REMOTE SENSING OF BELOW-CANOPY LAND USE FEATURES FROM THE MAYA POLITY OF CARACOL

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Abstract: *In 1929, Charles Lindbergh applied aerial reconnaissance to archaeological prospecting in the Yucatán. As most Maya remains were enshrouded bythe rainforest canopy, his campaign was not too enlightening. Recent remote sensing advances are now able to remove this obscuration. This is demonstrated across the massive city-state of Caracol which was abandoned ca. AD 950. After ~25 years of jungle surveys, ~12% of the ~200 km^2 polity had been mapped. After several weeks, airborne LiDAR provided a synoptic view of heretofore undocumented Maya land use settlement features including: 10s of kilometers of roads, 100s of kilometers of agricultural terraces, and 1000s of structures.*

Keywords: *airborne LiDAR, Maya land use, rainforest canopy*

Résumé: *En 1929, Charles Lindbergh appliqua la reconnaissance aérienne à une campagne de prospection archéologique dans le Yucatán. Les restes Mayas étant couverts par de la forêt dense, sa campagne ne fut pas très fructueuse. Les avancées récentes dans le domaine de la détection à distance sont désormais en mesure de palier à ce manque de visibilité. Nous le démontrons ceci au niveau de la ville-état de Caracol, qui fût abandonnée aux alentours de 950 AD. Après 25 ans d'enquêtes, approximativement 12% des quelques 200 km^2 de la surface totale ont été cartographiés. Le LiDAR a fourni une vue précise de l'utilisation du sol du territoire Maya ce qui inclue: des dizaines de kilomètres de routes, des centaines de kilomètres de terres agricoles, et des milliers de structures.*

Mots-clés: *LiDAR, Maya, canopée*

INTRODUCTION

Early applications of remote sensing to archaeology focused on arid or agriculturally-dominated regions because, in the absence of a dense vegetative cover, the remnants of ancient settlements were readily visible from the air. However, two years after his 1927 solo trans-Atlantic flight, Charles Lindbergh applied aerial reconnaissance to Maya archaeological prospecting.Upon completion of the 1929 Lindbergh-Carnegie expedition over the Yucatán to assess the feasibility of using *aeroplanes* to identify Maya temples from a bird's eye view, Kidder (1930) concluded that:

> "*Maya […] archaeologists […] have been so buried in the welter of forest, their outlook has been so stifled by mere weight of vegetation, that it has been impossible to gain a comprehensive understanding of the real nature of this territory, once occupied by America's most brilliant native civilization" (as cited by Sever and Irwin 2003)*"

Still perseverant, Ricketson and Kidder (1930) commented that:

> "*After discussing the technical aspects of the problem with Colonel Lindbergh we have reached the conclusion that an intensive survey of the region would amply justify its cost.*"

They also noted that a survey

> "*of the sort here outlined would require thorough planning and skillful organization. It is, however, perfectly feasible; and its results would be of outstanding value to many branches of research*."

Eight decades, a bevy of airborne and satellite remotely sensed images later, surveys of most Maya polities do not extend much beyond their monumental architecture-dense epicenters. The hopeful promise of a variety of remote sensing techniques (e.g., hyperspatial, hyperspectral, radar, thermal) that could lift the thick veil of tropical vegetation which covers the once Maya-dominated Mesoamerican landscapes had fallen short of the mark, that is, until recently (Fig. 1).

1. LIDAR REMOTE SENSING AT CARACOL

LiDAR (**Li**ght **D**etection **A**nd **R**anging) or laser-based remote sensing has been in existence since the late 1970s. Earlier transect profiling instruments measured heights of tropical rainforests (Arp *et al.* 1982), but showed little success in identifying below-canopy Maya features (McKee and Sever 1994). However, advances in sensor technology and geoprocessing algorithms yielded ground breaking examples of airborne LiDAR survey sconducted

