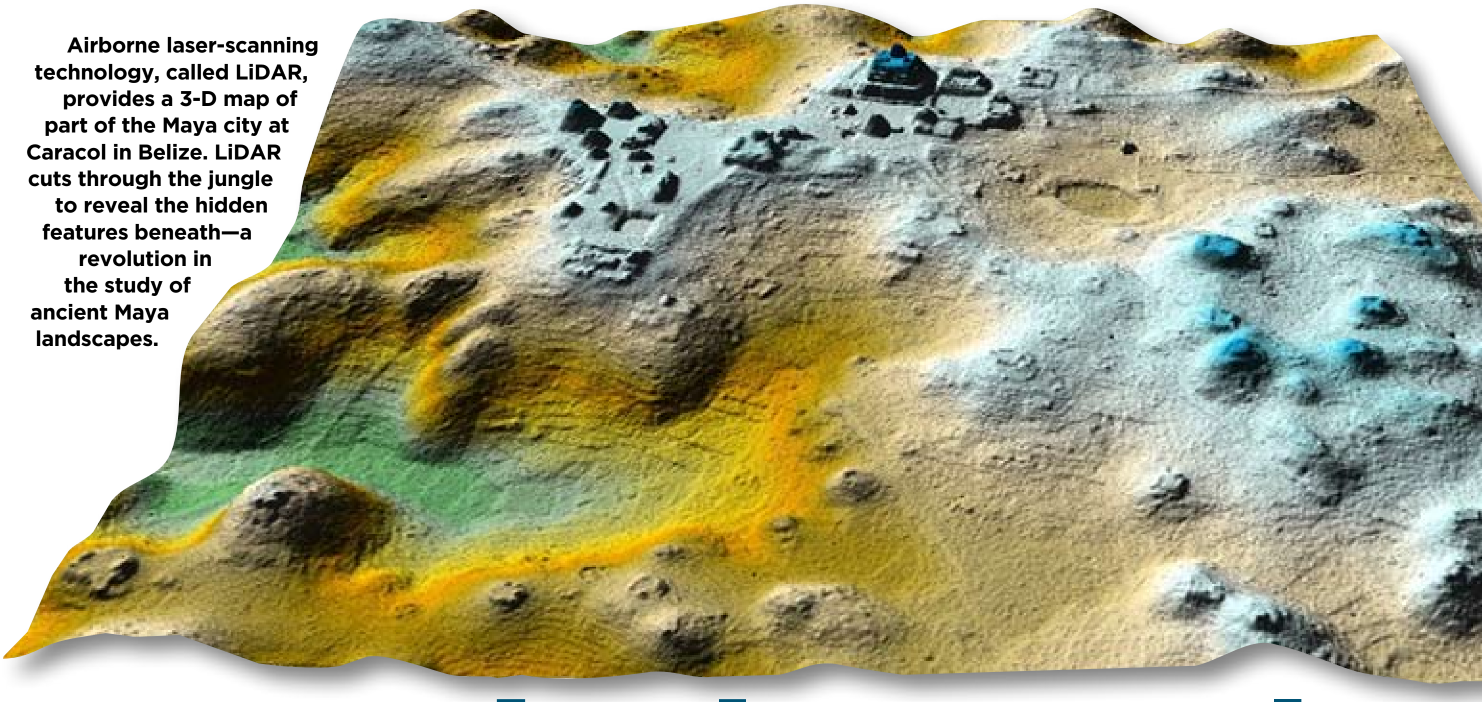
Airborne laser-scanning technology, called LiDAR, provides a 3-D map of part of the Maya city at Caracol in Belize. LiDAR cuts through the jungle to reveal the hidden features beneath—a revolution in the study of ancient Maya landscapes.



