

User Guide

Lidar Point Cloud (2016-18)

LIO Dataset

**Provincial Mapping Unit
Mapping and Information Resources Branch
Corporate Management and Information Division
Ministry of Natural Resources and Forestry**

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Executive Summary

Key Words

Lidar, Airborne Topographic Lidar, OMAFRA Lidar, Point Cloud, Elevation, Light Detection and Ranging, terrain, topography.

Abstract

This user guide is intended to go beyond metadata and give data users a sense of the purpose for which the data was collected, the technical processes, software, and applicable standards involved, suggested applications for the data (and general approaches to how to use it), and other details that will help data users. As such, this user guide details the acquisition specifications for the **Lidar Point Cloud (2016-18)** Land Information Ontario (LIO) Dataset and how it relates to the overall Ontario Airborne Topographic Lidar dataset

The Lidar Point Cloud was collected during the fall of 2016, spring and fall of 2017, and spring of 2018 through a collaborative partnership with the Ministry of Agriculture, Food and Rural Affairs (OMAFRA), the Ministry of Natural Resources and Forestry (MNRF) and a private contractor; it covers selected areas in Southern Ontario and portions of Northern Ontario. A contract was awarded to Airborne Imaging Incorporated for the collection of lidar for the three project areas: Cochrane, Peterborough and the Lake Erie watershed.

The lidar point cloud consists of two datasets: a classified lidar point cloud and a raw lidar point cloud.

The classified lidar point cloud is a collection of points containing elevation and intensity information derived from returns collected by an airborne topographic lidar sensor. The USGS Minimum classification scheme has been applied by the contractor to identify the type of target from which the return reflected, and differentiates between bare-earth terrain points, water, high and low noise returns.

The complete raw lidar point cloud, used for the creation of the classified point cloud was also delivered by Airborne Imaging.

Document History

Version	Date	Description
1.0	2017-10-11	AODA updates; Version 1.0 for release
1.1	2018-05-15	Update for completed acquisition in the Peterborough project area and available deliveries in the Lake Erie project area

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List of Acronyms

AGL: Above Ground Level

ASPRS: American Society for Photogrammetry and Remote Sensing

CGVD: Canadian Geodetic Vertical Datum

CSRS: Canadian Spatial Reference System

DEM: Digital Elevation Model

DTM: Digital Terrain Model

GIS: Geographic Information System

LIDAR: Light Detection and Ranging

LIO: Land Information Ontario

MNRF: Ontario Ministry of Natural Resources and Forestry

NAD: North American Datum

ATL: Airborne Topographic LIDAR

OMAFRA: Ontario Ministry of Agriculture, Food and Rural Affairs

PMU: Provincial Mapping Unit

USGS: United States Geological Survey

UTM: Universal Transverse Mercator

1. Product Description

1.1 Lidar Point Cloud (2016-18)

The purpose of the Airborne Topographic Lidar (ATL) acquisition was to acquire classified lidar digital elevation data and derivative products to support agricultural soil map renewal for selected geographic areas in southern Ontario and portions of northern Ontario. This data is intended for GIS and remote sensing applications that require a high resolution, high accuracy 3D elevation model.

These elevation models, known as Digital Elevation Models (DEMs), are invaluable for agricultural soil mapping, infrastructure assessment and development, forest modelling and management, land hazard/erosion mapping and flood control amongst other applications.

In the case of agricultural soil map renewal a key requirement was to produce a bare-ground Digital Terrain Model (DTM). A bare earth DTM is developed by filtering or removing surface features from the point cloud such as vegetation, buildings and bridge decks. To increase the number of lidar returns collected in forested areas the acquisition was timed during leaf-off periods in the Spring and Fall.

A DTM that was created from these point clouds by the contractor is available as a separate product. Refer to the metadata record “LIDAR – DIGITAL TERRAIN MODEL (2016-18)” for more information about that product.

1.1.1 Raw Point Cloud

The raw point cloud was delivered by the contractor in LAZ compressed format and contains all collected points, fully calibrated, georeferenced and adjusted to ground, organized and delivered in full swath-based overlapping files. See Appendix D: Detailed Vendor-Supplied Data Calibration, Collection, and Processing Information for more information about the calibration and adjustment processes. The LAZ compression was applied to source files structured in the ASPRS LAS Specification Version 1.4 R13 format. Even in LAZ compressed format these files are typically quite large with many files over a GB in size. See Appendix C: Raw Point Cloud for more detailed use information.

1.1.2 Classified Point Cloud

The classified point cloud is derived from the raw point cloud. A colour-coded 3D sample of the classified point cloud is displayed in Figure 1.

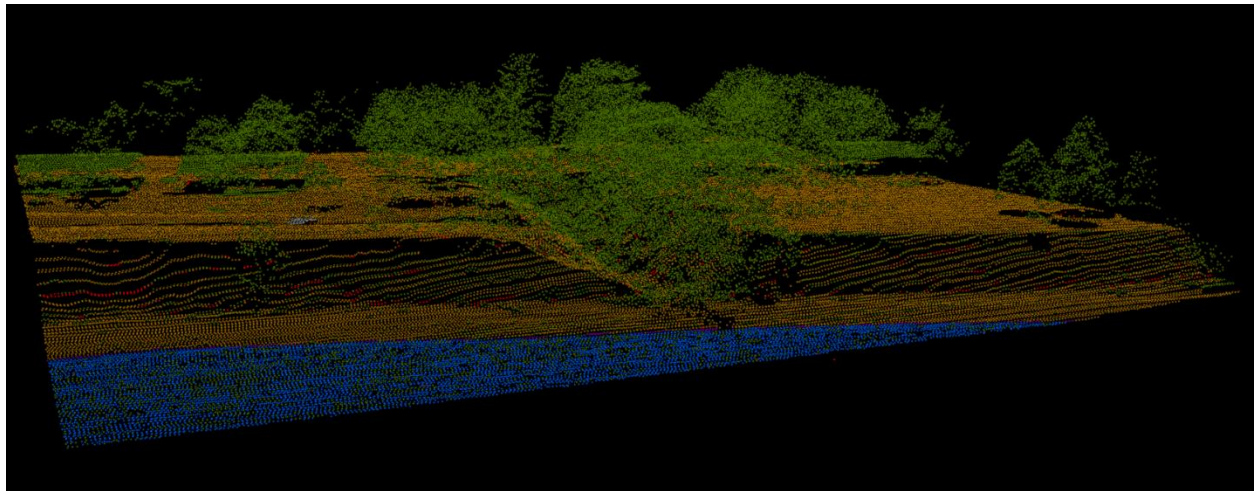


Figure 1: 3D visualization generated from classified point cloud data.

The classification scheme conforms to the USGS LIDAR Base Specifications (V 1.2) minimum classification and was applied by the contractor to identify the type of target from which the return reflected, which is as follows:

Class 1: Processed, but unclassified

Class 2: Bare earth

Class 7: Low noise

Class 9: Water

Class 10: Ignored ground (near a breakline)

Class 17: Bridge decks

Class 18: High noise

1.1.3 Related products

In addition to the classified and raw point clouds, the following products were delivered by the contractor:

- Breaklines: Hard breaklines representing interruptions to the surface defined by water bodies of 8,000 m² or greater surface area or in the case of streams greater than 30 m width at the time of collection (USGS LIDAR Base Specifications (V 1.2)).
- DTM: a 50 cm hydro-flattened, bare-earth gridded raster data product that has been generated by the contractor from the classified lidar point cloud and the hydrographic breaklines.

1.2 Acquisition

The Airborne Topographic Lidar data was collected during the fall of 2016, the spring and fall of 2017, and spring of 2018 through a collaborative partnership between the Ministry of Agriculture, Food and Rural Affairs (OMAFRA), the Ministry of Natural Resources and Forestry (MNRF) and a private contractor; it covers selected areas in southern Ontario and portions of northern Ontario. The acquisition was based on specifications for Quality Level 0 lidar as produced by the USGS in the LIDAR Base Specification (ver. 1.2, November 2014). These specifications have been localized for Ontario by the Government of Ontario Elevation Coordination and Consultation Committee, in a document titled “Ontario Specifications for Lidar Acquisition” and equate Quality Level 0 with Vertical Accuracy Class 5-cm.

In order to meet leaf-off and snow free ground conditions, the lidar data was acquired as follows:

- Cochrane project area in October to November, 2016, May to June and September, 2017
- Peterborough project area in November to early December, 2016, April to May and October, 2017
- Lake Erie project area in March to May, 2017

For the majority of the acquisition the following lidar system specifications and flight parameters were used by Airborne Imaging (2017a, 2017b):

- System: Leica ALS70-HP
- Flight Altitude: 1000m Above Ground Level (AGL)
- Speed: 140 knots
- Flightline Spacing: 550 m
- Single Pass Swath width: 690 m
- Scan Angle or Field of View (FOV): 38° effective (40° minus 1° clipped on each side of the scan edge)
- Scan Frequency: 53 Hz

- Scan Pulse Rate: 500 kHz
- Sidelap: $\leq 20\%$
- Overlap: $\leq 40\%$
- Point Density: 8 points per m²

A smaller portion of the acquisition was acquired using a different sensor system. The specifications and flight parameters follow:

- System: Riegl LMS-Q1560
- Flight Altitude: 700m Above Ground Level (AGL)
- Speed: 150 knots
- Scan Angle or Field of View (FOV): 58° (60° minus 1° clipped on each side of the scan edge)
- Scan Frequency: 313 Hz
- Scan Pulse Rate: 800 kHz
- Sidelap: $\leq 30\%$
- Point Density: 8 points per m²

Refer to Appendix D, or to the individual vendor-supplied metadata documents for additional detailed information about the data collection process. To see the exact acquisition date for a particular location and the sensor system used refer to the Lift Metadata shapefile attached to the LIO metadata record for the Lidar Classified Point Cloud.

1.3 Geographic Extent

Acquisition Areas 2016-2018

Acquisition of the lidar data is planned to occur over a two year period and include projects in the Peterborough area, the Cochrane area and in southwestern Ontario north of Lake Erie.

At the time of writing, portions of the Cochrane and Lake Erie projects and all of the Peterborough projects have been delivered and are available for distribution.

