19th General Assembly of WEGENER
on earth deformation & the study of earthquakes using geodesy and geodynamics

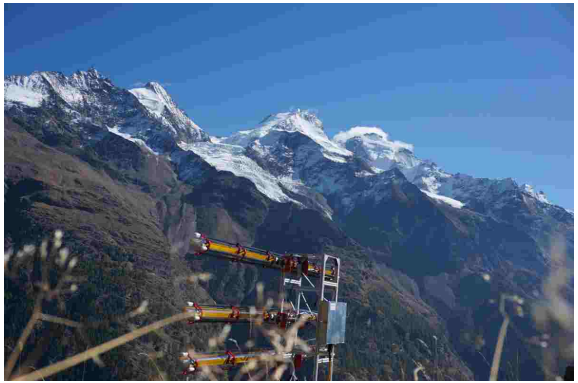
10-13 Sept. 2018 | Grenoble, FRANCE

Satellite and terrestrial radar interferometry and applications to the monitoring of the deformation of glaciers, rock glaciers and landslides

Tazio Strozzi
Gamma Remote Sensing, Gümligen, Switzerland

Aim of the presentation

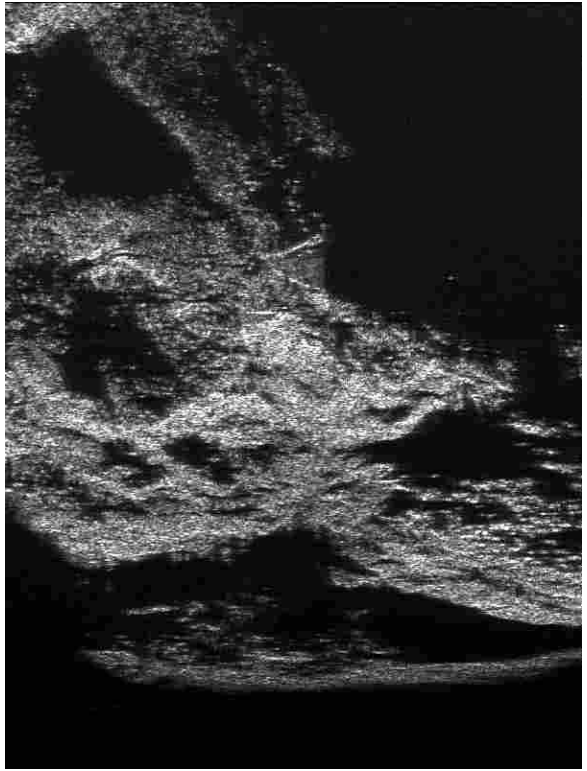
- Review radar-interferometric monitoring techniques applied to detect and quantify the surface displacement of glaciers, rock glaciers and landslides in mountain environments



- Show selected results obtained with the various satellite and terrestrial sensors of different spatial resolution and acquisition time intervals

Amplitude image

Slant-range (0.75 m resolution)
[1.2 km]

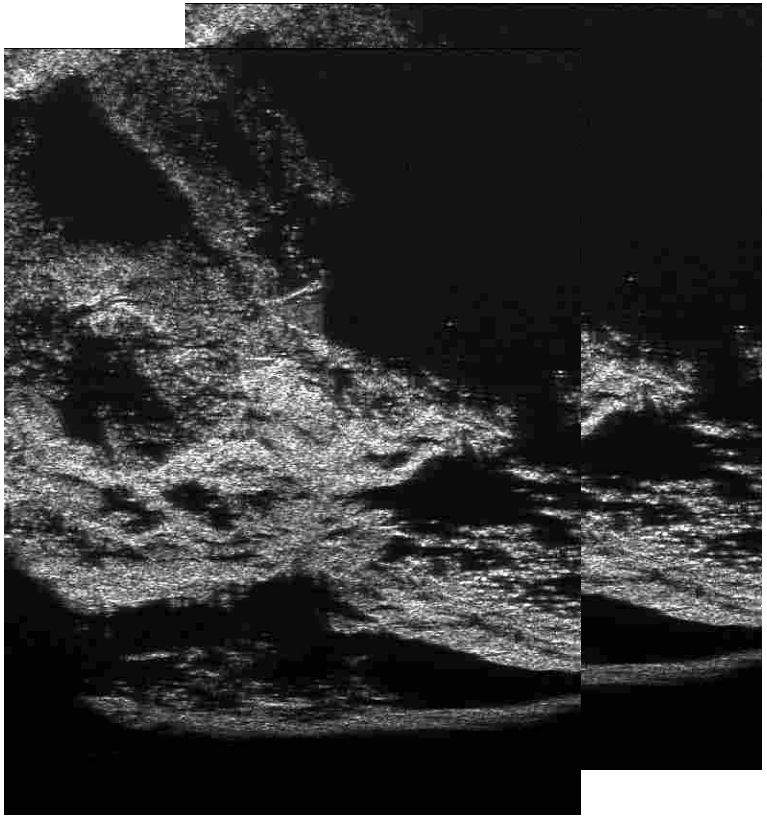


Azimuth [60°]
(8 m resolution @ 1 km)

Slant-range resolution: c/2B
(bandwidth B, speed of light c)

Azimuth resolution: λR/L
(wavelength λ, distance R,
antenna length L)

Radar interferometry



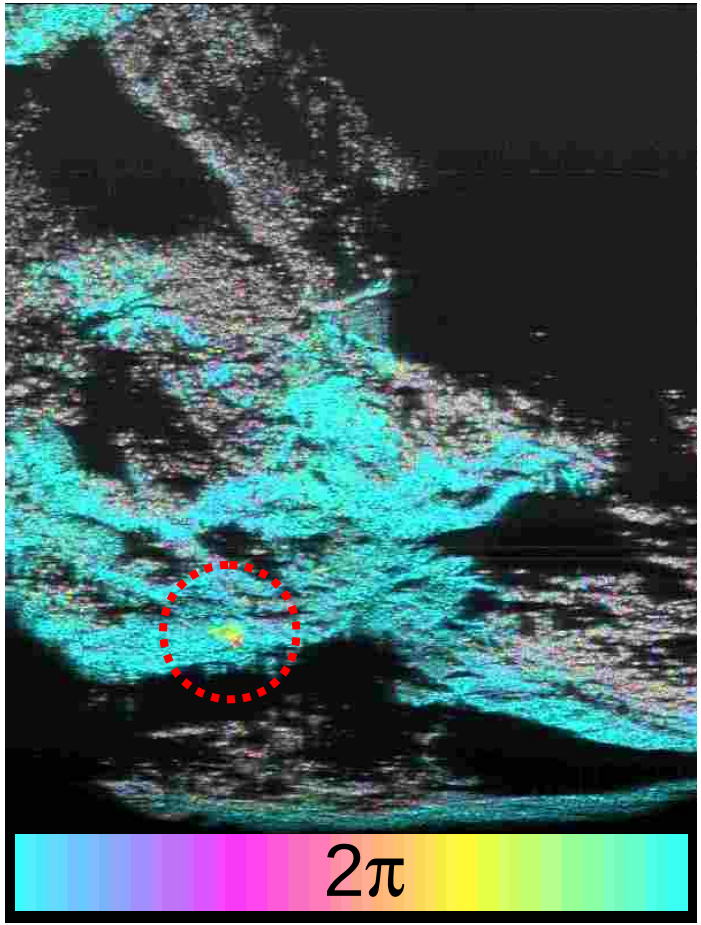
12.09.2007 17:00

12.09.2007 17:19

$$\phi = \phi_1 - \phi_2 = \frac{4\pi}{\lambda}\left(R_2 - R_1\right)$$

ϕ_1, ϕ_2:	phases of the two radar images
R_1 , R_2:	distances from the radar positions to the image scatterer
λ :	wavelength

Interferogram

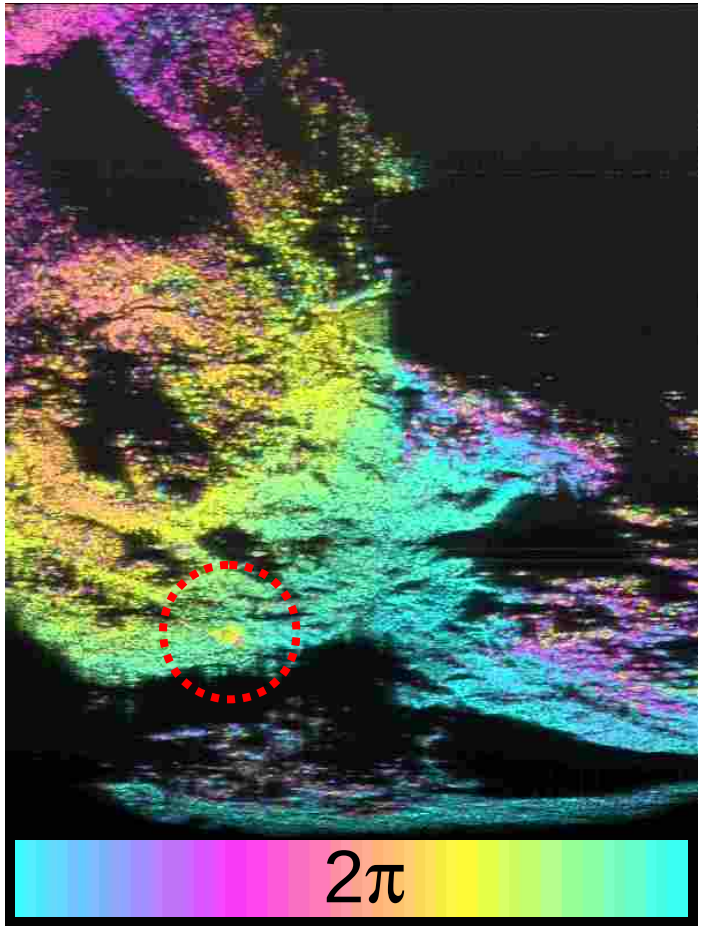


scan # 30 _ scan # 31

30 12.09.2007 17:00 → 17:19
31 12.09.2007 17:19 → 17:37

ΔT = 18 min.

The atmospheric phase



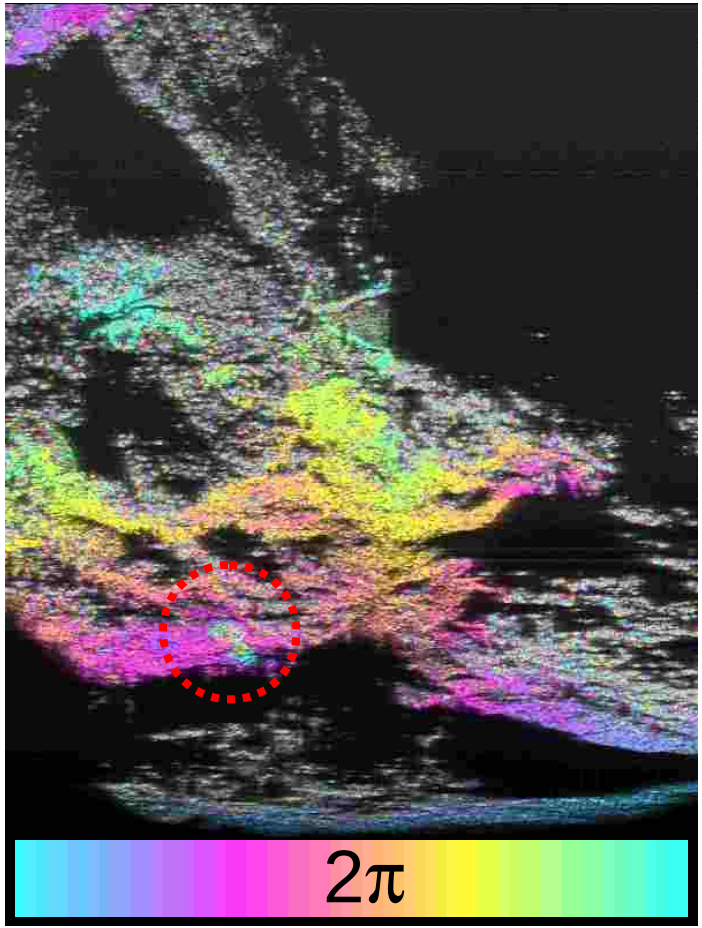
scan # 74 _ scan # 75

74: 13.09.2007 06:37 → 06:56
75: 13.09.2007 06:56 → 07:14

ΔT = 18 min.

Path length changes due to different atmospheric conditions (temperature, pressure, humidity) during the acquisitions of the two radar images

The phase noise

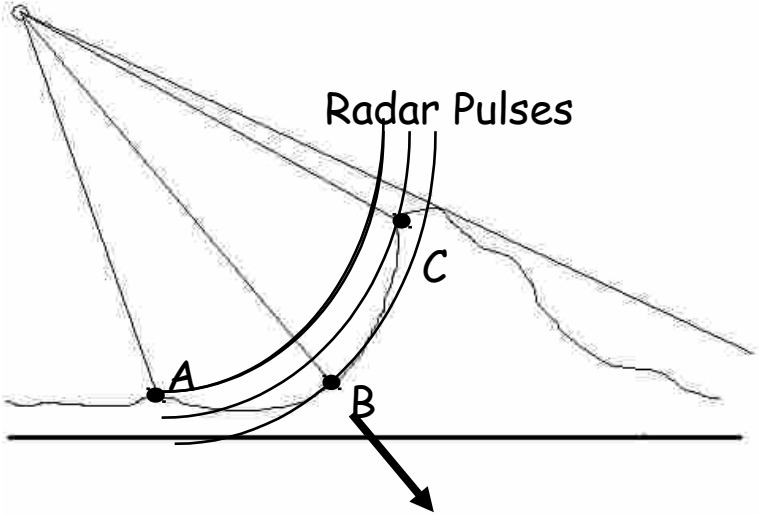


scan # 28 _ scan # 40

25: 12.09.2007 15:27 → 15:46
40: 12.09.2007 20:06 → 20:25

ΔT = 279 min.

