LANDSLIDE-LIKE DEVELOPMENT OF ROCKGLACIERS DETECTED WITH ERS-1/2 SAR INTERFEROMETRY

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ABSTRACT

Rockglaciers are permanently frozen sediments supersaturated with ice deforming steadily and slowly on periglacial mountain slopes. The frequency of alpine rockglaciers affected by "surge" (landslide-like) processes has increased during the last two decades probably in connexion with a signficant acceleration of rockglaciers deformation rate consecutive to permafrost warming. Flow velocities up to several metres per year can be observed. The analysis of 1-day ERS-1/2 differential SAR interferograms available for the period 1995-1999 has proved to be an adequate tool for detecting such very rapidly moving rockglaciers.

1. INTRODUCTION

Perennially frozen ground supersaturated with ice may be affected by slow steady-state gravity deformation – the so-called permafrost creep [1]. The process leads to the formation of rockglaciers, which are large masses of ice/rock debris mixture acting as conveyors of debris on mountain slopes (fig. 1a). In the Alps, active rockglaciers are common above 2200 to 2500 m a.s.l. Their deformation rate ranges typically between 0.1 and 2.0 ma^{-1} [2, 3]. Most active rockglaciers are well detectable with ERS, ENVISAT, JERS or ALOS SAR interferometry at monthly time lapse (fig. 1b), whereas the slowest are only visible at yearly interval [4-7].

2. LANDSLIDE-LIKE DEVELOPMENT OF ROCKGLACIERS MOTION AND ERS INSAR SIGNATURE

Destabilized (or "surging") rockglaciers showing morphological indices of landslide-like mass wasting (e.g. development of transversal cracks, surface subsidence of the upper section, rapid advance of the front position) that affects the terminal part or the whole of the landform have been reported recently from several regions in the European Alps [8]. One of the most spectacular case is the well documented destabilization of the Grueo-01 rockglacier in the Valais Alps (Turtmann valley) [9], with the development of large collapse structures during the last 20 years (fig. 2). Figure 3 illustrates its corresponding signature on ERS InSAR scenes. Obvious signals are detected on 1-day interferograms both in summer and winter time. They correspond precisely with the surging section of the rockglacier indicating a displacement of about 2-5 ma^{-1} in the satellite line-of-sight and the permanence of the deformation throughout the year.

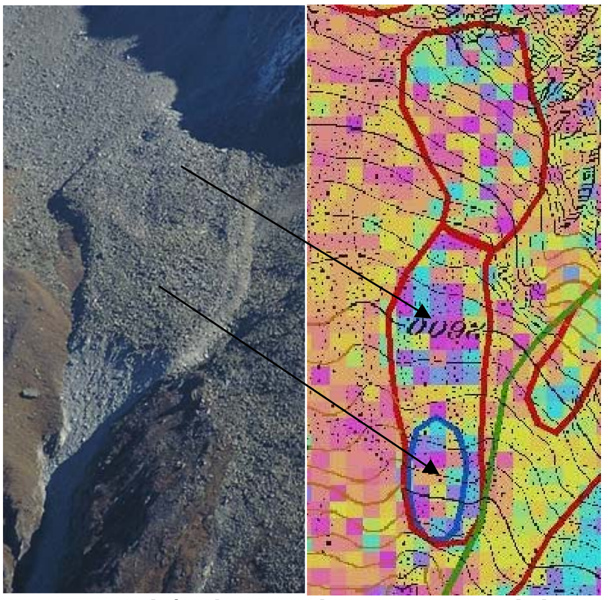

Figure 1. a) (left) The 400 m long Tsarmine rockglacier (western Swiss Alps); b) (right) its corresponding signal on a 35-day ERS SAR interferogram (19970903_19971008, descending orbit). Red polygons depict areas with 35-day signal of movement, the blue polygon an area with a slight 1-day signal in summer time.

3. SYSTEMATIC DETECTION

The systematic analysis of ERS-1/2 differential SAR interferograms for inventorying mass wasting in the periglacial belt of the Valais Alps (Switzerland) has revealed – what was not expected before – the occurrence of 15 to 20 rockglaciers that were affected by very rapid movement in 1995-1999 in the study area (fig. 4) [10-11]. Many of them are visible both on 1-day winter and summer scene, whereas the others only have detectable signal on summer interferograms (fig. 4). Most detected rockglaciers show morphological evidences of landslide-like destabilization (fig. 5-6).

