InSAR Theory

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ESA Advanced Training Course
Remote Sensing of the Cryosphere

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What is InSAR and what is it used for?

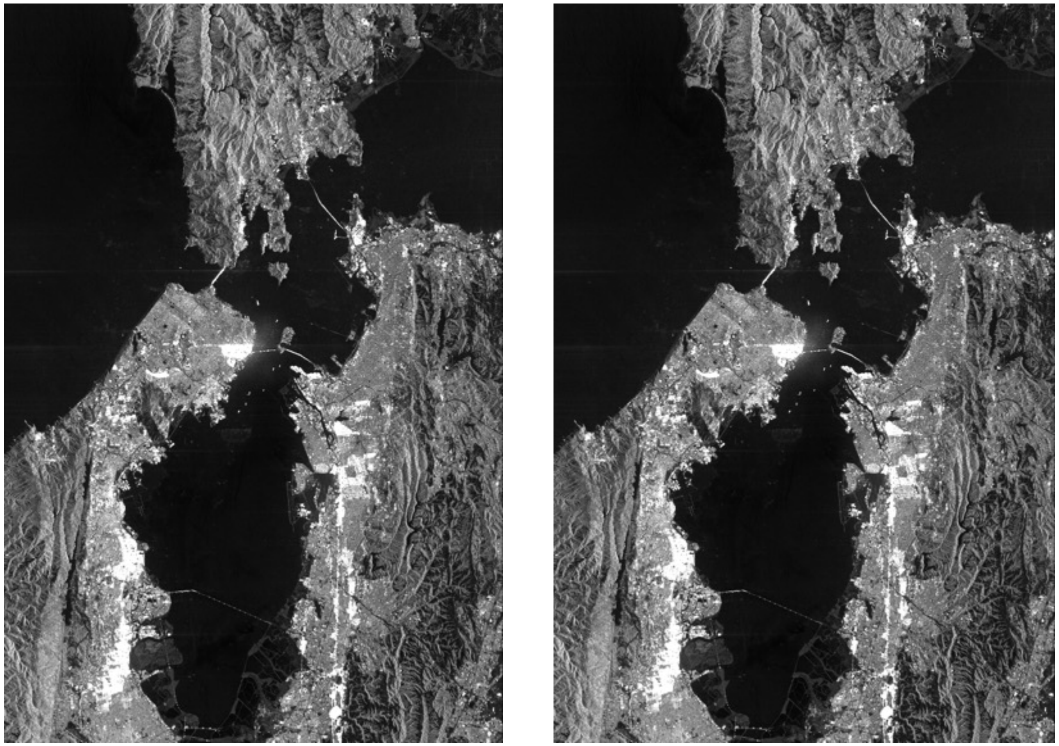
- Short for "Interferometric Synthetic Aperture Radar"

Sensitive to topography and displacement

Uses include:

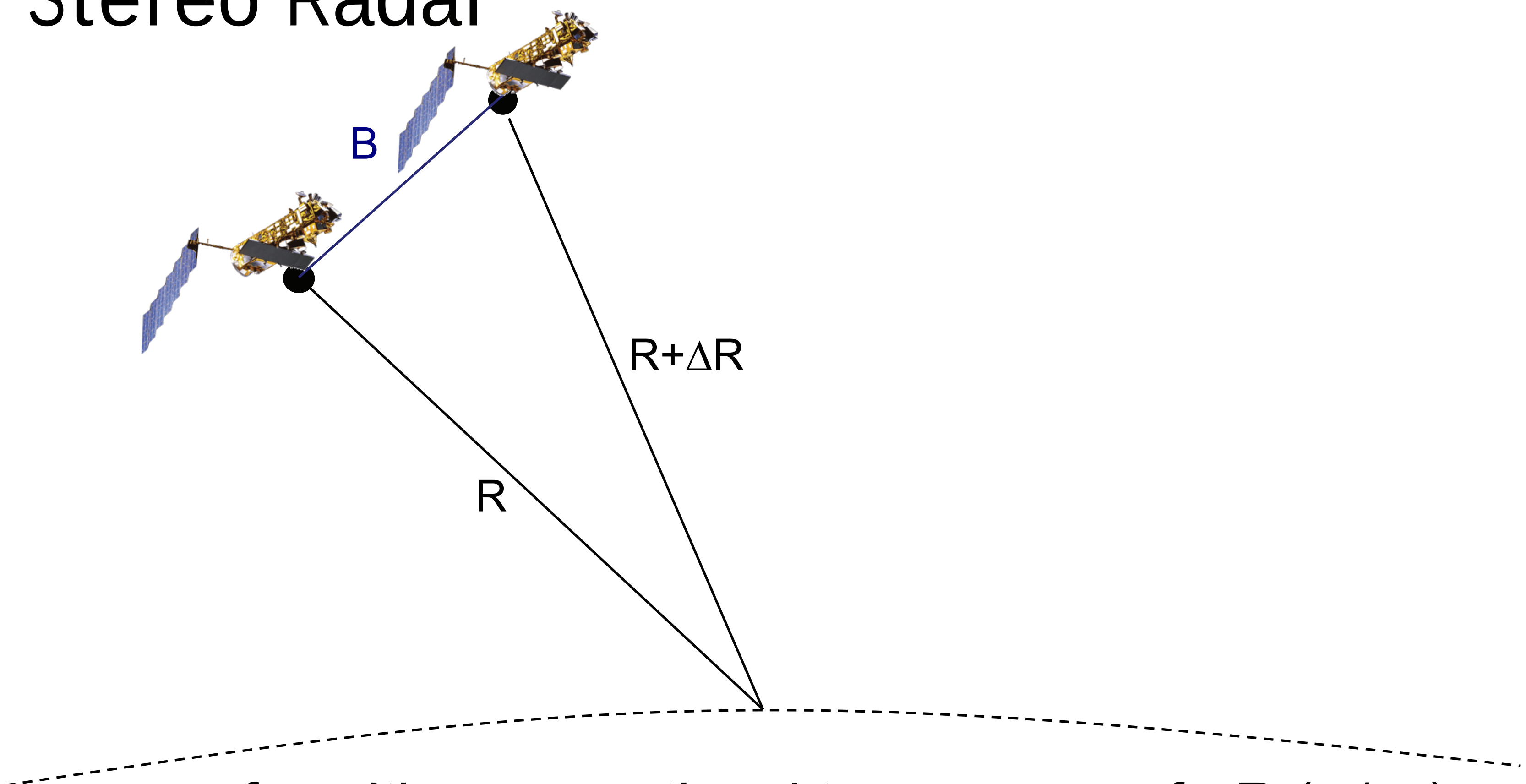
- Tectonics and earthquakes
- Volcanoes
- Glacial isostatic rebound
- Glaciology
- Oil and Gas extraction
- Hydrology
- Monitoring infrastructure

Stereo Radar



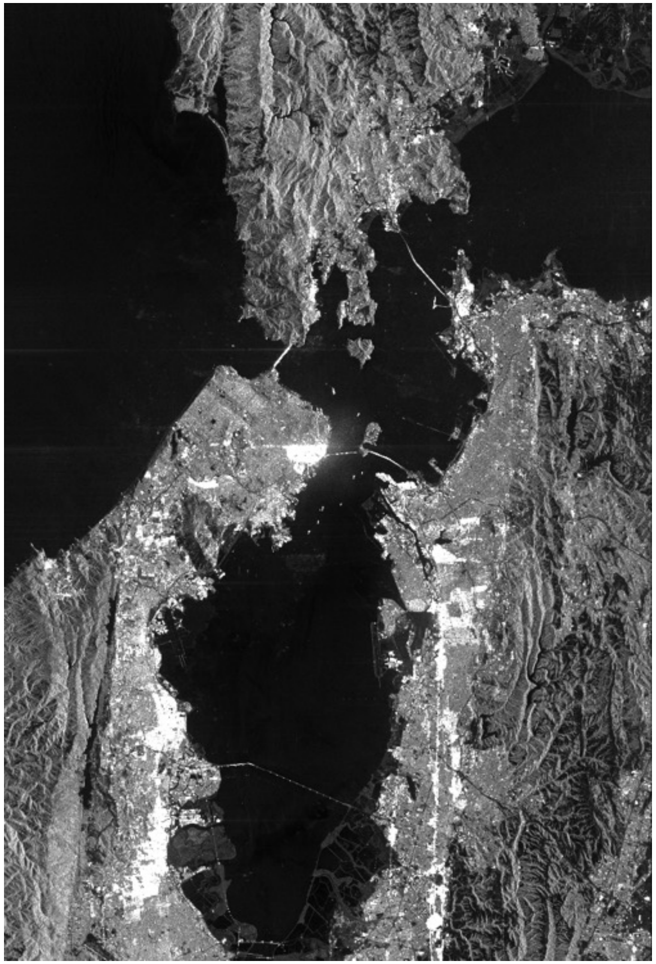
- 2 images from different positions give 3D position
- Note: different to stereo vision

Stereo Radar



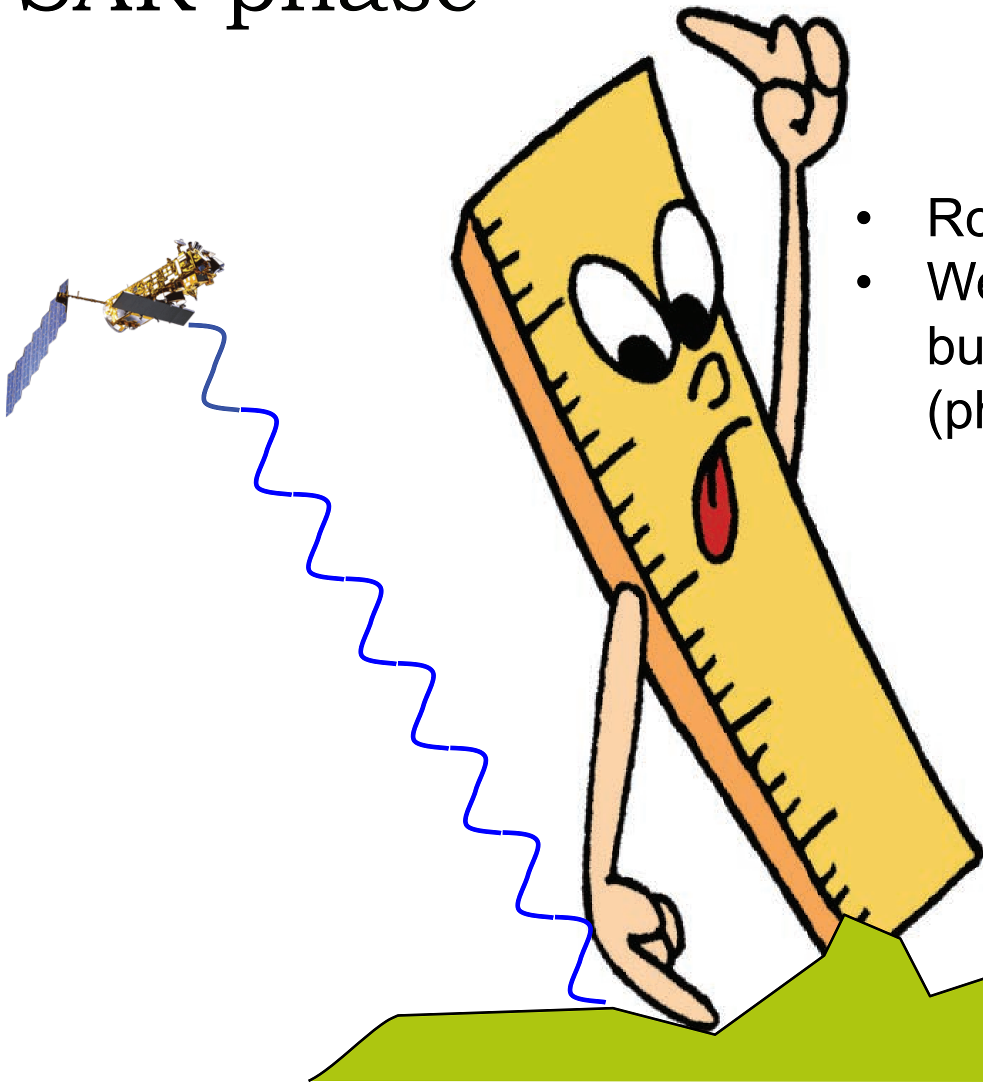
- Accuracy of position proportional to accuracy of ΔR (~1m)
- Accuracy scales with R/B! (~$10^6/10^2$)

What about the phase?

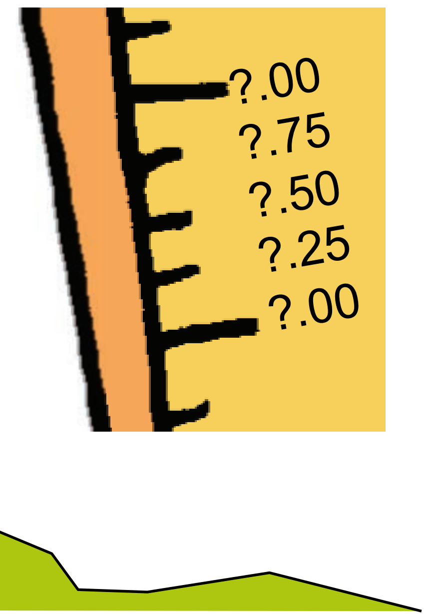


Electromagnetic waves have phase as well as amplitude – can we use this?

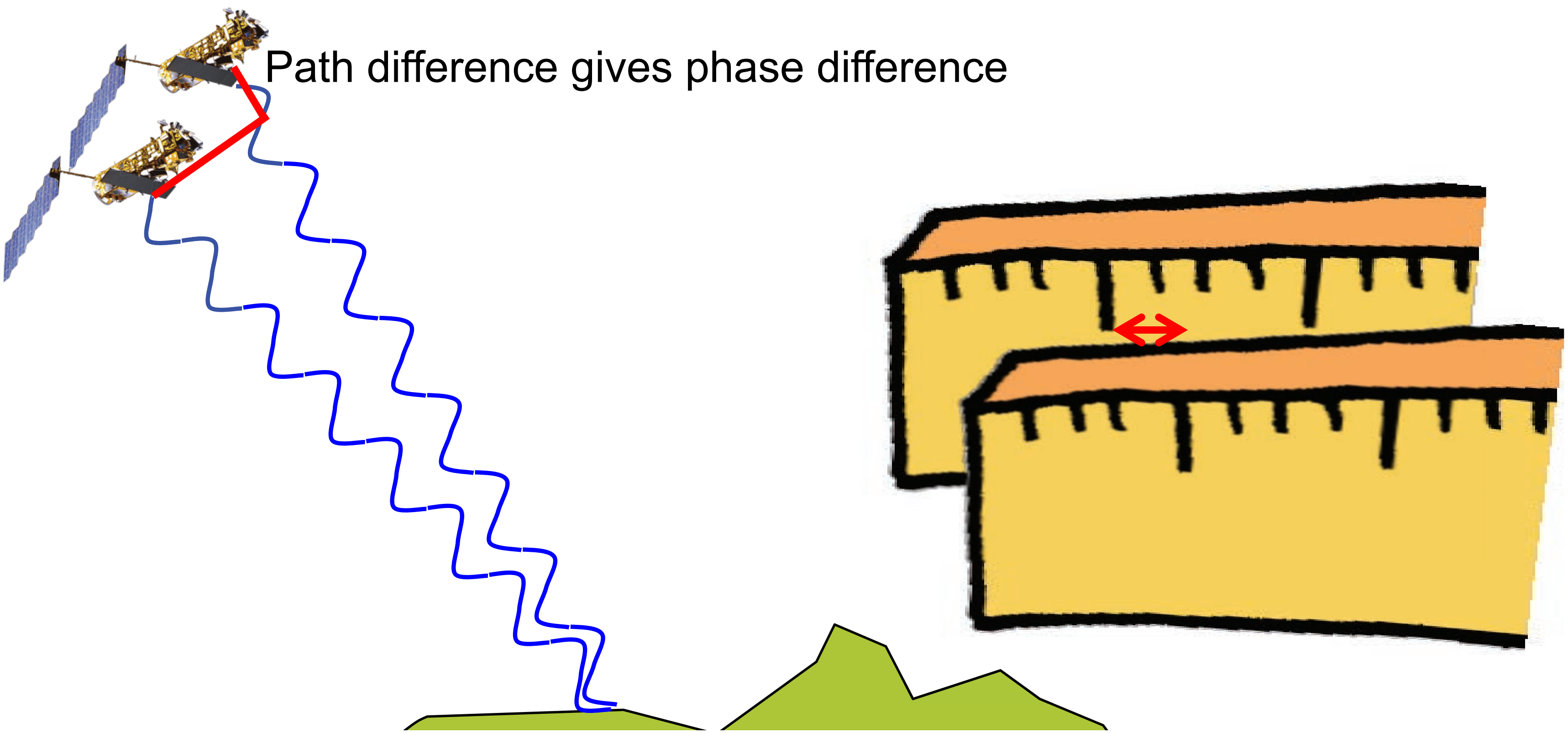
SAR phase



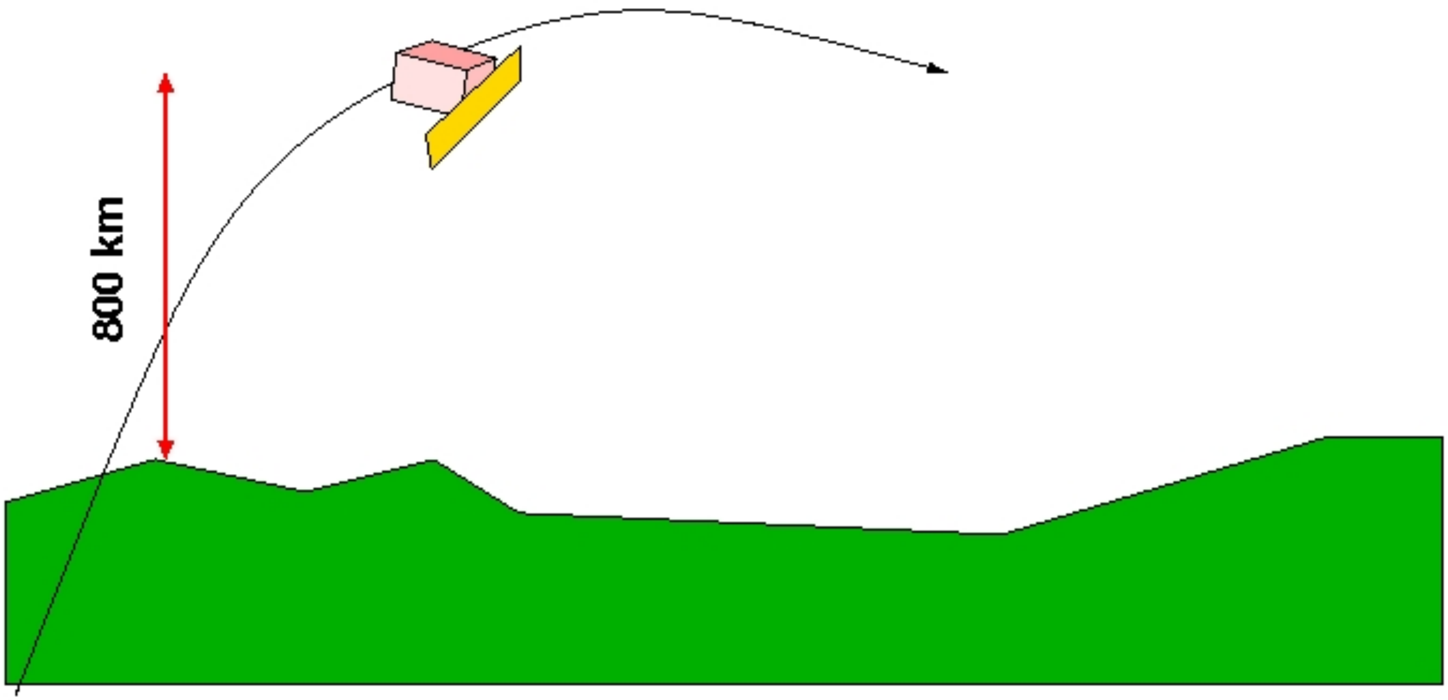
- Round trip ~ 30 million wavelengths
- We don't know the exact number, but can measure the fractional part (phase)

