Bewegungsdetektion und -quantifizierung mittels InSAR (Satelliten-, UAV- und Bodengestützt)
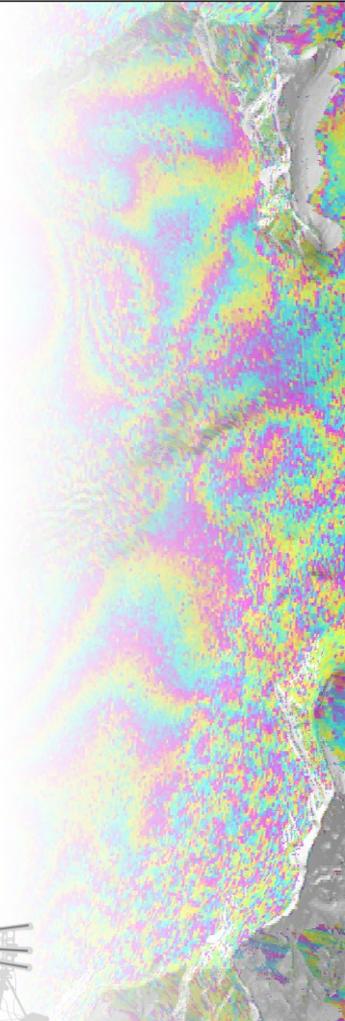## Stand der Entwicklung und Einsatzmöglichkeiten

Change detection and deformation monitoring using InSAR (spaceborne, UAV- and ground-based)
Current state of the art and field of application

Rafael Caduff & Urs Wegmüller

Gamma Remote Sensing AG, Gümligen, Switzerland - (caduff@gamma-rs.ch)

GAMMA REMOTE SENSING

- Nature cover with the co-seismic ERS-1 satellite interferogram of the 1992 Landers earthquake (California)

- Shows the displacement field in Line of sight in color cycles for each phase cycle of 28 mm (C-Band) -> at least 560 mm shift in range

- **Start of an increasing width of applications in surface deformation monitoring**

Massonnet, D., Rossi, M., Carmona, C. et al. The displacement field of the Landers earthquake mapped by radar interferometry. Nature 364, 138–142 (1993). https://doi.org/10.1038/364138a0
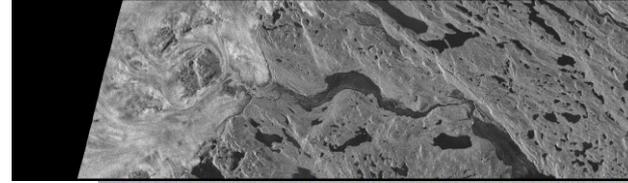
25 km
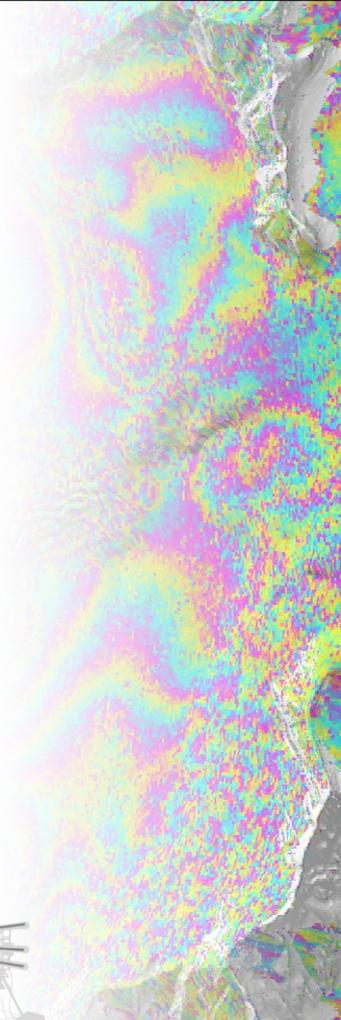
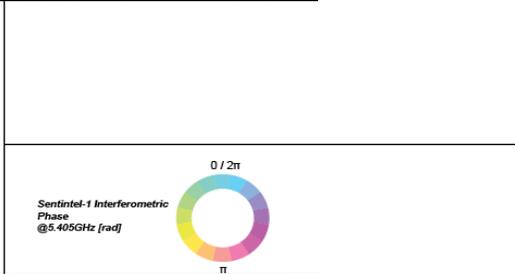**Active** microwave sensor

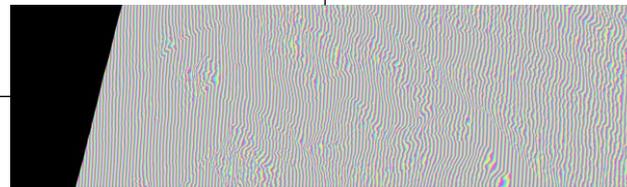Backscatter **magnitude**

T_0

Coherent **phase**

T_1

Complex valued SAR Image

GAMMA REMOTE SENSING
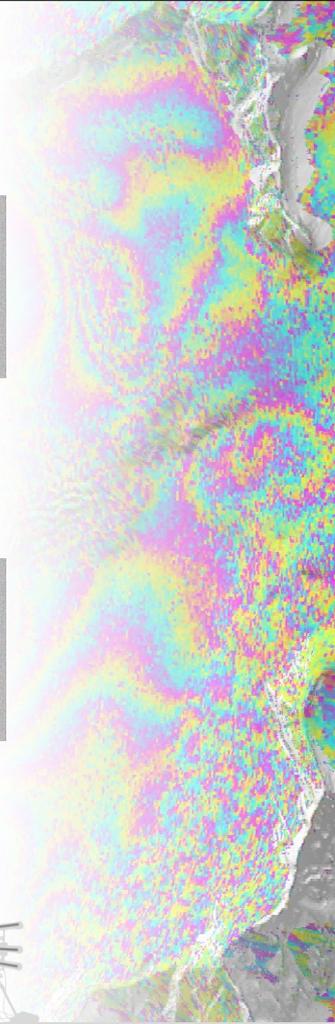
$$\varphi_{int} = \varphi_{topo} + \varphi_{atmo} + \varphi_{disp} + \varphi_{noise}$$

DEM elevation

+500 m

Simulated topographic phase (*φ topo*)

Sentintel-1 Interferometric
Phase
@5.405GHz [rad]

0 / 2π

π

- Calculation based on digital elevation model (DEM) and perpendicular baseline (distance between the two satellite tracks) that is calculated from the satellite orbit state vectors.

Differential Interferogram

GAMMA REMOTE SENSING

$$\varphi_{int} = \cancel{\varphi_{topo}} + \boldsymbol{\varphi}_{\mathbf{atmo}} + \varphi_{disp} + \varphi_{noise}$$
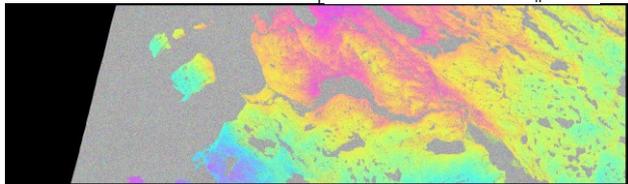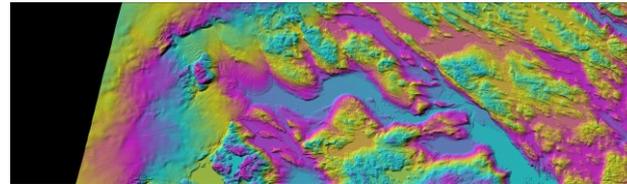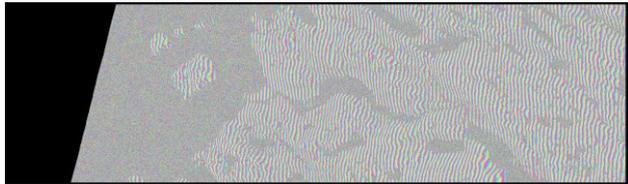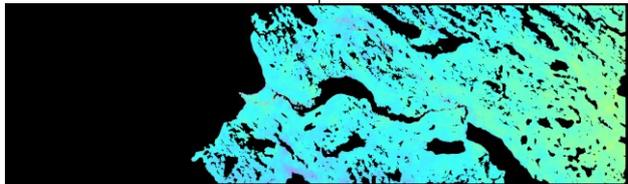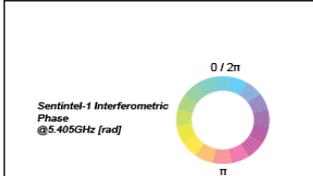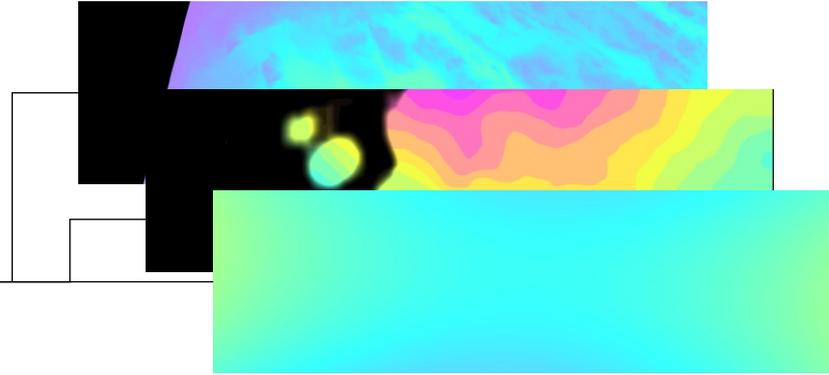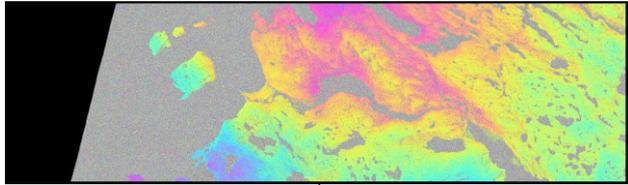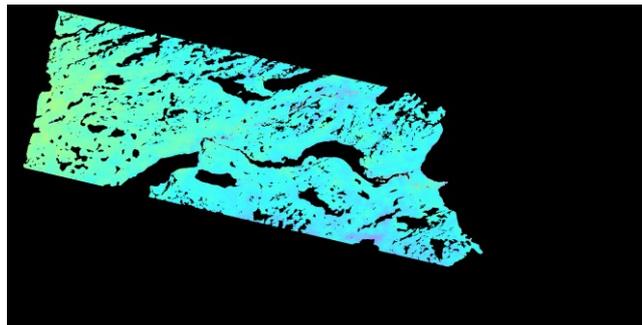