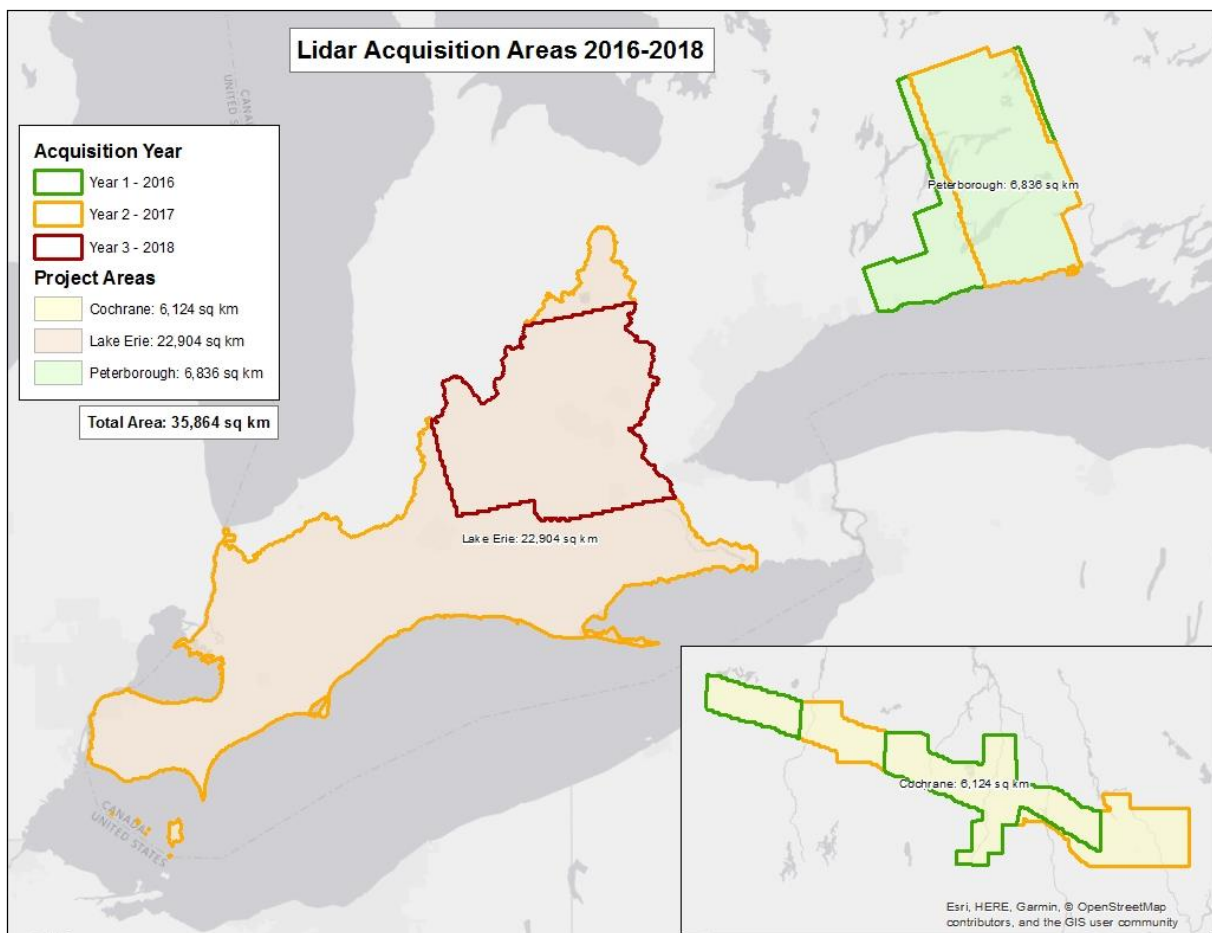


Figure 2: Planned lidar project areas.

Cochrane Available Extent

The Cochrane project lidar data encompasses a collection area of approximately 6,124 square kilometers representing a corridor along Highway 11 in northern Ontario between the Town of Cochrane and the Town of Hearst, as shown in Figure 3*.

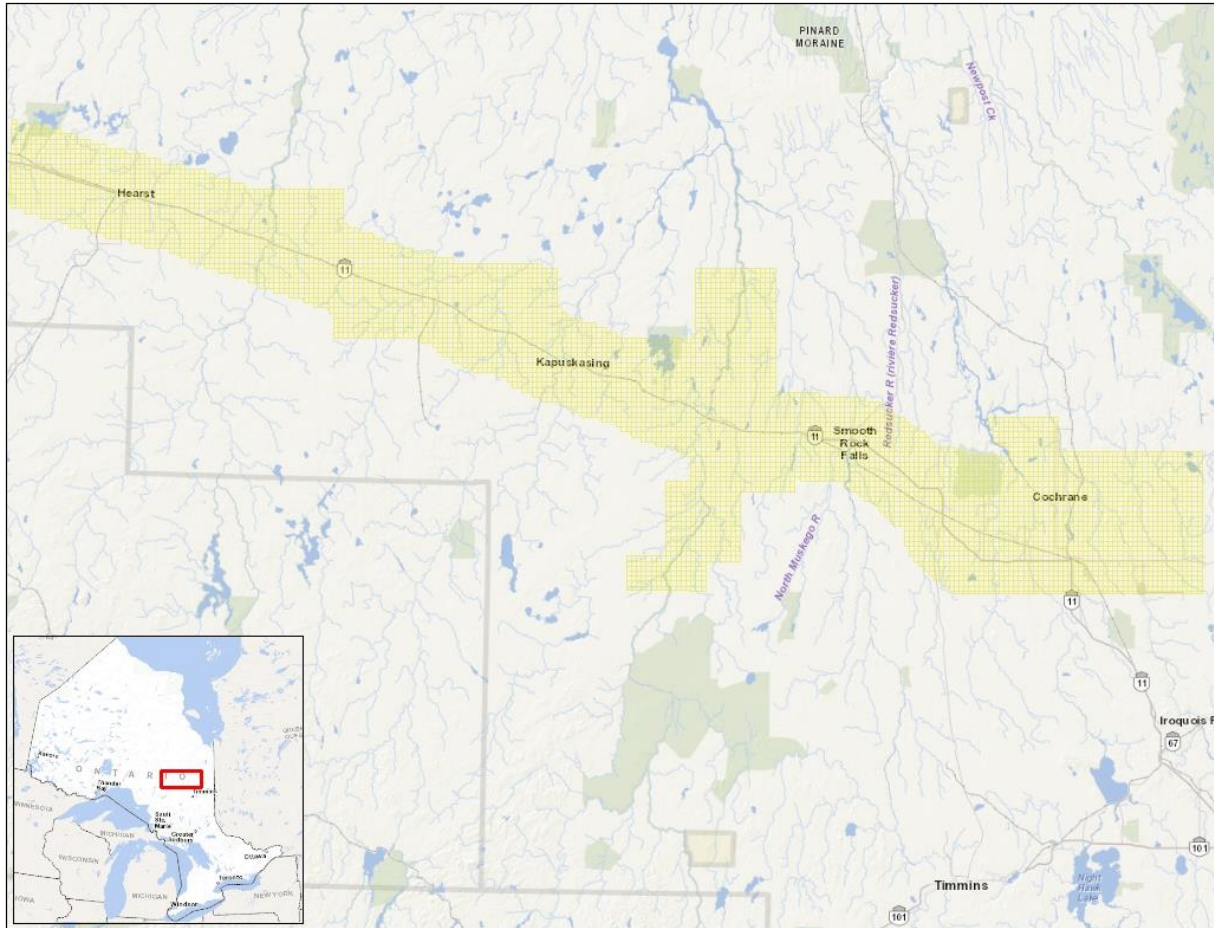


Figure 3: Cochrane project area classified point cloud tiles

Peterborough Extent

The available Peterborough project lidar data encompasses a collection area of approximately 6,836 square kilometers, as shown in Figure 4* representing an area covering all of the County of Peterborough, the County of Northumberland and the Municipality of Clarington.

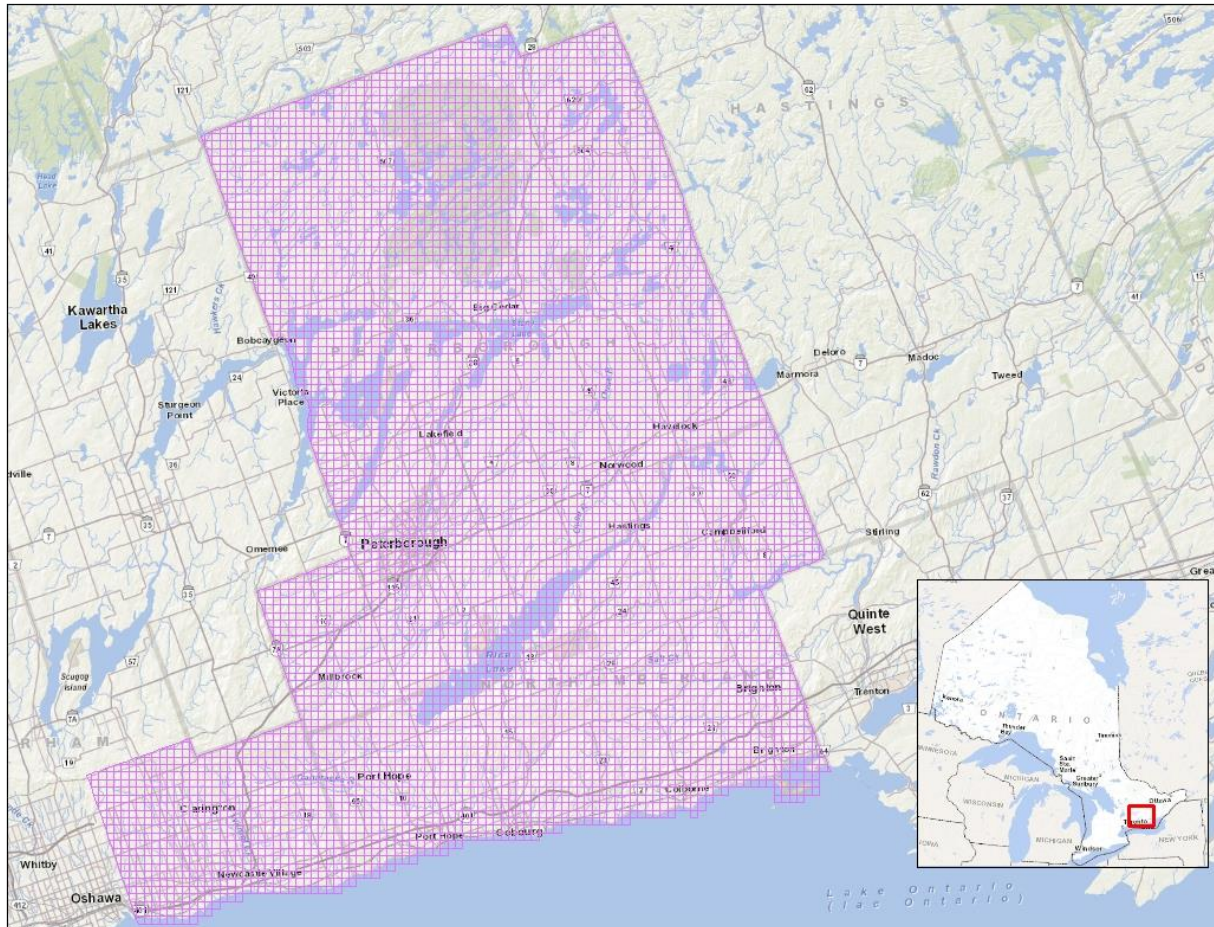


Figure 4: Peterborough project area classified point cloud tiles

Lake Erie Available Extent

The available Lake Erie project lidar data encompasses a collection area of approximately 12,750 square kilometers representing the western half of the Lake Erie watershed within Ontario, as shown in Figure 5*.

