

# MAPPING MATACANELA: THE COMPLEMENTARY WORK OF LIDAR AND TOPOGRAPHICAL SURVEY IN SOUTHERN VERACRUZ, MEXICO

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## Abstract

We systematically compare methods used for topographical mapping of the archaeological site of Matacanela, located in the Tuxtla Mountains of Veracruz. Specifically, we compare the results of ArcMap 10.2–processed, publicly accessible LiDAR-derived data, collected and distributed for no charge by the Instituto Nacional de Estadística y Geografía (INEGI) in Mexico—with the results of traditional topographical mapping, undertaken using a Sokkia total station. These INEGI data are coarse-grained in comparison to many of the pay-for-service LiDAR datasets that have been generated for Mesoamerican sites and regions, such as Caracol (Chase et al. 2011, 2012, 2014), Izapa (Rosenswig et al. 2013), and Tres Zapotes (Loughlin et al. 2016). Here, we consider the two approaches and the type and quality of data achieved by each, as well as the benefits and drawbacks of using either approach alone. We strongly encourage scholars working in Mexico to avail themselves of these data whenever appropriate.

## INTRODUCTION

Free data sets of LiDAR (Light Detection and Ranging) exist for Mexican researchers. Recently, Golden and colleagues (2016) provided information on one LiDAR dataset produced for biologists. Here we provide an example of how another dataset available to cartographers and archaeologists may be employed. The Instituto Nacional de Estadística y Geografía (INEGI) provides the derivatives of the LiDAR data collected for different locales within Mexico at no charge to researchers who agree not to use it for commercial purposes (INEGI 2015; Williams et al. 2015). Throughout this paper, we discuss the utility and limitations of these INEGI data through application at the site of Matacanela, located in the Tuxtla Mountains of Veracruz.

## LIDAR APPLICATIONS IN MESOAMERICA

The topographical mapping of sites is standard practice in archaeology. In Mesoamerica, as in other locations, it is useful for documenting monumental architecture, terraforming, and small-scale features, and situating them within broader contexts pertaining to the cultural landscape. More recently, the use of airborne LiDAR has increasingly aided the mapping of ancient landscapes (e.g., Chase et al. 2011, 2012, 2014, 2016; Loughlin et al. 2016; Rosenswig et al. 2013). This latter fact is well established, as is the realization that LiDAR can be especially efficient for covering large regions at a very fine grain of analysis—often to centimeters—in a matter of days. Because of LiDAR's ability to penetrate vegetation, and with additional processing to remove those

camouflaging layers, LiDAR is especially beneficial in areas with dense forest cover that impedes or slows standard topographical mapping and inhibits the retrieval of other basic archaeological information based on standard survey procedures.

The early use of LiDAR technology to examine archaeological landscapes began in Europe (Bewley et al. 2005; Shell and Roughley 2004; Sittler 2004), and has since spread worldwide (Bewley 2003; Crow et al. 2007; Faltýnová and Nový 2014; Gallagher and Josephs 2008; NOAA 2012; Pluckhahn and Thompson 2012; Riley 2009; Sithole and Vosselman 2004). In Mesoamerica, the benefits of LiDAR-based methods are well publicized and have been previously discussed for the regions surrounding Caracol (Chase et al. 2014) and Izapa (Rosenswig et al. 2013) in the tropical lowlands, and Angamuco near Lake Patzcuaro (Fisher et al. 2011; see also Carter et al. 2012), as well as other areas. As a result of the efficiency of LiDAR for mapping archaeological landscapes, its use is increasing in frequency (e.g., Chase et al. 2014; Hare et al. 2014; Loughlin et al. 2016; Pruffer et al. 2015). Different kinds of airborne LiDAR produce different results: point, flash, and waveform rely on different methods of collection (Chase et al. 2014, 2016; Doneus et al. 2008). In addition to the kind of airborne LiDAR, the data collection interval determines the ability to detect minor elevation changes. Data collection interval tends to correspond with cost. Archaeological projects specifically designed to incorporate LiDAR as a primary data collection strategy are likely to include funds to cover the significant expense it incurs. This expense, for many projects, may be prohibitive, especially if their aims are not regional in scope or if the projects are designed as doctoral dissertation studies that have lower funding ceilings.

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Archaeologists must also consider the limits of LiDAR data. The type of LiDAR used, how it is processed, and point density can all affect the data and how it can be interpreted. Point density reflects the number of laser returns per square meter. In general, a greater number of returns will typically increase the data accuracy, and permit greater detail visibility. Factors such as dense vegetation and post-collection processing, however, may affect the resolution (Prufer et al. 2015; Tinkham et al. 2011). Fernandez-Diaz et al. (2014) provide numerous examples highlighting data quality issues and canopy penetration. In a review of the data used for this paper, the authors examined other known and topographically mapped archaeological sites. For example, in the processing of these data, Loughlin (personal communication 2014) noticed that one of a pair of recorded mounds at the Epi-Olmec center Tres Zapotes was incorrectly classified as vegetation. In this instance, previously conducted topographical mapping of the site allowed for the error to be identified (Pool and Ohnerson 2003).

#### Balancing Resolution Concerns with Coverage and Budgets

Most research-grade commercial flyovers used by archaeologists contain more than 10 points per meter. By comparison, the original INEGI point cloud, often containing less than one point per meter, was processed to yield a five-meter elevation grid for Maticanela. The availability and price of the INEGI data, however, cannot be surpassed. Moreover, the INEGI LiDAR permit a scale of regional coverage that is typically out of the question for most archaeologists who are relying on standard topographical mapping procedures, and in many cases, can facilitate the construction of topographical maps before setting foot on site. Additionally, in regions where settlement pattern studies have already been documented, new funds intended to map known sites may not be given priority over the detection of unexplored areas. Although the data quality of research-grade LiDAR are far superior, lower point density datasets can nevertheless be especially useful aids in research design and budgeting, not only mapping.

The free LiDAR derivatives provided by INEGI facilitated the first topographical map of Maticanela's site core, outlying site areas including low platform groups, and nearby hinterland locations. Additional expansion of the LiDAR mapping program outward from this project's particular boundaries better facilitates regional integration of archaeological detail. In the case of Maticanela, the nearby Catemaco Valley, and the Hueyapan de Ocampo region, pedestrian archaeological surveys have been conducted, with only basic plan maps produced of obvious mounded architecture. If topographical maps were generated, they were only of formal architectural complexes and not of the surrounding landscape (Killion and Urcid 2001; Santley and Arnold 1996). The systematic application and evaluation of this INEGI dataset to a Tuxtlas case study is the first of its kind for the western Tuxtlas uplands, a region that has already been the subject of several studies of settlement patterns (Killion and Urcid 2001; Santley and Arnold 1996; Stoner 2012). The utility of this INEGI LiDAR data is that we can add new layers of depth that do not currently exist. These data will also help determine new potential areas for more intensive study in a region dominated by rugged terrain where many archaeological settlements are well beyond modern wheeled transportation corridors. In addition to mapping known sites with greater detail, new settlements will be located and a broader range of human-landscape modifications identified, ultimately improving the archaeological community's ability to preserve and interpret

cultural patrimony. Paired with other free remote sensing techniques (e.g., Google Earth satellite imagery), powerful free or low-cost tools are available to make archaeological site recording and preservation more effective and efficient.

#### MATICANELA

The archaeological site of Maticanela is located in the south-central Tuxtla Mountains, a volcanic massif that erupted from the sedimentary coastal plain of the southern Gulf lowlands (Figure 1). Two main peaks divide the uplands and several others add additional relief. San Martin Tuxtla, active as recent as the late eighteenth century, is in the northwest and Santa Marta Tuxtla is in the southeast. Other lower peaks include Cerro el Vigía, Cerro Cintepec, and San Martin Pajapan. Lake Catemaco, one of Mexico's largest freshwater lakes, lies between San Martin and Santa Marta. Lake Catemaco, the Catemaco River, and most other drainages on the south slopes of San Martin and Santa Marta are tributaries of the Rio San Juan, which itself empties into the Papaloapan Basin. Maticanela is located near the west flank of Cerro Cintepec, a Plio-Pleistocene volcano exploited for basalt by Olmec centers (Gillespie 1994; Williams and Heizer 1965). One has a commanding view of Lake Catemaco from the site, as well as access to the southern Tuxtlas foothills. Prehispanic occupation surrounds and underlies the modern community of Zapoapan de Cabañas, located in the *municipio* of Catemaco, Veracruz. The site's architectural core is divided by Federal Highway 180, which connects the Tuxtlas to regions to the north and west with those in the isthmian region to the south and east. Highway construction in the mid-twentieth century bisected at least two conical mounds at the site (Figure 2).