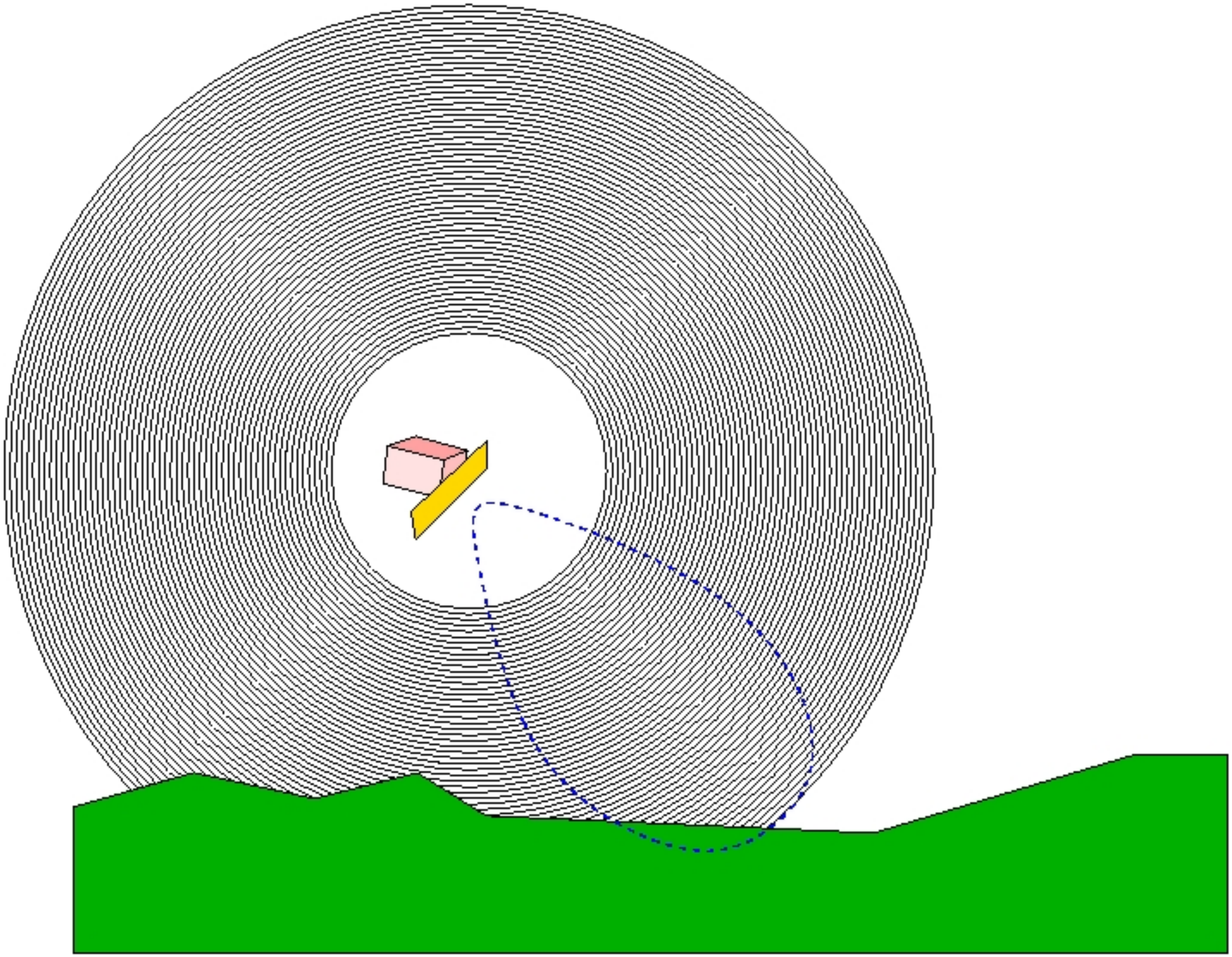


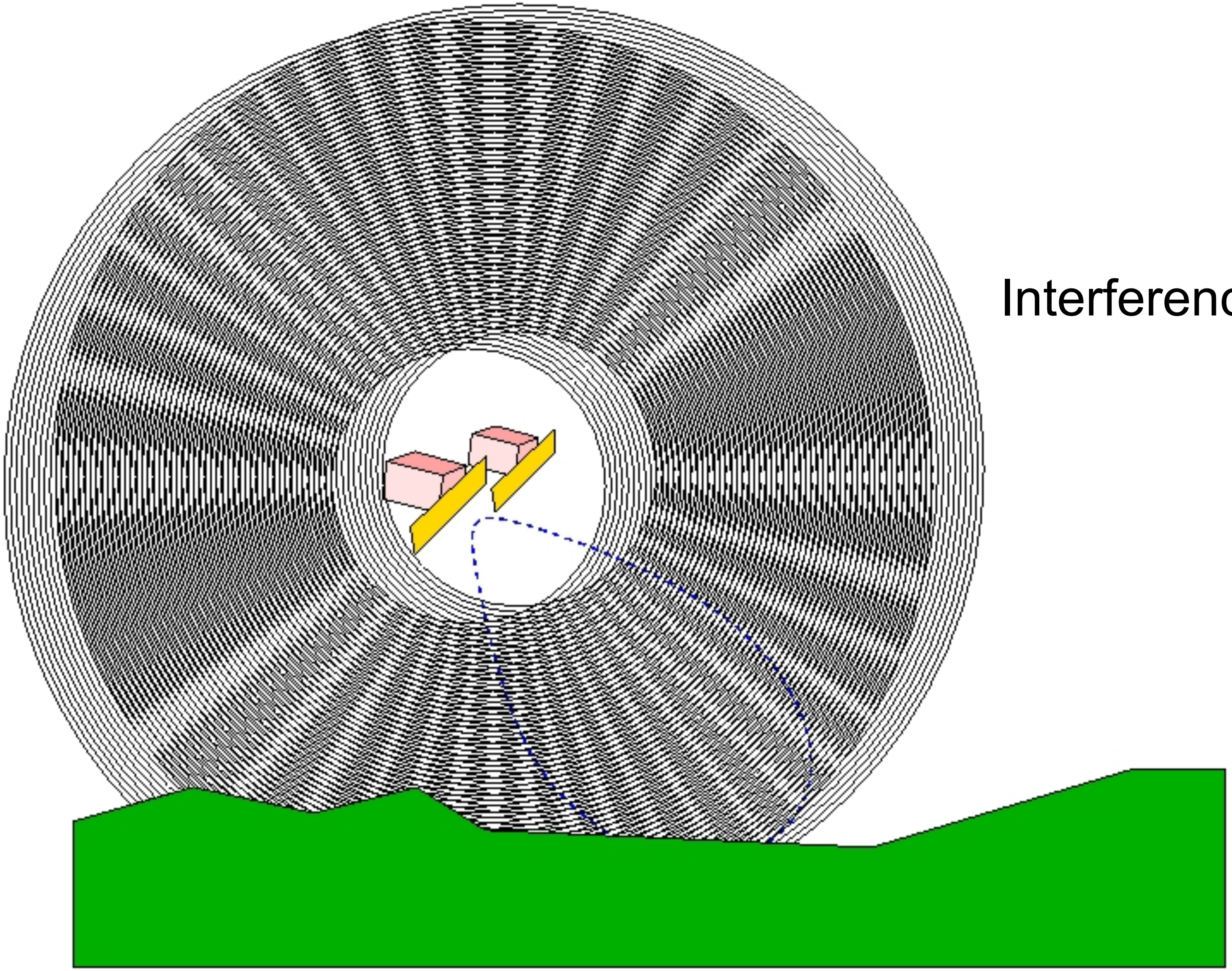
InSAR phase



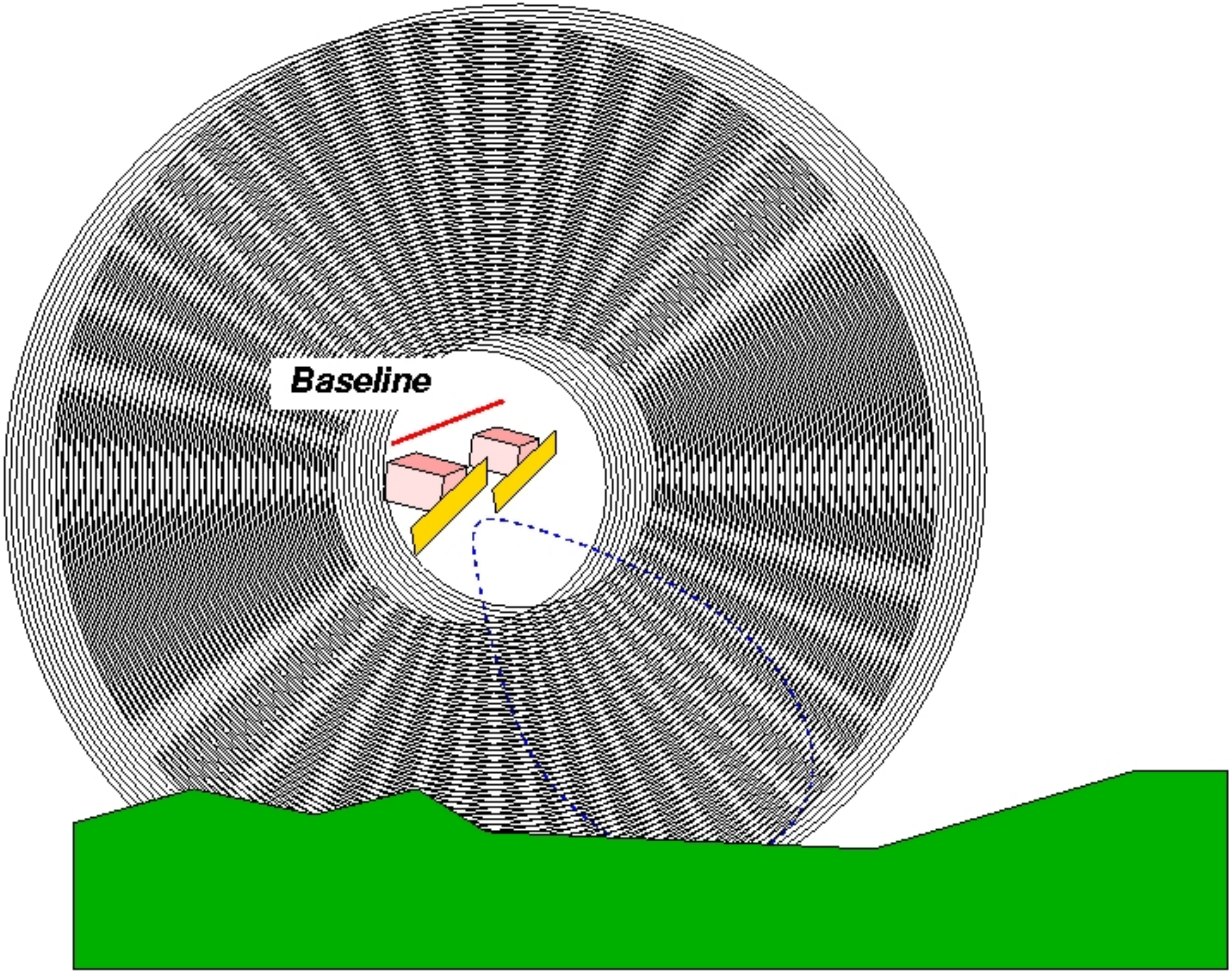
Interferemetric phase is phase difference