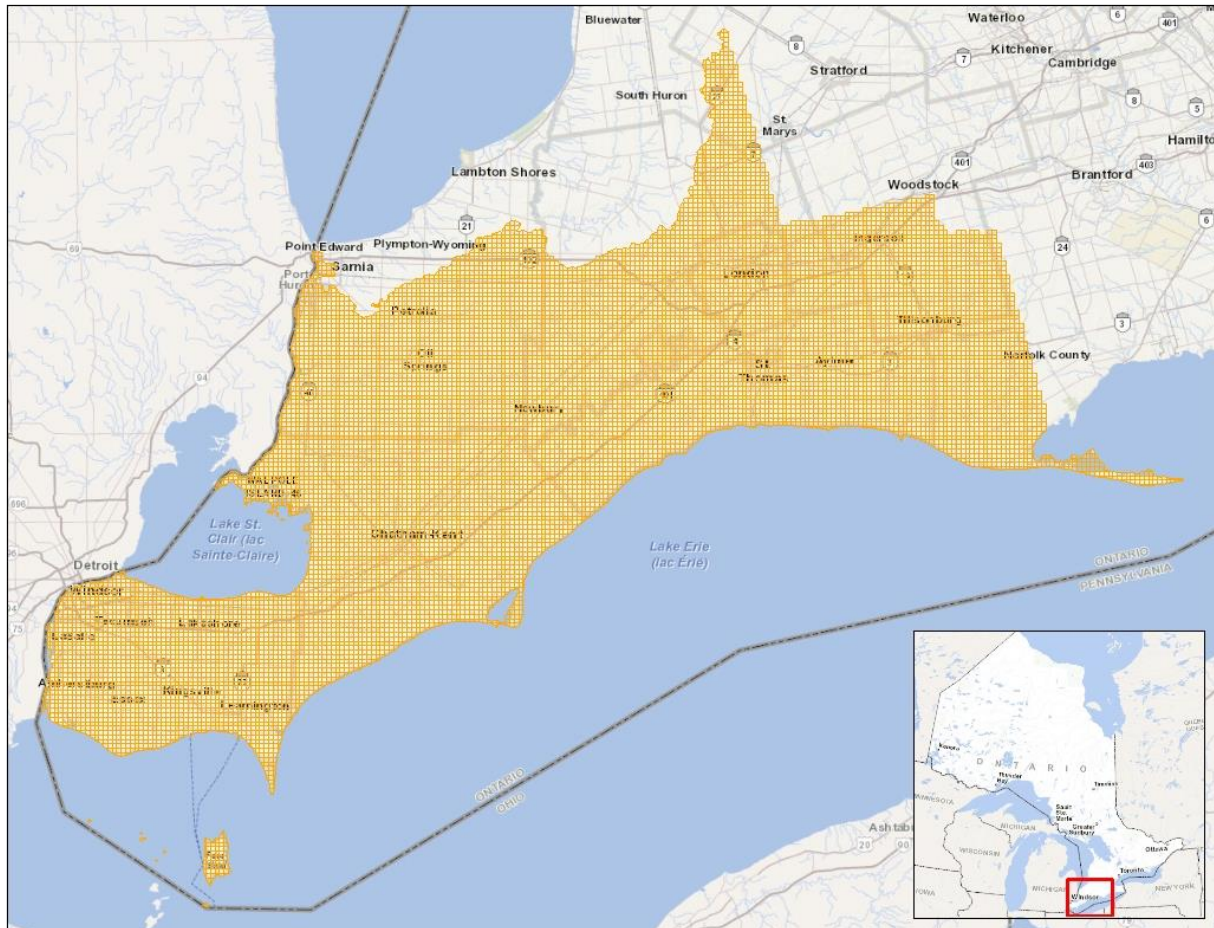


Figure 5: Lake Erie project area available classified point cloud tiles

*Note: Raw point cloud data may extend beyond boundaries of the project area. See Appendix C for more details.

1.4 Reference System

1.4.1 Horizontal Reference System

The horizontal coordinate system of the product is Universal Transverse Mercator (UTM) Zone 17. The horizontal datum of the products is the North American Datum of 1983 Canadian Spatial Reference System epoch 2010 (NAD83(CSRS)). This coordinate system was used for the entire project area, including those portions falling within UTM Zone 18.

The horizontal unit of measure (coordinate system axis units) for all raster grid cells is metres (m).

1.4.2 Vertical Reference System

The vertical coordinate system of the products is based on the Canadian Geodetic Vertical Datum 2013 (CGVD2013) of the Geodetic Survey Division, and is measured in metres above mean sea level.

The vertical unit of measure for the product is metres (m).

1.5 Accuracy Assessment

The Ontario Public Service Elevation Coordination and Consultation Committee (EC³) has published Elevation Accuracy Guidelines which explains and provided guidelines for assessing the accuracy of digital elevation data, which has been drafted to be consistent with the 2014 American Society for Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data.

Three absolute accuracy values were assessed and reported: Non-vegetated Vertical Accuracy (NVA) for the lidar point cloud, NVA for the DTM, and Vegetated Vertical Accuracy (VVA) for the DTM. This data set was produced to meet accuracy standards for Ontario Digital Geospatial Data for a 5 cm Vertical Accuracy Class equating to (NVA) of +/- 9.8 cm at 95% confidence level and VVA of +/- 14.7 cm at the 95th percentile.

The vendor has supplied a preliminary vertical accuracy assessment for the Cochrane project that will be updated once the entire area has been collected. The final report for the Peterborough project has been delivered and updated in this document. Upon completion of the Lake Erie project a vertical accuracy report will be produced and incorporated into this document.

For additional details about the method by which the vendor has calibrated the data and quantified the accuracy of the data, please refer to Appendix B, or to the individual vendor-supplied documents referenced in the metadata record.

1.5.1 Non-vegetated Vertical Accuracy

The independent assessment of vertical accuracy was made against the two sets of “Non-vegetated” GPS points surveyed, those being Fast Static and Real-Time-Kinematic (RTK). Based upon the assessment reported by the contractor for these two independent checks (Table 1), the data for both the Peterborough and Cochrane (preliminary) project meet the NVA vertical accuracy requirements (Airborne Imaging, 2017a, 12-13; Airborne Imaging, 2017b, 13-14).

Table 1: Non-vegetated Vertical Accuracy

LIDAR Project (2016)	Fast Static Vertical Accuracy (95%)	RTK Vertical Accuracy (95%)
Peterborough	8.6 cm / 127 points	9.4 cm / 223 points
Cochrane	5.1 cm / 93 points	5.9 cm / 94 points

1.5.2 Vegetated Vertical Accuracy

To establish the VVA the contractor compared elevations of points surveyed in selected vegetated land cover types to the lidar ground surface represented in the DTM.

For the Peterborough project, 12 of the 208 VVA points surveyed in 2016 had an absolute vertical difference greater than the 14.7 cm specification at the 95th percentile. Within the Cochrane project, 8 of the 93 VVA points surveyed in 2016 also had an absolute vertical difference greater than 14.7 cm. As seen in Table 2, these results in both the final Peterborough and preliminary Cochrane project accuracy reports have values that are slightly outside of the specifications (Airborne Imaging, 2017a, 13; Airborne Imaging, 2017b, 15).

Table 2: Vegetated Vertical Accuracy

LIDAR Project (2016)	Vegetated Vertical Accuracy (95th percentile)
Peterborough	17.4 cm / 208 points surveyed
Cochrane	17.9 cm / 93 points surveyed

2. Product Details

2.1 Point Cloud Data Delivery Format

The 1km classified point cloud tiles are stored in .LAZ files (compressed .LAS) representing 1km x 1km non-overlapping tiles. Refer to Appendix A if additional information is required about how to extract and view information contained in .LAZ files.

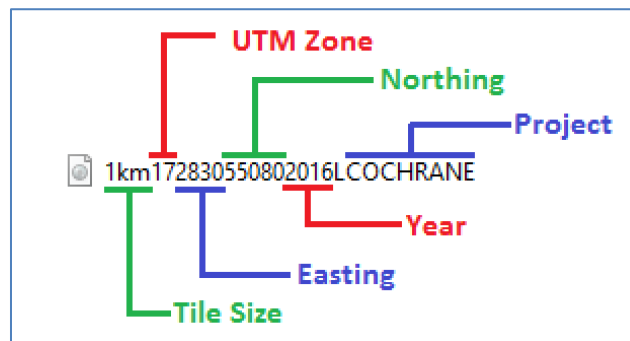


Figure 6: Tile names reflect tile size, UTM zone, Truncated Easting, Truncated Northing, year and project.

In the Cochrane project the classified point cloud product contains 6,638 tiles. The Peterborough project contains 7,093 tiles. In the Lake Erie project there are currently 13,264 tiles available.

2.2 How to Order the Point Cloud Data

Due to the size of the data and technical constraints for publishing datasets of this size online the classified point cloud dataset is currently only available by request and will need to be delivered via hard drives. Please contact: Land Information Ontario (Email: LIO@ontario.ca) directly if you wish to make arrangements to place an order.

2.3 Data Storage Requirements

Lidar data is very storage intensive. This data has been estimated to contain half a trillion points. For this reason, the data is not being made available as a packaged product for download.

Estimated size of products:

- 2016-17 Classified Point Cloud (Cochrane) - 266 GB
- 2016-17 Classified Point Cloud (Peterborough) – 443 GB
- 2017 Classified Point Cloud (Lake Erie) – 506 GB
- 2016-18 Lidar (all products) - estimated at 6Tb

2.4 Use Restrictions

The Lidar Point Cloud (2016-18) is Open Data. You are free to copy, modify, publish, translate, adapt, distribute or otherwise use the Information in any medium, mode or format for any lawful purpose. If you do any of the above you must use the following attribution statement “Contains information licensed under the Open Government Licence – Ontario” (see: <https://www.ontario.ca/page/open-government-licence-ontario>).

3. Links to Additional Information

Heidemann, H. K. 2014 LIDAR base specification (ver. 1.2, November 2014) U.S. Geological Survey Techniques and Methods, book 11, chap. B4, (<http://dx.doi.org/10.3133/tm11B4>)

Natural Resources Canada 2017 “Information about the Canadian Geodetic Vertical Datum 2013 (CGVD2013)” (https://www.nrcan.gc.ca/earth-sciences/geomatics/geodetic-reference-systems/9054#_Toc372901501)

Natural Resources Canada 2016 “The Canadian Spatial Reference System (CSRS)” (<https://www.nrcan.gc.ca/earth-sciences/geomatics/geodetic-reference-systems/9052>)

Renslow, M. S. (ed.) 2012 Manual of Airborne Topographic LIDAR American Society for Photogrammetry and Remote Sensing. ISBN 1-57083-097-5, ASPRS Stock # 4587

Whitebox Geospatial AT Project
(<http://www.uoguelph.ca/~hydrogeo/Whitebox/index.html>)

4. References

Airborne Imaging 2017a “Preliminary Report for project: Cochrane LiDAR”. Unpublished report prepared for Ontario Ministry of Natural Resources and Forestry, Provincial Mapping Unit.

Airborne Imaging 2018 “Final Report for project: Peterborough LiDAR”. Unpublished report prepared for Ontario Ministry of Natural Resources and Forestry, Provincial Mapping Unit.

American Society for Photogrammetry & Remote Sensing 2013 “LAS SPECIFICATION VERSION 1.4 – R13, 15 July 2013” (Retrieved from http://www.asprs.org/wp-content/uploads/2010/12/LAS_1_4_r13.pdf)

American Society for Photogrammetry and Remote Sensing 2014 “Positional Accuracy Standards for Digital Geospatial Data.” Version 1.0, November 2014. (Retrieved from: [http://www.asprs.org/wp-content/uploads/2015/01/ASPRS Positional Accuracy Standards Edition1 Version100 November2014.pdf](http://www.asprs.org/wp-content/uploads/2015/01/ASPRS_Positional_Accuracy_Standards_Edition1_Version100_November2014.pdf))

Ontario, Elevation Coordination and Consultation Committee 2016 Elevation Accuracy Guidelines. (Queens Printer for Ontario. Retrieved from: <https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home?uuid=825e1ef2-1ace-40f5-912c-d719d3f5992b>)

Ontario, Elevation Coordination and Consultation Committee 2016 Ontario Specifications for Lidar Acquisition. (Peterborough: Queens Printer for Ontario. Retrieved from: <https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home?uuid=7db3f342-e849-4315-9be2-1f1e95f9fc04>)

Ontario, Ministry of Natural Resources and Forestry (MNRF) 2015 Glossary of Technical Terms: Elevation Data. (Queens Printer for Ontario).

Ontario Specifications for Lidar Acquisition 1.1 2016
<https://www.sse.gov.on.ca/sites/MNR-PublicDocs/EN/CMID/OntarioSpecificationsForLidarAcquisition.pdf>

Appendix A: Getting Started: Display and use of Lidar Point Cloud Data

Opening and viewing the Classified Point Cloud

Both the classified and raw Lidar point clouds are delivered in .LAZ format. LAZ is an open-source format for compression of LAS files. There are various tools available that make use of the .LAZ format. One method of extracting the LAS file from the .LAZ is to make use of the laszip tool which is distributed as a component of LAStools distributed by [rapidlasso GmbH](https://rapidlasso.com) (<https://rapidlasso.com>). Note: At the time of writing, LAStools contains both open-source and commercially licenced components. It is important to review the licence agreement before using.

