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An inventory of Alpine glaciers: an open software approach

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Abstract

This contribution describes a database to collect inventory data about Alpine glaciers derived from heterogeneous sources integrating field surveys and remote sensing. It follows principles of international projects in the field. To improve perception of ongoing phenomena in the Alps, an online viewer has been also implemented exploiting open, free and standard technologies. Its main goal is easiness of interaction and of message communication.

1. Introduction

Glacier evolution is considered a major indication of global warming trends (Haeberli 2002). Its observation has therefore an increasing importance and many efforts have been made not only to improve existing methods but also to test the contribution of new technologies such as remote sensing and information technology.

Most of Italian glaciers are observed and monitored by researchers and volunteers belonging to various institutions, such as the Italian Glaciological Committee (CGI); they usually collect measures during field surveys. Since the end of 80s, they also maintain archives of photographs and some local aerial surveys has been conducted in order to assess the situation of a whole region. It has been recognised (Giardino 2001) that aerial images represent an unavoidable tool to observe glacier status:

1. they offer a homogeneous view of extended areas, often ill-reachable by human operators;
2. time series of aerial photographs favour multi-temporal analysis;
3. surveys of extended regions allow global evaluation of environmental status.

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The same advantages hold even in the case of satellite images: also medium-size spatial resolution sensors proved to be reliable in giving good results in this field (Paul 2002). Moreover, some recent Projects (such as GLASNOWMAP[3] and IGMS[4]) showed that the quality of observation is improved when remote sensing techniques are combined with Soft computing methods to classify snow and ice covers in the mountainous regions (Rampini 2004).

Nevertheless, while Earth observation may be reliable in many glaciated areas of our planet, in the Alpine environment, satellite images and aerial photographs call for integrated approaches, due to the reduced dimensions of the observed bodies (often comparable to the spatial resolution of sensors), to the complexity of orography and to the variability of the meteorological conditions. An inventory of Alpine glaciers must fruitfully take into account the results of many types of observations. In this framework a database model has been designed as well as further facilities aiming at creating a user friendly online visualisation environment (called glacier viewer) exploiting open source, standard and free software technologies.

The contribution describes the design principles of the database in Section 2, as well as the architecture and implementation characteristics of the online viewer in Section 3. Since the focus is on changes as both signs of actual climate modifications and hints of environmental vulnerability, the basic idea of the viewer is to let emerge static end dynamic aspects of the observed phenomenon. At the storing side, users (the data providers) are led in clearly separating what reflects a temporary aspect linked to a date of observation; at the viewer side, users (the application stakeholders) find tools conceived to encourage data comparison through time.

2. An archive for multi-source Alpine glacier observations

Since the end of Nineteenth Century, Alpine glaciers have been systematically observed and a huge amount of precious data have been collected: they form now a main source of knowledge in studies aimed at assessing ongoing climate changes. The emergence of Information Technology techniques further supported data collection and management and some projects in the field have created database structures to organise and analyse information.

The main internationally recognised example is the World Glacier Monitoring Service (WGMS) that in 1986 started to maintain and continue the collection of information on ongoing glacier changes (http:// geo.unizh.ch/wgms/) (Zemp/Hoelzle 2004). The tasks are to upgrade, collect and periodically publish glacier inventories and fluctuation of standardised data as well as to assess ongoing changes. The data

[3] "GLAciers and SNOW MAPping Information Service", ESA-DUP Program (2001-2003)

[4] "Italian Glacier Monitoring from Space", Italian Space Agency (ASI) in the strategic line "Terra e sistema climatico dallo spazio" (2001-2003), http://subzero.irea.cnr.it/asi/

are grouped in either changes in mass, volume, area and length of glaciers with time (Fluctuations of Glaciers or FOG), or statistical information on the distribution of perennial surface ice in space (World Glacier Inventory or WGI). They form therefore two databases which are linked together. The data of FOG, sensitive detectors of natural and anthropogenic-induced climate variability, refer to a long time range (the first results concern 1959-1965) and are diffused in seven paper volumes. The most recent volume (1990-95) contains information on 645 glaciers from 28 countries. The WGI database hosts records for over 67,000 glaciers throughout the world. Its entries (which include geographic location, area, length, orientation, elevation, and geomorphologic information) are based upon a single observation in time and can be viewed as a 'snapshot' of the glacier at this time. Data sources are visual observations and photographs. The WGI can be searched by glacier name or number, by geographic search (latitude and longitude), by altitude, size or length, and by many other parameters. A guided search by geographic region is also allowed. The WGI database follows a relational model and offers one table to store general, static data on each glacier, while dynamic information is hosted in other tables and associated with one specific year.

