Applications of InSAR for crustal deformation monitoring in Iceland

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University of Iceland

Outline

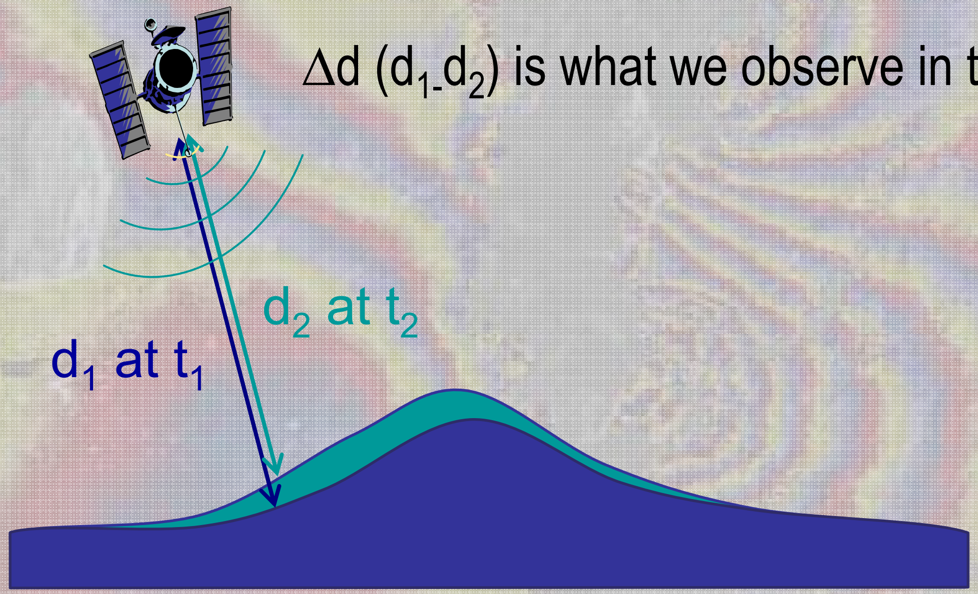
- Basic InSAR theory
  - What is an InSAR image?
  - Acquisition of images
  - Geometrical limitations
  - Data error sources

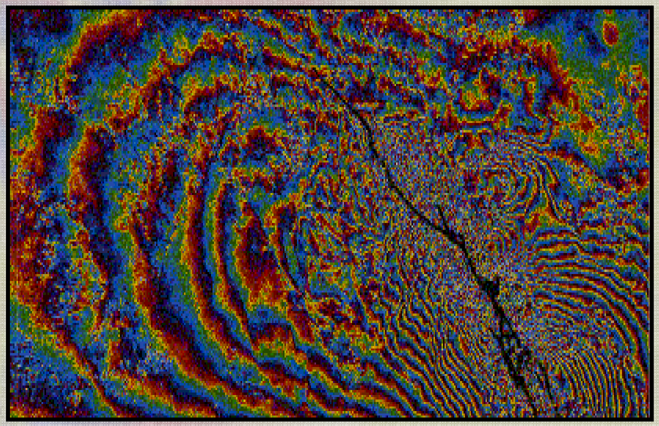
- Application examples from Iceland
  - Regional
  - Local

Basic InSAR theory

- InSAR image
  - An image displaying ground deformation

Δd (d_1-d_2) is what we observe in the interferogram as color fringes

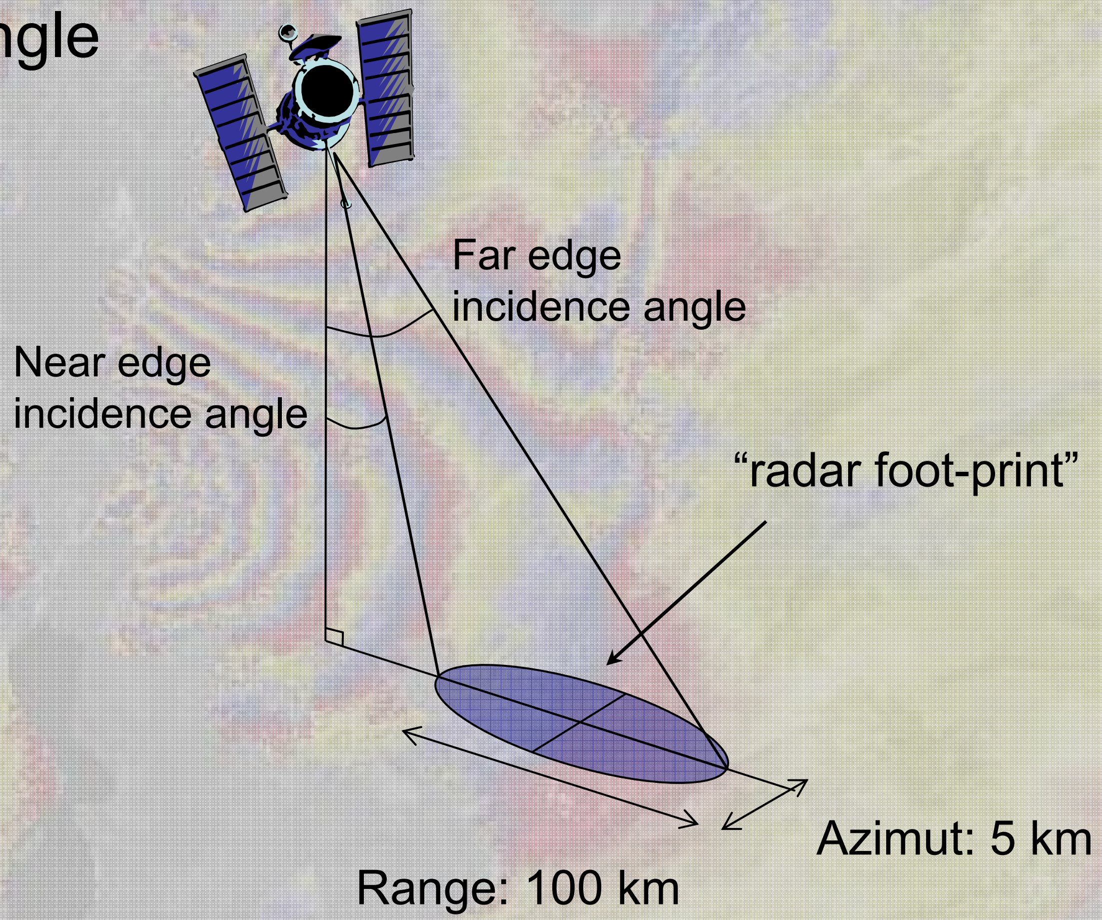




- Look angle
- Wavelengths and frequencies
- The SAR antenna

Basic InSAR theory

- InSAR image
  - Look angle



Basic InSAR theory

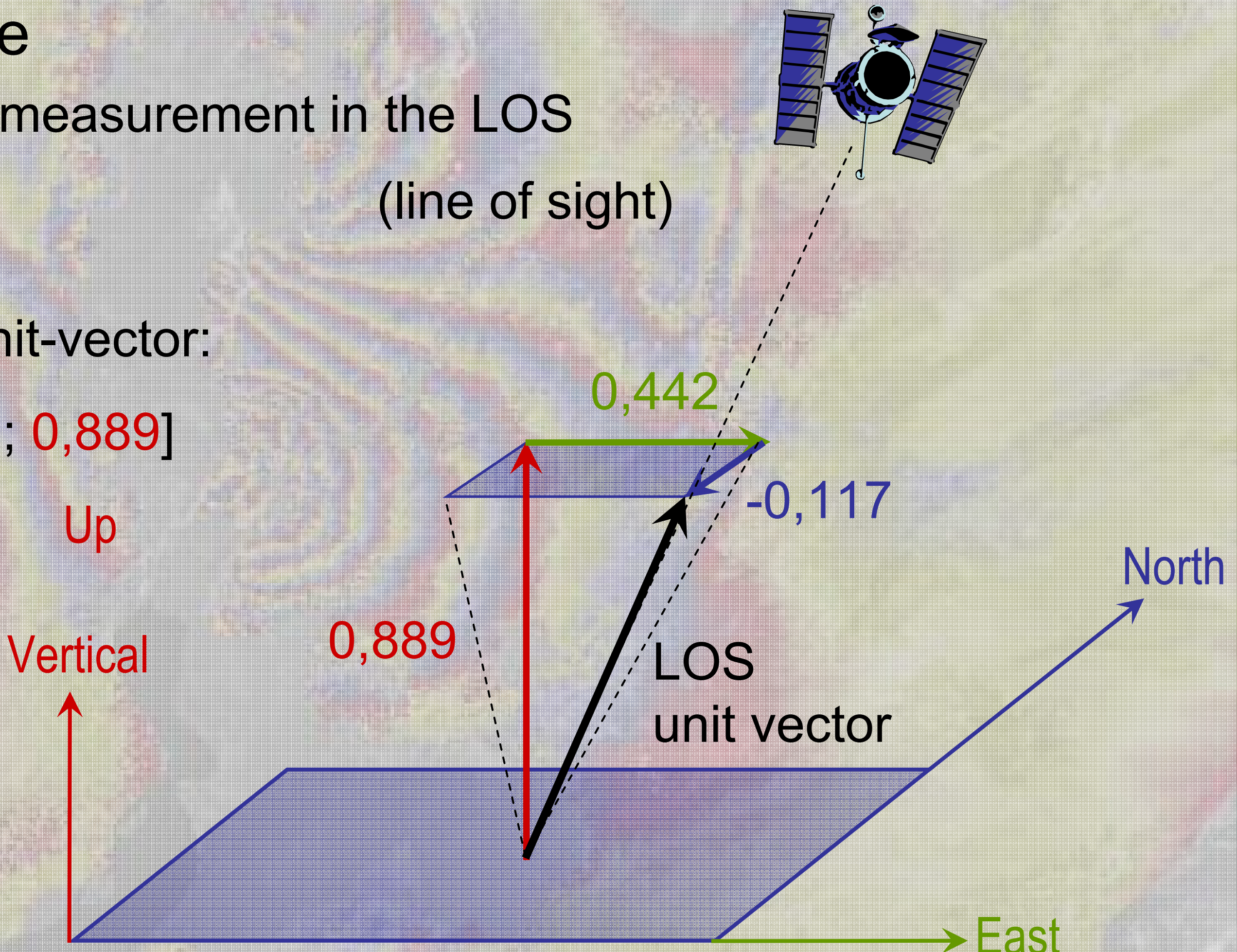
- InSAR image
  - Look angle
    - 1-D measurement in the LOS

      (line of sight)

Example of unit-vector:

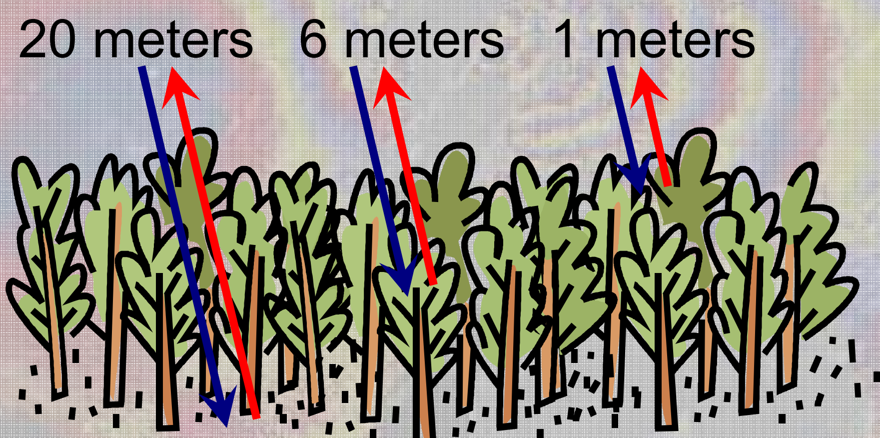
[0,442; -0,117; 0,889]

East North Up

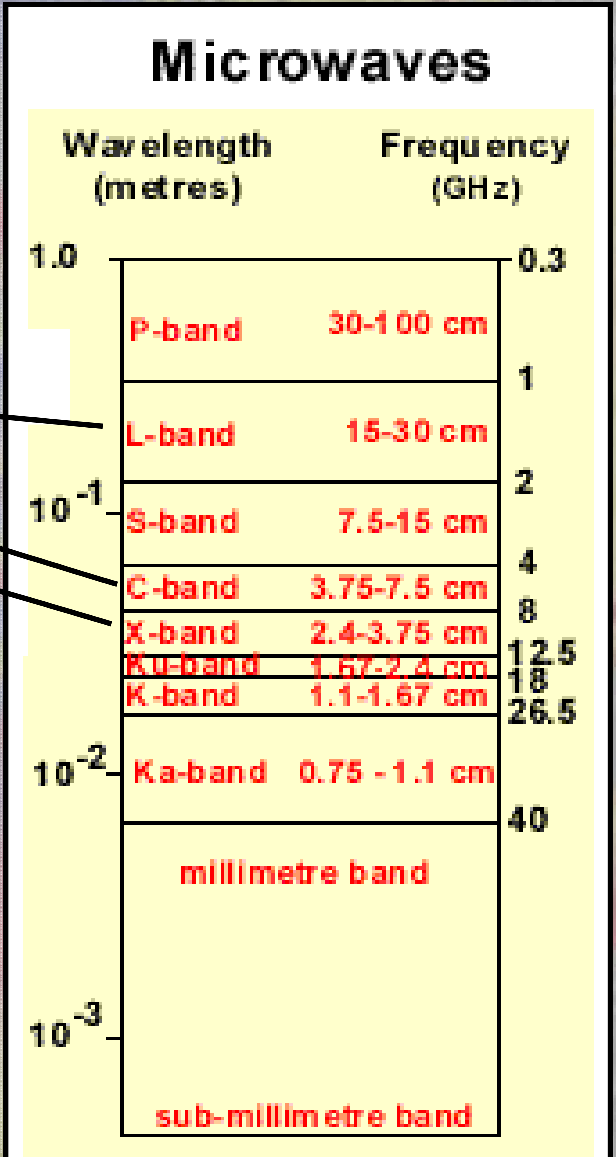


Basic InSAR theory

- InSAR image
  - Look angle
  - Wavelengths and frequencies

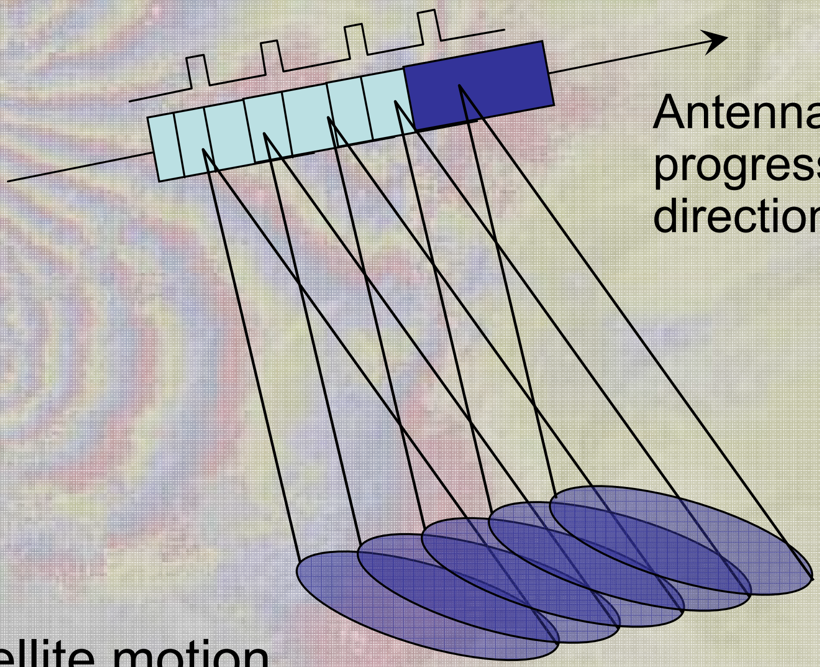


ERS images are C-band



Basic InSAR theory

- InSAR image
  - Look angle
  - Wavelengths and frequencies
  - The SAR antenna

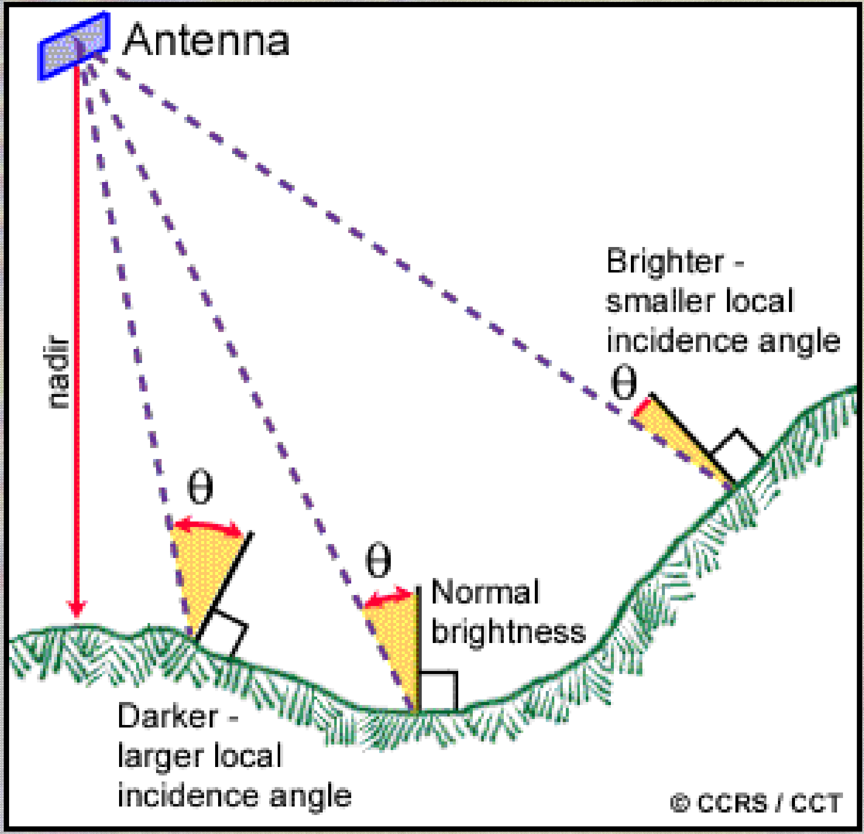


Signal recording during satellite motion

– Enhances azimut resolution 1000 times (5 km ⇒ 5 m)

