NEWS FEATURE

News Feature: Mapping the lost megalopolis

Laser imaging reveals long-lost traces of ancient civilizations hidden beneath tropical forest canopies.

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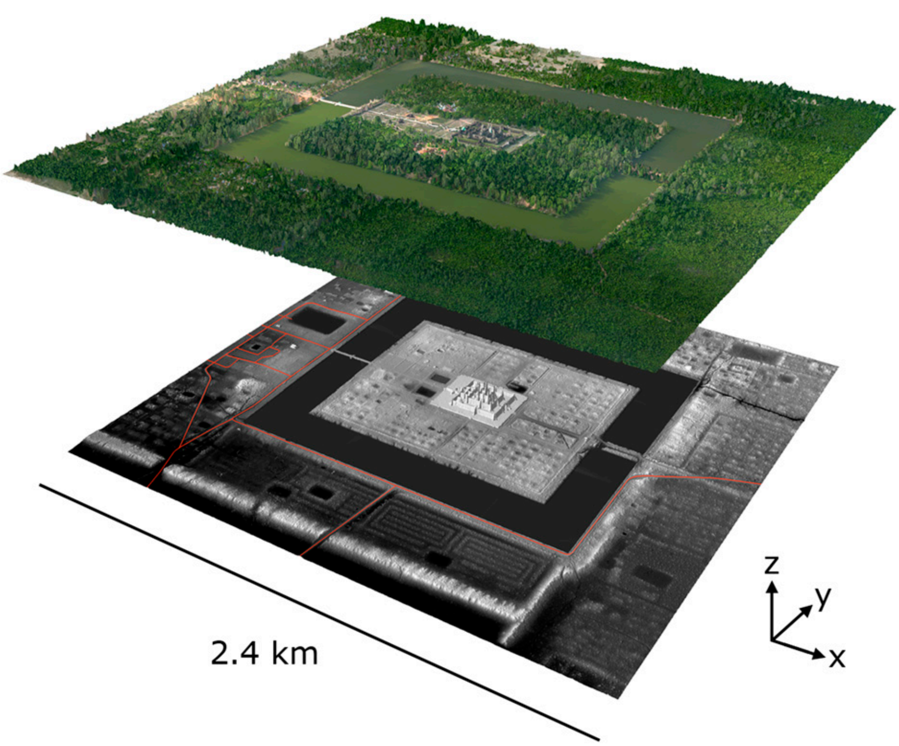
Archaeologists are known for getting their hands—and everything else—dirty. However, in April 2012, archaeologist Damian Evans boarded a helicopter and spent hours being flown over the dense foliage surrounding Angkor Wat, Cambodia's legendary complex of ancient stone temples. The heat inside the helicopter was intense, reaching upward of 40 °C, but Evans, a faculty member of the University of Sydney based in Cambodia, much preferred flying over the trees than trudging through the vegetation beneath them. The visible, known temples in Angkor were well-trodden and populated with visitors from all over the world. However, the outlying forest beneath Evans's ride, lush and green from the air, hid land mines left over from Cambodia's tumultuous past.

The small and sturdy helicopter swept low and slowly over the area. A laser mounted to the left skid of the chopper sent out a steady stream of 200,000 short laser pulses per second and recorded how long it took the pulses to return; a GPS system tracked the location. A computer program uses those travel times to calculate how far a pulse has traveled. Data from the pulses combine to produce a high-resolution, 3D map of both the canopy and the land hidden beneath it.

In recent years, archaeologists have used this technology, called LiDAR (a portmanteau of "light" and "radar"), to find ruins of structures—roads, canals, temples, reservoirs—long overgrown with vegetation and hidden from easy observation. LiDAR is revolutionizing what scientists think about the size of ancient cities and how ancient civilizations used the land. It has accelerated the pace of surveying nearly impenetrable areas to a rate that would have been unthinkable just a few years ago.



What hides beneath: Two views of Angkor Wat. The bottom image, created from LiDAR data, exaggerates the terrain beneath the trees and shows features hidden in the photo on top. Reprinted from ref. 1.

