

Dyke intrusion in Saudi Arabia 2009 (Jónsson, 2012)

InSAR in a Nutshell

Theory, Data Access and Data Processing



CLIENT II
International Partnerships
for Sustainable Innovations

Sabrina Metzger

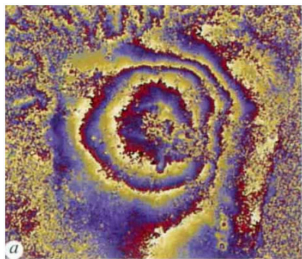


Interferometric Synthetic Aperture Radar

- 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!

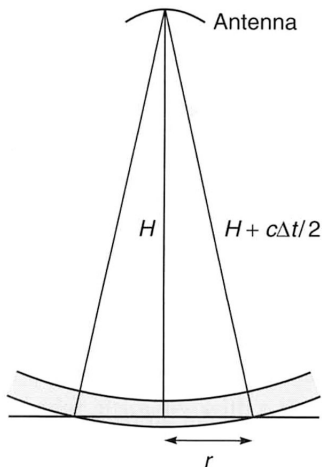


Do these fringes highlight
volcanic deformation or atmosphere?

(Massonnet et al., 1995)

Radar – Radio Detection and Ranging

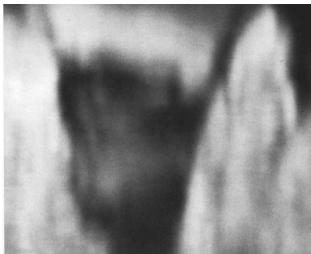
Concept



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 Aperture Radar (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!)

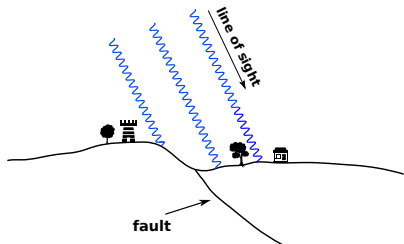


Radar antenna (10x1.3 m), (Photo: ESA)

Interferometry – Range change before/after event



radar satellite Sentinel-1
(credit: ESA)



$y_1 = |y_1|e^{i\phi_1}$ 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,

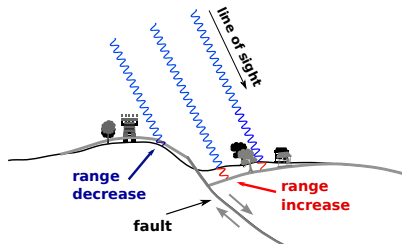
$$y_{intf} = |y_1||y_2|e^{i(\phi_1 - \phi_2)}$$

- 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

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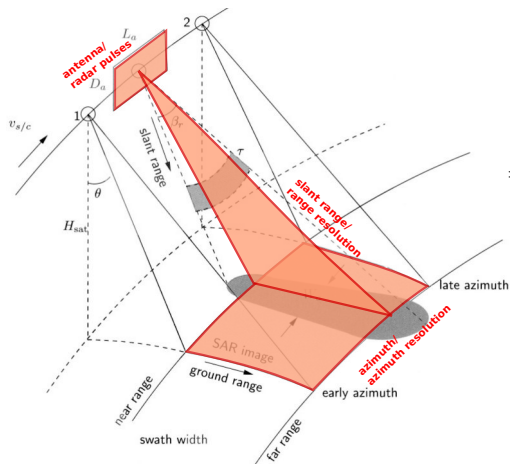
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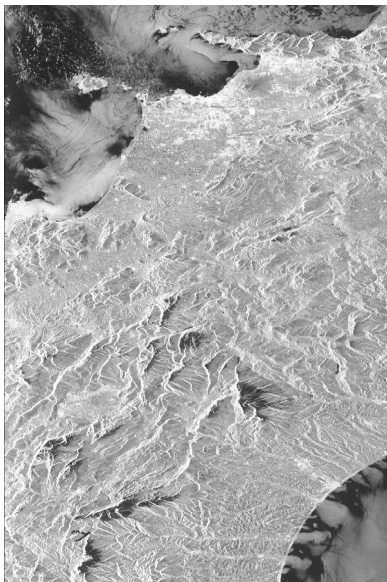
Radar coordinate system



