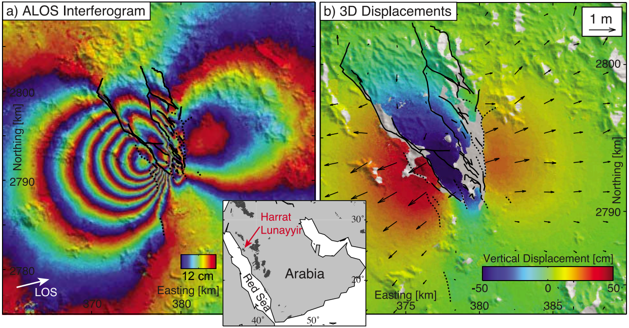


Dyke intrusion in Saudi Arabia 2009 (Jónsson, 2012)

InSAR in a Nutshell

Theory, Data Access and Data Processing

CATENA
CLIMATIC AND TECTONIC NATURAL HAZARDS IN CENTRAL ASIA

Federal Ministry of Education and Research

CLIENT II
International Partnerships for Sustainable Innovations

Sabrina Metzger

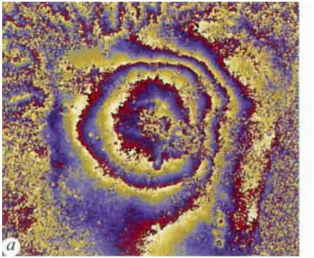
GFZ
Helmholtz-Zentrum Potsdam

Interferometric Synthetic Aperture Radar

- observe changes of the Earth's shape in high sensitivity
- rapid, high-resolution monitoring tool of remote areas
- "for free" (open-data, free software)

BUT data processing and interpretation is complex

⇒ Let's take a first step together!

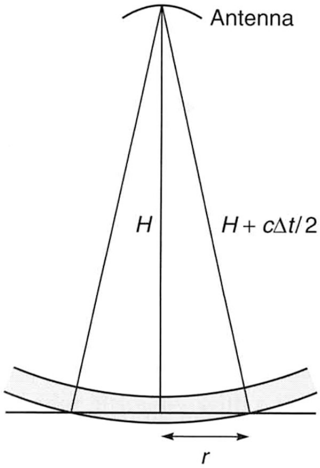


Do these fringes highlight
volcanic deformation or atmosphere?

(Massonnet et al., 1995)

Radar – **Ra**dio **D**etection **a**nd **R**anging

Concept



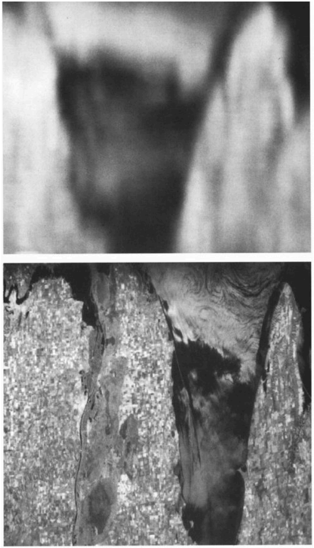
Radar altimetry concept (Rees, 2010)

- Antenna on satellite carrier emits and receives microwave very short pulses
- spherical pulse front, reflected on surface
- micro waves travel with light speed (300 000 km/s)

+ pulses penetrate clouds; no daylight needed

- pulses are delayed by air pressure and humidity changes

Synthetic **A**perture **R**adar (SAR)



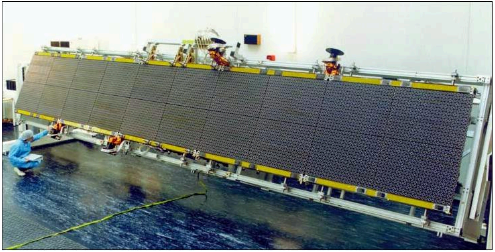
Top: radar, bottom: SAR (Massonnet & Feigl, 1998)

Synthetic Aperture means

1. radar pulse compression
2. using Doppler effects

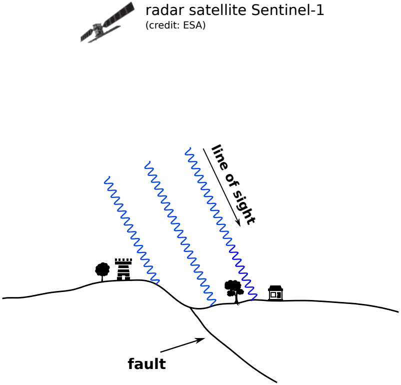
⇒ spatial data resolution is increased by 500-1000 (from km to m)!

