pca

postclassicalarchaeologies

volume 2/2012

SAP Società Archeologica s.r.l.

Mantova 2012

pca

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DESIGN

Paolo Vedovetto (Università degli Studi di Padova)

PUBLISHER

SAP Società Archeologica s.r.l.
Viale Risorgimento 14 - 46100 Mantova
www.archeologica.it

PRINTED BY

La Serenissima, Contrà Santa Corona 5, Vicenza

Authorised by Mantua court no. 4/2011 of April 8, 2011

ISSN 2039-7895

pca

postclassicalarchaeologies

volume 2/2012

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Post - Classical Archaeologies

Airborne LiDAR data analysis within the Alpine landscapes of Trentino: a methodological approach

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Application of LiDAR derived DTMs has demonstrated great potential in ancient landscape and site analysis, contributing to unknown data detection, new research strategies and conservation policy adoption and management. This paper presents the range of LiDAR data visualisation tools available, suggesting a procedure in DTM analysis able to optimise visualisation and interpretation of archaeological and geomorphological features, starting with the research activities developed in Trentino (Alpine environment).
Keywords: LiDAR, visualization tools, geomorphology, landscapes, Trentino

L'uso del DTM ricavato dal LiDAR si è dimostrato molto utile per l'analisi dei paesaggi archeologici e dei siti, contribuendo a fornire nuovi dati e aprendo nuove vie per la ricerca, la tutela e la gestione del paesaggio. Questo contributo presenta gli strumenti di visualizzazione LiDAR disponibili, suggerendo una procedura per l'ottimizzazione della visualizzazione del DTM per interpretare le features *archeologiche e geomorfologiche. Caso studio di questa ricerca è il Trentino.*
Parole chiave*: LiDAR, strumenti di visualizzazione, geomorfologia, paesaggi, Trentino*

1. Introduction

Since its introduction in archaeology, LiDAR DTM represents one of the most powerful tools for site and landscape analysis, due to the advantages compared to traditional remote sensing techniques such as aerial photography or satellite imagery: the accurate layout of the earth surface relief, pseudo-3d visualization and the filtering of woodland canopies.

In particular LiDAR DTM constitutes an established method for archaeological analysis in areas that have problems in visibility levels because of reforestation processes.

Received: 01-12-2011 - Accepted: 15-01-2012 - Revised: 06-03-2012

Many papers have underlined these advantages in woodland archaeological study, such as the work of Bernard Devereux and the research group at the University of Cambridge (Devereux *et alii* 2005), of Michael Doneus of University of Vienna (Doneus *et alii* 2008) and Ole Risbøl of the Norwegian Institute for Cultural Heritage Research (Risbøl, Gjertsen, Skare 2006).

Bernard Deveraux and his team have published LiDAR analysis results of the Welshbury hillfort, an Iron Age hilltop site of which little was known from aerial photographs due to the dense tree canopy on the hill slopes. Thanks to LiDAR DTM an articulated group of archaeological features was documented, such as site defensive ditches, access roads to the top area, medieval field systems and charcoal platforms (Devereux *et alii* 2005).

The study by Micheal Doneus has been devoted to the analysis of the defensive structures of the hill-top site of Purbach. He has also tested the use of a new type of sensor (full waveform scanner). This has allowed high-quality site mapping, recognizing the impressive defensive ditches and dikes in addition to internal features of the settlement like circular huts and a furnace (Doneus, Briese 2006; Doneus *et alii* 2008).Archaeological elements were recognised with LiDAR DTM technique during the analysis of Slovenian forested hill-top sites such as Sv. Elena, the *hillfort* of Zagrajec and Tonovcov Grad (Kokalj, Zakšek, Krištof 2011); the latter, a late-antique fortified site, where thanks to theairborne laser scanner a detailed map of the settlement (enclosed by walls with towers and composed by dwellings and churches)was obtained, improving the former geodetic survey of the structures.

Close to the more traditional intra-site analysis, some papers attempted to focus their attention on the archaeological elements of the landscape. For instance, recent work has implemented an automatic feature recognition for the historical terraced areas of the North Kohala region on the island of Hawai'i (McCoy, Asner, Graves 2011) and Simon Crutchley pointed to the problem of the evolution of agrarian landscapes in his work in the Savernake Forest (Crutchley 2009) and Southrey, Witham Valley, Lincolnshire (Crutchley 2006).

Significant data were collected by Crutchley, Bewley and Shell in the Stonehenge area (Bewley, Crutchley, Shell 2005). Thanks to their research, some unknown prehistoric and medieval field-systems were identified, and stratigraphic relationships between the archaeological features have been recognized.

Particular attention to the agrarian landscape of the fortified medieval settlement of Monte Iris (Basilicata, Southern Italy) has been devoted by

Lasaponara, Coluzzi and Masini (Lasaponara, Masini 2009; Coluzzi, Masini, Lasaponara 2010). Authors related this research with the analysis of the archaeological features of the medieval castle, occupied between the 11th to the 15th century. The authors identified in the LiDAR DTM the abandoned linear field-system strips that represented the agrarian background of the site.

In England, LiDAR DTM in field-system investigation has been also developed connected to research on deserted villages, one of the traditional topics of the emerging Medieval Archaeology (Beresford 1954; Beresford, Hurst 1971) and the conservation of *ridge and furrow* shaped agrarian organization represents a good field of airborne laser scanner application. Unfortunately, for the most part agrarian landscape examinations are limited to the presentation of isolated case studies, and references to this topic are often useful just to underline one of the numerous potentials of LiDAR analysis. The references to terraced slopes or field strips that appear in the works of Aled Rowlands and Apostolos Sarris on the island of Crete (Rowlands, Sarris 2007), some areas of Slovenia and in a methodological report by Keith Challis (Challis *et alii* 2008, Challis, Forlin, Kincey 2011), Ziga Kokalj (Kokalj, Zakšek, Krištof 2011) and Ralf Hesse (Hesse 2010) are only incidental.

A less developed topic in the archaeological LiDAR literature is represented by the analysis of historical roads and paths. A paper by Mark Kincey and Keith Challis (Kincey, Challis 2010) dealt with this, not only recognizing the shape and the organization of the medieval path of Mynydd Myddfai in the national park of Brecon (Wales)but also observing the erosion processes that damage its conservation. Moreover, an interesting case study that integrates LiDAR analysis with Roman burial sites has been proposed by Denis Francisci for the study of mobility in Val di Non (Trentino, Northern Italy: Francisci 2010).

