DETECTION AND QUANTIFICATION OF ROCK GLACIER DEFORMATION USING ERS D-InSAR DATA

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INTRODUCTION

Synthetic Aperture Radar (SAR) systems normally record both the amplitude and the phase of the backscattered echoes. However, the phase of a single backscattered image is of no use and therefore, conventionally the amplitude or intensity image is usually provided to the user. But on the contrary, 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 terrain [5,8,12]. This technique is known as SAR interferometry (InSAR) and can be extended to differential SAR interferometry (D-InSAR) to detect surface changes in the order of few cm [2]. Although the D-InSAR has been shown to successfully derive surface displacement in the radar line-of-sight caused by earthquakes [7] or mass movements in alpine and arctic terrain [9,10], 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 active, i.e. creeping rock glaciers and consequently the quantification of the observed surface deformation, its temporal change using D-InSAR methods and the prerequisites to perform such analysis on a regional scale is presented. In one of the study cases, the active Doesen rock glacier [4,6], where the coherency of interferometric pairs was very high and the perpendicular component of the baselines were almost zero, an average deformation rate of about -0.77 cm/35 days (summer 1992) in the radar line-of-sight was estimated. In the following sections the description of the SAR data compiled, the interferometric processing procedures used to generate the D-InSAR products and the discussion and quantification of the results achieved are presented.

DATA & PROCESSING

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 (Fig. 7 top) 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.

Table 1: Compiled ERS-1/2 SAR 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

Processing

First, the classical interferometric chain processing was applied to the image data selected [5]. 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 20m x 20m 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, 376 m, and that of the 06279-05778 was only 7 m which is perfect for D-InSAR applications. The left hand side part of Fig. 1 shows part of the SAR amplitude image of the terrain, where the location of the Doesen rock glacier is marked by the white rectangle. Lake Doesen can be used as a reference landmark. It is evident that the terrain is rugged and the relief energy is very high. In the right hand side part of Fig. 1 an aerial photo perspective view of the area of interest, i.e. the central part of the radar image, is shown, where the rock glacier and the lake are clearly seen in the W-E oriented inner Doesen valley.

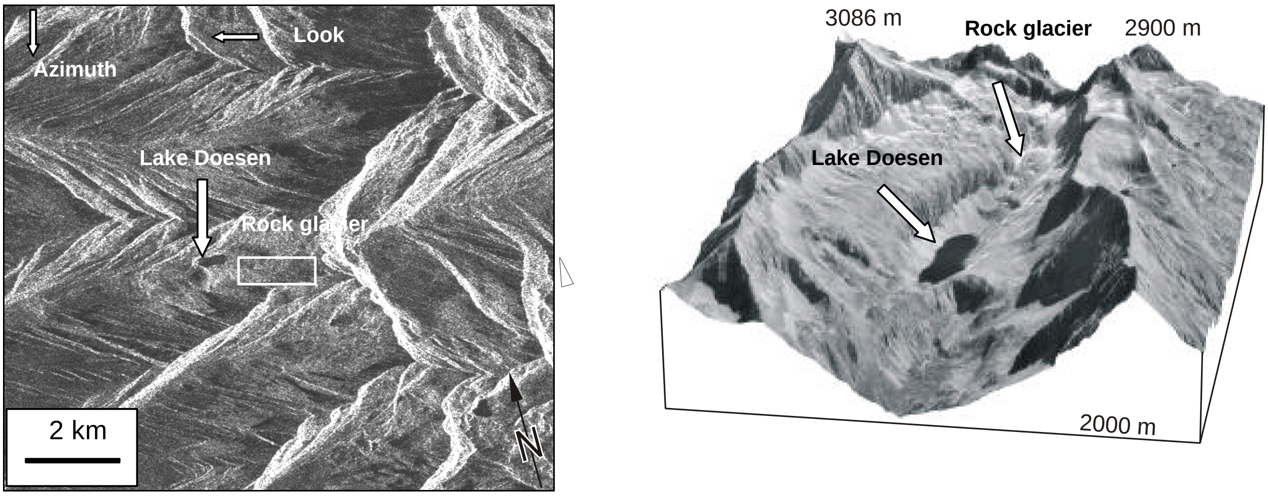

Fig. 1: ERS SAR sub amplitude image of the test area (left) and aerial photo perspective view from W direction of the area of interest (right).

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 [11]. Since one of the interferograms has an almost zero baseline perpendicular component (7 m) its flat terrain filtered interferogram can 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. 2 left and right respectively.

