle
  - ❖ Topography



Geometric distortions in radar images (Braun 2019)

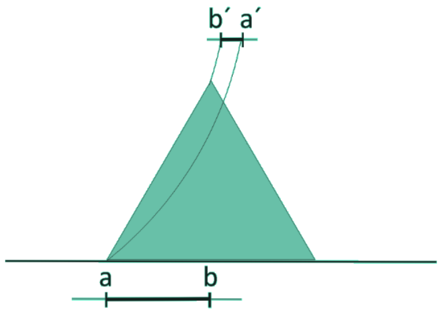
Geometric Effects in SAR images

Foreshortening



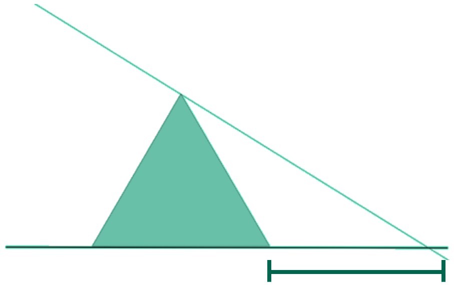
- Slopes oriented to the SAR appear compressed (Distance between a and b is shortened)
- Appears as very bright area
- More pronounced in near range (small incidence angle) than in far range (high incidence angles)

Layover

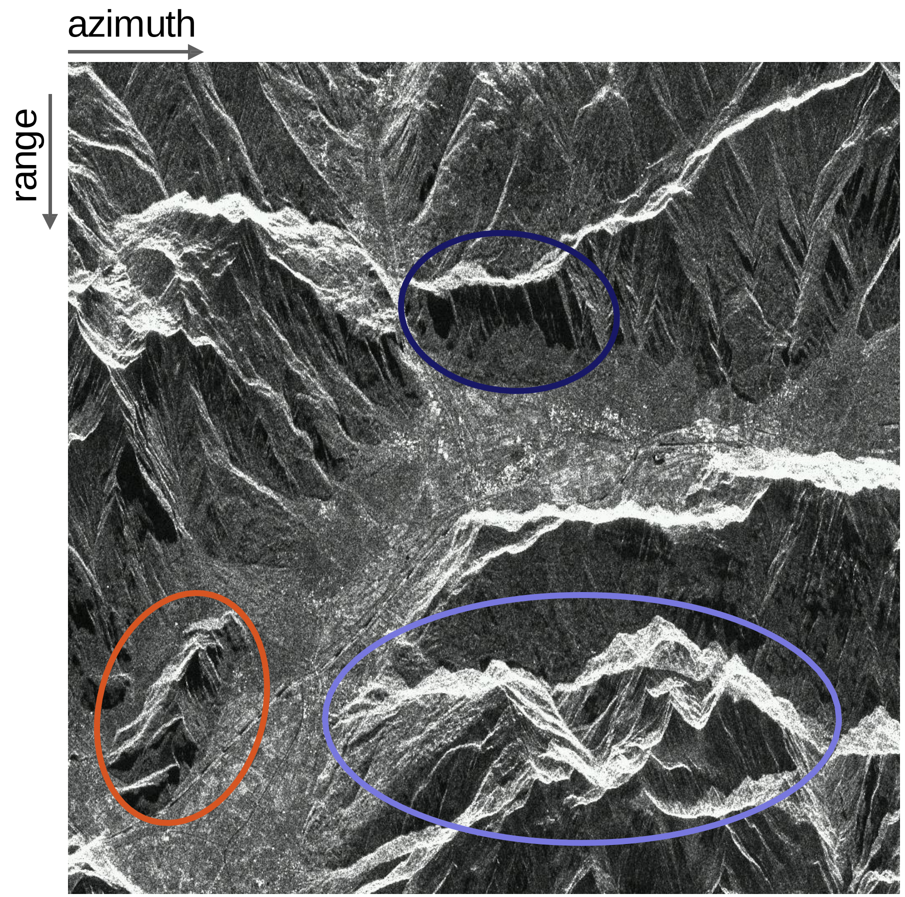


- Steep slopes oriented to the SAR lead to ghost images
- When radar beam reaches the top of a high feature (b) before it reaches the base (a)

Radar shadow



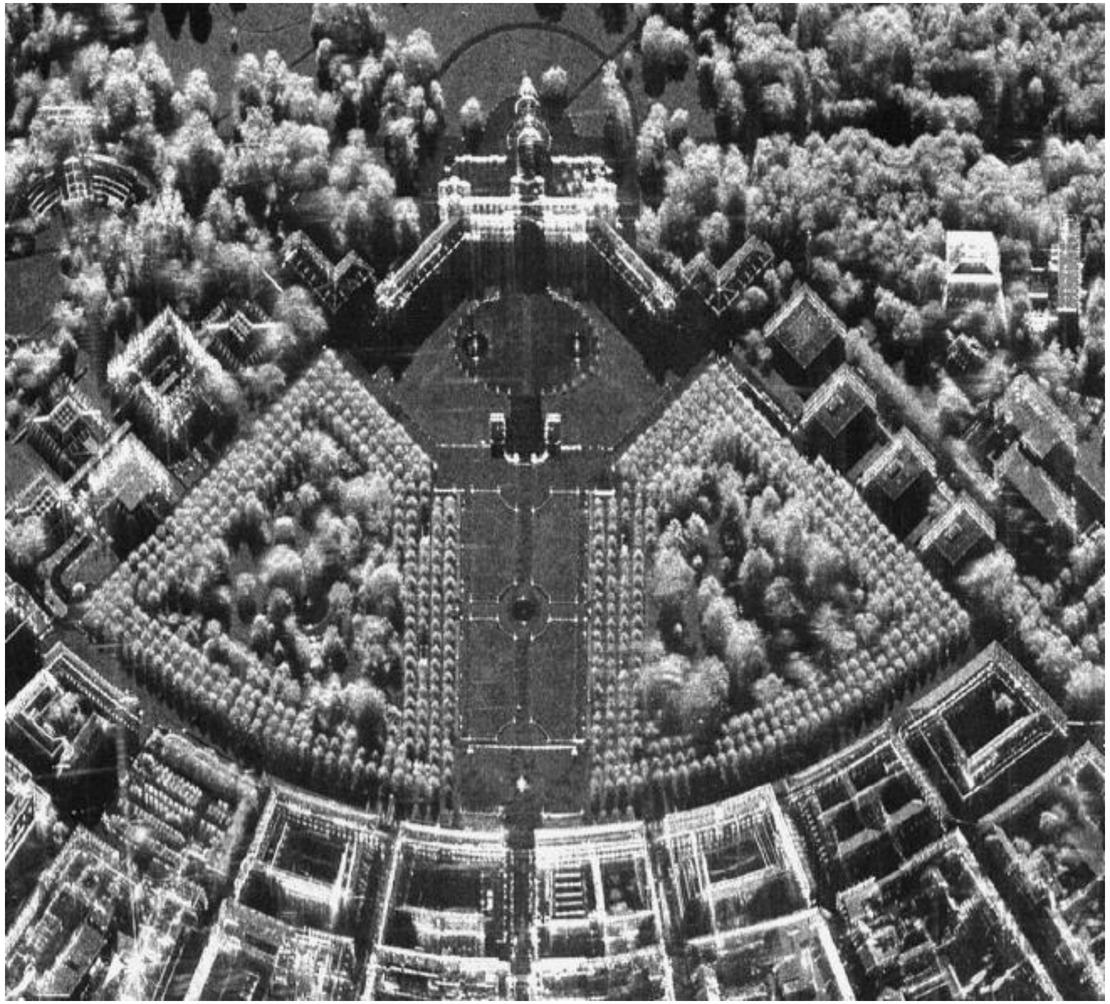
- Steep slopes oriented away from the SAR return no signal
- No signals can be transmitted to this area (as it is blocked by the slope), thus no signals can be scattered back from these areas
- Appears as black area in the image