Another experience is represented by the GLIMS (Global Land Ice Monitoring from Space) Project, launched in 1995 by the U.S. Geological Survey (USGS) and focused to the construction of a uniform database covering most of the glaciers of the world using homogeneous monitoring and classification methods, mainly based on satellite data (http://www.glims.org). The project uses primarily data from the ASTER (Advanced Space-borne Thermal Emission and Reflection radiometer) instrument aboard the TERRA spacecraft. All glacier parameters are organized in several tables linked by relationships. The two main tables are Glacier_Static and Glacier_Dynamic. The first stores static (unchanging) information, such as glacier name. The second stores all of the measured attributes of a glacier, some of which are stored in other tables conceptually residing within Glacier_Dynamic, as records of those tables are associated with one 'snapshot' in Glacier_Dynamic. The GLIMS relational database include also cross-references to polygons of ice, snow, etc.

The know-how of these two projects is very useful and they represent an unavoidable reference for all connected research. The most interesting issues of the WGMS and GLIMS databases are: the separation of static and dynamic data, the wide spectrum of collected parameters. As far as GLIMS, it opens the way towards satellite observations and offers tools to manipulate some stored data (transformation between image coordinates, northing and easting offsets from a local reference point).

Some of this paper's authors have participated since many years to projects aimed at monitoring Alpine glaciers through the integration of evidence derived from field surveys as well as remote sensing. A database has been developed in order both to collect and manage the projects' results, to create inventories, and to ease comparison and analysis. One more task is to harmonise stored data with those retrieved from the above cited world databases, to allow comparative studies with the long time series stored by them. Therefore the adopted data model follows some of the main ideas of the GLIMS and WGMS databases. The basic requirement is to let store and retrieve pieces of information derived from the Alpine glacier monitoring through time by integrating and comparing different sources of evidence (visual and photograph observation during field surveys and elaboration of aerial and satellite images). The design has taken into account different aspects, i.e.:

1. Data heterogeneity as different observation methods and authorities generate different parameters or parameter formats.
2. Data reuse issue: data must be stored once and reused whenever necessary; this issue also minimises data entry errors.
3. Comparison issue: data referred to the same spatial unit but changing through time must be linked in some way and be easily comparable.
4. Key role of temporal attributes that represent the main features to store and retrieve data changing through time.
5. Flexibility in the management of glacier bodies variations (by example separation of surfaces derived from previously unique areas).

The two last requirements are particularly necessary due to the dramatic climate variation of the last Summer on the Alpine region. Data reuse, comparison, data-entry errors minimising and flexibility are mainly faced by an extensive use of relationships and, whenever possible, of automatic data elaboration and transformation. In fact, an extensive analysis has been performed to identify primary data, i.e. data whose values can be derived only by a direct observation or by a prior computation (such as the lowest and highest elevations of a glacier body), and secondary data, the values of which are computed on the basis of primary ones (by example the range and the mean elevation). Transformation facilities have been also implemented in order to provide search results in different suitable units of measure, though the original values have been stored in one unit only.

As far as the spectrum of stored information, the experience of the research group showed that a lot of traditional glaciological parameters (which can be found in the WGMS databases, by example) can be also reliably derived by remote sensing observation and automatic image interpretation (see Table 1). In some cases they differ in terms of accuracy and of units of measure, so that further entities have been designed to host information about methods adopted and quality of obtained values. By example, when the extension of a glacier is obtained from different sources (such as satellites or orthophotos), its accuracy is calculated with different algorithms and depends on input parameters (such as the perimeter) but also on some characteristics of instruments. In any case, besides data values, the archive aims at storing also information on the source(s) of each observation and, when available, performed elaborations; suitable relations are defined to the purpose.