Lasers in the Jungle

Airborne sensors reveal a vast Maya landscape

by Arlen F. Chase, Diane Z. Chase, *and* John F. Weishampel

Even when one is almost directly on top of them, many Maya sites are impossible to see. In the jungle, small palms and brush can spring to 14 feet high in a year, filling the space between towering cedar, mahogany, ramon, and ceiba trees. When archaeologists *can* find large Maya sites, we cannot easily map them because it is expensive and labor-intensive. Even modern electronic distance meters have limited functionality; if we can't see through the trees, neither can they. So we cut paths with machetes, scramble through thick underbrush, and wonder what we might be missing. The ability to see through this dense, steamy jungle has long been the dream of Maya archaeologists.

These difficulties have led us to underestimate the accomplishments and ingenuity of the ancient Maya. There is little agreement among archaeologists over just how big some Maya cities were, how many people lived in them, or how intensively their residents modified the landscape. It often appears that sites in more easily studied areas of the world—plains, sparse forests, or areas cleared in modern times—are larger and more complex than their tropical forest counterparts. Does this impression reflect the inability of ancient humans to create large, sustainable settlements in the tropics, or is it the result of incomplete investigations, hampered by the complications of working in a rainforest?

For more than 25 years, we—a multidisciplinary team from the University of Central Florida—have struggled to document the jungle-covered archaeological remains at Caracol in western Belize. Caracol was occupied from 600 B.C. to A.D. 900 by a population that we believe peaked with at least 115,000 inhabitants. A system of radial roads, or causeways, links different parts of the site across most of Belize's lush Vaca Plateau. We have mapped, using traditional on-the-ground techniques, approximately 9 square miles of settlement, 1.3 square miles of terracing, and 25 miles of causeways. We have also studied the buildings and pyramids of the site's center, as well as 118 residential groups that consist of rubble foundations and stone buildings arranged around a central plaza. Our work so far clearly establishes Caracol as the largest known archaeological site in the southern Maya lowlands, but reconnaissance and scouting suggest that the city was even larger than was previously thought. Despite the quantity of data we have, there are still lingering questions about the site's true size and population, and about the density of the terrace systems that the ancient Maya constructed for agriculture. To answer these difficult questions without spending another 25 years in the field, we clearly needed a new strategy—a way to "see" through the dense forest covering the archaeological remains.

For the last three decades archaeologists all over the world have been using space-based imaging tools to better understand ancient landscape and settlement patterns.

Caracol has been studied and excavated for 25 years, but just a few weeks of LiDAR work created a detailed map of 80 square miles of the site—nearly eight times the area that had been previously mapped from the ground.

Like their colleagues, Maya archaeologists have turned to these techniques to overcome the complications of working beneath a forest canopy—but often with little success. Generally, we have only been able to see archaeological features that extend above the canopy, are in areas devoid of vegetation, or disrupt the forest in a bold way. Even large pyramids can escape the eye in the sky. A newer remote-sensing technology called LiDAR (Light Detection and Ranging), operated from a plane rather than a satellite, has helped us penetrate the jungle of Caracol and promises to revolutionize our understanding of Maya civilization. (Laser-based on-the-ground scanning, featured in "The Past in High-Def," May/June 2009, is also gaining traction in the archaeological world.)

In addition to a detailed study of existing satellite imagery, the Caracol remote-sensing project, funded by NASA, was designed to determine if LiDAR can be used to see below the canopy to provide images of a complete ancient Maya landscape. It was even more successful than we had hoped. Just a few days of flyovers and three weeks of processing yielded a far superior picture of Caracol than on-the-ground mapping ever had.

