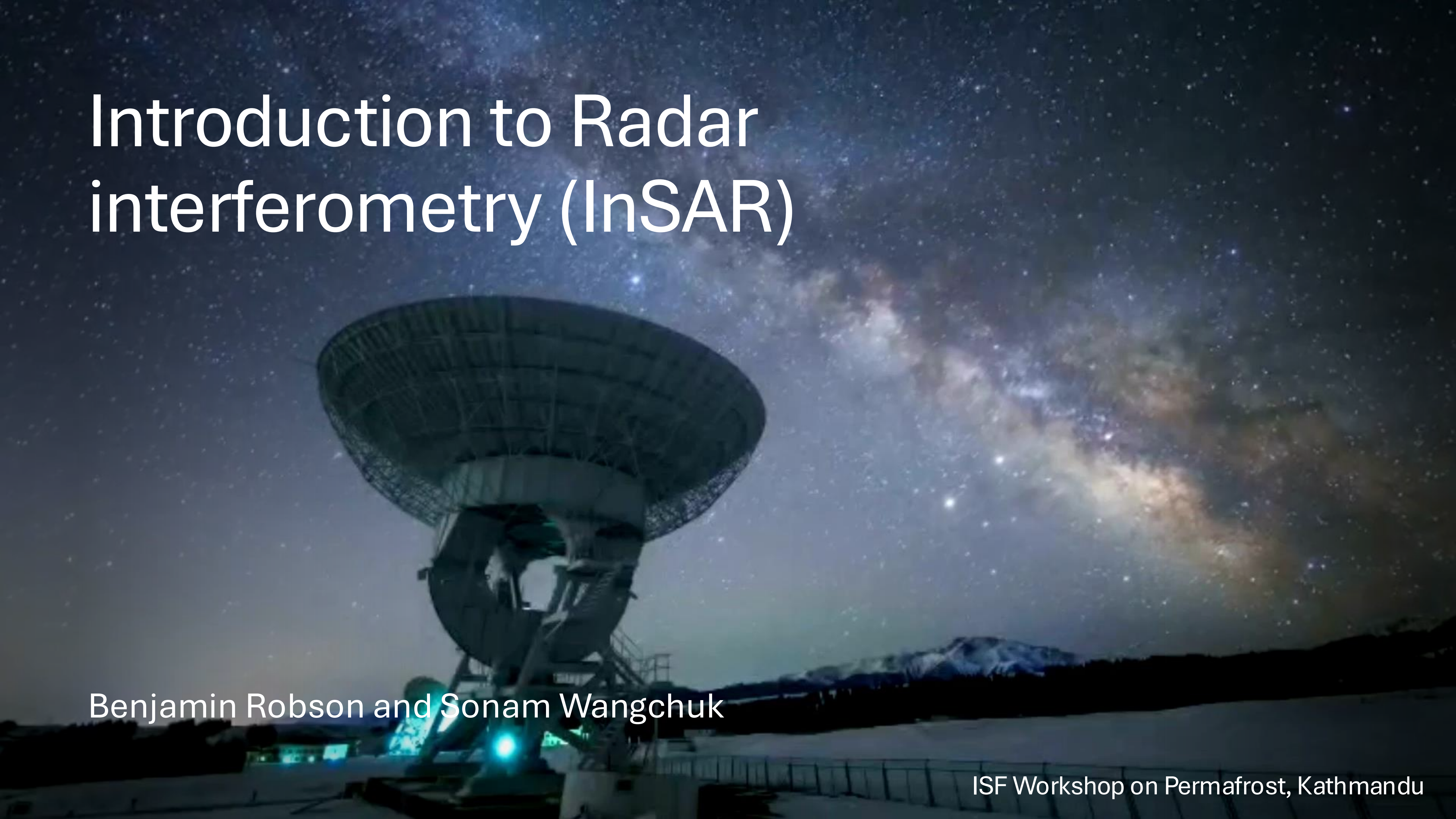
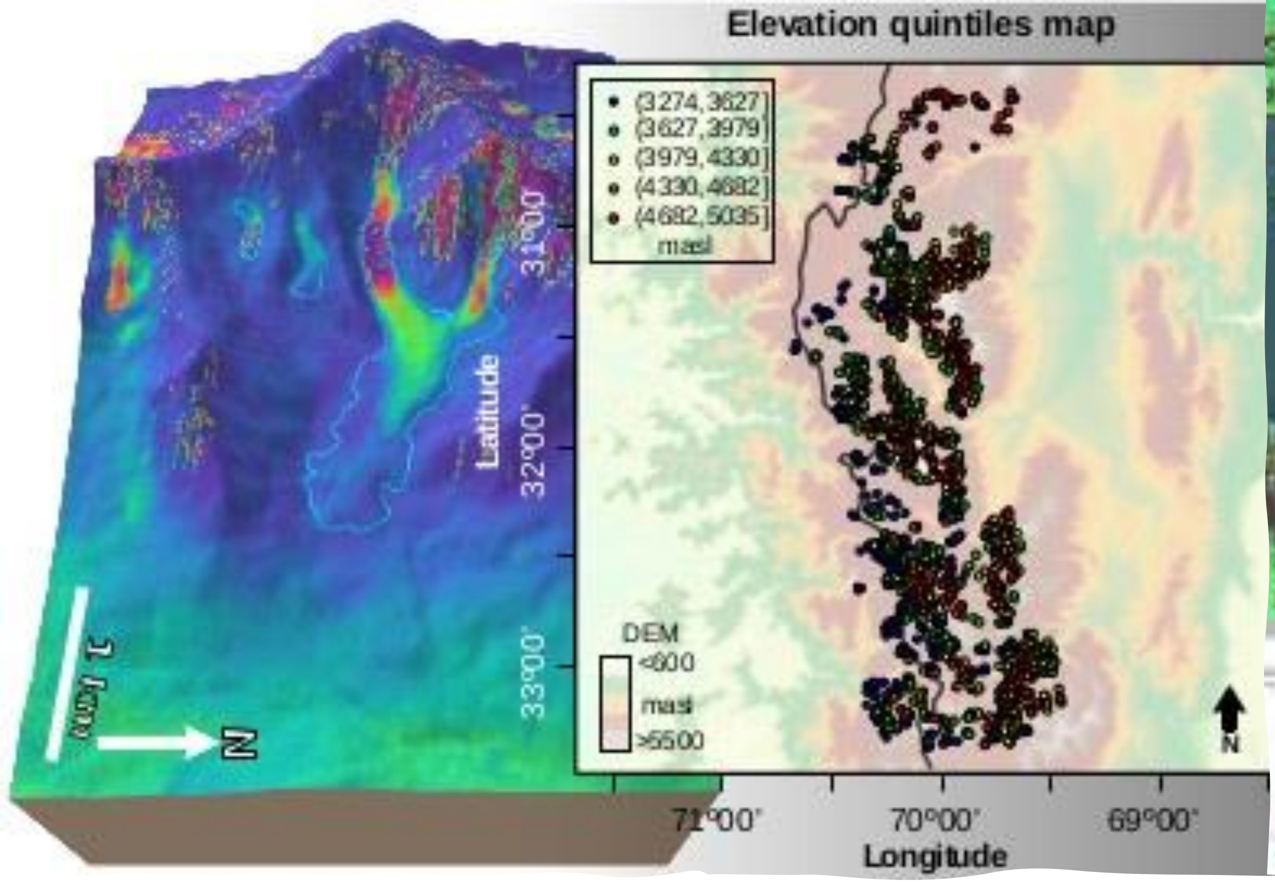
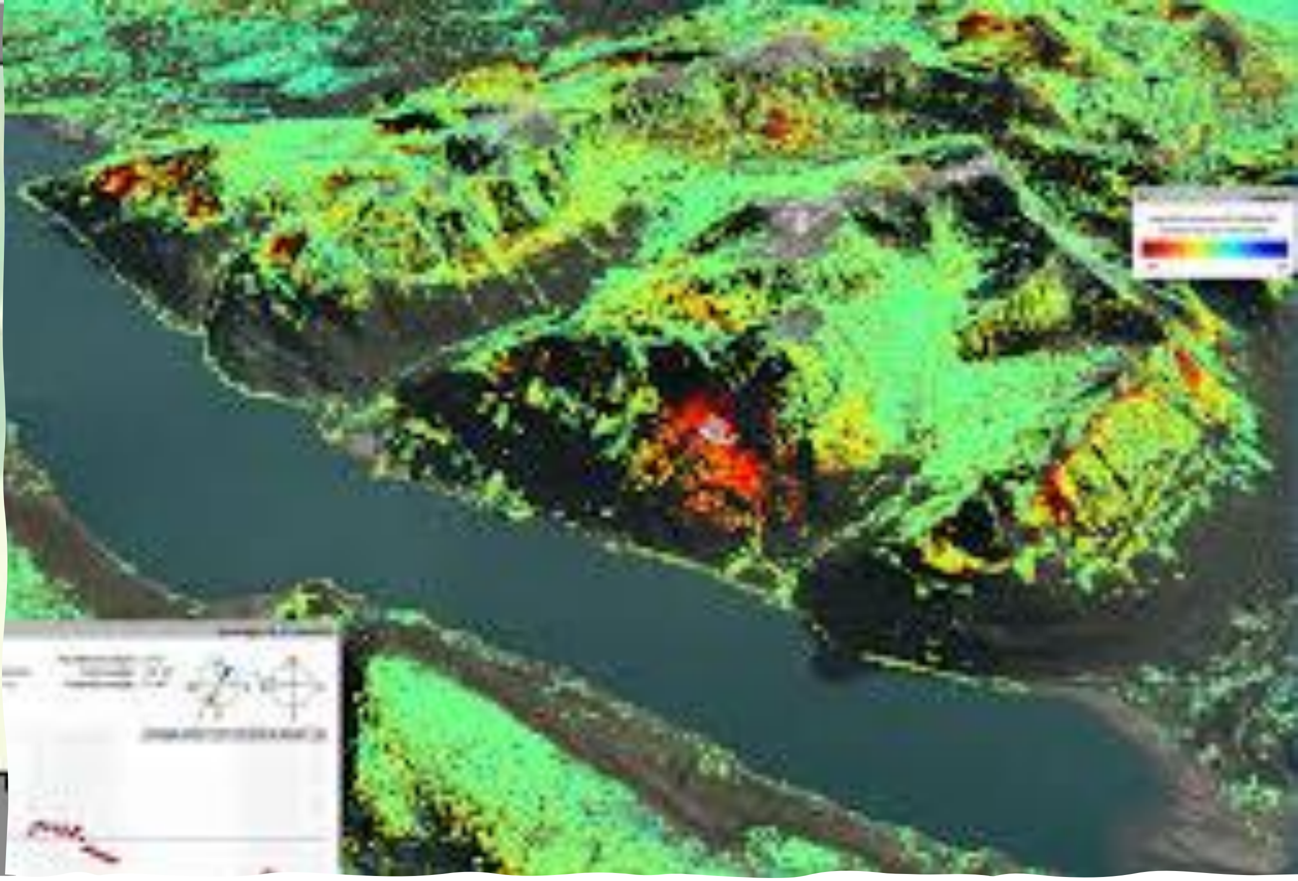


Introduction to Radar interferometry (InSAR)

Benjamin Robson and Sonam Wangchuk

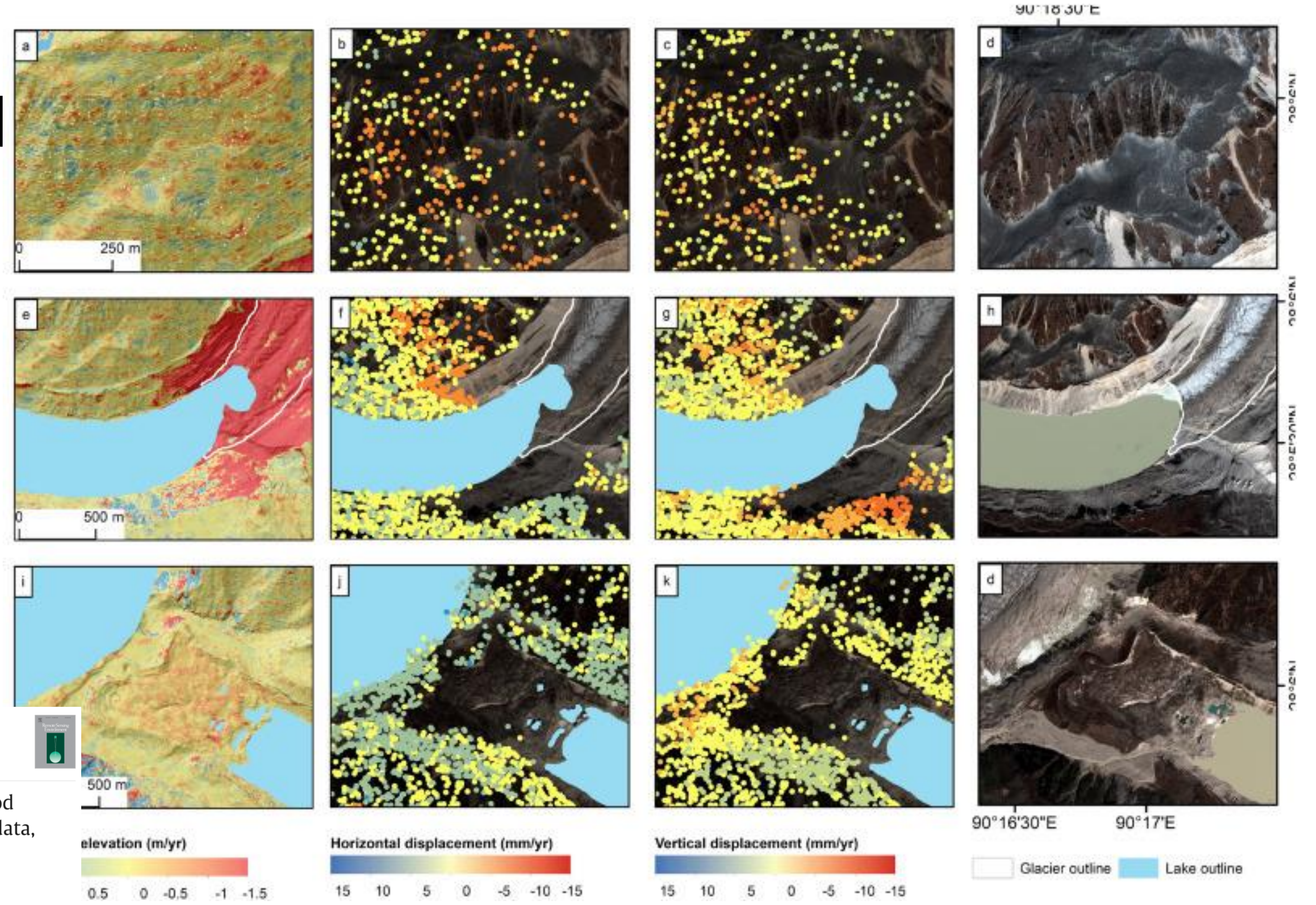
ISF Workshop on Permafrost, Kathmandu





What can we get out of InSAR?

Hazard



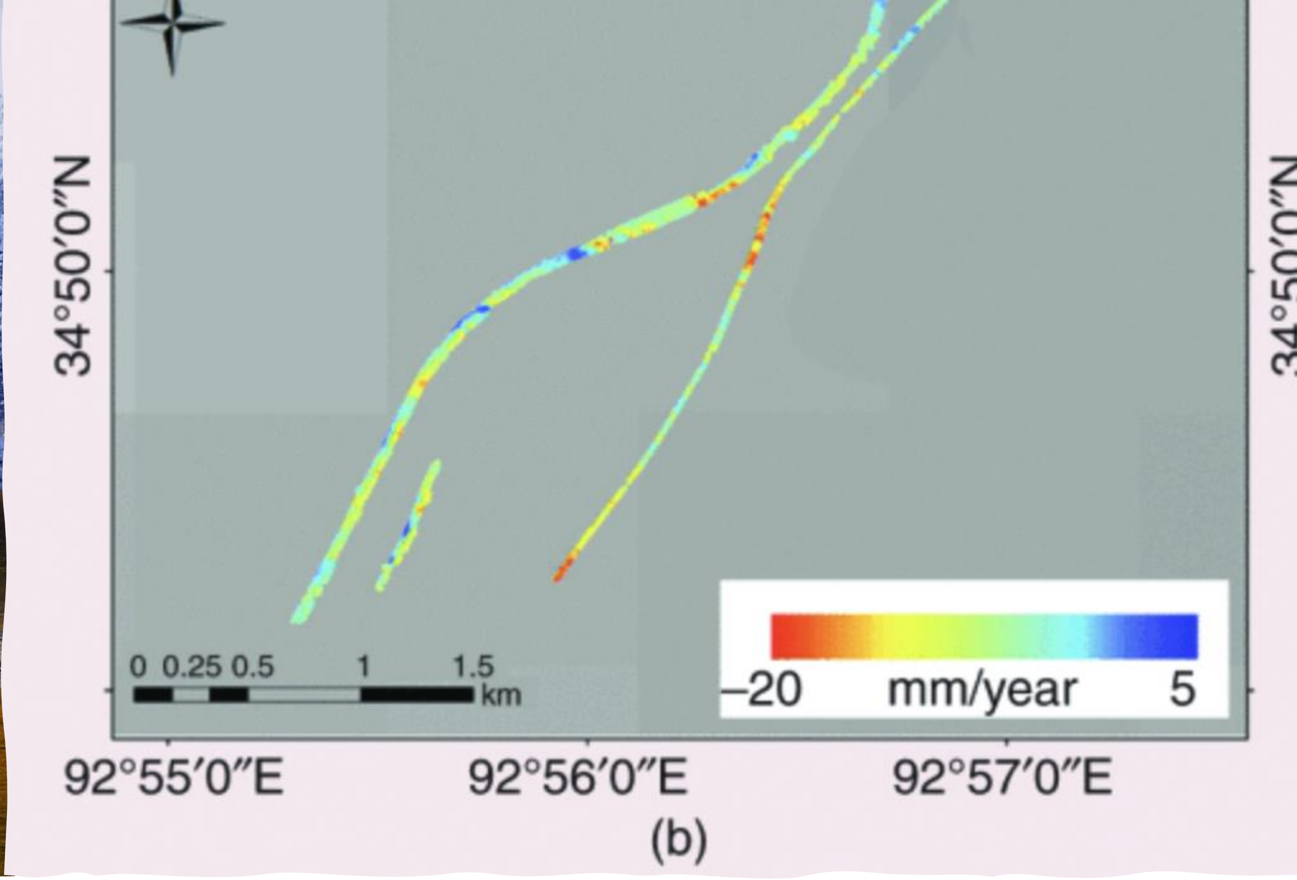
ELSEVIER

Remote Sensing of Environment

Volume 271, 15 March 2022, 112910

Monitoring glacial lake outburst flood susceptibility using Sentinel-1 SAR data, Google Earth Engine, and persistent scatterer interferometry

Sonam Wangchuk [a c], Tobias Bolch [a], Benjamin Aubrey Robson [b]



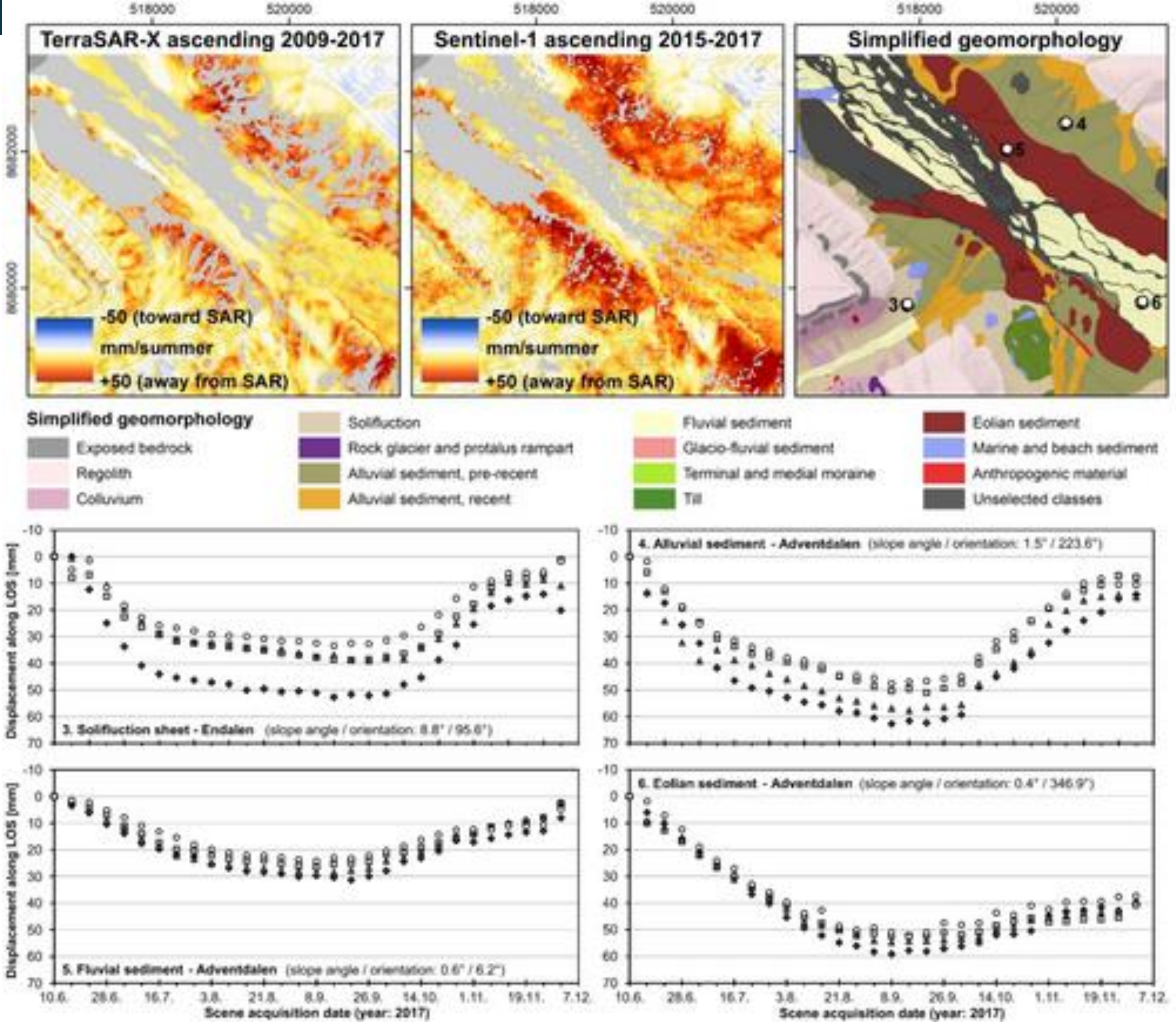
Infrastructure assessment

A Review of Satellite Synthetic Aperture Radar Interferometry Applications in Permafrost Regions: Current status, challenges, and trends

