Estimation of Alpine Permafrost Surface Deformation Using InSAR Data

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Abstract – **The detection of active rock glacier and the quantification of the observed surface movement as well as its temporal change using the D-InSAR method are presented. An average deformation rate of -7.7 mm/35 days in the radar line-of-sight, in the summer of 1992, was estimated. Whereas, the corresponding geodetic measurement, vertical component of 3D flow velocity, was about –8.0 mm/35 days. Additionally, the spatial distribution of the rock glacier surface deformation derived from the D-InSAR data matches the photogrammetric and geodetic generated results to a very high degree.**

I. Introduction

The phase difference of two backscattered SAR images of the same area on the ground taken at slightly different view angles can be utilised to generate digital elevation model (DEM) of the imaged surface [3]. This technique known as SAR interferometry (InSAR) can be extended to differential SAR interferometry (D-InSAR) to detect surface changes in the order of few cm [1]. Although the D-InSAR has been shown to successfully derive surface displacement in the radar line-of-sight caused by earthquakes [5] or mass movements in alpine and arctic terrain [6], a number of questions related to the properties of rock glaciers and the imaging geometry of the SAR sensor remain to be answered. These include the relative small size of the rock glaciers in comparison to the SAR pixel resolution, the rough surface topography composed of debris and rocks, the perennial snow patches and snow cover most of the year in the areas of interest, the rather small flow velocities of active rock glaciers in the range of centimetres to few meters (in some cases) per year, the look angle of the SAR sensor, and the geometric and temporal baselines requirements for successful D-InSAR data sets.

In this paper, the detection of a creeping rock glacier, the quantification and validation of the observed surface movements and its temporal change using the D-InSAR technique with ERS-1 SAR data and the prerequisites to perform such analysis on a regional scale are presented.

II. Data & Processing

A. Data Compilation

Five ERS-1/2 single look complex (SLC) image data sets acquired during the period 1992 to 1997 over the Hohe Tauern range (Central Alps) in Austria were compiled. In the selection of the data sets the weather conditions around the time of the acquisition were taken into account to reduce the possibility of atmospheric effects. From experiences during the geodetic field campaigns (1995-1999) and available aerial photographs, it has been observed that the Doesen rock glacier (46°59´N, 13°17´E, length 900 m, area 0.4 km^2) is almost snow free during the period August-September, except some minor areas of perennial snow patches. Therefore, the selection of the interferometric image pairs was concentrated in this season of the year. The orbits numbers of the selected ERS SAR scenes are listed in Table 1 below.

TABLE 1
Compiled ERS-1/2 Data Sets

Orbit Number	Acquisition date	Product type
05778 ERS-1	23.08.1992	SLCI
06279 ERS-1	27.09.1992	SLCI
21152 ERS-1	01.08.1995	SLCI
31673 ERS-1	05.08.1997	SLCI
12000 ERS-2	06.08.1997	SLCI

B. Processing

First, the classical interferometric chain processing was applied to the image data selected [3]. After co-registration, interferometric products from all possible combinations of the data sets listed in Table 1 above were generated. The InSAR multi-looking was chosen as 5 looks and corresponds to about 20 m x 20 m pixel ground resolution, which is good enough to allow the detection of the small size rock glacier. The orbit combinations 06279-05778 and 12000-31673 turned out to be the most coherent. However, the baseline perpendicular component of the 12000-31673 orbit pair combination was very large about 376 m, i.e. topography will dominate. Whereas, that of the 06279-05778 was only 7 m which is perfect for D-InSAR applications.

Three procedures, namely the 2-pass, 3-pass and 4-pass approaches are normally used for the generation of D-InSAR products. The 2-pass approach requires a precise digital elevation model (DEM) to be used for the simulation of the topographic interferometric phase. The 3-pass method requires no terrain model but an unwrapped interferogram of a relatively long baseline for the estimation of the topographic phase. The 4-pass method only requires the scaling of the interferograms by integer values. Theoretically, all three D-InSAR approaches could be applied in this case. Also, it is to be mentioned that if an interferogram has a zero or a very small baseline perpendicular component its phase values can be interpreted directly as radar line-of-sight displacement phase [7]. Since one of the interferograms has an almost zero baseline perpendicular component (7 m), its flat terrain filtered interferogram could be directly interpreted as displacement phase. This possibility could be exploited in this case. However, our test area is composed of very high relief and rugged terrain and even though the baseline perpendicular component is very small, relief effect is still present in the flatten interferogram. This point was checked by comparing the flatten interferogram with a simulated wrapped interferogram as shown in Fig. 1 left and right respectively.

