MONITORING OF DYNAMIC CHANGES IN ALPINE SNOW WITH TERRESTRIAL RADAR IMAGERY

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ABSTRACT

Remote sensing of snow with active and passive microwaves on terrestrial, aircraft and satellite platforms has a long tradition. However, the observation of dynamic processes on alpine slopes is difficult to achieve by fixed orbits and flight schedules. Terrestrial radar interferometers allow to overcome some of these constraints due to the portability of the system, the possibility to make repeat acquisitions in minute intervals, and the local observation capability.

Results in the Swiss Alps prove the potential of the methodology to measure rapid and local changes in snow parameters such as changes of the liquid water content, sudden mechanical impact on the snowpack due to skiers and avalanches. Using standard interferometric techniques a local snow displacement map was computed providing information about the spatial and temporal behavior of creeping snow.

***Index Terms*— snow, snow creep, avalanche, terrestrial radar, interferometry,**

1. INTRODUCTION

Remote sensing of snow with active and passive microwaves has a long tradition. Terrestrial instruments are used to investigate the interaction of snow with microwaves at selected locations, while air- and space-borne sensors are used to image a larger area. Satellite-based instruments have a defined observation geometry and observation schedule which hamper their potential to investigate dynamic processes in the snowpack spatially, especially on mountain slopes. Terrestrial imaging radars such as the GPRI (GAMMA Portable Radar Interferometer, [1]), overcome some of these constraints due to their portability and image acquisition time of less than 30 seconds and the possibility to make repeat acquisitions within minutes. Acquired images have a spatial resolution in the meter range and are complex with phase and amplitude information per image pixel.

The high density of acquired data allows to investigate the backscatter behavior spatially with time. Due to the coherent nature of the data it also allows to investigate the spatial distribution of the interferometric coherence with time. Combined the information can be used to track changes in the snowpack due to wind drift and melting but also the location of free riders and changes due to avalanche release. Furthermore the stacking of phase changes allows the production of displacement maps of the creeping snow.

Figure 1: GAMMA Portable Radar Interferometer (GPRI) mounted directly on the rock. The radar antennas rotate in azimuth and illuminate the target area in about 18 s.

2. TERRESTRIAL RADAR INTERFEROMETER

The GAMMA Portable Radar Interferometer (Figure 1) is a field usable coherent terrestrial imaging radar operating at 17 GHz. The instrument has one transmit and two receive antennas. The radar image is acquired using fan-beam antennas that are rotated in azimuth acquiring a focused image. The image resolution is 0.95m in range (-3 dB peak width with 200 MHz chirp bandwidth and -26 dB peak range sidelobe) and 6.8m in azimuth at 1km in range (-3 dB peak width proportional to slant range and -30 dB peak azimuth sidelobe). A 180 degree image scan can be attained in less than 20 seconds.

The system is steered by an internal instrument controller that can operate the instrument on a preprogrammed schedule autonomously. A more detailed instrument description is given in [1].

3. CAMPAIGN SETUP

The instrument was setup on a rock close to the Glogghüs ski lift station at Mägisalp (ski resort Meiringen-Hasliberg), in the Swiss Alps. The setup allowed to scan the surrounding mountains of the ski resort over an azimuth range of 170 degrees and range of up to 2.5 km (Figure 2). Two campaigns were conducted, a first test on 3 March

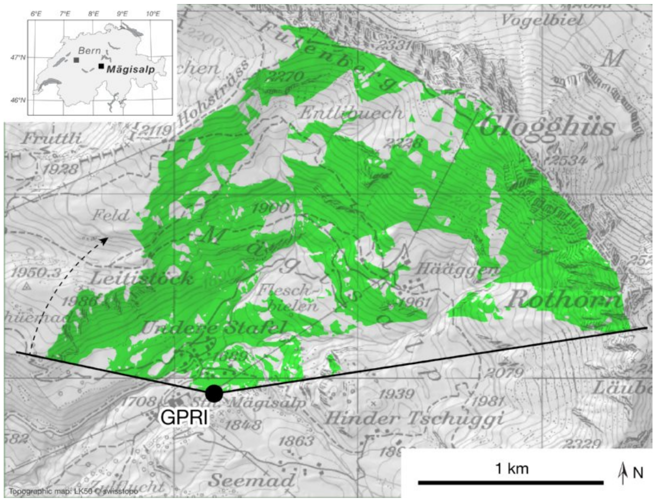

Figure 2: Map of the Test Site Mägisalp, Switzerland. Green areas indicate areas illuminated by the GPRI positioned close to the Glogghüs station ("GPRI").

2012 and a 24h campaign on 27-28 March 2013. In March 2012 the measurements were conducted during a sunny day. Typical wet spring snow was observed with a snow height of 2.3 m at the reference spot. In March 2013 the snow height was 2.0 m at the reference location. The weather was sunny at the beginning but turned cloudy with snow fall at the end of the campaign. Due to the changing conditions the snow pack underwent several melt-freeze cycles at the surface.