The current research project at Maticanela began in 2014 (Venter 2015) and includes topographical mapping (Cuevas Ordóñez and Shields 2015), geophysical prospection (Crothers et al. 2015), systematic surface survey (León Estrada and Seale 2015), excavation, and the analysis of materials from the site (Arnold 2015; Budar Jiménez 2015; Lindquist and León Estrada 2015; Venter 2015). The emphasis of this project was on internal settlement dynamics for the Classic-Postclassic transition (ca. A.D. 650–1000), a time period that has not been defined with chronological precision (Venter 2015). Thus, a subsurface-oriented strategy was crucial; it consequently diverted funds and time away from a more expansive project focused on horizontal excavations.

Early estimates of recovered data, along with a previously documented corpus of stone sculpture, indicate that Maticanela was occupied primarily during the Preclassic and Classic periods (ca. 1200 B.C.–A.D. 800), with some minor occupation during the Postclassic (ca. A.D. 800–1521). Castro Leal (1982; see also González Lauck 1991) suggested an Olmec component, based on a seated animal interpreted as a small jaguar, whereas Coe (1965) highlighted affinities with Late Classic Maya sites, characteristics that are now generally accepted as being part of a pan-Gulf lowlands suite of attributes (Venter and Pool 2014). Blom and LaFarge (1925–1926) attributed several sculptural components to Postclassic inhabitants. Santley (2007) suggested that the center was perhaps subsidiary to Middle Classic Maticapan, whereas Stoner (2012) has posited association with the center Teotepic, located on the north shore of Lake Catemaco (Arnold and Vanderwarker 2008; Thompson et al. 2011). Budar Jiménez (2015), in her assessment of stone boxes from the site, suggested that Maticanela's greatest

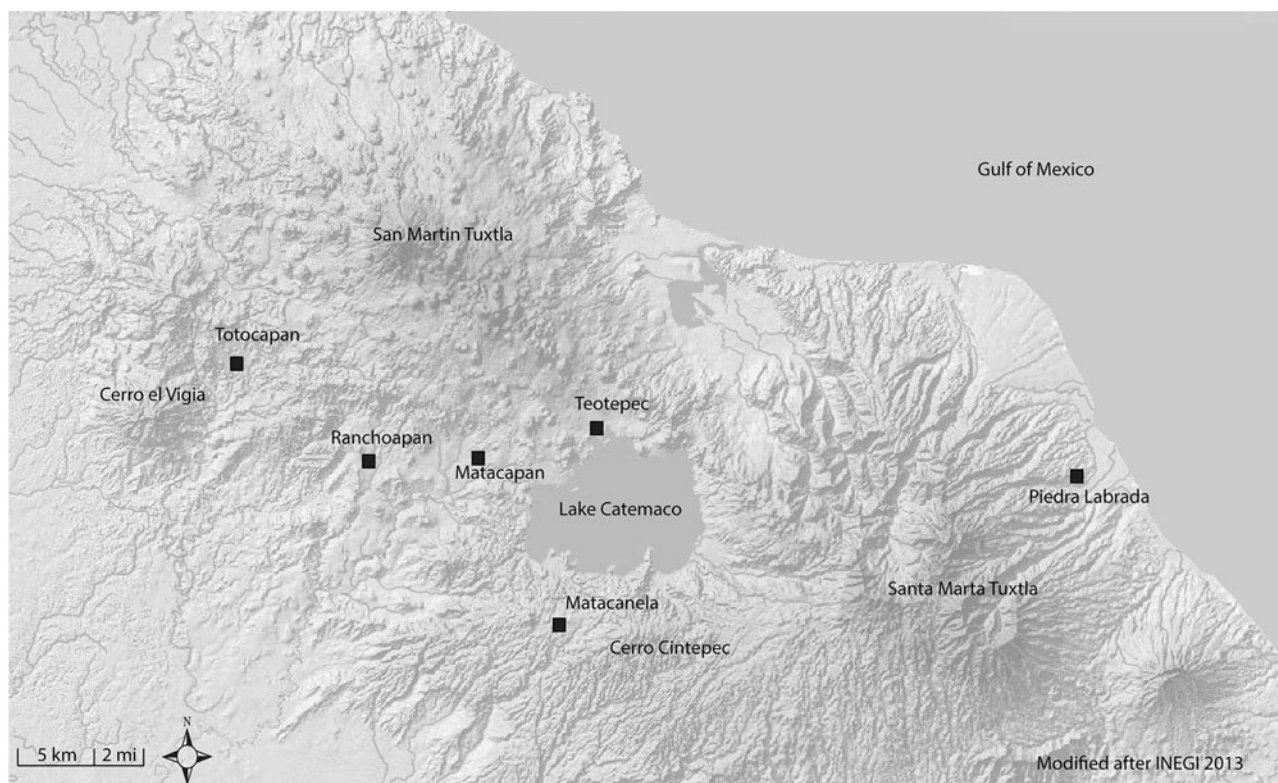


Figure 1. Regional map showing location of Matacanela in relation to select other Classic Period centers in the Tuxtla Mountains. Map by Venter.

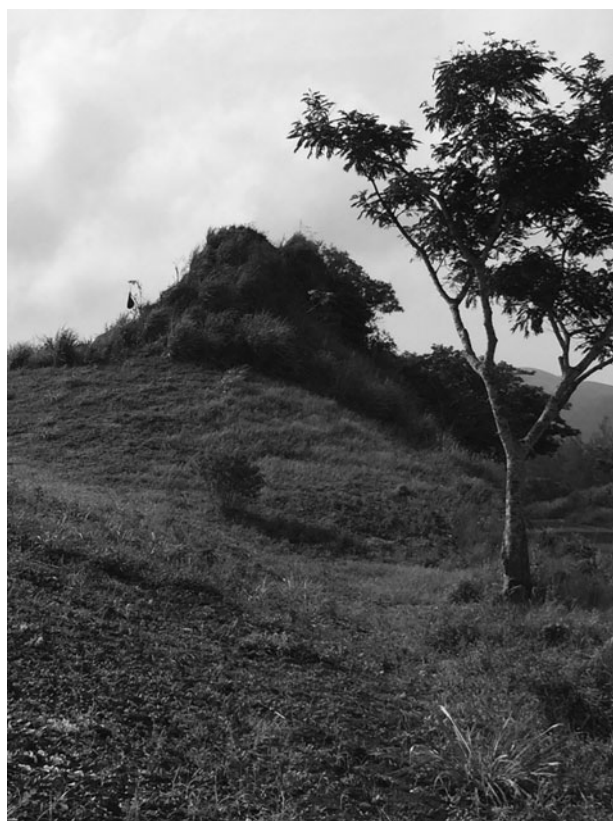


Figure 2. Highway and utility cuts through a mound at Matacanela. Photograph by Venter.

affinities may be with Piedra Labrada and nearby sites on the north slope of Santa Marta.

Initial assessments by the Matacanela Archaeological Project (MAP) of temporality were based on stylistic comparisons with regional data that suggest that the site area was first occupied as late as the Middle Formative, growing in extent during the Late Formative, reaching its height during the Middle to Late Classic periods. The recovery of just a few Postclassic diagnostics suggests that the site was largely depopulated during the Postclassic and Early Colonial periods, but refined earthenwares and majolica patterns, along with early twentieth century accounts (Seler-Sachs 1922; Blom and LaFarge 1925–1926), indicate reoccupation as late as the eighteenth century. Matacanela was a component of a tobacco plantation until the end of the Porfirio Diaz regime in the early twentieth century, when land reforms divided the site area into the *ejidos* (communal land holding groups mandated by the Mexican Constitution) of Zapoapan de Cabañas, La Victoria, and Pozolapan (Cartagena).

#### PREVIOUS MAPPING AT MATACANELA

Matacanela has been repeatedly visited by archaeologists, starting with Eduard and Caecilie Seler in 1922 (Seler-Sachs 1922) and followed by Blom and La Farge (1925–1926) a few years later. The stone sculpture from the site received most of the attention of these visitors in subsequent publications. Valenzuela (1945) and Ruppert (in Valenzuela 1945) were ostensibly more interested in understanding the site's occupational history and, as a result, conducted trench excavations in some of the site's principal mounds,

several of which are arranged into formal mound-plaza configurations. In a brief summary of the visit, Valenzuela (1945) compared the principal mound-plaza group in the site core to another at nearby Teotepec (Arroyo Agrio) but, unlike his work at nearby Matacapán and Agaltepec, he produced no map of Matacanela. Valenzuela suggested that two long mounds in a quadripartite plaza might represent a ballcourt, but the mounds he referenced do not appear to be those included in Pool's sketch map (see discussion below). Valenzuela's comparisons of the plazas at Matacanela and Teotepec led Urcid and Killion (2008) to suggest that Matacanela contained a rare upland example of a Long-Plaza Group (LPG), an architectural configuration common to areas south of the Tuxtlas but not to the north, where a different architectural configuration, the Standard Plan, is dominant (Daneels 2008; Stark 2008). Teotepec's LPG is characterized by the elongated plaza configuration that gives the particular mound-plaza group style its name. The in-line character of Teotepec's ballcourt, however, is more commonly found in Standard Plans, which are typically characterized by more square plaza dimensions. Ballcourts appended to LPGs are typically parallel to a framing long mound (e.g., Urcid and Killion 2008:Figure 16). Arnold (personal communication 2016) suggests that hybrid features of the two styles exist at Teotepec. Indeed, hybridity of attributes is something that would be expected along the boundary of two distinct architectural style zones.

