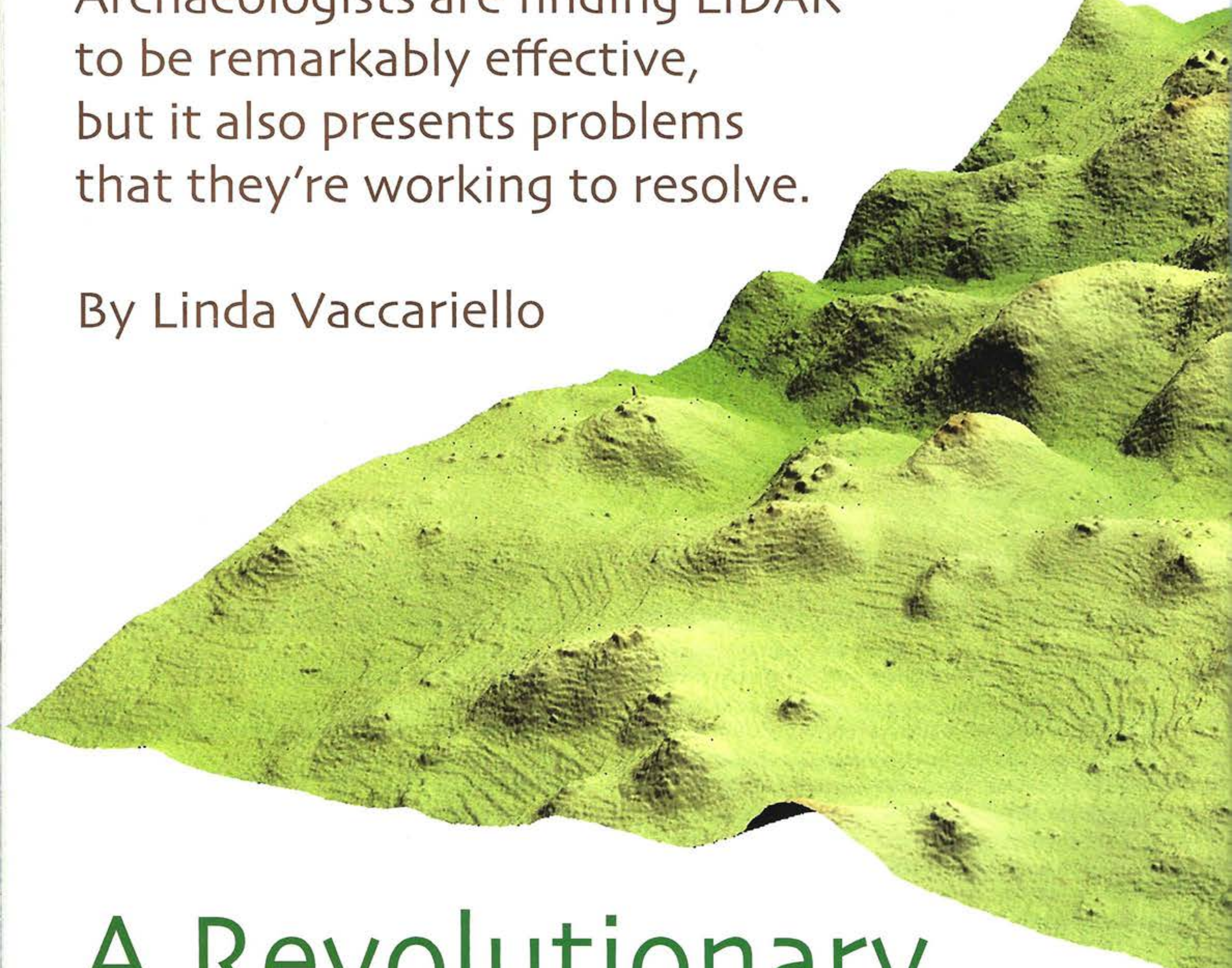
Archaeologists are finding LiDAR to be remarkably effective, but it also presents problems that they're working to resolve.

