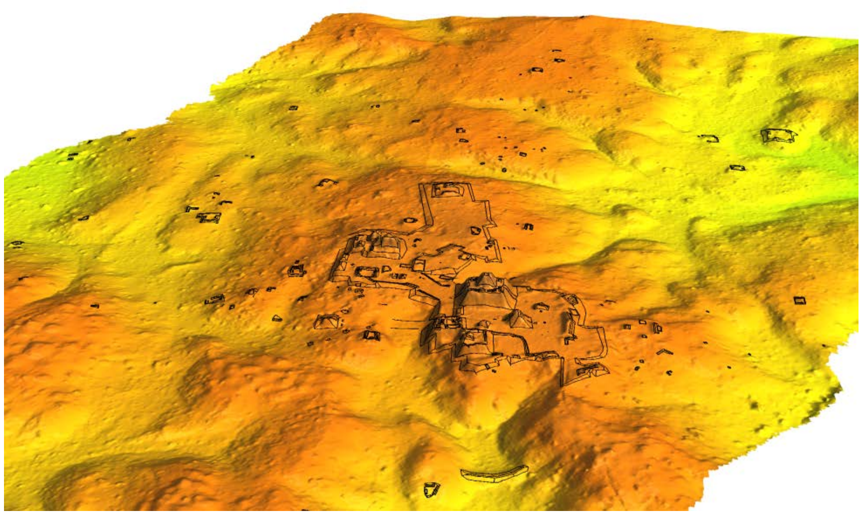
Holmul Archaeological Project

Preliminary analysis of 2015 LiDAR DEM of Holmul site Guatemala



Francisco Estrada-Belli, Tulane University, Dept. of Anthropology, New Orleans, LA 70118
email:franciscoeb@gmail.com
31/08/2015

Contents

Introduction 1

Previous archaeological work 1

Analysis of LiDAR data 4

LiDAR-aided on-screen editing of previously mapped structures 6

LiDAR-aided on-screen digitizing of new sites and features 14

Conclusions 23

References 26

Preliminary analysis of 2015 LiDAR data coverage of Holmul archaeological site, Peten Guatemala.

Francisco Estrada-Belli (Holmul Archaeological Project, Tulane University)

Introduction

In the Spring of 2015, NCALM flew their new Titan MW airborne LiDAR instrument over the Holmul site, collecting a data set of terrain data which was shared with the Holmul Archaeological Project. The dataset consisted of a bare-ground DEM raster or Digital Elevation Model with on-the-ground pixel resolution of 0.5 m. The Holmul dataset covers an area of 48 km2 shaped as a 2 km wide (northwest-southeast) and 30 km long (southwest-northeast) transect. The southernmost 7 km of this area were limited to 1km in width. The location and orientation of this dataset was remarkably well selected to include the main ceremonial centers in the region, Holmul, Cival, and several of their minor centers, some of which had previously remained hidden under dense tropical forest. At the onset of the analysis, it was believed that the Holmul LiDAR data could offer the opportunity to test 1) the greater efficacy in site discovery of the new **Titan MW** instrument and concomitantly 2) the accuracy of existing archaeological maps, 3) the validity of a pre-existing satellite image-based methodology for predicting the presence of buried architecture under one of the more pristine tracks of tropical forest in Mesoamerica.

Previous archaeological work

Since the year 2000, the Holmul Archaeological Project has investigated the Classic Maya city of Holmul and a surrounding. The initial study area was a 10x10km tile that was later extended to a polygon of approximately 300 km2 to include new sites and settlement potentially related to the two main centers in the region, Cival, for the Preclassic period (1000 BCE-300 CE) and Holmul for the Classic period (300-1000 CE). As of 2015, large stretches of upland terrain surrounding the two main centers have been surveyed. Field crews of 5-6 members recorded up to 11 so-called minor centers with monumental architecture and hundreds of residential structures over 11 consecutive campaigns (see Holmul Archaeological Project 2015, see also Estrada-Belli 2002, 2011) . The methodology used by the survey team involved 1) GPS navigation to locate the sites or settlement features followed by 2) tape-and-compass field mapping. 3) Total station survey was reserved for the sites with large monumental buildings arranged around plazas (minor centers). All the ceremonial sites cores were mapped by total station while some of the smaller ones (Hahakab and Sisia') had been preliminarily mapped by tape-and-compass. One site (Chanchich) has been mapped by another project's team (Fialko 2005) and was yet to be surveyed with total station by this project.

Years of excavations in the site cores and residential zones provide a slew of data to aid in the assessment of settlement chronology. Prior to the Holmul Archaeological Project campaigns of 2000-2014, a Harvard project led by archaeologist Raymond Merwin, conducted three seasons of excavations at Holmul between 1909 and 1911 (Merwin and Vaillant 1932), providing the initial chronology for this site and area. At remote sites, when excavation data were unavailable, especially in the initial stages of survey, surface material, which may be either by-product of natural erosion or looters' excavations, can be used to estimate the timing of a site occupation.

Site discovery in the Holmul region.

Holmul and Cival were known prior to the beginning of the Holmul Archaeological Project. Holmul had been known since at least 1909. Cival was also known since 1909 but only as the unspecified location of an early stela photographed by R.E. Merwin during the 1909-11 campaigns (i.e. near Holmul). The location of Holmul was marked on Guatemalan's IGN 1:50,000 map sheets by government officials, but its marker was soon found to be about 3km to the south of its actual location. Cival's location on government maps was marked 7km off to the east and spelled differently from the original report (i.e. Seibal II). Finding Holmul, however was not a problem because of a logging trail that leads directly to it from nearby Yaloch Lake where it connects with another logging trail originating in the town of Melchor de Mencos, 50 km to the south.

To find Cival, our project relied on information provided by Harvard explorer Ian Graham, who had visited the site in the 1970s in search of the "lost" stela photographed by Merwin. In addition to a general map of the central part of Cival, showing large Preclassic-style buildings, Ian had created a locator map noting the site next to a perfectly round *cival* or pond, and the mule train he took from Holmul. However the area's mule trains had long been obliterated by the jungle and replaced by modern logging trails along different routes. There was no way to match Ian Graham's trail to known logging trails. The pond noted by Graham however was clearly visible on satellite images, however. Using the coordinates from the image, the team drove 7 km to the north along an existing logging trail and walked 500m up to the main hilltop site next to the pond. Thus, by the 2001 season, the locations of Cival and Holmul had been corrected using the available accuracy of commercial handheld non-differential GPS units (-/+ 3-11 m).

Other minor centers closest to Holmul were located using information provided by park rangers who had worked in the area. Thus, the sites of T'ot, Riverona and K'o were accessed by logging trail and marked using handheld non-differential GPS units in 2001.

The survey of the settlement zone around Holmul was carried out initially by the transect methodology first employed in the 1960s by the Tikal Project (Puleston 1983). The method involves staking out baselines with a total station from the main plaza to the four cardinal directions. From the 25m-spaced stakes the crews walk for 100m in directions perpendicular to the baseline. With this method, structures and topography were recorded in 200m-wide swaths to 2km to the west, 1 km to the north and south and 2.3km to the east of Holmul. The latter transect was continued as a simple baseline for an additional 2.2 km southeast to connect with the site core of K'o. While this methodology provided great accuracy and continuous coverage of settlement features from the site center, it was deemed too slow and inadequate to reach more remote parts of the surrounding landscape and was abandoned in favor of a new method.

By 2002, a more comprehensive plan for discovering and mapping settlement around Holmul and Cival had been developed. The methodology included, as a first step, developing a contrast enhancement for a 2001 LANDSAT image that could be used as guidance to potential areas of settlement. This was accomplished by using an combination of infrared and visible bands to create a false-color composite (R:Band7,G:Band4,B:Band2) image and applying a histogram equalization stretch. This simple procedure highlighted certain areas in light/dark blue that coincided with the mapped settlement. The image was also processed using the Brovey sharpening algorithm accomplishing similar results (Estrada-Belli and Koch 2007). Using the image as a map, survey crews were directed towards those high-likelihood areas to locate and map structures. The procedure was eventually found to have approximately 99% success rate of site discovery in upland areas, although most structures discovered were small. Once located with a single GPS point, each structure was drawn to scale on grid paper using tape and compass. As noted earlier, sites with monumental architecture were surveyed with a total station and also drawn on grid paper. Field maps were drawn typically at the 1:1,000 scale. The scanned maps where then georeferenced using the corresponding GPS point (typically taken on a structure's corner) in ArcGIS and its map features (lines and polygons for so-called "Malerized" prismatic structures) imported into the region's UTM coordinate-based GIS database. Thus, each newly mapped feature could be added as overlay to the satellite image with all previously mapped features to check for accuracy.

In addition, two ceremonial centers were located by combining the satellite image methodology described above with least-cost analysis of paths leading to Holmul from the four cardinal direction. It was found that at least two paths coming from the north converged at the northern edge of the upland area at the average distance of other minor centers around Holmul. At the predicted location, field crews uncovered the Preclassic minor center of Hahakab. Similarly, a path leading to Holmul from the east traversed an upland area devoid of any recorded minor centers. At the predicted location, the Classic and Preclassic site of Hamontun was located (Estrada-Belli and Koch 2007), thus completing the ring of minor centers around Holmul and Cival.

Using the above methods, it has been possible to map residential settlement around the largest sites in the region over an area of approximately 55 km2 which represents 18 % of the total study region and 42 % of the area with potential for settlement as identified by the LANDSAT image enhancement (129 km2). The Holmul settlement was mapped up to 2.3 km to the east and west and 1km north and south. The Cival settlement was mapped up to 5 km to the west, 2km to the south and up to 6 km to the north. Also, the settlement zone around Hamontun was mapped in a 2km radius and a 1x1m square was mapped around K'o. At the end of the 2014 season, many gaps remained to be filled in the regional survey in order to achieve 100% coverage. These included intermediate areas between Cival and Holmul, between Holmul and T'ot, Riverona, K'o and Hamontun. The northern edge of the Holmul region where the site of Chanchich is located (6.3 km from Cival) in 2015 remained largely unexplored (Figure 1a).