(This has the same effect as using a 1000 x larger radar antenna!)



Radar antenna (10x1.3 m), (Photo: ESA)

Interferometry – Range change before/after event



$y_1 = |y_1|e^{i\phi_1}$ and $y_2 = |y_2|e^{i\phi_2}$ are the complex return signals from of SAR acquisitions. The interferometric phase difference is given by the complex multiplication,

$$y_{intf} = |y_1||y_2|e^{i(\phi_1 - \phi_2)}$$

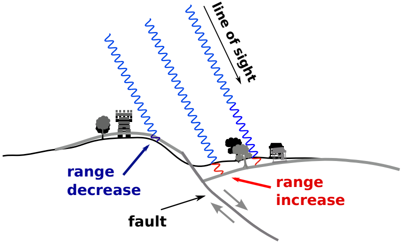
- Comparison of two data acquisitions with a time lag
- Phase difference $\delta\phi$ reveals deformation as function of time

Caveats:

- sensitive only along line-of-sight
- $\delta\phi$ is ambiguous and must be "unwrapped"
- interferogram represents topography, atmospheric condition and ground motion
- precipitation (snow, rain) and vegetation cause temporal decorrelation

Interferometry – Range change before/after event

radar satellite Sentinel-1
(credit: ESA)



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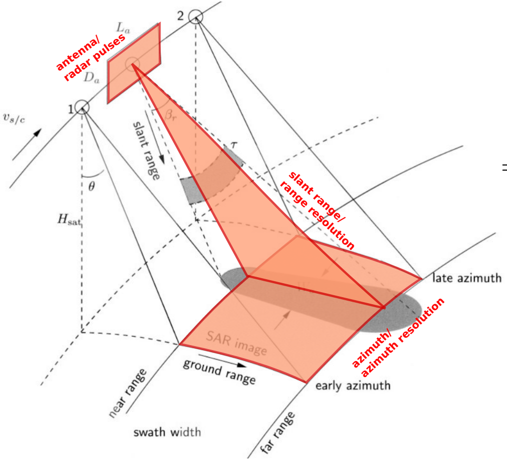
Radar coordinate system



Hanssen (2001)

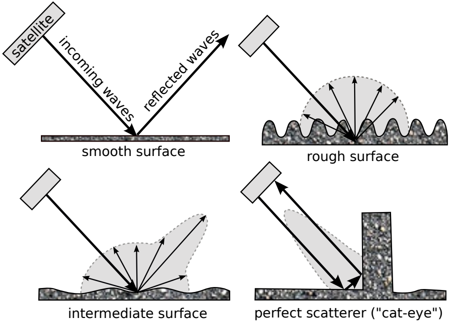
- The radar antenna is right-looking

$\Rightarrow$ Signals perpendicular to look direction remain undetected!

- SAR coordinate system is defined by
  - orbit flight direction $\sim 10^{\circ}$N
  - look angle $\sim 30^{\circ}$

SAR intensity image

Good back-scattering objects appear bright and dominate the respective pixel value, poor scatterers dark. InSAR works only with good (and stable!) scatterers.



What are good scatterers?

