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Mapping Maya Hinterlands: LiDAR Derived Visualization to Identify Small Scale Features in Northwestern Belize

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Abstract

This paper discusses the processes and methods of relief visualization of LiDAR-derived digital elevation models (DEM's) and classification of secondary data to identify archaeological remains on the ancient Maya landscape in northwestern Belize. The basis of the research explores various Geographic Information Systems (GIS) and cartographic techniques to visualize topographical relief. Graphic terrain maps assist archaeologists with predictive settlement patterns. The Relief Visualization Toolbox (RVT 1.3) aids to visualize raster DEM datasets in the predictive identification and interpretation of small-scale archaeological features. This dataset and methodology can be utilized to answer questions of population estimates, mobility costs, and effectiveness of ancient technological agricultural systems.

Keywords

Maya settlement patterns, Maya hinterlands, geospatial studies, LiDAR

The Maya landscape of the Classical period (250-900 CE) was both geographically expansive and diverse. The Maya culture was not cohesive in expression, nor unified under a single King; the Maya polities settled and constructed their landscape in multiple forms, consequentially preventing a single model to characterize them (Chase et al. 2011). A landscape perspective—the study of the interrelationship between human culture and the environment—has been a growing interest between various fields of research. The term landscape is usually defined in a broad and ubiquitous manner, explaining little of the concept and use of the term in a subjective physical, social, and cultural dimension. In this

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paradigm of archaeology, a landscape can best be understood "by what it *does* than what it is." (Whittlesey 1997). Anschuetz et. al. (2001:160-161), provides four interrelated principles to help clarify the landscape paradigm:

1. "Landscapes are not synonymous with natural environments;" they are a conceptual perception constructed and organized by the human experience with the external world.
2. "Landscapes are worlds of cultural product," representing a culture in space and time composed of the daily activities, beliefs, and values which perpetuate meaning to the environment.
3. "Landscapes are the arena for all of a community's activities;" containing the resources to sustain human populations and organize perception and action of a society, thus an area of use and the empty spaces in-between are interconnected within the environment.
4. "Landscapes are dynamic constructions," ever-changing with generations of community perception of space and arrangement in time.

The study of rural settlement patterns of the ancient Maya has been an area of difficulty considering the corpus and diversity of polities. In the past, typical mapping strategies in the Maya Lowlands involved regular pedestrian survey intervals using a mixed block transect documenting settlement within a set distance from either side of a baseline between major sites. These transects have involved narrow swaths collecting spatial data with various forms of mapping from tape and compass, Global Positioning System (GPS) units, and/or a total station; more expansive survey coverage has been too expensive and laborious to be possible (Robichaux 1995; Lohse 2001; Hageman 2004; Cortes-Rincon 2013; Chase et al. 2014).

Understanding settlement patterns of ancient cultures in response to the landscape has long-been the goal of archaeologists. With the drastic advancement of technology during the 21st-century, full-coverage mapping of broad areas has not been addressed until the advent of Geographic Information Systems (GIS) and remote sensing techniques, such as Light Detection and Ranging (LiDAR). GIS encompasses a series of specialized technological based programs used to create, analyze, and display geospatial data. Remote sensing is the art and science of collecting ground-based data using remote sensors mounted on airplanes or satellites. In the past decade, these technologies have become ever-more accessible to a wide range of disciplines. Mayan archaeologists have entered new domains of studying settlement spaces with the use of GIS and LiDAR by enhancing visualization of structures and mapping Maya sites' organization (Kvamme 2003; Masson 2014; Willisa et al. 2017; Ringle 2017). These tools have provided data valuable to understanding the Earth's surface and it's changing landscape.

Archaeologists today use LiDAR data to enhance three central themes of archaeological practice and methodology: (1) to efficiently map, document, and manage known and unknown disappearing ancient sites and landscapes; (2) to understand environmental formation processes in diverse landscapes; and (3) to provide more efficient modes of cultural heritage management for preservation and accessibility to researchers and the public (Hritz 2014; Schwerin et al. 2016).

These methods help gain a deeper understanding of Maya polities' settlement patterns, interaction, and development, and their influence and exploitation of natural resources.