The clarification of the quadripartite architectural format at Matacanela was an important goal of the current project because of the implications it has regarding political boundaries in the Gulf lowlands (Venter and Pool 2014). Clarification of this complex at Matacanela was aided by the processing of the INEGI LiDAR data and topographical mapping that are discussed here, as well as by shallow geophysical prospecting conducted in 2014 (Crothers et al. 2015).

In the 1970s, Francisco Beverido and Robert Squire included Matacanela in their regional survey but none of their results were published. It is unknown if they produced a map, as their notes are unavailable for review (Ponciano Ortiz, personal communication 2013). Thus, despite the history of early-to middle twentieth century site visits and excavations, no site plan or topographic map had ever been generated for Matacanela.

Only more recent visits have produced results relevant to the mapping of the site. The first known sketch of Matacanela's core was produced by Pool and Arnold in 1993 during a quick site visit. Although the map is not to scale, most of the mounds comprising Matacanela's architectural center are shown (Figure 3a). Pool's informal map shows the quadripartite plaza mentioned by Valenzuela; Pool delimited the plaza on its south side by a probable low ball court. Additional range and conical mounds are shown on both sides of the federal highway in Pool's map, some of which are arranged in formal complexes with varying degrees of access.

More recently, Omar Campos produced another plan map of a portion of Matacanela's architectural core (Figure 3b; Heredia 2007). This map also shows some of the same architectural elements as Pool's sketch but the orientation on this map is not correct and some structures are inaccurately depicted. Campos's map also seems to include a portion of the natural hill that delimits the north-east edge of the architectural core. The plaza, which Pool noted as quadripartite, Campos leaves open. He does not note the modification of the natural rise to create the east mound of the mound-plaza group. Campos also omits the low mound that delineates the south side of the probable ball court on Pool's map. To the south, Campos depicts three mounds, two of them with great height, with one that was cut by the federal highway. He also shows the southern formal complex depicted by Pool. Campos also shows multiple mounds on the west side of the highway, indicating, as does Pool, that the

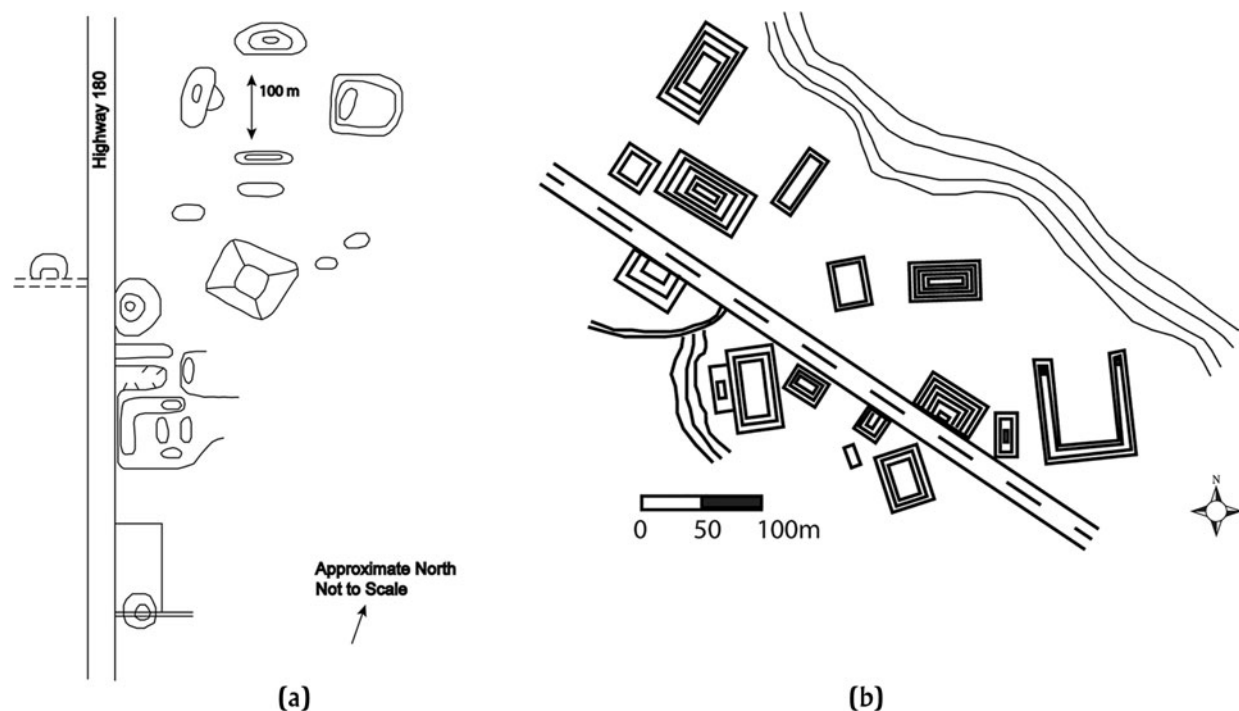


Figure 3. Prior sketch maps of Matacanela's architectural core: (a) unpublished field sketch by Christopher Pool, (b) sketch by Omar Campos (in Heredia 2007). Digitization by Venter.

settlement continues to the west. In the summer of 2011, an informal site visit by Venter and Arnold assessed the content of the two previous maps. Subsequent processing of LiDAR data and topographical mapping has created a more complete and detailed site plan.

#### LIDAR-DERIVED DATA FROM INEGI

In Mexico, INEGI provides its LiDAR derivatives at no charge. Although the point density of the INEGI data is low, it facilitated the first topographical map of Matacanela and environs (Williams et al. 2015). Stoner (Stoner and Pool 2015) used these regional LiDAR data in combination with published contour maps (in the case of Matacapán), to generate hybrid maps of Totocapán and Matacapán, two centers that are also located in the Tuxtla Mountains (Figure 1). Our application of LiDAR data to the Matacanela project area represents the first systematic critical assessment of their use in archaeological research design in the region. We hope that additional projects with access to low-resolution LiDAR in Mexico and elsewhere may benefit from our comparison of mapping methods. As a cautionary note, however, others have highlighted that lower resolution data and vegetative constraints will limit map accuracy and impede site identification (Fernandez-Diaz et al. 2014; Vaughn 2015). Vaughn (2015:43, 101), using similar quality INEGI data for northern Quintana Roo, determined these similar LiDAR derivatives were not entirely suitable for the detection of structures or undocumented Maya archaeological sites. Coarse resolution of the data, filtering algorithms used to produce the DSM and DTM, and vegetation ranging from wetlands to forests in various states of growth contributed to this determination. Fieldwork and ground-truthing are still necessary.

The airborne LiDAR data for Veracruz was collected in October 2010 by INEGI (2015). These data were collected as a point cloud of

laser returns, or LAS files. The LAS was classified into distinct categories such as ground, vegetation, or water. These points were then used to generate raster surfaces (GRID files). Two types of raster layers provided by INEGI were utilized. These were Digital Surface Models (DSM), which shows all surfaces, including trees and buildings, and Digital Terrain Models (DTM), which are processed to show only the bare earth surface (Figure 4). The data was intended to support a five meter grid-cell raster and a vertical resolution of one meter.

#### DTMs and DSMs –Working with LiDAR-Derived Data

The INEGI LiDAR, though low quality, is extremely useful as a pre-screening tool in advance of fieldwork. To better prepare project boundaries and field schedules, the DSM and DTM were used to examine a broad area around Matacanela prior to the initiation of fieldwork in 2014. A comparison between these newly generated maps and photos and notes from the previous year's visits showed a favorable relationship to what had already been documented. Notably detected were the parallel low long mounds that close the south side of the quadripartite plaza, lending greater evidence for the presence of a ball court (present in Pool's sketch, but partially absent from that of Campos [Figure 3]), additional low mounds around the margins of Matacanela's site core, and a great deal of detail regarding the landform on which the site is located—detail that is compressed on the 1:24,000 San Andrés topographic quadrangle. Subsequent shallow geophysical prospection of these mounds reinforced their ballcourt identification (Crothers et al. 2015). The presence of a ballcourt, found in combination with the other structures in this complex, places the construction style firmly within the range of variability documented for the southern LPG (sometimes referred to as the Villa Alta Quadripartite Architectural [Borstein 2005]) tradition, but with some features of the Standard Plan (discussed further below).