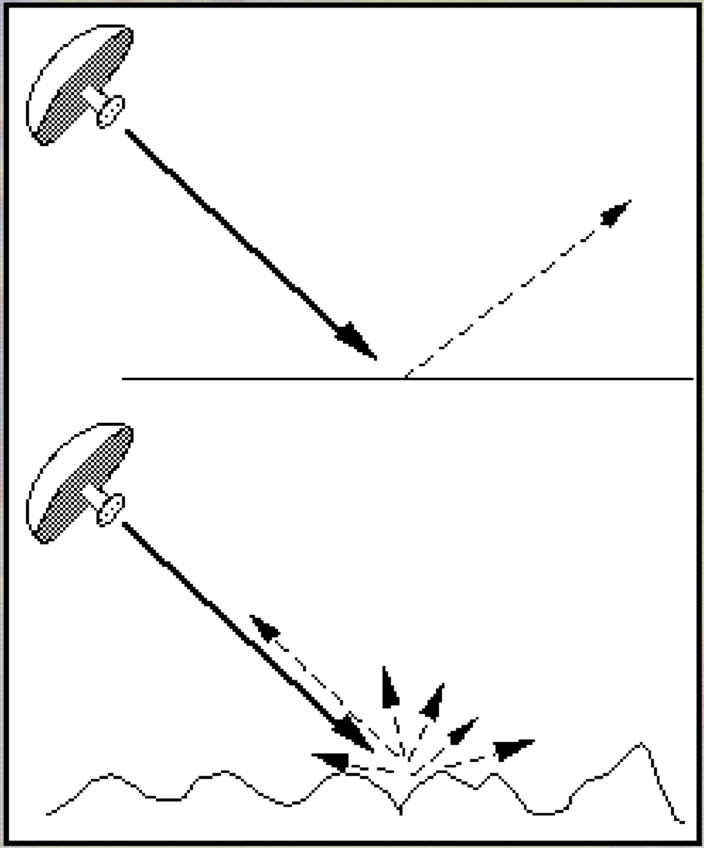
Basic InSAR theory

- Image acquisition
  - Brightness of target
    - Incidence angle



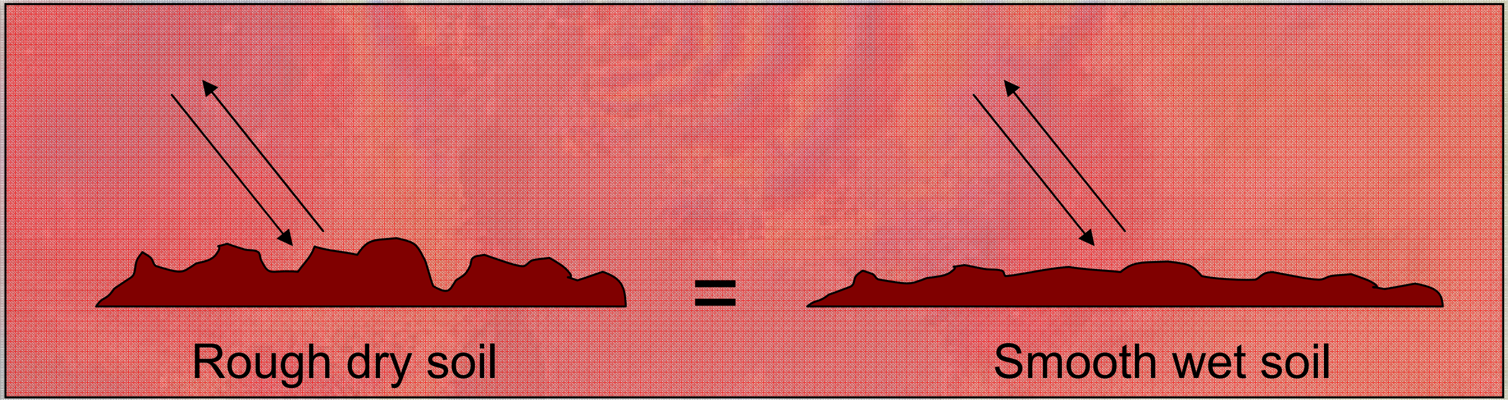
Basic InSAR theory

- Image acquisition
  - Brightness of target
    - Incidence angle
    - Surface roughness



Basic InSAR theory

- Image acquisition
  - Brightness of target
    - Incidence angle
    - Surface roughness
    - Target moisture



Basic InSAR theory

- Image acquisition
  - Brightness of target
  - Baseline separation
    - Repeat passes optimize data quality
      - Stereoscopic effect minimized

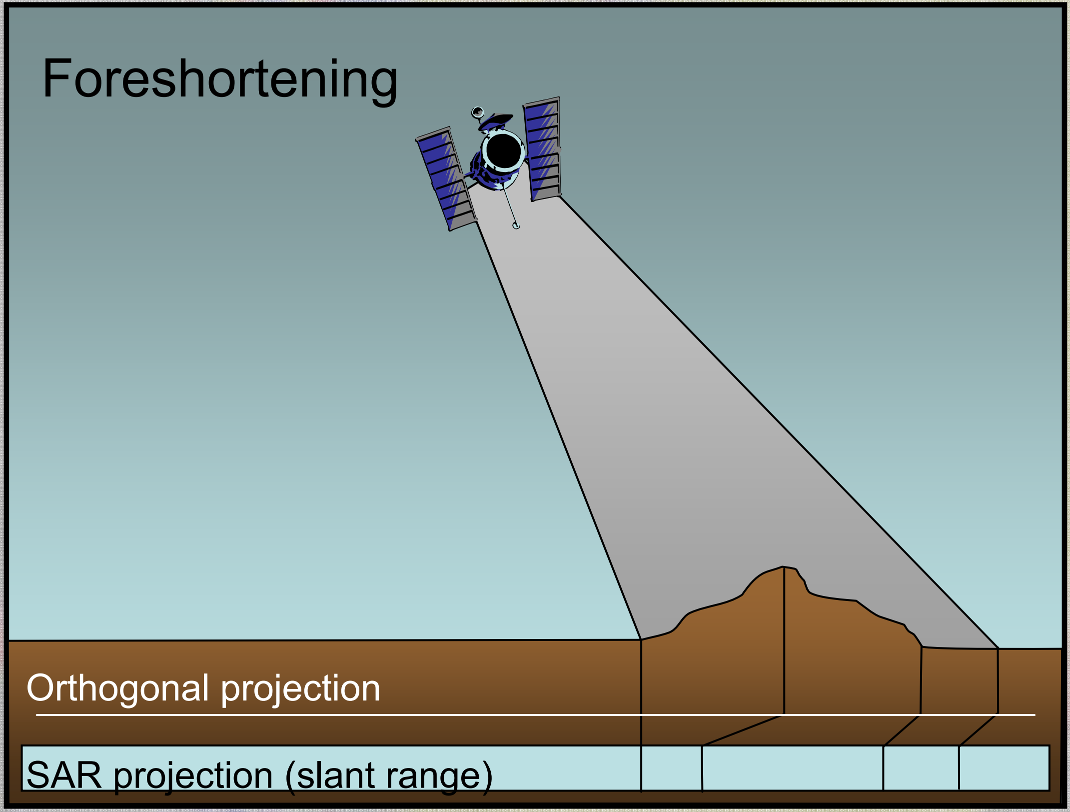
Surface conditions affects data quality

- Stable ground reflectors
- Low vegetation
- No wet-lands
- No ice or snow cover

Lava surfaces are optimal reflectors!!!

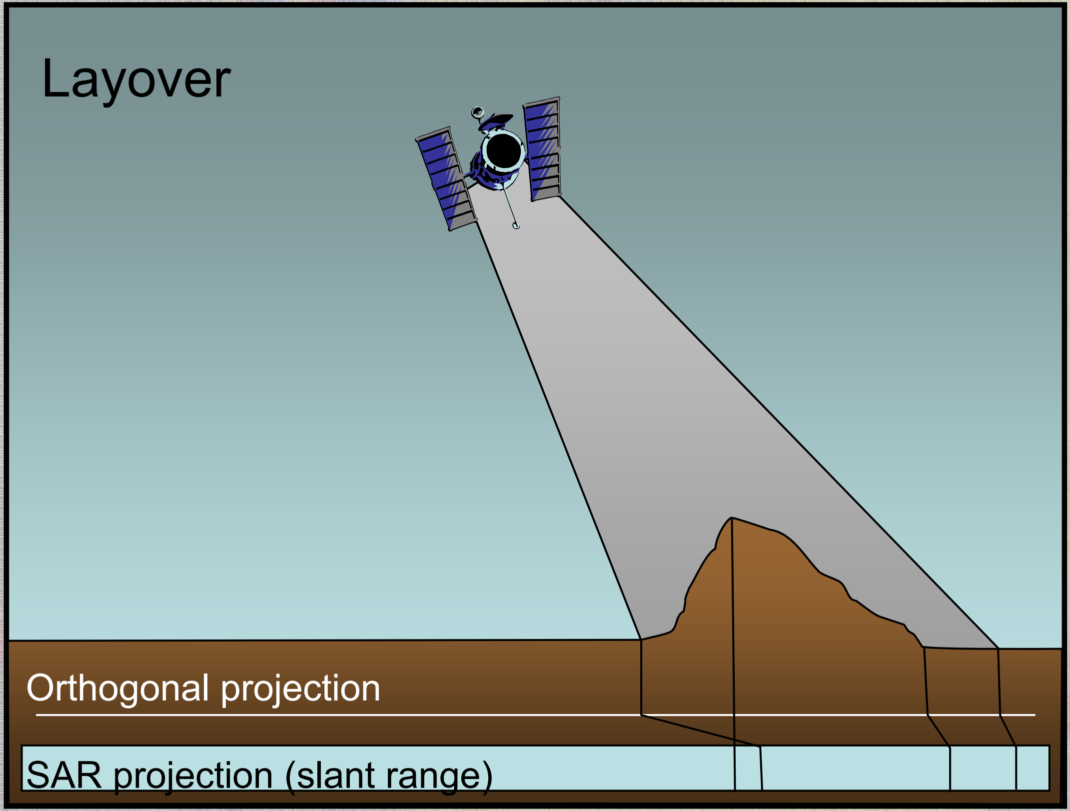
Basic InSAR theory

- Geometrical limitations
  - Topography



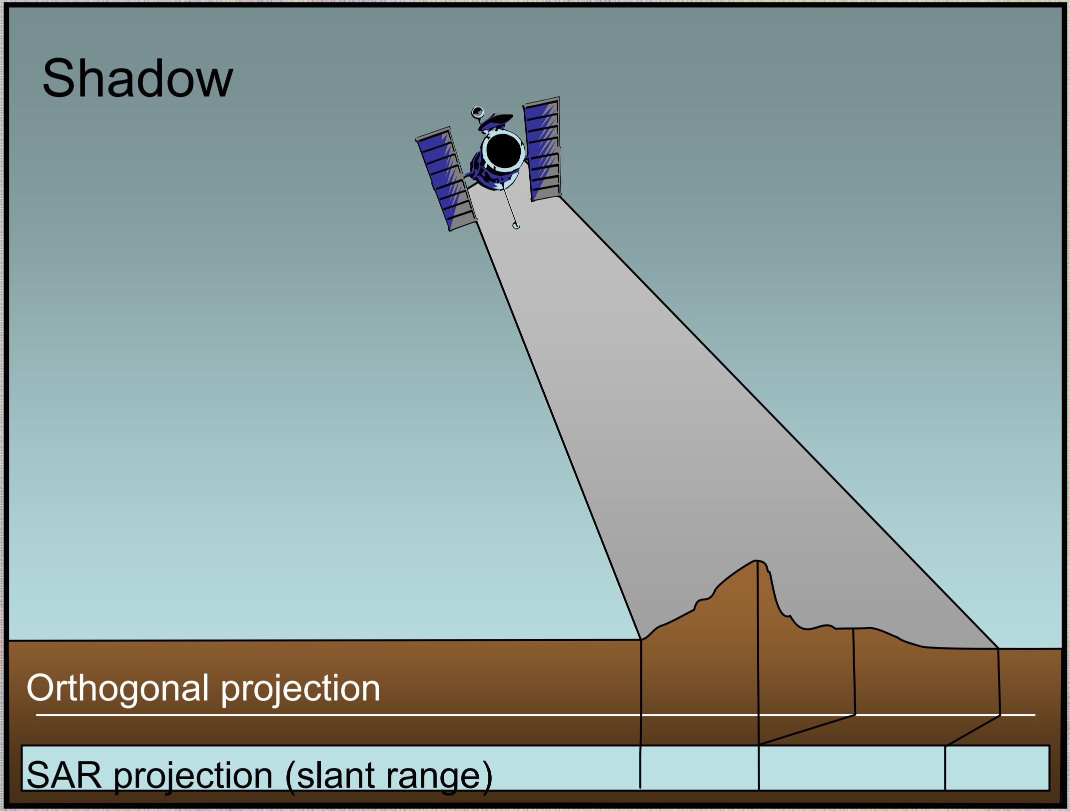
Basic InSAR theory

- Geometrical limitations
  - Topography



Basic InSAR theory

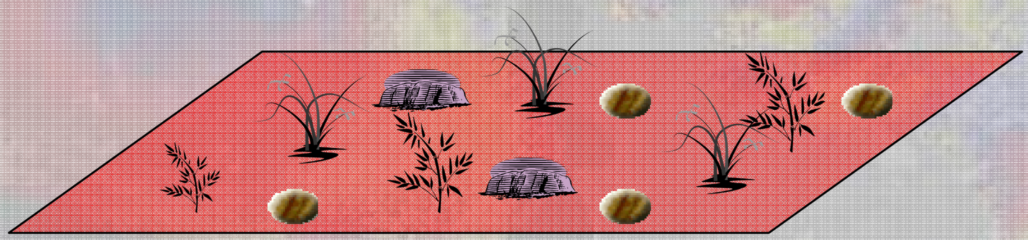
- Geometrical limitations
  - Topography