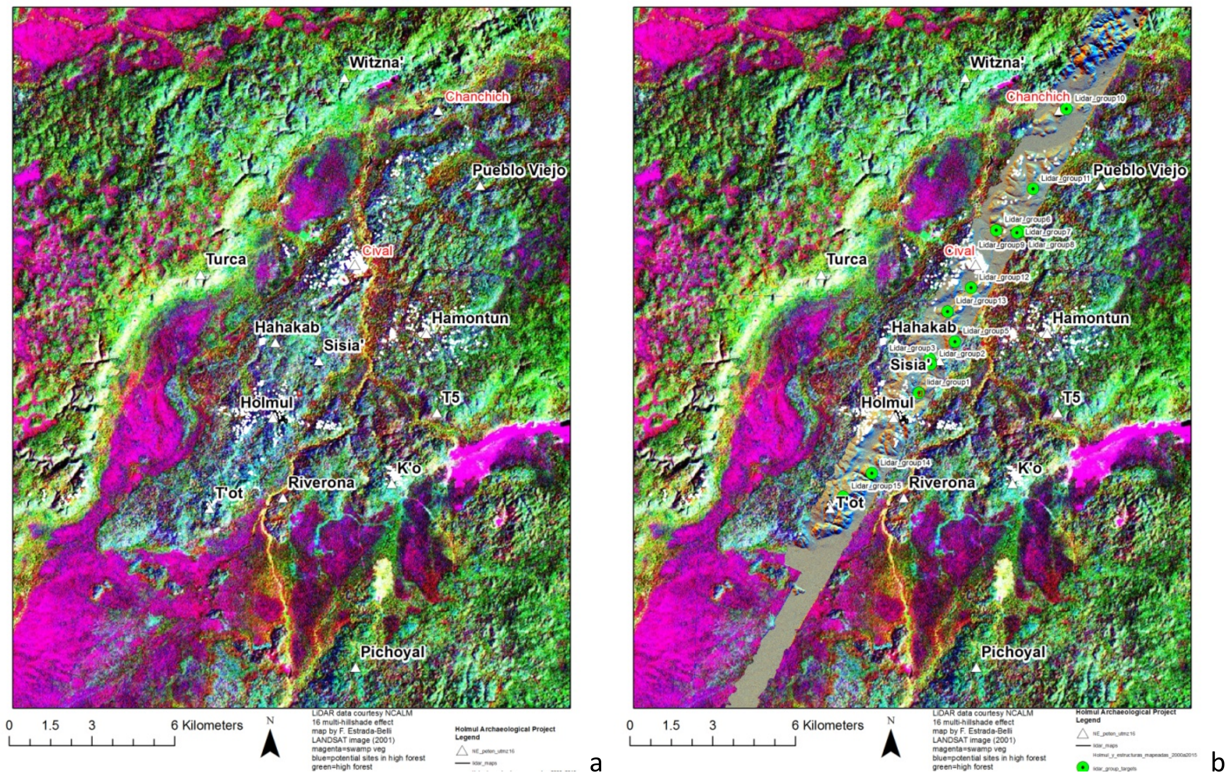


Figure 1. Known settlement sites in the Holmul Archaeological Project study region before (a) and after the LiDAR survey (b) displayed over a 2001 Landsat rgb composite image (bands 742).

Analysis of LiDAR data

As noted earlier, the Holmul LiDAR DEM is a 2km wide strip with a 30-degree azimuth over the Holmul upland area. The data was provided as two separate tiles (north and south tiles). The center of the strip passed over some of the major sites in the region capturing their monumental cores and settlement. These are (from South to North) T'ot, La Sufricaya, Holmul, Sisia', Cival and Chanchich (Figure 1b).

As a first step, the LiDAR dataset was checked against existing field survey maps. This was accomplished by displaying the LiDAR DEM tiles (".flt" file format) over the preexisting GIS dataset of the Holmul project, which features GPS points for known sites, mapped settlement, the enhanced LANDSAT image, roads/trails, streams and two regional DEMs, the 1999 AIRSAR DEM (10m resolution, Estrada-Belli and Koch 2007) and the 2002 ASTER GDEM (30m resolution, USGS 2015).

In order to improve the visibility of relief on the LiDAR dataset the elevation surface model was processed using an algorithm to generate a hillshade, or shaded relief image. Two different images were generated with light sources at 100 and 315 degrees azimuths and elevation at 35 degrees. The algorithm used was part of the "Relief Visualization Toolbox" written in IDL and freely distributed by the Institute of Anthropological and Spatial Studies (IAPŠ) at the Scientific Research Centre of the Slovenian Academy of Sciences and Arts (http://iaps.zrc-sazu.si/en/rvt#v). The two hillshade images were useful in detecting linear features that were oriented north-south and east-west initially. The hillshade, which is a grayscale image was displayed with a 30 % transparency over the DEM in order to combine the elevation colors with the directional shadows (Figure 2b). A third hillshade was later developed using the multiple-direction light source algorithm from the same toolbox using 16 directions and a elevation angle of 30 degrees. The resulting image appears to use a color scale from yellow to red to blue highlighting the relief with superior results compared to the previous images. The multi-hillshade image was subsequently used as the preferred background to detect, digitize and edit architectural features (Figure 3).

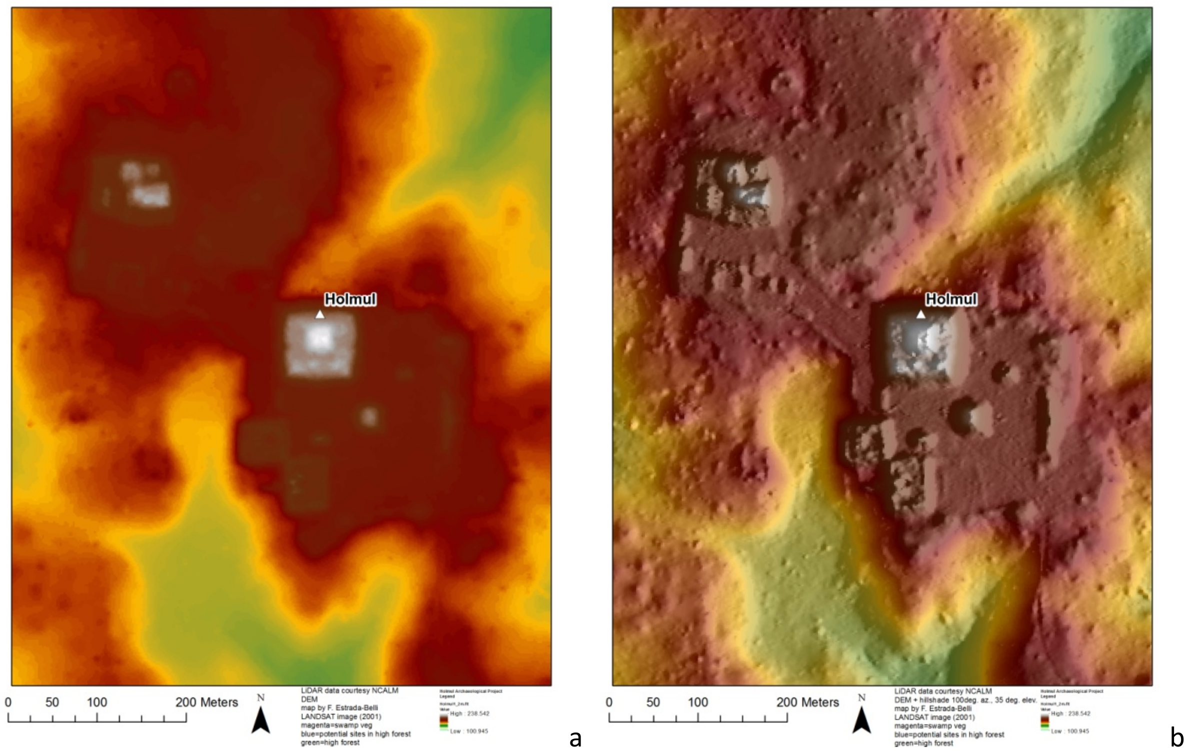


Figure 2. Raw LiDAR DEM over the Holmul site center (a) and hillshade (100 deg. light source) image as transparency over the DEM of the same area (b).

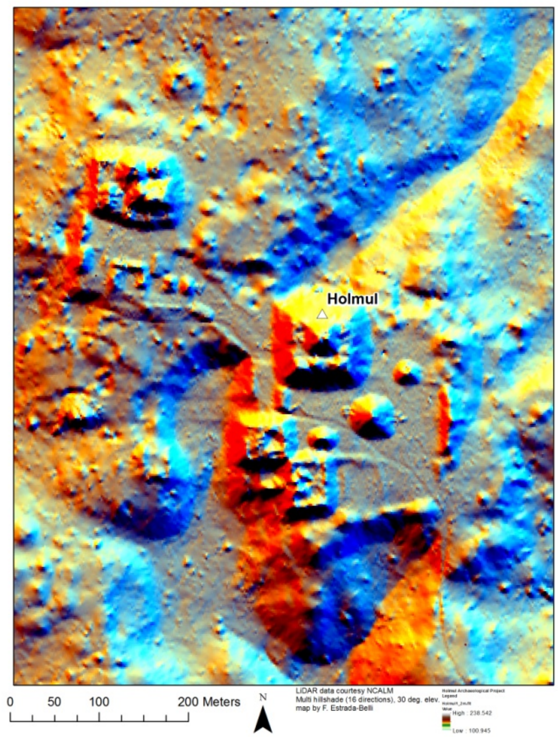


Figure 3. Multi-directional (16 dir.) hillshade image derived from LiDAR DEM data over the Holmul site core.

LiDAR-aided on-screen editing of previously mapped structures

Some degree of displacement was expected between the settlement field maps and their actual relief on the LiDAR data (hillshade). This was due to the known error inherent in the GPS commercial signal and low-end units used to record the locations. Some degree of rotation also was expected given that the maps had been drawn according to magnetic north over the years since 2001. Therefore, some on-screen editing was expected to be needed in order to bring the existing maps up to date with the more accurate position and representation of the on-the-ground features as detected by the LiDAR dataset (Figure 4a). Ahead of the editing, target features were visited in the field to get a sense of the accuracy of the representation of volumes and shapes seen on the LiDAR image. After a few inspections, it was concluded that LiDAR hillshade images provide an accurate representation of on-the-ground relief for mounds and other features (linear platform edges) that are over 1-2m in height above the natural surface. Smaller features may also be recognizable as bumps on the image, but given the ruggedness of the karstic terrain and the presence of large tree roots and other disturbances on the surface their identification on the image is ambiguous without ground-truthing. It was apparent, however, that larger structures could be accurately measured and drawn using the traditional prismatic convention directly on the LiDAR image with minimal need for field mapping. In many cases a brief inspection was all it was needed to confirm the proportions and shapes visible on the image. This task was facilitated by having the hillshade image-maps with archaeological features as overlays loaded on Android tablet GPS apps in the field.

