

Science

FINDINGS

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"Science affects the way we think together."

Lewis Thomas

Demystifying LiDAR Technologies for Temperate Rain Forests in the Pacific Northwest

"There is a whole new world hiding beneath the face of the familiar."

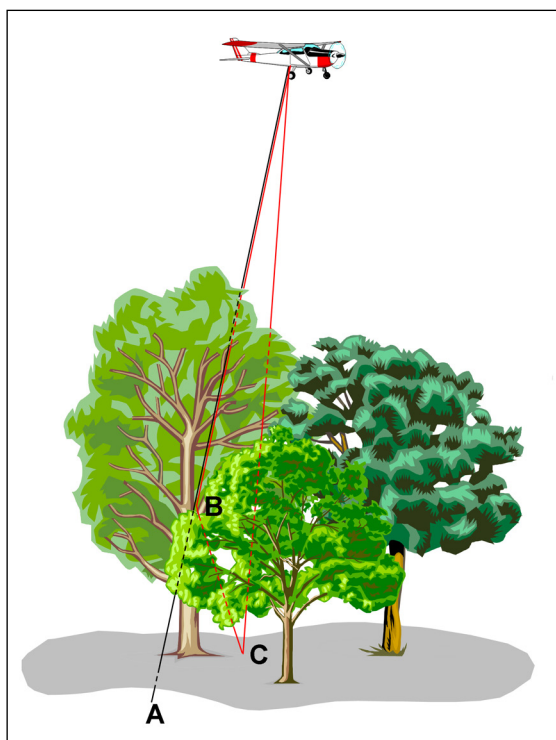
—Jonathan Lockwood Huie

A small plane cruises above the steep slopes of Oregon's Coast Range. It's early morning and the air is still. Flying low at about 3,000 feet, the plane adopts a methodical flight pattern, moving back and forth across 20,000 acres of mountainous topography where snatches of fog lie trapped in the deeply creviced range.

The aircraft is equipped with remote sensing technology. A laser instrument on board typically emits more than 100,000 pulses of light per second toward the ground. When each pulse encounters something solid below—a treetop, vegetation, the ground—some of its energy bounces back toward the plane. A very sensitive sensor records the number of nanoseconds it takes for the pulse to return and the strength of the return. During an 11-hour flight over the Siuslaw National Forest and adjacent private forestland, a billion precisely referenced points in space are generated. For an acquisition of 2 million acres, the size of several recent LiDAR campaigns in Oregon, dozens of billions of data points are recorded.

Once processed, these incredibly precise light detecting and ranging (LiDAR) data can provide a detailed, three-dimensional description of the forest below. These data are used to map, monitor, and assess the condition of forest resources.

"LiDAR enables a three-dimensional description of trees because it penetrates their



Airborne laser scanning, or LiDAR, data can be processed to yield detailed information about forest structure, wood volume, fire risk, levels of carbon sequestration, and more.

crowns," says Demetrios Gatzolis, a research forester with the Pacific Northwest Research Station. "For foresters, that is a big advantage. Other tools such as aerial photography and satellite imagery only capture the tops of trees."

The value of data, of course, lies in the analysis. Left unprocessed, billions of data points are simply space hogs taking up an exceptional amount of disk space on one's computer. Much of Gatzolis's recent work has involved testing and writing computer code that is used to translate gigabytes of data from airborne laser scanners into meaningful information.

IN SUMMARY

Light detection and ranging (LiDAR), also known as airborne laser scanning, is a rapidly emerging technology for remote sensing. Used to help map, monitor, and assess natural resources, LiDAR data were first embraced by forestry professionals in Scandinavia as a tool for conducting forest inventories in the mid to late 1990s. Thus early LiDAR theory and applications were developed for commercial forests typical of a region with gentle topography; conditions far different from those of the temperate rain forests of the Pacific Northwest.

To develop LiDAR data acquisition specifications and analysis methods specific to the Pacific Northwest, scientists with the Pacific Northwest Research Station improved calculations for local conditions. Their aim was to ensure that laser-based estimates of key forest inventory parameters such as vegetation height, and attributes such as volume and biomass were free from serious biases. Based on this research, recommendations for determining optimal LiDAR acquisition specifications have since been adopted as general specifications by the Oregon Department of Geology and Mineral Industries, which leads a consortium of laser data users in the state. These developments have been instrumental in making LiDAR a useful tool in forest management and planning within the region.

