MEASURING DEFORMATION AND TOPOGRAPHY WITH A PORTABLE RADAR INTERFEROMETER

Andreas WIESMANN, Charles WERNER, Tazio STROZZI, and Urs WEGMÜLLER

Gamma Remote Sensing AG, Switzerland

Abstract: Measurements of surface topography and ground-motion over the Rhone glacier in Switzerland and the Tessina landslide in Italy performed with a ground-based real-aperture interferometric radar are discussed. The phase difference between successive images acquired by the terrestrial interferometric radar from the same viewpoint are used to determine displacements on the order of a fraction of a wavelength. In the case of our Ku-band instrument, operating at a wavelength of 17.4 mm, the measurement sensitivity is better than 1mm.

The radar was deployed overlooking the Rhone Glacier in October 2007 for a series of measurements to evaluate its feasibility for the remote sensing of glaciers. Multiple images were acquired over a 6 hour period. Interferometric post-processing of these data yielded Line-Of-Sight (LOS) velocity estimates on the order of ~4 mm/hr (~35 m/year). The interferograms have good coherence even over several hours. We also acquired simultaneous interferometric image pairs with a vertical baseline of 25 cm and derived the surface topography from the interferometric phase by calculating the precise angle of the LOS relative to the baseline. Simultaneous acquisition of the image pairs eliminates interferometric decorrelation due to surface change and phase errors due to tropospheric variability and ground motion. Our results are in good agreement with topographic maps and photogrammetric data.

Another set of measurements was taken at the Tessina landslide in Northern Italy. Small parts of this landslide moved so rapidly that distinct signals of the deformation were already evident after 15 minutes. Multiple measurements were taken throughout the day to monitor the movement. Over the short intervals considered the coherence was high except for the forested areas where vegetation decorrelated the signal. The effect of the relatively strong atmospheric path delay distortions could be significantly reduced by stacking the individual observations.

1. INTRODUCTION

Repeat-pass interferometric Synthetic Aperture Radar (SAR) is a powerful technique for the observation of surface deformation from space e.g. Rosen et al. (2000), and ground e.g. Noferini et. al. (2005). Causes for deformation include tectonic, seismic, and volcanic activity, ice and rock-glacier motion, slope instability, and subsidence caused by anthropogenic or natural effects. Satellite based SAR interferometry is widely used and has a proven its potential in an increasing number of cases. In the recent years new processing techniques such as stacking (Strozzi et. al., 2000) or persistent scatterer interferometry

(Werner et al. 2003) helped to improve the range of applicability. However, some restrictions of the satellite data based methods remain:

- The observation geometry and acquisition time is given by the polar orbits: observation is either from east or west at a fix repetition interval and a given time of the day.
- In many cases conflicting modes of the sensor lower the chance of an acquisition suitable for interferometry.
- Data copyrights.
- Spatial resolution is given and affected by the observation geometry and the topography.

Some of these issues can be overcome by using a ground based system. In particular, the advantages of a terrestrial system are:

- Full control over the image acquisition strategy (Dense temporal sampling possible).
- Full control over the observation geometry to measure specific deformation.
- Higher resolution.
- Multi-aspect measurements possible to get more than one movement component.
- In-situ measurements provide rapid, timely information.
- Rapid deployment.
- High deformation accuracy (<1mm).
- Minimal to no topographic phase term because the baseline is very close to 0.
- Continuous monitoring for rapidly moving features!
- Suppress atmospheric related delay variations by averaging successive images
- Shorter atmospheric path length since the radar is relatively close to the area of interest.
- Capability to generate a DEM of the scene using dual-receiving antennas:
  - 1m height accuracy goal;
  - Simultaneous acquisition of the data over the baseline can map all terrain types because there is no temporal decorrelation.

There are different types of ground based radar systems suitable for interferometry in use. SAR systems with antennas moving on a rail perpendicular to the observation direction (e.g. Rudolf, 1999), point focussed radars scanning the image with a narrow beam antenna in two directions (e.g. Harries et al. 2006), RAR systems such as the GAMMA terrestrial portable radar interferometer scanning the image with a fan-beam antenna by rotating it around the vertical axis (Werner et. al. 2008). The different types of ground based radars have different advantages and disadvantages in portability, acquisition time etc. Here we will focus on GAMMA's terrestrial portable radar interferometer and discuss its potential based on first measurements.

