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Ancient Maya Regional Settlement and Inter-Site Analysis: The 2013 West-Central Belize LiDAR Survey

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Abstract: During April and May 2013, a total of 1057 km² of LiDAR was flown by NCALM for a consortium of archaeologists working in West-central Belize, making this the largest surveyed area within the Mayan lowlands. Encompassing the Belize Valley and the Vaca Plateau, West-central Belize is one of the most actively researched parts of the Maya lowlands; however, until this effort, no comprehensive survey connecting all settlement had been conducted. Archaeological projects have investigated at least

18 different sites within this region. Thus, a large body of archaeological research provides both the temporal and spatial parameters for the varied ancient Maya centers that once occupied this area; importantly, these data can be used to help interpret the collected LiDAR data. The goal of the 2013 LiDAR campaign was to gain information on the distribution of ancient Maya settlement and sites on the landscape and, particularly, to determine how the landscape was used between known centers. The data that were acquired through the 2013 LiDAR campaign have significance for interpreting both the composition and limits of ancient Maya political units. This paper presents the initial results of these new data and suggests a developmental model for ancient Maya polities.

Keywords: LiDAR; Maya archaeology; landscape archaeology; settlement patterns

1. Introduction

The control of spatial relations between archaeological sites has been one of the more problematic issues in settlement archaeology in the Southern Maya lowlands—until the relatively recent application of LiDAR to the Maya landscape. In part because of the difficulty in broadly understanding the ancient Maya use of space and particularly the scale and inter-related nature of sites, there has been a proliferation of differing views, theories, and paradigms for approaching past Maya spatial organization and relationships [1].

Until the advent of LiDAR (Light Detection and Ranging), mapping in the tropical forests of the Maya area was extremely time-consuming and usually was not extensive enough to provide the data necessary to inform a more comprehensive view of Maya spatial organization. Most mapping at sites in the Maya area focused on major centers and the areas immediately outside the concentration of central architecture (e.g., Tikal) [2]. With few exceptions, e.g., [3], areas between major centers were rarely examined and transects into outlying zones were usually limited in scope (e.g., Dos Pilas and Aguateca) [4].

While there was early recognition of settlement differences within the Maya region [5], for the most part, Maya centers have come to be categorized as either city-states [6] or as primate cities within a regional unitary state [7]. Because there was no uniform reconstruction of site relationships based on archaeological data, hieroglyphic texts were utilized to reconstruct political affiliations and alliances over space [8–10]. However, the epigraphic models, while widely adopted, are not always in alignment with existing archaeological data [11–13] or with alternative, but plausible, interpretations of Maya spatial organization [14–16].

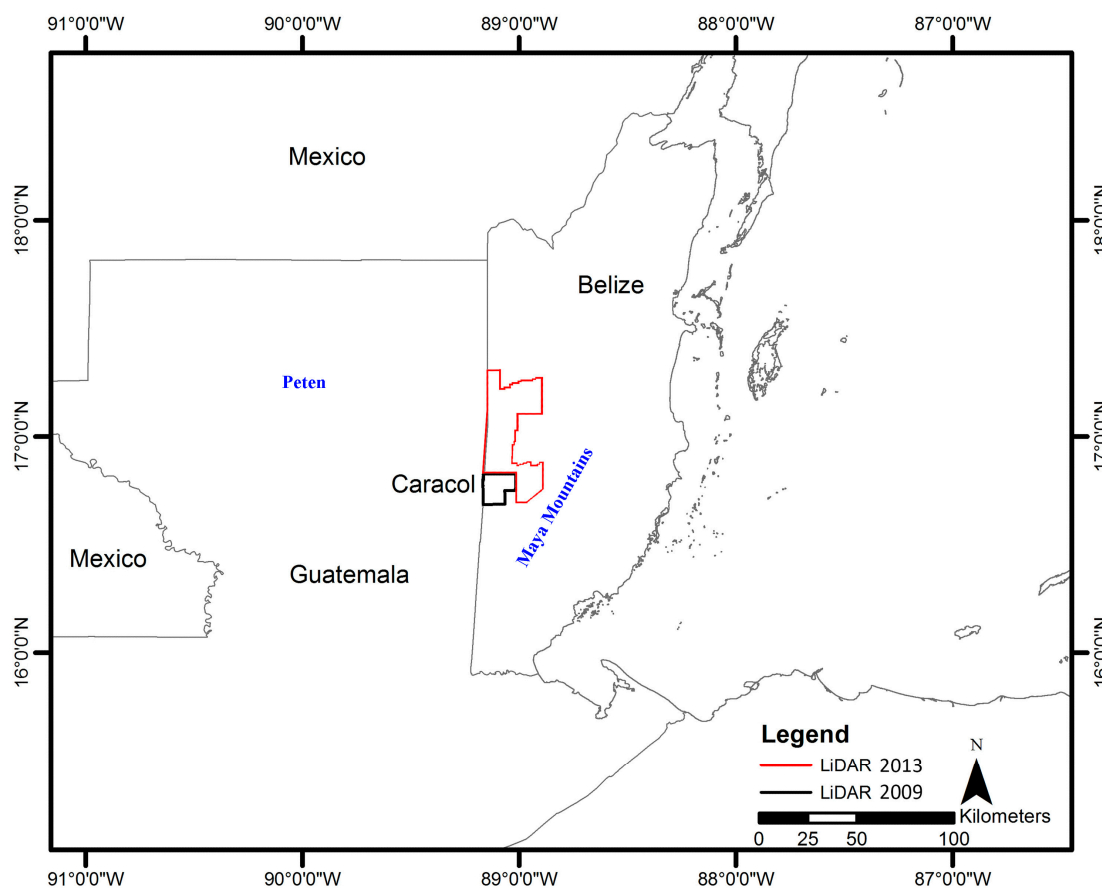
With limited settlement mapping, there were a number of basic questions that went unanswered in this specific context. How large were Maya sites and how many people were associated with a single center? Were the Maya truly “urban”? What was the relationship between dispersed residential settlement and more centralized monumental architecture? Did the Maya have unoccupied space between sites? How did the Maya support themselves? Why are Maya sites located where they are? What, if any, are the connections between various sites and how can one tell that these connections exist? In addition, finally, how do the landscapes of the Maya infill and develop over time?

After 50 years, settlement archaeology has attained only limited success in answering many of the above questions. However, ultimately, it will be settlement archaeology and the analysis of Maya landscapes that will provide answers concerning their ancient spatial organization.

2. Results and Data Subdivisions

LiDAR has proven to be a powerful tool for viewing the landscape [17,18]. Like the successful 2009 LiDAR survey of Caracol [19,20], the 2013 campaign over Western Belize was flown by the National Center for Airborne Laser Mapping (NCALM) and required 14 survey flights, totaling 71.34 flight hours over 14 consecutive days, from 27 April through 10 May 2013. This activity resulted in a total survey area in 2013 in Western Belize of 1057 km² that was additional to the 200 km² covered by the 2009 Caracol LiDAR campaign (Figure 1).

Figure 1. Map showing the areas in Belize that have been surveyed with LiDAR as a result of the 2009 and 2013 campaigns.



NCALM used an Optech Gemini Airborne Terrain Mapper (ALTM) mounted on a twin-engine Cessna 337 aircraft, flying at 600 m AGL and a ground speed of 60 m per second. Three hundred and twenty-five north-south survey flight lines were flown; these were spaced approximately 137 m apart, which resulted in triple swath overlap. The laser was operated at a pulse rate of 125 kHz with a beam divergence of 0.8 mRad and a scan frequency of 55 Hz. The nominal scan angle was 18 degrees with an edge cutoff of 1 degree. Some 42.95 h of laser-on time was necessary to record the approximately 15 laser shots per sq m that were fired.