EMERGING TECHNOLOGY

“LiDAR is very young technology,” Gatzliolis explains. Airborne laser scanning systems were introduced in the late 1970s and first used by the U.S. military. It wasn’t until global positioning systems (GPS) became commercially available in the 1990s that LiDAR became a feasible tool for use in other fields. Astrophysicists and meteorologists, for example, use it to study the gaseous composition and wind speeds in the atmosphere. It enabled a detail topographic map of Mars, as well as advanced mapping on Earth that revealed a previously unknown fault line. It is used to track the subtle movement of glaciers, and much more.

Forestry professionals in Scandinavia were the first to embrace LiDAR as a tool for conducting forest inventories. Thus, many of the initial “best practices” for acquiring LiDAR data and their application to forestry were developed for use in Sweden, Norway, or Finland. Most of the commercial forests in those countries have relatively simple structure and grow in areas with gentle topography. Those conditions are far different from the dense, multilayered canopies on rugged terrain that characterize the coastal temperate rain forests of the Pacific Northwest.

In the mid 2000s, when Gatzliolis and his colleagues compared LiDAR products generated by standard specifications and methods with field observations, they often noticed discrepancies. They hypothesized that elevation was being overestimated and thus tree height was underestimated. If tree heights were off, this would lead to further errors when tree heights



The rugged topography and dense tree canopies in the Oregon Coast Range required adjustments to typical LiDAR acquisition settings; prior to these adjustments tree heights were often being underestimated.

were fed into equations estimating wood volume and biomass—key forest inventory attributes used in forest management and planning.

Following their hunch, the scientists designed a study to verify that the discrepancies were indeed real.



KEY FINDINGS



- LiDAR-derived terrain models describing bare earth surfaces under dense temperate rain forest vegetation on steep slopes often substantially overestimate elevation and thus underestimate tree and vegetation height. The bias can be reduced by adjusting equipment to acquire data at narrower scan angles, lower scan frequencies, and by specialized processing of the laser return signal.
- A novel approach for correcting intensity—a LiDAR parameter used to discern species groups—now dramatically improves the accuracy of species-group classification over mountainous terrain.
- The assessment of site index, which describes forest productivity, is notoriously challenging and costly to obtain. For the first time, site index maps were produced by combining data management records from private and public lands with LiDAR data.

Purpose of PNW Science Findings

To provide scientific information to people who make and influence decisions about managing land.

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GROUND TRUTHING

For this study, Gatziolis selected a 20,000-acre area on the Siuslaw National Forest and some adjacent private land. Collecting the LiDAR data was the easy part; the harder part was obtaining the field measurements. Gatziolis recalls with a grimace the experience of hiking through neck-high brush to get to study plots. He used survey-grade instruments to establish the plot center. These tools are capable of accurately locating a point on the earth's surface within half an inch—but only with clear access to a satellite signal. More often than not, satellite reception was blocked by the tree canopy. To accommodate this, Gatziolis and his crew would triangulate from the nearest open areas and identify plot center. They then recorded the elevation throughout the plot and measured tree heights and diameters. Back in the office, Gatziolis used the LiDAR data to create a three-dimensional model of the plots and checked his results against the field measurements.

Indeed, after processing the LiDAR data from the Siuslaw acquisition and comparing them to the field measurements, Gatziolis's hunch was verified: the leading software for processing LiDAR was being fooled. The density of the evergreen tree canopies in western Oregon and Washington, combined with the terrain, were leading to inaccurate findings. Gatziolis explains: "The energy of the pulse was not strong enough to consistently get through the canopy. The model didn't have enough information because there were not enough ground returns."

Shortly after Gatziolis published these findings, he began hearing from other LiDAR users around the world. "I heard from people working in the Amazon and in Southeast Asia. They'd say 'you reported some problems in western Oregon, but I think we have worse problems here.'" Tropical rain forests with 6 or 7 canopy layers and such variety in vegetation were posing their own problems for interpreting LiDAR data.