Stable, edgy objects (in green) provide a high interferometric signal quality

landslide

fields

churches

construction site

cars

glacier, mountains

rock falls

rock glaciers, riverbeds

snow / rivers

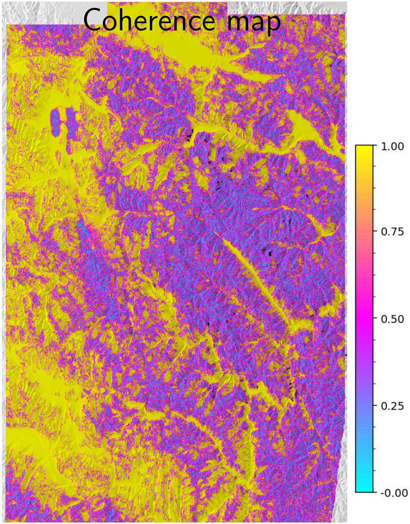
trains

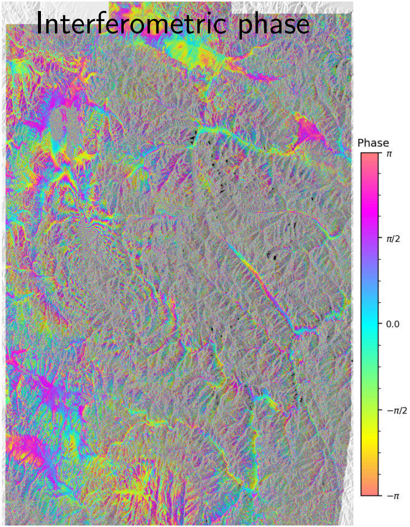
lava flows

forests / lakes

(photos: flickr cc)

Coherence – Measure of "cell stability"





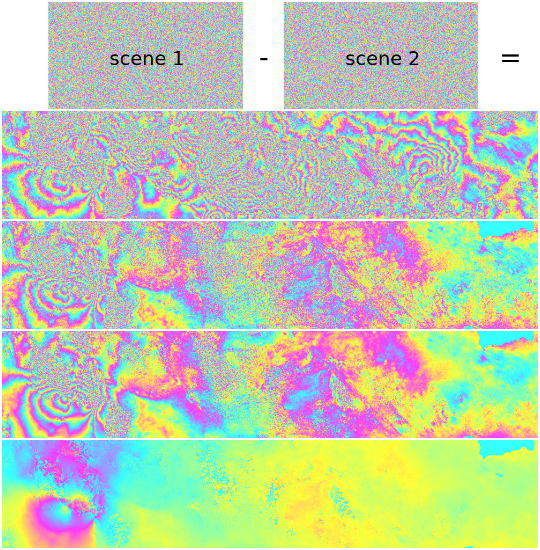
The coherence is an interferometric quality measure. Stable objects on the ground provide a high coherence. This is a prerequisite for correct unwrapping.

From SAR to InSAR

Main processing steps

1. **Coregistration**: Perfect alignment (sub-pixel accuracy!) of before- and after-SAR image
2. **Interferometry**: Calculate phase difference for each pixel
3. **Topographic signal removal** using a digital elevation model
4. **Subsampling ("multi-looking")**: Noise suppression and size reduction
5. **Filtering**: Further noise suppression, e.g. using adaptive phase filter
6. **Unwrapping**: "Uncoil" the signal and eliminate ambiguity
7. **Geocoding**: Coordinate transformation into WGS1984, UTM etc.

