Combining Optical and SAR data to monitor temperate glaciers

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Abstract

Monitoring temperate glaciers activity becomes more and more necessary for economical and security reasons and as an indicator of the local effects of global changes. This paper presents the beginning of a three year project which regroups four laboratories to develop and combine specific methods to extract information from optical and radar remote sensing data. Preliminary results are presented on three different information sources: airborne photography, space-borne multi-spectral images and SAR interferometry, which respectively allow the compution of high resolution DTM, the detection of glacial lakes and the measurement of glacier surface velocity. Results obtained on two glaciers located in the French Alps are compared and validated with ground measurments.

Keywords: Glacier monitoring, Photogrammetry, Digital Terrain Models, SAR interferometry

1 Introduction

To monitor glacier evolution by remote sensing requires the development of specific image processing methods to extract information from the huge amount of data acquired by airborne and space-borne systems. Optical and Synthetic Aperture Radar (SAR) images are complementary information sources which can be combined to derive different measurements such as the height to build Digital Terrain Models (DTM), or the displacement between two acquisitions to obtain glacier surface velocity fields. Large data sets are now available over several glaciers in the Alps: 20 years of airborne photography, more than ten years of multi-spectral and SAR images acquired respectively by SPOT and European Remote Sensing (ERS) satellites. But such data are rarely used because of the processing difficulty when methods are not adapted to the glacier context: high relief topography, large displacement within a few days...

This paper presents the first results of a 3 year project which started in 2004 and regroups 4 laboratories specialized in optical and SAR image processing and fusion techniques. A global strategy illustrated in Fig. 1 is proposed to fill the gap between the increasing number of images available and the information useful to model glacier evolution and to measure the risk in the surrounding areas. The three main research axes are:

- the construction of DTM and ortho-images from high resolution optical images, and the computation of differences after one or several years to detect changes such as volume variations, glacier retreat, lakes appering/disappearing...
- the computation of differential SAR interferograms by subtracting the topography provided by the previous results to obtain displacement fields over a few days only.
- the fusion of the measurements provided by the two first axes, and features detected in optical or SAR data, allowing their tracking and the computation of risk maps.

Two glaciers, “Mer de Glace” and “Argentière” located in the French Alps near Mont-Blanc have been selected as test sites to gather optical and SAR data. Ground measurements, which are regularly acquired in this area, provide complementary information useful either to increase the precision of remote sensed measures or to compare and validate experimental results.

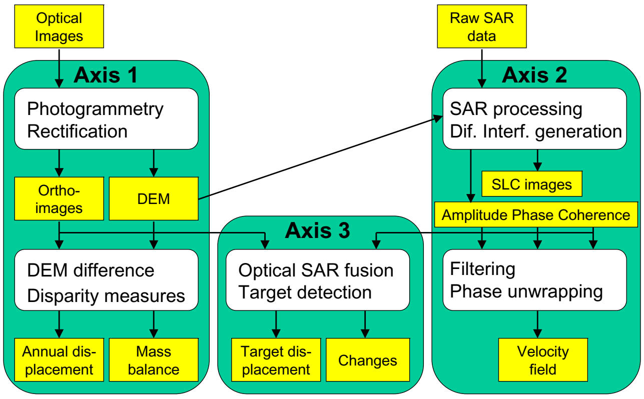

Figure 1: Flowchart of the processing steps to extract information from optical and SAR data to monitor glacier evolution.

2 Optical Data

Two different sources of optical data are used with a different purpose : airborne photography which allows the computation of very high resolution DTM of the glaciers surface and their borders, and space-borne multi-spectral images with a lower spacial resolution but a strong classification potential.

2.1 Airborne photography

For several decades, airborne photography has been an important source of information over a large number of glaciers. In the French Alps, the main glaciers of three different regions have been covered by airborne photography every 3 years, between 1975 and 1995 (Tab. 1).

	1975	1976	1978	1979	1981	1982	1983	1984
Mont-Blanc		×		×		×		
Savoie	×		×		×		×	
Oisans	×		×		×			×
	1985	1986	1988	1989	1990	1991	1992	1995
Mont-Blanc	×				×			×
Savoie		×		×			×	
Oisans			×			×		

Table 1: Glacier airborne photography of 3 different regions in the French Alps.