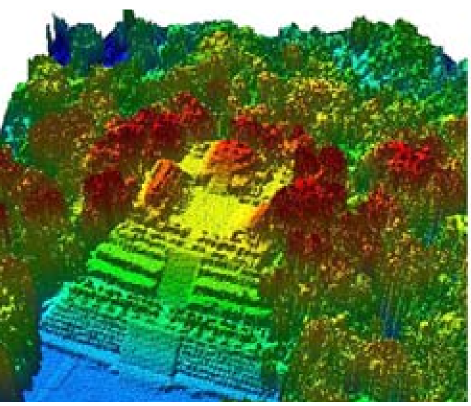
Airborne LiDAR works by sending out billions of laser pulses from a plane—in this case one operated by the National Science Foundation–supported National Center for Airborne Laser Mapping—half a mile above the forest canopy. Carefully calibrated sensors measure the pulses that bounce back. Initially, the lasers are refracted by the tops of trees, producing a detailed record of the forest cover. But treetops are porous, so some photons penetrate deeper, while others reach all the way to the ground and reflect back from the underlying surface terrain—and any buildings or ancient structures on it. The result is an accurate, three-dimensional map of both the forest canopy and the ground elevation beneath it. For looking at Maya sites, it was important to take the measurements at the end of the dry season, when the forest is the most depleted. This laser-sensing technology is not by itself new, but has been refined—we used a significantly advanced airborne laser swath mapping (ALSM) system that swept across a 1,500-foot-wide area with each pass of the plane. The Caracol data represent the first time that the ALSM technology has been applied across an extensive region in the Maya area, and the results were stunning.

Seemingly without effort, the system produced a detailed view of nearly 80 square miles—only 13 percent of which had previously been mapped—revealing topography, ancient structures, causeways, and agricultural terraces. The data show the full extent of Caracol, how the settlement was structured, and how the ancient Maya radically modified their landscape to create a sustainable urban environment, challenging long-held assumptions about the development of civilization in the tropics.

The LiDAR data confirm that Caracol was a low-density agricultural city encompassing some 70 square miles. Our previous on-the-ground work had documented multiple causeways, but the LiDAR images revealed 11 new ones and 5 new causeway termini (concentrations of buildings at the ends of roads), revealing the site's entire communication and transportation infrastructure at its height during the Late Classic Period (A.D. 550–900). Equally important, the LiDAR images clearly show unmodified hills and valleys at the edges of the surveyed area, indicating the limits of the site and providing hints about why the Maya of Caracol settled where they did and how the city expanded over time.

The study clearly confirms our earlier population estimates for Caracol, and also documents the extent to which the people of the city modified the land to feed themselves. We were particularly impressed with LiDAR's ability to reveal Caracol's agricultural terraces. We had documented these structures in on-the-ground surveys, but it was near-impossible to imagine the extent of the modified landscape. The

A LiDAR image of the Caana complex at the heart of Caracol, at left, shows the tree canopy surrounding a 140-foot-tall building (in an aerial photo at right). The lasers also penetrate the jungle to reveal structures hidden by that overgrowth.



In this LiDAR image of the Caracol epicenter, the jungle cover has been removed. Clearly visible—as ripples in the valleys and hillsides—are the agricultural terraces the ancient Maya constructed to feed the sprawling city.

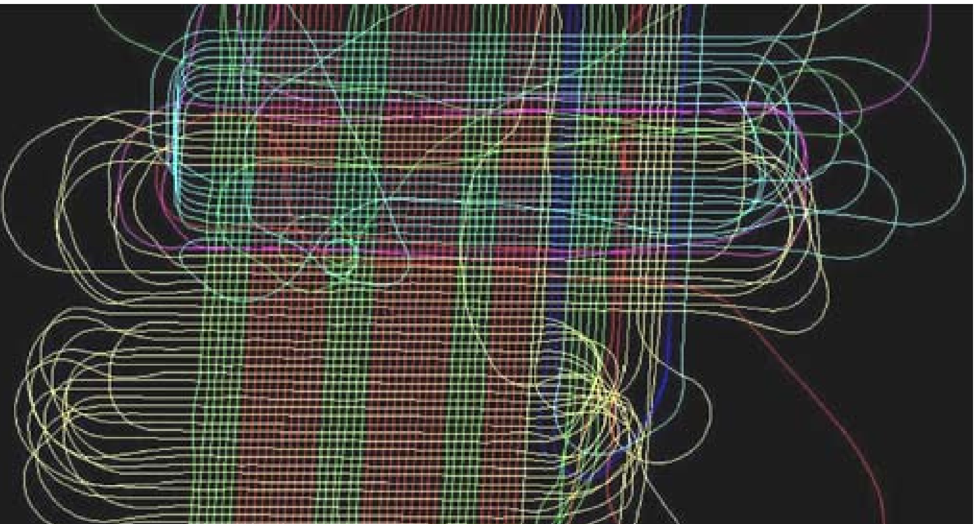
remote-sensing data show that almost all of the Caracol landscape had been altered; soil- and water-conserving terraces cover entire valleys and hills, making it clear that agricultural production and sustainability were critical to the ancient Maya. Airborne LiDAR is clearly the tool that Maya archaeologists have been waiting for.