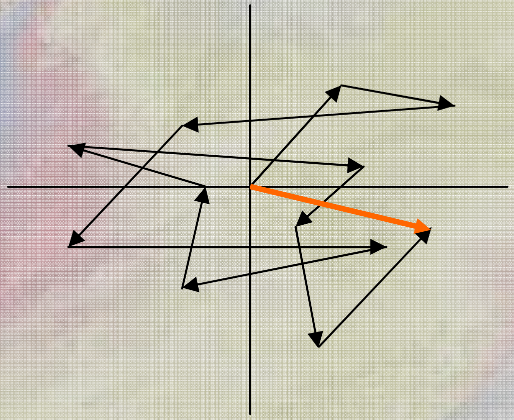


Basic InSAR theory

- Geometrical limitations
  - Topography
  - Surface reflector stability - Radar Speckle
    - Result of interacting scatterers on a sub-pixel level
      - The vectorized return from one ground pixel

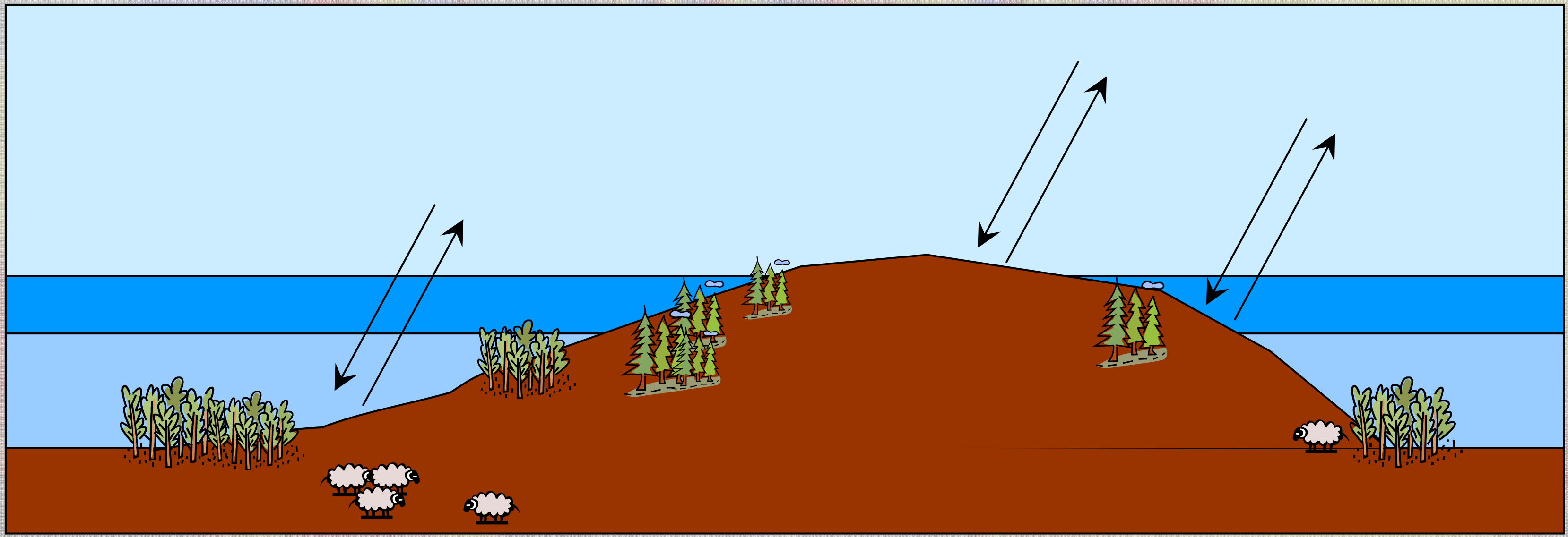
Random but reproducible!





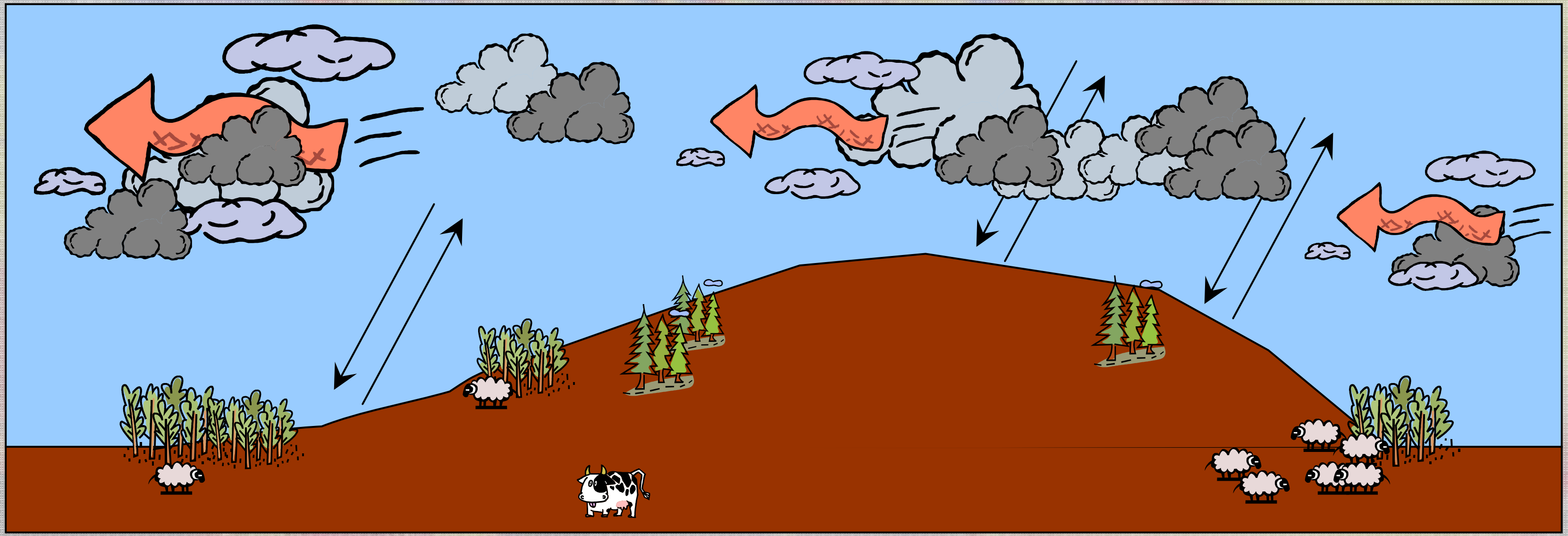
Basic InSAR theory

- Data error sources
  - Atmosphere/Troposphere
    - Stratification creates elevation dependant residuals



Basic InSAR theory

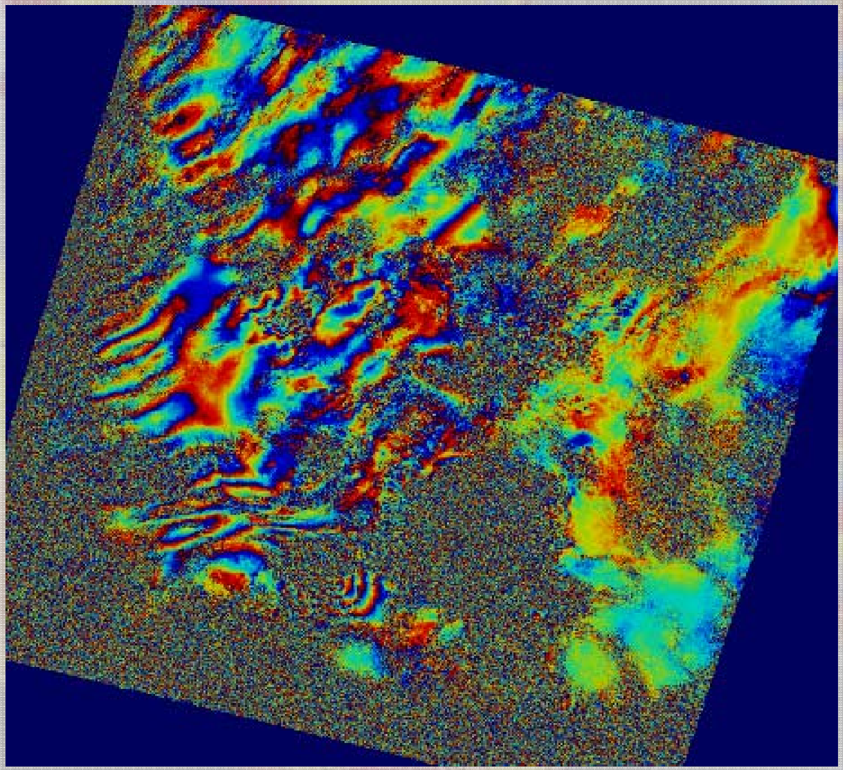
- Data error sources
  - Atmosphere/Troposphere
    - Turbulent mixing creates variable signal delays at all frequencies within scenes