Layover and shadowing



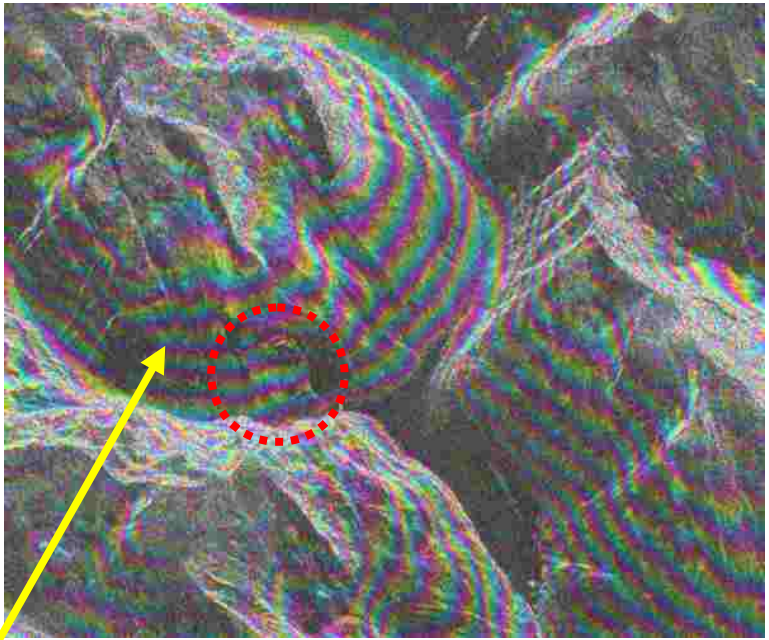
line-of-sight direction

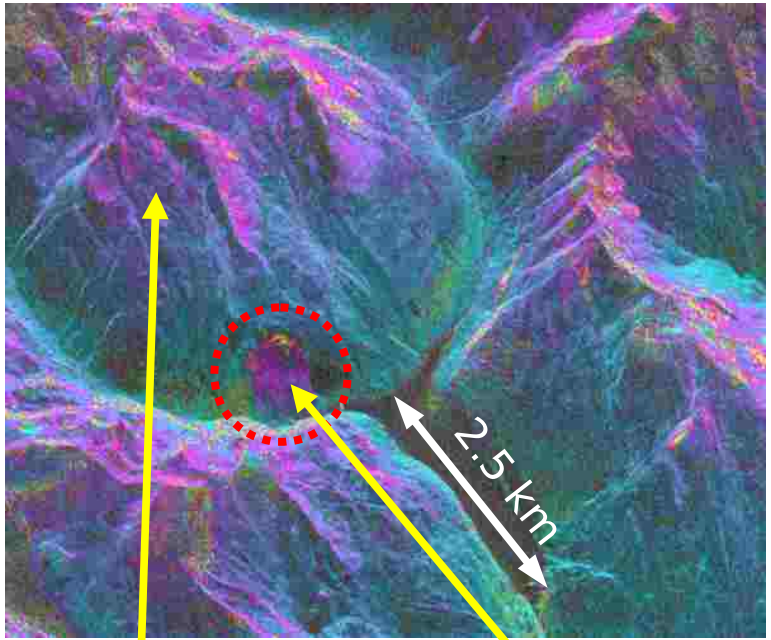
Lugano and the Monte San Salvatore

Differential interferometry

12 September 2007 – 28 October 2007 / 46 day / 650 m baseline

Interferogram → Differential interferogam





Topography

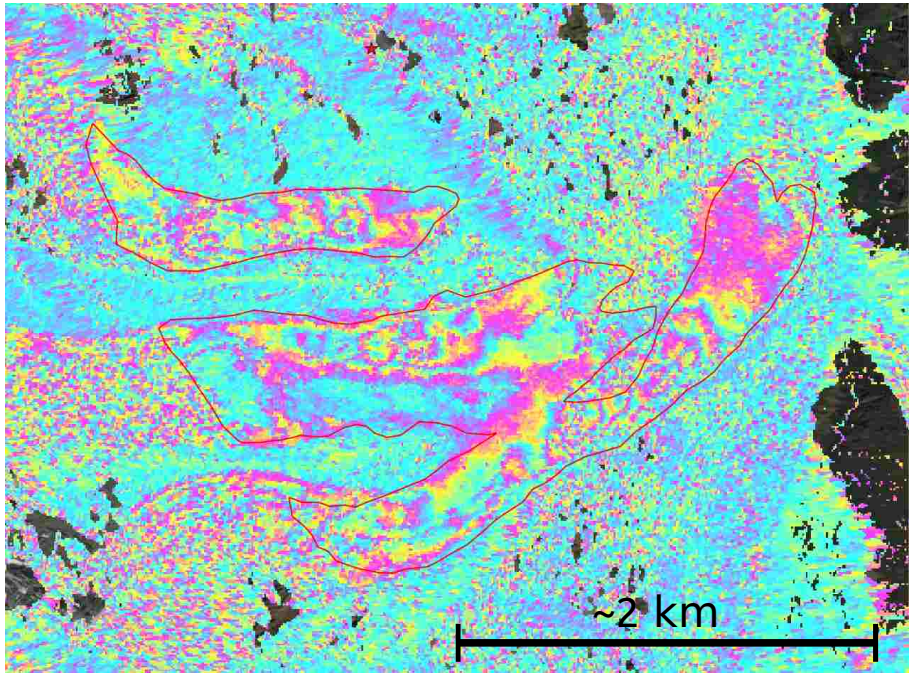
$2\pi \Leftrightarrow 11.8$ cm @ 1.27 GHz

Atmosphere

Displacement

Phase unwrapping

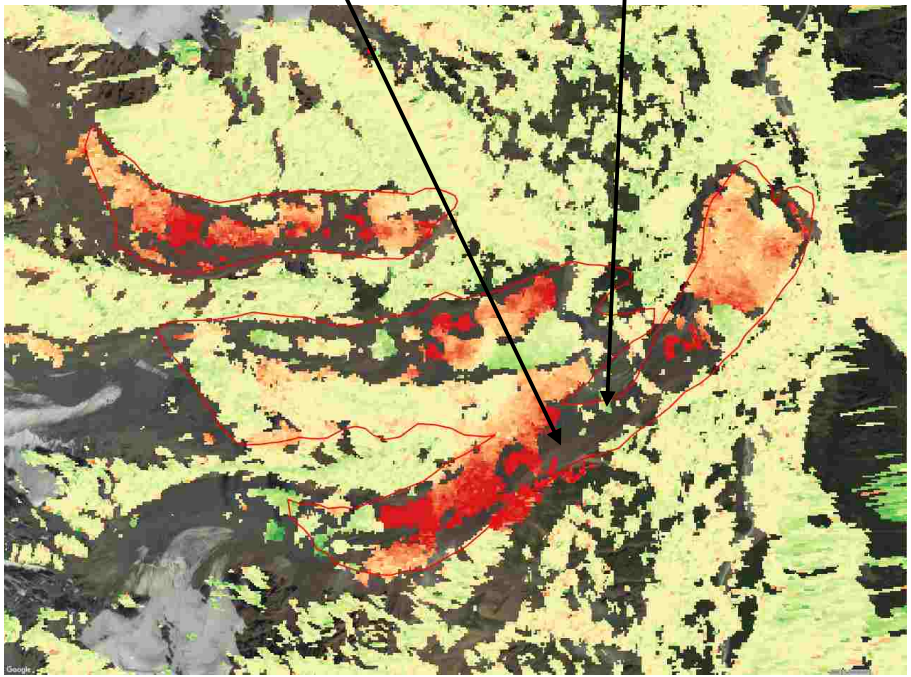
17.08.2007-02.10.2007



$2\pi \Leftrightarrow 11.8$ cm @ 1.27 GHz

Coherence mask

Errors

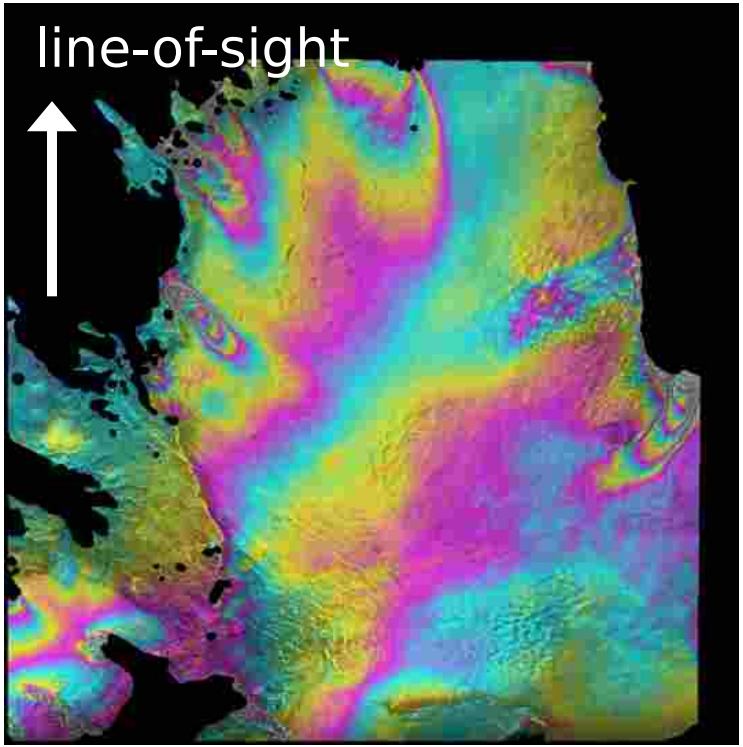


-10 cm +10

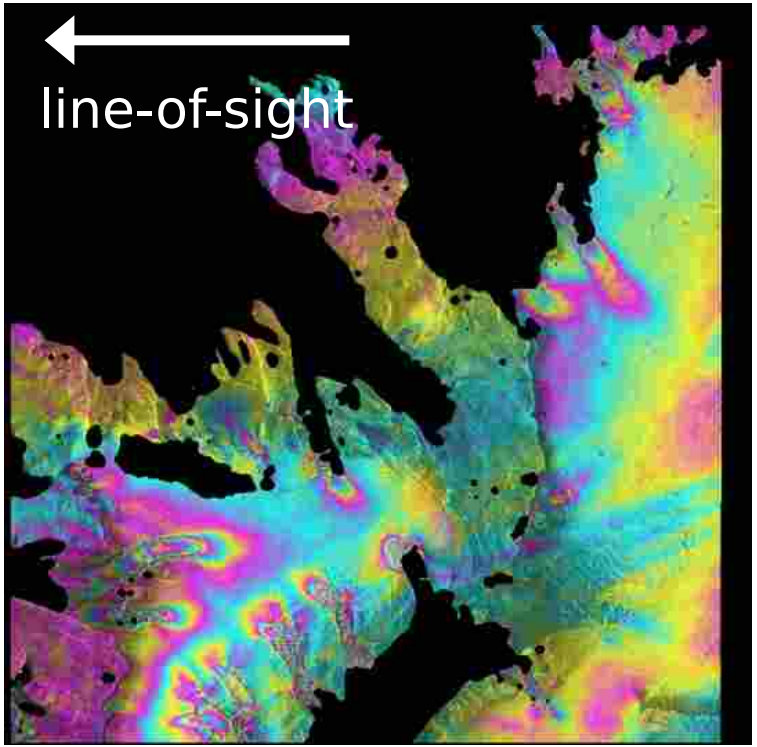
Glaciers

Kronebreen (Svalbard)