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.

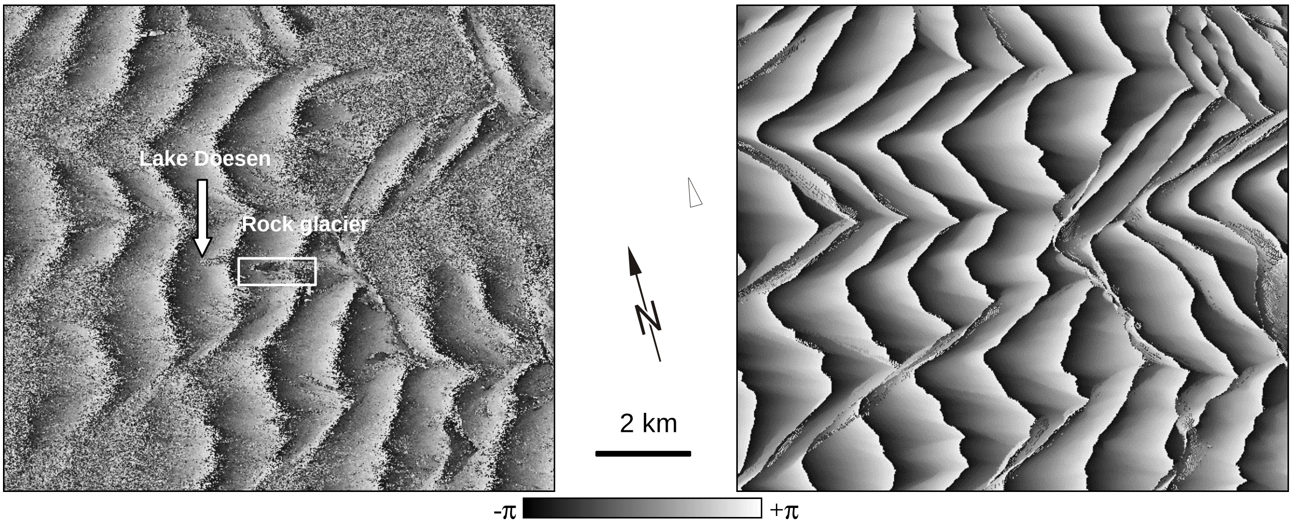

Fig. 2: 5 looks interferogram image of ESR-1 orbit pair 06279-05778; left real interferogram and right DEM simulated interferogram.

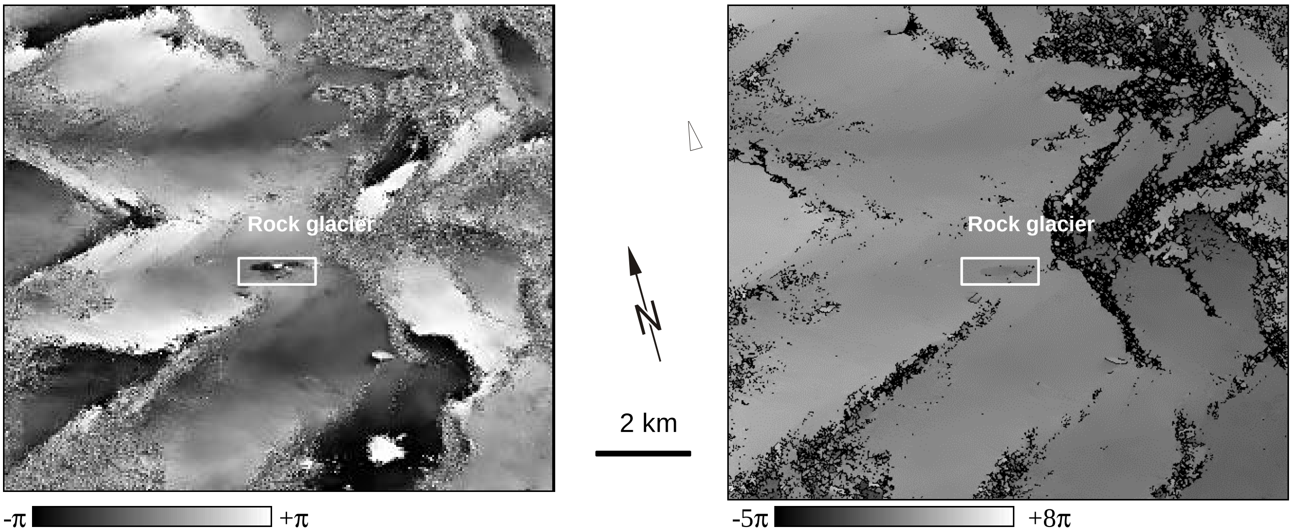

Fig. 3: Difference of interferogram of ERS-1 orbit pair 06279-05778 and DEM simulated interferogram; wrapped (left) and unwrapped (right).