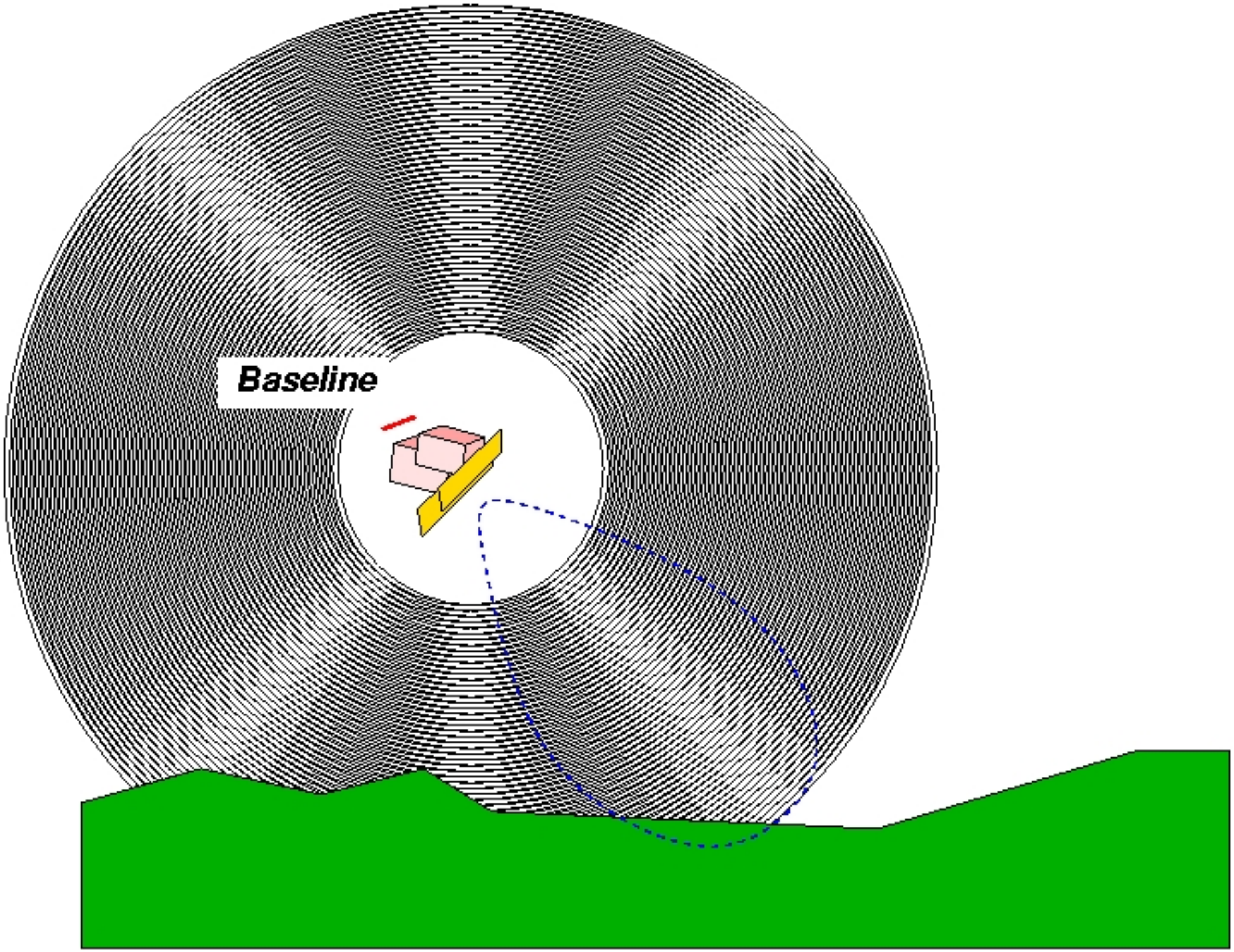

800 km

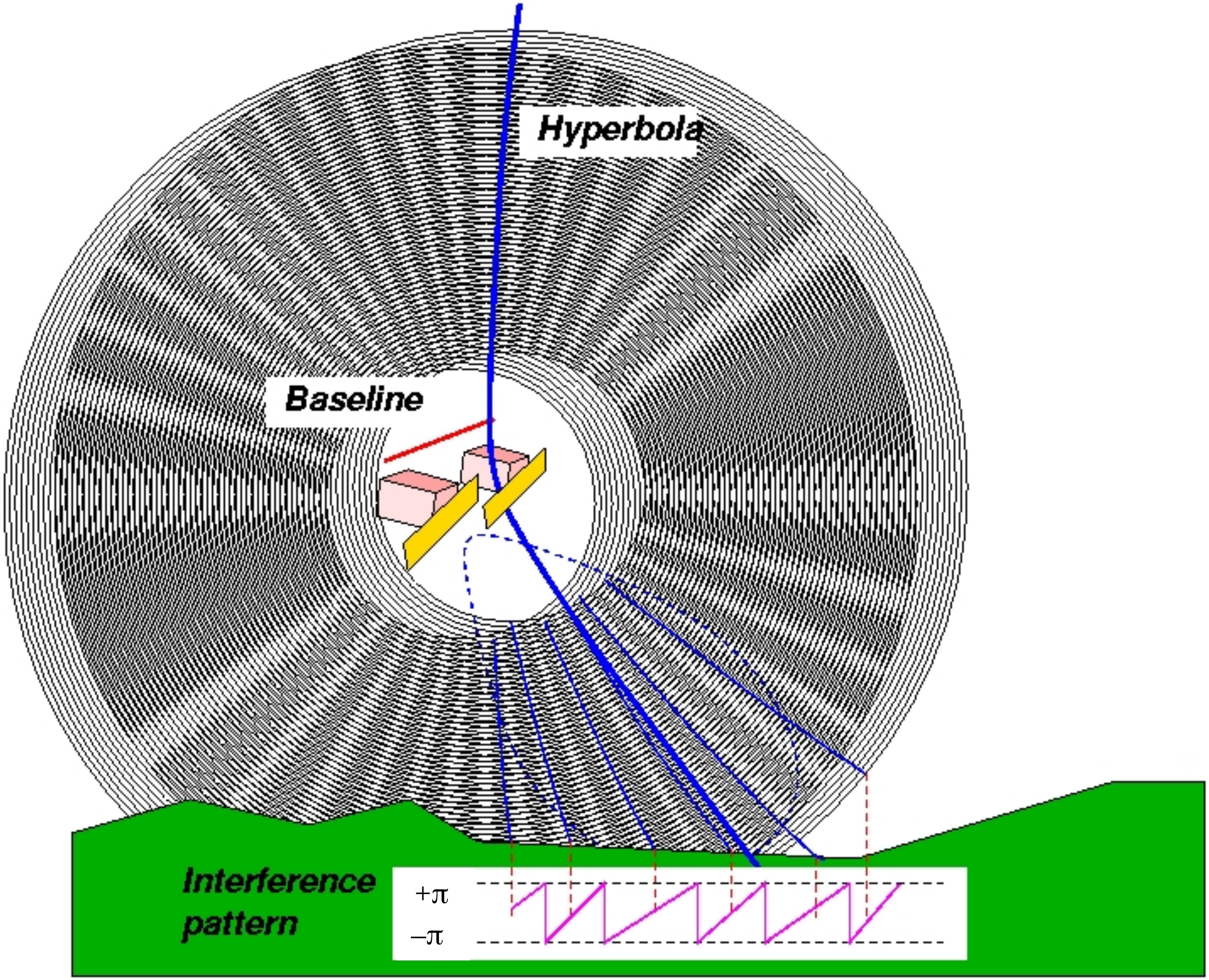




Interference Pattern

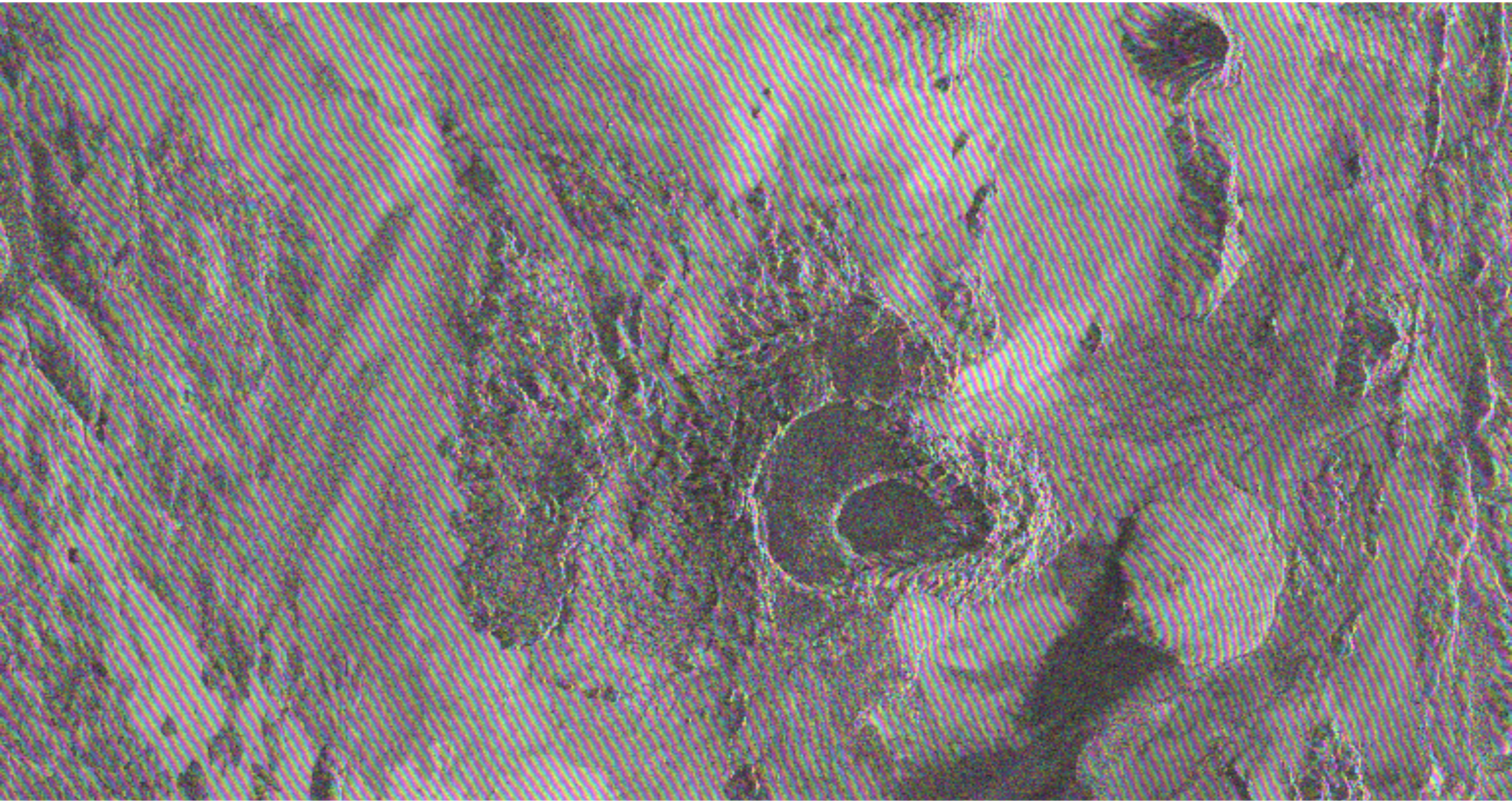

Baseline


Baseline



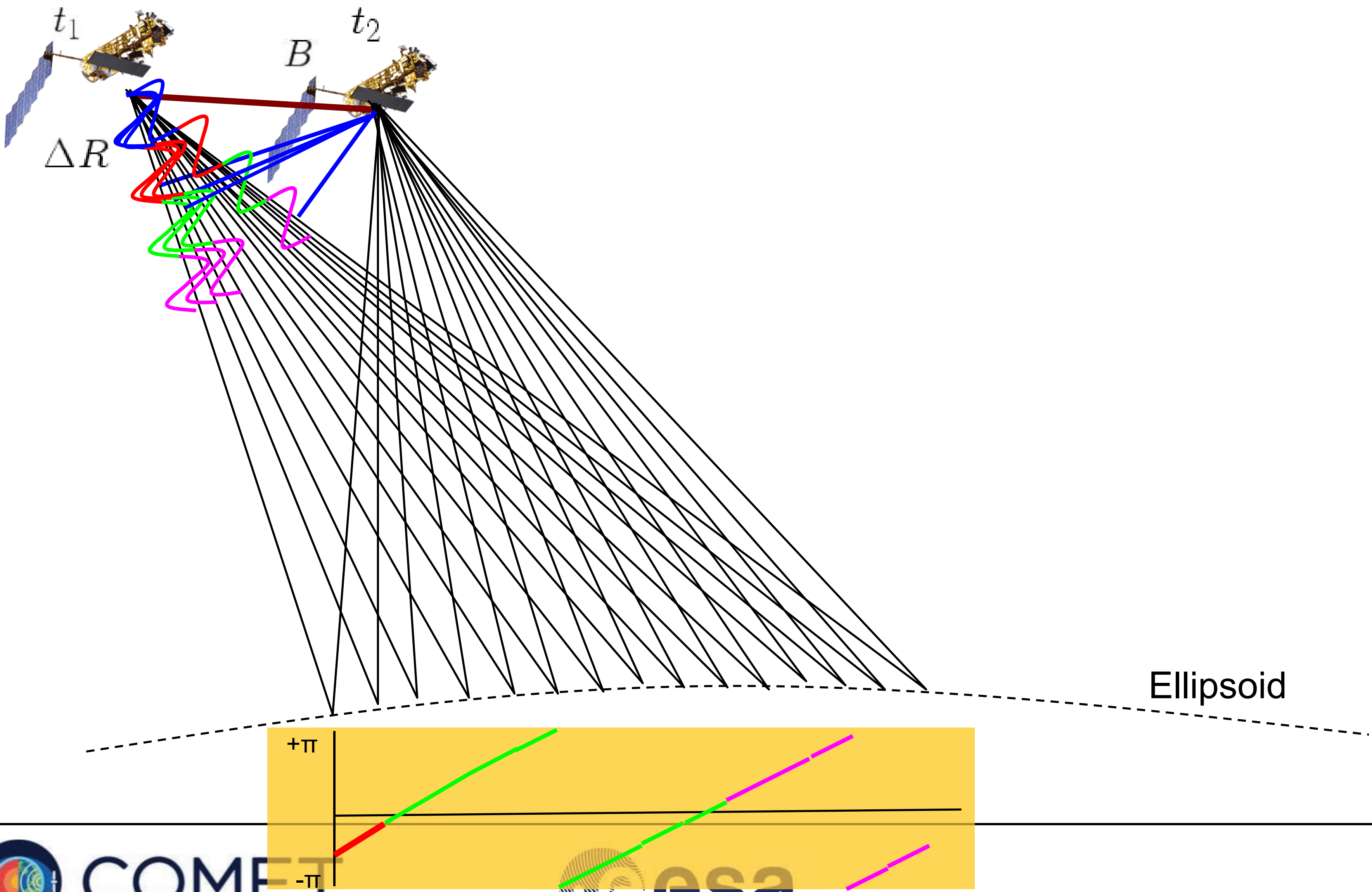
Interference phase at ground depends mainly on horizontal position, but also a little on the vertical position

Example in 2D: interferogram

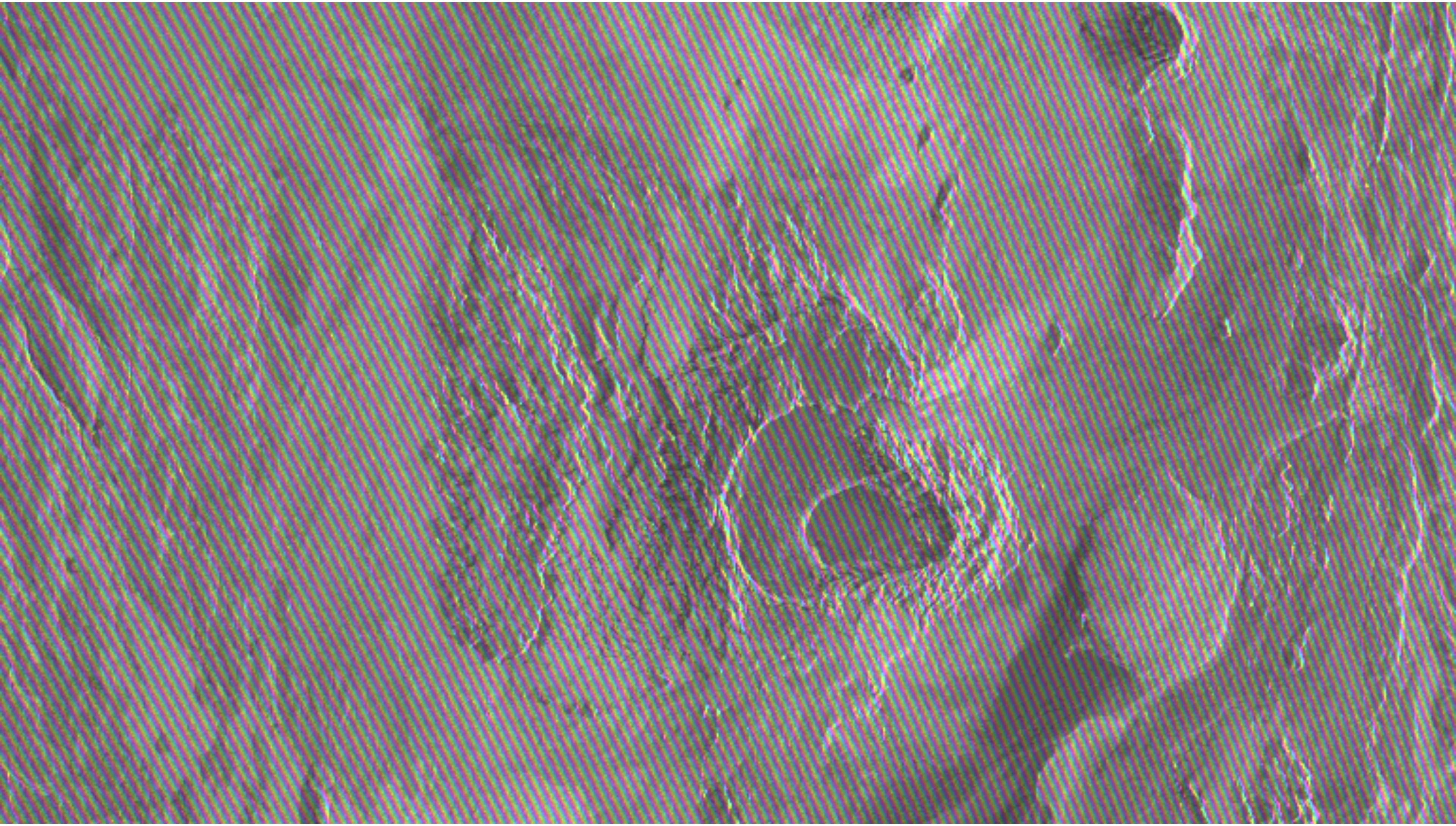


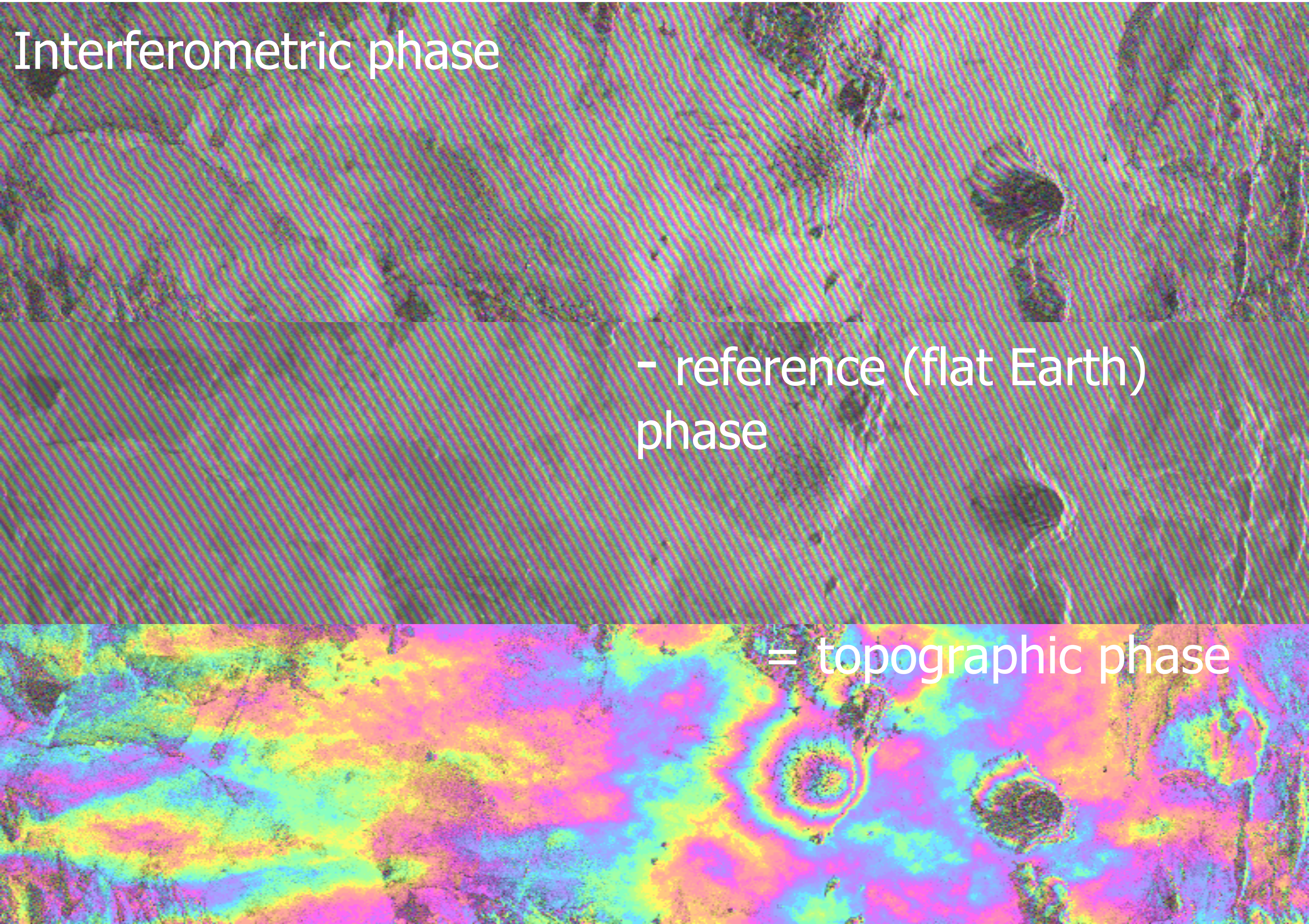
Mainly horizontal phase stripes (fringes), perturbed by ground elevation

Reference phase (Flat Earth Phase)