Otherwise LiDAR has shown appreciable tools for research programmes and cultural heritage management. For such purposes, LiDAR utilization as a geomorphological evolution analysis tool and as application for the archaeological reconstruction of a territory represents the research focus of the University of Birmingham. Integrating LiDAR DTM in a complex framework with geoarchaeological explorations, geophysical researches and survey and excavation, significant results were collected for paleo environmental reconstruction and the evaluation of the distribution and conservation of archaeological remains in several alluvial areas, as for instance in the Trent Valley (Howard *et alii* 2008; Challis, Howard 2006).

2. The LiDAR data analyzed within the APSAT project

LiDAR data used within the Apsat project were commissioned by *Provincia Autonoma of Trento* (Autonomous Province of Trento) and covered the whole territory of the province. They were collected for hydrogeological reasons first and not for specific archaeological purposes. We used two different grid files, the first pulse yielded DSM (Digital Surface Model) and the second pulse yielded DTM (Digital Terrain Model). Ground resolution of valley bottom and slope was 1 m, whereas in the uplands (generally above 1500m asl) it decreases to 2 m. Analysis procedures were always applied to the output grid, filtered, processed and clipped by the LiDAR survey company (CGR – *Compagnia Generale di Riprese Aeree, Parma*).

Scanner	Wavelength (nm):	Maxiumum pulse frequency (kHz)	Average-flight altitude (m)	Average flight speed	Maximum Scan Angle
ALTM 3100C OPETECH	0,4-0,8 nm	100.000 Hz	1000-1800 mt	250 km/h	25°
TOPOSYS II (Falcon)	1,56 nm	85.000 Hz	1500 mt	350 km/h max	7°

The laser scanners employed were an ALTM 3100C OPTECH and a TOPOSYS II (used just for the scan of Adige Valley). Table 1 shows characteristics of the instruments used.

Reforestation processes and the specialized agricultural developments (mainly of orchards and vineyards) in the valley bottom areas determined the exclusive utilization of the filtered DTM grids. This has allowed a clear visualization of the ground surface thanks to the removal of the vegetation. Nevertheless, research activities have focused on the analysis of DTM with 1 m ground resolution. It emerged that the 2 m ground resolution available for the uplands is not suitable for archaeological purposes, since it fails to visualise artificial evidence. Fortunately near-infrared orthophotographs played an excellent role in the detection of archaeological remains, allowing the recognition of several pastoral sites (abandoned *malghe*[1],enclosures, huts), mining areas and first world war trenches and forts.

[1] *Malga* is the Alpine highland stable where cattles are collected in summertime.

3. LiDAR DTM Analysis. Comparing different visualization tools

As shown above, production of digital elevation models of high resolution quality and high elevation accuracy has established LiDAR as a fundamental tool for archaeological prospection.

Due to its augmented utilization in archaeology, a range of techniques has been developed for the analysis of LiDAR data, both in discussing and testing the results of the main visualization tools and in new and more sophisticated DTM processing. Furthermore, a debate about correct raw data filtering for DSM or DTM generation has been generated. The sensor settings, filter used, nature of the topography (i.e. steep slope/flat plain) and land cover characteristics (e.g. dense woodland/pasture) affect the level of archaeological information quite considerably. This problem has been addressed both in the specialist literature (Meng, Currit, Zhao 2010; Sithole, Vosselman 2004) and in archaeological work (Doneus *et alii* 2008). Archaeologists are aware of the significance of this procedure, because it has direct implications for the quality of the Digital Terrain Model used for cultural landscape prospection, potentially erasing very ephemeral features or collecting false evidence caused by low vegetation (Doneus *et alii* 2008). Although filtered and grid data are usually used by archaeologists, more detailed and rich information can derive from specific data collection and filtering processing inspired by archaeological purposes. Even if some appreciable application has been devoted to the filtering of raw data of particular areas (Nebbia in press), APSAT project partners have been working mainly with filtered data, focusing its research on the LiDAR DTM analysis.

In this section the traditional visualization tool s*hillshading* and *slope* will be examined, with the aim of underlining their properties and limits. In the second part, the most significant analytical techniques will be presented and compared in different scenarios. Constrained colour ramp, Hillshading Principal Component Analysis, Solar radiation, Sky-view factor and Visible Sky will be presented. Other visualization tools such as Curvature (Kennely 2008) or Filtering as Local-relief models (Hesse 2010 i.e.: control generic Toolkit LiDAR) are also available for DTM representation but even though they have good and wide application possibilities we prefer to focus this paper on the former techniques.

We attempt to demonstrate that, in a complex environment like the alpine region of Trentino, a basic application of LiDAR DTM can generate a lack of archaeological information and, consequently, an underestimation of LiDAR research potential. The result of this methodological thinking will be to highlight how LiDAR analysis can improve the archaeological knowledge of landscapes that are permanently threatened by damage.

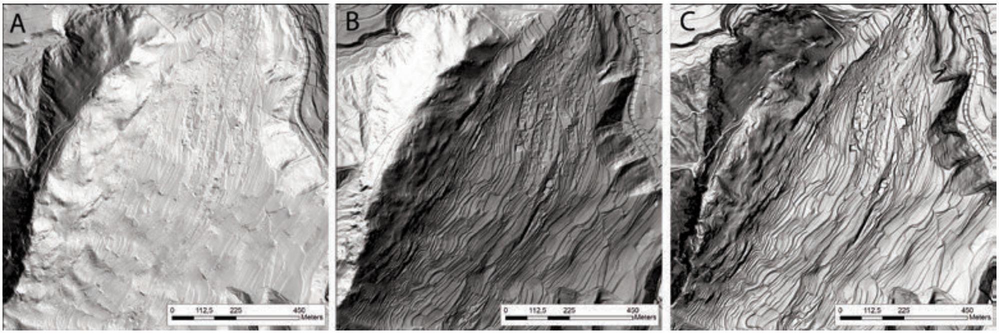

Fig. 1. Colle di San Pietro (Torcegno, Telve di Sopra). The different visualization of hill-shade on the hill slopes are evident on image A (azimuth=72) and B (azimuth=315). Slope analysis (C), based on slope degree calculation, is not affected by this visualization problem.

