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WHEN GLACIERS BREAK THE ICE BETWEEN SEVERAL SCIENTIFIC HORIZONS

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ABSTRACT

Twenty years of airborne photography, more then ten years of multi-spectral and radar images were a sufficient pretext for creating a cooperation between 4 French laboratories called the MEGATOR Group. Aim of this group is to demonstrate the interest of using high resolution optical and radar data to monitor temperate glacier activity. For this ambitious purpose, it was necessary to reassemble specialists coming from different application fields. Thus, surveyors participate for providing detailed and accurate optical products as well as terrain physical data which will be used in further radar processing steps. The extended abstract presents the results of the measurements and processing products of the MAP-PAGE team, as well as the perspectives of that exciting project.

1. INTRODUCTION

The problem of monitoring temperate glaciers was a unique opportunity for the MAP-PAGE team, specialized in geodetic surveying and imaging processes, to meet and work with people coming from completely different horizons and working on complex geophysical objects like glaciers. Indeed, in September 2004, four laboratories began a three-year project entitled MEGATOR (Mesure de l'Evolution des Glaciers Alpins par Télédétection Optique et Radar) with a support from the French Space Agency (CNES) through the French Research Agency (ANR – ACI Masse de Données). The four French laboratories are the LTCI (ENST Paris) for knowledge extraction and remote sensing data analysis, the LIS (INP Grenoble) specialized in signal processing, which include a team working on geophysical data, the LISTIC (Université de Savoie) specialized in information fusion and its application to SAR image analysis, and at last, the MAP-PAGE (INSA de Strasbourg) specialized in land surveying, more specially in geodesy and photogrammetry.

The MEGATOR project aims to develop a complete optical and SAR image processing methodology for monitoring temperate glaciers. For this purpose, three main research directions bind the laboratories of the MEGATOR group. Firstly, the elaboration of a digital terrain model (DTM) and ortho-images using high resolution optical images is important; the computation of differences after one or several years help to detect changes such as volume variations, glacier retreat, and lake appearing and disappearing. Secondly, the computation of differential SAR interferograms is possible by subtracting the topography provided by the previous results; thus displacement fields over a few days can be obtained. Thirdly, the fusion of the measurements provided by the two previous axes as well as features detected in optical or SAR data allow the tracking and the computation of risk maps.

2. THE ROLE OF THE MAP-PAGE TEAM

The MAP-PAGE team is involved in physical measurements and uses global positioning systems (GPS) and photogrammetric techniques for providing the products mentioned in the first research direction. In a second step, several terrain missions have been organized, where GPS profile measurements provide a support on the one hand for the glaciological interpretations and on the other hand for the validation of velocity fields computed on interferograms. All the new features and the exiting archives used to attempt the topics fixed by the MEGATOR project are finally collected into a Geographical Information System (GIS).

Space-borne optical images with their increasing resolution may be an interesting alternative for expensive airborne campaigns. The main advantage of such data is that they can cover the whole glaciers of a catchments area and allow land cover classification based on spectral signatures. This can be very useful to identify specific features (emerging lakes, ice cracks, glacier tongues...) for change detection and risk assessment [1]. Nevertheless, major disadvantage up to now remains in the spatial resolution of these images compared to aerial photography. In fact, the achieved accuracy for elevation changes and horizontal displacements approximate the spatial resolution, i.e. 15m for ASTER against less than 0.30 m for aerial photography [3].

So, a relevant advantage of using airborne photography data instead of spaceborne images is the very high resolution of digitalized photos or numerical camera acquisitions. They allow the computation of high resolution DTMs and ortho-images with a very accurate positioning obtained by using a few GPS control points. Another relevant advantage is the ability to reconstruct past glacier configurations. Indeed,

data from 1990 and 1995 are available over the glaciers suited by the MEGATOR group and will be of particular interest for interpretations over the last decades.

3. HIGH RESOLUTION DTM AND ORTHO-IMAGES COMPUTATION

In the framework of the project, a few series of photos have been selected over the Mer de Glace and the Argentière glaciers. In the original photos acquired over the Mer de Glace glacier in 1995, the pixel size corresponds to 36 cm at the bottom of the glacier (1000m ASL) and 18 cm at its top (2800m ASL). Along these glaciers, a set of ground control points (GCP) is available and had to be measured before processing the photos.