The following describes a sample method to extract and display the classified .LAZ files using laszip and ArcGIS:

1. In the LASTOOLS\Bin folder, run "laszip".exe
2. Select the location of the LAZ files and decompress to LAS format (Figure 7). The resulting LAS files will be saved in the same folder as the source LAZ files. Note: LASZIP will not notify you when it is finished. It is best to count the # of files to know when it is done.

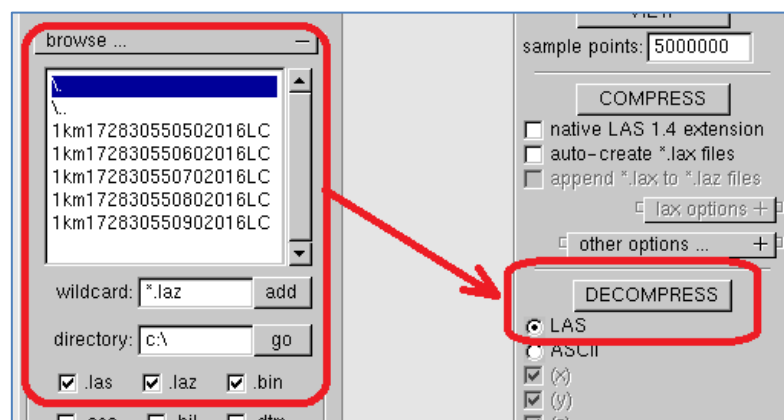


Figure 7: Decompressing LAZ files with laszip.

3. Use the Create LAS Dataset tool from ArcToolbox (Figure 8). Note: the output coordinate system will duplicate that of the first tile processed. All of the tiles within the Lake Erie, Peterborough and Cochrane projects use the same spatial reference, so this should not be a problem.

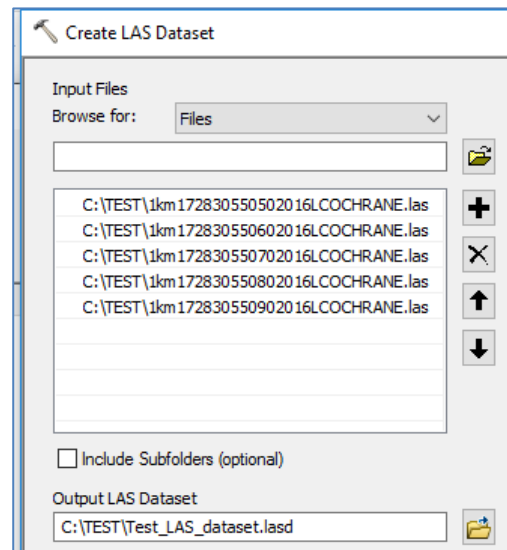


Figure 8: Creating LAS dataset using ArcToolbox

4. Open the LAS dataset in ArcMap and zoom in to a tile outline for viewing (Figure 9).

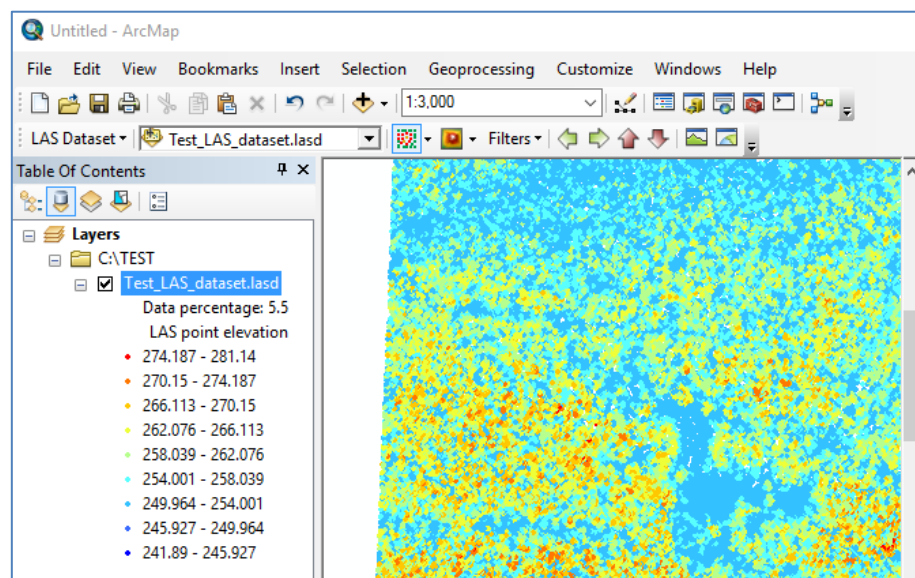


Figure 9: Viewing LAS dataset in ArcMap

5. Using the LAS Dataset Toolbar, the point cloud can also be displayed by classification code (Figure 10). The layer symbology will default to include all potential LAS classifications. The layer properties can be modified to display only the applicable minimum classification scheme that has been applied to the data, as detailed in section 1.1.2.

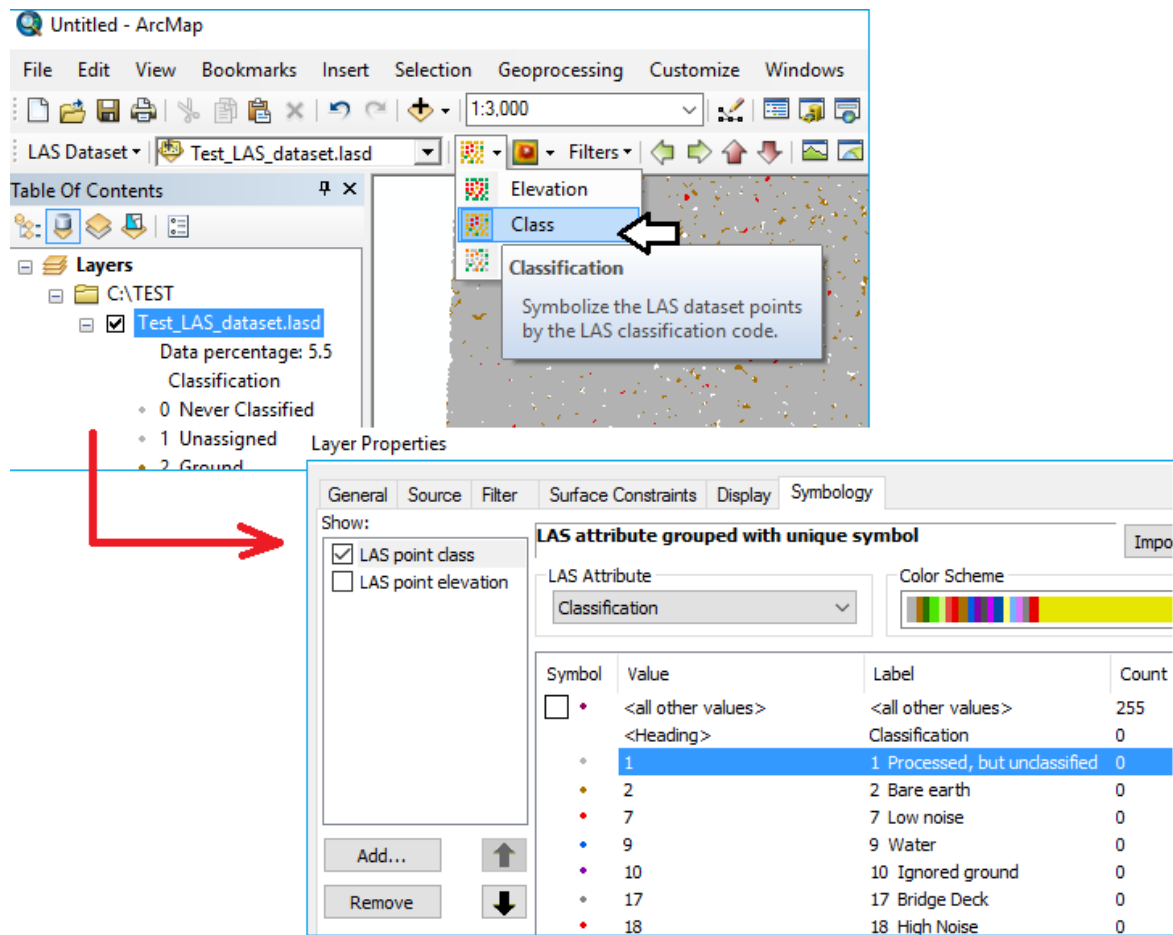


Figure 10: Display of the point cloud by classification scheme.

6. Portions of the LAS dataset may be selected for display in 3D or in Profile View using the LAS Dataset Toolbar (Figure 11).

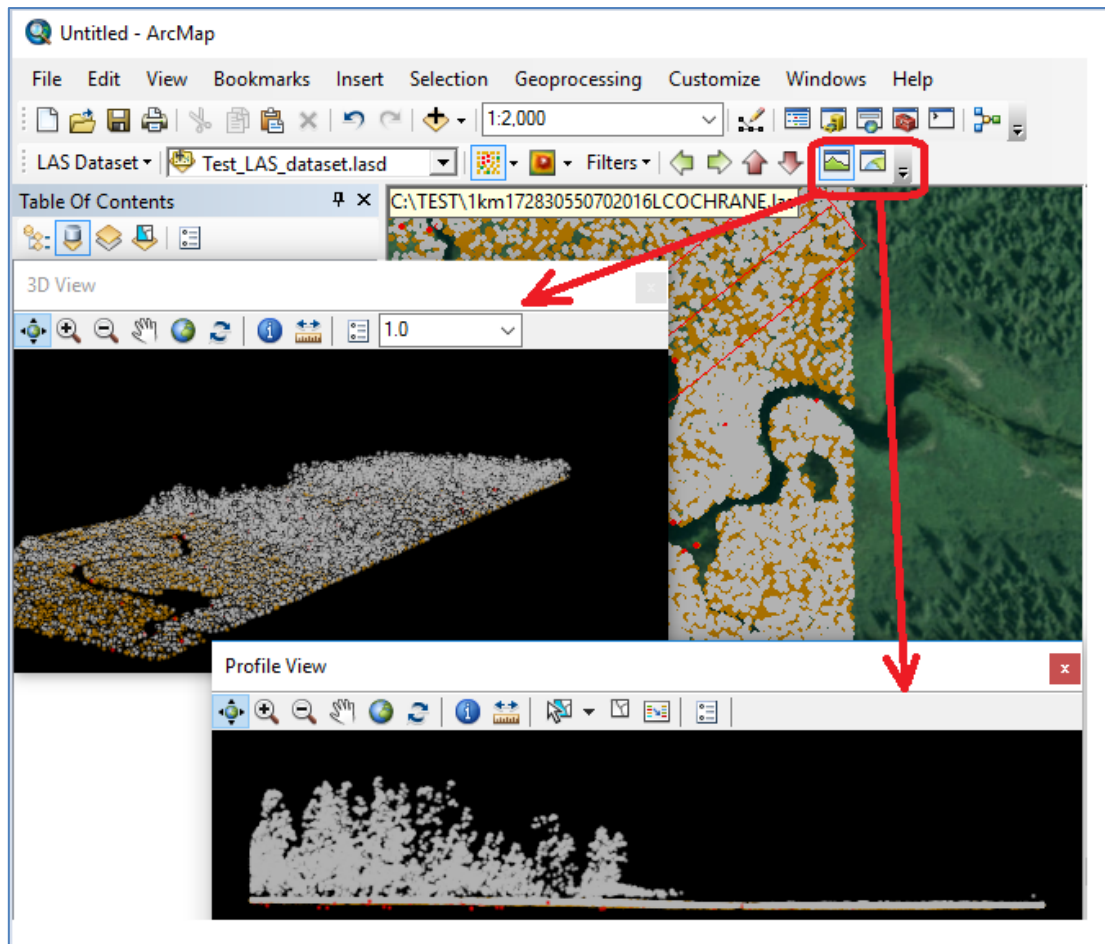


Figure 11: Display of classified points in 3D and Profile View.