By Linda Vaccariello

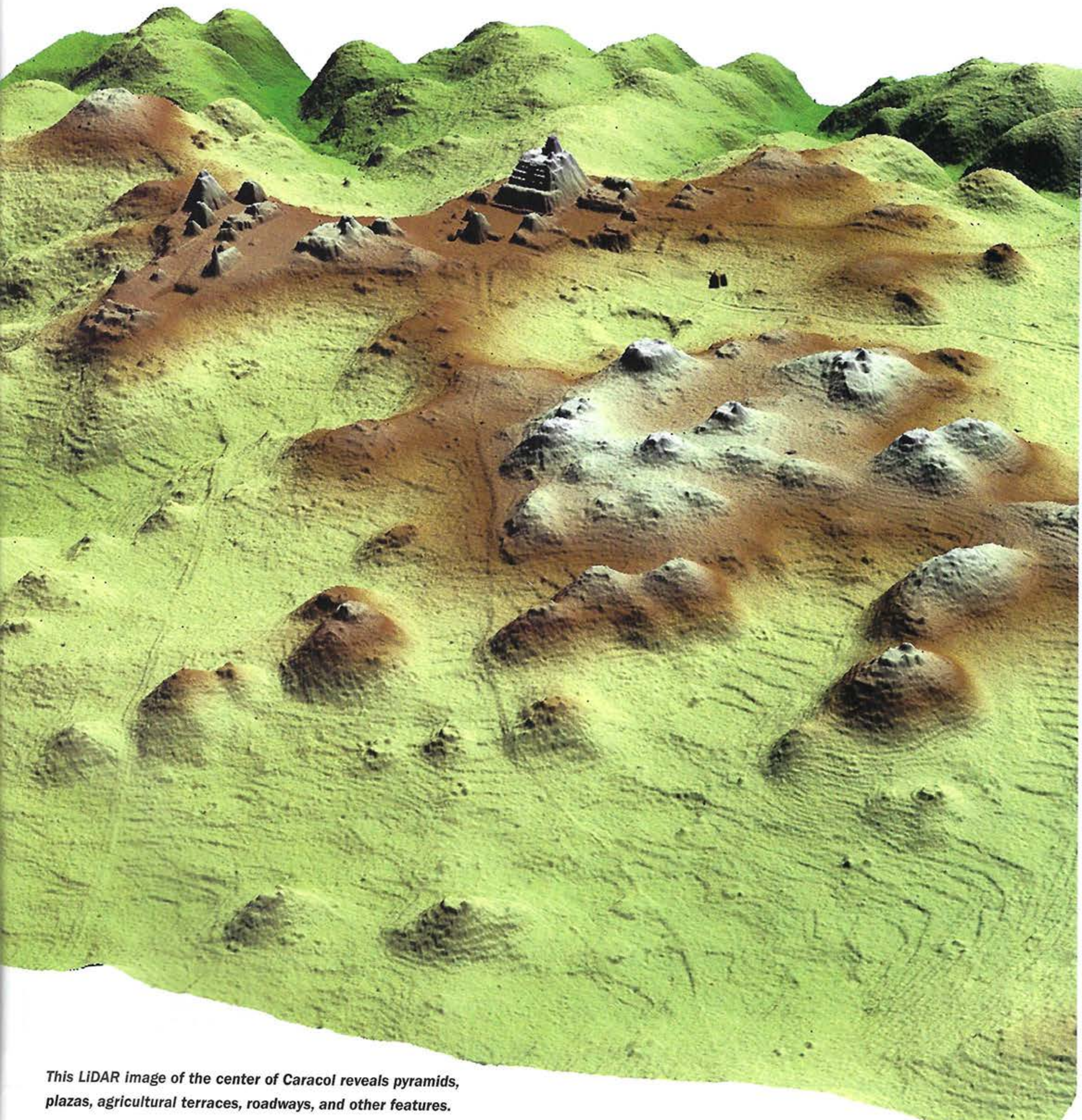


COURTESY OF ARLEN AND DIANE CHASE, CARACOL ARCHAEOLOGICAL PROJECT, UNIVERSITY OF NEVADA, LAS VEGAS

A Revolutionary Technology

Arlen Chase's recent field season at Caracol, the large Maya site in western Belize that he and his wife, archaeologist Diane Zaino Chase, have been investigating for more than thirty years, was nothing less than exhausting. Among the challenges was a forty-minute uphill slog through the rainforest to the excavation site every day. "It was a really hard season," Chase said. "Which, at my age, was pretty stupid." But in one way Chase's job is much easier than it was when he began exploring Caracol. Since 2009, he has been using data from LiDAR, the technology that is revolutionizing archaeology in areas with heavy vegetation by making it possible to digitally map remote sites with incredible accuracy.