ERS SAR 1 day

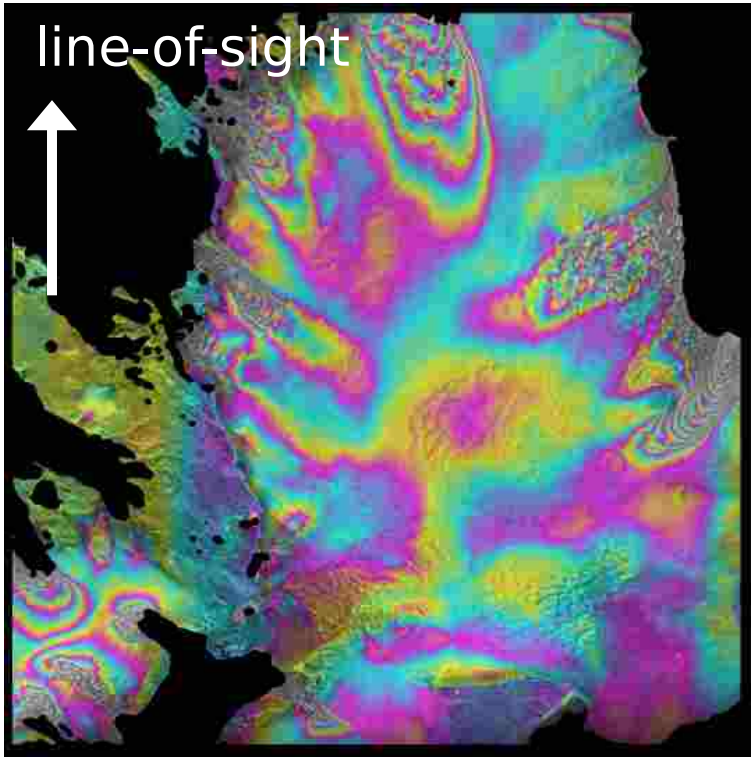


15/16 Dec. 1995, 60 m
DinSAR ascending

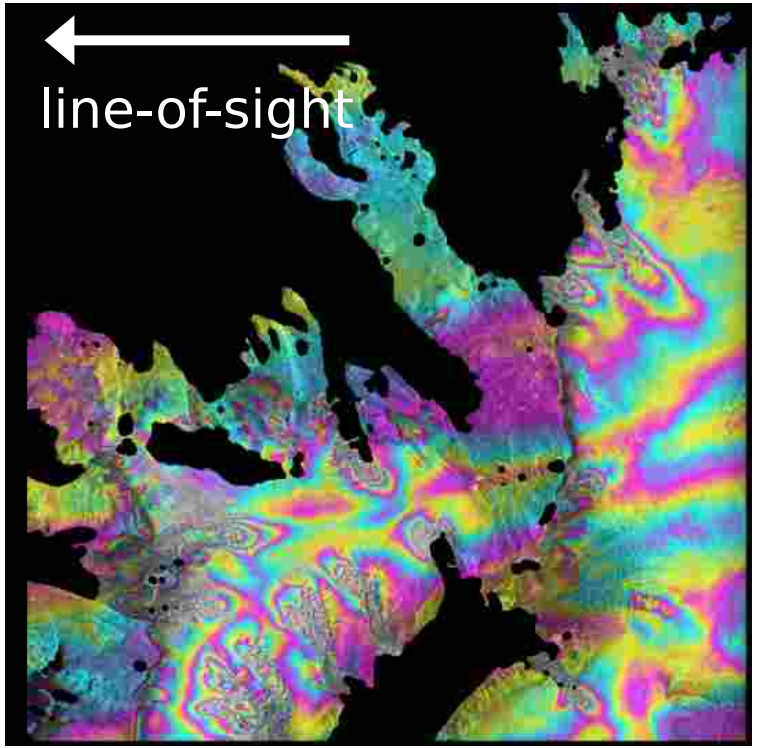


16/17 Dec. 1995, -45 m
DINSAR descending

ERS SAR 3 days

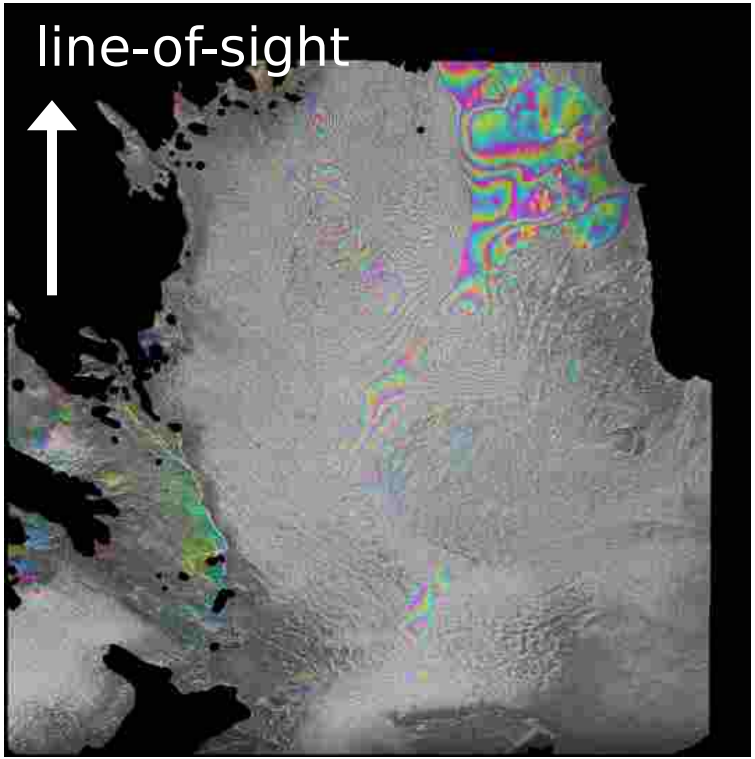


23/26 Mar. 1992, -90 m
DinSAR ascending

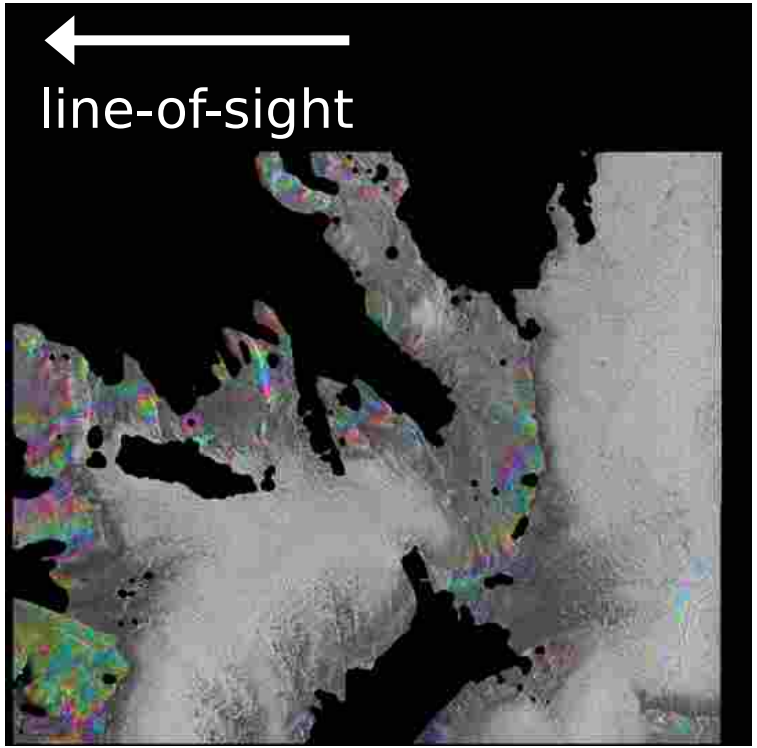


24/27 Mar. 1992, 15 m
DINSAR descending

ERS SAR 35 days



16 Dec. 95 – 20 Jan 96, -125 m
DinSAR ascending

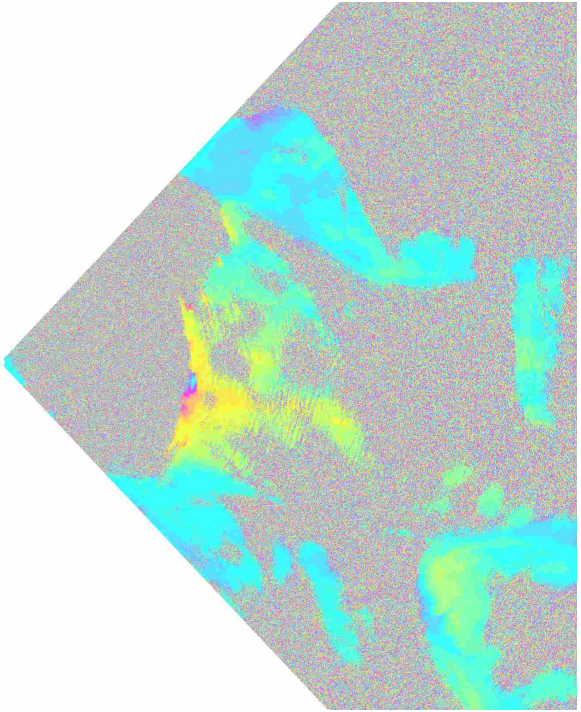


17 Dec. 95 – 21 Jan 96, -293 m
DINSAR descending

Kronebreen (Svalbard)
GPRI 2 minutes

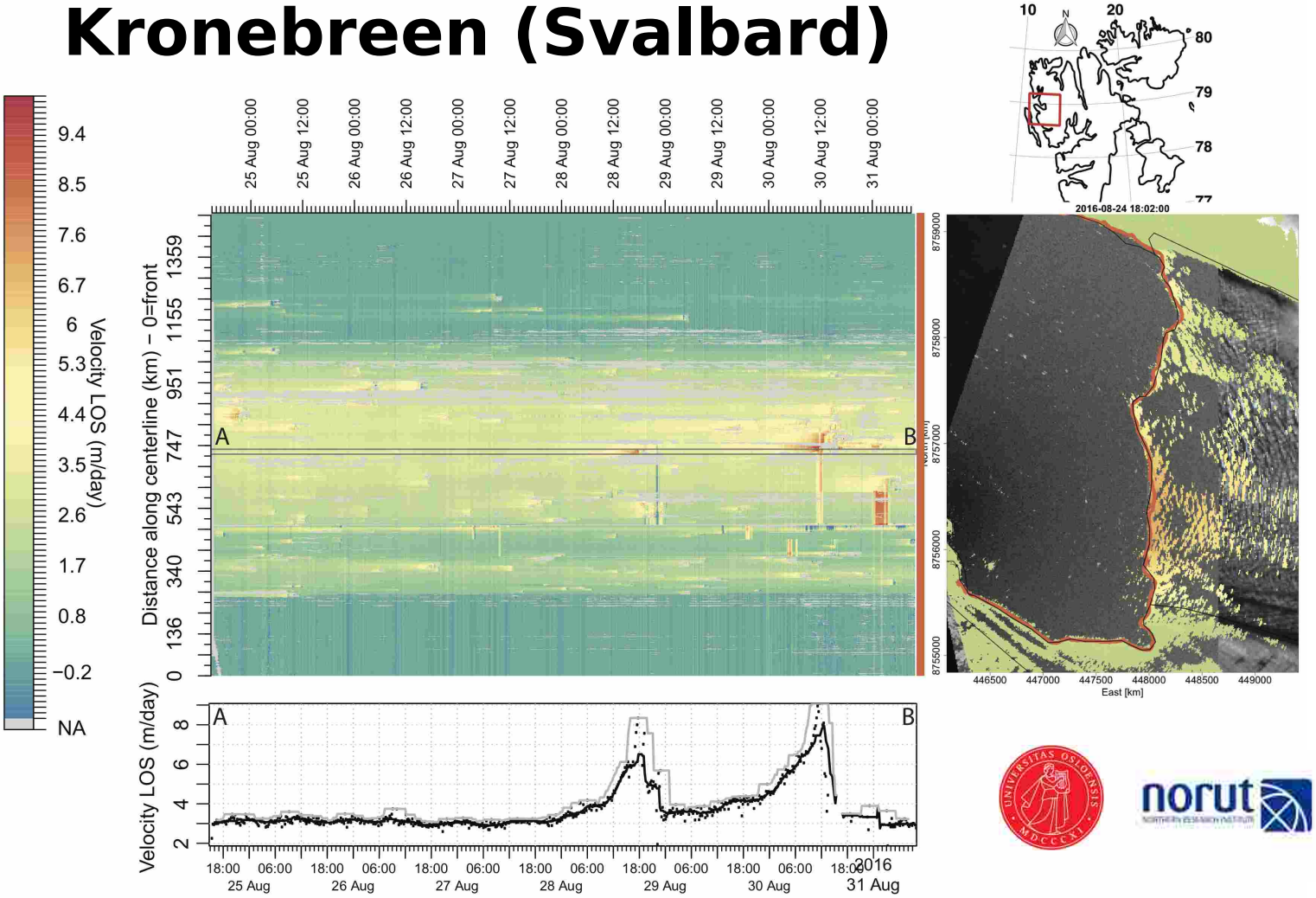
30.08.2016 10:08:17

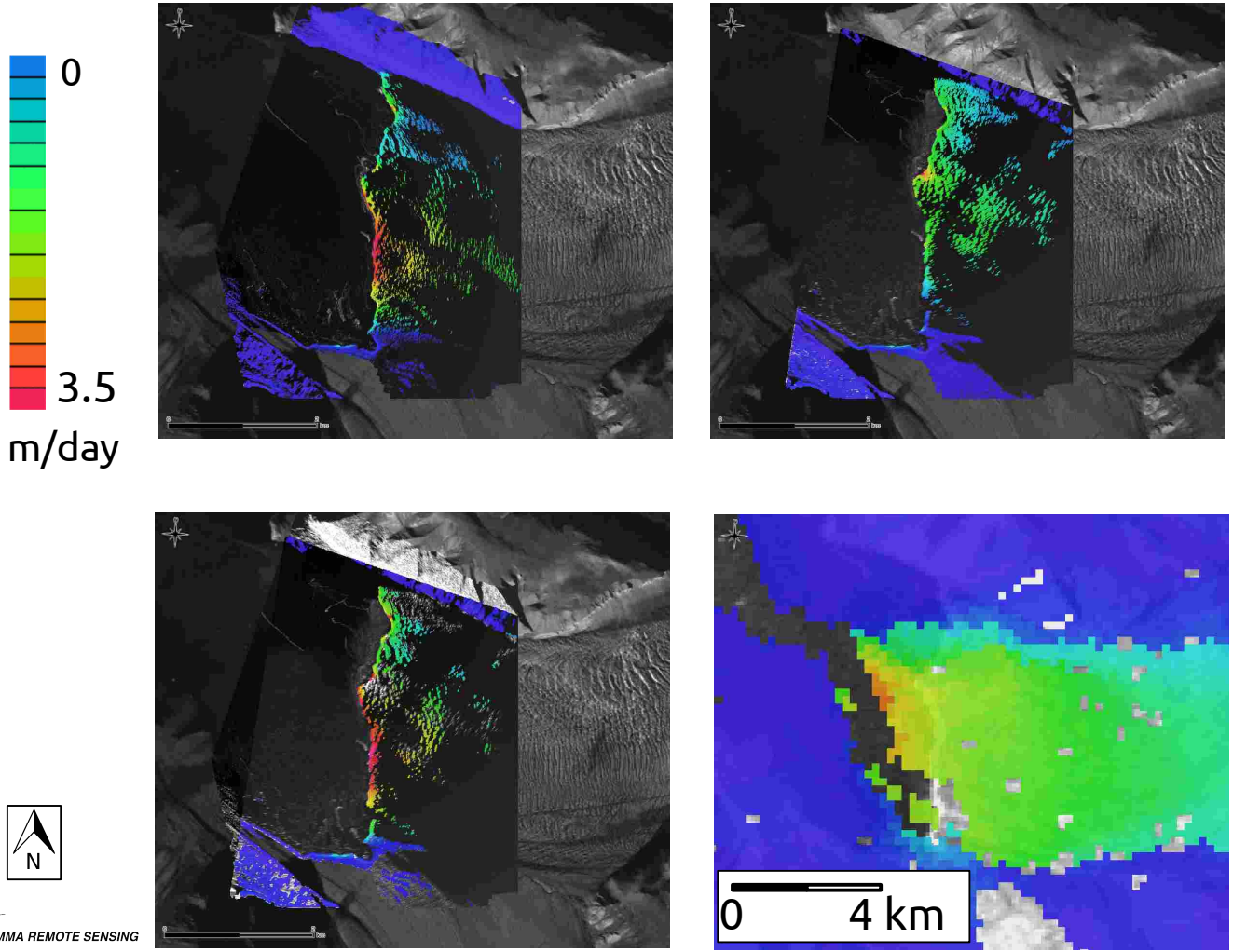
30.08.2016 10:10:17



$2\pi \Leftrightarrow 0.9$ cm

Kronebreen (Svalbard)