3.1. Hillshading

The hillshading technique is probably the most widely applied tool for LiDAR -derived DTM analysis, thanks to its ease of computing and interpretation. It is based on the calculation of the shading value produced for each DTM pixel by a hypothetical light source, of which the user can set the direction (azimuth) and altitude above the horizon. Despite its wide application, hillshading probably represents the most problematic LiDAR visualization tool, due to its several limitations in feature recognition. For instance, hillshading does not allow an integral and homogeneous visualization of a relief like a mountain or a hill because at least one of the slopes is covered by the calculated shadow (figs. 1a, 1b). Moreover, because of its visualization parameters, it fails to enhance those superficial elements parallel to the direction of the illumination source.

Although this problem is solvable when features are few and isolated by just setting the orientation of the light source, it nevertheless becomes difficult to overcome when archaeological elements appear close each to other and are characterized by several orientations. This limitation, well known in archaeological literature (Deveraux, Amable, Crow 2008; Kokalj, Zakšek, Ostir 2011), is widely recognizable in ancient agrarian landscape contexts, like ridge and furrow field systems. In these cases, alignment of the hypothetical light source with the orientation of the field strips produces an obliteration of several features, providing an incomplete and partial visualization of the archaeological elements.

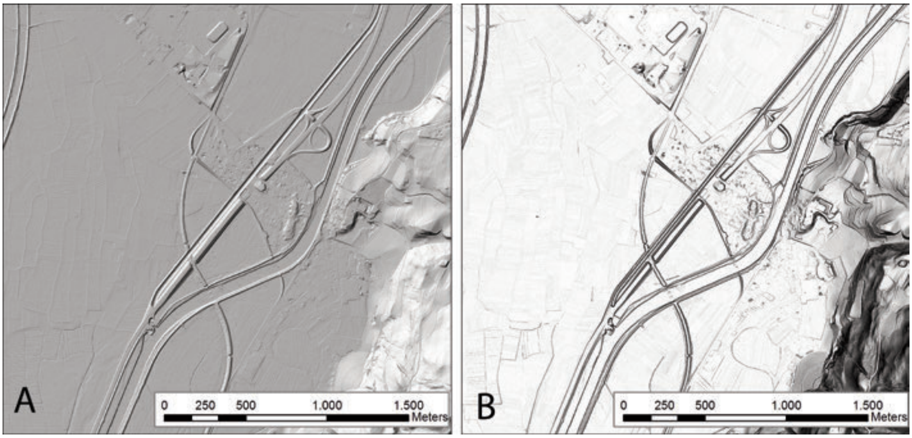

Fig. 2. Hillshade (A) and slope (B) visualization of a transect of Adige Valley, into the 'Piana Rotaliana'. The flat output of those visualizations is clear.

3.2. Slope analysis

Slope analysis calculates the slope value of each cell of the DTM either as percentage slope or degree slope. To these values, constrained between 0° and 90° in degree slope mode, a gray scale is usually applied, assigning black to high degree slope value and white to flat slope values. It could be assumed to be a discrete tool for a preliminary analysis of the data source, but some reservations need to be considered.

Generally, slope value is calculated with a weighted average of the 8 values of the neighbour pixels (3x3) and, although it is not affected by variables as in the case of hillshading, it also has several limitations in archaeological visualization. The average value of the slope, for instance, can produce a general levelling of a hypothetical articulated relief, such as the top area of a hilltop settlement. On the other hand, if applied to very low relief areas, such as alluvial valley bottoms, it has emerged that the result of slope visualization is a flat output that often fails to enhance the presence of significant paleoenvironmental evidence like paleochannels or debris flows (fig. 2).

3.3. Constrained colour ramp (CCR) in alluvial environments

Constrained colour ramps (CCR) are an elementary LiDAR DEM visualization technique which assigns a colour ramp (greyscale or colour scale) to an elevation interval set by the user. The output raster maxi-

Fig. 3. Nave San Rocco, Adige Valley. Aerial ortophotograph. The arrow shows the field system shaped by a meander paleochannel of Adige river.

mizes the details of the chosen interval, but obviously does not represent elements outside that elevation range. Applied with excellent results in low relief areas as valley floors (Challis 2006), CCR allows a defined visualization of geomorphological features (paleochannels, debris-flow, alluvial terraces) and artificial elements such as earthworks or field stripes. On slopes with medium or high gradient, the surface slant makes this application unsuitable, because different colour components are spread along the geomorphological relief and landscape results become illegible.

A good sample of CCR visualization technique has been applied to Adige Valley transect north to Trento, close to Nave San Rocco village. This area is delimitated by the Adige river on the eastern bank and by the Noce stream on the western one. Both these watercourses are now artificially embedded and their courses are very different from the ancient ones (Noce stream, for instance, is now embedded in an artificial channel, but

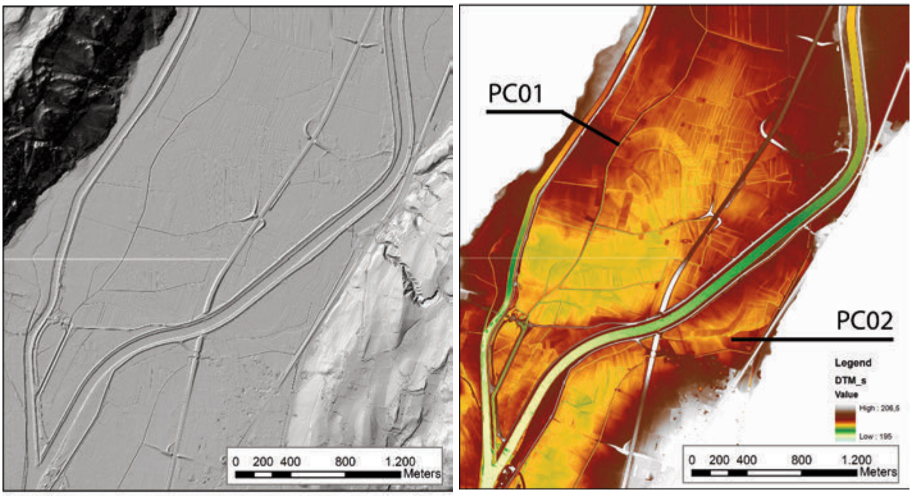

Fig. 4. Nave San Rocco, Adige valley. Hillshade (top) e Costrained Colour Ramp (above) visualization of the area. Paleochannels features (PC01 and PC02) are visible thanks to CCR visualization.

originally flooded into Adige at Mezzocorona, north of Nave San Rocco).