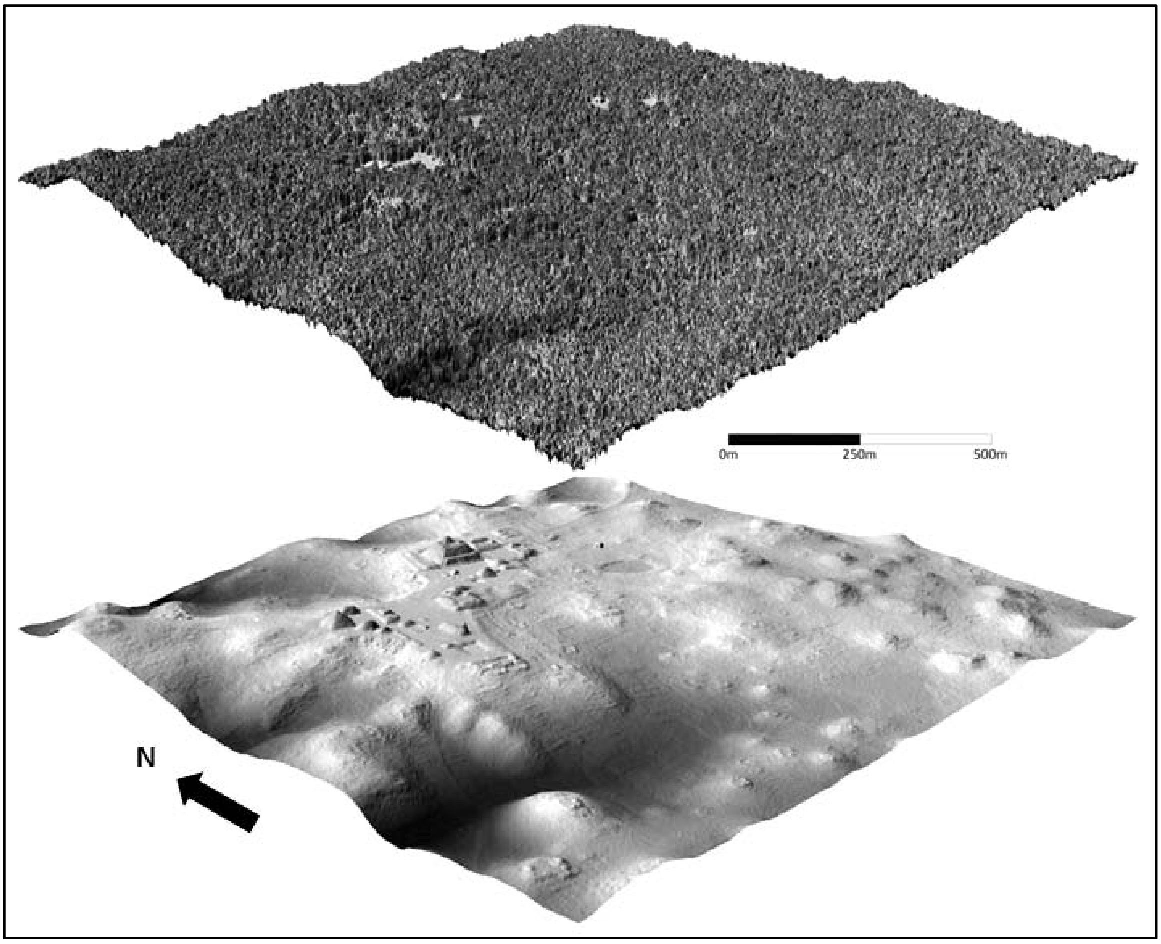

Fig. 1. Rendition of LiDAR detected tropical rainforest canopy being lifted off the ground surface revealing the epicenter of Caracol and scattered Maya features across the landscape (adapted from a graphic provided by R. Shrestha). The Caana pyramid on the north side of the scene is the tallest feature shown in pink

by Gibeaut *et al.* (2003), Devereux *et al*. (2005), Doneus *et al.* (2006), Risbøl *et al.* (2006), and Sittler and Schellberg (2006) to detect archaeological features that lay hidden below forest canopies. These surveys were in less dense woodlands, with the possible exception of Gibeaut *et al.* (2003) whose pilot study was at the Maya site of Copán in Honduras. Based on these successes, we sought and received funding from the NASA Space Archaeology program (Giardino 2011) to sponsor a remote sensing campaign (Weishampel *et al.* 2010) over the Maya polity of Caracol, the most extensive archaeological site in Belize. Afterits abandonment ca. AD 900, Caracol was reclaimed by thedenselowland broad-leaved moist forest that presently occupies much of western Belize.

