Monitoring temperate glaciers by high resolution Pol-InSAR data: First analysis of Argentière E-SAR acquisitions and in-situ measurements

T. Landes [1], M. Gay [2], E. Trouvé [2,3], J.-M. Nicolas [4], L. Bombrun [2], G. Vasile [2,3] and I. Hajnsek[5]

[1] Equipe Photogrammétrie et Géomatique - UMR MAP CNRS INSA Strasbourg - 24, Bd de la Victoire
F-67084 Strasbourg Cedex - Tel: +33 388 144 733 - Fax: +33 388 144 733 - tania.landes@insa-strasbourg.fr

[2] Grenoble Image Parole Signal et Automatique (GIPSA-lab) CNRS INPG - BP 46 – F-38402 Saint-Martin-d'Hères
Tel: +33 476 826 256 - Fax: +33 476 826 384 - lionel.bombrun|michel.gay@lis.inpg.fr

[3] Laboratoire d'Informatique, Systèmes, Traitement de l'Information et de la Connaissance -
Polytech'Savoie – Université de Savoie - BP 80439 – F-74944 Annecy-le-Vieux Cedex
Tel: +33 450 096 548 - Fax: +33 450 096 559 - gabriel.vasile|emmanuel.trouve@univ-savoie.fr

[4] Département Traitement du Signal et des Images - CNRS GET-Télécom Paris - 46, Rue Barrault –
F-75013 Paris - Tel: +33 145 818 129 - Fax: +33 145 813 794 - nicolas@tsi.enst.fr

[5] German Aerospace Center, Microwaves and Radar Institute, SAR Technology Department, PO Box 116,
G - 82234 Wessling - Tel: +498153282363 - Fax: +498153281135 - irena.hajnsek@dlr.de

Abstract— **This paper highlights the potential to measure temperate glacier velocities and surface characteristics by airborne interferometric and polarimetric SAR remote sensing. Indeed, a novel SAR airborne campaign took place in October 2006 over two Alpine glaciers. Simultaneously to the acquisition of repeat pass interferometric, polarimetric and multi-band data, in-situ measurements were carried out to provide useful information for the SAR synthesis, for backscattering analysis and for performance assessment. Analysis of the experimental data as well as early PolInSAR processing results regarding information extraction are presented.**

Key words: SAR interferometry, polarimetry, glacier monitoring, in-situ measurements, GPS, GPR

I. INTRODUCTION

The monitoring of temperate glacier fast evolution is an important issue for economical and security reasons. It is an indicator of the local effects of global climate change. Compared to sparse terrestrial ground measurements, Synthetic Aperture Radar 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. SAR interferometry or alternative techniques can be applied to measure glacier 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 [7], mainly during the cold season because of the strong temporal decorrelation in summer [11]. SAR polarimetry should increase the observation potential of glacier complex surface and sub-surface which are made of rocks, snow and ice. Up to now, only a few airborne campaigns have acquired PolSAR or Pol-InSAR data over Alpine glaciers [10].

This paper presents the first results of a new SAR airborne campaign which took place in October 2006 over two well-known glaciers located in the Mont-Blanc area in the Alps: the Argentière and the Mer de Glace glaciers. E-SAR repeat pass interferometric, polarimetric and multi-band data have been acquired by the collaboration between the DLR Microwaves and Radar Institute and the MEGATOR group (http://www.lis.inpg.fr/megator). In-situ measurements have provided useful ground measurements information for the SAR synthesis, for the backscattered signal analysis and for performance assessment.

II. POLARIMETRIC INTERFEROMETRIC SAR IMAGES

A. *E-SAR acquisitions and processing*

Together with the German Aerospace Center (DLR) a collaboration to measure the velocities and backscattering properties of temperate glacier has been initiated. With the DLR's airborne Experimental Synthetic Aperture Radar System - the E-SAR - multi mode data over two alpine glaciers were collected. The E-SAR system is well known for the data quality in collecting repeat pass interferometric SAR data at different frequencies. Results expected through this experiment, as well in data processing as in algorithms validation, constitute a new challenge for both partners.

During the 3 days campaign in October 2006, several flights following two main directions were performed: one in direction NE-SW along the Argentière glacier and one in direction SE-NW on the upper parts of the Mer de Glace (Tacul and Leschaux glaciers) and Argentière glaciers. The data collected by the E-SAR sensor during the first campaign are presented in Table 1. They include a) single polarisation X-band interferometric data dedicated to topographic measurements; b) dual polarisation C-band data which should allow the comparison between E-SAR high resolution and ENVISAT low resolution data; c) full polarisation L- and P-band interferometric data with spatial baselines for coherence analysis [8] and a temporal baseline for motion analysis.