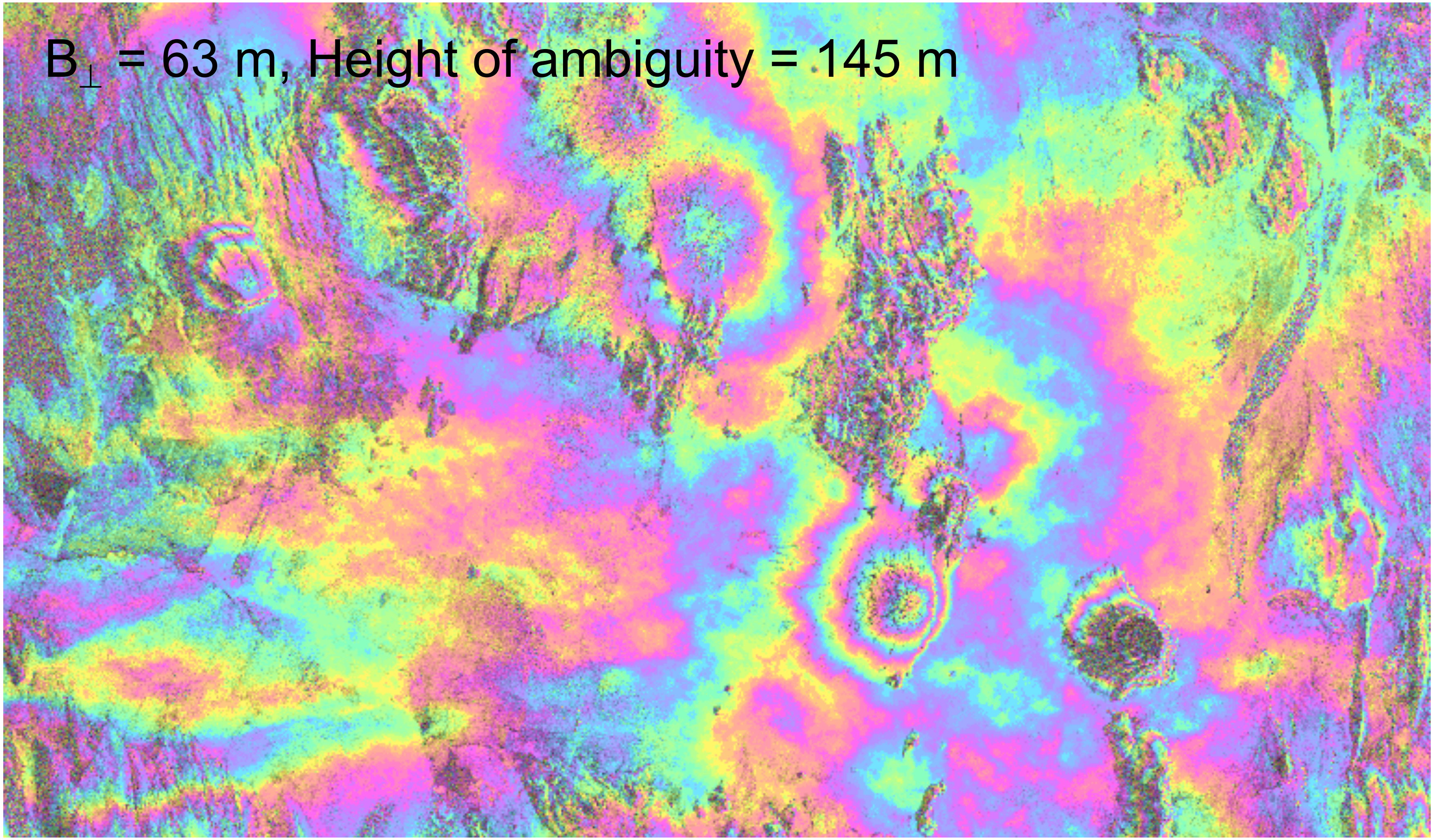


Example Reference Phase

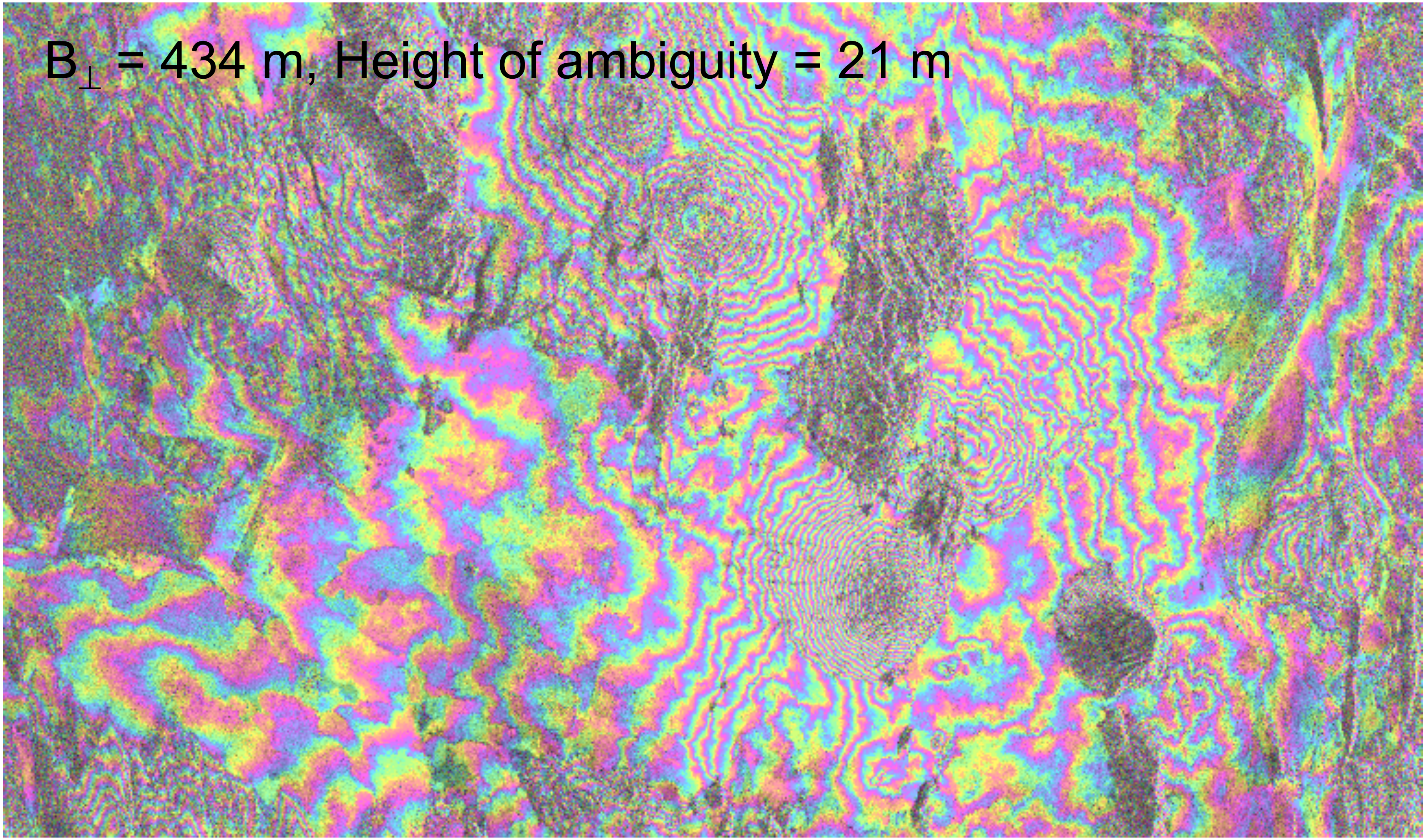



Interferometric phase
- reference (flat Earth) phase
= topographic phase

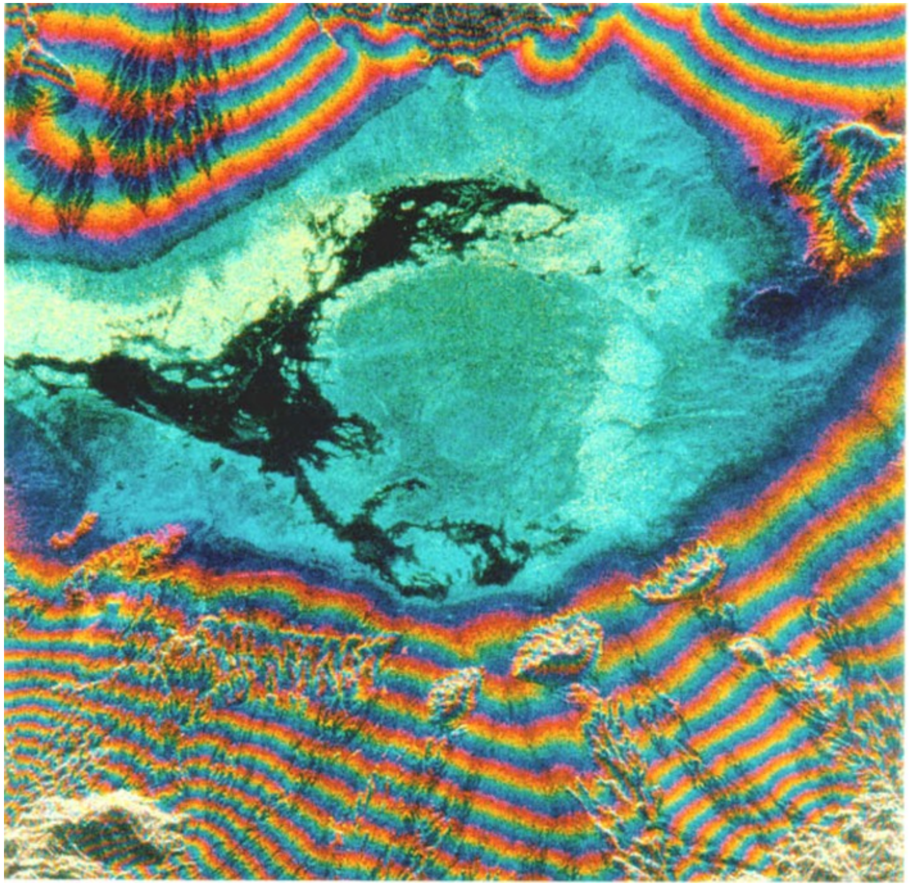
Baseline dependency, height ambiguity



Baseline dependency, height ambiguity

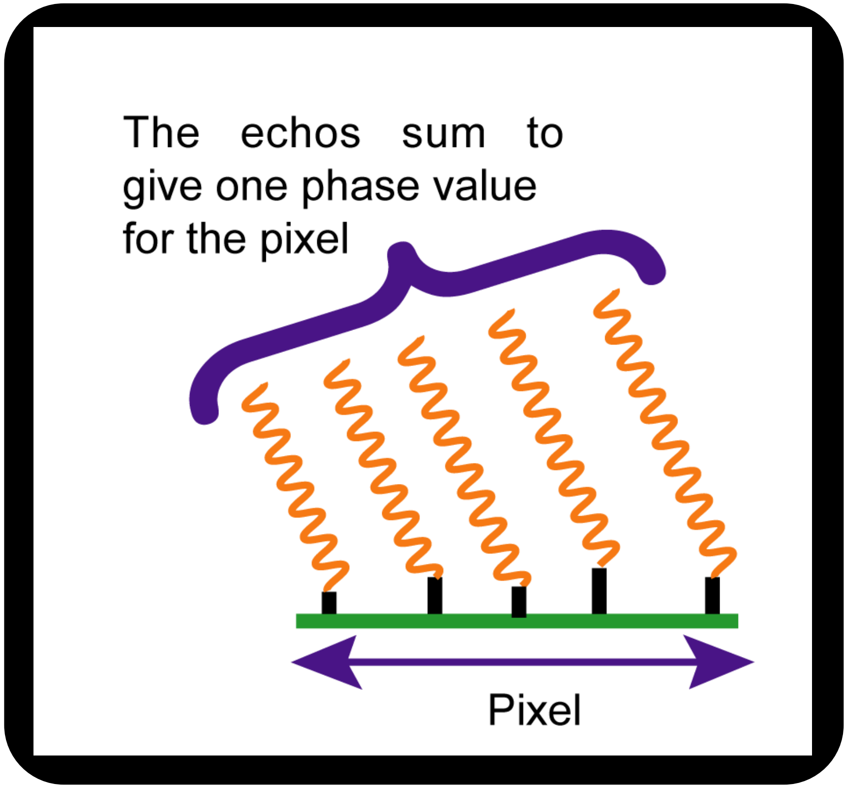


One of earliest interferograms



Cottonball Basin in Death Valley (Goldstein et al., 1988)

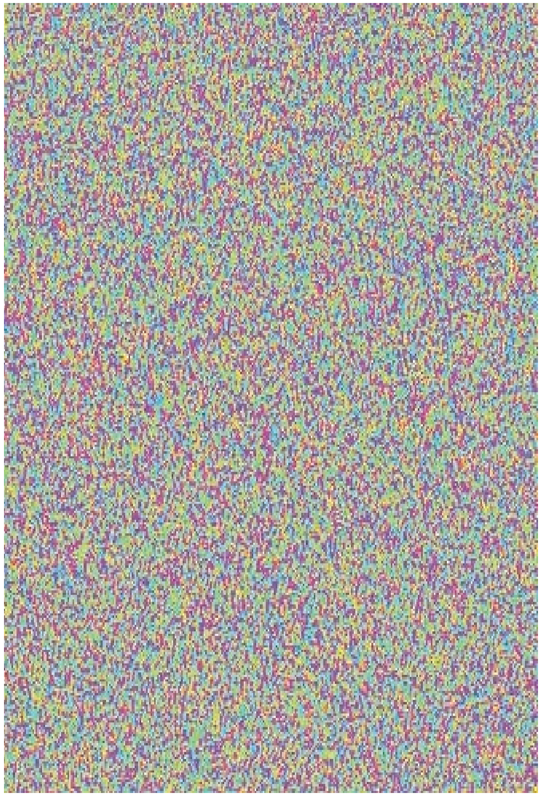
Speckle phase contribution



Distributed scatterer pixel

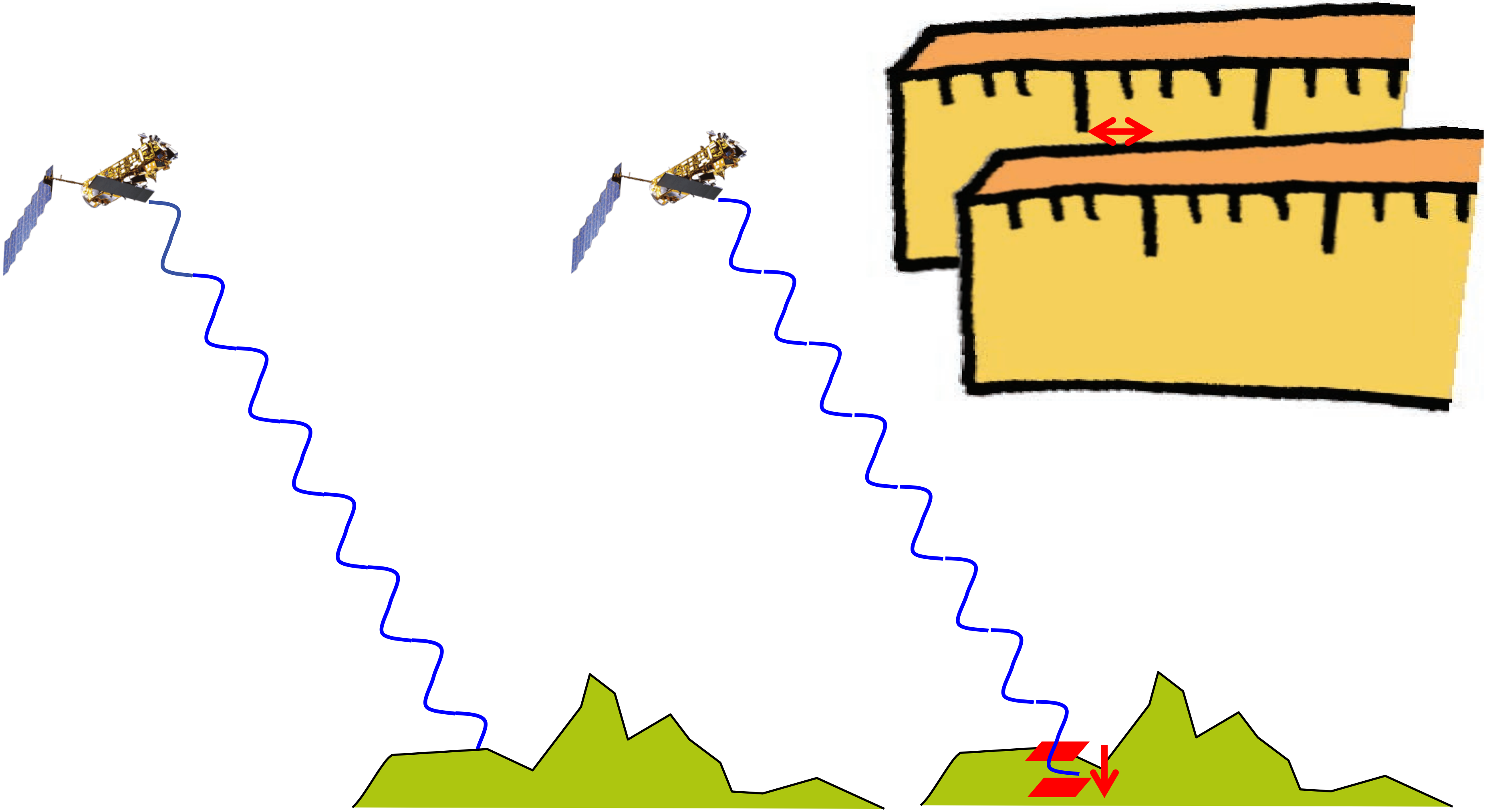
Phase is that of coherent sum of all scatterers

Phase of single image

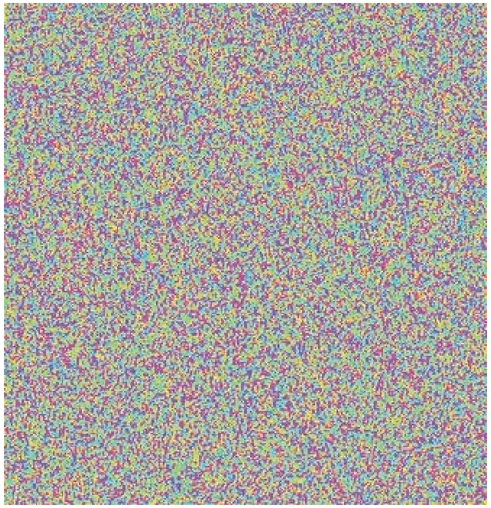


- Uninterpretable, due to pseudorandom phase added by ground scattering
- But ground scattering cancels (hopefully) in phase difference

InSAR phase: displacement

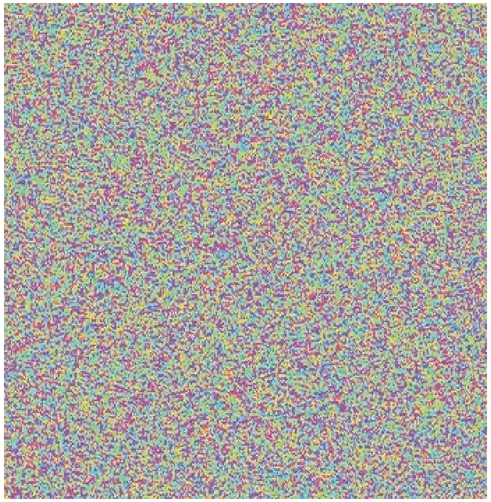


Example: Izmit, Turkey

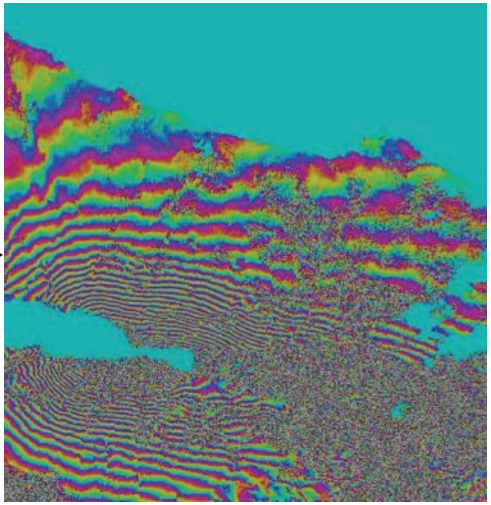


Amplitude

Phase

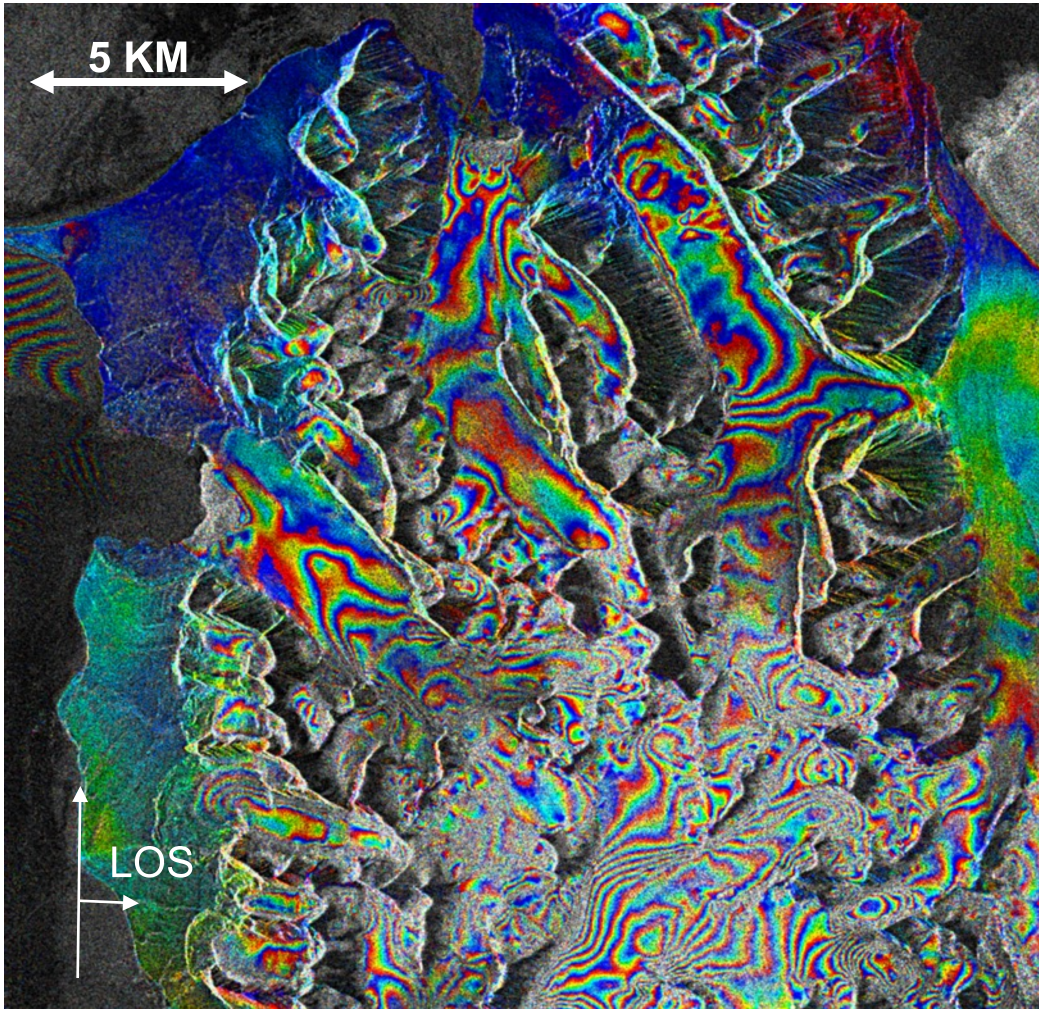


Interferogram



(after correction for reference and topographic phase)

Glacier Dynamics (Svalbard, Spitsbergen)