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 3. left. The D-InSAR interferogram was then smoothed using spectral filtering to reduced the speckle. The speckle filtered interferogram was then phase unwrapped. For the unwrapping the branch-cut method [3] was applied and the result is shown in Fig. 3 right. But to check consistency of results in the rock glacier area the residual interferogram was also unwrapped using the minimum cost network flow phase unwrapping algorithm [1]. The results of both phase unwrapping were scaled to cm level to produce the radar line-of-sight displacement map. A linear trend, especially in the range direction, was detected in the unwrapped residual interferogram which could be attributed to 1st order errors in the orbit data. To minimise this trend and any remaining topographic trends, a 1st 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 as can be seen in the plot on the middle of Fig. 4, while in the azimuth direction such a trend could not be observed, see plot on the left hand side of Fig. 4. The plot on the right hand side of Fig. 4 is for the range corrected version of the cm scaled displacement interferogram. Whereas, in Fig. 5 the 1st order least-squares best fit range corrected displacement maps are shown for both unwrapping methods.

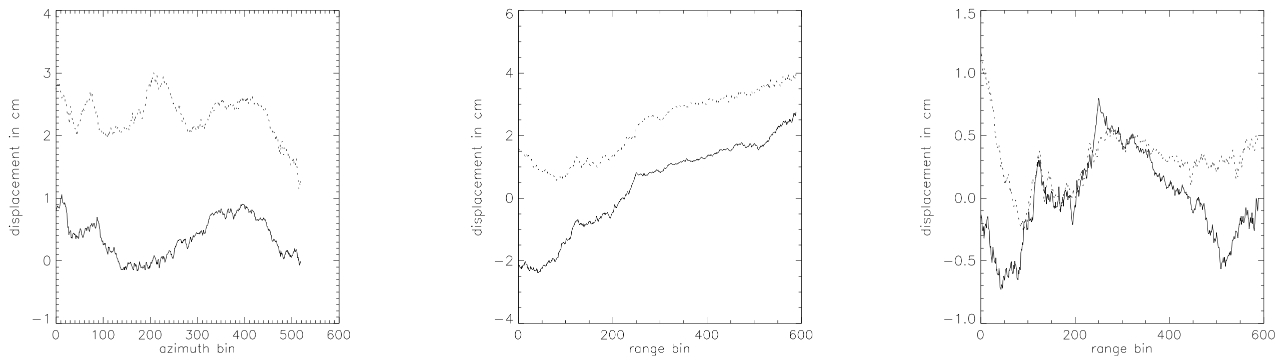

Fig. 4: Plots showing linear trends in azimuth (left) and range (middle) direction. Right hand side plot is the same as in the middle but corrected by least squares fit. Plots with dot line are for the branch-cut and solid line for the minimum cost network flow unwrapped displacement maps.

