GETTING TO THE POINT: THE APPLICATION OF LIDAR TECHNOLOGY IN FORESTRY

LiDAR is increasingly being used in forestry, but what is LiDAR, and why is it so useful in this field? This research update answers these questions and gives an overview of CFRU-funded research that uses LiDAR to enhance forest management in Maine.

Flying over Maine to obtain LiDAR data. Image: D. Hayes

What is LiDAR?

If you are part of the forestry community in Maine, chances are you have been hearing more and more about remote sensing and LiDAR. LiDAR, or light detecting and ranging, is a remote sensing technology for producing spatial information that can help you get a better sense of the three-dimensional structure of your forest.

LiDAR technology uses lasers to illuminate objects (such as trees) on the ground. In forestry, LiDAR is often collected using low-flying, fixed-wing aircraft equipped with laser scanners. The time that it takes a laser pulse to be reflected off of an object back to the sensor on the aircraft is proportional to the distance from the aircraft to that object. Therefore, each time the laser hits an object in a landscape, a point is generated in space, recorded by its longitude (X), latitude (Y), and height (Z) values. Each laser pulse emitted can be reflected back multiple times as it travels down through a forest canopy. In this way, LiDAR technology produces a collection of three-dimensional points, or a "point cloud", that resembles the shape of the landscape below. The first point in space at which a laser is reflected back to the sensor (e.g., the top of a tree) is called a "first return." A sequence of "returns" is produced (e.g., "second return") in this process, with the "last return" corresponding to the point in space at which the laser pulse hit ground.

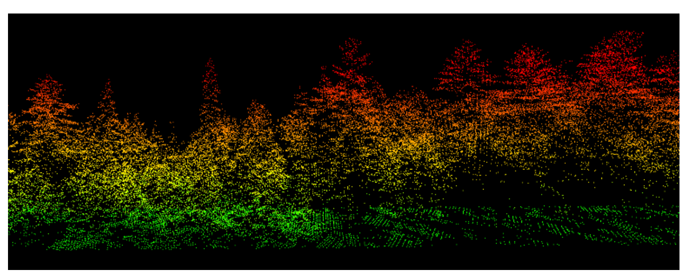
LiDAR data can be collected at different densities (density refers to the number of laser pulses emitted per square meter). The density at which LiDAR data are collected relates both to the sensor used as well as the height at which the laser pulses were emitted. Low-density LiDAR emits fewer laser pulses per square meter, which means that these point clouds are less detailed. For many purposes in forestry, 1 to 3 pulses per square meter is sufficient, but for individual-tree analyses, a higher density is necessary.

How Can We Access LiDAR Data in Maine?

By the end of 2019, the entire state of Maine will have representative LiDAR data, publicly available for free. This is the result of a multi-year, multimillion-dollar collaboration of many stakeholders in Maine (including CFRU), managed by the Maine GeoLibrary Board and the Maine Office of GIS. This type of LiDAR data has USGS quality level 2 nominal pulse spacing and vertical accuracy (i.e., QL2 specifications), which means that it has a density of 2 to 8 pulses per square meter. These data are available in two forms: you can obtain the filtered and classified point cloud (in which all outliers, or "noise", has been removed; see image below), or you can use data that has been processed into 2-meter raster digital elevation models, or DEMs (see next page for more information).

You can learn more about the status of the Maine LiDAR Acquisition project by visiting the Maine GeoLibrary website here:
https://www.maine.gov/geolib/programs/lidar/index.html

To download these data, you can go to the U.S. Geological Survey (USGS)'s National Geospatial Program website: https://www.usgs.gov/core-science-systems/national-geospatial-program/national-map.



LiDAR point cloud generated with 5 pulses per square meter (5 ppm). The green dots in this image represent the last returns, which correspond with the ground level. Red points represent the first returns, or the tops of the trees. Image: E. Ayrey.

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How is LiDAR Used in Forestry?