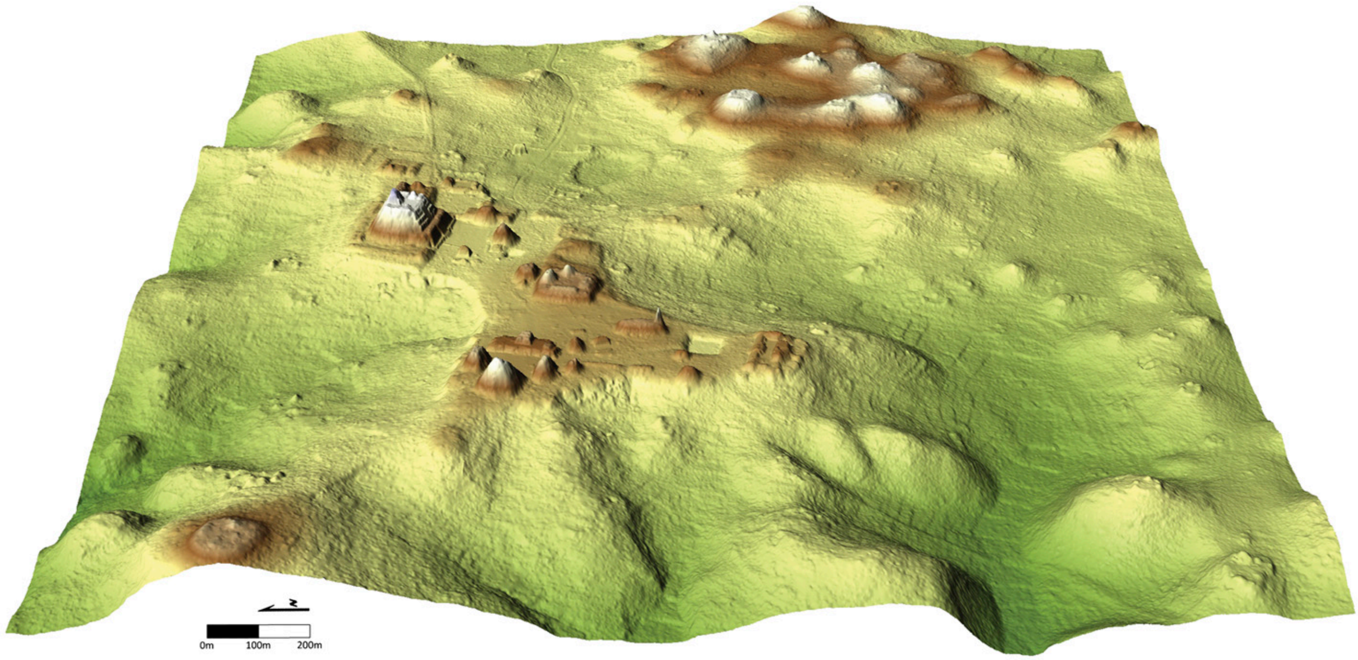
After 20 hours of flying over two days, the helicopter carrying Evans had surveyed 370 square kilometers (91,400 acres) and Evans had as much data about Angkor's hidden landforms as he might have gathered during his entire career.

"To achieve the same number of data points as we did with LiDAR would have taken decades on the ground," Evans says. In addition, Evans says he and his colleagues suspected that previous studies of the area were incomplete. "Our concerns were that previous research had missed three-quarters of the downtown metropolitan part of Angkor."

The urban sprawl around the temples of Angkor had already been identified as the largest integrated settlement complex of the preindustrial world. However, Evans's LiDAR map confirmed that existing surveys had been vastly underestimating the size of the formally planned street grid in the central area of the city.

In a 2007 PNAS study (1) that combined ground surveys with airborne radar mapping, Evans and his colleagues first found a chaotic, urban sprawl beyond the city walls of the Angkor Wat complex, and the temples were the center of large, urban landscapes. In a study based on LiDAR maps, published in PNAS in July 2013 (2), Evans et al. reported that the lasers illuminated in exceptional detail that the now-tangled land outside the temple walls had once, 1,000 years ago, been divided into neat rectangles like city blocks, with canals, ponds, and residences. The urban grids found inside the walls had been built outside, too, covering an area of 36 square kilometers.

"It's relatively easy to draw a line around temples, but the revelation from LiDAR is



LiDAR-based maps are helping scientists better understand ancient sites like the Mayan site of Caracol, in Belize. This colorized image shows the degree to which the people changed the landscape. Image courtesy of the Caracol Archaeological Project.

that you find this web of subtle traces of urban networks," Evans says.