Geometric Effects in SAR images

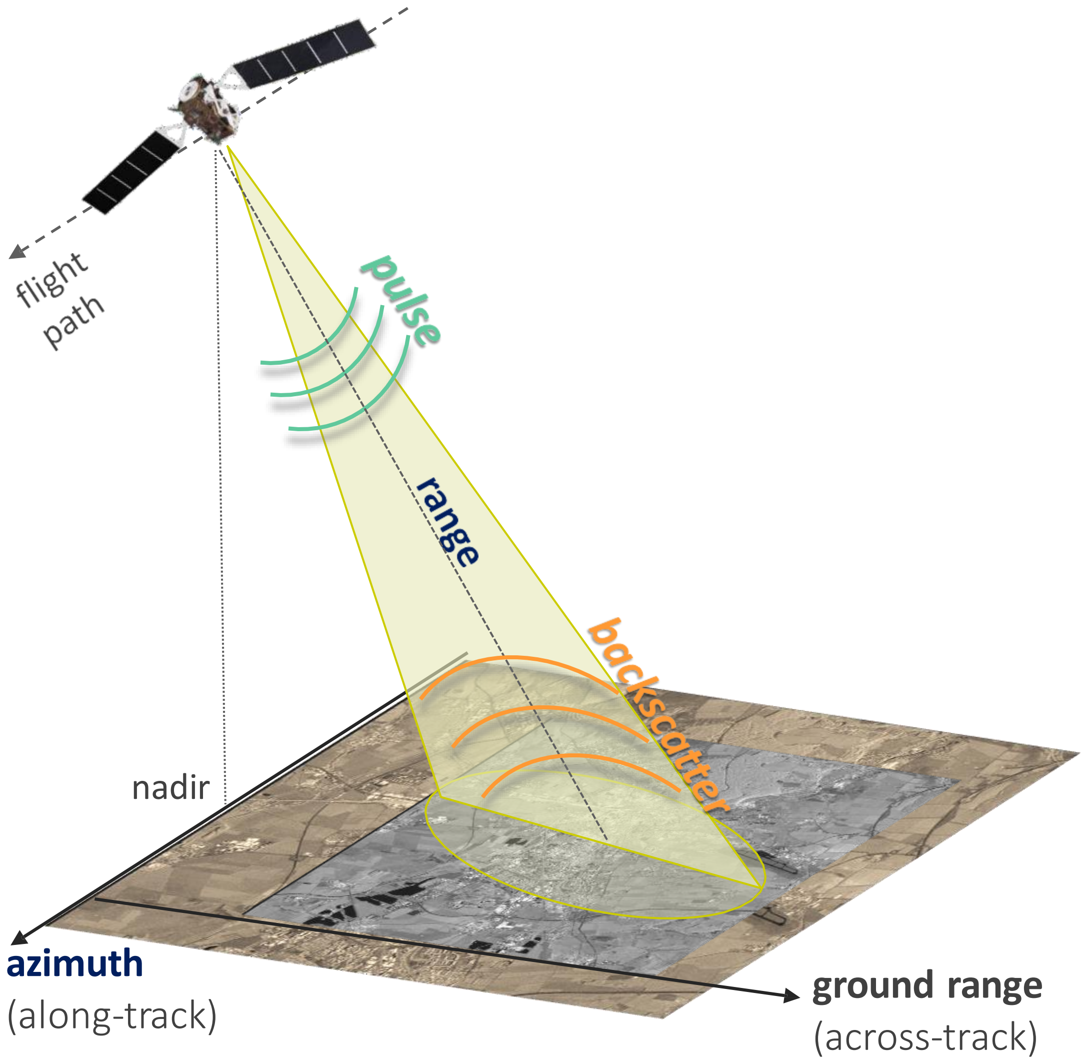
Effects of side-looking geometry

Google maps

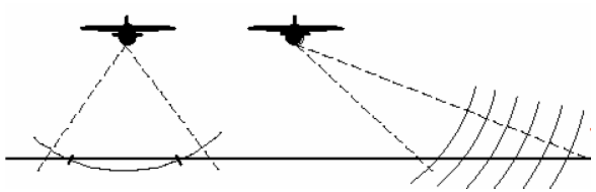


Andreas R. Brenner and Ludwig Roessing, Radar Imaging of Urban Areas by Means of Very High-Resolution SAR and Interferometric SAR, IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 46, NO. 10, OCTOBER 2008 (X-band)

Radar side looking imaging geometry



Is side looking really necessary?



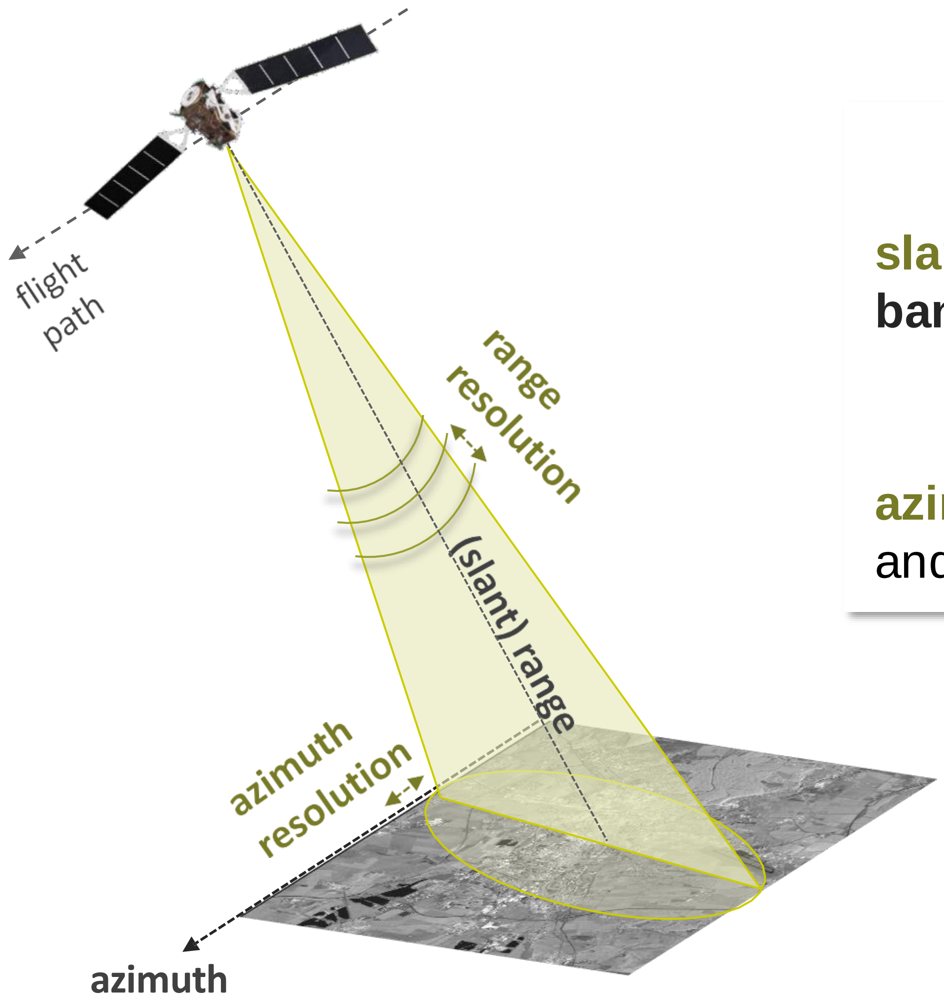
Nadir looking,
e.g. aerial photography

Side looking,
e.g. SLAR, SAR

range: scanning in the look direction at the speed of light

azimuth: scanning in flight direction at the speed of the sensor

Radar side looking imaging geometry



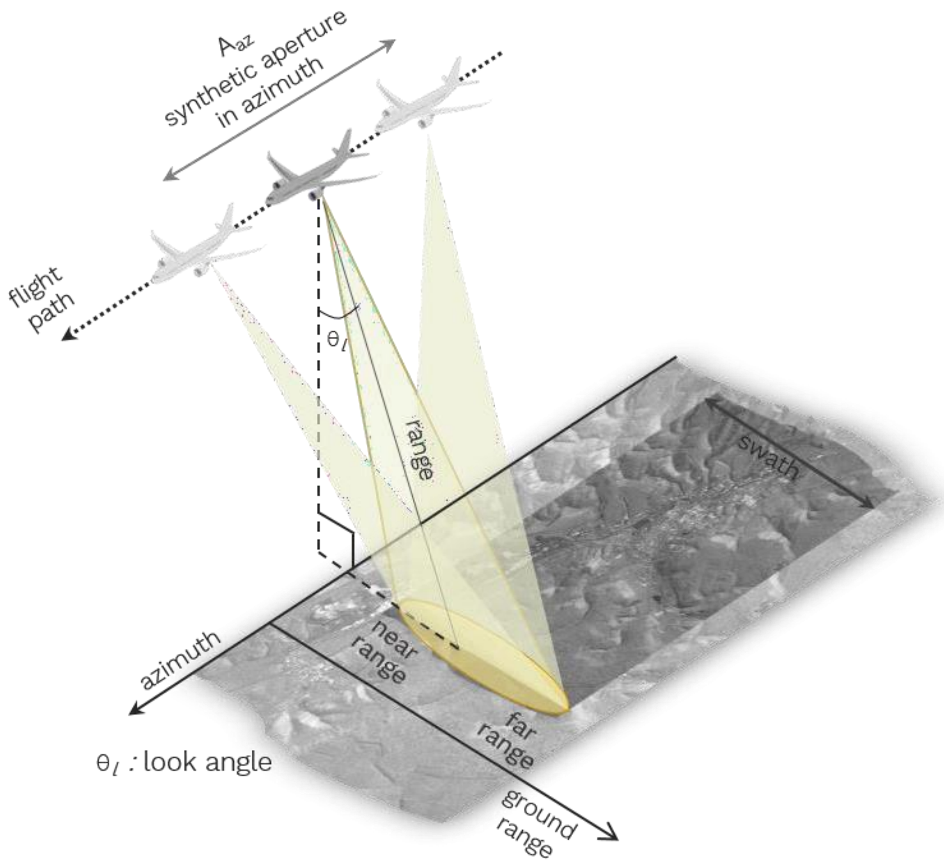
slant-range resolution depends on the **bandwidth of the system**

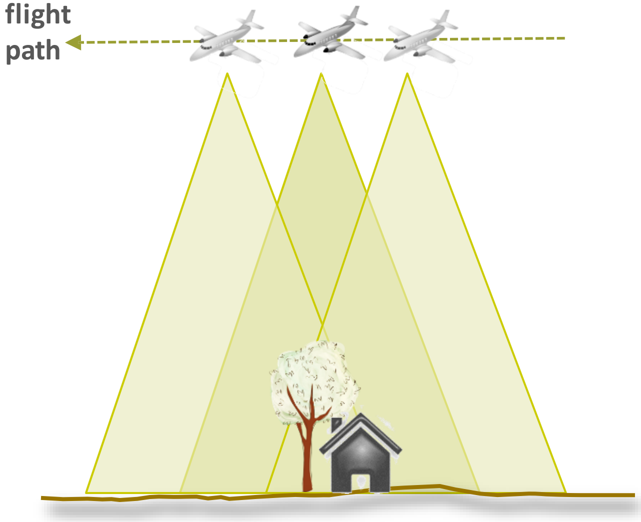
azimuth resolution is a function of the **antenna length** and **sensor height** over the Earth’s surface

Synthetic Aperture Radar (SAR)

The principle of extending the antenna

The key factor that is utilized in SAR is to synthesize a much longer antenna in azimuth direction by making use of the motion of the SAR sensor in order to achieve finer resolution.