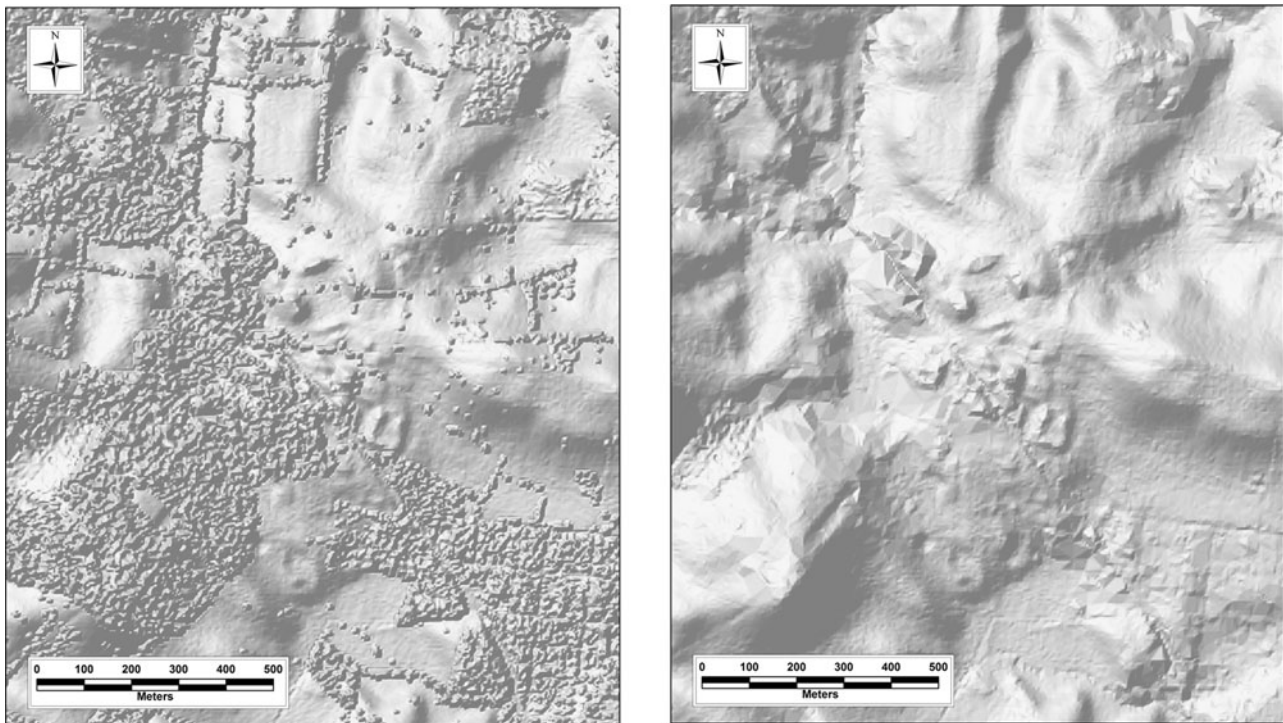


Figure 4. Side-by-side comparison of DSM (left) and DTM maps (right), with a hill-shaded relief model visualization of a coffee grove in Matacanela's site core. Images by Shields.

The two GRID files were opened using ESRI's ArcMap 10.2. Although there are low and no-cost GIS software programs (e.g., QGIS [Grass]), because of the wide institutional availability of ESRI software, we did not use them. In ArcMap 10.2, the region around Matacanela was clipped, allowing for easier manipulation of the data and generation of maps. Contours were created using the Spatial Analyst Extension within ArcToolbox. One-meter contours were generated from the DTMs. Additionally, for heuristic purposes, 25- and 50-centimeter (Figure 5) contours were also generated. While these finer contours likely have horizontal and vertical accuracy issues, if the point coverage was adequate within open and unvegetated areas, these contours and elevations might provide insights into areas that had relatively subtle architectural features. Maps showing all surfaces highlighted not only the landscape and terrain, but showed tree lines, field boundaries, and areas of dense vegetation. This information was particularly helpful in achieving a rough estimate of the number of parcel owners with whom to undertake negotiations regarding field survey access, and the type and duration of survey methods needed by area (e.g., surface artifact collection requiring vegetation removal). These data were especially useful when combined with information regarding slope.

Degrees of slope and aspect were also created using this ESRI extension. These provided insight into the relative steepness of the terrain and watershed drainage patterns. Slope is also a consideration when determining field survey methods. Broad areas of low slope (less than 5 degrees) in the upland areas around Matacanela are conducive to agricultural (crop) production and have the greater potential to contain farmsteads and house clusters. Maps generating various degrees of slope highlighted these favorable areas (Figure 6). Areas of steep topography were considered less likely to contain prehispanic residential and monumental architecture. Conversely, level areas (less than 5 degrees of slope) were considered more likely to contain suitable terrain. Intermediate slopes

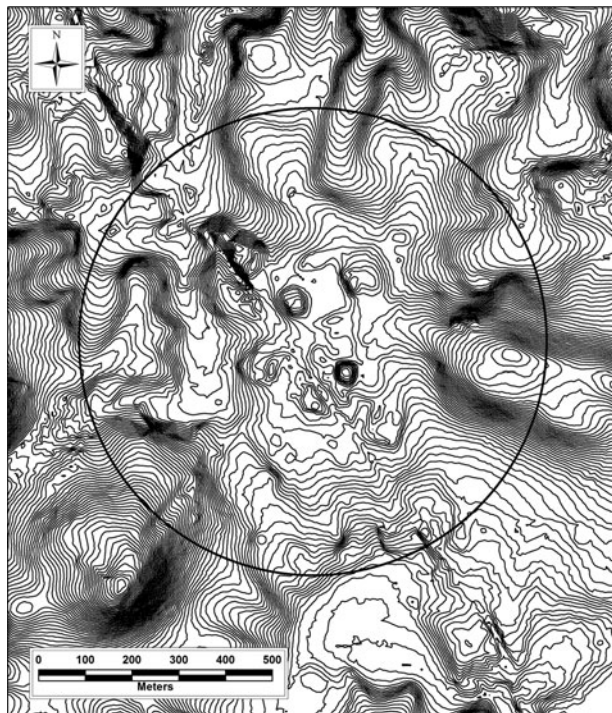


Figure 5. One-meter contour version of the site area with a 0.5-km buffer. Image by Shields.

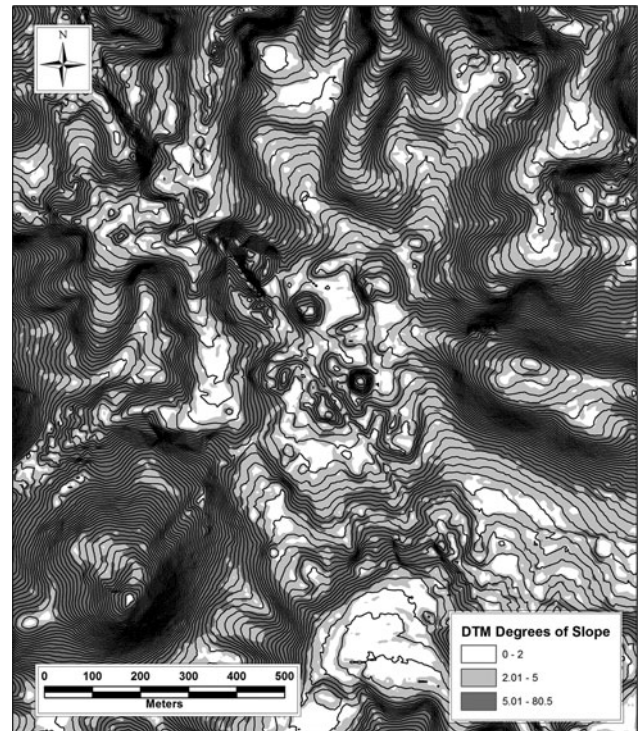


Figure 6. Slopes in central Matacanela project area. Image by Shields.

(5–10 degrees) were also likely to contain evidence for occupation, but slope wash was more likely to characterize these areas than those of a lower gradient. General watershed drainage patterns could also provide insight into agricultural practices and areas of arable land.