In the framework of the project described by this paper, a few series of photos have been selected over the Mer de Glace and the Argentière glaciers. Along these glaciers, a set of ground control points (GCP) measured by geodetic GPS with 10 cm accuracy are available. The 9×9 inch negatives scanned at a resolution of 15 microns yield series of 15360×15360 pixels images which cover a glacier with about 80% overlap. On the 1995 acquisition over the Mer de Glace glacier (Fig. 2), the pixel size in the original photos is 36 cm on the bottom of the glacier (1000m ASL) and 18cm on its top (2800m ASL). The flying height was 4650m ASL.

In the first step of the processing, the digital images are orientated by using the bundle block aerial triangulation (AT) technique [1]. On the Mer de Glace, approximatively 3700 AT points were computed, including 2000 three ray points (the same point measured in three following images), 500 four ray points and about 200 five ray points thanks to the important overlap. The RMS on the computed AT points is 20 cm in planimetry and 30 cm in altimetry. The high redundancy justifies the accuracy.

Then the images are used to compute the DTM by Photogrammetric Matching Techniques (KLT software package) based on correlation of image patches in two or more images. Break-lines and structure lines are defined by stereoscopic manual measurements. The resolution varies between 2 to 5 meters depending on the slopes. The global result is obtained with 80% automatic measurement (semi-automatic process guided by the operator who densifies weak areas by stereoscopic measurements). About 20% are fully manually measured when no results are obtained from the matcher in areas with important slopes or when images present poor contrast. Specific difficulties also arise when matching the crevasses: manual points have to be taken at the top and at the bottom. The result is controlled by stereo-viewing (superimposition of the DTM on the selected stereo-pairs). Fig. 3 illustrates the result obtained with the 1995 photos of the Mer de Glace.

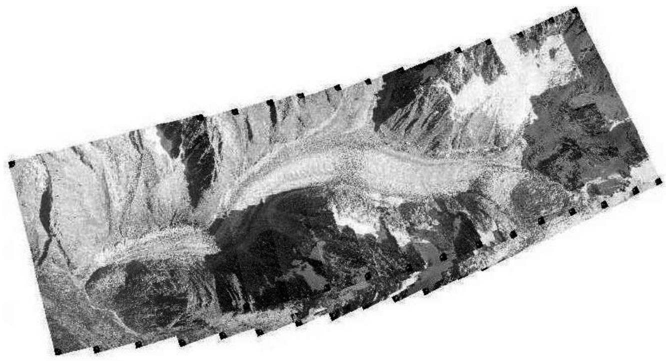

Figure 2: Layout of the set of the Mer de Glace photos from 1995 processed by photogrammetric methods.

2.2 Space-borne multi-spectral images

When the weather conditions makes their acquisition possible (usually during the summer season), multi-spectral satellite images are very useful to detect interesting features such as lakes, glacier borders... With 10 meter resolution for panchromatic images and 20 meters for multi-spectral images, the SPOT data used in this project (Tab. 2) cover large areas and allow classification of different land cover by their spectral signatures.

An original approach is proposed to automatically detect and characterize mountain lakes in multi-spectral SPOT images [2]. The classification is based on the Spectral Angle Mapper (SAM) algorithm which is robust to the illumination variations since angles between vectors are independent from their length. To reduce false alarms

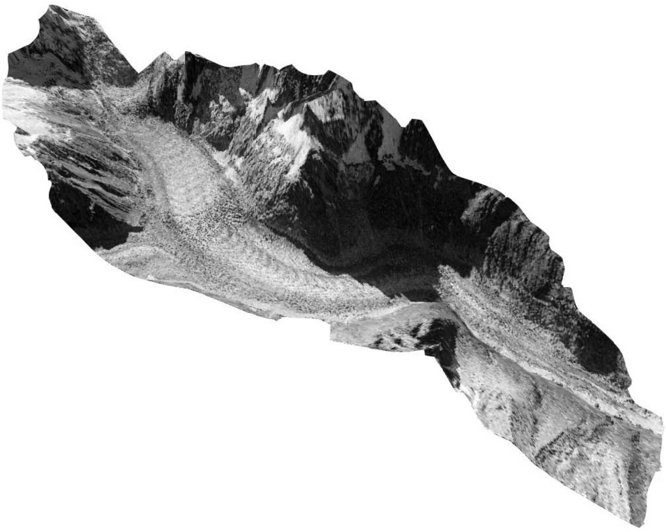

Figure 3: Mer de Glace glacier 3D-model (photos draped on the DTM) computed from the 1995 photos.

