Specifications for Airborne LiDAR for the Province of British Columbia

Ministry of Forests, Lands, Natural Resources Operations and Rural Development GeoBC

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Victoria (BC), Canada

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1.0 RECORD OF AMENDMENTS

Version No.	Revision made by	Page#	Revision Description	Approved by	Date
1.0	Harald Steiner	1-36	Re-write	Harald Steiner, PEng	31-Mar-2013
2.0	D. Garnham	1-40	Major revision of 1.0	Harald Steiner, PEng	21-Mar-2014
3.0	Isabelle Paquin Brett Edwards James Thompson Robert Prins	1-42	Revision to align with GeoBC 2016 DEM specifications	Harald Steiner, PEng	04-Oct-2016
3.1	Brett Edwards James Thompson	14, 27-29, 34, 37	Revisions to classes, data formatting, reporting, naming and other minor edits	Robert Prins	30-Apr-2018
4.0	Yuna Jiao Brett Edwards Jordan Godau	1-47	Re-write	Harald Steiner, PEng	30-Apr-2019
5.0	Samantha Grant Brett Edwards Jordan Godau James Thompson	1-54	Re-write	Harald Steiner, PEng	09-Apr-2020

2.0 INTRODUCTION

These specifications were compiled to provide geospatial data suppliers with common standards and clear requirements to produce LiDAR datasets collected by airborne LiDAR scanning systems (ALS). The objective is to obtain consistent, high-quality LiDAR product deliverables to the British Columbia Provincial Government.

These LiDAR specifications supersede all previous LiDAR specifications. It should be noted that this document is a living one, and it will be updated and maintained through ongoing feedback from industry experts and advances in LiDAR technology.

The term “Branch”, when used herein, shall mean GeoBC of the Ministry of Forests, Lands and Natural Resource Operations and Rural Development in the Province of British Columbia.

The Branch shall be the final authority on acceptance or rejection of submitted LiDAR data. All LiDAR material, data and products delivered to the Branch shall meet or exceed the following specifications.

For the purpose of these specifications, the word “shall” indicates a mandatory requirement and “should” indicates a desirable requirement.

3.0 PURPOSE AND SCOPE

This document has been created to outline clear specifications for the support of Quality Assurance (QA) and Quality Control (QC) of LiDAR data. The Branch refers to LiDAR data in this document as discrete return LiDAR data; this document does not address full waveform LiDAR data and deliverables.

This document is not meant to be prescriptive but does describe desired results and tolerances. More precisely, the purpose of these specifications is to ensure:

- Minimum standards regarding accuracy, deliverables, and quality;
- Proper and consistent deliverables;
- High levels of data integrity.

4.0 ACQUISITION AND QUALITY ASSURANCE

Quality Assurance (QA) is a set of activities that ensure the quality of LiDAR data in the development of LiDAR collection through project planning. In particular, the measures that are taken to ensure the quality of the source data, before and during the acquisition stage of the project.

4.1 LiDAR Acquisition Guidelines

Flight and mission planning are typically the responsibility of the vendor, as LiDAR sensors have variable requirements and operational parameters. Focus shall be put on ensuring specification standards and project specifications are met. The proposed flight plan covering the geographic area of interest (AOI) and expected buffered project area (*see* Section 4.6) shall be defined as a set of flight lines attributed with planned flying height and flight line overlap (at minimum 30% in all project areas unless otherwise indicated in a project contract). When planning the buffered project area (BPA), a flight line centre should be positioned on the border of the AOI before drawing additional flight lines.

Flying height is defined as the aircraft altitude above ground level (AGL) at nadir position adhering to flying height safety protocols. Keeping a constant flying height above ground reduces systematic errors that are difficult to detect such as laser range scale errors and ensures a consistent laser beam footprint which can affect the horizontal accuracy of the data. In some cases, where there are supporting sensor requirements such as aerial photography for producing rectified imagery, more than one pass may be required to capture data within the desired parameters.

The aircraft bank angle shall be maximum 15° (absolute maximum 20°) unless the safety of the aircrew/aircraft is at risk.

Environmental conditions for LiDAR data collection shall follow these guidelines:

- Atmospheric conditions shall be cloud and fog free between the aircraft and ground during all collection operations.
- Ground conditions are snow free. Very light, undrifted snow may be acceptable with prior approval from the Branch.
- Ground conditions shall be free of extensive flooding or other form of inundataion, without prior approval from the Branch.

The flight plans shall be provided as ESRI shapefiles, and the system specifications and operation parameters documented and submitted to the Branch. *See* Section 7.5 for Mission Planning Report requirements.

