GAMMA REMOTE SENSING

Terrestrial Radar – A method to detect millimeter snow glide deformation hours to days before wet snow avalanche release

Rafael Caduff, Andreas Wiesmann, Urs Wegmüller

GAMMA Remote Sensing AG, Gümligen, Switzerland



8th EARSeL workshop an Land Ice and Snow, 7-9 February 2017, Bern Switzerland

Snow on Slopes



Snow on Slopes





Mägisalp, Hasliberg BE 2012

Sometimes, the gravitational forces acting on the snowpack lead to impressive traces.

The formation of large extensional and compressional features is an indicator that a **full depth snow glide avalanche** may result.

But…

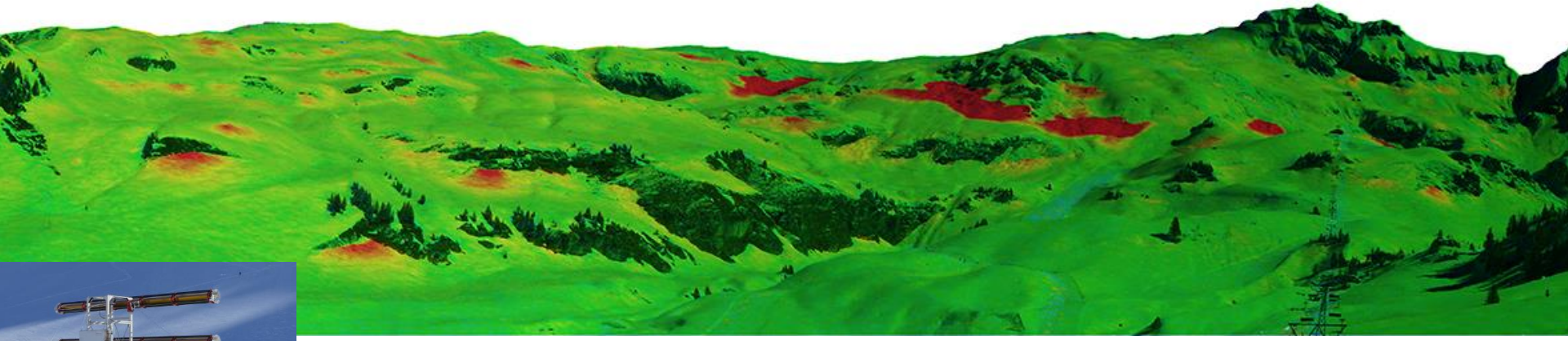
Not all full depth snow-glide avalanches are precurred by visible features!

Snow on Slopes



Terrestrial radar interferometry…

… allows a **kinematic analysis** of the snow slope.





Gamma Portable Radar Interferometer (GPRI)



frequency:
Ku-Band 17.1-17.3 GHz
(Wavelength: 1.74 cm)

precision:
Under ideal conditions 0.1 mm
Significant movement usually detected at ~1 mm

resolution:
Distance: 1 m
Angle: 8 m@1km
(Pixel oversampling for Point Scatterers → 2m@1km)

range of Operation:
20 m to up to several km

scan-Velocity:
~10°/s (360°) (acquisition intervals of 1-2 minutes are possible including post-processing)

total weight:
~55 kg

Short term vs. long term monitoring…



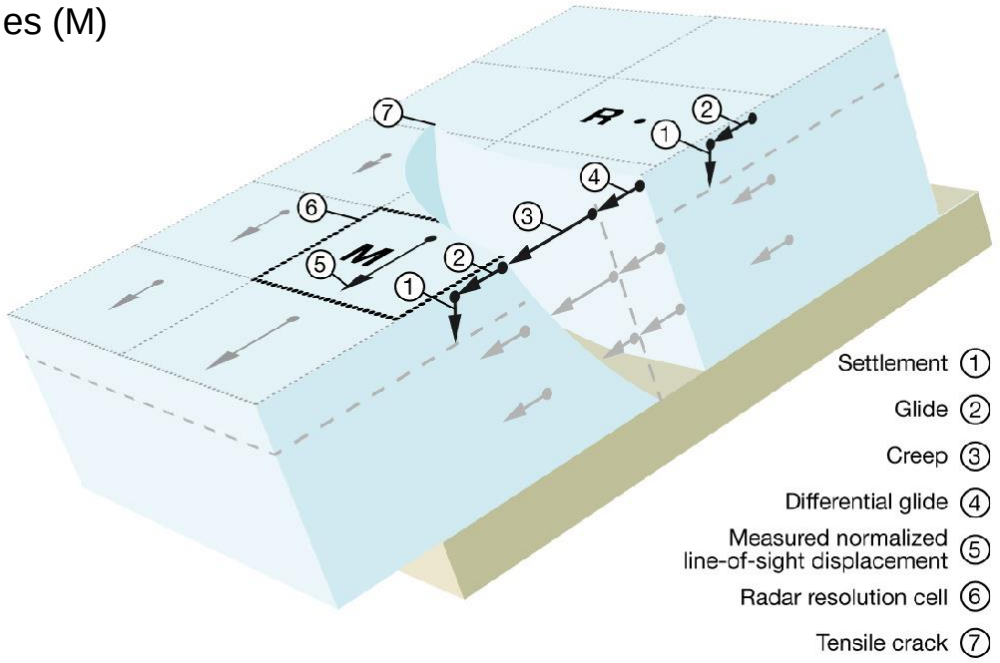


Long term monitoring (weeks to months) is possible, but needs proper preparation**. Weather protection (e.g. with a radome) is needed for operation as well in harsh conditions (strong winds, strong precipitation).**