Proc. of FRINGE 2007 Workshop, Frascati, Italy, 26 – 30 November 2007
(ESA SP-649, February 2008)

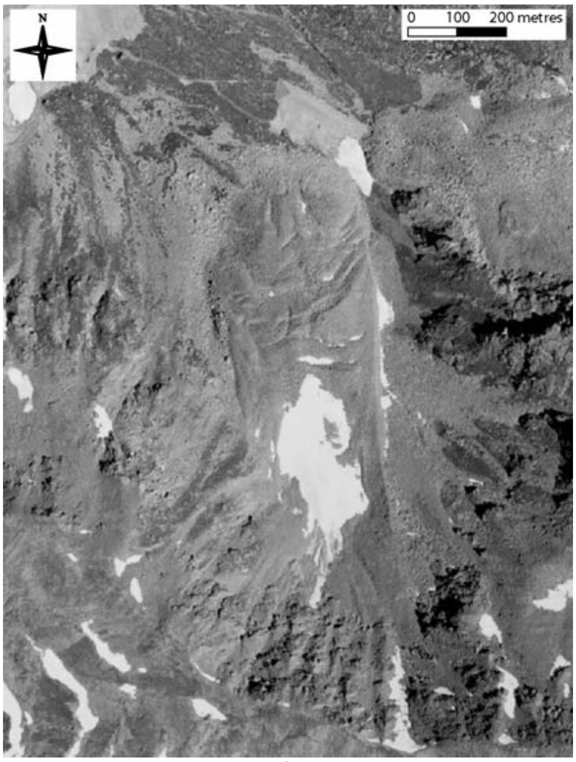

Figure 2. Orthoimage of the collapsing Grueo-01 (Ritzischumm) rockglacier tongue in 1999, with the development of large and deep transversal crevasses.

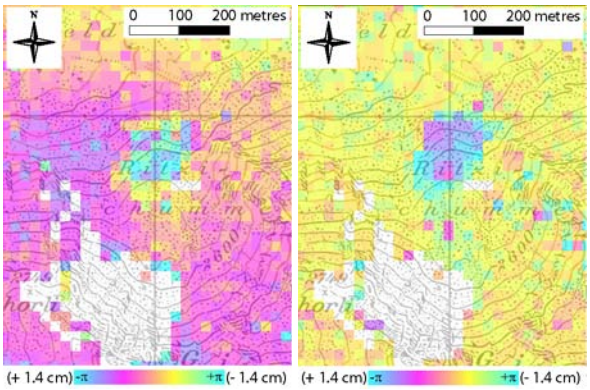

Figure 3. ERS InSAR signature of the collapsing tongue of the Grueo-01 rockglacier (western Swiss Alps) in summer (left : 19970729_19970730, descending orbit) and winter (right : 19970311_19970312) 1-day interferograms

Terrestrial surveys (by means of differential GPS) have been initiated since 2005 on several of these very rapidly moving landforms. They confirm both the magnitude order of the displacement rate - locally up to more than 4 ma^{-1}, with significant acceleration in summertime - and the spatial pattern of the areas affected by higher deformation rate (fig. 5-7), which have been detected by the analysis of the InSAR data. Ongoing terrestrial surveys also show that the mass wasting processes are still active a decade after the SAR data aquisition.

For the two examples illustrated in figures 5 (Petit-Vélan rock glacier) and 6 (Tsaté rockglacier), the recent terrestrial data shows moreover the downslope migration of the destabilized section of the two rockglaciers. Both front positions appear to be located 20-40 m downward in 2005-2006 compared to their respective location on the InSAR data in 1997. Similarly, the upper limit of the rapidely moving zone seems to have shifted a few tens of metres downwards. The amplitude of this migration fits with the estimations that can be made on the basis of field evidences.

