GUIDANCE FOR ACQUIRING, MANAGING, AND USING LIDAR DATA

Keith Weber, GISP. Idaho State University GIS Training and Research Center (ISU GIS TReC)
webekeit@isu.edu

Purpose

This paper provides current best practice guidelines for the acquisition, management, and use of airborne lidar data. Airborne lidar[1] uses laser pulses emitted from a sensor onboard an aircraft --and the reflected *returns* collected by that sensor-- to create a high spatial resolution digital model of the earths surface, called a digital terrain model (DTM). Lidar represents the state-of-the-art in topographic/surface mapping. Lidar presents challenges however and this paper seeks to provide guidance to allow the reader to overcome those challenges.

Acquiring Lidar Data

Availability of lidar data is increasing, and as of March 2023, approximately 40% of Idaho has lidar data coverage and the remaining 60% been either been flown and is being processed, or is planned for acquisition in the near future[2]. Because of the amount of hard drive disk space required to store lidar data, acquiring lidar should begin by determining an area of interest (AOI). An AOI might be the extent of a:

- Subdivision
- City or municipality
- County
- Watershed

Once an AOI has been identified, visit the Idaho Lidar Web Viewer to determine if lidar data already exists. If so, the Idaho Lidar Web Viewer supports direct download of lidar data to your computer. Before beginning that process however it is recommended that the reader next determine the type of lidar data required.

There are two broad categories or types of lidar data. The first, raw lidar point cloud (LPC) data, is by far the largest and unfortunately most difficult to use[3]. The difficulty of use can be easily overcome with training as is a worthwhile endeavor as LPC data offers the most capabilities and broadest range of applications. The second type of lidar data is derived from LPC and is the processed, ready-to-use lidar data. These data layers are stored in raster image format and any GIS professional well acquainted with the use of raster data will be able to immediately put these data to use. Both raw and processed lidar data are available through the Idaho Lidar Web Viewer.

In many cases, completed lidar data projects may not already exist for your AOI but are in the collection or planning phases. While acquiring a new lidar project area can be expensive and time consuming, it does not need to be cost-prohibitive. The first critical step toward acquiring lidar data for a new AOI is to contact the Idaho Lidar Consortium and learn about planned data collections and potential collaborations. This is important due to the logistics involved in a new lidar collection[4]. Such logistics involve contractual agreements with a vendor capable of collecting quality lidar data, mobilizing aircraft, sensors, and trained personnel to complete the collection. In addition, the vendor is responsible for processing, submitting these data for review/inspection, and making the necessary corrections prior to final delivery.

[1] This paper focuses on airborne lidar and does not cover terrestrial laser scanning (TLS)
[2] There is currently a 1-3 year time lag between acquisition and delivery of data.
[3] To learn how to use LPC data, consider complete a dedicated lidar workshop. Click the following link to learn about workshops offered by Idaho State University's GIS Training and Research Center.
[4] A video detailing the Lidar Collection Workflow is available through YouTube.

Fortunately, by working with the Idaho Lidar Consortium you will leverage lidar collection programs available through three federal agencies; the Federal Emergency Management Agency (FEMA) Cooperating Technical Partners (CTP) program, the United States Geologic Survey (USGS) 3D Elevation Program (3DEP), and the Natural Resources Conservation Program (NRCS) National Enterprise Elevation Program (NEEP).

Engaging in a new lidar collection can be overwhelming for an individual but working with experienced professionals at the Idaho Lidar Consortium, FEMA, USGS, and NRCS will make the process less daunting, especially when you understand each of these organizations share the same goal as you; acquiring high quality lidar data. To help you engage in conversations about lidar, understanding the terminology used to discuss and describe lidar is useful. For example, raw lidar data is normally called a lidar point cloud (LPC), and these data can be processed into a bare earth (BE) digital terrain model (DTM), or a highest hit (HH) top-of-canopy digital surface model (DSM) raster layer. To learn more about the fundamentals of lidar the reader is encourage to complete lidar training like the workshops available through Idaho State University's GIS Training and Research Center (ISU GIS TReC).

Understanding the type of lidar data your organization needs should be based on an assessment of how you plan to use lidar data and if your organization has the technical skills to process lidar data. For instance, if you need to calculate surface derivatives such as slope and aspect to support mapping and planning efforts, processed raster layers will likely satisfy these needs. Alternatively, if you need to delineate flow accumulation areas as precisely as possible for engineering projects, then acquiring raw LPC data is necessary.