The new study suggests the Angkor capitals were much more densely populated than was previously believed, offering more evidence to a growing idea that the Khmer civilization grew so large that it couldn't grow enough crops to keep up. Overpopulation, combined with the lack of sustainable agricultural methods, may have left the cities vulnerable to decades-long droughts that struck in the 14th and 15th centuries, the same time the Khmer kings abandoned Angkor.

From Space to the Surface

Although it's now upending the field of archaeology, LiDAR isn't new. NASA developed laser-sensing technology decades ago, using it not to study the surface of Earth, but to peer inside clouds. As laser pulses travel through a cloud, some are reflected back to a waiting sensor by water particles and other molecules in the cloud. Researchers can use that data to determine the dimensions and constituent particles of the cloud. In the 1970s, LiDAR went to space as part of the last three Apollo missions; astronauts used the technology to measure the height of lunar features near potential landing sites. In the 1980s and 1990s, scientists and engineers brought the lasers down to Earth, creating LiDAR systems that could be mounted on airplanes.

It wasn't until the early 2000s that the technology became inexpensive enough to be within the reach of most researchers. Ramesh Shrestha, now director of the National Center for Airborne Laser Mapping (NCALM) at the University of Houston, first worked with airborne LiDAR in 1999 on a project that used the technology to map coastlines along the panhandle of Florida. Shrestha and his colleagues used a machine that fired 3,000 pulses per second, "which was great at the time," he says.

Even with that first excursion, Shrestha says, "we knew that this technology could be revolutionary in its applications in archaeology."

Since then, the technology has proliferated—and sped up—at a quick pace. In only 15 years, LiDAR lasers went from firing 3,000 pulses per second to 200,000, like the one used by Evans at Angkor Wat. Additionally, within a few months, Shrestha says, the NCALM will start mapping with a device that uses two lasers and sends out 900,000 pulses per second at three different frequencies. Earlier this year, researchers at Lincoln Laboratory, a federal research and development laboratory at the Massachusetts Institute of Technology, debuted a system that could have scanned the Angkor project in 30 minutes. Within a few years, Shrestha expects to see LiDAR with full-color lasers, the data from which can be used to delineate among different types of vegetation or even measure water quality. UAV-ready LiDAR systems already exist, which means drones either do have or will soon be equipped with high-resolution laser-sensing devices.

Lasers in the Rainforest

LiDAR's first significant foray into archaeology came in 2009, when the Caracol Archaeology Project secured a grant from NASA's Space Archaeology Program to fund NCALM's mapping of 200 square kilometers (nearly 50,000 acres) of tropical rainforest, at 20 points per square meter, known to contain Maya ruins. The Caracol project, an effort to excavate and study the ruins at a site in the dense mountain forests of western Belize, was launched in the 1980s by husband-and-wife archaeology team Arlen and Diane Chase from the University of Central Florida. The ruins had been discovered in 1937 by a Belizean logger searching for marketable mahogany. Since then, waves of intrepid archaeologists have ventured to the site, creating maps by hand and documenting artifacts to better understand Caracol's significance in Maya history. When the Chases arrived in 1985, they found looters' camps scattered through the surrounding forests, the fire pits still warm. The epicenter of the ruins—including *Caana* (Sky Palace), still Belize's tallest man-made building—was blanketed in jungle.

Making accurate maps of the area required blood, sweat, tears, and machetes. Team members established sight lines by hacking through the jungle, ever watchful for tarantulas and scorpions, as well as tree vipers, coral snakes, and the fer-de-lance (or tommygoff), a deadly and aggressive pit viper with fast-acting venom. However, the Chases, who cut their wedding cake with a machete, found themselves at home among the ruins.

"Arlen and Diane are like little kids playing in a sandbox no one has played in before, saying 'no one has documented this!' and 'no one has documented that!'" says Chase collaborator and ecologist John Weishampel, also at the University of Central Florida, who has worked on numerous LiDAR studies of forested areas in Central America, including Caracol.

Over the years, the Chase family grew—their kids helped out at Caracol, naturally—and so did their maps. By 2001, the documented study area had grown from 16 square kilometers to 23, less than half the size of Manhattan. In the 1980s and 1990s archaeologists had clashed over the significance of the lost city: some viewed it as a backwater outpost with little significance on Maya civilization as a whole. However, the Chase's persistent work, which kept extending the known boundaries of the settlement, suggested the city was bigger and more important than anyone had guessed, far outsizing those 23 square kilometers.