GPRI

27.08.2016 3 hours

(a) left side

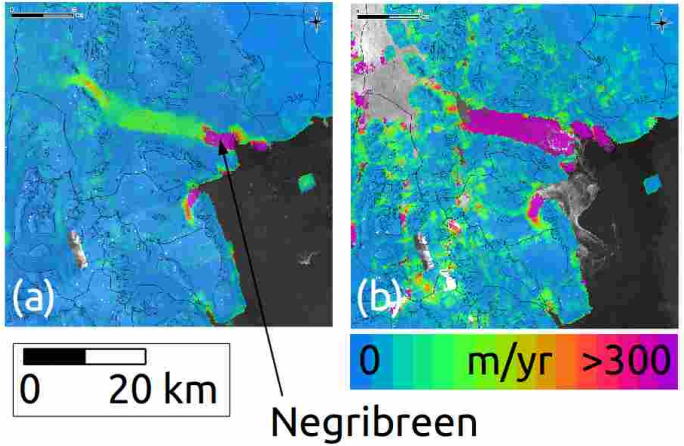
(b) right side

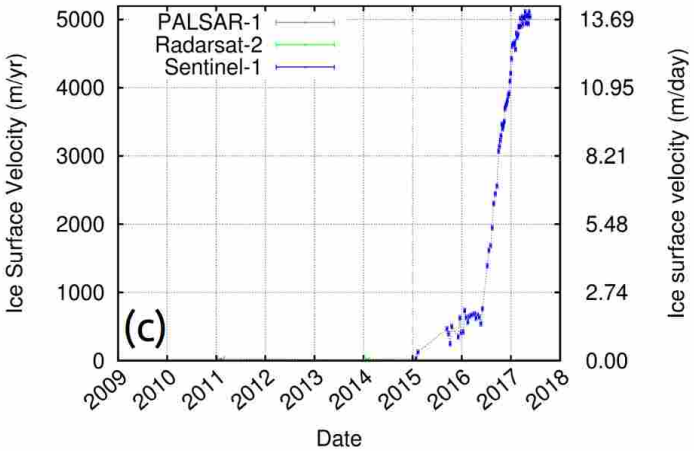
(c) GPRI horizontal

(d) Sentinel-1 20.08/01.09.2016

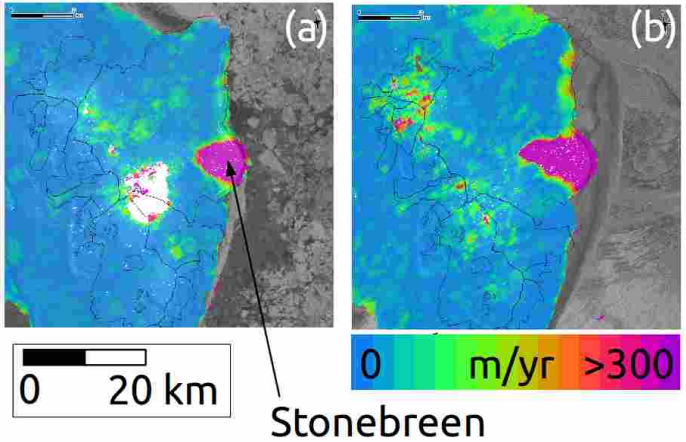
Surges on Svalbard with Sentinel-1

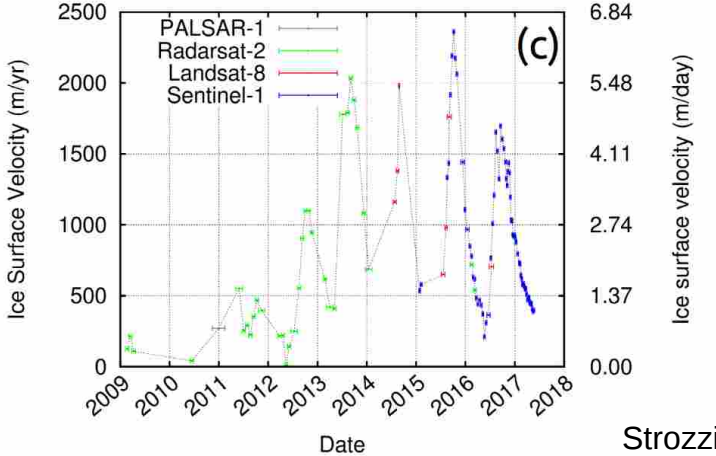
(a) 2015
(b) 2017





(a) 2015
(b) 2017





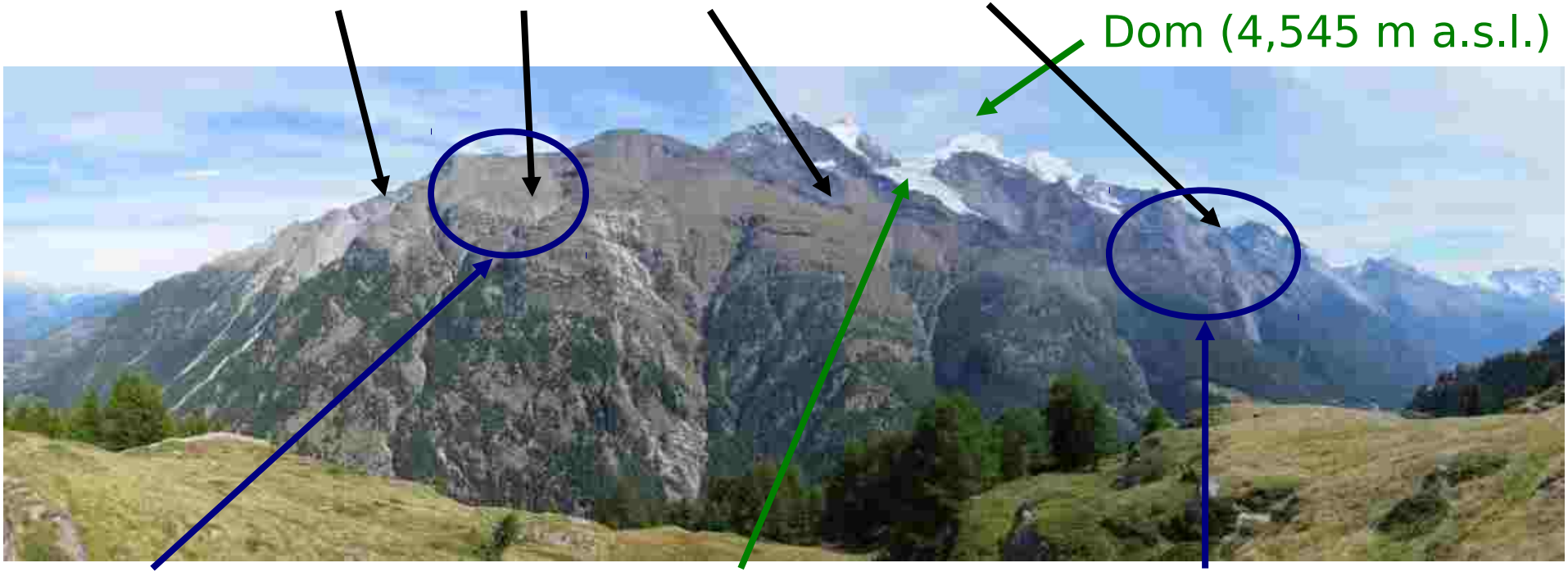
Strozzi et al., RS, 2018

Interferometry on mountain permafrost

- Compilation of an inventory of slope instabilities (“snap-shot”)
- Long-term monitoring of rockglacier motion as the most indicative short- to medium-term response of rockglaciers to environmental changes and thus as an indicator of mountain permafrost conditions in general

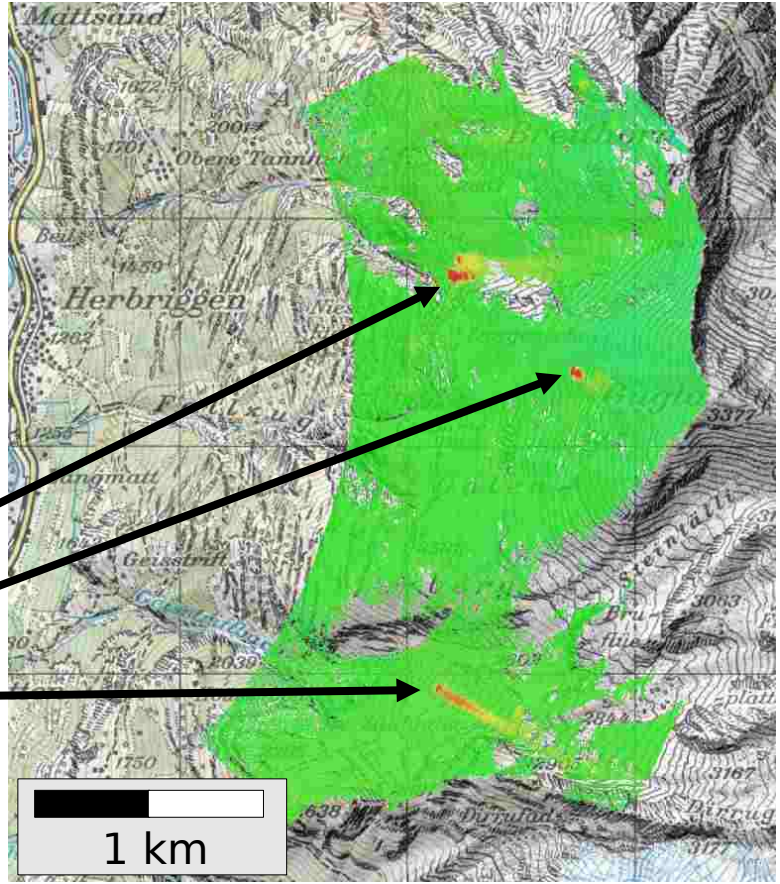
Mattervalley (Switzerland)

Grosse Grabe, Breithorn, Dirru and Grabengufer rockglaciers



GPRI 07.10.2015

Gugla-Bielzug rock glacier
Gugla-Längenschnee
Dirru rock glacier



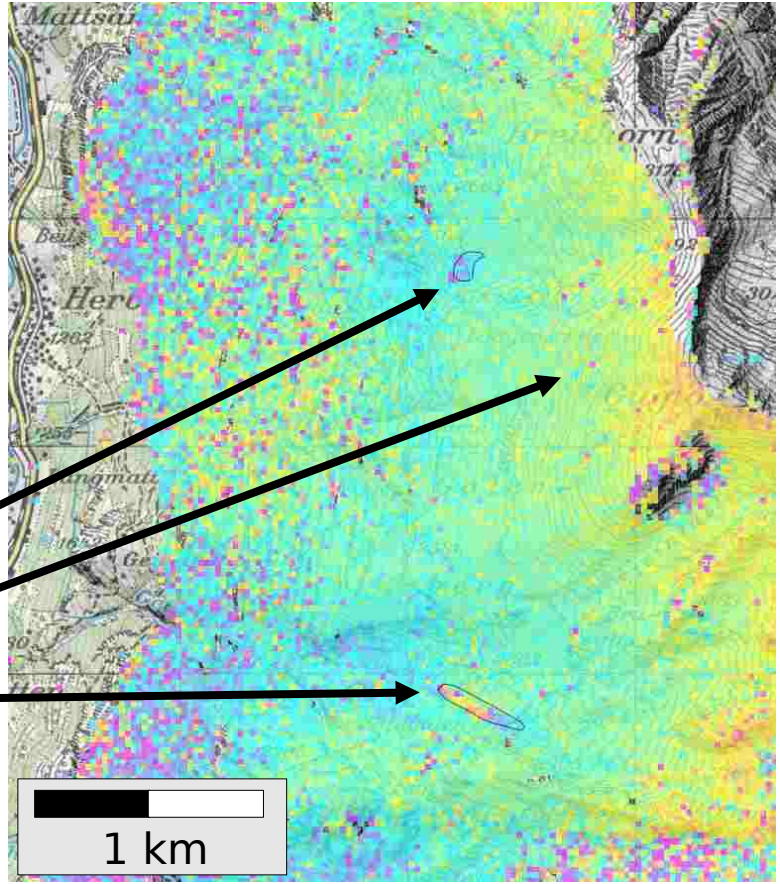
cm/day

ERS-1/2 InSAR 10/11.08.1995

GPRI 2015 > 3 cm/day

ERS-1/2 1995 ~1 cm/day

Gugla-Bielzug rock glacier
Gugla-Längenschnee
Dirru rock glacier



2π ⇔ 2.8 cm @ 5.3 GHz

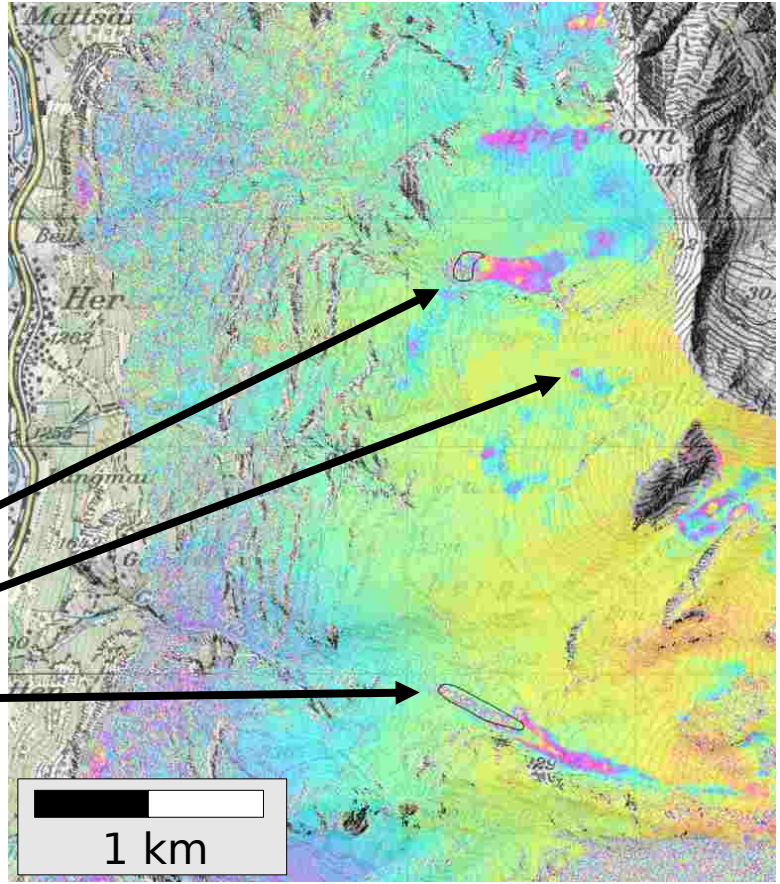
Cosmo-SkyMed InSAR 23-27.09.2011

CSK 2011 (4 days)

Breithorn and Dirru decorrelated at the front

Gugla ~0.25 cm/day

Gugla-Bielzug rock glacier
Gugla-Längenschnee
Dirru rock glacier



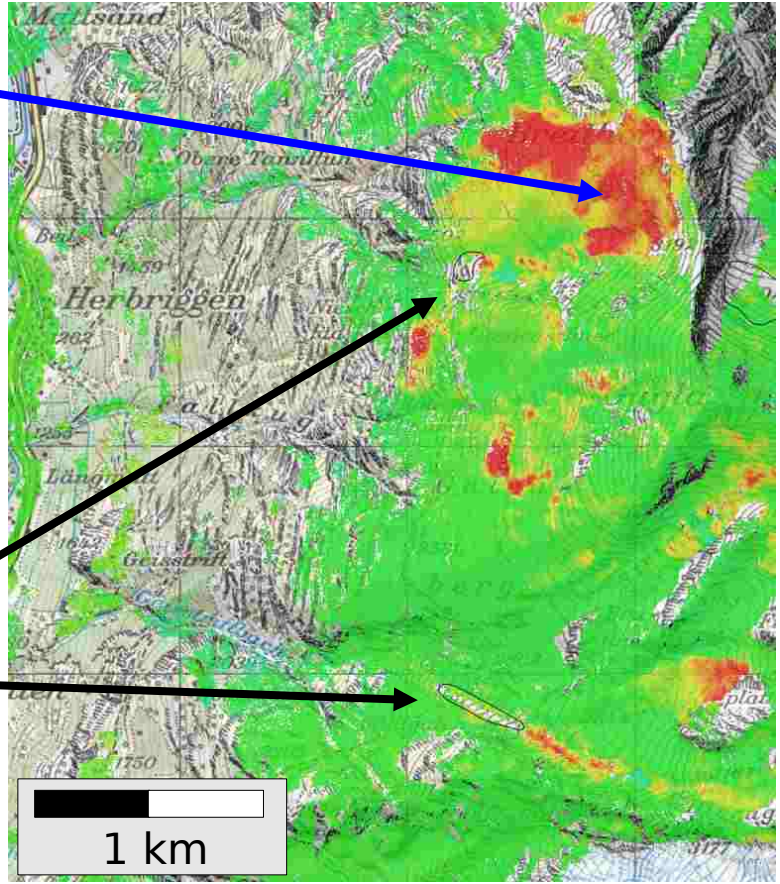
$2\pi \Leftrightarrow 1.6$ cm @ 9.65 GHz

TerraSAR-X 2008-2012 (11 days)