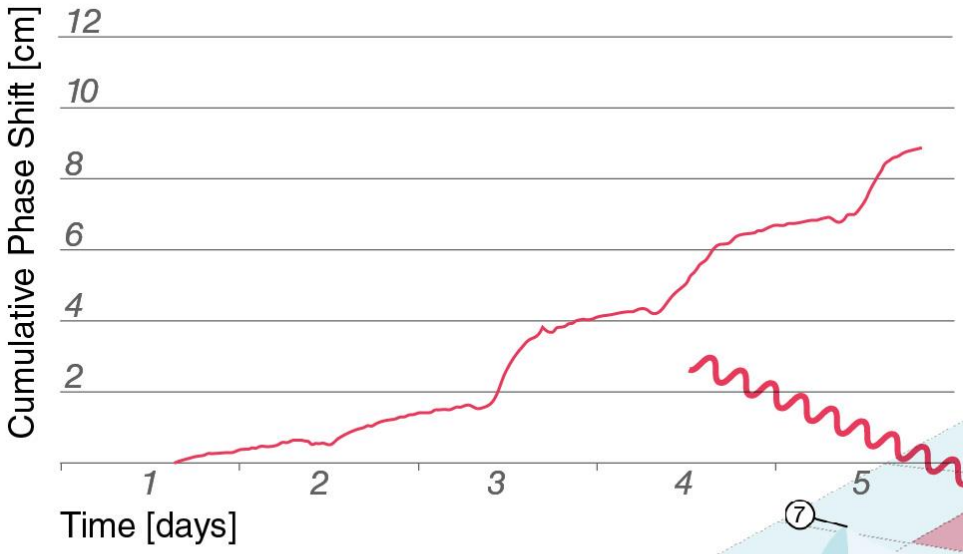
Snow-pack deformation processes

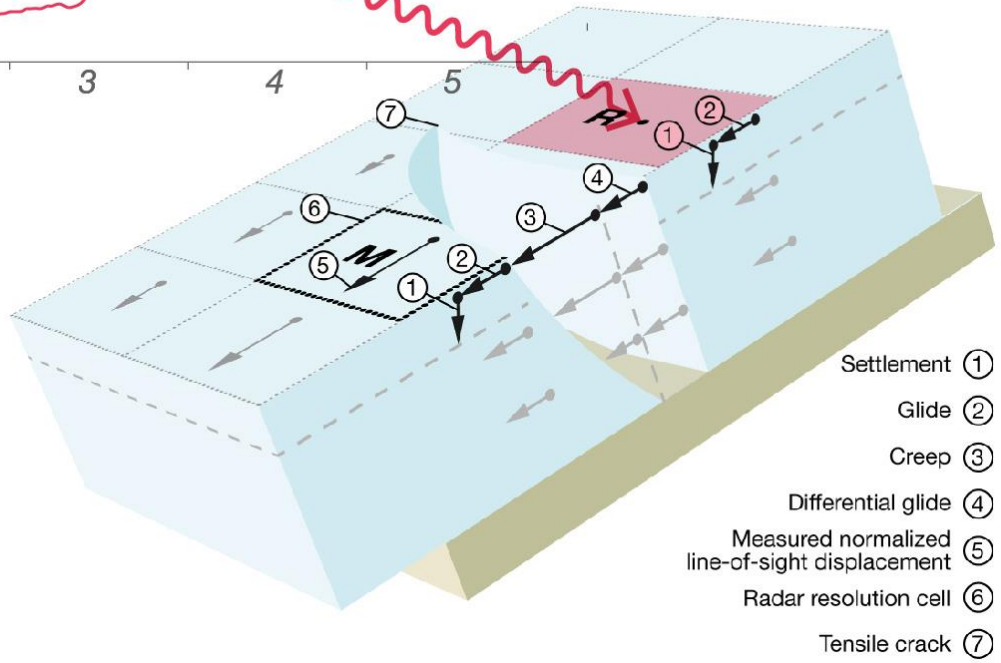
- **Snow Glide (2) is not the only movement of the Snowpack**

Separation of the global deformation signature such as Settlement (1), creep (3) of the local movement signatures can be acheived by normalizing the measured values (M) to a point in the snow, that shows no glide (R)