The 2009 study changed everything, says Arlen Chase. He'd spent more than a quarter-century tromping over the same land covered by the LiDAR mapping, and he says when he first looked at the LiDAR map he was bedazzled.

"It was just mind-boggling," Chase says. "I had walked this ground and I knew what it was going to look like, but it was like a magical world opened up."

The map, built from 4.28 billion individual x, y, z point measurements, showed in sharp detail monumental architecture, roads, residences, and agricultural terraces, in perfect agreement with evidence collected by explorers on foot (3–5). The LiDAR data also turned up causeways and highways not previously known to link the center complex to outlying sites and it revealed that the Caracol settlement covered at least 180 square kilometers (44,500 acres). As in the case of Angkor, LiDAR gave researchers strong evidence that Caracol was nothing short of an ancient megalopolis.

The Future of Laser Mapping

Even so, Weishampel and the Chases felt like they weren't seeing the whole picture. In April and May 2013, they again enlisted NCALM to conduct a LiDAR study. This time, the plane covered 1,057 additional square kilometers (nearly 250,000 acres)—one of the largest regions recorded with this technology to date—around Caracol and other regions in western Belize. The researchers anticipate mining the data for new insights into Maya culture for years to come, but already they've been able to see how central Caracol was connected to outlying settlements. Their findings have been published in recent articles in *Advances in Archaeological Practice* (6) and in *Remote Sensing* (7).

Weishampel says that most archaeologists are chiefly interested in the map of the ground, showing the location of hidden monuments and structures. "They're only using 5 to 10% of the data they've collected," he says. In his own research, Weishampel's taking a different tack, looking at the forest structure to figure out how ancient civilizations manipulated the landscape. "LiDAR can show how agriculture and terraforming led to changes in the way water flows and the way soil erodes," he says. "It's the thousand-year fingerprint that the Mayas basically left to us."

As with any burgeoning technology a little LiDAR begets a lot of curiosity. Evans, in Cambodia, is preparing for a 2015 LiDAR mapping of the Angkor complex that will cover four to five times the area of his previous mapping. Shrestha worked with researchers on using LiDAR to search for La Ciudad Blanca, a legendary lost metropolis in Honduras. The laser data revealed features that could be ancient ruins of the city. And for their next big project, NCALM is taking LiDAR to Antarctica in a project funded by the National Science Foundation that uses LiDAR to map changes caused by climate change.

LiDAR is ushering in a new age of archaeology, as well as new growing pains. Arlen Chase points out that in Belize—as well as other countries in Central America—"technology is outpacing policy." In the United States, scientists have to release data from publicly funded projects to the public. However, in Belize such data would be tantamount to a roadmap for would-be looters.

"Belize won't let the LiDAR data be released, so we have to figure out ways to make it accessible," Chase says. "And the technology is moving so rapidly no one is dealing with it."

Of course, in a few years those ethical concerns might be a moot issue. Given the rapid pace of development for LiDAR, it's only a matter of time before some company develops the ability to map from space: think of a LiDAR-based Google map. By then, Chase says, it will be too late to try to restrict access to the data.

"What we need are guidelines in place for the use of this stuff," he says. "Politics needs to catch up with the technology."

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2 Evans DH, et al. (2013) Uncovering archaeological landscapes at Angkor using lidar. *Proc Natl Acad Sci USA* 110(31):12595–12600.

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4 Chase DZ, et al. (2011) Airborne LiDAR at Caracol, Belize, and the interpretation of ancient Maya society and landscapes. *Research Reports in Belizean Archaeology* 8:61–73.

5 Chase AF, Chase DZ, Fisher CT, Leisz SJ, Weishampel JF (2012) Geospatial revolution and remote sensing LiDAR in Mesoamerican archaeology. *Proc Natl Acad Sci USA* 109(32): 12916–12921.

6 Chase AF, et al. (2014) The use of LiDAR in understanding the Ancient Maya landscape. *Advances in Archaeological Practice* 2(3): 208–221.

7 Chase AF, et al. (2014) Ancient Maya regional settlement and inter-site analysis: The 2013 West-Central Belize LiDAR Survey. *Remote Sens* 6(9):8671–8695.