LiDAR stands for light detection and ranging. It's a remote sensing technology that operates on the same principle that a bat uses to navigate a cave or find a mosquito to gobble. The bat sends out an ultrasonic chirp, the sound waves bounce back when they hit something solid, and the



This LiDAR image of the center of Caracol reveals pyramids, plazas, agricultural terraces, roadways, and other features.

bat calculates the distance between itself and that object based on how long it takes the sound to return. Instead of sound, LiDAR uses lasers, sending out thousands of pulses of light a second and calculating the distance of objects by analyzing the time it takes for the pulses to return. If the LiDAR unit is aloft in a helicopter or an airplane and linked to a GPS, the data from the reflected light can be used to produce a map of the terrain below, surveying large areas quickly and accurately.

LiDAR emerged in the 1960s, shortly after the first lasers were invented. The early applications were in the military, atmospheric science, and the space program. By 1971, Apollo 15 used the technology to map the surface of the moon. Today, LiDAR has a wide range of uses, from monitoring the earth's melting glaciers to preventing self-driving cars from crashing. LiDAR enables users to survey vast swaths of territory quickly and precisely. But it's the ability of this technology to digitally sweep away the vegetation and map

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The forest canopy partially covers Plaza Jobo at El Pilar in Belize. Archaeologist Anabel Ford and her colleagues were aware of Jobo prior to doing a LiDAR survey, but LiDAR has allowed Ford to map Jobo with much greater precision.

the land below that makes it so valuable to archaeologists.

A dozen years ago, Chase learned that NASA was making significant advances with LiDAR, advances that could make it possible to map the contours of the ground even in heavily-forested locations. If that was true, he wondered if it could be used to identify archaeological sites in the rainforest. There had been some small-scale LiDAR surveys by archaeologists in Europe, he said, and "We figured it would work over a large area."

He wanted to give it a try at Caracol, which was occupied from 600 B.C. to A.D. 900. Like many Maya sites, it is largely covered in jungle, where thick, low vegetation underneath towering trees made mapping slow, laborious, and expensive. In their first twenty-five years of work, using traditional techniques, Chase and his team had studied the monuments and public structures at the epicenter of the site and their groundwork had identified the typical settlement pattern: regularly spaced residential groups interspersed with terraced fields that were connected to the epicenter of the settlement by a series of causeways. They had mapped

about nine square miles of settlements, 1.3 square miles of agricultural terracing, and twenty-five miles of causeways.

Chase's ground mapping had established that Caracol was a large site. But he believed it extended even further. Researchers would expect to see residences and other evidence of settlement become sparser the further they got from a site's epicenter. But his team found no decline in settlement density nearly four miles from Caracol's epicenter. In 1994, Chase had estimated Caracol at approximately sixty-eight square miles with a population as high as 115,000. But "nobody would buy into that," he said, explaining that back then most researchers thought that even the largest Maya cities did not reach that size.

It happened that NASA was interested in learning if LiDAR could be used for archaeological research, so in 2009 the space agency funded a survey of Caracol that was carried out by the National Science Foundation's National Center for Airborne Laser Mapping (NCALM). The flyovers took only a few days. Chase used the data to produce a site map that suggested that Caracol was as large as he had conjectured—about seventy-seven square miles, and capable of sustaining a population of 115,000 or more. He figured that it would have taken him another quarter century of survey and excavation to confirm his theory. "I knew the site was huge," he said. "I was looking for technology that would allow me to" map it. "LiDAR was that technology."