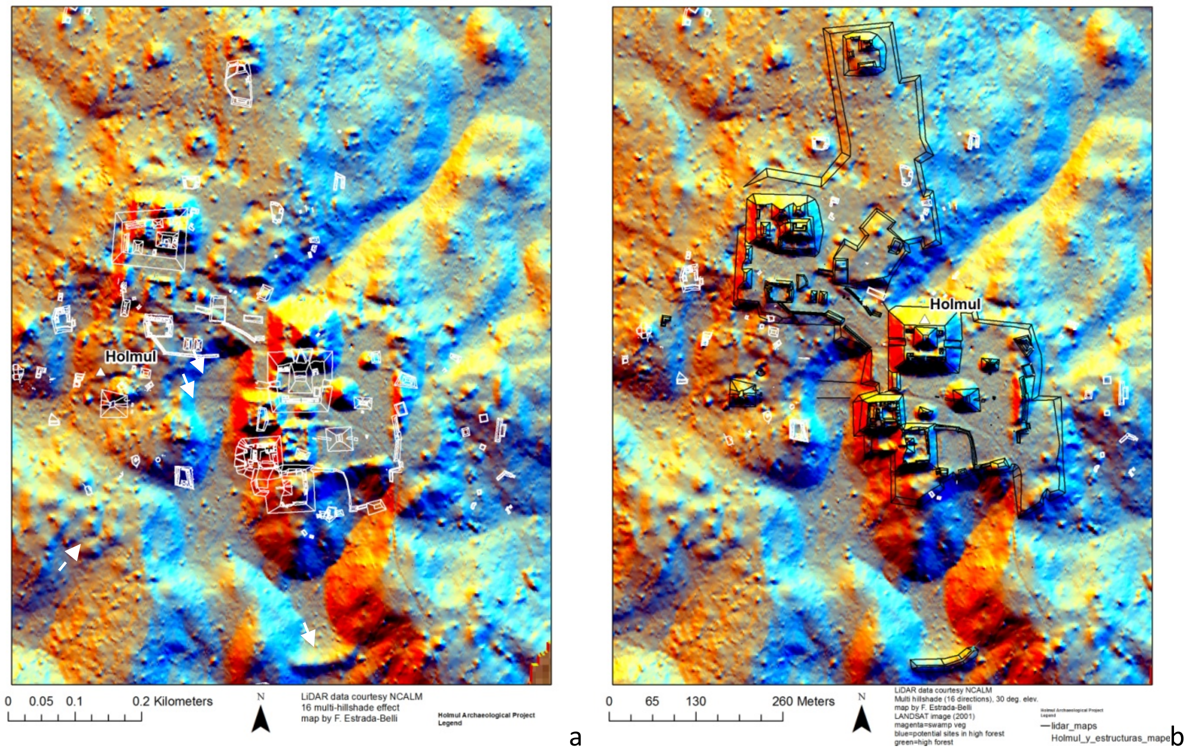


Figure 4. Holmul site core before (a) and after (a) LiDAR-aided map editing.

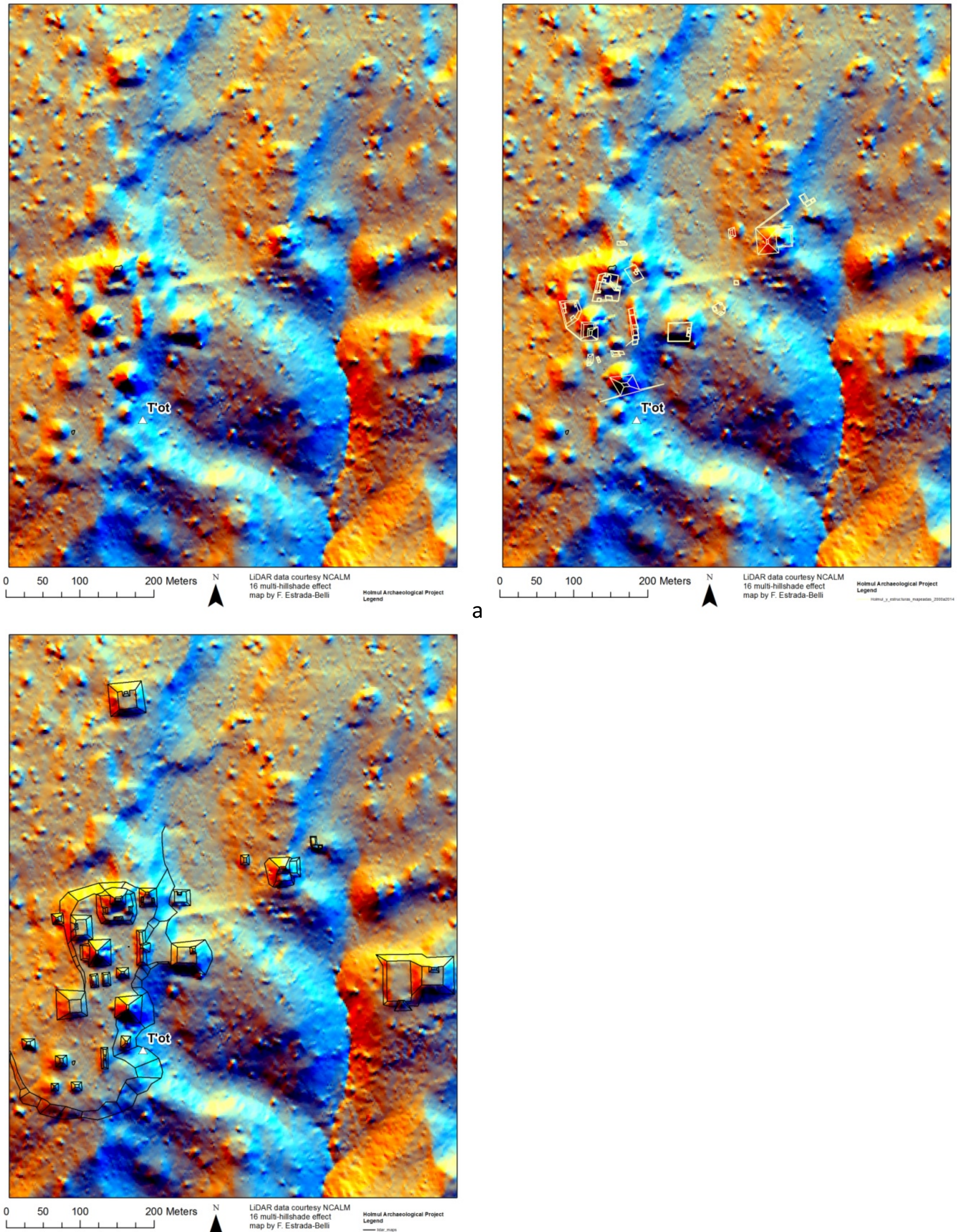
The map of the Holmul site core (Figure 4) had been compiled between 2000 and 2001 by at least three field surveyors using a combination of methodologies (i.e. total station and tape and compass, Estrada-Belli 2002). In addition to a general displacement, some internal inconsistencies, omissions and errors between the map and LiDAR image were evident. The causes of these inconsistencies could variably be attributed to dense vegetation, rugged terrain, surveyors' subjective interpretation, variable instrument accuracy and visibility. For example, a group to the north of the main plaza appeared to have been incorrectly mapped (by tape and compass) as much smaller than it actually was in the image and on the ground. Furthermore, a massive platform was evident along the edges of the site core that had not been noted before, as well as low walls on either side of the causeway connecting Group I and II (figure 4b, center) and a platform with several small buildings between the two groups (Figure 4b, center). Finally, a set of four structures around a plaza immediately to the east of the E-Group plaza was now readily recognizable as a small E-Group as well.

The image showed clearly two defensive walls in the drainage south of the site's causeway and a large rampart blocking a the same drainage further to the south of the main hill (see arrows in Figure 4a). While the walls had been previously noted, the rampart had remained undetected due to the ruggedness of the topography and the dense vegetation. Finally, on a low ridge southwest of the

Holmul plaza is a concentration of small mounds that was previously undetected. This appears to be a sizeable residential neighborhood closely connected to the main ceremonial area (Figure 4a, left of center).

Overall, the LiDAR data led to a much more complete and accurate map of Holmul than it had been possible with traditional methods. The new map shows 1) a much greater investment in the site-wide platform, 2) defensive and hydrological earth works and 3) a large elite group to the north connected to the site by a large plaza/platform.

To the south of Holmul the ceremonial center of T'ot appeared more monumental in the LiDAR image from its prismatic representations (Figure 5). The LiDAR image (Figure 5a) clearly shows an E-Group plaza surrounded by a Triadic group to the north, a ball court to the south and two large platforms further to the south. None of these structures were rendered accurately as to their shape and volume (Figure 5a). The Triadic group was misidentified as a residential compound. The E-Group radial pyramid and eastern structure had not been recognized while in fact they conform to the Cenote style E-Groups of the Late Preclassic period (Chase and Chase 1999). Furthermore, two large ceremonial platforms (about 8-10 m in height) 200m to the east and to the north of T'ot were not detected during the 2001 field survey (Figure 5b). The new LiDAR-aided map of T'ot correctly identifies the above listed structures in terms of their shape and volume (and hence their function) and led to the identification of a massive platform underlying the entire site core. The platform's edge is most visible on the north side of the site, where it appears to rise up to 10 m above the natural ground, while to the south and east it blends with the steep hillsides. Overall the LiDAR-corrected map of T'ot leaves little doubt as to the ceremonial function of its main buildings. Furthermore the structure's characteristic shape and arrangement (i.e. its E-Group and Triadic Group) and the associated ceramic data suggest that the site's architecture has received little or no modification since it was laid out in the Late Preclassic period.



a b c

Figure 5. The site core of T'ot as it appears on the LiDAR image (a) and as rendered before (b) and after (c) the LiDAR-aided mapping.

Numerous additional groups consisting of small to medium sized structure were noted on the LiDAR image but could not be included in the field testing and current analysis with the available time. A known group was located 1.4 km northeast of T’ot (Figure 6, Lidar_group14 in Figure 1b). This group’s existing map exhibited a simple arrangement of four low structures around a courtyard (Figure 6a). The LiDAR map and field testing however revealed that the group included a 10m high pyramid to the south, a second 5-7m high pyramid to the west and other ‘palace’ style (probably vaulted) structures on the northeast and northwest corners. The LiDAR-corrected map (Figure 6b) more accurately represents the monumentality of the complex suggesting it may have been a Preclassic-period elite group with attached ceremonial pyramids on an elevated plaza platform. Around it are additional residential structures on ridges overlooking the Holmul river to the south.