Initial applications of LiDAR in Mesoamerica have been carried out extensively as part of the Caracol Archaeological Project to reconstruct and characterize settlement patterns in Belize (Chase et al. 2010, 2014). The majority of the LiDAR surveys in the Maya region have been focused on large city-centers including Caracol, Mayapan, Tikal, El Mirador, and many other elite sites. These studies have included a small section around the sites; however, the research has largely ignored the hinterlands—the area lying beyond what is known or explored. This has created a clear gap in estimations of population size, spatial distribution, and further understanding relationships between regional centers and their supporting peripheral sites. LiDAR has provided an invaluable approach to map ruins, which are widely distributed and densely covered by Belize's diverse environment, but have lacked applications to the Maya hinterlands. This data acquisition process needs to be addressed in the regional study.

A long-term multidisciplinary research collaborative, in the Orange Walk District of northwestern Belize, has been operating under the auspices of the Programme for Belize Archaeological Project (PfBAP), under the direction of Dr. Fred Valdez Jr., since 1992. PfBAP has been an umbrella for a variety of sub-projects, which have ushered the continuation and success of archaeological research in the region (Valdez 2007). This research is set in the Rio Bravo Conservation Area – a continuation of the Yucatan Platform – underlain by limestone and marl deposits. The principal topography consists of a series of escarpments aligned southwest- northeast guiding three low lying drainages of the Rio Bravo, Booth River, and New River systems. Ecosystems range

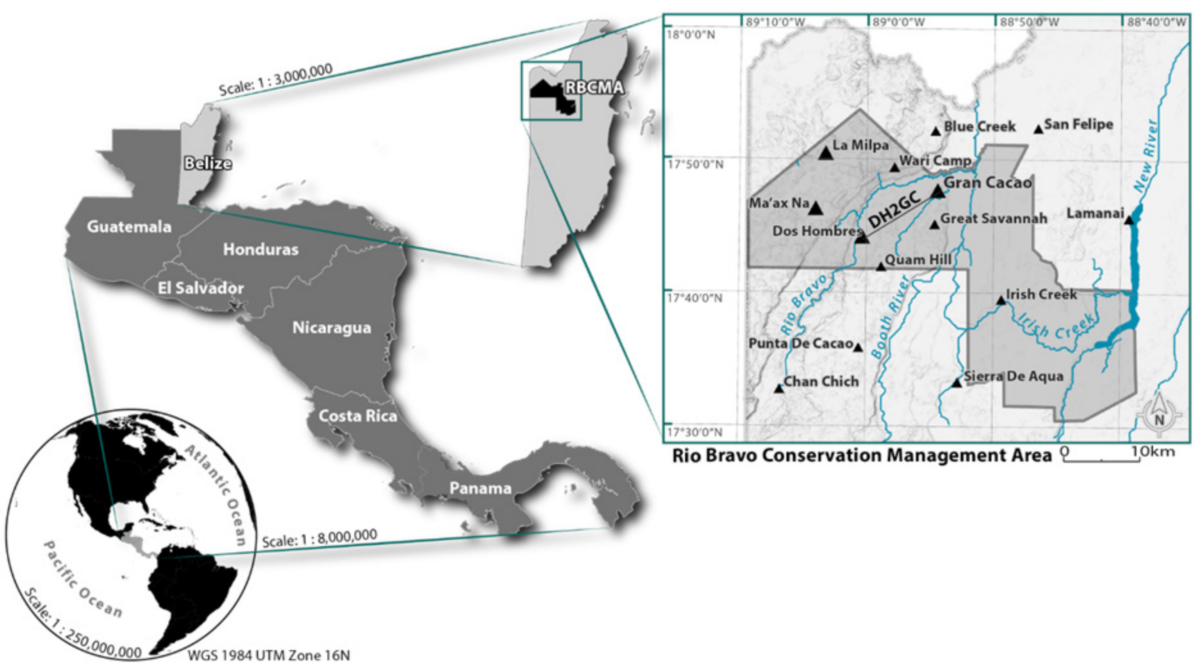


Figure 1. Location of DH2GC in the Rio Bravo Conservation Management Area, Belize, Central America.

from a complex mosaic of vegetation types, but is classified primarily as lowland broad-leaved moist forest.