Publisher: IEEE Cite This PDF

Zhengjia Zhang ; Hong Lin ; Mengmeng Wang ; Xiuguo Liu ; Qihao Chen ; Chao Wang ; Hong Zhang **All Authors**

Permafrost freeze + thaw

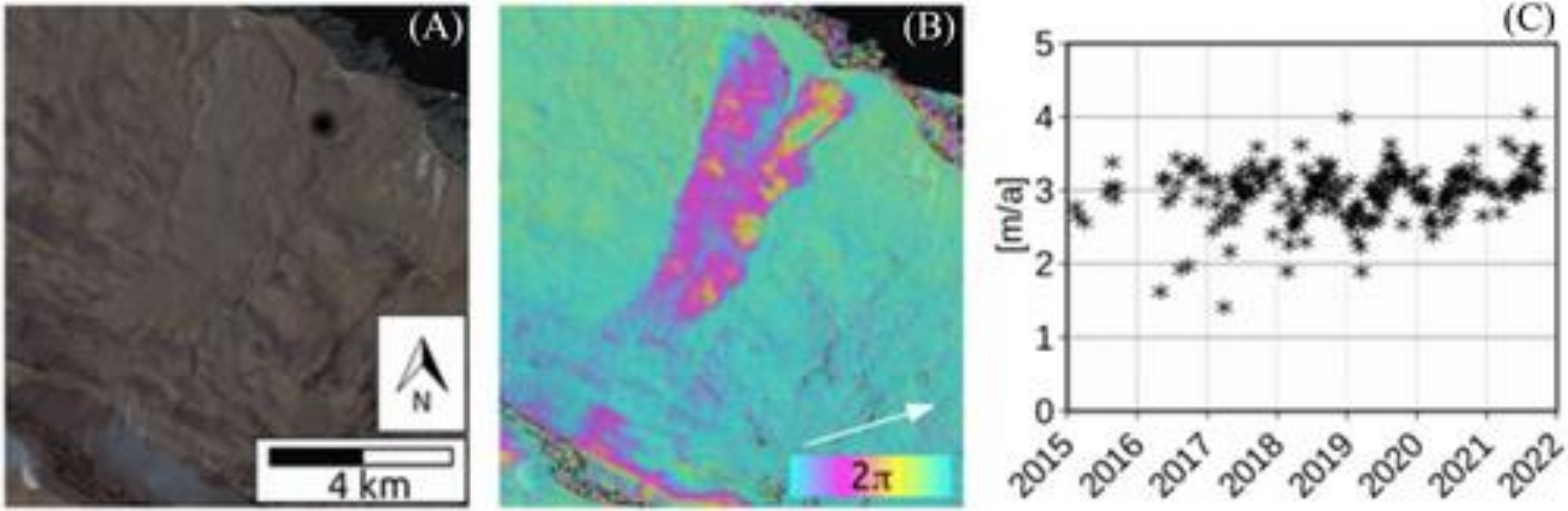


ELSEVIER
Remote Sensing of Environment
Volume 231, 15 September 2019, 111236

Seasonal dynamics of a permafrost landscape, Adventdalen, Svalbard, investigated by InSAR

Line Rouyet [a b c], Tom Rune Lauknes [a], Hanne H. Christiansen [c], Sarah M. Strand [c d], Yngvar Larsen [a]

Rock Glacier velocity

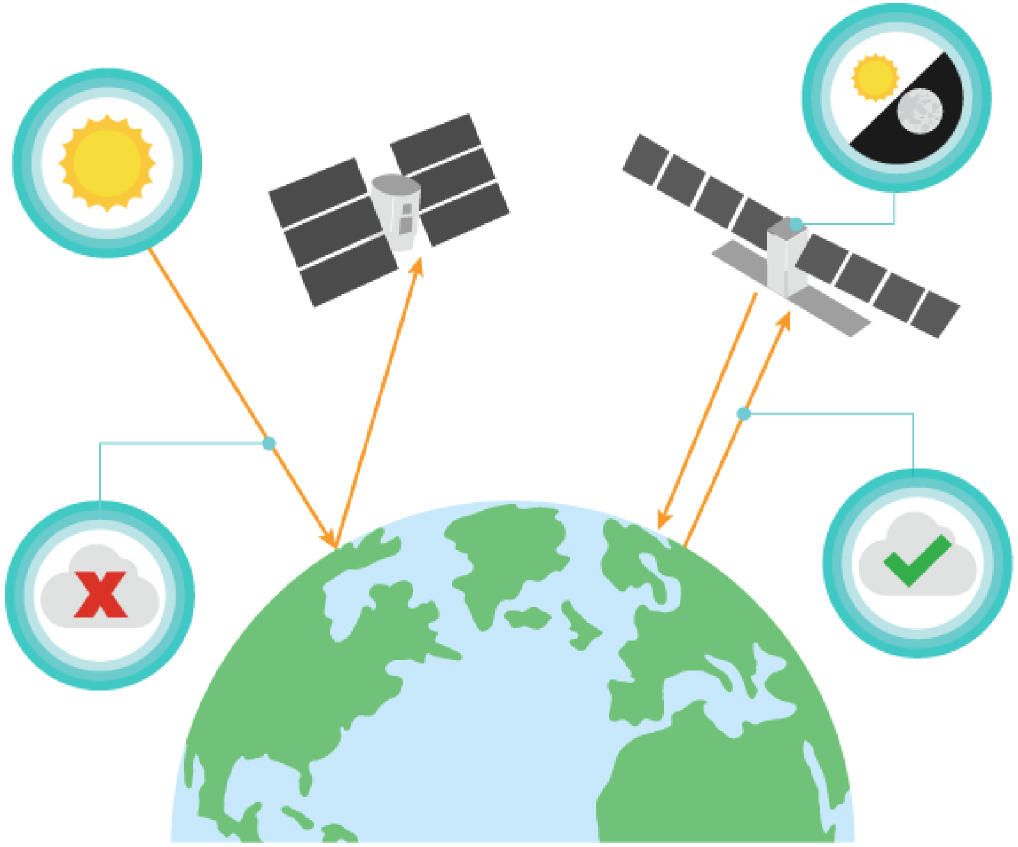


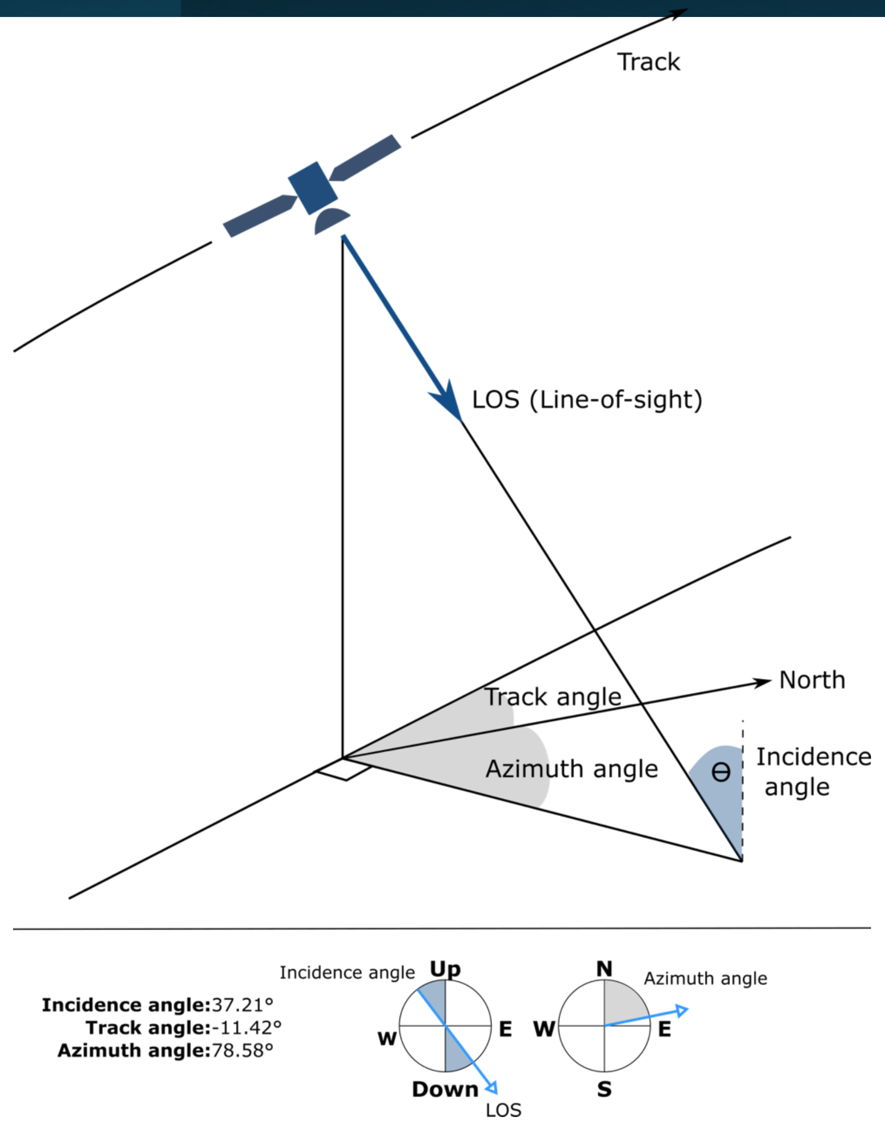
REVIEW ARTICLE | Open Access

Advances in InSAR Analysis of Permafrost Terrain

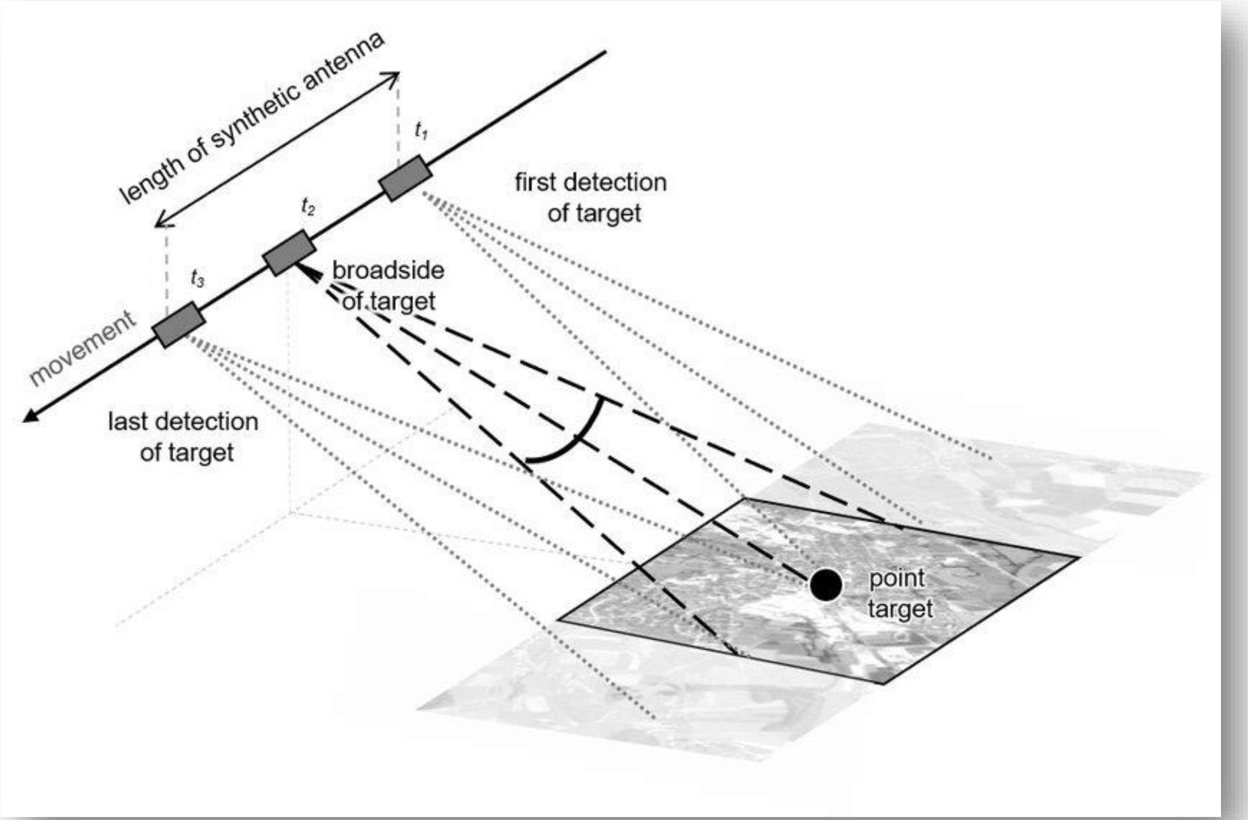
S. Zwieback, L. Liu, L. Rouyet, N. Short, T. Strozzi

Synthetic Aperture Radar (SAR)





Synthetic..?



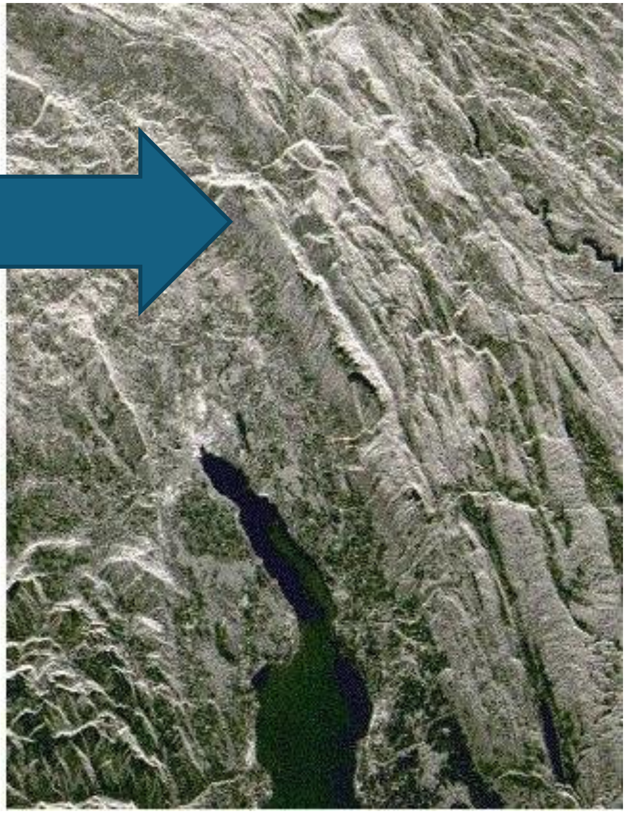
Source: Braun, A. 2019, Radar satellite imagery for humanitarian response. Bridging the gap between technology and application. 10.15496/publikation-32698.

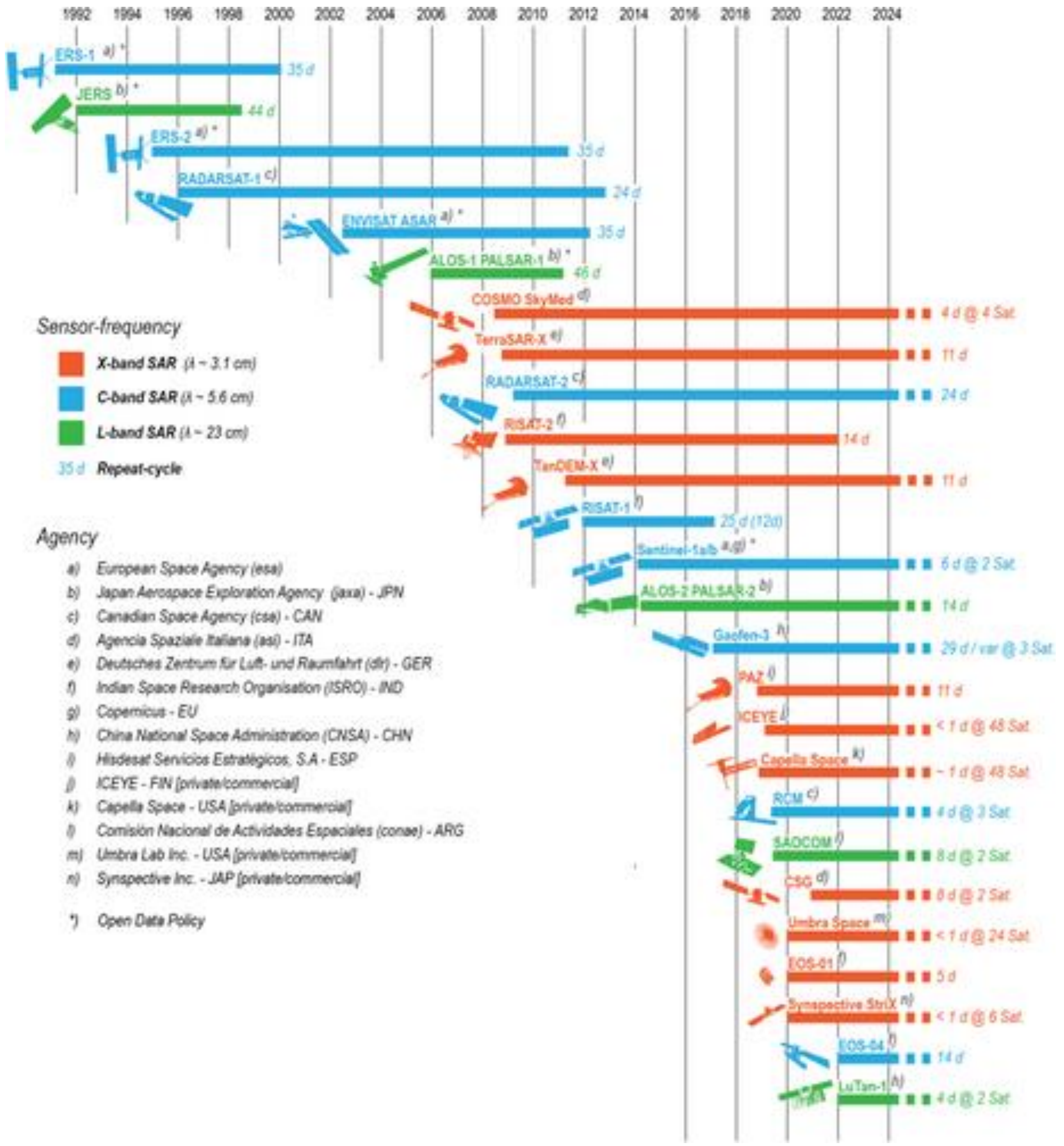
- The longer the antenna, the better the resolution.
- **Simulation** of a long antenna by combining data collected using a short antenna.
- Taking advantage of movement.

