Il Quaternario
Italian Journal of Quaternary Sciences
24, (Abstract AIQUA, Roma 02/2011), 135 - 137

Congresso AIQUA
Il Quaternario Italiano: conoscenze e prospettive
Roma 24 e 25 febbraio 2011

LiDAR APPLICATIONS TO QUATERNARY GEOLOGY OF HIGH MOUNTAIN AREAS: EXAMPLES FROM VAL DI FASSA (DOLOMITES)

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ABSTRACT: Zanoner T. *et al.*, *LiDAR applications to Quaternary geology of high mountain areas: examples from Val di Fassa (Dolomites).* (IT ISSN 0394-3356, 2011)
Information obtained from LiDAR-derived DEMs, photointerpretation and field survey were compared; results demonstrate the reliability of LiDAR in the recognition of landforms and deposits in the Dolomitic areas of Val Duron and Passo San Pellegrino.

RIASSUNTO: Zanoner T. *et al.*, Applicazione di dati LiDAR per lo studio della Geologia del Quaternario in aree di alta montagna: esempi dalla Val di Fassa (Dolomiti). (IT ISSN 0394-3356, 2011)
Si sono confrontati i risultati ottenuti dall'utilizzo di DEM da LiDAR, fotointerpretazione e rilievo sul terreno; i risultati dimostrano che il LiDAR è un valido strumento per il riconoscimento e la mappatura delle forme del terreno e dei depositi quaternari. I casi studio sono le zone dolomitiche della Val Duron e del Passo San Pellegrino.

Key words: Dolomites, Geomorphology, DEM, remote sensing, glacial deposits, paraglacial deposits

Parole chiave: Dolomiti, Geomorfologia, telerilevamento, DEM, depositi glaciali, depositi paraglaciali

The LiDAR (*Light Detection and Ranging*) is based on the use of a laser scanner measuring the distance existing among sensor and ground surface. If the scanner is transported by an aircraft and the acquisition corrected with an IMU (Inertial Measurement Unit) and a differential GPS, large areas could be surveyed in short time with a vertical precision of 7-20 cm (HERITAGE & LARGE, 2009). The method is rapid, relatively economic and allows survey of difficult terrain, as high-mountain regions, where conventional ground-based survey methods are impossible or very difficult and expensive.
The topographic data, acquired as clouds of points in ASCII format (x, y, z) could be processed obtaining Digital Surface Model and Digital Elevation Model (i.e. DSM and DEM) at various scales with a cell-size dimension of 0.5-2 m. The use of hillshade or other digital process could enhance the ground morphologies helping the recognition of landforms and structural features of an area.
Problems of distortions or artifacts (e.g. striping effect) on the images or on the derived DEM should be considered.
In the mountains, where rocky slopes could be very high, the LiDAR acquisition could be problematic because laser-based systems are affected by beam divergence if slope are steeper than 70°. This effect is accentuated at increasing distances from the scanner both in vertical and horizontal plane (HERITAGE & LARGE, 2009).
The LiDAR operates collecting the so-called first- and last-pulse. First-pulse measures the range to the first object encountered (in many this is vegetation, for example tree foliage); Last-pulse: measures the range to the last object (the ground surface under the foliage).
The recent instrumentations could record both the first and the last return and also the intermediate impulses (caused by ramifications of the plants) and this allows to obtain information on the surface and remove the vegetation and the urban built. It is possible to discriminate forms and deposits under vegetal cover that makes invisible the geology with the normal remote sensing and often also with the geological ground survey. Hence, airborne-laser scanning has become one of the primary choices for gathering precise and dense DEMs of large areas for a wide range of applications. LiDAR has currently become an important scientific tool in Forestry, Geology (*latu sensu*), Archaeology, Agriculture. It is a major tool for river and alluvial Geomorphology, but the applications related to the Quaternary Geology and Geomorphology in high-mountain environments are still few.
Despite its positive characteristics, at the moment the LiDAR topography is available only for limited Italian areas, but among them the whole area of the Province of Trento was surveyed and its cover a large portion of the Dolomites. In this work we tested the reliability of LiDAR-derived DEM for Quaternary Geology researches in two sample areas in the Dolomites: Val Duron and Passo San Pellegrino in the Val di Fassa Valley (Fig. 1).
These are two areas already studied and their are