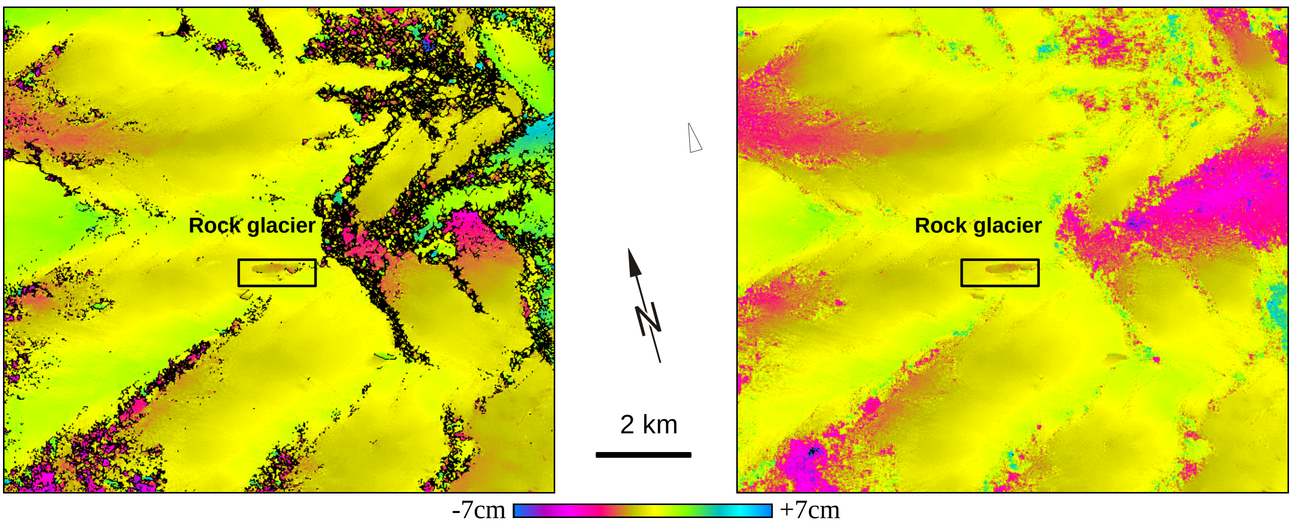

Fig. 5: Radar line-of-sight displacement map of the Doesen rock glacier: branch-cut unwrapped (left) and minimum cost network flow unwrapped (right). Pixels of unreliable phase values are coloured black.

QUANTITATIVE ANALYSIS

The quantitative analysis is based on the Doesen rock glacier area marked with box in Fig. 5 left. In this sub image we observed that there is still a local linear trend in the surroundings of the rock glacier area which are supposed to be stable, i.e. non-moving. Based on this observation we again removed the trend 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. 6 left 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). For comparative purposes the minimum cost network flow unwrapped displacement map is also presented in the right hand side of Fig. 6.

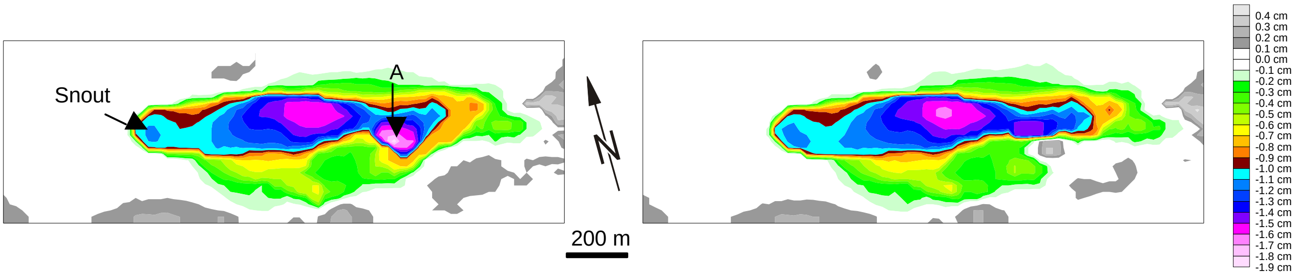

Fig. 6: Radar line-of-sight displacement map of the Doesen rock glacier (box area in Fig. 5 enlarged): branch-cut unwrapped (left) and minimum cost network flow unwrapped (right).