Processing example



random phases of two SAR images

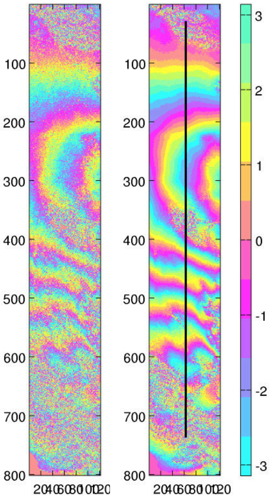
Raw interferogram

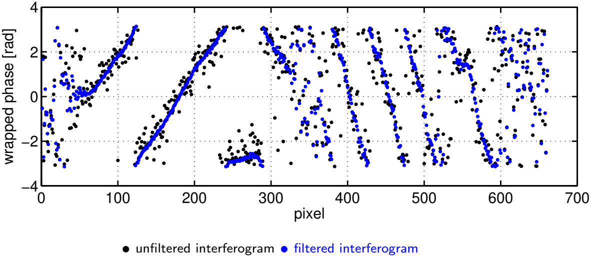
After DEM removal

After filtering

After unwrapping

Phase unwrapping



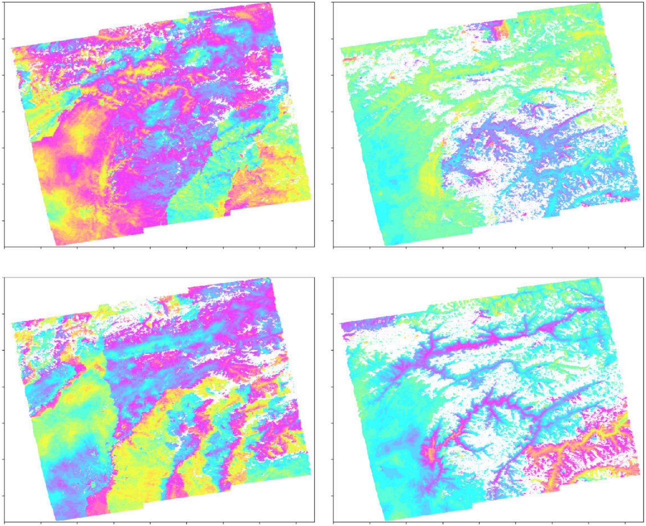


- The interferometric signal is "wrapped", similar to contour lines in elevation plots
- One "fringe" (phase cycle) corresponds to half a wavelength ($\lambda/2$) range change (Sentinel-1: $\lambda = 5.6$cm)

$\Rightarrow$ Signal must be "unwrapped" to obtain the full amount of displacement, i.e. shift neighboring points by a multitude of 2π.

Unwrapping error examples

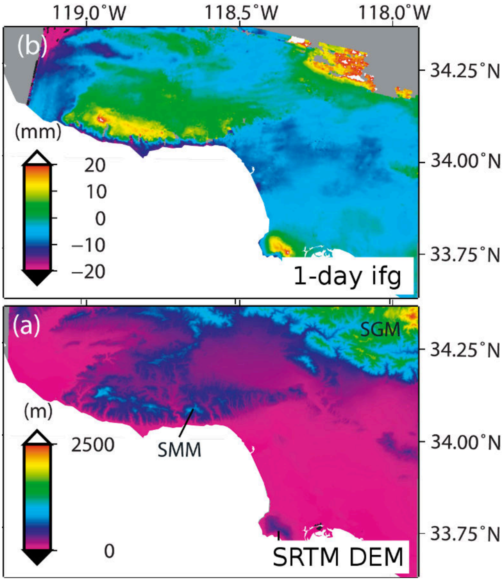
Block-like color chunks, elevated by N·2π



Atmospheric delay signal

1-day interferogram of Los Angeles (US)

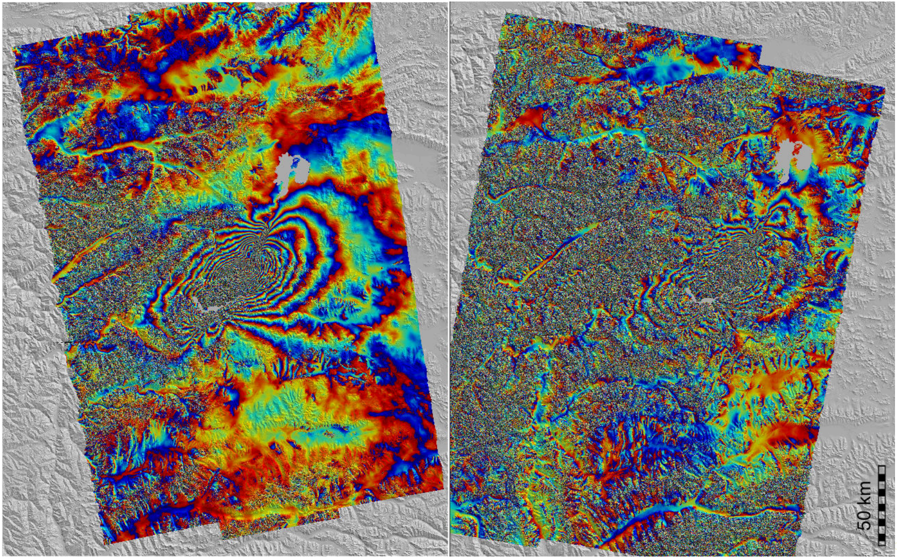
- no surface displacement expected, but
- atmospheric signal (mm to cm), depending of
  1. topography
  2. water vapour/air pressure
- mitigate atmospheric impact using weather models



