# Lidar Acquisition Guidelines for Forestry Applications

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# Background

To effectively support many natural resource management decisions, the US Department of Agriculture, Forest Service (USFS) requires information about the vertical and horizontal structure of vegetation and the underlying terrain. Light Detection and Ranging (lidar) data provide unique three-dimensional (3D) information that simultaneously measures the ground surface and forest canopy structure across broad acquisition areas. Based on the capability to provide detailed 3D information, lidar is frequently used in forestry applications (e.g., forest inventories, engineering operations, and habitat modeling) (Reutebuch et al. 2005).

One obstacle to acquiring new lidar data is the cost. To mitigate this, many federal government agencies have formed consortia with state and local governments, as well as academic and research institutions to share acquisition costs. The most notable large-scale effort is the 3D Elevation Program (3DEP), spearheaded by the United States Geological Survey (USGS). The USGS has collaborated with other federal agencies and states to initiate 3DEP in response to growing needs for high-quality topographic data and other data products derived from lidar data.

The primary goal of 3DEP is to systematically collect lidar data for high-quality topographic information in an eight year period over the conterminous United States, Hawaii, and the U.S. territories (USGS 3DEP website: http://nationalmap.gov/3DEP/). The USGS Lidar Base Specification document (https://www.usgs.gov/core-science-systems/ngp/ss/lidar-base-specification-online) details four quality levels (QLs) that define minimum acceptable parameters of the lidar data and are intended to help provide consistency among partner-funded lidar collections, especially for 3DEP (table 1). The USFS coordinates most of our lidar data acquisition through 3DEP because we benefit from cost-share funding from USGS and other agencies, and planning our data acquisitions through 3DEP helps reduce duplication of effort by ensuring that the government collects data once to satisfy as many agency business requirements as possible.

*Table 1: Adapted from 3DEP specifications, this table shows the four quality levels along with the associated Aggregate Nominal Pulse Density and non-vegetated vertical accuracy at the 95-percent confidence level in centimeters. Please refer to the USGS Lidar Base Specification documents (https://www.usgs.gov/core-science-systems/ngp/ss/lidar-base-specification-online) for more information.*

| Quality Level (QL) | Aggregate Nominal Pulse Density (ANPD) (pulses/m$^2$) | Non-vegetated vertical accuracy at 95-percent confidence level (cm) |
|---|---|---|
| ***QL0*** | ≥ 8.0 | ≤ 9.8 |
| ***QL1*** | ≥ 8.0 | ≤ 19.6 |
| ***QL2*** | ≥ 2.0 | ≤ 19.6 |
| ***QL3*** | ≥ 0.5 | ≤ 39.2 |

Partnership funding for 3DEP lidar acquisition projects is available through the USGS Broad Agency Announcement (BAA), which is typically announced every fall. Interested parties can contribute funds toward lidar data acquisition via the USGS Geospatial Products and Services Contracts, or they can request 3DEP funds toward lidar data acquisition where the USFS manages the data acquisition contract. When a state agency is leading the acquisition, the USFS can also contribute funds to a Co-Op contract. It is important that USFS users are aware of the appropriate acquisition specifications for their desired applications so that we can communicate to our partners which acquisitions specifications are non-negotiable and which specifications may be negotiable. To support USFS users with this, we address the following objectives in this document:

- Review recommended lidar specifications for forestry applications;
- Describe products that are typically delivered by the vendor and those that can be created from lidar data.

# Recommended Lidar Specifications

Acquisition specifications are heavily influenced by the intended application (e.g., topographic analysis vs. forest inventories). Therefore, specifications should be developed after careful planning and evaluation of project needs, while considering budgets, partnerships, and intended use of the lidar data. Acquisition planning is challenging and often entails tradeoffs. However, loosening certain specifications may impact the utility of the lidar data and should be carefully considered. This section highlights recommended specifications for forestry applications and considers the potential impact of specific parameters on the final products.

The 3DEP QLs provide consistency among the USGS and partners to acquire and use lidar for 3DEP applications. It should be noted that the 3DEP QL's are specifically designed to support high-quality *topographic* data, not specifically *vegetation* characterization. As such, the minimum acceptable 3DEP QL for vegetation characterization is QL2 (ANPD of 2 pulses/$m^2$). While we generally recommend QL1 data for more advanced applications, such as forest inventory modeling, we have found QL2 data to be suitable for most forestry applications (table 2).

In addition to pulse density, other critical acquisition specifications that we recommend for forestry-focused lidar acquisitions include: a scan angle of ≤30° (field of view (FOV) ≤60°), 50% swath sidelap and opposing flight lines (table 2). Scan angle, which refers to the angle off nadir that a sensor emits pulses, is important for forestry applications because a higher scan angle increases the distance a pulse must travel through the canopy before reaching the ground surface. This can reduce the number of ground returns and artificially inflate density and cover measurements, especially along the edges of swaths. With modern sensors, a scan angle of ≤30° increases the probability that the lidar pulse will penetrate heavy forest cover and adequately sample the forest structure and ground. Keep in mind, however, that a narrower scan angle increases the number of flight lines required and in turn increases cost (McGaughey et al. 2006).

