

Understanding LiDAR for Forest Applications

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What is LiDAR?

Over landscape scales ($\geq 10,000$ acres), spatially explicit information on forest conditions is necessary to achieve multiple management objectives. LiDAR (**L**ight **D**etection **A**nd **R**anging) enables land managers to make inferences on forest conditions. LiDAR systems principally operate by emitting pulses of light and recording the precise time it takes for that light to return to the sensor, from which the distance to an object is calculated. Each of these light pulse returns corresponds to a three-dimensional point in a LiDAR point cloud, a collection of many returns representing the landscape (Figures 1 and 2). Dense objects (tree boles, rocks and ground surfaces) typically result in a single return, while less dense objects (tree crowns and foliage), may result in multiple returns. In addition, energy is absorbed by the reflecting object, and the amount of energy returning to the sensor, commonly referred to as an intensity value, can help further discriminate between various objects. These data can be collected from either airborne or fixed terrestrial locations, and mobile terrestrial LiDAR is becoming increasingly common. Terrestrial LiDAR, as the name implies, is typically collected from multiple ground locations, then combined into a single point cloud. Airborne LiDAR is operated from a fixed-wing aircraft, where the LiDAR sensor is coupled with precise location and movement information to accurately place the data in physical space. Airborne LiDAR provides data over larger areas (e.g., $> 1,000$ acres) at point densities from less than 1 point per m^2 , up to 15 points per m^2 , depending on the quality level of the data collection. Terrestrial LiDAR typically provides data over smaller spatial extents (e.g., < 100 acres) and at much higher point densities (e.g., 1,000 points m^2).

What types of data does LiDAR provide?

Specific to forestry and landscape-scale ecological restoration, discrete-return airborne LiDAR proves to be the most widely used, due to large area coverage and penetration of tree canopies by multiple laser returns. Usage typically starts with a pre-processed (removal of spurious returns), classified (ground and vegetation points) LiDAR data point cloud, typically provided by a vendor. From these data, users then can create various products, or data layers, that can be used for assessment, monitoring, and decision-making. For example, direct outputs might include canopy height or ground elevation. Derived products, such as predicted basal area or biomass, could then be used to prioritize restoration treatment areas.

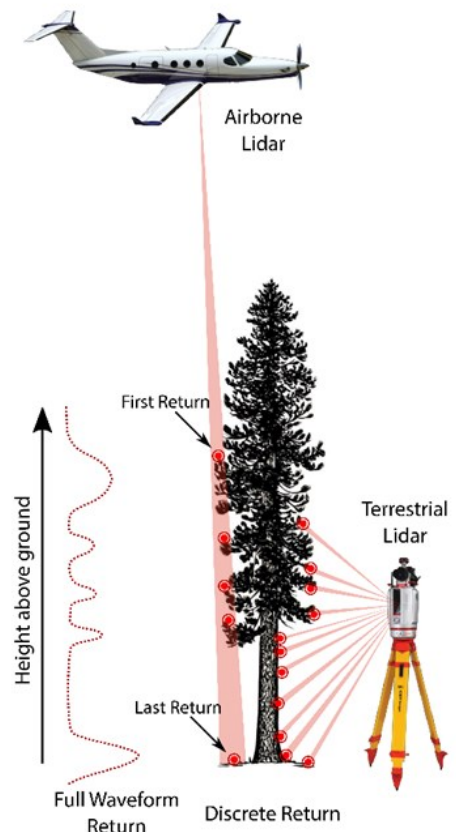


Figure 1: Airborne and terrestrial LiDAR use the same principles, but collect data from different platforms. Discrete return LiDAR uses precisely recorded travel time of light to provide structural (height and location) information. Full waveform LiDAR collects the entire profile of returned energy.