Orchards and vineyards are diffuse here and only few isolated farms are spread west of Nave San Rocco settlement. In this area, field system organization reveals the presence of a palaeobend of the Adige River, but no other geomorphological features are observable by aerial orthophotography (fig. 3). The transect of the valley floor – 2400 metres long north-south – is very flat, and the difference in altitude from the highest northern point to the lowest southern point is only 1,10 m (the range is constrained between 200,80 and 199,70 m asl).

Data analysis from DTM LiDAR visualization of the area is dependent on the technique used in output processing. Like aerial photography, hillshading and slope visualizations can only show contemporary agrarian organization, underlining the flat relief of the surface. Nevertheless, constrained colour ramp can emphasise the microrelief of the area, showing elements that are otherwise unrecognizable. The elevation interval of the images shown above has been set between206.5 m and 195 m asl, and so footslopes are excluded by the raster representation. In this way, at least two paleochannels emerged, and their shapes are clearly visible. Enhanced by a yellow colouration (that indicates low elevation value in the colour ramp applied) we can observe the first Adige palaeochannel east of Nave San Rocco (PC 01) with the relict meander already mentioned and the second one west of the actual course (PC 02), characterized by a curvilinear shape (fig. 4).

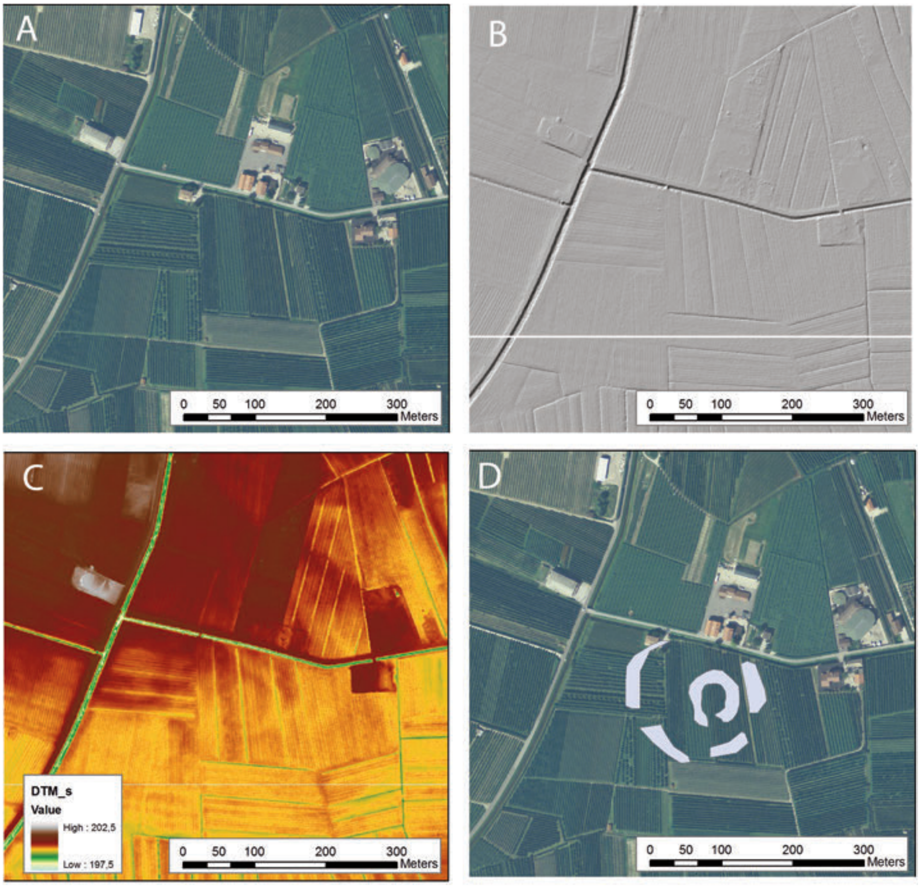

Fig. 5. Nave San Rocco, Prà del Giudice place. Aerial ortophotograph (A), Hillshade (B) and CCR visualization (C). Image D shows digitalization of circular anomalies.

Close to the enhancement of these paloenvironmental evidence-fundamental for landscape geomorphological evolution understanding and archaeological remains distribution (Howard *et alii* 2008) – CCR also reveals good qualities in artificial features recognition. For instance, in the same area, very low relief anomalies are visible thanks to constrained colour ramp. South of the relict Adige paloachannel PC 01, in *Prà del Giudice* place, a double ditched circular enclosure, is visible on output raster (fig. 5).Although field survey did not reveal any archaeological evidence, this feature appears interpretable as a medieval mound, also due to some analogies with other similar and contempouraneus sites (a good example in Campana *et alii* 2009).

However, CCR does not provide the same result in every alluvial dataset. As noted above, in areas like alluvial fans, constrained colour ramp shows its limitations because of the significant slope value of the surface. This effect is observable for instance within the alluvial fan of Caldonazzo, where despite its relatively flat gradient, different colour ramp components are organized on curvilinear altimetric intervals (fig. 6).

3.4. Principal component analysis on alluvial fan slopes: Olle, Novaledo, Caldonazzo

Within remotely sensed image processing, principal component analysis applies a multivariate statistical transformation to an imagery dataset that aims to reduce redundancy of the information and to simplify it in a new, summary group of rasters (Mather 2004, pp. 149-158).