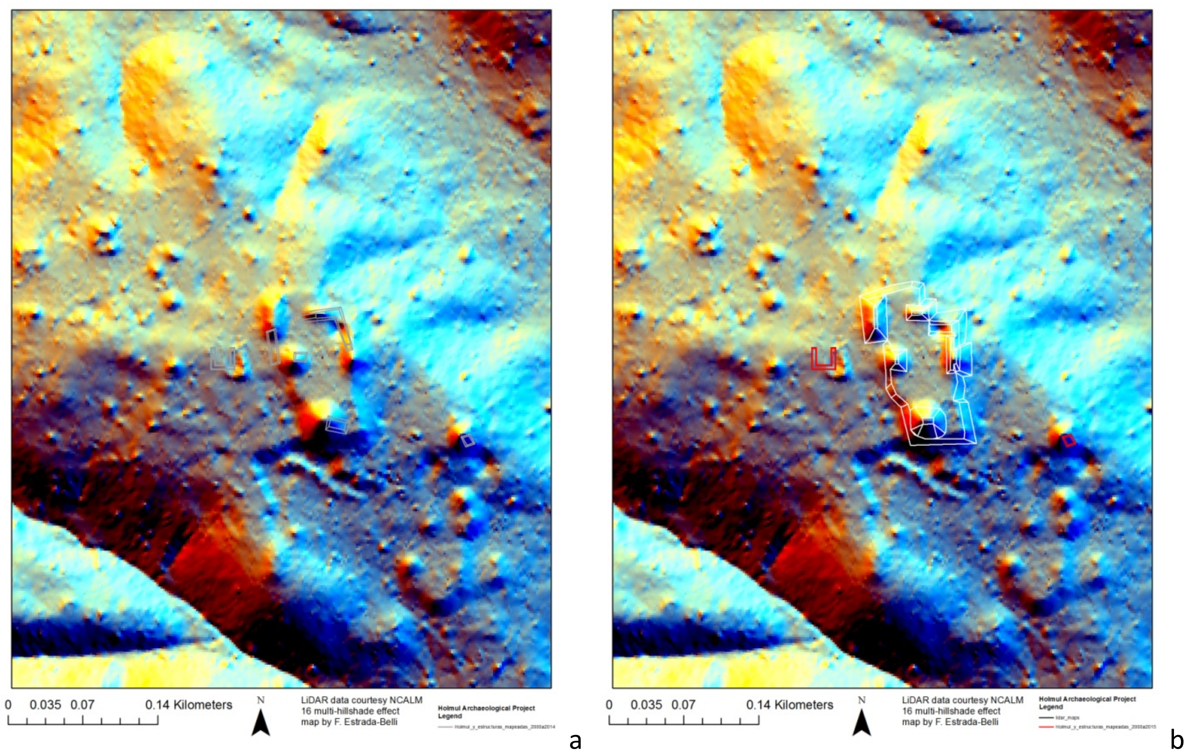


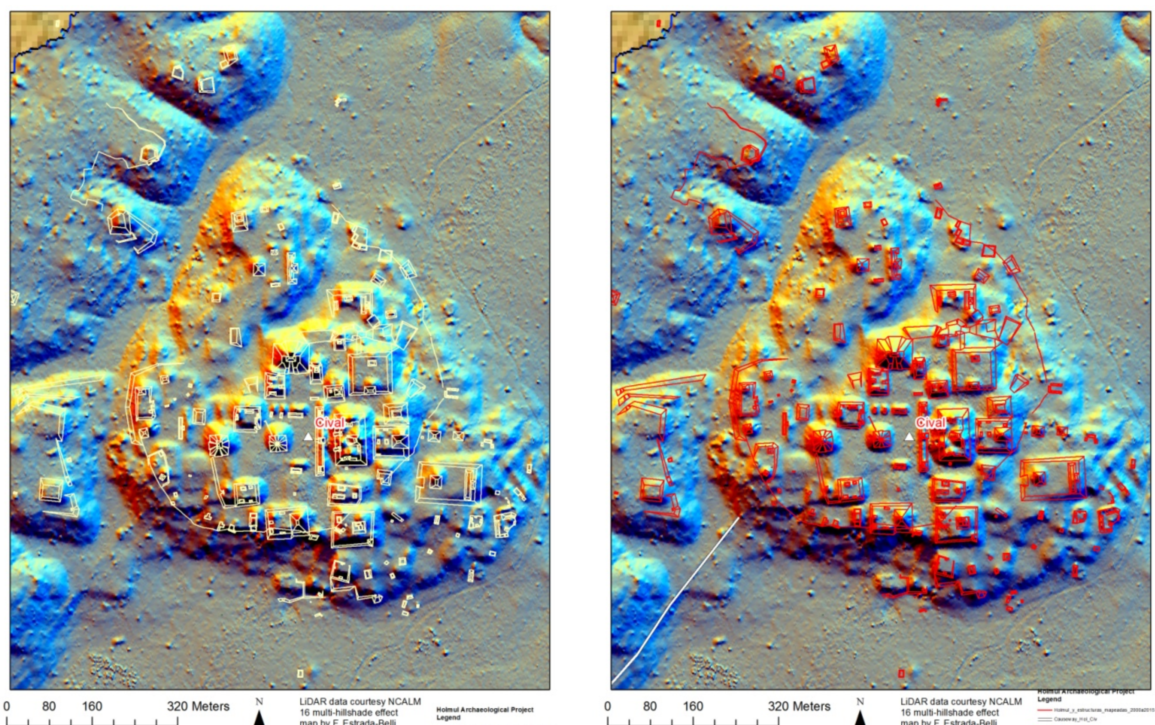
Figure 6. Preclassic elite/ceremonial complex on a ridge 1.4 km north of T’ot before (a) and after LiDAR-aided corrections and ground-truthing.

LiDAR-aided correction was necessary also at Cival, the largest ceremonial center in the region during the Preclassic period. Cival boasted major pyramid and platform architecture over a 500x500m-wide hilltop. Additional plazas were built on adjacent ridgetops as well. The Cival map had been completed in 2006 with total station and presented fewer discrepancies with the LiDAR image than the Holmul one. The entire map was displaced a few (3-4) meters to the south and west due to the known GPS signal error. However, most mapped platforms and structures seem to conform to the LiDAR relief.

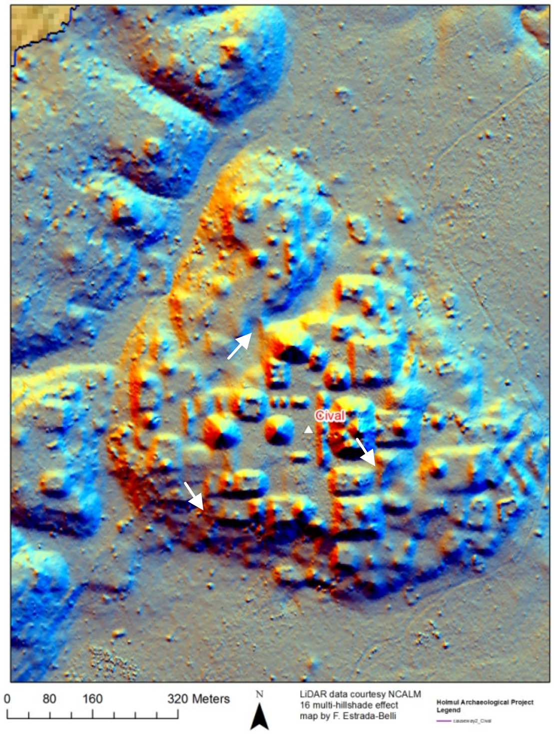
One exception was the E-Group plaza on the east, which appeared titled a few degrees clockwise in relation to the other platforms at the site and the relief map. This was probably due to an error in resetting the total station in that section of the site as other groups further to the east and south subsequently carried the same error (Figure 7a).

The LiDAR hillshade image (Figure 7c) shows other remarkable details otherwise only visible on the surface in the best of conditions (cleared understory, leaves raked). For example, the image shows the defensive wall that encircles most of the site as a faint linear relief on the southern and eastern edges of the hilltop. This is remarkable because this feature is only one row of stones high on the surface and is invisible to most unaware persons even standing on it. Also of note, a rampart or land bridge connecting the north hill to the North Pyramid. This feature had been noted earlier but now appears more clearly related to blocking the drainage to create a large water reservoir in the upper section of that drainage, i.e. behind the three main pyramids (North Pyramid, Str. 20 and Str. 9, see a similar feature at Holmul in Figure 4).

On the southwestern corner of the site core is a linear feature that apparently is the first section of the Cival-Holmul causeway (see next section). As it leads out of the main hill, the causeway follows the western edge of the large sinkhole to the south of Cival (Figure 7b).



a b



c

Figure 7. The cival site core map before (a), after (b) corrections aided by the LiDAR image (c).

Finally, in addition to aiding in the correction of the above noted errors in the Cival map, the LiDAR image also conveys a general sense of orthogonal consistency of the major platforms and structures of the site. The narrow linear spaces between the platforms may even resemble “avenues” to some. These spaces, however, are essentially a results of the construction of elevated platforms throughout the site with consistent orientation along the site’s major axis and should not be considered avenues in the real sense. The site’s east-west axis was set at Cival in the Middle Preclassic period (ca 800 BCE) targeting the sunrise on the day of the equinox as during construction of the E-Group plaza and most of the larger platforms at Cival were built incrementally in the following period (400 BCE-200 CE).

The next target of LiDAR aided correction (from south to north) was a group of mounds on a ridge 2.3 km to the north of Holmul and 3.5 km south of Cival identified as Sisia’. The site had been mapped preliminarily by tape and compass in 2012 and features an E-Group plaza. The existing map of Sisia’ featured a central E-Group plaza with a tall (8-10m) platform to the north supporting a single temple/elite palace superstructure and a long palace-like building further to the east. To the south, is a ball-court and a smaller platform supporting small structures. The map presented little or no discrepancy with the LiDAR data, except for the expected magnetic drift. The new LiDAR augmented map also shows the edge of the platform onto which the site is constructed and a causeway ramp that leads to a separate monumental group a short distance to the west. An additional group of two small pyramidal structures was also detected on a separate ridge to the southwest of the plaza. Finally, the new map shows the volumes of the larger structures more accurately.