Parameters	**Meas. unit**
Lowest elevation (front elevation)	mt a.s.l.
Highest elevation (highest altitude of the accum. basin)	mt a.s.l.
Mean elevation	mt a.s.l.
Equilibrium Line Altitude (ELA)	mt a.s.l.
Range	mt.
Highest width	mt.
Highest length (along the most important flowline)	mt.
Median slope	%
Total area	m^2
Area of snow coverage (accumulation basin area)	m^2
Area of ice coverage (ablation basin area)	m^2
Accumulation Area Ratio (AAR)	%
Perimeter	mt.

Table 1
List of parameters derived from satellite observations of Alpine glaciers

Following the principles of international databases, information on glaciers are separated in 'static' and 'dynamic'. The first one represent all aspects that are not perceived as subject to variation at the time scale of glacier observation (such as the glacier name, its codes and geographic co-ordinates). The second set collects all those parameters whose validity is strictly related to a date of observation (like the glacier extension, its minimum and maximum elevation, etc.).

The data model has been conceived for implementation by a DBMS (DataBase Management System) coupled with a GIS (Geographical Information System) to host also glacier boundaries and other spatial features regarding the observations (such as the polygons of the ablation zones, as well as the segments representing width and length of the glaciers). A first prototypal archive has been completed in MS Access by storing the observations from remote sensing images derived by IREA-CNR researchers in the framework of the above cited IGMS Project. The data archived refer to some test glaciers in the Central and Western Italian Alps, which were also *in situ* surveyed.

3. An online viewer to compare glacier observations

Environmental information represented as spatial data and organised in databases and GISs are often distributed as online inventories which, though precious in assessing ongoing situations, do not foster easy data comparison through years (see by example the online inventory of Italian glaciers by CESI Greeninfo - http://www.cesi.it/greeninfo/ghiacciai- and the archive of glaciers of the Provincia di Trento in the Italian Alps -http://www.sat.tn.it/Home/ghiacciai.htm-). One more recent tool is represented by Web-GISs, i.e. systems to distribute maps on the Web: in these systems, interaction with users and visualisation mime the traditional behaviour of GISs and Internet is a mere infrastructure allowing data diffusion. They overcome the distance gap but do not care the gap between common users and the system: interaction tools are too complex and data visualisation does not offer a simple interpretation key. One example can be found at the address http://glaciers.pdx.edu/gdb/maps/images.php).

Besides above hurdles of available software tools, the need of new ways of communicating in the Internet is felt for two main reasons:

- the most natural way to 'perceive' spatial data is to visualise them as 2D or 3D images. This visualisation step is not a simple one as the same information can be displayed in different ways (depending by example on conventions, scales, purposes, etc.) also in a traditional context which mimes the habits of paper cartography; moreover the transition to the digital world, where maps can be integrated with photos, videos, sounds, graphs, animations, etc., enables to conceive new ways of perceiving spatial information. It is not a negligible issue, which has generated a research field, called ViSC (Visualization in Scientific Computing), aiming at increasing understanding of scientific phenomena by their better perception (Wood/Brodlie 1996). Animation is just one of the elements of ViSC: it is a favourite choice to better simulate the behaviour of spatial data through time (Biegger 2002).
- Spatial data often constitute an unavoidable component of decision processes in many fields of the human life (environmental risk, urban management, demography, etc.): they must therefore be managed by personnel without specific expertise both in data interpretation and in computer science; the key messages which could influence the decision process (by example the overcoming of an emergency threshold in some areas, the evidence of a trend through time, etc.) must be communicated clearly and simply.

The new technologies on the Web seem to offer solutions to above challenges. In particular, XML (eXtended Markup Language) which allows to exchange open and textual information, defining structured text files which can be matched by programming languages (such as filtering tools) acting at any component of the Internet architecture. XML tags can be freely defined to reflect the semantics of any application universe and the structure of the documents to be dealt with. The document content is completely independent on its visualisation which can be designed in different fashions following users' preferences or device needs.