Concerning LiDAR analysis (Deveraux *et alii* 2008), PCA has been applied to hillshading datasets produced by the illumination of the same area from several directions (according to Devereux's procedure, 16 directions

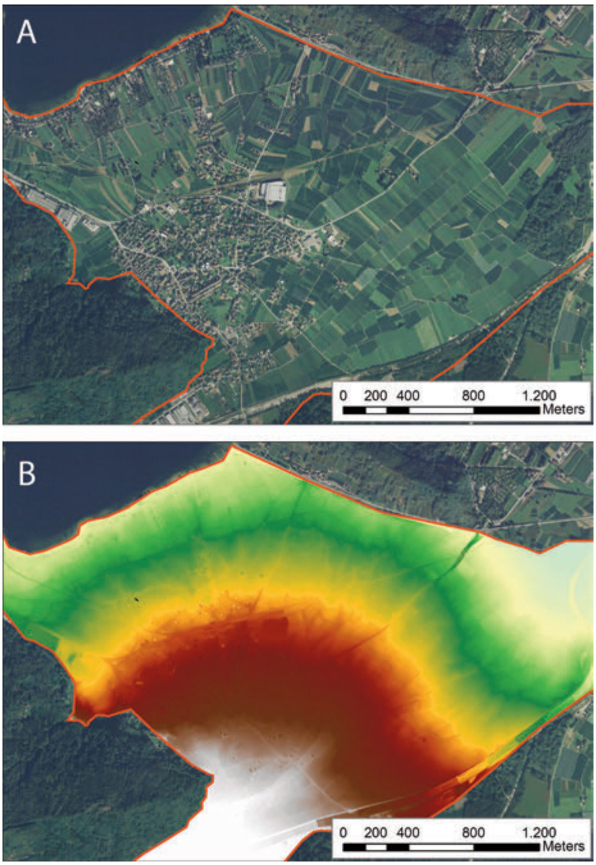

Fig. 6. Caldonazzo. CCR application (B) on Caldonazzo fan surface demonstrates its limitation in visualization of medium acclivity areas.

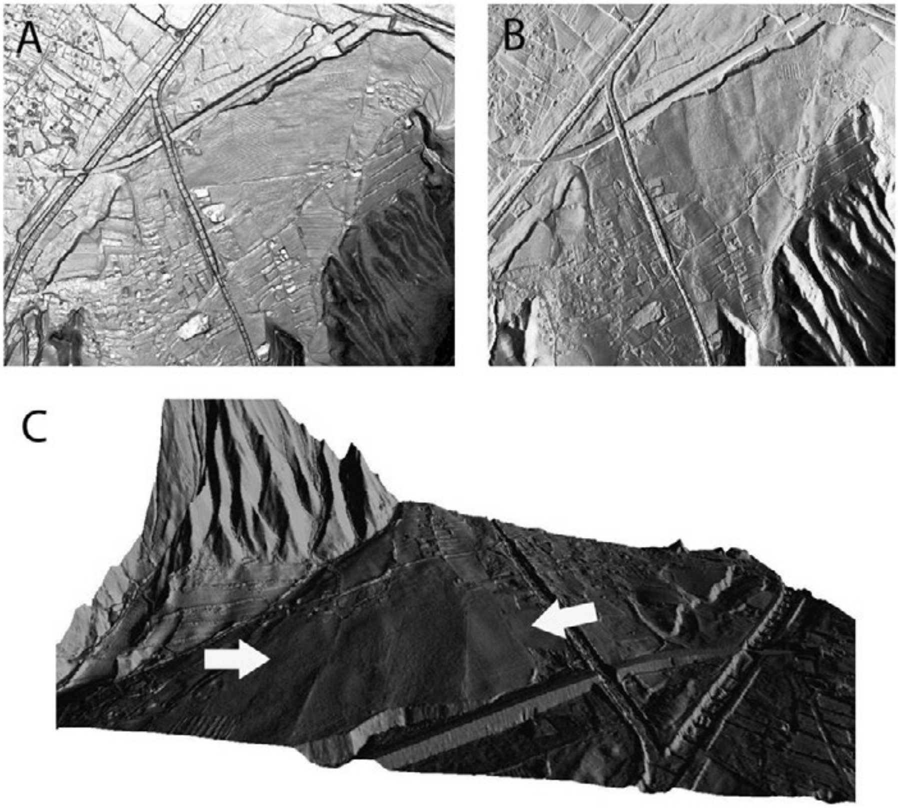

Fig. 7. Spagolle, Castelnuovo. Hillshade (A) e Principal Component 2 (B) visualization of the fan. In PCA result, also in pseudo 3d image, debris flow features are recognizable.

with systematic 22,5° variation in azimuth). This procedure has a double aim: on the one hand, processing 16 hillshades of the same scene, it tries to overcome the failings that hillshading presents in showing the feature aligned with the light source, on the other hand it concentrates at least 95% of total information in only three images (Principal Component 1, 2 and 3) that can be visualised separately or within a false colour multiband raster.

Applied first to the archaeological site of Welshbury, PCA has provided a more comprehensive view of the different archaeological evidence of the area, characterized by several shapes and heterogeneous directions, thereby overcoming the limited and incomplete visualization produced by singular hillshading (Deveraux *et alii* 2008).

Within the APSAT project, PCA has revealed good results in analysing the alluvial fan and the valley floor, where traditional hillshading and slope visualization exhibit many limitations in the recognition of archaeological

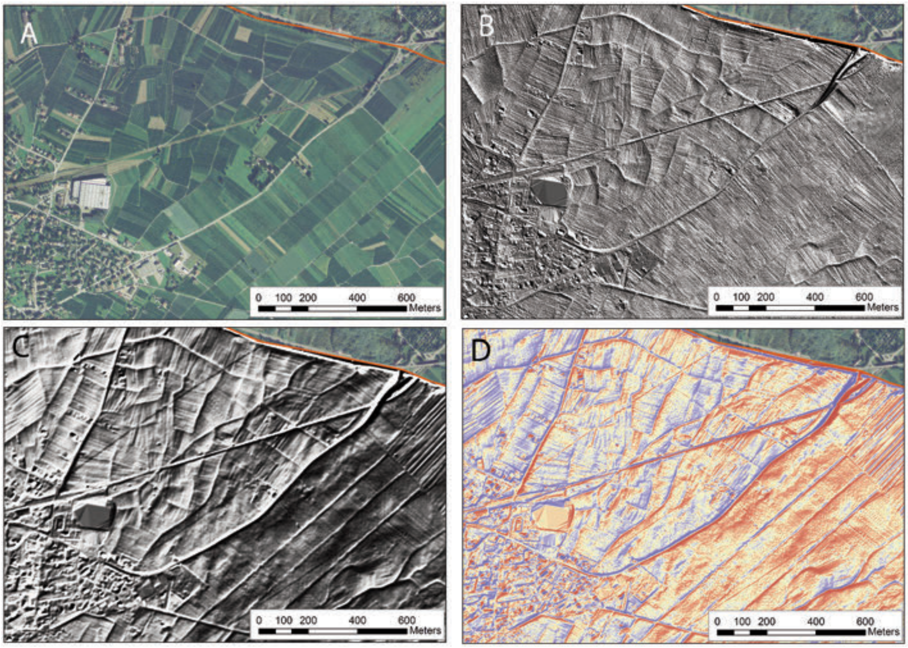

Fig. 8. Caldonazzo Fan. The presence of ridge and furrow shaped elements (yellow arrow) and debris flow features (blue arrow) are visible on the PCA output (C and D). They aren't recognizable in hillshade visualization.

and paleoenvironmental features. Furthermore, PCA has improved the lack of information that constrained colour ramp showed in those areas, as previously underlined.