TABLE I. IMAGES ACQUIRED DURING THE OCTOBER CAMPAIGN

Test site	Freq. Band	Polarization	Remarks
Argentière	X	VV	Single Pass Interferometry Ascending
	X	VV	Single Pass Interf. Descending
	L	QP	L-Band Master
	L	QP	L-Band Slave
	C	VH/VV	C-Band Master
	C	HV/HH	C-Band Slave
	P	QP	P-Band Master
	P	QP	P-Band Slave
Mer de Glace	X	VV	Single Pass Interferometry
	L	QP	L-Band Master
	L	QP	L-Band Slave longterm
	C	VH/VV	C-Band Master
	C	VH/VV	C-Band Slave longterm

There is a high challenge to process SAR data in high alpine region, where the topographic variation is more than 2000 m in elevation. This causes geometric as well as topographic effects on the complex interferometric coherence and therefore it disturbs the physical observable of the interferometric coherence - the volumetric part. New processing techniques were developed in order to overcome this problem [9].

B. First PolInSAR processing results

Processing results are expected regarding two specific research axis: PolSAR / PolInSAR information extraction and velocity measurements. The results presented in this paper correspond to the information extraction stage: coherency matrix estimation with the Intensity Driven Adaptive Neighbourhood (IDAN) approach [12], followed by conventional PolSAR decomposition [1] and PolInSAR coherence optimisation [3].

The first data which have been analysed is a 10-metres baseline L-band polarimetric interferometric pair acquired on two passes with only 15 minutes interval. The temporal decorrelation and glacier motion should be negligible and most effects observed in the PolSAR and PolInSAR features are related to the backscattering mechanisms involved in the resolution cells and their orientation. A specific area, the Tacul glacier, has been chosen to illustrate the variability of Alpine glacier responses in the high-resolution L-band PolInSAR data. On the colour compositions of the amplitudes (Fig. 1-a) and the optimized coherences (Fig. 1-b), one can observe the curved stripes due to the “Forbes’s bands” phenomena: this periodical feature corresponds to one year displacement of the Tacul glacier. Indeed, at summer time a larger amount of rocks fall on the ice in the upper part of the glacier than in winter time when rocks are much more stable. This phenomenon is combined with a smooth “stare case” shape in the upper part of the Tacul glacier.

After an initial 4 lines complex averaging of the datasets in order to obtain approximately square pixels with 1.5m x 1.8m sampling in range and azimuth respectively, the 6x6 coherency matrices have been estimated by using intensity driven adaptive neighbourhoods as spatial supports [12]. This approach is used to obtain a large number of samples (typically 100 pixels) which are more likely to respect the stationarity hypothesis than boxcar windows. This allows us to reduce the effects of the speckle noise on the coherency matrix and on the PolSAR features such as the entropy H and the alpha angle. It also makes the coherence optimisation procedure more stable. This enables us to compute PolInSAR features such as A1 and A2 parameters which reveal the difference between the first and second coherence levels, and the first and the third coherence levels respectively [5].

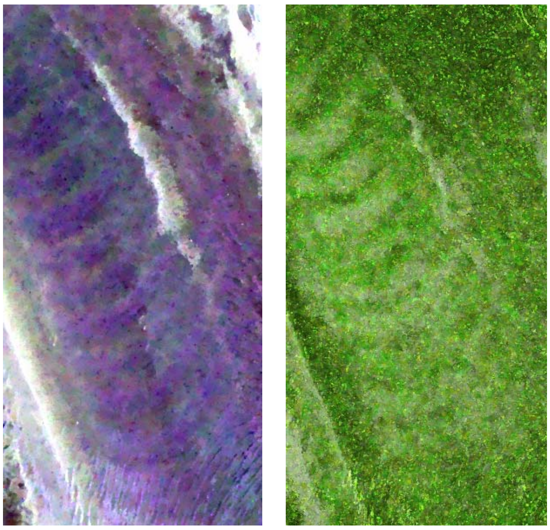
The IDAN filter and both PolSAR and PolInSAR features have been computed by using the PolSARpro software. The results are illustrated in Fig. 2 by the crisp classifications performed in the feature spaces: the H-alpha space is divided into the conventional 9 zones [2] and the A1-A2 space into 8 zones [4]. Typical values of the two class centres corresponding to the Forbes’s bands in the H-alpha and A1-A2 feature spaces are reported in Table II.