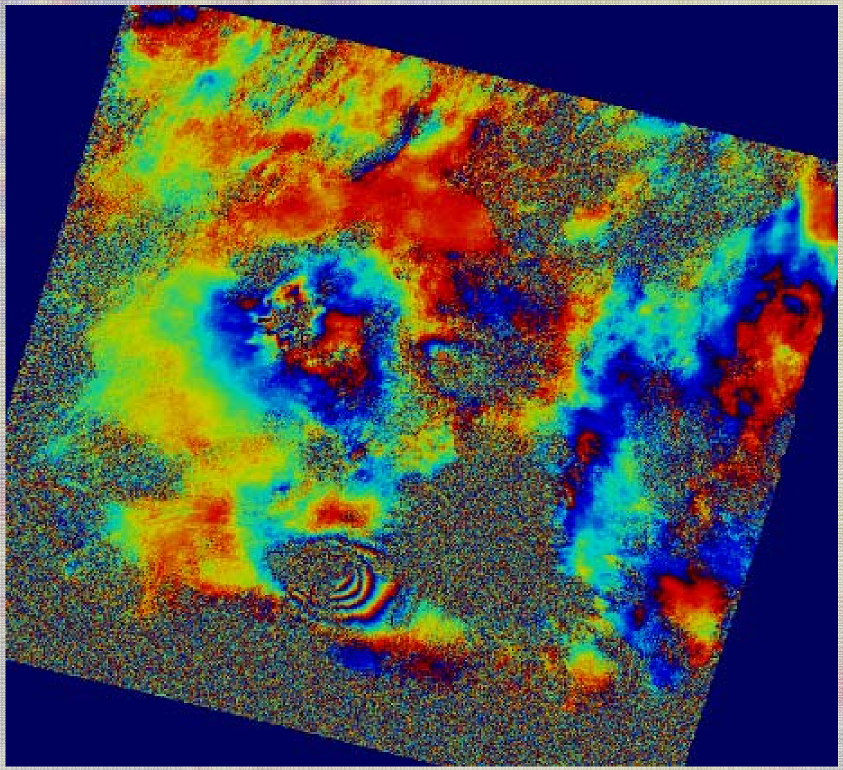
Basic InSAR theory

- Data error sources
  - Atmosphere/Troposphere

λ=2.83 cm



03/08/93 – 20/09/96

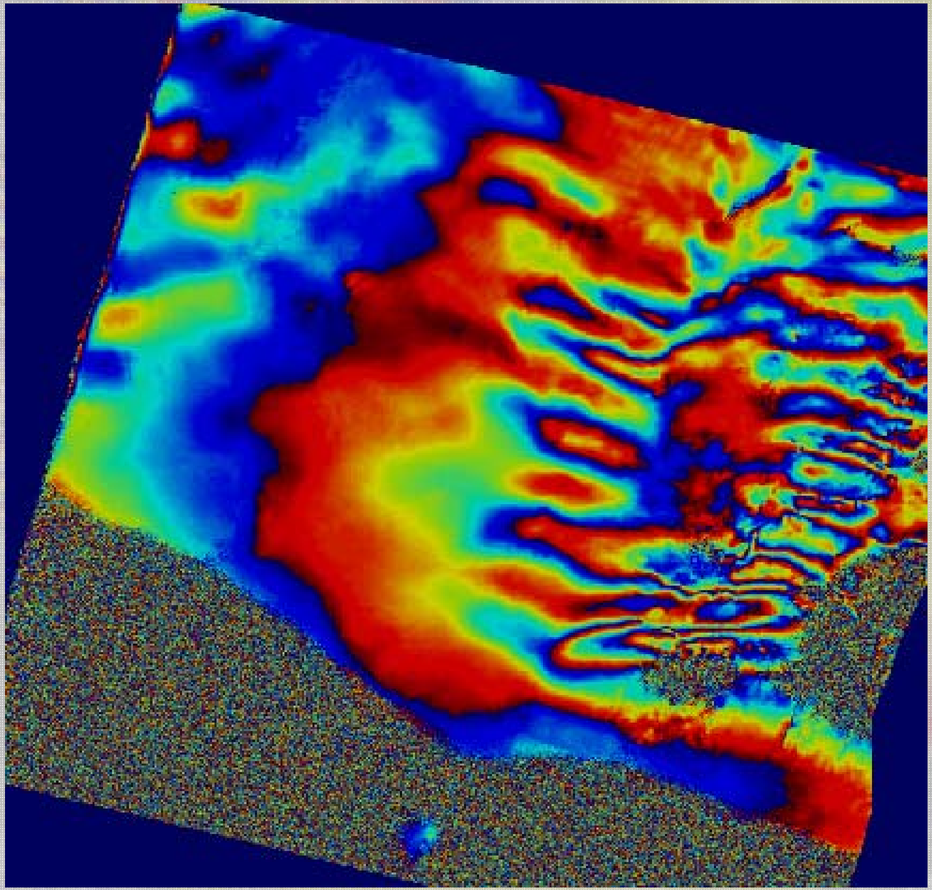


03/08/93 – 27/06/97

Basic InSAR theory

- Data error sources
  - Atmosphere/Troposphere

λ=2.83 cm

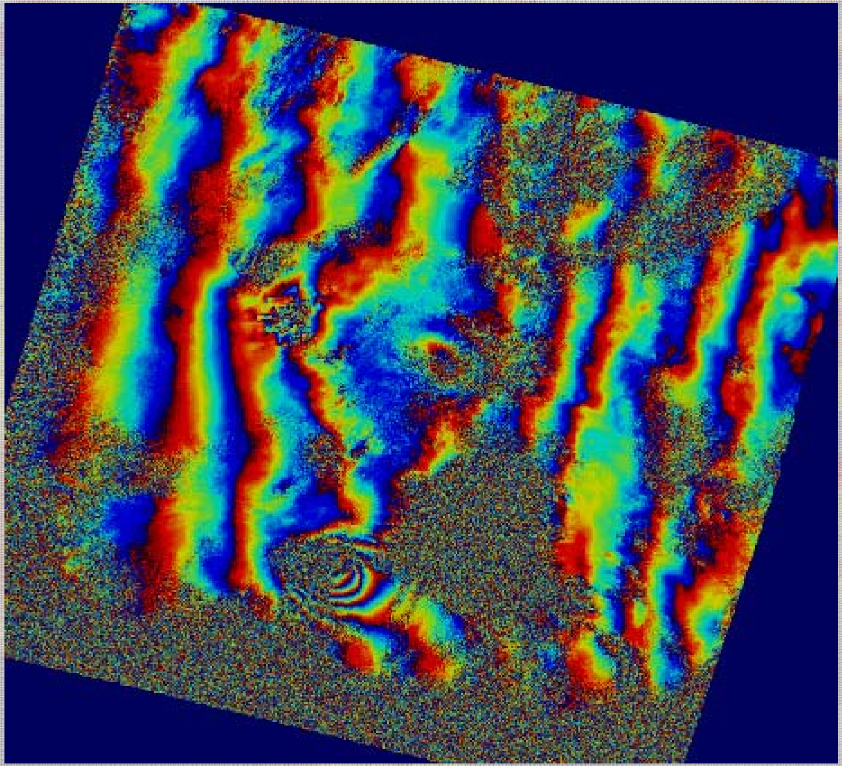


15/08/95 – 16/08/95

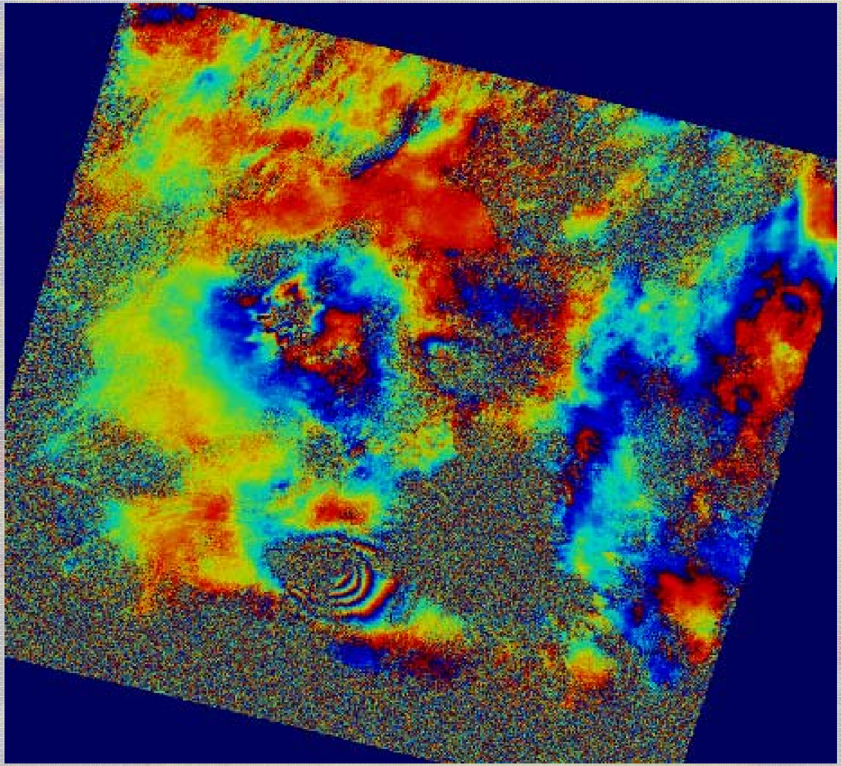
Basic InSAR theory

- Data error sources
  - Atmosphere/Troposphere
  - Orbital errors

λ=2.83 cm



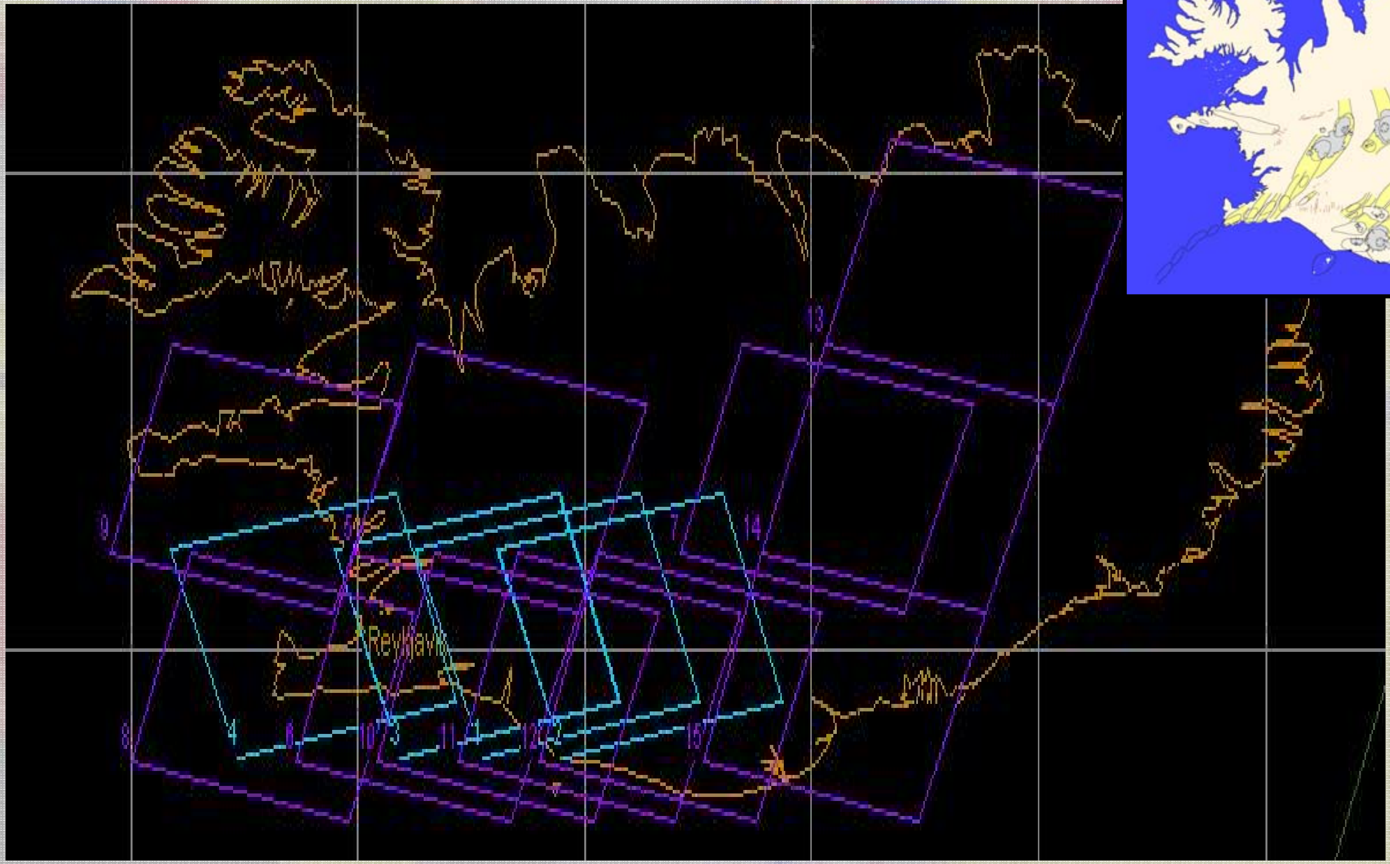
Residual orbital fringes



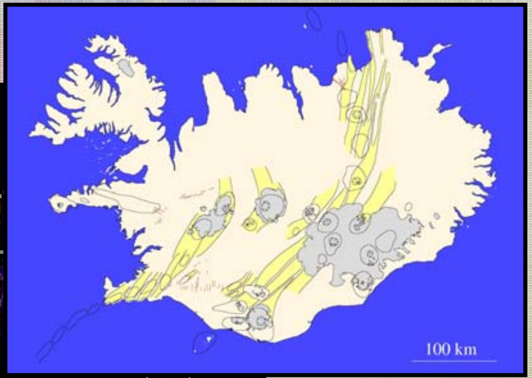
Cleaned version

InSAR applications in Iceland

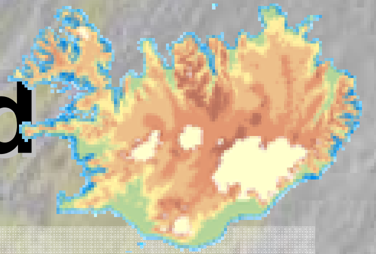
- ERS data coverage



Tectonic map



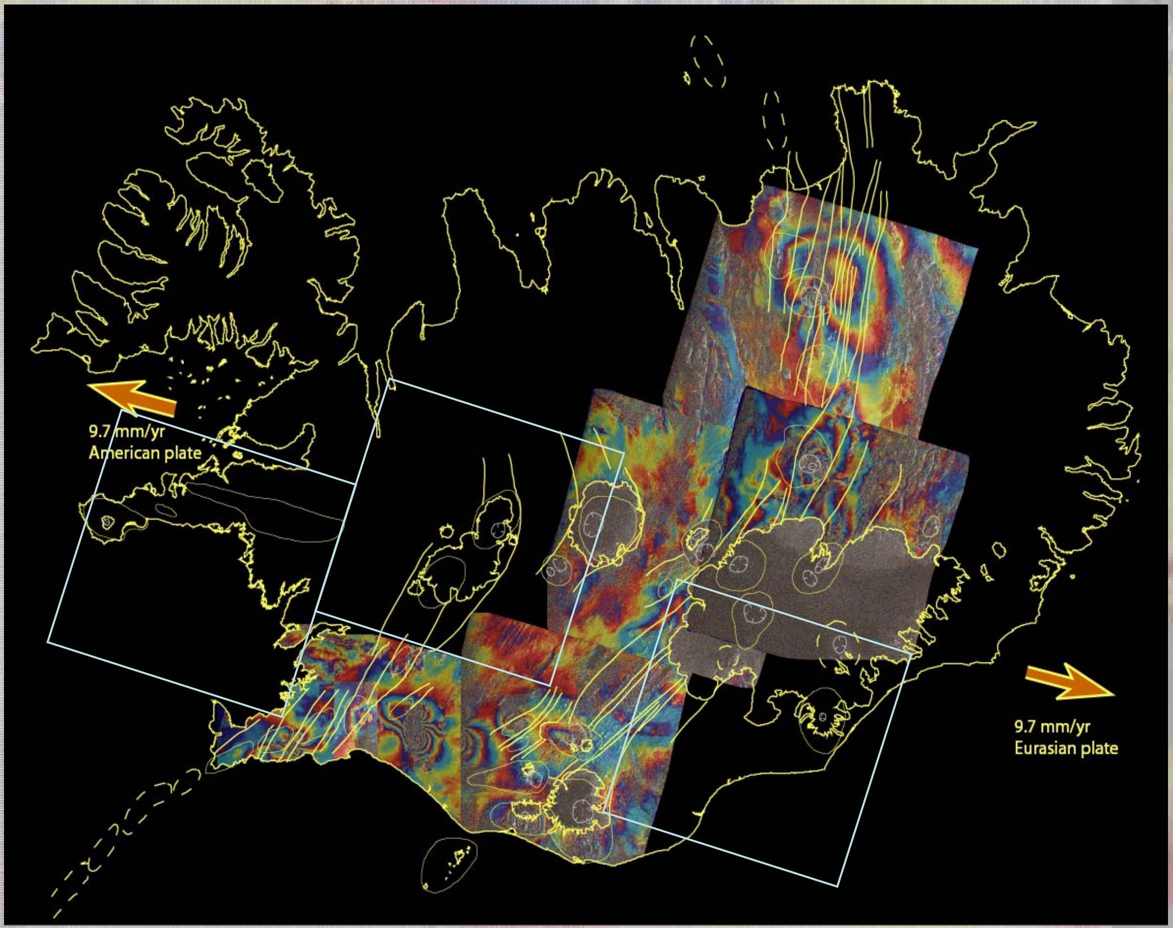
InSAR applications in Iceland



Signals from:

Plate spreading
Deep magma recharge
Magma chamber
- subsidence
- inflation

Sill intrusion
Co-seismic faulting
Aseismic faulting
Poro-elastic rebound
Co-eruptive deformation
Glacial rebound
Glacial ice deformation
Pressure changes due to geothermal utilization



λ=2.83 cm

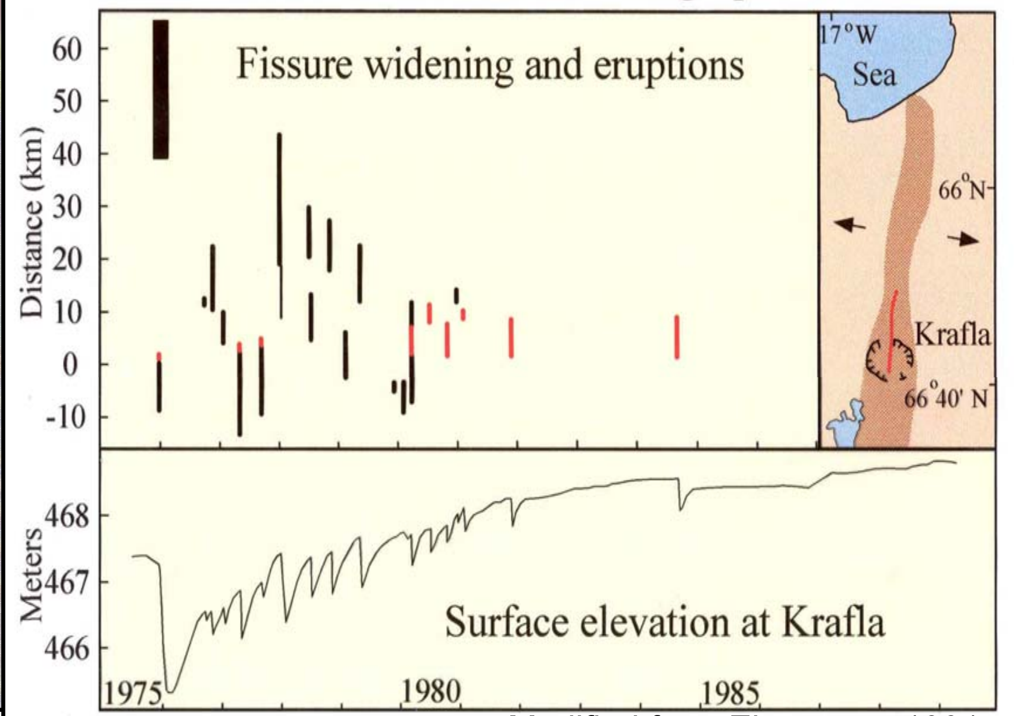
InSAR applications in Iceland

- "Regional" signals e.g. plate spreading
  - Subtle, continuous deformation
  - Geometry of segment important
  - Data strips from north to south coast (~300 km)
  - 100 km wide swath
  - Relative 1-D measurements

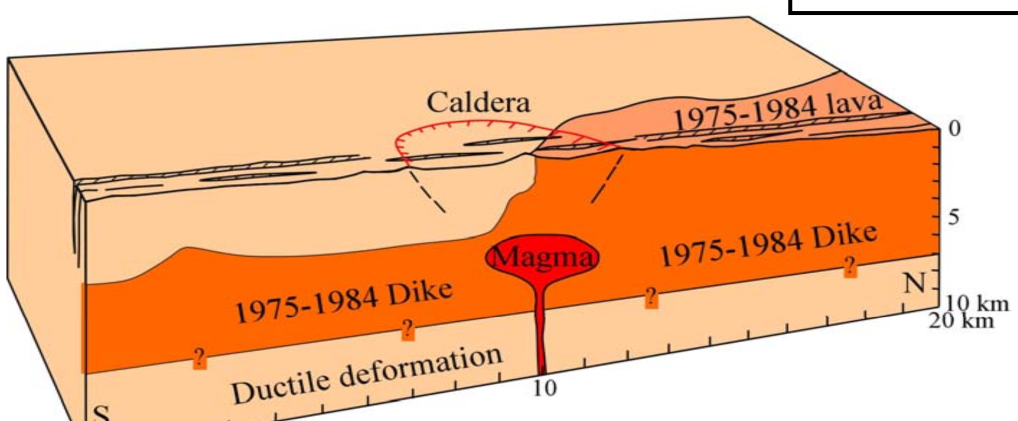
➡ **Combination with GPS preferable!**

InSAR applications in Iceland

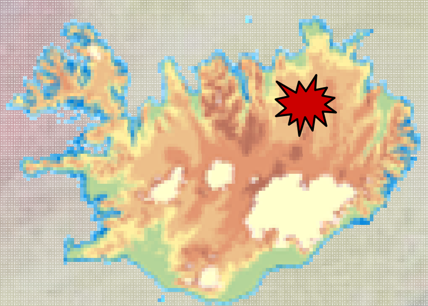
- Krafla fires (1975-84)
  - ~20 intrusive episodes
  - - 9 eruptive episodes
- Co-rifting deformation
  - Max widening: 9 m
  - 80 km long segment
  - Vertical: meter scale