Appendix B: Potential Lidar Point Cloud Derivative Products

Digital Terrain Model

A Digital Terrain Model (DTM) refers to the bare earth surface (lowest surface, last reflective surface, or LIDAR last-return) representing the surface of the "bare-earth" terrain, after removal of vegetation and manmade features.

Photogrammetry has traditionally generated DTMs when elevations are generated by manual compilation techniques. Unless specified to the contrary, the bare-earth surface includes the top surface of water bodies, rather than the submerged surface of underwater terrain.

Similar to a DSM, a DTM can be structured either as a vector dataset (comprised of mass points and optionally 3D breaklines) to model bare-earth elevations or a raster dataset that is interpolated from the vector elevation data to model bare-earth terrain elevations.

Using modern elevation point cloud classification algorithms and file formats, such as LAS, a DTM can represent a mass point dataset that has been classified for 'bare-earth' terrain elevations (MNRF 2015, 23-24).

As part of the contract for the Ontario Lidar Data collection, Airborne Imaging Inc. has processed the classified point clouds using breaklines in order to provide a hydro-flattened DTM (Figure 12), which is separately available for download through Land Information Ontario. However, advanced data users may choose to use the raw or classified Lidar point clouds in order to dynamically display functional surfaces using GIS software or produce custom DTMs in order to meet their own requirements or specifications.



Figure 12: Example of a hillshade view of the Lidar DTM.

Digital Surface Model

A Digital Surface Model (DSM) is based on the highest reflective surface of ground features captured by the sensor. This surface may also be referred to as the first reflective surface or LIDAR first-return. The DSM may include treetops, rooftops, and tops of towers, telephone poles, and other natural or manmade features; or it may include the ground surface if there is no vegetative ground cover. The reflective surface may include any artifact present when the sensor mapped the area, including passing cars and trucks and similar features not normally considered to be part of a digital terrain model. Figure 13 provides an example of a DSM generated from the Lidar Point Cloud and shows the surface of tree canopy and structures not visible in the DTM.

Similar to a DTM, a DSM can be structured either as a vector dataset (comprised of mass points and optionally 3D breaklines) to model surface elevations or a raster dataset that is interpolated from the vector elevation data to model surface elevations.

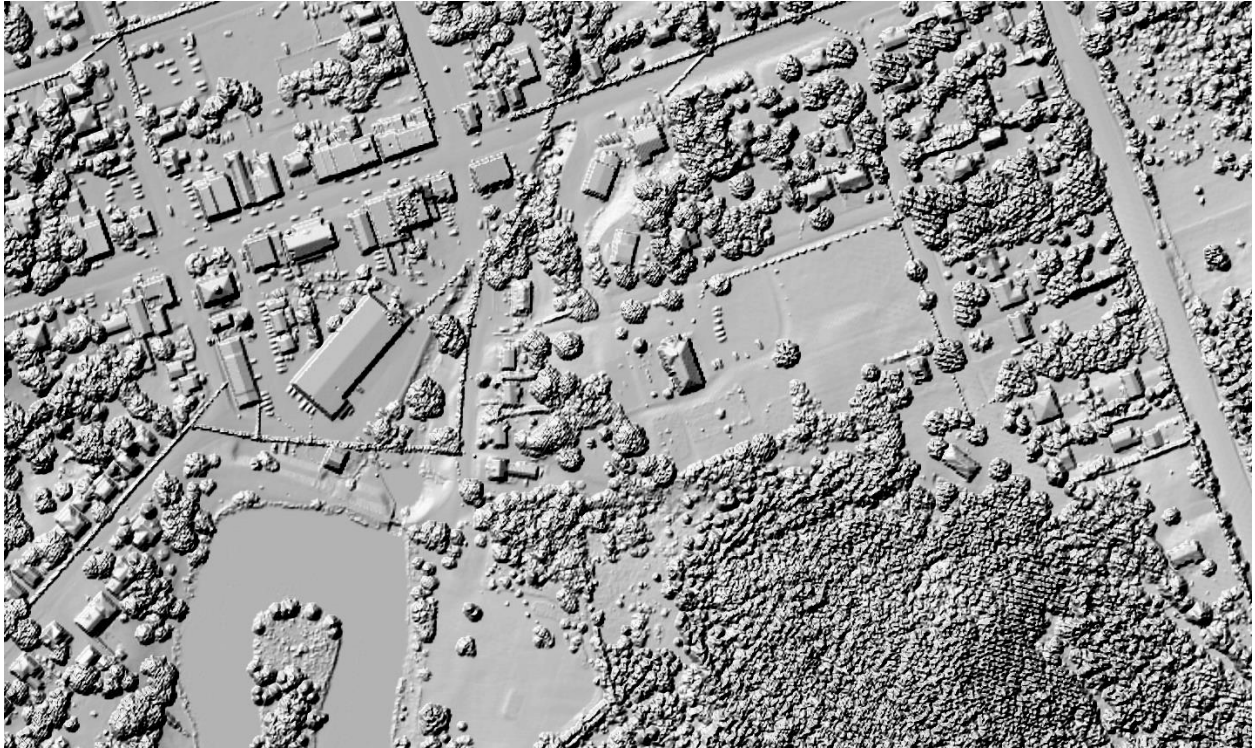


Figure 13: A sample DSM derived from the Lidar Point Cloud.

Using modern elevation point cloud classification algorithms and file formats, such as LAS, a DSM can represent a mass point dataset that has been classified for 'surface' elevation features (MNRF 2015, 23).

Intensity Image

For discrete-return lidar instruments, intensity is the recorded amplitude of the reflected lidar pulse at the moment the reflection is captured as a return by the lidar instrument. Lidar intensity values can be affected by many factors, such as the instantaneous setting of the instrument's automatic gain control and angle of incidence and cannot be equated to a true measure of energy. In full-waveform systems, the entire reflection is sampled and recorded, and true energy measurements can be made for each return or overall reflection. Intensity values for discrete returns derived from a full-waveform system may or may not be calibrated to represent true energy.

Lidar intensity data make it possible to map variable textures in the form of a gray-scale image (Figure 14). Intensity return data enable automatic identification and extraction of objects such as buildings and impervious surfaces, and can aid in lidar point classification.



Figure 14: Image created using lidar return intensity values.

In spite of their similar appearance, lidar intensity images differ from traditional panchromatic images in several important ways:

- Lidar intensity is a measure of the reflection of an active laser energy source, not natural solar energy.
- Lidar intensity images are aggregations of values at point samples. The value of a pixel does not represent the composite value for the area of that pixel.
- Lidar intensity images depict the surface reflectivity within an extremely narrow band of the infra-red spectrum, not the entire visible spectrum as in panchromatic images.
- Lidar intensity images are strongly affected by the angle of incidence of the laser to the target, and are subject to unnatural shadowing artifacts.

The values on which lidar intensity images are based may or may not be calibrated to any standard reference. Intensity images usually contain wide variation of values within swaths, between swaths, and between lifts (MNR 2015, 33-34).

Canopy Height Model

A canopy height model (CHM) represents the height of vegetation above ground. In its simplest form, the CHM can be produced by subtracting the DTM from the DSM (Figure 15).

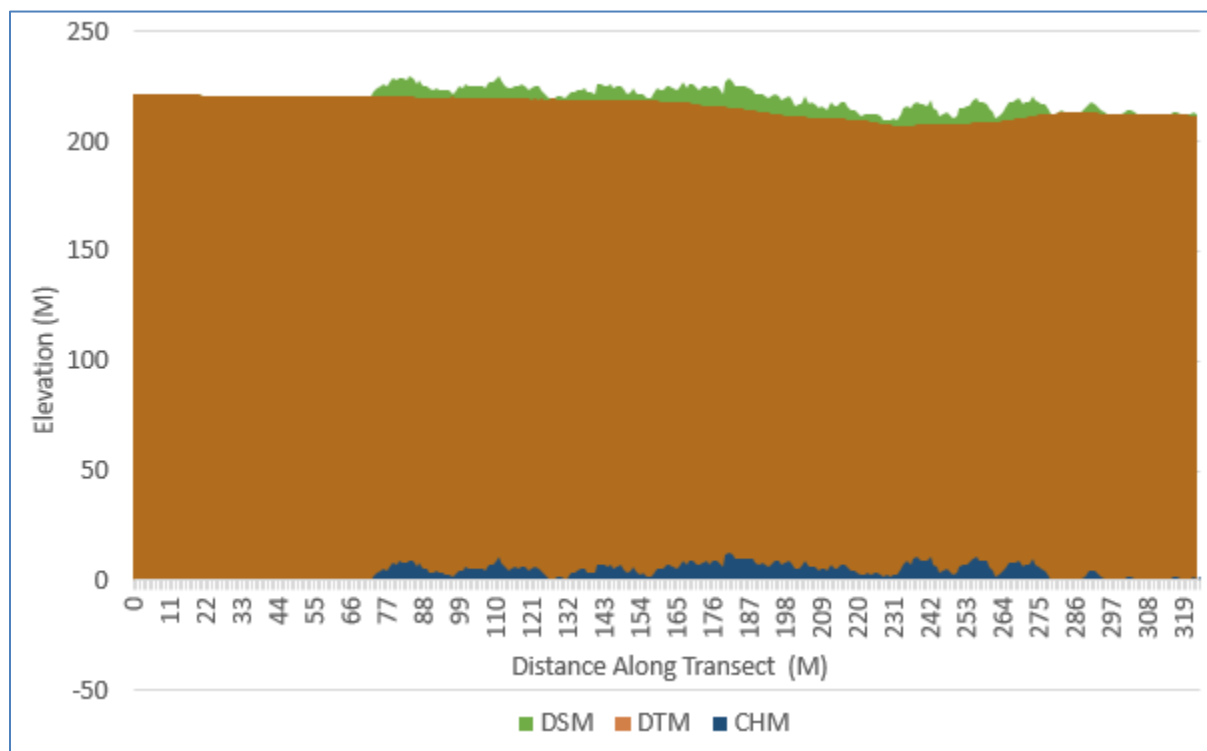


Figure 15: Graph of DSM, DTM and CHM values along a sample transect.

The CHM can be used as an input into more advanced analyses such as estimation of above ground biomass, however, as provided, the Ontario Lidar classified point cloud does not differentiate between vegetation and other structures, such as buildings, so in practice, additional feature extraction algorithms would be required to improve the accuracy of a CHM derived from this data.

Feature Extraction

As provided, the classified lidar point cloud only classifies returns according to USGS LIDAR Base Specifications (V 1.2) minimum classified point cloud classification scheme, however users may wish to apply further classifications to the returns depending on the purposes for which the data is being used. These classifications may be used as a filter to improve the elevation data for a given application, or for the purposes of identifying and mapping a certain category of natural or anthropogenic features. Extraction and/or classification of buildings is a common example. (Figure 16).