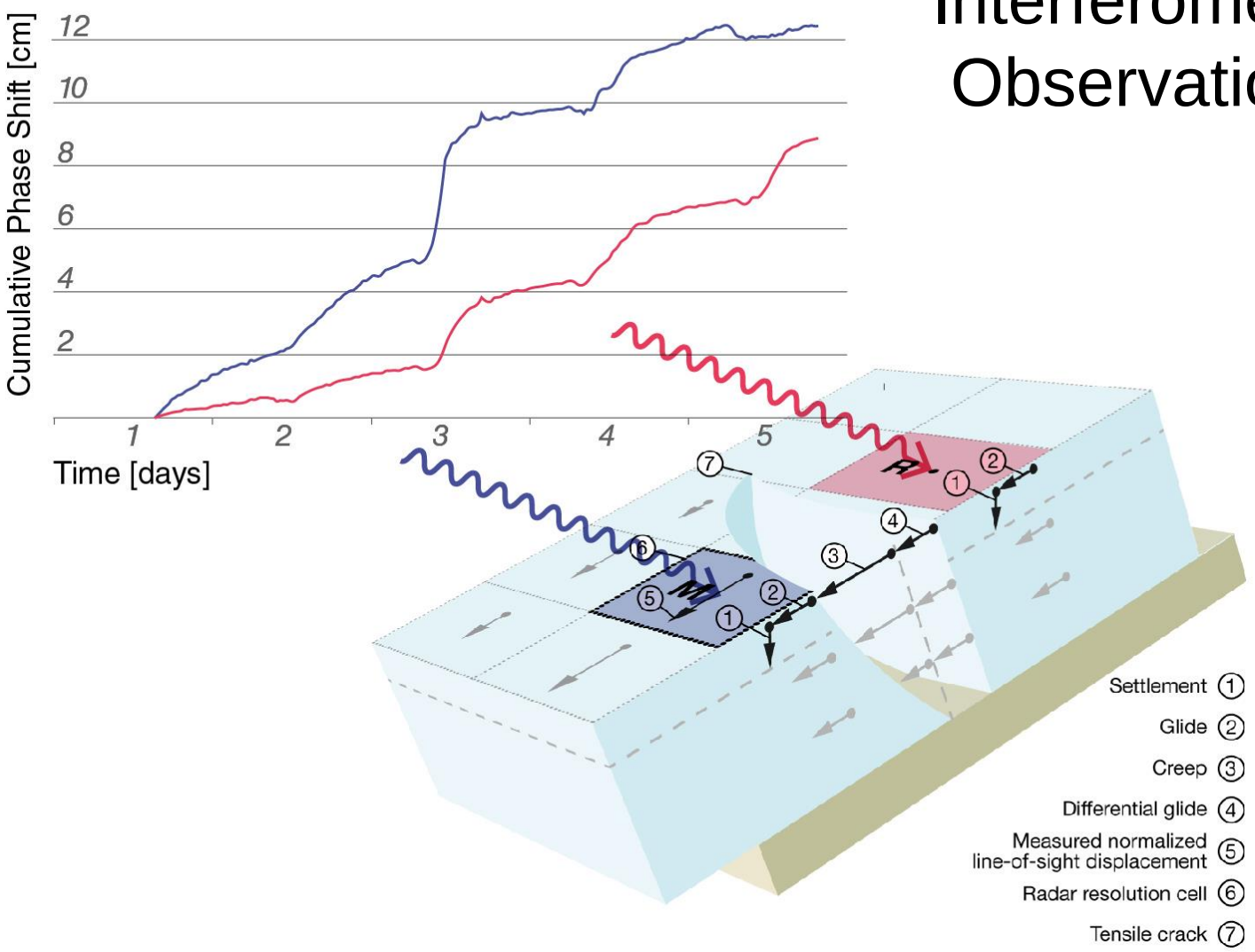


Interferometric Observations

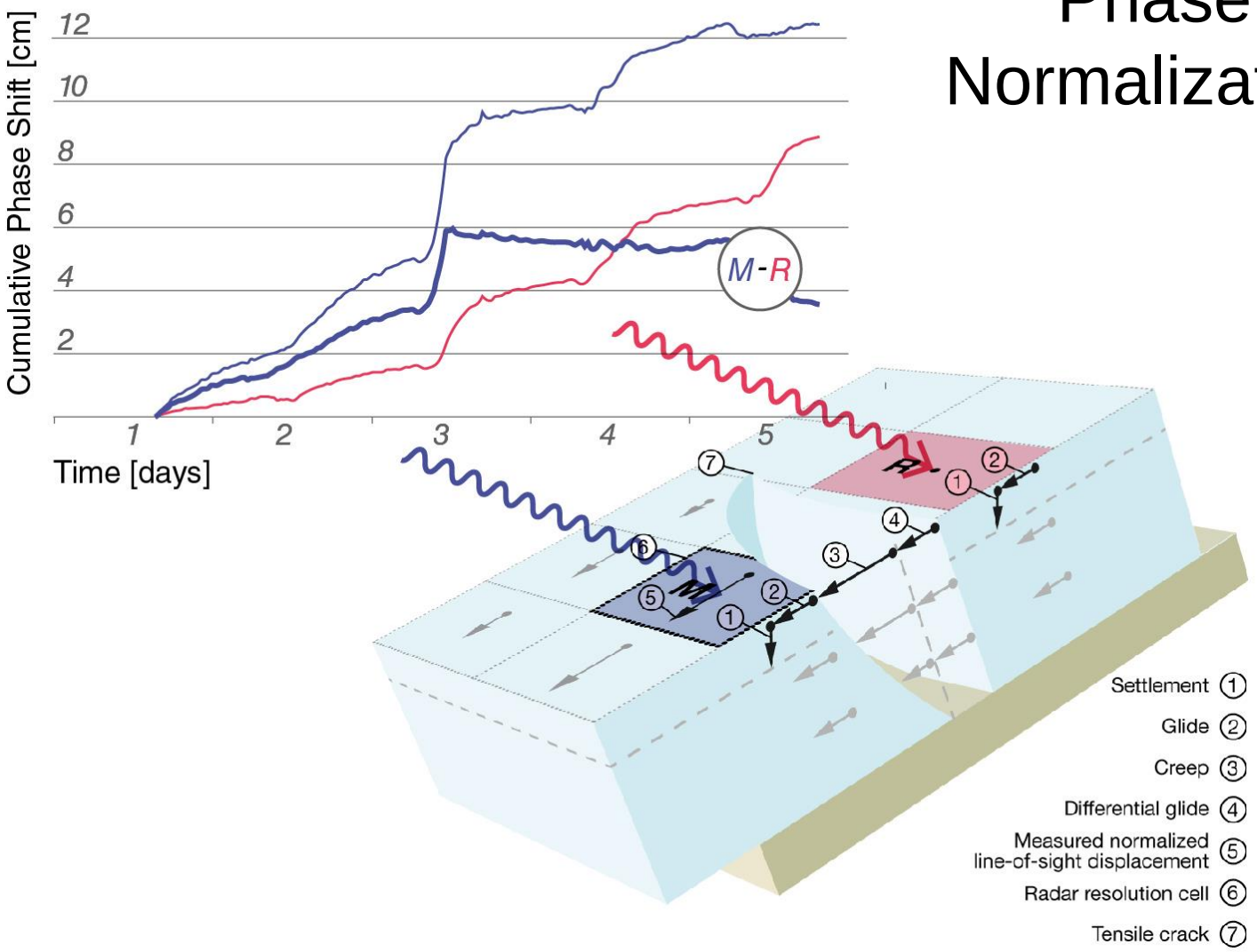




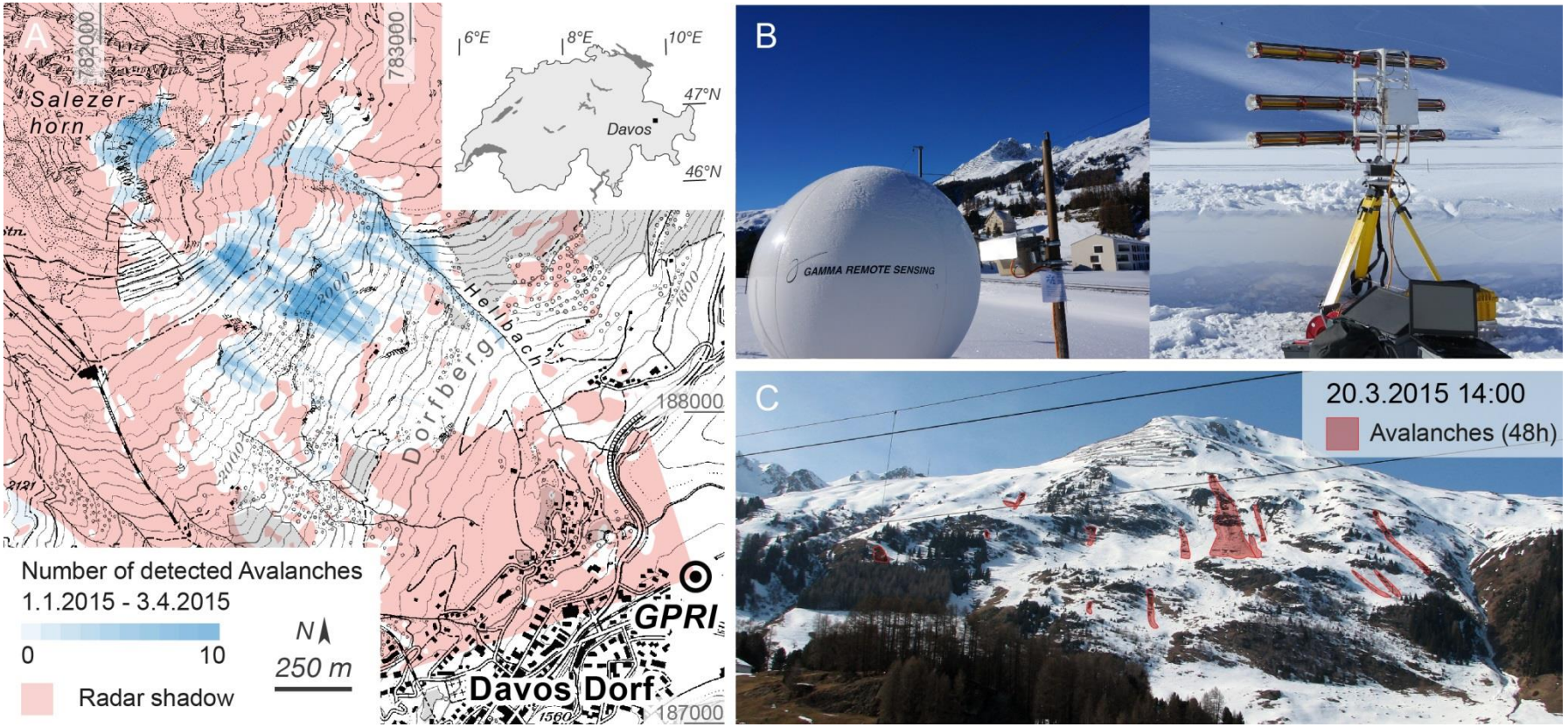
Interferometric Observations



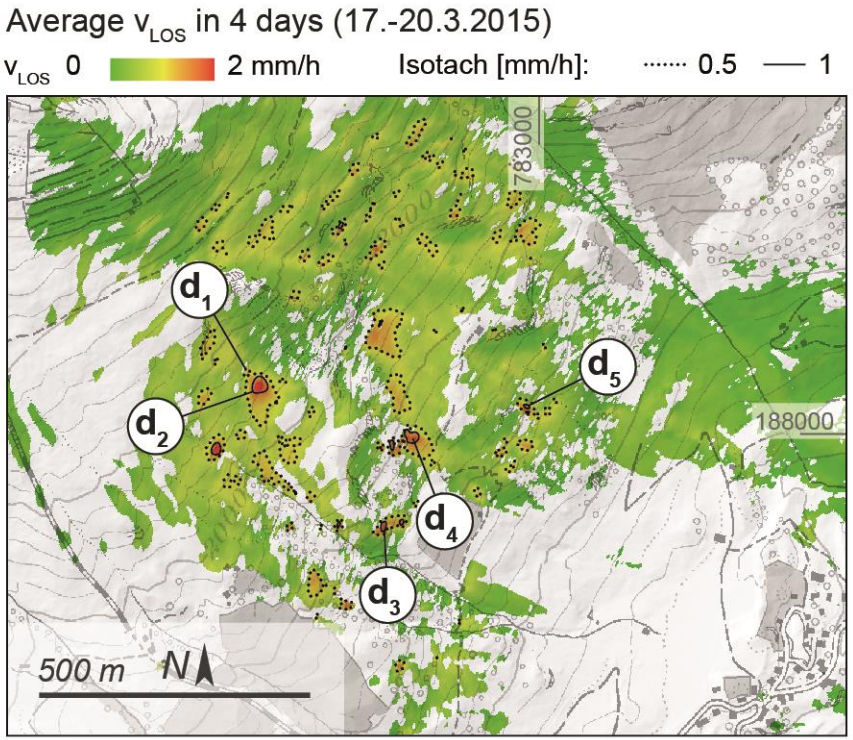
Phase Normalization