In the first step of the processing, the digital images are orientated by using the bundle block aerial triangulation (AT) technique, well known processing in the photogrammetric domain. Aero-triangulation is an extension of stereo-restitution methods that enables a global restitution of a block of photos and the reduction of ground control points. Bundle block adjustment is an iterative method based on the use of photo coordinates as observations. Then, the application of the central projection method enables the conversion of these observations into terrain coordinates in one step [4]. This requires a block of photos with at least 60% overlap and 20% side-lap (often more) and a set of GCPs located on both sides of the glacier. Figure 1 shows the location of GCPs entering in the aerotriangulation process superimposed on the block of photos.

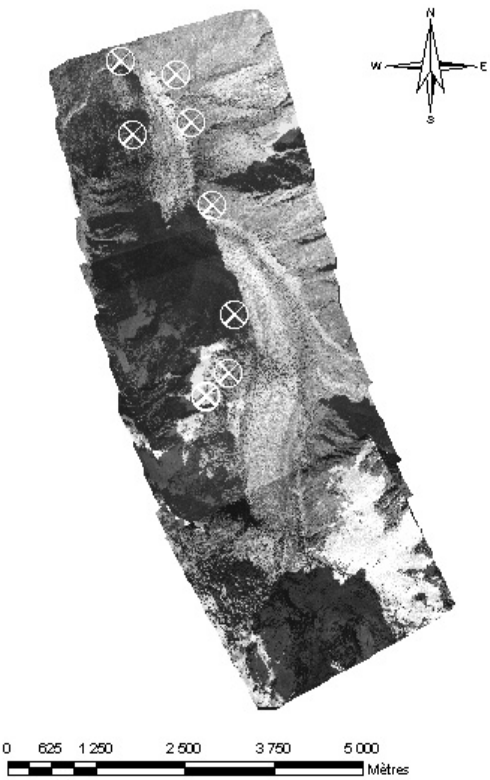

Figure 1. Set of the photos taken over the Mer de Glace in 1995. Circular marks represent the GCPs measured by GPS.

It is obvious, that the distribution and the amount of GCPs are not optimal, especially in the inaccessible parts of the glacier. Unfortunately, only a few targets fixed in the past on rocks along the glacier were visible on the 1995 images.

The results of the aerotriangulation are very satisfying and a high accuracy is obtained. Thus the RMS error on the computed AT points deliver an accuracy $\sigma_{X,Y} = \pm$ 20 cm and $\sigma_Z = \pm$ 30cm.

Then these images are used to compute about 5 million complementary points on a regular grid by photogrammetric matching techniques (KLT software package) based on the correlation of image patches in two or more successive images. Break-lines and structure lines are defined by stereoscopic manual measurements and define physical discontinuities in slope. As expected, the matching was problematic when saturation of the optical images occurred. In that case, the automatic correlation fails, so manual stereoscopic measurement is necessary to supplement the terrain model. Specific problems also arise in matching ice cracks. Indeed, manual points have to be taken at the top and bottom of that broken relief. The result is controlled by stereo-viewing (superimposing previously matched points and selected stereo-pairs). The global result is obtained with 80% automatic or semi-automatic measurements, where semi-automatic processing means guided by the operator who increases the density in weak areas by stereoscopic measurements. About 20% are completed manually in areas where important slopes or poor contrast prevents reliable matching.

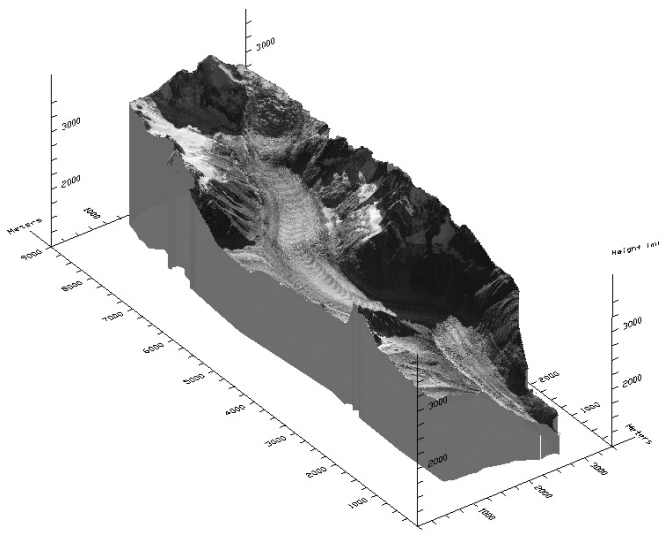

Figure 2. Mer de Glace 3D-model (orthophotos from 1995 draped on the computed DTM).