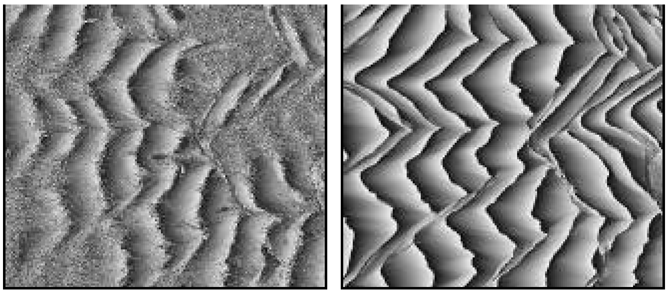

Fig. 1. Flaten interferogram (left) and simulated one (right).

The simulation was performed by resampling an available 50 m resolution DEM of the area to a 20 m resolution DEM to correspond to the 5 look interferogram. Before the simulation ground control points (GCPs) were measured simultaneously on the amplitude image and topographic maps. The GCPs were used to adjust the orbit data to a pixel accuracy. Despite the adjustment the simulated interferogram was found to be shifted by +7 pixels in range and -26 pixels in azimuth with respect to the SAR measured interferogram. Layover effect could also be observed along the ridges where no data are available, although interpolation was carried out, in a 21x21 pixels window, to fill the gaps or the pixels with missing phase information.

The simulated interferogram was co-registered to the SAR measured one to within a pixel accuracy. The unwrapped or absolute value simulated interferogram was then used to remove the relief component from the interferogram of the orbit pair 06279-05778 by multiplication in the complex domain and the residual interferogram is the D-InSAR product as shown in Fig 2. left. The D-InSAR interferogram was then smoothed using spectral filtering to reduced the speckle. The speckle filtered interferogram was then phase unwrapped using the branch-cut method. The results of the phase unwrapping were scaled to cm level to produce the radar line-of-sight displacement map as shown in Fig. 2 right. A linear trend, especially in the range direction, was detected in the unwrapped residual interferogram which could be attributed to 1^{st} order errors in the orbit data. To minimise this trend and any remaining topographic trends, a 1^{st} order least-squares best fit in range and azimuth was applied to the unwrapped displacement interferogram. From the least-squares fitting it turned out that this trend was only in the range direction, while in the azimuth direction such a trend could not be observed.

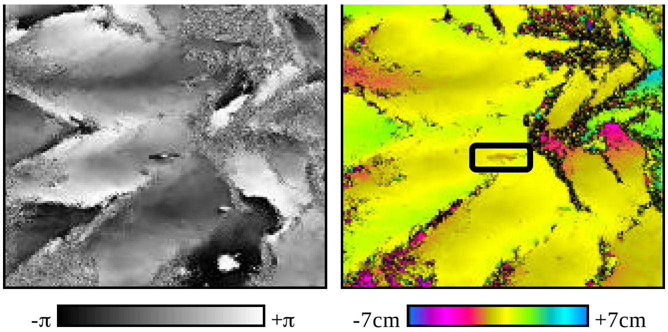

Fig. 2. Displacement map, wrapped (left) and unwrapped scaled (right).

III. Quantitative Analysis

The quantitative analysis is based on the Doesen rock glacier area marked with box in Fig. 2 right. In this sub image we observed that there is still a local linear trend in the surroundings of the rock glacier area which were supposed to be stable, i.e. non-moving. Based on this observation the trend was removed by applying the same least squares fit technique mentioned above. The error was estimated from the residuals in the non-moving areas which resulted in an rms error of ±1.0 mm. The final result is shown in Fig. 3 (upper) and presented as a displacement map of 1.0 mm intervals in a colour code. The areas with in-significant displacements are coded white (1 x rms error).