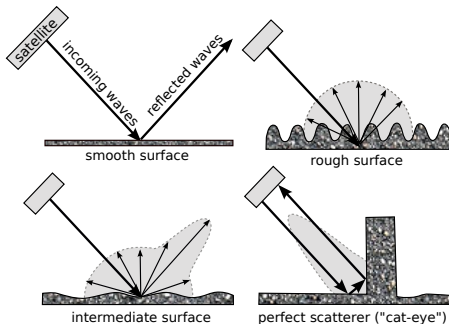
Hanssen (2001)

- The radar antenna is right-looking
- ⇒ 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

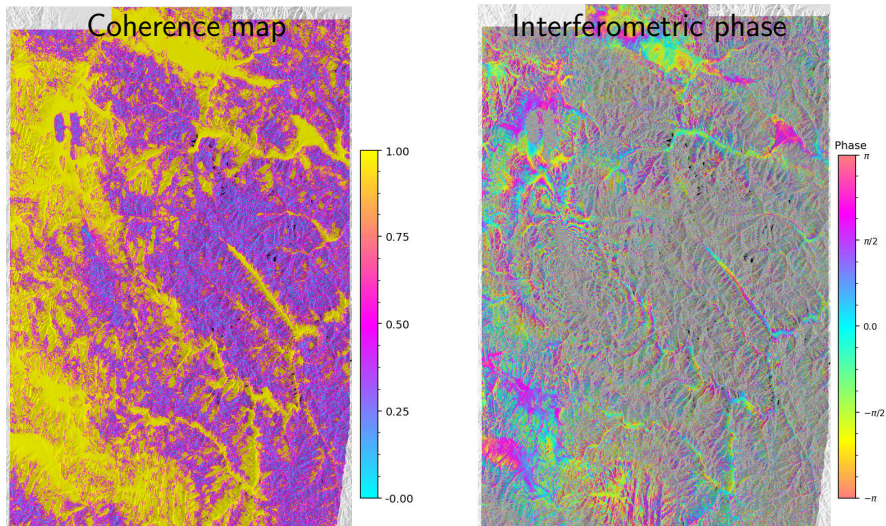


forests / lakes



(photos: flickr cc)

Coherence – Measure of “cell stability”



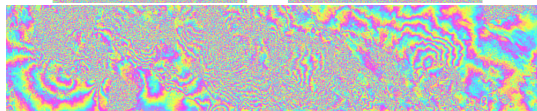
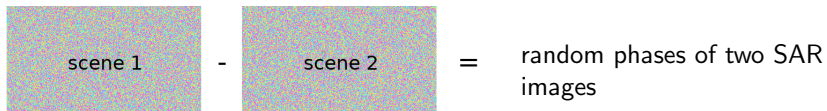
The coherence is an interferometric quality measure. Stable objects on the ground provide a high coherence. This is a prerequisite for correct unwrapping.

From SAR to InSAR

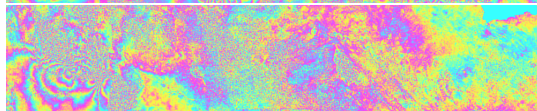
Main processing steps

- 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.