Gatziolis and his colleagues began pinpointing ways to better adjust LiDAR equipment during flyovers. To do this, they worked closely with Watershed Sciences, Inc., a LiDAR data vendor based in Oregon. They discovered that better information could be obtained by adjusting equipment to acquire data at narrower scan angles, using lower scan frequencies, and slightly changing the technique for processing the laser return signal. These adjustments have since been adopted as general specifications by the Oregon Department of



Demetrios Gatziolis

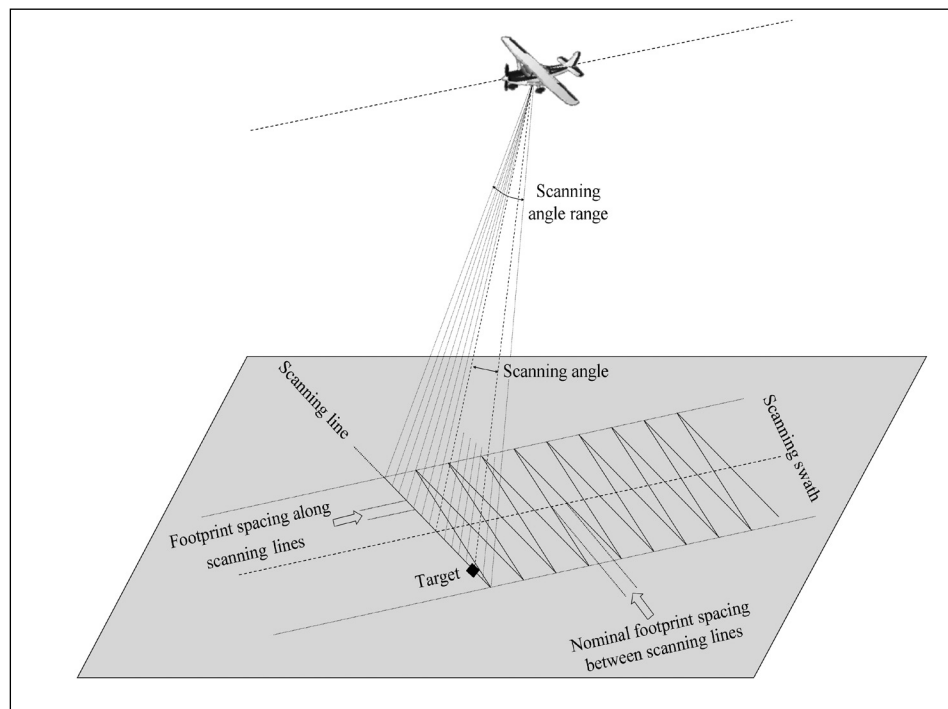
Ground truthing is essential for verifying modeling techniques. Above, field crew measure trees growing on a slope near Harlan, Oregon.

Geology and Mineral Industries, which leads a consortium of laser data users in the state.

The researchers also began reworking the mathematical algorithms and writing new computer code so that modeling based on LiDAR data will produce results that better match conditions on the ground. As part of this, Gatziolis developed an

automated processing technique that delivers consistent LiDAR intensity data which helps users more accurately classify groups of tree species.

"It's easy to be lulled into thinking the perceptions from computer visualizations of LiDAR data are accurate," Gatziolis explains. "You have this nice picture on the



Researchers found that narrowing the scan angle is one adjustment that improves the accuracy of estimated tree or vegetation height over mountainous terrains.

screen; it appears plausible and is aesthetically pleasing. Unfortunately they can contain serious systematic errors that remain undetected unless there is a provision for independent evaluation.”

Field measurements are costly and time-consuming to obtain. Gatzliolis points out, however, that for large laser acquisitions, researchers may be able to use the field measurements collected as part of the national Forest Inventory and Analysis (FIA) program to assess the accuracy and precision of their LiDAR output. Since the 1930s, FIA crews have been inventorying forest conditions on public and private land across the country.

ESTIMATING PRODUCTIVITY

As a side study, Gatzliolis used the LiDAR data from the Siuslaw acquisition to assess site index, a measure of the land’s ability to grow trees. “When I was pleading with tree farm owners to let me put study plots on their land, they educated me about rules the government puts on their management practices. One of their top complaints was that they couldn’t use the most productive land to grow trees as it was next to a creek and within the riparian buffer.”

In Oregon, landowners are required to maintain riparian buffers along most streams to protect water quality. Limited management is permitted within these buffers. “Although it wasn’t the original intent of my work,” Gatzliolis says, “I thought maybe I could help determine where the most productive land actually was.”