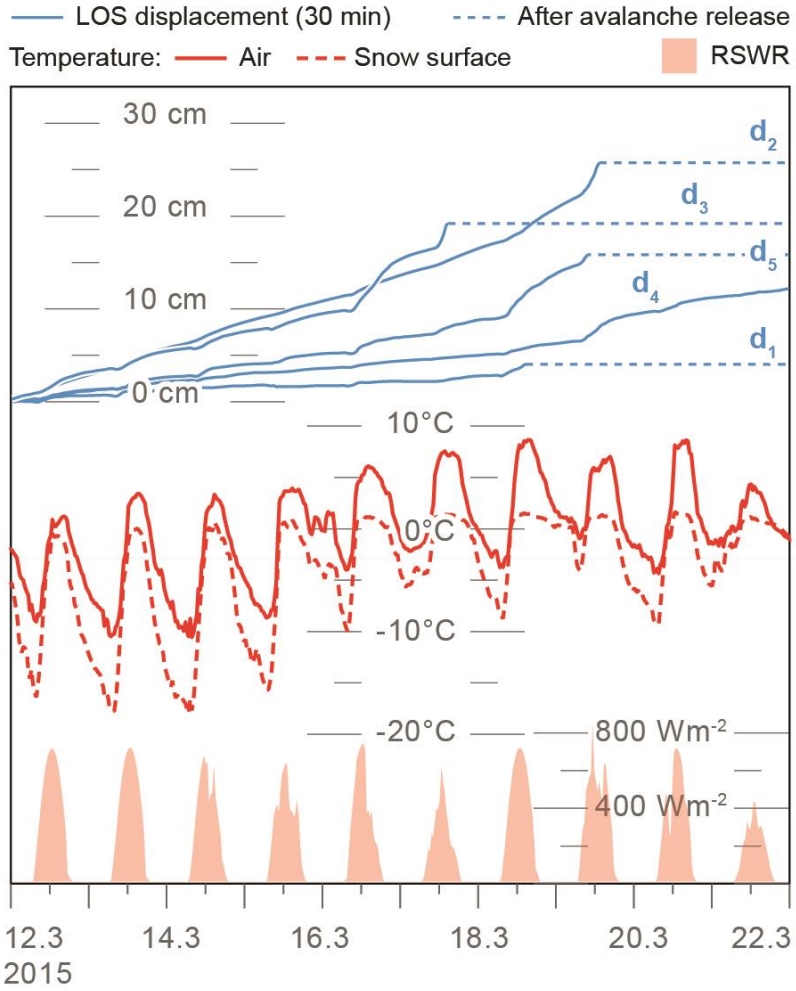


Dorfberg Davos: Snowglide as Wet Snow Avalanche Precursor

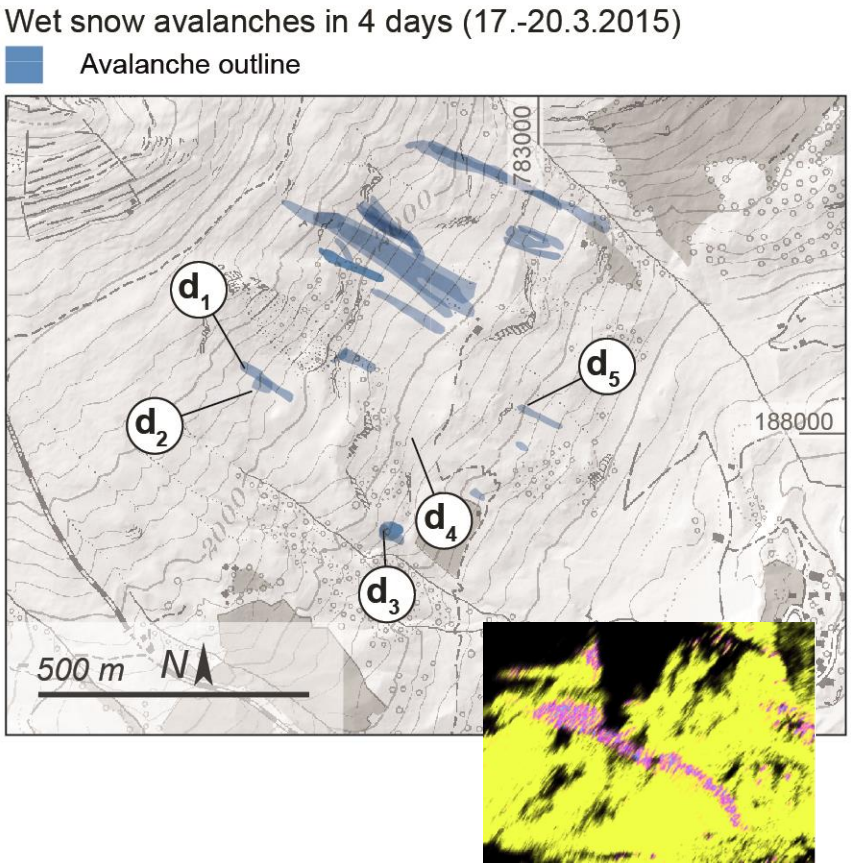


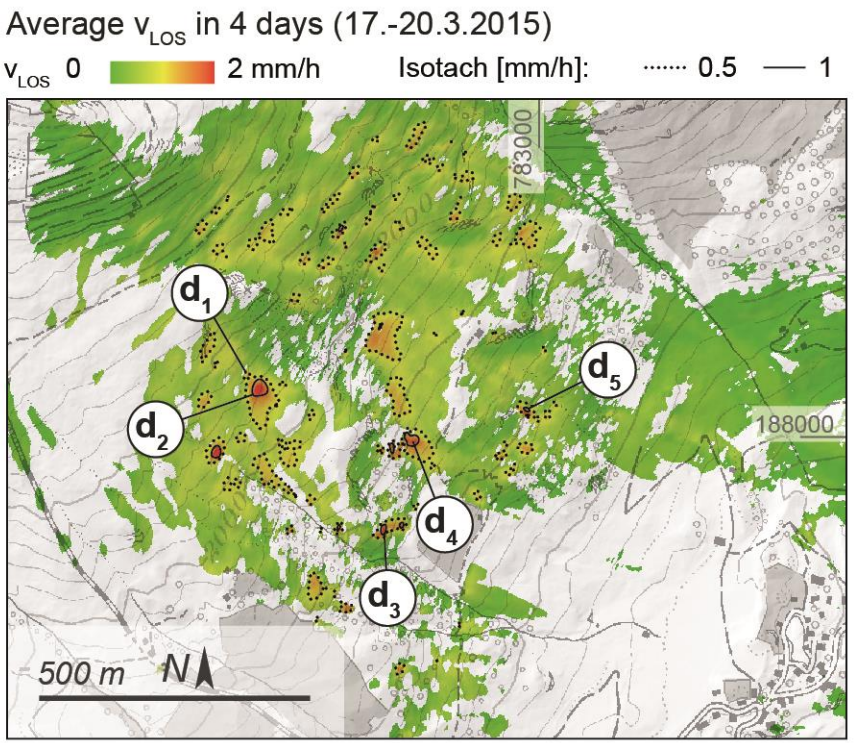
Comparision of Snow Glide Activity map with Avalanche Activity