Fig. 2. Image of the Caanaarchitectural complex amidst the expansive sea of lush tropical vegetation

Caracol was rediscovered in 1937 by loggers and then visited in 1938 by A.H. Anderson, the Archeological Commissioner of British Honduras. In the early 1950s, the Caracol epicenter, comprised of several monumental Maya structures – including the pyramid “Caana” or “Sky Palace” which remains the largest building in Belize (Fig. 2), was mapped by Linton Satterthwaite from the University of Pennsylvania. Between 1985 and 2009, Drs. Arlen and Diane Chase from the University of Central Florida continued surveying (Chase 1988), mapping ~23 km^2 beyond the epicenter. They identified >114 plazeula groups, >4,400 structures, and ~150 ha of agricultural terraces (e.g., Chase and Chase 1998, 2001). During this period, only the canopy immediately surrounding the epicenter area (~8.7 ha), a small fraction of the estimated ~200 km^2 site, was cleared for archaeological excavation. The rest, which was known to be substantial based on numerous surveys, remained

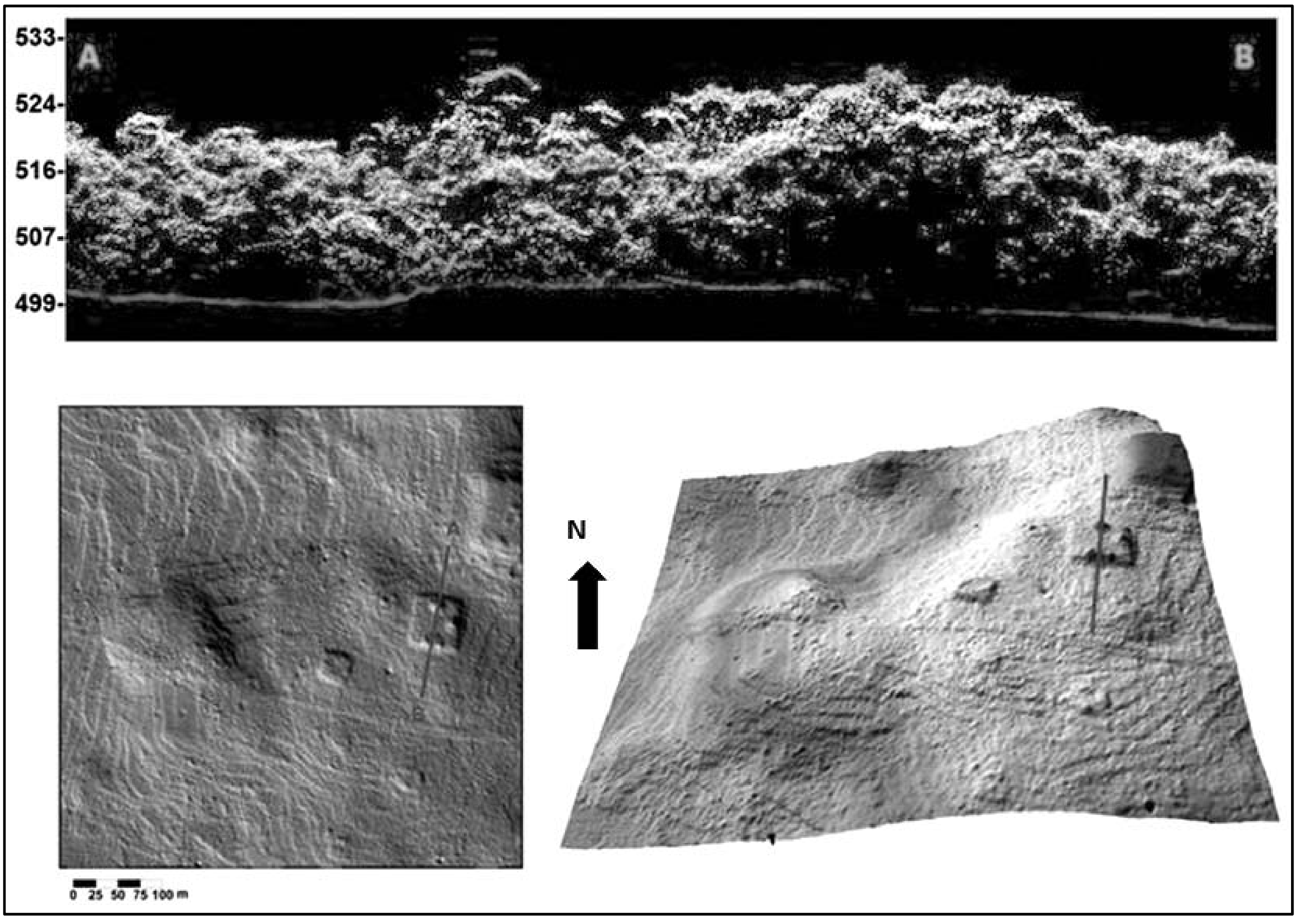

Fig. 3. Transect (A-B) through the LiDAR point cloud data depicting the tropical forest canopy that enshrouds the underlying portion of the Ceiba terminus. The colors and numbers correspond to elevations above sea level. The hillshaded DEM image (lower left) and the corresponding 2.5-dimensional image (lower right) reveal the main causeway and the foundations of several structures which are embedded in the terraced hillside

obscured below the rainforest canopy. Based on these assessments, it was estimated that Caracol supported a population that exceeded 100,000 at its peak (~650 AD).

Because airborne LiDAR, from an unrelated NASA mission, was able to provide accurate ground topography revealing detailed drainage networks below dense, closed canopy wet tropical rainforest in Costa Rica (Hofton *et al.* 2002) and forest structural information (Weishampel *et al*. 2000a; 2000b), we were optimistic that it would be able to delineate ancient Maya architectural features and land use patterns. To maximize leaf-off conditions, the National Science Foundation’s National Center for Airborne Laser Mapping (NCALM) sensor was flown over Caracol in late April 2009 towards the end of the dry season. Over a five day period, representing 25.4 hours of flight time (9.2 hours of laser on time), the NCALM Cessna aircraft carrying an Optech Gemini scanning LiDAR system crisscrossed a 200 km^2 area with 62 north-south and 60 east-west flight lines (Chase *et al*. 