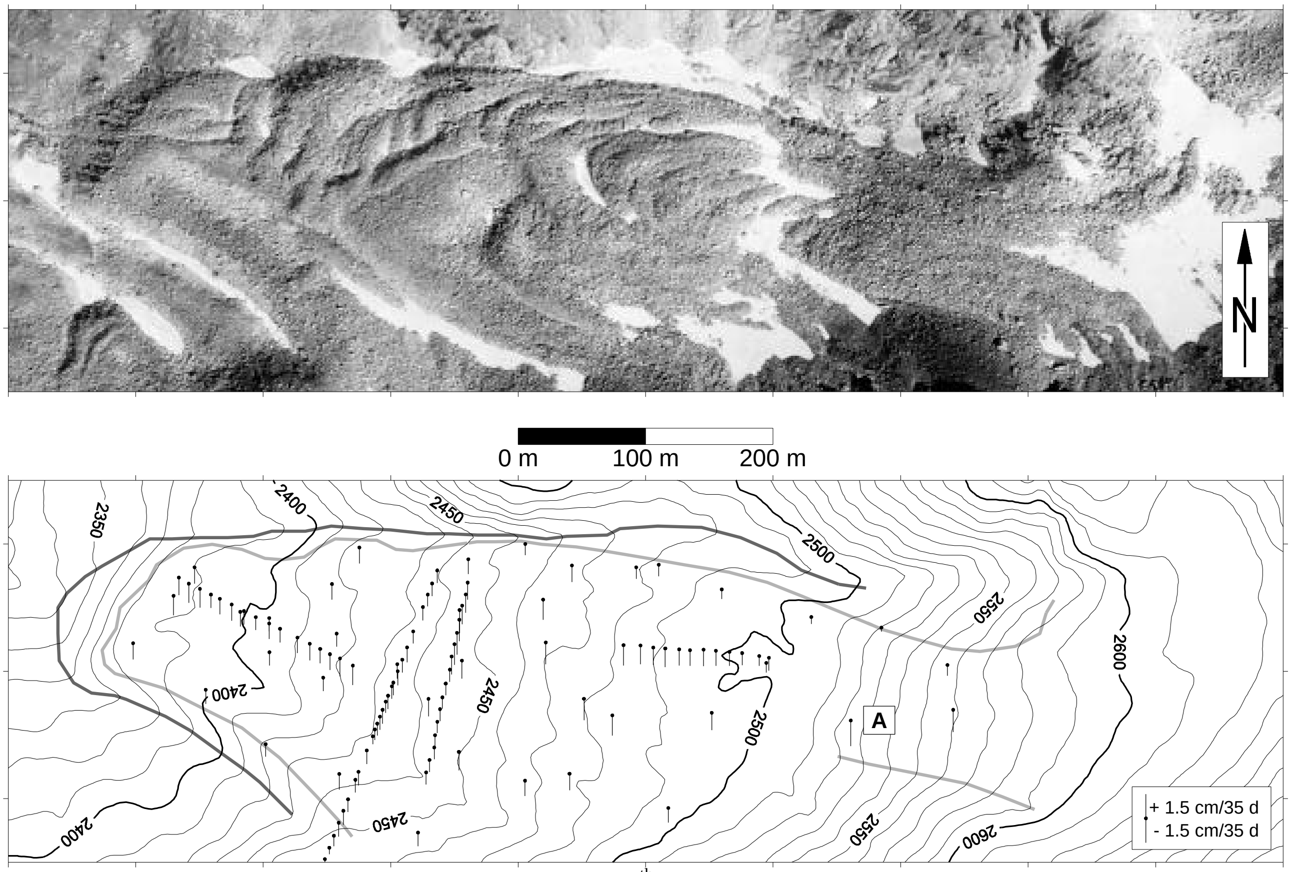

Fig. 7: Orthophoto map of Doesen rock glacier August 15th 1993 (top) and a map of the vertical flow component of observation points scaled to 35 days for the period 1996-1997 (bottom).

Fig. 6 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 [4]. Thus the horizontal flow velocity of the rock glacier can not be deduced from this results. The obtained results were compared to photogrammetric and geodetic measurements carried out on the Doesen rock glacier in the past [4]. As an example we present a comparison of the D-InSAR results with geodetic measurements obtained in the period 1996-1997 as shown in Fig.7 bottom. The maximum vertical deformation measured in the D-InSAR data was –1.86 cm/35 days. Whereas, the maximum vertical flow for the time period 1996-1997 was observed in the same region, point A in Fig. 7 bottom, and amounts to -16.1 cm a^{-1} which corresponds to -1.54 cm/35 days. Additionally, we compared the changes at the snout of the rock glacier which resulted in –1.15 cm/35 days in the D-InSAR data, while the equivalent geodetic value is -1.04 cm/35 days. It is to be noted that the accuracy of the geodetic measurements is about 1.0 cm a^{-1} and the measurements are subject to seasonal and annual variations.

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.

CONCLUSIONS

The detection and quantification of deformations in a small size active rock glacier using InSAR data has been successfully demonstrated. A mean deformation rate of the rock glacier surface of -0.77 cm/35 days was estimated, whereas the corresponding geodetic measurements of the vertical flow of the rock glacier is about -0.8 cm/35 days. Additionally, the spatial distribution of the rock glacier surface deformation derived from the D-InSAR data matches the photogrammetrically and geodetically generated results to a 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 incoherent.

This is very encouraging result and more investigations have to be performed with regard to looking into other rock glaciers, the optimal topographic phase estimation and removal, and the possibility of generating the 3D rock glacier flow velocity field and the separation of flow and ice related components.

ACKNOWLEDGEMENTS

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