The Dos Hombres to Gran Cacao Archaeology Project (DH2GC) has been conducting research on the Maya hinterlands, under the auspices of PfBAP, since 2009. DH2GC is a 12-km transect between two Maya city-centers: Dos Hombres and Gran Cacao. In 2016, an interdisciplinary grant allowed PfBAP researchers to acquire LiDAR for part of their research areas. LiDAR has allowed for this project to expand into new unknown reaches of the Maya Lowlands and has extended the DH2GC project to connect with other unknown site centers. For this paper, the authors have focused on the hinterlands near the center of Dos Hombres (Figure 1).

What is LiDAR?

LiDAR is a remote sensing technique, also known as airborne laser scanning (ALS), which has become a leading tool for generating three-dimensional datasets of the Earth's surface and it's land cover characteristics. Airborne LiDAR sensors deliver light in the form of pulsed laser to measure variable time and distance of multiple pulse returns from the Earth's surface. Additionally, these sensors apply an arbitrary scaled measure of intensity of light return to aid with feature detection (Fernandez-Diaz et al. 2016). This provides advantages when studying in tropical rainforests due to the dense vegetation and canopy cover that can conceal culturally modified landscapes from traditional survey methods and/or aerial imagery.

LiDAR data is represented in three main forms: a point-cloud, a Digital Elevation Model (DEM), and/or a triangulated irregular network (TIN). Each form of representation can hold information for a variety of purposes. For example, a point cloud can produce a DEM (bare earth) or a digital surface model (canopy), which can be used for surface, vegetation, or structural analysis. For this research, a high-resolution (0.5-meters) DEM was extracted from the LiDAR point-cloud to provide a base layer for multiple types of visualization manipulation using different algorithmic techniques.

In the interest of maintaining the original integrity of the data along with unfamiliarity with fundamental software techniques, visualization manipulation of DEMs has traditionally been avoided by cartographers and GIS specialists (Patterson 2006). A DEM is inherently a representation of the Earth's surface and manipulation of the data further depicts an abstract reality by portraying features more prominently than others or not at all (Gartner 2014). This abstraction can create a powerful map for use by archaeologists; however, significant studies in image-processing techniques of LiDAR data have been primarily focused in other disciplines. As archaeologists are becoming more adept with geospatial programs and gaining a deeper understanding of LiDAR methodology in archaeological research, a number of authors have published studies on new analytical techniques. This paper discusses the application of airborne LiDAR and specific visualization techniques of DEMs, to assist Mayan archaeologists with identifying, interpreting, and mapping small-scale archaeological features in Mesoamerica.

DATA AND METHODS

Data Acquisition and Post Processing

Ground-based mapping on the hinterlands near Dos Hombres has been a part of the DH2GC archaeological field school since 2009. As previously mentioned, a baseline connecting the site of Dos Hombres to Gran Cacao has been established with a grid of perpendicular lines spaced

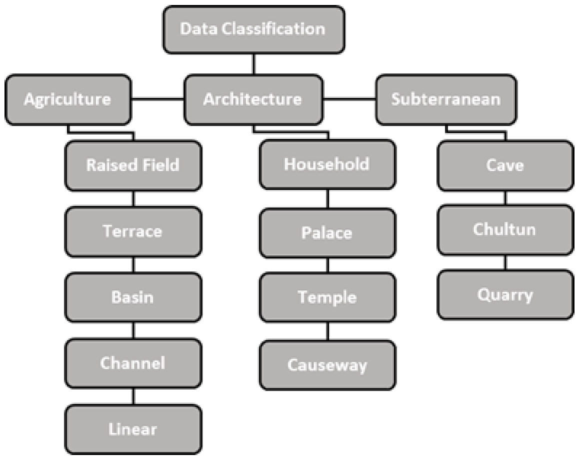


Figure 2. A Classification Scheme of Field Collected Data in the Dos Hombres Hinterlands.

every 50-meters. Students and researchers have been mapping features and household groups using a variety of techniques, such as tape and compass, GPS units and/or total station. Nomenclature of groups and features follow the grid path. For example, a household group may be assigned a grid coordinate of "N150E75", meaning this group is 150-meters north of the zero point and 75-meters east of the N150 point. Mapped landscapes primarily include agricultural, architectural, and subterranean features (Figure 2). At the HSU Archaeology Research Laboratory (ARL), students have processed data excavated from the site including lithics, ceramics, soils, and other cultural material to characterize further the Maya use of the landscape in the region.