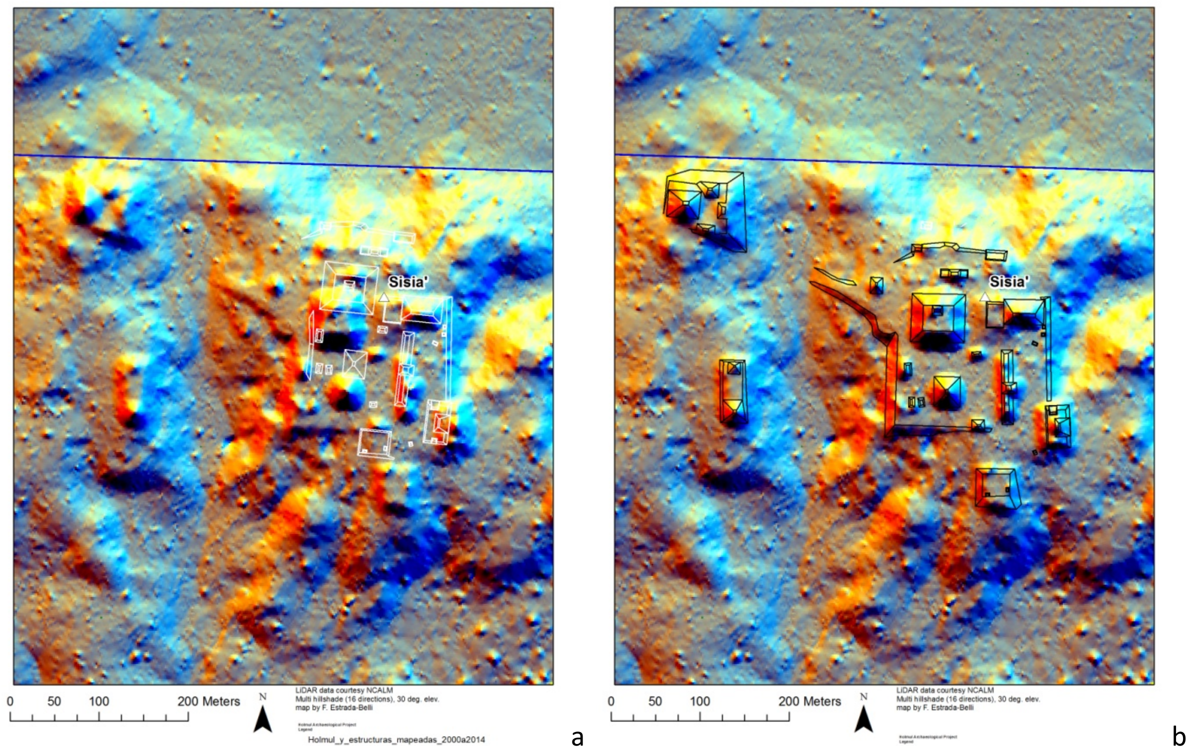
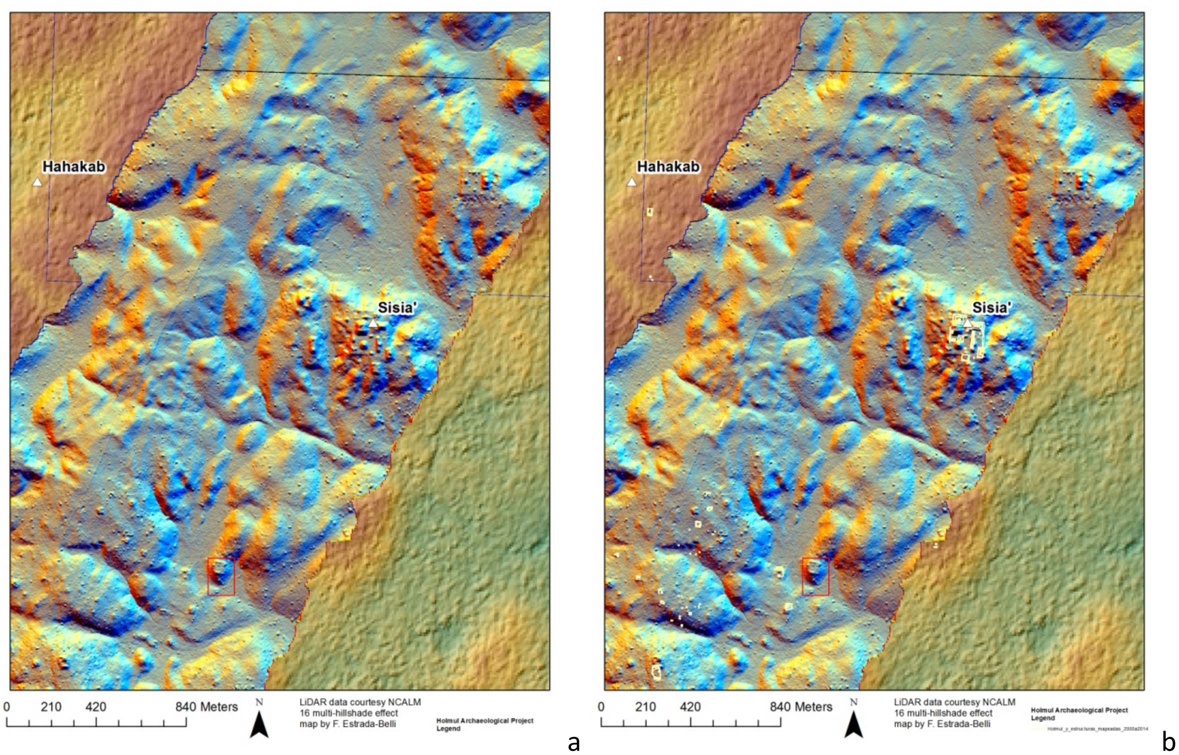


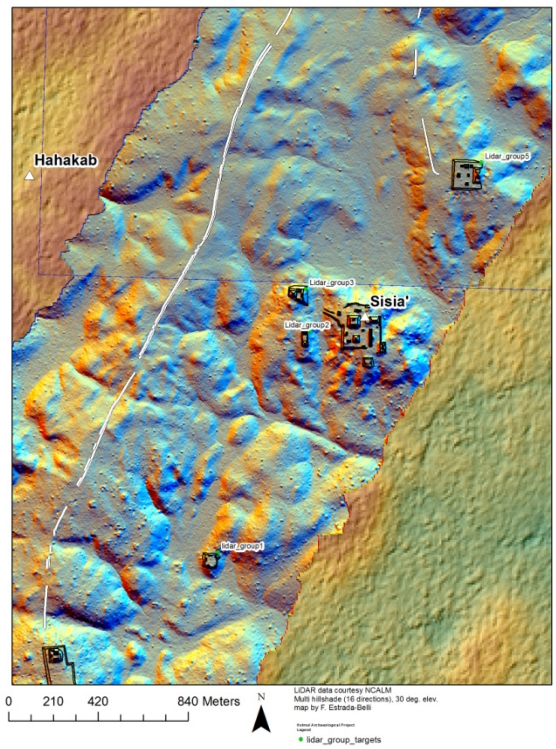
Figure 8. The map of Sisia’ before (a) and after (b) LiDAR-aided corrections and additions.

LiDAR-aided on-screen digitizing of new sites and features

The LiDAR surface data revealed features of archaeological settlement in 20 new locations. These are distributed throughout the unexplored gaps in the existing the field survey between the ceremonial sites of T'ot, Holmul, Cival and Chanchich (Figure 1b). Each of these areas includes groups of large and medium-sized pyramidal and range structures ranging in height from 1-2m to 8-10m. Other location were identified as "probable" groups of structures, as well. These appear as irregularly shaped low mounds (less than 1-2m in height, and less than 8-10m in length) on the image. Given their small size and ambiguous shape and the limited time available for field testing they were not selected for this analysis. Therefore, most of the new features identified in this analysis of LiDAR data can be classified as ceremonial/monumental due to their size and shape and their frequent arrangement in plazas on elevated platforms of rectangular shape. The detection of these features also validates the methodology previously used to predict the presence/absence of ruins under the forest canopy on LANDSAT images and described above.

The most remarkable new feature discovered thanks to the LiDAR data is a causeway connecting Cival and Holmul site cores through the undulating terrain of the upland ridge that separates them. This feature appears to be about 10 m wide and as little as 1-2m high above the natural ground in most places throughout its 6.3 km length. Two small sections of it had been mapped near Cival and Holmul (see Figure 9b) but were not recognized as a causeway due to its relative low relief. The causeway is not perfectly linear but it appears to follow the ridgetop between the two sites with as few changes in direction as possible.





c

Figure 9 Holmul-Cival intermediate area showing southern section of causeway departing from Holmul site core on LiDAR multi-hillshade (a) with other mapped settlement before (b) and after (c) LiDAR-aided mapping.

Immediately to the south of Sisia' and approximately at the mid distance with the Holmul center (1.2km) is a group of five structures on an elevated rectangular platform (Lidar_group1 in Figure 9c). The outline of the platform and structures was clearly distinguishable from the natural rolling hills nearby. Although this group was not inspected in the field, from its layout it appears to have the characteristics of a Preclassic elite compound with a 4-5 m high ceremonial pyramidal structure on the northeast corner and a smaller one on the opposite corner. In addition to the above mentioned groups located on a hill west of Sisia' (Lidar groups 2 and 3 in Figure 9c) is a larger group located on the next ridge to the north of Sisia', at 700m distance (Lidar Group 5, Figure 9 and 10). This group features a long structure on the east with a tall central mound (12-15 m high) and a small platform on the west, north and south. These structures appear to follow the arrangement of E-Groups were it not for the addition of two structures on the north and one in the center. As a result its functional identification must await ground-truthing. The structures appear to be built on a 128x122 m wide platform that on three sides rises 5-7m from the surrounding ground.

From this group departs a second causeway to the north, in the direction of Cival. However only a 1km-long section between Lidar Group 5 and the next group to the north, Lidar Group 13 is sufficiently visible on the LiDAR image (Figure 10). The causeway arches slightly between these two sites, following the contour of the ridge. Lidar group 13 appears to be much smaller than Lidar Group 5 with four small structures on each side of a 45x50m wide platform that is about 4m high above the natural ground.

Further along the same route into Cival center from the south is another hilltop group (Lidar Group 13 in Figure 10). This groups consists of a range structure on the south, an access inset stairway on the north, and an ancillary structure at the top of said stairway. Its main structure faces directly to the main Cival hill across the site's main water source (sink-hole/*cival)*. The layouts of all three groups are consistent with a Late Preclassic construction date. The layout of Lidar Group 13 in particular is consistent with elite palatial compounds of the Late Preclassic period, common in the Cival center and elsewhere.

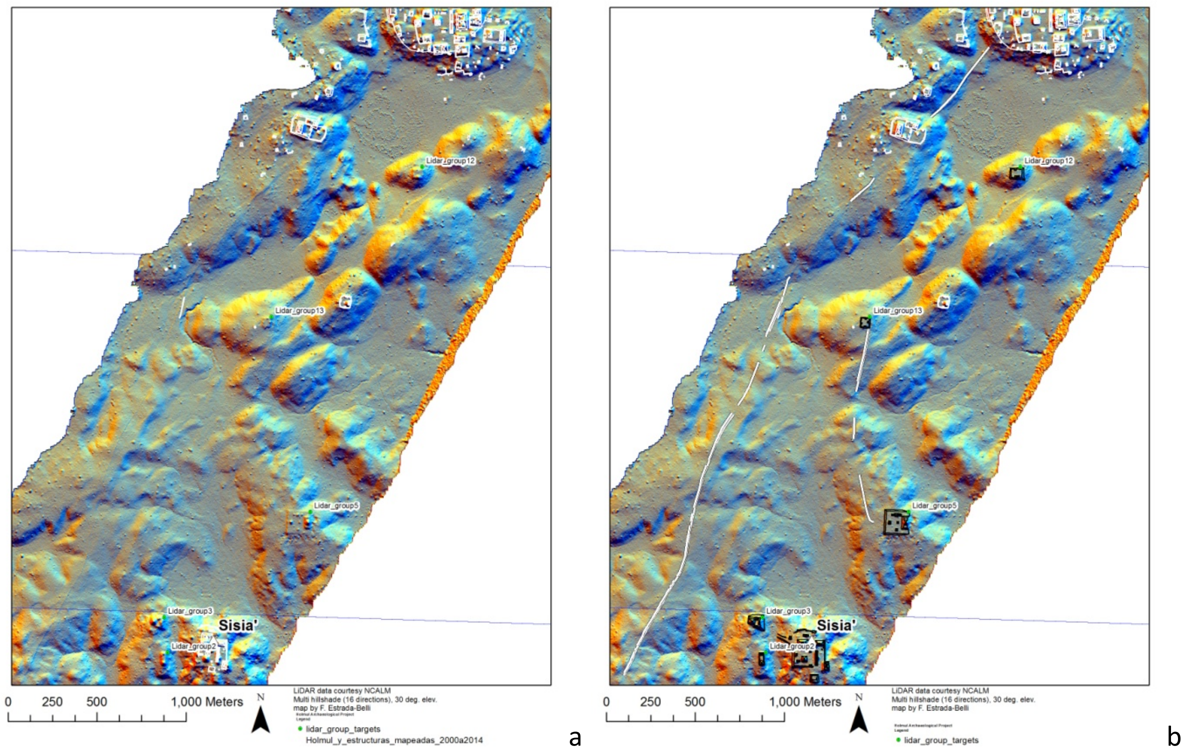


Figure 10. North section of Holmul-Cival causeway bypassing the minor center of Sisia' (see above) and LiDAR-discovered groups 2-5 and 12, 13, before (a) and after (a) LiDAR-aided mapping. Between groups 13 and 5 is a second stretch of causeway previously undetected. A large ramp leads from the Sisia' plaza to LiDAR group 3, which is on a separate hill.