2010). On average, there were 20 laser measurements per square meter at the top of the canopy; of these, 1.35 points per square meter yielded a ground class point, i.e., it hit a surface below the forest canopy. The number of ground point returns varied with the canopy density and the presence of canopy gaps. Of the 4.28 billion measurements, 6.75% were assumed to represent ground returns. After several weeks of data processing by NCALM, the accuracy of these points were assessed andinterpolated to generate a bare earth digital elevation model (DEM) that was used to locate a myriad of archaeological features and provide a synoptic viewof the Caracol landscape.

2. EXAMPLES OF LIDAR-ENABLED FINDINGS AT CARACOL

Radiating from the Caracol epicenter is a series of causeways, an estimated 75 km of intra-site roads, which connect surrounding hamlets and large residential settlements. The DEM provided ~177 km^2 of previously unmapped below-canopy features including: three new termini, i.e., causeway destinations denoted by the presence of large open plazas and a dense cluster of structures, 10s of kilometers of causeways, and 100s of kilometers of agricultural terraces, and 1000s of new building structures (Chase *et al*. 2010; 2011a). These data are helping to facilitate a more holistic understanding of the organization of the urban, suburban, and rural landscapes that comprised Caracol (Chase *et al*. 2011b), which because of its integration with terraces (Healy *et* *al.* 1983) was dubbed a “Garden City” (Chase and Chase 1998). One of the most striking findings of this airborne survey is the pervasive limestone terracing network covering nearly 80% of the 200 km^2 area; it represents a substantial, concerted labor investment (Fig. 3). These data are helping to permit better estimates of the Caracol population and are also providing model parameters that will help determine how the ecological – agricultural environment was able to sustain this sizeable urban center for some 650 years (AD ~250 to AD 900).