GPS observations collected at ground stations operated continuously during the survey and were combined with GPS and inertial measurement unit (IMU) data collected aboard the aircraft to derive high quality aircraft trajectories and orientation. These data were processed with Optech proprietary software to obtain “point clouds” containing evenly spaced reflections from surfaces (including vegetation) returning sufficiently strong signals to be detected by the LiDAR sensor. Classification of individual points in the point cloud was done using selected routines in commercial software TerraScan version 13.009 (Terrasolid Inc., Finland). The main ground classification routine classified ground points by iteratively building a triangulated surface model, as described by Axelsson [21]. The algorithm started by selecting some local low points assumed as sure hits on the ground, within a specified window size. The nominal ground classification parameters used for this project were: Window Size: 25.0 m; Max Terrain Angle: 89.0 degrees; Iteration Angle: 9.0 degrees; Iteration Distance: 1.4 m. Points identified as outliers because of their low elevation relative to neighboring points were retained, as the area is known to contain openings to caves, which are potentially of archaeological significance [22]. On average, 2.8 returns per sq m were classified as ground return, but that varied widely depending on the local density of vegetation.

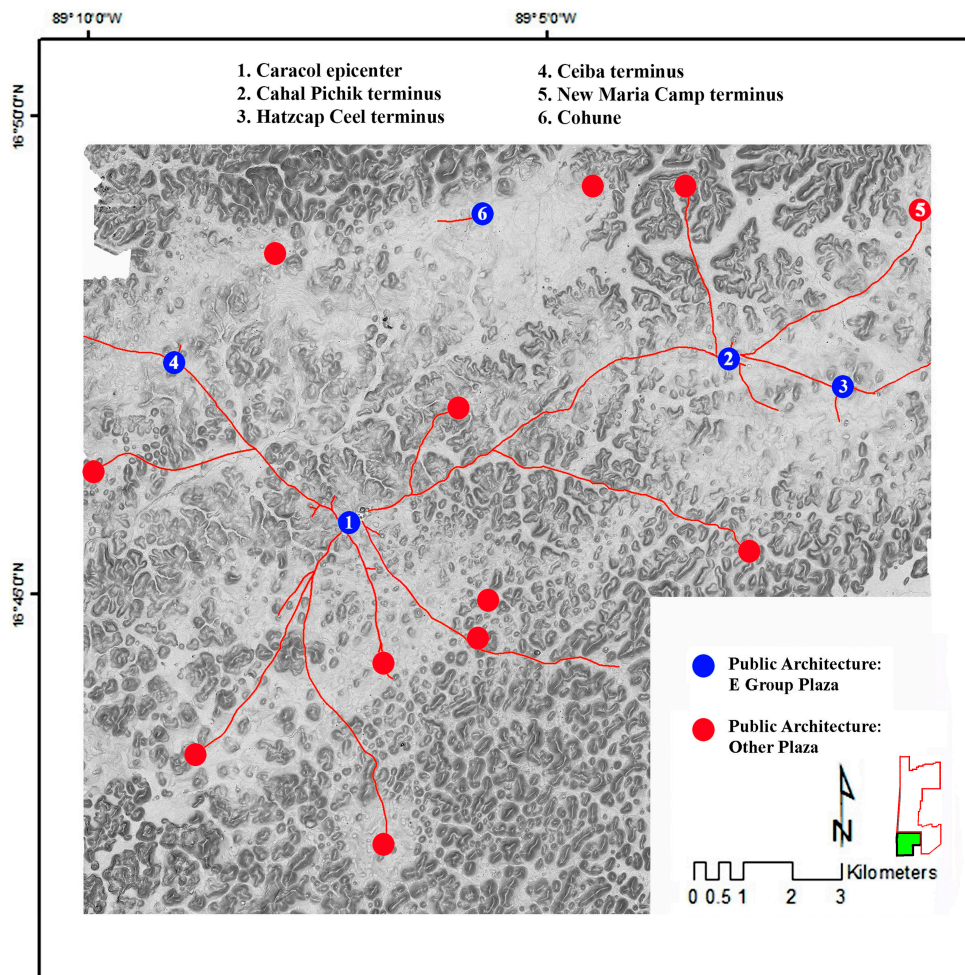
After completing the classification, the ground points were processed using the Ordinary Kriging Algorithm [23], as developed in commercial software Surfer Version 11 (Golden Software) to produce the ground Digital Elevation Model (DEM). The Kriging parameters used were a linear variogram model with nugget effect (error variance of 0.15 m and a micro-variance of 0 m). A 4-quadrant sector search was used with a 20 m search radius to ensure that the minimum (five points per quadrant) was met. Resolution of the bare earth DEM produced by NCALM was 1 m. The DEM was then processed to create hillshade images using ArcMap Ver 10.0 (Esri), with a sun azimuth of 315 degrees (NW), a sun elevation of 45 degrees, and a vertical Z-factor of 1.

2.1. 2009 Caracol LiDAR Survey

In April 2009 the Caracol Archaeological Project (www.caracol.org) engaged in the first extensive use of LiDAR to record a broad spatial area of Maya settlement [19,24]. A successful grant to the Space Archaeology Program of the National Aeronautic and Space Association (NASA) yielded funding for what was seen as being an experimental approach to gaining surface information through the application of LiDAR, an aerial delivery system that uses laser pulses to gain entry through enveloping foliage. As a result of this funding, NCALM was subcontracted to record 200 km² of landscape in the vicinity of Caracol at a density of 20 points/km² (Figure 2). This survey was carried out at the end of April 2009 and the data were transmitted to the project in June 2009.

The usefulness of LiDAR as an archaeological survey tool was first established in temperate forested landscapes [25–27]. LiDAR has been used to identify archaeological remains in forested areas in Europe [28], Canada [29], and the Americas [30], although the ease of this identification varies with the kind of tree cover and the amount of modern disturbance [31–33]. It has subsequently become evident that LiDAR is also useful in tropical forested landscapes, as has been shown in the point cloud that was produced around Caracol, Belize [20,34,35], the piedmont zone of Chiapas, Mexico [36], and Angkor, Cambodia [37].

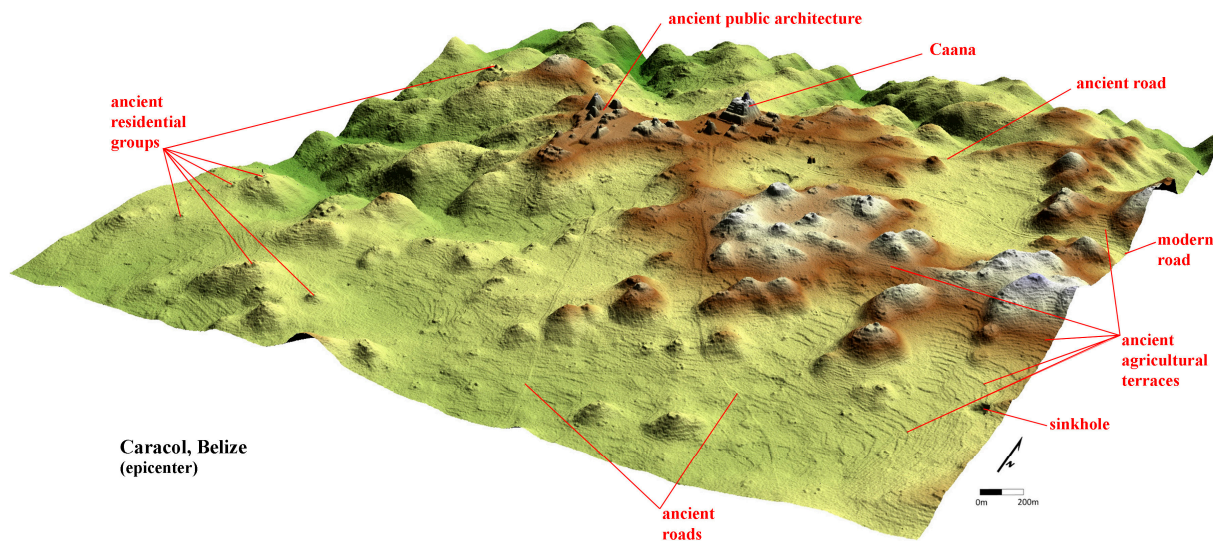
Figure 2. The 2009 LiDAR DEM of the Vaca Plateau with an overlay of Caracol's causeways and the distribution of the site's public plazas and architecture. The area between this public space is infilled with agricultural terraces and Maya residential groups. Architectural complexes mentioned by name in the text are numbered.



