Integration of Different Kind of Remote Sensing Data as a Tool for Quantitative Analysis of Glacier Evolution

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Abstract

Alpine glaciers dynamics may serve as an indicator of Climate Change. In the Alps glaciers are strongly related to environmental and economic factors, but also to touristic ones.

Since some years, a geodatabase containing data related to some test glaciers evolution since Little Ice Age to present day in the Western Italian Alps, is being developed by some of the Authors. The structure of this database is made with the idea to be easily updated with new surveys and with new sensors data when they' will be available.

In order to fulfil this request we are developing a true temporal GIS able to manage, visualize and analyse the high amount of 4D data.

This geodatabase will be used for different purposes: analysis of mass balance in relation to geographic parameters (aspect, slope, bedrock morphology, ice thickness), moraines mapping and analysis to support field reconstructions, mapping of different kind of features (seracs and crevasses i.e.) to support glacier dynamics analysis. Furthermore, it can be a useful base point for a web-mapping use of this data (environmental paths, geosites descriptions etc.).

Moreover a more integrated quantitative analysis can be carried out by the use of a geosensors network. A geosensor can be defined as a tool to acquire different kind of spatio-temporal data. GPS, total stations, digital cameras, laser scanners can be therefore defined as geosensors.

GIS will be able to integrate this network of several sensor data type, offering to the research an added value in terms of a common ground for the fusion of data and in a forecasting perspective.

KEY WORDS: Glaciers, GIS, geodatabase, remote sensing

1. Introduction

In the last decades there has been a growing interest in the state of cryosphere, because of its sensitivity to climate changes. Alpine glaciers in particular react directly to the changes in the Southeuropean microclimate. Since the Little Ice Age (LIA) maximum (approx. 1850) these glacial bodies have suffered a general retreat and an ice mass loss of about 50% has been estimate.

Alpine Glaciers have a main importance in alpine environment for their naturalistic and economic value.

They represent an economic resource for mountain communities that have a tourism-based economy, they are a fresh-water storage, recharging in winter season and releasing water in the summer, acting as regulators for the recharge of artificial basins that produce electric power.

On the other hand, by modelling morphology, microclimate and hydric regime, glaciers can be the cause of natural disasters.

Understanding how glacial bodies react to climate changes is important not only for scientific purposes, but also for economic ones. Modelling the glacial bodies allow to reconstruct and understand their evolution and, on the basis of specific parameters (i.e.: ablation rate, Equilibrium Line Altitude, etc.), make hypothesis on their "health state".

The problem with modelling former glacier is the shortage of usable data. Nowadays many satellites permit to manage remote sensing data of the present situation, but analysing the past, the metric data become rarer or less precise.

Since some years different kinds of data have been merged in a common geodatabase to make all the metric data from Little Ice Age to present day comparable in some test glaciers.

Figure 1: Location of Lys and Rutor glaciers, in the North-Western part of Italian Alps.

These data derive from 1:10000 cartography, aerial photos and ground surveys.

In particular this paper describes the preliminary results on the georadar and GPS surveys made in July 2006 on the Rutor glacier and briefly describes the state of the art of Rutor and Lys recent evolution geodatabase.

Test areas are located in Aosta Valley, in the North Western part of the Italian Alps. The glaciers analysed are the Rutor and the Lys, two of the ten biggest glacial bodies in Italy, with a present surface area respectively of 800 ha and 1100 ha. In Fig. 1 geographic location of the test areas are shown.

2. Planimetric database and surface reconstructions

17 terminus positions have been traced for the Rutor glacier and 10 terminus positions have been traced for the Lys glacier. For both test glaciers, the terminus position in their Little Ice Age maximum extent has been traced basing on geomorphologic surveys [Orombelli 2005].

The other reconstructions derives from official cartographies, historical planimetries traced by different authors [Sacco 1917, Bossolasco 1928, Sacco 1934, Peretti 1934], orthophotos (reconstructed by a digital photogrammetric station) and, for the last years, GPS surveys.