During the recent field season, Chase and his team were investigating one of Caracol's termini. The termini were the city's marketplace plazas where goods were exchanged. The archaeologists had mapped causeways and excavated several termini before the LiDAR survey, concluding that some of the termini were created at once-distant settlement sites that ultimately became engulfed by the growing city, while other termini were built to serve the increasingly dense population around Caracol's epicenter. The LiDAR results suggested that there were five termini and eleven causeways the team had not found before. Now they're getting a more detailed understanding of how the city grew and was managed over the centuries by excavating and comparing artifacts and other evidence from different termini. Because LiDAR doesn't reveal when a structure was built or how it was used, "you have to have the archaeology to go along with it," Chase said. But thanks to LiDAR's "big picture" view of Caracol, and more than thirty years of excavation, they "now know how it all fits together."

An airborne LiDAR unit sends out hundreds of thousands of pulses of light per second, then records these pulses as they bounce back from the obstacles they encounter: trees, undergrowth, and the ground itself. The aircraft makes multiple passes over the terrain being surveyed, shooting pulses of light and recording billions of returning pulses. Digitally separating the pulses that hit the ground from those that hit the tree canopy and other vegetation produces a point cloud of data of the forest floor. There are software programs that process the point cloud data as a digital elevation model (DEM), visualizing the various changes in elevation that could indicate human-built structures.

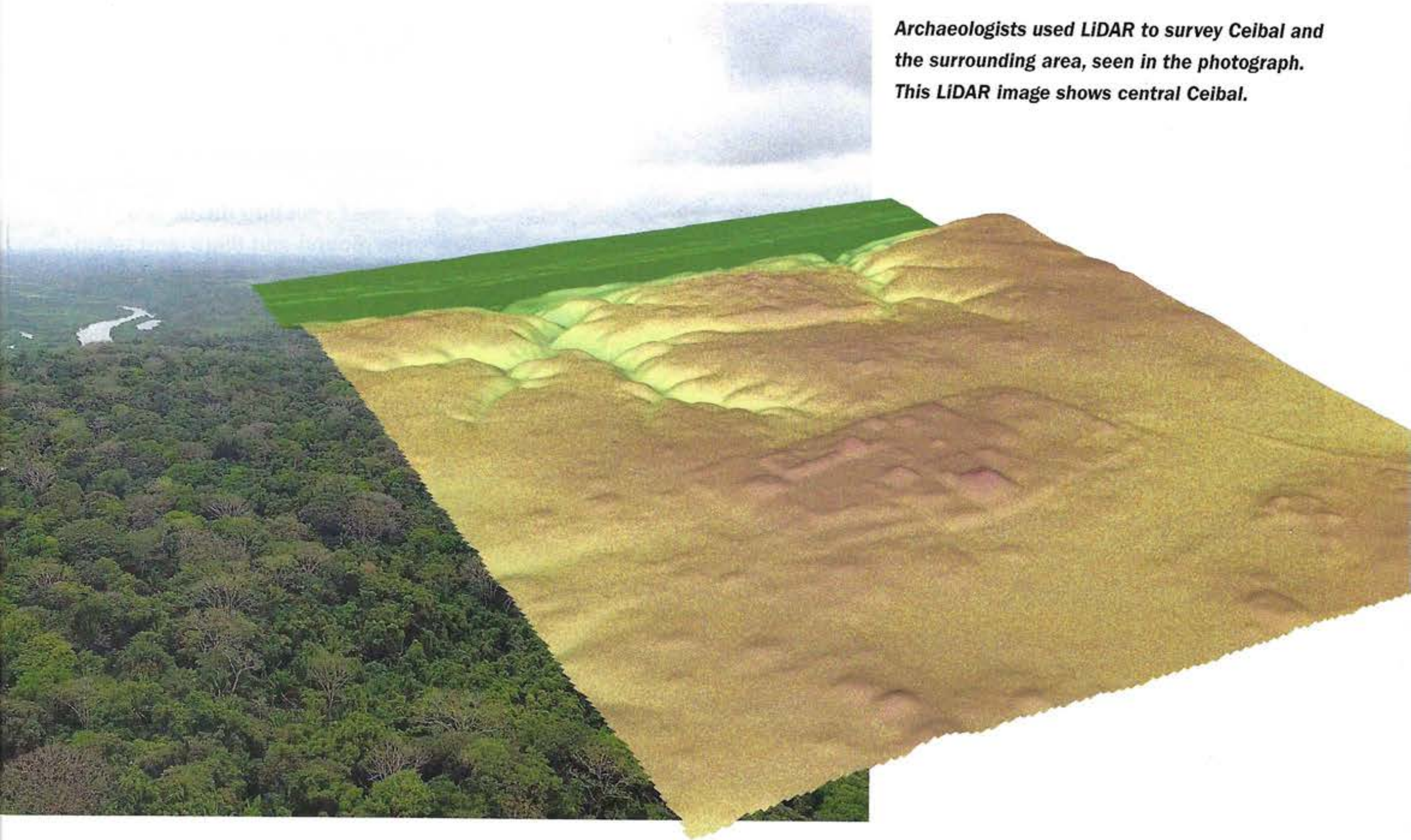
It can be fairly easy to identify the ruins of a large pyramid in a DEM. But picking out the subtler archaeological remains can require a computer program that can identify a specific feature. Arlen and Diane Chase's son, Adrian, a graduate student at the School of Human Evolution and Social Change at Arizona State University, created a custom computer algorithm to locate nearly 1,600 small reservoirs in the residential areas of Caracol. (Their interest in reservoirs had to do with testing a hypothesis about elites controlling the water supply.) Another researcher had already created a program to identify the area's caves; Adrian modified it to pick out the residential reservoirs. The Chases had an advantage working with their son; Adrian's undergraduate degree included a double-major in anthropology and computer science. "That's an unusual combination within archaeology," Chase said, adding that there's a need for more specialists who are trained in the fine details of the technology.