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12 day interferogram

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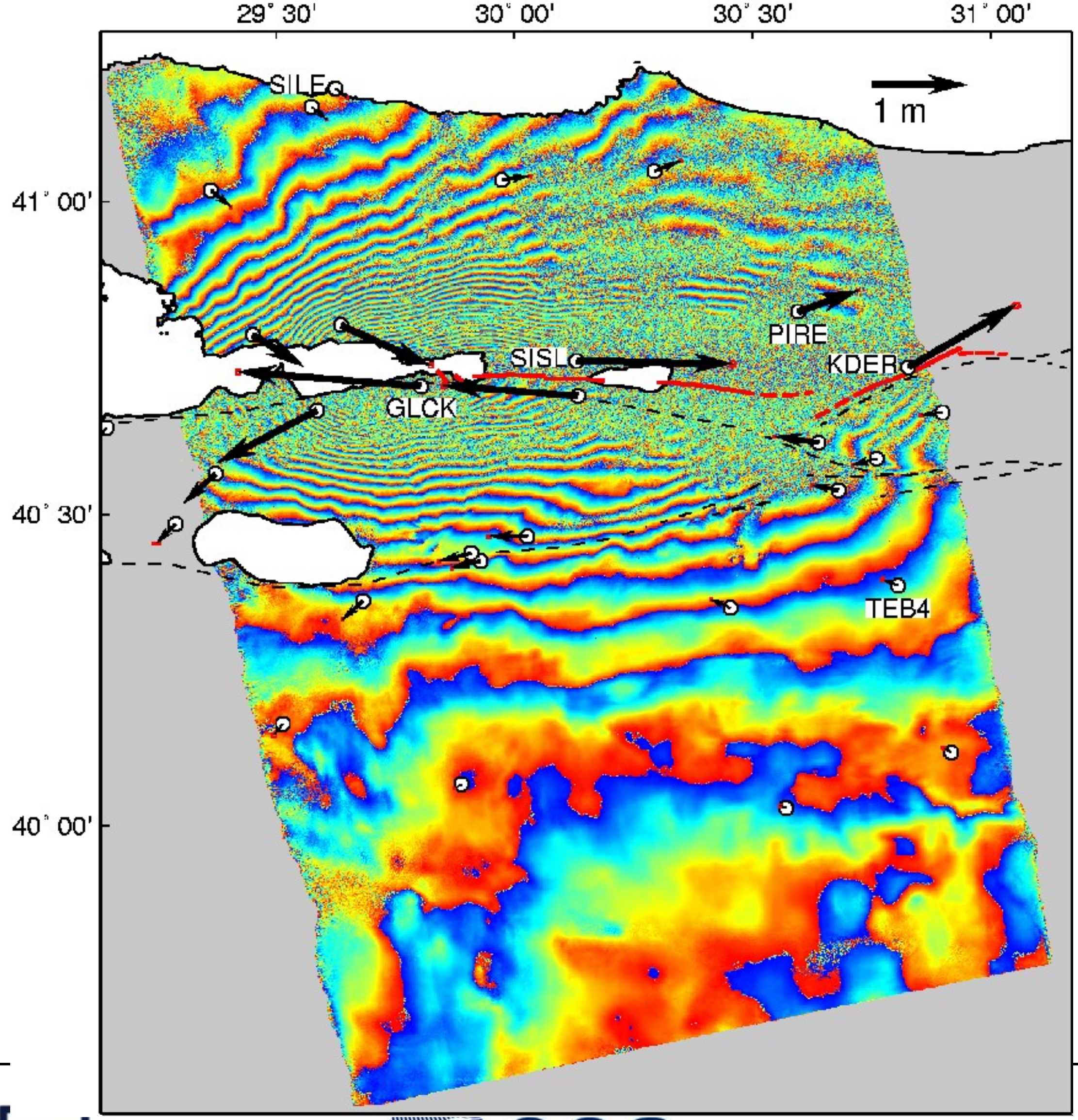
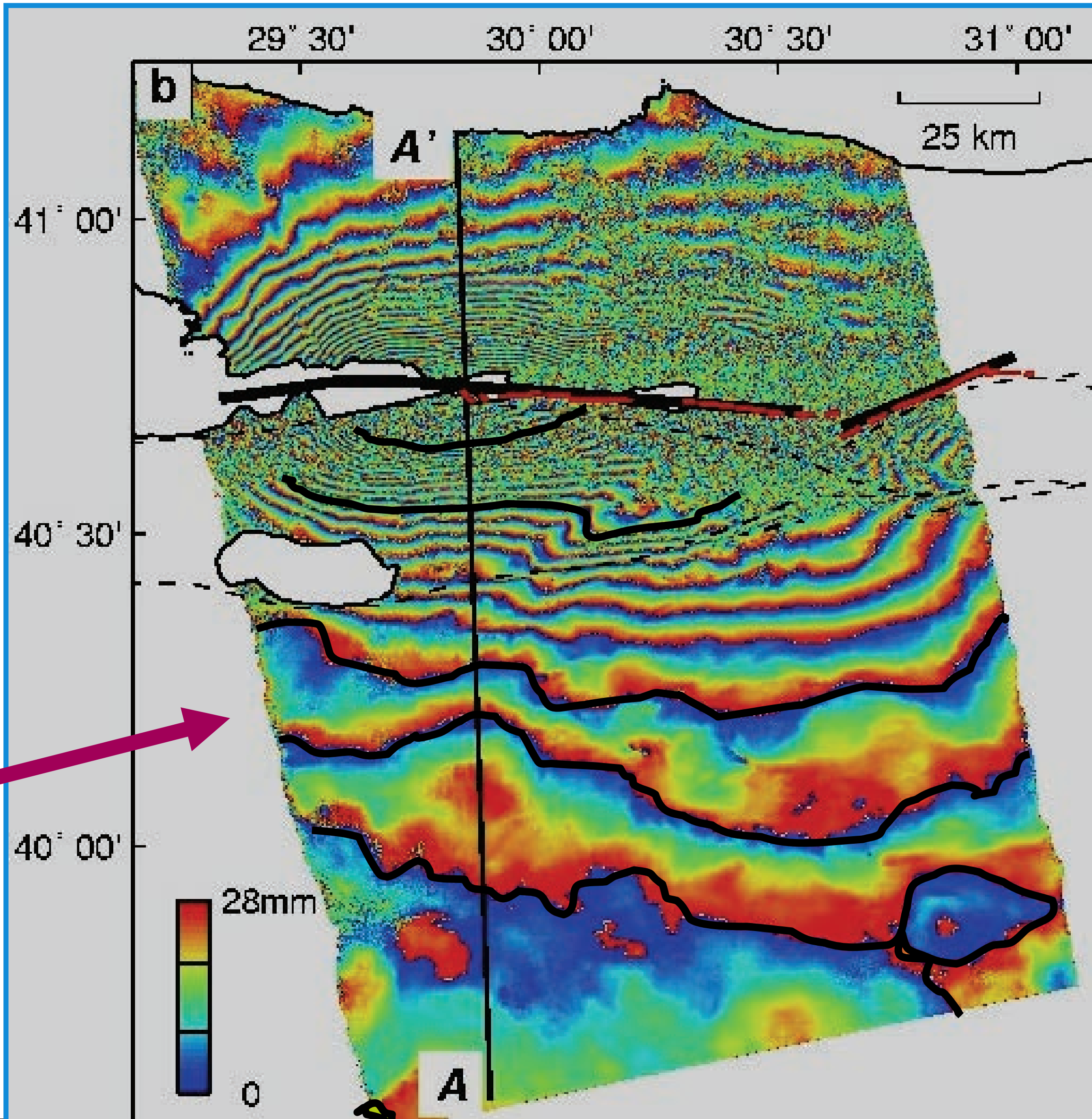
The 1999 Izmit earthquake displacement field





(-20) 567 mm range decrease

(-10) 283 mm range decrease

(-3) 85 mm range decrease

(-2) 57 mm range decrease

(-1) 28 mm range decrease

(0) 0 mm range change

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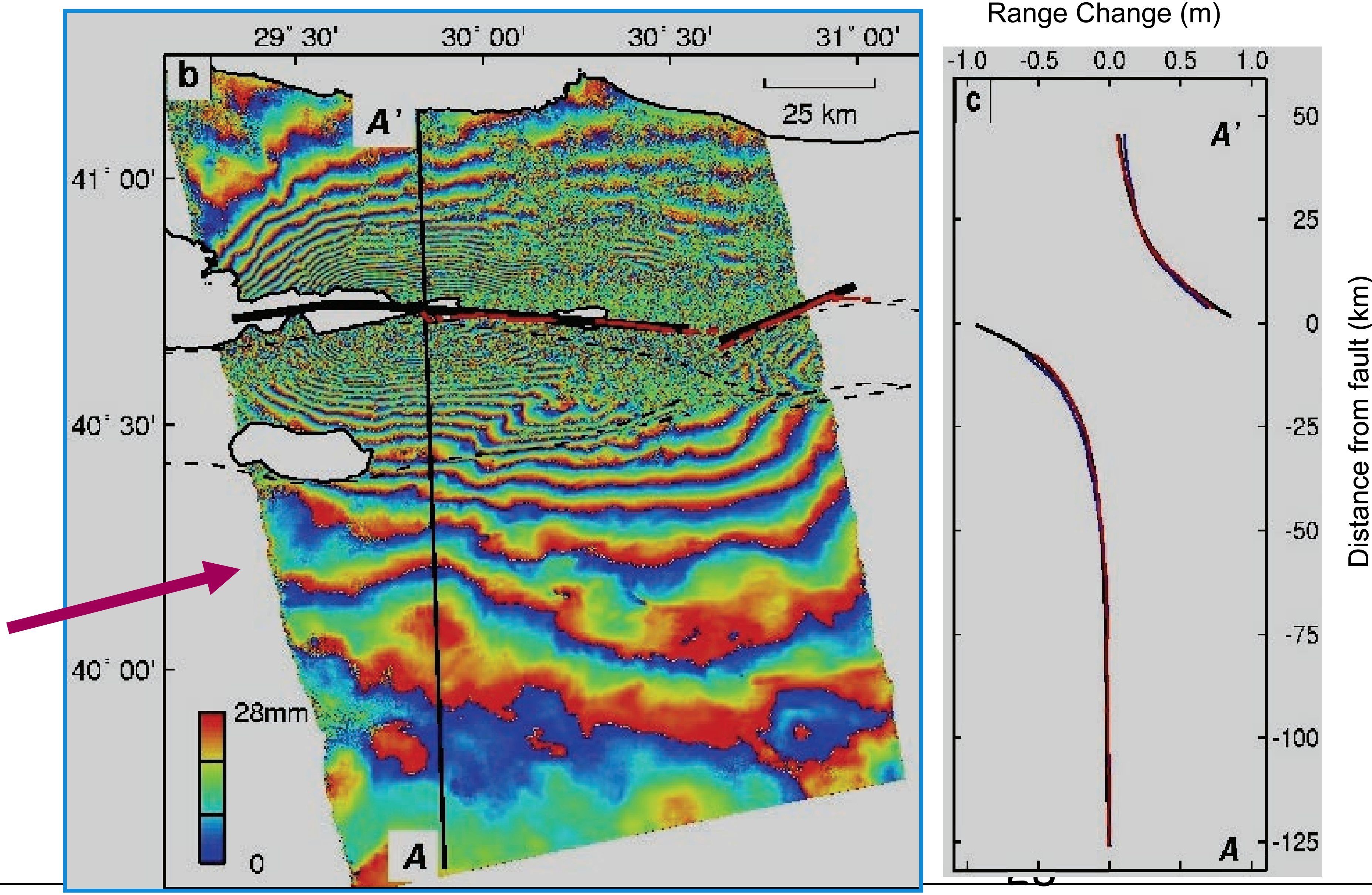
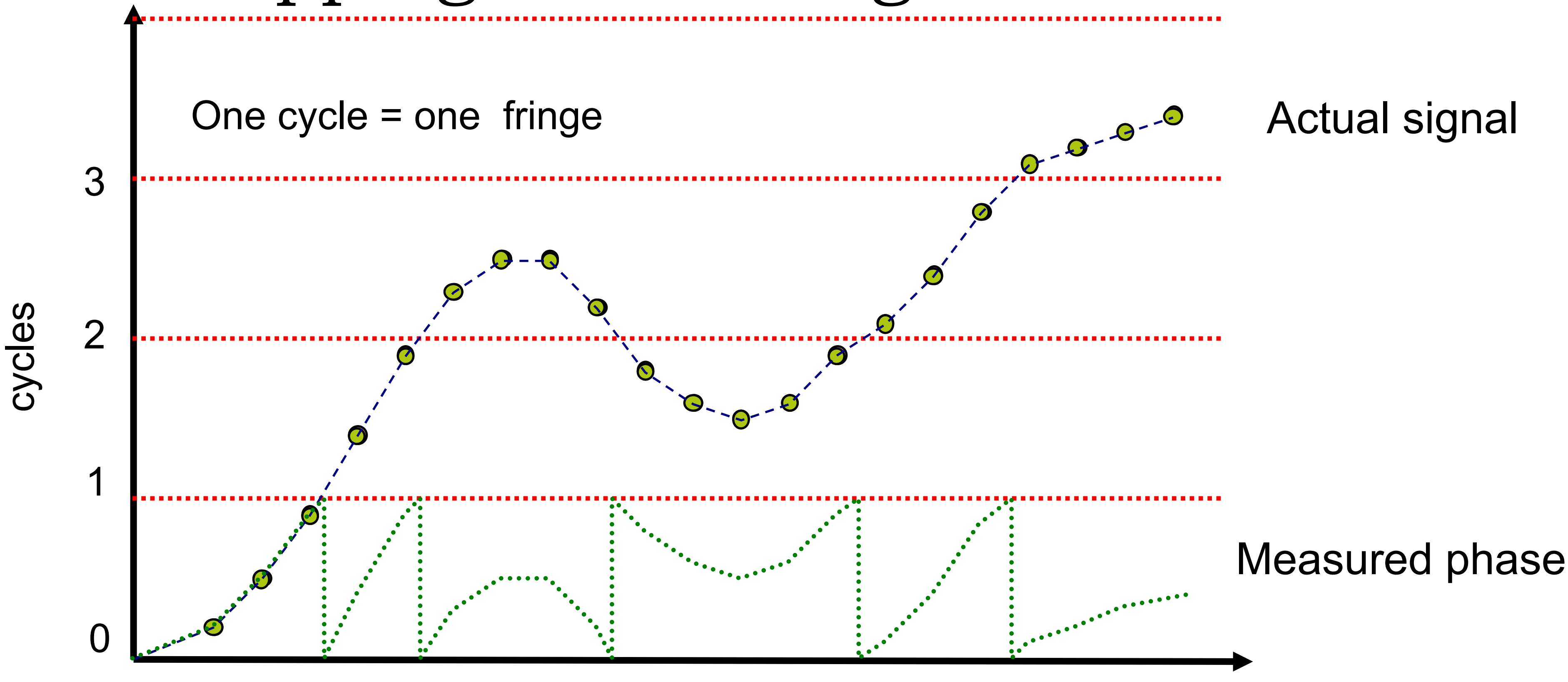


b
29° 30'
30° 00'
30° 30'
31° 00'
41° 00'
40° 30'
40° 00'
A'
A
25 km
28mm
0
Range Change (m)
c
-1.0
-0.5
0.0
0.5
1.0
50
25
0
-25
-50
-75
-100
-125
Distance from fault (km)

Unwrapping Phase Images



- Phase unwrapping is the reverse - finding the integer *shift* values for each point.

General approach

- Strictly: phase unwrapping is ill-posed problem (not possible to obtain unique solution)
- Heuristic approach: Assume true (unwrapped) phase values of neighboring pixels lie within one-half cycle

One-dimensional example

Assumption: phase differences between adjacent samples are element of [-0.5, 0.5) cycles

Wrapped data (in phase cycles):

$\psi(x)$: 0.5 0.75 0.0 0.25 0.5 0.75 0.0 0.25

Gradient:

0.25 -0.75 0.25 0.25 0.25 -0.75 0.25

Add integer to make phase difference between +/- half a cycle

0.25 +1 0.25 0.25 0.25 0.25 +1 0.25 0.25

Integration:

0.5 0.75 1.0 1.25 1.5 1.75 2.0 2.25

Another possible solution that violates our assumption:

-0.5 -0.25 1.0 1.25 1.5 1.75 2.0 2.25

+1.25 !

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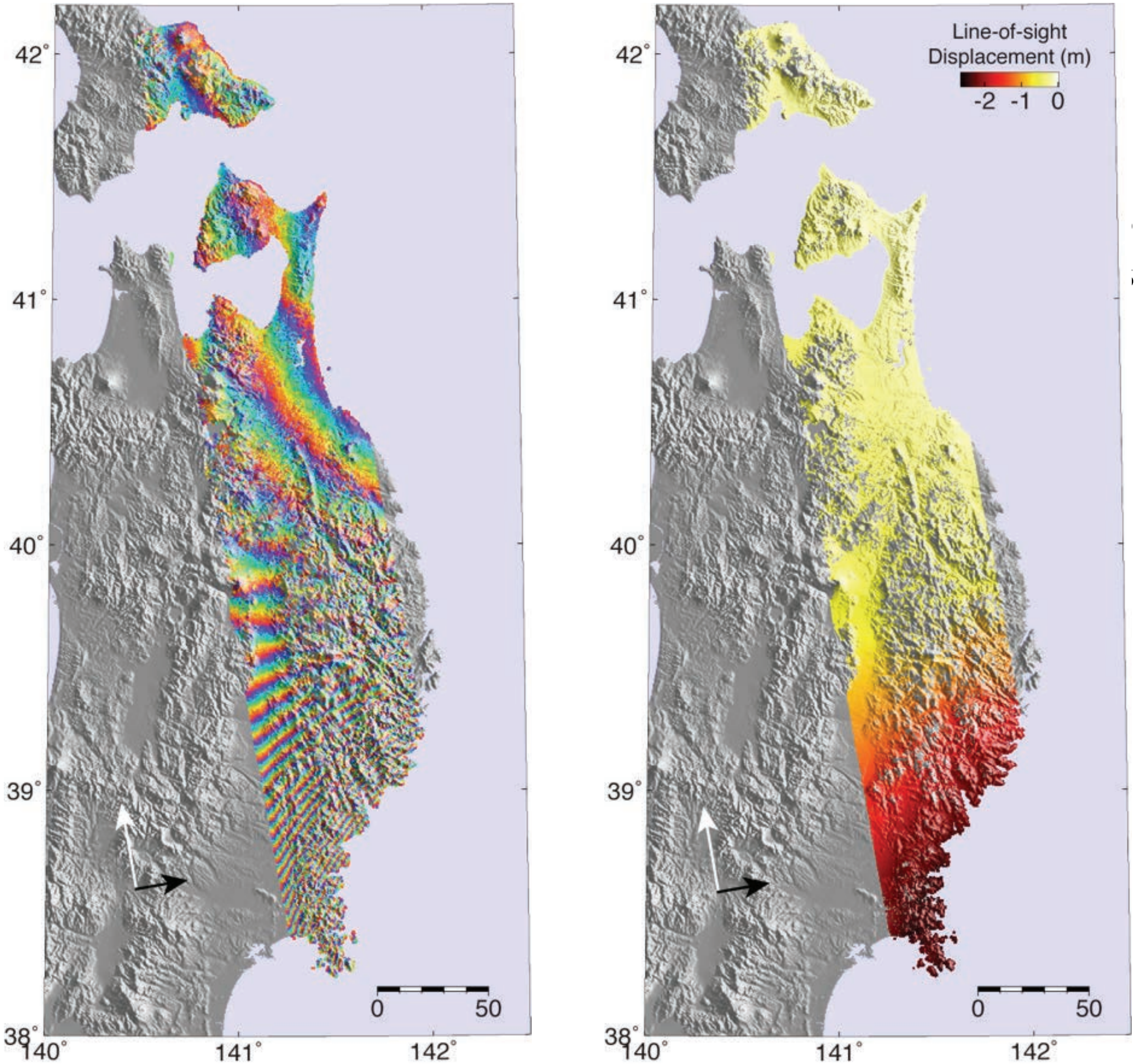
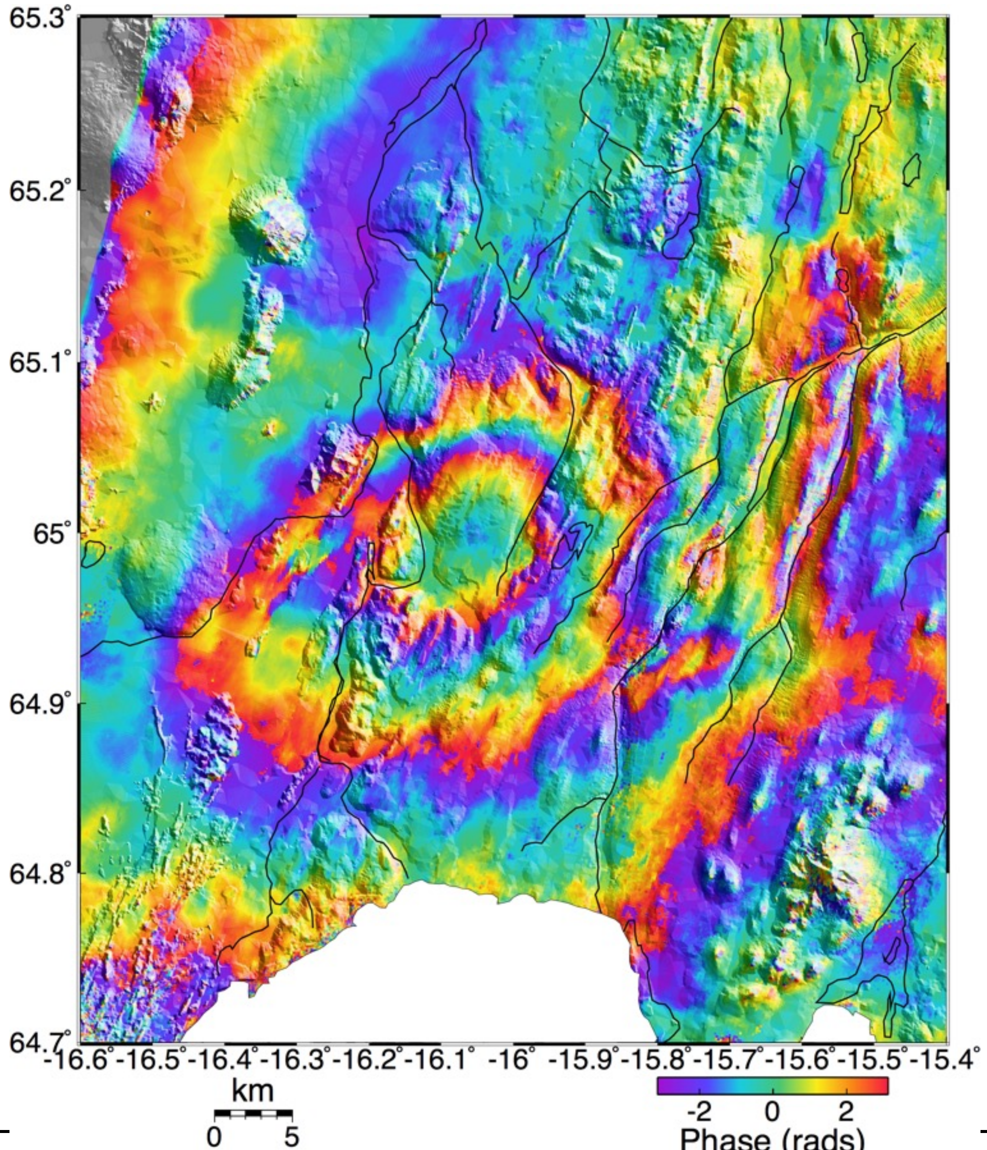
2011 Tohoku Earthquake