Filtered Differential Interferogram

Simulated atmospheric and ionospheric phase (φ atmo)

- Iterative calculation based on

GAMMA REMOTE SENSING

$$\varphi_{int} = \cancel{\varphi_{topo}} + \cancel{\varphi_{atmo}} + \boldsymbol{\varphi}_{disp} + \varphi_{noise}$$
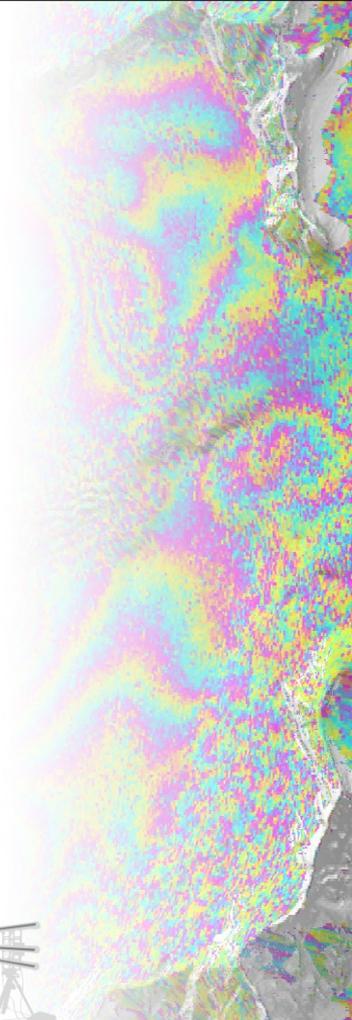
Point displacement time-series
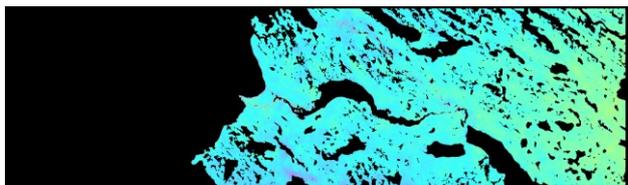
Geocoded filtered differential Interferogram
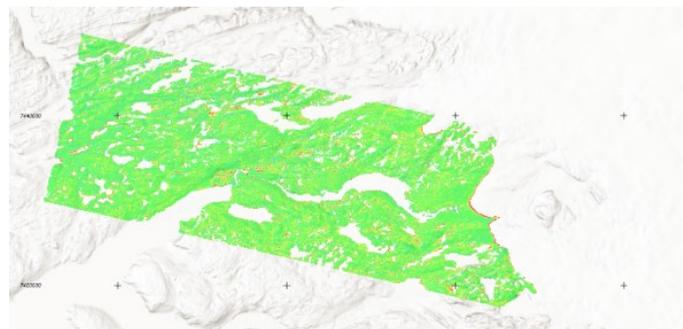
Line-of-sight displacement map

GAMMA REMOTE SENSING
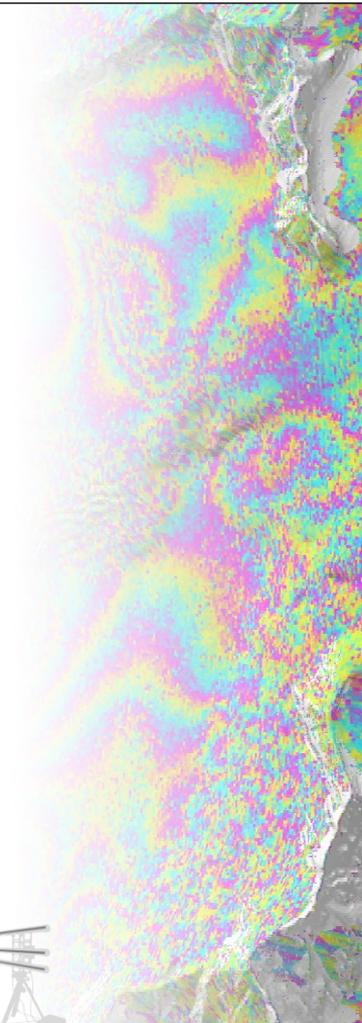
Radar interferometry is **active sensing method** with which it is possible to detect and **quantify relative ground motion along the line of sight**.

- Precision

Depends on the used wavelength, the number of acquisitions, the ground cover properties and the kinematic of the motion.
A precision of **1 mm/yr** can be achieved (for X- and C-Band).

- Spatial ground resolution

Highest resolutions of **50x50 cm** can be achieved (with staring-spotlight mode) with the downside of drastically reduced coverage. Sentinel-1 IW Mode for Global coverage has **20x5 m** nominal image resolution.

- Repeat intervals

Repeat intervals depend on the orbit. Interferometric applications need repeat paths that are as close together as possible. Repeat orbits of **35 days** were used for ERS, Sentinel-1 constellation of A and B has **6 day** repeat cycle. Commercial constellations can achieve programmed repeat intervals of **less than 1 day**.
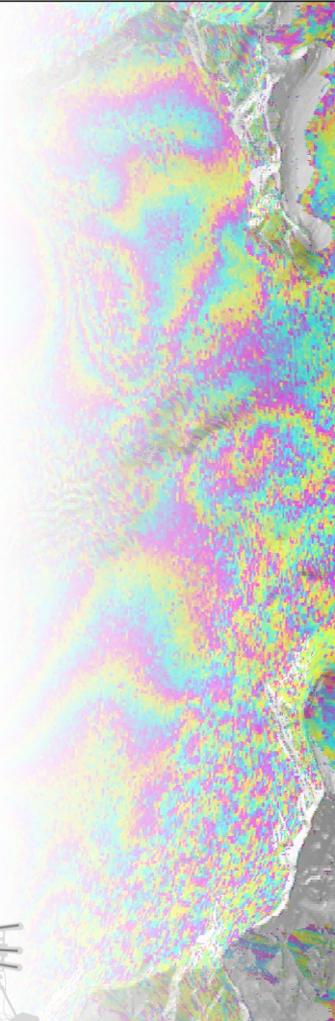
- Costs

Public missions deliver **data free of charge** (esa missions), commercial data takes can cost **few thousand $ each image**.
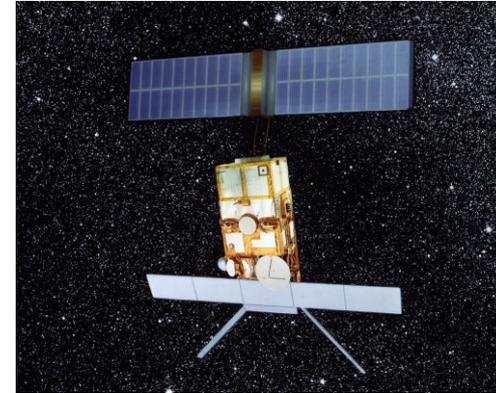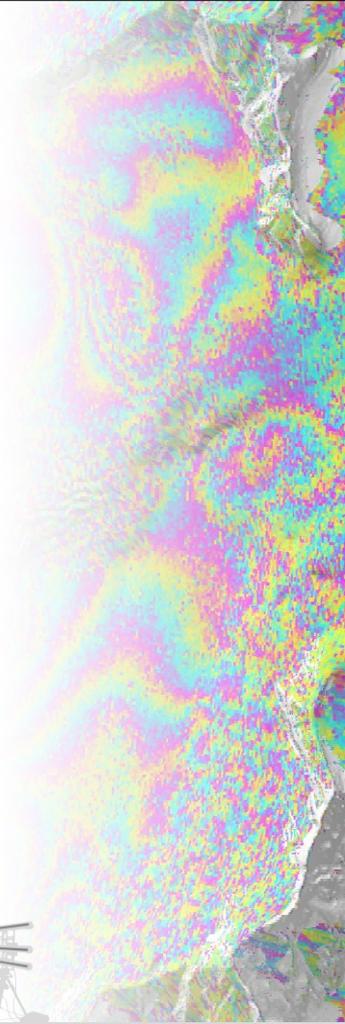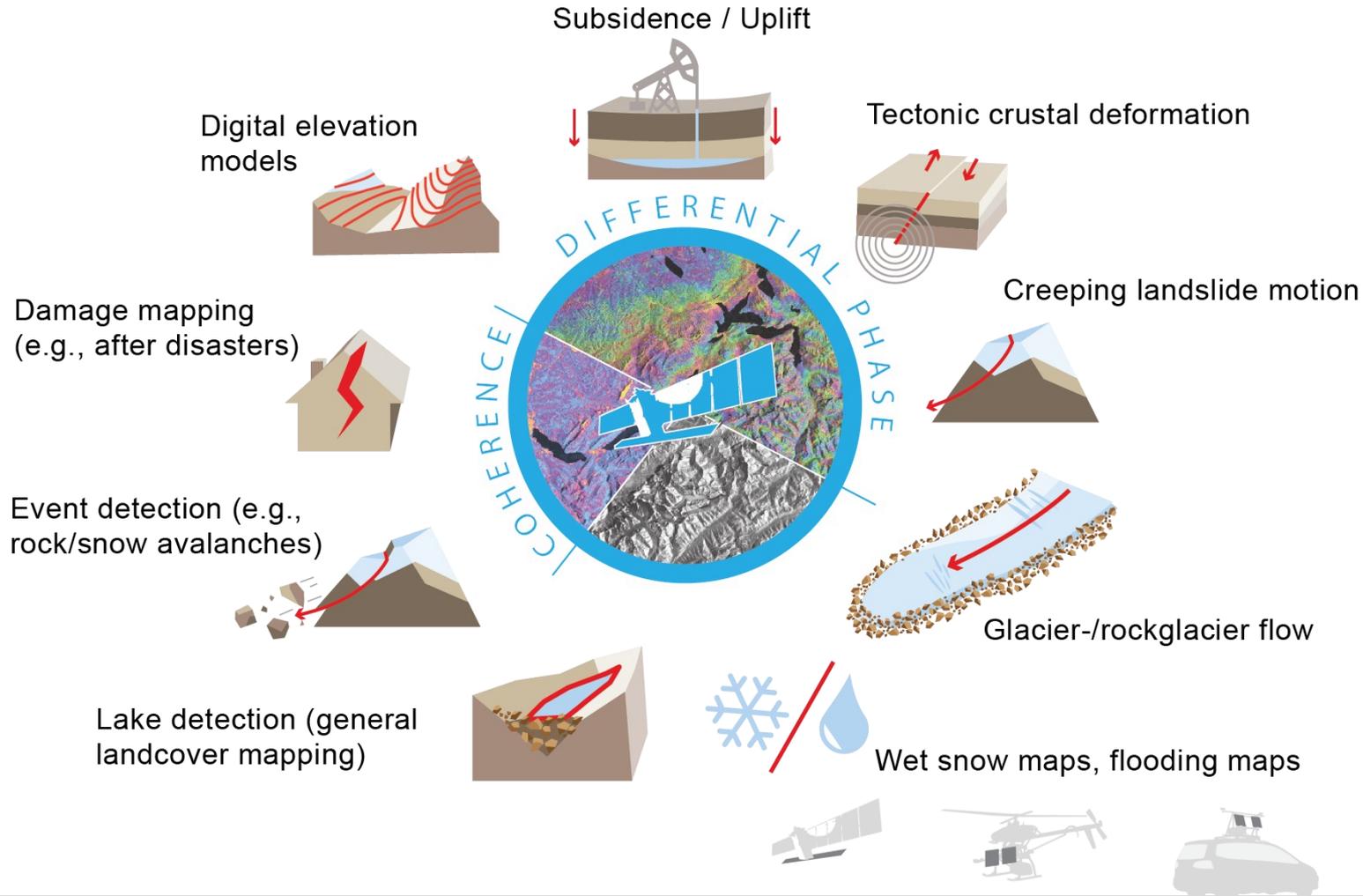