Another kind of information on the frontal retreat derives from the Italian Glaciological Committee (CGI) surveys, where the distance between the terminus and some ground control points has been measured yearly for almost every glacier lying on the Italian side of the Alps since the first decades of the IIXX century.

These two kind of geographic data have been compared to verify their coherence.

The surface reconstruction was made for the LIA maximum (by using morphologic methodology), for 1975 and 1991 (from 1:10000 cartography) for 1925, 1988 and 1994 (by photogrammetric data).

For the LIA surface models, contour lines was traced every 50m, linking points of equal elevation on opposite side of the LIA perimeter and drawn perpendicularly in correspondence to the mean elevation of the glacier and progressively more concave or convex moving towards the glacier top or terminus, in accordance with S. Porter methodology [Porter 1975].

The accuracy of the generated models was statistically calculated using some GCPs, and it is estimated to be about ±2,5 meters in altitude.

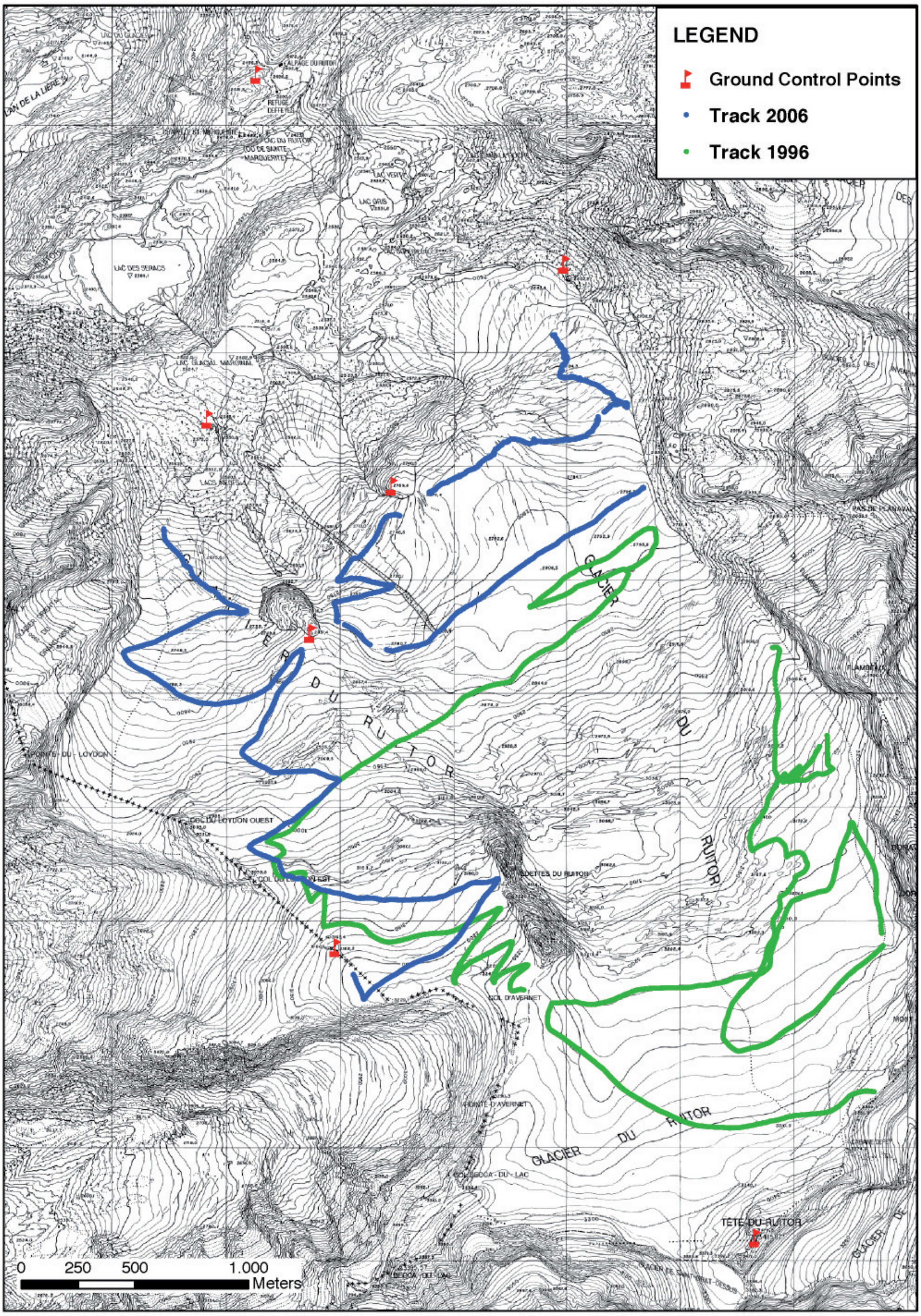

Figure 2: The georadar and GPS survey track. The red flags represents the GCPs in the Rutor area, the blue lines represent the survey tracks in 2006, and the green lines represent the survey tracks in 1996.

3. Georadar and GPS survey (July 2006)

A Ground Penetrating Radar survey was made on Rutor glacier in July 2006, to complete an analogous survey made in 1996. Furthermore, a ground control points network was created on the basis of a IGM point downvalley.

This GCP network is useful as a dataset for photogrammetric reconstructions and will serve as a base point for future surveys (The Environmental Agency of Aosta Valley region which supported the survey will use these data for mass balance analysis).

In Fig. 2 the GCP positions and the GPR tracks are shown. The blue ones are the 2006 paths, while the green ones are the 1996 paths. Merging 1996 and 2006 data will permit to generate a surface model of Rutor bedrock and consequently to measure the total glacier volume (only volume differences between different periods of time have been calculated so far).

Furthermore, comparing derivate parameters (i.e.: slope, aspect) obtained from different surface models and from the bedrock model, will serve for a better understanding of the glacier dynamic and flow.

During the survey, kinematic DGPS tracks were been recorded and will be compared with surface data deriving from 1975, 1988, 1991 and 2003 surface digital models. Some 2006 tracks crosses 1996 tracks and will be used to verify the accuracy of the survey.