Slant Range

Source: https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/ers/instruments/sar/applications/radar-courses/content-2/-/asset_publisher/qIBc6NYRXfnG/content/radar-course-2-slant-range-ground-range

Ground Range





1992
1994
1996
1998
2000
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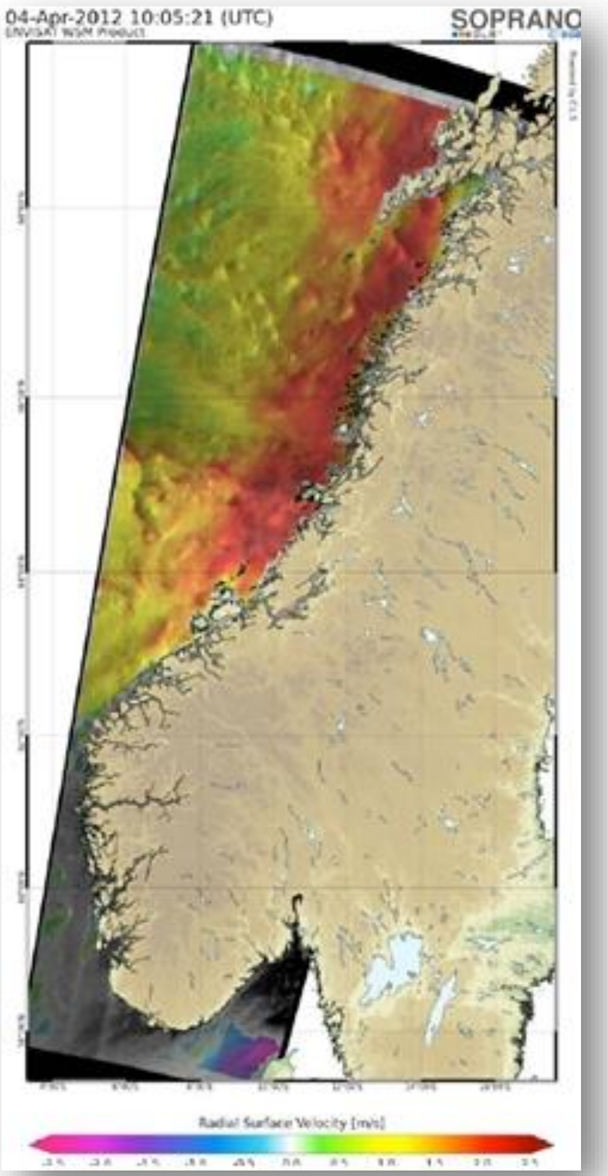
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
ERS-1 a) *
35 d
JERS b) *
44 d
ERS-2 a) *
35 d
RADARSAT-1 c)
24 d
ENVISAT ASAR a) *
35 d
ALOS-1 PALSAR-1 b) *
46 d
COSMO SkyMed d)
4 d @ 4 Sat.
TerraSAR-X e)
11 d
RADARSAT-2 c)
24 d
RISAT-2 f)
14 d
TanDEM-X e)
11 d
RISAT-1 f)
25 d (12d)
Sentinel-1a/b a,g) *
6 d @ 2 Sat.
ALOS-2 PALSAR-2 b)
14 d
Gaofen-3 h)
29 d / var @ 3 Sat.
PAZ i)
11 d
ICEYE j)
< 1 d @ 48 Sat.
Capella Space k)
~ 1 d @ 48 Sat.
RCM c)
4 d @ 3 Sat.
SAOCOM l)
8 d @ 2 Sat.
CSG d)
8 d @ 2 Sat.
Umbra Space m)
< 1 d @ 24 Sat.
EOS-01 f)
5 d
Synspective StriX n)
< 1 d @ 6 Sat.
EOS-04 f)
14 d
LuTan-1 h)
4 d @ 2 Sat.
Sensor-frequency
X-band SAR (λ ~ 3.1 cm)
C-band SAR (λ ~ 5.6 cm)
L-band SAR (λ ~ 23 cm)
35 d Repeat-cycle
Agency
a) European Space Agency (esa)
b) Japan Aerospace Exploration Agency (jaxa) - JPN
c) Canadian Space Agency (csa) - CAN
d) Agencia Spaziale Italiana (asi) - ITA
e) Deutsches Zentrum für Luft- und Raumfahrt (dlr) - GER
f) Indian Space Research Organisation (ISRO) - IND
g) Copernicus - EU
h) China National Space Administration (CNSA) - CHN
i) Hisdesat Servicios Estratégicos, S.A - ESP
j) ICEYE - FIN [private/commercial]
k) Capella Space - USA [private/commercial]
l) Comisión Nacional de Actividades Espaciales (conae) - ARG
m) Umbra Lab Inc. - USA [private/commercial]
n) Synspective Inc. - JAP [private/commercial]
*) Open Data Policy

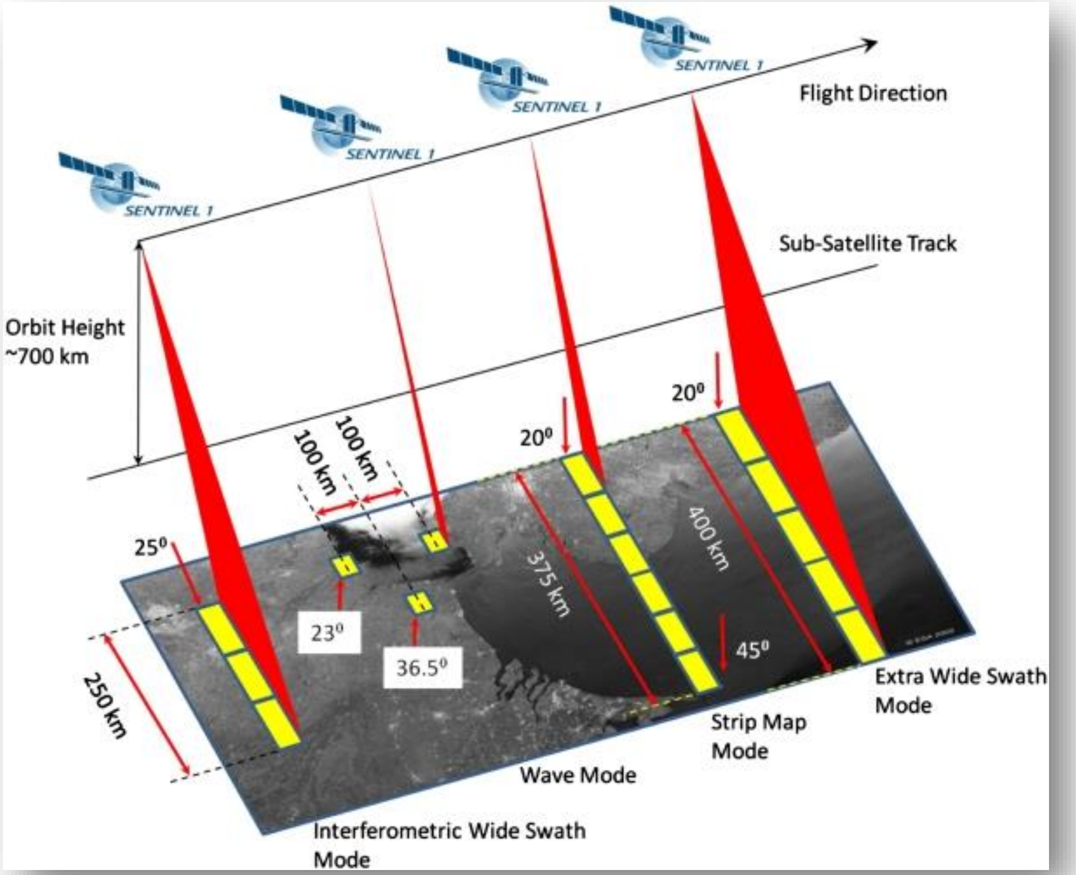
Formats of Sentinel 1

- Single Look Complex (SLC):
  - Backscatter and Phase Information.
  - Slant Range
- (Grid) Ground Range Detected (GRD)
  - No phase information
  - Slant range
- Level 2 Formats:
  - Ocean Wind field (OWI)
  - Ocean Swell spectra (OSW)
  - Surface Radial Velocity (RVL)



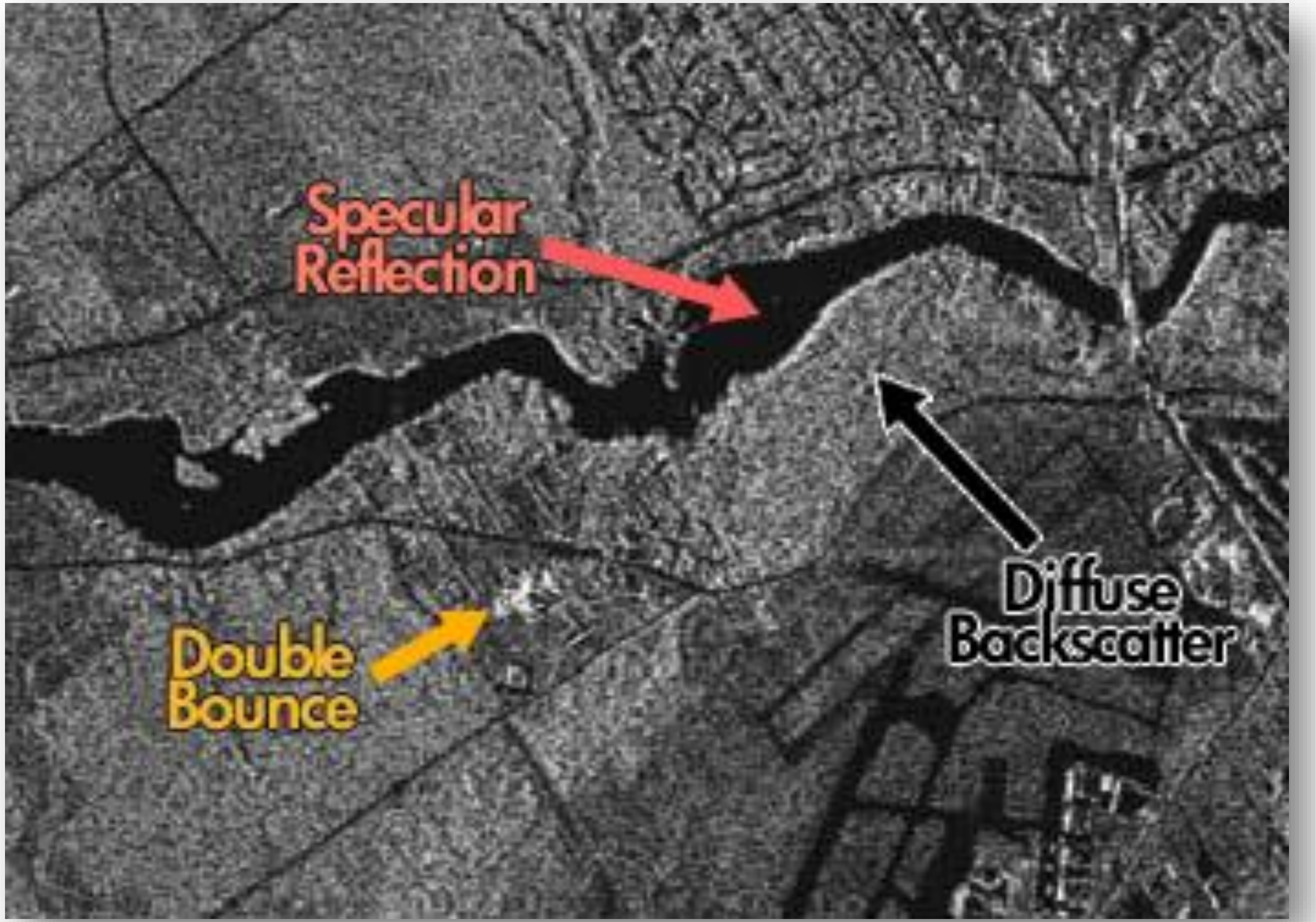
Acquisition modes of Sentinel 1:

- Strip Map (SM)
  - *80x80 km, res. 5 m*
- Interferometric Wide swath (IW)
  - *250 km, res. 5x20 m*
- Extra-Wide swath (EW)
  - *400 km, res. 20x40 m*

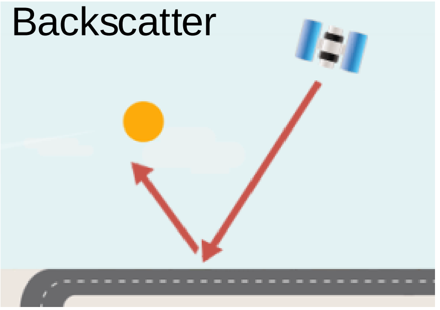


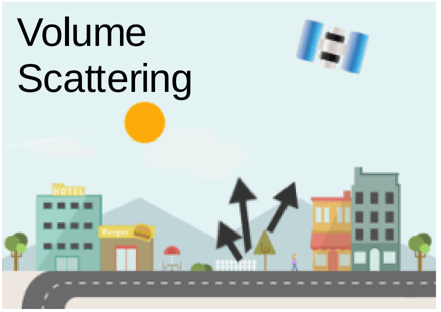
Basics of SAR

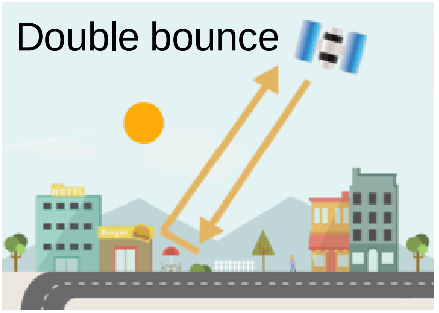
Backscatter



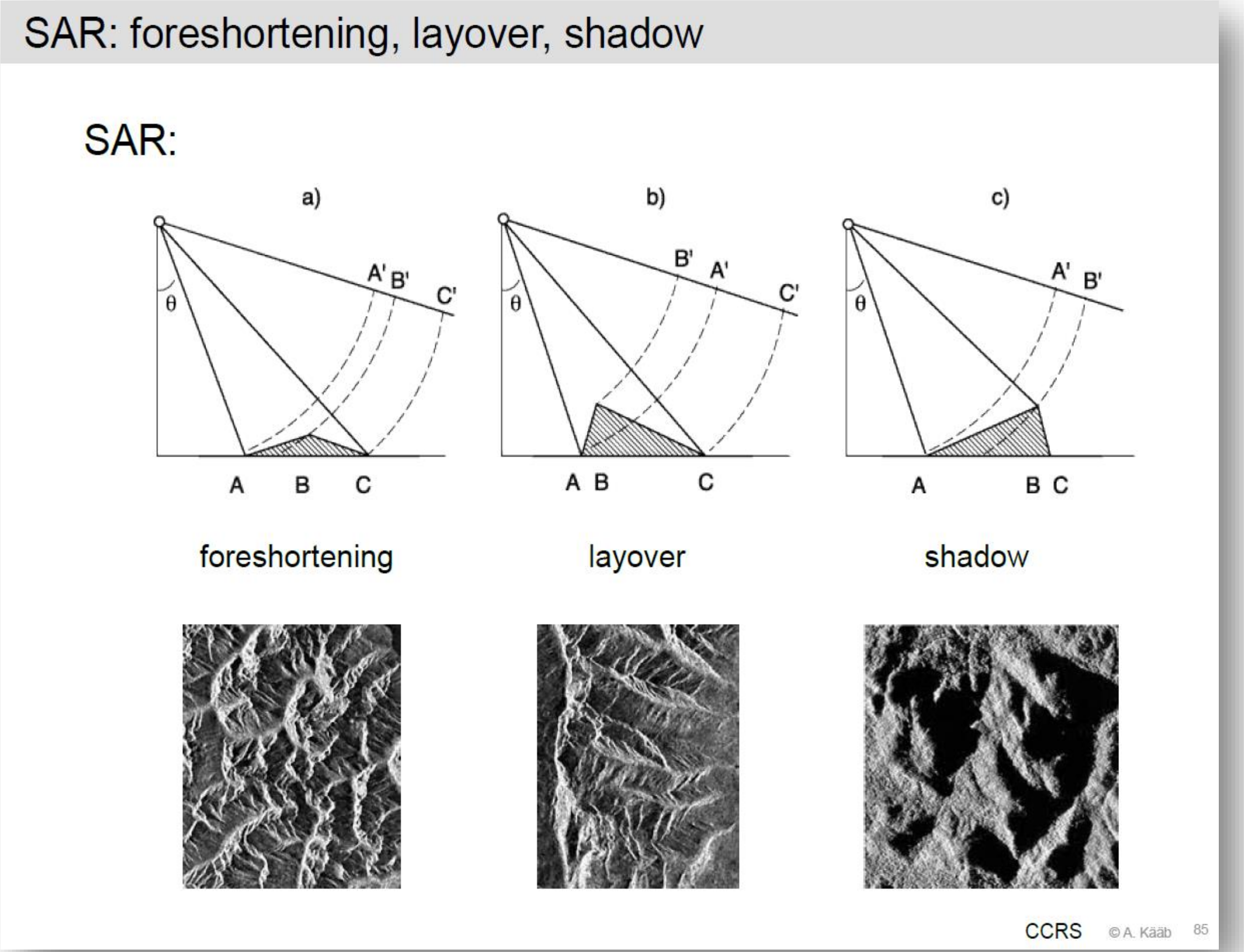
(Diffuse backscatter)







Three problems with SAR data



Influences of layover and shadow

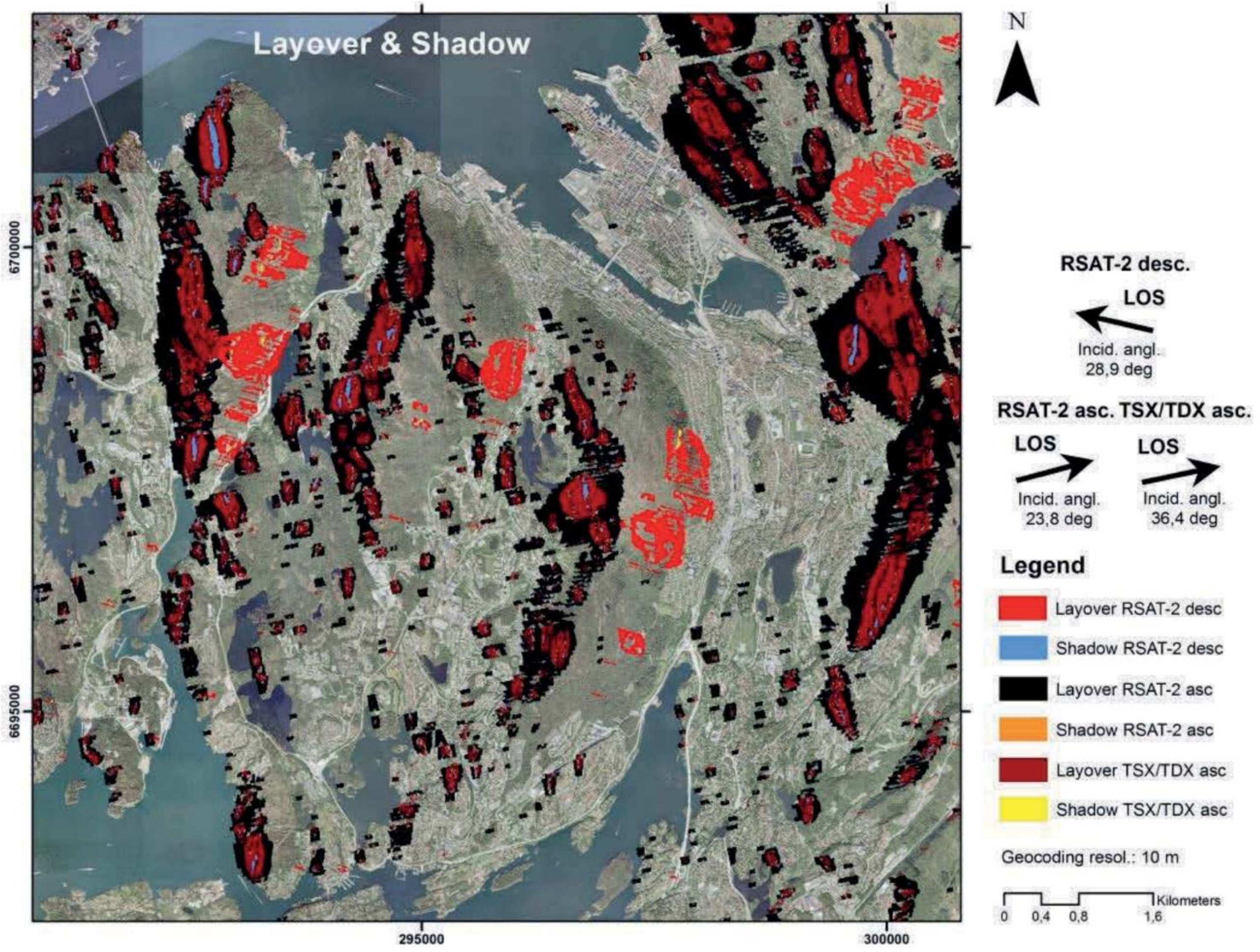
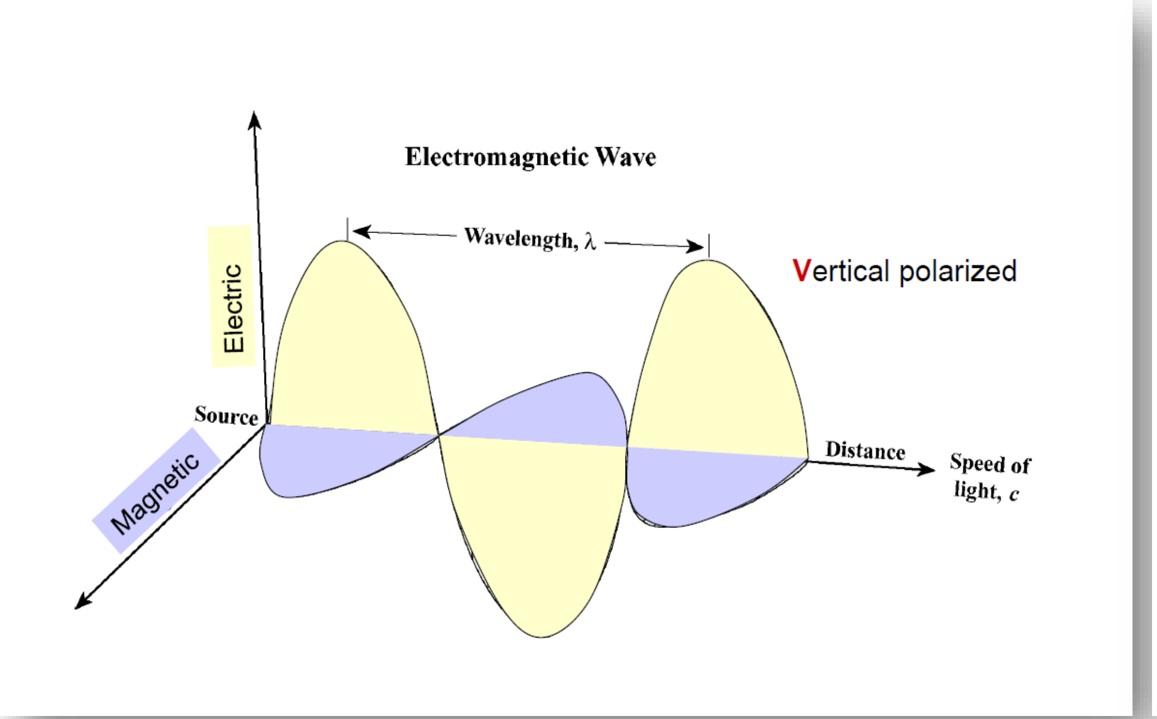
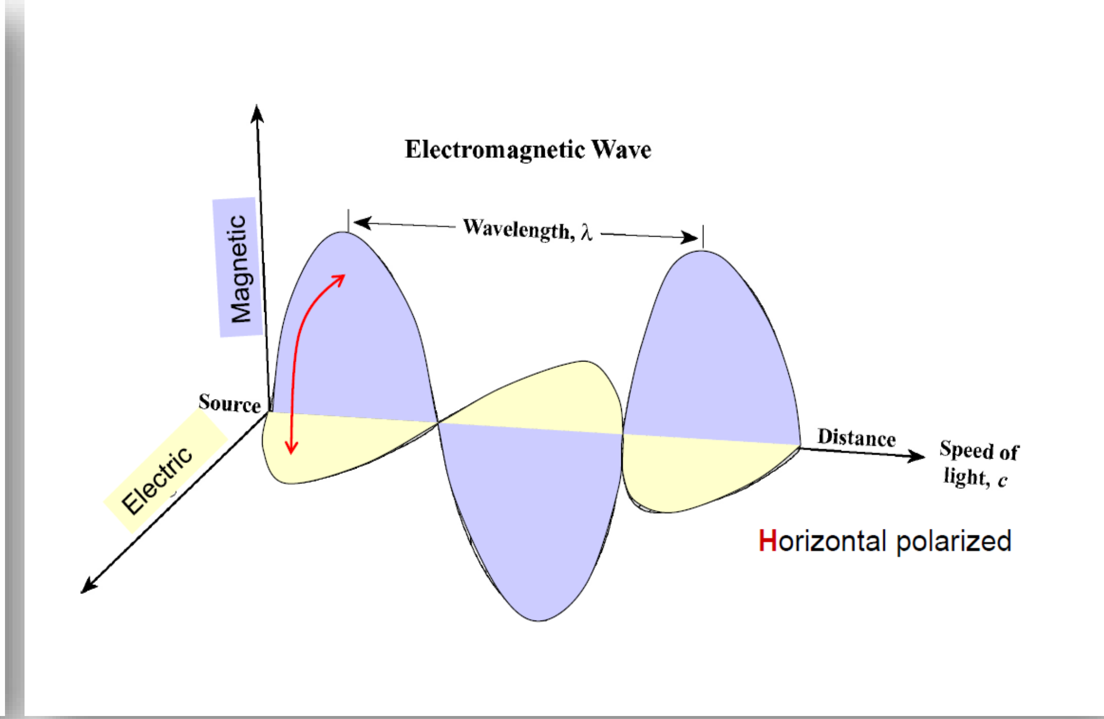


Figure 29: Zoom on Bergen (lower left blue square in Figure 26 & Figure 27). Area covered by RSAT-2 Standard mode, RSAT-2 Ultrafine mode & TSX/TDX StripMap mode [Cetinic, et al. 2015 (in prep.)].