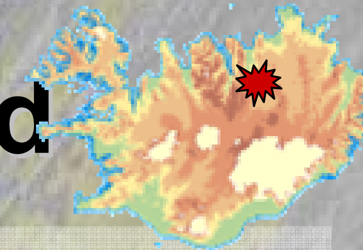
Modified from Einarsson, 1991



Modified from Björnsson et al., 1979



InSAR applications in Iceland



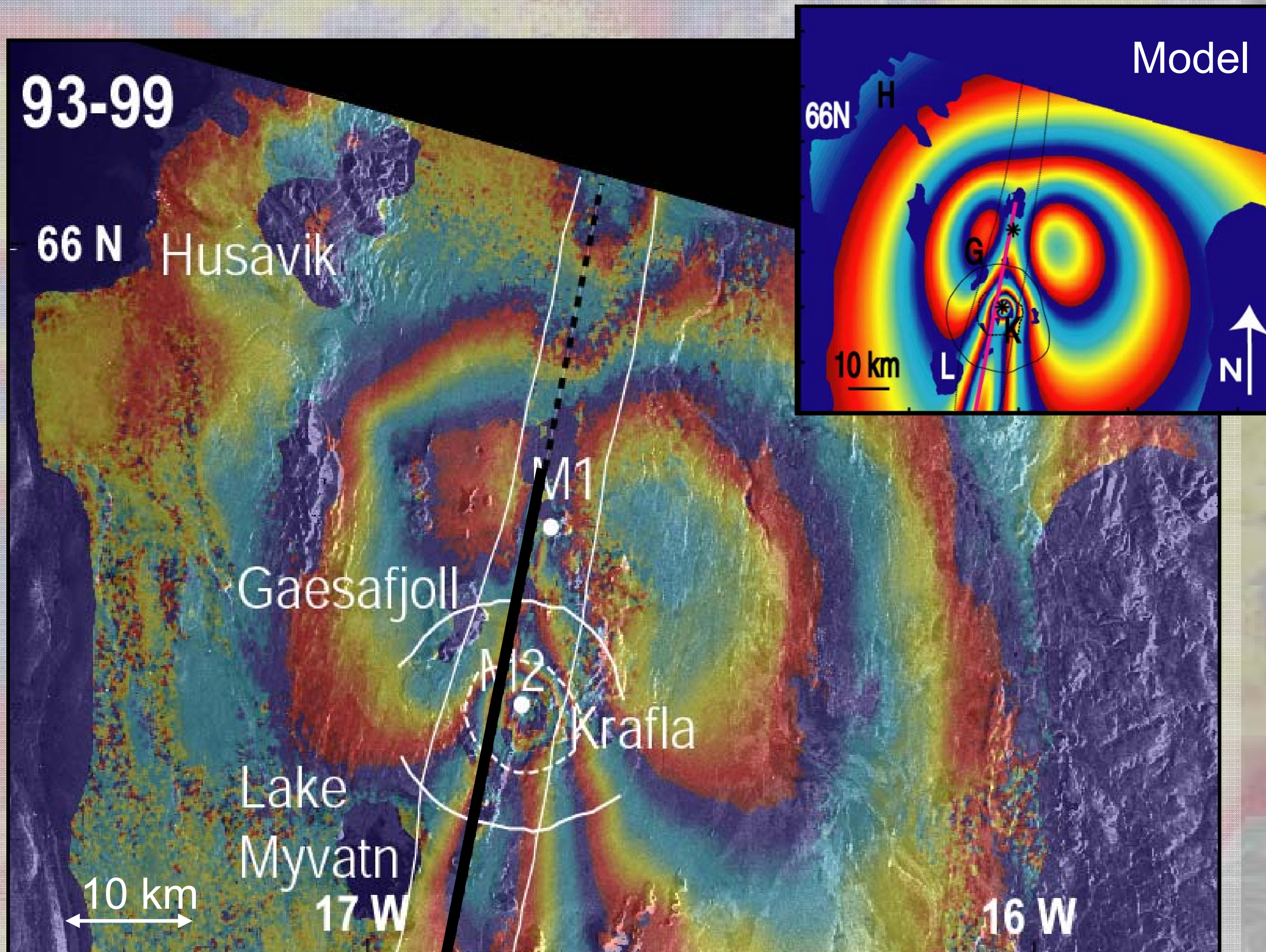
- Krafla

Point source M1:
21 km depth

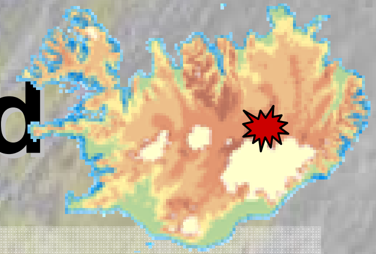
Point source M2:
2.4 km depth

Buried disloc:
4.6 km depth

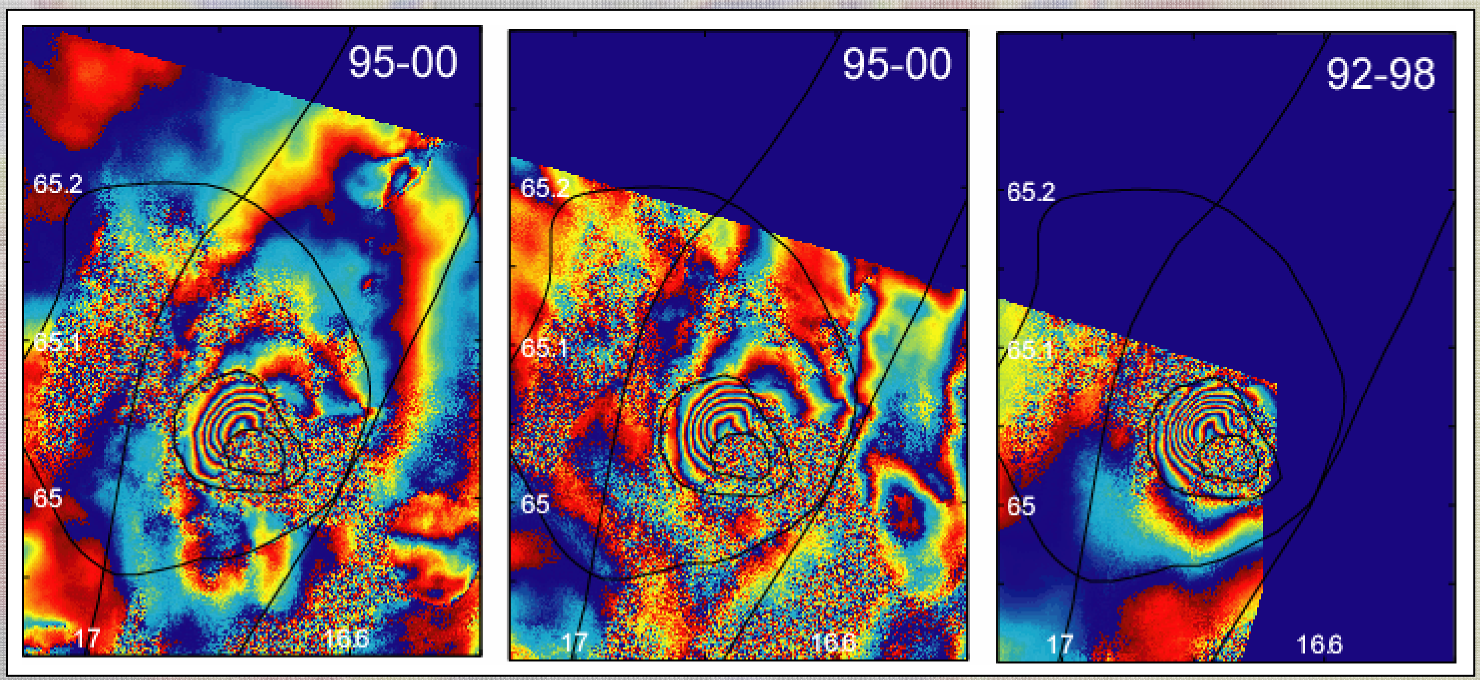
λ=2.83 cm



InSAR applications in Iceland

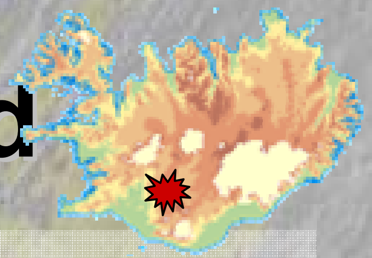


- Askja Volcano
  - Subsidence measured since 1983 (levelling)
  - Magma chamber cooling/contraction
  - Gravity indicates a possible draining component

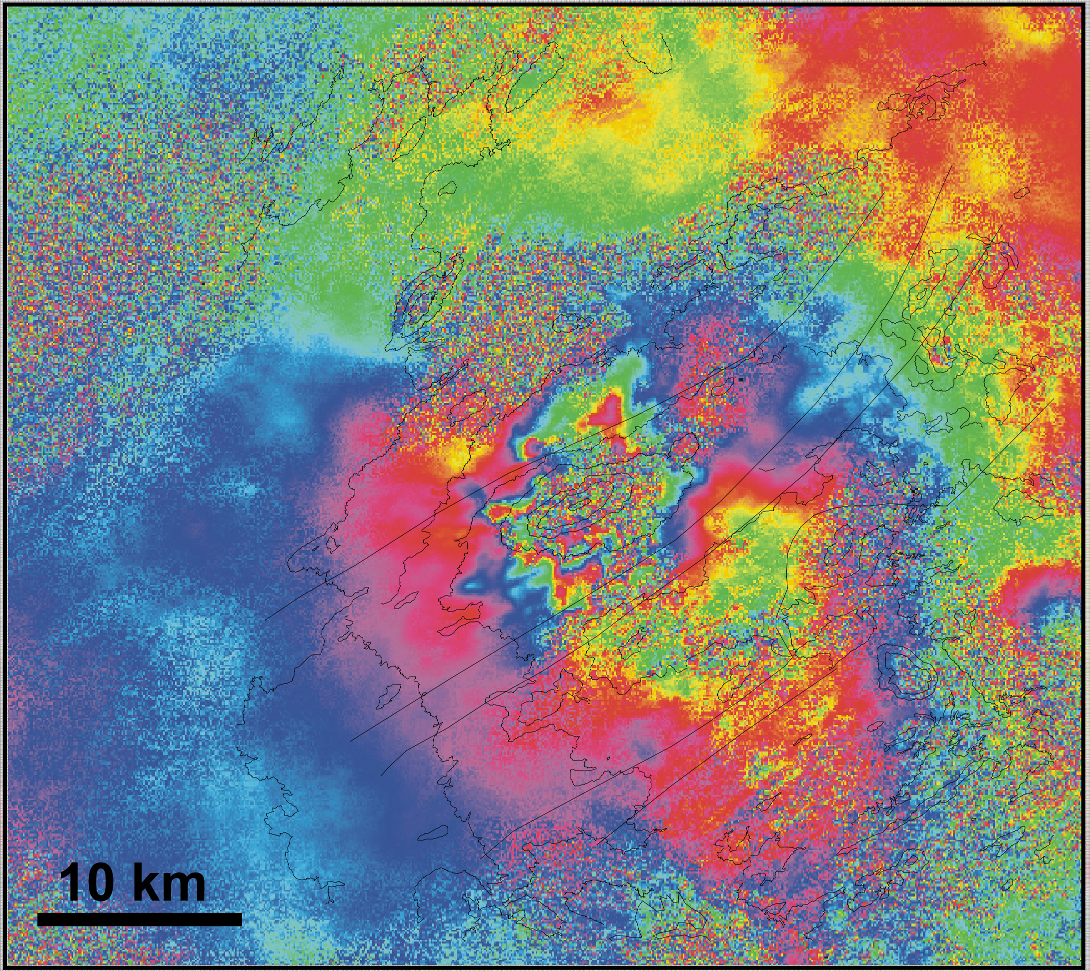


Track 238 Track 009 Track 281

InSAR applications in Iceland



- Hekla Volcano

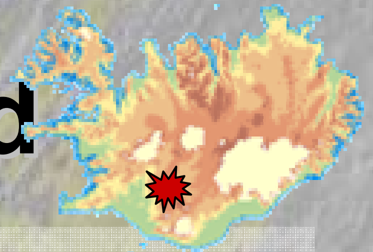


Repose period:

- Lava compaction
- Deep inflation?
- Substrate loading?

1993 – 1997

InSAR applications in Iceland

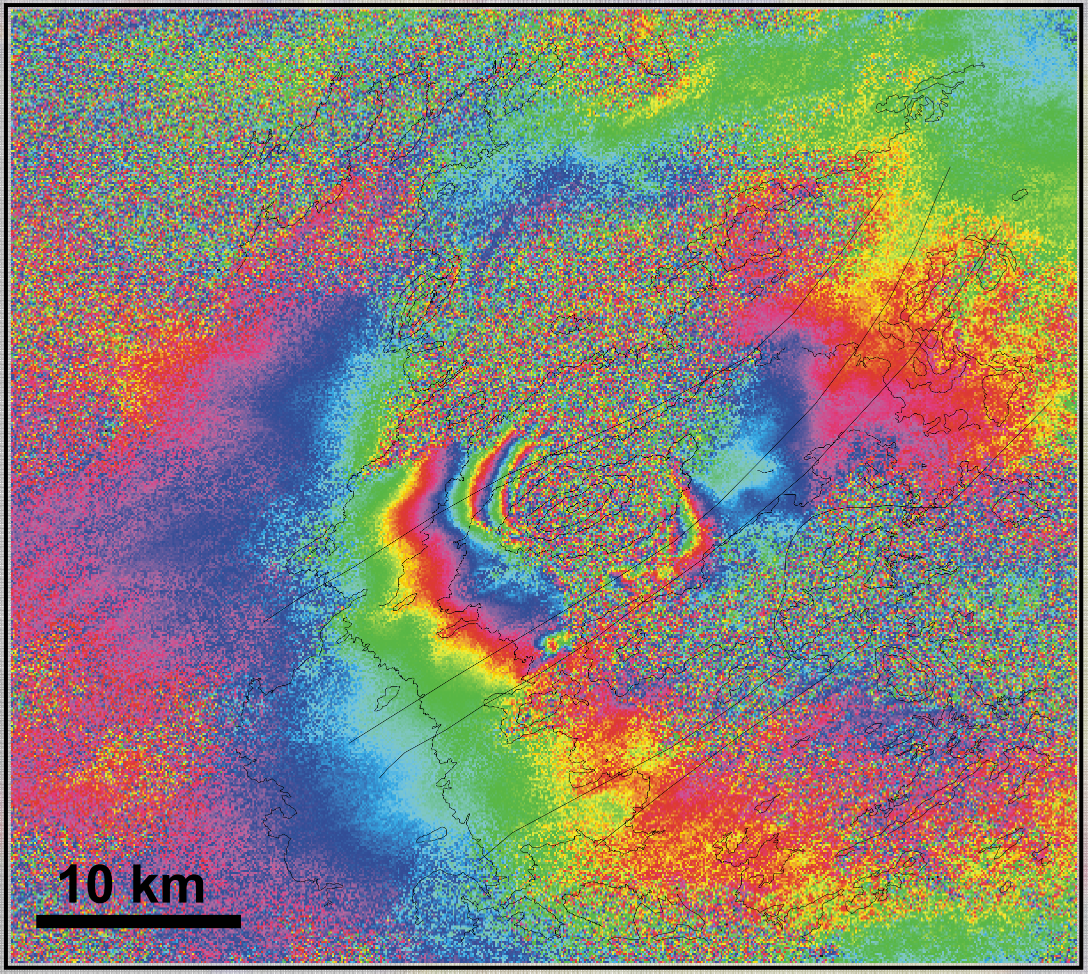


- Hekla Volcano

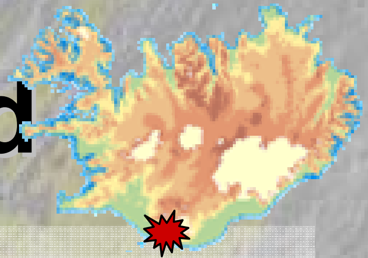
Eruptive period:

- Deep deflation
- Feeder dike

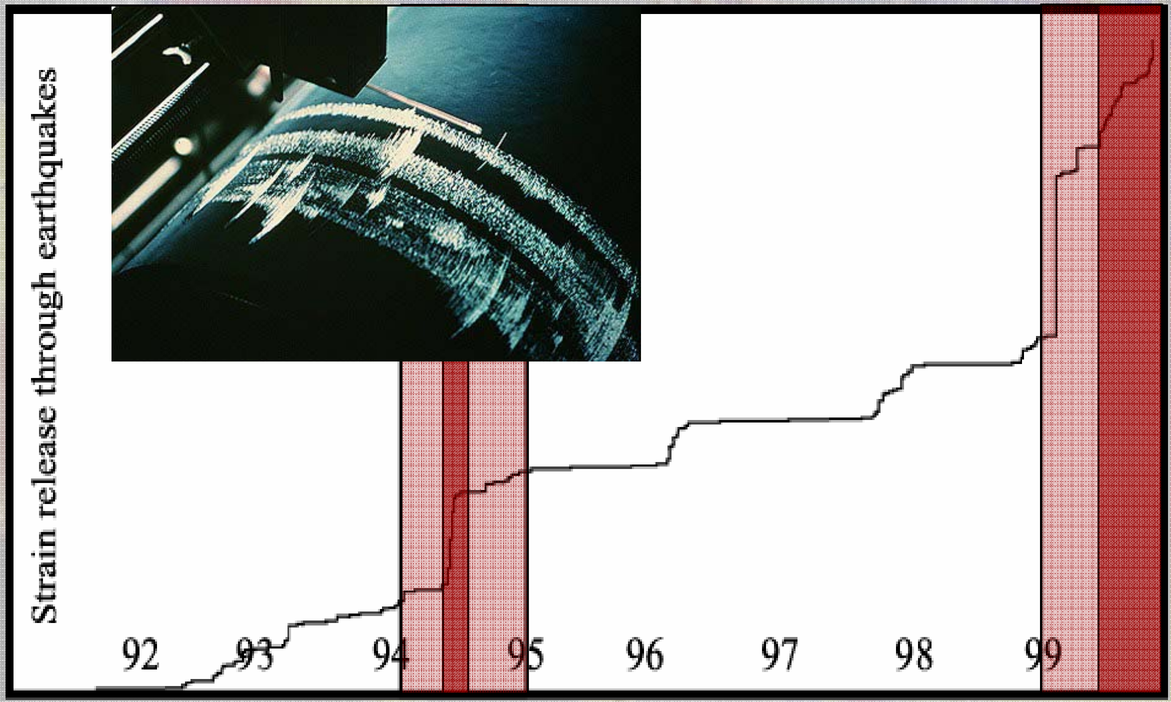
1998 – 2000

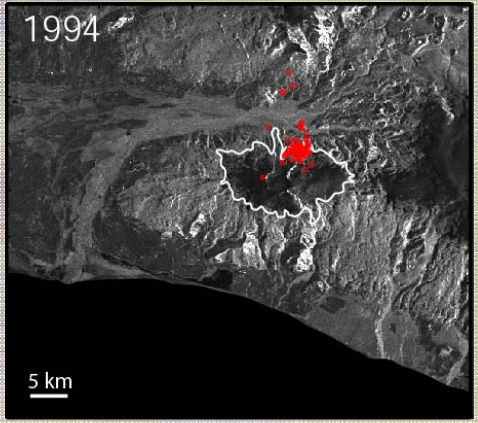


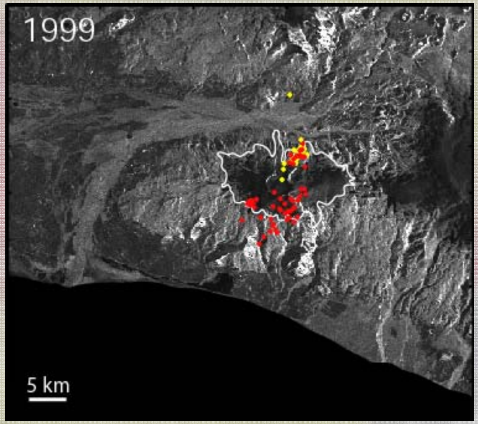
InSAR applications in Iceland



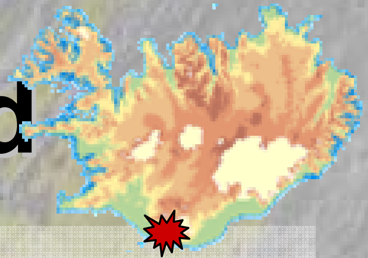
- Eyjafjallajökull Volcano
  - Ice-cap covered strato-volcano (1666 m.a.s.l)
  - Characterized by low activity level
  - Two seismic swarms in the 1990es







InSAR applications in Iceland

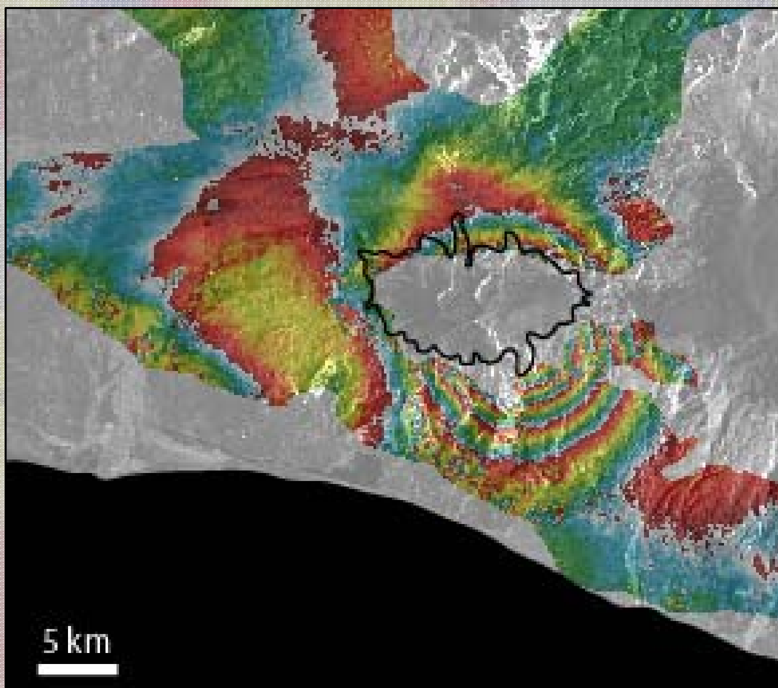


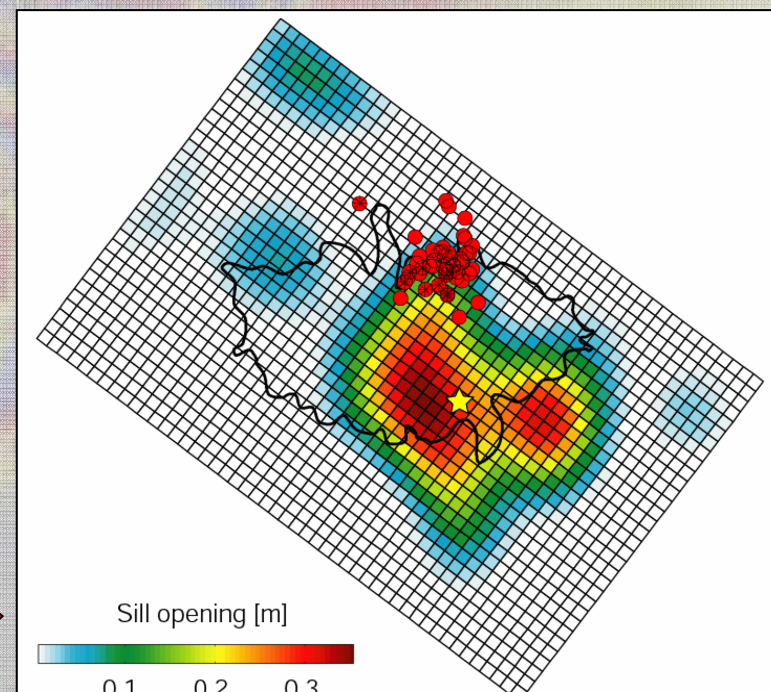
- Eyjafjallajökull Volcano
  - 1994 seismic swarm

Previous work:

Seismic study: Dike intrusion in N flank

GPS study: Point source in S flank

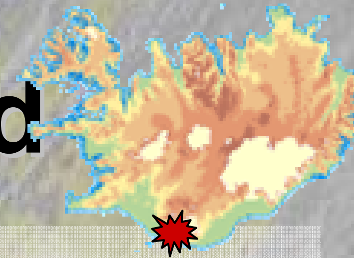




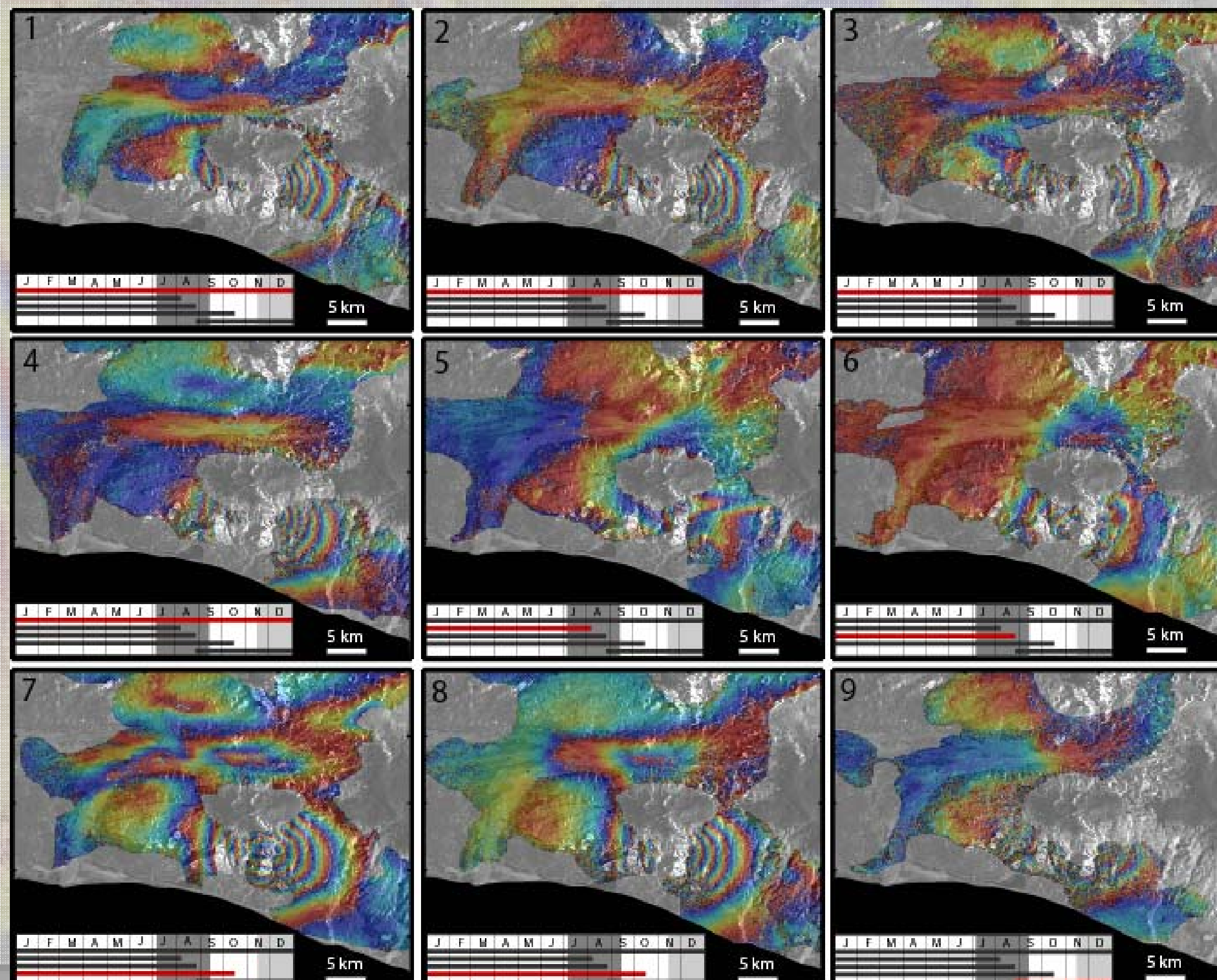
InSAR based modeling result:

Sill intrusion at 4.5-6.0 km depth

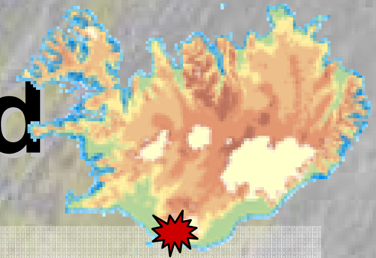
InSAR applications in Iceland



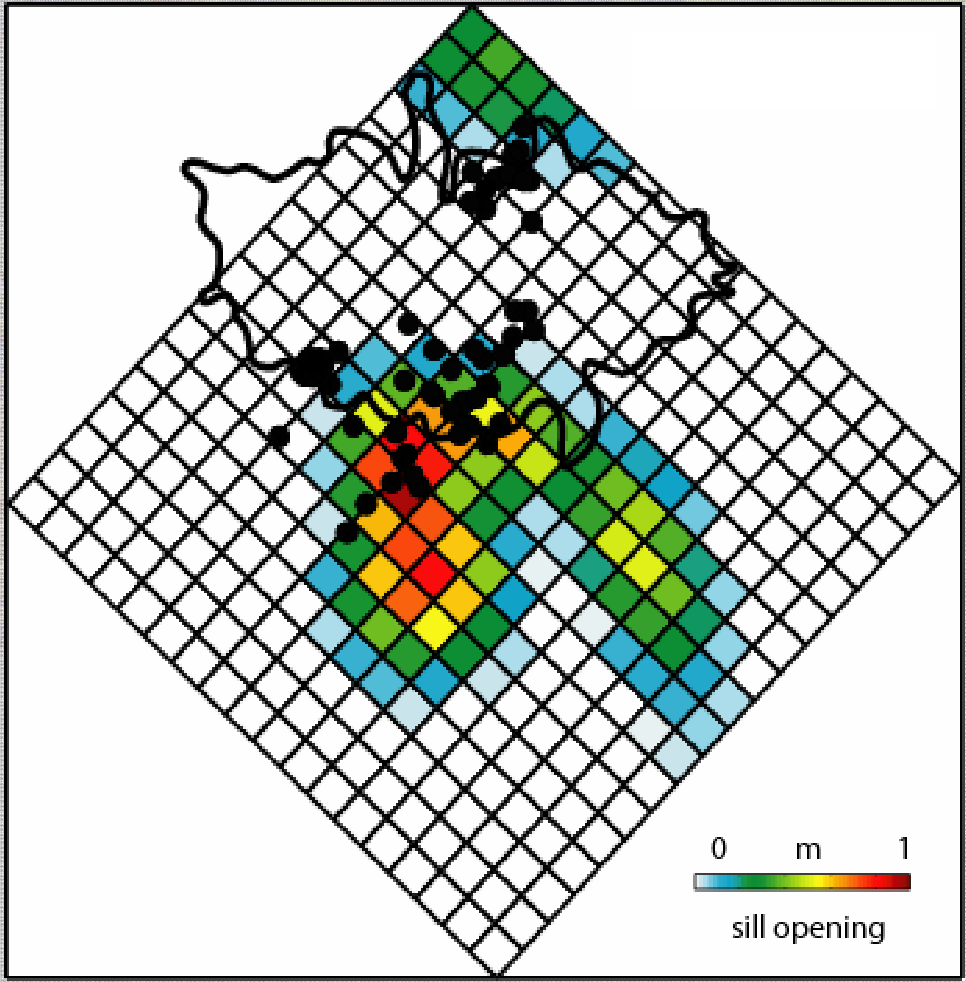
- Eyjafjallajökull Volcano
  - 1994
  - 1999



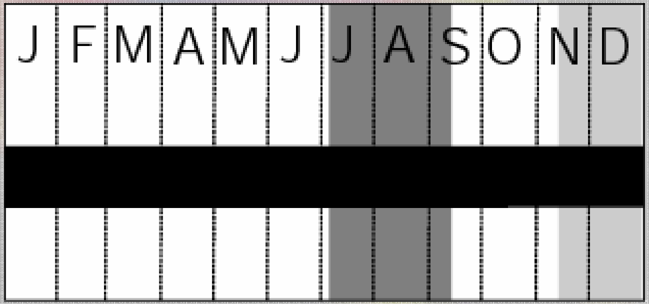
InSAR applications in Iceland



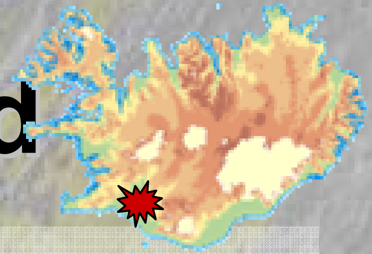
- Eyjafjallajökull Volcano
  - 1994
  - 1999
    - Sill evolution