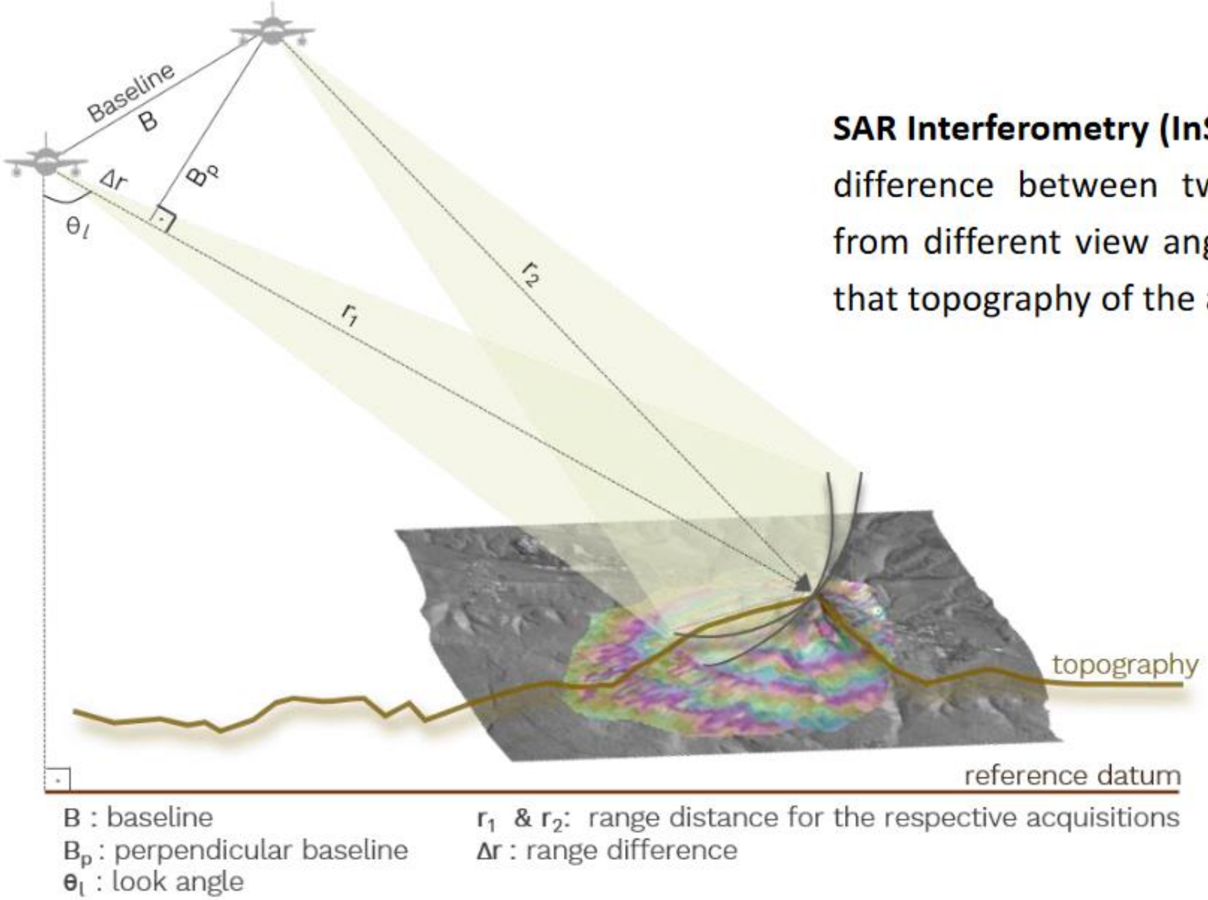




Side view

Synthetic Aperture Radar (SAR)

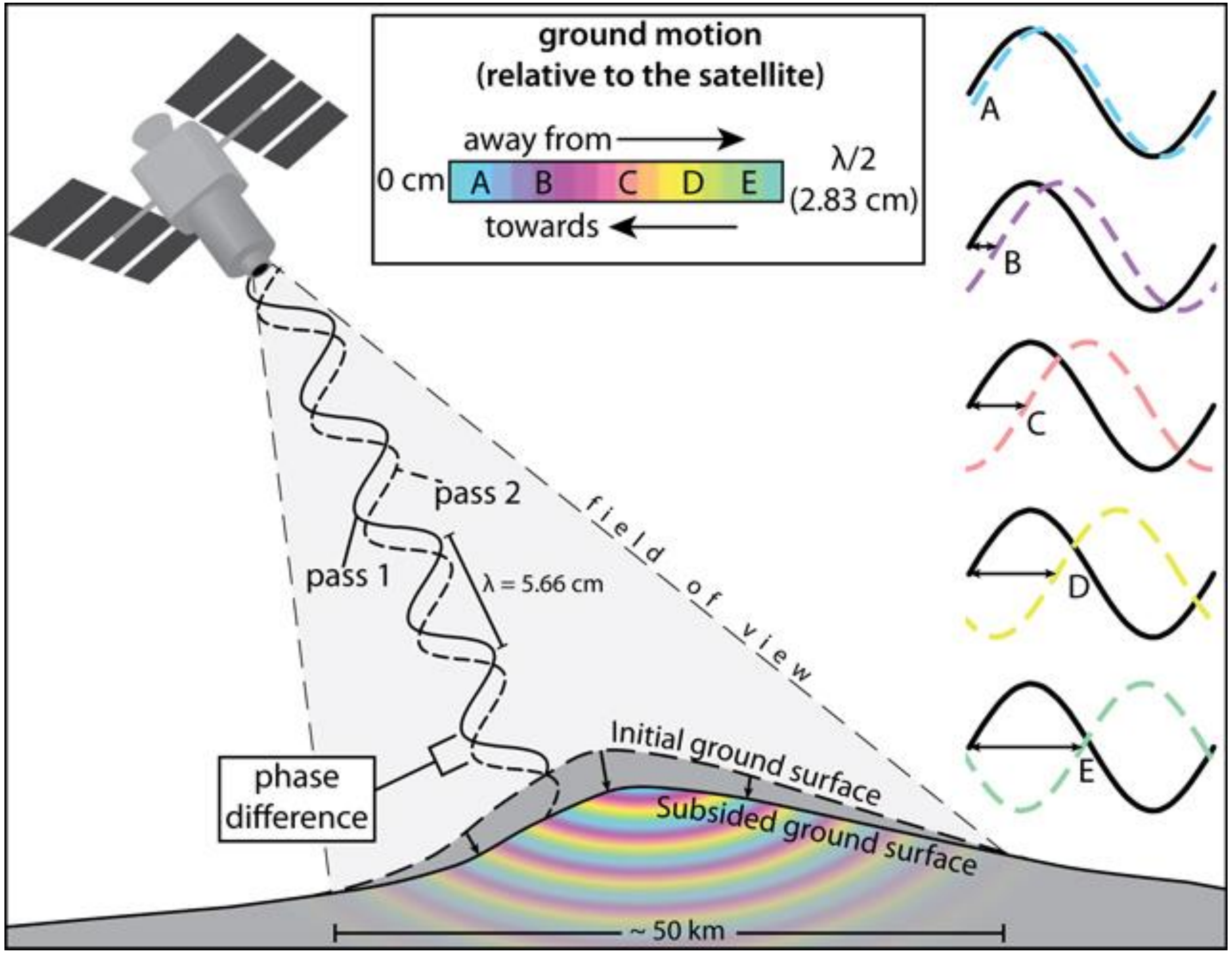
Determining elevation



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.

Synthetic Aperture Radar (SAR)

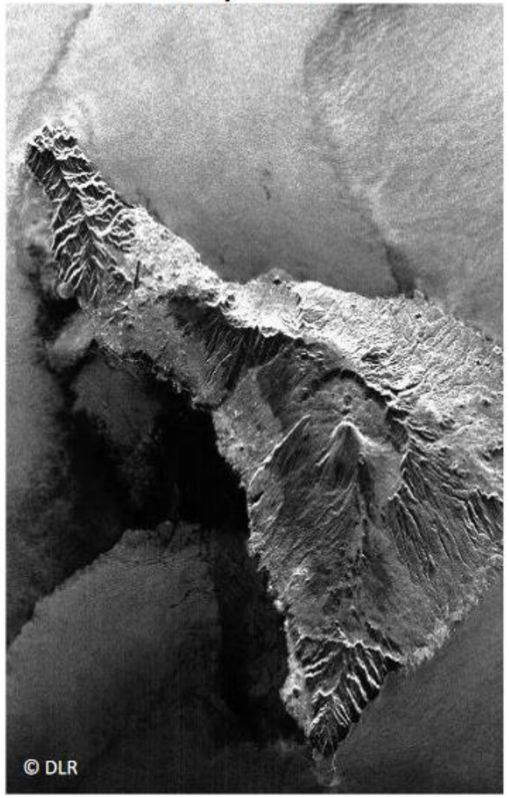
Determining elevation

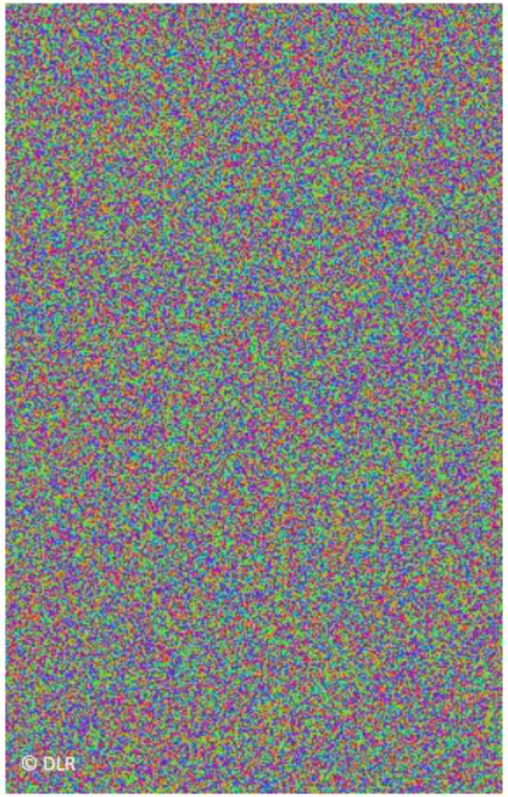


Synthetic Aperture Radar (SAR)

