Monitoring Alpine Glaciers with ALOS SAR and Optical data

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Abstract
The monitoring of temperate glacier activity is one of the applications which require the combined use of optical and SAR data. It should become feasible thanks to the ALOS PRISM and PALSAR sensors. In this paper, we present the interest of using L-band polarimetric interferometric SAR data and high resolution panchromatic stereoscopic data to monitor moving temperate glaciers made of ice, snow and rocks. The scientific issues are described and a test-site located in the Mont-Blanc region in the Alps is proposed for specific experiment and validation. The Mont-Blanc test-site includes two well-known glaciers (Mer-de-Glace and Argentière glaciers) where a large data set has been collected: ERS, RADARSAT and ENVISAT data, airborne E-SAR data (X, C, L and P bands), airborne photographs, GPS and GPR in-situ measurements…

Keywords: SAR differential interferometry (D-InSAR), SAR polarimetry, temperate glacier

1. INTRODUCTION

The monitoring of temperate glacier fast evolution is an important issue for economical and security reasons and as an indicator of the local effects of global climate change. Compared to sparse terrestrial ground measurements, remote sensing is expected to allow regular observations of glacier activity and to provide dense measurements of physical parameters which are necessary to detect significant changes and to constrain glacier flow models. Optical data can be used to derive by correlation techniques high accuracy digital terrain model (DTM) and surface displacement fields, but only during the summer season and below the equilibrium lines where snow disappears for a few months [1]. Synthetic Aperture Radar data is a complementary source of information since SAR Interferometry (InSAR) or alternative techniques can be applied to measure glacier topography and displacement fields which can reach several decimetres per day in the Alps. Spaceborne data from ERS-1/2 tandem mission have been successfully used to derive velocity fields, mainly during the cold season because of the strong temporal decorrelation in summer [2]. To investigate the potential and processing issues of high resolution or polarimetric SAR data in different bands (X, C, L and P), two airborne SAR campaigns took place over the proposed test-site in October 2006 and February 2007. E-SAR repeat pass interferometric, polarimetric and multi-band data have been acquired thanks to the collaboration between the DLR Microwaves and Radar Institute and the MEGATOR group (http://www.gipsa-lab.inpg.fr/megator). The first results confirmed the high potential of SAR polarimetry in the analysis of the glacier complex surface and sub-surface made of rocks, snow, firm and ice [3]. The repeat pass space-borne data expected from the new generation satellites (ALOS, TerraSAR-X, RadarSAT-2, COSMO-Sky-med) should allow us to investigate different issues such as coherence preservation, atmospheric perturbations, uncertainty assessment…

2. MONT-BLANC TEST-SITE

The "Mont-Blanc" test site is located in the Alps, near the borders between France, Italy and Switzerland. It goes from "Les Bossons" glacier (45°50'N/6°51'E) in the South, up to the "Trient" glacier (46°59'N/7°01'E) in the North. It covers several glaciers near the Mont-Blanc and the Chamonix valley, including the Mer-de-Glace (45°55'15''N/6°55'45''E, 1600-3000 m) and Argentière (45°56'15'''N/7°00'30''E, 1500-3200 m) glaciers, which are instrumented and observed by many scientific teams. This test site is very interesting for the processing of remote sensed data and the validation of glacier monitoring feasibility, for several reasons:

- the geophysical specificity of the glacier behaviour (continuous motion and temporal changes),
- the large datasets acquired in this specific area from different sensors in the last 15 years and expected in the three coming years,

- the accessibility of the studied glaciers which makes ground measurements easier for the interpretation and the validation of the extracted information.

The high velocity of these Alpine glaciers (in average 270 mm a day in summer on the Mer-de-Glace and Argentière) and their strong topography (in the surroundings of Mont-Blanc) are challenging features for SAR differential interferometry. Moreover, the velocity field is far from being uniform on the whole glacier surface and also varies with the seasons. One important feature of the temperate glacier is that, along the different layers within the glacier cross-section, the temperature profile lies constantly at 0°C. Different ice and snow mixtures, as well as rocks of different sizes and orientations are spread all over the surface of the glacier (cf. Fig. 1). This diversity, observed on the proposed glaciers, leads to different backscattering mechanisms. Their effect will be observed either in PALSAR dual polarization mode and their influence on the coherence level of associated interferograms will be investigated, or in fully polorimetric mode making the use of PolInSAR techniques such as coherence optimization even more interesting. This will allow us to observe the penetration of the L-band in the different parts of the glaciers which should be partly snow covered at the time of the expected fully polarimetric acquisitions (end of spring). These results will be very interesting to correlate with the bottom displacement measured in cavities beneath the Argentière glacier.