Breithorn landslide

Gugla-Bielzug rock glacier

Dirru rock glacier



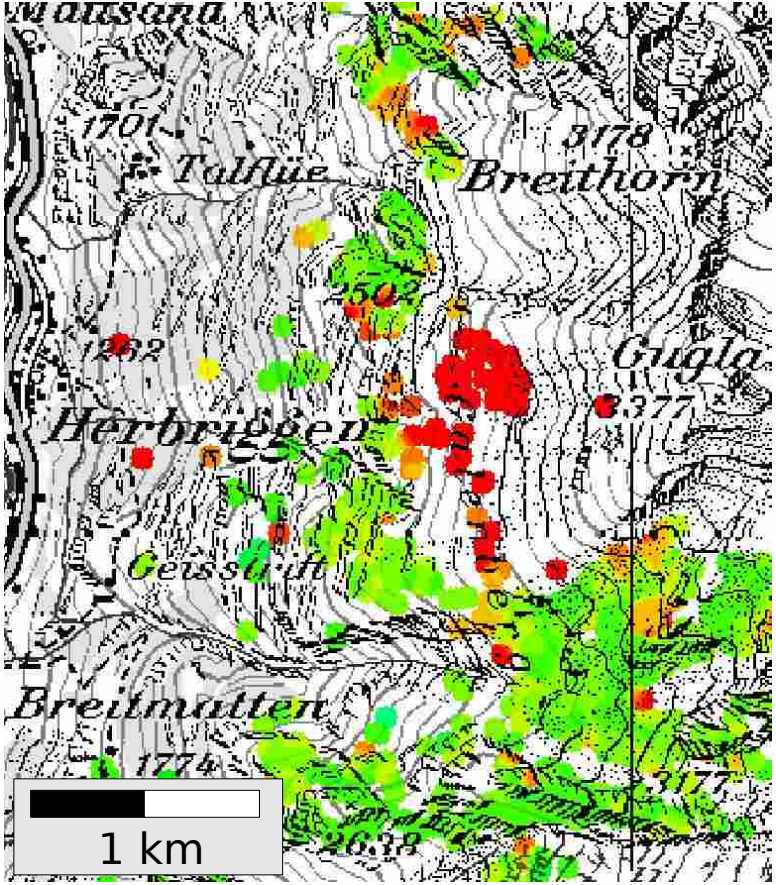
Radarsat-2 PSI 2008-2012

Persistent Scatterer Interferometry

→ consider stable point-like targets that can be used for long time-intervals and large baselines

→ achieve high accuracy and retrieve the signal on single strucuteres by using multiple data

cm/year



Inventory of slope instabilities

Magnitude of displacement

> 100 cm/year

50-100 cm/year

10-50 cm/year

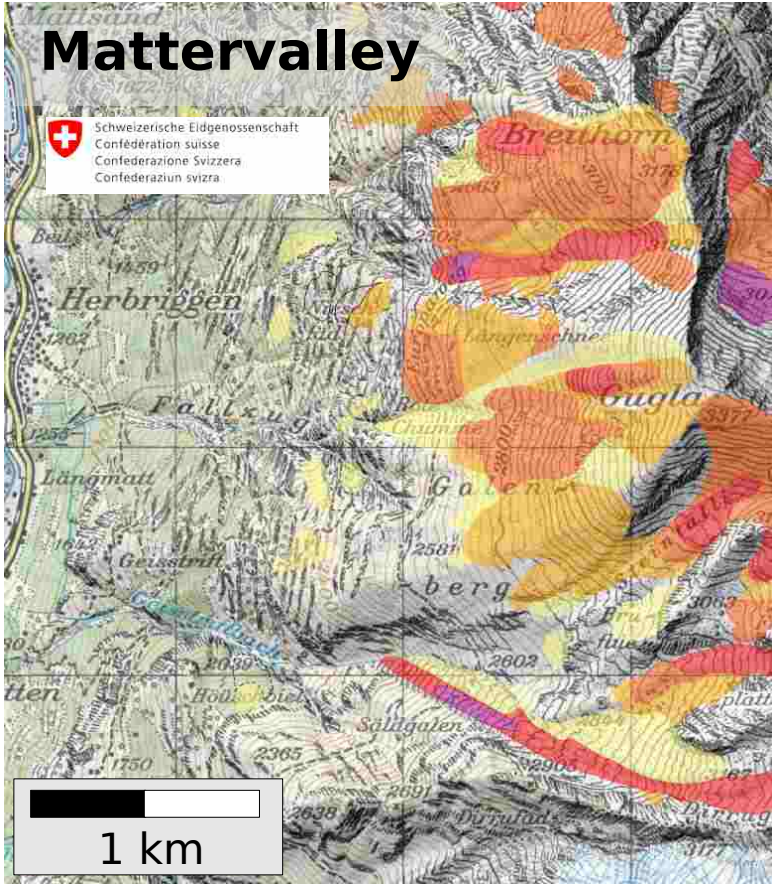
2-10 cm/year

0-2 cm/year

Active ???

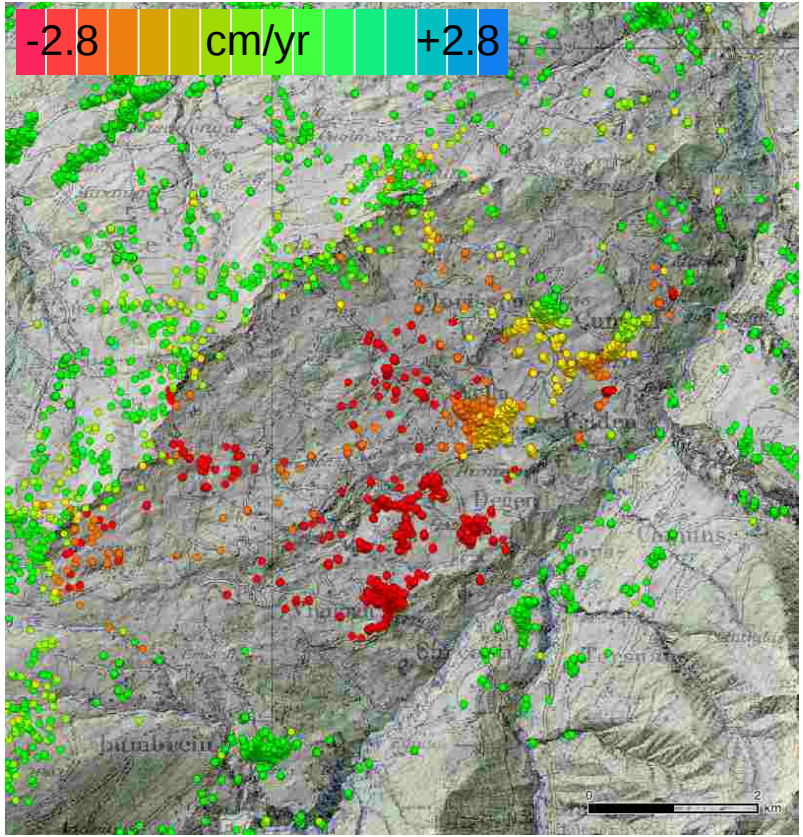
Uncertain

glacier

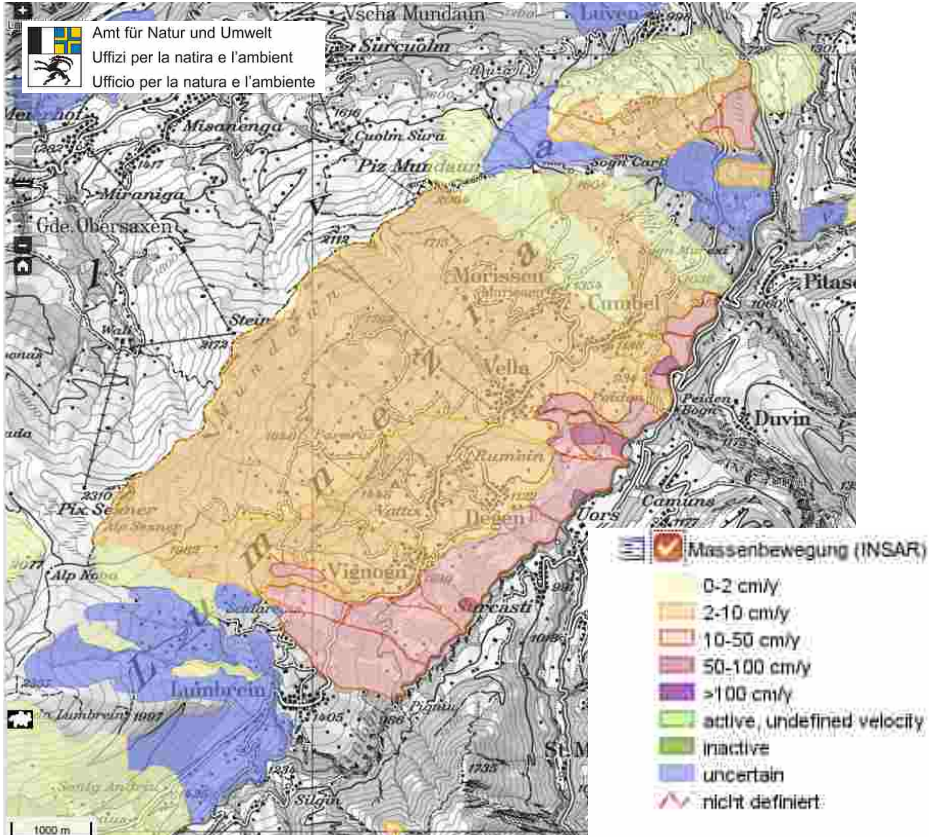


Lumnezia landslide (Switzerland)

Sentinel-1 PSI 2015 - 2018

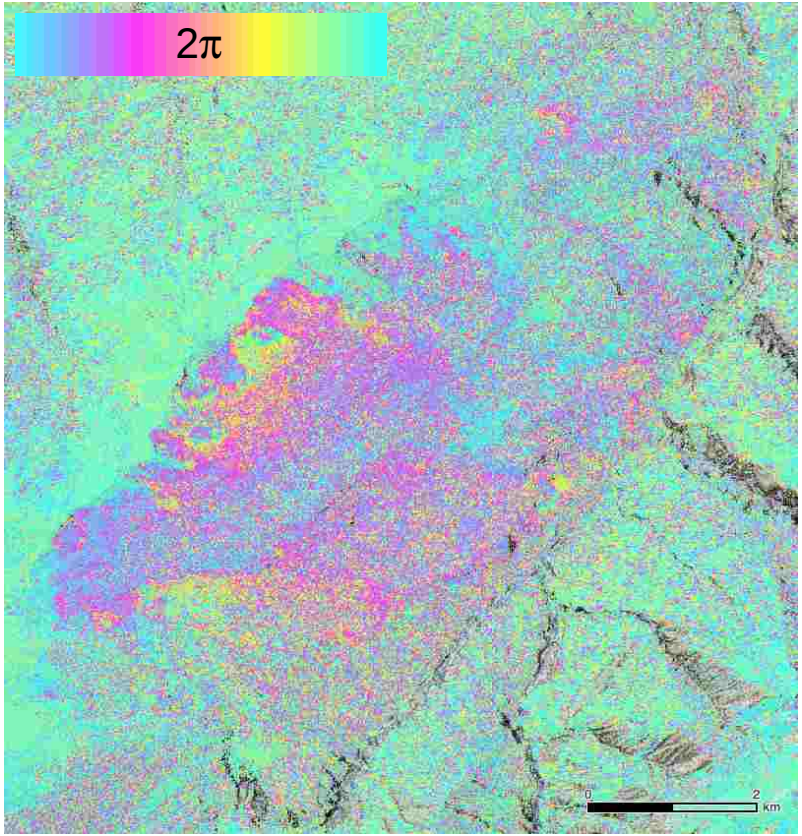


Inventory of slope instabilities

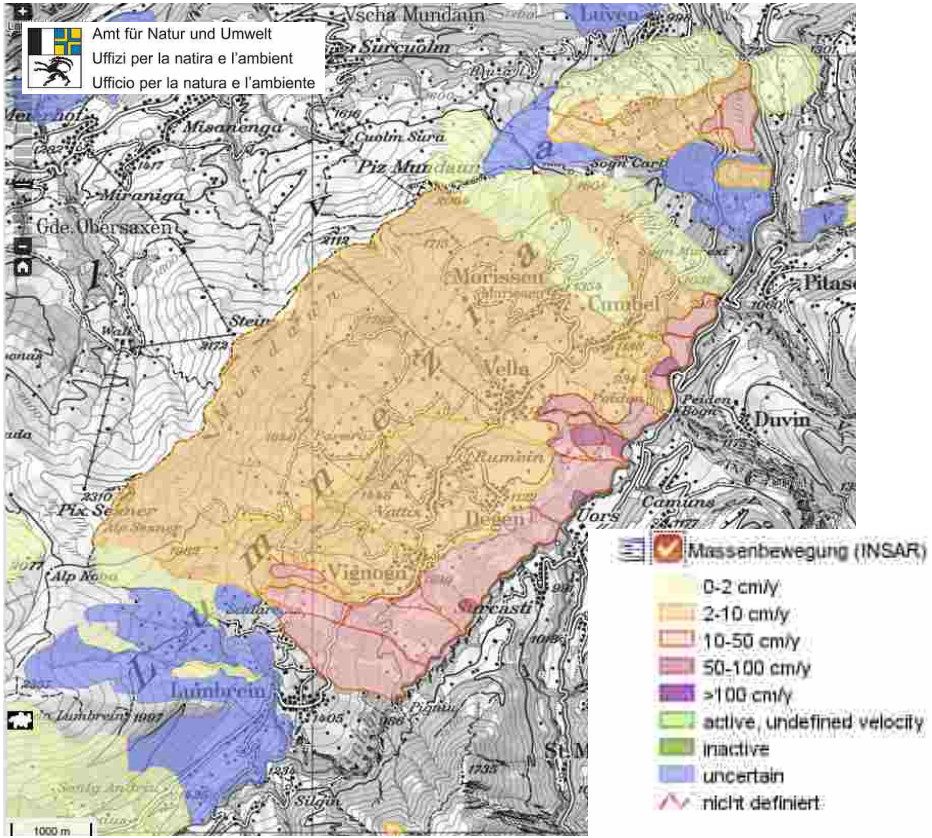


Lumnezia landslide (Switzerland)

PALSAR2 06.09.2014 → 05.09.2015



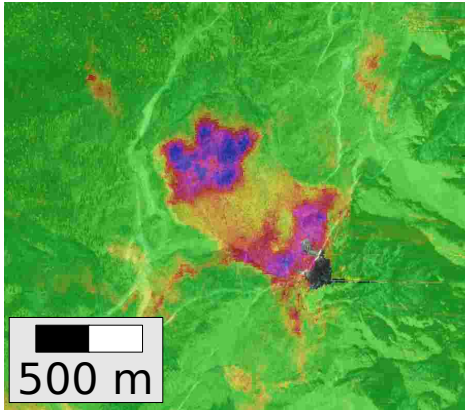
Inventory of slope instabilities



Long-term monitoring of rockglacier motion

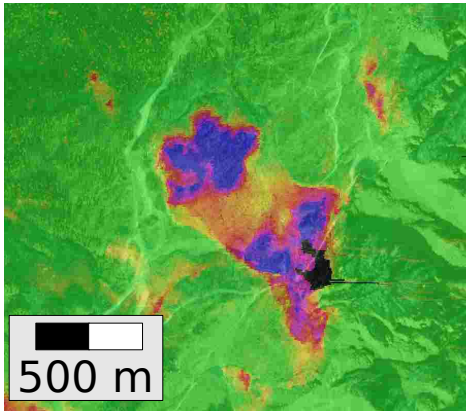
- The InSAR data are used as a base for an inventory of slope instabilities, including rock glaciers
- At least eleven rock glaciers moving at a unusual rate of 1 cm/day or more (“destabilized rock glaciers”) were identified in the Western Swiss Alps
- Interferograms were considered in the set-up in-situ monitoring sites, showing increased velocity of rock glaciers in recent years
- How can we contribute to the monitoring of the rock glacier velocity with radar interferometry?