4. Analysis of present time database

We present here a short summary of the analysis on the test glacier recent evolution:

Rutor glacier: the glacier perimeter was reconstructed in 17 different years, from its maximum extent in the Little Ice Age (first half of XIX century) to 2004. Analysing the terminus position, a frontal retreat of about 2 km, spaced out by two advance periods was calculated. The first period is located between 1916 and 1926, the second one, with smaller advances, is located in the first half of the Eighties. An evidence of the advance in the Eighties is also reported on the time series published on the Italian Glaciological Committee Bulletin.

On the basis of the perimeter reconstructions, the glacier's area was calculated for the same 17 years. The surface loss from the maximum holocenic extent to present days is about 31%

The Rutor glacier Digital Elevation Models of 1975 and 1991 were produced starting from cartography, the DEM of 1988 starting from aerial photos and the DEM of LIA starting from cartographic reconstruction.

The difference analysed between the surface models shows an ice loss of about 400 millions cubic meters between LIA and 1975, with an annual specific variation of -0,21 m, a moderate positive mass balance between 1975 and 1988 and a strong retreat, with an ice loss of about 85 million cubic meters and an annual specific variation of 3,14 m, between 1988 and 1991.

The values of the advance in the period between 1975 and 1988 have the same order of magnitude of the analysis accuracy, so they cannot be considered as a proper quantitative measure, but they represent an important result as they agree with the linear measure made by CGI and the general behaviour of the Alpine glaciers in the same period. The first half of the Eighties is known as a "cold" period, favorable to glaciers advance.

Lys glacier: in the last decades the Lys terminus has been characterised by a wide debris coverage, which made difficult to trace the ice limit. In the map it is possible to distinguish two different kind of limits: the "visible" limits and the "covered" limits. The glacier limits have been traced on the basis of historical cartographies and more recent Technical Cartography. In a field work made in September 2004 the visible limit and the debris-covered ice limit were traced. Something important seems to be occurring to the Lys glacier. In 2004 the western ice toe broke; the debris covered ice doesn't seem to be linked to the glacier ice and can thus be classified as dead ice.