Images were acquired on a repeat interval of 2 minutes in 2012 and 3 minutes in 2013. During the campaign in 2013 the acquisitions were stopped between 00:15 UTC to 06:00 UTC. Figure 3 shows a radar image in radar geometry (azimuth vs range) of the test area. Rock faces and the ski lift appear bright, while shadowed areas are black. The photo panorama above is for reference. The illuminated area is shown in green color in Figure 2.

4. DATA PROCESSING

The data from the GPRI are converted to single look complex (SLC) images. The images are then co-registered if necessary and standard techniques are applied for the interferometric analysis and the image orthorectification. For the interferometric analysis it is necessary to select image pairs with high coherence. In order to overcome the high temporal decorrelation of snow due to metamorphism in the snowpack, images were acquired at a 2 or 3 minute repeat interval. It turned out that at this interval the interferometric coherence is still high and the phase can be interpreted (Figure 4). Already after 15 minutes the coherence can be strongly affected by changes in the snowpack due to solar radiation (Figure 7). Consecutive image pair interferograms are computed and unwrapped. This stacked interferograms are then used to derive the line of sight displacement time series. Thanks to the high temporal sampling and strong displacement rates no spatial or temporal filtering was applied. However, for shorter intervals atmospheric effects can have a nominal impact on the displacement signal. The georeferencing is based on the Swiss 5m Lidar DEM. For visualization of the data photographs calibrated using structure from motion techniques [2] were employed.

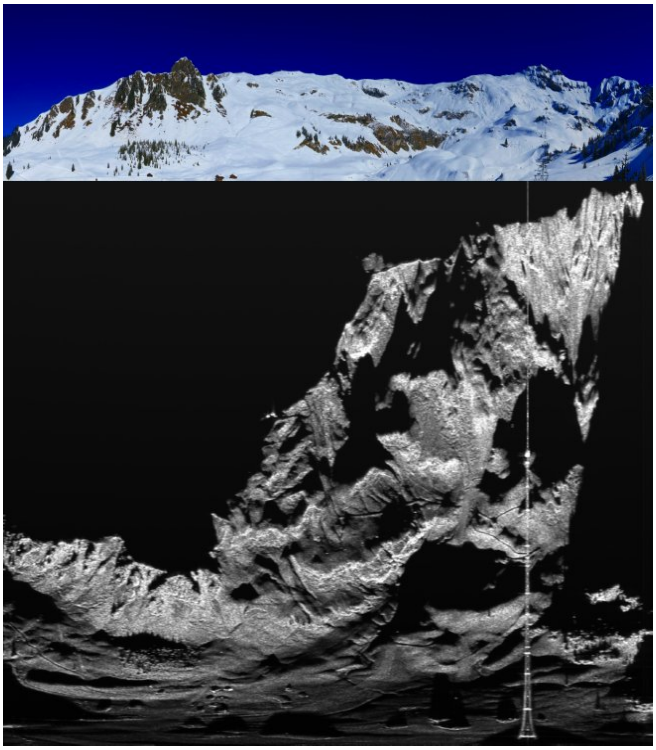

Figure 3: Radar Image in radar geometry (azimuth in horizontal direction vs range in vertical direction) of the test area. The photo panorama above is for reference.

5. RESULTS

In the following we will discuss the temporal backscatter behavior, the interferometric coherence and finally the observed phase changes.

5.1. Backscatter change

Figure 5 is a red-green-blue (RGB) composite in photo geometry. It shows the backscattering in the morning in red, in the afternoon in green and during the night in blue. Three main areas can be observed, the blue area on the left, cyan on the right and various scattered bright areas. Areas in cyan show strong signal in the morning and during the night while the snow is frozen, but low signal in the afternoon due to wet snow [3]. Rocks are stable strong scatterers and show up in white. In the area that is already illuminated by the sun in the morning, smaller cyan areas can be seen. These areas are due to the local topography either shaded from the sun