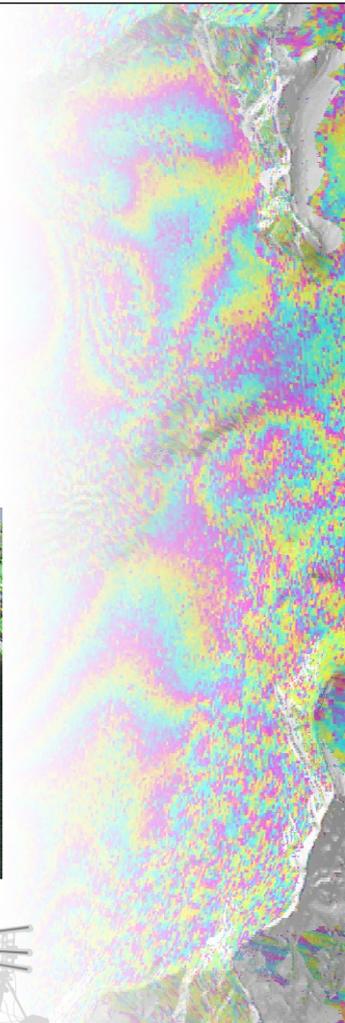ERS-1 (Launch 1991) © esa

Sentinel-1 (Launch 2014) © esa

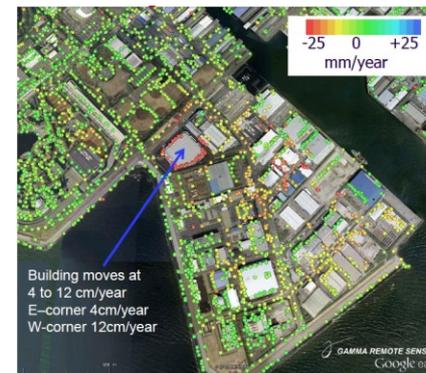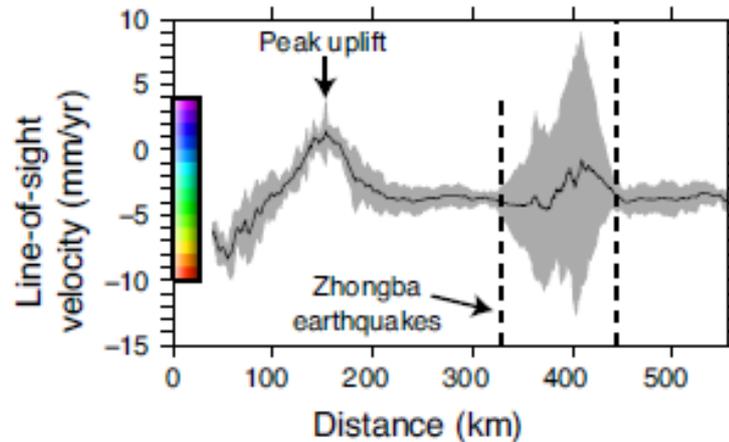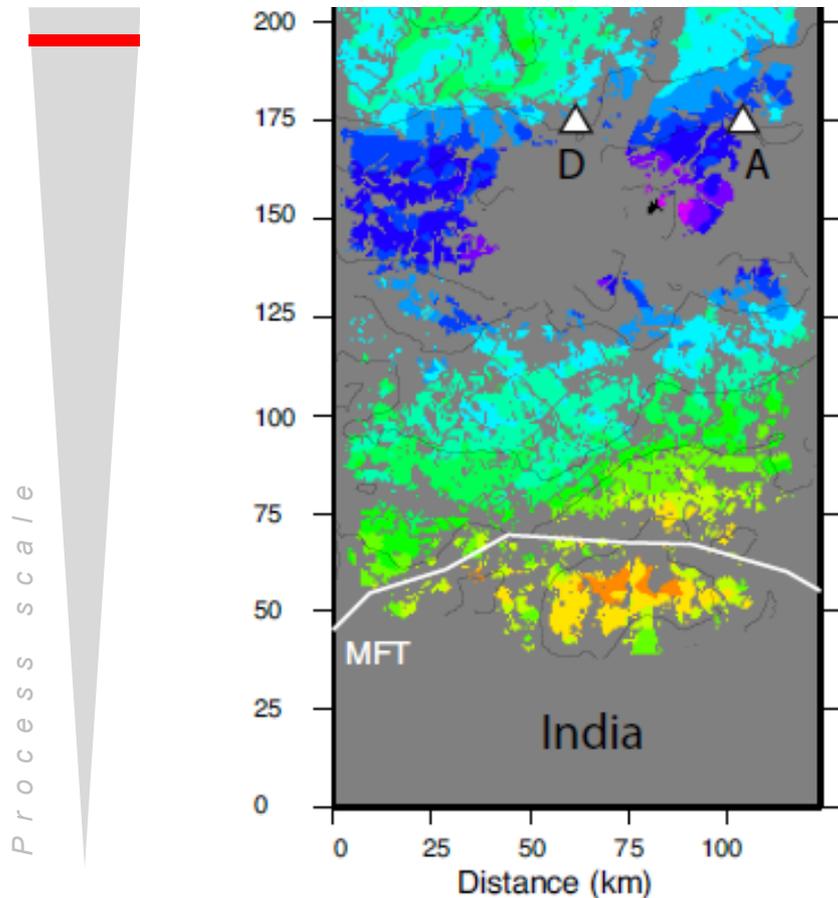# InSAR – Broad Field of Applications

GAMMA REMOTE SENSING

Process scale

- Creeping tectonic motion (tectonic uplift)

- Crustal deformation (earthquakes)

- Large scale ground subsidence

- Glacier motion (e.g. with tracking)

- Landslide Motion

- Urban area deformation monitoring

Ground Motion Service Germany

Grandin, R., Doin, M.-P., Bollinger, L., Pinel-Puysségur, B., Ducret, G. ,et al.
Long-term growth of the Himalaya inferred from interseismic InSAR
measurement. Geology, Geological Society of America, 2012, 40 (12),
pp.1059 - 1062. 10.1130/G33154.1

Process scale

Envisat data (©2011 ESA
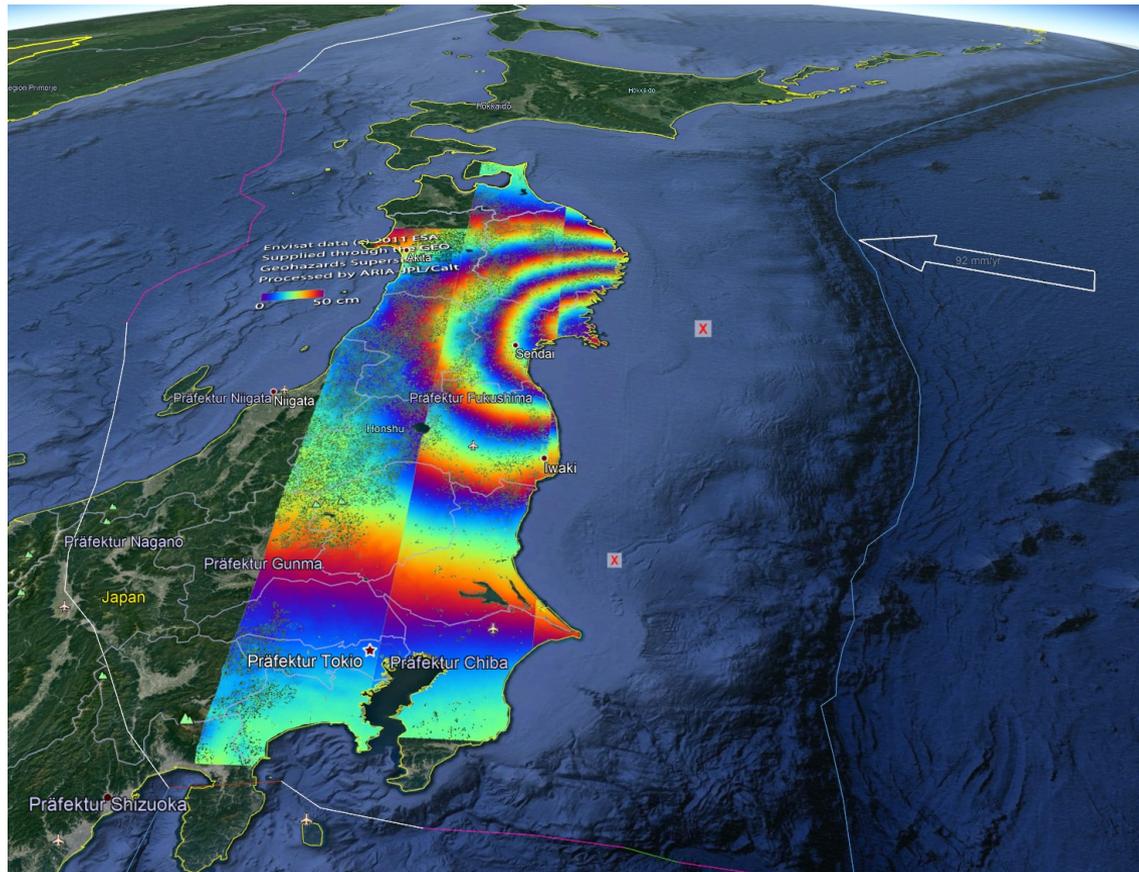Supplied through the GEO
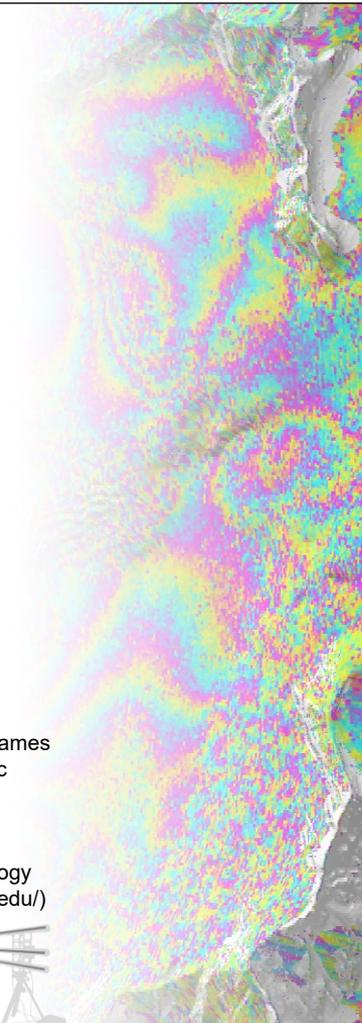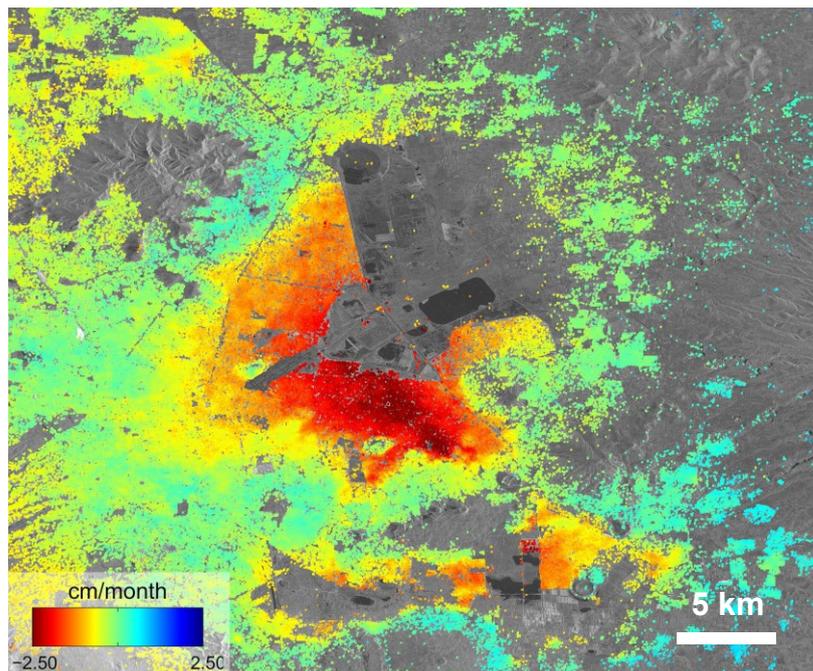Geohazards Supersites
Processed by ARIA JPL/Calt

