

# TERRESTRIAL SCANNING LIDAR TECHNOLOGY APPLIED TO STUDY THE EVOLUTION OF THE ICE-CONTACT MIAGE LAKE (MONT BLANC, ITALY)

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### ABSTRACT

Terrestrial scanning lidar (light detection and ranging) surveys represent the most powerful tool to accurately map inaccessible surfaces like outcrops and glacier toes. A laser scanner enables researchers to acquire thousands of X,Y,Z points per second, complete with intensity that can then be constructed into accurate 3D models.

Since June 2003, three terrestrial scanning lidar surveys were done using Optech's ILRIS-3D to monitor the evolution of the subaerial ice cliff which bounds to the north of the ice-marginal Miage Lake (Mont Blanc Massif, Italy). The comparison between the repeated surveys clearly illustrates an important retreat of the ice cliff, with values in the range of several tens of meters in more than a year.

A drainage of the lake occurred in early September 2004. A laser scanner survey, carried out on September 8<sup>th</sup>, 2004 provided data for constructing a Digital Elevation Model (DEM) of the exposed lake bed. The overall volume of the lake was computed and a contour map of the lake bottom was obtained.

### 1. INTRODUCTION

Terrestrial Scanning Lidar (TSL) is capable of surveying thousands of X,Y,Z points per second complete with intensity. TSL allows the contemporaneous acquisition of geometrical data and information about the physical and structural properties of the investigated surface.

The measurement range can be up to 1000 m; (portable class one equipments can easily reach a distance of 700-800 m), which is very useful for unstable slope and ice cliff characterization and monitoring.

At present there are many applications and tools for the use of TSL in the architectural field due to the fact that short-range 360-degree laser scanners have been available for some time. Applications to investigate and control unstable areas are presently not common. Spatial information technologies offer interesting opportunities for geological and architectural surveys to display form, geometry and colour. Laser scanning has developed into a leading method of remote sensing for landslide detection and monitoring and environmental applications.

Terrestrial scanners are the most innovative and promising instruments for panoramic view surveys. The capability of acquiring hundreds of thousands of points per second with high accuracy results in detailed surveys supplying very important and valuable results. For this reason, it is very important to use a robust software for data processing that is equipped with both basic and advanced survey functionalities. Operating flexibilities allow the user to explore all the points and build models of the surveyed surface. Proper surface

analysis softwares offer the possibility to filter data and create geometric primitives.

The main principle of laser scanning, or lidar (light detection and ranging) technology is the calculation of the time of flight of each laser pulse.

Lidar principle is similar to the one of ordinary radar, except that lidar systems send out narrow pulses or beams of light rather than broad radio waves. A receiver system and time interval meter calculates, counts and processes the returning light.

Lidar depends on knowing the speed of light, approximately 0.3 metres per nanosecond. The lidar system calculates how far a returning light photon has travelled to and from an object using the following formula:

$$\text{Distance} = (\text{Speed of Light} \times \text{Time of Flight}) / 2$$

Thus lidar operates on this principle:

1. Laser generates an optical pulse.
2. Pulse is reflected off an object and returns to the system receiver.
3. High-speed counter measures the time of flight from the start pulse to the return pulse.
4. Time measurement is converted to a distance by using the formula above.

The system records the Cartesian coordinates X, Y, Z of every measurement as well as the intensity of the beam, dependant on the object level of reflectivity.

Every kind of material reflects the laser beam in a different way; ice represents one of the most difficult ones. Using this technology with ice was an incredible challenge for understanding its potentiality under really

critical conditions.

Since June 2003, three terrestrial scanning lidar surveys have been carried out in order to monitor the evolution of the subaerial ice cliff bounding to the north of the Miage Lake. A complete drainage of the lake occurred in early September 2004 (fig. 4). After the drainage, a laser scanner survey was carried out on September 8<sup>th</sup> 2004, providing a Digital Elevation Model (DEM) of the exposed lake bottom, from which the overall volume of the lake was calculated.

The experience gained during the described application demonstrated that TSL can be used for monitoring unstable ice cliffs. The capability to operate remotely without accessing dangerous areas, is important for glacial risk assessment studies.