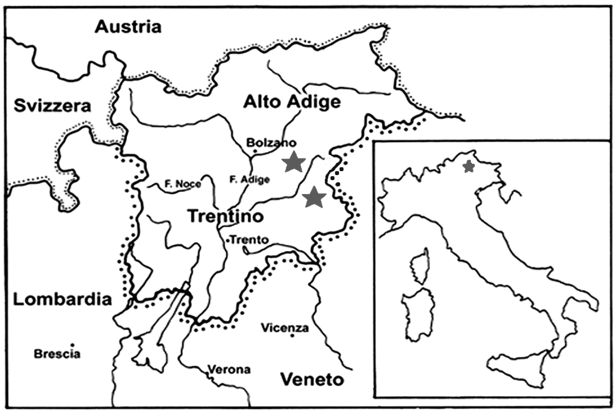

Fig. 1, Location of the studied areas.
Ubicazione delle aree studiate.

characterized by the presence of major glacial, paraglacial and periglacial landforms and deposits (CASTIGLIONI, 1926; 1930; ROSSI, 1955; 1962; BIANCHI CASTIGLIONI, 1960; CASTIGLIONI, 1964; PANIZZA *et al.,* 1978; CARTON & PELFINI, 1988).

For this study the topographic analyses and elaborations were carried out on the DEM derived by the LiDAR survey realized by the Provincia Autonoma di Trento between 2006-2008. The DEM supported by this institution was already filtered of the anthropic features and corrected. The LiDAR survey had a point density of a minimum of 8 points per cell when cells are 2.5x2.5 m and a minimum of 12 points for cells of 5x5 m. The sensor recorded the first and the last return of the laser beam and the mean percentage of penetration of forest cover (deciduous forest) was about 90%. The altitude precision obtained spans between 10 and 30 cm.
In this work, beside LiDAR data, conventional remote sensing analyses were performed, consisting in photo interpretation of the areas through binocular stereoscope and monitor analysis of digital orthophotos at scales ranging from 1:5,000 to 1:10,000. All these indirect interpretations were subsequently checked with a geomorphological-geological field survey carried out at scale 1:10,000 using the topographic base the Carta Tecnica Provinciale of Trento.
The ground survey demonstrated the validity of the indirect analysis previously performed. The use of remote sensing information, in particular the LiDAR, is largely usefull to characterize landforms and deposits which, sometimes, are very difficult to understand or even to see in the field due to vegetation cover and/or the lack of clear outcrops.
The research benefits of the detailed information concernig the geological bedrock (mainly Permian and Triassic formation), collected through the geological maping carried out in the last 15 years in this area and already overlapped to the LiDAR-derived DEM (Marco Stefani, unpublished). This geological data allowed to identify and discriminate some areas were the pre-Quaternary substratum consists of silico-clastic formations with a surface aspect apparently similar to the some Quaternary deposits.
In the test areas there are some cases which can illustrate the different characteristics of the 3 methods used for the geomorphological analysis (i.e. field survey, photo interpretation and analysis of LiDAR data). These highlight how important are the LiDAR images in resolving some geomorphological problems. In both the zones the DEM, filtered from vegetation, allow to identify slope and glacial deposits that in the former researches were generally mapped in a worse way and sometimes even unknown or overestimated.
As wrote before, the use of these tools and other methods based on remote sensing needs to be carefully checked with ground truths; but, after validation, the areas where field survey is needed and essential could be reduced in their number and extent. However our experience supports the idea that LiDAR and photointerpretation could not replace the field work. Moreover, the field work is important to achieve the right scale of survey, because sometimes, especially with the LiDAR-