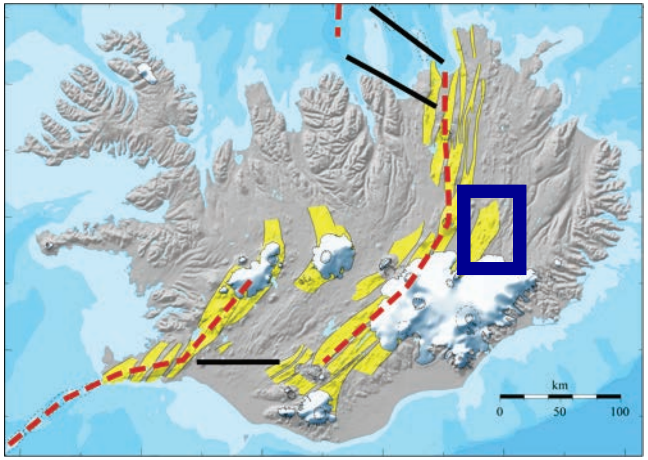


cm (L Band)
towards

Integrated phase

Dike Intrusion in N. Iceland





Each color fringe is 28 mm displacement in direction of satellite

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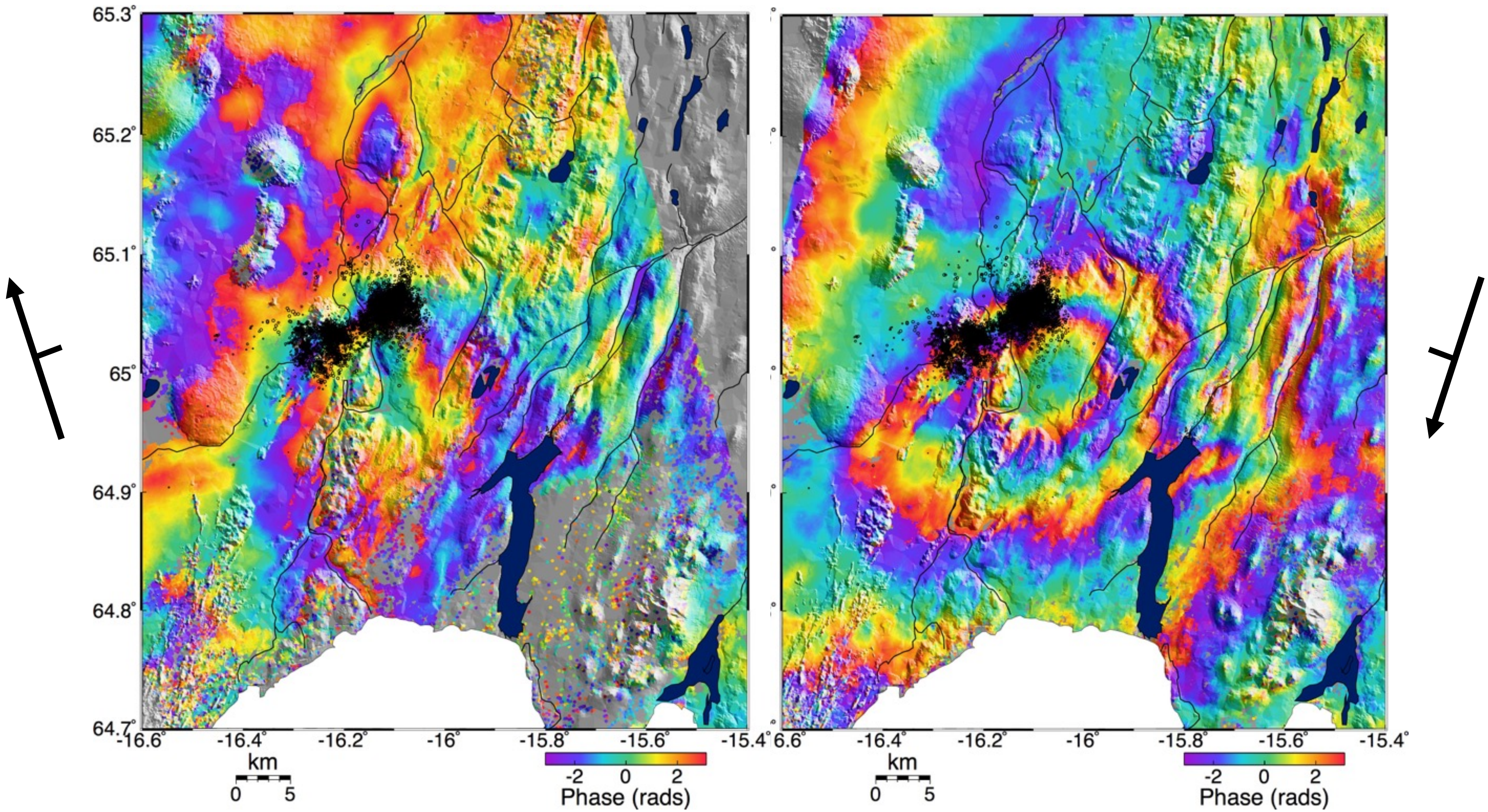
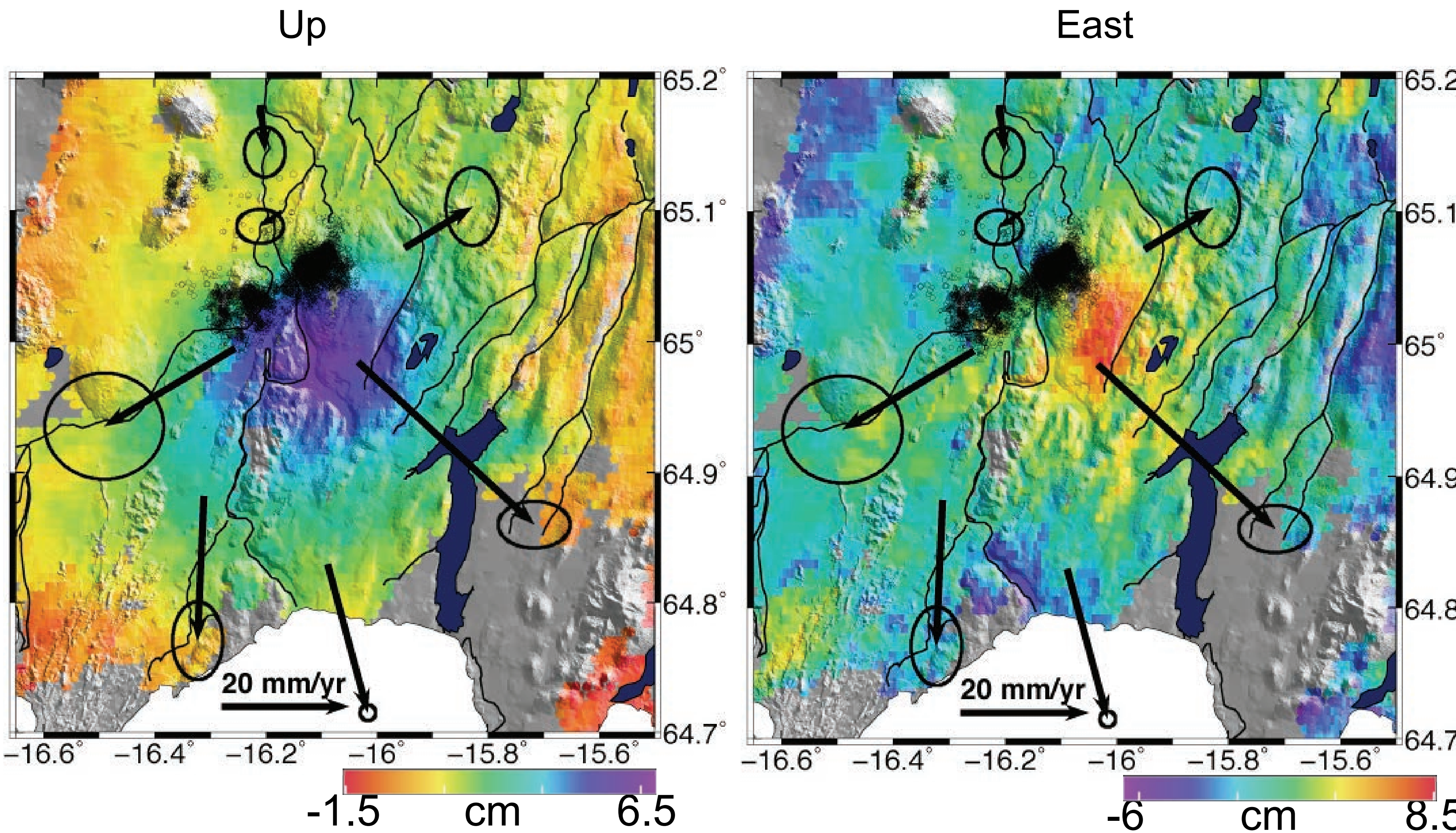
Two Side-looking Geometries



Decomposed InSAR + GPS



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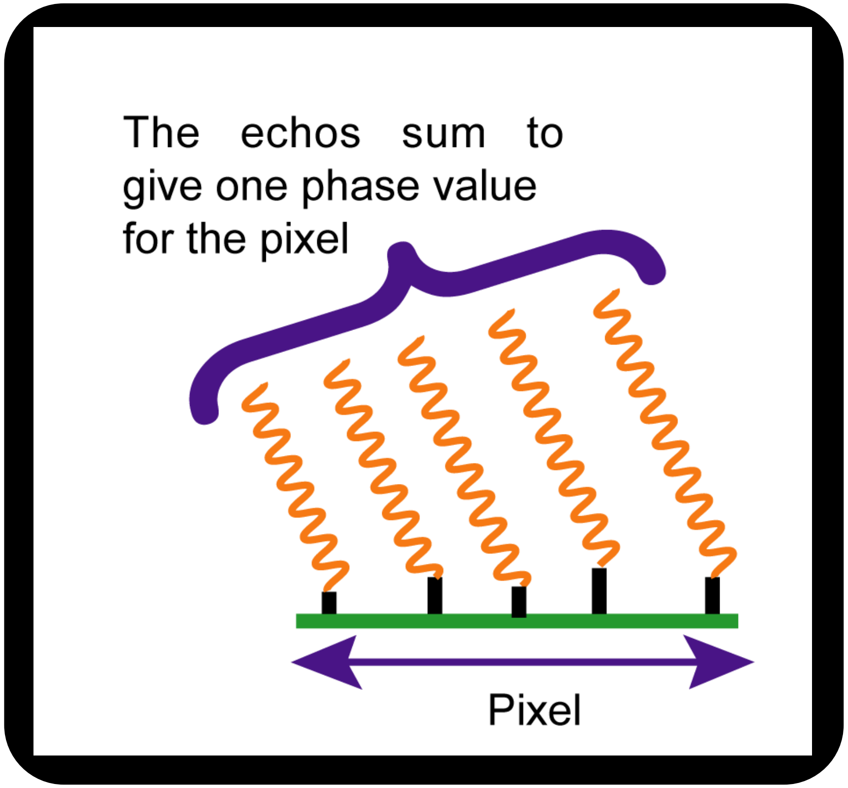
Main condition for interferometry

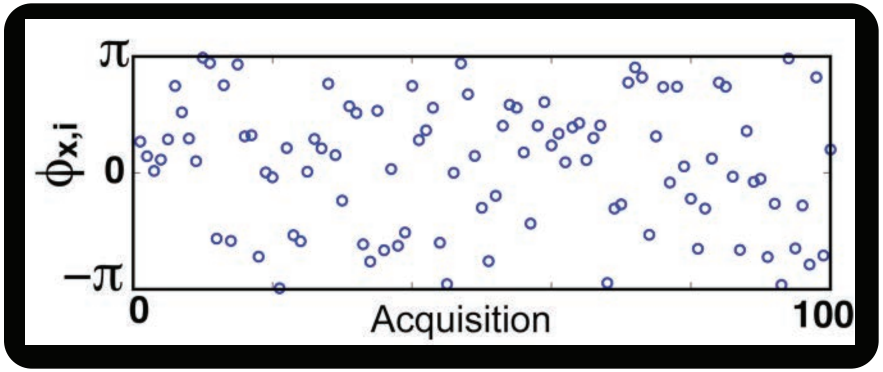
Coherence!

Cause of coherence loss



Distributed scatterer pixel

If scatterers move with respect to each other, the phase sum changes



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Coherence (Complex Correlation)

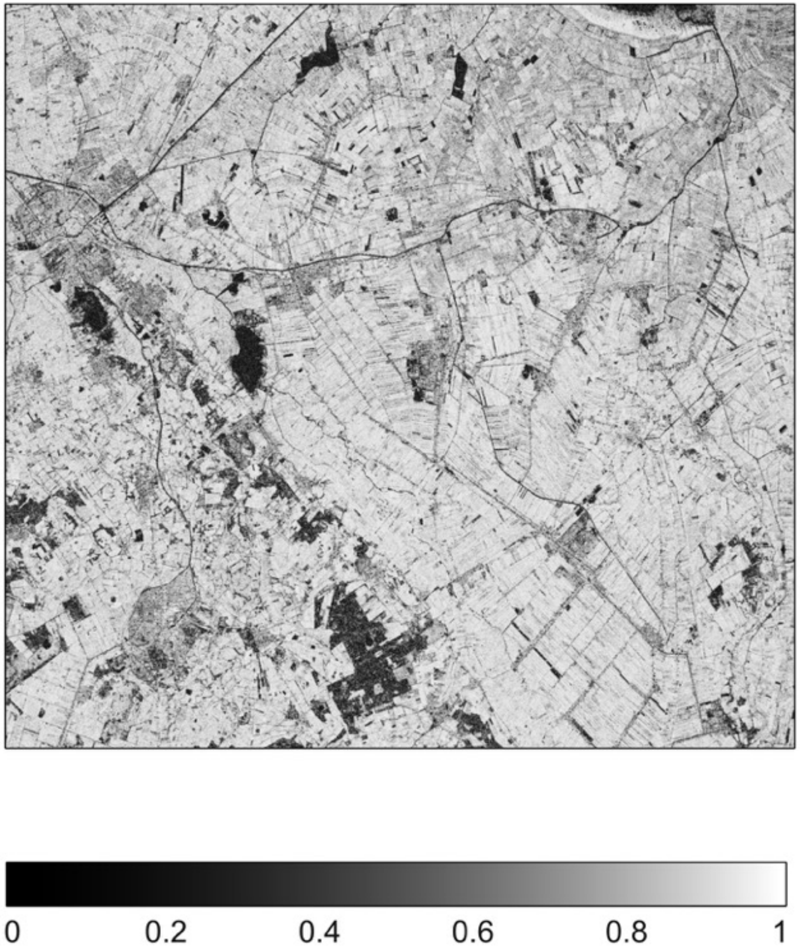
Estimation of coherence magnitude from neighbouring pixels:

$$|\hat{\gamma}| = \frac{\left| \sum_{n=1}^{N} y_1^{(n)} y_2^{(n)} \cdot e^{-j\phi^{(n)}} \right|}{\sqrt{\sum_{n=1}^{N} |y_1^{(n)}|^2 \sum_{n=1}^{N} |y_2^{(n)}|^2}}$$

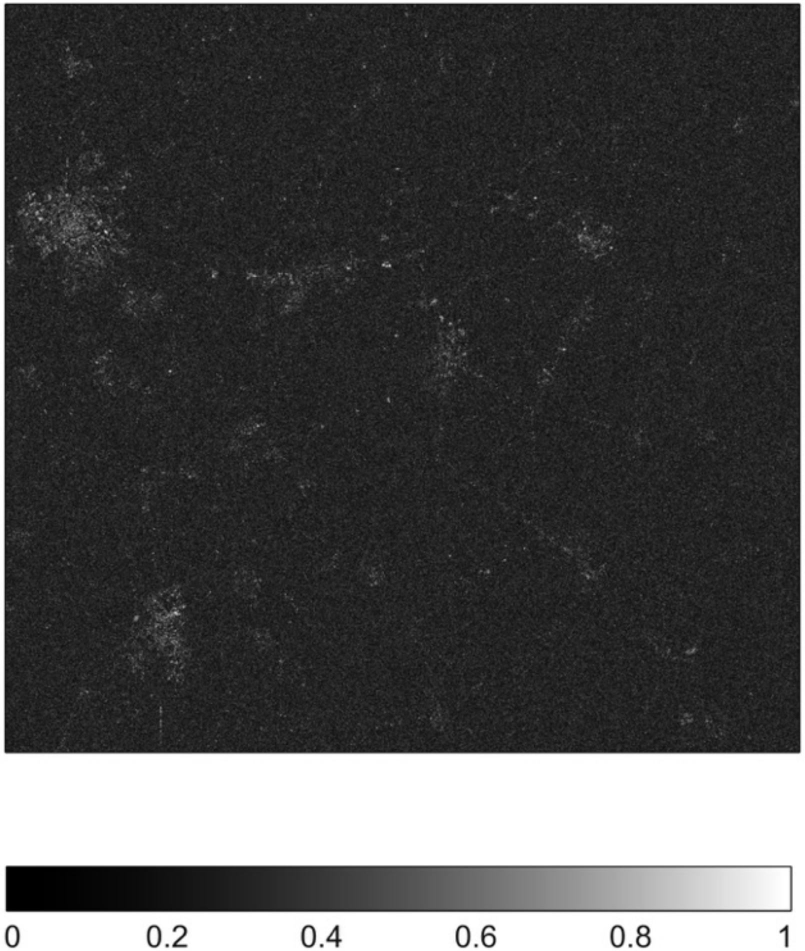
Coherence magnitude is a measure of the correlation (values 0 – 1)

Coherence loss as function of time

1 day interval



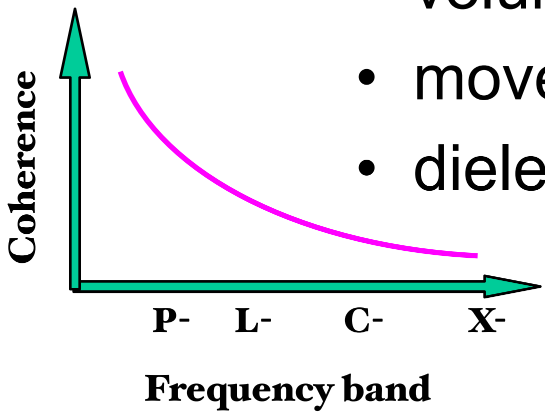
3.5 year interval

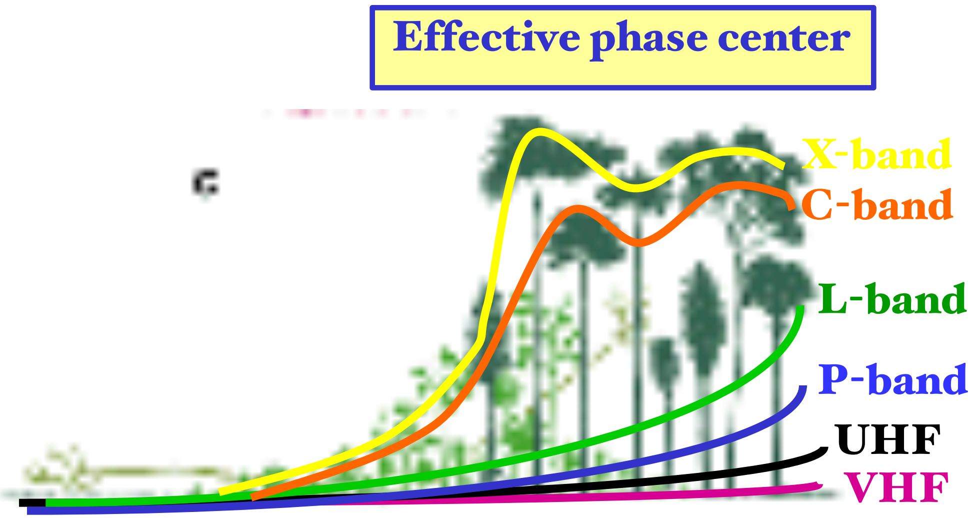


Coherence and wavelength

Loss of correlation is due to:

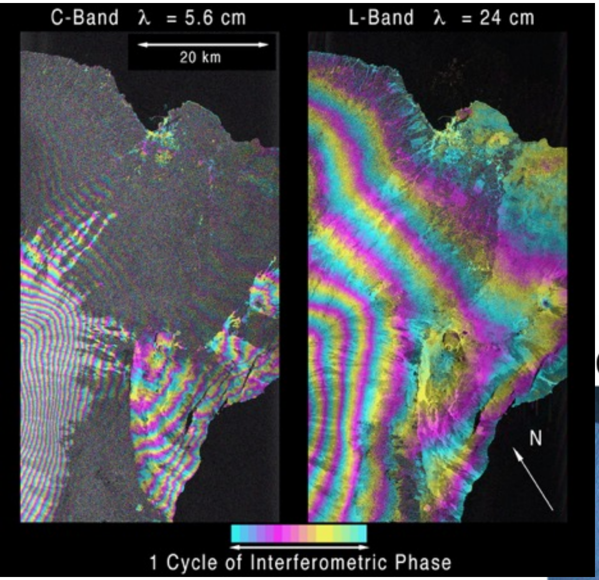
- volume of vegetation
- movement of vegetation
- dielectric change (moisture)



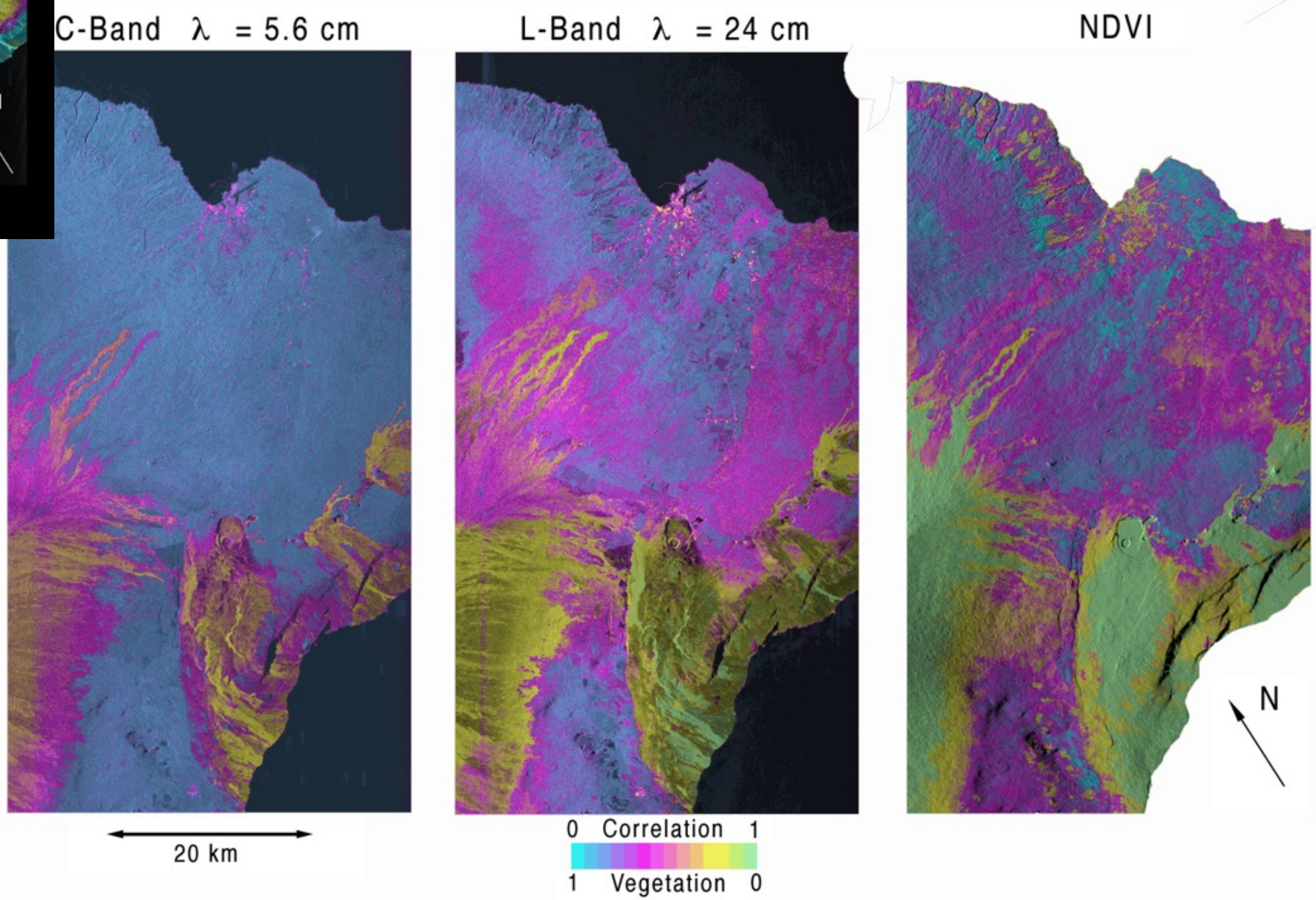


Source: H.Zebker

Coherence as function of wavelength



Results SIR-C mission,
Simultaneous C and L band
ΔT=6 months



Source: H.Zebker

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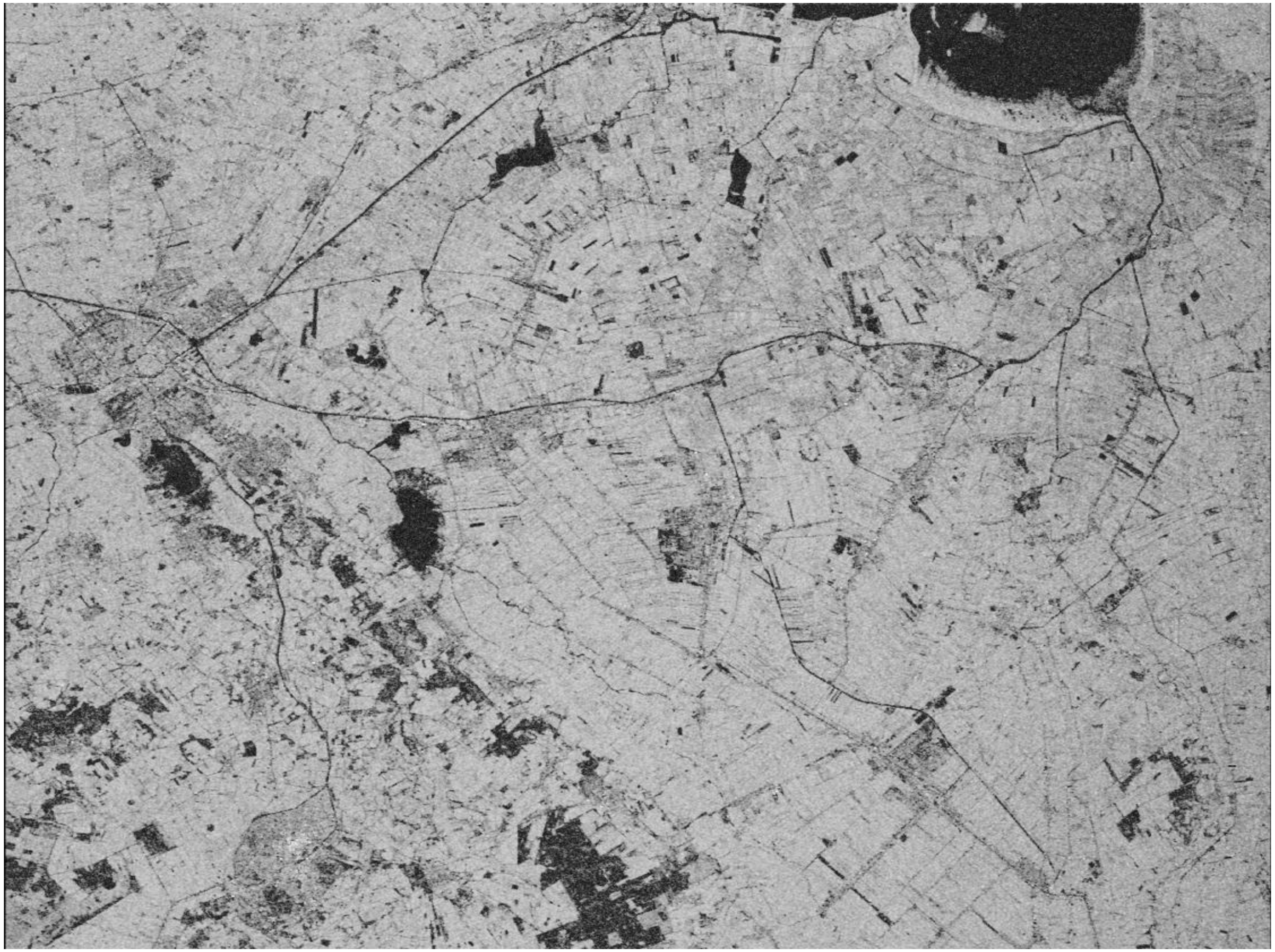
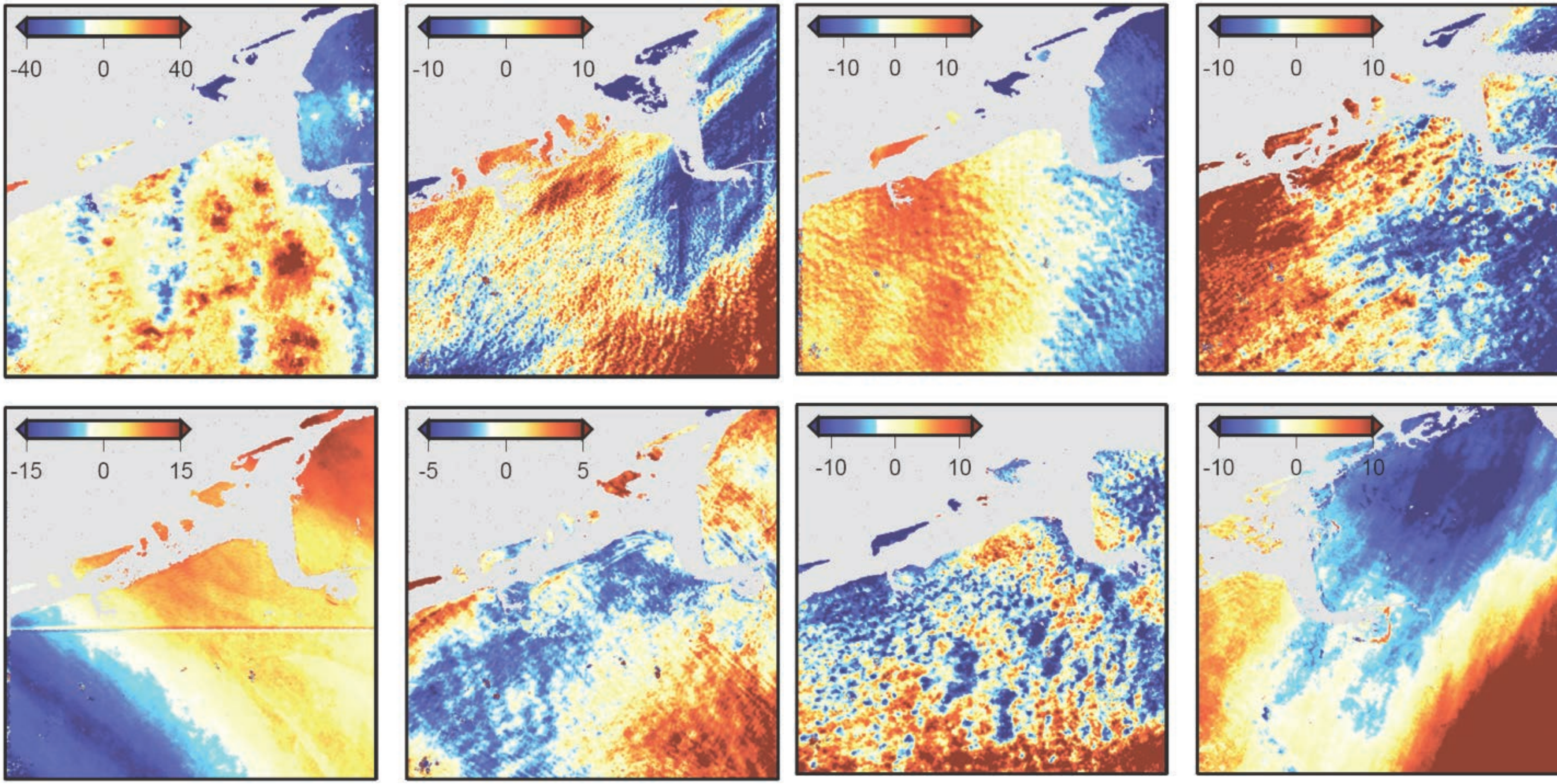
Water detection using coherence



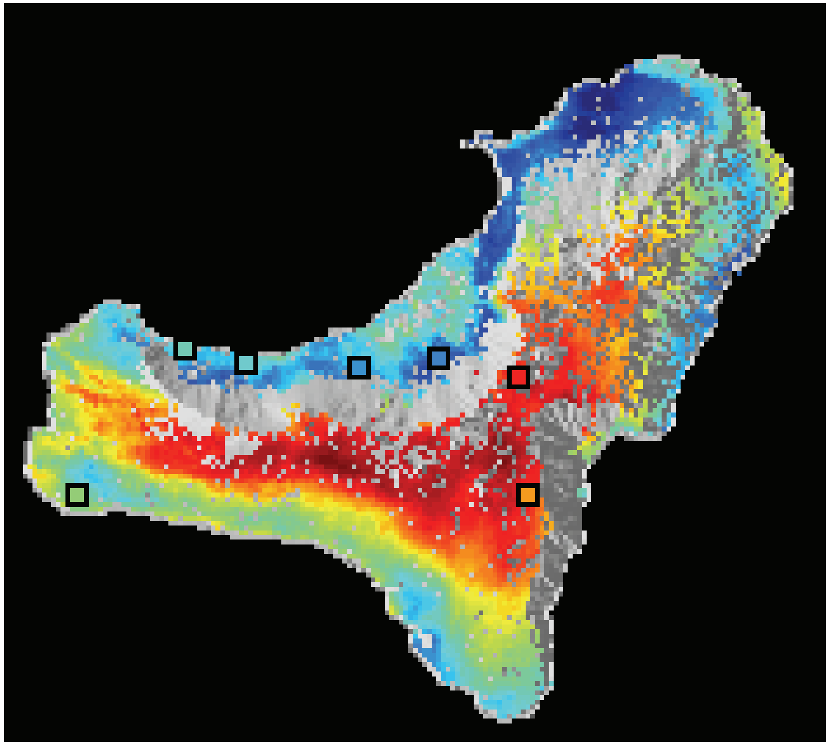
• Water has zero coherence over short times

Tropospheric variability

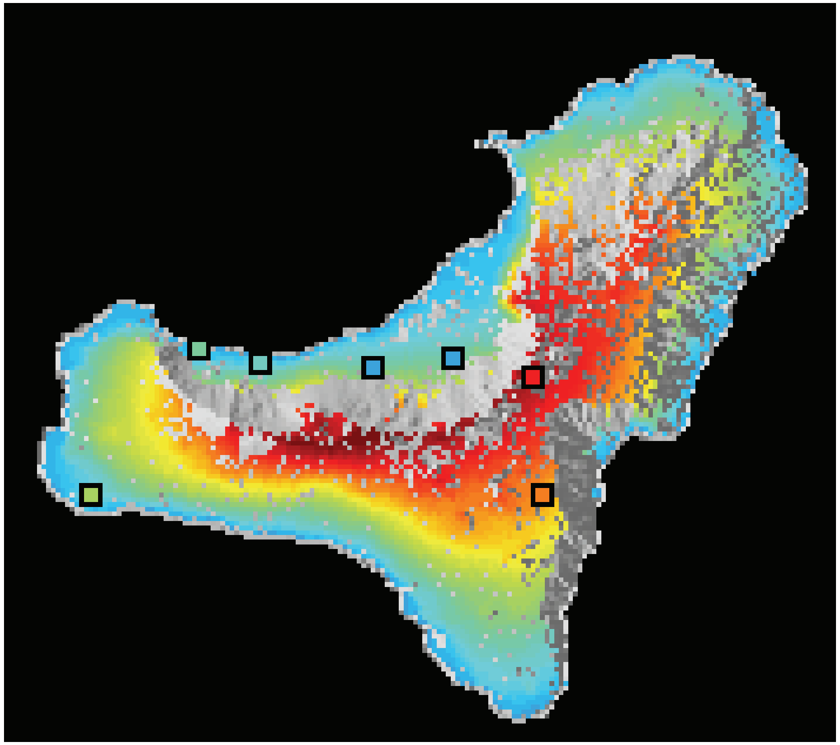


One day interferograms in Netherlands show change in phase delay through troposphere. Mostly due to water vapour distribution.

Topography-correlated tropospheric phase delay



Interferogram (El Hierro Island)



Elevation (scaled to match phase)

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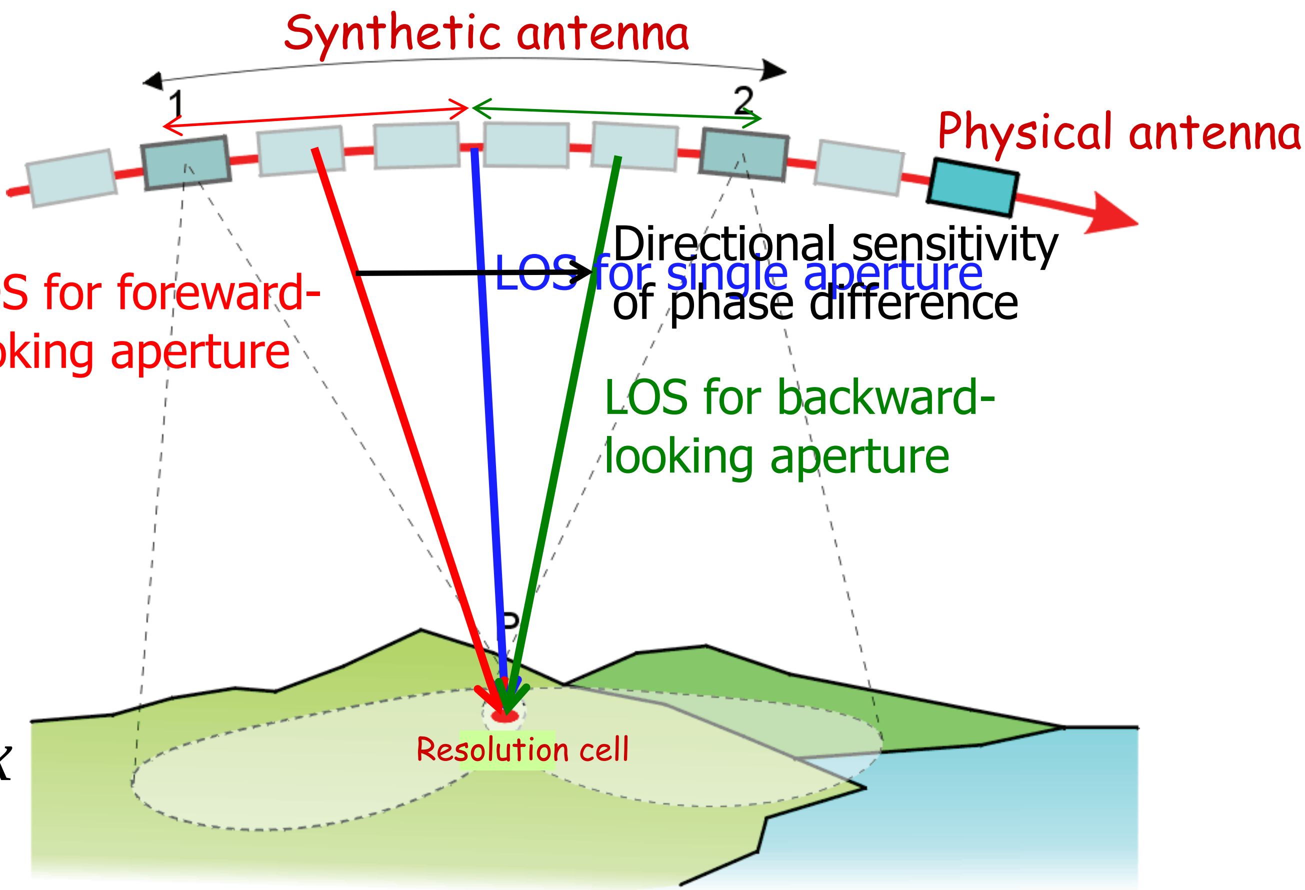
Multiple Aperture InSAR
a.k.a Spectral Diversity



$$\phi_{MAI} = \frac{2\pi}{l} x$$

where l is antenna length and x is azimuthal displacement

Sentinel-1 TOPS issues

(Terrain Observation with Progressive Scans)