For our archaeological interpretation needs, a particular PCA method has been developed for obtaining the most effective visualization of such areas, addressing two different goals: the removal of the noise produced by vineyards and orchards lines (very diffuse in alluvial fans) and the enhancement of the microrelief evidence recorded by LiDAR DTM.

The noise reduction was made possible by applying a low-pass filter of 3x3 or 5x5 raster cells resolution to the original DTM (Mather 2004, pp. 181-188). Then, using the EsriArcgis 9.3 *Modelbuilder*, 16 hillshading images were produced automatically with a 22.5° interval. Some adjustments were adopted to emphasize the morphology of the 'depurate' surface: elevation data (z) was multiplied by 2 and an oblique light was set (azimuth=20°). Moreover, to avoid the projection of shadows by the surrounding mountains or hills, a clip of the only valley bottom area was produced and then analyzed. This application method, developed empirically with systematic tests, produced the recognition of several features otherwise not visible by the processing of slope and hillshade visualiza-

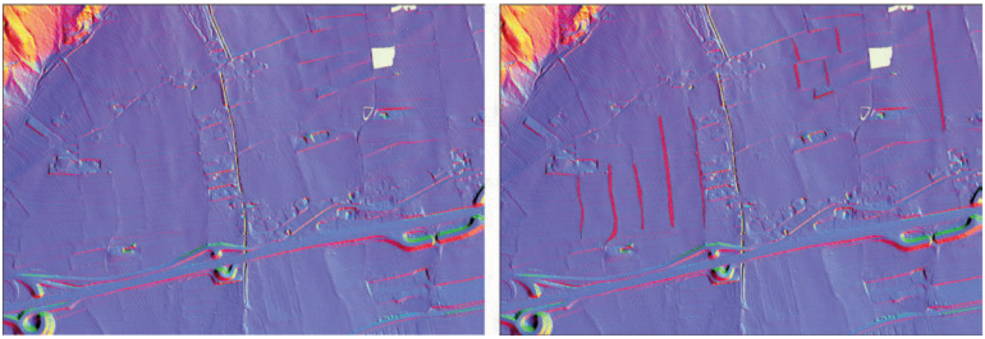

Fig. 9. Novaledo. Thanks to PCA visualization some relict field system boundaries are visible. The image is a composite multiband image of the 1st, 2nd and 3rd principal components.

tion. For instance, at Spagolle of Castelnuovo (Valsugana Valley), LiDAR analysis focused on the portion of an alluvial fan of medium to steep slope in which wide agrarian spaces are present close to some pastures. PCA methodology has allowed the mapping of an ancient flow that was observed in a section during the preliminary survey of the area (fig. 7). In the 16th century this event caused the abandonment of a dwelling (recognized in the same section and subsequently excavated by the local Superintendency) and the modification of the agrarian space of the alluvial fan. Unlike PCA analysis, traditional visualizations did not show this, limiting the understanding of the contemporary field system organization.

The Caldonazzo fan is a very flat alluvial area with low steep slopes, intensively exploited mostly by apple orchards. Thanks to the removal of modern agricultural lines, PCA allowed the discrimination of two different agrarian spaces, not recognizable from their morphological shape (fig. 8). This visualization highlights an area characterized by the presence of 'ridge and furrow' shaped anomalies, organized within a radial parcellary probably dating back to the Middle Ages, whereas in the neighbouring eastern area many debris-flow features are visible: they are the remains of the previous channel of the stream of Centa, which was artificially embedded in 1775.

At Novaledo, PCA analysis made it possible to identify some anomalies relating to the fossilized features of an ancient, regularly planned field system, reused in part by the present-day field boundaries (fig. 9). It seems linked to the farm of San Desiderio, a place cited in a document of 1027 AD that helps to define a chronological development of the agrarian fields of the area.

PCA was applied also for the analysis of the so-called Roman *cen-*

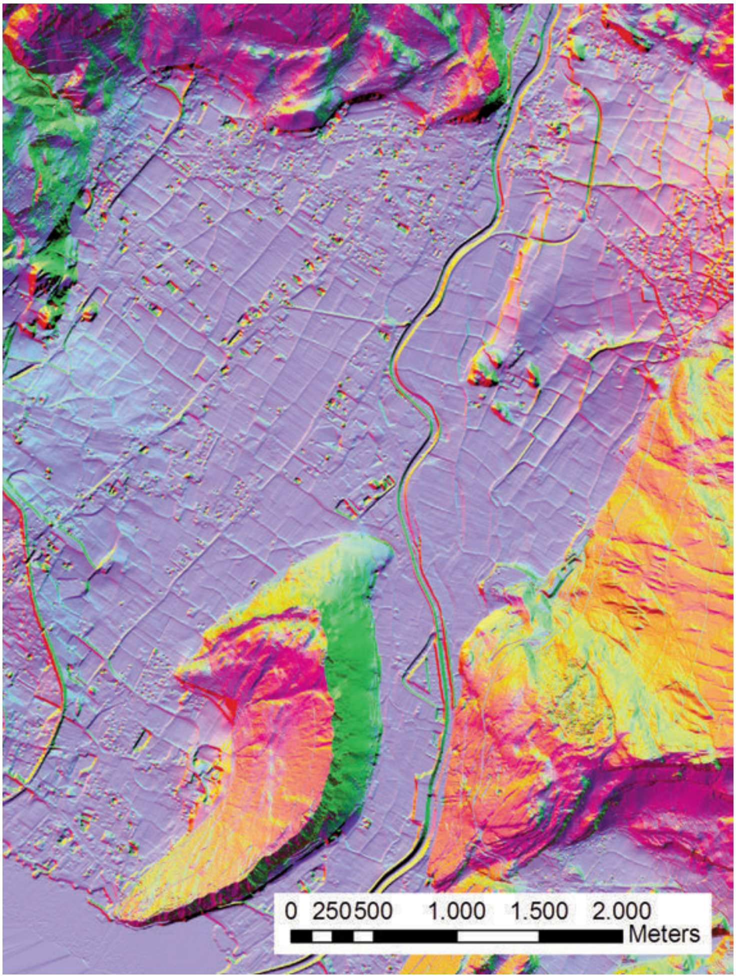

Fig. 10. Riva, Lake of Garda. PCA analysis hasn't shown any palimpsestic agrarian system into the regular parcelization area.