At Caracol, because the landscape was largely undisturbed by modern settlement, and because more than 25 years of mapping had already been undertaken at the site, it was possible to verify the accuracy of the LiDAR data with already recorded sections of residential groups [38], terraces [39], and road systems [40]. Once this was done, the effectiveness of LiDAR as a method of archaeological survey in the Maya area was established [41,42]—and its effectiveness in similar tropical forest environments in other parts of the world has now been verified [37].

However, while the 2009 LiDAR survey of Caracol demonstrated a landscape completely filled with agricultural terraces, residential groups, and roads leading to public plazas (Figure 3), only the approximate limits of the site of Caracol appeared within this DEM. While the northern and southern limits of the city could be ascertained at the boundaries of the 200 km² area, the eastern and western limits of the site could not be fixed. Thus, while the site of Caracol took up most of the 200 km² area in the LiDAR survey, it was not possible to determine exactly how the site was situated relative to the broader landscape or to other sites. To gain this information, it became clear that even broader regional coverage was needed.

Figure 3. 2.5D LiDAR rendering of the bare earth Caracol epicenter and surrounding residential groups, agricultural terraces, and roadways [20] (Figure 7 modified).



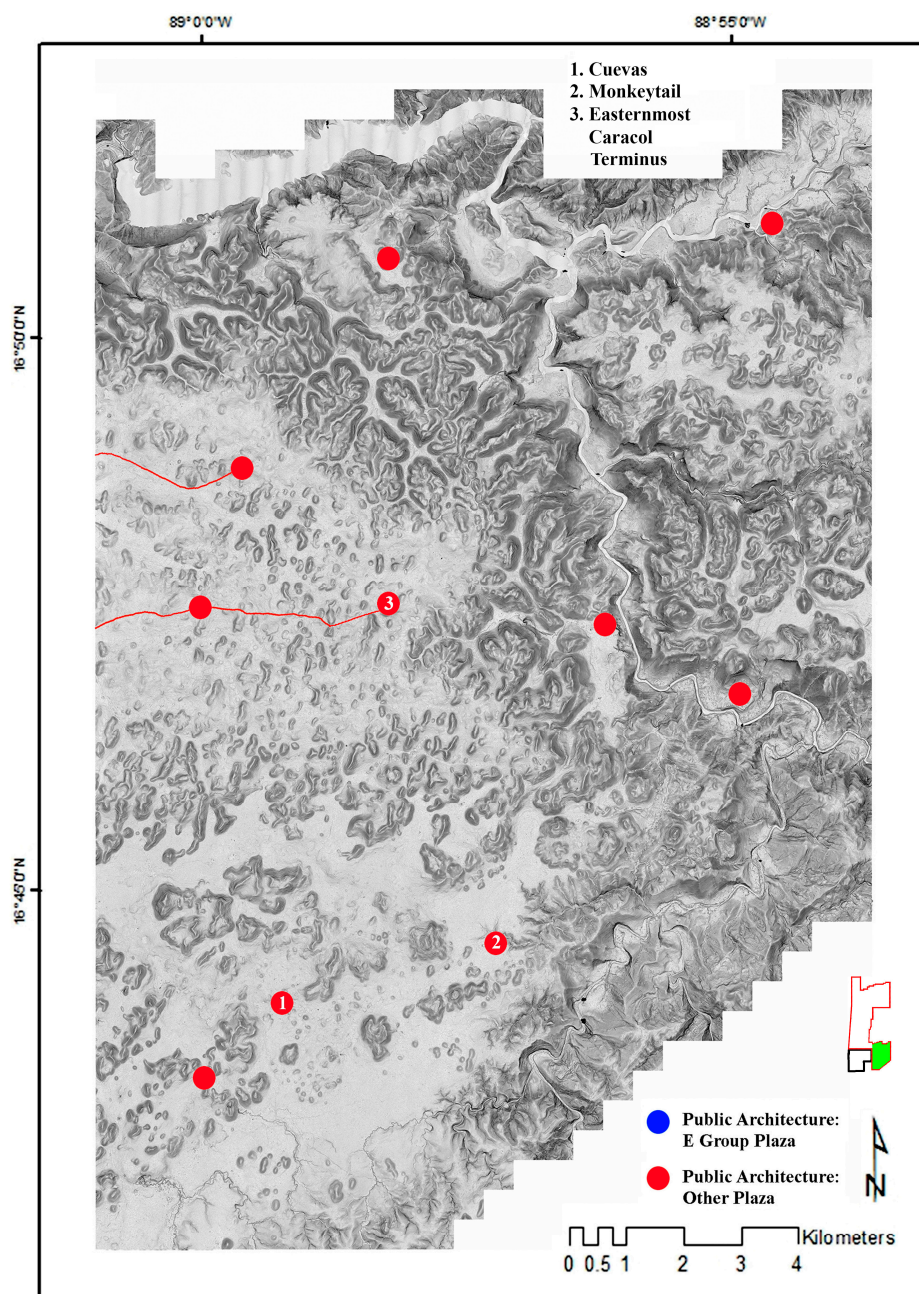
The opportunity to undertake such a survey soon arose. The earlier success of LiDAR programs in Europe [25–27] and the Americas [29,30] in penetrating forested areas to see surface archaeological remains was replicated in the 2009 Caracol LiDAR survey [19,20,34]. Because of the detail contained in the three-dimensionality of the point clouds that had been generated for Caracol, most archaeological projects working in western Belize (and other parts of the Maya area) became interested in accessing LiDAR data for their own specific research sites. The ability to hillshade the point clouds to highlight not only anthropogenic features but also the actual topography meant that these data permitted a ground surface view that was not possible with traditional archaeological maps—and visual inspection of the DEMs was capable of providing a great deal of detail that could be both interpreted and augmented with known archaeological data and previous ground-checks. Because the limits of Caracol were not evident in the original survey, the Caracol Archaeological Project was immediately in discussion with other funding agencies to secure backing for another LiDAR program. Other archaeological projects were soon in similar discussions. The Alphawood Foundation indicated that they would be willing to support a comprehensive LiDAR program in Western Belize, if considered in a coordinated, rather than piecemeal, fashion. Therefore, all of the interested parties (Caracol Archaeological Project; Belize Valley Archaeological Project; Minanha Archaeological Project; Cuevas Archaeological Project; Mopan Valley Archaeological Project; Mopan Valley Preclassic Xunantunich Archaeological Project) made a single grant submission in which the only funding requested was for the LiDAR itself. As a result of this integrated effort, the Alphawood Foundation agreed to fund the acquisition of 1057 km² of new LiDAR data at 15 points/km². This aerial survey was flown by NCALM in April and May of 2013, and the data were distributed to the vested parties at the beginning of September 2013.