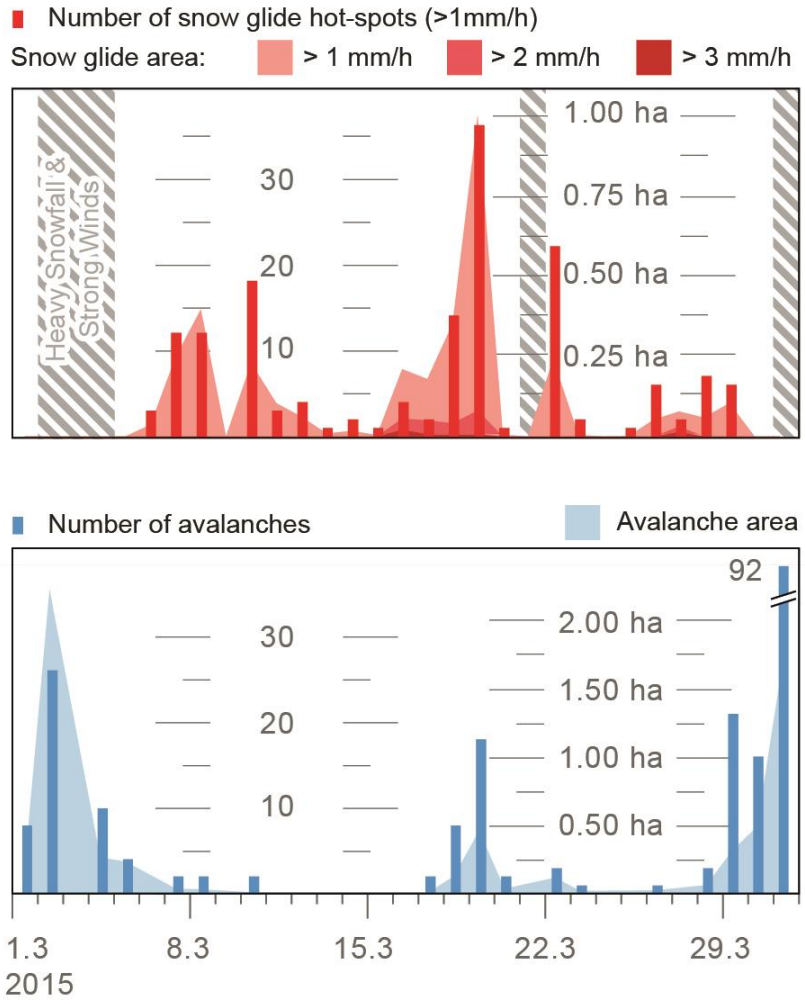


Comparision of Snow Glide Activity map with Avalanche Activity

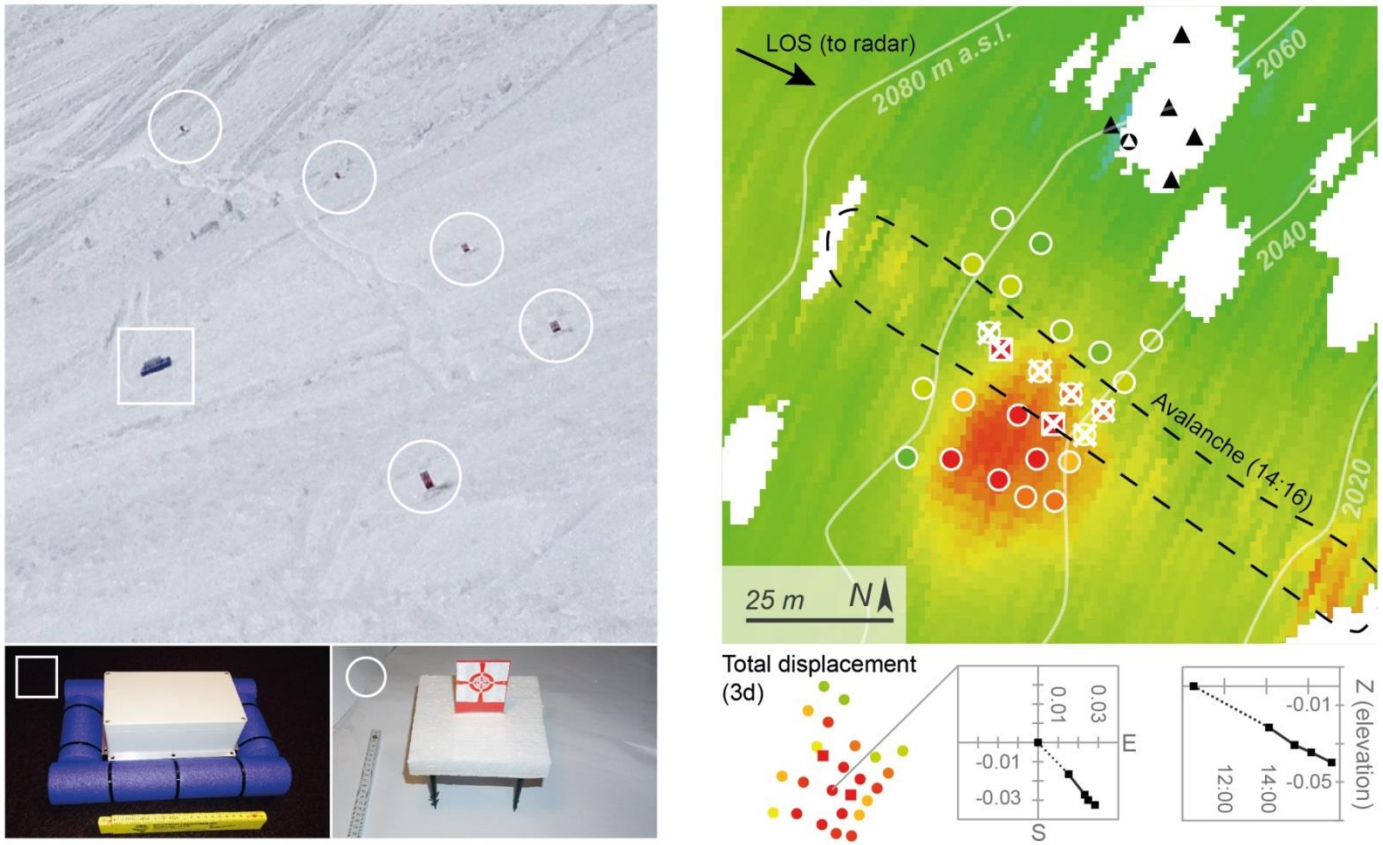




Comparision of Snow Glide Activity map with Avalanche Activity



Validation of small deformation patch was done…



… with Total Station measurements on reflective lightweight-targets of a previously detected snow glide area**. The measured results showed wery good agreement in the Line of Sight (LOS) of the radar.**

GAMMA REMOTE SENSING



Stable Points (rock, steel-barrier, **average**)

Snow (normalized average)

Snow (1, 2, 3, **average**)

Snow-Depth

Air

Snow-surface

Differential Phase [Rad] [cm]

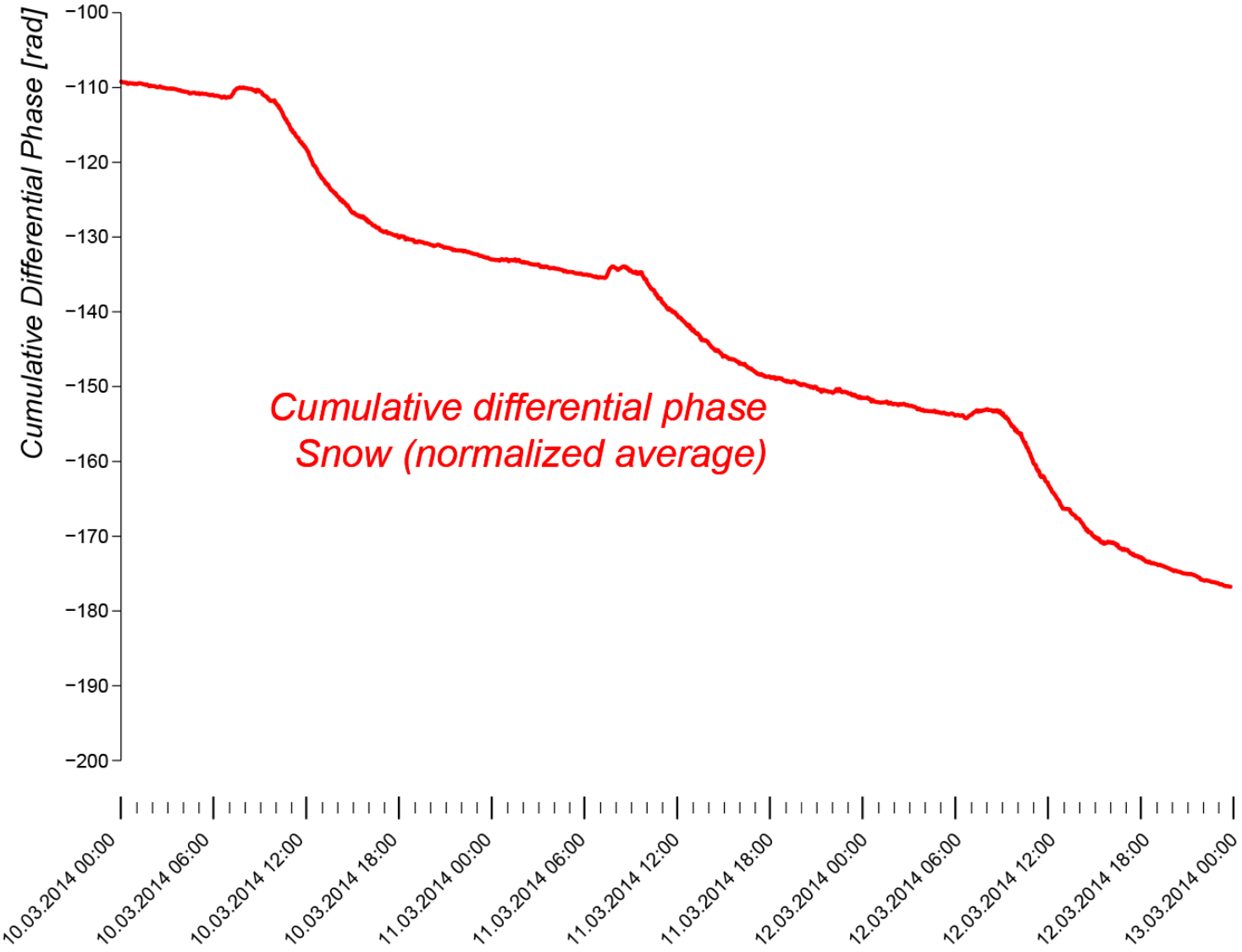
Snow Depth [SLF Davos]

