# THE LASER THAT'S CHANGING THE WORLD

## THE AMAZING STORIES BEHIND LIDAR, FROM 3D MAPPING TO SELF-DRIVING CARS

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abuzz about this cool thing he'd created, but also about the apparent fault scarp. Word got out. Craig Weaver, a geophysicist with the US Geological Survey and the University of Washington, called Berghoff and asked to check out the lidar-based map. Weaver had used a sonar vessel in Puget Sound to locate an earthquake fault dated to about 900 CE. He had traced it right up to the Bainbridge Island beach. But Weaver had not been able to find it on land. On Berghoff's map, he recognized it immediately: the Seattle Fault.

Weaver reached out to David Harding at NASA, who had flown lidar over the Pacific Northwest with Lefsky and others. Despite all his work with trees, the geologist remained interested in lidar's use in his nominal field and saw opportunity. He and Weaver marshaled federal support of what would become the Puget Sound Lidar Consortium, which within a couple of years had mapped a region 2,350 kilometers square (580,000 acres) surrounding the Seattle Fault zone on either side of Puget Sound.[38]

The Kitsap PUD is still using lidar data—the region has been re-flown since, and Kitsap County and the Olympic Peninsula are scheduled to be scanned again in 2018, Berghoff says. It's no more about earthquakes than that original 1996 survey was.

Lidar helps the utility understand the pressures on either end of a pipe from a reservoir, determine the paths of fiber-optic lines, and establish the locations and sight lines of cell phone towers. "We use it almost daily for our engineering," he says.

A water utility cartographer's curiosity about a new technology led to a deeper understanding of one of America's most worrisome earthquake zones. It's only fitting, then, that a disaster recovery mission led to the first lidar-based map in archaeology. In March 2000, a University of Texas at Austin team led by James Gibeaut flew UT's lidar over the coast of Honduras as part of a Hurricane Mitch impact-assessment mission. UT had been scanning the Texas coast with an Optech ALTM since 1997 to estimate beach erosion and sand loss and also understand hurricane-related flooding.[39]

When their schedule allowed, the UT team took side trips to scan the Copan archaeological site near the Guatemalan border. They stripped out the vegetation using Optech's and their own algorithms, creating the first digital elevation model of an archaeological site. It matched up nicely with a ground survey conducted earlier by Harvard University researchers.[40] Similar work started happening elsewhere. In 2001, UK researchers used an Optech lidar—now capable of scanning terrain with thirty-three thousand laser pulses per second—to survey the region surrounding the Stonehenge World Heritage Site. They digitally removed the foliage to spot extensions to known field systems and barrow cemeteries as well as entirely new sites. The authors concluded that they believed lidar would, in archaeology, "be as significant as the introduction of aerial photography was in the 1920s."[41]

The turning point for archaeological lidar happened back in Central America. John Weishampel, the NASA Goddard postdoc whose dot-connecting had led to Michael Lefsky's pioneering work on lidar in understanding forests, had moved on to the University of Central Florida by 1998, when he worked with a NASA Goddard mission to fly the LVIS instrument over the La Selva Biological Research Station in Costa Rica. This was in preparation for the Vegetation Canopy Lidar NASA mission. The idea was to see how the space lidar might deal with a range of land cover, from grasslands to dense tropical forest.[42] The instrument performed well, bringing back ground returns such as unknown streambeds through the thick forest cover. Weishampel continued working on lidar missions related to forest canopy structure. He also got to know University of Central Florida archaeologists Arlen and Diane Chase.

The Chases had been doing field research at the Maya Caracol site in Belize for twenty years. From January through March, they and a team of about thirty people had been bushwhacking and digging through the rain forest, slowly uncovering more and more of what seemed to them to be a large Maya city. Other archaeologists were skeptical. The terrain was too hilly for much agriculture. Where would they have grown enough food? The Chases' response: they must have terraced it. Indeed, they found thousands of remnants of agricultural terraces in addition to causeways and ruins of residential areas. And while Landsat images hinted that the settlement may have extended six miles or farther out of the center of Caracol, they couldn't find the edge of the settlement when they looked with boots on the ground.[43] At one point, Arlen Chase showed the Landsat images to Weishampel.

"Not to make it sound too bad, but it was pitiful," Weishampel recalls. "Arlen said, 'From these images, we can see these roadways.' And I was like, 'Bullshit. You can't see anything.'"[44]

Weishampel looked into the literature on lidar in archaeology. There wasn't much: the University of Texas group's work in Honduras (they had tucked away their Copan sidelight toward the end of a paper devoted to the primary mission of hurricane damage assessment), the British scans at Stonehenge and elsewhere, some German flights over ruins from the Middle Ages. Lidar could spot archaeological ruins though the canopy in these places. It should work at Caracol too. Starting in 2005, Weishampel and the Chases applied for grants to pay for such flights.

It was slow going.

"We went through like five iterations because everyone told us we were crazy," Arlen Chase says.[45]

The Chases were not the sort who give up easily. These were people who for years had camped in the jungle for months at a time, shooing snakes and bugs and whacking through underbrush to create sight lines for surveying equipment they lugged up and down so many hills. They had seen enough to argue that Mesoamerican cities were as grand as those anywhere else in their era and that Caracol might, at its peak in about 650 CE, have housed 115,000 people, maybe more. They had recently spent three years trying to uncover the extent of agricultural terracing necessary to sustain so many mouths.