Figure 1. Mer-de-Glace glacier surface, May 2004

3. TEAM AND PROJECTS

The ALOS ADEN proposal on this test-site has been initiated by a group of 4 laboratories (cf. author affiliations) working in a French national project (MEGATOR, 2004-2007) dedicated to the development of processing methods for temperate glacier monitoring by optical and SAR remote sensing. This research group has been enlarged with new partners (IETR - Université de Rennes, LGIT - Grenoble/Chambery and Laboratoire de Géologie, ENS Paris) in a new project (EFIDIR, 2008-2011).

The goals of these projects are:

- to develop and combine optical and SAR data processing techniques,
- to investigate new sensor potential: high resolution, SAR polarimetry...
- to gather experts in information processing and geophysics to improve SAR displacement measurements for different applications: glaciers, earthquake, volcanoes...

The partners of MEGATOR project have been developing an experimental data base on the proposed test-site (http://www.demorecherche.univ-savoie.fr/megatorrecherche). It includes space-borne SAR images from ERS1/2 satellites used to derive displacement fields by differential interferometry (cf. Fig. 2), airborne photographs used to derive high resolution DTM by photogrametry (cf. Fig. 3) and airborne SAR data acquired during two E-SAR campaigns together with ground measurements such as GPS velocity profiles (cf. Fig. 4), snow stratigraphic profiles… The E-SAR data include X and C band intereferometric data and L and P band polarimetric interferometric (Pol-InSAR) data. A first PolSAR analysis of an L-band image acquired over Argentière glacier is illustrated in Fig. 5.

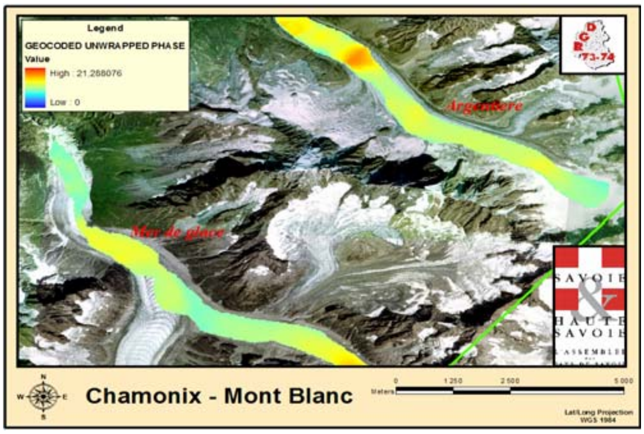

Figure 2. Mer-de-Glace and Argentière glacier 1-day displacement measured from ERS tandem data, March 96.

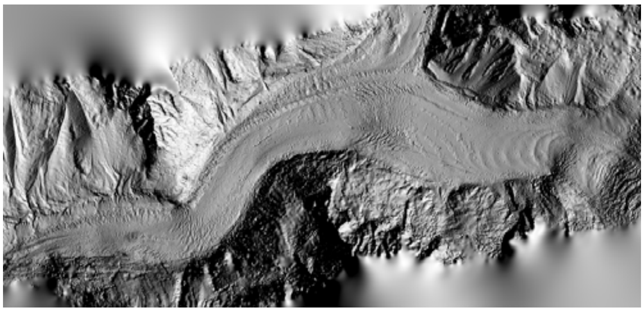

Figure 3. Mer-de-Glace and Tacul glaciers, high resolution DTM from airborne photographs, August 95.

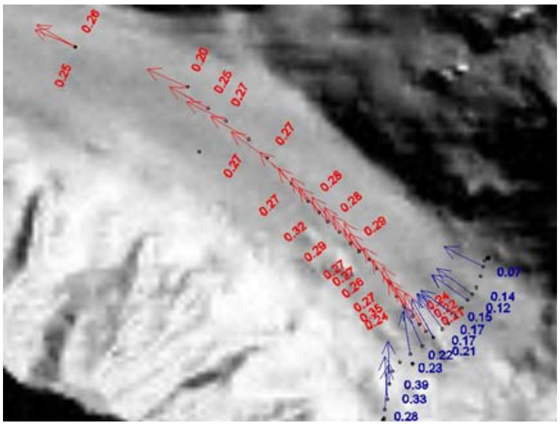

Figure 4. Argentière glacier, 3-day displacement vectors observed by differential GPS, October 2006