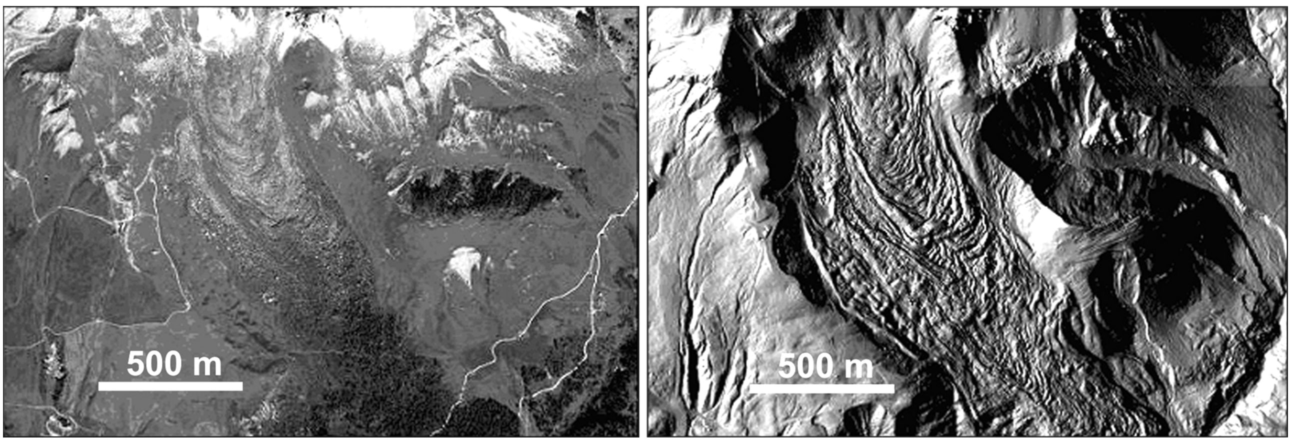

Fig. 2, The Val Tegnuosa rock glacier in the orthophoto (left) and in the LiDAR-derived DEM (right).
Il rock glacier della Val Tegnuosa visto nell'ortofoto (sinistra) e nel DEM da LiDAR (destra).

derived images, there is the risk to be trapped in a too detailed analysis, which consumes time and energy and sometimes leads to lose the sense of the general setting inducing errors of interpretation.
In the Val Duron, the LiDAR images enphasizes the structural component of the landscape, allowing a better understand of a river capture originally described by PANIZZA et al. (1978); this was tectonically driven by a structural pattern which induced also an important landslide. In fact in this valley LiDAR permits to recognize also two landslides that have probably blocked the valley for sometime. One of these slope features probably occurred during deglaciation, the other had not been detected before this research due to the forest cover. Other landforms which are nicely highlighted by LiDAR are represented by fluvial terraces, alluvial cones and talus screes.
Near the Passo del S. Pellegrino, beside morfostructures, gravitational processes and river terraces, LiDAR was really helpful in analysing karst morphology (e.g. doline field), glacial, paraglacial and periglacial phenomena, as described in the following examples.
Near the place of Fuciade, photointerpretation didn't provide safe information about the genesis of a complex shaped deposit. Field survey revealed a glacial and paraglacial origin but without LiDAR data it was hadrly to map clearly a rock glacier and separate it from an adjacent glacial deposit.
The DEM allowed to map rapidly and in detail the lobes of the rock glacier, while they have a lower evidence in the aerial photos. Due to hummoky topography field survey doesn't provide a map with a detail cmparable to the one obtained from LiDAR. The correct representation of the lobes is important to support considerations on the variations of speed and direction experienced by a rock glacier. A nice example is represented by the Val Tegnousa Rock glacier, already considered in BIANCHI CASTIGLIONI, 1960 and in CARTON ,1980. With Lidar-supported investigations it is possible to distinguish the various stages of development that the rock glacier has undergone.
Other forms that can be better mapped using LiDAR are the moraine ridges at the altitude of Passo San Pellegrino, which presently are completely covered with vegetation and often broken up or smashed by anthropogenic or natural causes. Due to these motivation their identification and thus also their mapping is not always easy from aerial photographs or with the ground survey. After careful analysis it's possible to reconstruct the different phases of glacial advances and retreats.

The authors thank the Protezione Civile and Servizio Geologico of the Provincia Autonoma di Trento for the LiDAR-derived DEM used in this research. DEM were processed by F. Ferrarese.

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Ms. received: January 15, 2011
Testo ricevuto il 15 gennaio 2011