LiDAR data can be directly and indirectly used for a variety of forestry applications. Two products in particular that are more directly derived from LiDAR data are digital elevation models (DEMs) and canopy height models.

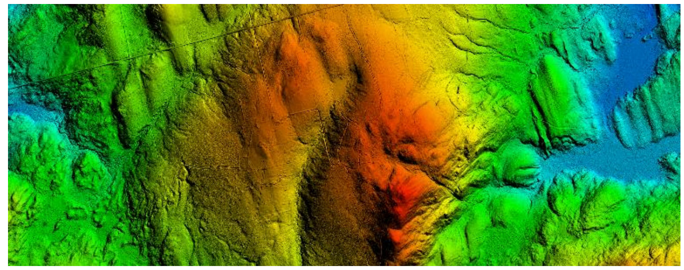
DEMs, also referred to as digital terrain models (DTM), show the topography of a landscape over which LiDAR data have been acquired. The "last returns" represent the bare earth terrain and are used to map elevation across the landscape. DEMs have a wide range of uses in forestry, such as determining slope and evaluating hydrology of the terrain. DEMs from LiDAR are used in depth-to-water-table modeling, which is the aim of a CFRU-funded project led by Dr. Paul Arp (University of New Brunswick). Using LiDAR DEMs and algorithms that his team has developed, Dr. Arp is able to produce high-resolution maps showing potential wet areas. They hope to produce these maps across the state of Maine.

DEMs are also useful in site selection for research or harvesting, and represent one of the criteria used to help select sites for the CFRU's new Maine's Adaptive Silviculture Network (MASN). They can also be used in analyses: Dr. Anil Kizha. (University of Maine) uses DEMs to determine effects of terrain type on best management practice costs.

Canopy height models can also be directly derived from LiDAR. By subtracting the elevation of the last return from the maximum elevation of first returns, you can produce an estimate of canopy height for each grid cell in a raster map. This information is used for individual tree detection, stratifying stands in forest inventory, and calculating metrics describing forest structure.

LiDAR metrics can also be used indirectly to predict other attributes. As part of a CFFU-funded project led by Drs. Mindy Crandall and Amber Roth (University of Maine), collaborator Anthony Guay used LiDAR data when modeling deer wintering area. In their CFRU-funded study of Bicknell's thrush habitat, Dr. Roth and her MS student Kaitlyn Wilson are using LiDAR models produced by Elias Ayrey (PhD candidate) to quantify used and available habitat for this vulnerable species.

In combination with data from forest inventory plots, LiDAR can also be used to develop enhanced forest inventories (EFIs), which predict and map a host of different forest characteristics and inventory variables remotely across landscapes.