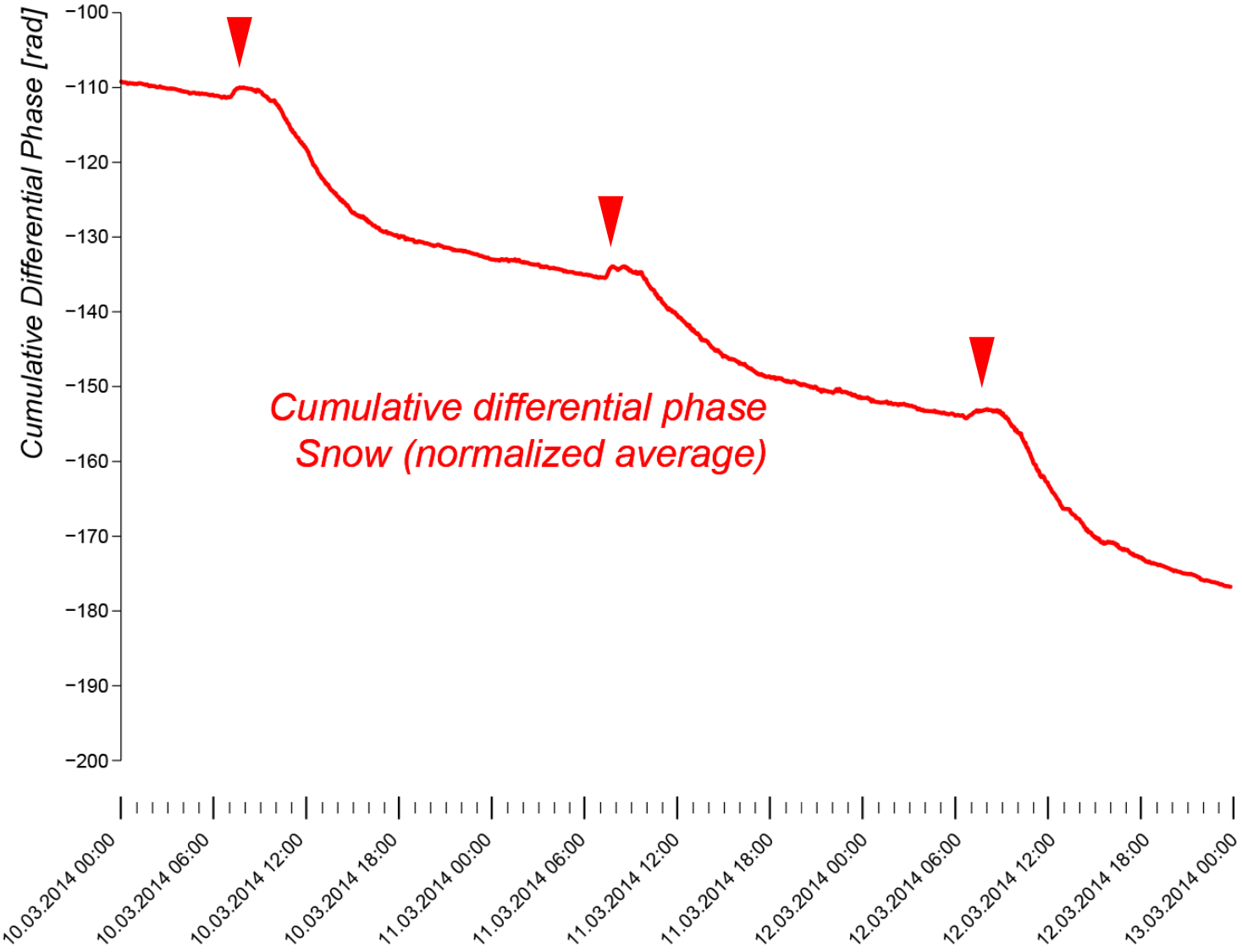
Temperature

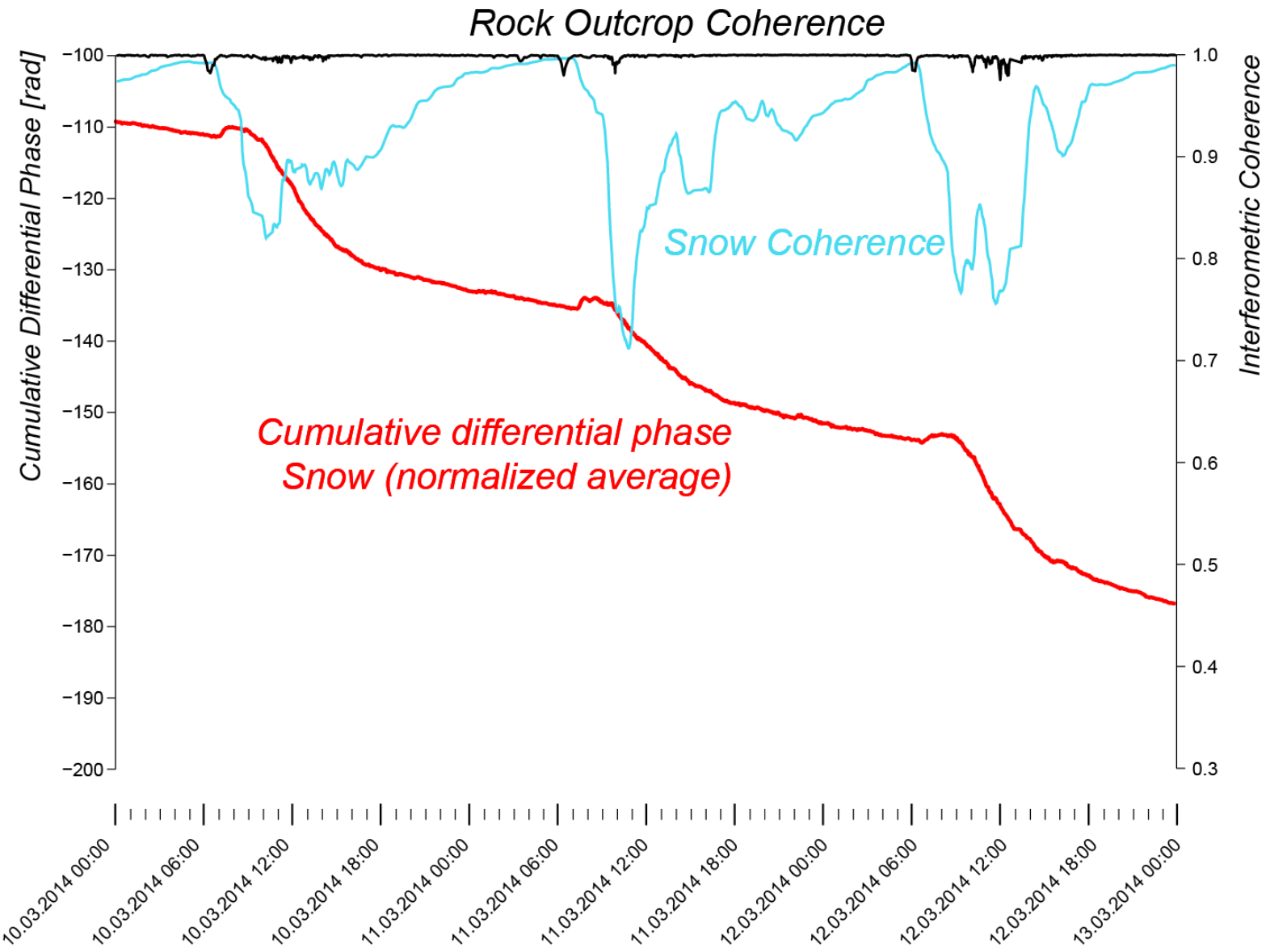
12.02.2014 19.02.2014 26.02.2014 05.03.2014 12.03.2014 19.03.2014 26.03.2014 02.04.2014