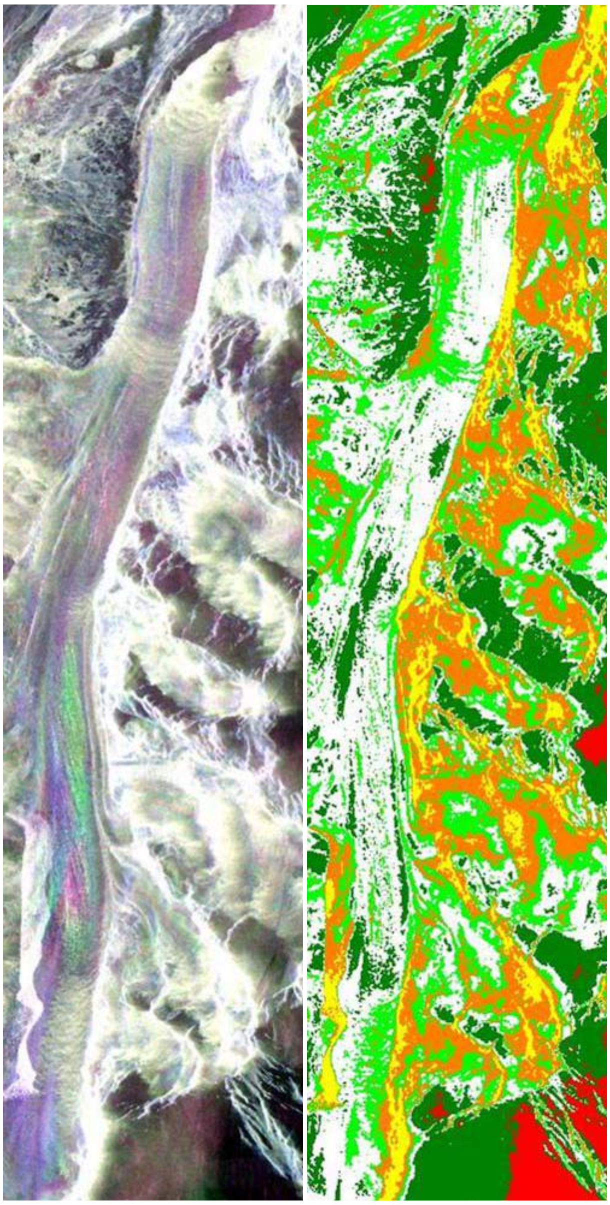

Figure 5. Argentière glacier, E-SAR L-band PolSAR image, left: amplitudes in Pauli basis, right: Wishart classification.

4. ALOS PROPOSAL

4.1 Research axes

The teams involved in this ALOS proposal will develop processing techniques in 3 main research axes (cf. Fig. 6):

- in photogrammetry, to measure the glacier surface topography and derive annual displacement fields and volume balance from PRISM data,
- in SAR imagery, to analyze the L-band backscattering of the snow/rocks/firm/ice mixture from PALSAR data to detect subsurface features and measure 46-day displacements by differential interferometry and/or target tracking using polarimetric decompositions,
- in data fusion, to combine these different information sources together with results obtained with X-band (from TerraSAR-X) and C-band (from ENVISAT and RadarSAT-2) data in order to obtain a global understanding of the glacier evolution which integrates the topographic variations, velocity fields and surface and subsurface detected features.

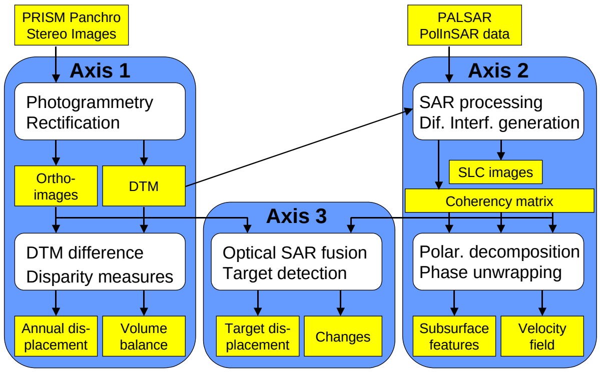

Figure 6. Research axes on PRISM and PALSAR data to monitor temperate glacier activity

4.2. Data requirements

This research activity requires different data from PRISM and PALSAR ALOS instruments.

The PRISM stereoscopic panchromatic high resolution images will allow the computation of accurate up to date DTM's when the snow disappears between May and September. The associated high resolution ortho-images will provide information on surface cover and allow the detection of different features such as rocks, crevasses and glacier limits which are necessary for risk management. Measured every year, such information will allow comparison and change detection, providing important information on the global evolution with much higher resolution than ground measurements performed only in a few points. These results will also be useful for the processing of the PALSAR data, allowing, for instance, to subtract the topographic fringes in interferograms or to analyze backscattering mechanisms with a priori information on the glacier surface.