2. GAMMA’S PORTABLE RADAR INTERFEROMETER

Starting in 2005 GAMMA Remote Sensing developed and built a portable real aperture FMCW radar interferometer for displacement measurement and height mapping (Patent pending). The major technical characteristics of the instrument are:

- Frequency: 17.2 GHz (wavelength: 0.0176 m)

- Acquisition time: < 20 min for 90 degrees
- Operational range: 0.1 to 4 km
- Antenna aperture: 0.4 x 60 degrees
- Range resolution (look direction): 0.75 m
- Azimuth resolution (perpendicular to the look direction): 6.9 m at 1km, 13.9 m at 2km
- Precision: < 2 mm along look direction
- 1 transmit and 2 receive antennas

The GAMMA ground-based radar interferometer has also the ability to produce high resolution digital elevation models permitting precise geolocalization of the deformation maps and, to a certain extent, to measure volume change. Multiple acquisitions to reduce errors are easily possible thanks to the rapid acquisition time of less than 20 minutes. The instrument is built to permit a rapid deployment. The receive-only mode has the potential of reduction of external radio-frequency interferences. For a more detailed description it is referred to Werner et al., 2008

3. GROUND MOVEMENT MEASUREMENT

3.1 Measurement principle

The GAMMA portable radar interferometer (GPRI) is a real aperture FMCW radar using fan beam antennas to illuminate the target area. The antennas are mounted in parallel on a rotational scanner. The radar image is built up line by line by rotating the antennas in azimuth about the vertical axis. The range resolution of the radar is determined by the 200 MHz bandwidth and is equal to approximately 75 cm. The azimuth resolution is determined by the antenna beamwidth and slant range. In the case of the TRI, the azimuth beamwidth is 0.4 degree yielding an azimuth resolution of about 7m at a slant range of 1km. Each image line is acquired in approximately 2ms hence there is little or no movement of the scene to introduce decorrelation. Phase differences between successive images acquired from the same viewpoint are used to determine line-of-sight displacements from the differential phase. The instrument operates at 17.2 GHz with a displacement measurement sensitivity better than 1 mm.

Two receiving antennas form an interferometric baseline that can be used to precisely measure the look angle relative to the baseline thereby permitting derivation of the surface topography. Adjusting the baseline is used to tune the height sensitivity versus phase unwrapping complexity. For a detailed description it is referred to Werner et. al., 2008.

3.2 Tessina Landslide

3.2.1 Background

The Tessina landslide is located in the Alpago Basin, Eastern Italian Alps, some 90-km north of Venice. The landslide, which was first triggered in October 1960 following 1 month of abundant rainfall, is a complex movement with a source area affected by rotational and translational slides in the upper sector. Downhill the slide turns into a mud flow through a narrow steep channel. The Tessina landslide is the subject of numerous studies and since 1992 a ground-based monitoring and alarm system was devised and installed, simultaneously with the realisation of control works in some urban settlements located along the valley, in order to mitigate the related risk (Pasuto et al., 1999).

The landslide mainly involves the Flysch Formation (Eocene) consisting primarily of densely interbedded marls and sandstone with a thickness of about 1000–1200 m. This formation makes up the impermeable bedrock of the entire sliding area and crops out at the foot of Mt. Teverone, which is mainly made up of Fadalto Limestone (Cretaceous). The Flysch Formation appears strongly folded and fractured as a consequence of the intensive tectonic activity in the area, which is characterised by the occurrence of significant structural discontinuities. This has produced a high secondary permeability in the formation, thus helping the occurrence of numerous springs, especially in the landslide source area, some of these with perennial flow. Surficial Quaternary deposits including colluvium and glacial till have also been mobilised by the landslide (Hervas et. al. 2003).

3.2.2 Measurement campaign

The fast and non-linear displacement behavior of the Tessina landslide makes it an interesting test site to demonstrate the potential of ground based radar measurements. A dedicated campaign was held from the 11th to the 13th of September 2007. The observation point was chosen by the geodetic control point (Figure 1). During the 3 days more than 100 scans of the area were acquired, also during night-time. The weather conditions were good with little wind and good visibility during the whole campaign.

Figure 1 left - GAMMA terrestrial radar interferometer. Right - Target area.