0   50 cm

92 mm/yr
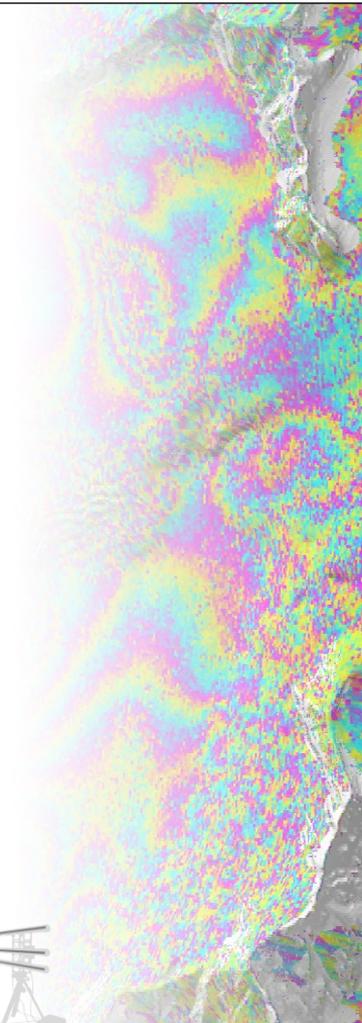
Mw 9.1 Tohoku-Oki Japan
earthquake captured with 3 frames
of ENVISAT ASAR co-seismic
interferograms

© Tectonics Observatory ::
California Institute of Technology
(http://www.tectonics.caltech.edu/)
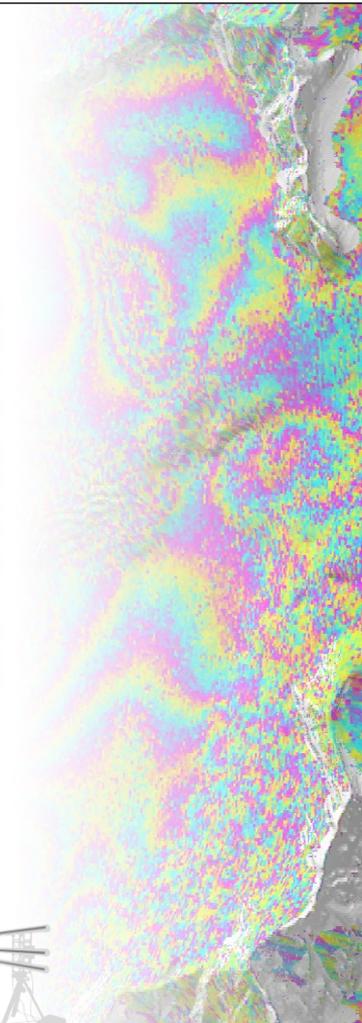
Process scale

cm/month

−2.50   2.50

5 km

Mexico City ground subsidence measured using 5 Sentinel-1 scenes in 2014
© Copernicus data (2014)/ESA/DLR Microwave and Radar Institute–SEOM InSARap study
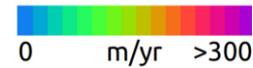

Gotthard Base Tunnel

5 km

0   +7 [mm/yr]
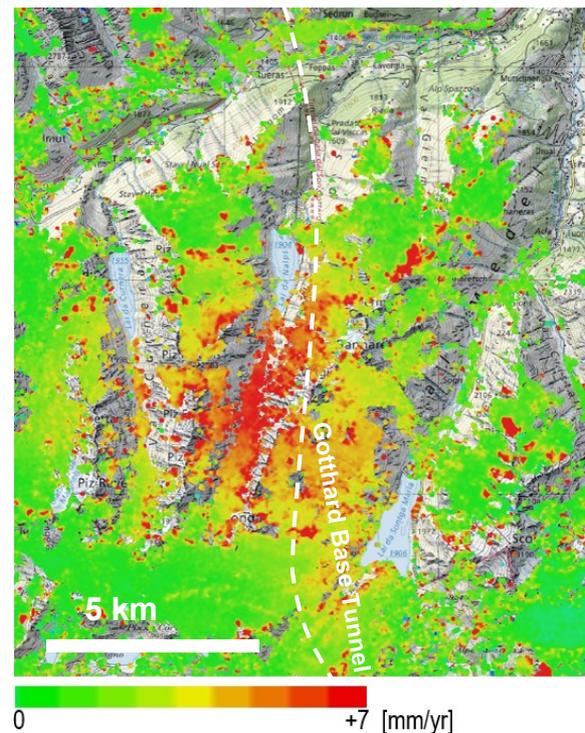
Val Nalps: Radarsat-2 data combined ascending & descending, only vertical direction. Data from 2011-2019.
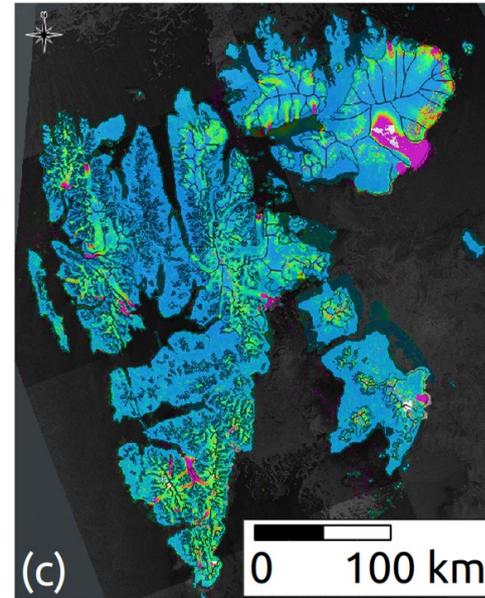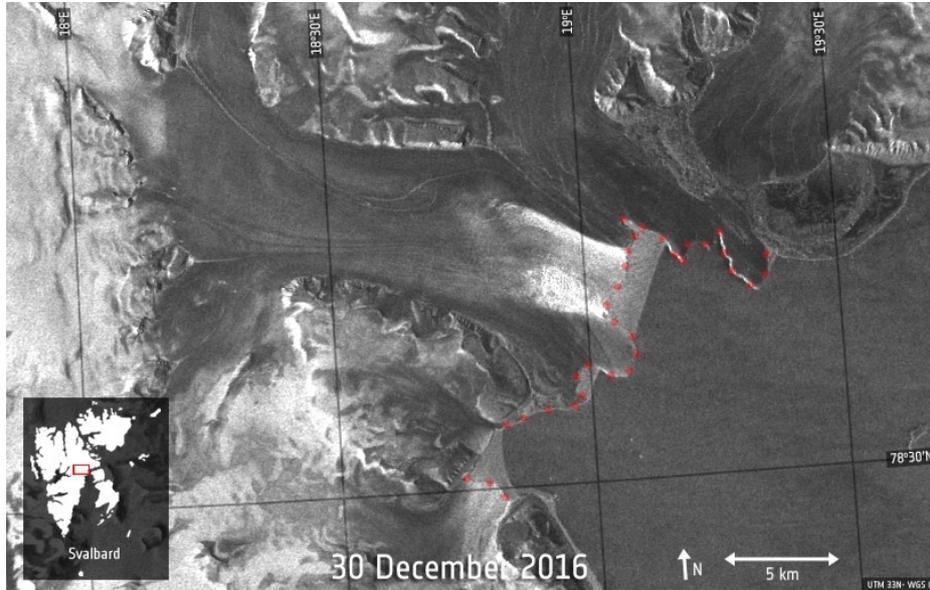
Radar images from the Copernicus Sentinel-1 mission show the sudden advance of the Negribreen glacier in Norway in early 2017 [image credit: ESA, the image contains modified Copernicus Sentinel data (2016–17), processed by T. Strozzi (Gamma)]