2.2. 2013 Western Belize LiDAR Survey

The 2013 LiDAR survey was subdivided into three distinct packets of data. The first section lay east of the original Caracol survey area, extending to the Macal River and then south to cover the area

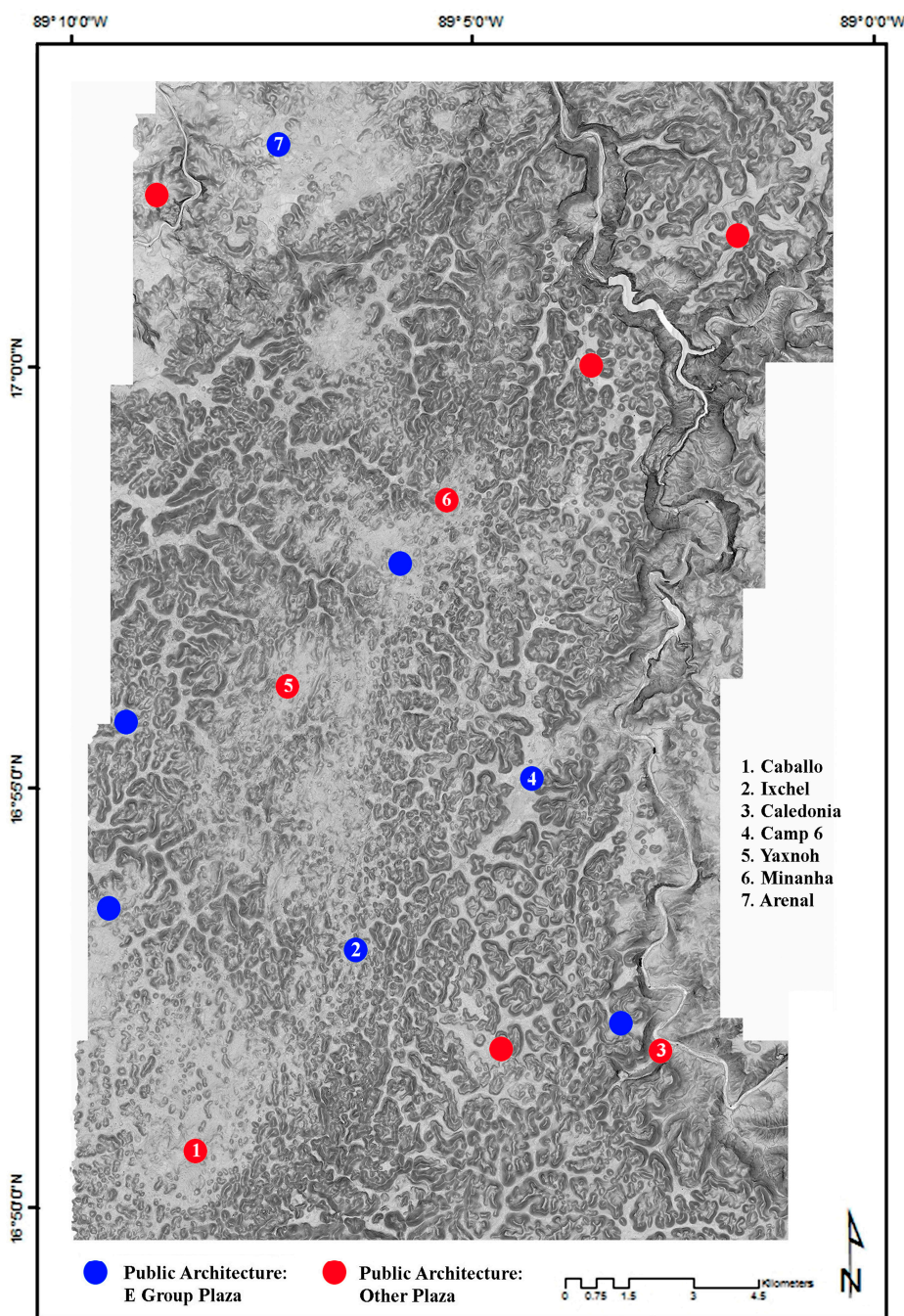
around the site of Cuevas [43] (Figure 4). This section of the survey was designed to find the eastern limit of Caracol, to document settlement in the Cuevas area, and to see what, if any, spatial relationship existed between Cuevas and Caracol. Because much of the eastern and central sections of the 2013 survey areas are covered by heavily forested areas that contained no population, visual inspection alone of the DEMs permitted the identification of ancient road systems, agricultural terracing, residential settlement, and concentrations of public architecture. Much like the 2009 survey area, visual inspection alone also permitted the recognition of settlement drop-off within the landscape [20].

Figure 4. The 2013 LiDAR DEM of the eastern survey area showing the distribution of sites with public architecture and the eastern extent of Caracol, as represented by the continuation of the site’s road systems and three new public plazas. Architectural complexes mentioned by name in the text are numbered. The Chilillo Dam (constraining the Macal River) is in the northern extent of this DEM.



The second packet of data ran north from the original Caracol survey area to the Belize Valley and was bracketed by the Guatemala-Belize border to the west and the Macal River to the east (Figure 5). This section was designed to delineate the settlement and terraces that existed in this very hilly region, especially around and between the known sites of Caledonia [44], Camp 6 [45], Caballo [46,47], Ixchel [48], Minanha [49,50], and Arenal [51].

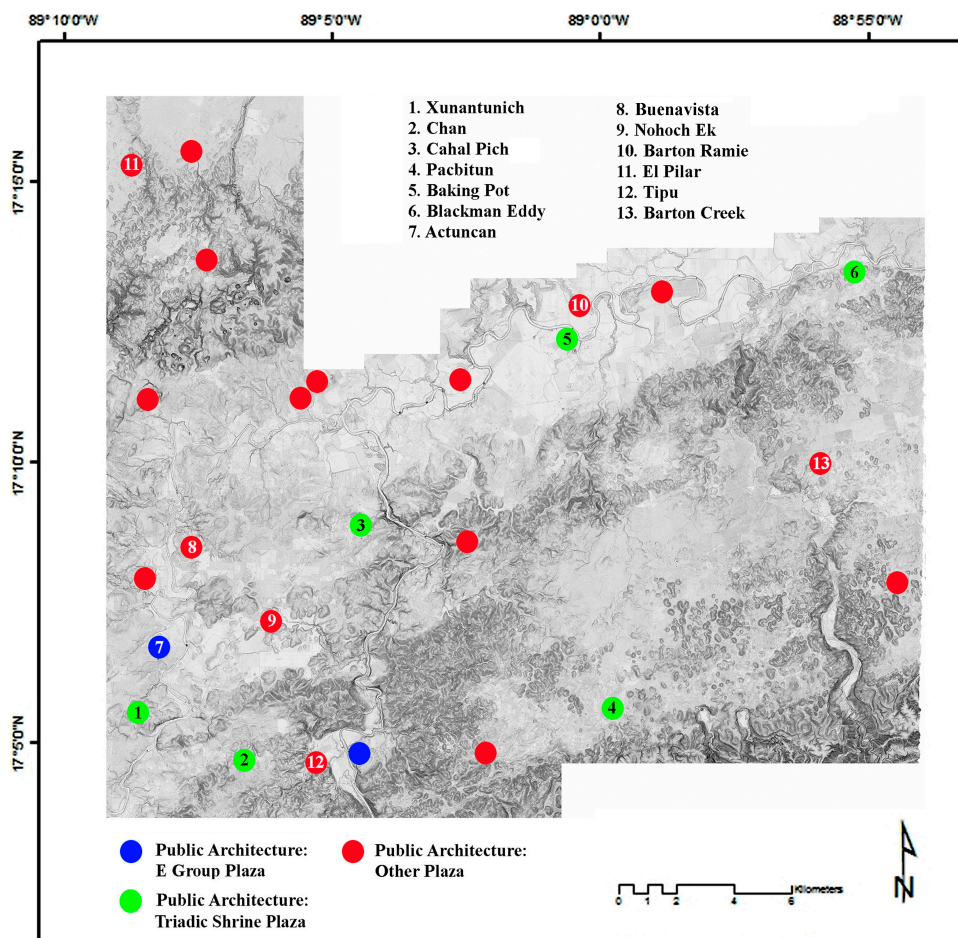
Figure 5. The 2013 LiDAR DEM of the central survey area showing the distribution of sites with public architecture (Macal River to the east; Guatemala border to the west). Architectural complexes mentioned by name in the text are numbered.



