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

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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

Azimuth [60°]
(8 m resolution @ 1 km)

Slant-range resolution: $\frac{c}{2B}$
(bandwidth $B$, speed of light $c$)

Azimuth resolution: $\frac{\lambda R}{L}$
(wavelength $\lambda$, distance $R$, antenna length $L$)
Radar interferometry

\[ \phi = \phi_1 - \phi_2 = \frac{4\pi}{\lambda} (R_2 - R_1) \]

- \( \phi_1, \phi_2 \): phases of the two radar images
- \( R_1, R_2 \): distances from the radar positions to the image scatterer
- \( \lambda \): 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

$\Delta T = 18$ 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

$\Delta T = 279 \text{ min.}$
Layover and shadowing

Radar Pulses

Lugano and the Monte San Salvatore
Differential interferometry

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

Interferogram → Differential interferogram

Topography

2π ↔ 11.8 cm @ 1.27 GHz

Atmosphere

Displacement

2.5 km
Phase unwrapping

17.08.2007-02.10.2007

Coherence mask

Errors

$2\pi \Leftrightarrow 11.8 \text{ cm} @ 1.27 \text{ GHz}$

$-10 \text{ cm} \rightarrow +10 \text{ cm}$
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
Kronenbreen (Svalbard)
GPRI 2 minutes

30.08.2016 10:08:17
30.08.2016 10:10:17

$2\pi \leftrightarrow 0.9 \text{ cm}$
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

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

Breithorn landslide

Hobärg glacier

Grabengufer landslide

Dom (4,545 m a.s.l.)
Gugla-Bielzug rock glacier
Gugla-Längenschnee
Dirru rock glacier

GPRI 07.10.2015

3 cm/day

1 km
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

$2\pi \leftrightarrow 2.8 \text{ cm @ 5.3 GHz}$
CSK 2011 (4 days)

Breithorn and Dirru decorrelated at the front

Gugla \( \sim 0.25 \) cm/day

Gugla-Bielzug rock glacier
Gugla-Längenschnee
Dirru rock glacier

\[ 2\pi \Leftrightarrow 1.6 \text{ cm @ 9.65 GHz} \]
TerraSAR-X 2008-2012 (11 days)

Breithorn landslide

Gugla-Bielzug rock glacier
Dirru rock glacier

30 cm/year
0

1 km
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 structures by using multiple data

1 km

1 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

Mattervalley
Lumnezia landslide (Switzerland)

Sentinel-1 PSI 2015 - 2018

Inventory of slope instabilities

-2.8 cm/yr +2.8
Lumnezia landslide (Switzerland)

PALSAR2 06.09.2014 → 05.09.2015

Inventory of slope instabilities
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

Sentinel-1

2015  2016  2017  2018  2019

m/yr

0 cm/yr -50

500 m
Disko Island (Greenland)

Sentinel 13-19.10.2017

2π ↔ 2.8 cm

Rate of motion m/yr

Tsarmine rock glacier (Switzerland)

2π ↔ 1.6 cm

Image matching (offset-tracking)

Cosmo-SkyMed 27.08.2010-14.08.2011
Tsarmine rock glacier (Switzerland)
Moosfluh landslide (Switzerland)

Hugo Raetzo
Swiss Federal Office of the Environment
SRF Einstein
23.08.2018
Satellite Radar Interferometry and DGPS

Displacement rate (cm/year)

Date

DGPS (seasonally)
DGPS (yearly)
TerraSAR-X
ERS/JERS/ASAR/PALSAR
Displacements from robotized total station

01.2015 - 09.2016


Courtesy A. Manconci
Velocities larger than 20 cm/day since September 2016
Moosfluh landslide (Switzerland)

GPRI 28.09.2017 06:23 → 09:03
Moosfluh landslide (Switzerland)

TSX PSI 2008 - 2016

Sentinel-1 26.08.2018 → 01.09.2018
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