Distelhorn rock glacier (Switzerland)



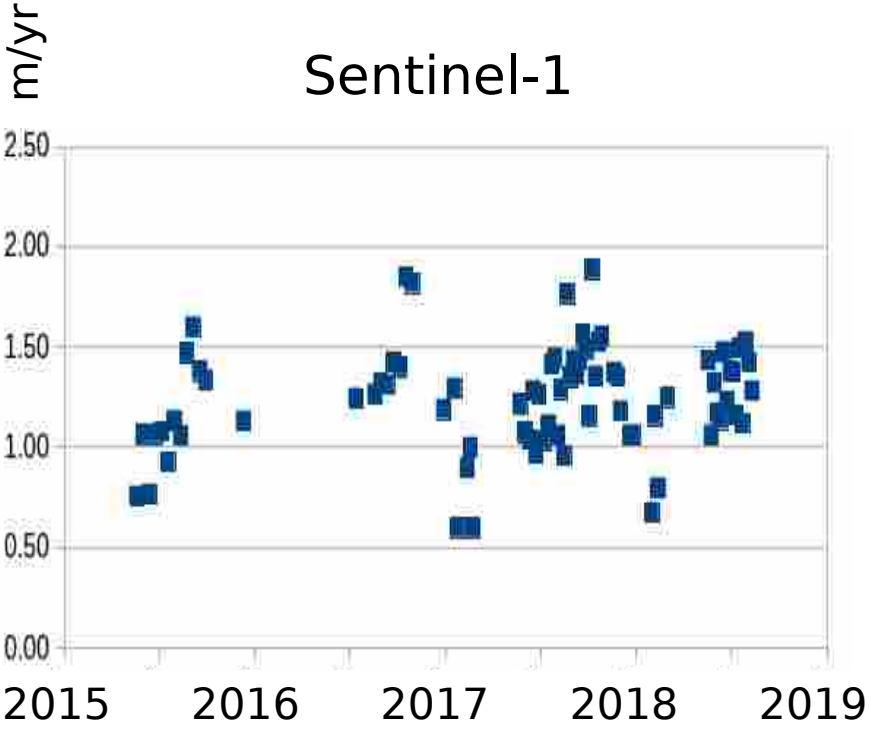
TerraSAR-X
Summer 2009

LOS



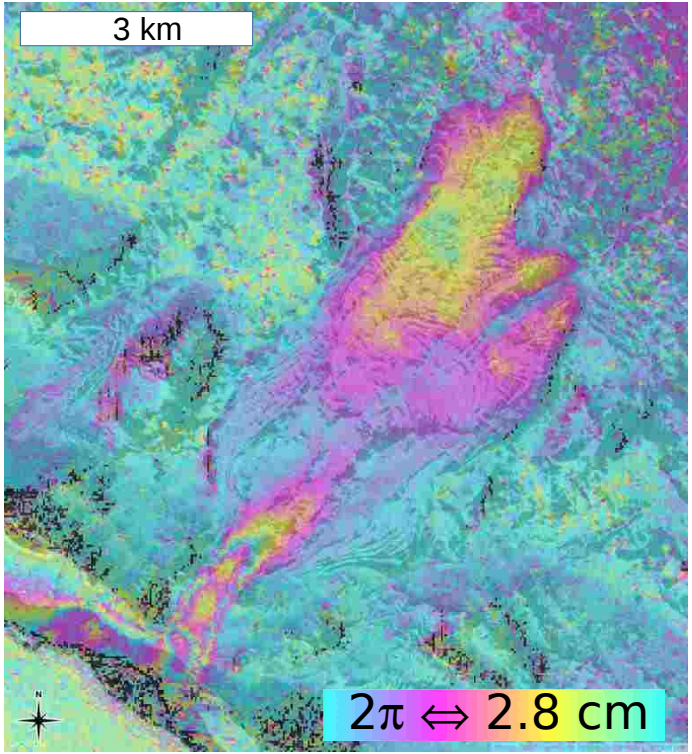
TerraSAR-X
Summer 2016

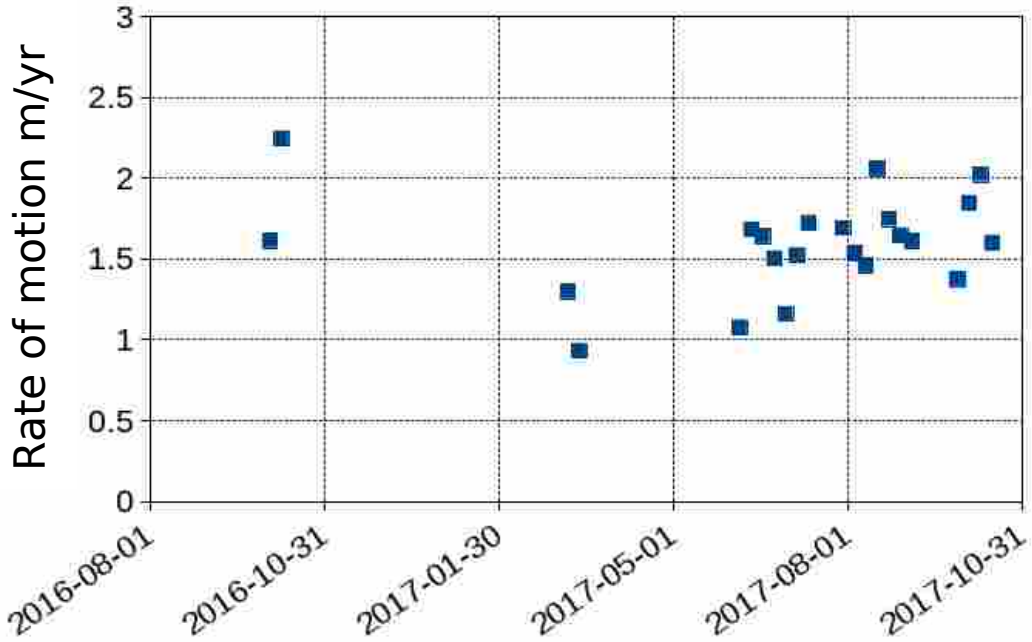
0 cm/yr -50



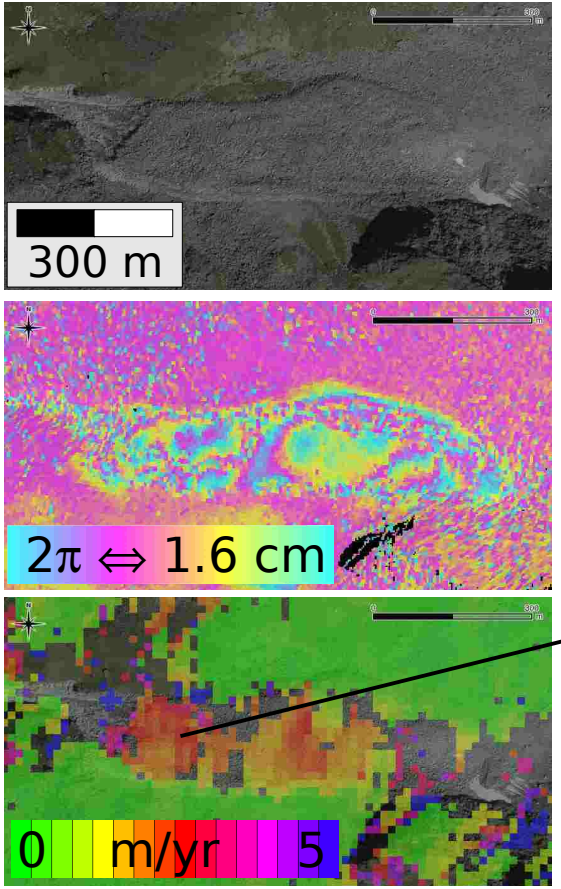
Disko Island (Greenland)

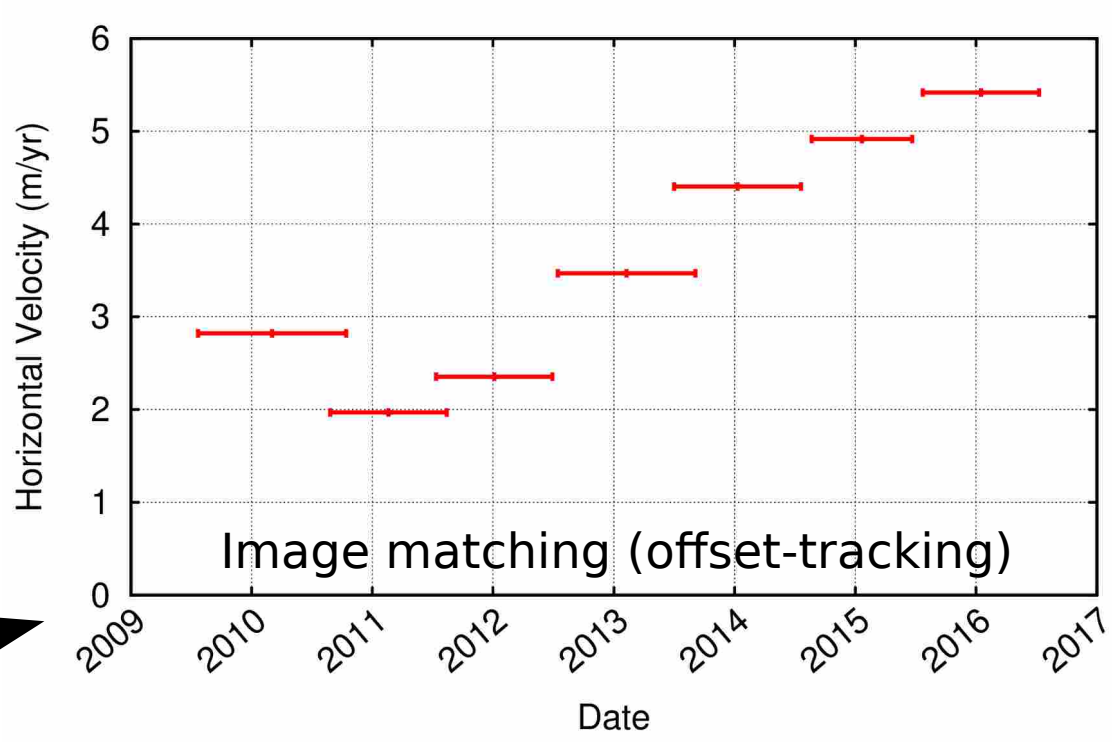
Sentinel 13-19.10.2017





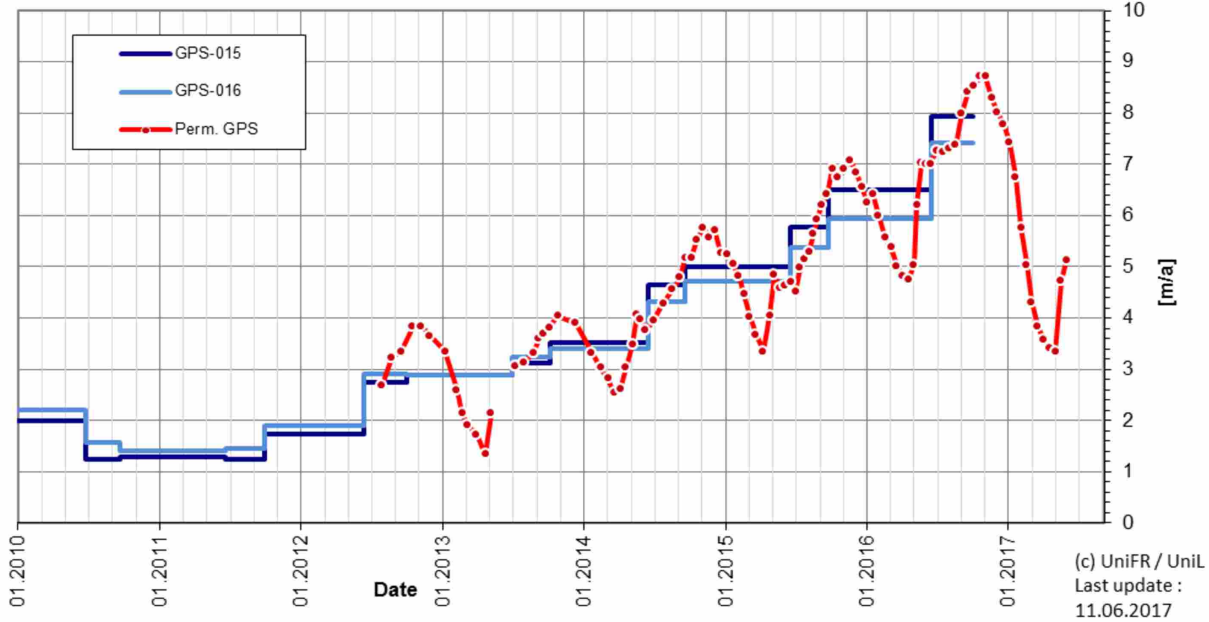
Tsarmine rock glacier (Switzerland)