The third section of LiDAR survey was designed to encompass the Belize Valley, running from the border and Xunantunich [52] to the high plateau region east of Pacbitun [53] and from the Maya

Mountains in the south to just north of the Belize River. The border section was also extended to the north in order to include the site of El Pilar [54] within the survey (Figure 6).

Figure 6. The 2013 LiDAR DEM of the northern survey area, representing the Belize Valley, showing the distribution of sites with public architecture. Architectural complexes mentioned by name in the text are numbered. The Macal (on which Site 12 is located) and Chiquibul (on which Site 1 is located) Rivers join together at the modern city of San Ignacio (north of Site 3) to form the Belize River.



2.2.1. Eastern Survey Section

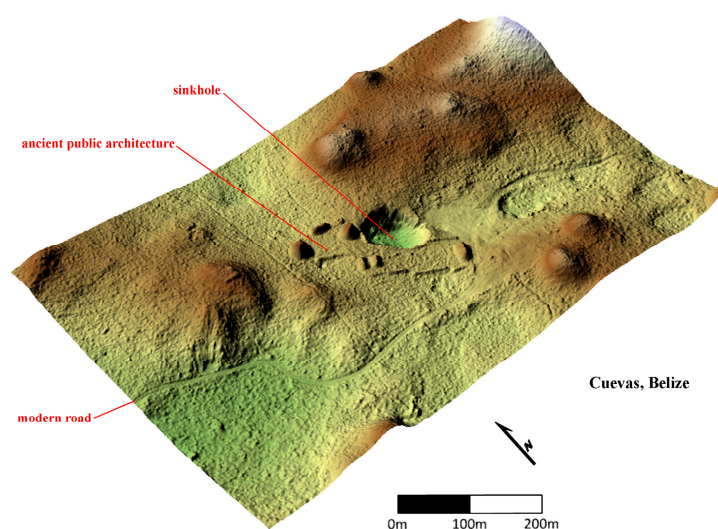
Analysis of the eastern survey section was quite informative. Caracol settlement and terracing was found to continue in dense concentration on the high ground due east of the limit of the 2009 LiDAR survey. Causeways also continued beyond the known Caracol road system and the public architectural concentrations that have been designated as Hatzcap Ceel and New Maria Camp (Figure 2). The causeway leading east from Hatzcap Ceel ran approximately 3.5 km to a large plaza and then out the other side of this plaza, continuing 4 km east to yet another large plaza and ballcourt. This final public plaza appears to be walled and is located on the high ground at a point overlooking a valley that descends to the Macal River. Another three-kilometer long causeway joined New Maria Camp to another large plaza with ballcourt located to the east in the uplands above the Macal River. These new eastern causeways extend far to the east, enough to support the suggestion that the site of Caracol was

extracting resources from this part of the Macal River or the Maya Mountains. Extensive survey and excavation were done along the banks of the river in this area [55], just prior to the flooding caused by the Challilo Dam. The recovered archaeological data from this region show a strong relationship to Caracol ritual patterns, as would be expected; foreign tradewares were also encountered in many residential groups along the banks of the river and probably came into this area by means of Caracol's causeways. Most important from the standpoint of understanding the eastward extension of the causeway system is that granite sections along the sides of this part of the Macal River showed evidence of extensive processing of pre-forms for metates (Woodye, personal communication, 2012). The existence of these pre-forms suggests that the metamorphic stone that occurs here was being mined for a basic necessity in any ancient Maya household. Manos and metates were (and still are) used to process maize into a comestible item. Because granite manos and metates were superior to the softer limestone versions of these artifacts, which introduced far more grit into the ancient diet, there was a ready market for these stone artifacts. Thus, it is likely that the granite metates and manos found throughout the Peten of Guatemala and Northern Belize were coming from this part of the Maya area and were being transported through the Vaca Plateau along Caracol's causeways. Control of such a vital resource may at least partially explain Caracol's siting and prominence in the western flank of the Maya Mountains.

Southeast of these Caracol road systems, the settlement and terracing gradually decreases, emphasizing the separation between Caracol and its southern neighbor Cuevas (Figure 7).

Cuevas appears in an area that is largely devoid of continuous settlement or terracing. Other groups and monumental space occur within the terrain around Cuevas, but at some distance. A walled plaza exists about 2 km southwest of Cuevas and large residential groups exist approximately one kilometer northeast and northwest of Cuevas. The group to the northeast of Cuevas is situated atop a ridge and has a causeway that runs due east for approximately four kilometers, ending up in the walled plaza site of Monkeytail (Figure 5). Like Caracol's easternmost public plaza, Monkeytail is situated near a corridor to the Macal River. However, settlement between Cuevas and Caracol is sparse, suggesting that this part of the Vaca Plateau was not within Caracol's direct urban sphere.

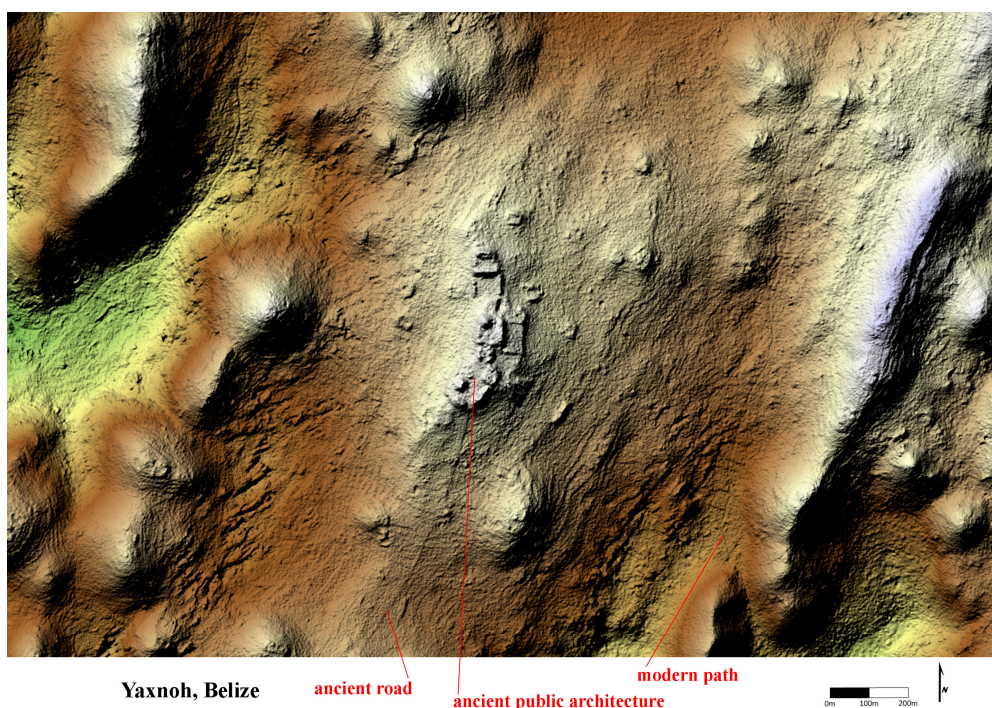
Figure 7. 2.5D LiDAR bare earth rendering of the site of Cuevas, that is located on the edge of a sinkhole leading to an extensive cave system.