Colorado State University archaeologist Chris Fisher used LiDAR to map Angamuco, a settlement occupied by the Purépecha, who lived in Central Mexico and were contemporaries of the Aztecs. After learning about Chase's success with LiDAR in Caracol, Fisher conducted a LiDAR survey of Angamuco, and then spent a year teaching himself how to work with the data. ("I'm still learning," he said.) He assumed Angamuco would be a modest settlement. Instead, LiDAR revealed that the site contained a city covering about ten square miles. "It changed my project," he said. Since then his team has excavated for three seasons, verified 7,000 architectural features, and grappled with questions that the LiDAR data has raised. For example, Angamuco's monuments and public plazas were built at eight locations on the city's edge rather than the more common practice of being centralized in one spot. "We don't know why that is," Fisher said. So his team is excavating at each location, trying to solve the puzzle that LiDAR has presented.

In 2013, Anabel Ford, director of the Mesoamerican Research Center of the University of California in Santa Barbara, had a LiDAR survey done of the El Pilar Archaeological Reserve for Maya Flora and Fauna in the Belize River area on the Belize-Guatemala border. Ford and her research partner, geographer Thomas Pingel of Northern Illinois University, developed a DEM technique called bonemapping to process and visualize LiDAR data. Bonemapping (so called because it uses

COURTESY OF TAKESHI INOMATA AT THE UNIVERSITY OF ARIZONA.

Excavators work at Ceibal's royal palace. The excavation data has informed the archaeologists' interpretation of the LiDAR data.



Archaeologists used LiDAR to survey Ceibal and the surrounding area, seen in the photograph. This LiDAR image shows central Ceibal.

COURTESY OF TAKESHI INOMATA AT THE UNIVERSITY OF ARIZONA.

a type of digital imaging originally developed for interpreting x-rays) is particularly effective at creating a visual representation of anomalies on the ground that could be cultural resources, according to Pingel.

Ford has been studying El Pilar since 1983, and has identified hundreds of structures, including temples, plazas, and residences through standard fieldwork. When she got the LiDAR survey results she compared them to her prior mapping of the site's major features. "Our mapping was very good," she said, "but there were differences." LiDAR's GPS is highly accurate compared to the standard GPS that most archaeologists use in the field. So she adjusted her map accordingly. Then she and her team used Pingel's bonemapping visualization to identify "go-to" points—about 1,600 spots on the bonemap where there might be cultural remains. These became their field mapping destinations.