Svalbard: Glacier velocity field derived from Copernicus Sentinel-1 data (2016-2017)

Process scale

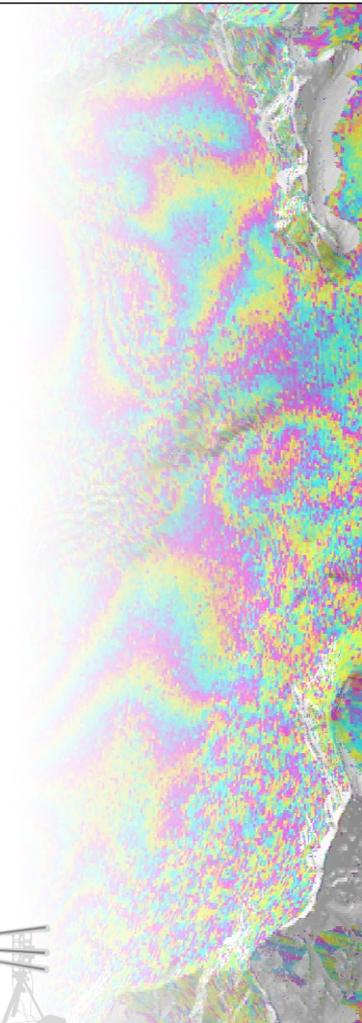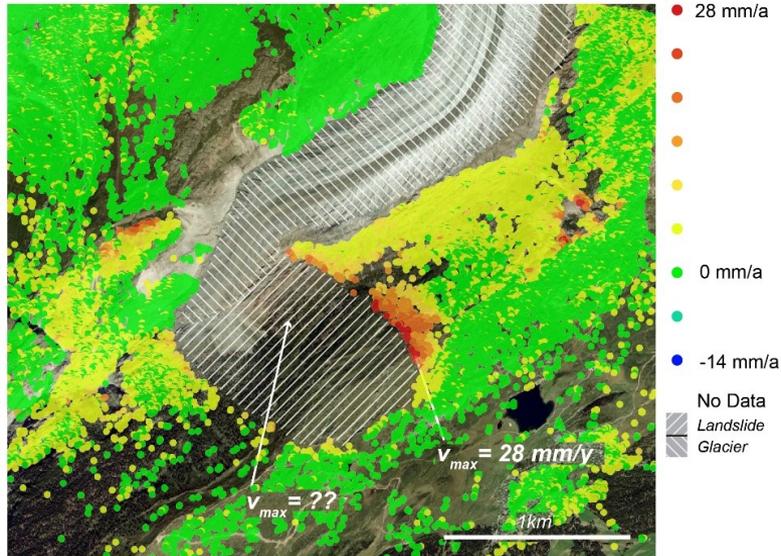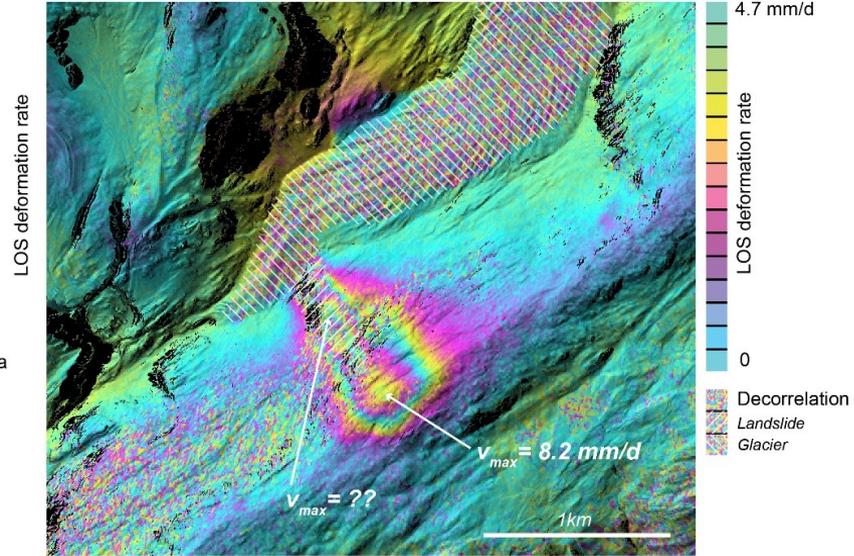TerraSAR-X IPTA Displacement analysis of the Moosflue Area above the great Aletsch Glacier (Swiss Alps) for the year 2013. Precise measurements of slow to moderate movements are possible. Fast movements (Glacier and Main part of the Moosflue Landslide) cannot be measured with this method.

Sentinel-1 12-day interferogram covering the main movement of the Moosflue Landslide. The deformation field and the maximum displacement can be determined for the upper part. The fast movement of the lower part of the landslide leads to decorrelation and therefore missing information.

Building moves at
4 to 12 cm/year
E–corner 4cm/year
W-corner 12cm/year
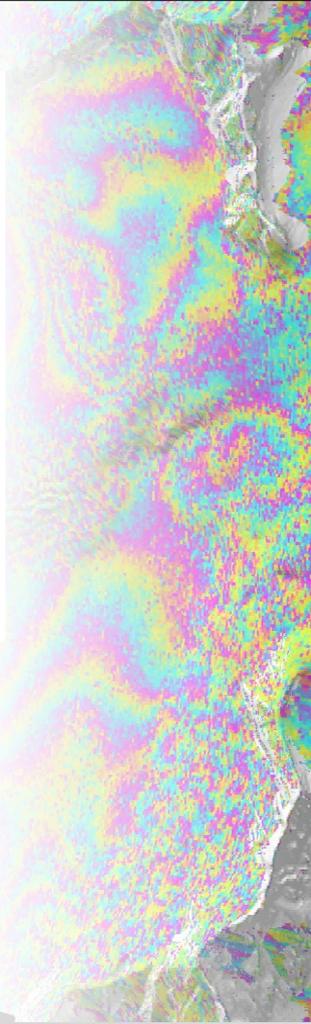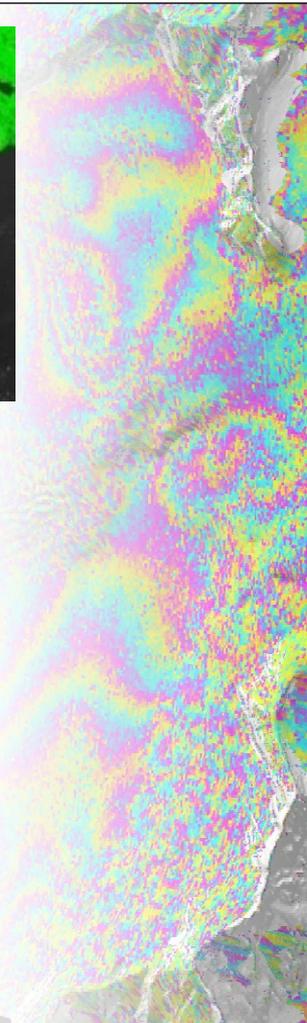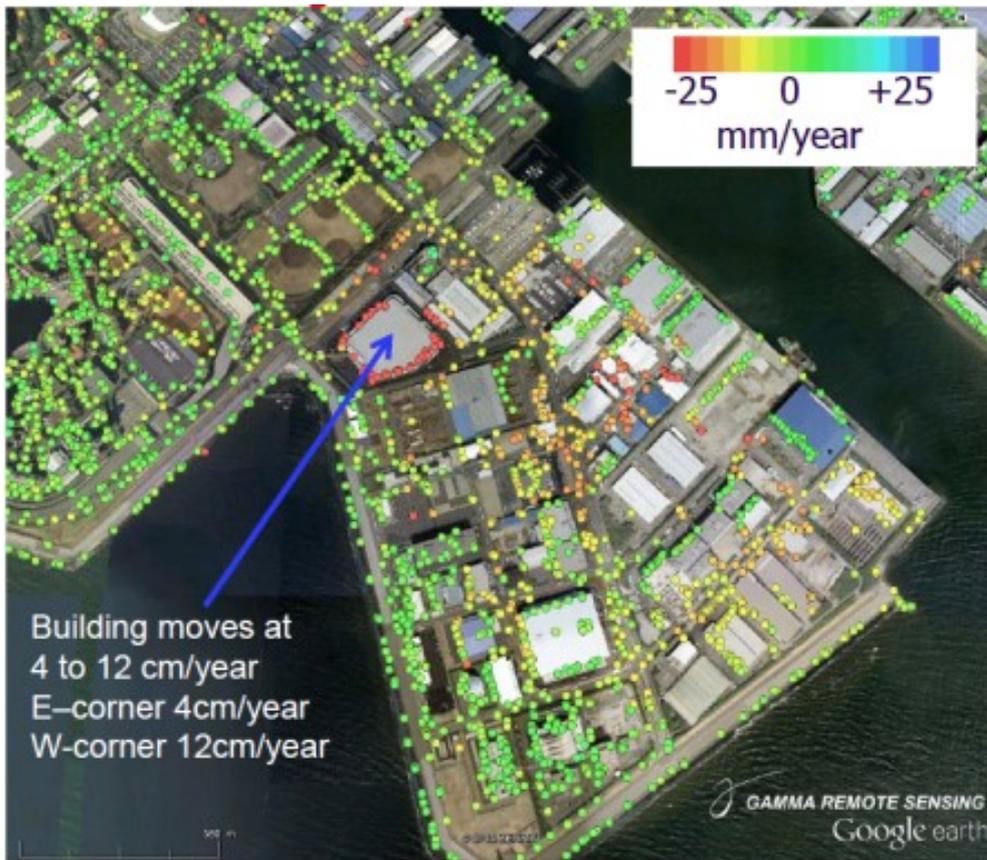
Funabashi, Japan, persistent scatterer interferometry
using 28 ascending PALSAR (L-Band) Scenes.