Satellite	Date	Band(s)	Latitude	Longitude
SPOT 1	07/20/00	MS	45°55′34″N	6°53′15″E
SPOT 1	07/31/00	MS	45°55′29″N	6°53′18″E
SPOT 1	08/26/00	PAN	46°04′53″N	6°52′42″E
SPOT 2	08/29/00	PAN	46°11′53″N	6°50′32″E
SPOT 2	09/25/00	MS	45°55′26″N	6°52′12″E
SPOT 4	10/04/00	MS	45°55′26″N	6°51′50″E

Table 2: Panchromatic (PAN) and Multi-Spectral (MS) images acquired by SPOT satellites over the Mont-Blanc area

and miss-detections, the classification results are aggregated with spatial information resulting from a segmentation based on irregular pyramid techniques. A comparison of the results with ground surveys show that the SAM analysis of SPOT data is an efficient tool to detect and monitor glacial lakes and to provide information to a risk prevention management system.

3 SAR Data

Satellite SAR images are used more and more to observe glaciers in particular because of two great advantages: the active SAR sensor acquires images independently from the weather conditions and it measures both amplitude and phase of the backscattered signal. At the resolution of the data which were up to now available (about 20 m with ERS images), the amplitude is often difficult to use to extract precise information on specific features, but the next generation of SAR satellites should provide meter resolution images and fully polarimetric data, which will be very useful to detect different features and backscattering mechanisms. The phase includes a geometric deterministic component which makes SAR interferometry feasible and offer the opportunity to measure the glacier displacement between two acquisitions on repeat passes. Several approaches can be used to separate the topographical fringes from the displacement phase signal [3].

In this project, 10 raw SAR images from ERS 1 and ERS 2 have been selected to study the feasibility of SAR interferometry in order to extract surface velocity fields of the studied glaciers. This data set presented in Tab. 3 includes different time intervals (1 day with tandem couples, 3 and 35 days), different seasons (spring and summer) and ascending and descending passes.

Dates	Δt	Satellite	Orbit	Frame
03.10.1996	1 day	ERS-1	24330	2673
03.11.1996		ERS-2	04657	2673
07.09.1995	1 day	ERS-1	20830	0909
07.10.1995		ERS-2	01157	0909
08.13.1995	1 day	ERS-1	21331	0909
08.14.1995		ERS-2	01658	0909
08.17.1991	3 days	ERS-1	00449	2682
08.20.1991		ERS-1	00492	2682
08.29.1991	3 days	ERS-1	00621	2682
09.04.1991		ERS-1	00707	2682

Table 3: ERS SAR raw data acquired over Mont-Blanc area.

The processing techniques used to form interferograms consist of computing single look complex images (SLC) either by the standard DIAPASON softwares [4] or by a new technique based on beam-forming in the temporal domain followed by interferometric registration performed by RAT software [5]. The SAR processing in the temporal domain has the advantage to be more flexible in the adjustment of several parameters, including taking the local height into account which will become necessary when higher resolution images will become available.

The following steps of the processing consist of:

- reducing the phase noise and obtaining a robust coherence estimation by using amplitude driven adaptive neighborhoods and local phase slope compensation to ensure the signal stationarity over the estimation windows [6],
- unwrapping the phase by a weighted least square algorithm [7] using the coherence estimate as weights,
- transforming the projection of the displacement provided by the unwrapped interferogram into a velocity field, with conventional assumptions: uniform speed, parallel to the surface gradient.

The different steps are illustrated in Fig. 4 with the 1996 tandem couple. The experimental results obtained on these descending images show a high preservation of the coherence within one day intervals in the spring season. Comparisons have been performed with ground measurements providing one year displacement on several points. They show a good agreement between the InSAR speed measurements and the average speed on the Mer de Glace and the Argentière glaciers [8].

By using DEMs with different resolutions, several simulations have been performed, in order to asses the glacier visibility in ERS ascending and descending acquisitions.