Between June 2nd and June 4th, 2016, a total of 274.6 km^2 of LiDAR was flown by the National Center for Airborne Laser Mapping (NCALM) for a consortium of archaeologists working in northwestern Belize. The LiDAR data was collected with an Optech Titian terrain mapping system set to a pulse repetition frequency of 175 kHz and flown with a swath width of 600-meters (Table 1). The processed LiDAR data produced a DEM gridded to a 0.5-meter resolution. Full details of the data collection and processing methods for this work are discussed elsewhere (Fernandez-Diaz et al. 2016).

LiDAR DEM Visualization Methods

The methods of LiDAR DEM visualization took on a multidisciplinary approach, encompassing image processing techniques developed by a diversity of researchers in various fields. General goals were to enhance terrain topography while illuminating small localized features.

Table 1. LiDAR scanning parameters of the Blue Creek Region (Belize).

Scanner Type	Optech Titian
Platform	Piper Aircraft
Date	July 2–4, 2016
Swath Width (m)	600
Flying Height (m)	570
Percent Overlap	50
Pulse Repetition Rate (kHz)	175
Spatial Resolution of the Final Elevation Model (m)	0.5

For interpretation, we utilized a paired system where at least two researchers would agree on the outcome. First, a remote sensing analyst, who is proficient in LiDAR and various visualization methods, helped with productibility. Second, a field researcher who has ground-based knowledge saves time and effort in mapping and additional analysis.

Relief shading and topographic enhancement

Relief shading, also referred to as analytical relief shading, of DEM's has been used by archaeologists as an auxiliary tool for mapping culturally modified landscapes; however, this visualization technique poses a variety of limitations (Hesse 2010). In the case of this research, the detection of potential archaeological features depends to a large degree on the chosen illumination angles. Researchers like Zakšek et. al. (2011: 398), acknowledge this limitation and address two major drawbacks: "identifying details in deep shades and inability to properly represent linear features lying parallel to the light beam".

The first phase of LiDAR visualization involved enhancing basic relief shading with conventional cartographic terrain techniques. As an attempt to do so, we created two curvature raster's (profile and planform) extracted from the 0.5-meter DEM. Curvature is defined as the second derivative of the slope and displays the shape or curvature of a surface as either concave or convex; profile and planform address the directions in which the curvature of a landform can be calculated either parallel or perpendicular (ESRI 2016). The curvature function has been used most widely in geomorphology and cartography to enhance topographic detail and visualize high frequency information, such as change in landforms and their characteristics on medium resolution DEM's (Kennelly 2008; Štular et al. 2012). Although, the use of this function on our high-resolution DEM

Table 2. Software and settings used to generate the various visualization type.

Visualization Type	Software	Settings
A. Relief Shading/Contours	ArcMap 10.5	315° Sun azimuth, 45° Sun elevation, 1m contour
B. Principle Component Analysis (PCA)	RVT 1.3	16 directions, 35° Sun elevation
C. Slope Gradient	ArcMap 10.5	No parameters required
D. Sky-View Factor (SVF)	RVT 1.3	16 directions, 5-meter radius
E. Anisotropic Sky-View Factor	RVT 1.3	Same as SVF with 355° direction of anisotropy
F. Openness — Negative (ONEG)	RVT 1.3	32 directions, 20-meter radius (taken from SVF)
G. Openness — Positive (OPOS)	RVT 1.3	32 directions, 20-meter radius (taken from SVF)
H. Local Dominance (LD)	RVT 1.3	Min. radius 10 – Max. radius 20
I. Red Relief Image Map (RRIM)	RVT 1.3/ArcMap	LD settings with slope raster
J. RRIM/Local Dominance	RVT 1.3/ArcMap	LD settings & yellow histogram with slope raster
K. Local Dominance/OPOS	RVT 1.3/ArcMap	LD settings & yellow histogram with OPOS

to visualize and identify small-scale features had limiting results. The application of planform and profile curvature modifications to our DEM, for example, exaggerated ground return noise and thus obscured archaeological features, a limitation also emphasized by Štular et al. (2012).

DEM manipulation methods

The second phase of this research involved evaluating more nascent and complex visualization methods. The RVT 1.3 toolbox was used as a basis for this project to calculate a variety of analytical image processing techniques because of its accessibility and ease of producibility (ZRC SAZU 2010). Conducting our own literature review and personal trials identified key advantages and disadvantages for our project area. These techniques included principal component analysis of analytical relief shading from multiple directions (Devereux et al. 2008), slope gradient (Doneus and Briese 2011), sky view factor (Kokalj et al. 2011), positive and negative openness (Yokoyama et al. 2002), and local dominance (Hesse 2016) (Table 2).