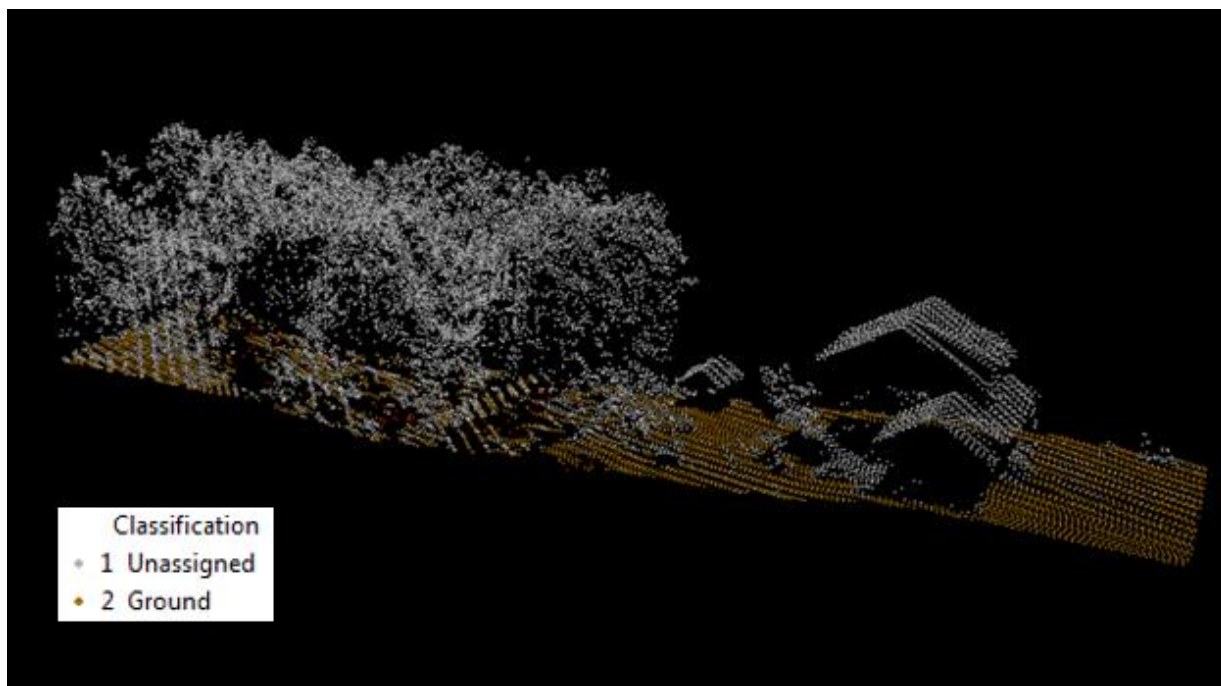


Figure 16: With the human eye, we can interpret trees and buildings from the unassigned values in this sample point cloud.

Various software packages exist to assist with lidar point cloud processing. The point cloud can be classified manually or the classification can be automated by using standard or individually customized processing algorithms that may identify signatures of features taking into consideration factors such as the relative elevation and intensity values of returns in relation to one another.



Figure 17: Electrical transmission towers and lines represented but unclassified in the point cloud.

Utility lines (Figure 17), wind turbines (Figure 18), even aircraft taxiing on runways are represented three dimensionally in this point cloud dataset in the form of unclassified lidar returns. What can be extracted from this data may be limited only by your imagination and available resources.

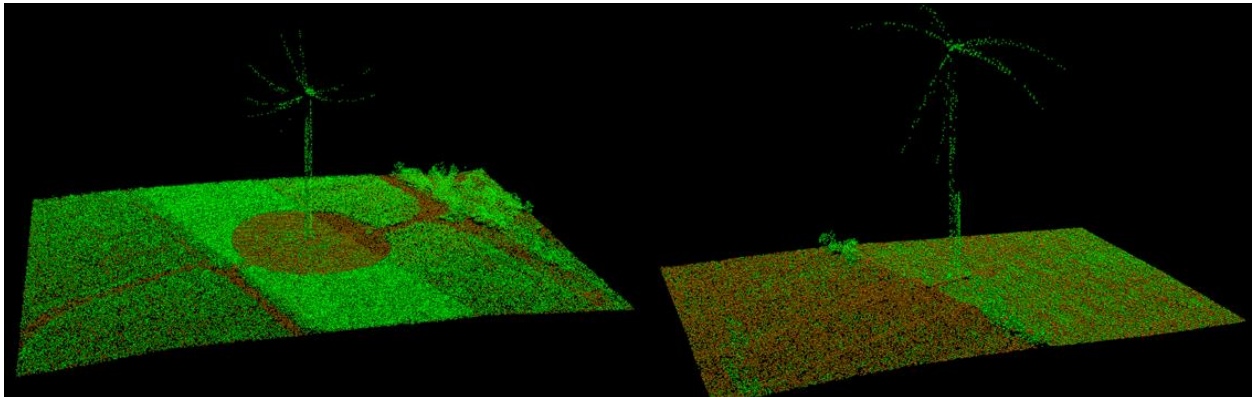


Figure 18: Two examples of wind turbines as represented in the point cloud.

Appendix C: Important Considerations and Product Limitations

Raw Point Cloud

The classified point cloud was created by merging and tiling the raw point cloud, which is organized by lift and flightline swath. The lift represents a single takeoff and landing cycle for the aircraft collecting the lidar data (Figure 19).

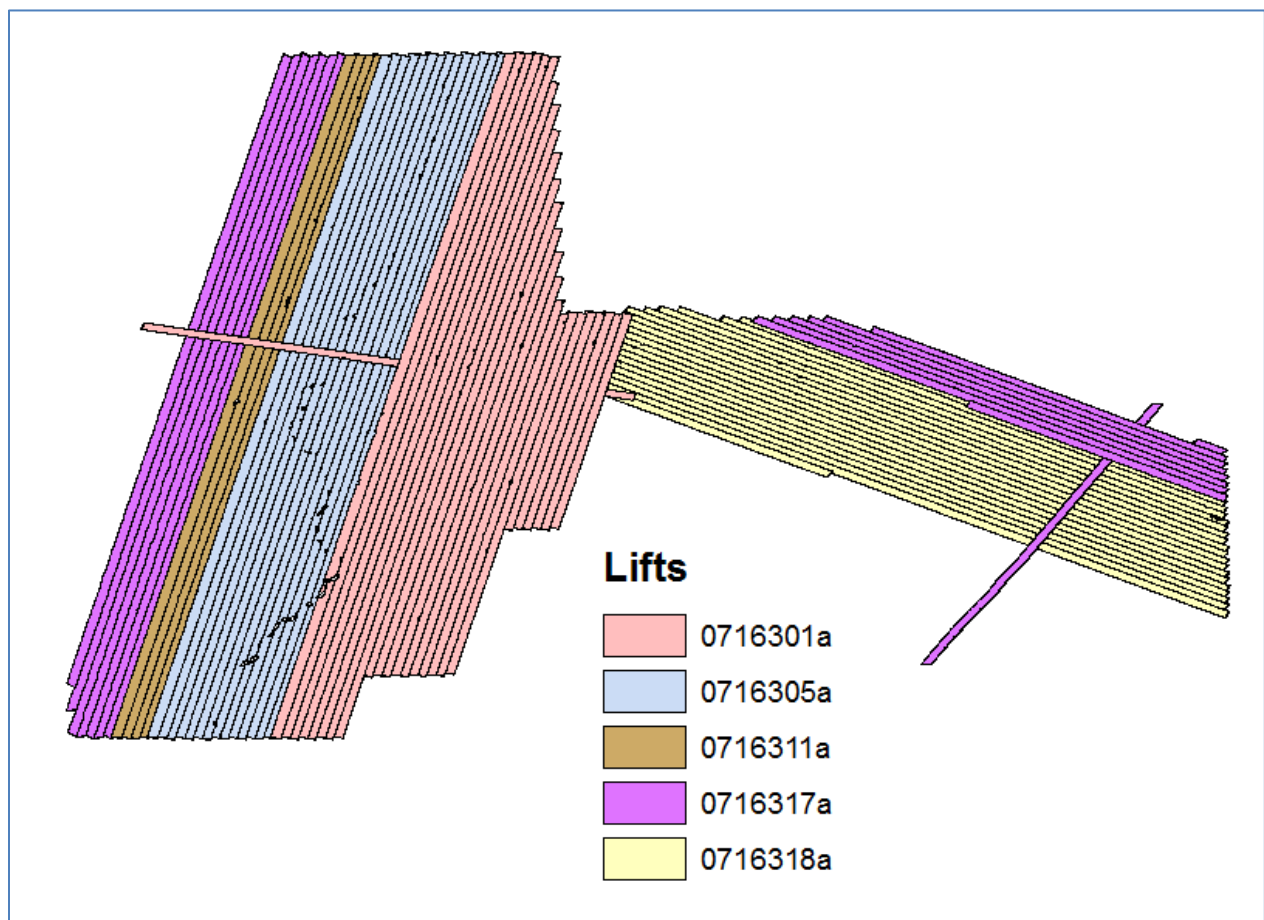


Figure 19: An example of raw point cloud lifts, with flightlines.

The raw point cloud data is stored in .LAZ (compressed LAS) files each of which contain the data collected within an individual numbered, overlapping flight line within the lift (Figure 20).

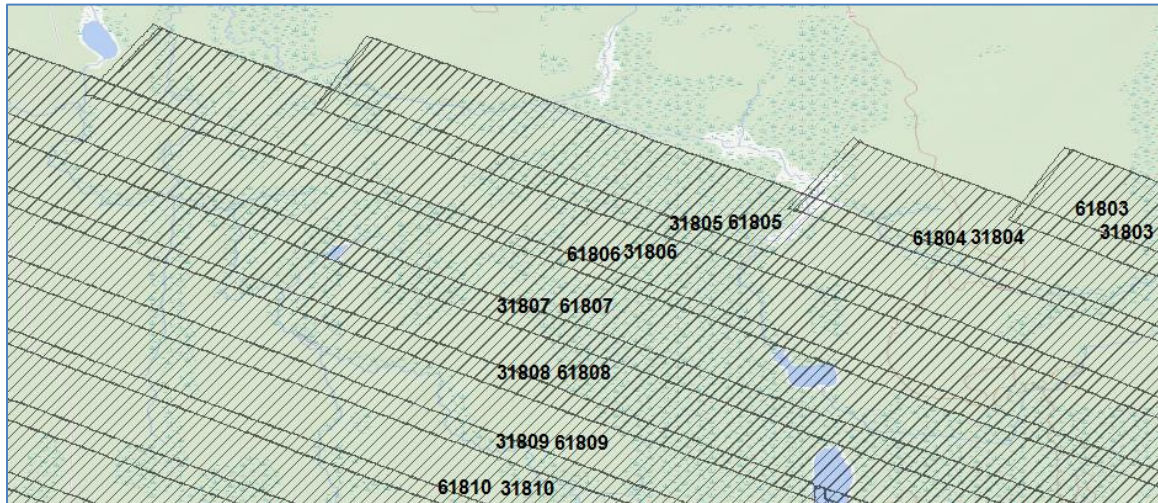


Figure 20: Example of numbered flight lines.

The current available raw data for the Cochrane project consists of 12 lifts and a total of 354 flight lines. The raw data for the Peterborough project consists of 19 lifts and a total of 615 flight lines.

The contractor has provided the following explanation of the raw data file naming conventions:

Mission (lift) and flight line naming convention

Airborne Imaging's convention for naming missions (or lifts) is the following:

e.g. 0716288a where

07 is the Lidar system unique identifier. System 07 and 79 are Leica ALS70-HP.

16 is the collection year (2016)

288 is the Julian day of acquisition (sequential day of the year since January 1)

a is the sequential mission or lift of the day (a = 1st mission, b = 2nd mission, ...)

While importing the raw point cloud swaths into tiles, the flight line numbers adopted are as follows.

e.g. 071628804 where the first seven characters are the same as described in the mission folder name above, plus a sequential strip number for that day:

“04” is the fourth strip acquired that day, 05 is the fifth ...

Note that the Leica ALS70 sensor measures data from two channels on each strip which we separate for calibration and manipulation purposes. Because of limitations of the 64bit field to store the strip identifier, we typically add 300 to the Julian day for the second channel.

So basically from sensor 07, on Julian Day 288, there would be two .las files for strip 04 named: 071628804 and 071658804.