2.2.2. Central Survey Section

The central survey section (Figure 5) contains a series of smaller sites within a very mountainous region. Many of these have been reported in the archaeological literature and have undergone excavation (as detailed below); however, the LiDAR also demonstrates that there are other early architectural centers within this part of the Maya Mountains that did not become large settlements. Previous work within the central survey section has included work at Camp 6 [43], Caledonia [42], Ix Chel [48], Minanha [49,50], and Arenal [51]. Following brief work in the 1920s at Camp 6, Caledonia was one of the earliest sites worked in this part of the survey area. It is located on the south bank of the Macal River just north of where the concrete bridge crosses the river to provide passage to Caracol and Cuevas. While Caldeonia can be seen in the LiDAR, it appears decimated from having been used as a firing range for British artillery some two decades ago. A previously unrecorded E Group (see extended discussion of this architectural form below) is immediately northwest of Caledonia on high ground. Some five kilometers north of the Vaca Plateau and Caracol's northern limit, along the western edge of the survey area, is another flat plateau that is heavily terraced and is occupied by the large site of Caballo, first recorded in 1990 by the Caracol Archaeological Project. Even then, Caballo was badly looted, although a carved stone altar depicting a Maya day sign was recorded at the site by Nikolai Grube [47]. The LiDAR shows that Caballo is quite an extensive site with causeways that run east-west across the middle of its plateau. Apart from this area of fairly level ground, most of the region further north in the central survey section is exceptionally hilly or comprised of very rugged terrain. Further to the north, in the center of this section, occupying a north-south ridge, is the site of Yaxnoh; this medium-size center with a series of linked architectural groups and a causeway extending to the south had not been previously recorded before this LiDAR survey (Figure 8).

Figure 8. 2.5D LiDAR bare earth rendering of the newly-found site of Yaxnoh, Belize.

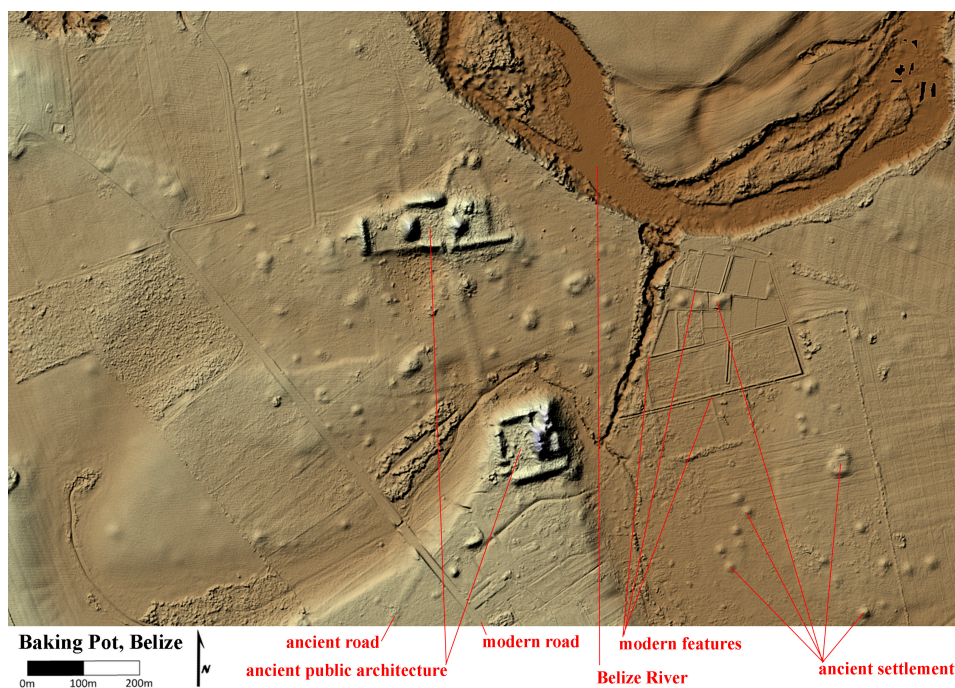


Further south is the site of Ixchel, initially known because of a cave from which a speleothem was recovered and tested [48]. East of Yaxnoh and north of Ixchel in a north-south valley is what remains of the site labeled by Thompson [45] as Camp 6; the LiDAR indicates that this area has seen modern disturbance. Proceeding even further to the north, the site of Minanha is encountered [49,50] and then the site of Arenal [51], as well as several smaller sites. Thus, in spite of relatively inhospitable terrain, nodal settlements are fairly regularly spaced throughout this section of the Maya Mountains.

2.2.3. Belize Valley Survey Section

Within our study area, perhaps the best known area archaeologically is the Belize Valley (Figure 6) [56]. Excavations have been undertaken in the Belize Valley for almost a century and currently there are a number of archaeological projects that continue operating at different sites within this region. The Belize Valley—and specifically the site of Barton Ramie—was the area chosen by Gordon Willey [5,57,58] for his initial settlement survey that was designed to define how Maya society was structured. However, in his quest to understand the non-elite classes of the Maya, he bypassed excavation in the larger monumental architecture that articulated with the general settlement [59], meaning that his initial work did not fully resolve the complex issue of the structure of ancient Maya society [60,61]. Willey is to be credited, however, with his focus on the non-elite at Barton Ramie, something that was often included only as an afterthought in many subsequent archaeological projects that focused predominantly on large monumental architecture. Initial work in the Belize Valley focused on Xunantunich [62,63], Nohoch Ek [64], and on Baking Pot [65] (Figure 9).

Figure 9. 2.5D LiDAR bare earth rendering of the site of Baking Pot, located on the Belize floodplain (Belize River in upper right).

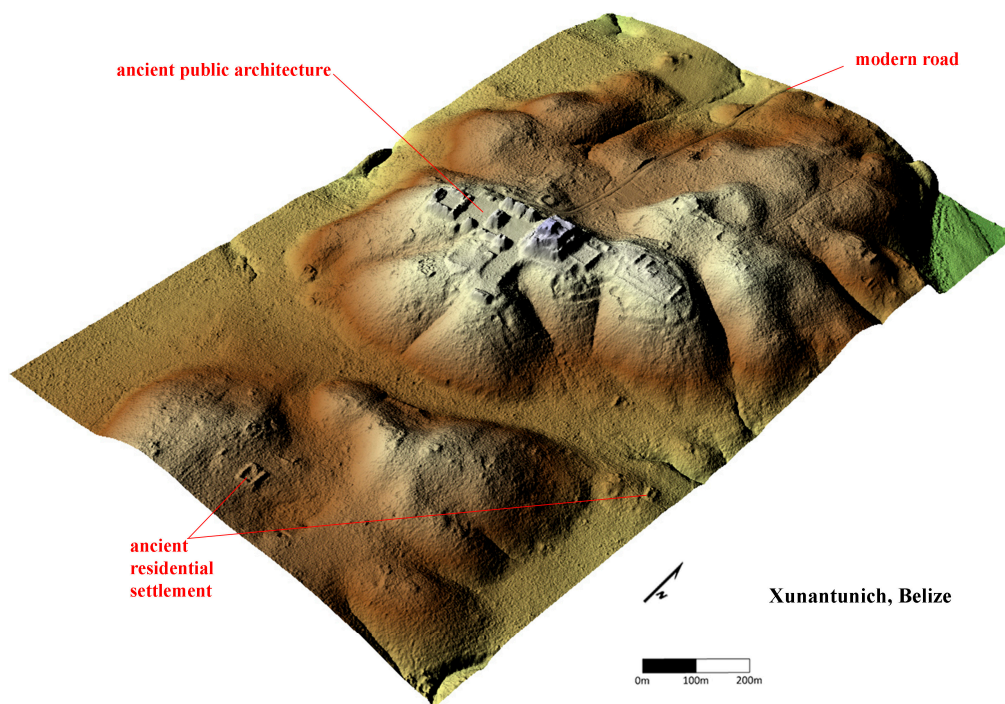


More recent work has focused on Pacbitun [53,66], Negroman-Tipu [67], Cahal Pech [68], Blackman Eddy [69], Buenavista del Cayo [70], Actuncan [71], Chan [72], and several smaller sites in

the upper Belize River valley [73]. Ongoing archaeological research continues at Xunantunich [74], Buenavista [75], Cahal Pech [68], and Baking Pot [76,77]. To the northwest of the Belize Valley, archaeological work has also been undertaken at El Pilar [54].