Satellite InSAR – Summary

Satellite-InSAR boundary conditions

- No absolute measurements
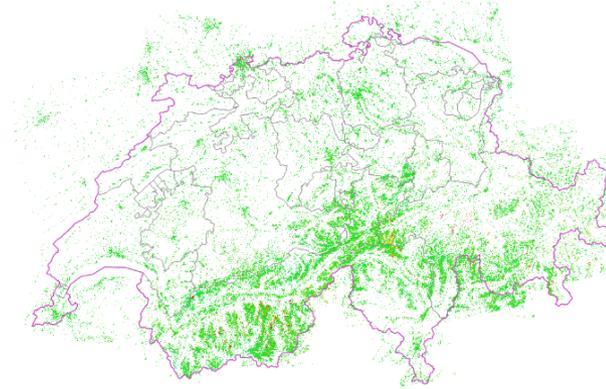
- Only sensitive along line-of-sight

    - Intensity tracking (cross-and along-track detection possible)

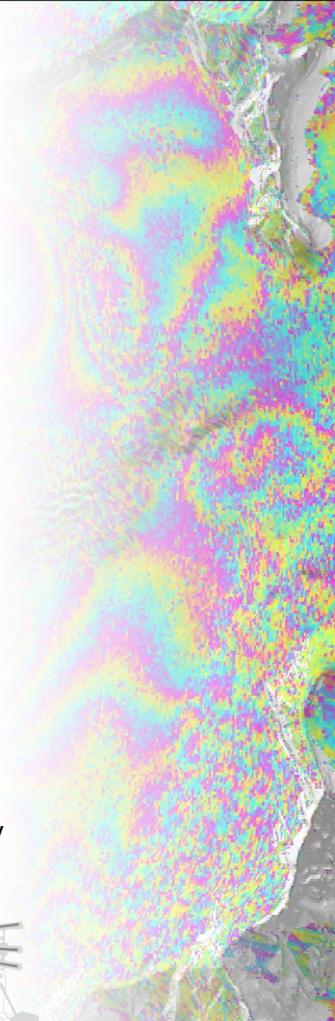- Side looking radar geometry (shadow and layover gaps in steep terrain)

Compilation of PS-interferometry over Switzerland from ERS (1991-2000), ENVISAT ASAR (2004-2010), CSK, TSX und RSAT2 (2011-2019)
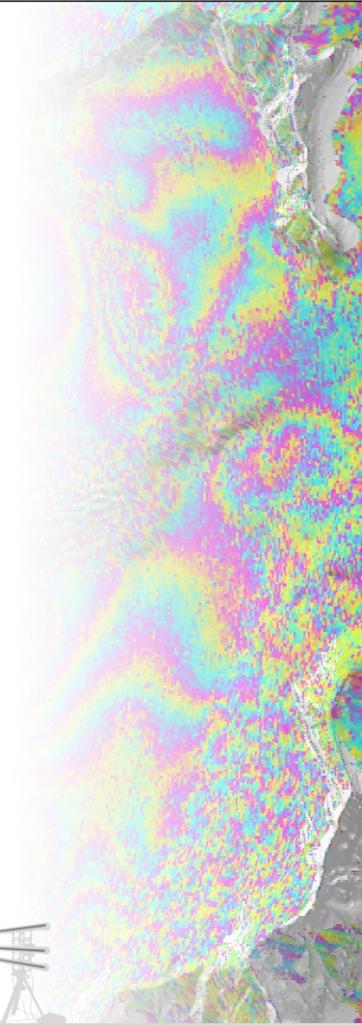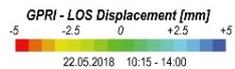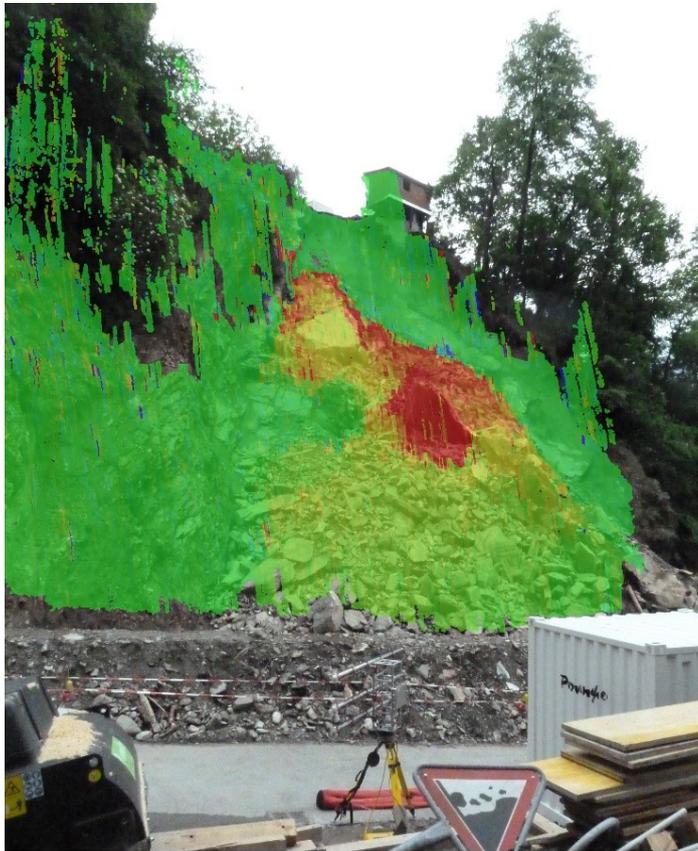
+

- Wide area mapping

- Marker-less mapping (no in-situ installation needed)

- In case for satellite-InSAR: Archive data!

- High precision and accuracy (mm-range for Satellite InSAR)

- Can be cost-effective (for large scale and using free satellite data)

- Increasing number of systems (commercial and open-data provider)

–

- Coherence needed (No information on vegetated areas)

- Measurement range is sensitive to unwrapping errors

- Can be expensive (for small scale and using commercial satellite data or very high resolution)

- Exact location of the scatterer in the footprint not precisely known (if no reflector is used)

GPRI - LOS Displacement [mm]

−5   −2.5   0   +2.5   +5

22.05.2018   10:15 - 14:00

GAMMA REMOTE SENSING

Real aperture radar (RAR)

Synthetic aperture radar (SAR)