At this stage of the processing, a DTM can be computed with a resulting horizontal resolution ranging between 2 and 5 meters depending on the slopes. Generally, a 5 m grid is respected, except in very steep areas, where one point every 2 meters was necessary in order to guarantee the required

altimetric accuracy. By superimposing the ortho-images processed with the 1995 photos on the produced DTM, a 3D model of the Mer de Glace is obtained as presented in Figure 2.

4. GROUND FIELD MEASUREMENTS

4.1. Control points measurements

As already mentioned, one aim of the measurement campaign is to provide control points for the orientation of the photos covering the glaciers under study. The reliable points, i.e. simultaneously visible in the photos and reachable (and remaining!) on the glacier have been selected in the preparation stage. These reference points have been observed in differential GPS mode (Duquenne et al., 2005). Indeed, a base station has been located on a geodetic point, and the other points have been measured with the remaining antennas. The instruments used are five GPS receivers from the 1200 system (Leica Geosystems). In order to achieve an accuracy which is adapted to the orientation accuracy, the reference station has been placed on a known geodetic point and occupied during the whole day. Thus, using permanent GPS stations located in the surroundings of the area, coordinates of the reference points are available with at least 10 cm accuracy in X,Y and Z.

4.2. Corner reflector measurements

In October 2006, a radar imaging campaign has been organized. The aim of this project is to demonstrate the interest of using aerial high resolution polarimetric interferometric SAR data to monitor temperate glacier activity. The project implies the German Space Agency (DLR) as well as the 4 French research laboratories belonging to the MEGATOR group. In order to be able to calculate the trajectory of the airplane carrying the E-SAR radar imaging system, one control point was occupied by GPS every day during 10 hours, with one second registration frequency tact.

The GPS rapid static surveying methodology, also known as relative positioning, allows accurate measurement of the relative positions of two receivers tracking the same GPS signals. This is done by computing precise carrier phase-based baseline. This kind of measurements is useful for locating the exact position of the corner reflectors during the three days of acquisition.

Figure 3 shows a corner reflector used for the radar acquisition in L-Band. These calibration targets are necessary for the geocoding and for the processing of the radar images acquired by the DLR. Accuracies of 1-4cm in X, Y and Z on the measured points can be reached from such GPS surveying techniques.

Figure 3 : Measurement of the position of a corner reflector by GPS (Argentière glacier).

4.3. GPS profile measurements

In September 2005, GPS profile measurements have been carried out on the Leschaux glaciers located ahead of the Mer de Glace on points marked beforehand on the glacier (Figure 4). In this way, GPS measurements on 23 points along a longitudinal profile of 1700 meters located between altitudes of 2100m and 2300m have been achieved during 3 consecutive days. Figure 5 presents the displacement vectors, where the direction of the displacement is represented by an arrow and the length of the vector is indicated in meters next to the arrow.

Figure 4. Rapid static GPS measurements (Mer de Glace)

A similar operation has been reproduced in 2006 on the Argentière glacier during 3 consecutive days. This time, a transversal and a longitudinal profile have been materialized on the upper part of the glacier. The transversal profile with a length of about 1000 meters is composed of 21 points and is located in the accumulation zone between altitudes of 2890 and 2970m. The longitudinal profile with a length of 3 kilometres is composed of 21 points and is located along the glacier between altitudes of 2750 and 2890m. Figure 6 shows the displacement vectors calculated on basis from the GPS measurements realized this year.

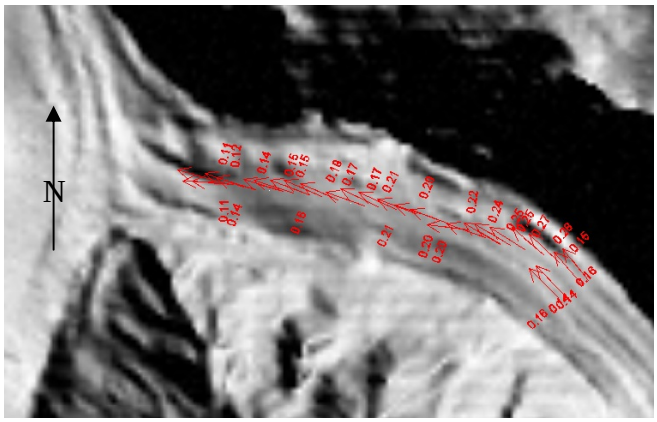

Figure 5. Displacement vectors observed on the Leschaux glacier in 2005

The results obtained for the 2005 campaign (Figure 5) demonstrate the shift of the Leschaux glacier during the 3 days. Indeed, the movements reach 28 cm at some places with an average displacement of 19 cm.