A complex SAR image can be decomposed into …

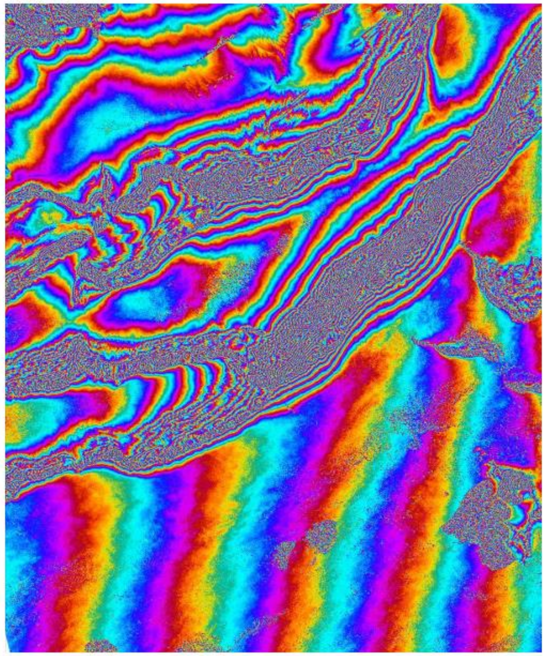
Amplitude & Phase

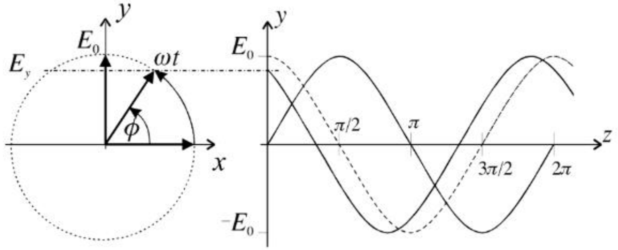




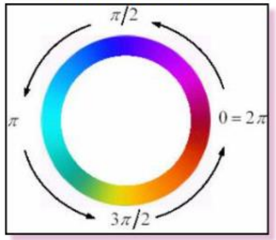
Synthetic Aperture Radar (SAR)

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



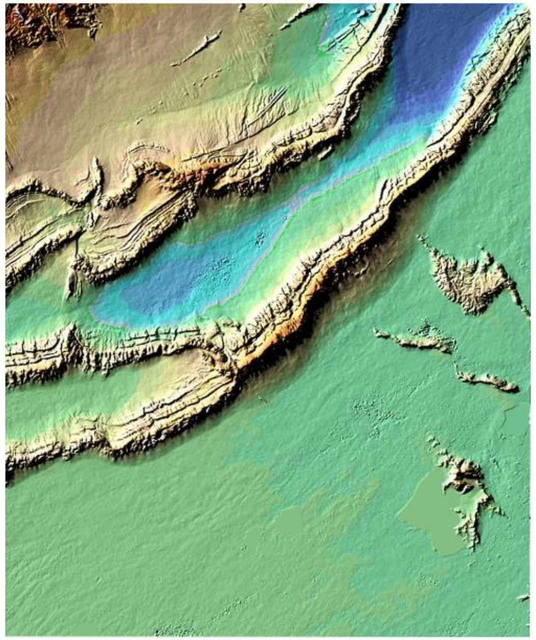


color wheel



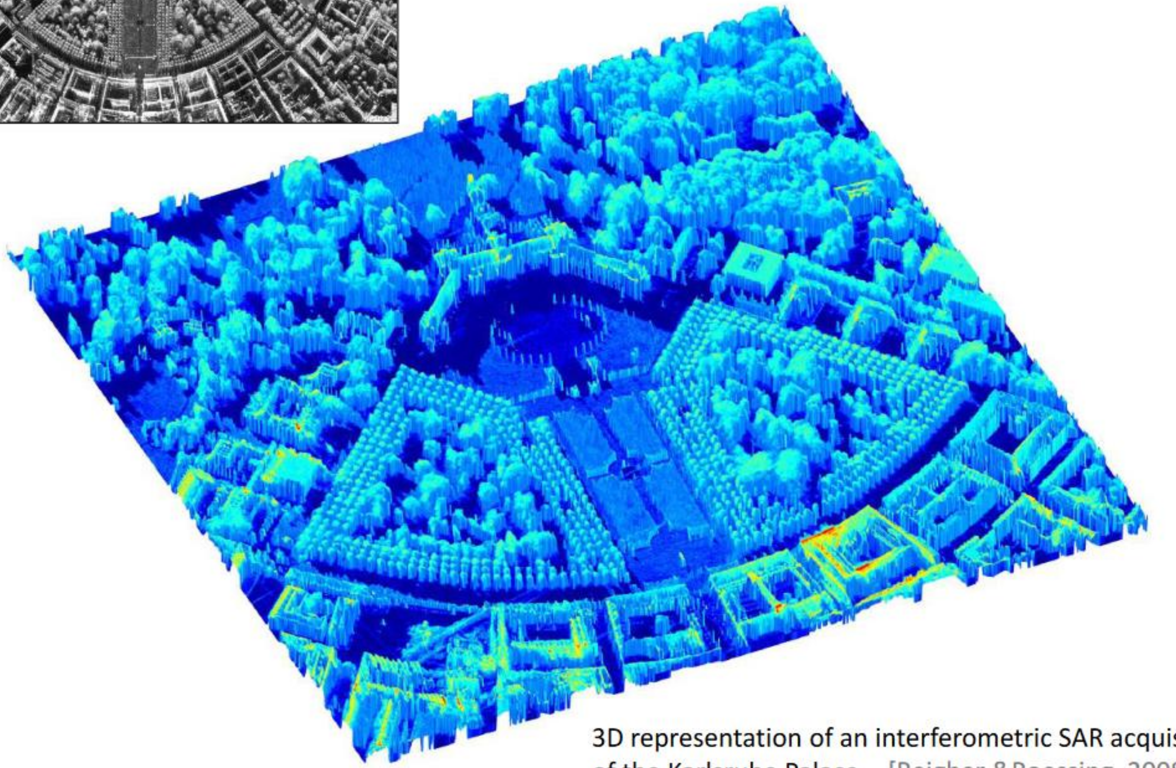
Phase is always ambiguous w.r.t. integer multiples of 2π
→ phase unwrapping required!

Final DEM



Synthetic Aperture Radar (SAR)

Trees acquired at superhigh resolution (X-band)



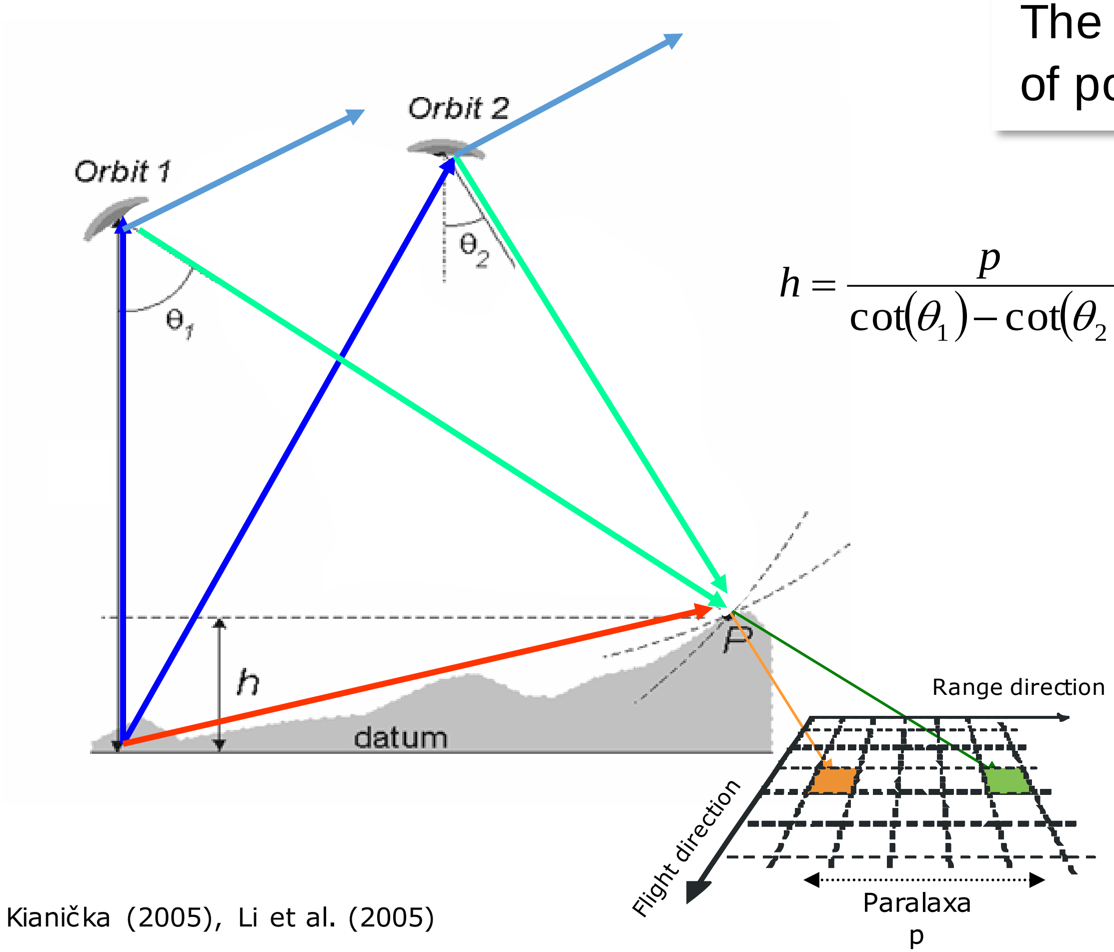
3D representation of an interferometric SAR acquisition
of the Karlsruhe Palace [Reigber &Roessing, 2008]