To determine site index, one needs to know the tree’s age, species, and height. This information is then fed into equations and measured against growth curves to see how the tree’s growth compares with its species’ potential growth in optimal conditions. Normally this is a fairly laborious and costly endeavor. In this case, however, Gatzliolis already had the LiDAR data containing information on tree height for the area. Conveniently, he found planting dates in management archives from the Siuslaw National Forest and in operation plans shared by tree farm owners, thus eliminating the need to take core samples from individual trees and count growth rings to determine their age.

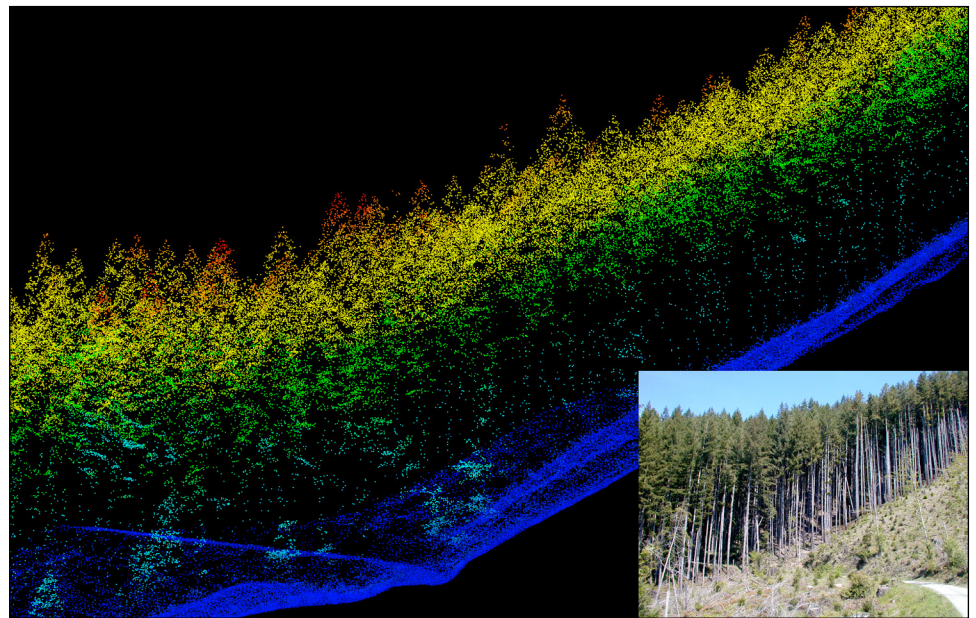
Gatzliolis found that within the study area, the highest site index was not along the creek. It was 100 feet upslope, outside the buffer zone within which management operations are regulated. “When I talked with a biologist, he said, of course it’s too wet down by the creek. But knowing and proving it is a different story.” Gatzliolis points out that this study

The cost of acquiring LiDAR data has dropped steadily in the last decade. “With the same budget, it is possible to do much more than before,” Gatzliolis explains, “This appeals to land managers.”

Seven years ago, the amount of data collected in a single acquisition was a problem—the sheer volume of data was more than a standard hard drive could handle. Now, the data collected from the Siuslaw study can fit on a thumb drive. Efficient processing of the data is still another matter. That requires far more computer processing power than available from the average laptop computer.

Much of the forested area in Oregon has been scanned at least once with high-density LiDAR. It’s common for researchers from various federal and state agencies to pool resources and share LiDAR acquisitions—a hydrologist and forester can both gain useful but different information from the same cloud of data.

“As a forester, my data are the trees. A hydrologist needs a detailed description of the ground. Instead of each of us paying for two independent acquisitions, we can do one together and then focus on the data that we each need. We sometimes say, ‘your noise is my data,’” Gatzliolis explains. This type of collaboration can help make LiDAR-based investigations financially feasible.



This synthetic image shows the distribution of laser returns colored by height. Objects near or on the ground are depicted with dark blue tones, while those near the top of trees have warmer colors.

examined a small area where water is not the limiting factor to growth. In a drier environment where water is the limiting factor, the findings would be different.

“In my current research,” Gatzliolis says, “I’m trying to teach the computer how to convert the LiDAR cloud data to three-dimensional models of the trees that are there and then assess the lighting regimes within the tree stand. Initial results indicate that wherever high-density LiDAR data is available, it is now possible to compute if and for how long during a specific day of the year an area of interest receives direct sunlight.”