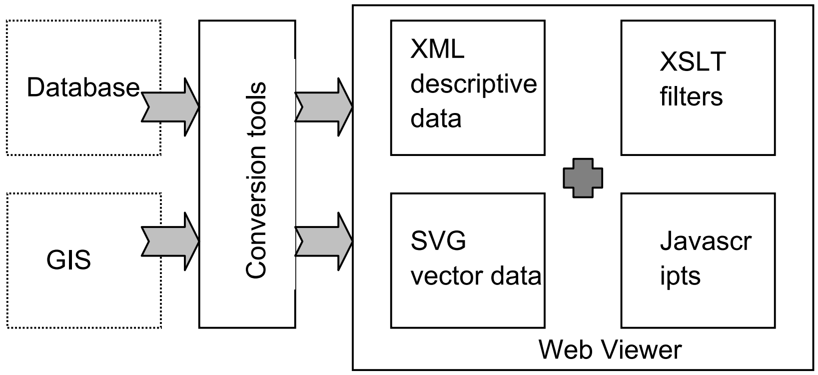


Figure 1
Technologies of the viewer implementation: they are open source, free and standard

In order to allow a friendly and distributed access to the data of the glacier archive described in the above Section 2, an online viewer has been designed and implemented in a prototypal version. Its main purpose is to facilitate the access to data regarding each glacier and the comparison of observations so far. Open, standard and free technological implementation solutions have been chosen (Figure 1). XML is used for data description and exchange, and SVG (Scalable Vector Graphics) for visualising data and realising the interaction and animation tools.

SVG is a XML language for describing two-dimensional graphics online. It allows for three types of graphic objects: vector graphic, images and text. Graphical objects can be grouped, styled, transformed. SVG drawings can be interactive and dynamic. Animations can be defined and triggered either declaratively (i.e., by embedding SVG animation elements in SVG content) or via scripting. SVG also encourages graphic materialisation on different devices (such as desktop or mobile computers) as well as precision printing.

Static and dynamic data about each glacier are extracted from the inventory and translated into XML (MS Access allows exporting towards XML files); then a designed XSLT (eXtensible Stylesheet Language Transformation) file filters the data of interest for the viewer and prepares their materialisation as distinct tables, each one corresponding to a timestamp. To extract the co-ordinates of polygons, stored as shapefiles, we used the Avenue script 'Get Vertices', available for free at ESRI Web site, that stores the coordinates of each vertex into a table.

Two user environments are available: the first one, called "*Data from satellite observations*" opens a drawing area and an index of buttons to select one or more years (corresponding to the years of observations). When the user clicks on one button the associated boundaries appear in the drawing area (the Figure 2 shows this environment in the case of the Adamello glaciers[5] when the first (1986) and last years (2003) are selected): the contours of each year overlap so that their extensions can be compared at a glance. In the same Figure 2 the pointer representing the mouse position is over the boundaries of one of the glaciers (Avio Centrale): in this way a table appears with the associated non-dynamic data. These data do not change through time but only if the pointer is moved over another glacier.