Li et al., 2006

Interpretation Example

Identify ground motion signals



Interpretation Example

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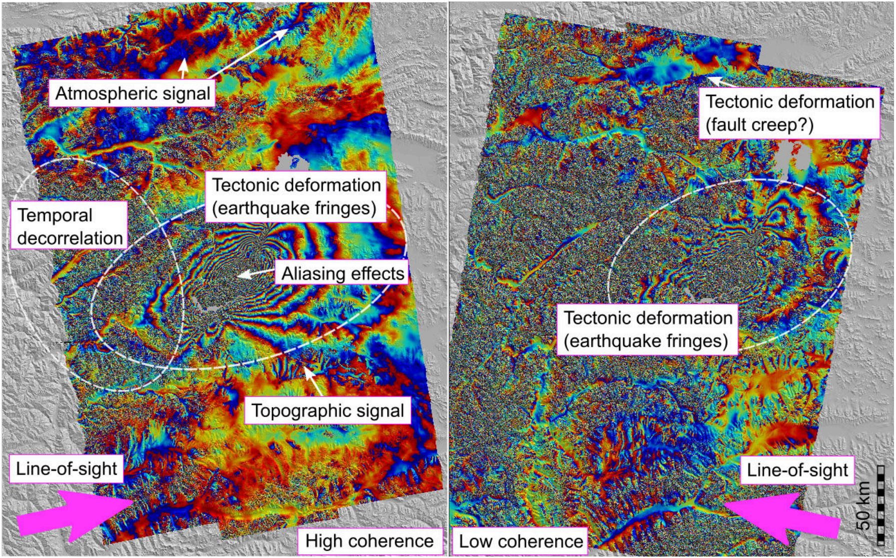


Take-home messages

- Interferometric phase differences of before/after-event radar image pairs show changes of the Earth's surface **in multitudes of half a wavelength**
  (Sentinel-1: 2.8 cm per fringe)
- These observations are **one-dimensional and in range direction** ("line-of-sight") of the radar satellite only
- Prerequesites are **stable back-scatter conditions** on the ground; snow and vegetation cause data decorrelation. Coherence measures the data quality.
- Interferograms also mirror **atmospheric conditions** (water vapor, air pressure) **and the topography leading to false interpretation**. These impacts are mitigated using weather and elevation models or time-series analysis.
- Today, many radar data are **freely available** (e.g. ESA Sentinel-1) and can be processed "at home"...

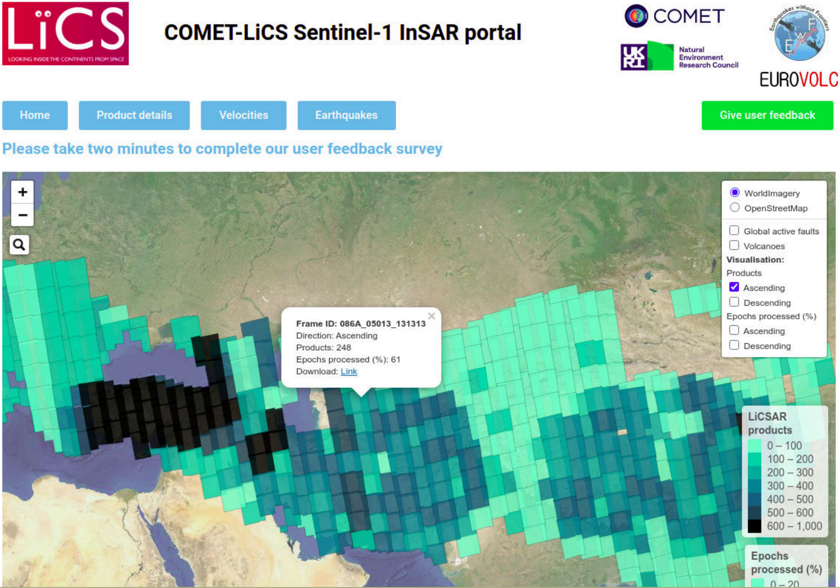
...therefore, start working with InSAR data!

A) **Interferogram interpretation**: Download pre-processed interferograms from the LiCSAR-server as geotiffs and feed them into your ArcGIS/GEarth!

B) **Interferogram formation**: Process your own interferogram from raw data using the open-source ESA Sentinel-1 toolbox!