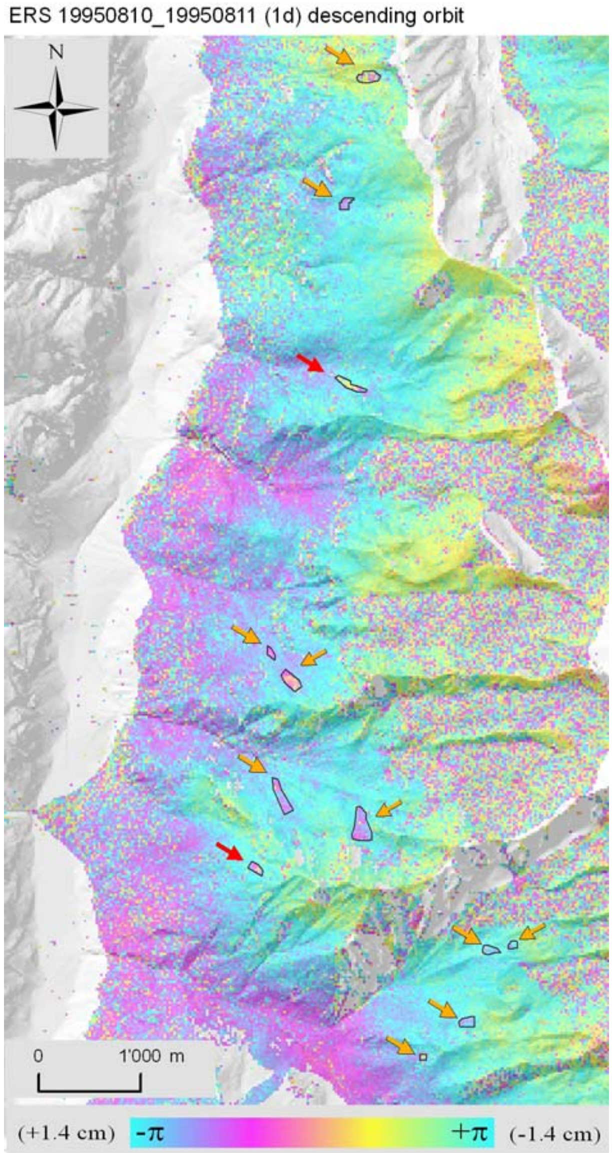

Figure 4. High concentration of rapidly moving («surging») rockglaciers detected on the orographic right side of a tributary of the Rhone valley (Valais Alps) on ERS-1/2 1-day interferogram (here 19970729_19970730, descending orbit). Red arrows indicate features with summer and winter signals, orange arrows point on features with summer signal only.