[5] They are five glaciers forming one group, in the Central Italian Alps

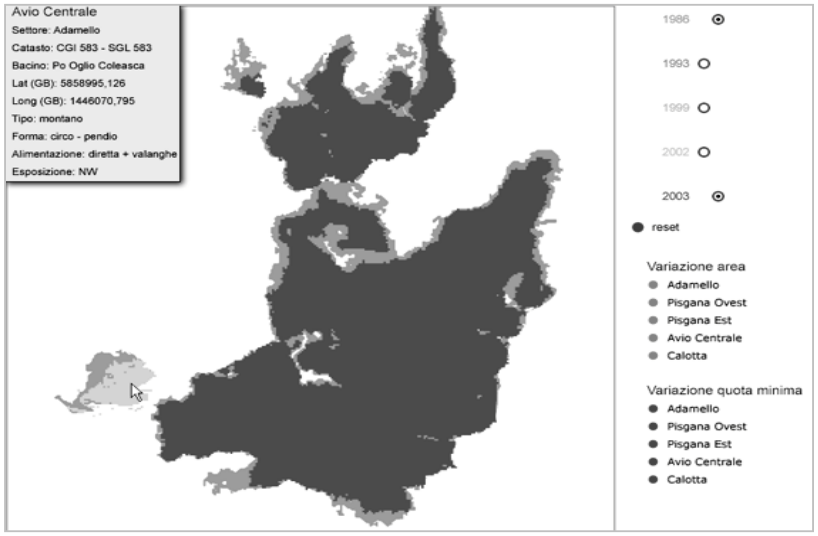
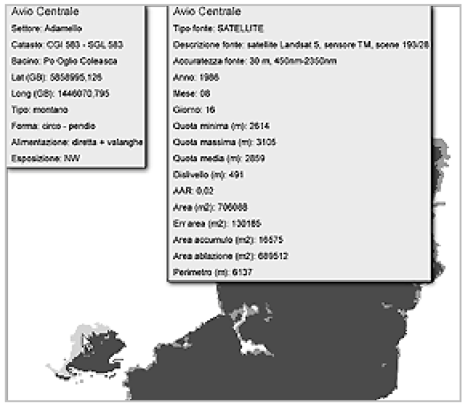
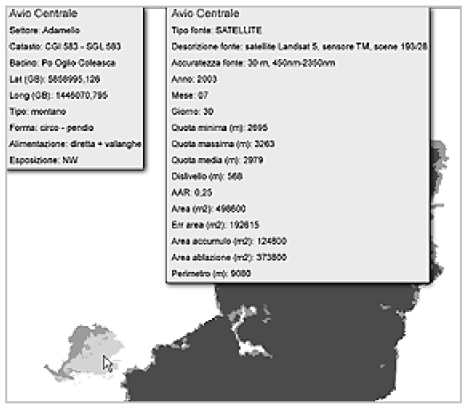


Figure 2
Interface of the viewer with a table of static data referred to the pointed glacier

On the contrary, the table of dynamic data changes depending on the year: it is fired by clicking on each boundary of the same glacier (see Figure 3a and 3b which show the tables of 1986 and 2003, respectively; it can be observed by example that the lowest elevation moved up from 2614 to 2695 mt.). Two more types of hyper-links are available in this environment in order to qualitatively and quantitatively appreciate variations in time of two crucial parameters, i.e. glacier area and lowest elevation (Figure 2). They open windows sketching a graph of the parameter trend; the values associated with each year appear by positioning the mouse over the points of the graph. With the very simple actions that we have described so far, a wide knowledge on the glaciers is easily obtained: the user interaction does not require any specific expertise on database or GIS but exploits the set of behaviours provided by any plain Web site (mouse-over, mouse-click, index navigation).



(a)



(b)

Figure 3
Interface of the viewer with tables of dynamic data (a for 1986; b for 2003)

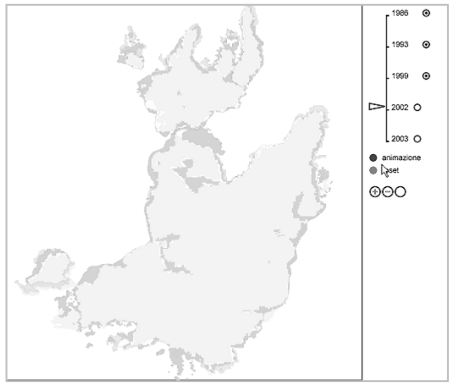


Figure 4
Interface of the viewer while the animation is showing the glacier boundaries

Following the principles of ViSC, the viewer provides also an environment (called “*Spatio-temporal application*”) for animated visualisation, a style which is assuming a growing importance to cope with the increasing amount of data and results changing through time. It is focused on the visual comparison of glacier extensions year-by-year (Figure 3). The index of buttons of the previous environment is here coupled with a timeline. It is sufficient to click on the “Animation” hotword to fire the appearance of the glacier boundaries while an arrow slides along the timeline to indicate the time reference. Zooming facilities allow to animate target areas of the glacier of interest.

4. Conclusions

We are working to improve the system architecture exploiting facilities for XML databases in order to discard the conversion step (see Figure 1). Moreover, in the present viewer, interface elements and styles are once for all defined by the designer: they are in some way ‘hardwired’ in the XSLT and scripts; we are working in order to associate visualisation tools with distributed data which can be modified by the users to customise interaction styles (Carrara 2003).

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