3.2.3 Deformation map

Figure 2 shows the deformation map in equidistant map projection. The color indicates movement from 0 to 60 m/y along the line of sight. The result shows clearly the active area corresponding to the mud flow with a displacement rate of up to 60 m/y while for the remaining area the displacement was smaller than the resolution of our instrument during the observation period. The displacement map was received by stacking a set of interferograms with about 30 minutes of temporal baseline acquired during September 12 and 13.

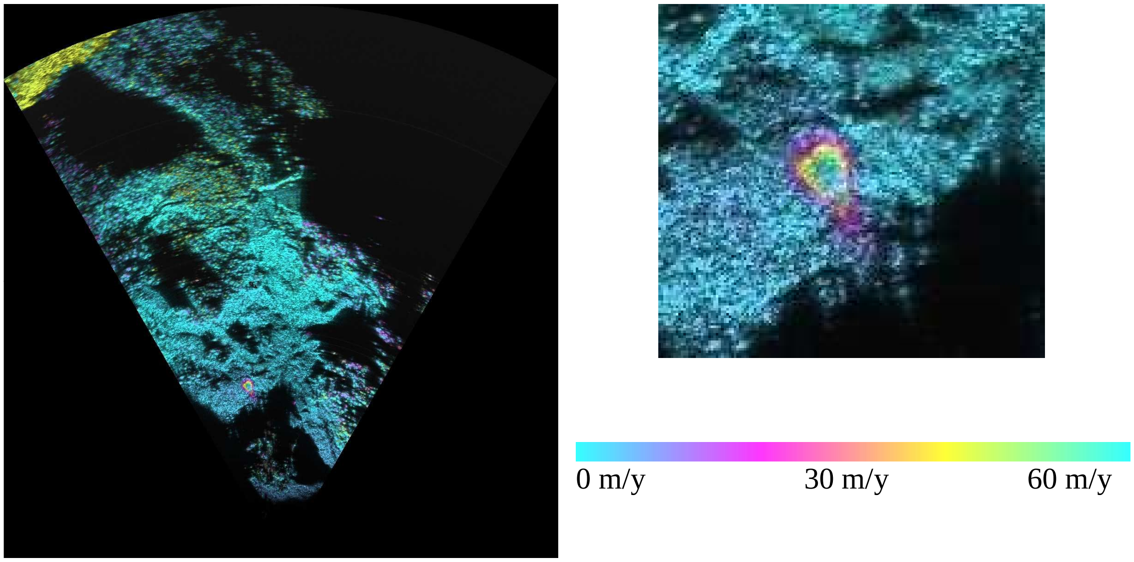

Figure 2 left - Displacement map in map projection. Right - Zoom of the active zone.

3.2.4 Deformation monitoring

To monitor the temporal displacement of the detected active area successive images were acquired over 18 hours. From this set of images the displacement could be computed for each interval. Figure 3 shows the displacement of 3 selected points in the active zone. It shows that after an initial increase in speed of the movement along the line of sight the displacement rate slowed down after 18:00 and increased again at 04:00 the next morning.