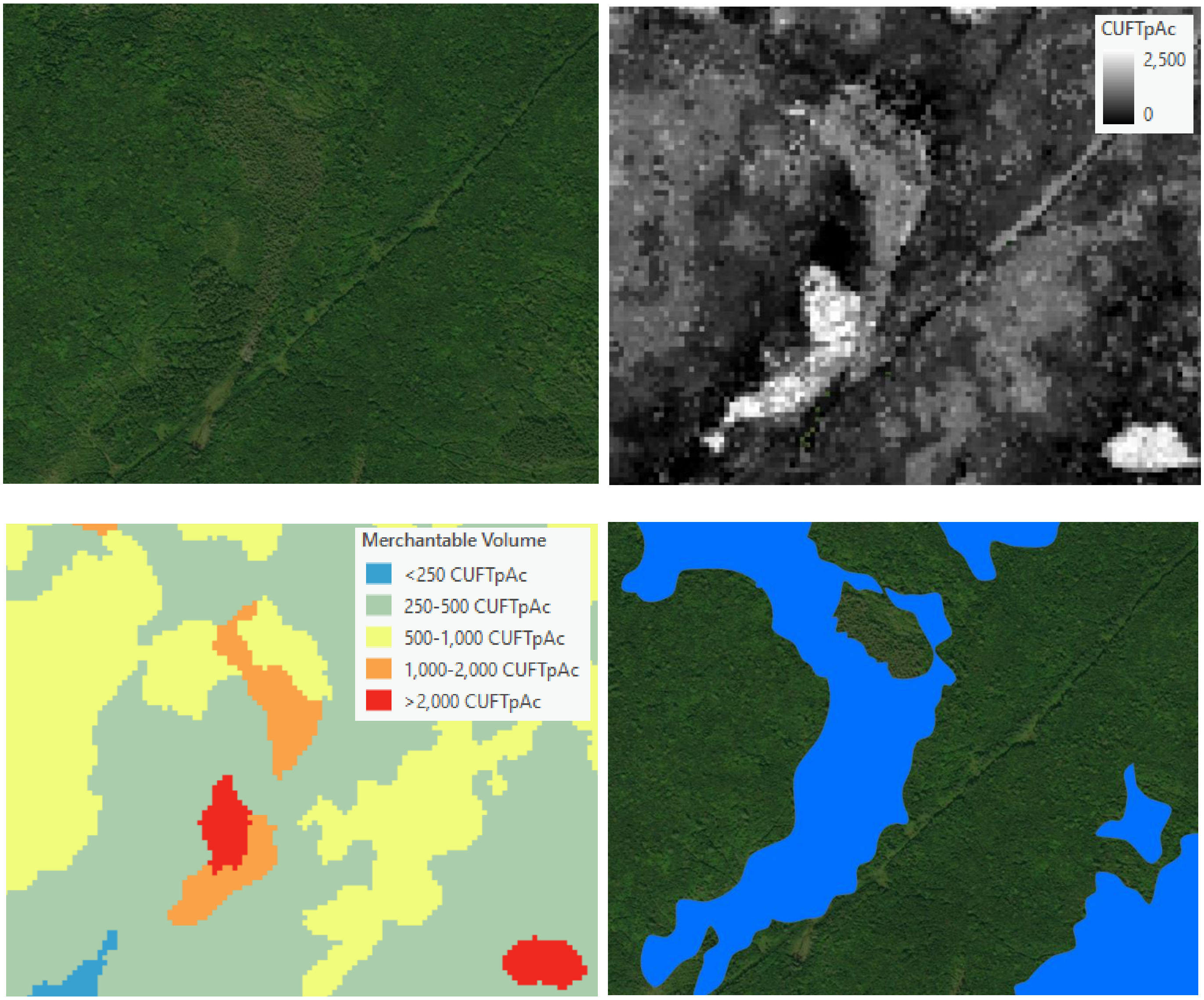
Bare earth DEM (2-meter grid cells) derived from state-wide QL2 LiDAR data obtained in 2017. Image: The Wheatland Lab.

How Can We Enhance Forest Inventories using LiDAR?

When it comes to forest inventory characteristics - such as stem density, merchantable volume and percent softwood- LiDAR is useful in that predictive models built with these data can be applied over all areas and across large landscapes, something that would be impossible using field-based methods alone. The predictions made from these LiDAR models are called "enhanced forest inventories", or EFIs. To create these EFIs, forest inventory plots (termed "calibration plots") are matched up with LiDAR data acquired at the same locations. Then, using a variety of techniques, relationships between the ground-based measurements and LiDAR metrics form the basis of a model used to extend these measurements across a landscape to areas without plot information.

How best to use LiDAR data with inventory plot information to create EFIs is the focus of a CFRU-funded initiative led by Dr. Daniel Hayes (Wheatland Lab, University of Maine). Partnering with Seven Islands Land Company, Dr. Hayes's team is evaluating the use of the publicly available LiDAR data in Maine to create EFIs over large-area forest properties. They are investigating some of the key questions EFI applications, including whether variable radius plots can be used for LiDAR calibration (fixed-area plots are more commonly used), along with the ideal number of calibration plots and how they are distributed across the variation in forest conditions. Collaborating with the Advanced Computing Group at the University of Maine, the team is developing a workflow to accurately and efficiently produce these EFIs over large areas. In addition, they are exploring ways in which to make these EFIs and other LiDAR-derived map products more accessible to forest managers, and will hold workshops designed to increase the usability of this information by practitioners.