## 2. THE SURVEY AREA

Miage Lake (Val Veny, Valley of Aosta) constitutes both a main tourist site for many decades and a long-standing object of scientific study. Recently, interest in the lake has been renewed especially in the context of natural hazards associated with the dynamics of Miage Glacier, which is the third Italian glacier by area (11 km<sup>2</sup>) and one of the main debris-covered glaciers of the Alps. Its terminus reaches one of the lowest elevations in the Alps, at 1730 m and 1775 m on the south and the north lobe, respectively. With an area of 36 000 m<sup>2</sup> in 2003 (Diolaiuti et al., 2004), Miage Lake is contained within a morainic amphitheatre formed by a staircase-like sequence of breach-lobe moraines associated with the large right-lateral moraine, where the glacier curves out of the Mont Blanc massif to block the trough of Val Veny (fig. 1). Miage Lake perimeter lies against the proximal slopes of moraine ridges (which in the east extend to a height of 40 m above the summer lake surface), excepted to the north where it is bounded by an arcuate ice cliff of up to c.30 m in height. The different basins of the lake range in depth from the ≤ 6 m-deep west basin, to > 30 m in the east basin. During the warm season, calving of ice from the ice cliff is frequent. Bergs vary in size, the majority being < 50 m<sup>3</sup> volume, but on rare occasions calving involves a hazardous volume of ice. For example, the calving wave generated by a collapse of c. 10000 m<sup>3</sup> on August 1996 injured a dozen of tourists (Tinti et al., 1999).

Miage Lake has been affected by at least 17 drainage events since one century: 1916, 1930, 1950, 1955, 1959, 1960, 1961, 1962, 1963, 1964, 1967, 1968, 1975, 1980, 1986, 1990 and 2004 (Chiarle, 2000; Giardino et al., 2001, Deline et al., 2004). Observations during the last event suggest that an increased discharge of water from the lake, due to the opening or enlargement of a passage by the interplay of marginal crevasses or cavities, could lead to the emptying of the lake (Deline

et al., 2004).

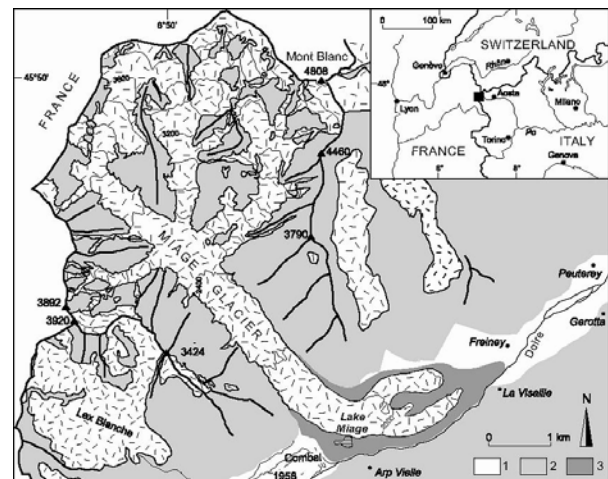


Figure 1 – The survey area

## 3. SURVEY

### Equipment

- an Optech ILRIS 3D ([www.optech.ca](http://www.optech.ca)) terrestrial laser scanner was used for surveying the ice cliff and the lake bottom. This scanner can work up to 1000 m in ideal conditions depending on surface reflectivity and visibility. The field of view is 40° x 40° while the sampling rate can reach a maximum of 2000 points per second. At a distance of 100 m the laser beam diameter is about 30 mm (perpendicular shot) and the accuracy on a flat surface is about 3-5 mm.
- static GPS phase measurements were carried out in order to establish a geo-referenced baseline to which the point cloud was referred.
- a topographic total station was used for geo-referencing the targets positioned into the surveyed scene during the first survey (July 2003), with reference to the previously mentioned GPS baseline. The position of the targets is represented in fig. 3 (blue points). The following lidar surveys were geo-referenced by overlapping the unchanged areas on the reference surface (June 2003).

### Acquisition geometry

As the whole area couldn't be covered by a unique scan, up to 14 single scans, partially overlapped, were acquired from up to three different positions (Figure 3 – red points) and subsequently merged into a single reference system.

### Targets

Few targets must be positioned in the scanned scene if the lidar survey must be geo-referenced to a user specified coordinate system. Black square panels 50 cm wide with a white circle in the middle were used. Difference in intensity between black and white is clearly visible on the point cloud, helping to easily determine the centre of each target. The processing software enables the selection of the points constituting

the white circle by intensity and the automatic evaluation of its centre with an accuracy of a few millimetres. The cartographic coordinates of the centre of each target have been previously measured on field by combined GPS and topographic total station surveys (fig. 2).