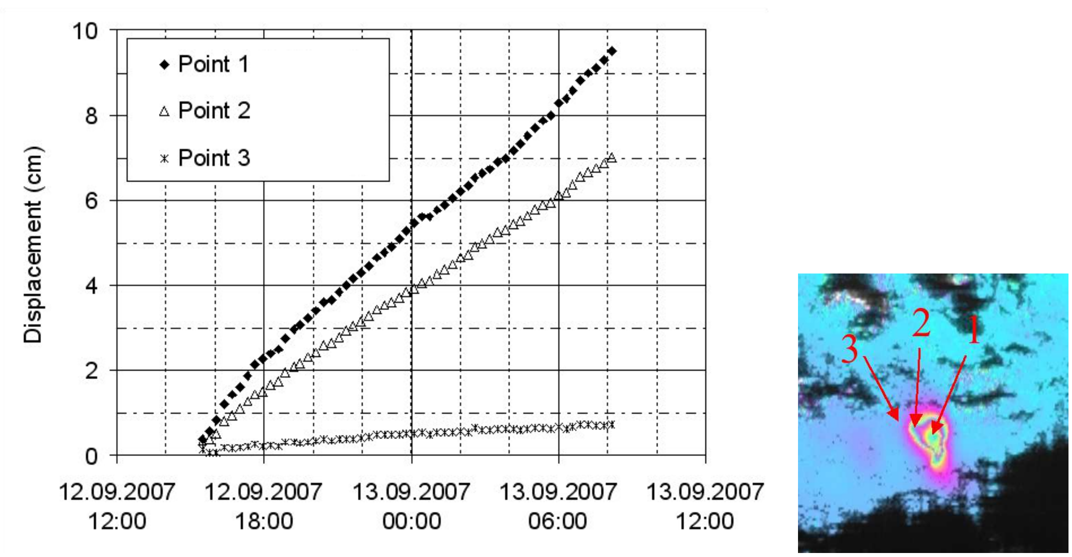

Figure 3- Displacement along the line of sight versus time of 3 selected points in the active zone area (right). The plot clearly indicates the non-linear displacement in this area.

3.3 Rhone Glacier

3.3.1 Background

Glaciers represent a unique resource of fresh water for agriculture and industry, an important economic component of tourism and hydro-power production, and a potential source of serious natural hazards. Due to their proximity to the melting point, glaciers are considered good natural indicators of global climate change. Images of retreating and vanishing mountain glaciers are a major icons in the perception of climate change in the public. In glaciology, climatology but also in case of risk civil protection there is a strong interest in knowing more about the glacier retreat, mass balance, flow rates and its temporal behaviour. Remote sensing techniques can help retrieve and monitor these parameters. We will discuss the potential of the terrestrial radar interferometer in this perspective.

3.3.2 Measurement campaign

A dedicated campaign was conducted on 17. October 2007. The observation point was 200m above the Hotel Belvedere, giving a good view on the Rhone Glacier (Figure 4). On that day the weather was clear with moderate wind. Temperatures were below 0 degrees in the morning and increased during the day so that the snow on the glacier melted.

Figure 4 - GAMMA terrestrial radar interferometer in Front of the Rhone glacier.

3.3.3 Glacier flow rate map

On 17. October 2007 14 radar scans of the Rhone glacier were acquired. From 4 interferometric pairs a LOS displacement map was computed (Figure 5). Although computed over a very short time interval, the result is in good agreement with that derived from photogrammetry with aerophotographs taken with one year time interval in 2005 and 2006 (Bauder, personal communication). In the lower part of the glacier the displacement in the radar product is smaller due to the change in flow direction of the glacier and the resulting smaller contribution in the direction of the line of sight.

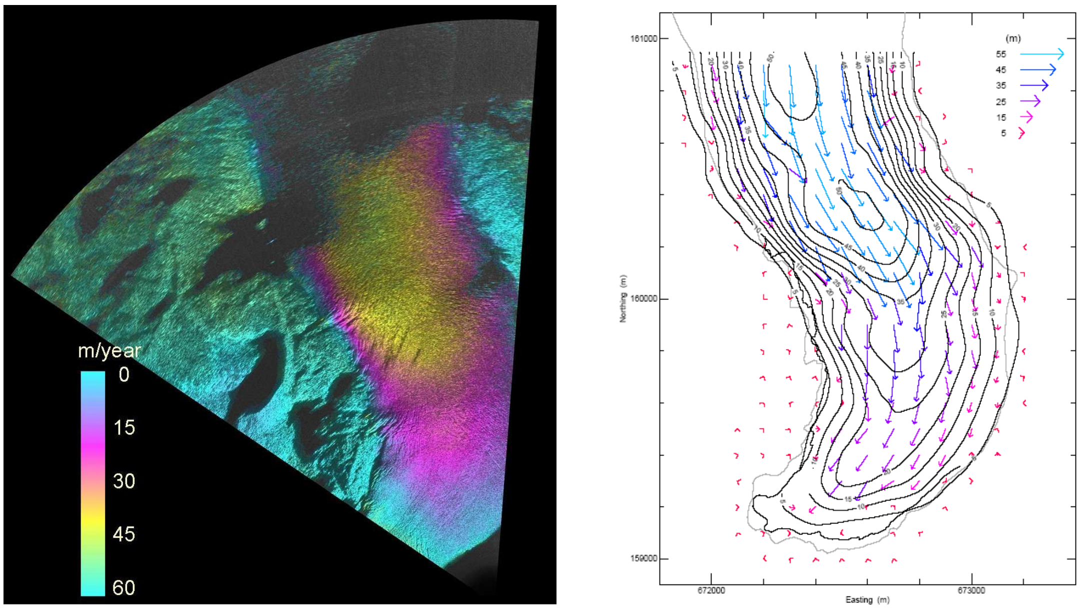

Figure 5 Left - Displacement map estimated from 4 interferometric pairs with a total time span of 80 minutes in map projection. Right - Yearly flow direction and speed derived from photogrammetry (Bauder, personal communication).