Polarisation: vertical and horizontal



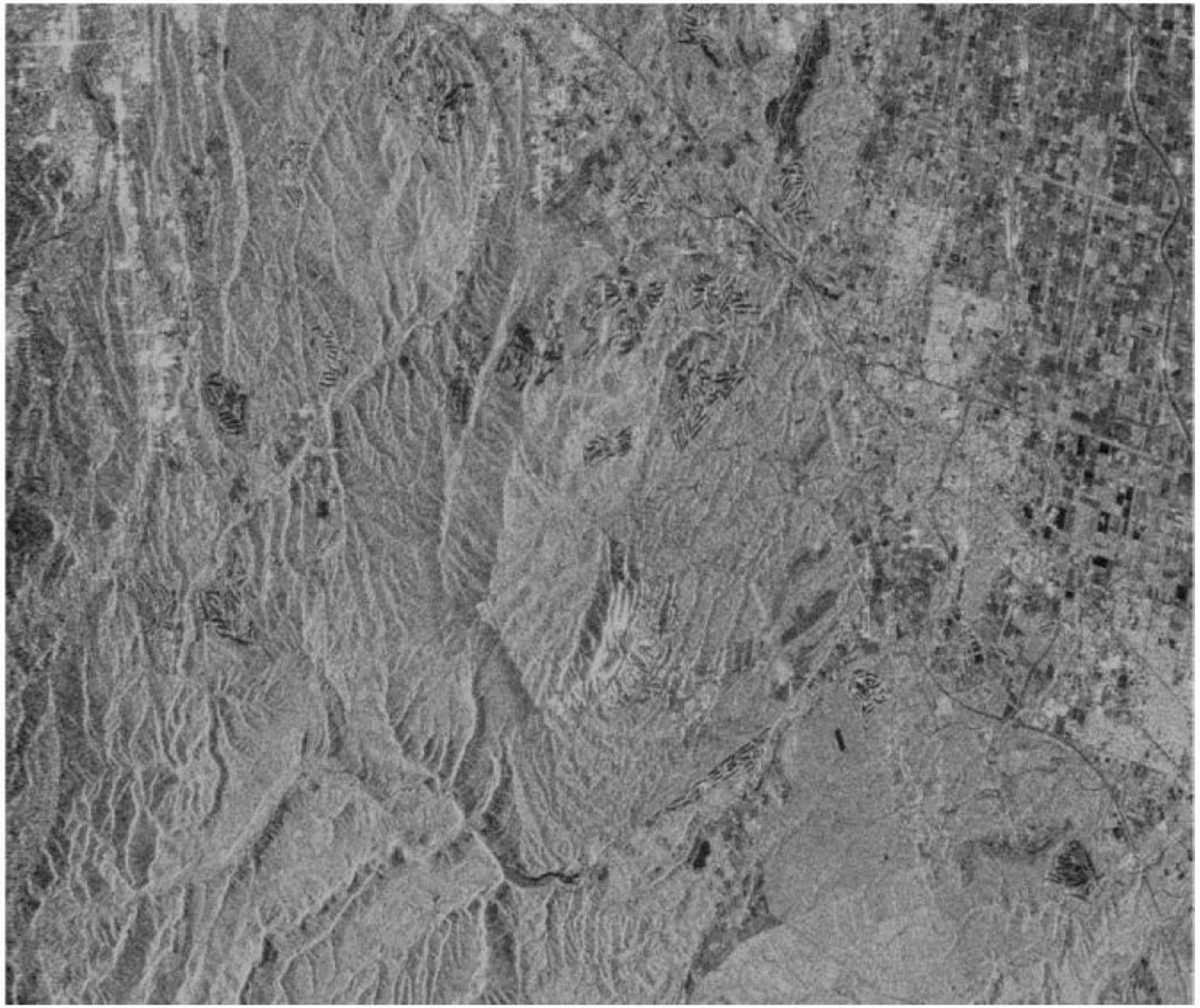


Source: Andy Kääb, UiO

SAR Data can be polarised:

- Horizontal Horizontal (HH) – co-polarisation
- Horizontal Vertical (HV) – cross-polarisation
- Vertical Horizontal (VH) – cross-polarisation
- Vertical Vertical (VV) - co-polarisation

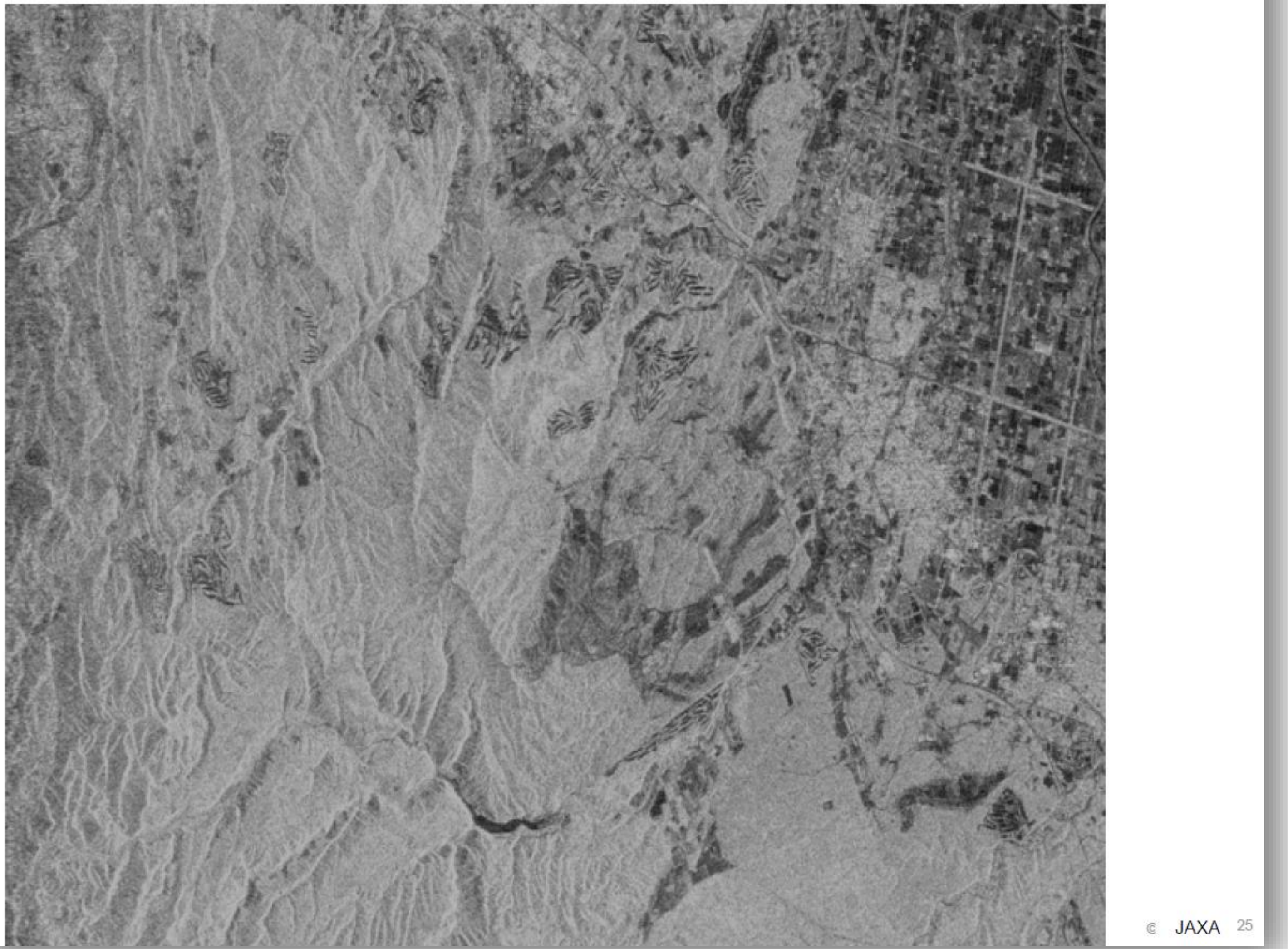
ALOS PALSAR HH-polarization



Source: Andreas Kääb, UiO

Andy Kaab,
University of
Oslo

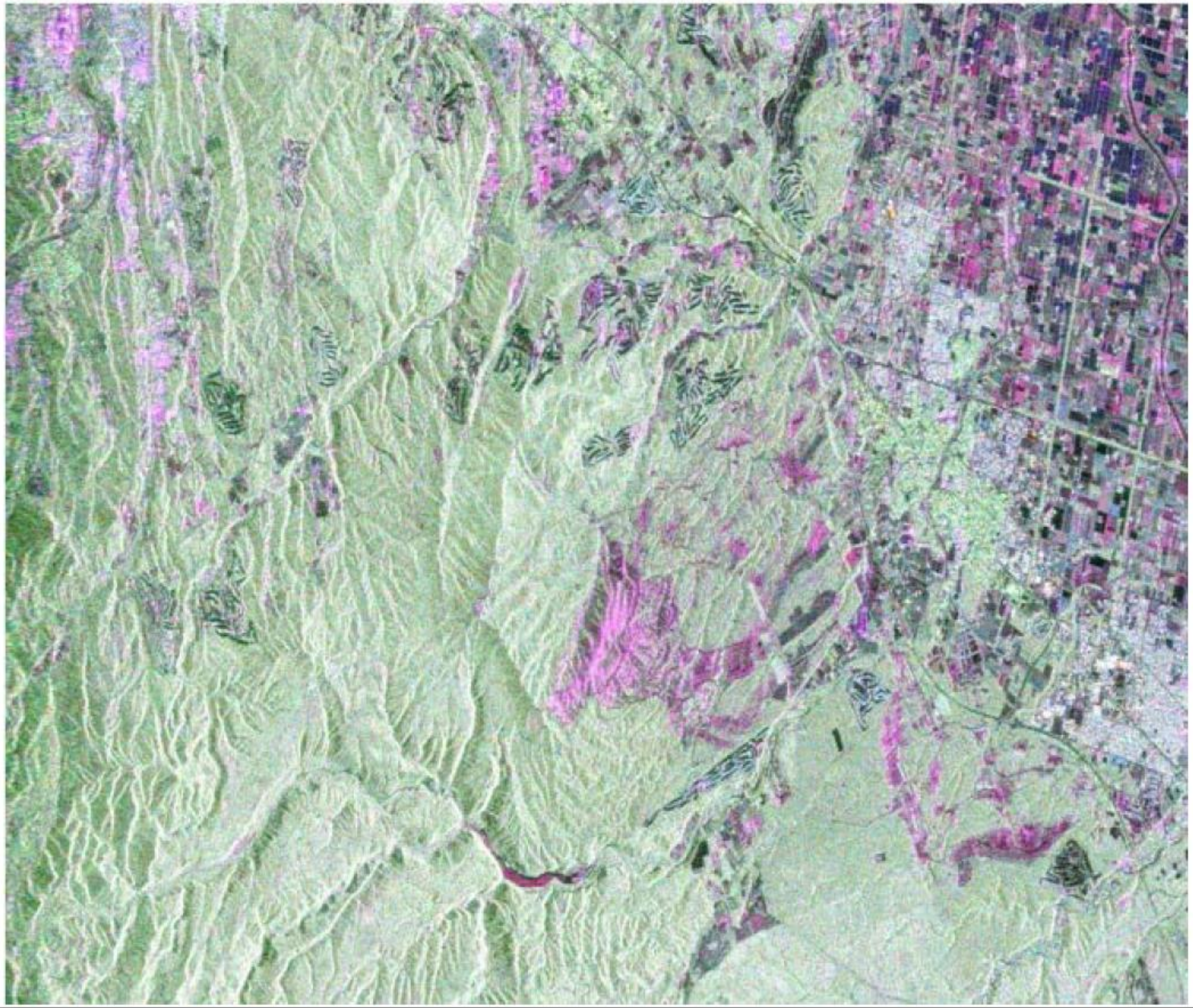
ALOS PALSAR HV-polarization



Source: Andreas Kääb, UiO

Andy Kaab,
University of
Oslo

ALOS PALSAR composite (HH, HV, VV)

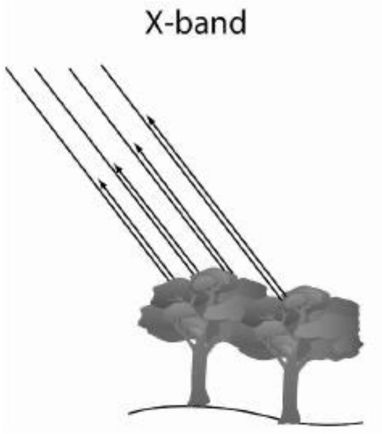


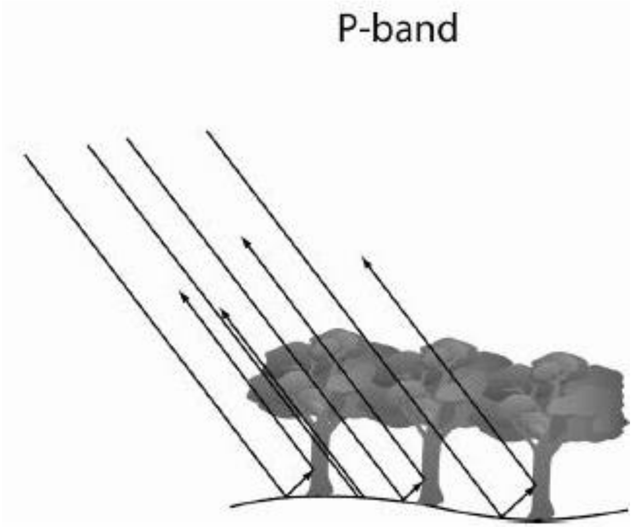
© JAXA 26

Source: Andreas Kääb, UiO

Andy Kaab, University of Oslo

The band (wavelength) used is important





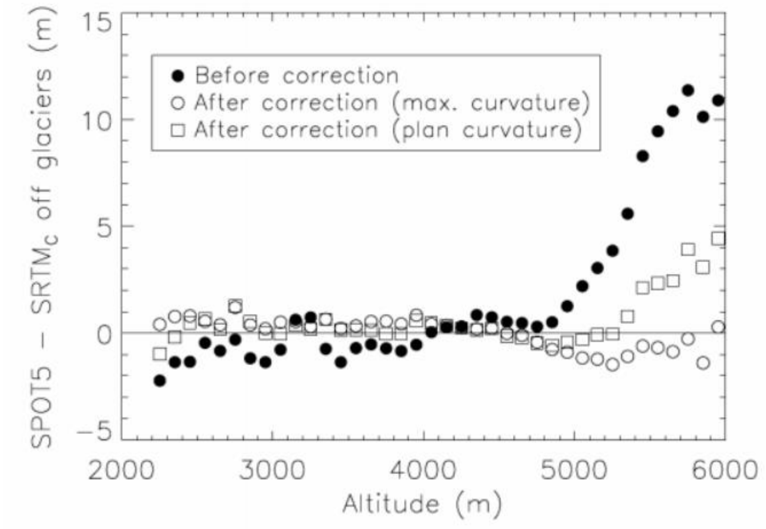


Figure 2: *Elevation differences off glaciers between SPOT5 and SRTM C-band DEMs as a function of altitude. Filled circles represent the raw elevation differences, open circles represent the elevation differences after a correction based on terrain maximum curvature and squares the ones after a correction based on terrain plan curvature.*

Source: Gardelle et al, 2012

Summary so far

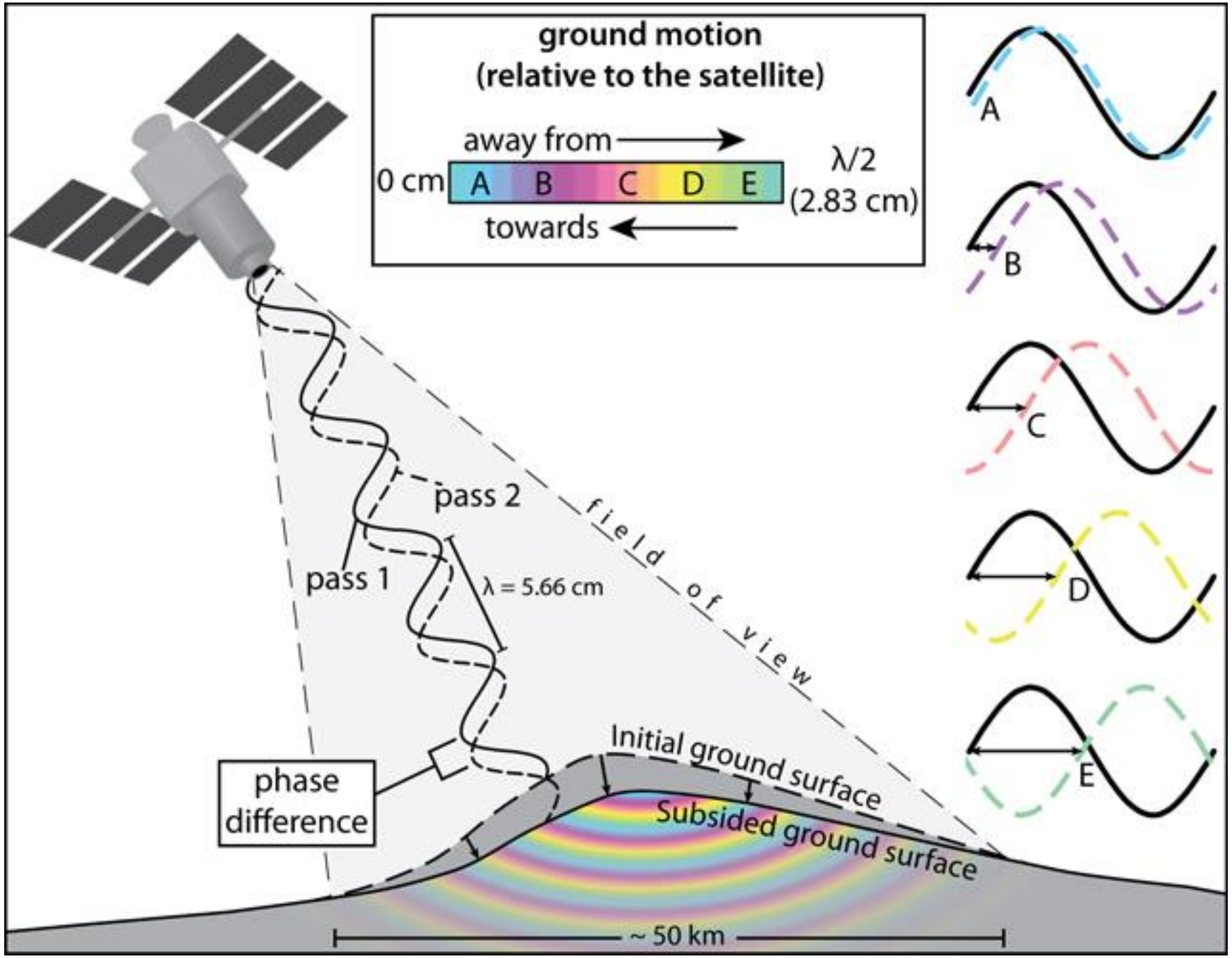
- When working with SAR data, the following is important:
  - The surface roughness → influences backscatter
  - The relief of the area –> influences the shadowing
  - The orientation of what you are monitoring → radar is sideways looking