C) **Time-series analysis**: Calculate your own InSAR time-series within one day! (Prerequisites: modern laptop, decent internet speed, 20GB disk space)

A) LiCSAR interferogram server



A) Download of interferograms, coherence and height maps

Index of /public/nceo_geohazards/LiCSAR_products/58/058A_05279_131311

Name	L
Parent Directory	
epochs/	20
interferograms/	20
metadata/	20

"interferogram": interferograms sorted by date1_date2; "metadata": height and coordinate information

Index of /public/nceo_geohazards/LiCSAR_products/58/058A_05279_131311/interferogr

Name	Last modified	Size	Description
Parent Directory		-	
20141009_20141102/	2020-04-29 17:03	-	
20141009_20141208/	2020-04-29 17:03	-	
20141009_20141220/	2020-04-29 17:04	-	
20141102_20141208/	2020-04-29 17:05	-	
20141102_20141220/	2020-04-29 17:05	-	
20141102_20150101/			
20141208_20141220/			
20141208_20150101/			
20141208_20150113/			
20141220_20150101/			
20141220_20150113/			
20141220_20150125/			
20150101_20150113/			
20150101_20150125/			
20150101_20150206/			

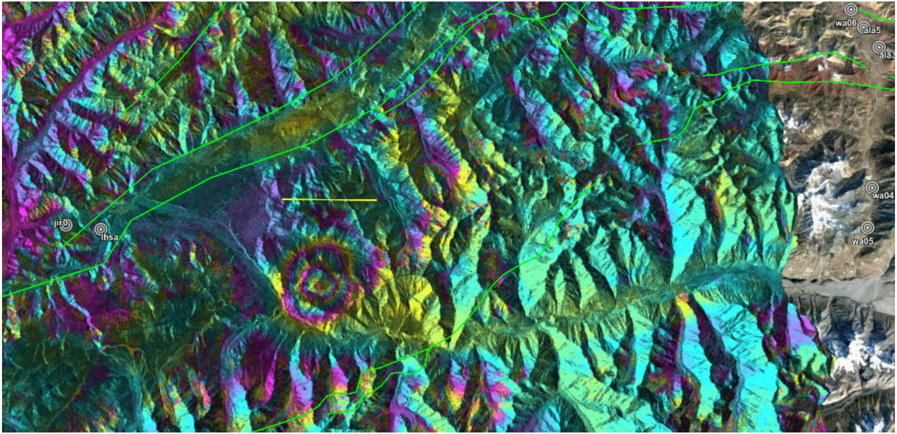
Index of /public/nceo_geohazards/LiCSAR_products/58/058A_05279_131311/

Name	Last modified	Size	Description
Parent Directory		-	
20180403_20180421.geo.cc.png	2019-10-13 21:43	477K	
20180403_20180421.geo.cc.tif	2019-10-12 14:21	4.9M	
20180403_20180421.geo.cc.tif.aux.xml	2019-10-22 18:09	360	
20180403_20180421.geo.diff.png	2019-10-13 21:43	1.3M	
20180403_20180421.geo.diff_pha.tif	2018-12-02 19:54	23M	
20180403_20180421.geo.diff_unfiltered.png	2020-04-29 21:41	1.3M	
20180403_20180421.geo.diff_unfiltered_pha.tif	2020-04-29 21:41	20M	
20180403_20180421.geo.unw.png	2019-10-13 21:43	1.3M	
20180403_20180421.geo.unw.tif	2018-12-02 19:54	26M	

"png": thumbnails; "cc": coherence; "diff": ifg before unwrapping; unw: ifg after unwrapping