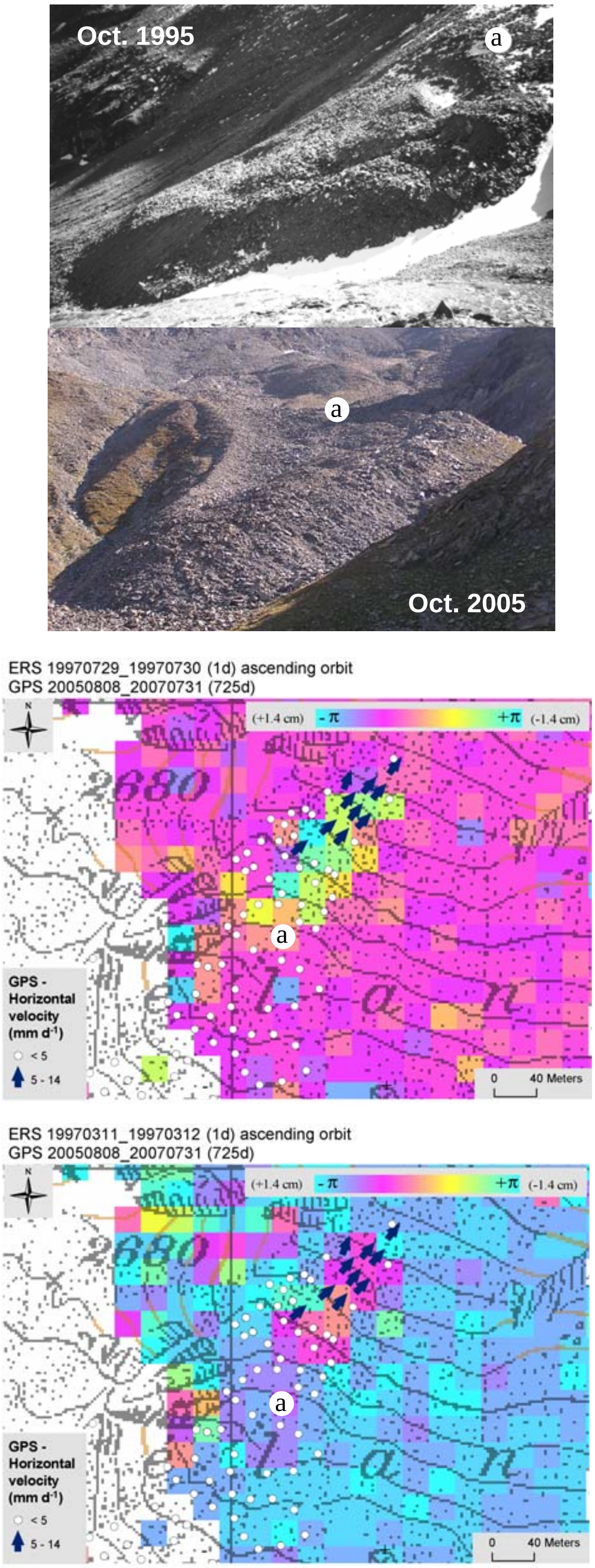

Figure 5. The Petit Vélan rockglacier (western Swiss Alps) with the onset of the surge by 1995 (top), the collapsed tongue in 2005 (middle up) and 1-day summer (middle down) and winter (bottom) ERS interferograms compared with recent GPS data. Note the developping scars in 1995 in the rupture zone (a).

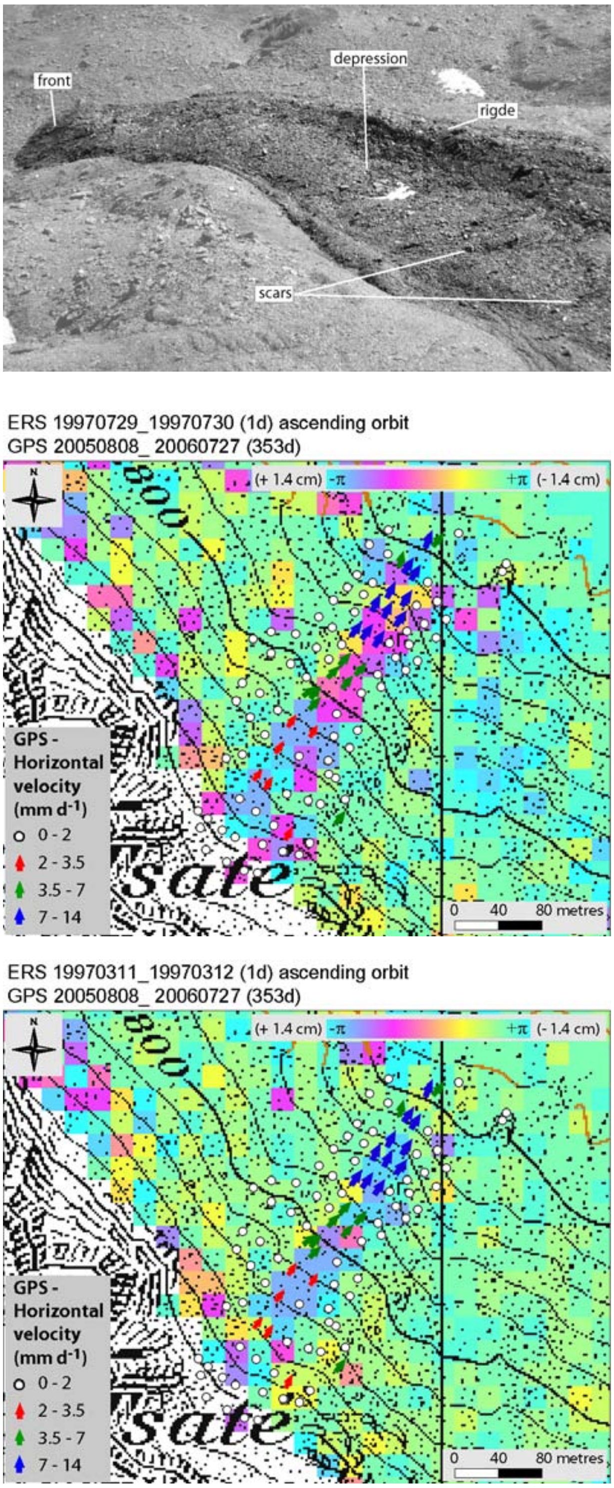

Figure 6. Morphology of the destabilized Tsaté rockglacier (western Swiss Alps) (up) and signals on 1-day summer (middle) and winter (down) ERS interferograms compared with recent GPS data. A mean horizontal velocity of about 4 ma^{-1} has been measured in situ between summer 2005 and summer 2007. The deformation rate increased dramatically in autumn 2007 with a seasonal velocity reaching up to 15 ma^{-1} !