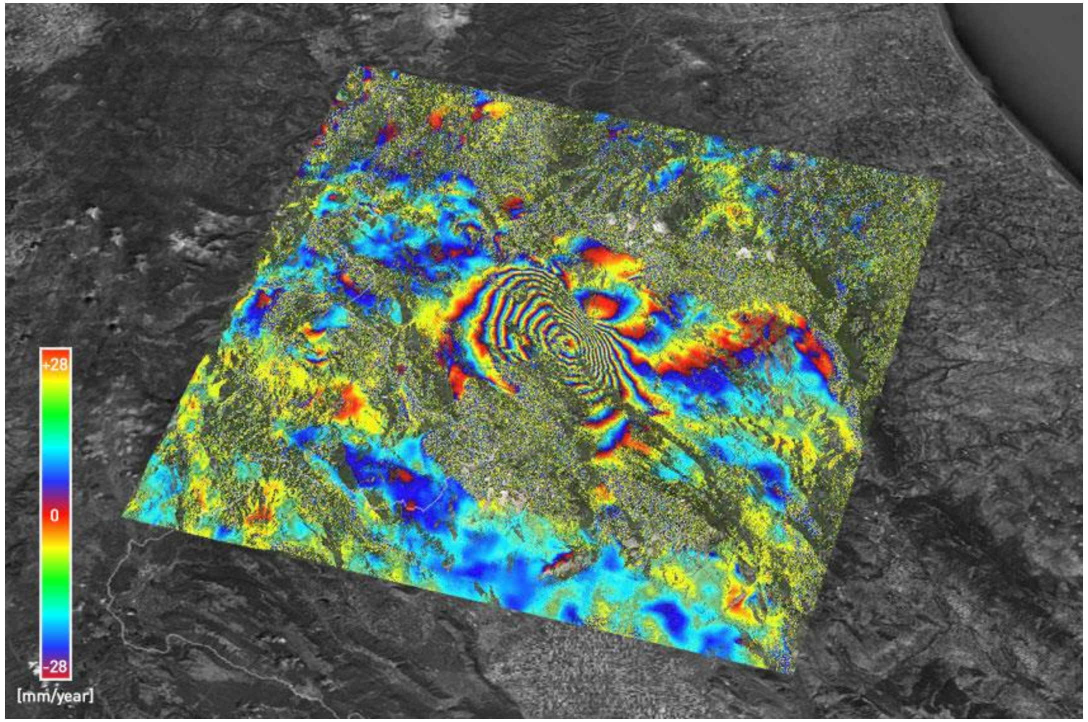
Now onto InSAR:

Requires two SAR images seperated by a temporal baseline

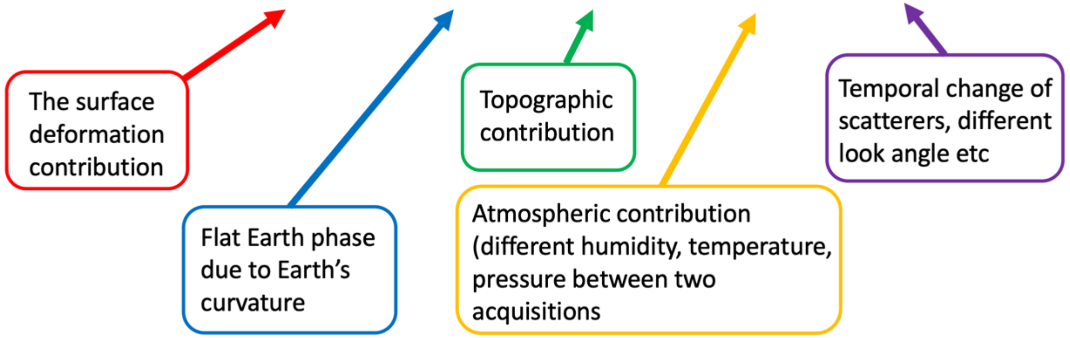
InSAR is the comparison of two SAR scenes

- We measure the change in phase between two images seperated by a temporal baseline (typically 6, 12, 24… days with Sentinel-1)
- We know the **wavelength** of the sensor…
- ….so we can convert a change in **phase** to a **deformation**
- Requires the area to be **coherent**





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

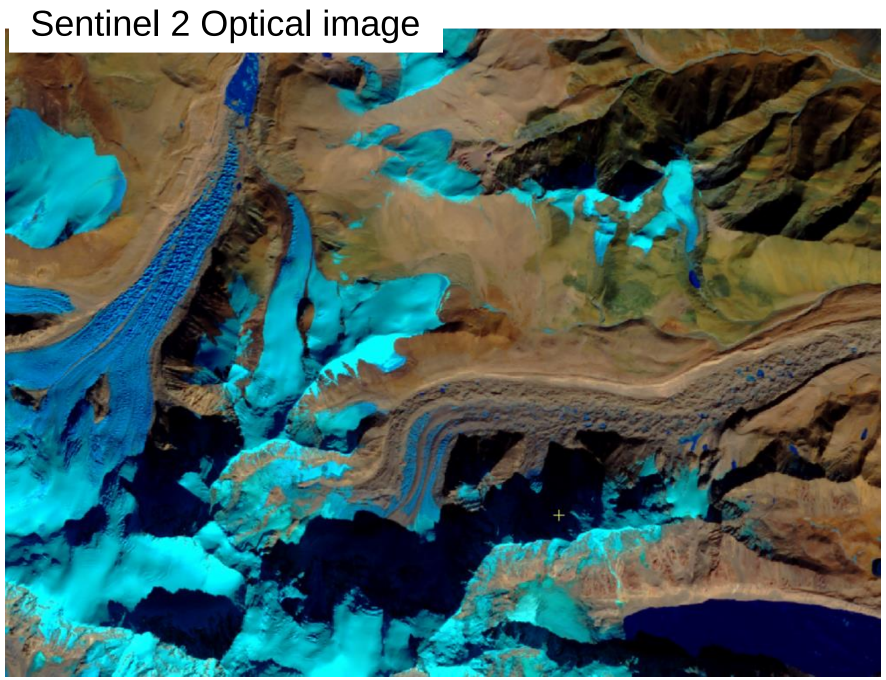


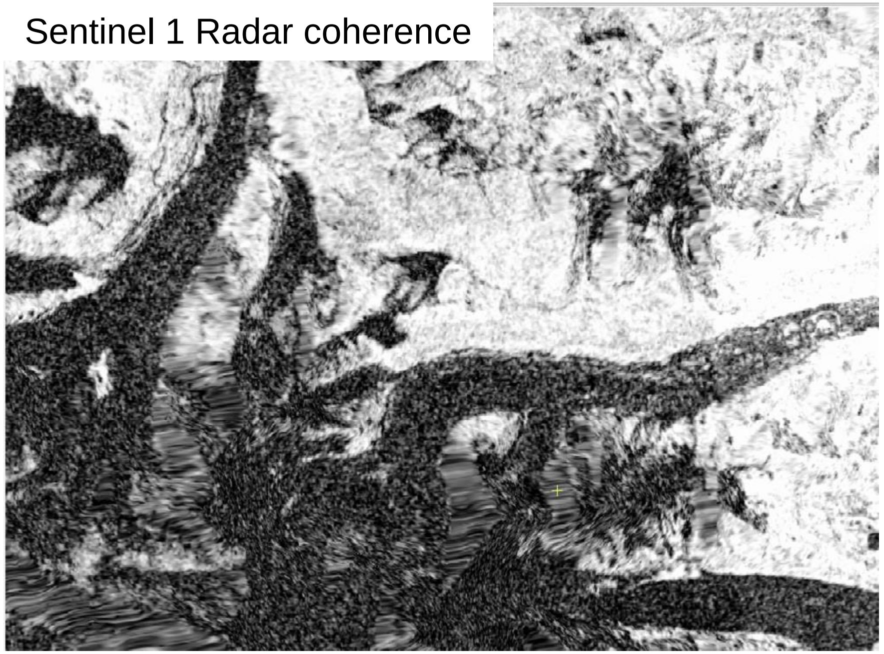
If we have coherence over our area of interest...

- Then we can measure the change in **phase** between two acquistions

SAR coherence

- “the degree of correlation between the two radar images”
- A function of
  - Surface properties
  - Time (temporal decorrelation)
  - Baseline between satellites
- Sometimes the coherence can be a result in itself
  - Detecting changes, for example landslides, urban development, glacier activity





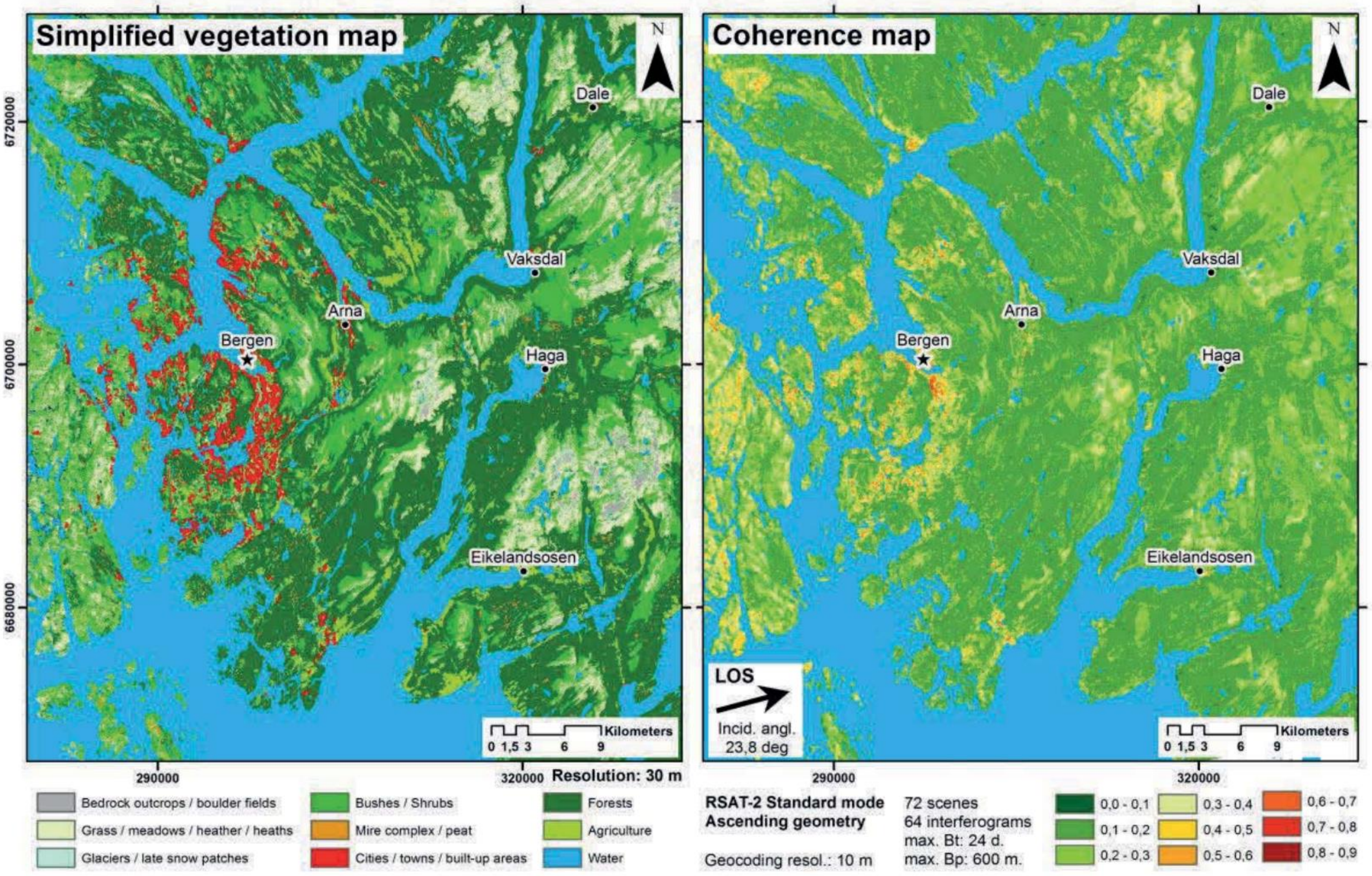


Figure 30: Left: simplified vegetation map over Bergen area (8 classes) based on vegetation map from [Johansen, 2009 & Johansen, et al. 2009]. Right: Example of mean coherence map from RSAT-2 Standard mode dataset (using only interferograms with a temporal baseline of 24 days).

Seasonality and coherence

- Winter:
    - Wet surfaces
    - Snow
    - Decreased vegetation

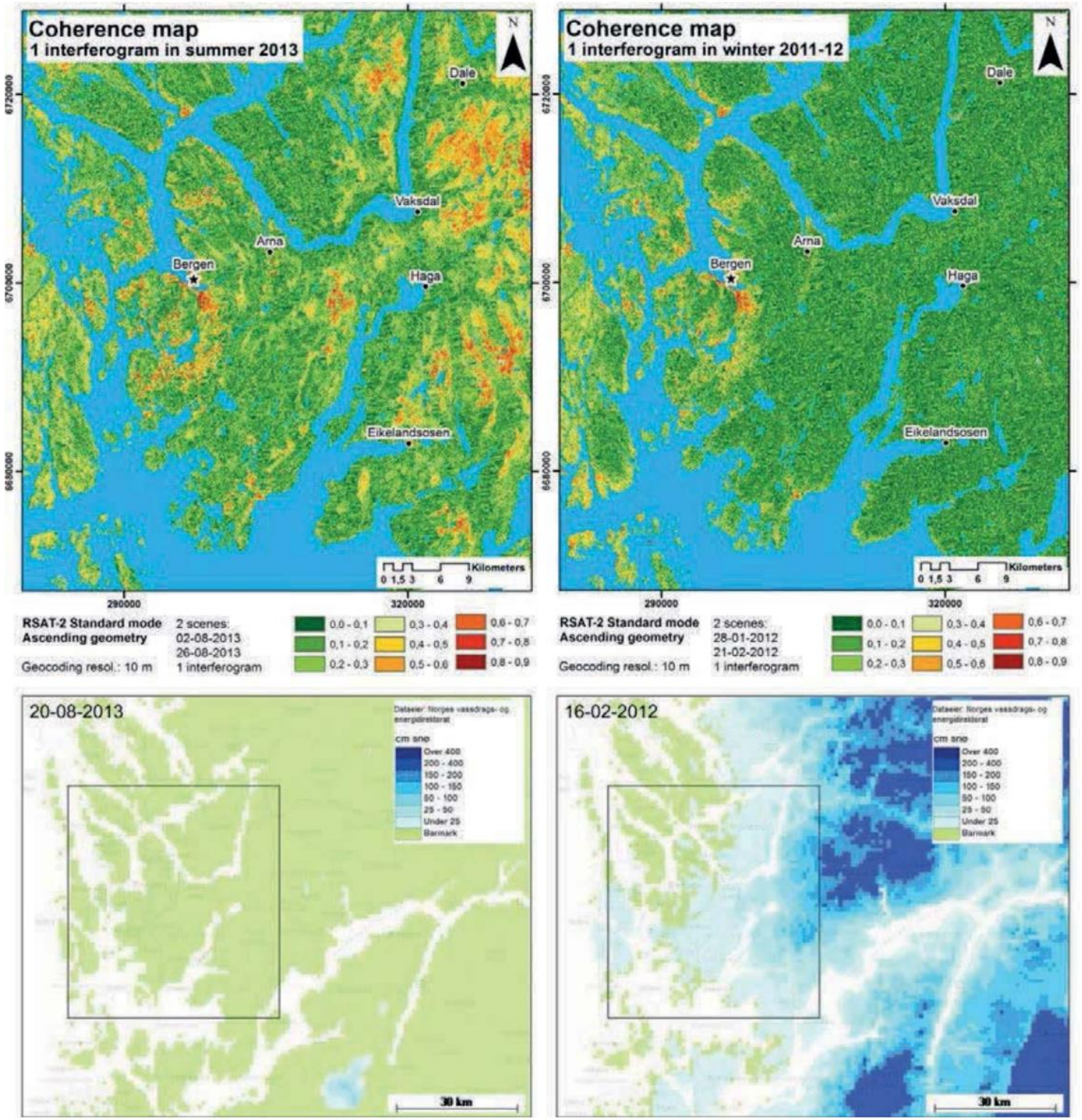
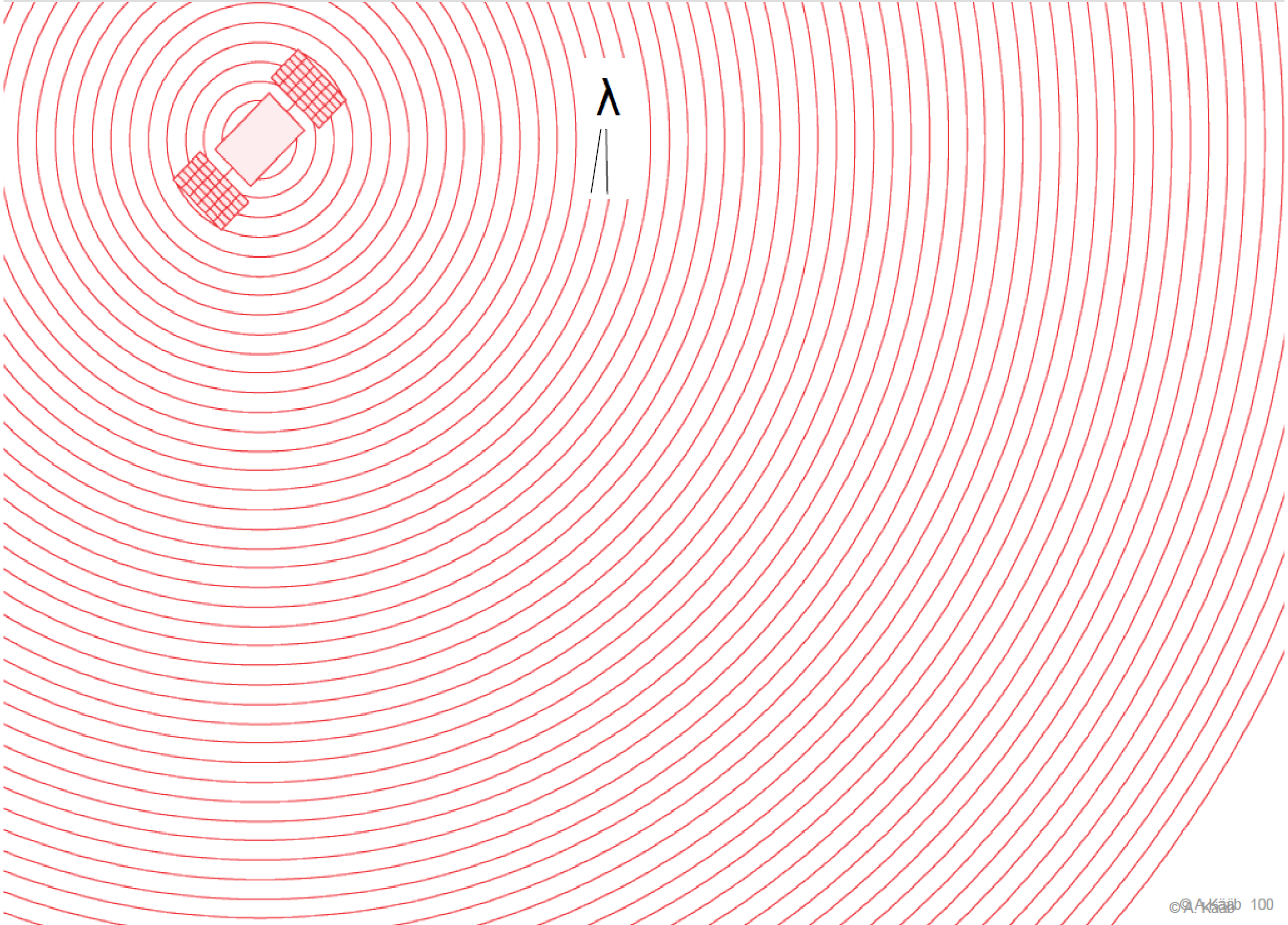


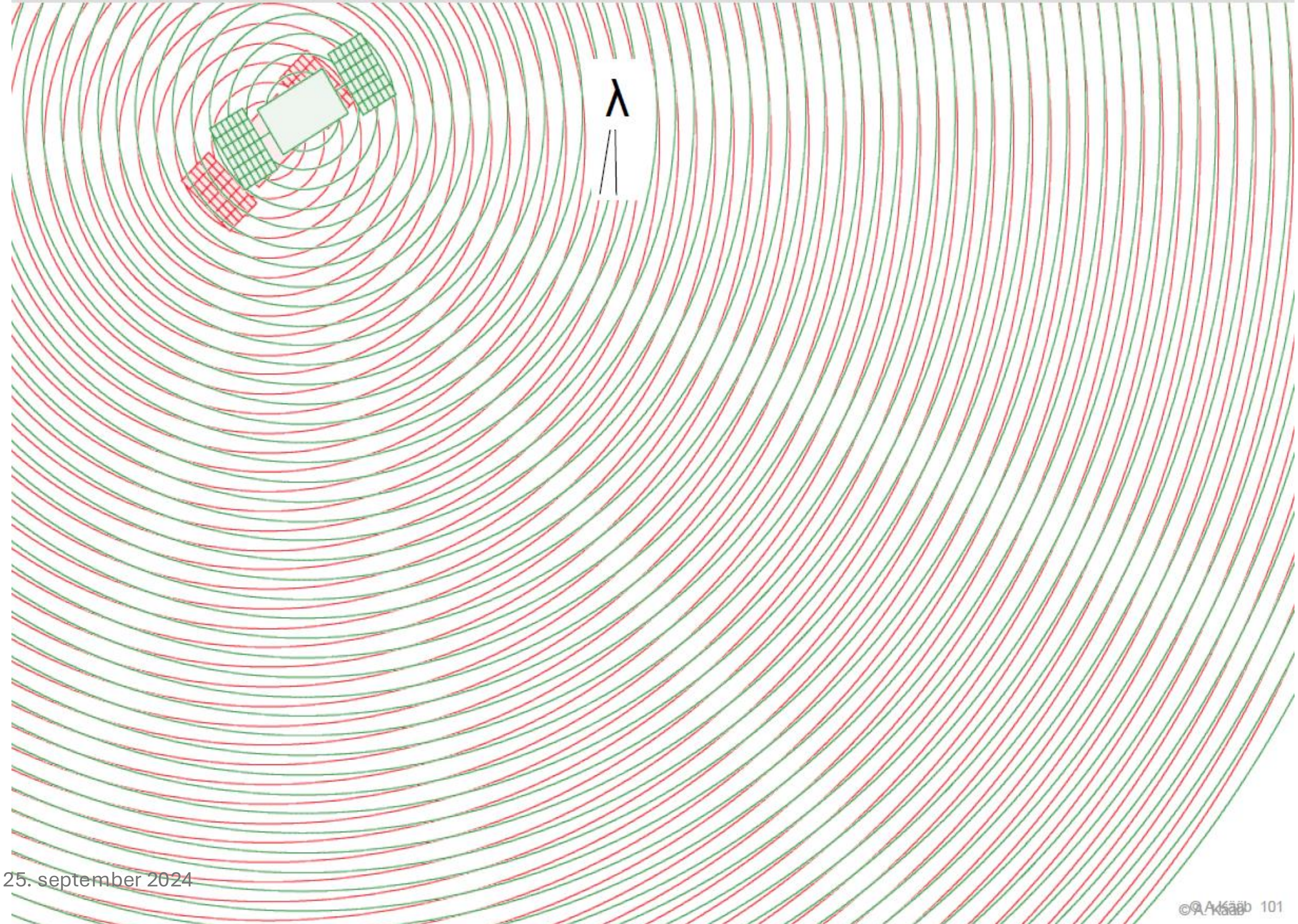
Figure 31: Examples of the effects of snow cover on the coherence (RSAT-2 Standard mode dataset). Top left: coherence map based on 1 interferogram in summer 2013. Top right: coherence map based on 1 interferogram in winter 2011-12. Bottom: Snow depth at the same period as the interferograms. From www.senorge.no (download: 16-02-2015).