On a ridge 1-1.5 km north of Cival, is a cluster of settlement structures that had escaped detection during the field survey even though they are located in a 'signature' zone of the satellite imagery (Figure 1) and are located near mapped settlement. These are Lidar Groups 6 to 9.

Lidar Group 6 is the westernmost of the cluster (Figure 11). It features three small mound structures arranged in a triadic pattern open to the south. The platform that supports them is 40x58m wide and about 6-7m high above the natural ground. The main structure (northern) is 3m high. Considering the reduced dimensions of this group and its formal layout it is more likely that it had a residential function for the elite than a purely ceremonial one.

The eastern cluster of structures includes Lidar Groups 7 to 9. These are less formally arranged structures around patios and with little or no basal platforms. Their function is most likely residential. At the center is Lidar Group 7, which has a small platform on the west facing a 41m long structure on the east. The plaza is 35m wide. The layout is tentatively interpreted as that of an E-Group, and therefore ceremonial in nature. However, if confirmed, its dimensions would fall below the range of E-Group sizes in the Holmul region (n=13).

To the south of this cluster of structures is Lidar Group 16 which appears to have a layout similar to Lidar Group 6 described earlier but rotated 90 degrees, i.e. facing west. The dimensions of its basal platform are 32x35m and, like the Lidar Group 16, may be residential in function rather than ceremonial due to its small size.

Finally, Lidar Group 17, in the center of this area (Figure 11) appears to feature a 5-6m high pyramid next to a low ancillary structure. Because of the reduced size it is difficult to determine the function of these structures without excavation.

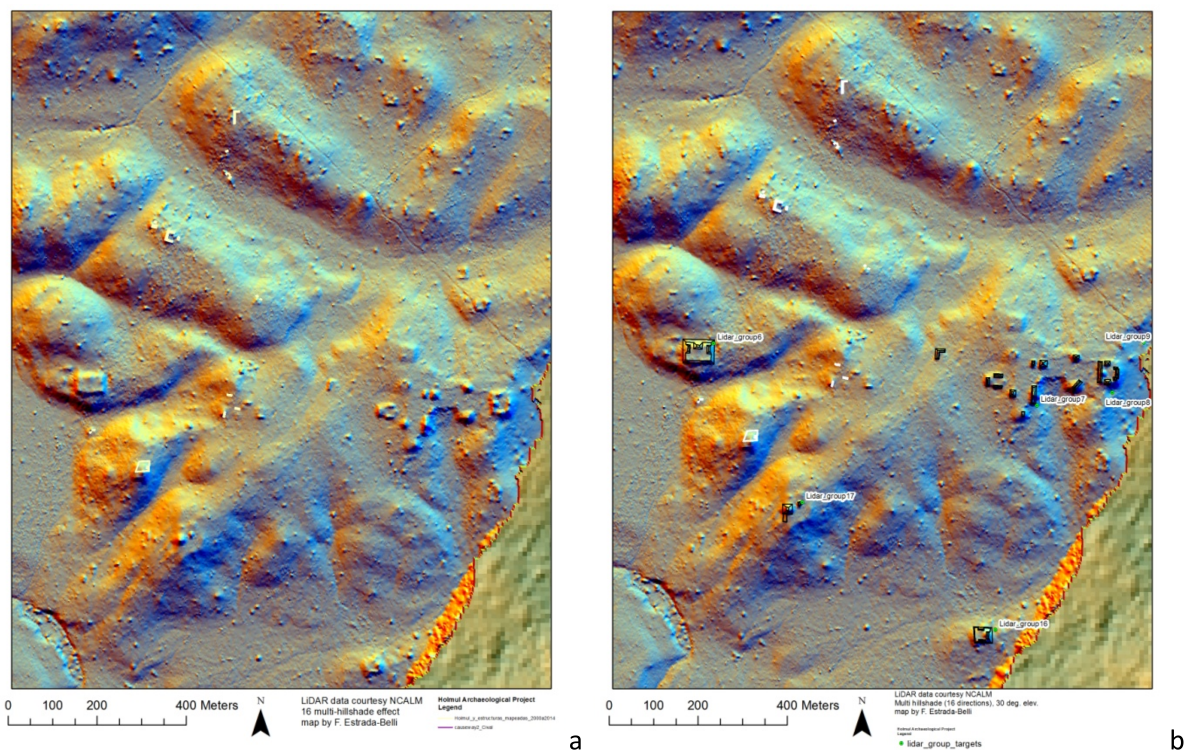


Figure 11. Settlement maps of an area to the north of Cival in which Lidar Groups 6, 7, 8 and 9 were discovered, before (a) and after (b) LiDAR-aided analysis. Two logging trails appearing as narrow 'grooves' cross one another in the upper left corner of the image.

Moving further to the north along the LiDAR transect we encounter Lidar Group 11 (Figure 12) this is a small group of three structures on a low (<2m high) platform. The structures are fairly small in size and their arrangement asymmetric, suggesting a residential function. The layout suggests a Late Preclassic date.

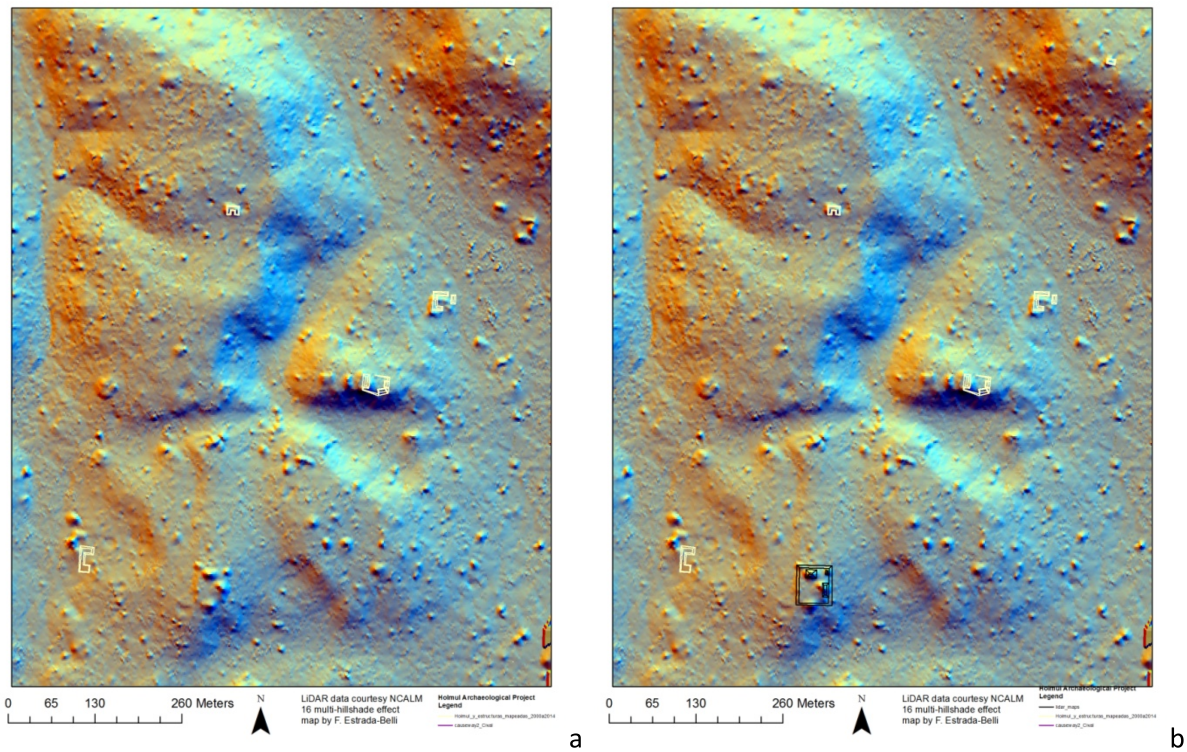


Figure 12 Area of residential settlement between Cival and Chanchich before (a) and after (b) LiDAR-aided mapping of Lidar Group 11.

North of Lidar Group 11 is a 800m long stretch of causeway that appears to connect it with the Chanchich ceremonial center. While the causeway is barely visible at the scale of Figure 13, a ramp on the south end of the Chanchich platform appears more clearly. The causeway, if confirmed by future testing, appears to be of similar width (about 10m) as the other two sections discovered to the south of Cival.

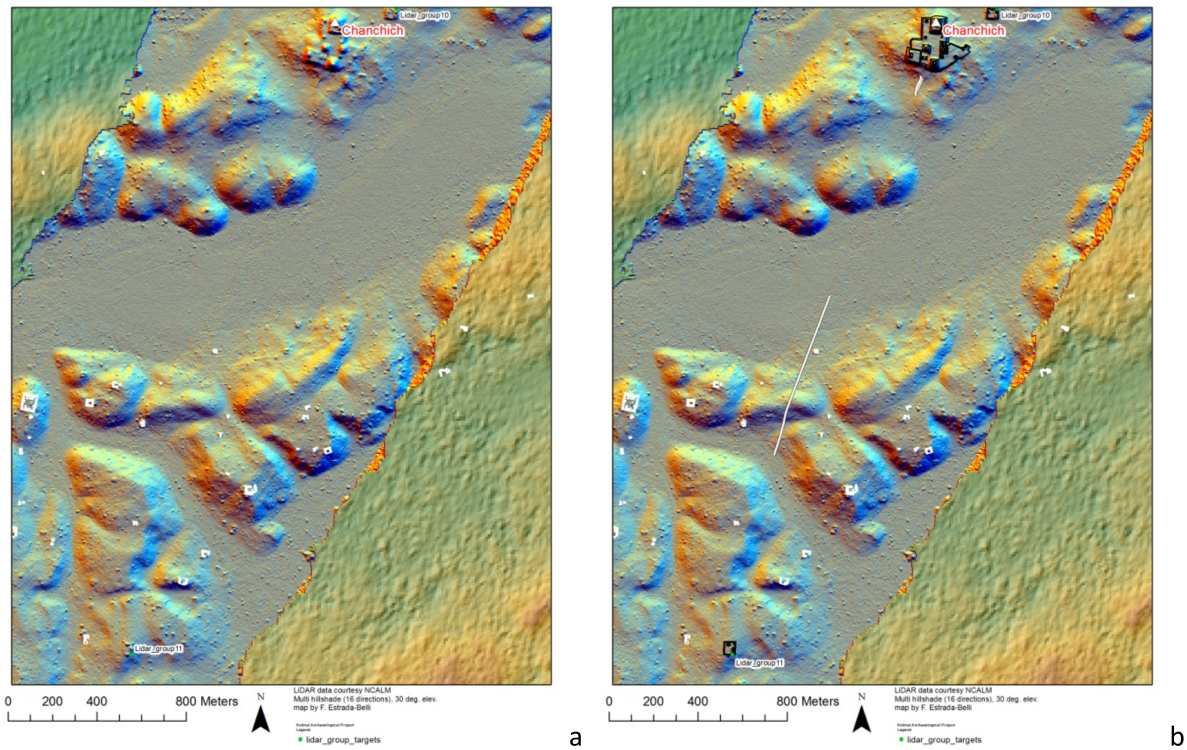


Figure 13. Settlement area south of Chanchich before (a) and after (b) LiDAR-aided mapping of a causeway linking it to Lidar Group 11 to the south.