*Table 2: Recommended specifications by quality level and applications.*

| Quality Level (QL) | Swath Overlap | Scan Angle/ Field of View | Raster Deliverables | Recommended for: |
|---|---|---|---|---|
| ***QL1*** | 50% sidelap (100% overlap) | ≤30˚ (≤60˚ FOV) | 1m DEM, 1m DSM Optional: 0.5m DEM, 0.5m DSM | -Forest inventory modeling -Rain forest environments |
| ***QL2*** | 50% sidelap (100% overlap) | ≤30˚ (≤60˚ FOV) | 1m DEM, 1m DSM | -General forestry applications |

Sidelap refers to how much overlap exists between scanning swaths. 50% sidelap provides 100% total overlap, so each area is being scanned twice. Ensuring 50% sidelap in conjunction with opposing flight lines is crucial for forestry acquisitions to eliminate data occlusions (data shadows) from vegetated areas. Figure 1 shows the canopy cover raster from a 2015 QL2 acquisition on the Uwharrie National Forest in North Carolina, and it exemplifies the acquisition artifacts that can result from acquisitions that do not adhere to these overlap and scan angle specifications. In this case, the greater number of first returns in the canopy in areas of swath overlap created a stripe pattern that mirrored the flight lines and adversely impacted the utility of this and other cover and density metrics.

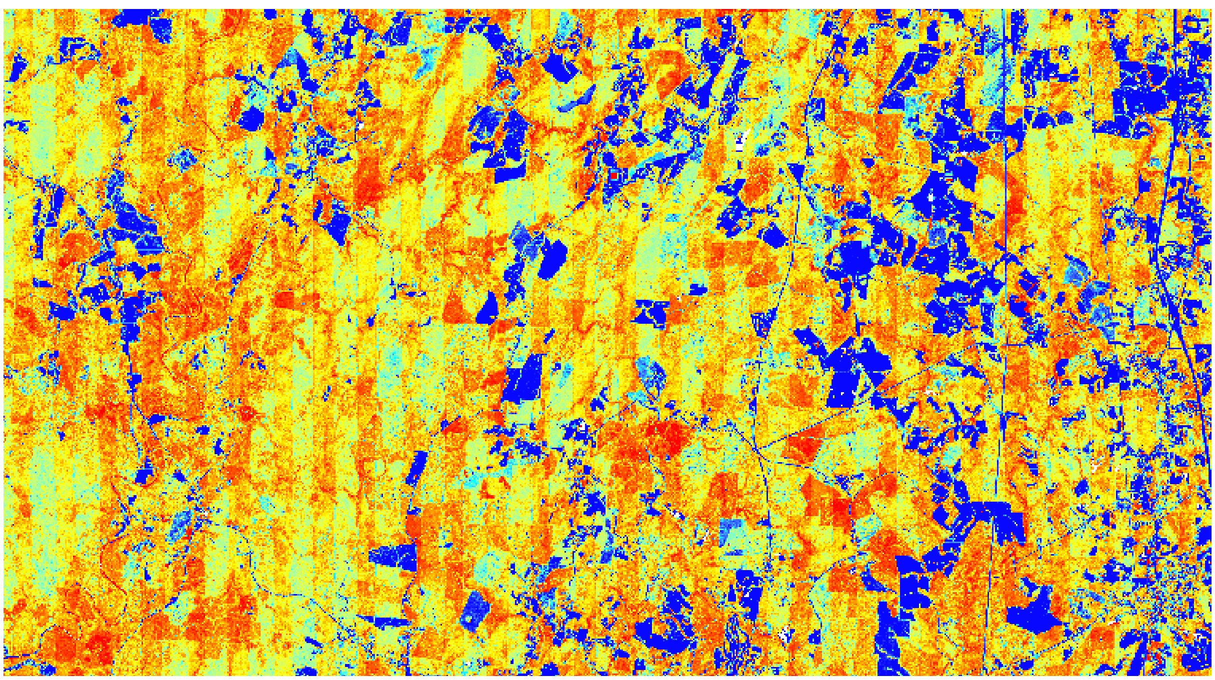

*Figure 1: 10 meter canopy cover raster from North Carolina displaying flight line artifacts*

One final consideration is that 3DEP acquisitions are *often* flown during "leaf-off" conditions because the focus is on efficiently acquiring topographic (e.g., bare earth) products. Therefore, if you are partnering with 3DEP for an acquisition, you may consider negotiating for "leaf-on" conditions during the acquisition if obtaining forest structure is imperative to your project. Many 3DEP partner agencies are amenable to "leaf-on" conditions because it serves their business needs, especially if the acquisition is also planned to be QL1, which helps ensure a good ground surface. If leaf-off data is your only option, you will still be able to obtain canopy height information, but canopy cover and density values will be negatively skewed in deciduous canopies. All the considerations discussed above are outlined in a table in GTAC's example Statement of Work for lidar acquisitions.