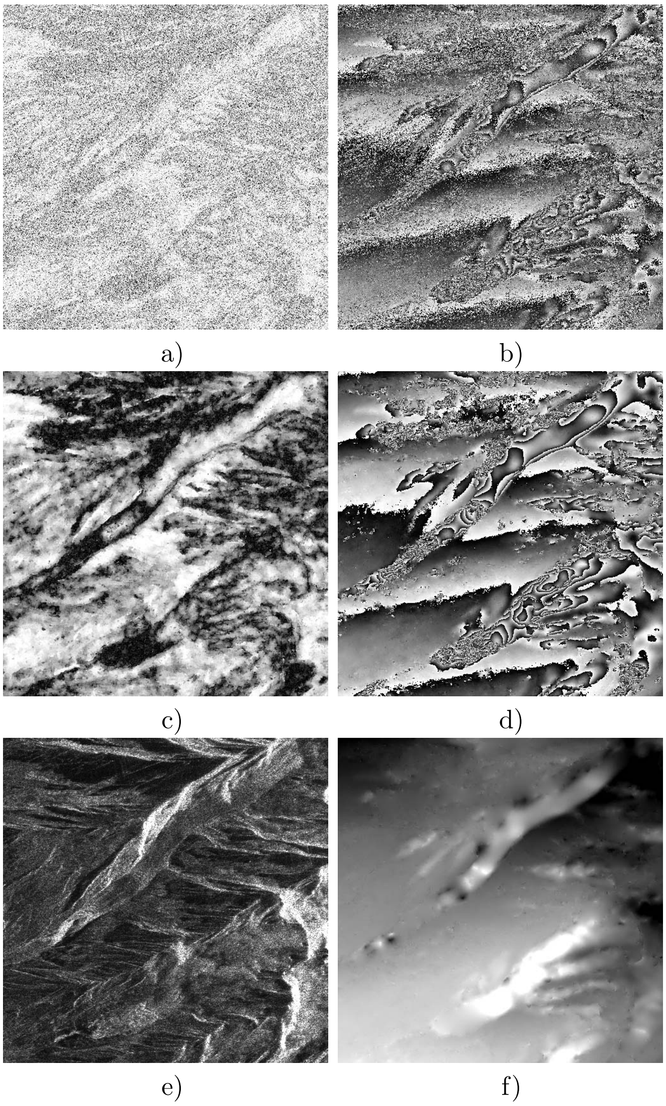

Figure 4: March 10-11 1996 Interferogram over Argentière glacier: a) coherence, b) phase e) amplitude after initial multi-looking; c) coherence d) phase filtered by adaptive neighborhood technique, f) unwrapped phase.

Despite the good orientation of the glaciers with respect to ERS orbits, only 10 % of the Mer de Glace are visible in the ascending passes (due to foldover of strong relief).

On the descending ERS-1 pair acquired in the summer of 1991 at a 3 day interval, the standard interferometric corregistration by patches algorithm has been applied. The obtained interferograms have a good overall quality, showing a high level of coherence on the nearby mountains and in the Chamonix valley. However the coherence is very low on the studied glaciers. The loss of interferometric coherence can be explained either by an important change of the glacier surface state and altitude, or by a strong glacier displacement that would affect the global corregistration algorithm. In order to investigate which assumption holds, we introduced a controlled displacement on a single ERS SLC image and built the interferogram between the original and the displaced SLC. By varying the induced displacement, we studied the robustness of the corregistration algorithm. The results present a correct coherence level even for much larger displacements than the one of the studied glaciers within 3 day intervals. In conclusion, with 3 days intervals during the summer season, the variations of the glacier surface state and altitude, in temperate alpine glaciers such as those of the Chamonix valley, are stronger than the standard SAR intereferometric chain tolerances for ERS data (C band).

4 Conclusions and perspectives

The preliminary results presented in this paper on two glaciers in the Mont-Blanc area show the benefits of using both optical and SAR remote sensing data to regularly obtain measurements on the whole glacier surface. The higher resolution of recently lunched and future optical and SAR satellites (SPOT-5, RADARSAT-2, CSK...) will increase the potential of remote sensed data to monitor glacier evolution. The next steps in the project described in this paper will focus on the fusion of the obtained measurements and extracted features to derive higher level information such as hazard factors and risk maps.

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