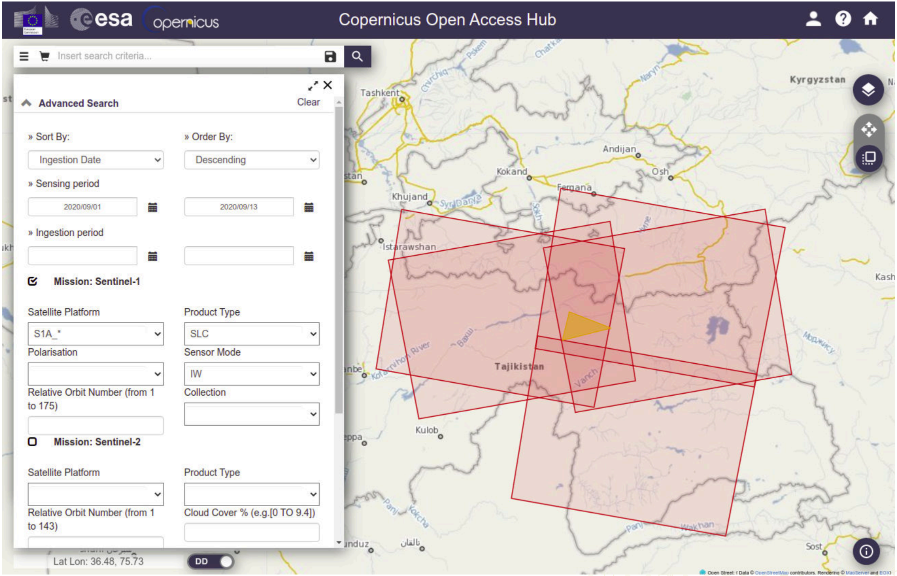
A) Visualisation in Google Earth

Freely available sources: ifg – LiCSAR; faults – CA Fault Database; earthquake kml – USGS



NB: LiCSAR interferograms are unwrapped automatically and thus contain unwrapping errors, looking like big color jumps!

B) Sentinel SAR raw data



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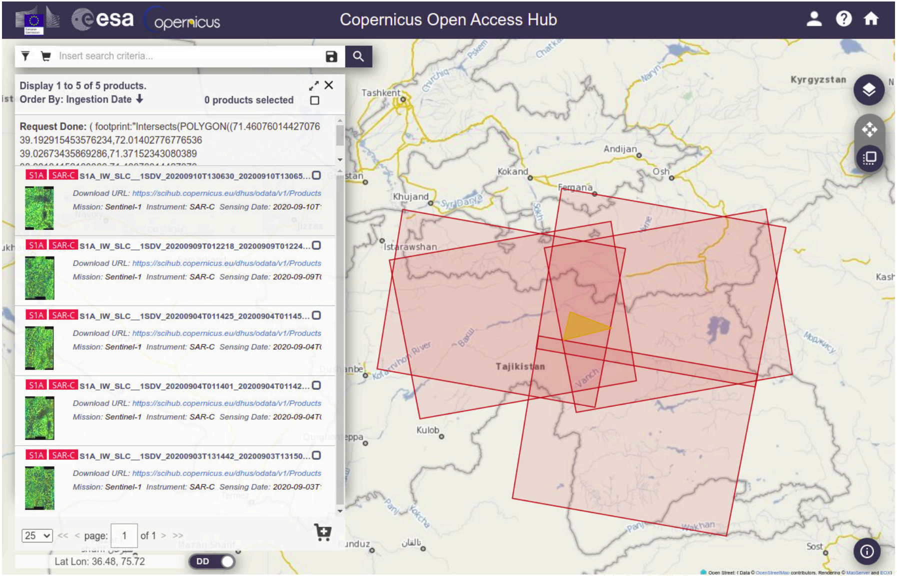

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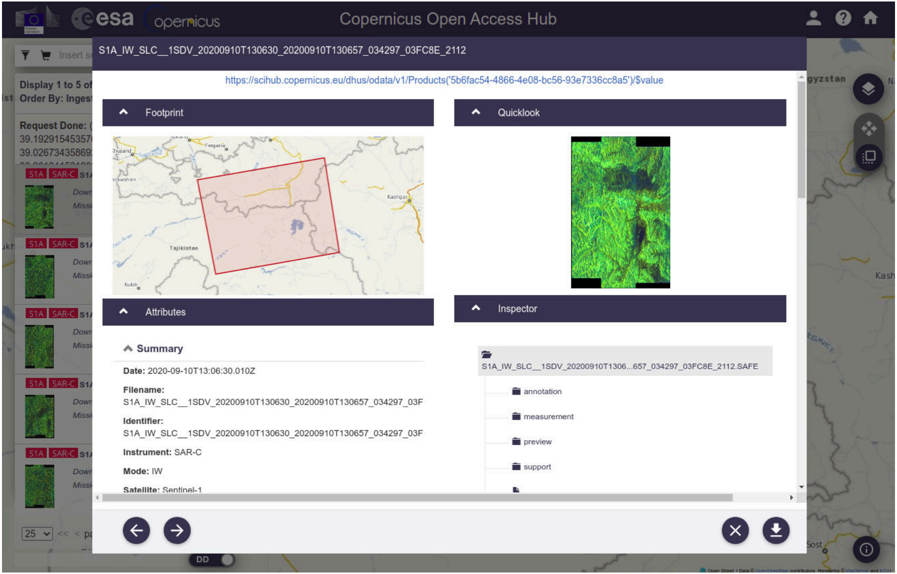