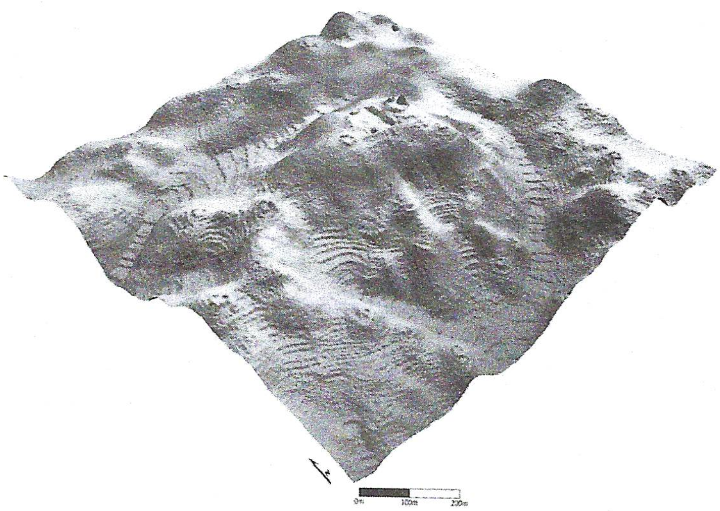
"My god, it was all we could to do get two square kilometers of terraces mapped," Chase says. It wasn't enough to quiet the skeptics.[46]

Finally, in late 2007, NASA came through with enough grant money to enlist the National Science Foundation's National Center for Airborne Laser Mapping, or NCALM. NCALM couldn't fly the mission during the 2008 dry season, though, because it was upgrading its Optech lidar to the latest version, one capable of scanning at a hundred thousand pulses per second. A Cessna carrying the new hardware took to the skies over Belize in late April 2009, covering two hundred square kilometers (seventy-seven square miles) surrounding the center of Caracol—ten times as much as the Chases had hand-mapped over the years. The Optech ran for about nine hours across several flights, taking more than four billion measurements.[47]

Weishampel was in Nebraska correcting Advanced Placement Environmental Science exams when NCALM sent him the Caracol lidar data. He opened the files on his laptop computer. It didn't take an archaeologist to see that the lidar had done its job. "You zoom in and it's unbelievable," he says. "It's an epiphany." On his laptop screen he was seeing Caracol as no one had in more than a thousand years. Back in a University of Central Florida conference room, Weishampel projected an image derived from the lidar data onto a pull-down screen. It was quiet for a moment. Arlen Chase then spoke.

"Holy shit," he said.

Weishampel helped Chase navigate the geographic information system (GIS) software to peruse "this world that he had spent decades in but couldn't see." Chase saw features he had discovered years ago and ones a few feet from them that he had missed. There were causeways and the remnants of dwellings. And there were thousands and thousands of terraces—90 percent of the landscape had been modified by people who used no wheeled transportation and kept no beasts of burden. There were clusters of *plazuela* dwellings, reservoirs, causeways, caves, and much more that were new to the couple who knew the place like no one else.[48]



**A lidar scan of Caracol's Puchituk Terminus taken in 2009. The extent of the site and its agricultural terracing helped change archaeologists' views on the size and sophistication of Maya civilization. (Image courtesy of Arlen and Diane Chase, Caracol Archaeological Project.[49])**

"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," the

Chases and Weishampel wrote. The implications extended beyond Caracol. The Caracol lidar data changed fundamental assumptions about Mesoamerican civilization by proving that the city was big, sustainable, and interconnected. "For too long, Maya archaeologists have been blinded by the jungle, able only to sample once-wondrous cities and speculate about vanished people," they continued. "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."[50]

Others caught on quickly. Weishampel presented results at a remote sensing meeting in India in late 2009; University of Sydney archaeologist Damian Evans was among the thirty or so people there. At the same time, the Chases were showing the images to archaeological audiences, including Evans's advisor, Roland Fletcher, who led the Greater Angkor Project in Cambodia. Fletcher and Evans soon had a grant to fly a helicopter-mounted lidar system over Angkor, which they did in early 2012. Others have followed in Southeast Asia, Mexico and Central America, Europe, India, the Middle East, the United States, and elsewhere. Also in 2012, documentary filmmaker Steve Elkins, inspired by the Caracol lidar work, enlisted NCALM in a search for the legendary lost "White City" in Honduras's Mosquitia rain forest. They found an expanse of ruins.[51]

In 2013, the Chases and other archaeologists landed an Alphawood Foundation grant to have NCALM scan another 1,000 square kilometers (386 square miles) of western Belize near Caracol. In 2016, the Guatemalan Pacunam Foundation kicked off a three-year lidar campaign in which NCALM would fly 14,000 square kilometers (5,405 square miles) of the same Maya lowlands to which Caracol belongs. The first year they scanned 2,100 square kilometers (810 square miles), uncovering sixty thousand ruins, including pyramids, causeways, quarries, dwellings, tombs, and defensive fortifications, further suggesting that Maya civilization in Central America was "more comparable to sophisticated cultures such as ancient Greece or China than to the scattered and sparsely populated city states that ground-based research had long suggested."[52] It was among hundreds of lidar archaeology missions that have flown since that first flight over Caracol in 2009.

There's still good old-fashioned fieldwork to do on the ground in Caracol and elsewhere to investigate the secrets lidar scans have revealed. Lidar's proliferation has brought questions as to whether detailed lidar-derived archaeological maps should be publicly available—and thus available to looters. Regardless, there's no doubt that lidar is safe in its position as an indispensable tool in understanding forests; their implications on biodiversity, climate change, and power infrastructure; and the treasures long hidden beneath them.