A REAL-APERTURE RADAR FOR GROUND-BASED DIFFERENTIAL INTERFEROMETRY

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ABSTRACT

Satellite interferometry has been used extensively for ground-motion monitoring with good success. In the case of landslides, for example, space-borne SAR interferometry has a good potential to get an overview on the slope stability. The role of a space-borne INSAR as an element in a landslide or rock fall warning system is constrained by the specific space-borne SAR imaging geometry, the typical multiple-week repeat-interval, and uncertainties in the data availability. Most of these limitations can be overcome with an in-situ radar imaging system. GAMMA has developed a portable radar interferometer that utilizes real-aperture antennas to obtain high azimuth resolution. Images are acquired line by line while rotating the transmitting and receiving antennas about a vertical axis. Phase differences between successive images acquired from the same location are used to determine line-of-sight displacements. The instrument operates at 17.2 GHz and has measurement sensitivity better than 1 mm. The instrument uses two receiving antennas with a short baseline to form an interferometer. Phase differences between simultaneous acquisitions by these antennas are used to calculate the precise look angle relative to the baseline, permitting derivation of the surface topography. Expected statistical noise in the height measurements is on the order of 1 meter. In this contribution the design, measurement principles and characteristics of GAMMA's Portable Radar Interferometer (GPRI) are presented.

***Index Terms*—** GAMMA, Radar Interferometer, landslide, glacier, RAR.

1. INTRODUCTION

Satellite interferometry has been used extensively for ground-motion monitoring with good success. In the case of landslides space-borne SAR interferometry has good potential to obtain an overview of slope stability. Furthermore, relatively slow, temporally uniform movements can be quantitatively monitored from space. Of particular interest is the two dimensional coverage potentially achieved and that there are rich data archives readily available to be explored for the time after 1991. The results achieved have caught the interest of a relatively wide user community involved in a broad range of applications. Nevertheless, some important requirements cannot be met by satellite SAR interferometry. Given the typical multiple-week repeat-interval, some uncertainties what concerns the data availability, some delay in getting the data as well as limitations related to the SAR imaging geometry, signal decorrelation and other problems this technique is for example clearly not sufficient as a landslide or rock fall warning system. In other cases the spatial resolution or the sensitivity of the space-borne INSAR technique may be insufficient.

In recent years several in-situ radars have been developed and used for applications including measurement of landslides and volcanoes [1, 2]. To achieve good azimuth resolution these systems acquire data along a linear track to form a synthetic aperture. These systems are clearly complementary to the space-borne technique and show good potential. Furthermore, laser scanners and photogrammetry systems are being used for similar purposes.

2. MOTIVATION FOR TERRESTRIAL INTERFEROMETRIC OBSERVATIONS

In our contacts with important users of slope and rock instability information we identified a significant demand for two-dimensional, readily available and accurate measurements. Over the last years ground-based SAR instruments used for this purpose demonstrated a good potential for deformation mapping and monitoring. An important aspect is that these in situ instruments can be used more specifically to monitor landslides, rock falls, or infrastructure than space-borne systems. The observation geometry and observation times can more freely be selected and can be used to optimize the measurements for the specific case. The ground-based radar instruments are also complementary to ground-based laser scanners. Strengths of the radar systems can measure up to several km in distance and have high sensitivity for measurements of motion. Another important advantage is that the correspondence of repeat measurements is very well controlled through the coherence of the interferograms.

Considering this potential we decided to develop a ground-based radar system for this purpose. In our design we included some new concepts to optimize the performance of the instrument. Important design objectives which were only partially realized in previous instruments include:

- Similar spatial resolution as existing ground based radar systems
- Similar deformation sensitivity as existing ground based radar systems
- Similar or better applicability range as existing ground based radar systems
- System shall be portable
- Coverage of a wide view angle in a single image
- Reduction of image acquisition time
- Measurement of topography as an additional product, but also for use in the georeferencing of the deformation results

Taking this into account we came to the instrument described in the following.

3. INSTRUMENT DESCRIPTION

As a consequence, GAMMA has developed a portable radar interferometer GPRI (Figure 1). Unlike previous terrestrial radar instruments [1,2] it does not use aperture synthesis to obtain good azimuth resolution. The GPRI uses real-aperture antennas, 2 meters in length. There is one antenna used to transmit and two receiving antennas. The three antennas are mounted parallel to one another on a rigid 1 meter high tower mounted on a precision rotational scanner. The radar image is built up line by line by azimuthally rotating the antennas 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 terrestrial interferometer, the azimuth beamwidth is 0.4 degree yielding an azimuth resolution of about 7m at a slant range of 1km. The two receiving antennas are separated vertically forming a spatial interferometer useful for measurement of height information.