The site of Chanchich lies at the northeastern edge of a upland ridge that separates two large bajos (Figure 1) and had not been mapped by our team prior to the LiDAR flight. The map published by Fialko in 2005 (Figure 15) shows a predominantly Late Prclassic-style layout with an E-Group in the center, a pyramidal complex to the north, ballcourt to the south and two additional palace-like platforms to the west and south. The LiDAR-aided map (Figure 15) shows the shape of some of the building a bit more accurately. For example the E-Group eastern structure is a bit shorter and with larger end-structures than in Fialko's rendering. The LiDAR image also confirms the presence of a long structure atop the northern platform and a complex two-level pyramid on its northern edge. The platform rises 8-10 m above the plaza. The northern structure on its summit rises an additional 8-10m and features a triadic arrangement of small structures at the very top.

In addition to the above noted causeway ramp on the south end of the plaza, the edge of the platform that supports the entire ceremonial core and stretches east to include some ancillary structures can clearly be seen on the LiDAR image as a linear, manmade, feature. The LiDAR image also shows the two residential groups to the northeast of the site core as larger and more complex that rendered in the existing map. Their location on small hills rising from the Holmul river flood plain betrays a focus on seasonally flooded soils for agriculture by the Preclassic inhabitants. The Chanchich site core is the second largest after Holmul among the Preclassic minor ceremonial centers (i.e. excluding Cival) in the region with a plaza area of 5,200 m2. Its layout, featuring a large pyramid to the north of the E-Group plaza, closely matches that of Preclassic Holmul and Dos Aguadas. The two groups located to the northeast of the center are also likely of Preclassic date and elite-residential in function.

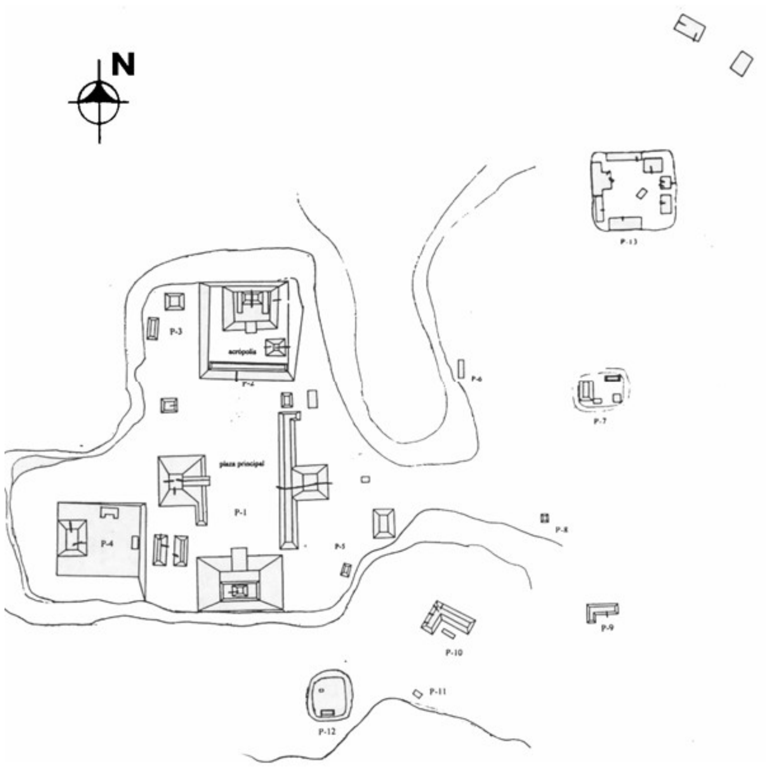


Figure 14. Map of Chanchich by Fialko (2005)

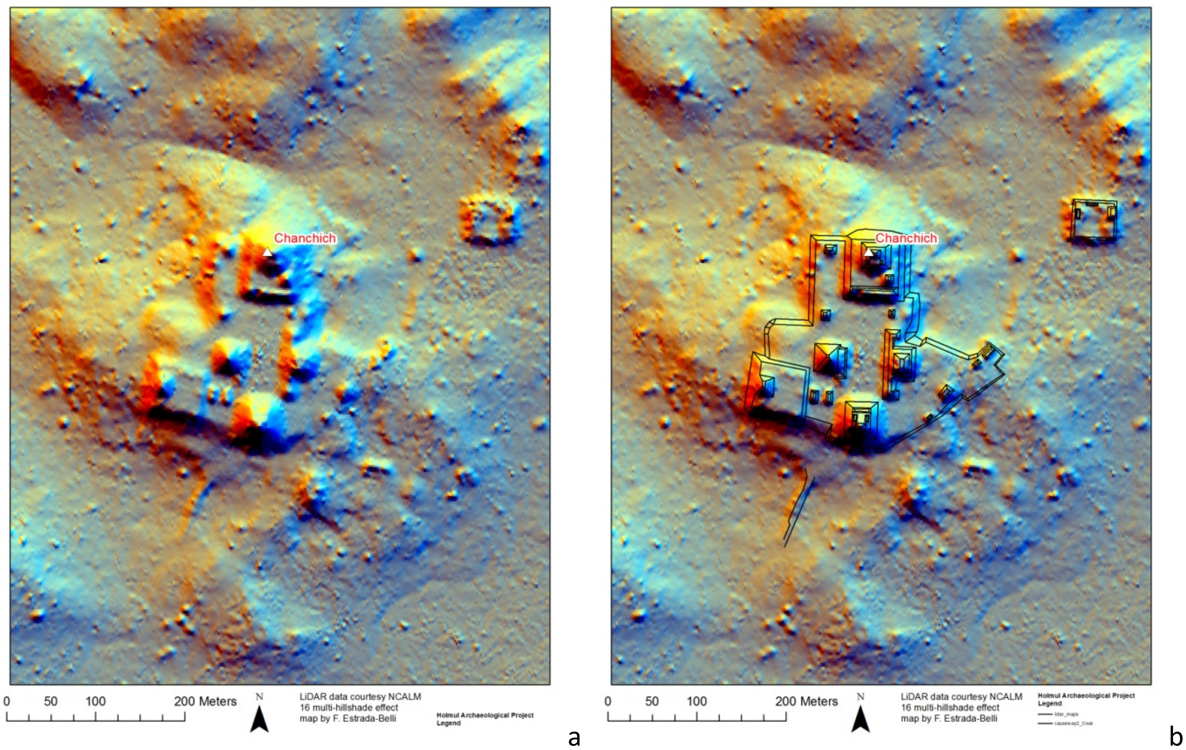


Figure 15 LiDAR image of the site core of Chanchich before (a) and after (b) on-screen mapping.

To the north of Chanchich is a limestone escarpment that rises up to 200m above the plain in some spots. Perched on one of the hills that make up the escarpment is a rectangular platform with little or no visible architecture on its summit (Figure 16) at a 2.2 km distance from Chanchich. It measure 52x52m in width and 5-10 m in height along the sloping side of the hill. It is difficult to determine the function of a large platform such as this, although it most likely dates to Late Preclassic period.

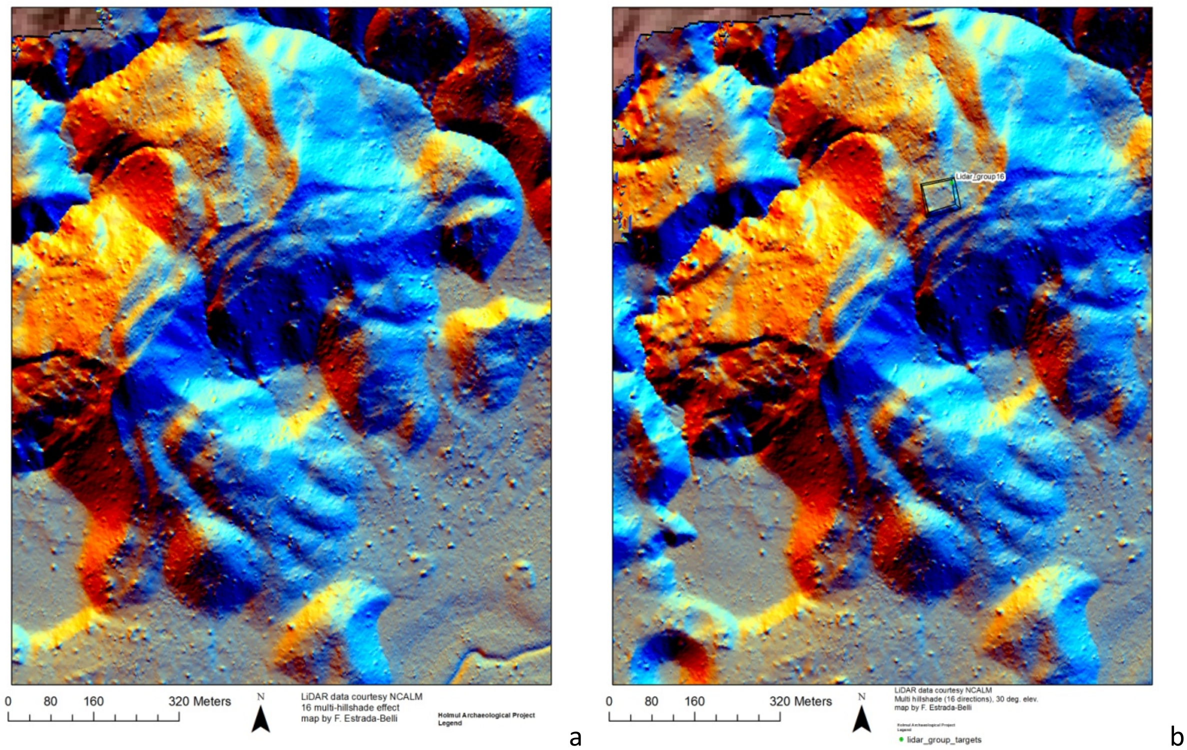


Figure 16. Large platform on escarpment edge to the north of Chanchich, before (a) and after (b) LiDAR-aided mapping.

At the northern extreme of the LiDAR data set are two additional groups, Lidar Groups 19 and 20, located adjacent to the Holmul river bed. Lidar Group 19 appears to have been bisected by a logging trail heading to the north carving a large gap in its basal platform. The group features six structures arranged along the three edges of the platform leaving the southwest corner open. Five structures are low and residential in nature while one, on the east appears to be a small pyramidal structure. This is likely a funerary shrine dedicated to a lineage ancestor. Lidar Group 20 presents a more regular (and undamaged) platform that is elongated in the northwest-southeast axis. Its four low structures appear to be residential in nature. Both groups may date to the Preclassic and/or Classic period.