Principal Component Analysis (PCA) summarizes and combines the results of several analytical relief shadings from multiple directions (Devereux et al. 2008). Relief shading in 64 directions can be used, but 16 provided best results for this research. RVT 1.3 was used to create an 8-bit image showing the first three components as an RGB image (Red-315°, Green-15°, and Blue-75° azimuth with 35° sun elevation).

Slope gradient is the first derivative of a DEM, and is defined as the maximum amount of rise (or change) in elevation (Štular et. al. 2012). It is typically displayed in a greyscale scheme where darker areas represent steeper slopes regardless of rising or falling. A disadvantage of this image is that it is hard to distinguish between positive/convex (e.g. protuberance) or negative/concave (e.g. depression) features (Kokalj et. al, 2017). This dataset was used frequently in our research because it retains a smoothed representation of ground topography with reduced noise, which is straightforward to interpret and works well when combined with other forms of visualization.

Sky View Factor (SVF) is an alternative method of relief mapping which represents the proportion of the sky observable from a point on the earth surface assuming equal (diffuse) illumination from all directions within a hemisphere (vs. direct lighting in relief shading) (Kokalj et al. 2011). Settings can be switched to specify a maximum number of search directions within a defined search radius (pixels). Certain antistrophe can be applied to the SVF to emphasize brighter directions and highlight small features in flat areas. A search direction of 8 with a radius of 10-pixels (10-meters) was used for the SVF and 355° of anisotropy for the Antistrophic SVF.

Openness is similar to SVF, in that it is also a method which uses diffuse lighting, but considers the entire sphere for illumination instead of just the celestial hemisphere (Yokoyama et. al. 2002). Openness can be calculated by determining the mean zenith angle (positive) and the mean nadir angle (negative) of all horizons (Kokalj et. al. 2017). With a search direction of 32 and a radius of 20 pixels (10-meters), two positive and negative openness grayscale images were produced.

Local Dominance (LD) is computed by calculating the dominance of an observer in each pixel in relation to the surrounding pixels with a specified height and a defined search radius (Hesse 2016). LD does not utilize the Sky View Factor, but results in a similar, if not the same, visualization as an inverse negative openness image, where high values are displayed as protuberances and low values as depressions. Unlike openness however, a minimum radius can be specified for LD which helps reduce the abundance of small-surface noise and creates a smoother image (Kokalj et. al. 2017). It was appropriate for this research to 1) specify a minimum radius (above 10) and maximum (below 20) to highlight small prominent localized features/depressions, and 2) adjust the histogram range to isolate dominant features.

Combining multiple raster's

The final phase of this visualization process addresses the advantages of combining multiple raster's datasets to create detailed topographic images and highlight certain features. Our research primarily focuses on settlement and distribution of small localized structures in a semi-flat topography—thus an emphasis on topography and low-lying structures became an interest for this process. For example, a combination of a slope raster draped over local dominance with a yellow histogram stretch can distinguish convexities and concavities on the topography while highlighting low-lying structures. A slope raster was chosen as a base layer because of its smoothed texture and ability to display the change in slope despite size of feature. Local dominance was chosen because this type of visualization is best for highlighting protuberances and depressions in a light to dark grayscale and, when switched from yellow to black, can contrast well with the slope base-layer.

This same effect can be achieved by subtracting the Openness Positive from an inverted Openness Negative underlaid beneath a red colored slope raster—a technique coined Red Relief Image Mapping (RRIM) by Chiba et al. (2008). With the raster calculator function in ArcGIS, this simple calculation of image combination can be achieved. Combining multiple images is convenient for visualization purposes because they can easily be viewed in other image processing softwares and produce quality maps for print. It is important to note that with multiple combinations, visualizations gain a greater level of abstraction from reality.