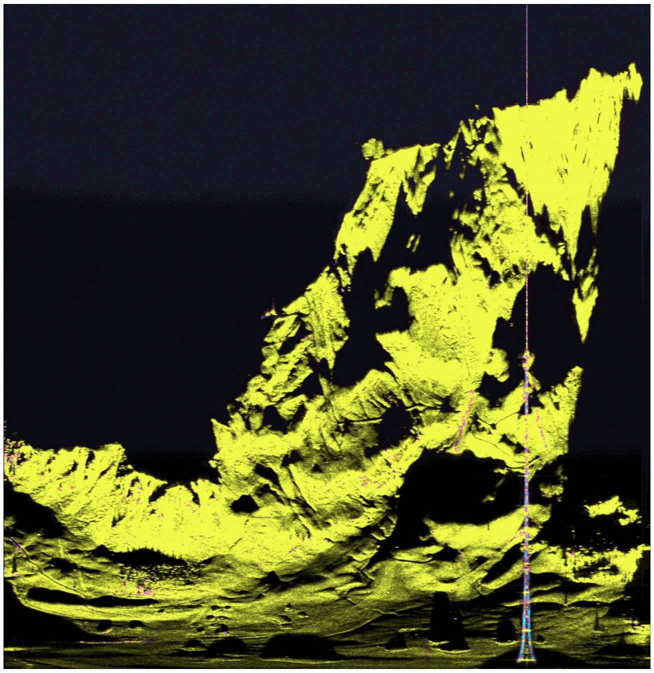

Figure 4: Interferometric coherence 9:03-9:06 28. March 2013 in radar geometry. Yellow indicates areas with high coherence, cyan and blue areas with low coherence. After 3 minutes areas with trees, used slopes and the ski lift show low coherence.

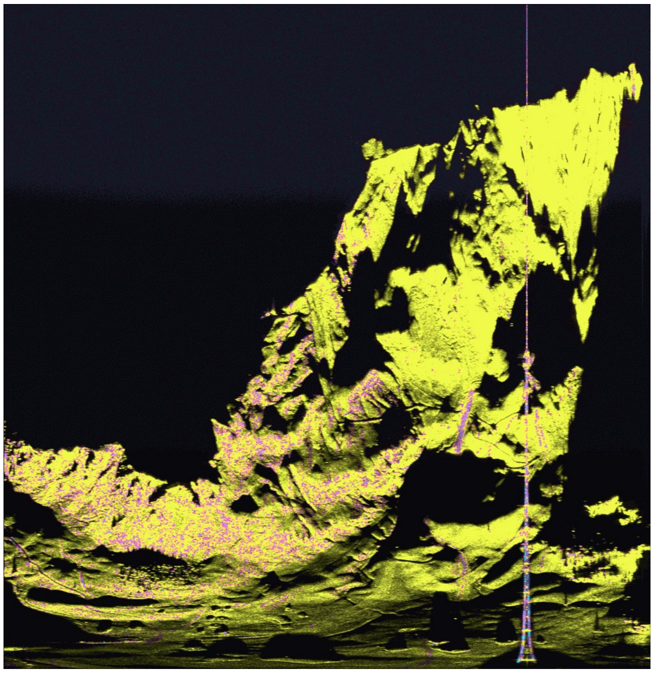

Figure 7: Interferometric coherence 9:03-9:15 28. March 2013 in radar geometry. Yellow indicates areas with high coherence, cyan and blue areas with low coherence. After 15 minutes areas with trees, used slopes, the ski lift but also snow covered areas illuminated by the sun show low coherence.

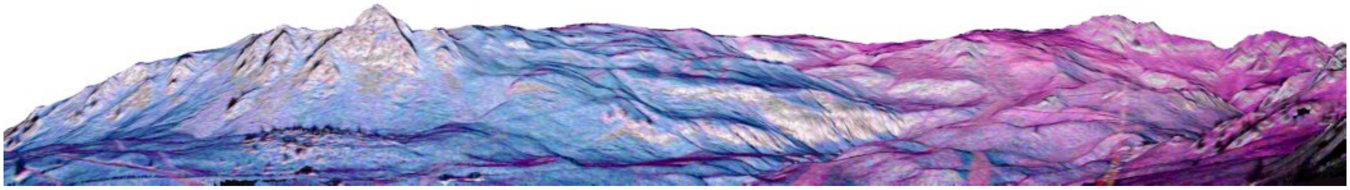

Figure 5: RGB composite of radar backscattering (panoramic view) in the morning (red channel), afternoon (green) and night (blue) of 27. March 2013..

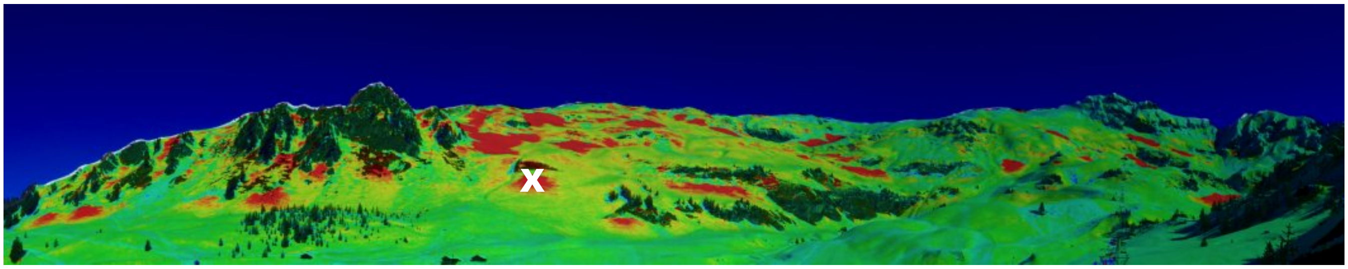

Figure 6: Panoramic view composite of the averaged displacement rate derived from interferometric GPRI data analysis for March 27/28 2013. Red indicates areas that have a displacement rate of 12 cm / day or more towards the observation point. Green indicates areas without displacement.X indicates the location of the time series presented in Figure 9.

or at very low sun incidence angle, and consequently the snow is still frozen in the morning.