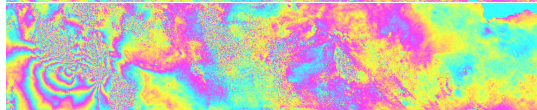
Processing example



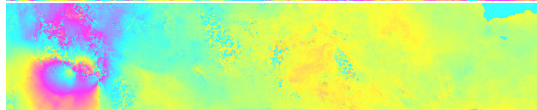
Raw interferogram



After DEM removal

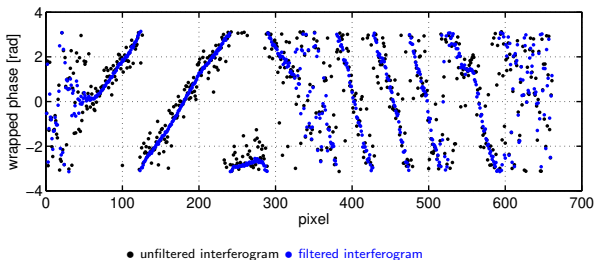
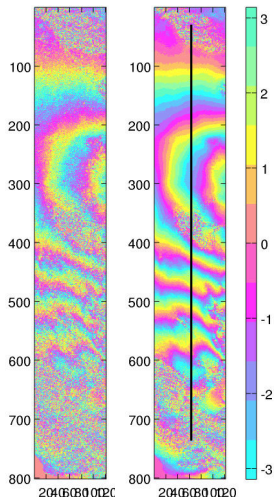


After filtering



After unwrapping

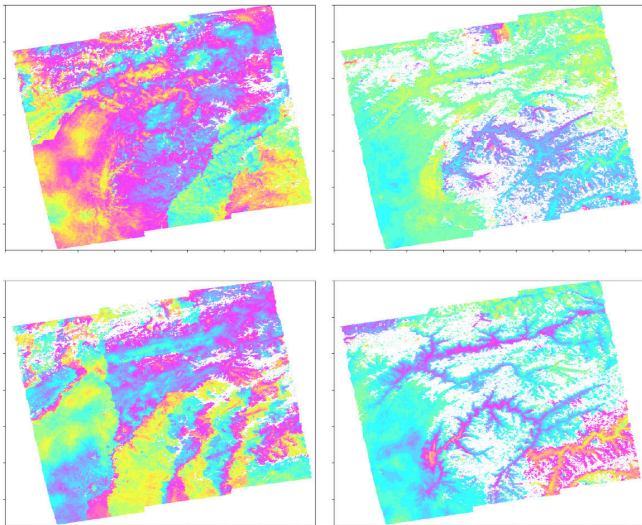
Phase unwrapping



- 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: $\lambda = 5.6\text{cm}$)
- ⇒ Signal must be “unwrapped” to obtain the full amount of displacement, i.e. shift neighboring points by a multitude of 2π .

Unwrapping error examples

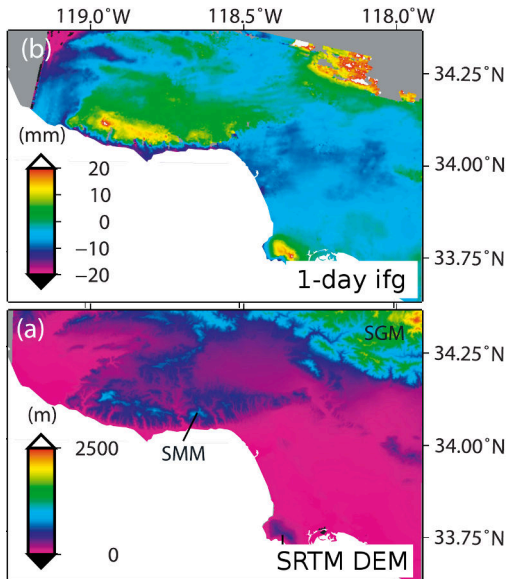
Block-like color chunks, elevated by $N \cdot 2\pi$



Atmospheric delay signal

1-day interferogram of Los Angeles (US)