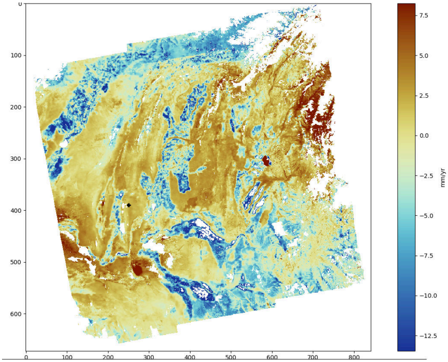
B) Calculate your own interferogram

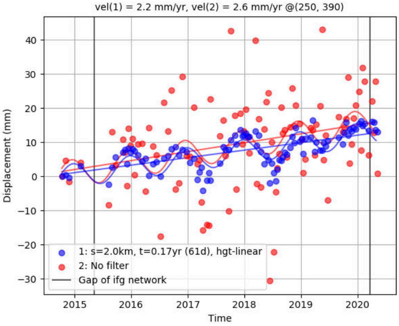
1. Install the ESA Sentinel-1 Toolbox on your computer [Link]
2. Create a user account on the ESA Open Data Hub. ([Link] The data can be downloaded here at the Alaska facilities (better for old data!), or directly in the toolbox.)
   Mandatory filter parameters are:
   - Mission: Sentinel-1 A or B
   - File type: SLC
   - Beam mode: IW (Interferometric Wide Swath)
   - Before/after scene must be of the **same** relative orbit number and polarization!
3. Follow the Toolbox Manual on how to process data [Link]
4. Find additional help on the ESA webpage an the forum [Link]
5. The fastest way is to first load zipped SLC data (File → Open Product) and then use a pre-defined processing chain that automatically performs all processing steps (Tools →GraphBuilder → File → Load Graph → TOPSAR Coreg Interferogram ML.xml), after you have filled in all processing parameters and hit the "Run" button.

C) Process your own time-series

The software automatically downloads pre-processed interferograms and performs a time-series analysis. Output format are geotifs. This approach is most suited for small-signals like subsidence and very fast.

- Install LiCSBAS-Software [Link]
- Follow LiCSBAS Manual





Literature

- Massonnet, D. and Feigl, K. L. (1998), Radar Interferometry and its application to changes in the earth's surface, Reviews of Geophysics, 36, 441-500 [Link]
- Hanssen, R. (2001), Radar Interferometry: Data and Error analysis, Kluwer academic publishers, ISBN 0-7923-6945-9 – 100+ EUR, very thorough
- ESA (2007): InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation (ESA TM-19) [Link]
- Uni Alaska, F. A. Meyer, open lecture material on SAR/InSAR [Link]
- UNAVCO, InSAR Course Materials [Link]
- Lu, Z. and Dzurisin, D. (2014), InSAR Imaging of Aleutian Volcanoes: Monitoring a Volcanic Arc from Space, Springer Praxis Books, ISBN 978-3642003479

Free SAR processing software

Data access

- ESA Scihub (Rolling Sentinel archive) [Link]
- ASF Hub (Full Sentinel archive, including older scenes) [Link]
- COMET-LiCS InSAR portal (pre-processed Sentinel-1 interferograms) [Link]
- Geohazard Exploitation Platform TEP [Link]

Interferogram formation

- STEP – Sentinel-1 tool box [Link] [Tutorial]
- GMTSAR – command line, GMT library [Link]
- ISCE – command line [Link]
- GAMMA – (at some costs!) command line, high-quality software [Link]

Time-series analysis

- LiCSBAS – command line [Link] [Tutorial]
- pyRATE – in python [Link]
- StaMPS – Matlab (Octave?) library [Link]