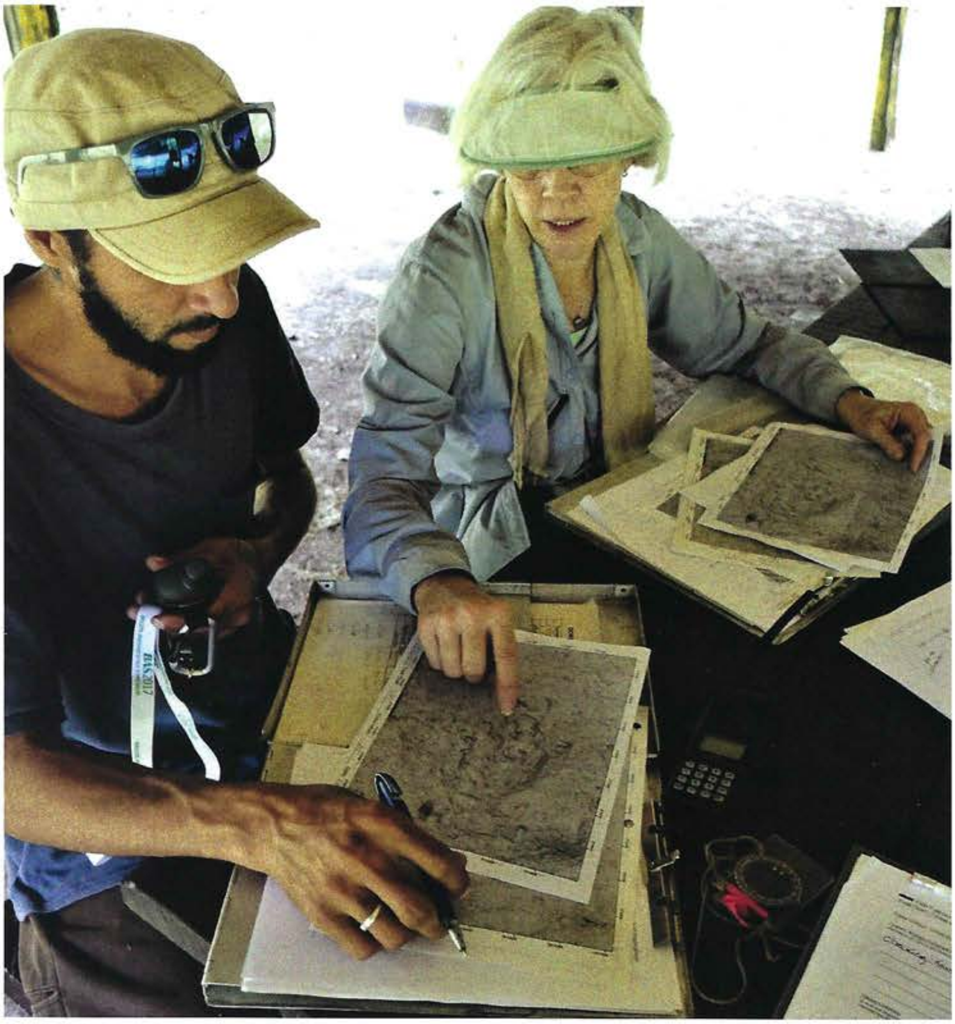
Since then, they have visited over a thousand go-to points, mapping 1,335 new cultural features, verifying 611 domestic structures, and mapping the locations of seven civic monuments. In other cases go-to points turned out to be nothing more than a thick pile of leaf debris or a large tree buttress. They have also surveyed areas where there were no go-to points and found subtle features that didn't appear on the bonemap. "So there are things that LiDAR is not picking up," she said. "But for the most part, for the residential architecture and, of course, the big stuff, it's very good," she said. "You have to go out and see. Boots on the ground, you know?"

University of Arizona archaeologist Takeshi Inomata has been directing the investigation of Ceibal, a Maya site in Guatemala, for thirteen years. In 2015, he used LiDAR to map the extent of development beyond the site's center. The LiDAR survey covered approximately 180 square miles and showed the locations of more than 15,000 possible Maya features. "Before LiDAR, it was simply impossible to cover such a wide area," he said.