Since its maximum holocenic extent, Lys glacier had suffered a frontal retreat of about 2,8 km and a surface reduction of about 25%

By using Porter's methodology to recostruct the LIA surface, it has been possible to generate a DEM to compare it with the other models: the 1925 one (based on a stereo-photogrammetric survey), the 1975 and the 1991 ones (obtained from 1:10˙000 scale regional cartography), and the 1994 one (based on ENEL data). Unlike the Rutor data, in this case no glacier advance is highlighted by volumetric data, except for the interval 1991-1994. Anyway these data are not relevant (the time interval is too short) and it is probably due to errors in the cartographies; no other data confirm a glacial advance in the first half of the Nineties.

The Lys mass balance in these time periods shows an ice loss of 250 millions of cubic meters between LIA and 1925, 90 millions of cubic meters lost between 1925 and 1975 and 70 millions of cubic meters lost between 1975 and 1991 with annual specific variation respectively of -0,21 m, -0,15 m and -0,37 m.

5. Preliminary analysis on 2006 surveys

No georadar data have been completely analysed yet, but the preliminary evaluations show that in the lower area of the glacier the ice depth doesn't reach 10 meters, while in the upper part of the 2006 survey (at an altitude of about 3200 meters) the ice depth reaches maximum values of about 50 meters. The ongoing analysis of the radar tracks are showing the main flux lines an the morphological structures that control the surface evolution.

GPS data recorded in July 2006 were compared with the available surface models in the database. The time interval 1991-2006, shows an inverse correlation between altitude and ice loss (Fig. 3), which is characteristic of a glacial retreat phase. These data show a mean annual specific ice loss of 1,5 meters in the lower part of the glacier, while seems that a mean Equilibrium Line Altitude for this time interval is about 3150 m.

The correlation between mean ablation and altitude is good (r^2=0.82), as it was expected in a period of continuous and constant retreat.

On the contrary, the same analysis made on the time interval 1975-1991 shows a completely different behaviour: no correlation exists between altitude and mass balance in the considered points. This is due to a different climatic condition: between 1975 and 1991, the cold period of the Eighties caused a positive mass balance and a glacier advance. The glacier flux worked to redistribute the excess of mass in the accumulation basin to the lower areas of the glacier.

The analysis of the DEMs shows the same behaviour of the Rutor glacier in this time interval: a negative mean mass balance, equally distributed on the glacier area, but no frontal retreat.

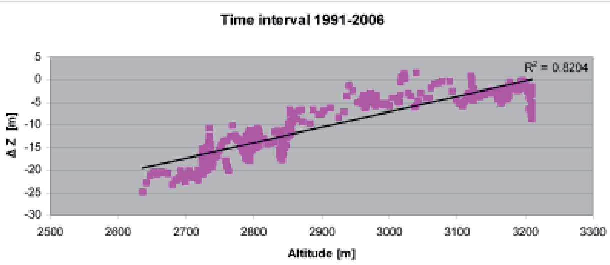

Figure 3: Relations between the altitude and the mass balance between 1991 and 2006, along the 2006 GPS track.

6. Conclusions

The recent evolution of Lys and Rutor glacier was analysed by reconstructing the glaciers surface, area and terminus position in different years.

Merging data coming from different sources in a common database gives an higher density of information in a defined period and test area. The biggest problem that rise is the different accuracy of the reconstructed data and the possibility to compare them.

The DGPS network of GPSs created in 2006 try to solve part of the problem: a common base of GCPs makes comparable the surface models generated both from photogrammetric methods and from cartography, and is a solid base for georeferencing next surveys.

Photogrammetric surface models of 2003 are in progress and will be soon analysed and compared with the present database. An evaluation of the effective volume of ice stored in the Rutor glacier basin will be calculated by crossing this model and the georadar data.

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