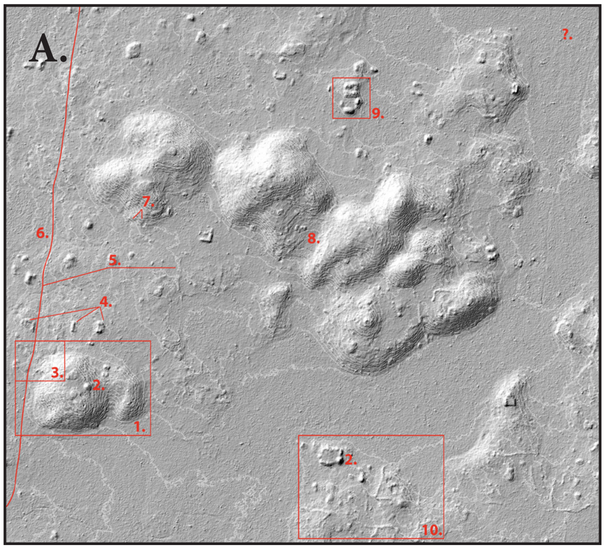
RESULTS AND DISCUSSION

Our methods of visualization have followed a long chain of steps. We started with a LiDAR-derived digital elevation model representing numerical values of elevation as rasterized pixels, manipulated these values using complex

Table 3. Assessment of visualization techniques for representing selected archaeological features in the region.

	Households	Depressions	Causeways	Terraces	Raised Fields	Linear
Relief Shading	+	-	+	o	o	-
PCA	+	+	++	+	o	+
Slope	+	+	o	+	-	+
SVF	+	++	+	++	-	++
Openness — Negative	+	-	-	-	-	+
Openness — Positive	++	++	++	+	+	++
Local Dominance	++	++	++	+	++	++

- *not suitable*; o *indistinct*; + *suitable*; ++ *very suitable*



1. N950 – Ceremonial Site
2. Temple/Shrine
3. Quarries
4. Households
5. Maya Road
6. Modern Logging Road
7. Water Basins
8. Sloped Terraces
9. Courtyard Group
10. Courtyard/Agriculture

? Possible Raised Fields

Figure 3. relief shading overlaid with 1-meter contours as a basic form of terrain representation. Figure (A.) displays field collected data on the hinterlands near Dos Hombres for comparison with the following maps.

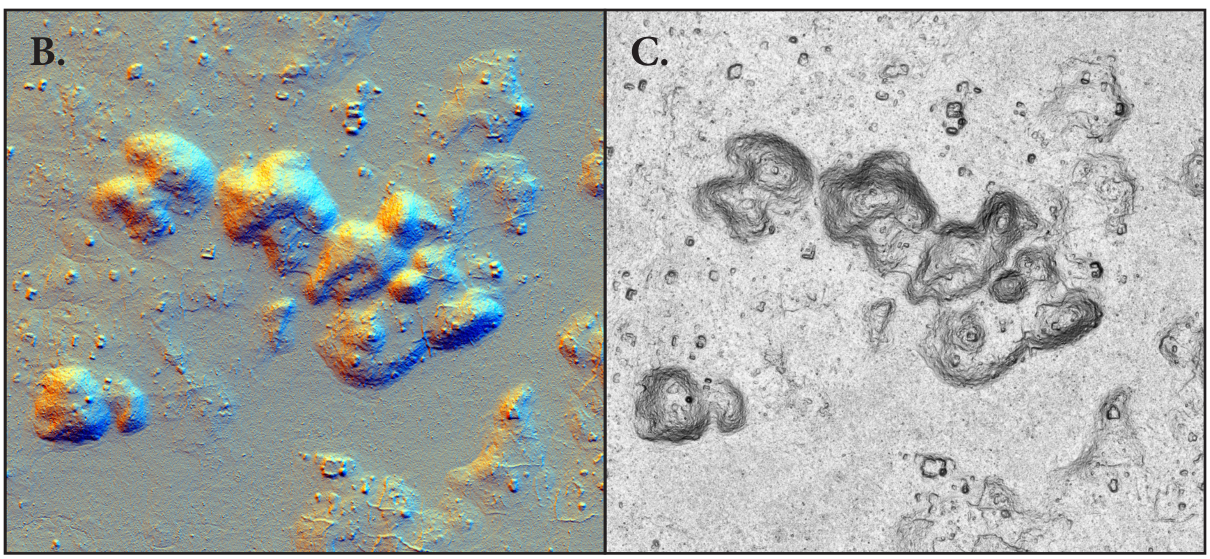


Figure 4. Principal component analysis (B.) and slope (C.) enhances topography and terracing.

analytical techniques with RVT 1.3, and displayed these images with greyscale/color mapping and histogram stretch in ArcMap 10.5 to examine individual traits and advantages for each technique in our project area (Table 3, Figure 3–6).