Inomata's work examines settlement patterns and social changes over time, therefore identifying the settlement chronology of Ceibal was essential. During previous excavations he had noticed a series of stylistic changes in the structures that appeared between 1000 B.C. and A.D. 950. Analyzing the LiDAR data, he and his colleagues discerned different architectural arrangements consistent with the stylistic changes seen in the structures they excavated, which allowed them to estimate the dates of the apparent structures the LiDAR survey revealed.

"We could estimate changes in settlement distributions through time by combining the LiDAR data and our excavation data," Inomata said. They ground truth the LiDAR data by doing test excavations and surface collections at the locations of the apparent structures. "Before LiDAR we just surveyed selected areas to see what we would find," he said. LiDAR allows them to be "much more efficient."

Though it's efficient, LiDAR is also expensive. Archaeologist Thomas Garrison of Ithaca College is involved in a LiDAR survey of the Maya Biosphere Reserve in



Anabel Ford and a colleague review LiDAR imagery.

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Guatemala that received extensive press coverage earlier this year. The massive survey, which covered roughly 800 square miles of this vast nature reserve, cost $600,000. But, he pointed out, traditional archaeology is costly, too. He spent several years ground mapping El Zotz, a site in the reserve, and covered only about one square mile. "I would guess that [to accomplish that] we probably threw $100,000 at the mapping team, including equipment and staff." A large LiDAR survey is a one-time expense that can be used by many researchers for many years. This is why Garrison and researchers working on other projects in the Maya Biosphere Reserve approached a Guatemalan non-profit, the PACUNAM Foundation, to fund the survey, which mapped multiple archaeological sites. Archaeologists working at these sites are now using that data in their respective research projects.

The LiDAR images from the Maya Biosphere Reserve, like those from Caracol and other areas, indicated that the Maya world was not composed of scattered, sparsely-populated city-states, but that it featured densely-populated, interconnected urban centers where agriculture and water were carefully managed. And, like other researchers who have used LiDAR, archaeologists using the PACUNAM survey are seeing new features they need to investigate. "What was special about our project was really the scale of it," said Garrison. "Now all of these projects that have this data have to address the issues that have come up for them locally," he said. "Everyone needs to get into the field...get to the ground and dig it, and try to understand it."

The very existence of a LiDAR survey presents a peculiar problem: who gets to see it? These surveys are rich with scientific data that could be invaluable to researchers in many disciplines, and consequently a funding organization such as the National Science Foundation has an interest in making the data from the LiDAR surveys that it supports accessible to a broad range of scientists. But archaeologists fear that making the LiDAR data public could threaten cultural remains. "The maps produced prior to LiDAR weren't digitally referenced in terms of latitude and longitude," Chase said. "But LiDAR is." Consequently, someone possessing LiDAR data and a GPS could locate a site and loot it.

In Chase's case this is not a problem because he's investigating Caracol with the permission of the Belizean government, which has stipulated that the LiDAR data can't be shared. But other research projects may not be subject to similar restrictions. "It's an ethical dilemma that hasn't been resolved," he said. The PACUNAM Foundation is discussing a process for vetting researchers who want to use LiDAR data from the Maya Biosphere Reserve, according to Garrison. It's part of a larger, long-term plan for managing the data from that survey. "These are things we have to deal with professionally and ethically," he said.

While acknowledging LiDAR's efficacy, Ford said that it's "no magic wand." Garrison agreed, saying "LiDAR doesn't solve all our problems. In many ways, it creates problems." At El Zotz, for example, the LiDAR survey revealed evidence of a previously unknown fortress in a remote area. It took Garrison's team two and a half hours of hiking in 100-degree heat to reach the fortress. "Now, if we actually want to work there, it's a logistical issue," he said. That is, indeed, problematic. "But it's a new problem," said Garrison. "So it's exciting."

LINDA VACCARIELLO *is the former executive editor of* Cincinnati Magazine. *Her article "Life On The Frontier" appeared in the Fall 2017 issue of* American Archaeology.