For oblique views and a 3-dimensional perspective, data layers were opened and viewed using ESRI's ArcScene, with viewshed tools in both the 3D Analyst and Spatial Analyst extensions (Figure 7). These data were useful for identifying view shed and line-of-sight, particularly of the core of the site. Although the information generated from oblique and 3-D perspectives was not used in the preparation of the project budget, they may be especially important to the evaluation of settlement and its integration into systems of

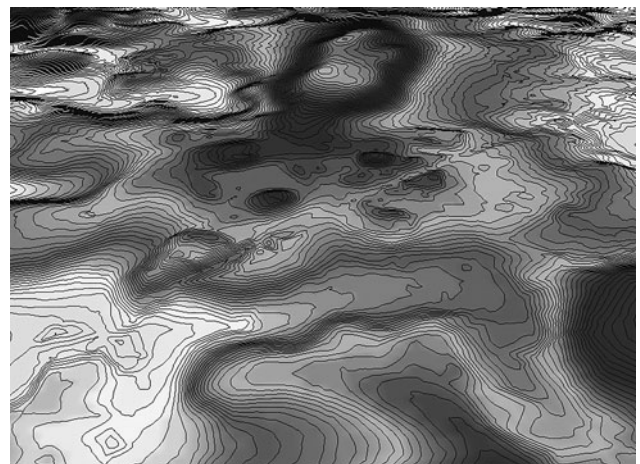


Figure 7. Oblique perspective of the architectural core facing east-southeast (note the path of Highway 180). Image by Shields.

political authority (e.g., Sullivan 2002), where lines-of-sight may have been important in regards to rulership and the creation and maintenance of community solidarity through demonstration of a shared ideology, as indicated by architectural symbols.

Multiple enhancements to the raster were made to facilitate interpretation and visualization. The data were resampled using Cubic Convolution. Contrast and brightness were adjusted. Under the Symbology Tab, Hillshade was turned on, a low Z-factor was applied, and an appropriate color ramp was selected. Typically, no Stretch was applied. To work with and highlight specific elevations, the raster was Classified and Defined Intervals were selected. This enabled the color ramp to match specific elevations and contours while excluding higher and lower elevations not relevant to the project at hand. This work was quickly and easily completed prior to the initiation of fieldwork, over the course of a few evenings.

### LiDAR-Derived Topographic Maps

Multiple maps were created from these data in the months prior to fieldwork. Maps showing the bare earth highlighted terrain and accurately reflected the ground surface within dense vegetation (Figure 4). These maps identified mounds, earthworks, and landforms with research potential.

One-meter contours were generated for the Matacanela research area, the center of which is shown in Figure 5. This process enabled the first accurate topographical map of Matacanela and its environs to be generated. Maps showing all surfaces highlight not only the landscape and terrain, but tree lines, field boundaries, and areas of dense vegetation (Figure 4). Oblique perspectives, while not accurate for mapping of assessments of scale, still provided insights into view sheds and architectural organization on the landscape (Figure 7). Slope is also a consideration when determining field survey (Figure 6). Broad areas of low slope in the upland areas around Matacanela are conducive to agricultural production and have the potential to contain farmsteads, house clusters, and other evidence for occupation and landscape modification. Maps generating various degrees of slope highlighted these favorable areas.

Together, these maps and images informed the project team prior to the initiation of fieldwork. They facilitated cost and time assessments for the purposes of budget preparation; identified key locations and landforms for initial investigation; and guided decisions on the

levels of investigative effort. They also mapped larger areas quickly and easily, and at a relatively accurate scale so that on-the-ground mapping efforts could be more focused on key research areas.

### MAKING THE TOPOGRAPHIC MAP

For the generation of the traditional, on-the-ground topographic map, various topographic interpretations were made with the use of satellite pictures, INEGI's 1:24,000 topographical quadrangles (San Andrés), and, of course, the topographic charts generated by the elevation models provided by INEGI. Subsequent confirmation of topographical relief was made on site by walk-over survey to detect both large and small structures and platforms. The mapping was made in a systematic way, with a Sokkia total station equipped with a wooden tripod, two reflectors and caps, one azimuthal compass, wooden sticks, one handheld GPS, and radios.

The process of generating the topographic map revealed 21 above-surface structures. These structures are much more nucleated than many centers in the region, perhaps because of the restricted availability of level terrain in this plateau-like location. The concentration of formal mounded architecture in the northern portion of the plateau would have facilitated an enhanced view of Lake Catemaco to the north, as well as sites along its shoreline and on the islands of Agaltepec and Tenaspi. Most other known regional centers are located in broad river valley floodplains and adjacent stream terraces, or along the shore of Lake Catemaco. Topographical mapping using the Sokkia total station indicates that Matacanela's tallest structure (from foot to peak), located on the west side of the quadripartite mound-plaza group, currently measures approximately 9 meters in height (Figure 8). Intensive cultivation in recent centuries has likely caused some erosion of the original height of this and other mounds.

The 2014 map extended 1,450 m northwest-to-southeast, and measured 500 m on its widest axis. Additional mapping conducted in 2015 expanded this area in all directions, provided additional coverage of the mounds located to the west of Highway 180, and added detail to some of the structures identified during survey and through the INEGI LiDAR (Figure 9). Because of the size and relief in the 2015 mapping boundary, the map is produced here using one-meter contour intervals.

With the western semi-conical mound as its anchor point, the quadripartite mound-plaza group is oriented approximately 60 degrees east of north; topographical mapping indicates that this



Figure 8. View looking northwest along the approximate centerline of the quadripartite mound group at Matacanela. Photograph by Venter.

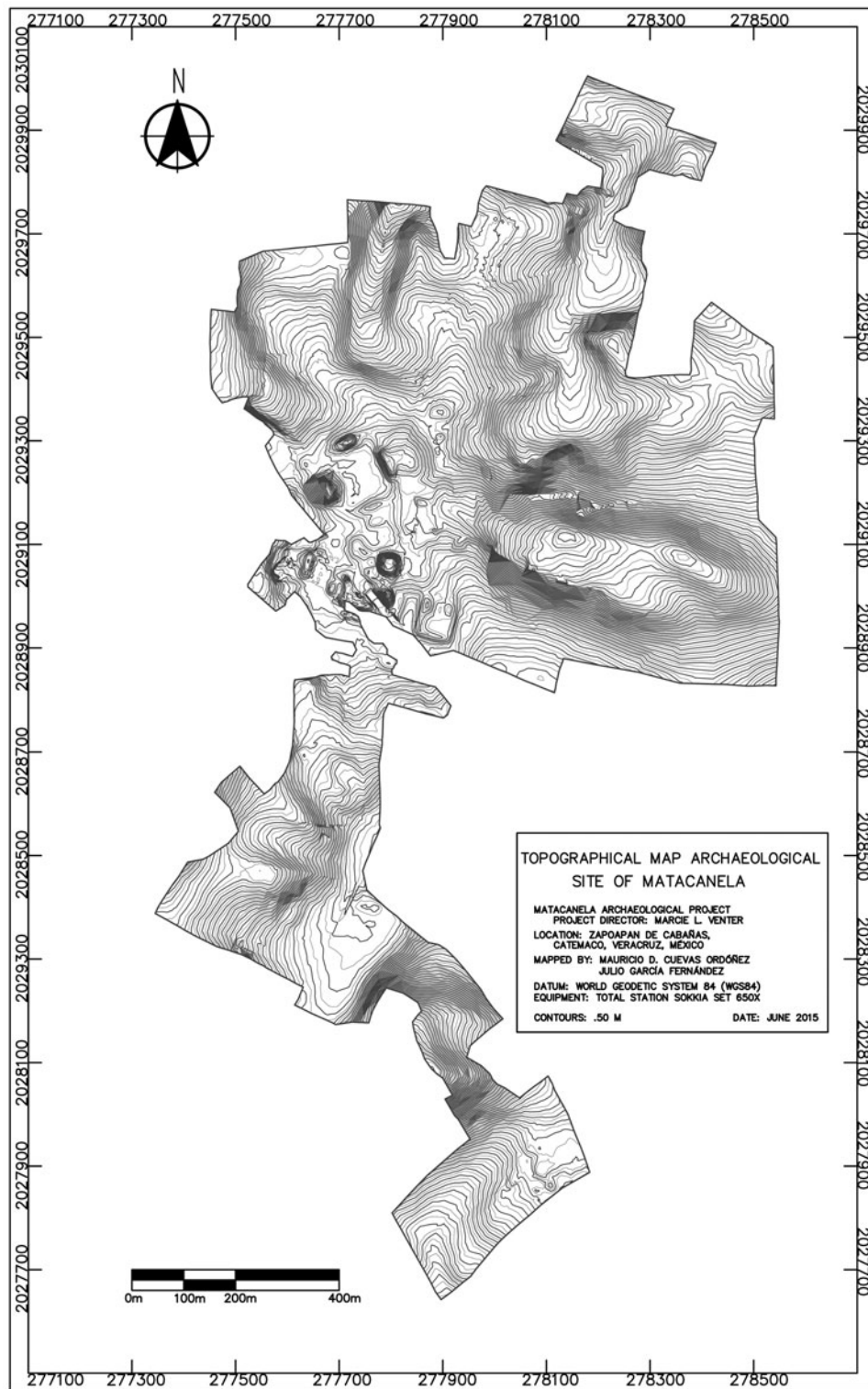


Figure 9. 2015 Topographical map expansion. Map by Cuevas Ordóñez and Julio García Fernández.

complex is delimited by a ball court in the south, as suggested by Pool's sketch (Figure 3a), the LiDAR maps, and electromagnetic induction survey (Crothers et al. 2015). The confirmation of this appended parallel ballcourt, combined with the squarer dimensions of the plaza, yields an interesting contrast to the LPG at Teotepac.