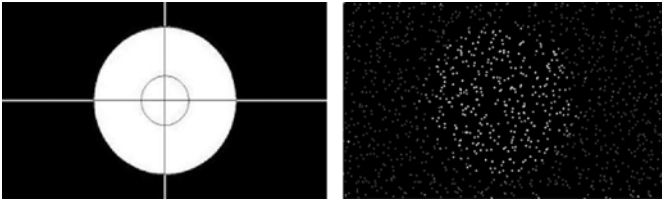


Figure 2 - Target used for geo-referencing the lidar surveys (left) and radiometric answer of the points (right)

#### Field surveys

The first survey was carried out on June 2003. Eight scans of the ice cliff bounding the lake to the north were carried out at an average distance of 300 metres were carried out from two positions (A and B in fig. 3), located on the opposite side of the lake. The point spacing varies from 70 mm to 100 mm. During the first survey five targets were positioned into the scanned scene and their position determined in the cartographic reference system (UTM32\_ED50), as previously mentioned. The July 2003 survey represents the reference surface the following surveys have been compared with, in order to evaluate the ice cliff evolution.

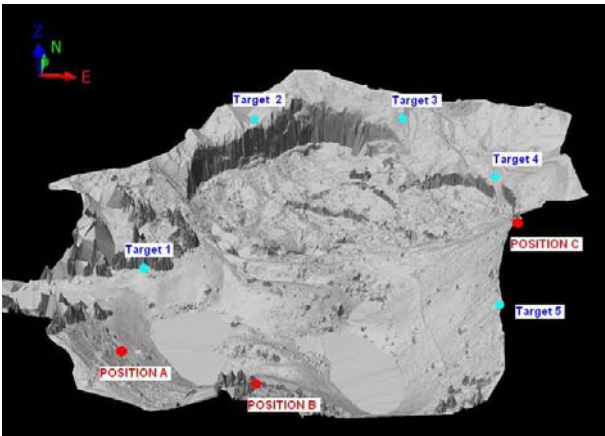


Figure 3 – Positions of the survey and the targets

The same area was surveyed again about one year later (June 2004) from the same positions A and B.

No targets were positioned in the scanned scene as the June 2004 point cloud was geo-referenced by overlapping it on the unchanged areas of the previous surface, represented by the moraine ridge bounding the lake to the east and to the west.

The third and last survey was carried out on September the 8<sup>th</sup>, 2004, after the complete drainage of the lake occurred in early September 2004. Due to the drainage, the most part of lake bottom was exposed and could be

scanned. In order to ensure a proper area coverage, 14 scans from three different positions were carried out from three viewpoints (Figure 3) Only a small part of the western lobe of the lake couldn't be reached. An average point spacing of 15 cm was considered satisfactory. Like the previous survey, the September 2004 one was geo-referenced by overlapping the moraine ridges on the reference surface (July 2003).



Figure 4 – Oblique aerial photo of the empty lake basin (A. Tamburini, 16.09.2004), that can be compared with the model obtained from the September 2004 survey (fig. 3)

#### 4. CREATION OF THE SOLID MODELS

Data processing was carried out by using the commercial software InnovMetric PolyWorks. The main processing phases are described below.

##### Alignment of individual scans

After cleaning individual scans from outliers and vegetation, a targetless scan alignment was carried out by merging individual scans into a single reference system.

As vegetation doesn't keep coherent from one scan to the other, due to wind, growth etc., it must be removed before any processing. Moreover, in order to enable a multi-temporal analysis of the scanned area, unvaried areas must be included into the point cloud. The moraine ridges bounding the western and eastern side of the lake were used to this purpose, as previously mentioned.

Each scan has its own reference system centered on the lidar equipment. For this reason individual scans are merged into a unique local reference system.

The IMAAlign module of the InnovMetric PolyWorks software ([www.innovmetric.com](http://www.innovmetric.com)) was applied. This software enables the choice of some common tie points (recognizable features like big stones, etc.) for linking up different scans.

A first rough alignment is carried out by manually marking three or more common points selected within the overlap area of two adjacent scans. Then an automatic ICP (Iterative Closest Point) algorithm is applied, in order to perform a spatial rotation and

translation without scale variation of the second scan with respect to the first one, which is assumed as reference. Six independent parameters (3 rotation angles around the XYZ axes and 3 spatial translation) are computed, providing a roto-translation matrix for each aligned scan. This procedure is applied to each individual scan enabling the creation of a unique point cloud of the scanned scene.

The local reference system is centered on the first individual scan that was assumed as temporary reference for the alignment.

#### Geo-referentiation of the entire model

The IMInspect module of the InnovMetric PolyWorks software was applied in order to detect the centre of the targets positioned in the scanned scene during the first survey. Once detected, the proper cartographic coordinate values are assigned to each target center and the entire model roto-traslated in order to best fit the new coordinates. A new global roto-translation matrix is computed.