3.3.4 Glacier height mapping

An important parameter in glaciology is the glacier mass. The capability of GAMMA's terrestrial radar interferometer to receive with two antennas allows to receive a surface height map. This map can then be compared with existing height maps to derive information on changes in the glacier mass. Figure 6 (left) shows the derived height map. One colour cycle corresponds to 100m height change. Along a transect (white line in Figure 6 left) the heights derived from the terrestrial radar interferometer are compared to those obtained from the Swisstopo DHM25 of 1993 in Figure 6, right. The comparison shows a significant decrease of about 30 m of the ice in the lower part of the glacier . Indeed, the glacier tongue retreated quite a bit during the last decade and a lake is forming at the glacier front. On the other hand, in the higher parts of the glacier the filtered radar heights derived from an average of several scans (red line) and the DHM heights (blue line) are in good agreement. The gaps in the radar derived height profile are due to shadowing effects at the selected observation geometry.

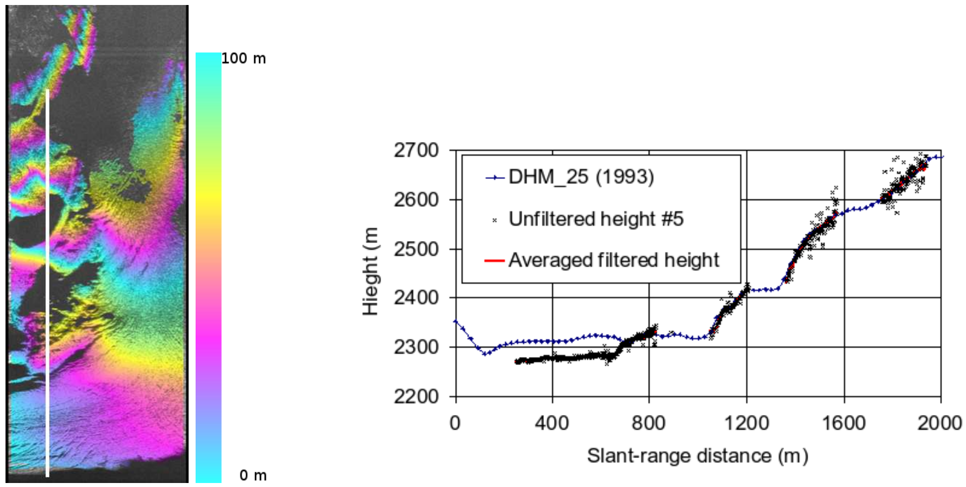

Figure 6 left - Height map in radar geometry (azimuth versus slant range = distance from sensor). The white line indicates the selected transect. Right - Height profiles of the radar height map of 2007 and the Swisstopo DHM25 heights of 1993 along the transect.

4. CONCLUSIONS AND OUTLOOK

After a short introduction of GAMMA's terrestrial radar interferometer, a portable coherent ground based real aperture radar (RAR) system, results of two measurement campaigns were presented covering displacement mapping, displacement monitoring and height mapping. In a first campaign the Tessina landslide in Italy was investigated. A rapid moving section of the landslide was detected with displacement rates of up to 60 m/y. A 16h monitoring revealed non linear deformation behaviour. In a second campaign the Rhone glacier was mapped. A line of sight velocity map was derived and successfully compared with velocities derived by means of photogrammetry. The derived height map that was received by interferometrically combining the results of the two receiving antennas showed good agreement with the DHM25 height map of Swisstopo in the upper part of the glacier. In the lower part the results indicate a 30m height loss due to melting of the glacier tongue in the last 15 years.

These two examples demonstrate that GAMMA’s terrestrial radar interferometer is robust and gives reliable results that can be confirmed by repeated measurements. Thanks to the portable instrument and short setup time, the method is cost effective and has short reaction time. To improve the methodology and the instrument further campaigns will be conducted.

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Corresponding author contacts

Andreas Wiesmann
wiesmann@gamma-rs.ch
GAMMA Remote Sensing AG
Worbstrasse 225, 3073 Gümligen
Switzerland
Tel: +41 31 9517005, Fax: +41 31 9517008