This type of information can be used in assessments of habitat suitability, tree regeneration potential, and location-specific stream shading and temperature regimes.

Nickolay Strigul, a professor at Washington State University, is incorporating this modeling into his work examining the self-organizing patterns of forested ecosystems. “This technique allows us to judge shade for individual trees and helps us understand how they compete for space,” Strigul explains. “This is otherwise very hard to determine from an aerial view, and from the ground it would take an enormous amount of time. Using LiDAR in this way creates an unbelievably powerful tool and opens up another dimension into what we can do.”

“It helps us understand nutrient flows and ultimately better understand carbon cycles,” Strigul continues. Trees that create more shade have bigger, fuller canopies. This makes shade a good proxy for helping evaluate productivity of individual trees. The trees that are

getting more nutrients and water ultimately sequester more carbon because they have the resources to grow bigger compared to a tree in a less-productive site. With calculated information about the performance of individual trees, researchers can better estimate the carbon dynamics of a forest.

It's applications like this that get people excited about LiDAR. Assuming acquisition specifications and analysis methods are adjusted to local conditions, the unprecedented ability to identify the distribution of forest resources means that LiDAR output can contribute much to forest management and planning.

*"Coming together is a beginning,
keeping together is progress, working
together is success."*

—Henry Ford

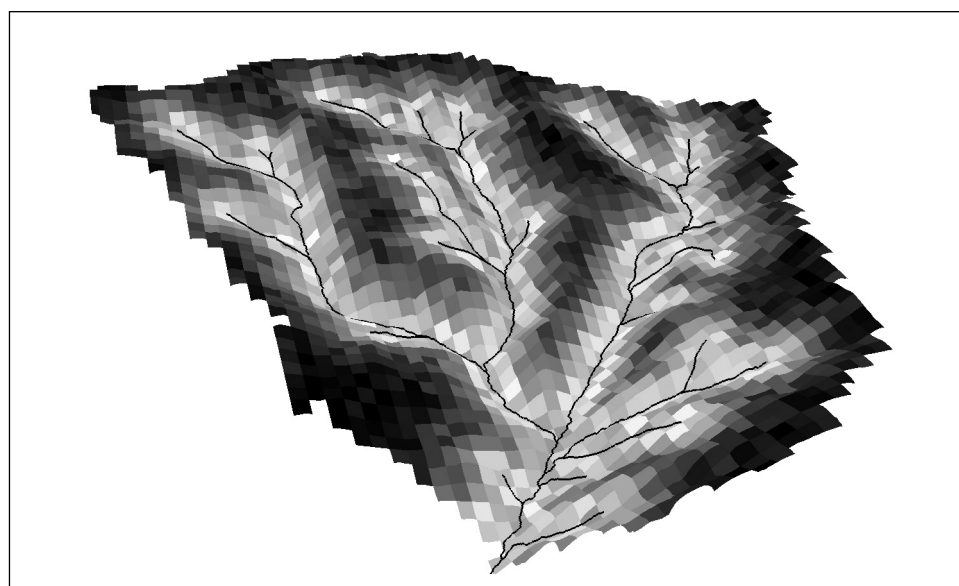
FOR FURTHER READING

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In a novel application, a station scientist used LiDAR data to evaluate site index in the Oregon Coast Range. The lighter tones in the figure above denote areas of higher forest productivity. The dark lines are the stream network.

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LAND MANAGEMENT IMPLICATIONS



- LiDAR processing software that is dynamically adaptive to local topographic conditions and continuous analyst evaluation is essential for processing LiDAR data collected over mountainous terrain. If processed without these, the generated information would likely lead to suboptimal or wrong decisions when applied to the Oregon and Washington Coast Range or other similar regions.
- Advances in processing LiDAR data are improving their utility for a variety of applications such as assessing wood volume, carbon sequestration levels, biomass, canopy cover, stand structure, land productivity, wildfire risk, and more.
- Ground truthing is essential to any modeling exercise. For larger LiDAR acquisitions, hand-collected data from Forest Inventory and Analysis plots across all biomes within the United States can be used to assess the accuracy and precision of LiDAR outputs.
- When combined with local expertise, LiDAR outputs are ideal for tactical decisionmaking. This research helps to identify areas where LiDAR output may not be accurate, and thus enables users to plan accordingly.

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