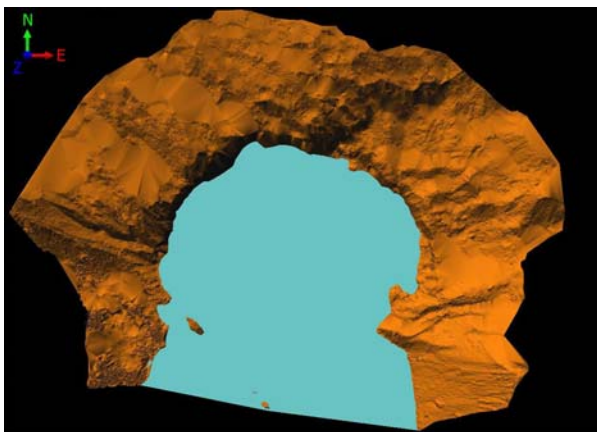
The described procedure was applied only to the first point cloud (July 2003), as previously mentioned.

#### Solid model creation

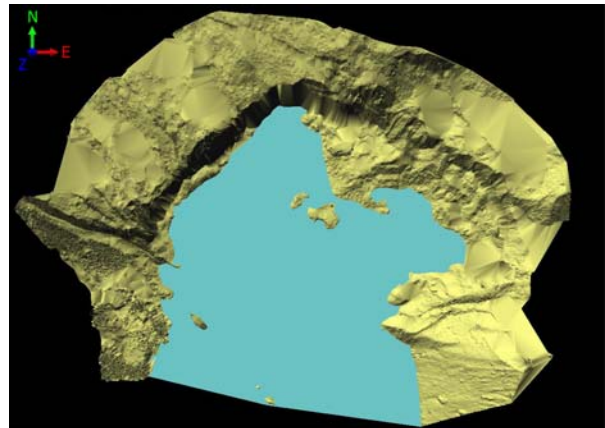
The IMMerge module of the InnovMetric PolyWorks software was applied in order to build a geo-referenced TIN (Triangulated Irregular Network) model of the scanned surface. An average side of 30 cm was considered satisfactory.

The holes of the model were filled in by applying the IMEdit module of the InnovMetric PolyWorks software.

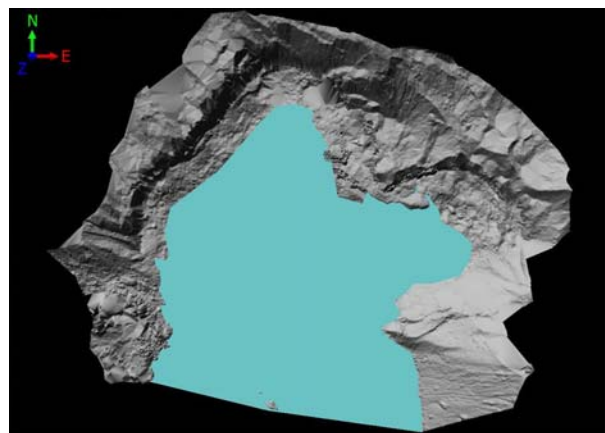
The final results are showed in fig. 5, 6 and 7, representing the June 2003, July 2004 and September 2004 models respectively. A flat blue surface represents the pre-drainage water level in fig. 7.



*Figure 5 – TIN model of July 2003*



*Figure 6 – TIN model of June 2004*



*Figure 7 – TIN model of September 2004*

## **5. TIN MODEL ANALYSIS**

The analysis of the September 2004 solid model provided a detailed bathymetric survey of the lake. Moreover the comparison between models provided quantitative information about the evolution of the ice cliff and the extension of the ice calving processes.

#### Bathymetric survey

By subtracting the DEM (Digital Elevation Model) of the lake bottom from a flat surface representing the pre-drainage lake surface, a contour map of the lake bottom was obtained (fig. 8).

An overall volume of about 323000 mc, with a maximum depth of more than 23 m was computed.

Details of the morphology of the lake bottom are clearly visible on the model. As an example, the northern basin is separated from the southern one by an arcuate moraine ridge, which develops along the ice foot. This can be argued by the presence of crevasses on the bottom of the northern basin; the morphology of the southern basin looks completely different, confirming such an interpretation. If points are picked along the crest of the moraine ridge, they can be exported vs CAD or GIS environment, enabling a cartographic representation of such a morphologic feature.