LiDAR results dwarf what was possible before, even through long-term archaeological projects, such as those at Tikal in Guatemala and Calakmul in Mexico, but the technology has drawbacks. It may not record the remains of completely perishable structures, which may leave only a few lines of stone, though our results suggest it can distinguish features less than a foot high. On-the-ground confirmation, traditional mapping, and excavation are still necessary to add information about how buildings were used, details, and dating. But because LiDAR covers large areas so efficiently, it could ultimately replace traditional mapping in tropical rainforests, and drive new archaeological research by revealing unusual settlement patterns and identifying new locales for on-the-ground work. At Caracol, for example, we found previously unknown clusters of complex architecture that are not directly tied to the Late Classic causeway system. Possibly areas of craft or pottery production or the remains of earlier settlements, these are prime targets for future archaeological investigation.

Understanding the scale of a modified Maya landscape will also help us compare the Maya with other ancient civilizations more effectively. Remote-sensing techniques used in the Amazon Basin and Southeast Asia have revolutionized our thinking about ancient cultures there. Satellite imaging, combined with on-the-ground GPS mapping, for example, demonstrated that complex and populous societies occupied the Amazonian rainforest before European contact. And at Angkor in Cambodia, remote sensing helped delineate a metropolitan area that covers nearly 400 square miles and led to new interpretations of the site's complex water systems and eventual abandonment. At Caracol, we see a large, low-density, agricultural city that thrived in a tropical environment. But where the people of Angkor made extensive and difficult-to-maintain hydrological changes to grow enough food to feed themselves, Caracol's inhabitants focused on the intensive creation of sustainable terraced fields. These terraces not only controlled water flow during the rainy season, which reduced erosion, but also retained water longer. Using the terraces, the ancient Maya could produce multiple harvests of maize, beans, squash, and other crops in a single year, and nutrients could be replenished by fertilizing the earth with night soil and compost. Combined with the appropriate spacing of settlements and reservoirs, the recycling of garbage, and a causeway system to communicate and distribute resources, the agricultural terrace system was designed to work with its environment—and support the daily needs of more than 100,000 city dwellers.

For too long, Maya archaeologists have been blinded by the jungle, able only to sample once-wondrous cities and speculate about vanished people. The airborne LiDAR data will help us finally dispel preconceived notions about ancient tropical civilizations—that they were limited in size and sophistication—by letting us peer through the trees. In a broader sense, we will even be able to connect sites with one another and detect political boundaries to reconstruct ancient tropical polities in full. Imagine being able to see and map the entire Maya world—its fields and pyramids, its houses and trade routes, its interactions and conflicts. But that is in the future. For now, it is enough to be able to see the entire urban landscape of one ancient Maya city, and know that palm fronds and tangled forest will no longer automatically obscure our view of the past. ■

LiDAR is operated from a plane half a mile above the jungle. This illustration shows the twin-engine Cessna's route over 23 hours in the air. In that time, the system made more than 4 billion measurements of the landscape below.



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