The upper image in Fig. 3 clearly reveals the spatial distribution of the deformation of the rock glacier surface in the radar line-of-sight. Due to the radar geometry the measurements are primarily sensitive to the elevational change of the rock glacier surface, which is composed of a flow component and a component due to loss and/or gain of ice [2,4]. Thus the horizontal flow velocity of the rock glacier can not be deduced from these results. The results were compared to photogrammetric and geodetic measurements carried out on the Doesen rock glacier in the past [4]. As an example, a comparison of the D-InSAR results with geodetic measurements obtained in the period 1996-1997 as shown in Fig. 3 (middle and bottom) are presented. The maximum vertical deformation measured in the D-InSAR data was about –18.6 mm/35 days. Whereas, the maximum vertical flow for the time period 1996-1997 measured in the same region, point A in Fig. 3 (middle), amount to -16.1 cm a^{-1} which scales to –15.4 mm/35 days. Additionally, we compared the changes at the snout, point S in Fig. 3, of the rock glacier which resulted in –11.5 mm/35 days in the D-InSAR data, while the equivalent geodetic value is –10.4 mm/35 days. It is to be noted that the accuracy of the geodetic measurements is about ±10.0 mm a^{-1} and the measurements are subject to seasonal and annual variations.

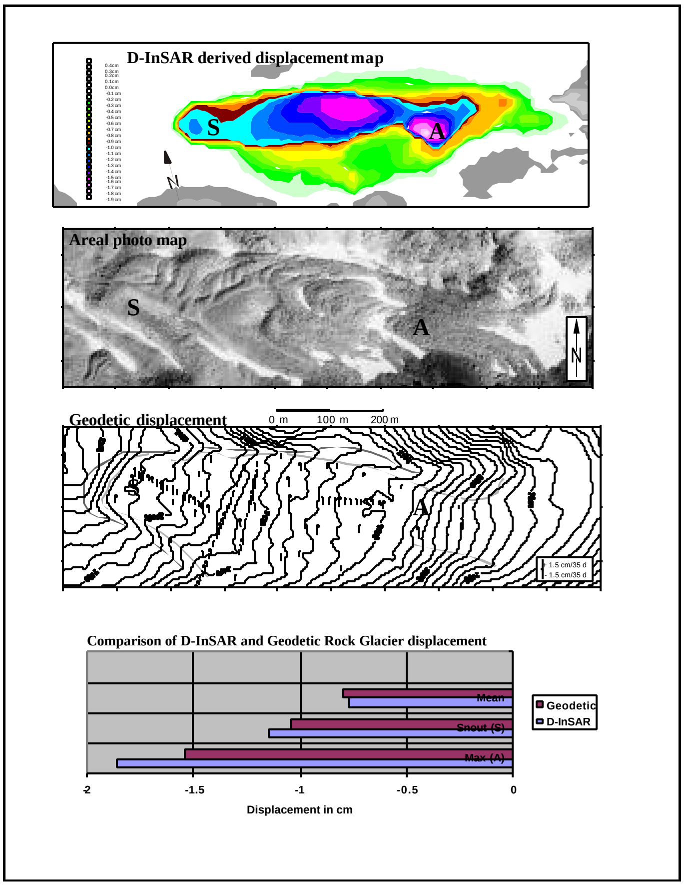

Fig. 3. Comparison of D-InSAR displacement with geodetic data.

Unfortunately, the other image pair combinations were mostly incoherent in the area where the rock glacier is located. This led to our inability to generate more displacement maps in order to infer the 3D rock glacier flow velocities. The acquisition time period of August to September seemed to be the optimum time for InSAR data acquisition, because in this period of the year most of the glacier is snow free.

IV. CONCLUSIONS

The detection and quantification of deformations in a small size active rock glacier using ERS InSAR data has been successfully demonstrated. A mean deformation rate of the rock glacier surface of about -7.7 mm/35 days was estimated. Whereas, the corresponding geodetic measurement of the vertical component of the 3D flow velocity field of the same rock glacier was about -8.0 mm/35 days. Additionally, the spatial distribution of the rock glacier surface deformation derived from the ERS InSAR data using the D-InSAR technique matches the photogrammetrically and geodetically generated results to a very high degree. From these comparative results it can be concluded that, what is measured by the D-InSAR is the surface deformation which relates to a very high extend to the vertical flow component of the 3D rock glacier flow velocity field.

For a successful detection and quantification of rock glacier deformation in the Alps, InSAR data of very small perpendicular baseline components and InSAR multi-looking of 5 looks are required. The temporal baseline must be very short and the optimum acquisition period is August – September; otherwise the data will be mostly incoherent.

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