Inside all .las files, the strip number (28804 and 58804) corresponds to the point source ID in the .las files. The Lidar system number is also stored in the .Las files in the "user_data" field. (Airborne Imaging 2017a, 7)

Point Spacing

The spatial distribution of geometrically usable points will be uniform and regular. Although lidar instruments do not produce regularly gridded points, collections shall be planned and executed to produce an aggregate first return point cloud that approaches a regular lattice of points, rather than a collection of widely spaced, high-density profiles of the terrain. (Ontario Specifications for Lidar Acquisition 1.1 2016, 17) While this is the ideal scenario, several factors prevent this from being achieved.

The point cloud was collected with a target density of 8 pulses per square meter, however users may observe in some areas linear gaps of 0.5m to >1m in width and widening away from nadir. These gaps in the measured point cloud collected by the Leica ALS70 sensor are caused by a combination of the scanning pattern of the laser and the splitting of the laser beam. At nadir, or below the aircraft the along track distance between scans are relatively evenly spaced. Figure 21 shows how on the outside edges, the along track spacing of the scans is very tight at the peak of the zigzag and greater in between scans.

In order to increase the number of returns measured, Leica has a proprietary technology that for each outgoing laser pulse, the laser beam is split into two and recorded back on separate channels.

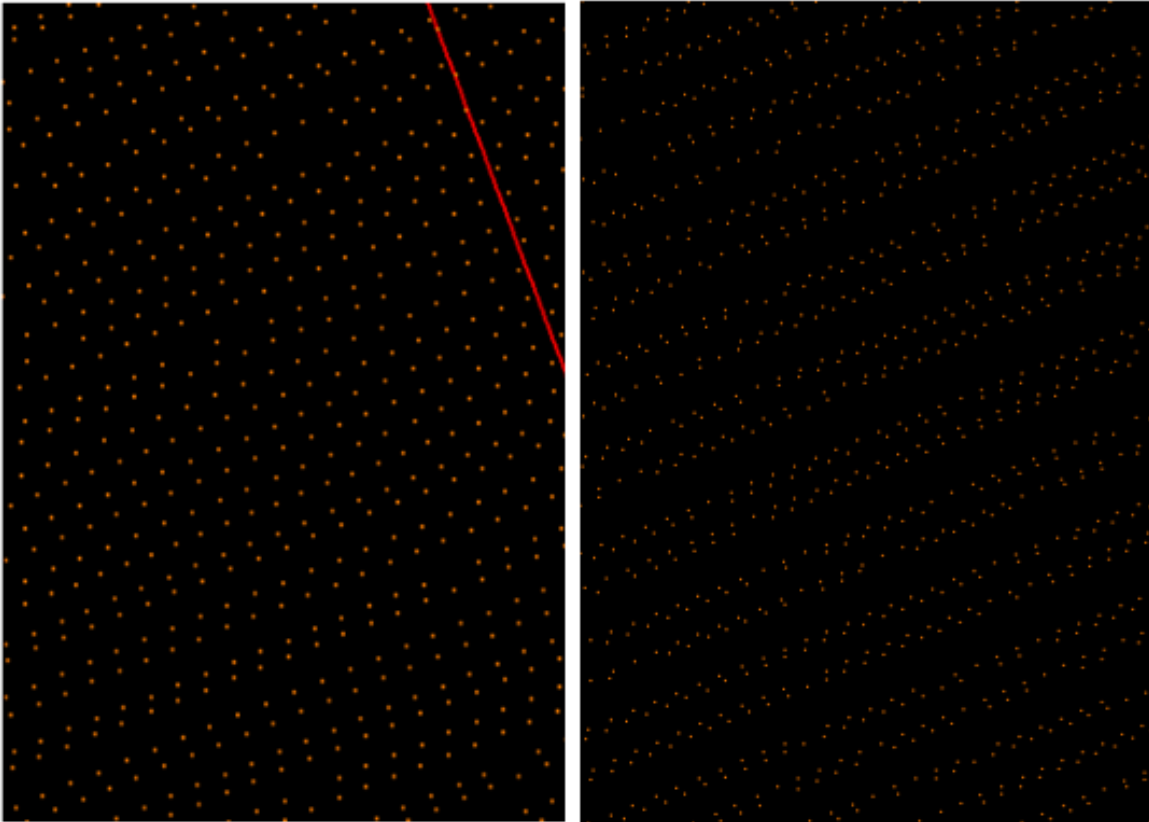


Figure 21: Spacing variations between scan lines.

This results in a forward horizontal separation of about 40 meters for the two measured points at ground level for the same outgoing pulse. Depending on the flight altitude, speed and real-time roll, pitch and yaw movement of the aircraft, the measured points from the two channels will sometimes be “in-phase” (or aligning) and sometimes be “out-of-phase” (staggered) (Figure 22).

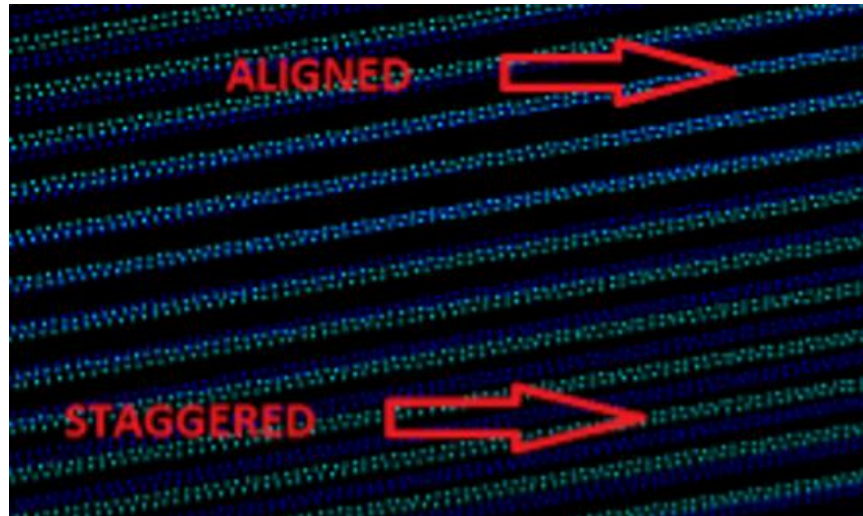


Figure 22: Aligned and staggered point return spacing.

Figure 23, below, illustrates a case where fluctuations in the motion of the aircraft cause changes in pitch which effect the along track pulse spacing resulting in an accordion effect in the point cloud. In this example the two channels for the split pulse are coloured as blue and yellow. As the nose of the aircraft drops the sensor tilts backwards, resulting in the compression of points in the along track direction. As the nose of the aircraft is pulled up the points are stretched farther apart.

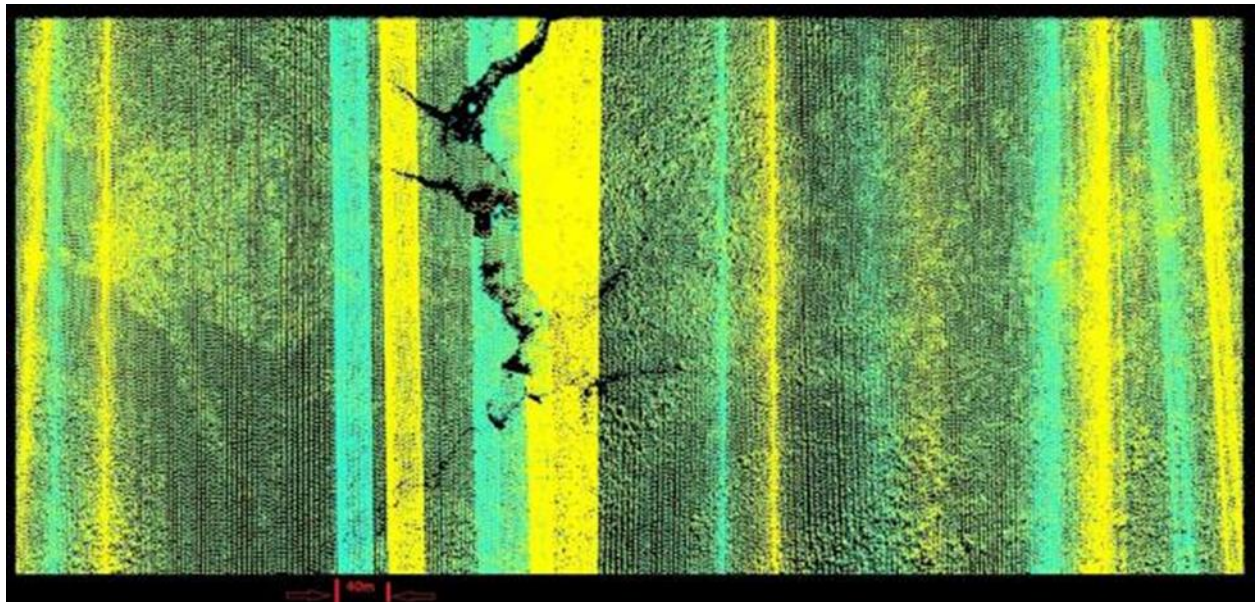


Figure 23: Accordion effect due to changes in aircraft pitch

Points coded as noise appearing below surface.

The classified point cloud as seen in Figure 24 includes points coded as noise which have Z values below the level of ground. These points most likely represent atmospheric interference (clouds). According to the product specifications, the data provider was not permitted to delete points from the point cloud therefore these points were classified as Class 7 – Low Point (noise). Similar interference resulting in erroneous points above ground are classified as Class 18 – High Noise.

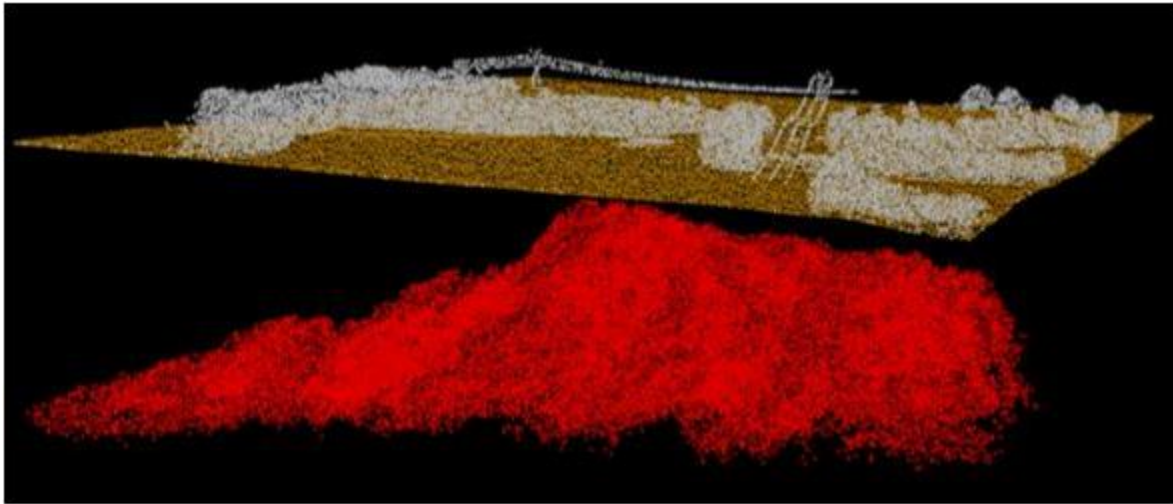


Figure 24: Points coded as noise appearing below ground level.

Tile boundaries extend beyond the collection area boundary

Tile cells outside of the project extent area are recorded with a value of No Data however a small amount of raw data was collected that extends a short distance beyond the project extent (Figure 25). If analysis is required in these areas just outside the project extent, skilled users may consider deriving their own custom DTM from the raw lidar point cloud data.