Interferometric SAR (InSAR)



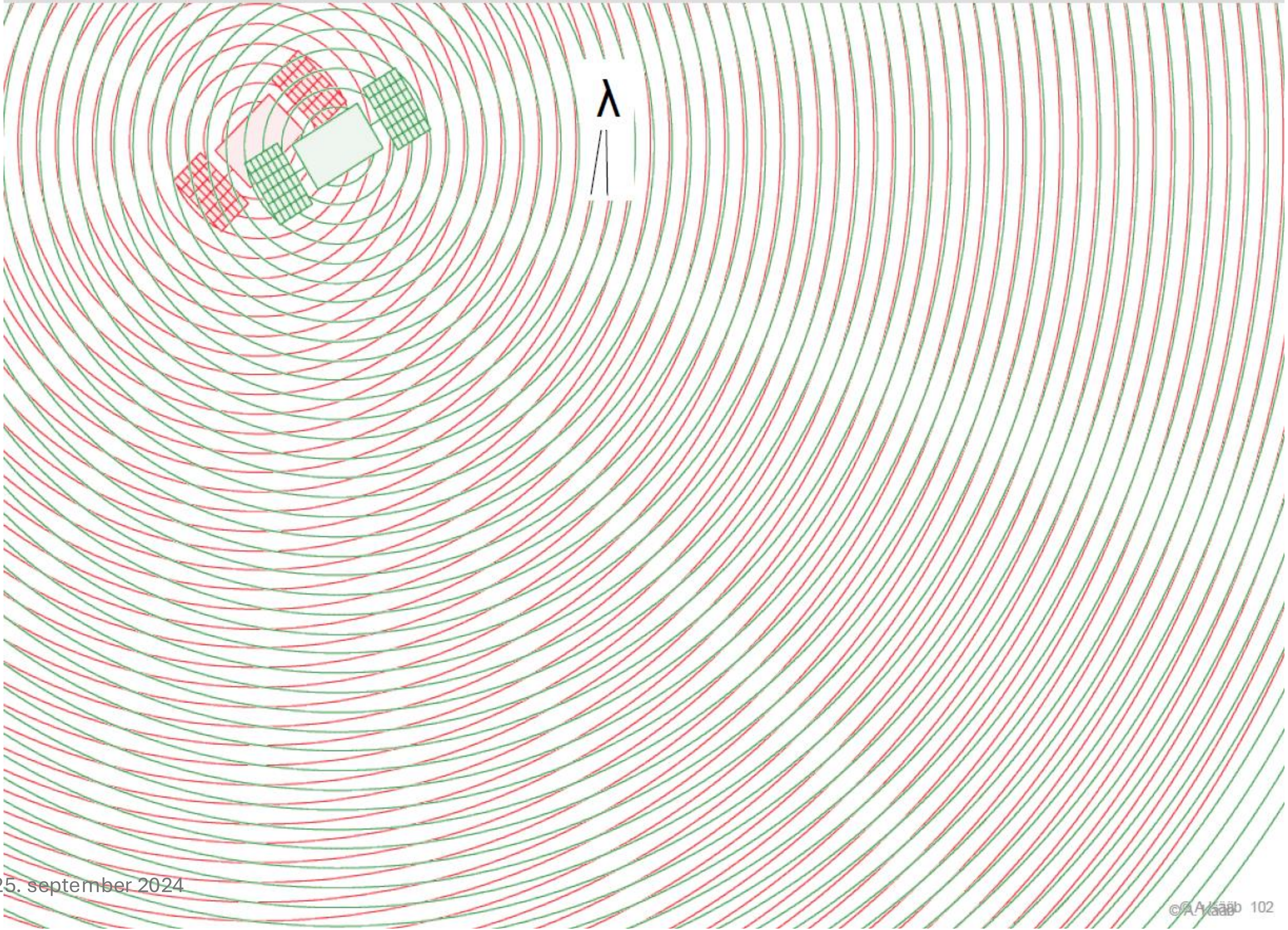
Andy Kaab, University of Oslo

Interferometric SAR (InSAR)



Andy Kaab,
University of
Oslo

Interferometric SAR (InSAR)



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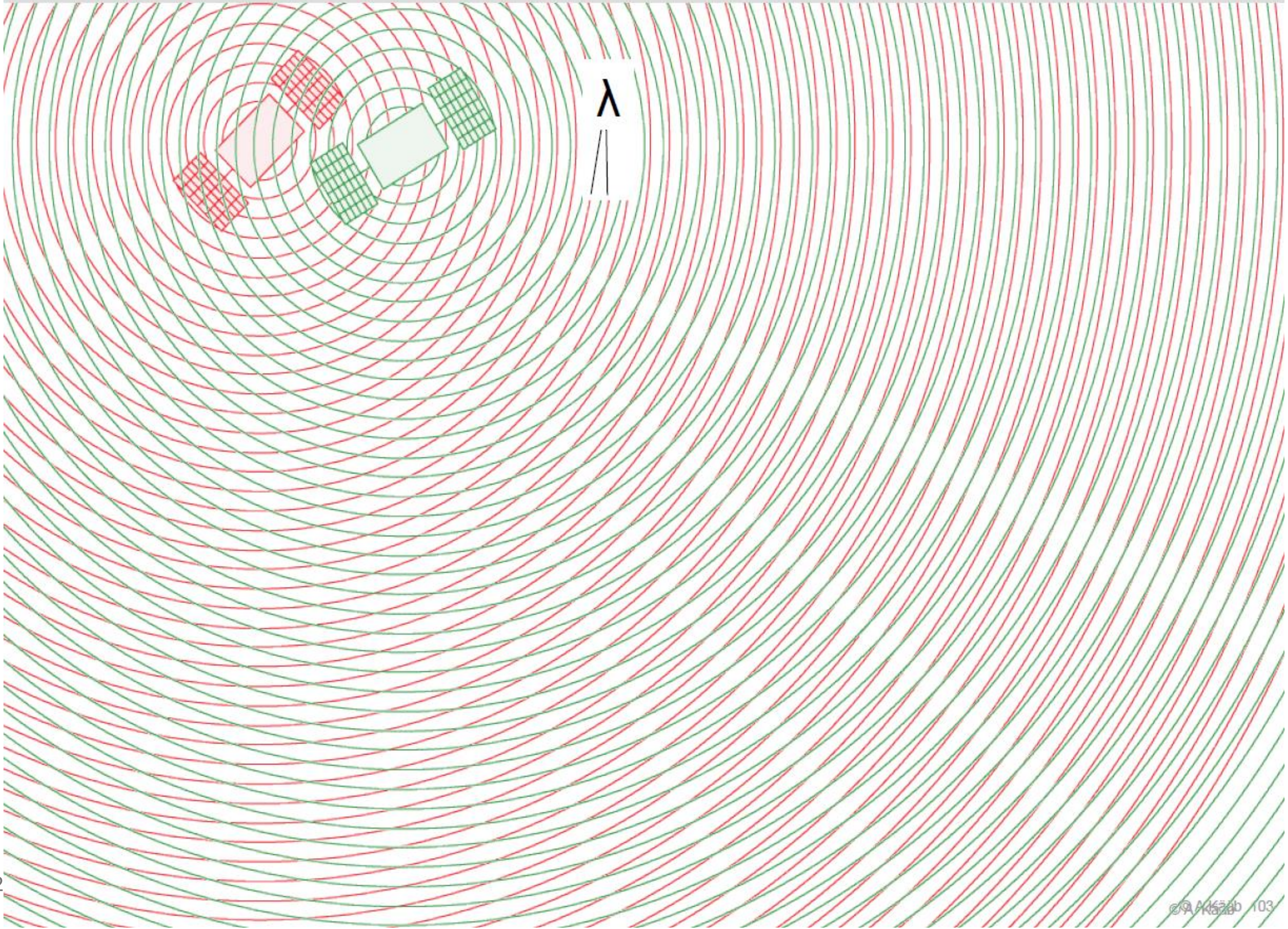
University of
Oslo

Interferometric SAR (InSAR)



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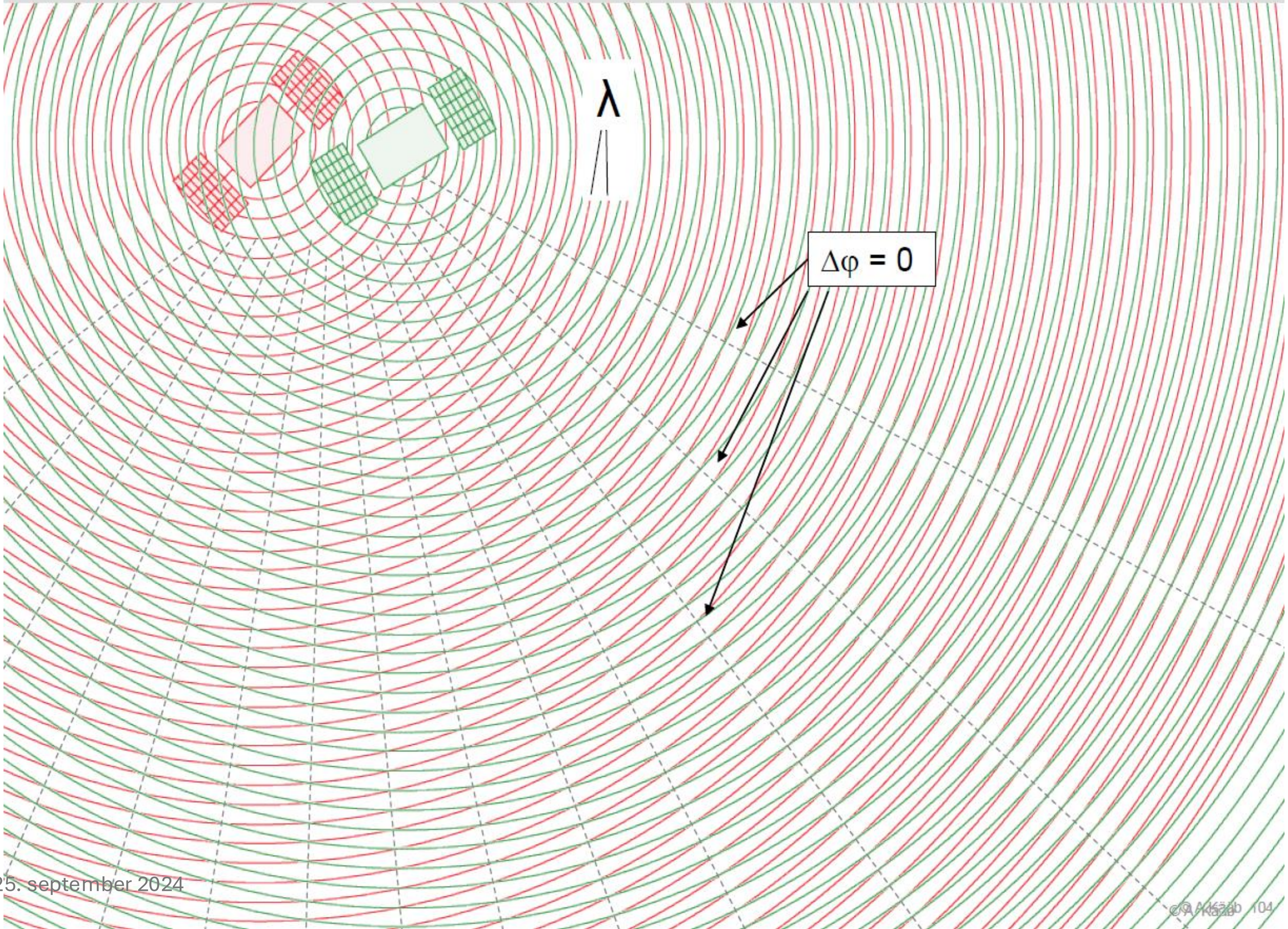
Interferometric SAR (InSAR)



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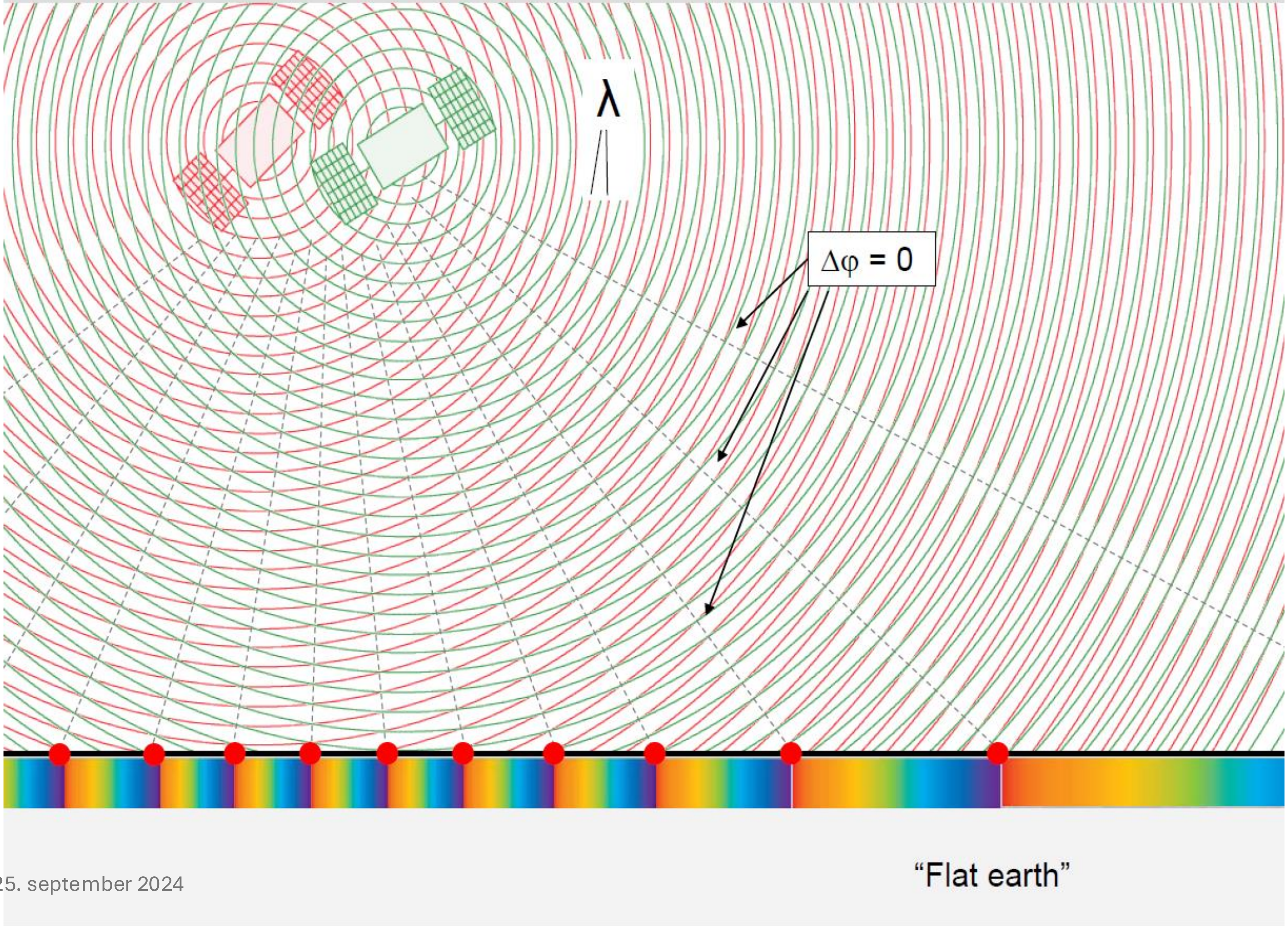
Oslo

Interferometric SAR (InSAR)



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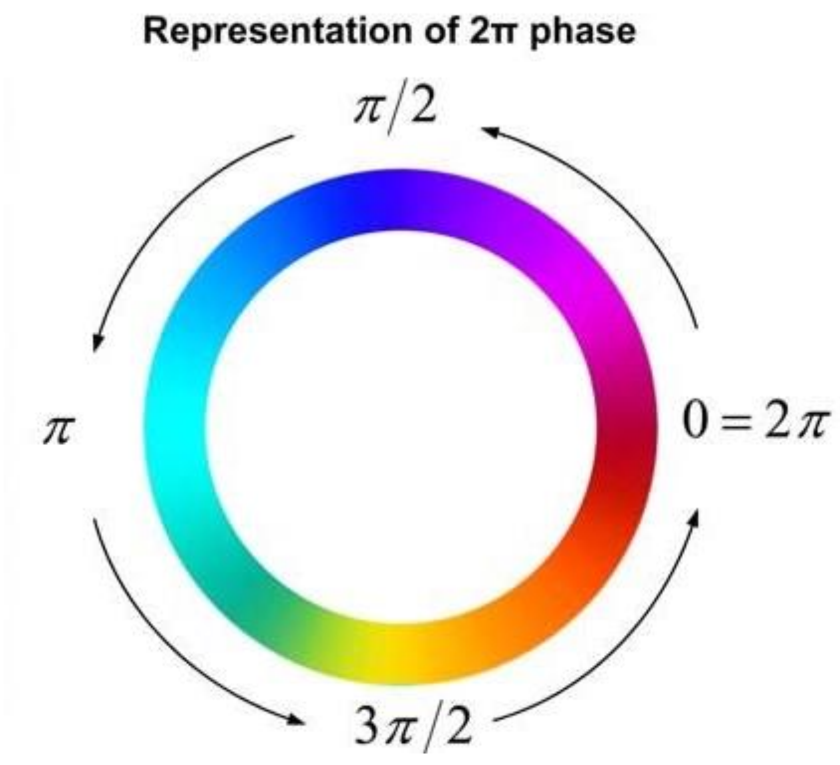
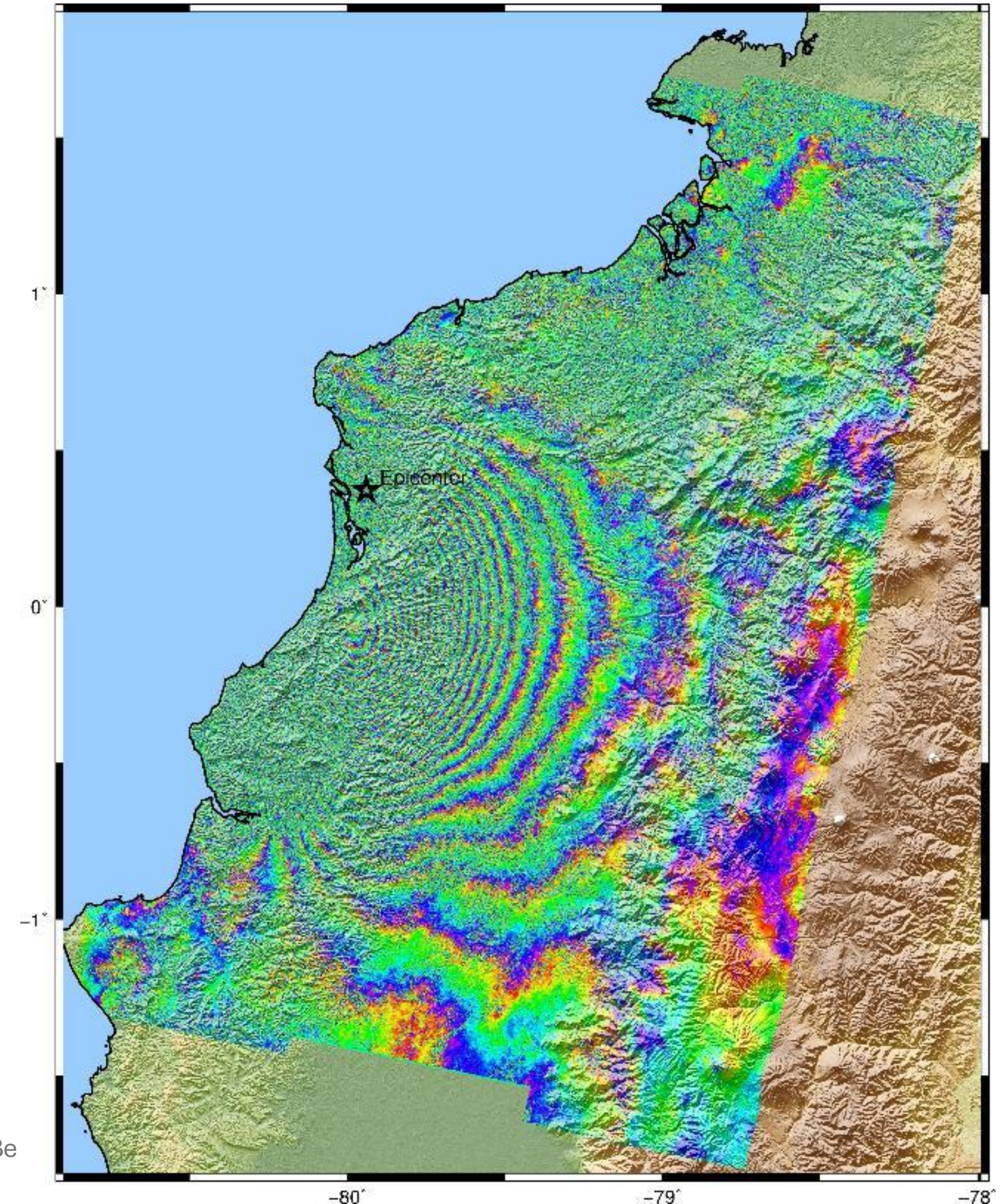
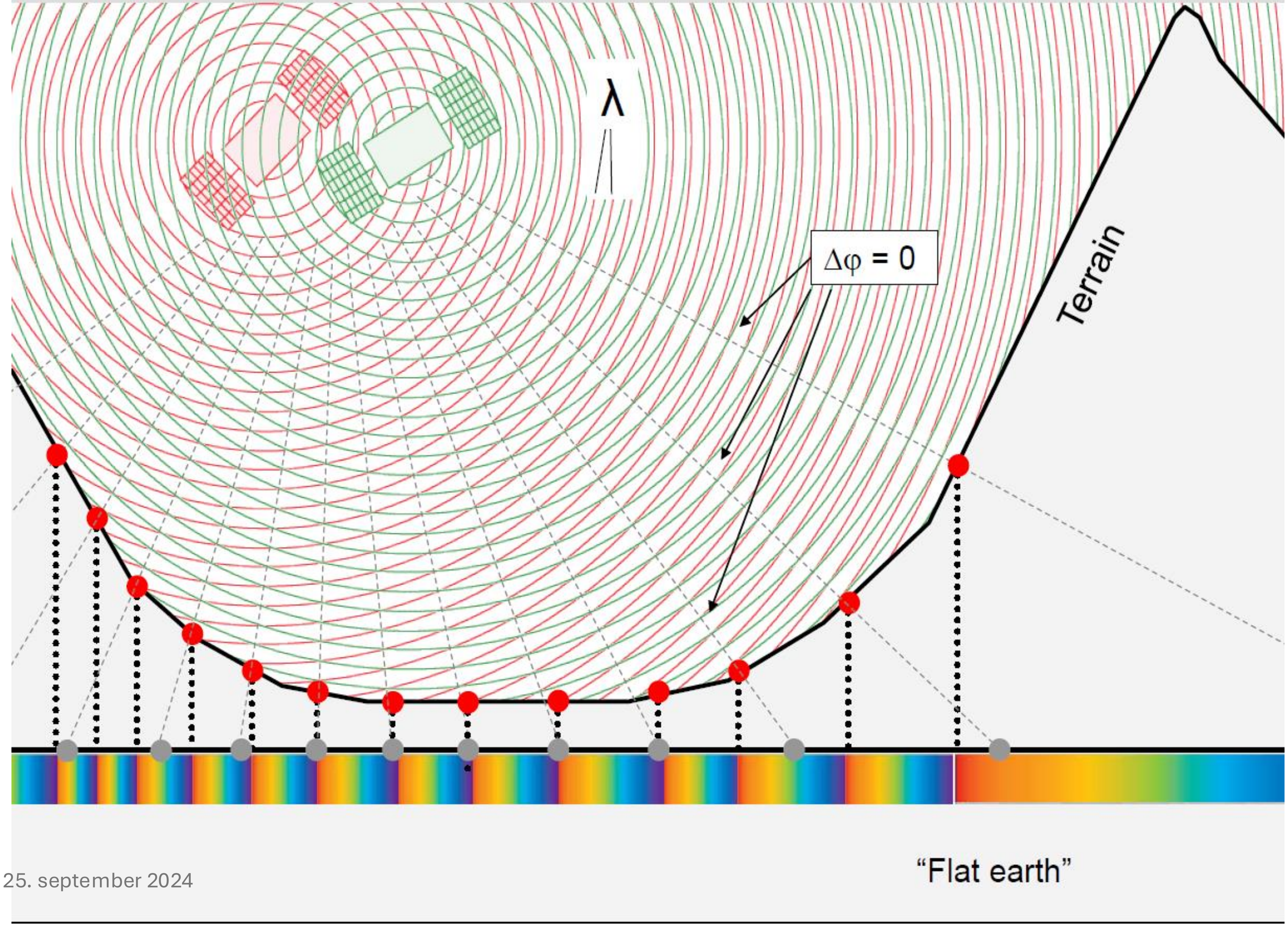
Interferometric phase patterns (fringes)