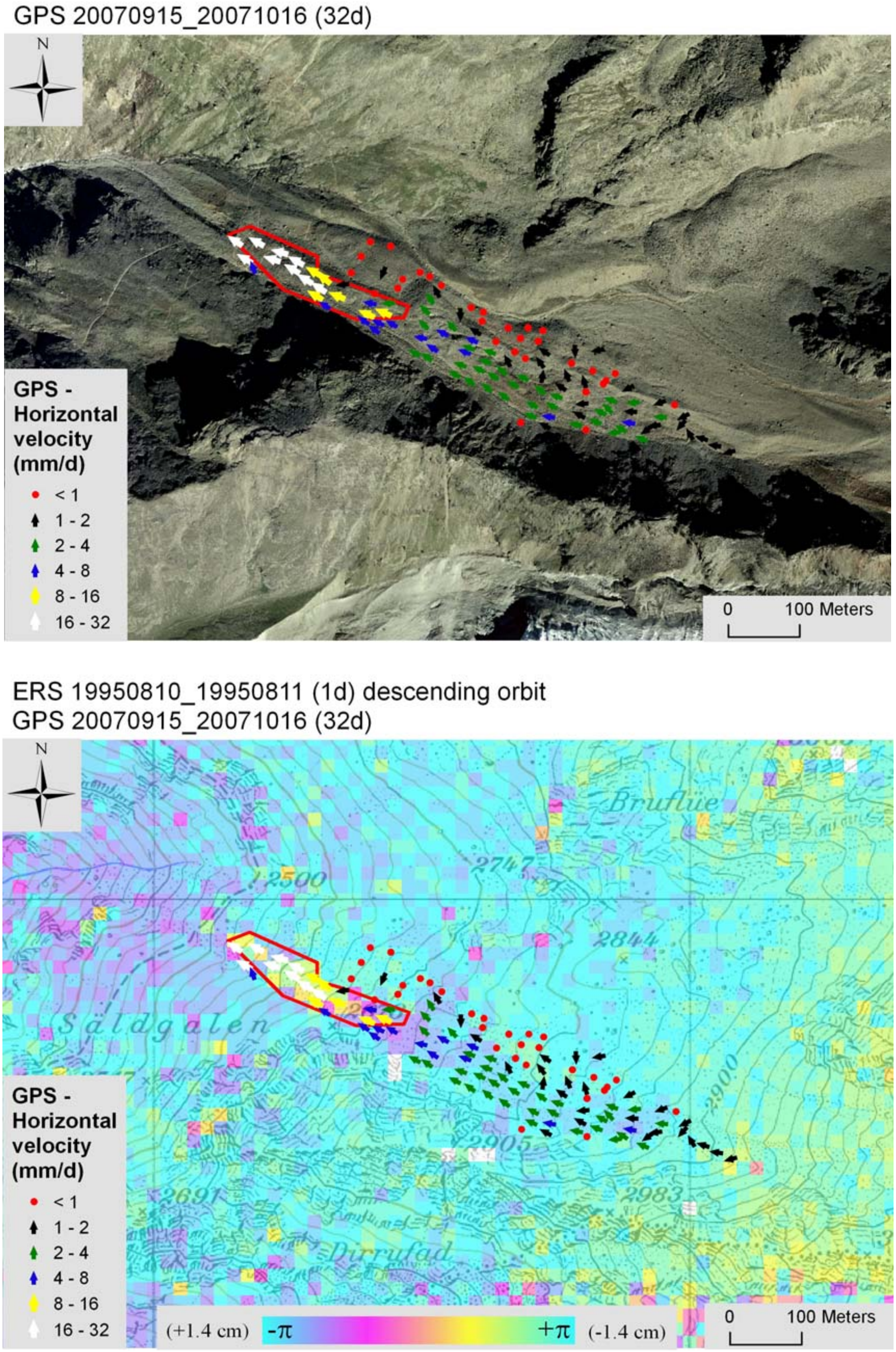

Figure 7. The Dirru rockglacier (Zermatt valley): orthoimage, recent GPS survey and 1-day ERS SAR interferogram in summetime. The red polygon depicts the area with daily ERS InSAR signal.

4. CURRENT LIMITATIONS AND PERSPECTIVES

The higher deformation rate of rapidly moving rockglaciers is too large to be detected correctly on C-band and L-band monthly SAR interferograms. Figure 8 shows that, conversely to a 1-day ERS InSAR scene (fig. 7), the rapidest part of the rockglacier – with a movement rate exceeding 1 cm per day – is not evidenced on a L-band 46-day ALOS PALSAR interferogram. The signal even appears in this particular case to be smooth, possibly due to the less favourable slope angle of this steeper part of the rockglacier. Indeed, since the end of the ERS-1/2 tandem mission, there is no more adequate SAR data available for the survey of rapid movements. In future, the C-band SAR system on the intended European satellite system Sentinel-1, expected to be launched in 2011 with a 12-day repeat cycle, should improve the detection of the activity of these very rapidly moving rockglaciers.