TABLE II. CLASS CENTRE TYPICAL VALUES FOR THE FORBES’S BANDS CENTRE AND SURROUNDING AREAS.

	H	alpha	A1	A2
Centre	0.55	28°	0.25	0.5
Around	0.72	35°	0.4	0.75

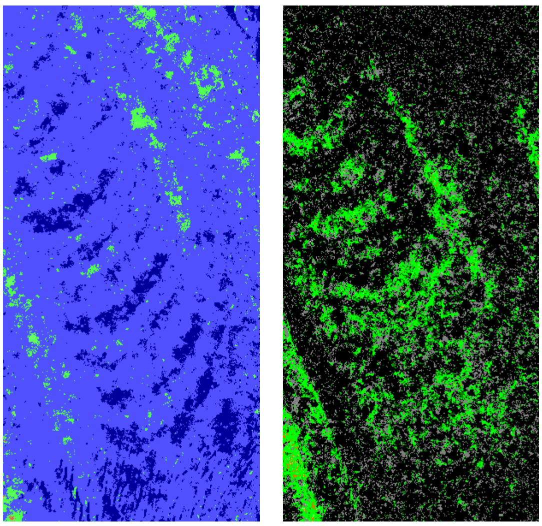
According to the Forbes’s band structure, the centre of the band corresponds to the “dirty areas” with numerous stones covering the glacier surface. The corresponding mechanism can be interpreted by a dominant surface backscattering with lower entropy and alpha angle values than in the surrounding areas where the ice is “cleaner”. In this area, the entropy and alpha angle are higher, corresponding to a combined surface and volume mechanism probably due to a partial penetration of the ice surface in L-band. The 35° alpha angle is still far from the typical 45° of volumic scattering. This can be explained by the fact that the glacier surface is never really clean ice at this time of the year, and the features are estimated with large adaptive neighbourhoods (more than one hundred pixels), which results in lower alpha values and higher entropy values

[6]. Regarding the coherence levels, the stone cover of the centre parts of the Forbes's bands yields to high coherence in the different polarimetric configurations and accordingly lower values of A1-A2 features than in the surrounding areas where the 3 optimized coherence levels are significantly different.



a) Intensities in Pauli basis   b) Optimized coherences

Figure 1. Forbes bands on the Tacul glacier – E-SAR L-band PolInSAR acquisition, coherency matrices filtered by IDAN approach.



a) H-alpha classification   b) A1-A2 classification

Figure 2. Early classification performed on PolSAR H-alpha and PolInSAR A1–A2 features resulting from coherence optimisation. Use of conventional feature space partitioning and color tables after PolSARpro software.

Further analysis consists in comparing such classifications with the in-situ measurements acquired at the same days on the upper part of the Argentière glacier.

III. IN-SITU MEASUREMENTS

During the 2006 campaign, several measurements like GPS, GPR and stratigraphic profiles were performed in order to get ground measurements for SAR backscattering analysis.

A. *GPR measurements and stratigraphic profiles*

GPR (Ground Penetrating Radar) measurements were carried out using different frequencies, to provide the penetration depths and subsurface features. The GPR transmitter-receivers used in this project works at 50, 100 and 250 MHz and are piloted by a computer. The whole equipment has been drawn on the accumulation zone as well as in the middle part of the glacier, along two profiles. Despite the difficulties encountered to displace the cumbersome equipment, good and reliable signals were received at 100 and 250 MHz. Only the 50 MHz antenna has caused problems. The interpretation of the 250 MHz data allowed distinguishing the firn-ice interface located between 5 and 10 metres depth (Fig.3).

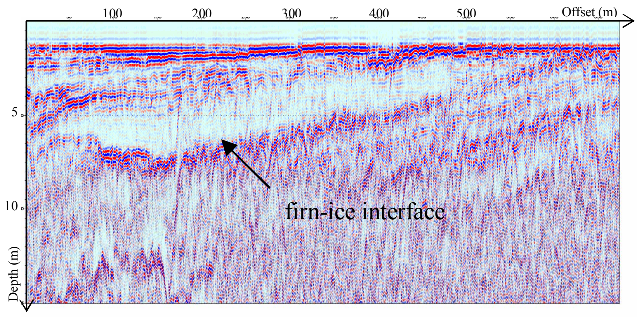


Figure 3. Longitudinal profile observed by GPR in 250 MHz frequency

Also stratigraphic profiles were carried out with the aim to measure the snow layer characteristics. Thereby, two stratigraphic profiles were dug in the first two metres of the snow mantel, at two positions in the accumulation zone. The temperature, density, the snow grain type as well as its size were acquired along the vertical snow profile (Fig.4).