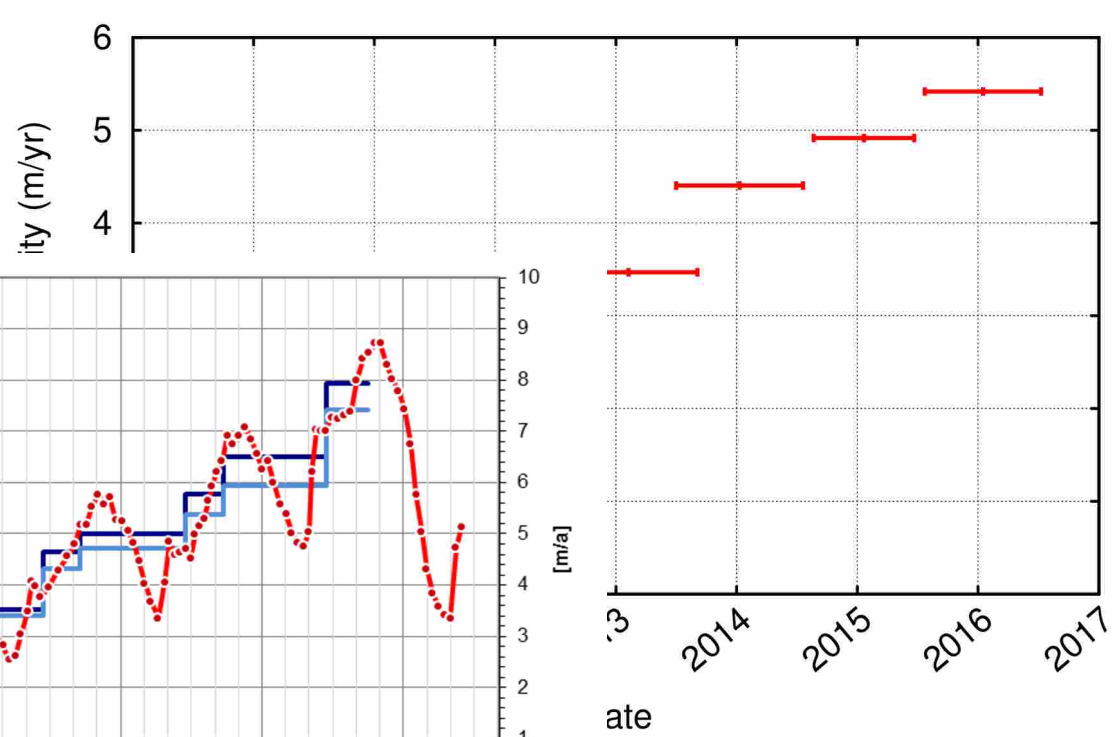




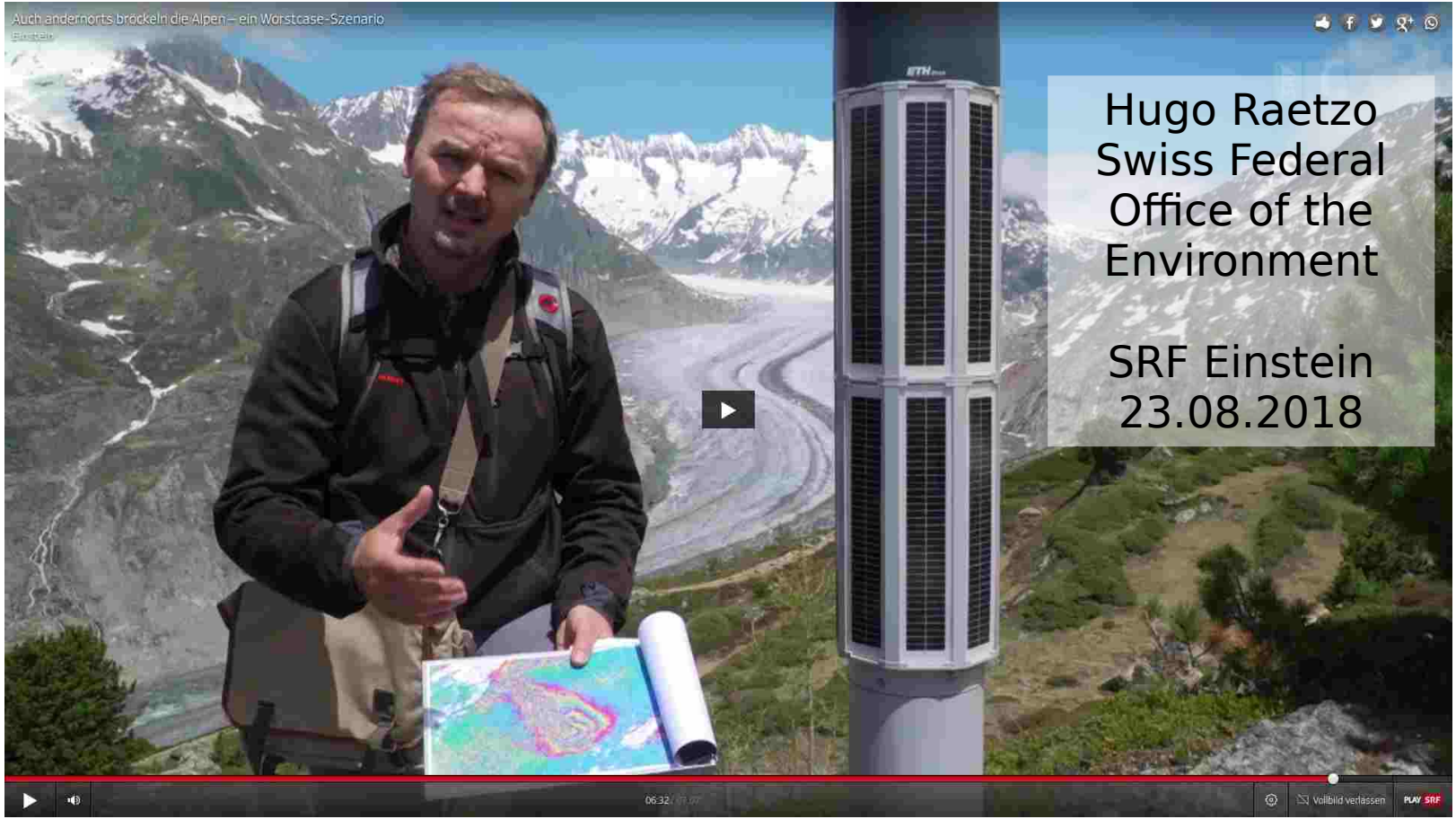
Cosmo-SkyMed 27.08.2010-14.08.2011

Tsarmine rock glacier (Switzerland)

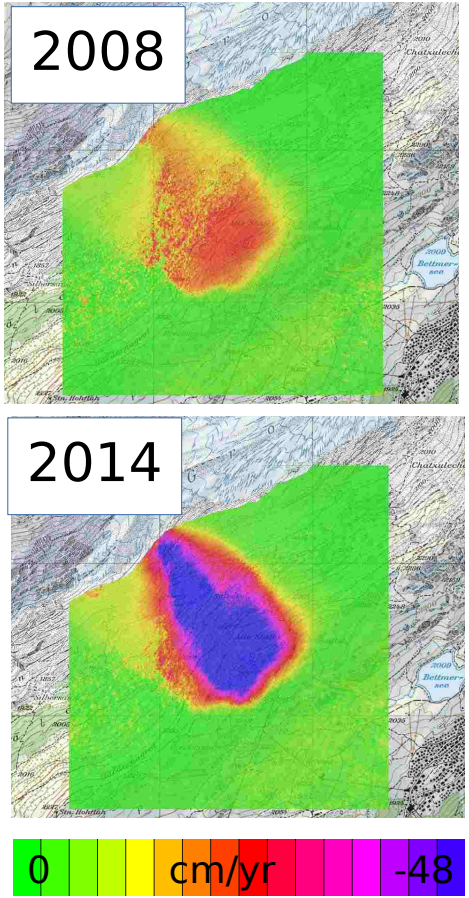


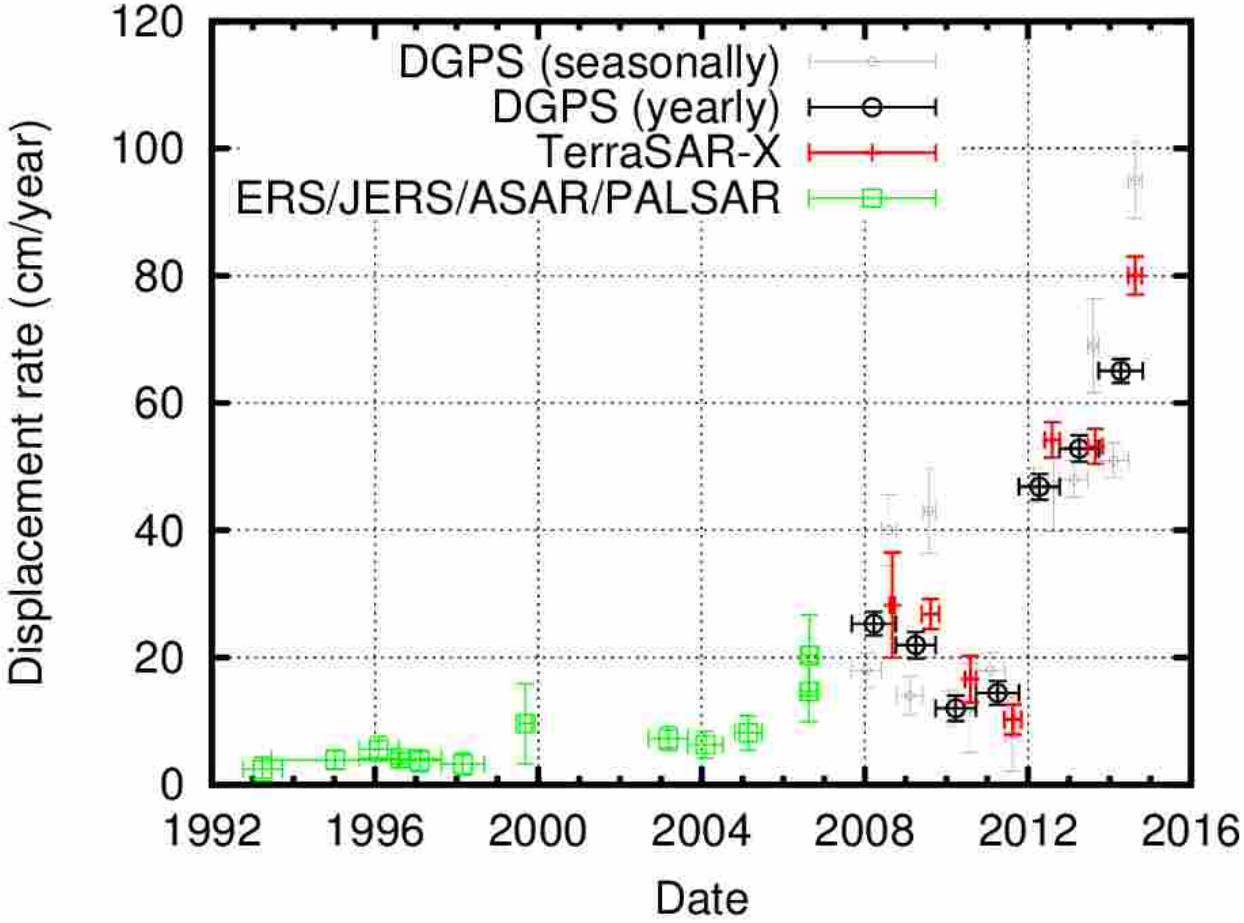


Moosfluh landslide (Switzerland)