The PALSAR data are expected in 3 different modes to investigate different issues at different seasons:

- single polarisation interferometric images in winter season to analyse the coherence preservation and, if the level is sufficient, to derive 46-day displacement fields,
- dual polarisation images in spring and summer seasons for target detection and tracking by bivariate correlation,
- Quad polarisation interferometric images in winter season to apply coherent/non-coherent decompositions for surface/subsurface feature classification.

To comply with the ALOS systematic observation strategy, the sought-after PALSAR data have to be acquired in ascending passes. Because of the high topography and the main orientation of the glacier valleys in this area, the glacier visibility is reduced in ascending passes with low incidence angle (cf. Tab. 1). According to the simulations performed from a DTM (cf. Fig. 7), the Quad-Pol mode operated at about 20° would image only a small part of the studied glaciers. Moreover, the Quad-pol data acquired in this area show that the Mont-Blanc test-site is not imaged by the regular tracks (it is between tracks 643 and 644). Accordingly, despite of the lower resolution, specific acquisitions, with about 30° incidence angle, are necessary to image the studied glaciers with ALOS Quad-pol data.

Table 1. Glacier visibility in PALSAR images

Incidence angle	20°	30°	45°
Ascending pass	36 %	79 %	99 %
Descending pass	76 %	96 %	94 %

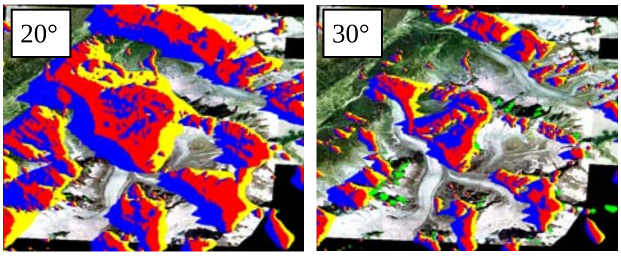

Figure 7. Glacier visibility for ALOS PALSAR data, ascending pass with 20° and 30° incidence angle. Layover: yellow, red, blue mask; Shadow: green mask.

5. CONCLUSIONS AND PERSPECTIVES

The main contributions of this project are methodological:

- processing algorithms for HR interferometry and PolSAR/PolInSAR classification,
- fusion of optical and SAR features for target tracking and change detection,
- specific techniques dedicated to glacier monitoring.

It will also provide the Ice/SAR community with a thematic contribution in terms of:

- understanding of snow/ice L-band SAR backscattering,
- assessment of L-band interferometric potential and limits on heterogeneous fast moving temperate glaciers.

The Mont-blanc area has been proposed as a test-site for “new generation” spaceborne SAR data. Results obtained with ALOS data will be compared with results obtained in X-band (TerraSAR-X and COSMO-SkyMed) and C-band (ENVISAT and Radarsat 2), and benefit from the in-situ measurements and experiments performed in this test-site. For instance, a corner reflector (CR) provided by the DLR and a continuous GPS recording station have been fixed on the ice on the upper part of the Argentière glacier during the February 2007 E-SAR campaign (cf. Fig. 8). Two other non-moving continuous GPS stations have been installed, one near the glacier at 2700 meter height and one down in the Chamonix valley. Despite the difficulties to maintain this equipment on the moving and changing glacier surface, it should allow us to detect the CR with a high accuracy in SAR images whilst its position is known by the GPS data. The CR displacement will be used either as ground truth for performance assessment or as complementary data for solving D-InSAR phase unwrapping ambiguity. The 3 continuous GPS stations will be used to study the electromagnetic path delay variations and to correct the atmospheric perturbations in the SAR based glacier motion measurements.

Finally, the analysis of the whole dataset acquired by the different sensors, performed with the available prior information on glacier activity, will allow experts to investigate many issues in glacier modeling, evolution tracking and associated risk management.

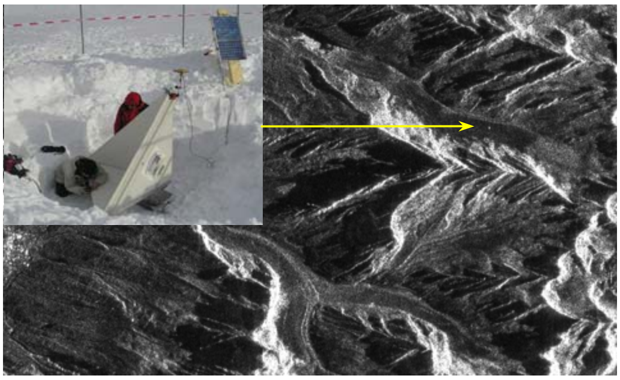

Figure 8. Corner reflector and continuous GPS installed on Argentière glacier; ENVISAT VV image, February 2007

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