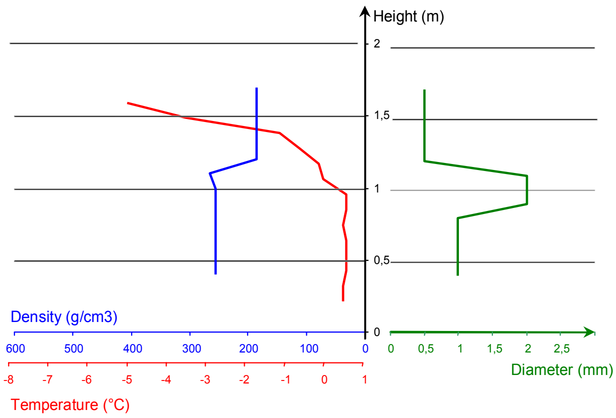


Figure 4. Stratigraphic profile at 2976 m altitude (10th of october, 11:30 am)

Fig.4 shows that the density is correlated to the evolutions of the snow mantel since the end of the summer, with average densities of 250g/cm3 at the given altitude. Furthermore, it is interesting to note that the temperature increases with the depth (0.6°C under 1m depth). This is explained by a relapse of snow which led to the conservation of a temperature dating from the end of the estival season.

B. *GPS measurements*

During the three days of acquisition, differential GPS (Global Positioning System) measurements have been performed to locate the exact position of characteristic points.

Firstly, it was necessary to derive the accurate position of perfect backscatters represented by 7 corner reflectors adequately distributed over the test area. Their exact position is necessary for later SAR processing. Secondly, it was interesting to generate velocity profiles, which constitute ground measurements for Differential PolInSAR. For this purpose, a transversal and a longitudinal profile have been materialized by 42 regularly spaced sticks. The transversal profile with a length of about 1 km was located in the accumulation zone (around 2950 m altitude). The longitudinal profile with a length of 3 km was located along the glacier (over 2750 m altitude). The GPS rapid static surveying methodology used provides accuracies of 1-4cm in X, Y, Z.

Fig.5 shows the 3-days displacement vectors deduced from the GPS calculations along both profiles. The results prove that the ice moves depend on the slope and on the area. Indeed, one can note that the points along the transversal profile did not move as much as the points along the longitudinal profile (21 cm against 27 cm in average respectively). Displacements in the accumulation zone must directly be related to the firn moves, and not the ice like for the longitudinal profile. These results also illustrate the high velocity of the Argentière glacier reaching in average 150 mm a day. Furthermore, this phenomenon is confirmed by expert knowledge and annual glaciological campaigns.

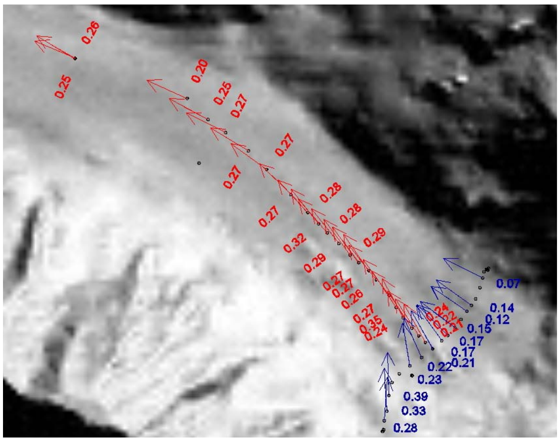


Figure 5. Three days displacement vectors observed by GPS on Argentière glacier (in blue: transversal profile; in red: longitudinal profile)

IV. CONCLUSION AND PERSPECTIVES

This paper presented the first results of the analysis of datasets acquired during a SAR and field campaign, including PolInSAR decompositions and GPS velocity profiles. Among the research axis which will benefit from this experimental dataset, we will investigate the potential of temperate glacier displacement measurement by airborne SAR Interferometry with the polarimetric L-band data acquired with 0-meter baseline and 24-hour temporal baseline. The coherence level observed on the 4 glaciers covered by these acquisitions (Tacul, Leschaux, Talèfre and the upper part of Argentière) seems to make it possible to compute reliable phase differences. An optimal fusion of the interferograms obtained in different polarisation configurations for displacement measurement is still an open issue. The GPS velocity profiles acquired on the same days on the Argentière glacier will provide the ground measurements which are necessary to assess the performances of new methods in Differential Polarimetric SAR Interferometry (D-PolInSAR).