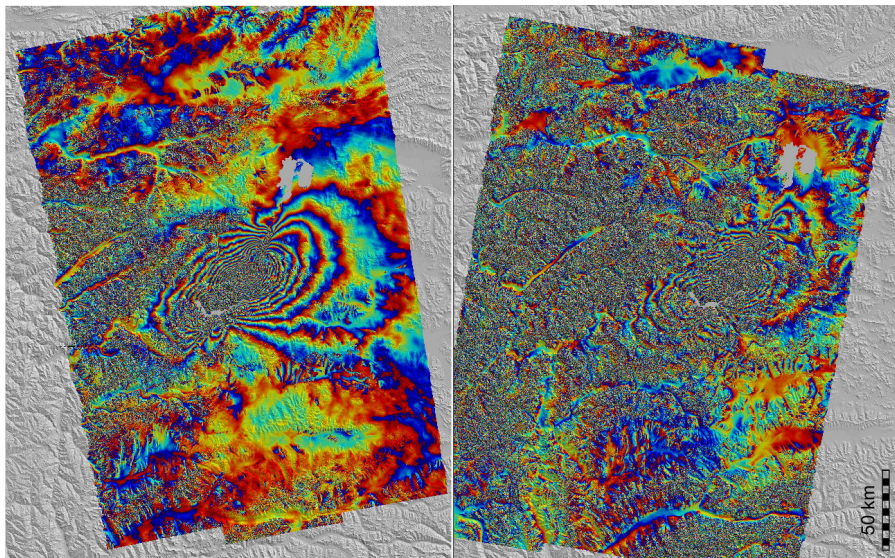
- no surface displacement expected, but
- atmospheric signal (mm to cm), depending of
 - ① topography
 - ② water vapour/air pressure
- mitigate atmospheric impact using weather models



Li et al., 2006

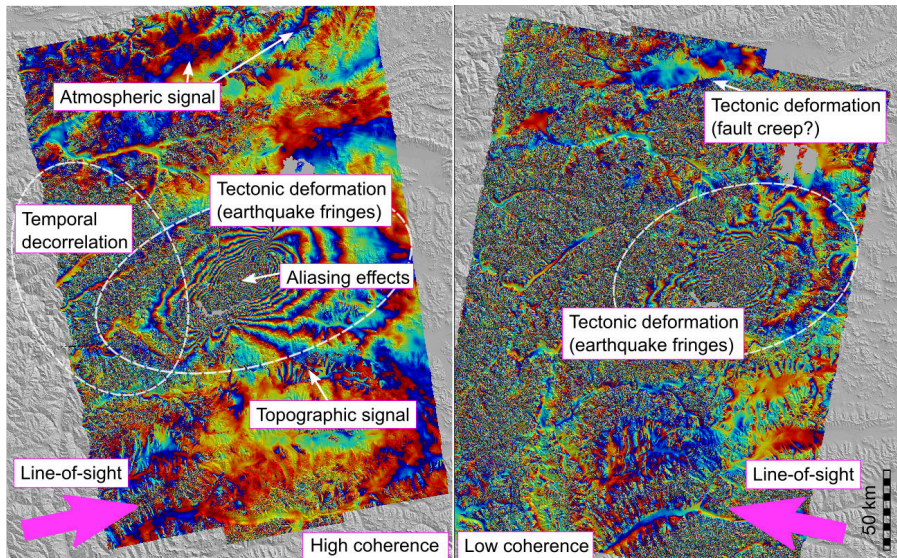
Interpretation Example

Identify ground motion signals



Interpretation Example

Identify ground motion signals



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
- Prerequisites 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