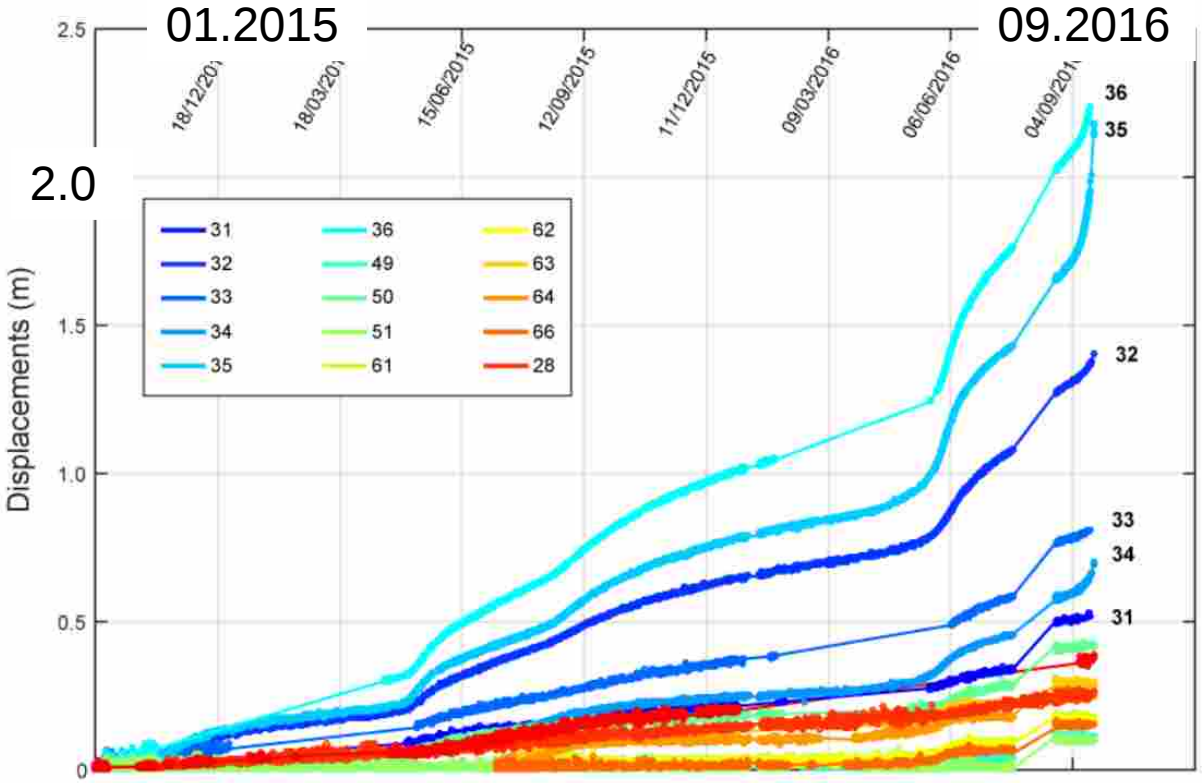


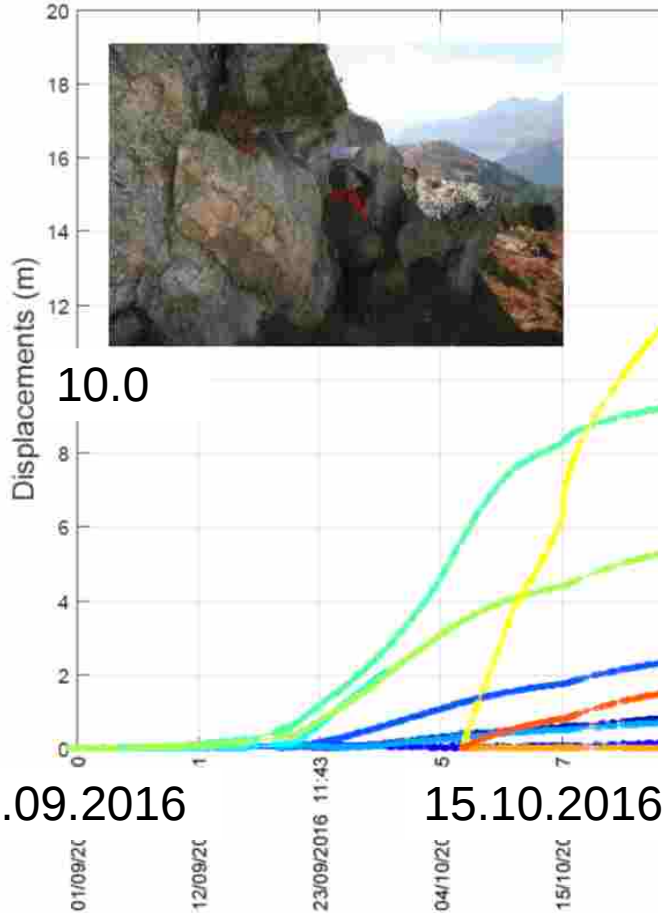
Satellite Radar Interferometry and DGPS





Displacements from robotized total station





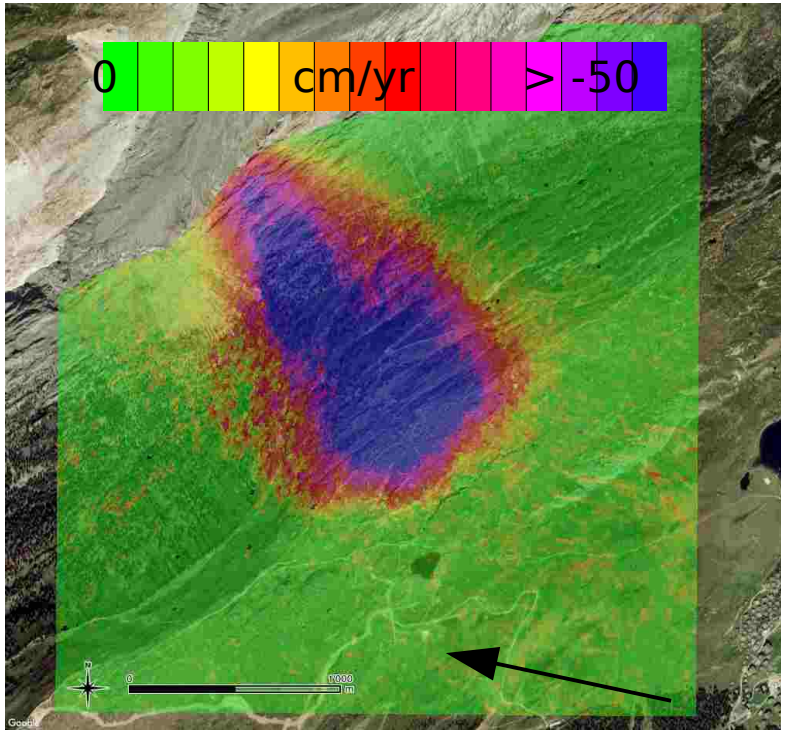
ETH zürich

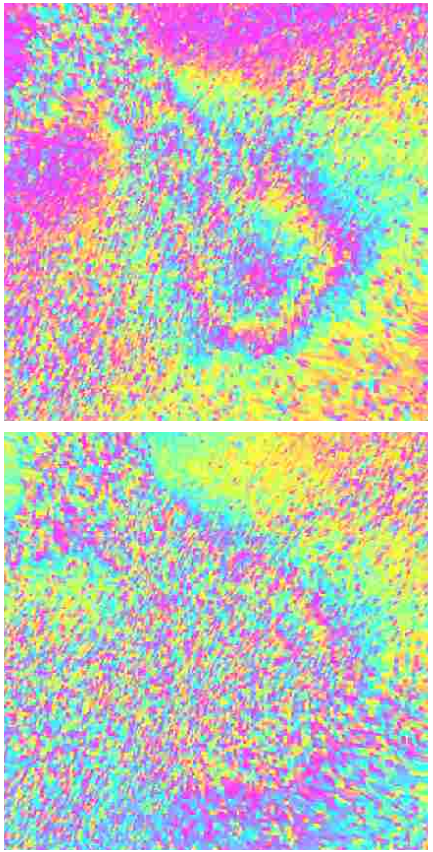
Courtesy A. Manconi

Sentinel-1 InSAR

Velocities larger than 20 cm/day since September 2016

Sentinel-1 InSAR Summer 2015



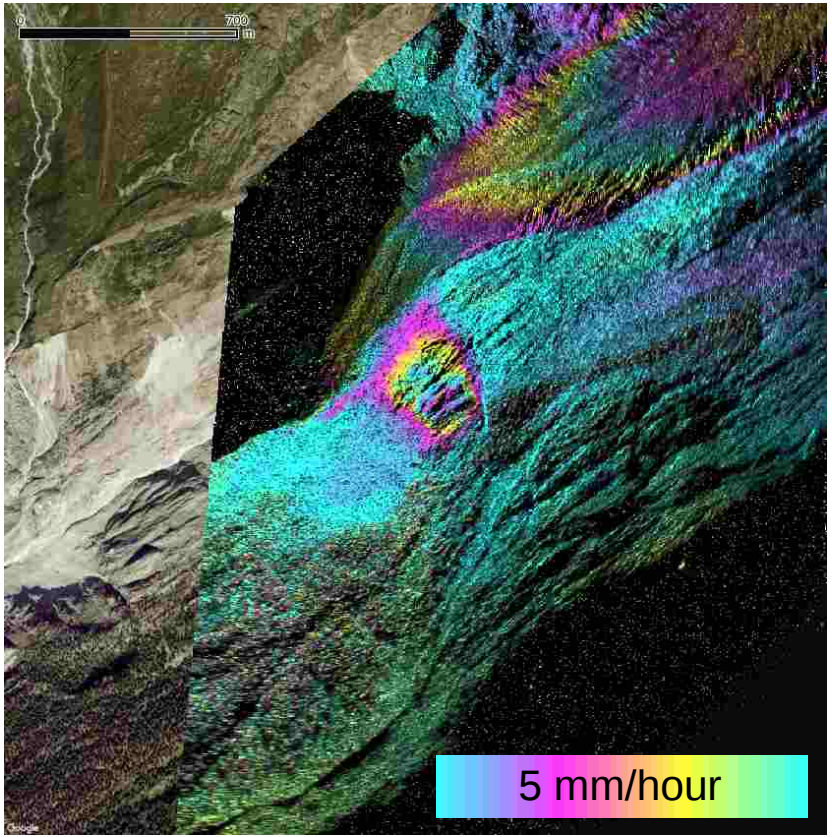


12-24.08.2016

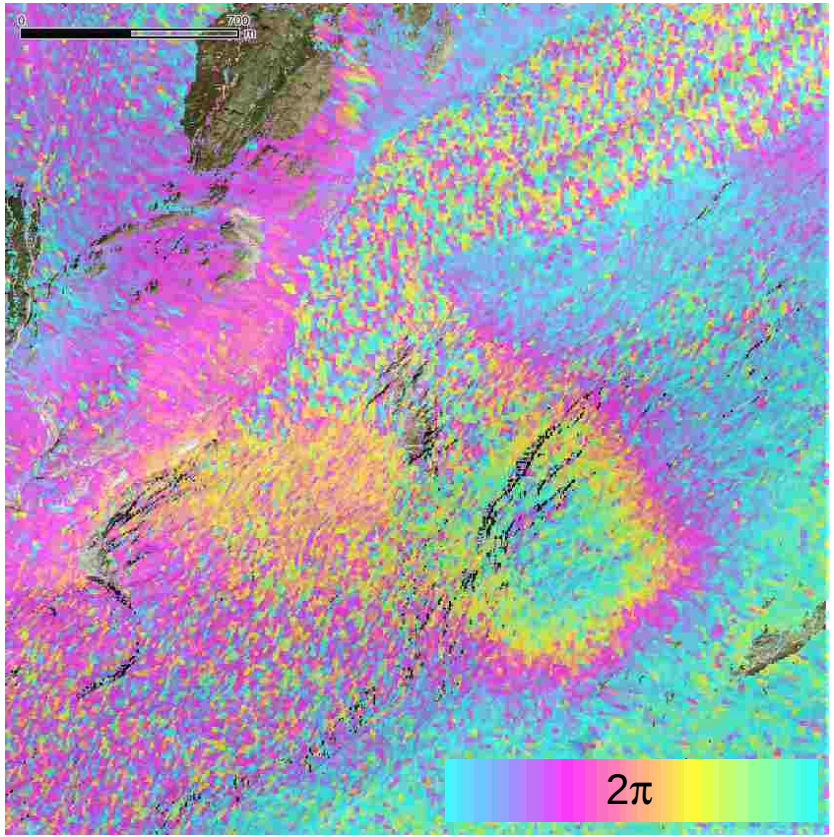
05-17.09.2016

Moosfluh landslide (Switzerland)

GPRI 28.09.2017 06:23 → 09:03

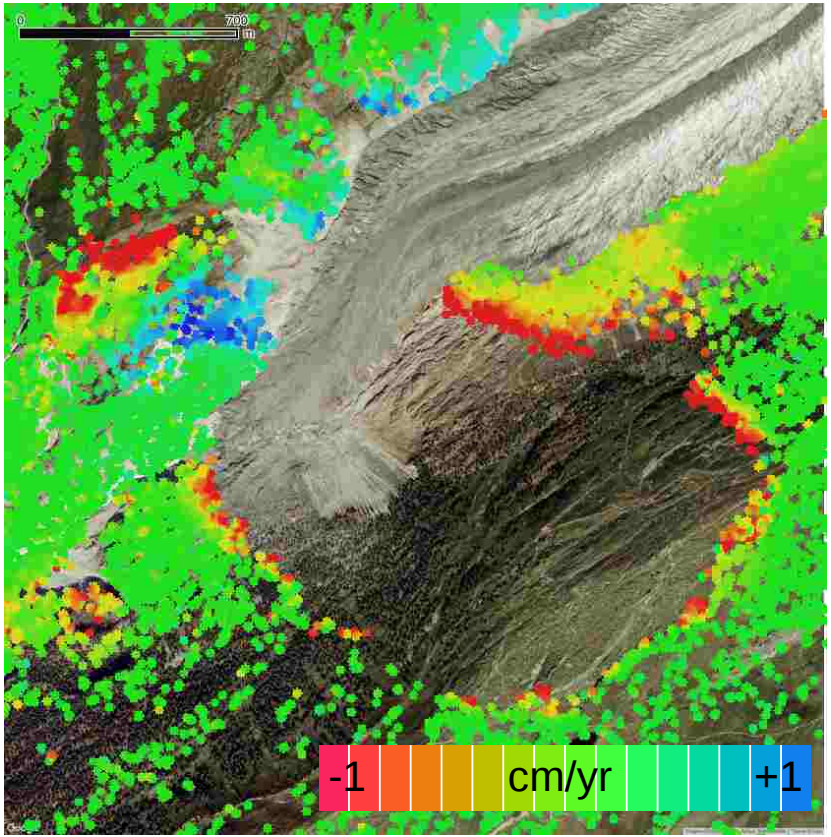


Sentinel-1 20.09.2017 → 26.09.2017

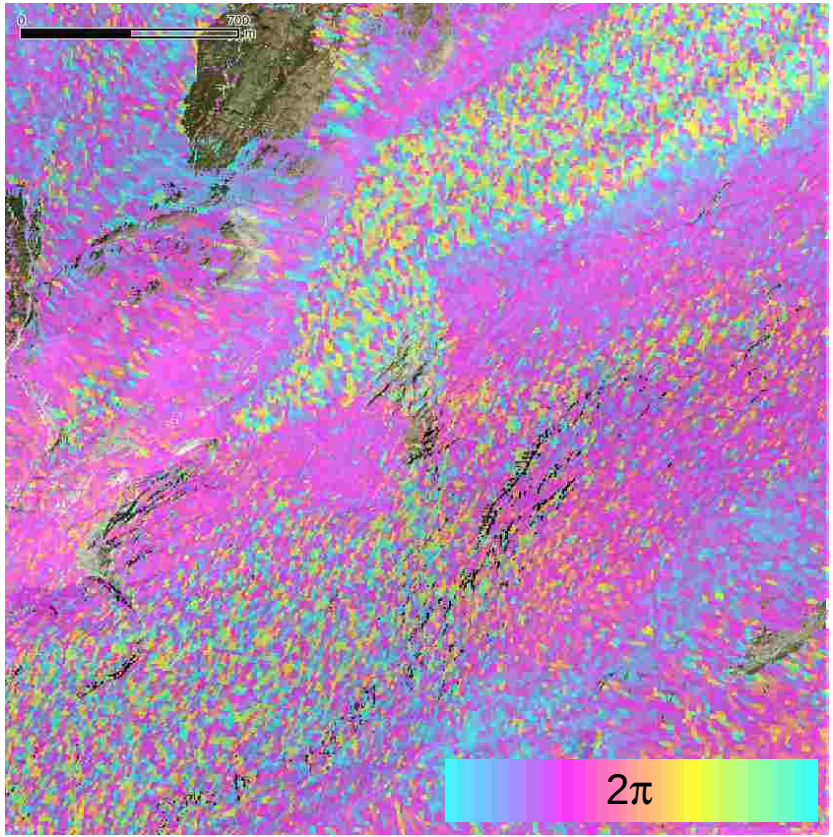


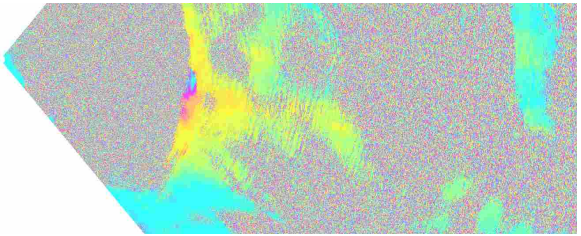
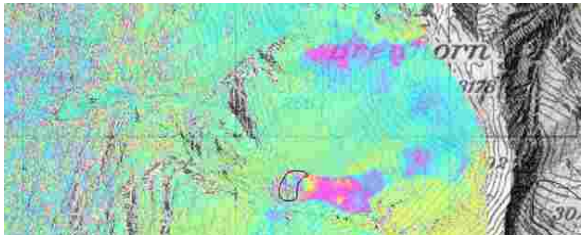
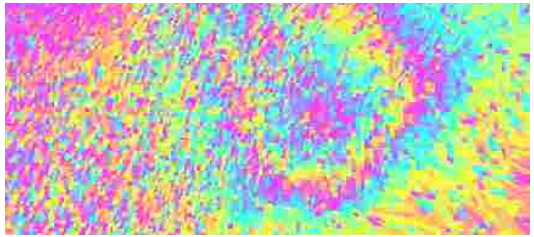
Moosfluh landslide (Switzerland)

TSX PSI 2008 - 2016



Sentinel-1 26.08.2018 → 01.09.2018



Thank you for your attention

Review radar-interferometric monitoring techniques applied to detect and quantify the surface displacement of glaciers, rock glaciers and landslides in mountain environments