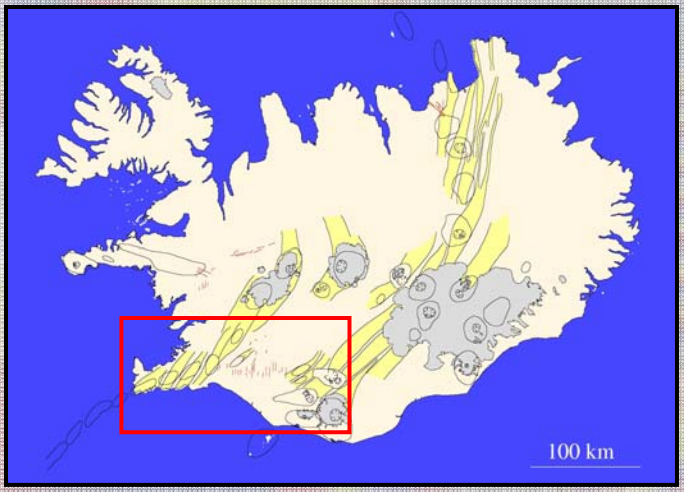
Timespan of modeled intrusion

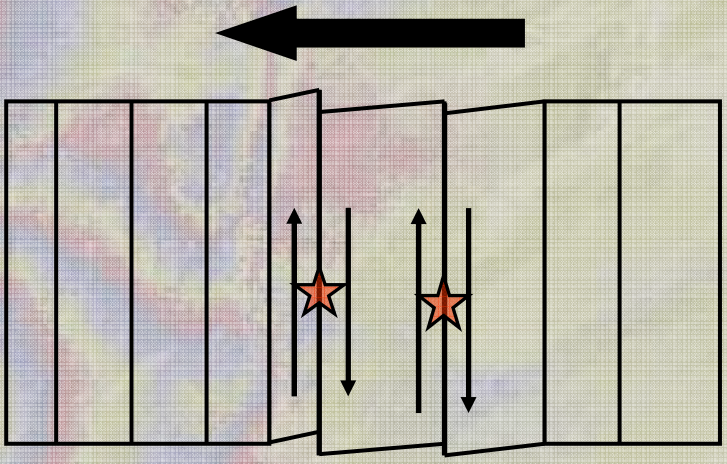


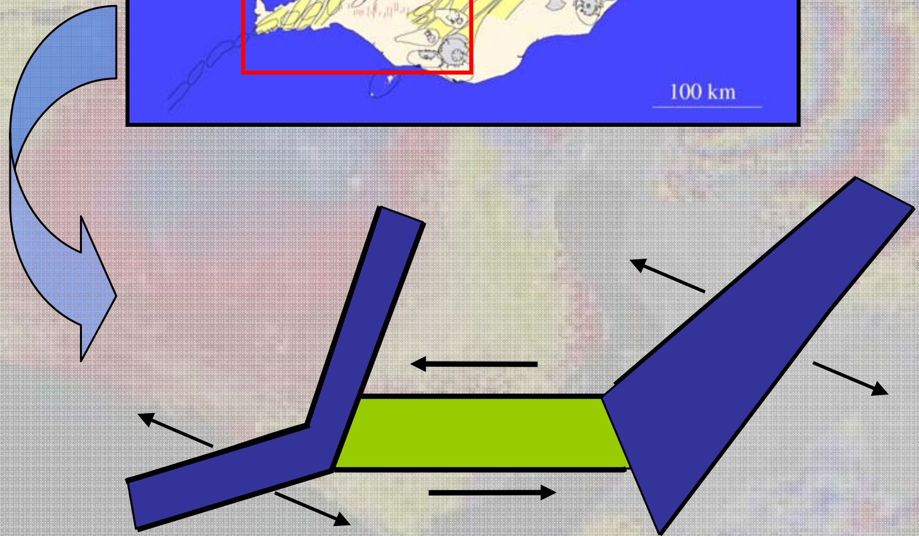
InSAR applications in Iceland

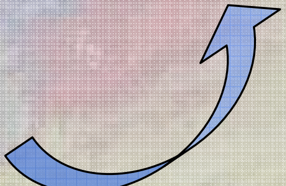


- South Iceland Seismic Zone
  - A zone of ”Bookshelf tectonics”

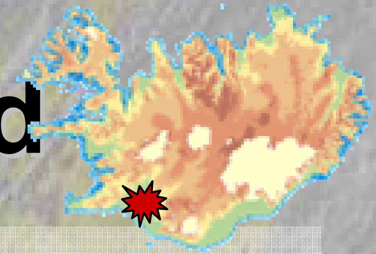




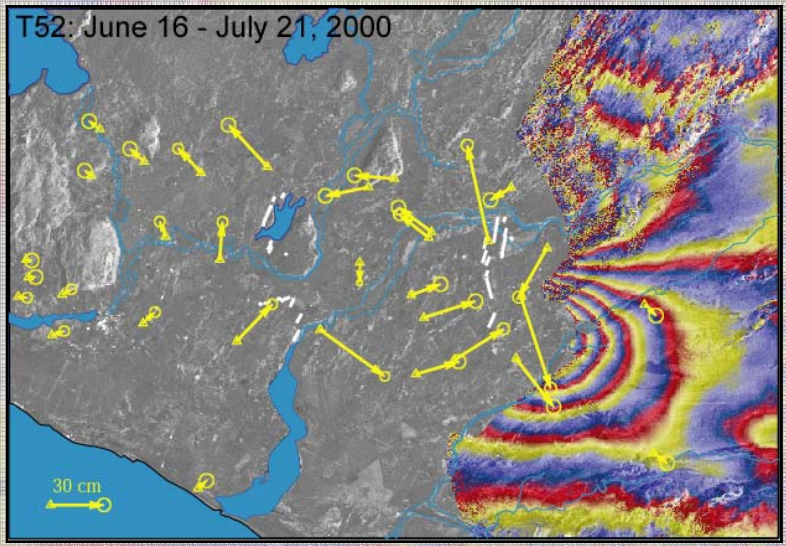


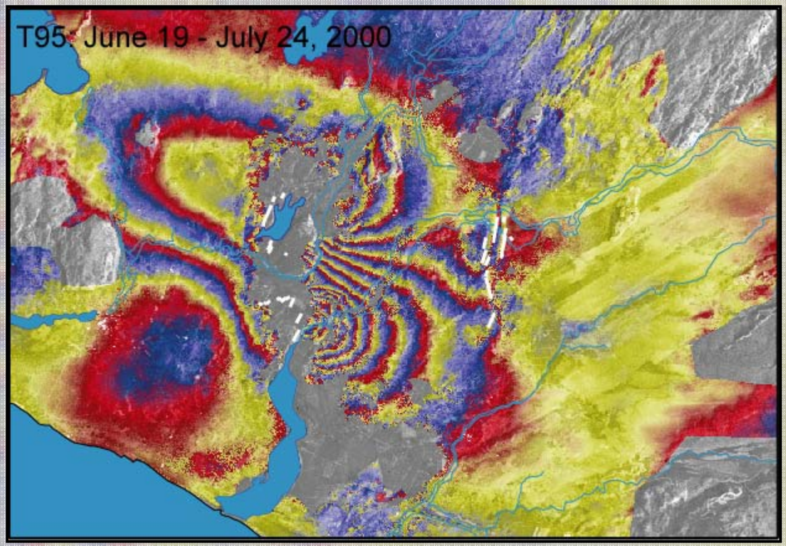


InSAR applications in Iceland

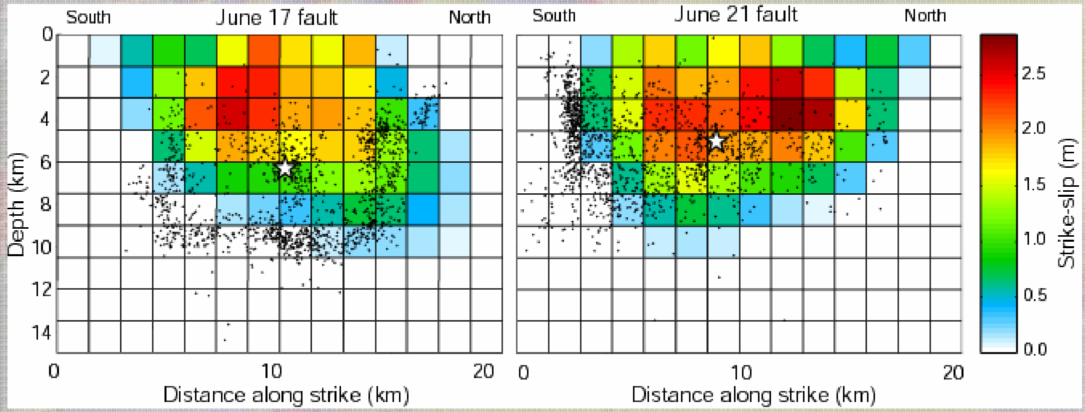


- South Iceland Seismic Zone

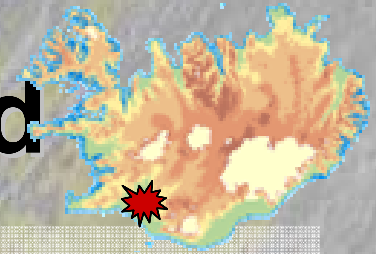




- 80% energy released in uppermost 6 km
- Equals 12-31 yrs of accumulated strain

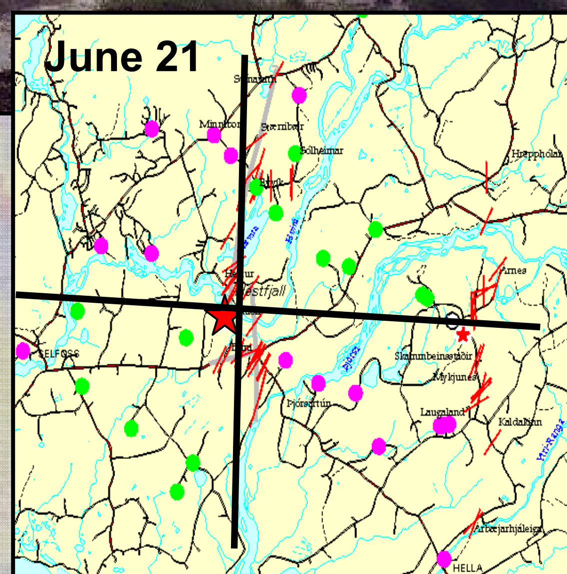


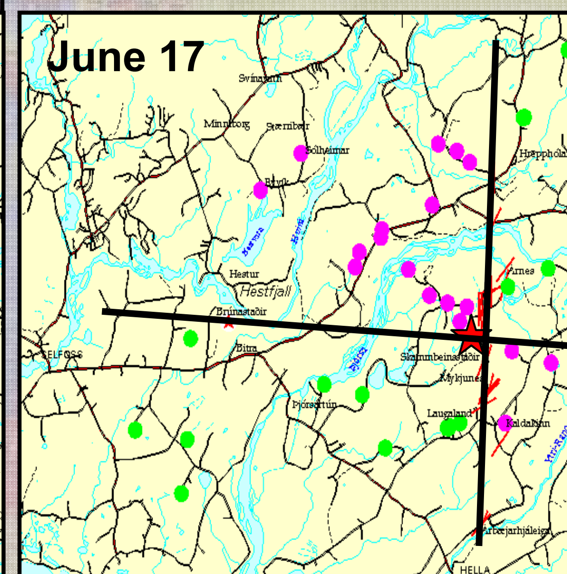
InSAR applications in Iceland



- South Iceland Seismic Zone

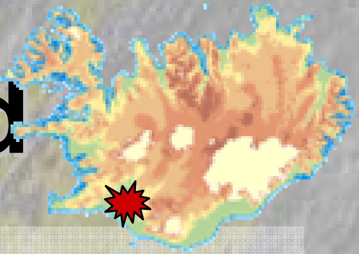
Co-seismic well-water response



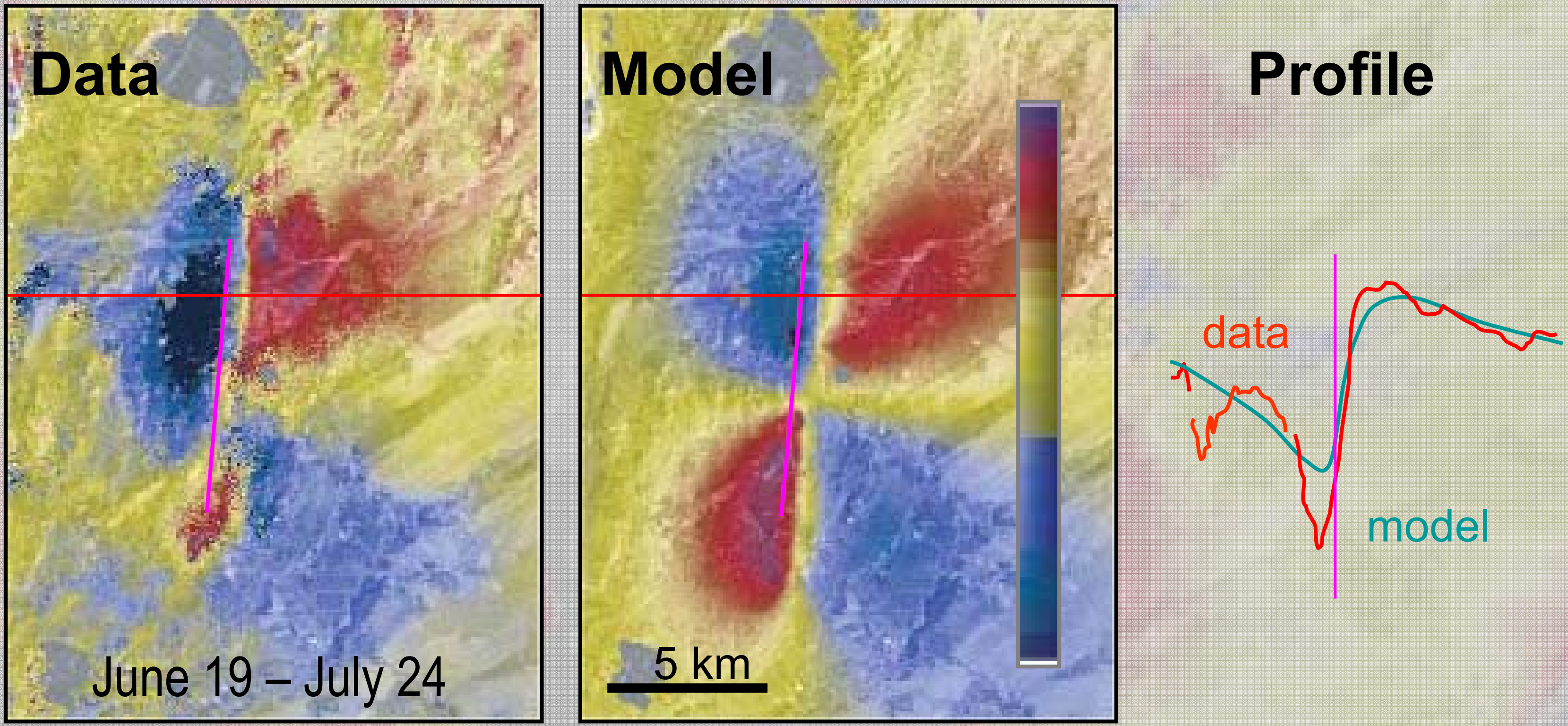


● Water level rise ● Water level drop http://www.os.is

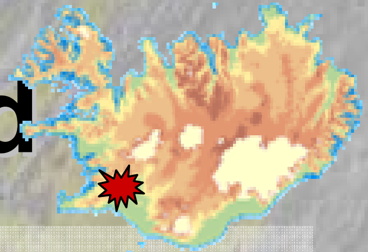
InSAR applications in Iceland



- South Iceland Seismic Zone
  - Poro-elastic rebound during 35 days



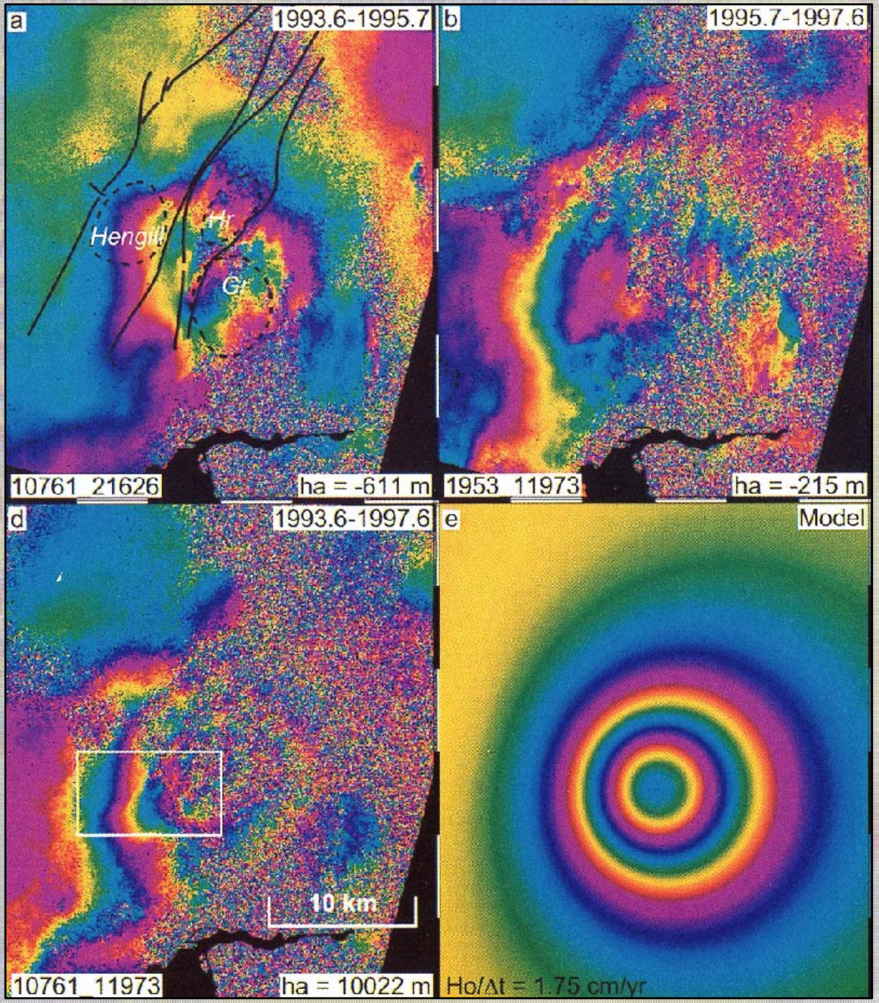
InSAR applications in Iceland



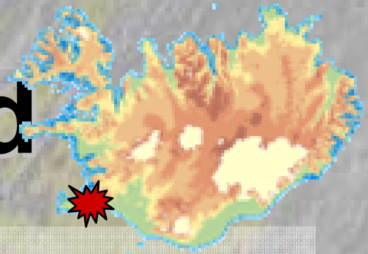
- Hengill triple junction
  - Unusually persistent elevated earthquake activity during 1994-1999
  - ~80.000 events detected
  - Uplift of 19 mm/yr