The LiDAR data from this well-studied area still contained surprises. Xunantunich has massive plaza areas to the north of the hilltop that supports the core of the site; there is also what appears to be a moat or embankment on the hilltop just east of the site's central acropolis, known as "El Castillo" (Figure 10). Evidence for drained field canal systems are found in the vicinity of Baking Pot; this represents a kind of ancient agricultural system not previously identified in the Belize Valley. A previously-unknown site is located approximately 3 km east of El Pilar. Pacbitun appears to have a causeway running north to a group located on a hilltop 2 km away. Finally, a very large site, not previously reported and here designated as "Barton Creek," is in the upland area east of the actual Barton Creek.

Figure 10. 2.5D LiDAR bare earth rendering of the hilltop site of Xunantunich.



3. Discussion

The 2013 LiDAR survey of West-central Belize, covering 1057 km² (additive to the collection of 200 km² at Caracol in 2009), constitutes one of the largest regions recorded with this technology specifically for archaeology. The selection of 15 points/m² for the 2013 LiDAR program was based on a re-analysis of the point density of the 2009 LiDAR (collected at 20 points/m²). Little detail was lost in the 2009 LiDAR when re-configured at 15 points/m², but 10 points/m² showed a diminution in visual accuracy and five points per sq m resulted in significant loss of detail. One of the strengths of the 2013 LiDAR survey is that it was carried out over both forested and open landscapes. Much of the central (Figure 5) and eastern (Figure 4) sections of the LiDAR survey are under relatively virgin forest with no permanent settlement. This fact means that the bare earth DEM for this region is rich in

archaeological detail that has not been very disturbed by modern populations. The only non-ancient features that are evident in these DEMs are old logging roads and modern deforestation along the border area [78]. These areas of modern disturbance have resulted both in surface modification (caused in some cases by chaining to remove trees, which also disturbs the ancient mounds) and changes in vegetation patterns (specifically, the introduction of low growth shrubs and grasses), making visual interpretation of the LiDAR more difficult.

The third segment of the 2013 LiDAR program in the Belize Valley (Figure 6) is perhaps the most difficult to interpret visually because of this area's heavy modern populations and large-scale agricultural production, all of which have introduced new landscape features and vegetation patterns, as well as replaced some of the ancient ruins with modern settlement. Even if looted (the resulting holes from this illicit activity are quite visible in the LiDAR), the major concentrations of public architecture are still quite visible because of their height above the ground surface. However, much of the low-lying ancient settlement is more difficult to ferret out of the DEMs because of modern disturbance—and the features require human visual inspection for absolute identification. The ways that modern disturbances both reflect and distort the LiDAR data form a future research area for both LiDAR and archaeology; this interface will see more testing, ground-truthing, and use of the actual LAS files to enhance the visualization of the LiDAR data. A further limitation of the LiDAR is something shared with all forms of survey. It does not, in and of itself, provide temporal information; LiDAR is best used in concert with on-the-ground verification and excavation.

From the standpoint of archaeology, the regional LiDAR data described here open up significant new avenues for exploration. While it is generally possible to see the various sites, the agricultural fields, and the landscape, how does this new data add to our archaeological understanding of ancient Maya settlement? The 2013 LiDAR data were collected in order to test the various models of socio-political organization that had been proposed within archaeological literature. Most of the models that have been promulgated for the ancient Maya were based on very limited spatial data. These models vary in their form, ranging from seeing the Maya of the Classic Period (*ca.* 250–900 C.E.) as being independent city-states [6,79] to regional states [12,80] to huge hegemonic “superstates” [9,10]. Each of these models implies different expectations in terms of spatial layout: city-states would be represented spatially by discrete individual centers of relatively equal size and concentrated population distributed fairly evenly over the landscape; regional states would be represented by larger primate centers with a supporting series of smaller centers distributed in the nearby countryside; hegemonic superstates would be represented by even larger primate centers with demonstrated contact with other centers at some distance from themselves as evidenced by material culture remains and/or hieroglyphic texts. What the 2013 LiDAR data show is that ancient Maya spatial organization does not easily fit into any of the expected models and that a mix of socio-political organizations must have existed in different parts of the Maya area at any one time (compare expansive Caracol (Figures 2 and 4) with the sites in the Belize Valley (Figure 6), see also the discussion below). Future archaeological research based on data derived from the 2013 LiDAR survey in the inter-site areas will help to refine our understanding of Maya socio-political organization and its development.

The first point that emerges from these data is the regularity in the way that public architecture is distributed over the landscape. Based on mapping at Caracol, we recognized that there were clusters of public architecture embedded in the settlement every three to eight kilometers; archaeological excavation

demonstrated that these concentrations of public architecture varied in terms of time of construction; some had been purposefully constructed at the beginning of the Late Classic Period (*ca.* 600 C.E.) while others antedated the physical expression of Caracol, the city, by several centuries [40]. Those concentrations approximately three kilometers distant from the epicenter had been constructed at the beginning of the Late Classic Period to serve the needs of a burgeoning population [81]. Archaeological data showed that the concentrations of public architecture that were five to eight kilometers distant from the Caracol epicenter had been pre-existing sites, co-existing with Caracol, that later became engulfed within the broader Caracol city as it expanded in the Late Classic Period (550–850 C.E.).

The earliest public architecture recognized in the Maya area are called “E Groups” and are believed to have been built for communal rituals relating to the solar calendar [82]. When they appeared in the Preclassic Period (B.C.E. 1000–150 C.E.), they are believed to represent independent centers of population [83] and have been linked by some researchers [84] to the appearance of royal architectural compounds. Five early E Groups occur within the Caracol landscape; all were investigated archaeologically and proved to have been constructed as independent units in the Late Preclassic Period (B.C.E. 150–150 C.E.; see Figure 2); while the forms of these early groups were preserved, only the one in the Caracol epicenter showed extensive modification and use in the Early Classic Period (*ca.* 400–500 C.E.) [85]. This form of early pre-existing spacing in public architecture is also evident to Caracol’s north (see Figure 6). In spite of exceedingly rough terrain, the spacing of public architecture every five to eight kilometers is in evidence in the western foothills of the Maya Mountains. It is also certainly present within the fertile bottomlands of the Belize Valley, where the regularity in public architecture and sites has been commented on by numerous researchers [86,87].

What this early settlement distribution of public architecture indicates is that distinct Maya groups tended to distribute themselves in a regular fashion over the landscape. The early nature of this distribution has been confirmed throughout the southeast Peten of Guatemala by the occurrence of almost 200 early E Groups throughout this region [85]. As mentioned above, there are five E Groups within the city of Caracol that also represent early independent settlements—and similar E Groups are also found throughout the western Maya Mountains in the LiDAR survey. The regularity in placement of public architecture in the Belize Valley is also early, confirmed both by the archaeology of the Belize Valley which has produced some of the earliest ceramic materials in the Maya lowlands [88] and by its own E Group variant [89]. Thus, at least in the Late Preclassic Period, the spatial organization of Maya public architecture over the landscape appears to have followed fractal principles [90].

The real question, however, is why did the later Maya landscape become infilled with settlement between some concentrations of public architecture and not between others? In addition, why were new nodes of public architecture constructed? When viewed through the LiDAR surveys, the uniqueness of Caracol relative to the other settlements is very apparent. At Caracol, the landscape between the public architecture was filled with residential groups and terraces (see Figure 3)—to the point that new areas of public space were necessary (and were created) within the burgeoning settlement to serve as administrative and marketing areas [40,91,92]. The causeways at Caracol also reflect the fact that the distributed public architecture at the site and the settlement were part of an integrated political order with control vested in the unique architectural complex of Caana (see Figure 3), located in the center of the site. Given the lack of readily available water—as well as the remoteness of

the site—the extensive spread of settlement at Caracol contrasts greatly with the other areas within the LiDAR survey— particularly the Belize Valley.