The DEM contains a rich array of features that will require years to explore on the ground. In addition to anthropogenic features, using a filtering technique to detect sharp elevation gradients, >60 potential cave openings (e.g., Fig. 4) were identified in the rolling karst topography (Weishampel *et al.* 2012b). As the Maya believed caves represent portals to their underworld, known as *Xibalbá*, it is expected that many of these geomorphic depressions will contain a variety of archaeological remnants. A similar technique is being applied to locate aguadas or small reservoirs that the Maya used to store water (Chase 2012) which may provide insight to how Caracol was able to cope with drought conditions.

Though LiDAR reveals literally thousands of ancient Maya features to explore across the Caracol landscape, it also shows the current state of deforestation along the Guatemalan border (Weishampel *et al.* 2012a). The April 2009 campaign documentedthat more than 11% of the forest canopyin the Caracol Archaeological Reserve – an area that had concealed the ruinsfor nearly a millennium

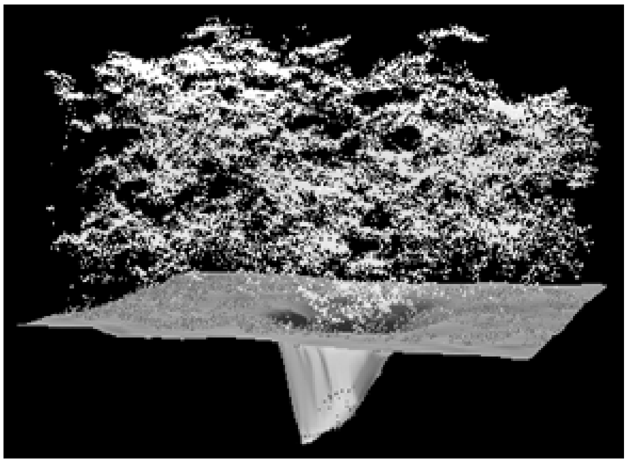

Fig. 4. An example of a ground depression, which may represent a cave entrance, in the karst topography (designated by gray) detected below the rainforest canopy

– had been cleared, facilitating easier access for looters and potentially depriving Belize of its cultural heritage.

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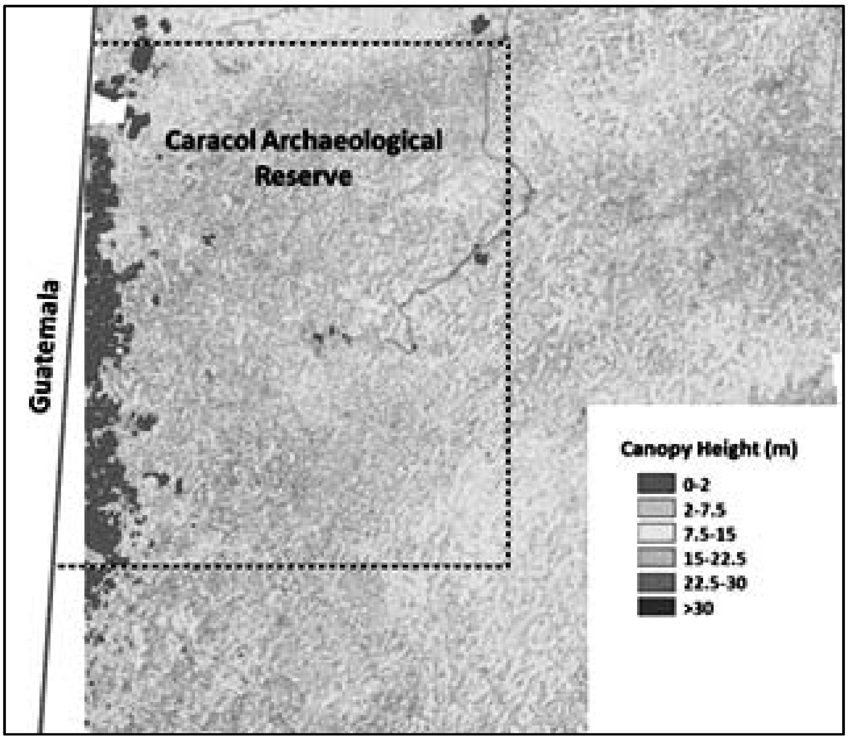

Fig. 5. Canopy topography of the 10,340 ha Caracol Archaeological Reserve (designated by the dashed line) showing the pervasive deforestation and encroachment (in magenta) along the border with Guatemala

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