➡ Inflow of magma at about 7 km depth

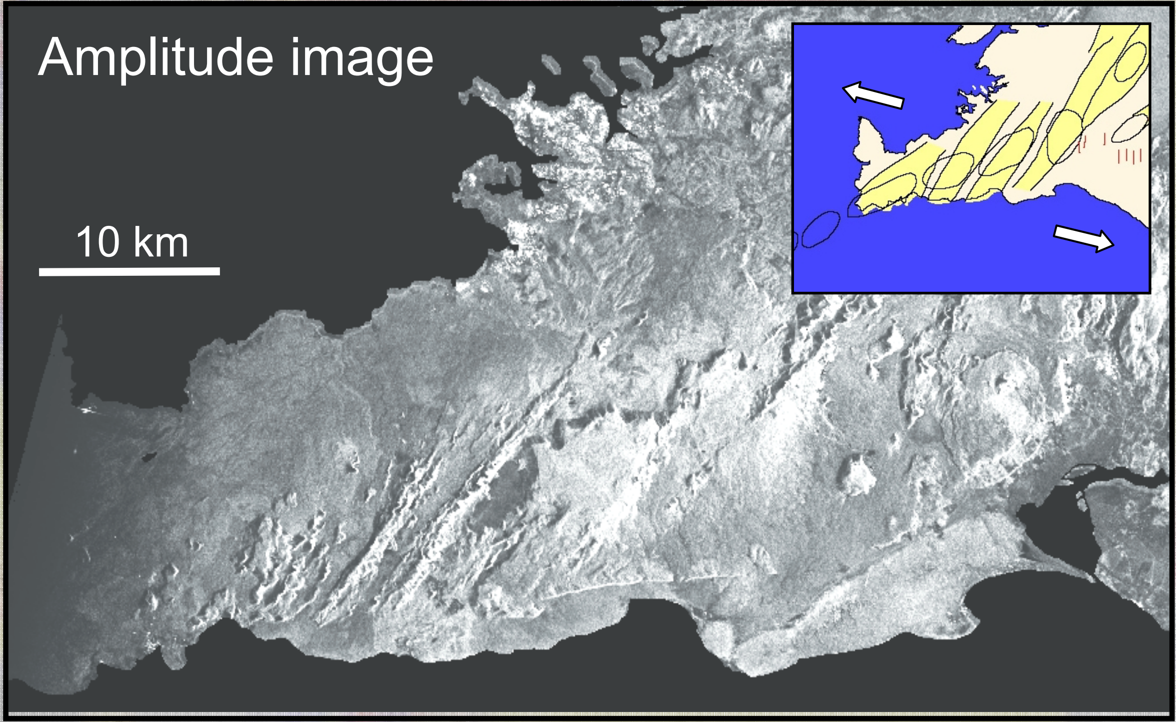
➡ Pressure increase may have triggered seismicity



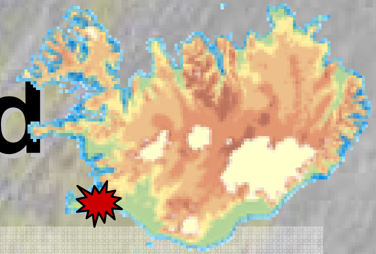
InSAR applications in Iceland



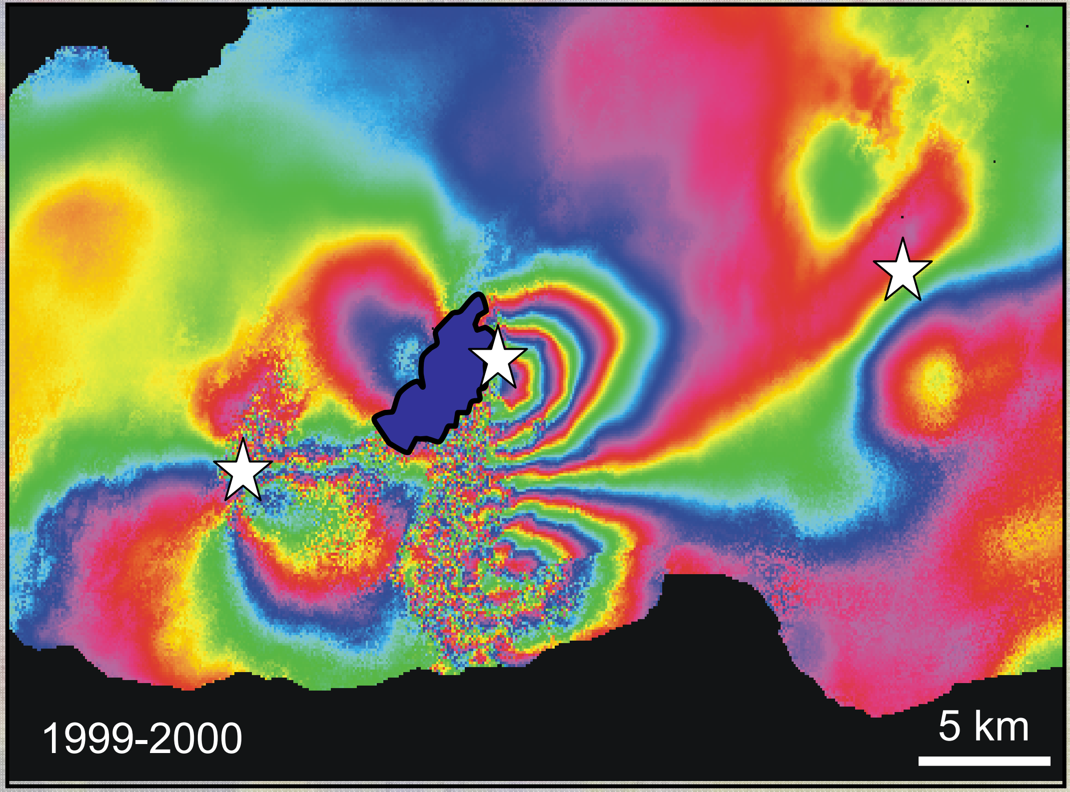
- Reykjanes Peninsula
  - Triggered seismic activity following the SISZ events
  - Plate spreading
  - Subsidence due to geothermal pressure decrease



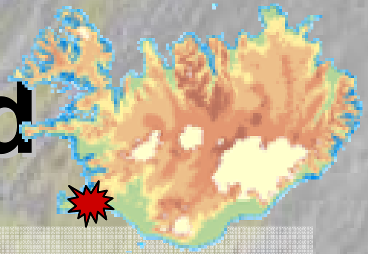
InSAR applications in Iceland



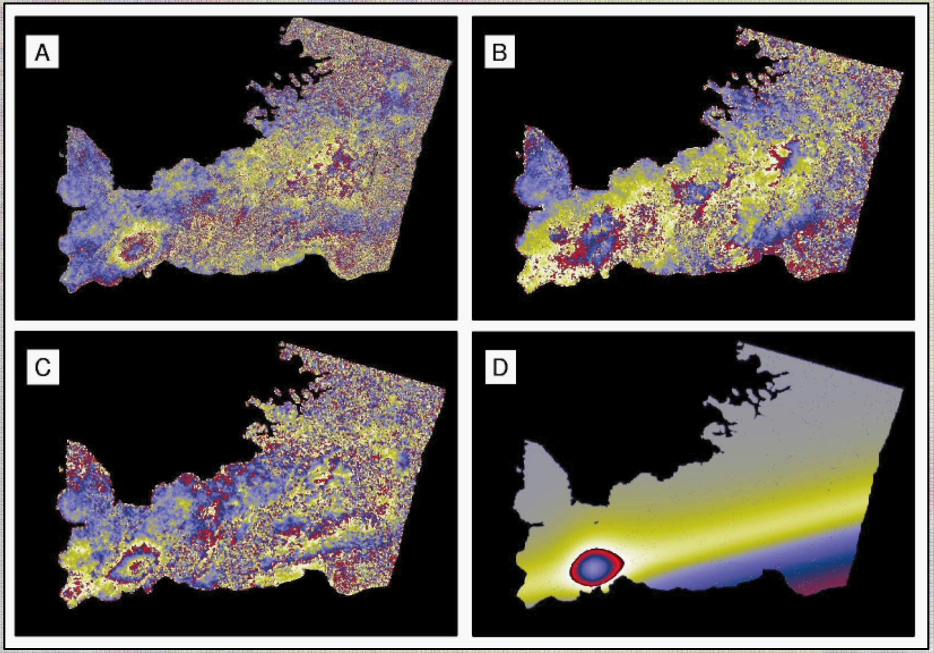
- Reykjanes Peninsula
  - Three triggered earthquakes
  - Magnitudes all about 5
  - Modeling indicates that one event had an aseismic component



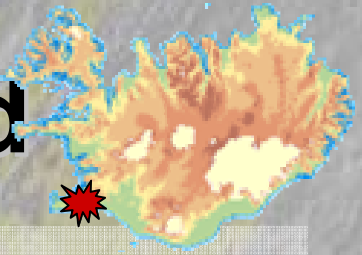
InSAR applications in Iceland



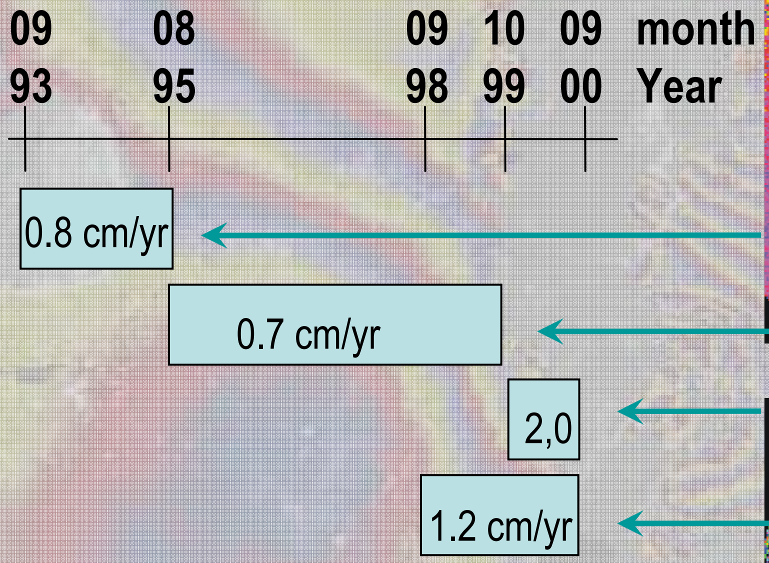
- Reykjanes Peninsula
  - Oblique plate spreading
    - Plate boundary locked at ~5 km depth
    - Ductile flow at greater depth
  - Not fully balanced by inflow of magma
    - subsidence at the plate boundary (6.5 mm/yr)

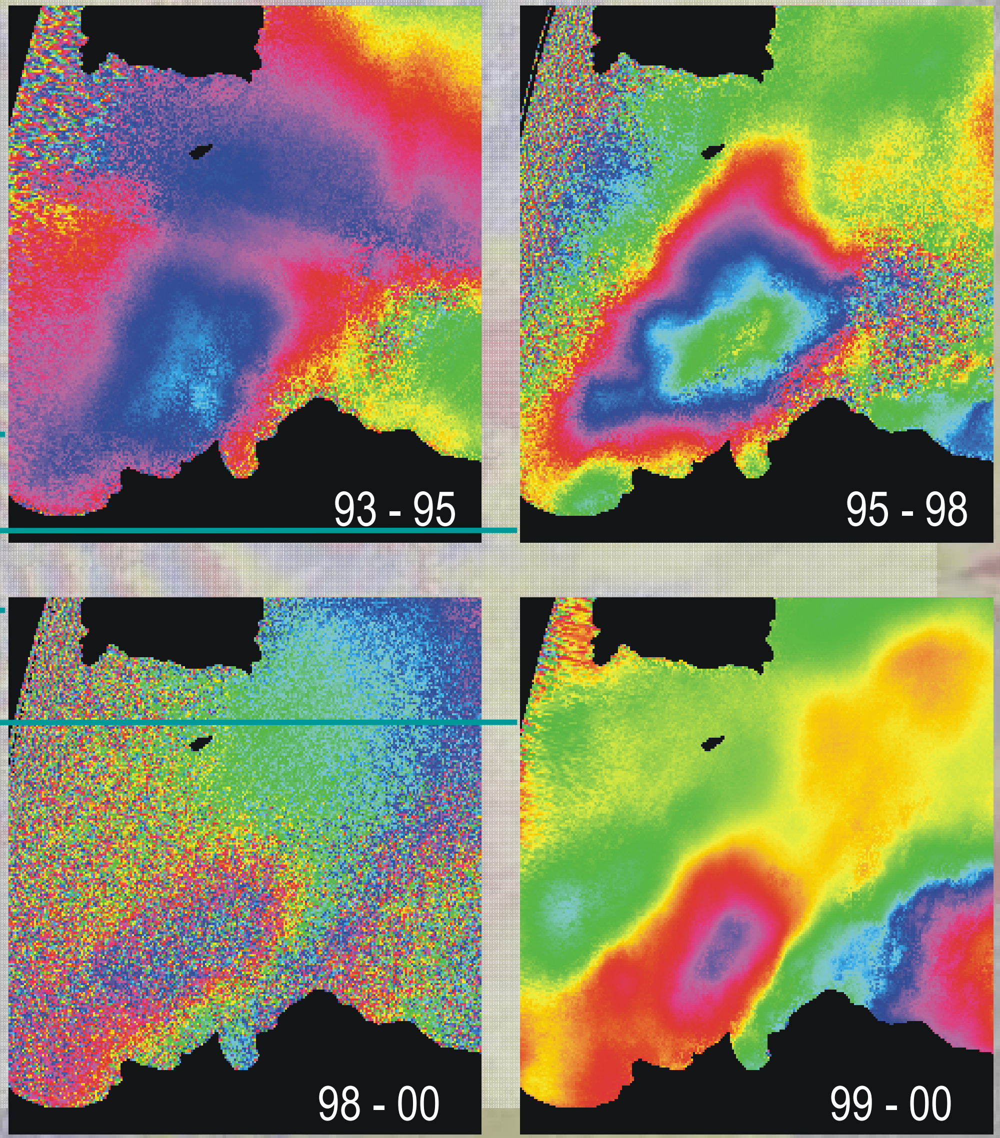


InSAR applications in Iceland



- Reykjanes Peninsula





Different subsidence rates due to increased exploitation

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THANK YOU