The Belize Valley was the perfect area for continuous integrated settlement. It was typified by extremely fertile soils that were replenished on a yearly basis as the Macal River flooded its banks after exiting the steep foothills of the Maya Mountains. The Belize River not only supplied water to inhabitants on its shores, but also acted as a ready communication system and trading avenue. Yet, while settlement is somewhat denser on the higher land between the Macal and Chiquibul Rivers, the rest of this central area does not present the continuous settlement that is found in the Caracol region. And, importantly, any physical expressions of political integration (such as roadways between nodes) are lacking, presumably indicative of the differences among the sites and of their individual histories. While several of the Belize Valley sites had their own internal causeway systems—Cahal Pech [93], Baking Pot [65], Xunantunich [94], Buenavista [70], and Pacbitun [66,95]—these causeways did not connect separated nodes of public architecture as they did at Caracol; rather, the roads appear to have generally connected elite groups and acropoli to public architecture. The same is true for the sites of Arenal, Yaxnoh, and Caballo located in the central survey section. The one known exception is a Pacbitun causeway that connects the site to a cave, which was presumably used as an important ritual area [66].

Thus, a key settlement difference between Caracol and the other sections of the 2013 LiDAR survey is that formally constructed roads join nodes of public architecture together within the Caracol landscape and nowhere else. While shorter roadways appear at some sites elsewhere in the survey area, they do not link monumental space together. While the Belize River would have served as a focus for transportation in the Belize Valley, it did not effectively unite the autonomous sites located in that valley. We know that the form of an urban settlement is to some degree both determined and conditioned by its roads [96]; populations are drawn to roads. The long-distance roads in the Caracol landscape would have been conducive to first linearly-settled populations and then populations that expanded out from the roads. Thus, the trigger for the Late Classic integrated road system at Caracol may have been an alliance between Late Preclassic Caracol and Late Preclassic Cahal Pichik that resulted in the construction of a linking roadway. Over time, Caracol's expanded road system became a way for integrating an ever-increasing population, all of which was guided by a centralization focused on the unique architectural complex of Caana.

Clearly, then, different pressures and processes were at play within all three subsets of data. In the Belize Valley, settlement integration was relatively modest and, consequently, each site in the valley reveals a relatively distinct history and its own defined public core. Although the residential settlement is somewhat concentrated around these public plazas, it is still quite dispersed compared to the Caracol area. While drinking water, fertile soils, and water transport were available to encourage denser settlement and greater integration, these processes were generally absent. Apparently, there were insufficient pressures and/or advantages to spur an intensification of political unification in the Belize Valley. The situation at Caracol was clearly different. This can be seen physically in the density of both settlement and terraces that cover approximately 200 km², as well as in the solar system of the causeways that connects the distributed public architecture to the site epicenter (Figure 2). It can also be seen socially in a shared Caracol identity [91] and a purposeful management style that stressed symbolic egalitarianism [97], especially in the ritual domain [98].

Thus, these LiDAR data offer some insight as to how large integrated systems may arise, particularly because they can be coupled with information from decades of excavation. Archaeologists often focus on critical resources such as water and agricultural land as being key to the successful evolution of internal complexity. These are differentially distributed within Western Belize. In the Belize Valley, water was available to all the settlements; in the Maya Mountains and Vaca Plateau, the absence of rivers meant that reservoirs needed to be constructed and maintained to ensure safe drinking water. Similarly, while soils were readily available in all areas for extensive farming, the floodplains of the Belize River presented incredibly rich agricultural land that were replenished during floods and were suitable for intensive agriculture without much modification. Elsewhere, however, including in the hilly areas bordering the floodplains of the Belize River and its tributaries, the landscape needed to be extensively modified to carry out intensive farming. What this suggests is that in more challenging terrain, greater organizational skills were required and that, in some instances, these skills may have been translated over time into better integration and centralization.

4. Conclusions

The 2013 LiDAR survey increased the amount of LiDAR data collected in western Belize by 528.5% in a span of 14 days (from 200 km² to 1257 km²). It also increased the spatial size of Caracol by 20%, from 160 km² of continuous integrated settlement [20] to 200 km² of continuous integrated settlement; because Caracol extends west into Guatemala, an area not covered by LiDAR survey, the site is actually even larger. Like the earlier 2009 LiDAR survey, the 2013 LiDAR survey led to the discovery of numerous previously unidentified archaeological features—ranging from housemounds and agricultural fields to monumental architecture and causeways. Importantly, while western Belize is among the most continuously researched regions in the Maya area, this research constitutes the first time that the sites within this area could be connected by regional survey. The large size of Caracol has implications not only for our understanding of ancient Maya socio-political organization, but also relative to interpretations of the world-wide phenomenon known as low-density urbanism [99]. Regional LiDAR surveys elsewhere in the Maya area are also required to demonstrate that this site is not unique.

In certain instances in the Maya area, a single node of monumental architecture came to dominate a broadly-settled agricultural landscape, but archaeological data indicate that different organizational strategies were employed. Sometimes, such as the case at Caracol, the continuously settled landscape was highly integrated through a dendritic outwardly-focused road system that linked internal nodes to the epicenter. In other cases, such as at Tikal, Guatemala and Calakmul, Mexico, the continuously settled landscape was more centrally-focused and less spatially integrated [1]. Even though presenting different forms and structured organizations, these continuously settled landscapes are all currently classified together as forms of low density urbanism [77,99]. As more LiDAR is gained for some of the other spatially large sites in the Maya area, it may become possible to better parse—and better understand—exactly what constituted Maya low density urbanism.

There is great variation in the size, composition, and layout of ancient Maya sites within the survey area, as well as in their landscape adaptations. Some sites were centered in broad regional landscapes that were continuously settled while other sites were fairly isolated from their neighbors. This can be

seen through comparing Caracol and the linear settlement along the Belize River with centers in the central portion of the LiDAR survey. The floodplains and immediate foothills along the Belize River present a strip of relatively continuous settlement that contains a series of embedded sites consisting of multiple public plazas; however, none of these sites exhibit any constructed landscape features that would indicate that they were ever integrated with each other. In fact, their distinctive archaeological records have been interpreted to indicate that such integration did not exist [54]. In contrast, Caracol presents an expanded area of continuous settlement with an extremely integrated network of roads and architectural constructions. However, the foothills of the Maya Mountains between the Belize Valley and Caracol present an area of non-continuous and non-integrated settlement focused on nodes of monumental architecture, each presumably having a fairly independent history.

Remote sensing, and particularly LiDAR, has made a huge difference in the field of Maya archaeology. The ability to undertake spatial analysis of Maya sites without painstaking on-the-ground survey and the capability to view the ground plans of sites through the tree cover are huge benefits in attempting to reconstruct ancient spatial organization. The 2013 West-central Belize LiDAR campaign has provided data that will be mined for years to come. Importantly, it helps to resolve some of the former problems of scale and focus that bedeviled Maya settlement archaeology for so long. The LiDAR data help to better elucidate the variation in settlement size and intensity that is found throughout the Maya area and they also provide a basis for understanding polity size and organization. Importantly, the data show that some of the ingrained concepts of Maya spatial organization and polity size that were developed prior to the advent of LiDAR will need to be re-thought. However, in spite of the wealth of information provided in the new LiDAR data, it is almost impossible to add a temporal dimension without excavation. To fully contextualize and understand ancient Maya settlement, the LiDAR data must be conjoined with on-the-ground excavation data. Given the amount of archaeological research that has taken place within the 2013 survey zone, this is indeed possible and will constitute the next step in reconstructing the diachronic spatial organization of the ancient Maya. Remote sensing has clearly altered the field of Maya archaeology, ultimately showcasing the scale and complexity of ancient settlement that was possible within a sub-tropical environment.

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Author Contributions

All the authors contributed equally to this text.

Conflicts of Interest

The authors declare no conflict of interest.

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