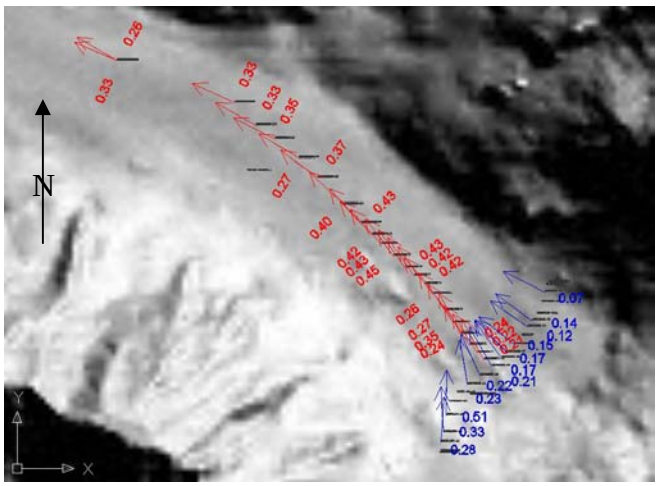

Figure 6. Displacement vectors observed on the Argentière glacier in 2006

By comparing the transversal profile to the longitudinal profile for the 2006 campaign (Figure 6), it can be concluded that the points along accumulation zone do not move as much as the points along the longitudinal profile (17 cm against 35 cm in average). It confirms also the high velocity of the Argentière glacier known to reach in average 270 mm a day.

Moreover, by comparing Figures 5 and 6, it becomes clear that the displacements observed on the Argentière glacier are globally higher than those observed along the Leschaux glacier. Nevertheless, both longitudinal profiles present similar vector orientations confirming the fact that the main movement of the glacier follows the main slope. The shift value is directly correlated to the velocity of the glacier flow and is probably also dependent on the ice thickness.

At this stage, further investigations and analysis need to be performed on the orientation and value of these displacement vectors, with the help of the whole MEGATOR Group. These interesting results have also to be compared with the displacement vectors extracted from SAR interferometry acquired by satellite or airborne radar systems.

4.4. Laserscanning of the glacier front

Simultaneously to the experiences done by the different specialists in the upper part of the glacier, the front of the Argentiere's glacier was monitored by using laser scanning methods.

The terrestrial laser scanner system used for this purpose is the Trimble GX laserscanner. It uses a 532 nm green laser beam with a standard range of 200m and an "overscan" mode up to 350m. The field of view is limited by 360° x 60°, with an asymmetrical vertical part of about 40° above the horizon. The scanning speed is up to 5000 points per second. The scanner uses an auto focus method for the laser which showed to be very useful mainly for close range applications. This feature guarantees a constant small laser spot even at different distances within a scan. The size varies from 0.3 mm at 5 m up to 1.5 mm at a distance of 25 m. This makes sense in combination with a spatial resolution as high as up to 3.2 mm at 100 m. The built in video camera is used for both, framing of the area of interest as well as colouring the point cloud.

4.4.1. Description of the experiment

The experimental monitoring process consisted into three different scans achieved at three consecutive days. The scanning process was repeated three times to acquire at different periods the same part of the front of the glacier (Figure 7). Two additional scans were done on detailed parts of the front, and a last scan from another point of view. The resolution of the acquisition process was set to 75mm at 100m for the long distance scans (target distance between 120m and 350m) and 50mm at 100m for detailed scans. The scanning time was about 40' to 75'. The measured point clouds were composed of 400000 to 760000 points.

4.4.2. Experimental workflow

The position of the scanning station and the registration targets were precisely determined by GPS, so that the point clouds could be automatically georeferenced. Then, the Trimble's "Realworks Survey 6.0" software package was used for the segmentation of the point clouds and for the definition of a new reference system. In fact, the vertical front of the acquired glacier can be projected into a horizontal scene and then exported into the ESRI's GIS package "ArcGIS" with the "3D Analyst" extension used for the computing of DTM aspects.

Figure 7. Laser Scanning of the glacier front

4.4.3. Results of the 3-day scanning

The results presented in Figure 8 confirm the evolution of the glacier front and the notable displacement of the ice mass. Some further investigation and some supplemental processes have to be performed in order to quantify the ice masses displacements. Then, the results must be compared to other local measurement processes which monitor the horizontal displacement of the front.