Whereas the LPG at Teotepac contains the long plaza axis typical of LPGs, the in-line ballcourt is a feature more common in Standard Plans. The position of these two sites at the intersection of the two architectural style zones indicates that the site planners were differentially incorporating elements found to the south and the north.



Heterogeneity in material styles is to be expected of boundary zones where interactions are comparatively unfettered or regulated. Daneels (2008), Pool (2008), Stark (2008), and Urcid and Killion (2008) have linked mound-plaza configurations in the Gulf lowlands to the expression of political authority. The mixing of elements of two regional arrangements suggests that the strategies used in the expression of political affiliation may have been somewhat malleable at centers that sat at the margins of the two zones (Venter and Pool 2014).

Two additional tall mounds are located to the south of the quadripartite mound-plaza group at Matacanela, with the conical mound cut by the federal highway. The mounds registered by Campos and Pool on the other side of the federal highway are also visible on the topographic map, along with the L-shaped composite platform south of the settlement. The “L-” or broken “U”-shaped superimposing structure depicted by Pool is also visible, along with end mounds and an interior “step.” This platform is bound on the north-east by a low platform. This composite platform parallels a range mound; together, the two give the appearance of a large ball court, but it is uncertain that the configuration truly represents an arena for the ball game. Several additional low platforms were included in the 21 structure total from the 2014 season. Others were detected during the LiDAR processing, during systematic surface collections, or during the 2015 topographic mapping program (Figures 10a and 10b).

#### A QUICK COMPARISON

Side by side, one can see the relative accuracy of the LiDAR-derived mapping. But the ground-based mapping yields additional data on specific features that would be missed, especially at the 50-cm contour intervals shown in Figure 10a. For example, LiDAR-derived maps indicate the presence of mounds to the west of Highway 180, but standard topographic mapping declutters the

area, making contrasts sharper, allowing for structures to be better delineated not only for their form, but for their size. Also, the large mound cut during highway construction and subsequent utility work is not well defined by the LiDAR imagery. Again, standard topographical procedures better define the structure. Other examples demonstrate how, even for the area of greatest monumental investment, on-the-ground topographical mapping allows for greater accuracy, despite the cost and time investment. Low resolution LiDAR is not without its advantages, however, and this current discussion would not be necessary had higher resolution LiDAR been available.

#### Benefits of using the INEGI LiDAR Data

There are multiple benefits to using these LiDAR data, both at Matacanela and elsewhere in the Mexican coverage area. First, data collection can cover a large region, and can be collected quickly when the environmental conditions are ideal. Second, unlike traditional topographical mapping, there are no landowner restrictions to collecting the data. Data derivatives can be processed quickly and easily, along with image and contour manipulation. Third, data processing can remove vegetation and structures to show only the bare earth surface, making the generation of accurate maps easier, especially when there are areas of dense vegetation. Fourth, maps showing all surfaces can highlight areas of dense vegetation, which can highlight survey issues early. It is also useful at mapping tree lines, which often indicate field boundaries or property lines, and can serve as reference points during fieldwork. Fifth, maps depicting the slope of the topography can identify areas of disturbance, as well as broad level areas conducive to pre-historic occupation and farming. Sixth, contours can be accurately generated at one-meter intervals. Finally, closer contour intervals, while not necessarily accurate for architectural detail and excavation purposes, can still show relative terrain features.

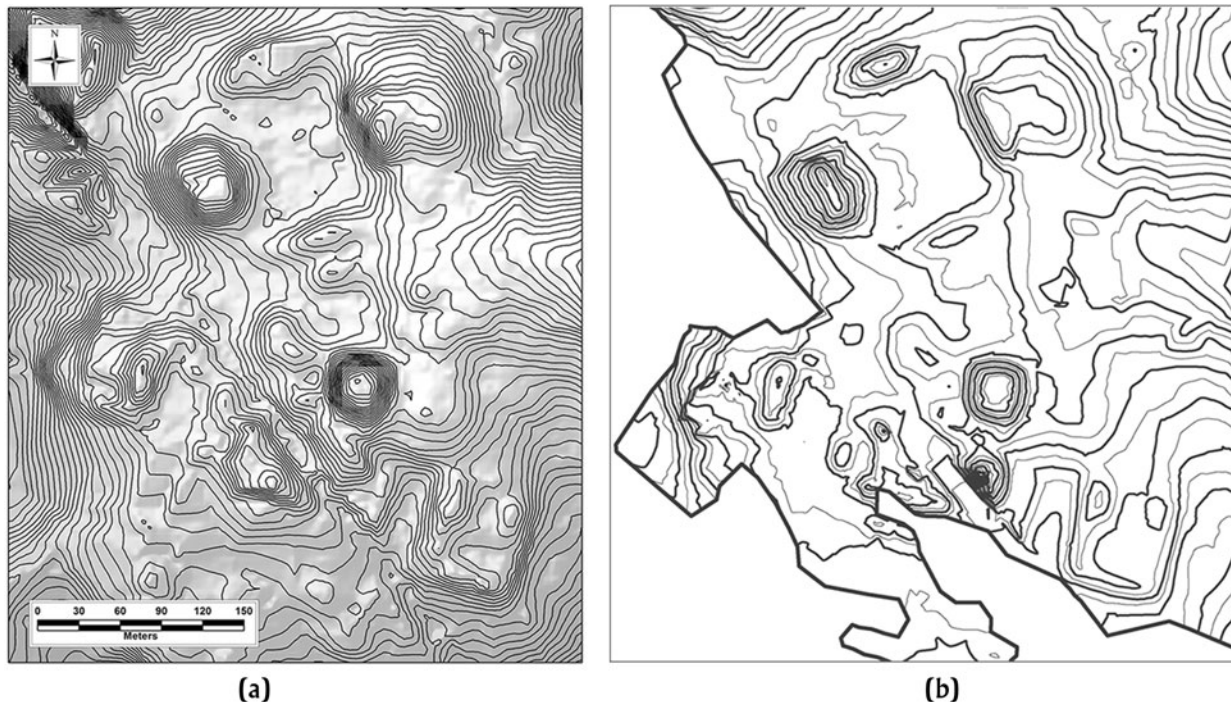


Figure 10. Comparison of (a) LiDAR (contours and hillshade) and (b) 2015 topographic mapping results. Images by (a) Shields and (b) Cuevas Ordóñez.

### Limitations of Using the INEGI LiDAR Data

Not all LiDAR data is created equal and even research-grade point densities do not negate the need for fieldwork (Loughlin et al. 2016). As detailed by others (e.g., Fernandez-Diaz et al. 2014), some of the following limitations may apply to both lower resolution and higher resolution data. First, as a static data set, LiDAR data will not reflect recent changes to the environment and modifications to the landscape. The frozen moment in time reflected in the data may, however, provide important temporal reference points that allow subsequent landscape changes to be measured, contributing to the reconstruction of environmental histories and facilitating site preservation monitoring. Second, depending on the density of the LiDAR collection, there can be serious accuracy issues (note, however, that total station ground points may have the same issue). Some data sets enable the accurate creation of 10-centimeter contours. At one meter, the data set used for Matacanela is much less accurate. Third, as a result, the low-point density airborne LiDAR may not accurately capture subtle landforms and architecture. Fourth, though efficient, LiDAR collection can be relatively costly and sometimes weather dependent. Finally, there can be data classification issues in the processing of LiDAR, meaning that algorithmic adjustments are sometimes necessary so that mounds may be correctly classified and not removed from the imaging.

### Combined Approach

LiDAR derivatives provided good preliminary information to assist in fieldwork planning. They facilitated the generation of contour estimates over a broad area. Yet the data had limitations

that could be overcome only by ground-based topographic survey where detail was needed. While the accuracy is better with total station mapping, this method can be time consuming, expensive, and can be limited by vegetation and uncooperative landowners. Time considerations are compounded by a hilly volcanic landscape such as the Tuxtlas. When used together correctly, they allow for a more efficient use of time and money, allow for situational flexibility, and yield data that is sufficient for field projects such as this one.

### FINAL CONSIDERATIONS

These LiDAR-based data enabled the first topographical map of Matacanela and its environs to be generated, the project area to be defined, and for cost and time assessments to be estimated for the purposes of budget preparation. Utilization of the INEGI data by other archaeological researchers working in Mexico should become commonplace, especially for preliminary exploration and planning purposes, when dense vegetation is not a limiting factor, and when costlier LiDAR procedures cannot be accommodated. Because of the uncertainty of the quality and resolution of the LiDAR data, we felt that topographical mapping of the site area was an important step to “ground-truth” the LiDAR, as well as to collect more fine-grained measurements from small-scale architectural features, artifact concentrations, and other cultural and natural features that may have been missed during the flyovers. The provisioning of this no-cost dataset by INEGI in Mexico is a tool that even relatively small budgets can and should attempt to utilize as a complementary field analysis strategy.