COMET-LiCS Sentinel-1 InSAR portal



EUROVOLC

Home

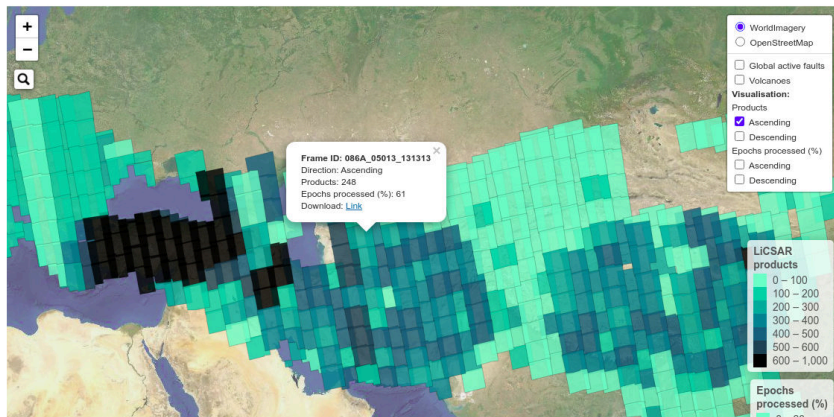
Product details

Velocities

Earthquakes

Give user feedback

Please take two minutes to complete our user feedback survey



A) Download of interferograms, coherence and height maps

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

Name	Index of
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/interferog

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/

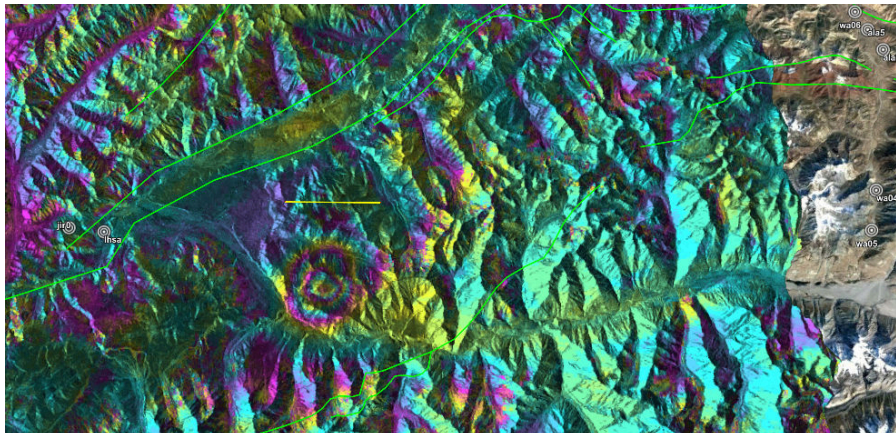
Name	Last modified	Size	Description
------	---------------	------	-------------

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

The screenshot displays the Copernicus Open Access Hub search interface. The top navigation bar includes the ESA and Copernicus logos, the text "Copernicus Open Access Hub", and user icons. A search bar at the top left contains the text "Insert search criteria...".

The "Advanced Search" panel on the left is expanded, showing the following filters:

- Sort By:** Ingestion Date
- Order By:** Descending
- Sensing period:** 2020/09/01 to 2020/09/13
- Ingestion period:** (empty)
- Mission:** Sentinel-1 (checked)
- Satellite Platform:** S1A_*
- Polarisation:** (empty)
- Relative Orbit Number (from 1 to 175):** (empty)
- Mission:** Sentinel-2 (unchecked)
- Satellite Platform:** (empty)
- Relative Orbit Number (from 1 to 143):** (empty)
- Product Type:** SLC
- Sensor Mode:** IW
- Collection:** (empty)
- Product Type:** (empty)
- Cloud Cover % (e.g. [0 TO 9.4]):** (empty)

The main map area shows a satellite image of Tajikistan with several red rectangular overlays representing SAR swaths. A yellow triangle on the map indicates the satellite's position. The map includes labels for cities like Tashkent, Andijan, Osh, Fergana, and Khujand, and rivers like the Syr Darya and Amu Darya. The bottom left corner shows the coordinates "Lat Lon: 36.48, 75.73".

B) Sentinel SAR raw data

The screenshot displays the Copernicus Open Access Hub interface. At the top, the ESA and OpenGIS logos are visible. The main header reads "Copernicus Open Access Hub". Below the header, there is a search bar with the text "Insert search criteria...".