turiatio of Riva del Garda. Their chronology is actually under debate, and they probably date to the high or Late Middle Ages rather than to the Roman period (Brogiolo in press). Within that alluvial plain, PCA has not revealed a stratigraphic modification of the field systems, which appear very defined and conservative (fig. 10). The high degree of hydrogeological stability, quite unusual for an alpine context as that of Riva, could supported that hypothesis. Several valley floors or lateral alluvial fans of Trentino exhibited indeed many violent episodes of geomorphological instability during the last two millennia, mostly at the end of the roman period (Coltorti, Dal Rì 1985; Bassetti 2004).

3.5. Sky-View Factor, Visible Sky and Solar radiation analysis for the analysis of hill-top sites

Sky-view factor (SVF) has been developed within LiDAR DTM analysis for archaeological purposes by the research team of the University of Lubljana and represents a method able to overcome the 'directional' problems of hillshading (Kokalj, Zakšek, Ostir 2011). SVF and Visible sky area geophysical parameters that show the visible portion of the sky from every point of the DTM. The angle of the horizon is calculated along several directions (usually 8 or 16) and within a set search radius. The mean value of the calculated angles represents the portion of the hemispherical visibility. Visible sky is expressed in gradients (from 0 to 100) whereas SVF is a normalized value (between 1 and 0). Based on the same principle (the calculation of visible sky) solar insolation models (SIM) such as diffuse solar radiation, or total solar radiation are tools that are also able to produce more than a single output, offering several visualization choices (Challis, Forlin, Kincey 2011) based on the ability to set different periods of time (a day, a month, a year, etc).

Depending on the surrounding topography, SVF and Visible Sky are just set by the amplitude of the search radius. For the authors, the best amplitude for archeological aims is between 5 and 10 metres, a variation that makes it possible to highlight archaeological remains like walls, trenches, and small quarries.

This technique demonstrated its clear potential in the analysis of Tonovcov Grad, a late antique hilltop site (Ciglenečky 1998). As noted above, SVF allowed the reconstruction of the complete settlement plan, improving the previous geodetic survey and representing an optimal tool for forthcoming research (Kokalj, Zakšek, Ostir 2011).

SVF, Visible sky and Solar radiation analysis represent tools that have wide application possibilities. Nevertheless, empirical research activities have demonstrated that these tools work effectively within hilltop area visualization or on steep slope areas. Indeed, if applied to flat surfaces they lack many geomorphological and archaeological features much like slope and hillshade visualizations.

We could add that these tools appear suitable for intra-site analysis and feature enhancement rather than for landforms analyses. Indeed, the tools based on hemispherical visibility exhibited limitations in detecting geomorfological evidences in flat areas (valley floors, plateaus, alluvial fans). Within intra-site analysis, they have shown appreciable results, allowing the identification of several archaeological features, particularly when compared with the relative lack of information presented by hillshading and slope visualizations.

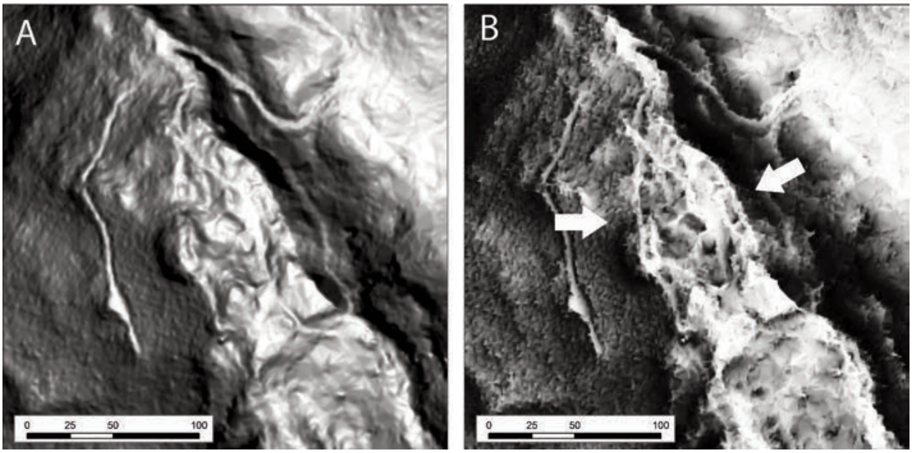

Fig. 11. Monte San Martino, Bleggio Superiore. Slope visualization (A) and visible sky visualization (B). In the latter, possible dwellings organized close to the margins of the hilltop area are recognizable.

An augmentation of archaeological visualization is represented, for instance, in the Visible sky application at Monte San Martino, Bleggio Superiore (fig. 11). The upper area, lying at 1450 m asl, has a north-south length of 250 m with a total surface of 21.000 square meters. The hilltop site – not excavated yet – was fortified during Late Antiquity and the Early Middle Ages, and the remains of a church and some parts of the walls are still visible in the upper area of the relief. In the northern part of the hilltop slope DTM visualization reveals only a few irregularly shaped depressions, but VS (with 10 m search radius) shows the rectangular outlines of some features, localized on the edges of the top area. This evidence, corresponding with small walls or rectangular features on the superficial rocks, as demonstrated by a survey (Colecchia, Forlin in press), can probably be interpreted as dwellings built close to the external walls. Another contemporary castle nearby (San Martino di Lomaso) has shown a similar solution in site planning (Cavada 2010).

In addition, SVF, VS and Solar radiation revealed very good results in the identification of residual walls (maybe small terraces or enclosures)that were not recognizable by slope visualization within an area close to Montesei di Serso, a Bronze age and Iron age hilltop settlement (fig. 12). Those features, which can probably be interpreted as stone field boundaries or enclosures, are visible thanks to a SVF with a search radius of 5 m. Slope analysis however fails to render them, showing only the modern terraced system.