5. ACKNOWLEDGMENTS

ERS and ENVISAT SAR data courtesy of CP1.2338, © ESA. JERS SAR data courtesy J-2RI-001, © JAXA. ALOS PALSAR data courtesy P-175-001, © JAXA. DHM25 © 2003 swisstopo.

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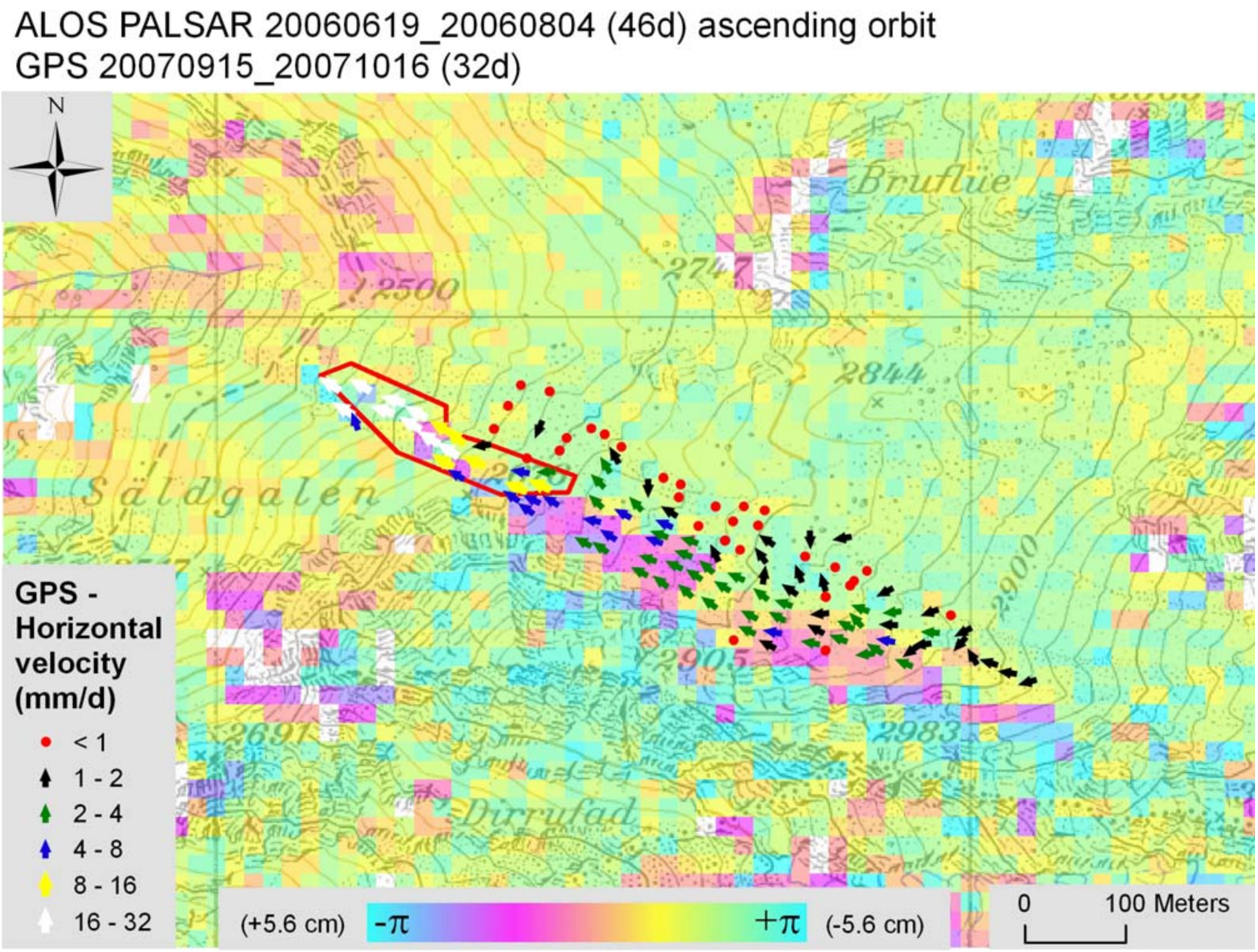

Figure 8. The Dirru rockglacier (Zermatt valley): recent GPS survey and a 46-day ALOS PALSAR interferogram. The red polygon depicts the area with daily ERS InSAR signal (see fig. 7)

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