University of Be

Interferometric SAR (InSAR)

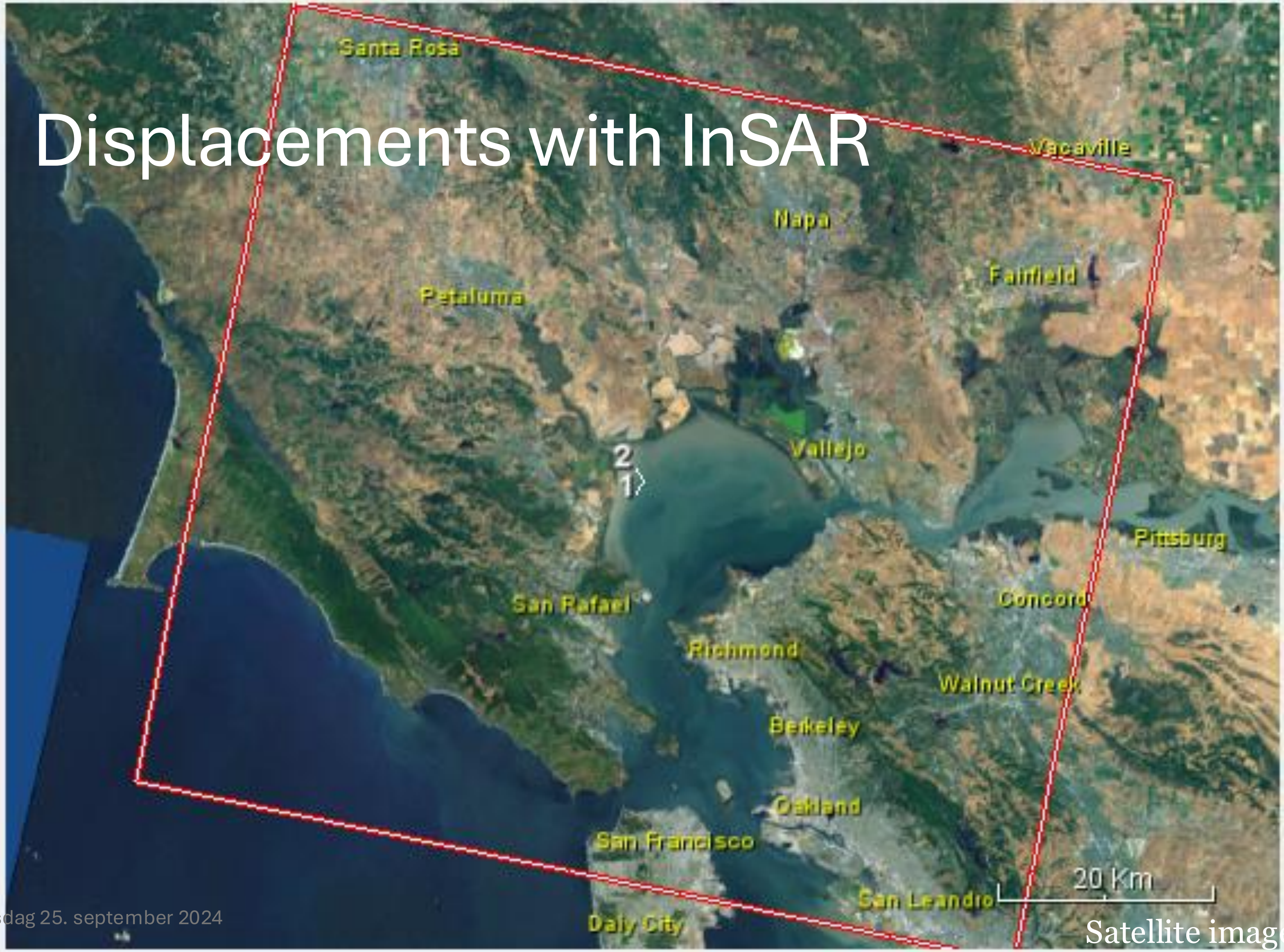


Interferometric SAR (InSAR)

- We can therefore use InSAR to work out:
  - Topography (DEM) if we assume **no displacement** between the acquisitions
  - Displacements/Velocities (**if we remove the effect of the topography**) (Differential Interferometry)
    - Either by comparing two pairs of SAR images (4-pass interferometry)
    - Simulating phase differences due to topography with a DEM (2-pass)

  - …as long as we know the baseline of the satellites and remove atmospheric noise

Displacements with InSAR



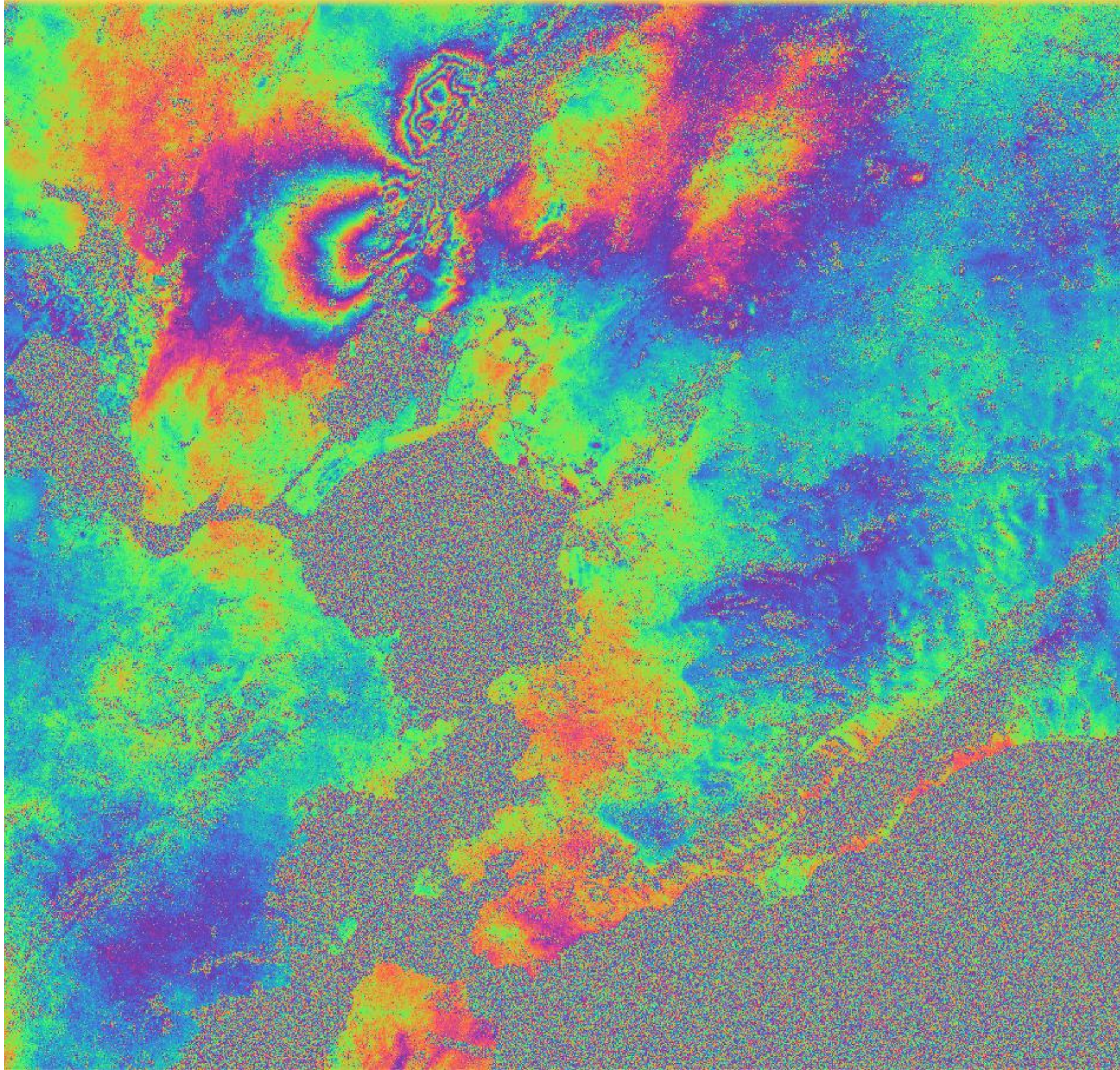
Satellite imag

Coherence

Where can we expect to get reliable estimates of radar phase?

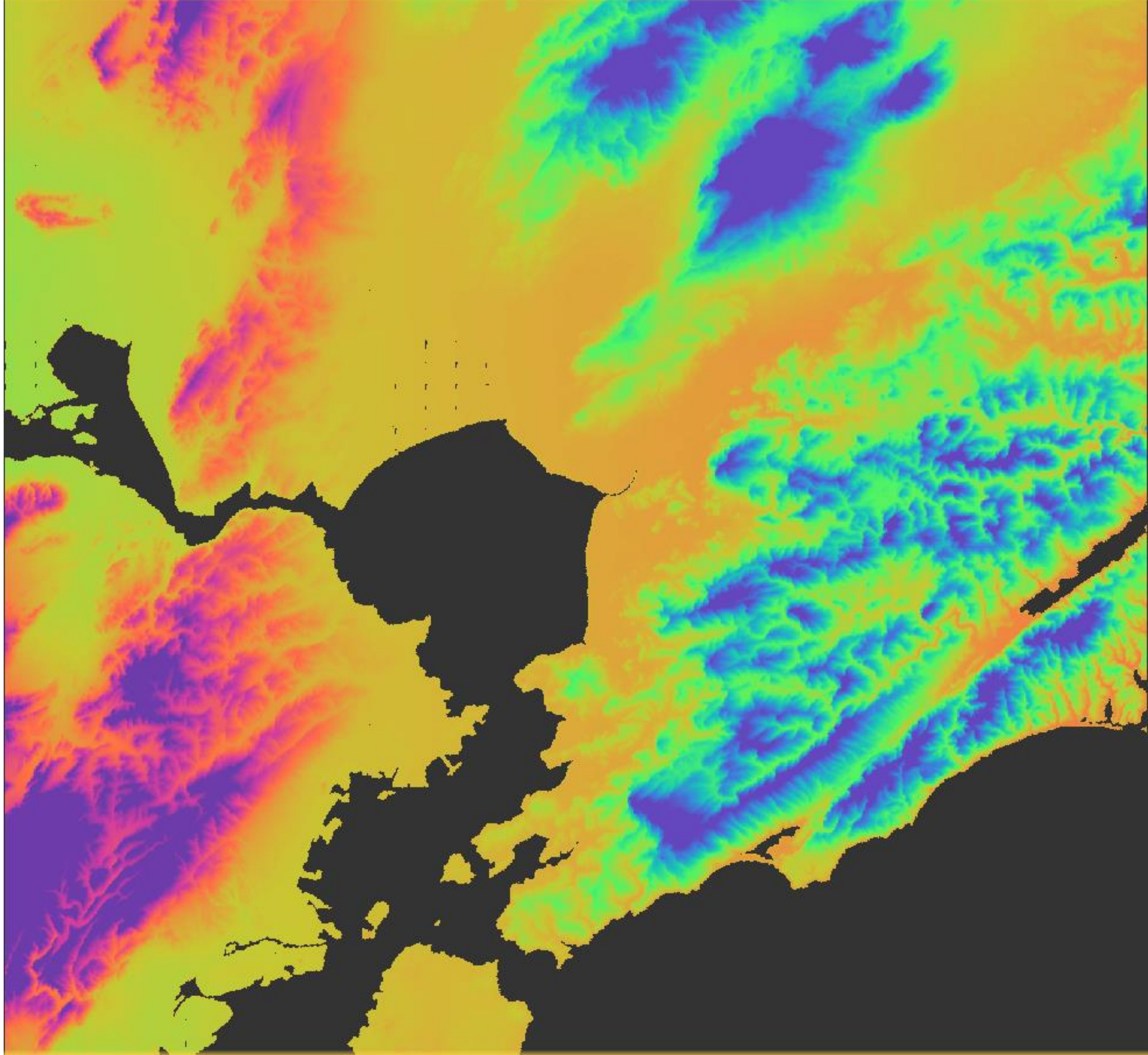
Interferogram: Phase patterns

- Changes in phase due to displacement, topography, atmosphere, and baseline
- Any noticeable patterns?

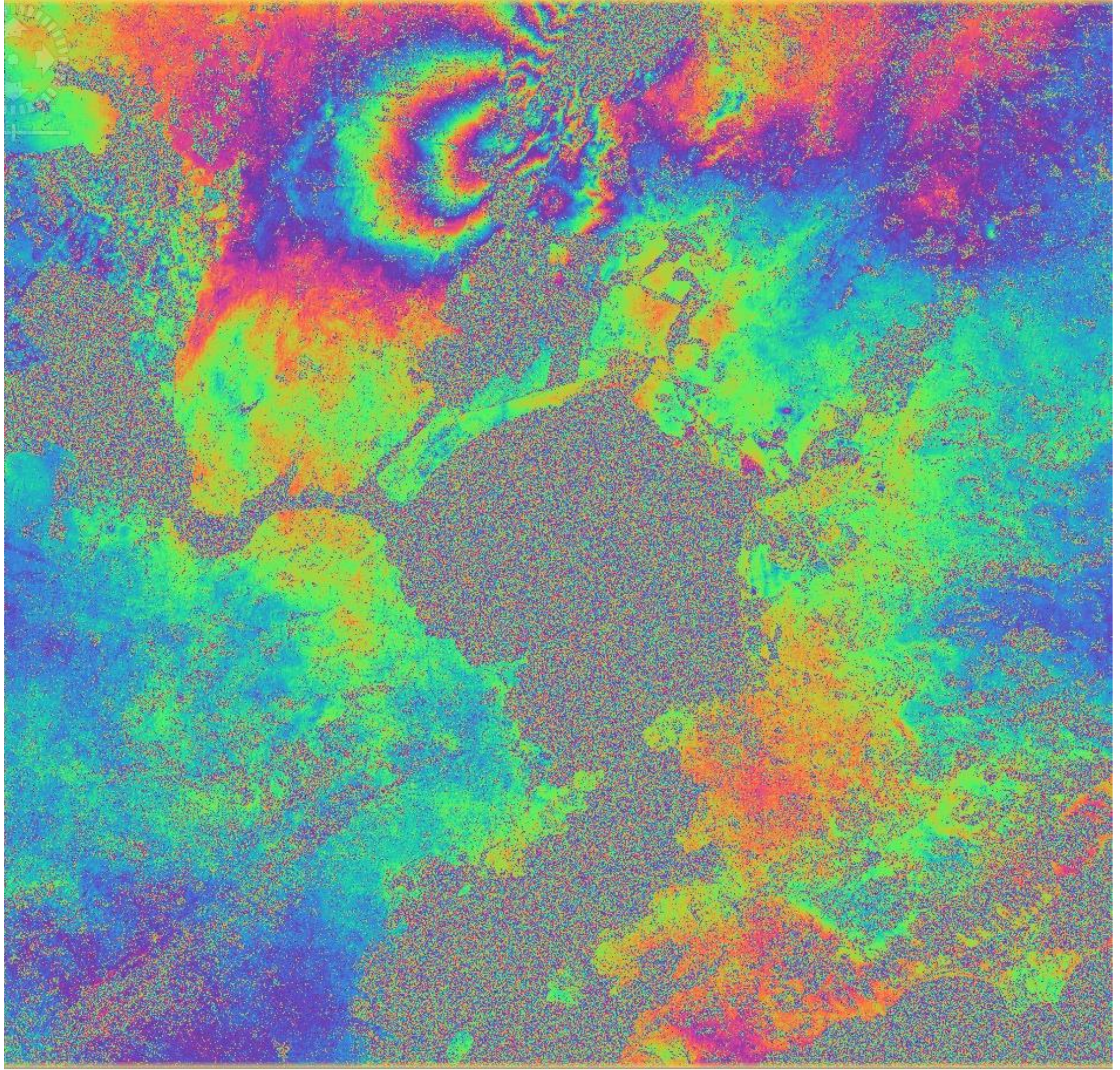


Topographic simulated phase

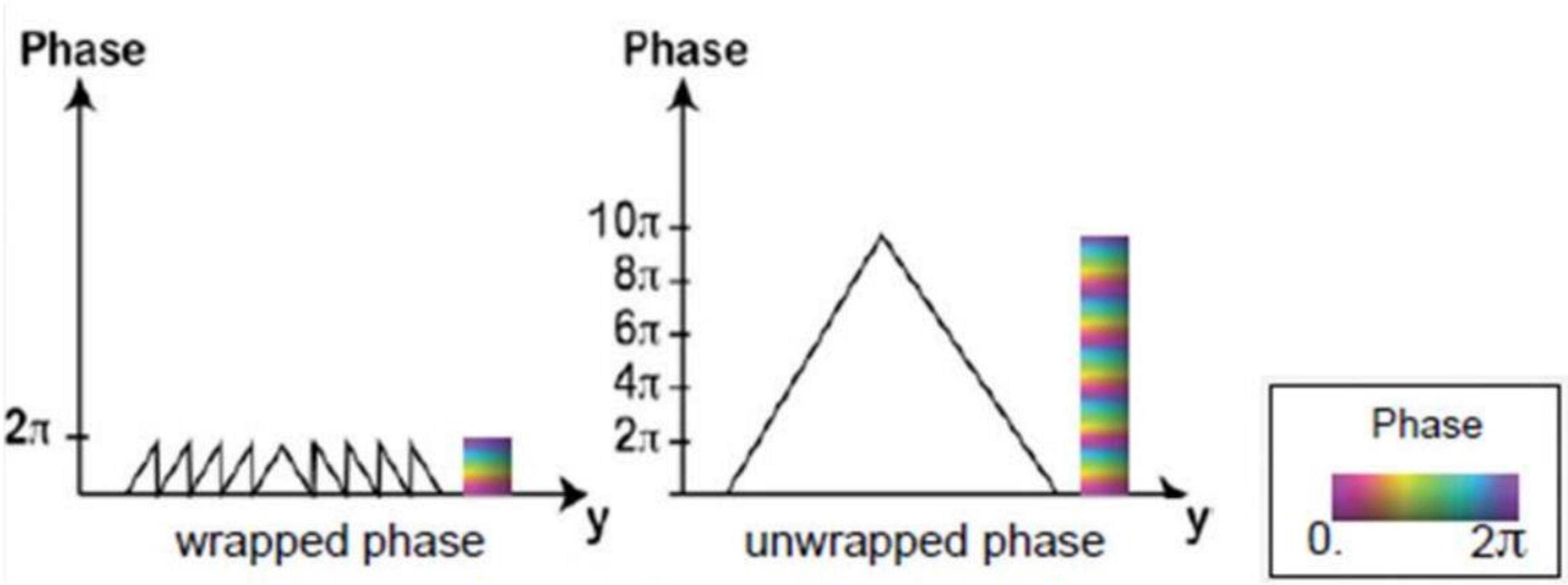
- This is how the phase patterns would look like if it **just topography** influencing the result
- We therefore subtract this from our interferogram