Enhanced Forest Inventory: An Example



Using the publicly-available LiDAR data, researchers at the Wheatland Lab can create maps of forest characteristics they have modeled using LiDAR metrics (such as merchantable volume, e.g., top right map displaying cubic feet per acre, or CUFTpAc) across the landscape (e.g., the forest shown in the top left image). To make these maps more user-friendly and accessible, the team is exploring ways to re-classify and visualize these modeled predictions. The map on the lower left shows merchantable volume divided into five size classes, which helps allow for rapid assessments of merchantable volume across the landscape. By combining predictions of several different forest characteristics, such as percent softwood, merchantable volume, and crown closure, EFI can enable selection of different areas of the landscape based on combinations of specific values of these characteristics, thereby potentially identifying new forest stands. In the map on the lower right, the areas in blue represent softwood forest with > 80% crown closure and >250 cubic feet per acre of merchantable volume. Images: The Wheatland Lab.

What Should You Consider When Taking Inventory, to Make the Best Use of LiDAR?

While LiDAR is promising and has many applications, it is not without limits. There are several considerations that you can make to be proactive in your forest inventories, ensuring that the information you gather about your forest has the greatest potential to be used with LiDAR data to make accurate predictions and evidence-based decisions. These include:

- Conditions: Ideally, the forest inventory plots you take to calibrate your model should represent the *full range of conditions you see in your forest*.
- Locations: It is important to get high-accuracy GPS locations of your forest inventory plots, especially if you want to generate high-resolution predictions. Simply put, having *high-accuracy GPS locations will make it easier to match up your data on the ground with LiDAR point cloud data* collected at the same locations you measured on the ground.
- Time: One limitation of LiDAR is that it represents one moment in time. It is important to *know the date that the LiDAR data you are using were obtained*, so you know which plots can be used with that data (i.e., so you do not include a harvested plot in a model that uses LiDAR data obtained before the plot was harvested).

CFRU summer field crew member Jacob Burgess looks through a prism when conducting a variable radius plot inventory for the CFRU's Maine's Adaptive Silviculture Network. Researchers at the Wheatland Lab are evaluating the use of variable radius plots as calibration plots for LiDAR-based enhanced forest inventories. Image: J. Zukswert.

What's Next for LiDAR in Forestry?

- Free and publicly available LiDAR data across Maine creates many opportunities for you to learn more about your land and make evidence-based decisions.
- Research on the use of LiDAR data to enhance forest inventories is already quite advanced, taking advantage of sophisticated modeling and high-performance computing.
- The next research frontier is the use of machine learning and artificial intelligence methods to develop LiDAR models of forest characteristics. In theory, these techniques could make EFI processes more possible across larger landscapes. For recent examples, read up on University of Maine PhD candidate Elias Ayrey's research: http://abovemaine.com/research/

For More Information:

Weiskittel, A., Ayrey, E., and Hayes, D. 2015. LiDAR and Forestry: Opportunities, Challenges, and Future Directions. NESAF News Quarterly 76(3): 5-8.

Young, J., Roth, B., and Walters, D. 2016. Maine Statewide Light Detection and Ranging (LiDAR) Data Acquisition. Cooperative Forestry Research Unit: 2015 Annual Report. University of Maine, Orono, ME. 48-50.

Maine GeoLibrary Board:
https://www.maine.gov/geolib/programs/lidar/index.htm

USGS National Geospatial Program:
https://www.usgs.gov/core-science-systems/national-geospatial-program/national-map.

Wheatland Lab, University of Maine (research and training in EFI)
http://wheatlandlab.org/

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The Cooperative Forestry Research Unit is a stakeholder-driven research cooperative housed at the University of Maine, under the Center for Research on Sustainable Forests.