Solar radiation and SVF demonstrate good results also on circular

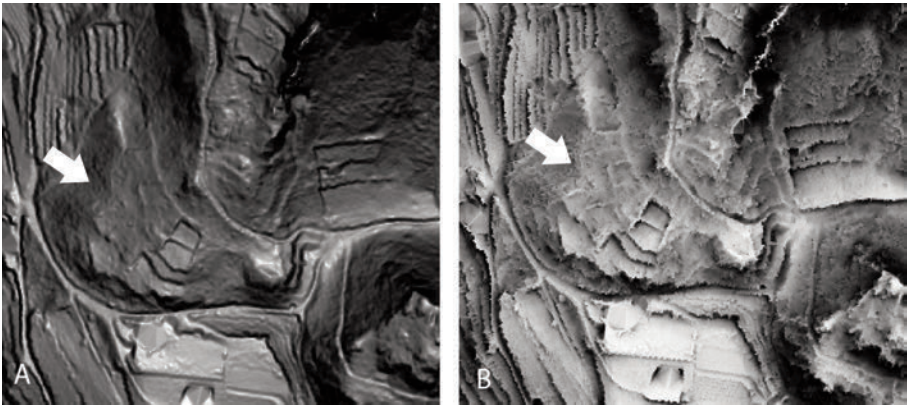

Fig. 12. Montesei di Serso, Pergine Valsugana. An ancient field system, probably subdivided by small dry stone walls, is shown by the Visible sky image (B). Such features are not visible in the slope visualization image (A).

features, like quarries and mine pits. As noted by Ziga Kokali (Kokali, Zakšek, Ostir 2011), analytical hillshading and hillshading PCA are not appropriate where concave circular depressions are in question. Nevertheless slope visualization also appears unsuitable for extracting this evidence, mostly when pits are very small and clustered. An example of such a context is the medieval silver mine area of Monte Calisio (east of Trento). LiDAR DTM here shows an impressive distribution of mine pits spread over area of 50 square km, now completely covered by forest. Circular depressions generally have a diameter between 20 and 3 m, with depths that reach 18-20 m.

Slope visualization of the mine pits generally shows a grayscale circular shape reflecting the steep external rings, sides and bottom (generally flat) of the hole. If it produces a good visualization when pits are isolated, it nevertheless shows a noisy output when they are clustered, and discrimination between the several pits is difficult.

Vice versa, diffuse solar radiation or sky-view factor can enhance the depression of the pits, showing an immediately recognizable black circular feature which is very defined relative to the external space (fig. 13).

4. The DTM visualization tools applied to Trentino's areas: comparing the results

The presented data show how fundamental the use of advanced methods of DEM visualization is, not merely tools such as hillshade or slope.

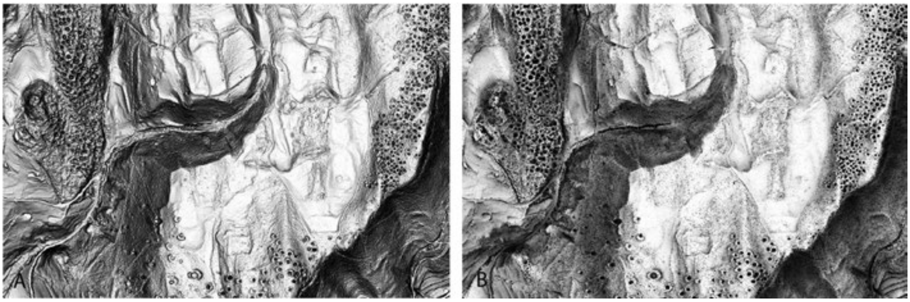

Fig. 13. Fornace. Mine pits of Monte Calisio, Doss del Cuz Place. Sky view-factor denotes a clear result about pits shape and distribution (B), sensibly clearer than the slope visualization.

It has been suggested 'that to gain the maximum benefit from LiDAR data, archaeologists should avoid reliance on a single visualization technique, but rather work with a suite of complementary techniques, recognizing that some are more suited of feature detection and others to the elaboration of the form of features once detection' (Challis, Forlin, Kincey 2011). The richness of LiDAR data needs an articulated toolkit for analysis which is able to enhance and improve archaeological interpretation. If the detection of archaeological features depends, most of all, on their shape and organization, the geomorphological environment also plays a great role in the visualization of evidence. Thanks to the results of this study, we can note that different geomorphological areas require specific analysis tools. Constrained colour ramps seem the best visualization tools for the analysis of alluvial areas characterized by very flat relief, where paleochannel or debris-flow features often lie and are still recognizable on the surface. PCA of analytical hill-shading, if correctly calibrated for archaeological purposes as this paper underlined, is an appropriate method for alluvial fan slope analysis, both for the extraction of geomorphological evidence and the identification of anthropogenic features (such as ancient field-boundaries).

Sky-view factor, visible sky and solar radiation analysis represent the best tools for processing the top areas like hilltop settlements or castles and probably the most appropriate method for intra-site analysis. Despite its limitations, slope visualization (thanks to its immediate application) has to be considered a good visualization for a preliminary LiDAR analysis that has to befollowed by a more accurate study.

The examples shown above have tried to demonstrate the possibilities of articulated LiDAR analysis; however the extraction of the information recorded in LiDAR DTM is not immediate and easy. When applied in such a complex landscape as the Alpine environment, we have to remember that no single technique is able to reveal all archaeological and paleoenvironmental features, but instead an integrated use of the more sophisticated DTM processing tools can provide an appreciable improvement in the knowledge of our archaeological landscape. We suggest to choose different available tools appropriate for the geomorphological characteristics of the analyzed contexts and the shape and topographical organizations of features.

Acknowledgements

I would like to thank Elisa Possenti (University of Trento) and Gian Pietro Brogiolo (University of Padua) for their supervision of my research. I am really grateful to Keith Challis (University of Birmingham), Andy Howard (University of Birmingham) and Mark Kincey (University of Durham) for having introduced me to the LiDAR applications in archaeology. I also have to thank Vince Gaffney and Henry Chapman (University of Birmingham) for their generous hospitality at Vista Centre, University of Birmingham, during my visiting period. Many thanks go to Mark Kincey also for his helpful and fundamental comments.

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