- **Interferomgram with topography removed**
- **How to interpret an interferogram?**
  - Total displacement: number of fringes x half wavelength



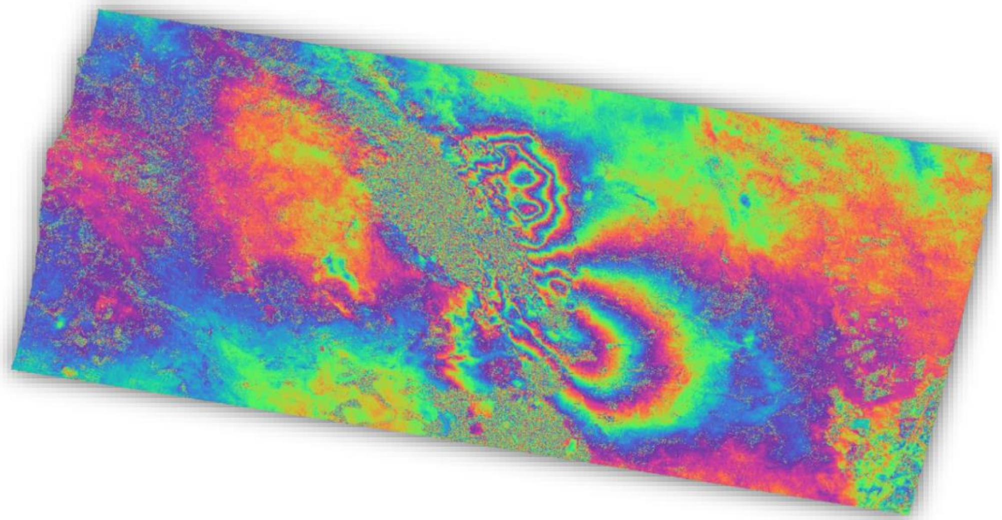
Phase Unwrapping



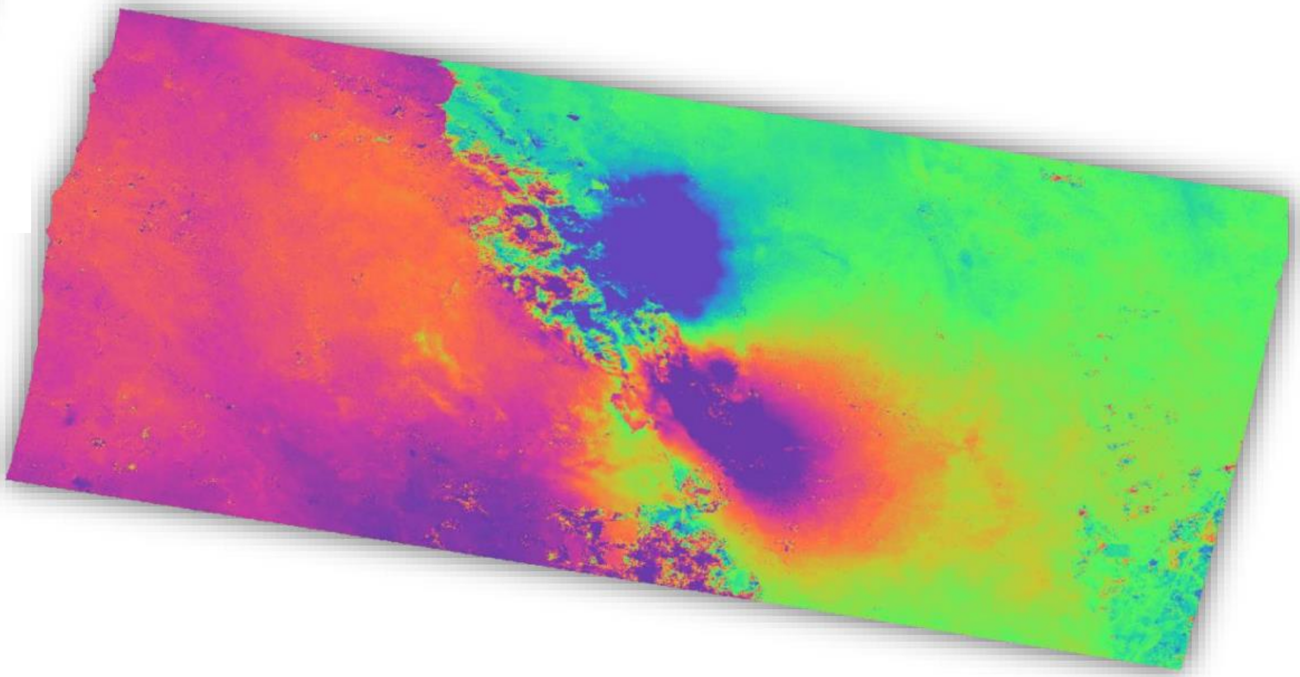
Wrapped Phase and Unwrapped Phase

Source: ESA

Unwrapping



Geocoded Interferogram



Geocoded Unwrapped Phase

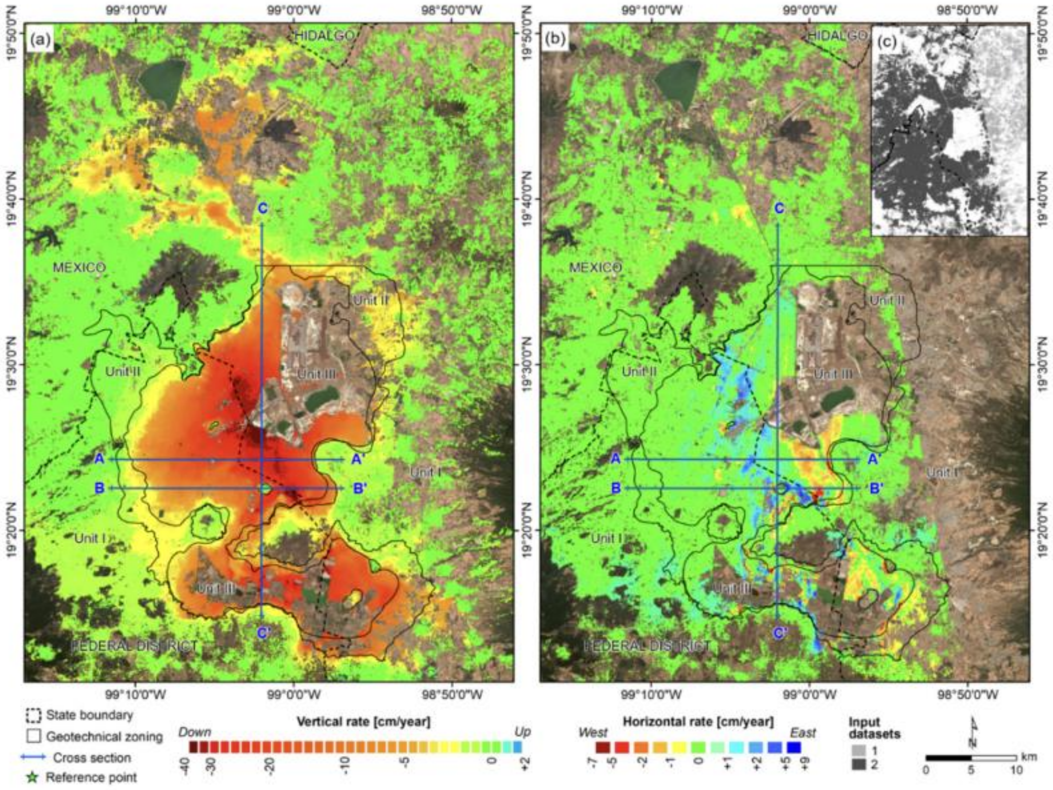
Table 1. Rough estimation of the minimum displacement rate in an interferogram as a function of the temporal baseline for the C-Band of Sentinel 1.

Temporal Baseline [Days]	Minimum Detectable Displacement [cm/Year]	Maximum Detectable Displacement [cm/Year]
6	17	170
12	8.5	85.2
24	4.2	42.6
36	2.9	28.4
48	2.2	21.3

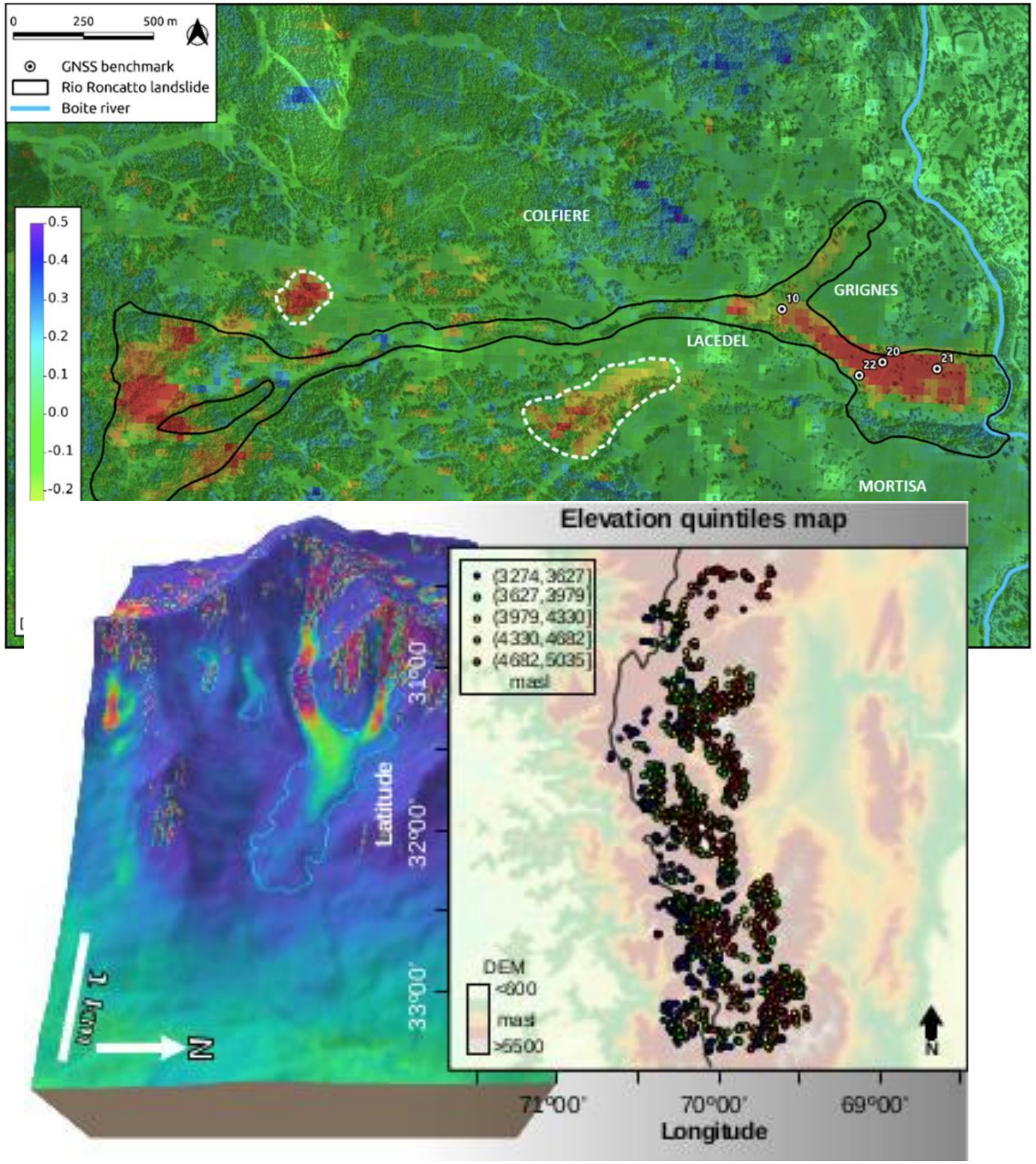
Villarroel *et al.*, 2018

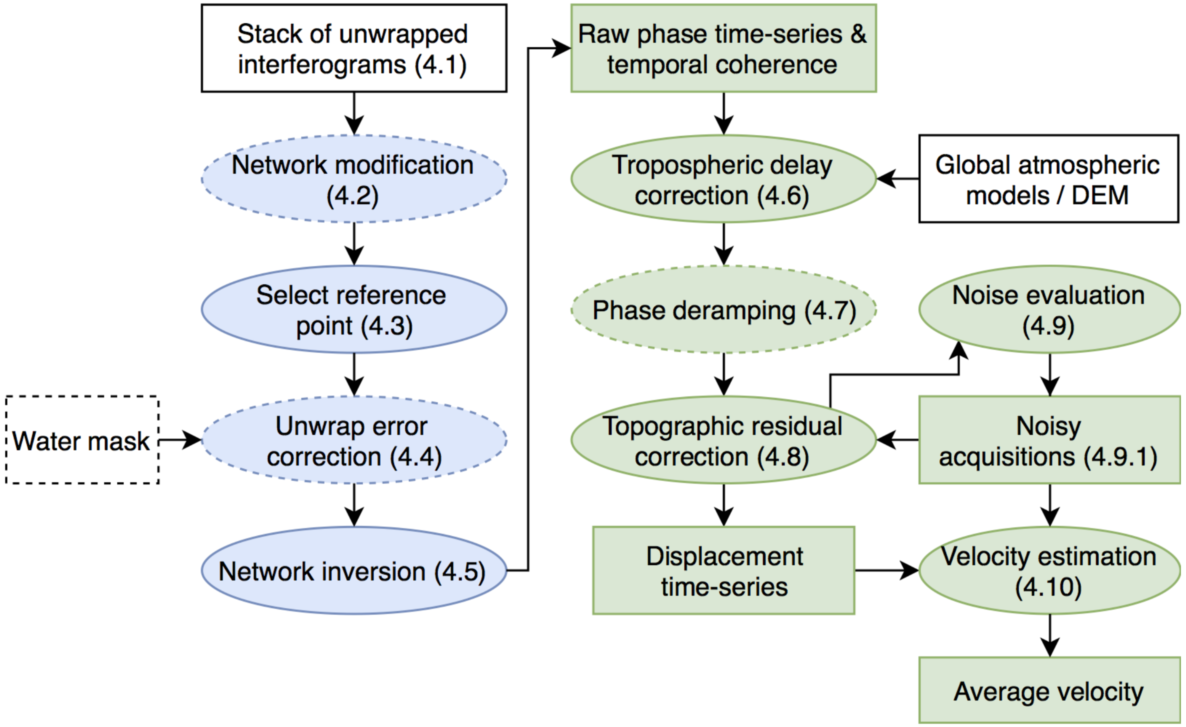
Applications of InSAR

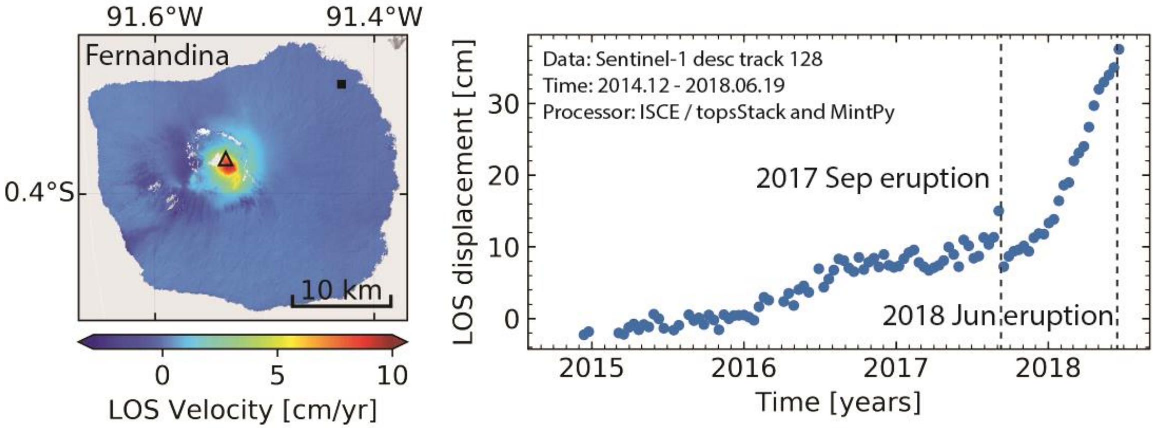
- Rock glacier velocity, but also landslides, subsidence…



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



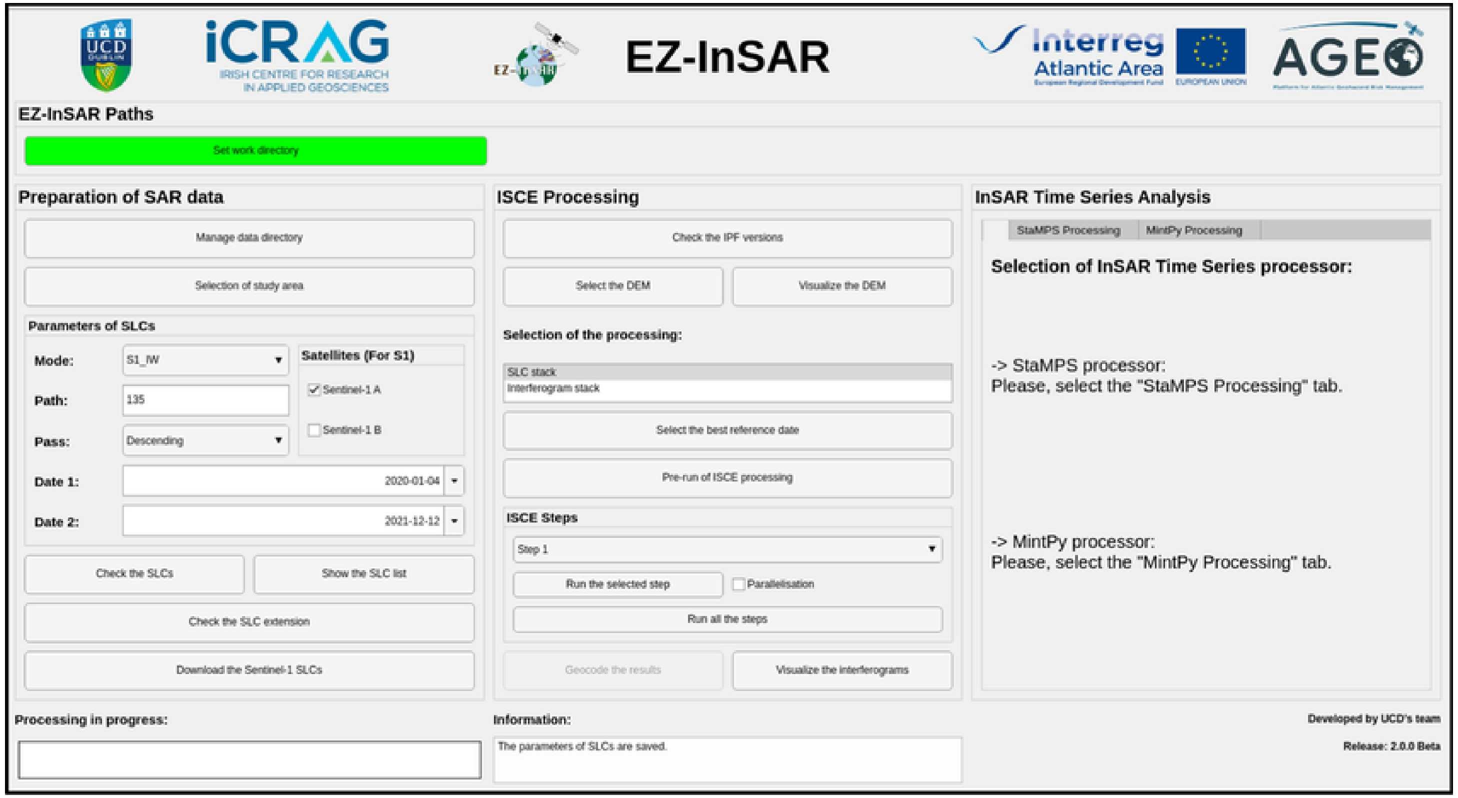




Time-series analysis - SBAS

SBAS – Time series analysis

- The more images we use….
- …The better we can remove atmospheric influences
- Also means we can look at seasonal changes
- A range of software packages – PyRate or Mintpy most popular
- EZInSAR – nice software package that integrates downloading, processing interferograms, and SBAS



Practical information for the exercise

- Use SNAP to process two TerraSAR-X images over Tapado Rock Glacier
- Optionally, repeat the processing with freely available Sentinel-1 data
- This afternoon: demonstration of time series analysis with Mintpy