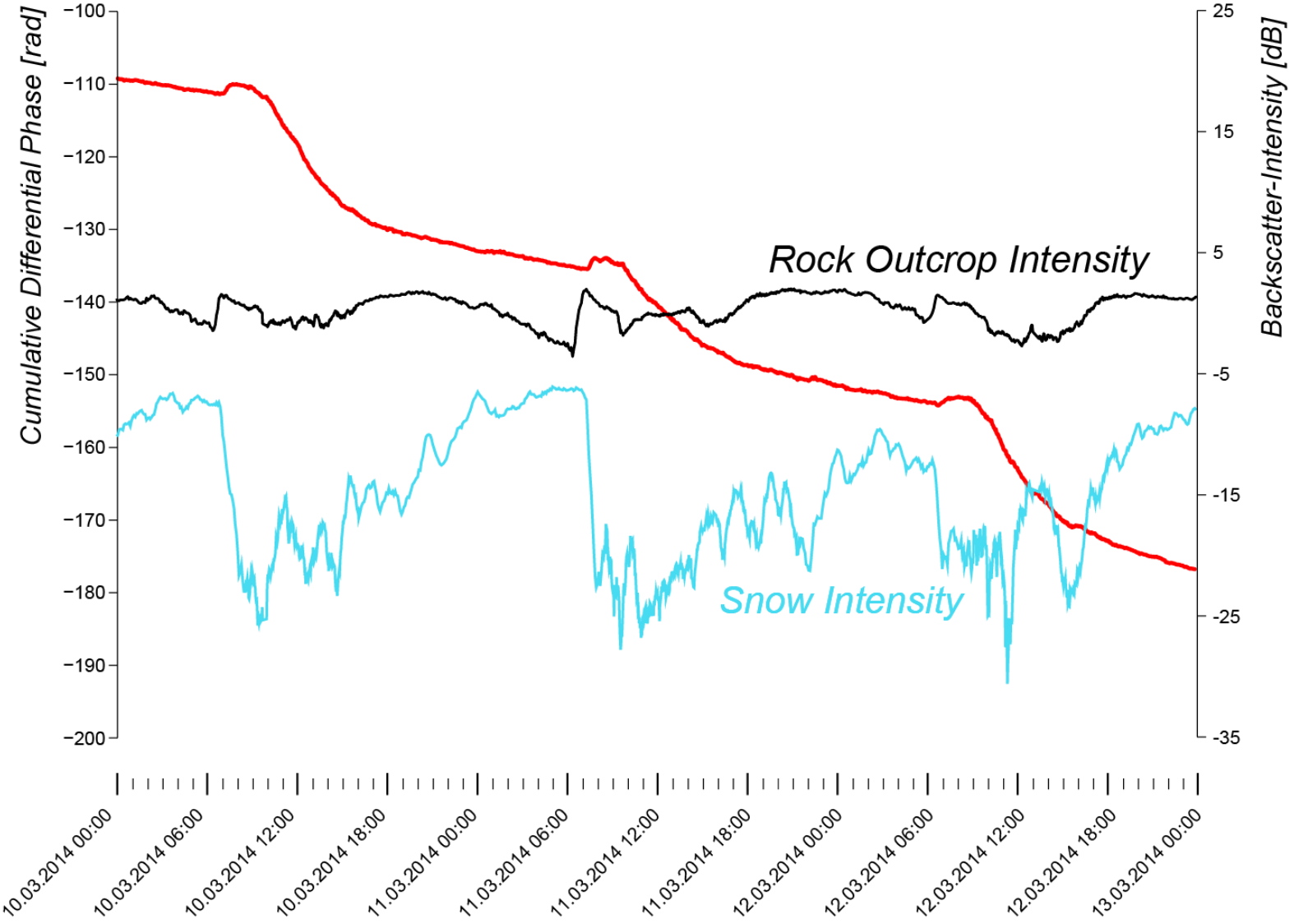
GAMMA REMOTE SENSING

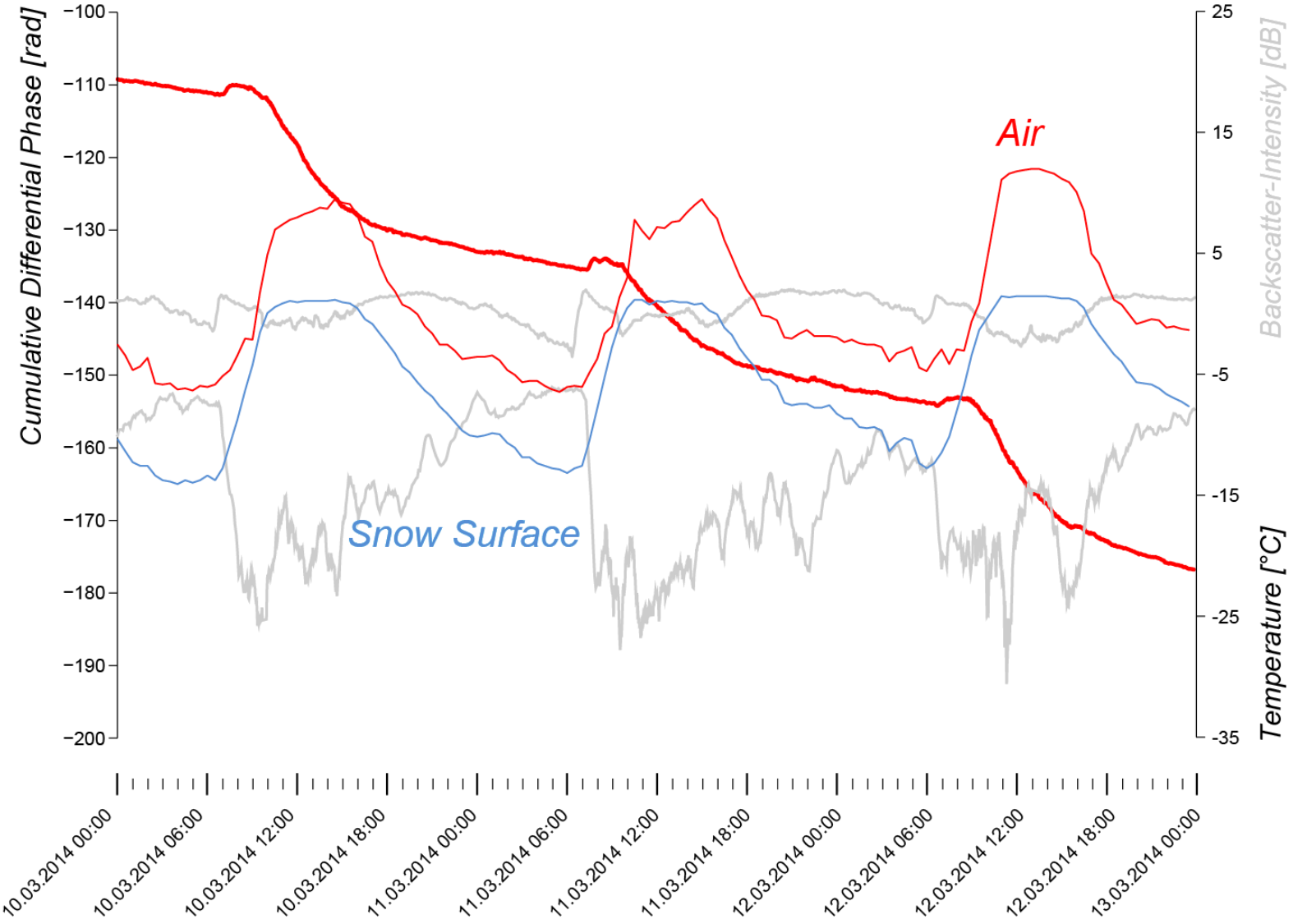



Cumulative Differential Phase [rad]
−100
−110
−120
−130
−140
−150
−160
−170
−180
−190
−200
Cumulative differential phase
Snow (normalized average)
10.03.2014 00:00
10.03.2014 06:00
10.03.2014 12:00
10.03.2014 18:00
11.03.2014 00:00
11.03.2014 06:00
11.03.2014 12:00
11.03.2014 18:00
12.03.2014 00:00
12.03.2014 06:00
12.03.2014 12:00
12.03.2014 18:00
13.03.2014 00:00