### RESUMEN

En este trabajo, comparamos sistemáticamente los métodos utilizados para la cartografía topográfica de la zona arqueológica de Matacanela, situado en las montañas de Tuxtla, de Veracruz. Específicamente, se comparan los resultados de datos derivados de LiDAR que están provechados sin cargo por el Instituto Nacional de Estadística y Geografía (INEGI) en México, con los resultados de mapeo topográfico tradicional, mediante una estación total Sokkia. Estos datos INEGI son de grano grueso en comparación con muchos de los conjuntos de datos de LiDAR de pago-por-servicio que se han generado para sitios y regiones de Mesoamérica, como Caracol (Chase et al. 2012), Izapa (Rosenswig et al. 2013) y Tres Zapotes (Loughlin et al. 2016). Para efectos de planificación del proyecto, los datos derivados de LiDAR de INEGI fueron procesados y mapas generados mediante GIS. Estos datos de LiDAR permitieron el primer mapa topográfico de Matacanela y sus alrededores que se generen, el área del

proyecto a definir y costo y evaluaciones de tiempo estimado para efectos de la preparación del presupuesto antes de campo de trabajo. Sin embargo, debido a la incertidumbre de la calidad y resolución de los datos LiDAR para detectar elementos bajos, cartografía topográfica de la zona era considerada un paso importante para evaluar el LiDAR y para recoger más mediciones de grano fino de pequeños elementos arquitectónicos, las concentraciones de artefactos y otras características culturales y naturales que pueden haberse omitidos por el proceso. Aquí, tenemos en cuenta los dos enfoques y el tipo y calidad de los datos alcanzados por cada uno, así como las ventajas e inconvenientes de la utilización de cualquiera de los dos enfoques solos. Les recomendamos a los especialistas con acceso a estos datos INEGI o a otras bases de datos similares, que aprovechen la oportunidad de añadir análisis complementarios comparables a sus herramientas arqueológicas estándar.

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## REFERENCES

- Arnold, Philip J., III  
2015 Surface Ceramic Distributions at Matacanela, Southern Veracruz, Mexico. Paper presented at the 80th Annual Meeting of the Society for American Archaeology, San Francisco.
- Arnold, Philip J., III, and Amber Vanderwarker  
2008 Informe técnico del Proyecto Arqueológico Teotepec: La primera temporada (2007) y petición para la segunda temporada (2008). Report submitted to the Consejo de Arqueología, Instituto Nacional de Antropología e Historia, Mexico City.
- Bewley, Robert H.  
2003 Aerial Survey for Archaeology. *The Photogrammetric Record* 18: 273–292.
- Bewley, Robert H., Simon Crutchley, and Colin A. Shell  
2005 New Light on an Ancient Landscape: LiDAR Survey in the Stonehenge World Heritage Site. *Antiquity* 79:636–647.
- Bloom, Frances, and Oliver La Farge  
1925–1926 *Tribes and Temples*. Middle American Research Institute Publication Series, No. 1. Tulane University, New Orleans.
- Borstein, Joshua  
2005 Epiclassic Political Organization in Southern Veracruz, Mexico: Segmentary versus Centralized Integration. *Ancient Mesoamerica* 16: 11–21.
- Budar Jiménez, Lourdes  
2015 Prehispanic Sculpture from Matacanela. Paper presented at the 80th Annual Meeting of the Society for American Archaeology, San Francisco.
- Carter, William E., Ramesh L. Shrestha, Christopher Fisher, and Stephen Leisz  
2012 Geodetic Imaging: A New Tool for Mesoamerican Archaeology. *Eos* 93:413–415.
- Castro Leal, Marcía  
1982 Tigrillo Olmeca de Matacanela, Veracruz. *Revista Mexicana de Estudios Antropológicos*, Tomo XXVIII. Sociedad Mexicana de Antropología, Mexico City.
- Chase, Arlen F., Diane Z. Chase, Christopher T. Fisher, Stephen J. Leisz, and John F. Weishampel  
2012 Geospatial Revolution and Remote Sensing LiDAR in Mesoamerican Archaeology. *Proceedings of the National Academy of Science* 109:12916–12921.
- Chase, Arlen F., Diane Z. Chase, Jaime J. Awe, John F. Weishampel, Gyles Iannone, Holley Moyes, Jason Yaeger, M. Kathryn Brown, Ramesh L. Shrestha, William E. Carter, and Juan C. Fernandez Díaz  
2014 Ancient Maya Regional Settlement and Inter-Site Analysis: The 2013 West-Central Belize LiDAR Survey. *Remote Sensing* 6: 8671–8695.
- Chase, Arlen F., Diane Z. Chase, Josh F. Weishampel, Jason B. Drake, Ramesh L. Shrestha, K. Clint Slaton, Jaime J. Awe, and William E. Carter  
2011 Airborne LiDAR, Archaeology, and the Ancient Maya Landscape at Caracol, Belize. *Journal of Archaeological Science* 38:387–398.
- Chase, Arlen F., Kathryn Reese-Taylor, Juan C. Fernandez, and Diane Z. Chase  
2016 Progression and Issues in the Mesoamerican Geospatial Revolution: An Introduction. *Advances in Archaeological Practice* 4: 219–231.
- Coe, Michael D.  
1965 Archaeological Synthesis of Southern Veracruz and Tabasco. In *Archaeology of Southern Mesoamerica, Part Two*. Handbook of Middle American Indians, Vol. 3, edited by Gordon R. Willey, pp. 679–715. University of Texas Press, Austin.
- Crothers, George, Justin Carlson, David Gárate López, and Matthew Litteral  
2015 Electromagnetic Induction Survey at Matacanela to Detect Off-Mound Structures and Landscape Features. Paper presented at the 80th Annual Meeting of the Society for American Archaeology, San Francisco.
- Crow, Peter, Sue Benham, Bernard J. Devereux, and Gabriel S. Amable  
2007 Woodland Vegetation and its Implications for Archaeological Survey using LiDAR. *Forestry* 80:241–252.
- Cuevas Ordóñez, Mauricio, and Carl Shields  
2015 Mapping Matacanela - The Complementary Work of Topographical Survey and LiDAR. Paper presented at the 80th Annual Meeting of the Society for American Archaeology, San Francisco.
- Daneels, Annick  
2008 Ball Courts and Politics in the Lower Cotaxtla Valley: A Model to Understand Classic Central Veracruz? In *Classic Period Cultural Currents in Southern and Central Veracruz*, edited by Philip J. Arnold III and Christopher A. Pool, pp. 197–224. Dumbarton Oaks Research Library and Collections, Washington, DC.
- Doneus, Michael, Christian Briese, Martin Fera, and Martin Janner  
2008 Archaeological Prospection of Forested Areas using Full-waveform Airborne Laser Scanning. *Journal of Archaeological Science* 35:882–893.
- Faltýnová, Martina, and Petr Nový  
2014 Airborne Laser Scanning and Image Processing Techniques for Archaeological Prospection. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XL:231–235.
- Fernandez-Diaz, Juan C., William E. Carter, Ramesh L. Shrestha, and Craig L. Glenni  
2014 Now You See It...Now You Don't: Understanding Airborne Mapping LiDAR Collection and Data Product Generation for Archaeological Research in Mesoamerica. *Remote Sensing* 6: 9951–10001.
- Fisher, Christopher T., Stephen Leisz, and Gary Outlaw  
2011 LiDAR: A Valuable Tool Uncovers an Ancient City in Mexico. *Photogrammetric Engineering and Remote Sensing* 77:963–967.
- Gallagher, Julie M., and Richard L. Josephs  
2008 Using LiDAR to Detect Cultural Resources in a Forested Environment: An Example from Isle Royale National Park, Michigan, USA. *Archaeological Prospection* 15:187–206.
- Gillespie, Susan  
1994 Llano del Jicaro: A Monument Workshop. *Ancient Mesoamerica* 5:231–242.
- Golden, Charles, Timothy Murtha, Bruce Cook, Derek S. Shaffer, Whittaker Schroder, Elijah J. Hermit, Omar Alcover Pirpi, and Andrew K. Scherer  
2016 Reanalyzing Environmental LiDAR Data for Archaeology: Mesoamerican Applications and Implications. *Journal of Archaeological Science: Reports* 9:293–308.
- González Lauck, Rebecca  
1991 Algunas consideraciones sobre los Monumentos 75 y 80 de La Venta, Tabasco. *Anales del Instituto de Investigaciones Estéticas* 62: 163–179.
- Hare, Timothy, Marilyn Masson, and Bradley Russell  
2014 High-density LiDAR Mapping of the Ancient City of Mayapán. *Remote Sensing* 6:9064–9085.
- Heredia Barrera, Luis  
2007 La arquitectura como indicador de fronteras culturales durante el Clásico Tardío, en la región de Abasolo del Valle, en el Sur de Veracruz, México. Unpublished Maestría thesis, Departamento de Arqueología, Escuela Nacional de Antropología e Historia, México City.
- Instituto Nacional de Estadística y Geografía (INEGI)  
2015 Mapa digital de Mexico. Electronic resource, <http://gaia.inegi.org.mx/mdm6/>, accessed December 4, 2015.
- Killion, Thomas W., and Javier Urcid  
2001 The Olmec Legacy: Cultural Continuity in Mexico's Southern Gulf Coast Lowlands. *Journal of Field Archaeology* 28:3–25.
- León Estrada, Xochitl, and Heather Seale  
2015 Settlement at Matacanela: Preliminary Interpretations. Paper presented at the 80th Annual Meeting of the Society for American Archaeology, San Francisco.
- Lindquist, Shayna, and Xochitl León Estrada  
2015 The Obsidian of Matacanela. Paper presented at the 80th Annual Meeting of the Society for American Archaeology, San Francisco.
- Loughlin, Michael, Christopher Pool, Ramesh Shrestha, and Juan Fernandez  
2016 Mapping the Tres Zapotes Polity: The Effectiveness of Lidar in Tropical Alluvial Settings. *Advances in Archaeological Practice* 4: 301–313.
- National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center  
2012 *LiDAR 101: An Introduction to Lidar Technology, Data, and Applications* (Revised). NOAA Coastal Services Center, Charleston. Electronic document, [https://coast.noaa.gov/digitalcoast/\\_/pdf/lidar101.pdf](https://coast.noaa.gov/digitalcoast/_/pdf/lidar101.pdf), accessed December 4, 2015.