As a guideline to follow for visualization, analysis, and interpretation, we suggest beginning with a natural relief shading and an overlaid color-cast DEM. This form of visualization, despite its limitations, is most easily discernible, and a color-cast DEM helps understand levels of elevation and hierarchy of landforms. It becomes quickly natural to identify certain features when one compares this visualization to ground-based research and field-collected geospatial data. Additionally, relief shading in multiple directions

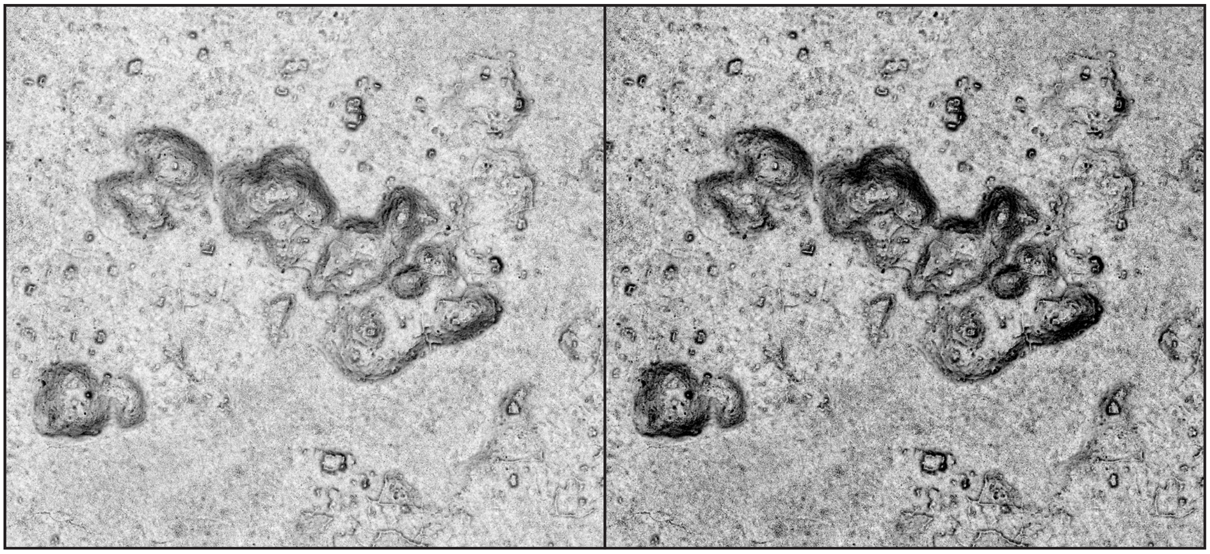


Figure 5. Sky-View Factor (D.) and Anisotropic Sky-View Factor (E.) accentuates ground texture.