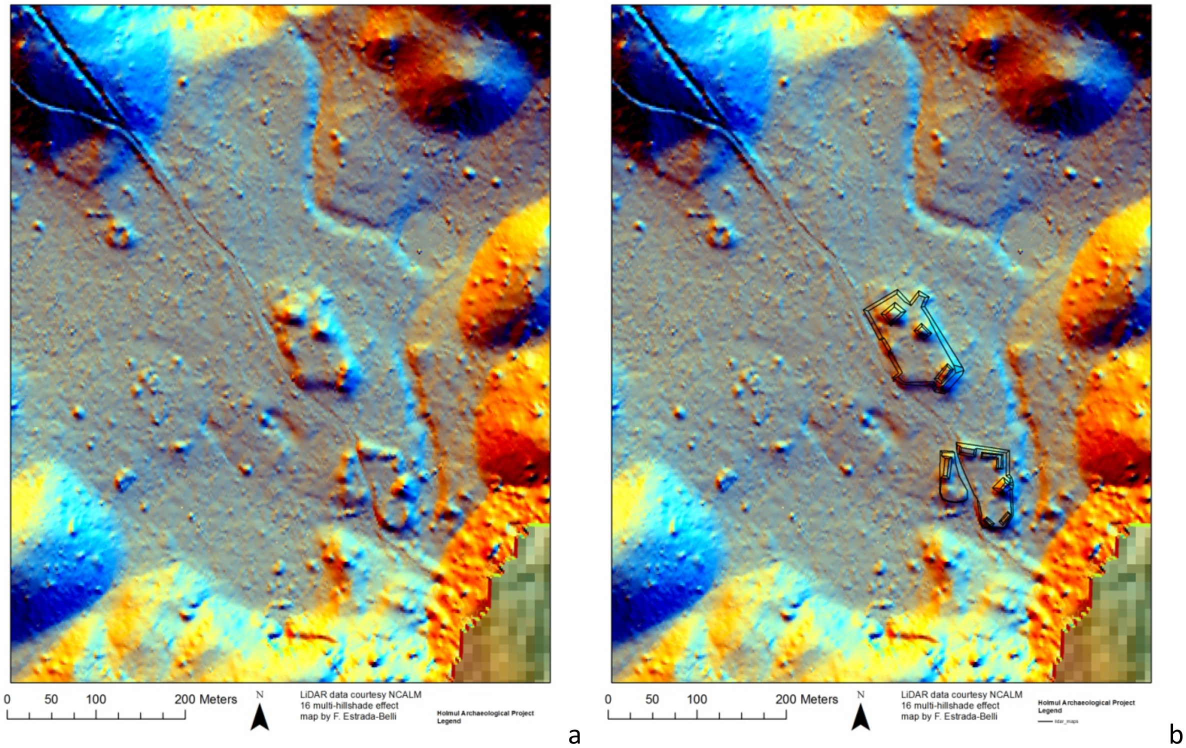


Figure 17. Lidar Group 19 and 20 along the Holmul river to the north of Chanchich, before (a) and after (b) LiDAR-aided mapping.

Conclusions

Several previous Maya case studies have demonstrated the effectiveness of LiDAR bare-ground DEMs applied to mapping archaeological features under dense forest canopy (Chase et al. 2011, 2012, 2014 Rosenswig 2013). In the Holmul region, the use of LiDAR further highlighted the enormous benefits this technology brings to archaeological mapping not only with regards to aiding to the discovery of monumental architecture but also greatly reducing the cost of documentation in the long run. In particular, the Holmul case study offered the opportunity to test 1) the greater efficacy in site discovery of the new Titan MW instrument and concomitantly 2) the accuracy of existing maps generated via foot survey and 3) the validity of a pre-existing satellite image-based methodology for predicting the presence of buried architecture under one of the more pristine tracks of tropical forest in Mesoamerica.

It is fair to say that this LiDAR dataset exceeded any expectation on the part of this archaeologist. As in previous case studies, LiDAR images for the first time provided accurate representation of the land forms and settlement features with a level of detail that is otherwise simply impossible to achieve with currently available methods. These data greatly improve our ability to understand the relationship between the various components of human settlement and natural environment.

A second outcome of the implementation of LiDAR is that it forces a reconsideration of the limits of traditional field survey in terms of our ability to collect a representative and detailed sample. When compared to the existing maps, the 0.5m resolution LiDAR dataset locates settlement features more accurately than handheld units commonly used under forest canopy thanks to its more sophisticated GPS technology. Once identified, previously mapped features can be easily shifted to their actual location using on-screen editing tools. Furthermore, it is possible to clearly delineate shapes and volumes of mound architecture on LiDAR DEMs to such a degree that, after ground-truthing, several important architectural complexes at Holmul, T'ot and other nearby sites were-re-interpreted and re-drawn. An added benefit of this technology is that it does not require clearing of the forest undergrowth, unlike traditional survey, while providing more detailed results. As a result, it is possible to maintain an archaeological site's unique wildlife supporting vegetation while recording it at a lower cost (for large areas).

The LiDAR dataset included certain areas that represented gaps in the existing coverage. In these areas, several architectural groups were located for the first time. In each case the resolution of the LiDAR image was such that it allowed for the clear identification of size, shape and orientation of settlement features. It was found that most mound features over 1m in height and 5-7m in length were easier to recognize on the LiDAR image than smaller ones without the benefit of field inspection. In this sense, the re-mapping of Chanchich monumental core and of its nearby settlement, which had been out of reach for our team for some time, was finally possible. Another, most remarkable outcome of this application, was the discovery of three causeways, two between Cival and Holmul and one between Cival and Chanchich. The Holmul-Cival causeway had gone completely unrecognized due to its low profile and width (10m), in spite of two short sections having previously been mapped. In addition, the high resolution image revealed important earthworks of defensive or hydrological nature at Holmul and Cival that had previously gone unnoticed.

Even within its limited extent (in width), the carefully placed 2015 Holmul LiDAR dataset, significantly expanded our data sample for settlement and environment in this area. While the analysis is only at the initial stage, these data are already enhancing our ability to make inferences on how settlement units relate to one another and to their environment through time. There is no doubt that as the analysis continues, we will gain new insights on human-environment dynamics.

The discovery of the causeways and new ceremonial centers associated with the period of apogee of Cival (Preclassic period) revealed many characteristics of the Late Preclassic settlement that were previously underappreciated. Mainly, major and minor ceremonial centers appear to be far more formally consistent and interconnected than previously thought. The extent of the Cival 'hinterland' was also underestimated (especially to the north) as one major center had not been recognized to be linked to Cival (Chanchich). Overall, the extent, consistency and interconnectedness of Preclassic monumental architecture in this region indicates a higher level of socio-political integration for that period than previously estimated. This, in turn, has significant implications to our understanding of Maya political organization for that period.

Also, a stronger relationship between Cival and Holmul came into focus for the first time thanks to the discovery of the causeway. The apparent 'special' relation that the elites of the two sites enjoyed in the Preclassic period partially explains the rise of Holmul as a dynastic center when activity at Cival ceased during the Preclassic-to-Classic transition (200-300 CE). Moreover, similar (and therefore Preclassic) earthworks at Cival and Holmul clearly revealed a much greater investment in water catchment than previously estimated for the Preclassic period. These findings are significantly altering previous notions not only on local cultural developments but on lowland Maya civilization in general.

Finally, the methodological benefits of applying LiDAR bare-ground data to archaeological survey go well beyond the ability to locate, recognize and interpret architectural features under the forest. With regards to monumental architecture, the present LiDAR dataset conveyed sufficient clarity for the mapper to interpret and digitize structures of certain size on the screen at the same scale used in the field (1:1,000). This greatly reduces the need for time-consuming survey and removal of undergrowth vegetation. In this sense, LiDAR-aided mapping has the potential to truly revolutionize mapping of archaeological sites in remote and forested regions of the Maya Lowlands, in more ways than previously thought. While many have pointed out that LiDAR may never fully replace field mapping, LiDAR data significantly reduce the need for it. In addition to providing unprecedented completeness and accuracy in the representation of human and natural landscape features, LiDAR data allow for faster results than traditional foot survey by many orders of magnitudes (weeks vs decades for large areas) while, at the same time, greatly reducing the need for additional field work. Therefore, the widespread adoption of LiDAR mapping in forested areas in the long run will also reduce operating costs for archaeological research by a tremendous amount.

References

Chase A. and D. Chase, (1999) "External Impetus, Internal Synthesis, and Standardization: E-Group Assemblages and the Crystallization of Classic Maya Society in the Southern Lowlands," in: Grube, N. (ed.) *The Emergence of Lowland Maya Civilization.* MarktSchwaben: Verlag Anton Saurwein, 87–102.

Chase, A.F.; Chase, D.Z.; Awe, J.J.; Weishampel, J.F.; Iannone, G.; Moyes, H.; Yaeger, J.; Brown, M.K.; Shrestha, R.L.; Carter, W.E.; Fernandez Diaz, J.C. (2014)Ancient Maya Regional Settlement and Inter-Site Analysis: The 2013 West-Central Belize LiDAR Survey. *Remote Sensing* 2014(6): 8671-8695

Chase, Arlen F., Diane Z. Chase, John F. Weishampel, Jason B. Drake, Ramesh L. Shrestha, K. Clint Slatton, Jaime J. Awe, William E. Carter (2011) Airborne LiDAR, archaeology, and the ancient Maya landscape at Caracol, Belize *Journal of Archaeological Science* 38(2): 387-398

Estrada-Belli, F. (2002) Anatomía de una ciudad Maya: Holmul. Resultados de investigaciones arqueológicas en 2000 y 2001. *Mexicon*, 24(5), 107–112

(2011) T*he First Maya Civilization. Ritual and Power in the Maya Lowlands before the Classic Period*. New York, Routledge.

Estrada-Belli, Francisco and Magaly Koch (2007) Remote Sensing and GIS Analysis of a Maya City and Its Landscape: Holmul, Guatemala. In. *Remote Sensing in Archaeology*. James R. Wiseman and Farouk El-Baz (eds.) pp. 263-81. New York, Springer.

Fialko, Vilma (2005) Diez años de investigaciones arqueológicas en la cuenca del río Holmul, región noreste de Petén, in: , J.P. Laporte, B. Arroyo y H. Mejía (eds.), *XVIII Simposio de Investigaciones Arqueológicas en Guatemala, 2004*, pp.244-260. Museo Nacional de Arqueología y Etnología, Guatemala.

Holmul Archaeological Project (2015) Holmul Archaeological Reports 2000-2014. Electronic Document, http://www.bu.edu/holmul/reports/, accessed Aug. 31, 2015.

Merwin, Raymond E. and George Vaillant (1932) *The Ruins of Holmul*. Cambridge, MA: Peabody Museum of American Archaeology and Ethnology, Harvard University.

Puleston, Dennis (1983) *The Settlement Survey of Tikal*. Philadelphia: University Museum, University of Pennsylvania.

Rosenswig, Robert M. ,Ricardo López-Torrijos, Caroline E. Antonelli, Rebecca R. Mendelsohn (2013) LiDAR mapping and surface survey of the Izapa state on the tropical piedmont of Chiapas, Mexico. *Journal of Archaeological Science 40(3): 1493-1507*

United States Geological Survey (2015) Earth Explorer Data Portal. Electronic document, http://earthexplorer.usgs.gov/, accessed August 31, 2015.