Synthetic Aperture Radar (SAR)

Image analysis methods

Radargrametry

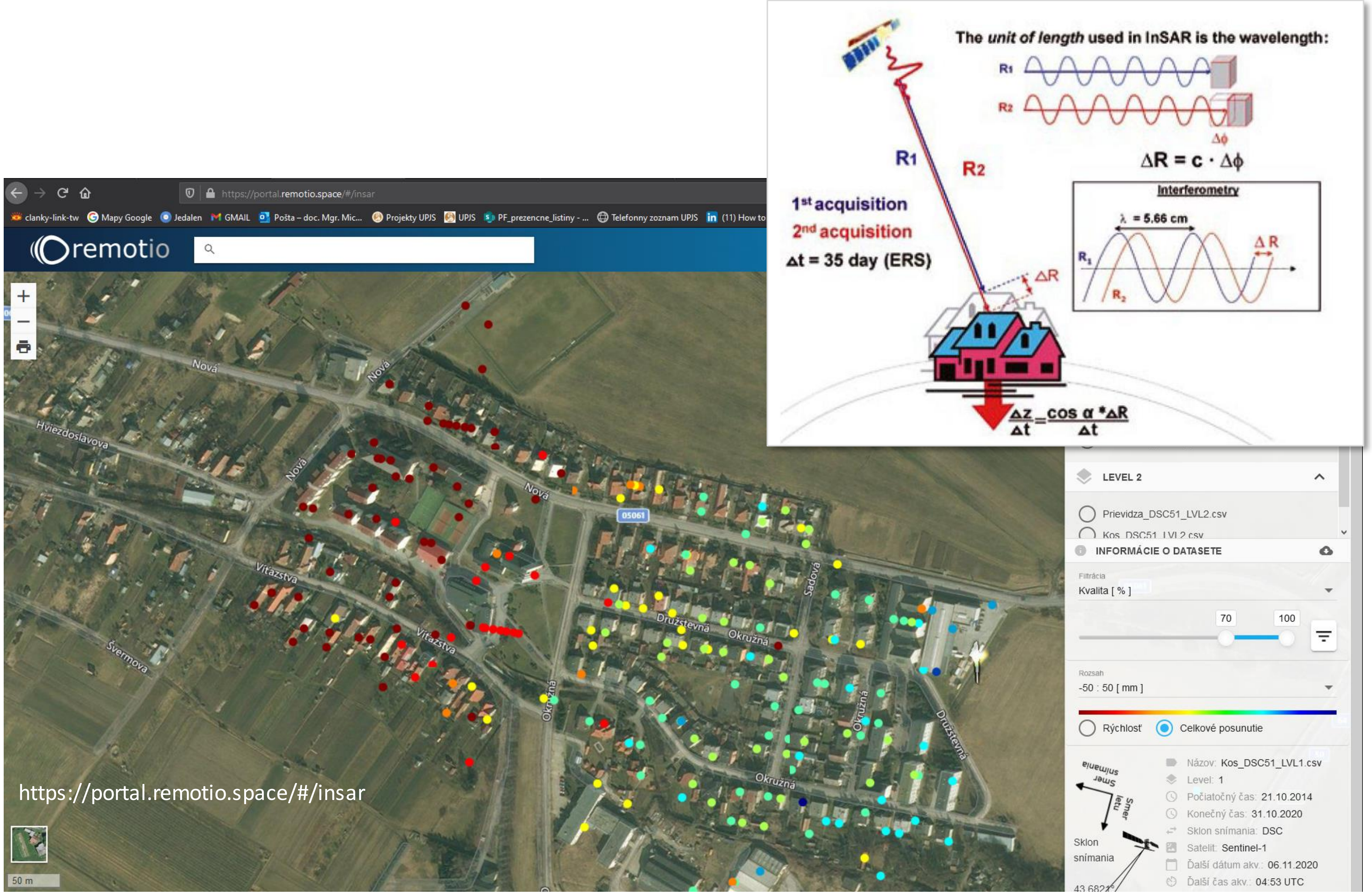
The principle of measuring the parallax of point P using SAR stereo images.



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

Kianička (2005), Li et al. (2005)

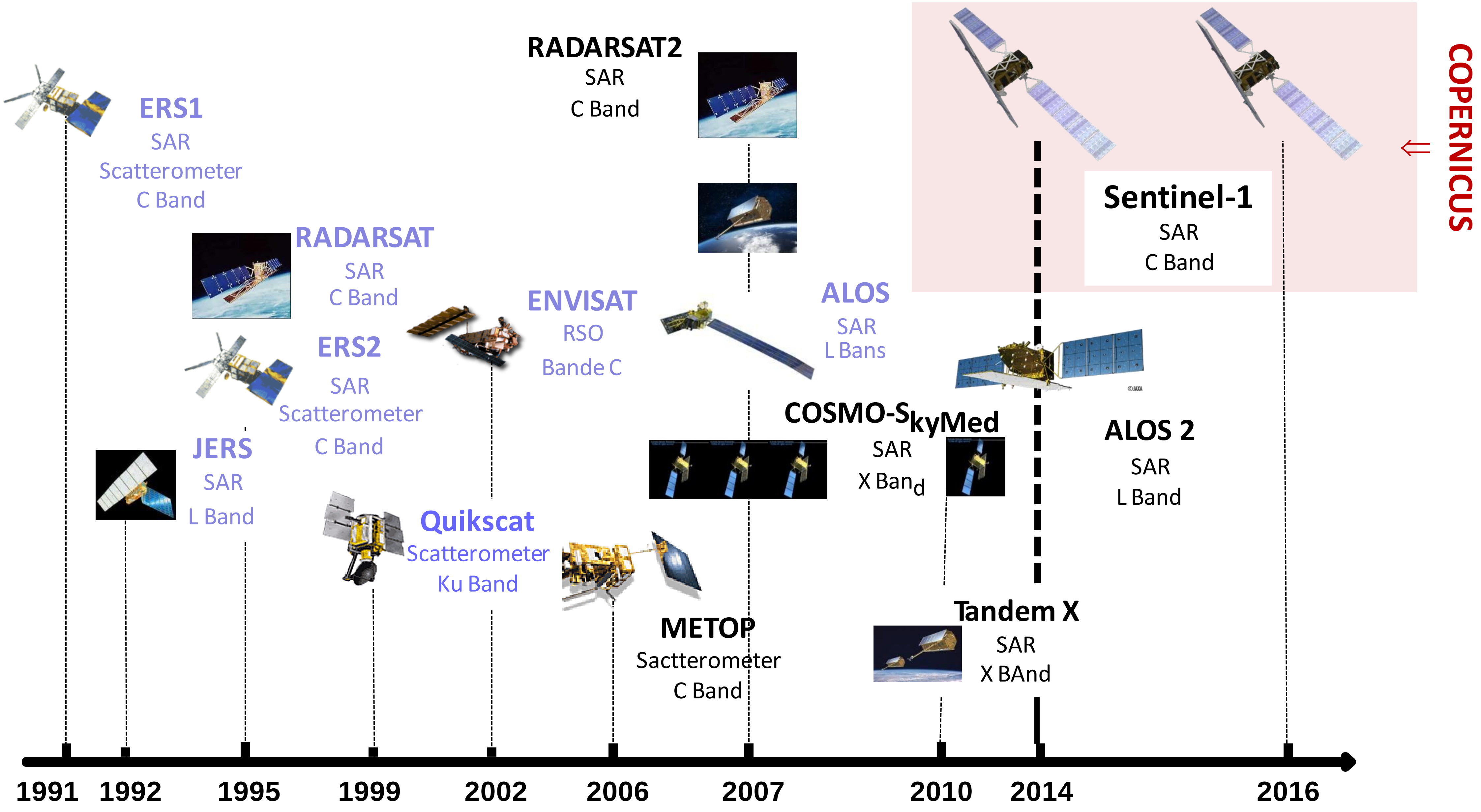
Persistent scatter SAR interferometry - PSInSAR



Persistent scatter SAR interferometry - PSInSAR

- Measurement of movement in points intensely reflecting radar signal, thus not using all pixels of the radar record as in D-InSAR, many of which have unstable coherence of reflected radiation over time (reflectivity over time changes) due to changes in moisture, vegetation growth.
- Such objects, well and stably reflecting microwaves, occur naturally - rock outcrops, cliffs, or artificially - roofs, buildings, building corners, antennas, pipelines.
- The method determines the change in wave phase due to slight movement of the signal reflector.
- This way, surface deformation/movement of objects on it can be determined with millimeter precision.
- Compared to GNSS measurements, the advantage of PSInSAR is the ability to monitor a large number of points over a larger area and lower cost.