Each antenna is mounted in a carbon-fibre truss designed to both light and rigid. Curvature of the antennas beyond a few mm could seriously degrade the image resolution. The antenna positions can be adjusted vertically and there is the facility to slightly change the rotational angle of one antenna with respect to the central antenna for precise pointing. The antennas can be tilted vertically to illuminate the region of interest. In elevation, the antennas have a beamwidth of approximately 45 degrees.

In addition to the antennas and scanner, the instrument has a digital chirp generator, a microwave assembly that contains the transmitter and 2 independent receiver channels an analog to digital converter (ADC), and a laptop computer. The laptop computer controls the data acquisition and is used for later data analysis.

A relatively high radar frequency of 17.2 GHz was chosen both to obtain good azimuth resolution and high sensitivity to motion. A temporary permit has been obtained from the governmental communications office to operate at this frequency in Switzerland

The instrument is portable and can be battery operated. The installation effort is relatively small and individual measurements can be taken in less than 15 minutes for an 80 degree scan.

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

For a more detailed description it is referred to [3].

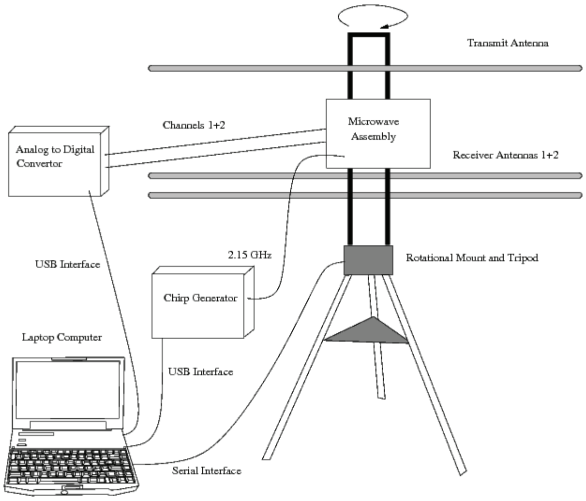

Figure 1: Portable Radar Interferometer Hardware components.

4. Measurements

4.1 Rhone Glacier, Switzerland

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 2). The weather was clear with moderate wind. Temperatures were below 0 deg. C. in the morning and increased during the day so that the snow on the glacier melted.

On 17 October 2007 14 radar scans of the Rhone glacier were acquired. From 4 interferometric pairs a LOS displacement map was computed (Figure 3). Although computed over a very short time interval, the result is in good agreement with that derived from photogrammetry with aerial photographs 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

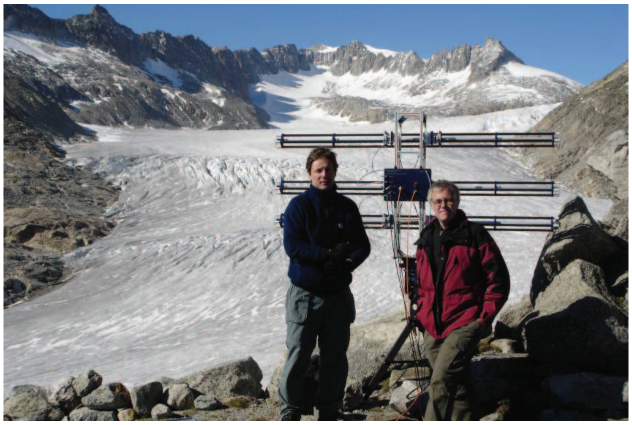

Figure 2: GAMMA terrestrial radar interferometer in Front of the Rhone glacier.

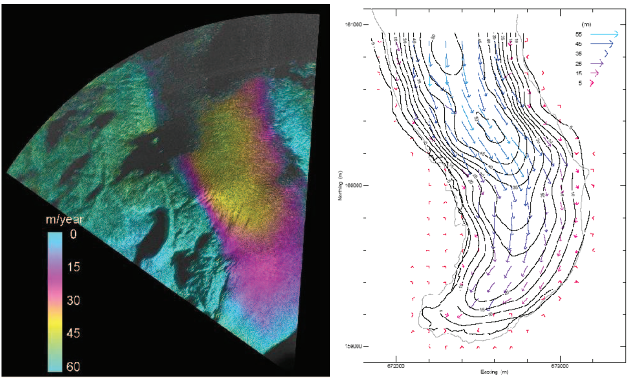

Figure 3 Left: Displacement map estimated from 4 interferometric pairs with a total time span of 80 minutes in map projection. Right: Yearly flow direction and speed derived from photogrammetry (Bauder, personal communication).