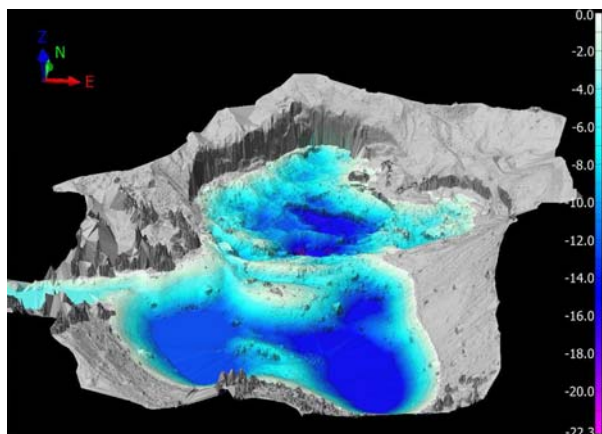


Figure 8 – Bathymetry of the Miage lake after the September 2004 emptying

### Comparison between models

As all the models are geo-referenced in the same coordinate system, they can be easily compared showing the evolution of the ice cliff through time (fig. 9 and 10).

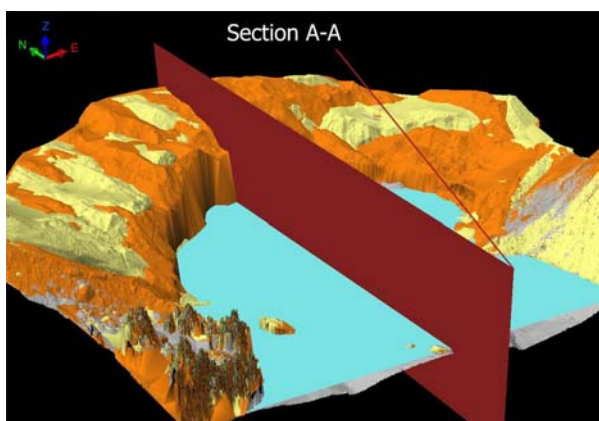


Figure 9– Section plane A-A

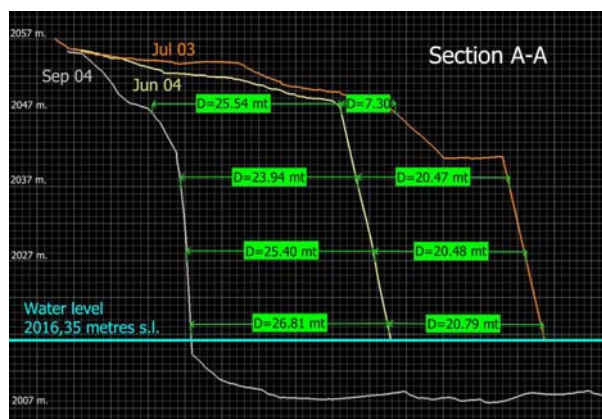


Figure 10 – Cross section A-A

Cross sections along pre-defined vertical planes can be easily obtained. As an example, a N-S cross section in the central part of the ice cliff is shown in fig. 10. A retreat of the ice cliff higher than 45 m can be measured from July 2003 to September 2004.

## 6. CONCLUSIONS

A significant experience in the use of terrestrial scanning lidar applied to study the evolution of the Miage lake during the last couple of years was carried out. The main results are summarized in the following items

- laser scanning offers an effective method for monitoring unstable areas, like landslides and glacier snouts without accessing them
- commercial equipments and processing softwares make it possible to easily obtain detailed surface models in a very short time
- the analysis of 3D models of the surveyed areas provides a never known amount of data and information about the main geomorphologic features of the studied areas
- starting from the point cloud, geometric information can be easily exported vs CAD and GIS environment, enabling thematic map performance

## 7. REFERENCES

- CHIARLE M. (2000) - Analisi dei pericoli naturali in ambiente glaciale. PhD. Thesis, Politecnico di Torino, 206 pp.
- DELINE P. , DIOLAIUTI G., KIRKBRIDE M.P., MORTARA G., PAVAN M., SMIRAGLIA C. & TAMBURINI A. (2004) - Drainage of ice-contact Miage Lake (Mont Blanc Massif, Italy) in September 2004, Geogr. Fis. Dinam. Quat., 27 (2), 113-119
- DIOLAIUTI G., KIRKBRIDE M.P., SMIRAGLIA C., BENN D.I., D'AGATA C. & NICHOLSON L. (2005) – Calving processes and lake evolution at Miage Glacier (Mont Blanc, Italian Alps). Ann. Glacio., in press.
- GIARDINO M., MORTARA G. & BONETTO F. (2001) - Proposta per la realizzazione di un catasto aerofotografico dei ghiacciai italiani, Suppl. Geogr. Fis. Dinam. Quat, 5, 89-98
- TINTI S., MARAMAI A. & CERUTTI A.V. (1999) – The Miage Glacier in the Valley of Aosta (Western Alps, Italy) and the extraordinary detachment which occurred on August 9, 1996. Phys. Chem. Earth (A), 157-161.

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