# Information for Vendor

If you are seeking to purchase lidar data on your own and not through the USGS contracts, the first step is to work closely with your Contracting Officer to ensure that you are following proper acquisition protocols. You will also need to clearly communicate your data requirements to any potential vendor(s). In addition to typical specifications for the lidar acquisition, it is important to clearly communicate items that should be included in the contract and with the delivery to acquaint the vendor with project-specific requirements. Such items include:

- The location of the acquisition area, including a narrative, maps, and shapefile(s);
- Potential problems the vendor needs to be aware of, such as flight-restricted areas and ground access;
- The lidar survey specifications, including:
  - Data-acquisition parameters;
  - Accuracy specifications, and how you will test for or otherwise ensure data accuracy;
  - Completeness and consistency of the dataset;
- Deliverables:
  - Spatial reference framework (datum, projections, units, etc.);
  - Formats and data organization (consistent file names, accessible file formats);
- Time frame for data acquisition and delivery;
- Contact information for communication between vendor, client, and local points of contact;
- Insurance/liability clauses;
- Contract nullification conditions; and
- Data ownership.

For a more complete look at what to include in a contract, reference GTAC's example Statement of Work for lidar acquisitions.

# Lidar Derived Products

Airborne lidar produces data-rich point clouds made up of millions of points that represent the world in a collection of x, y and z coordinates. To extract useful geospatial information from the point cloud, filtering and classification algorithms are used to generate additional geospatial products, or "lidar derived products," from the original point clouds. The lidar derived products provide landscape-level three-dimensional information (typically in raster format) to land managers that were not available prior to the collection and manipulation of the point cloud. Below, we detail a series of common lidar derived rasters, some of which are frequently delivered by the vendor upon request, and others that are typically derived by the client.

- **Bare earth surface model:** a high resolution (1 meter) Digital Elevation Model (DEM) that provides topographic information and 3D viewing of the landscape. It is generated by filtering the raw point cloud to identify "ground returns" and then creating a bare earth surface from the filtered points. Note: It is highly recommended that you pay the lidar vendor to generate this product; in most cases, it is a cost savings. This is a standard deliverable for 3DEP acquisitions.
- **Digital surface model (DSM):** derived by creating a surface from the first return of each pulse. It is essentially a 3D model of all objects on the surface of the earth such as trees, buildings, and infrastructure superimposed on the topography. It contains elevation values above sea level rather than "height" above ground. A DSM is sometimes referred to as a "highest hit surface." It is commonly used to create a canopy height model.
- **Canopy height model:** derived by subtracting the bare earth surface model from the DSM. This results in a raster representing tree height above the ground in forested areas along with the height of other objects in non-forested areas (bridges, powerlines, buildings, etc.).
- **Hillshade model (bare earth and DSM):** a gray scale rendering that highlights elevation/height changes in the landscape. The surface is illuminated by a hypothetical light source, making elevation/height changes easier to visualize.

To further exploit the lidar data, there are a number of forest structure metrics – referred to as "first order lidar metrics" – that can be derived from the raw point cloud to explain the canopy structure in terms of height, cover and density statistics (McCallum et al. 2014; Mitchell et al. 2015). A complete list of canopy structure metrics that can be generated from the point cloud are described in the FUSION software manual. In addition, the Geospatial Technology and Applications Center (GTAC) has compiled "First Order Lidar Metrics: A Supporting Document for Lidar Deliverables" to aid USFS staff in confidently characterizing forest canopy structure.

- **Height metrics:** A variety of statistics are produced that describe the canopy height at a specified scale (grid cell size). These metrics include basic distribution statistics such as the mean, mode, variance and maximum height values, among many others.
- **Cover metrics:** This group of statistics includes different measurements of canopy cover and canopy density. Canopy cover is calculated by taking a ratio of first returns above a height threshold divided by the total number of first returns. This is comparable to photo interpreted estimates of canopy cover but more consistent across large landscapes. Canopy density is calculated by taking the ratio of all returns above a height threshold divided by the total number of all returns.

# Summary

This document outlines lidar acquisition specifications needed to characterize forest structure, as well as other key factors to consider for the contracting and acquisition process. It is up to the user to work with partners to create a Statement of Work that captures the necessary specifications for their project. 3DEP provides an ever-increasing opportunity to collaborate on lidar acquisitions and share costs, but you must be aware of the various quality levels and how acquisition specifications interact to create a lidar product. For further information or lidar acquisition consultation, please contact your Regional

Remote Sensing Coordinator or GTAC, and they will assist you in taking full advantage of the lidar resources available to you.

# References

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