5.2. Interferometric Coherence

The interferometric coherence is an indicator for the stability of the scatterers in the target area. Consequently changes in the snow structure due to snow metamorphism processes but also due to skiers or avalanches lead to a decrease in coherence. Figure 8 shows a mosaic of 3-minute coherence images indicating the fresh traces of a free rider. Disturbance of the snow due to an avalanche release causes the same sudden effect while snow metamorphism causes

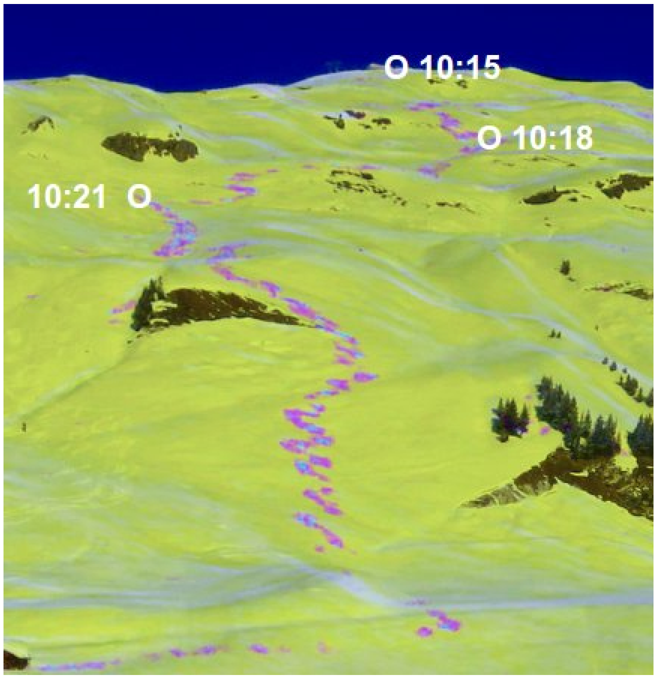

Figure 8: Panoramic view of the coherence map. Areas with high coherence are shown in yellow. Low coherence is shown in cyan and blue. The cyan traces down the slope indicate the traces left by a free rider disturbing the snow and consequently lowering the coherence.

the coherence to decrease over a longer time span (Figure 4 and 7).

5.3. Displacement

The panoramic view in Figure 6 shows the composite of the averaged displacement rate derived from March 27/28 data superimposed on a photo-panorama. Green areas show no displacement while in red areas a displacement of 12 cm/day or more was observed. For a selected point the displacement history is shown in Figure 9. It shows the variability of the displacement rate with time. While creep is faster during the day when the sun illuminates the target, it slows down during the night when temperatures fell well below 0° C. The resulting displacement map is in very good agreement with snow features visually observed in the field such as cracks and avalanche cones. A quantitative validation was not possible due to the lack of validation data.

6. CONCLUSIONS

In this paper we have shown that terrestrial radar interferometry can provide valuable local snow information in real-time. The backscattering information provides valuable information about the snow state, especially the presence of liquid water in the snowpack [3]. The interferometric coherence proved to be very sensitive on sudden changes such as ski tracks, but also on changes in the snowpack due to snow metamorphism. Finally it was possible to derive a local snow displacement map, indicating areas of creeping snow.

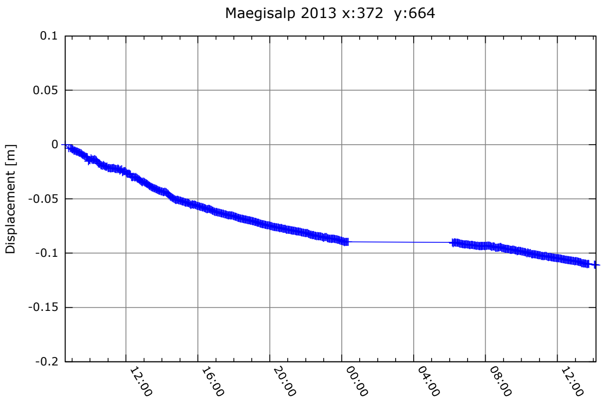

Figure 9: Line of sight displacement of the snowpack at location X in Figure 6.

Further longer term campaigns will be needed to develop methodologies towards avalanche applications.

7. REFERENCES

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