Examples of Spaceborne Radar sensors



Examples of Spaceborne Radar sensors

Satellite	Owner	Band	Resolution	Look Angle	Swath	Lifetime
ERS-1	ESA	C	25 m	23°	100 km	1991-2000
ERS-2	ESA	C	25 m	23°	100 km	1995-2012
Radarsat-1	Canada	C	10 m - 100 m	20°- 59°	50 - 500 km	1995-2013
ENVISAT	ESA	C	25 m - 1 km	15°- 40°	100 - 400 km	2002-2012
ALOS	Japan	L	10 m -100 m	35°- 41°	70 - 360 km	2006-2011
Cosmo	Italy	X	ca. 1 m - 16 m	…	…	2007-
TerraSAR-X & TanDEM-X	Germany	X	1 m - 16 m	15°- 60°	10 - 100 km	2007/2010-
Radarsat-2	Canada	C	3 m - 100 m	15°- 59°	10 - 500 km	2007-
ALOS-2	Japan	L	3 m – 100 m	8°-70°	25 – 350 km	2014-
Sentinel-1	ESA	C	5 m – 50 m	20°-46°	20 - 400 km	2014-

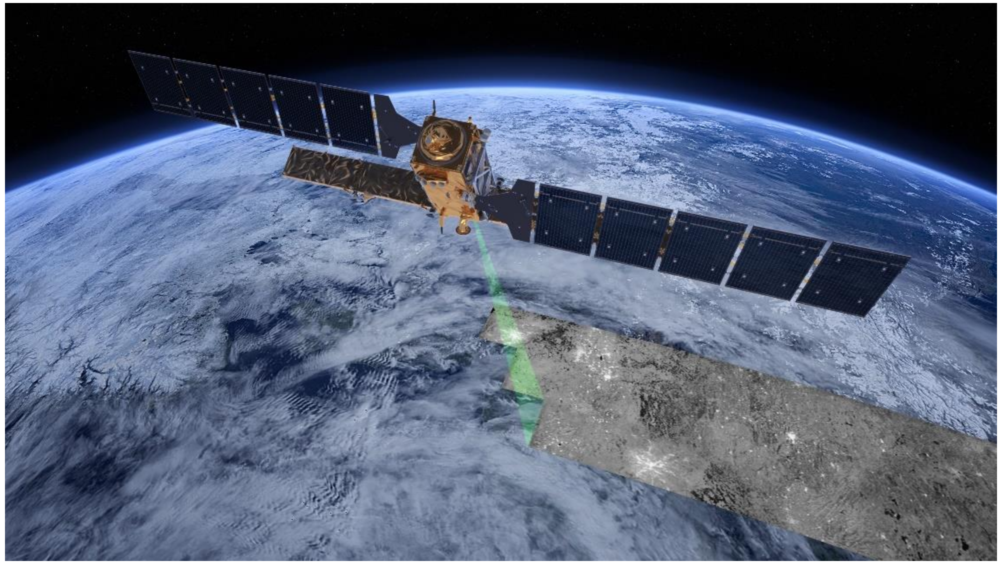
Sentinel-1 – Radar vision

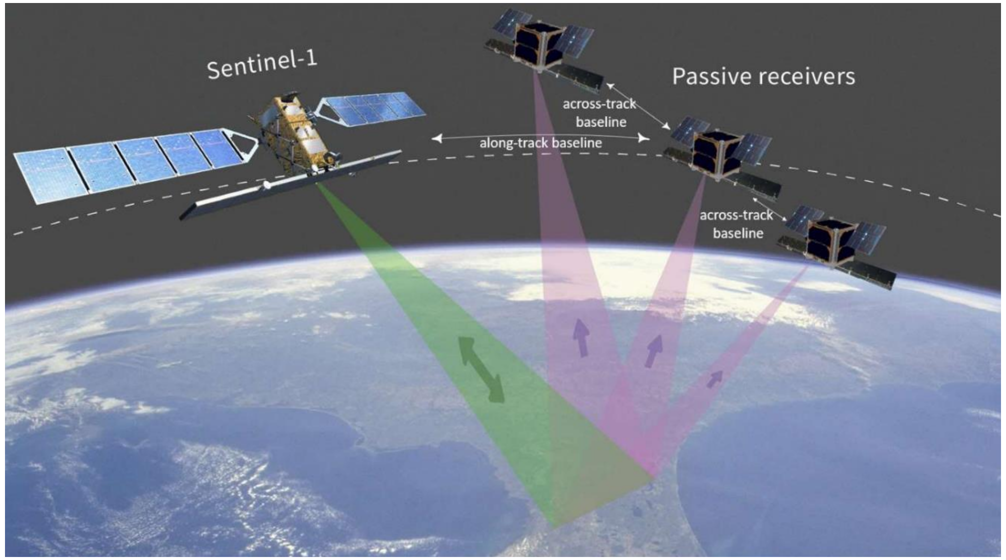
Mission profile:

- C-Band SAR mission at 5.4 GHz
- Multi-polarisation
- Sun synchronous orbit at 693 km mean alt.
- 6 days repeat cycle at Equator with 2 satellites
- 4 operation modes

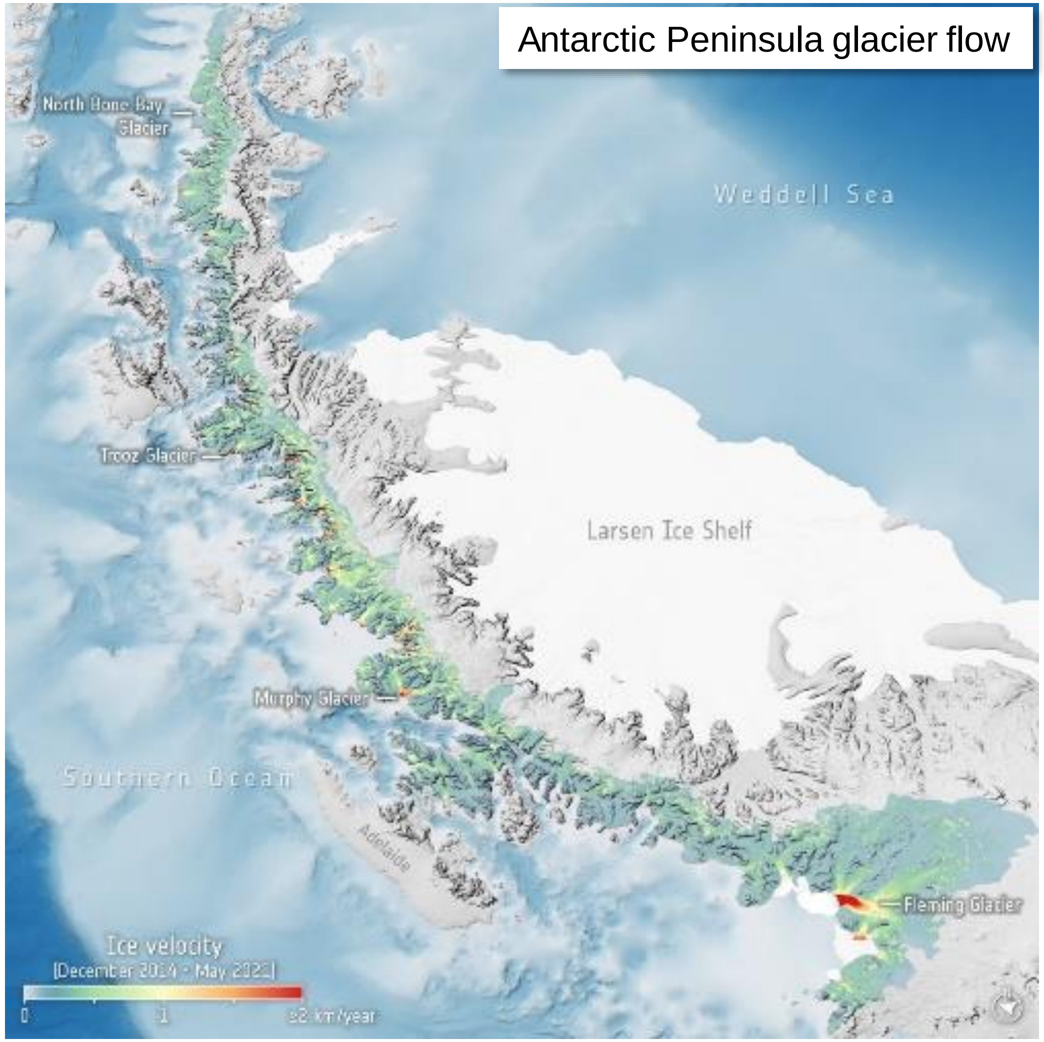
Mission objectives:

- Marime and land monitoring
- Emergency management



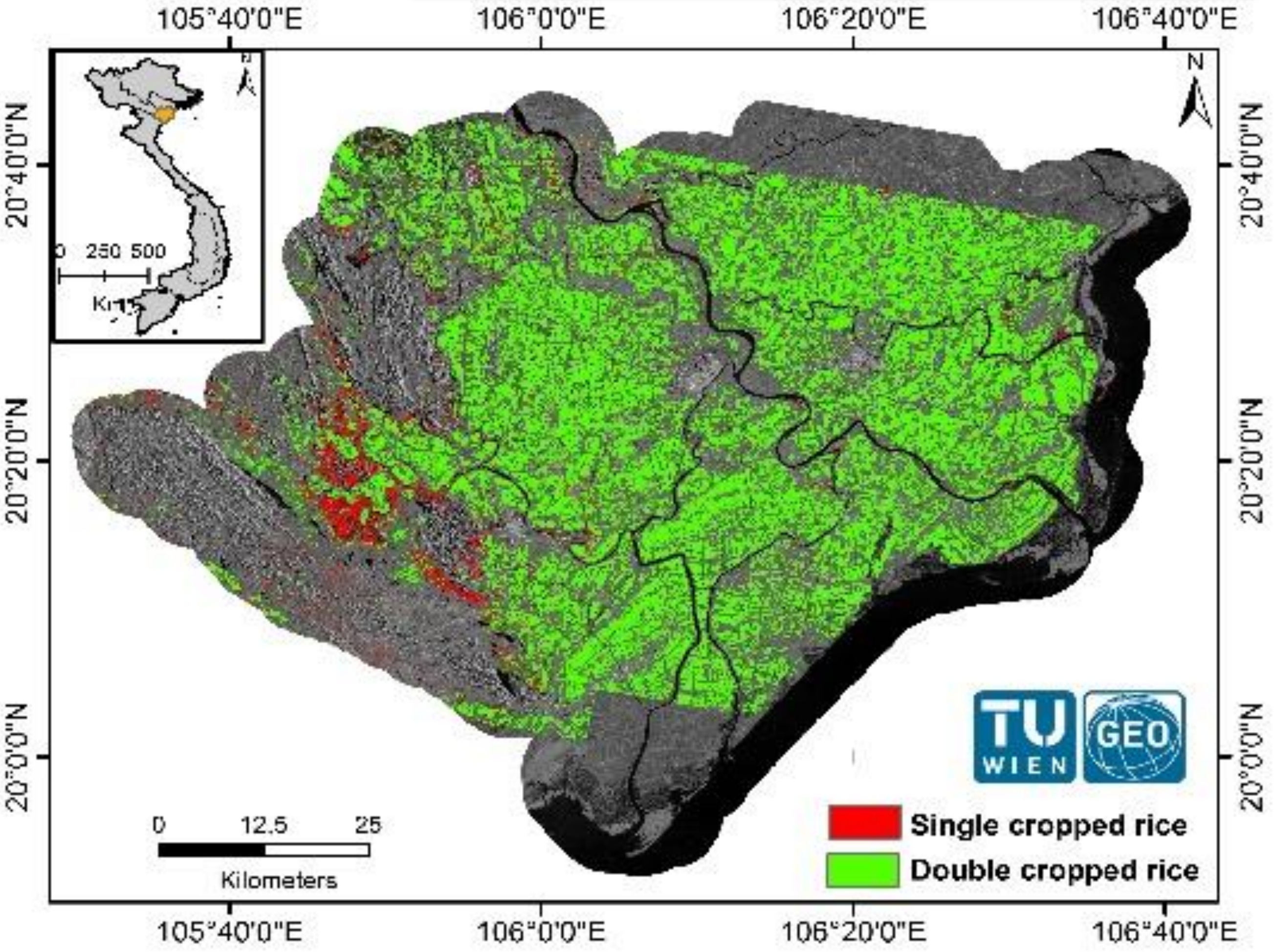


Sentinel-1 – Applications

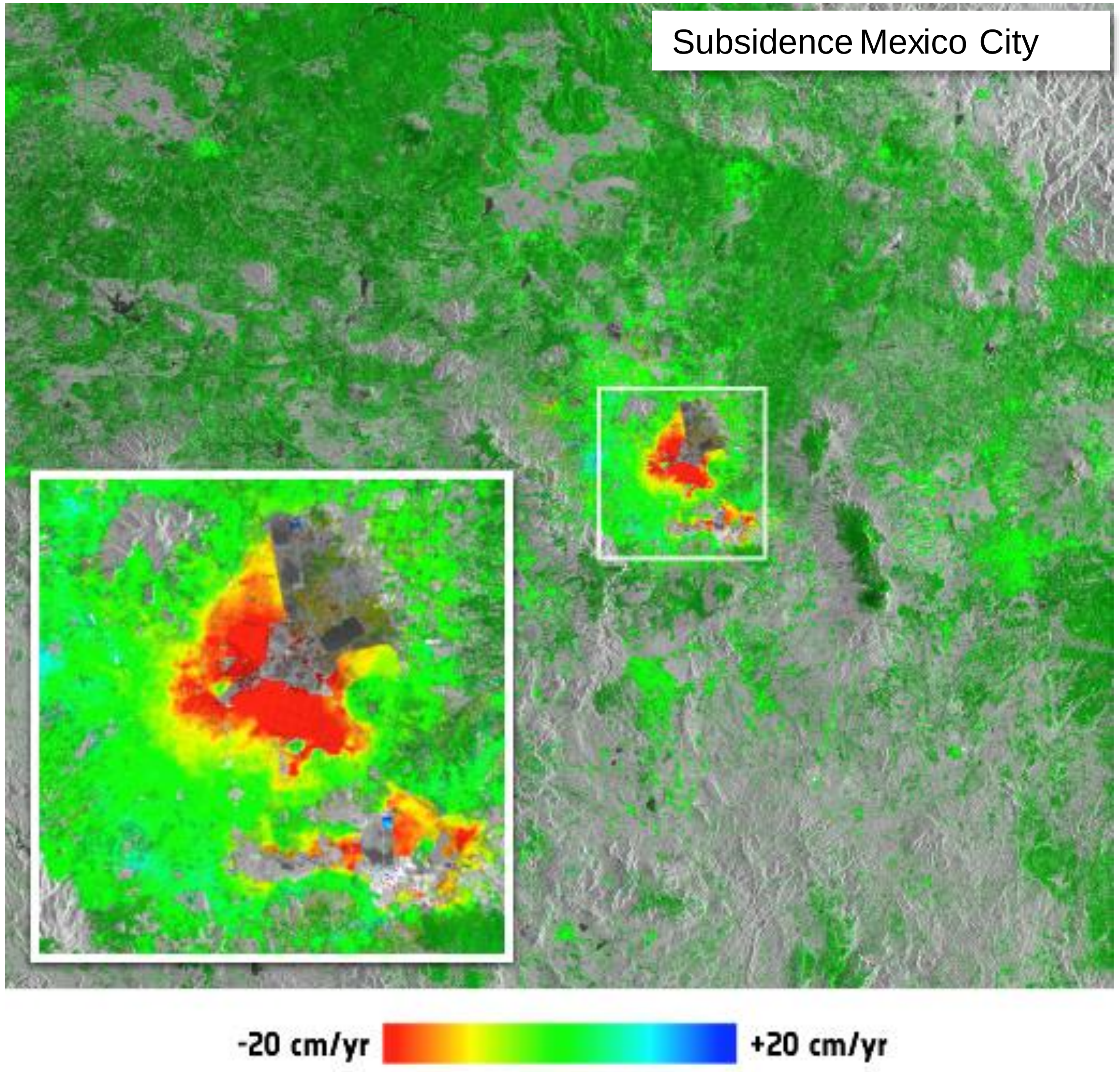


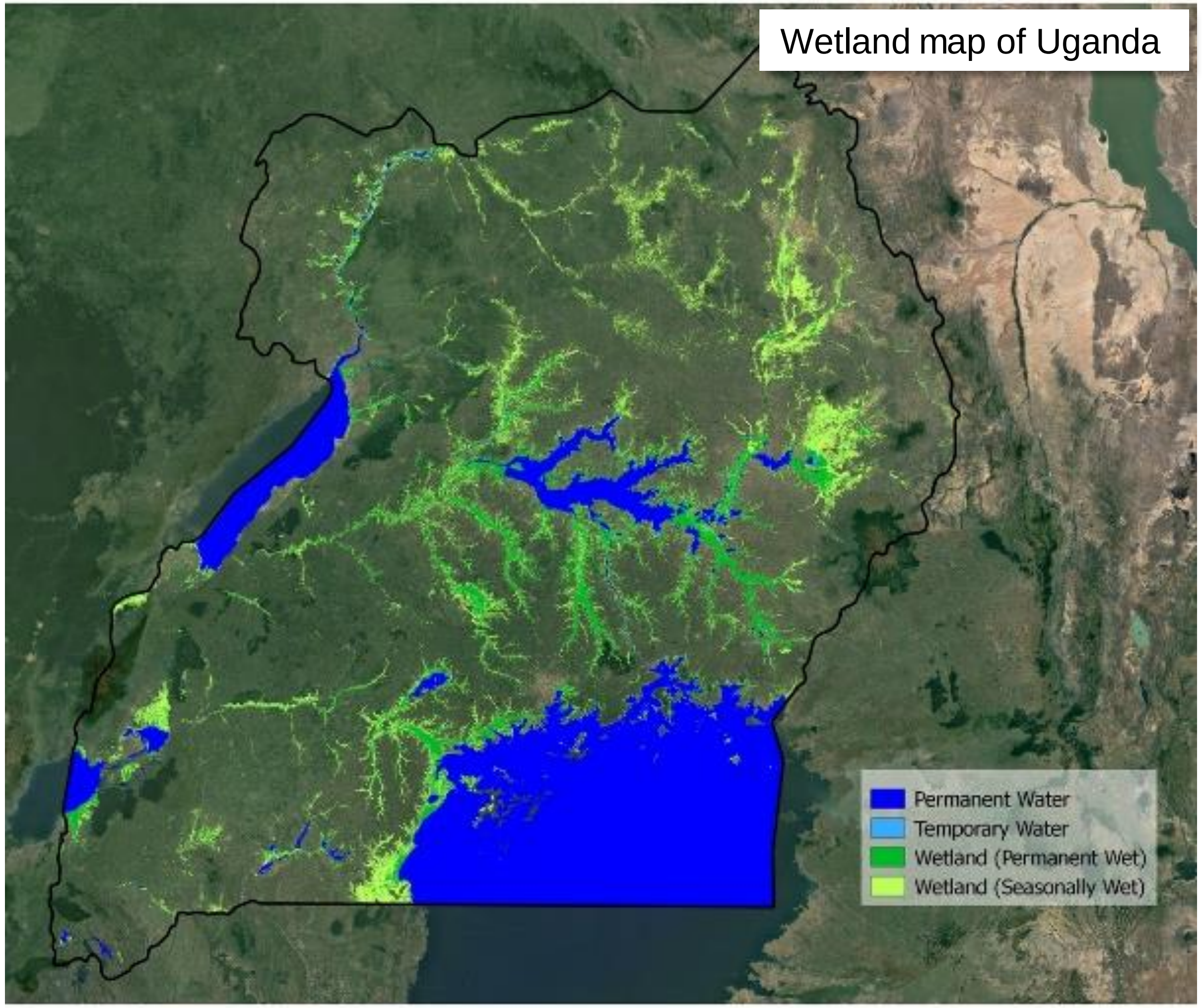
Antarctic Peninsula glacier flow

Rice-cropping systems in Vietnam's Red River Delta