Slotted-waveguide antenna
Fan beam

Horn antennas forming
synthetic aperture

Real aperture beam formation

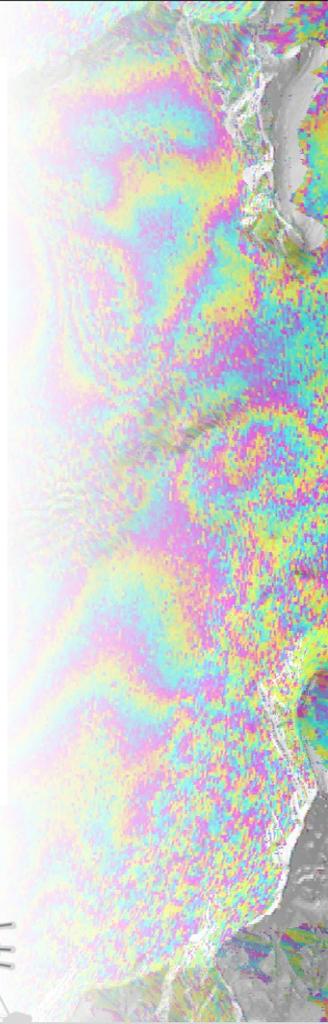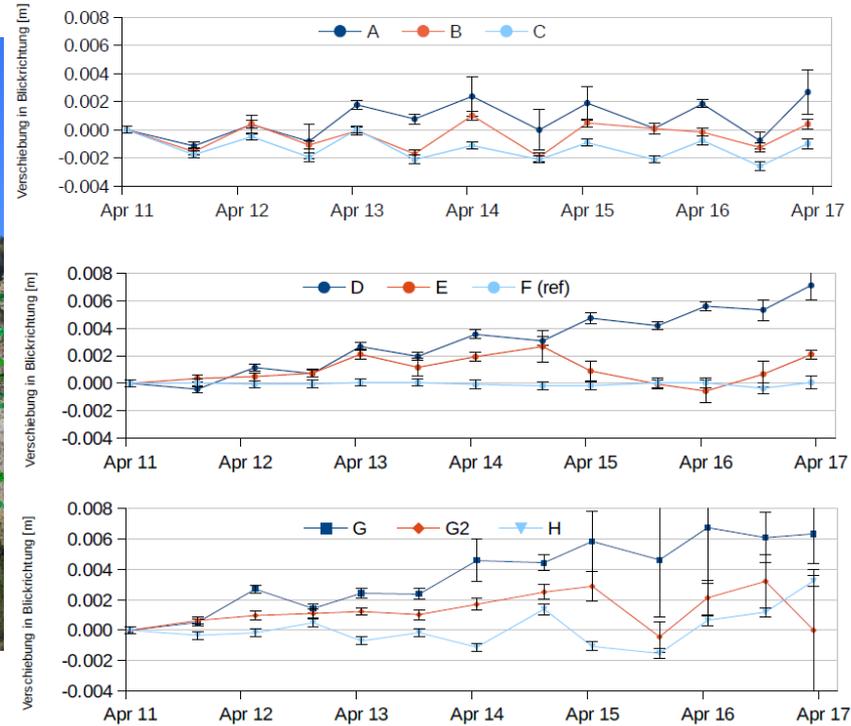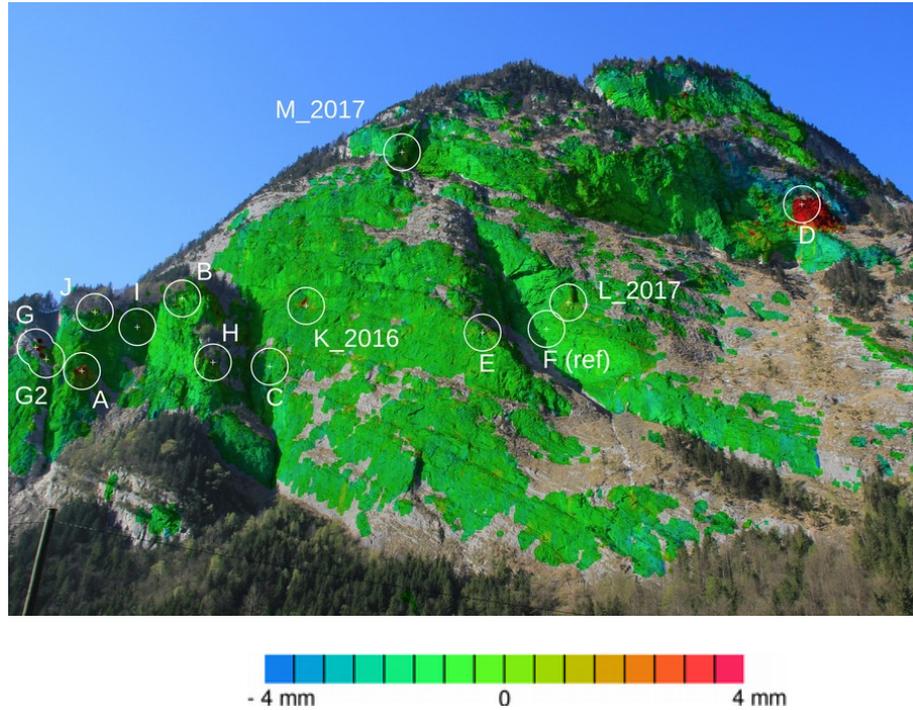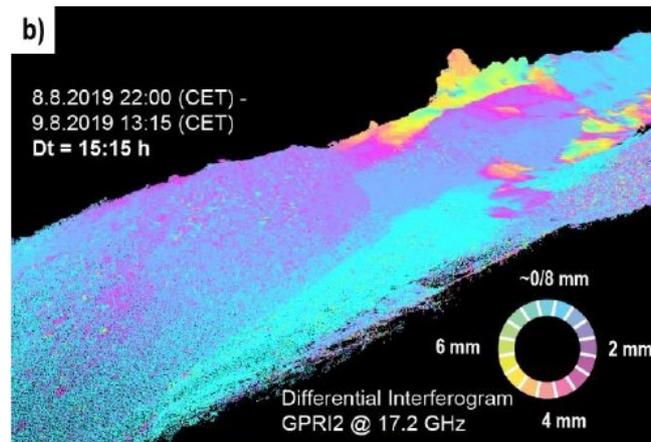Synthetic aperture beam formation
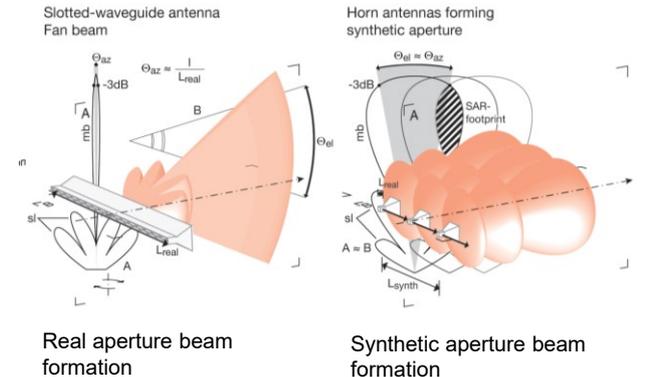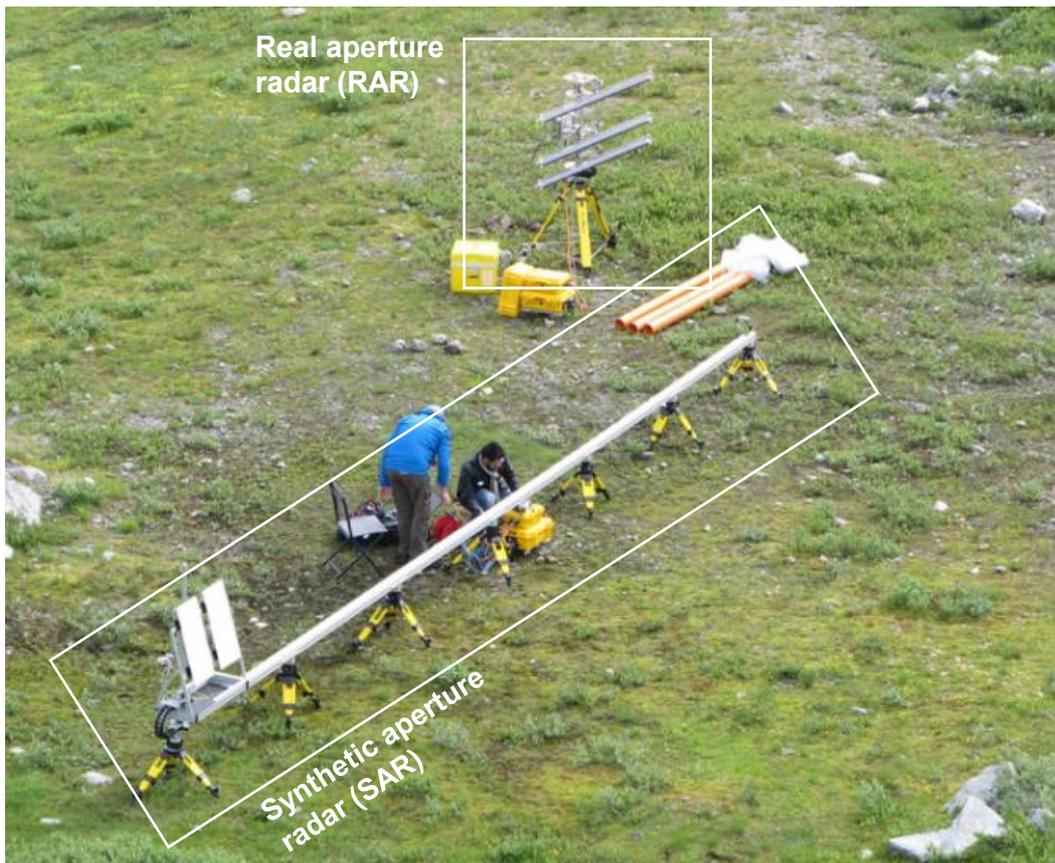
Caduff, R., Schlunegger, F., Kos, A., and Wiesmann, A. (2015) A review of terrestrial radar interferometry for measuring surface change in the geosciences, Earth Surf. Process. Landforms, 40, pages 208– 228, doi: 10.1002/esp.3656.
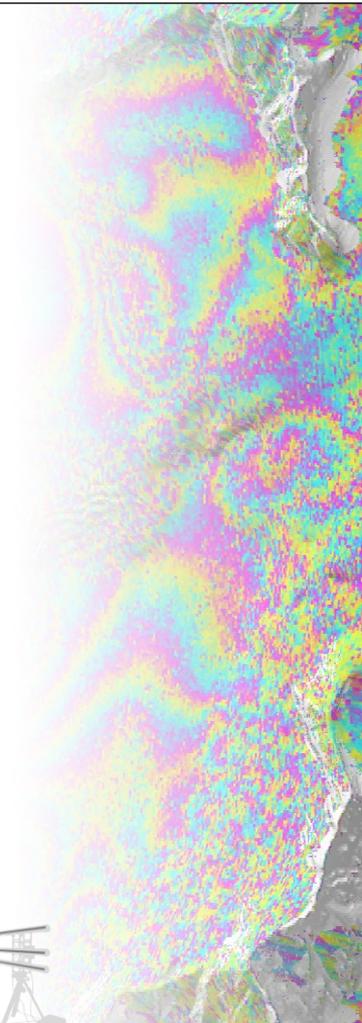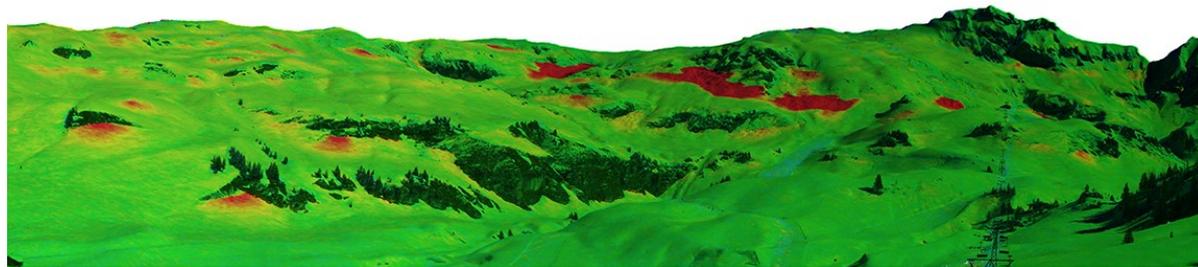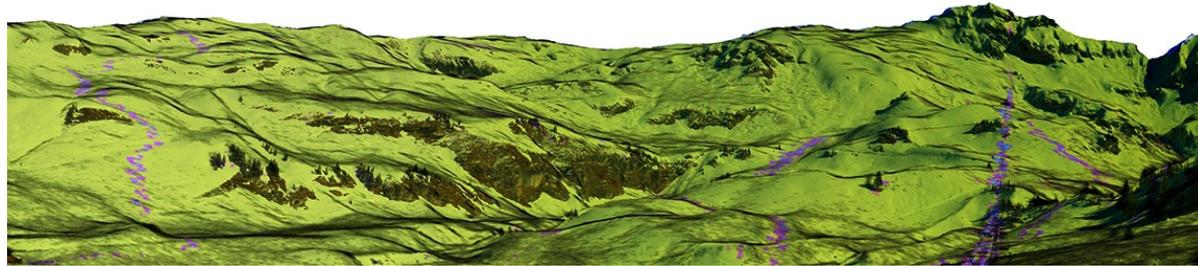
GAMMA REMOTE SENSING

a) Setup of the terrestrial radar interferometer (GPRI) at location W. b) 15h Ku-Band interferogram from the west-flank in precise photo geometry. Different sectors with different kinematics could be delineated c) and identified as superficial movement (white) and most importantly as set of outcropping basal glide planes(red).