ACKNOWLEDGMENT

The authors wish to thank all participants of the experiment performed in October 2006: R. Horn, M. Keller, C. Andres (DLR-HR Oberpfaffenhofen); P. Grussenmeyer, M. Koehl, E. Smigiel, S. Guillemin (MAP-PAGE, CNRS-INSA Strasbourg); J.-M. Vanpe, L. Hotte (GIPSA-lab, CNRS-INP Grenoble); I. Petillot, L. Valet, Ph. Bolon (LISTIC, Université de Savoie); G. Lehureau, L. Denis, F. Tupin (TSI, CNRS-GET Télécom Paris); N. Longepe, L. Ferro-Famil (IETR, CNRS-Université de Rennes 1); J. Deparis (LGIT, CNRS-INP Grenoble); L. Moreau (EDYTEM, CNRS-Université de Savoie); R. Lecluse.

REFERENCES

[1] S. Cloude and E. Pottier, "A review of target decomposition theorems in radar polarimetry". IEEE Transactions on Geoscience and Remote Sensing, 34(2) :498–518, 1996.

[2] S. Cloude and E. Pottier, "An entropy based classification scheme for land applications of polarimetric SAR". IEEE Transactions on Geoscience and Remote Sensing, 35(1), 1997.

[3] S. Cloude and K. Papathanassiou, "Polarimetric SAR interferometry". IEEE Transactions on Geoscience and Remote Sensing, 36(5) :1551–1565, 1998.

[4] L. Ferro-Famil, E. Pottier, H. Skriver, P. Lumsdon, R. Moshammer and K. Papathanassiou, "Forest mapping and classification using L-band POLINSAR data". In POLINSAR 2005 Workshop, Frascati, Italy, 2005.

[5] J.-S. Lee, M. Grunes, T. Ainsworth, I. Hajnsek, T. Mette and K. Papathanassiou, "Forest classification based on L-band polarimetric and inteferometric SAR data". In POLINSAR 2005 Workshop, Frascati, Italy, 2005.

[6] J.-S. Lee, T. Ainsworth, M. Grunes, C. Lopez-Martinez, "Montecarlo Evaluation of Multi-look Effect on Entropy / Alpha / Anisotropie Parameters of Polarimetric Target Decomposition", Igarss 2006, Denver, USA, 2006.

[7] K.E. Mattar, P.W. Vachon, D. Geudtner, A.L. Gray, I.G. Cumming and M. Brugman. "Validation of alpine glacier velocity measurements using ERS tandem-mission SAR data". IEEE Transactions on Geoscience and Remote Sensing, 36(3):974–984, 1998.

[8] K. Papathanassiou, I. Hajnsek, H. Rott and T. Nagler. "Polarimetric SAR interferometry for snow cover parameter estimation". In POLinSAR 2005 workshop, ESA ESRIN, Franscati, Italy, 2005.

[9] P. Prats, K.A.C.de Macedo, A. Reigber, R. Scheiber, J.J. Mallorqui: "Comparison of Topography- and Aperture-Dependent Motion Compensation Algorithms for Airborne SAR"; IEEE GRSL, accepted, July, 2007.

[10] O. Stebler, A. Schwerzmann, M. Luthi, E. Meier, and D. Nuesch." Pol-InSAR observations from an alpine glacier in the cold infiltration zone at L- and P-Band". IEEE Geoscience and Remote Sensing Letters, 2(3):357–361, 2005.

[11] E. Trouvé, G. Vasile, M. Gay, L. Bombrun, P. Grussenmeyer, T. Landes, J.M. Nicolas, Ph. Bolon, I. Petillot, A. Julea, L. Valet, J. Chanussot, and M. Koehl. "Combining airborne photographs and spaceborne SAR data to monitor temperate glaciers. Potentials and limits". IEEE Trans. Geosci. and Remote Sensing, to appear - 2007.

[12] G. Vasile, E. Trouvé, J.-S. Lee and V. Buzuloiu. "Intensity-driven-adaptive-neighborhood technique for polarimetric and interferometric sar parameters estimation". IEEE Trans. Geosci. and Remote Sensing, 44(6):1609–1621, 2006.