- Pluckhahn, Thomas J., and Victor D. Thompson  
2012 Integrating LiDAR Data and Conventional Mapping of the Florida Center Site in South-central Florida: A Comparative Approach. *Journal of Field Archaeology* 37:289–301.
- Pool, Christopher A.  
2008 Architectural Plans, Factionalism, and the Proto-Classic-Classic Transition at Tres Zapotes. In *Classic Period Cultural Currents in Southern and Central Veracruz*, edited by Philip J. Arnold III and Christopher A. Pool, pp. 121–158. Dumbarton Oaks Research Library & Collection, Harvard University Press, Washington, DC.
- Pool, Christopher A., and Michael A. Ohnersorgen  
2003 Archaeological Survey and Settlement at Tres Zapotes. In *Settlement Archaeology and Political Economy at Tres Zapotes, Veracruz, Mexico*, edited by Christopher A. Pool, pp. 7–31. Monograph 50. Cotsen Institute of Archaeology, University of California, Los Angeles.
- Prifer, Keith M., Amy E. Thompson, and Douglas J. Kennett  
2015 Evaluating Airborne LiDAR for Detecting Settlements and Modified Landscapes in Disturbed Tropical Environments at Uxbenka, Belize. *Journal of Archaeological Science* 57:1–13.
- Riley, Melanie A.  
2009 Automated Detection of Prehistoric Conical Burial Mounds from LiDAR Bare-Earth Digital Elevation Models. Unpublished Master's thesis, Department of Geology and Geography, Northwest Missouri State University, Maryville.
- Rosenswig, Robert, Ricardo López-Torrijos, Caroline E. Antonelli, and Rebecca R. Mendelsohn  
2013 LiDAR Mapping and Surface Survey of the Izapa State on the Tropical Piedmont of Chiapas, Mexico. *Journal of Archaeological Science* 40:1493–1507.
- Santley, Robert S.  
2007 *The Prehistory of the Tuxtla*. University of New Mexico Press, Albuquerque.
- Santley, Robert S., and Philip J. Arnold III  
1996 Prehispanic Settlement Patterns in the Tuxtla Mountains, Southern Veracruz, Mexico. *Journal of Field Archaeology* 23:225–249.
- Seler-Sachs, Cecilie  
1922 Altertumer des Kanton Tuxtla im staate Vera Cruz. *Festschrift Eduard Seler*, edited by W. Lehman, pp. 543–556. Verlag von Strecker und Schröder, Stuttgart.
- Shell, Colin A., and Corinne F. Roughley  
2004 Exploring the Loughcrew Landscape: A New Approach with Airborne Lidar. *Archaeology Ireland* 18:20–23.
- Sithole, George, and George Vosselman  
2004 Experimental Comparison of Filter Algorithms for Bare-Earth Extraction from Airborne Laser Scanning Point Clouds. *ISPRS Journal of Photogrammetry and Remote Sensing* 59:85–101.
- Sittler, Benoit  
2004 Revealing Historical Landscapes by Using Airborne Laser Scanning. In *Laser Scanners for Forest and Landscape Assessment: Proceedings of the ISPRS Working Group VIII/2, Volume XXXVI, Part 8/W2*, edited by M. Thies, H. Spiecker, and H. Weinacker, pp. 258–261. Institute for Forest Growth, Freiburg.
- Stark, Barbara L.  
2008 Polity and Economy in the Western Lower Papaloapan Basin. In *Classic Period Cultural Currents in Southern and Central Veracruz*, edited by Philip J. Arnold III and Christopher A. Pool, pp. 85–120. Dumbarton Oaks Research Library and Collections, Washington, DC.
- Stoner, Wesley D.  
2012 Modeling and Testing Polity Boundaries in the Classic Tuxtla Mountains, Southern Veracruz, Mexico. *Journal of Anthropological Archaeology* 31:381–402.
- Stoner, Wesley D., and Christopher A. Pool  
2015 The Archaeology of Disjuncture: Classic Period Disruption and Cultural Divergence in the Tuxtla Mountains of Mexico. *Current Anthropology* 56:385–420.
- Sullivan, Timothy D.  
2002 Landscape of Power: A Spatial Analysis of Civic-Ceremonial Architecture at Tres Zapotes, Veracruz, Mexico. Unpublished Master's thesis, Department of Anthropology, Southern Illinois University, Carbondale.
- Thompson, Victor D., Philip J. Arnold III, Thomas J. Pluckhahn, Amber M. VanDerwarker  
2011 Situating Remote Sensing in Anthropological Archaeology. *Archaeological Prospection* 18:195–213.
- Tinkham, Wade T., Hongyu Huang, Alistair M. S. Smith, Ramesh Shrestha, Michael J. Falkowski, Andrew T. Hudak, Timothy E. Link, Nancy F. Glenn, and Danny G. Marks  
2011 A Comparison of Two Open Source LiDAR Surface Classification Algorithms. *Remote Sensing* 3:638–649.
- Urcid, Javier, and Thomas W. Killion  
2008 Social Landscapes and Political Dynamics in the Southern Gulf Coast Lowlands (500–1000 CE). In *Classic Period Cultural Currents in Southern and Central Veracruz*, edited by Philip J. Arnold III and Christopher A. Pool, pp. 259–291. Dumbarton Oaks, Washington, DC.
- Valenzuela, Juan  
1945 La segunda temporada de exploraciones en la región de Los Tuxtla, estado de Veracruz, Mexico. *INAH Anales* 3:81–94.
- Vaughn, Andrew  
2015 Space, Settlement, and Environment: Detecting Undocumented Maya Archaeological Sites with Remotely Sensed Data. Unpublished Master's thesis, Department of Anthropology, Georgia State University, Atlanta.
- Venter, Marcie L.  
2015 Introduction to the Maticanela Archaeological Project: Collapse and Political Reorganization in a Lowland Mesoamerican Society. Paper presented at the 80th Annual Meeting of the Society for American Archaeology, San Francisco.
- Venter, Marcie L., and C. A. Pool  
2014 Late Classic Frontiers and Boundaries in the Southern Gulf Lowlands. Paper presented at the 79th Annual Meeting of the Society for American Archaeology, Austin.
- Williams, Alana, Emily Kleber, and Ramón Arrowsmith  
2015 Guide for Downloading and Initial Processing of High Resolution Topographic Data for Short Course “LIDAR Derived DEMs applied to Landslide, Fault, Earthquake Rupture, and Landscape Changes.” ASU/Open Topography. Electronic document, [https://cloud.sdsc.edu/v1/AUTH\\_opentopography/www/shortcourses/UNAM\\_Mexico15/20150322\\_UNAMshortcourse.pdf](https://cloud.sdsc.edu/v1/AUTH_opentopography/www/shortcourses/UNAM_Mexico15/20150322_UNAMshortcourse.pdf), accessed April 29, 2017.
- Williams, Howel, and Robert F. Heizer  
1965 Sources of Rocks used in Olmec Monuments. In *Contributions of the University of California Archaeological Research Facility: Sources of Stones used in Prehistoric Mesoamerican Sites*, pp. 1–39. Department of Anthropology, Berkeley.