What Quality Level (QL) do I need?

If using existing lidar data you will not be able to choose the quality level of those data as that is determined during contracting and data acquisition. However, if your AOI is fortunate enough to have repeat collections of lidar, you may indeed have a choice. Furthermore, if you are involved in the planning of a new lidar collection, understanding and selecting the correct quality level is critical. To begin building this understanding note the difference in point density (lidar points collected per meter^2) in **Table 1**. Note the dramatic difference between QL1 and QL2 data and consider the following scenario. Let's assume you want to create a 1-meter spatial resolution bare earth DTM to support ongoing projects in your organization. Further, assume the delivered LPC data contains 25% bare ground classifications. If you are using QL2 data with only 2 points collected per square meter, then many areas will not have an actual ground collection observation and any bare earth DTM produced from these data will contain many 1-meter pixels where the elevation data for those pixels was interpolated or estimated from adjacent pixels. In contrast, a QL1 product with 8 points per square meter and the same 25% ground classification rate, should always have 2 actual lidar ground data observations per pixel. Note also, having only 25% classification rate cannot reliably support creating a 0.5-meter bare earth DTM.

Table 1. Summary of lidar quality level specifications

Quality Level (QL)	Point density	Vertical Uncertainty (m)
QL0	≥ 8.0	≤ 0.04
QL1	≥ 8.0	≤ 0.08
QL2	≥ 2.0	≤ 0.08
QL3	≥ 0.5	≤ 0.16

If you plan to use lidar data to model the flow of water or other fluid across the landscape for flood zone mapping or post-wildfire debris flow projections, then breakline data will be required to produce a hydro-flattened bare earth DTM. A hydro-flattened bare earth DTM is a necessary pre-cursor to subsequently creating a hydro-enforced DTM. Furthermore, the location of bridges, culverts, and other geographic features allowing for the man-made, directed flow of water beneath the surface (e.g., roads) is also necessary to produce a hydrologically-enforced bare earth DTM (hydro-enforced)[5]. I suggest discussing these needs while planning a new lidar collection and include a hydro-enforced DTM as part of the deliverables for your project. Understand however, that additional project deliverables like these will result in higher costs. Those additional costs may be reasonable if your organization does not have the ability to create a hydro-enforced DTM which requires not only the location of culverts for example but the elevation of each culvert at the inlet as well as the elevation at its outlet. Further, your organization will need the requisite GIS or Lidar software to process these data. In this situation, a consideration of the return on investment (ROI) is merited.

Realistically modeling flow through culverts and other man-made water diversion structures is not possible without creating a hydro-enforced DTM. Creating such a model is not simple and requires a knowledgeable operator along with specialized software such as Esri's ArcHydro. This capability comes at a real cost that might exceed the cost of adding the hydro-enforced DTM to the deliverables required of the contractor (note: be certain the contractor has the necessary experience to create a hydro-enforced DTM).

Data Acquisition Suggestions

Having worked extensively with lidar for several years, it is clear that not all lidar collections are of equal quality even when a project technically satisfies quality level one (QL1) specifications[6]. In practical terms, a quality lidar collection must achieve the contracted QL specification but in addition, the collection should also deliver:

- Geospatial metadata following FGDC or ISO standards
- A report detailing achieved nominal point spacing (NPS) and both horizontal and vertical accuracy. How these values were determined should be clearly explained in the document
- A GIS feature class index and printable map document of the delivered lidar data
- Correctly projected and defined LPC data (stored in LAS file format)
- A minimum of 25% classified ground returns
- Correctly projected and defined raster layers (stored in TIF file format) using 32-bit floating point pixel depth and either 0.5-meter or 1.0-meter cell size. At a minimum, the following raster layers should be delivered as part of a quality lidar project:
- Bare earth (BE) layer
- Highest hit (HH) layer
- Intensity (INT) layer

In my professional experience, most vendors are capable of providing quality lidar data, however the responsibility falls on the user to request the deliverables listed above.

Managing Lidar Data

Lidar data is truly Big Data as a QL1 lidar project for the average Idaho county can easily consume a terabyte of hard drive space (e.g., Lidar LAS files for Bingham County, Idaho requires nearly 1 TB of hard drive space and contains over 16 billion ground return points). Allowing access to lidar data across your organization's shared server space is recommended. This will eliminate the need for all users to download or copy lidar data to their desktop computer. In practice, a limited number of individuals will need to access and use raw LPC data (e.g., LAS files) while a larger number of

[5] See https://www.usgs.gov/special-topics/coastal-national-elevation-database-%28coned%29-applications-project/science/hydrologic
[6] Topographic data Quality Levels (QLs) https://www.usgs.gov/3d-elevation-program/topographic-data-quality-levels-qls

individuals will make use of processed layers such as the bare earth DTMs.