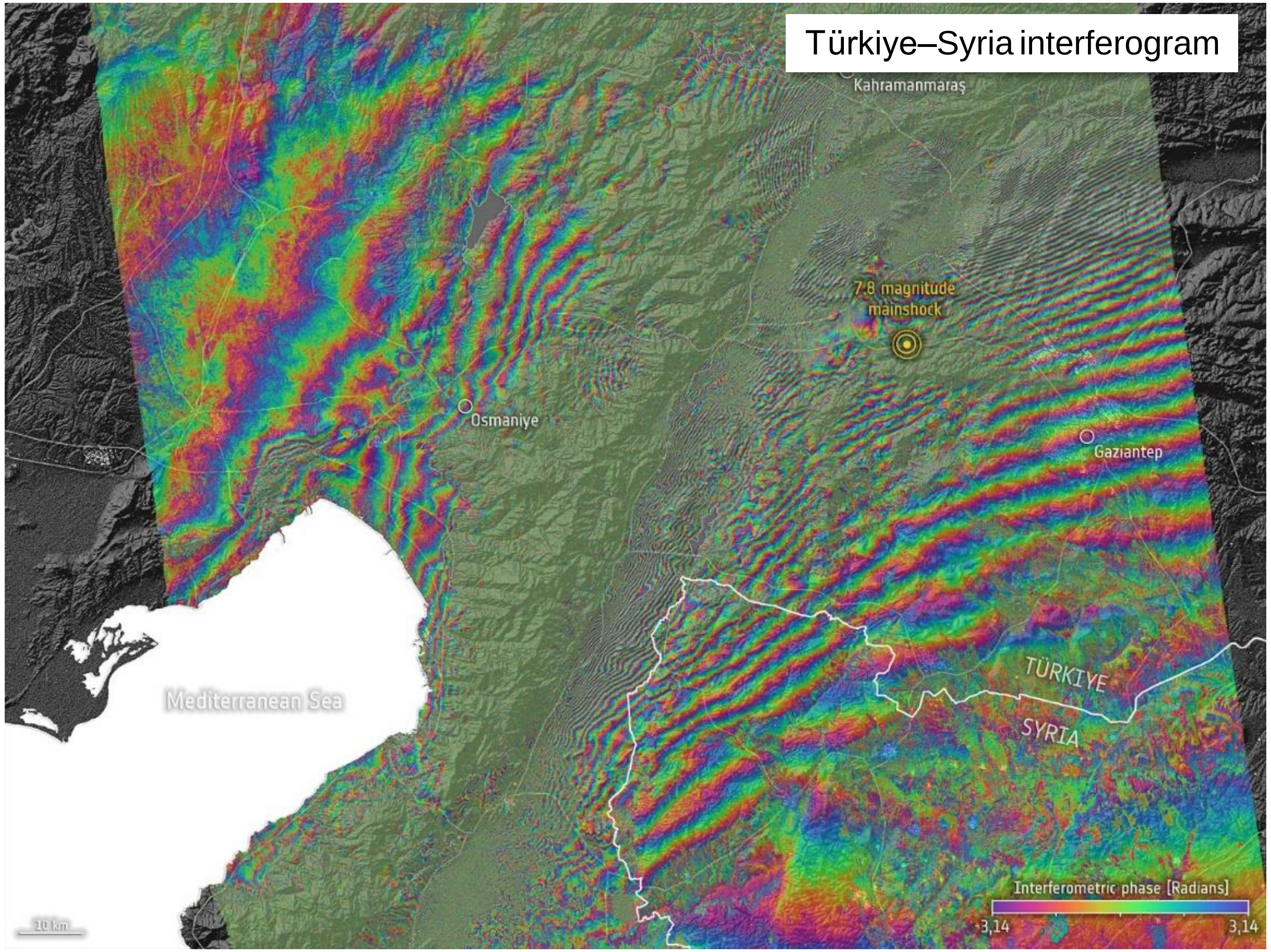


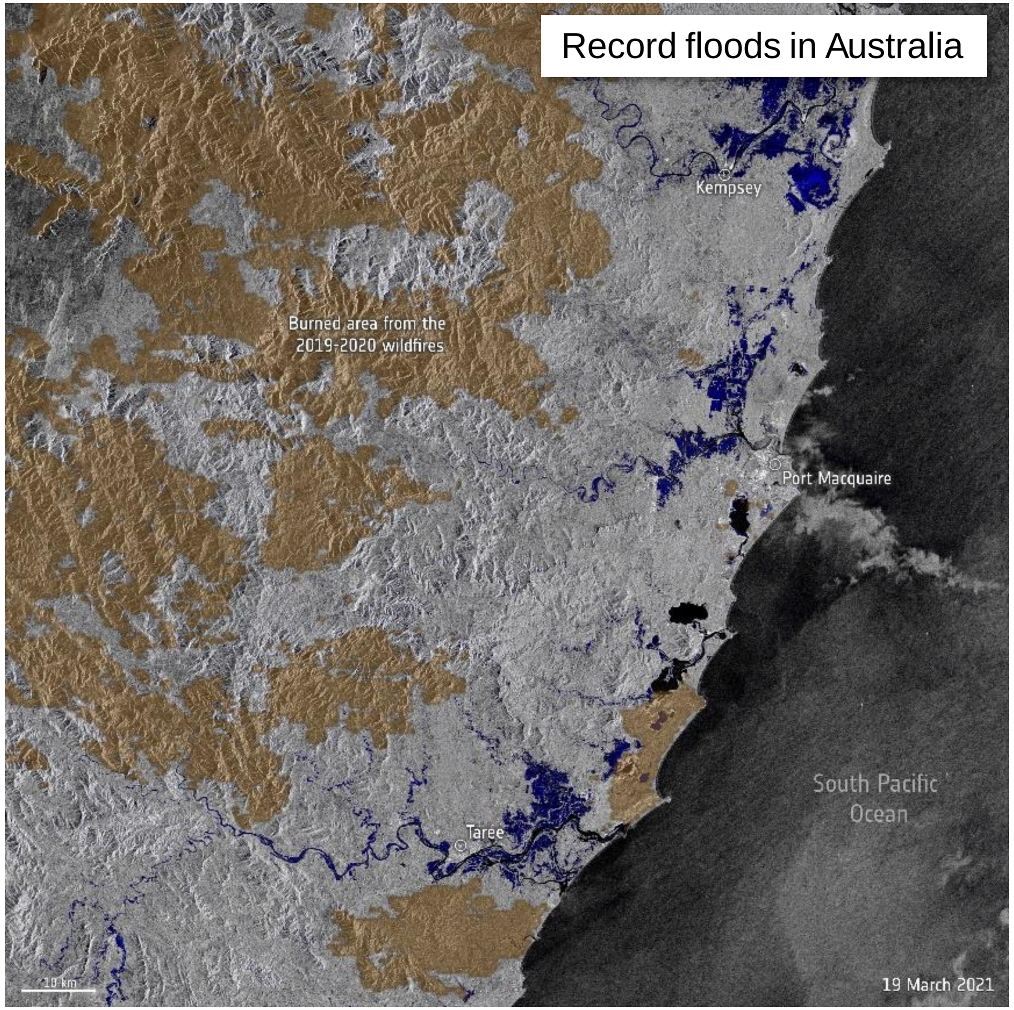
Sentinel-1 – Applications





Sentinel-1 – Applications





For more information, see the tutorial:
5. Basics of Radar Remote Sensing - data processing using SNAP software

Thank you for the attention