Cumulative Differential Phase [rad]
−100
−110
−120
−130
−140
−150
−160
−170
−180
−190
−200
Cumulative differential phase
Snow (normalized average)
10.03.2014 00:00
10.03.2014 06:00
10.03.2014 12:00
10.03.2014 18:00
11.03.2014 00:00
11.03.2014 06:00
11.03.2014 12:00
11.03.2014 18:00
12.03.2014 00:00
12.03.2014 06:00
12.03.2014 12:00
12.03.2014 18:00
13.03.2014 00:00


Rock Outcrop Coherence
Cumulative Differential Phase [rad]
Interferometric Coherence
Snow Coherence
Cumulative differential phase
Snow (normalized average)
−100
−110
−120
−130
−140
−150
−160
−170
−180
−190
−200
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
10.03.2014 00:00
10.03.2014 06:00
10.03.2014 12:00
10.03.2014 18:00
11.03.2014 00:00
11.03.2014 06:00
11.03.2014 12:00
11.03.2014 18:00
12.03.2014 00:00
12.03.2014 06:00
12.03.2014 12:00
12.03.2014 18:00
13.03.2014 00:00


Cumulative Differential Phase [rad]
Backscatter-Intensity [dB]
Rock Outcrop Intensity
Snow Intensity
−100
−110
−120
−130
−140
−150
−160
−170
−180
−190
−200
25
15
5
-5
-15
-25
-35
10.03.2014 00:00
10.03.2014 06:00
10.03.2014 12:00
10.03.2014 18:00
11.03.2014 00:00
11.03.2014 06:00
11.03.2014 12:00
11.03.2014 18:00
12.03.2014 00:00
12.03.2014 06:00
12.03.2014 12:00
12.03.2014 18:00
13.03.2014 00:00


Cumulative Differential Phase [rad]
−100
−110
−120
−130
−140
−150
−160
−170
−180
−190
−200
Backscatter-Intensity [dB]
Temperature [°C]
25
15
5
-5
-15
-25
-35
Air
Snow Surface
10.03.2014 00:00
10.03.2014 06:00
10.03.2014 12:00
10.03.2014 18:00
11.03.2014 00:00
11.03.2014 06:00
11.03.2014 12:00
11.03.2014 18:00
12.03.2014 00:00
12.03.2014 06:00
12.03.2014 12:00
12.03.2014 18:00
13.03.2014 00:00

Summary

- Terrestrial Radar Interferometry gives the possibility of a fast mapping of the current deformation of the snow glide motion on an entire slope
- Accuracy is 0.5 mm/hour *(relative values reach 0.25 mm/hour)* for the deformation
- Update time of deformation may reach 1 minute but optimal update of averaged (noise reduction!) maps give good results in bin intervals of 15-30 minutes
- Fresh snow deformation and heavy wind-drift masks glide motion (compaction exceeds glide motion)
- During transition times (from dry to wet snow), phase noise ist highest and therefore the accuracy lowest
- Some snow-glide hotspots do result in avalanche formation others do not

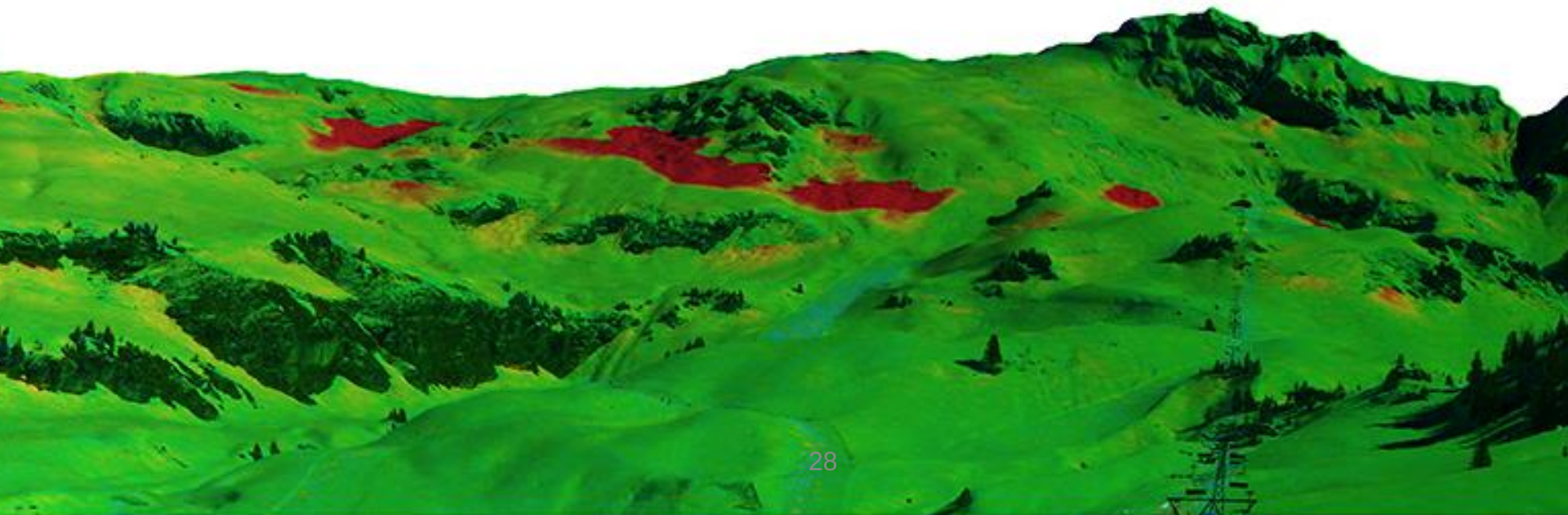
Outlook

- Mapping the snow-glide motion and avalanche activity on an entire slope gives important insights on the snow kinematic

- An early stage location of snow glide hotspots creates opportunities for in-situ instrumentation with other sensors to answer further questions, why failing occours or not → Important step towards a «slope scale» avalanche forecast and hazard mitigation

- **Terrestrial interferometry data gives a valuable insight in further kinematic processes but as well other snow properties such as possibly snow height and snow wetness**
  → Further investigations of the potential has to be investigated

Thank you for your attention!



References and Further Reading

Caduff, R.; Wiesmann, A.; Bühler, Y.,; Bieler, C, & Limpach, P. (2016), 'Snow glide activity and its potential as wet snow avalanche precursor when monitored with terrestrial radar interferometry', *INTERPRAEVENT 2016*.

Caduff, R.; Wiesmann, A.; Bühler, Y. & Pielmeier, C. (2015): Continuous monitoring of snowpack displacement at high spatial and temporal resolution with terrestrial radar interferometry. Geophysical Research Letters 01/2016; 42. DOI:10.1002/2014GL062442.

Wiesmann, A.; Caduff, R. & Matzler, C. (2015): Terrestrial Radar Observations of Dynamic Changes in Alpine Snow. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 07/2015; 8(7):1-7. DOI:10.1109/JSTARS.2015.2400972

Caduff, R.; Schlunegger, F.; Kos, A. & Wiesmann, A. (2014). 'A review of terrestrial radar interferometry for measuring surface change in the geosciences', *Earth Surface Processes and Landforms. DOI: 10.1002/esp.3656*.

Contact Information

GAMMA Remote Sensing AG, Switzerland
Worbstrasse 225
CH-3073 Gümligen
+41 31 951 70 05
www.gamma-rs.ch

Rafael Caduff
caduff@gamma-rs.ch