It is important to understand the difference between the two different file formats used to store LPC data; LAZ and LAS. A LAZ file is effectively a compressed or zipped LAS file. The same LPC data can be stored in LAZ or LAS format but the resulting LAZ file will be only 10% the size of the equivalent LAS file. This sounds very appealing; however, ArcGIS Pro currently cannot use LAZ files directly to perform the geoprocessing steps used in lidar data analysis. Instead, ArcGIS Pro requires the LAZ file first be extracted or converted to LAS format. In practice, this workflow requires even more hard drive space and time. Therefore, it is recommended that ArcGIS Pro users download and use LAS files instead of LAZ files.

While the original source data is available through the ILC and lidar servers at ISU's GIS TReC, it may be wise to archive a copy of your data within your organization. This decision is entirely up to you however and the suggestion is provided here for your consideration.

Instead of downloading the bare earth DTMs (the most commonly used lidar product), consider using the streaming web image service from ISU's GIS TReC. The Lidar Image Service Stream (LISS) provides pit-filled bare earth DTM data that is streamed to a computer running ArcGIS desktop. The LISS is available as an Esri Image Service[7] as well as an open source Web Coverage Service (WCS)[8].

The LISS provides the user with immediate access to all pit-filled bare earth DTM data available in the State of Idaho. By default, elevation (in meters) is provided however the user can opt to use an embedded processing template (also known as a raster function) to use elevation in feet (NOTE: this is the meters to feet processing template). Similarly, users can access aspect, slope in percent, slope in degree, and hillshade data within the same image service. Switching between these templates takes only a few seconds. With this image service, users can complete the same spatial analysis as having data downloaded to their hard drive.

Using Lidar Data

Lidar is a more accurate and precise source of elevation data compared to previous generations of digital terrain models such as the National Elevation Dataset (NED)[9]. Lidar is not perfect however. One error that is common in lidar bare earth DTM layers is the presence of pits. A pit, like the name implies, is a pixel with abnormally low elevation values compared to the values of adjacent pixels. As a result, flow direction and accumulation models derived from these data can be grossly underestimated if pits are not corrected. It is reasonable to assume that pits exist in a standard bare earth DTM (NOTE: the processed lidar data used in the GIS TReC's LISS uses pit-filled bare earth data). For this reason, the fill geoprocessing tool should be used before running any flow accumulation processes. If anomalous results continue to be detected, a second iteration of pit filling *may* be required. However, routine repeated pit filling is not advised as slight depressions that actually exist in the surface could be filled unnecessarily. Finally, end-users of lidar data should understand these data require the skills of a knowledgeable GIS specialist to ensure the data is processed correctly and results from lidar spatial analysis are valid and reliable.

[7] To access the REST service, connect to https://giscenter.rdc.isu.edu/server/rest/services/Lidar/Lidar_Idaho/ImageServer

[8] To access the SOAP WCS, connect to https://giscenter.rdc.isu.edu/server/services/Lidar/Lidar_Idaho/ImageServer/WCSServer?request=GetCapabilities&service=WCS

[9] For a discussion of lidar accuracy the reader is referred to a TECH Talk presentation available on YouTube at https://youtu.be/-DAC9cJGDsI

Helpful Links
FEMA Elevation Guidance https://www.fema.gov/sites/default/files/documents/fema_elevation-guidance_112022.pdf
FEMA CTP program https://www.fema.gov/flood-maps/cooperating-technical-partners
FEMA Policy Standards https://www.fema.gov/sites/default/files/documents/fema_policy-standards-flood-risk-analysis-mapping-rev-13.pdf
Idaho Lidar Web Viewer https://giscenter.isu.edu/styler/?appid=163bf5887aa04f308a15fe8e44963bf8
Idaho Lidar Consortium https://www.idaholidar.org/
Lidar workshops and training https://giscenter.isu.edu/Workshops/index.htm
Lidar Collection Workflow video https://youtu.be/2TSbrwzjA2g
USGS 3DEP https://www.usgs.gov/3d-elevation-program