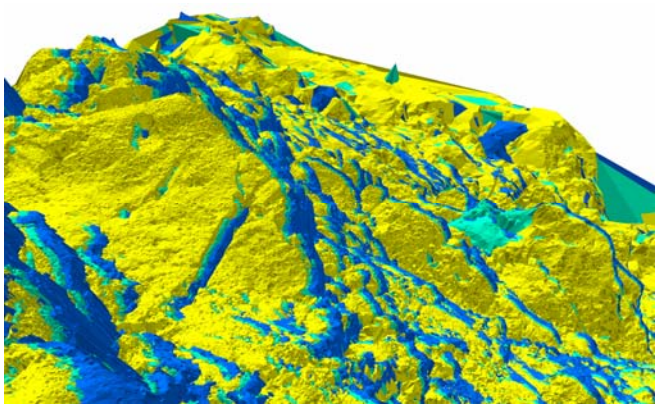
Figure 8. Superimposition of the scans realized at day 1 (in blue), day 2 (in cyan) and day 3 (in yellow).

One major result is that the scanning process delivered some great results, on the one hand because the 3D scanning system was used at its distance limit and on the other hand because it provided return measurements even from not well reflective ice surfaces.

5. DATA AND RESULTS MANAGEMENT

The MEGATOR project focuses one's research on the one hand on the processing methodologies and on the other hand on the management of captured, newly created or well used datasets. This latter theme is very important in order to share and transmit results to other researchers. It is also essential for communicating about the project within the scientific community. The principal purpose is to define a unique way and a unique shared server for managing and diffusing the original datasets of the project.

5.1. Design of geo-DBMS

The design of a geo-database management system begins with the creation of a metadata structure associated to each dataset. The metadata consist of the related information about product identification, geospatial reference systems, data quality, data distribution constraints. In this way, the spatial database includes data's descriptive information classified into different sections. By adding information like keywords and author's names, the system makes it possible for other researcher to locate the data with the catalogue's search tool and to find out the "what" aspects of the data. For example, what information is in the data set? What area is covered? The purpose is also given to describe the "why" aspects. For example, why was the dataset created? Geographic extent of the data has to be described using latitude and longitude values, and if the data is projected, the associated spatial reference. At least, data quality information has to be properly added. They consist in logical consistency report, completeness report, attribute accuracy description, positional accuracy valuation, process step description, source of information (satellites, wavelength…).

5.2. Use of geo-DBMS

All project participants received an account to log in the database. Two possibilities are offered: the first is the ability to find datasets created and deposed by other researchers. Search tools with multi-criteria requesting based on the different metadata's descriptive fields is available to find out the compatible datasets. The second possibility consists in the deposit of the own geo-data contribution and the related metadata on the server. In the same way, all participants have the ability to download the datasets of their interest.

The geo-database management system is comparable to a Geographical Information System where the major functionalities concerns data input, management, analysis and presentation. The design of a webGIS is in progress with graphical interface, geospatial requesting and image processing possibilities. The datasets distributed via the website to all users will be prepared for local presentation, animation, thematic mapping and for integration in local processing workflows.

6. CONCLUSION

The project will be carried on with a further measurement campaign planned in a few months with the same German partner DLR and its radar system E-SAR. Performed again jointly to a ground field measurement campaign, this next radar campaign should allow the validation of the correlations observed between physical terrain

measurements and image processing results. The polarimetric diversity provided by the E-SAR system will increase knowledge about backscattering processes in glaciers areas. On the one hand, high resolution data acquired by E-SAR system will supply a good ground characterization and thus enhance thinner structures, like superficial water accumulations and ice cracks. On the other hand, multi-band acquisitions are expected to provide information on the glacier surface and bedrock as well as the position of interglacial water accumulations, which are rather risky and often cause casualties.

Exactly two years after project beginning, the MEGATOR Group is satisfied by the first results achieved by each laboratory. Actually, the friendly relationships between the different laboratories take an important part in the success of the expected operations and results.

The MAP-PAGE team is contributing to the project by the processing of optical data and by the performing of surveying measurements on the glaciers. The production of the high resolution DTM enables now the computation of differential SAR interferograms; moreover, the displacement fields observed by GPS will be compared to those extracted from the image processing workflow and will enable to validate them. Consequently, through the interesting results exposed here, the MEGATOR Group will take two steps forward in its effort to demonstrate the interest of combining optical and SAR data to monitor temperate glacier activity.

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