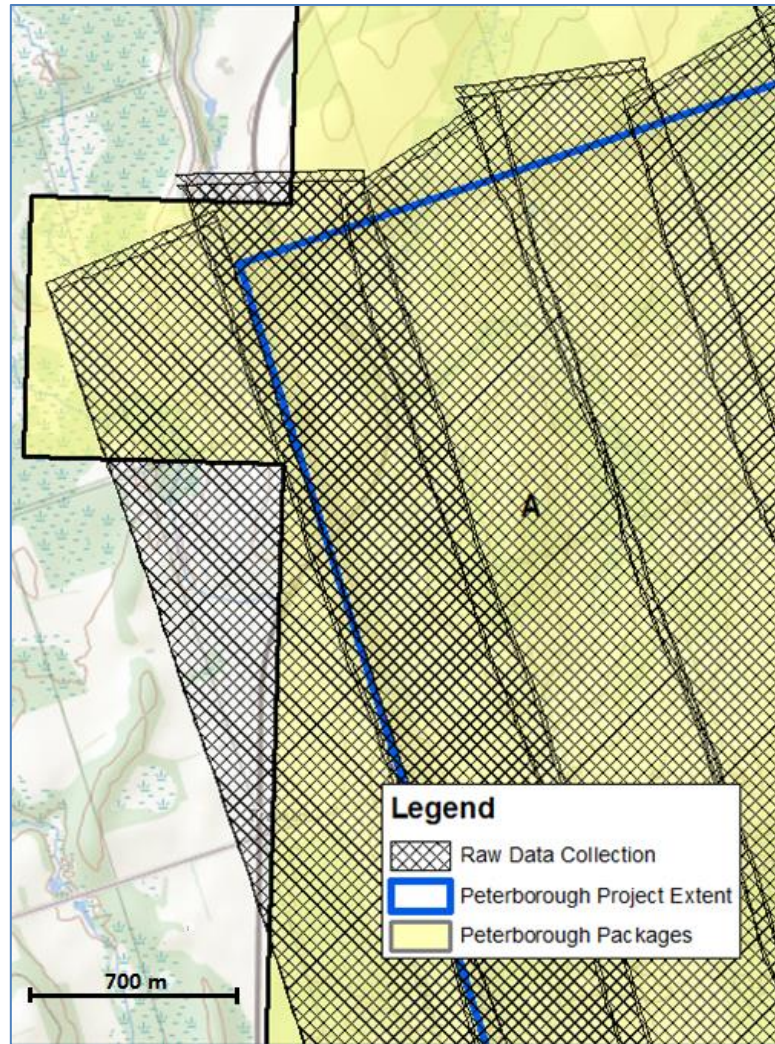


Figure 25: Detail comparing the project and package extents against the raw data collection swaths.

Appendix D: Detailed Vendor-Supplied Data Calibration, Collection, and Processing Information

The metadata documentation supplied by the vendor in .xml format for both the Cochrane and Peterborough project areas provide the following details about the Lidar acquisition process:

Data Collection

The data acquisition phase of the project involves planning flight line coverage, aircraft operations, ground control and calibration as well as logistics for moving personnel and equipment in and out of the project area. Flight line planning is based on existing maps or digital files supplied by the client of the project area. Some of the factors that affect flight planning include ground terrain, location of cities, location of airports, airport flight patterns, etc. Flight lines are plotted on digitized maps so that the coordinates of flight lines can be used in the aircraft's flight management and navigation system. One of the most important and determining factors of flight operations planning is computing GPS satellite visibility models to determine flight exclusion times when there are not enough GPS satellites to track or the PDOP (Positional Dilution of Precision) values are out of tolerance. Airborne will only collect LiDAR data when it is possible to track a minimum of 6 GPS satellites with a PDOP of less than 3.0. Due to the ever-changing satellite geometry, Airborne Imaging will fly multiple day operations during optimum periods of GPS coverage, weather permitting. GPS Reference Station locations are selected which utilize existing federal geodetic control network, CSRS first order vertical to insure accuracy of the LiDAR survey is maintained. The goal is to locate survey control where the published horizontal coordinates have been determined by GPS observation and orthometric heights (elevations) have been determined by precise differential leveling. Ellipsoidal heights are calculated from accepted orthometric elevations and geoid-ellipsoid separations are determined using the geoid model requested by the client, in this case CGVD2013.

Calibration

A calibration site is an area of survey control that is flown twice during every mission, usually at the beginning of a mission and again when the aircraft returns from a mission. This procedure can identify any systematic issues in data acquisition or failures on the part of the GPS, IMU or other equipment that may not have been evident to the LiDAR operator during the mission. The calibration site is usually selected near the airport in a relatively open, tree-less area where several large buildings are located. A profile is surveyed on an open road from a truck-mounted GPS receiver. The post-processed kinematic coordinates are derived from a base station that is part of our geodetic network (normally within two kilometers). At the start of each data acquisition mission, the aircraft flies perpendicularly to the road profile, then turns around and fly over the same area in the opposite direction. The data from the two passes allows us to align the large buildings in the along track direction to relatively calibrate the pitch component. The data from the two passes also allows us to solve for the roll component by making the outside edges of the data match within specifications. The road profile allows us to monitor and correct for any scale error in the point cloud. The vertical comparisons between the point cloud data and the road profile quantify statistically the absolute accuracy of the Lidar data. The aircraft then proceeds to the project area and the operator selects the first flight line to be surveyed. When the aircraft is on line, the operator initiates data collection and stores the data on a removable hard disk drive. A terrain viewer formats and displays the acquired data so that the operator can monitor the data quality in real time. After all flight lines have been completed for the mission, the aircraft returns to the calibration site. The same procedure of flying twice in opposite direction over the road profile is repeated at the end of the mission to monitor if any change or drift in calibration values occurred during the mission. After the mission is completed, the project manager performs kinematic post-processing of the aircraft GPS data in conjunction with the data collected at the Reference Station in closest proximity to the area flown. Double difference phase processing of the GPS data is used to achieve the greatest accuracy. The GPS position accuracy is assessed by comparison of forward and reverse processing solutions and a review of the computational statistics.

Any data anomalies are identified and the necessary corrective actions are implemented prior to the next mission.

QC Data Collection

Ground truth validation is used to assess the data quality and consistency over sample areas of the project. To facilitate a confident evaluation, existing survey control is used to validate the LiDAR data. Published CSRS survey control, where the orthometric height (elevation) has been determined by precise differential leveling observation, is deemed to be suitable. Ground truth validation points will be collected to establish RMSE accuracies for the LiDAR project. These points must be gathered in flat or uniformly sloped terrain (<20% slope) away from surface features such as stream banks, bridges or embankments. After collection, these points will be used during data processing to test the RMSE accuracy of the final LiDAR data products.

Data Processing

Airborne has post-processing methodology designed to use the data from the LiDAR unit, and combines the calibration site and overlap analysis, to create the X,Y,Z raw product. In post-processing, surface values derived from LiDAR data are tested against the known ground surveyed values to determine the correct calibration parameters for each mission. This will immediately identify any systematic issues in data acquisition, or failures on the part of INS, GPS or other equipment that may not have been evident to the LiDAR survey operator during the mission. In order to eliminate the effects of artifacts left in the bare-earth, the original, raw LiDAR data are processed with an automated, artifact removal technique and then followed up by manual inspection of the data. The raw LiDAR data are processed into tiles conforming to the client's requirements. These tiles contain points of all-returns from the LiDAR unit and are stored in individual binary files. Point classification or artifact removal is done using a product by TerraSolid software running on Microstation V8 called TerraScan and TerraModel. The TerraScan software uses macros that are set-up to measure the angles and distances between points to determine what classification a point should be: ground, vegetation, ... The angle and distance values in the macros can be varied to be

more or less aggressive with the classification of points from vegetation to ground by varying the incidence angles and estimated distances among neighboring points. Unless the client specifies, the man-made structures like bridges and buildings are left in the vegetation class. Anything not classified as ground or vegetation is placed into the "low points (noise)" class. "Low points" are normally either very high above the vegetation (spikes) or much below the ground (pits). Clouds, birds, pollution, or noise in the data can cause outlier points, for example. After an automated macro is run, a manual QC effort is made to fine tune the classification of points among the different categories. To better understand areas for improvement, the points that are classified as bare earth are extracted and turned into viewable TIN and grid surfaces. These surfaces are viewed in conjunction with the point cloud for inspection of areas that appear rough, artificially flattened or cut, no data areas, or have other viewable errors. In cleaning up ground points, an effort is concentrated in areas where few ground points have been left in the bare earth model and the ground appears rough or lower and flatter than it may be in reality. The scarcity of ground points may be a result from no penetration through a dense vegetation layer, or too aggressive values with the macro. A manual inspection of these areas plays a major role in resolving any issues or irregularities with the bare earth model. A manual effort is also made to make sure that bridges have been removed from the bare earth model or that any special features, determined by the client are correctly identified as ground or non-ground. This special feature list can include: large rock outcrops, piers and docks, levees, construction sites, and elevated roadways. Both Bare Earth and Full Feature grids are created. Selecting out all points that have been classified as bare earth, from the TerraScan binary files, and creating a TIN and grid surface creates bare earth grids. Extracting out all non-error points from the TerraScan binary files and creating a TIN and grid surface from the highest elevations create highest surface grids. As grids are created, grid cell locations are set to precisely correspond and register between the Bare Earth and Full Feature grids. Cell easting and northing coordinates are calculated as integer multiples of the cell size, so that adjacent tiles can be merged without re-sampling or pixel-shift. As a final step for data processing, all data are exported as deliverables. Any geographic projections or datum shifts are applied to the final, edited versions of the data. The data

are clipped into a tiling scheme, specified by the client, and all files are exported into the format and maximum sizes specified. Upon completion of all exports, files are randomly checked on the deliverable media to ensure transferability and the data are shipped to the client.

QC Data Processing

Airborne has developed a rigorous and complete process, which does everything possible to ensure data will meet or exceed the technical specifications. Experience dealing with all ranges of difficulty in all types of topographic regions has led to the development of our quality assurance methods. QA/QC procedures are continued through all iterations of the data processing cycle. Data pass through an automated set of macros for initial cleaning, a first edit by a trained technician, and a second review and edit by an advanced processor, and finally exported to a final product. All final products are reviewed for completeness and correctness before delivering to the client. All final products pass through a six-step QC control check that verifies that the data meet the criteria specified by the client.

- Step 1 - Completeness Review - All GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database
- Step 2 - LiDAR data is post processed and calibrated - Data is inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the LiDAR unit or GPS. - This initial inspection is repetitive since point density and data integrity are checked by the field personnel prior to leaving the project site.
- Step 3 - Classification of Points- all points are classified as ground and non-ground features. Any non-regular structures or features like towers, water bodies, bridges, piers, are to be classified into the category specified by the client for these feature types.

- Step 4 - Quality Controlling the Bare-Earth model - Adjustments are made to fine-tune and fix specific errors. These areas generally involve fixing those areas where the removal of features was too aggressive, particularly along mountaintops, shorelines, or other areas of high percent slope. Vegetation artifacts leave a signature surface that appears bumpy or rough. Spurious vegetation values and remnants from the bare-earth model are removed.
- Step 5 - Vertical Comparisons - The Lidar ground surface is compared to independently surveyed points on unobstructed roads. These check points are collected by truck mounted kinematic GPS and post-processed from a nearby base stations. A Triangulated Irregular Network (TIN) is created from the point cloud's ground class and vertical differences computed from where the check points intersect the triangles. In the event of a vertical bias observed, the point cloud is occasionally shifted vertically to match the kinematic ground truth. This resulting RMSEz on open flat terrain can be used to determine the Fundamental Vertical Accuracy (FVA) at the 95% confidence level.
- Step 6 - Final QC- Deliverables Check - Checks for file naming convention, integrity checks of the files, conformance to file format requirements, media readability, and file size limits (if any), and finally reports as completed.