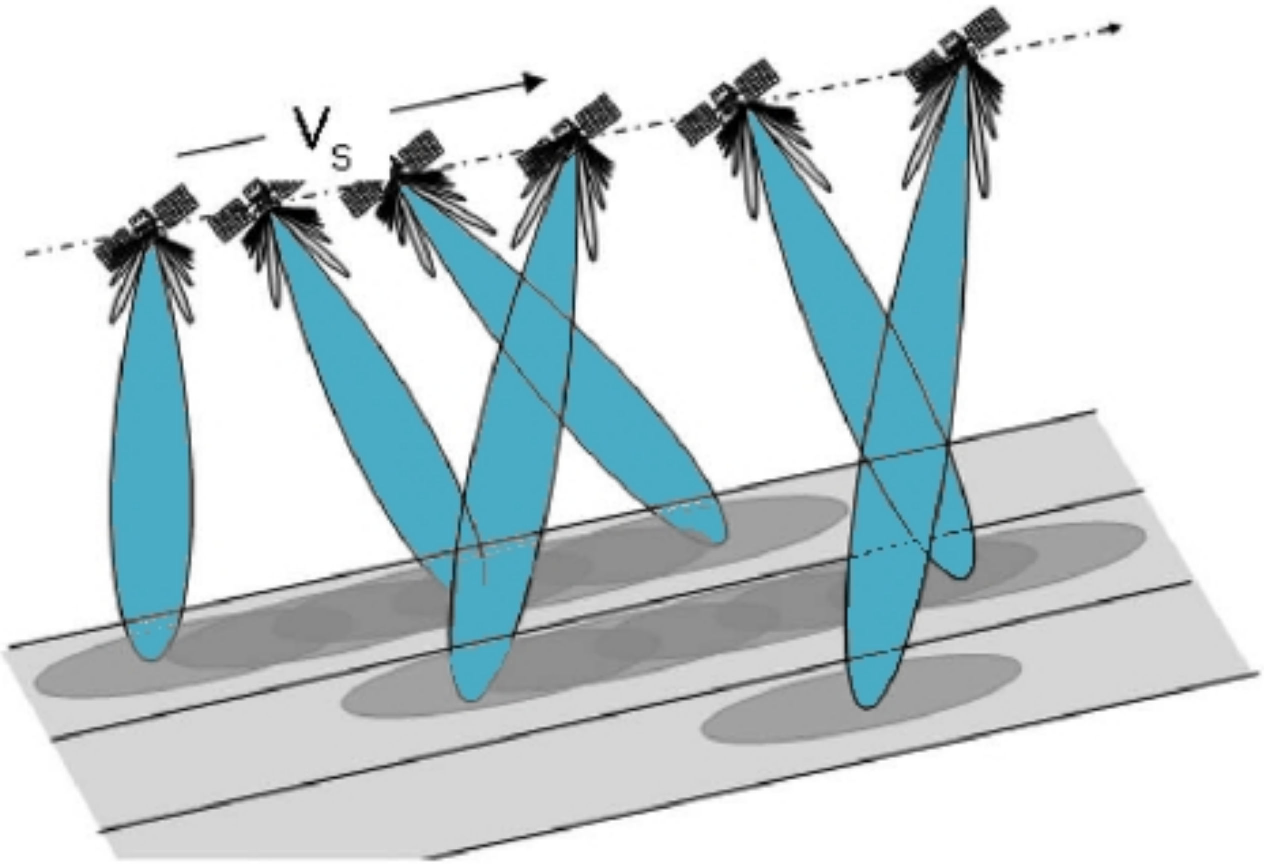
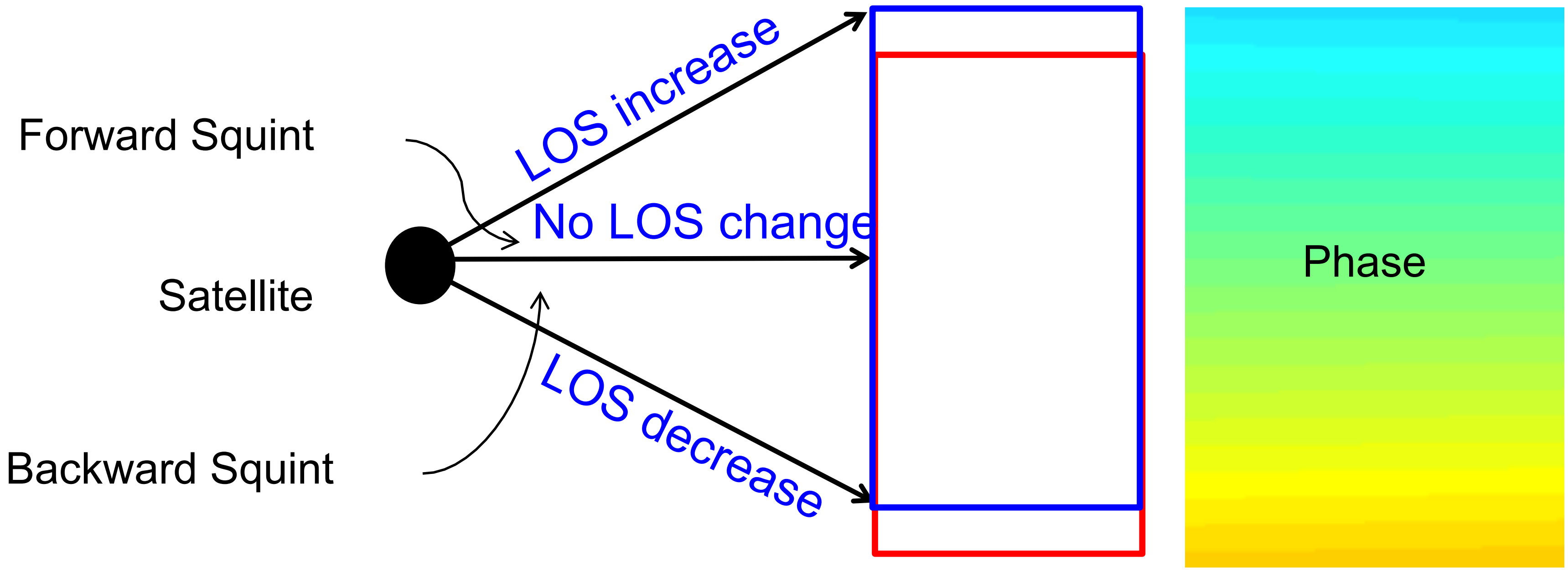
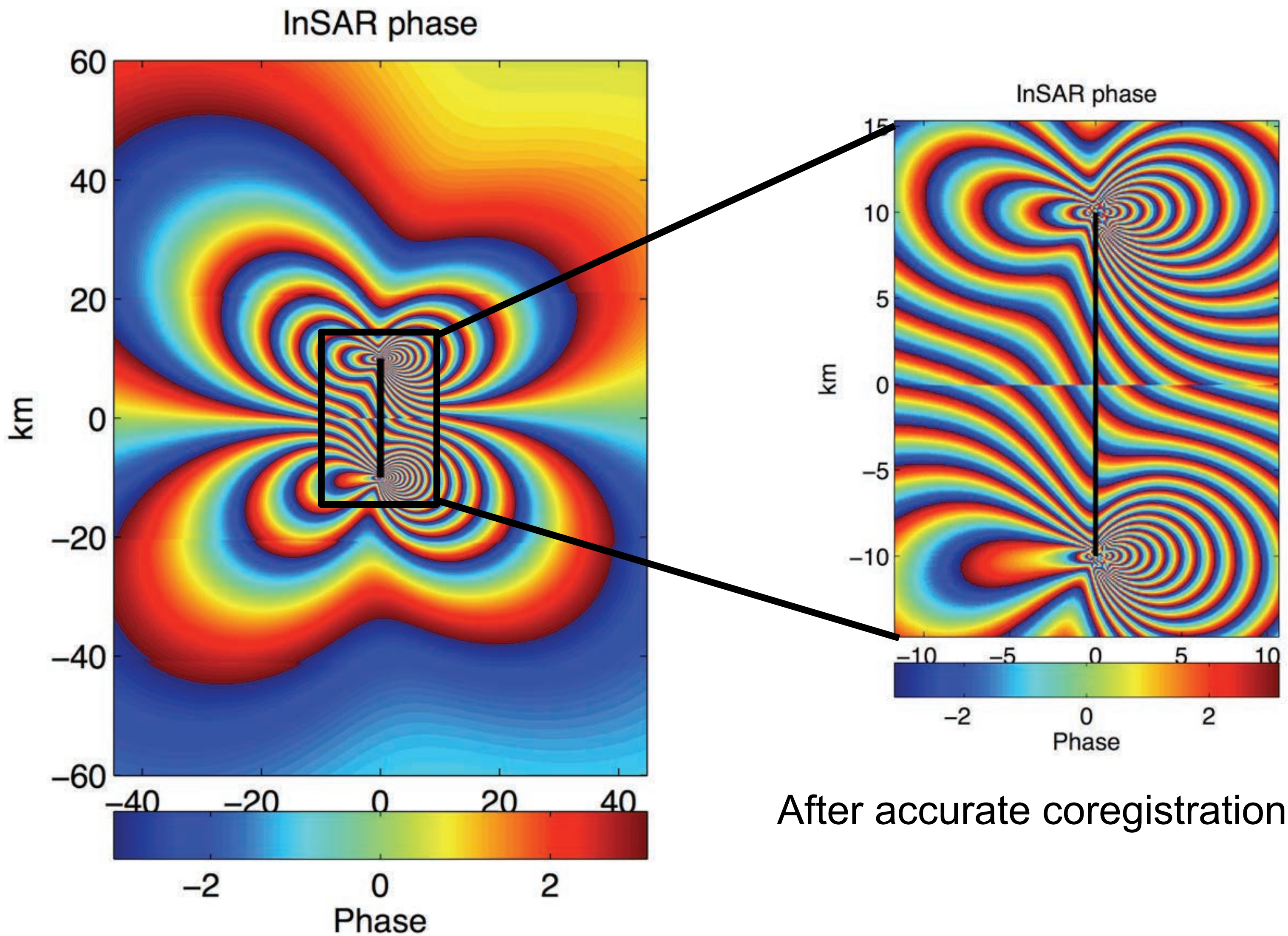


Image: ESA

Effect of along-track displacement

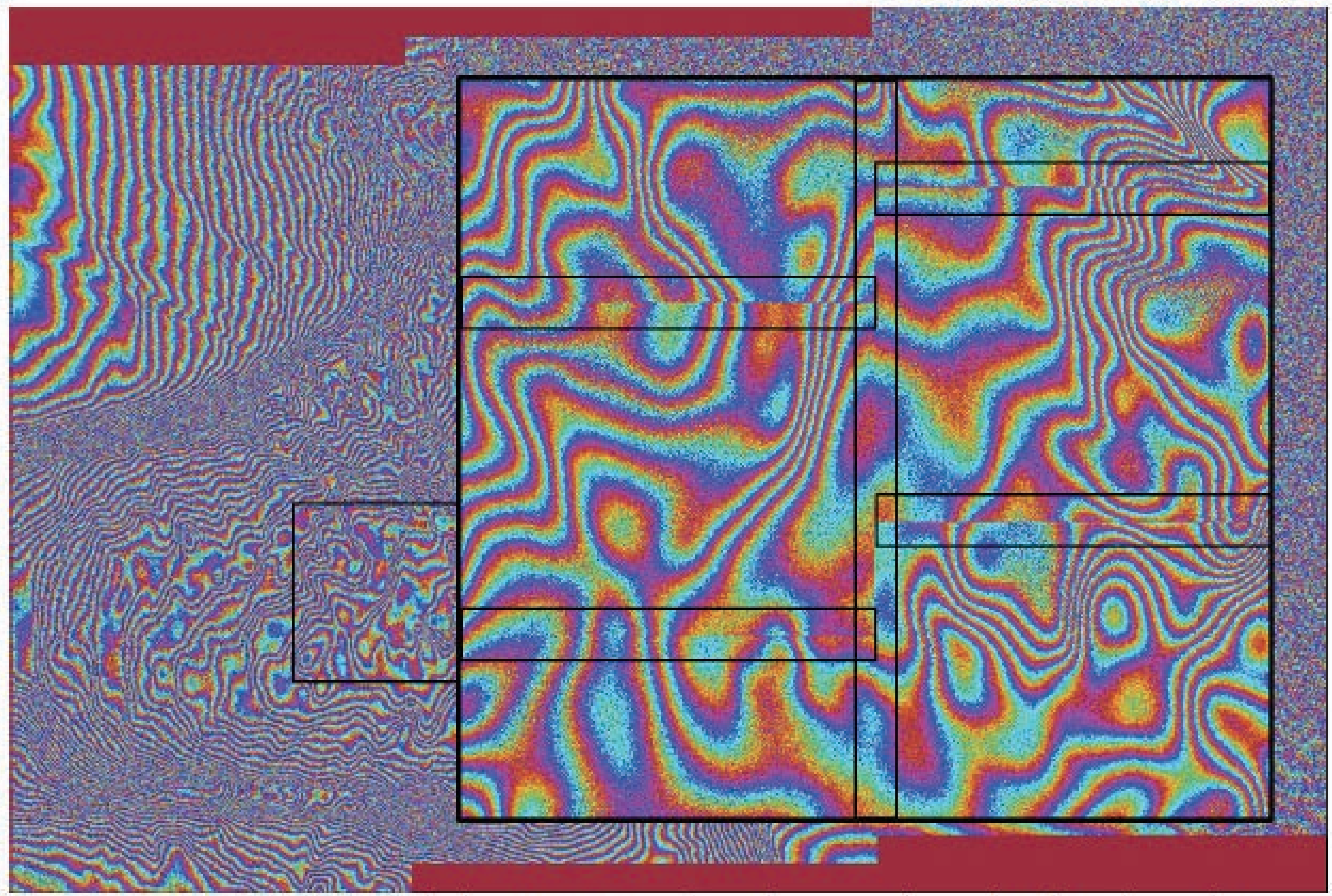


Sentinel-1 simulated earthquake



After accurate coregistration

Pine Island Glacier



Prats-Iraola et al, 2014

Burst overlaps

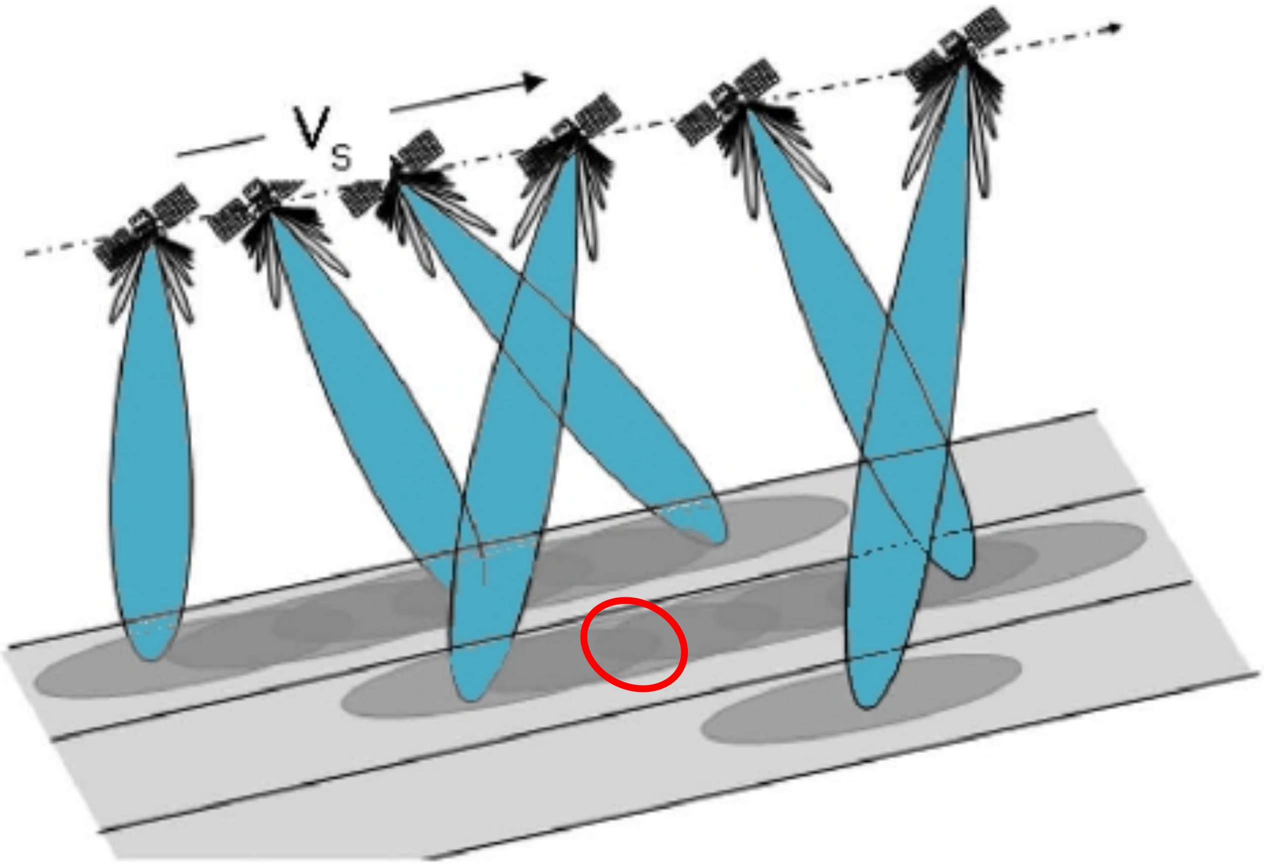
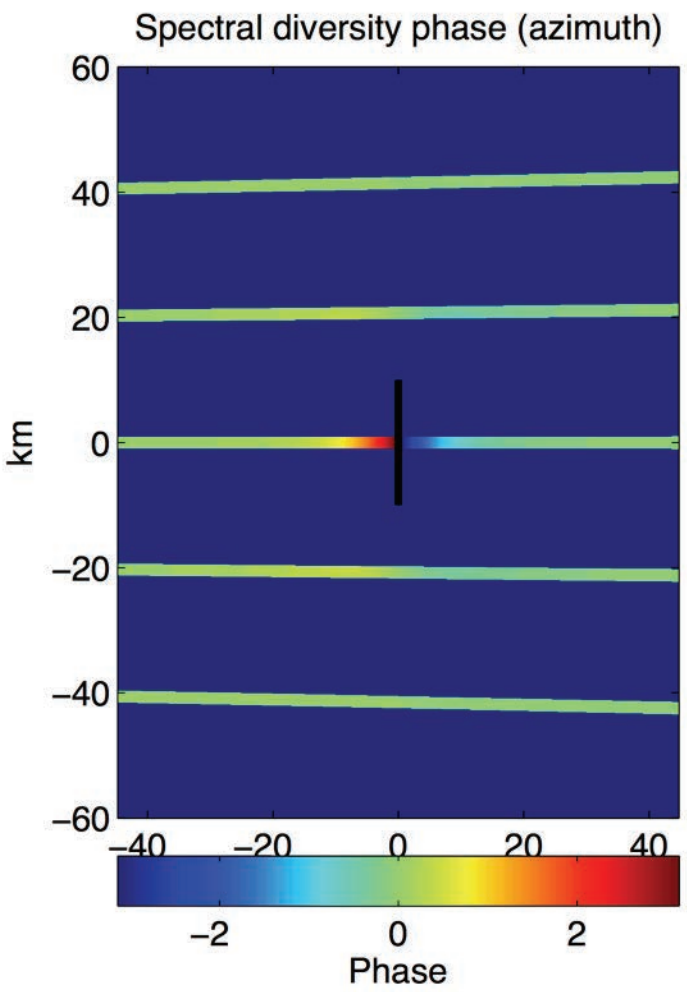


Image: ESA

Multiple aperture InSAR on burst overlaps



~1.7 m azimuth displacement for one phase cycle

Summary

- InSAR is a powerful tool because it can measure topography and deformation with high spatial sampling, without even going there
- Sentinel-1 represents a new era as the first operational mission
- Capability will continue to improve as more missions come online