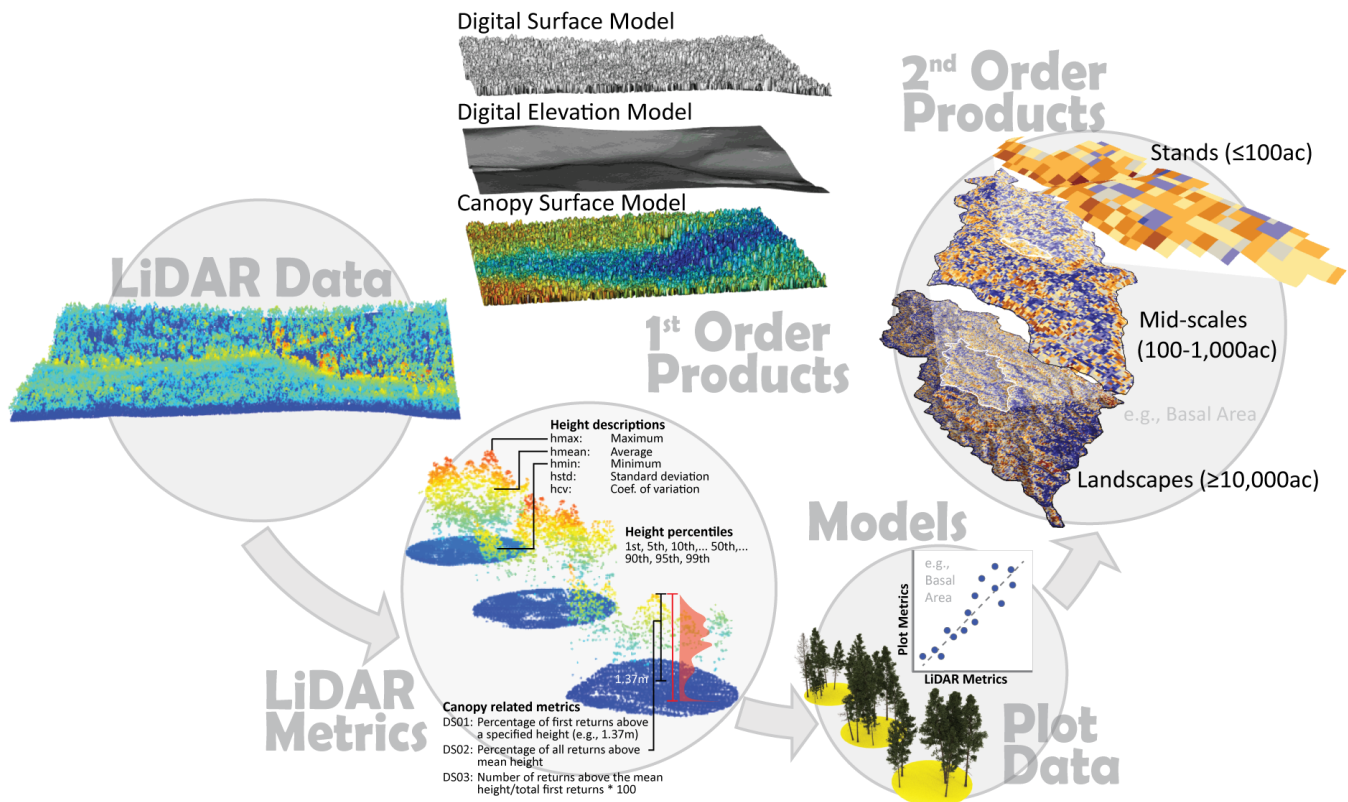


Figure 2: Diagram depicting how LiDAR data are processed to produce first-order products and LiDAR metrics, which are then paired with field plot data to develop predictive models to produce forest characteristics, or second-order products, at stand to landscape scales.

First-order products consist of rasterized (pixel-based, like a digital image) summaries of point cloud properties (Figures 1 and 2). Common first-order products include digital elevation models (DEMs), digital surface models (DSMs), and the difference between the two: a canopy height model (CHM). For estimating attributes associated with forest conditions, it is common to remove the effect of topography (i.e., transform the data from elevation to height above the ground). Users of first-order products include remote sensing and spatial analysts in academia, non-government research organizations, federal research stations, and federal regional data centers. These technical users can then derive a variety of LiDAR metrics (Figure 2). These metrics are paired with field measurements to characterize forest characteristics over large landscapes as second-order products (Figure 2).

Second-order products are derived by relating plot data (e.g., basal area, volume, mean tree size) to first-order products then using these relationships to predict forest attributes across the landscape (Figure 2). While technical skillsets are needed to create second-order products, the end results can be used by federal, state, tribal and other land managers to inform natural resource conditions, prioritize management needs, and monitor management effectiveness. Some potential applications include:

- Forest age structure and diversity
- Biomass, carbon, and volume estimation
- High-resolution habitat and potential biodiversity modeling
- Modeling ecosystem services across scales
- Forest road mapping or hydrologic flow analyses