An important parameter in glaciology is the glacier mass. The capability of GAMMA's terrestrial radar interferometer to receive with two antennas generation of a surface height map. This map can then be compared with existing height maps to derive information on changes in glacier mass. Figure 4 shows the derived height map. One color 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 DEM of 1993 in Figure 5. The comparison shows 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.

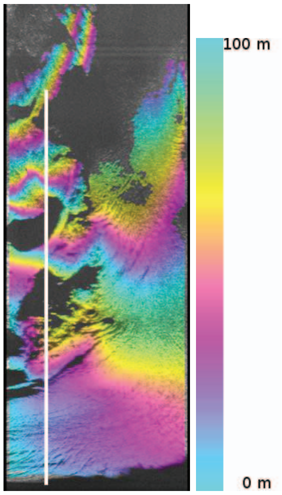

Figure 4: Height map in radar geometry (azimuth versus slant range distance from sensor). The white line indicates the selected transect.

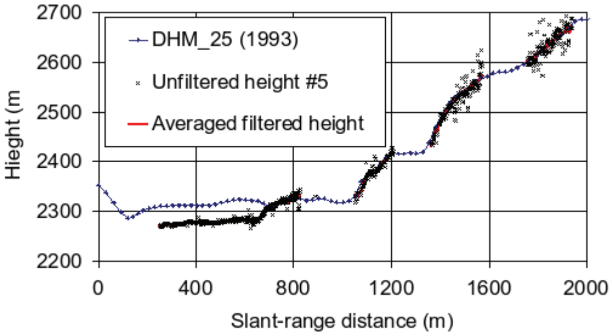

Figure 5: Height profiles of the radar height map of 2007 and the Swisstopo DHM2

4.2 Tessina Landslide, Italy

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. 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 6 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 clearly shows 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.

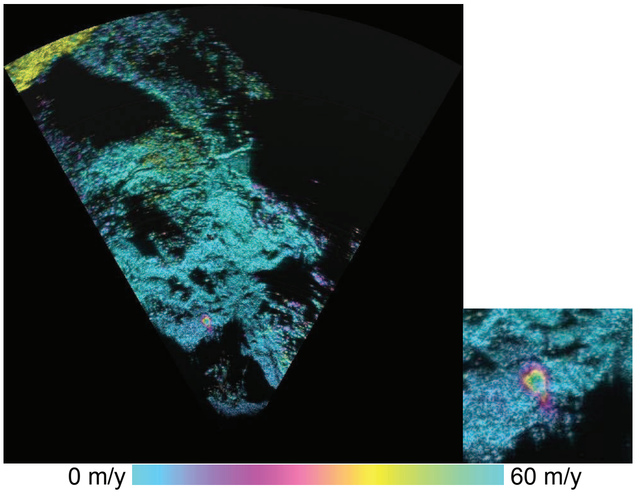

Figure 6 left: Displacement map in map projection. Right: Zoom of the active zone.

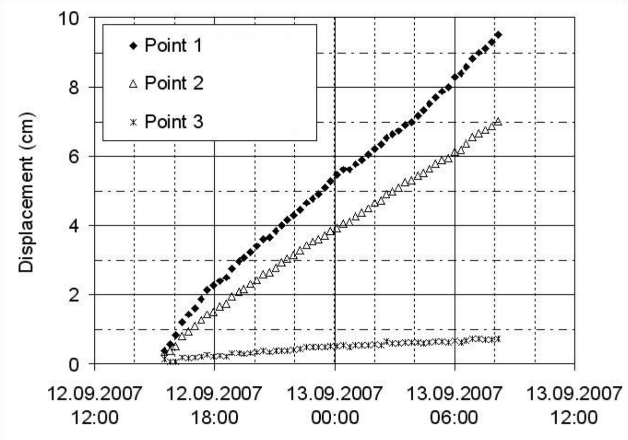

Figure 7: Displacement along the line of sight versus time of 3 selected points in the active zone area (right). The plot clearly indicates the non-linear displacement in this area.

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 7 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.

4. CONCLUSIONS

These initial acquisitions 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.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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