The search results section shows "Display 1 to 5 of 5 products." and "Order By: Ingestion Date". It indicates "0 products selected". The first product is highlighted, showing a "Request Done" status with a footprint polygon. The product details include:

- Product ID: S1A_IW_SLC_1SDV_20200910T130630_20200910T13065...0
- Download URL: <https://scihub.copernicus.eu/dhus/odata/v1/Products>
- Mission: Sentinel-1 Instrument: SAR-C Sensing Date: 2020-09-10T13:06:30.000Z

Four other similar product entries are listed below, all with a sensing date of 2020-09-04T. Each entry includes a small thumbnail image of the SAR data and a download icon.

On the right side of the interface, a map of Tajikistan is displayed. The map shows several overlapping red rectangular swaths, representing the ground coverage of the SAR data. A yellow triangle on the map indicates the satellite's position and look angle. The map includes labels for cities like Tashkent, Andijan, Osh, and Fergana, and rivers like the Amu Darya and Syr Darya. The map also shows the borders of Kyrgyzstan and Kazakhstan.

At the bottom of the interface, there is a pagination control showing "page: 1 of 1" and a "DD" button. The map coordinates are displayed as "Lat Lon: 36.48, 75.72".

B) Sentinel SAR raw data

The screenshot displays the Copernicus Open Access Hub interface for Sentinel SAR raw data. The main content area is titled "S1A_IW_SLC_1SDV_20200910T130630_20200910T130657_034297_03FC8E_2112" and includes a URL: [https://scihub.copernicus.eu/dhus/odata/v1/Products\('5b6fac54-4866-4e08-bc56-93e7336cc8a5'\)/\\$value](https://scihub.copernicus.eu/dhus/odata/v1/Products('5b6fac54-4866-4e08-bc56-93e7336cc8a5')/$value). The interface is divided into several panels:

- Footprint:** A map showing the geographic footprint of the SAR data in Tajikistan, outlined in red.
- Quicklook:** A small thumbnail image showing a green and blue SAR image of the same area.
- Attributes:** A section containing a **Summary** with the following details:
 - Date:** 2020-09-10T13:06:30.010Z
 - Filename:** S1A_IW_SLC_1SDV_20200910T130630_20200910T130657_034297_03F
 - Identifier:** S1A_IW_SLC_1SDV_20200910T130630_20200910T130657_034297_03F
 - Instrument:** SAR-C
 - Mode:** IW
 - Satellite:** Sentinel-1
- Inspector:** A file tree view showing the structure of the data file: S1A_IW_SLC_1SDV_20200910T1306...657_034297_03FC8E_2112.SAFE, with subfolders for annotation, measurement, preview, and support.

The interface also features a left sidebar with a search bar, a list of data products, and a right sidebar with navigation icons. At the bottom, there are navigation arrows and a download icon.

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.)

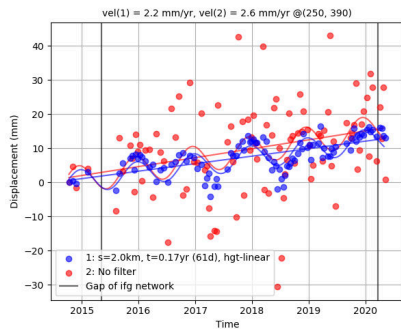
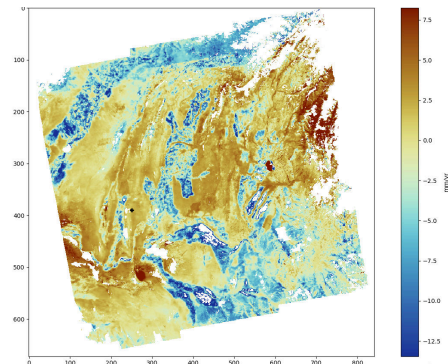
Mandatory filter parameters are:

- 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 [\[Link\]](#)