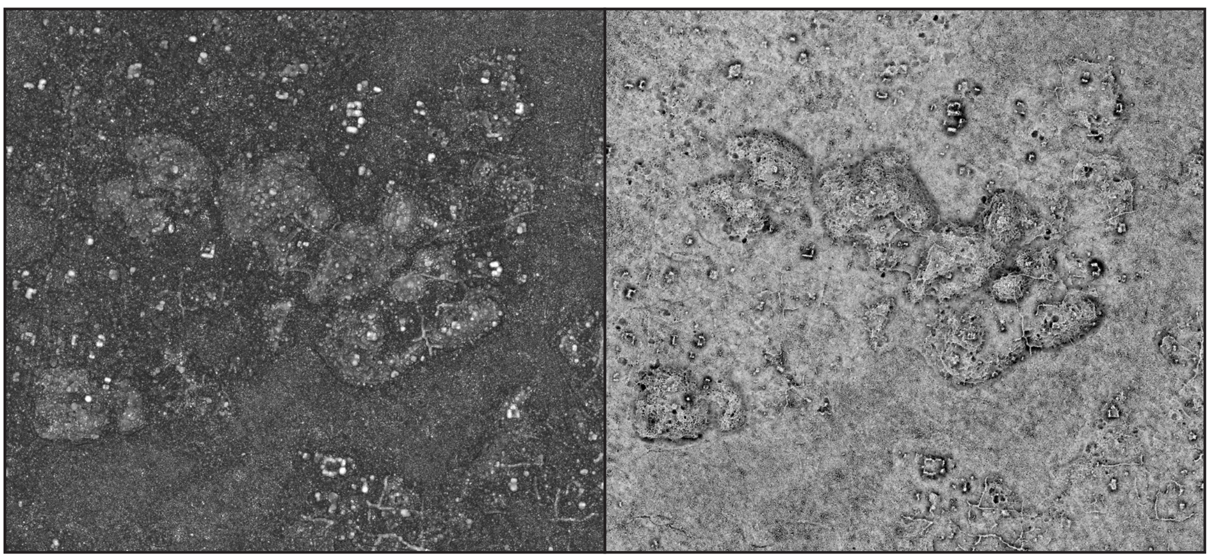


Figure 6. Negative Openness (F.) and Positive Openness (G.) Enhances Convexities and Protuberances.

can help portray the general topography and aspect while depicting most structures on the landscape. In our project area, a prominent mapped temple atop of N950 knoll stands out in conical form and later investigations confirm a second previously unknown temple to the southeast.

In an area of moderate to steep terrain, such as our region, a slope raster helps to enhance topography and low-relief structures. This dataset was frequently combined with other images because of its smoothed texture and reduced surface noise. However, we argue this visualization lacks attention to detail in lower-elevation areas like *bajos* and flood zones due to its smoothed nature.

Sky View Factor (SVF), on the other hand,

Table 4. Assessment of visualization techniques for representing general cultural landscapes in the region.

	Suitability (+) →					(–)
Agriculture	Slope	Local Dominance	SVF	PCA	Openness Negative	
Architecture	Local Dominance	Slope	SVF	Openness Positive	Openness Negative	PCA
Roads	Local Dominance	Openness Positive	SVF	PCA	Slope	Openness Negative
Soil/Vegetation Differences	Openness Positive	SVF	PCA	Openness Negative		

provides a visualization quite the opposite of slope because it accentuates the ground texture; however, structures sometimes become more difficult to interpret in SVF because of the increased surface noise (Štular et. al. 2012). Anisotropic Sky-View Factor (ASVF) became preferred because it accentuates differences in ecological zones; not to say ASVF is detecting vegetation types, but it is increasing surface texture, which is a result of differences in soil texture from vegetation and can be visualized.

The use of positive openness highlights topographic convexities, e.g. ridges of structures and rims of depressions; however, in a relatively flat area we suggest negative openness does not work well to highlight the lowest parts of concavities (Yokoyama et. al. 2002). These images do not display the topography or surface texture as well as the SVF, but work primarily well for visual feature detection of protuberances. Both visualization types could be used in the case of automatic feature detection; however, we suggest local dominance because of its minimum radius setting and reduction of surface noise (Kokalj et. al. 2017).

Respectively, local dominance is useful for most terrains and to identify culturally-modified features on the landscape; however, this visualization lacks a sense of depth, texture, or topography (Hesse 2016). Local dominance becomes useful for feature detection and classification of low and high points, but settings need to be adjusted appropriately for user preference and best outcomes. This type of technique is also useful for highlighting possible low-lying raised fields, which are not distinguished well in any other form of visualization. Further field research is required to confirm this interpretation (Table 4).

CONCLUSION

Applications of LiDAR visualization in the field of archaeology have been addressed by a limited few. Various authors have published nascent techniques of LiDAR visualization in archaeological research, but the field is far from being fully explored. This paper presents a comprehensive look at LiDAR-visualization applications and findings, which will be useful for much deeper and valuable analysis. One aspect in which improvements can be expected is the optimization of data processing, with the goal of automatically detecting anthropogenic features for archaeological prospection, protection, and heritage management. High-resolution DEM's derived from airborne LiDAR are becoming increasingly available on a regional and national scale, and have emerged as a valuable new data source in archaeology.

The aforementioned outlined processes will help Maya archeologists with preparing, interpreting, and analyzing various LiDAR-visualization techniques for their project area. The process is simple and can be achieved by any researcher with an understanding of GIS fundamentals. This research is in its preliminary stages, but further geospatial analysis will shed light on size and boundary (if any) of Maya sites, the heterarchical relationship between commoner settlement and regional centers, landscape settlement patterns, and exploitation of natural resources.

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