Caduff, R., Strozzi, T., Hählen, N., & Häberle, J. (2020, November). Accelerating Landslide Hazard at Kandersteg, Swiss Alps; Combining 28 Years of Satellite InSAR and Single Campaign Terrestrial Radar Data. In Workshop on World Landslide Forum (pp. 267-273). Springer, Cham.
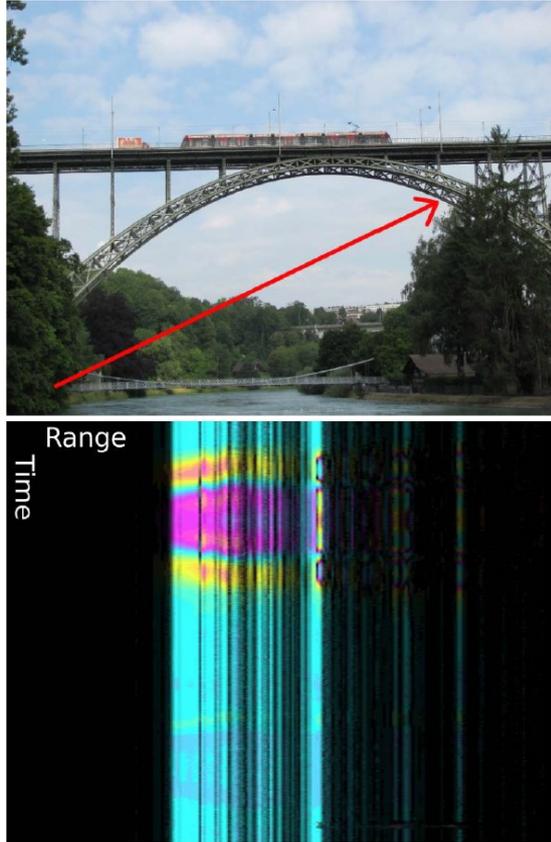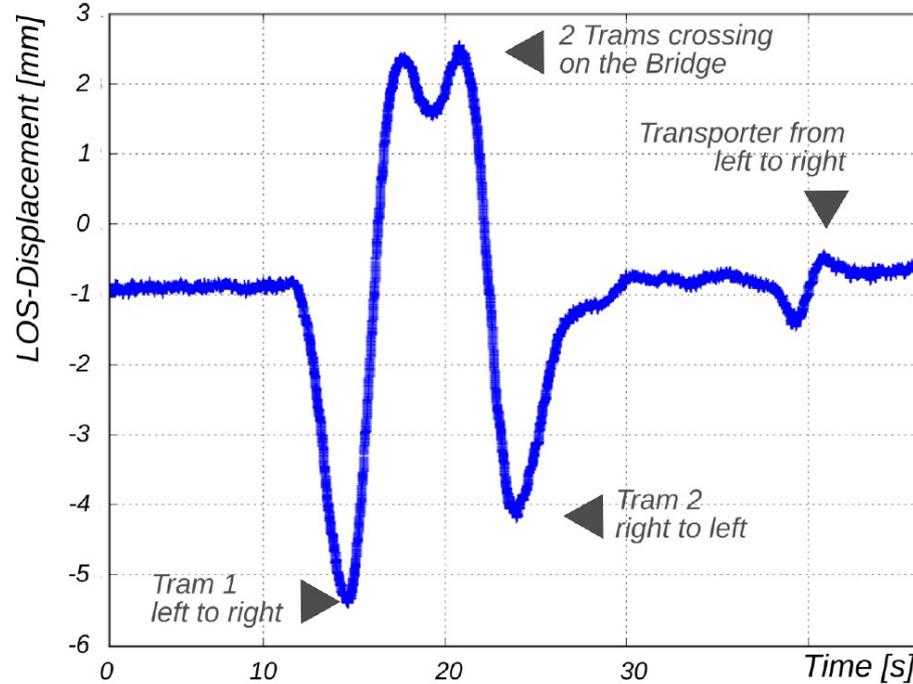
Caduff, R., Wiesmann, A., Bühler, Y. and Pielmeier, C. (2015), Continuous monitoring of snowpack displacement at high spatial and temporal resolution with terrestrial radar interferometry. *Geophys. Res. Lett.*, 42: 813– 820. doi: 10.1002/2014GL062442.

0 ▮ 12 LOS displacement [cm/day]
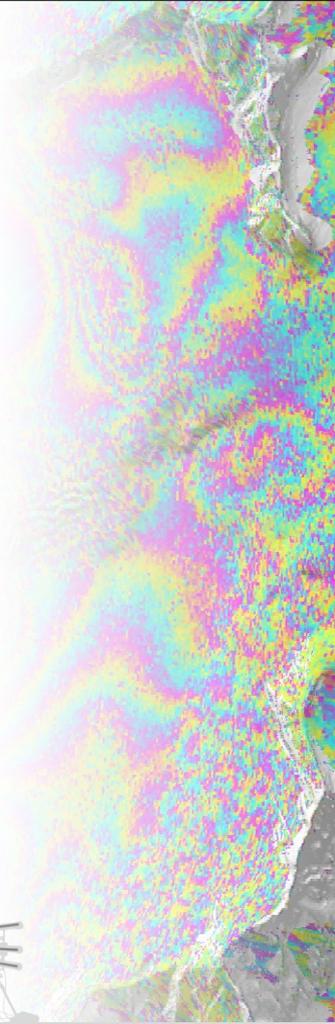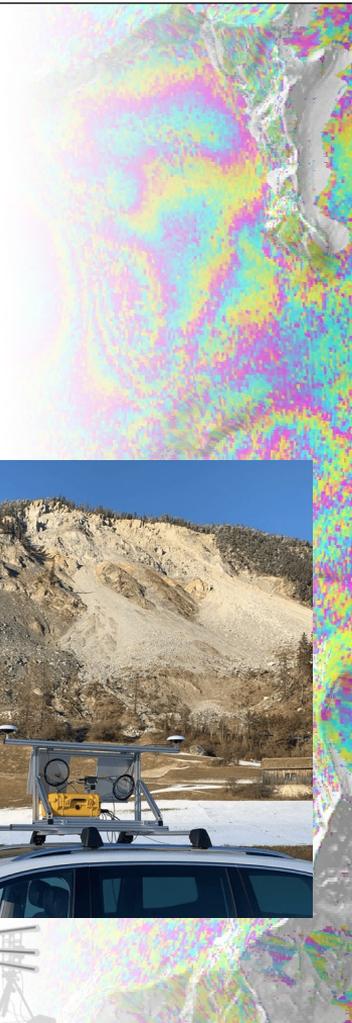
Deformation measurements of the Kornhaus-Bridge (Bern) during traffic with the fixed look mode

Werner et al. (2012)

Werner, C., Wiesmann, A., Strozzi, T., Kos, A., Caduff, R., & Wegmüller, U. (2012, April). The GPRI multi-mode differential interferometric radar for ground-based observations. In EUSAR 2012; 9th European Conference on Synthetic Aperture Radar (pp. 304-307). VDE.

Mobile mapping of surface displacements by car-borne repeat-pass SAR interferometry

Car-borne L-band SAR data acquisition of 2 SAR images at a 4-day time interval (2020-01-20,14:21 — 2020-01-24,11:25).

Frey, O., Werner, C. L., Manconi, A. and Coscione, R. "Measuring surface displacements using a novel UAV/car-borne radar interferometer: including a case study on a fast-moving landslide in Brinzauls." Abstract Volume 18th Swiss Geoscience Meeting. Berne, Zurich: (SCNAT); ETH Zurich, 2020. pp. 502-502.
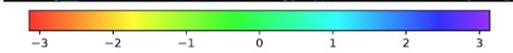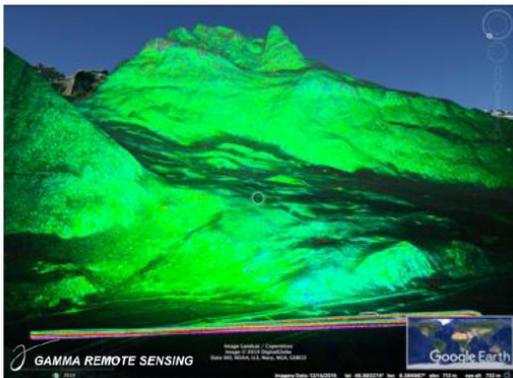
Area of interest on the campaign day. On the lower right, the local GNSS reference station is situated to obtain a highly precise post-processed kinematic GNSS solution of the UAV position.
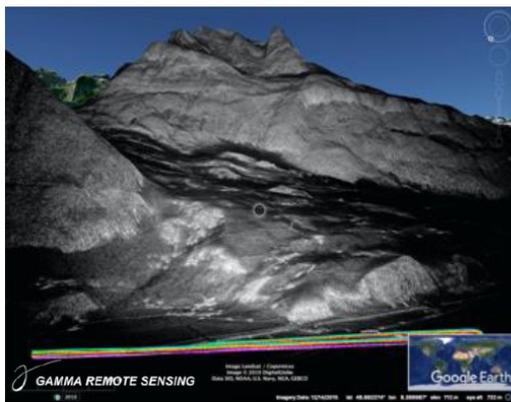

Google Earth (GE) view of UAV-borne L-band SAR backscatter intensity image with UAV flight trajectories in the foreground.

Google Earth view of UAV-borne L-band differential interferometric phase (left) and coherence (right) for nominally zero spatial baseline and a temporal baseline of 3 minutes. The flight tube of these two repeat-tracks are within 1m radius. With the exception of forested areas in the near range and areas with severe foreshortening a very high coherence is obtained and the interferometric phase is also stable.
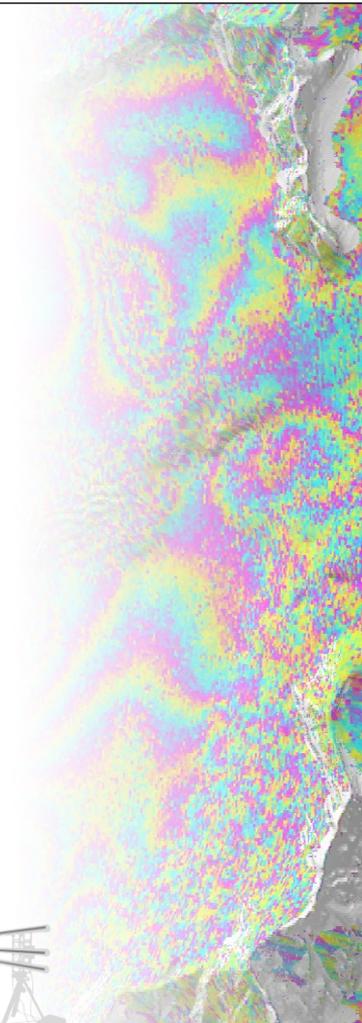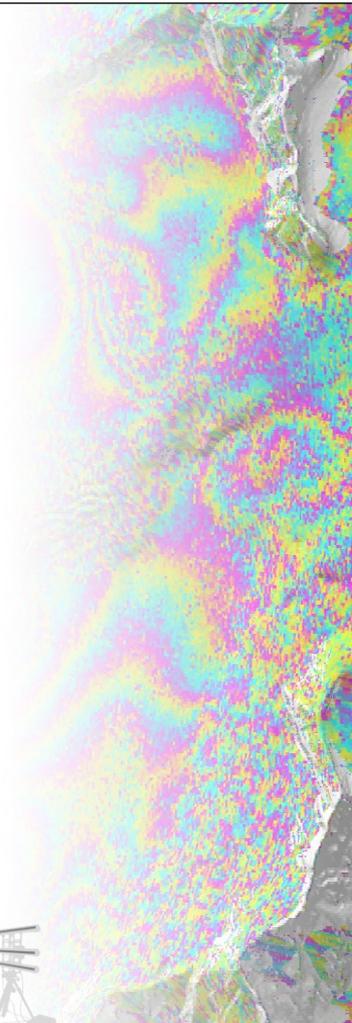
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caduff@gamma-rs.ch