Errors due to LiDAR system malfunctions shall be recorded and reported to the Branch through flight reporting (*see* Section 7.6). A malfunction is defined as a failure anywhere in the acquisition platform that causes an interruption to the normal operation of the system. Any sensor changes, failures or replacements prior to or during the data collection shall also be reported.

4.2 LiDAR Error Budget

Errors can be categorised into two groups: random and systematic. Systematic errors, with respect to LiDAR, are errors that can be compensated for through a LiDAR system calibration (*see* Section 4.3); whereas random errors include those errors that remain once systematic errors are removed.

Typically, the most common source of systematic errors in LiDAR data are caused by angular misalignments and lever-arm offsets relating the various components of the scanning system. Other potential sources of systematic errors include scan angle errors and range scale errors. Regardless of the source of error, any indication of systematic errors in the data before, during, or after data processing shall be reported to the Branch. All systematic errors shall be accounted for and corrected upon data submission.

Random errors will always remain in the point cloud after systematic errors have been corrected. Remaining random errors should be small in magnitude and randomly distributed throughout the data.

4.3 System Calibration

Calibration, when applied to a LiDAR acquisition system (herein referred to as LiDAR system calibration), refers to the process of identifying and correcting for systematic errors in the sensor configuration (misalignments and offsets), hardware, software and/or procedures. LiDAR system calibration and maintenance shall be performed to ensure proper function of the LiDAR system.

Normal aircraft operations can induce slight variations in component mounting, therefore a LiDAR system calibration shall be performed at least once. For redudnacy, it is recommended to fly an additional calibration at the end of the project. If any modifications are made to any of the calibration parameters (including sensors), the vendor shall provide a LiDAR system calibration report after any modifications, in addition to the original LiDAR system calibration report.

The ideal calibration site is clear of vegetation and has both flat and sloped surfaces of different aspects. For example, an airport is ideal as it contains a significant amount of flat terrain, along with sloped rooftops. Additionally, LiDAR system calibration flights (to determine systematic errors) should be conducted at an altitude in order to meet the laser pulse footprint specification listed in Section 4.7.

A report containing all calibration parameters and results shall be submitted to the Branch prior to acquisition (*see* Section 7.3). The LiDAR point data from this calibration shall be submitted to the Branch prior to acquisition (*see* Section 7.1). An instrument calibration performed by the manufacturer shall be provided to the Branch upon request.

4.4 LiDAR Data Adjustments

The Branch defines data adjustment as correcting LiDAR point cloud data for un-modelled errors that remain after performing a LiDAR system calibration. These additional errors may be corrected via data adjustment methods (e.g. strip adjustment, Helmert transformation, etc.) so long as the vendor supplies a detailed adjustment report describing the methodology, software used, and all output results.

4.5 Ground Control

This section shall utilize the following terms, as defined by the Branch:

- Primary Geodetic Control Points (first-order) – Canadian Active Control System (CACS) or GNSS occupied on passive Canadian Base Network (CBN) stations.
- Secondary Geodetic Control Points (second-order) – GNSS occupied on an existing provincial monumentation (e.g. brass cap, GCM, etc.), where new coordinates shall be independently produced (i.e. published coordinates of the monument are not to be used).
- Ground Control Point(s) (GCPs) – Newly established, on-site survey points used for geometric adjustment of the LiDAR point cloud; no previously existing marker.

All aerial LiDAR survey missions shall be referenced to Global Navigation Satellite System (GNSS) observed control points. GNSS ground control surveys that fulfill minimum Branch requirements shall adhere to the following guidelines:

- In the case of differential GNSS processing, project control shall be referenced to at least one Primary Geodetic Control Point - fixed Canadian Base Network (CBN) or Canadian Active Control System (CACS) Station.
- In the case of single point positioning (observed on Secondary Geodetic Control or GCP), Natural Resource Canada's (NRCan) Precise Point Positioning (PPP) post-processing service shall be used.
- Vertical datum used shall be CGVD2013 for all submitted control. Refer to the latest published geoid model from the Geodetic Survey of Canada (https://webapp.geod.nrcan.gc.ca/geod/data-donnees/geoid.php).
- The vertical accuracy of the GCPs shall be five times better than those outlined in Table 2.
- The horizontal accuracy of the GCPs shall be ten times better than the theoretical horizontal accuracy of LiDAR outlined in Section 6.5.3.
- GNSS observations shall be conducted by an experienced designated professional (e.g. Geomatics Technologist, Professional Land Surveyor, Geomatics Engineer, etc.).
- Unless otherwise specified in the project contract, the GeoBC approved epochs follows those outlined and adopted by NRCan (https://www.nrcan.gc.ca/earth-sciences/geomatics/canadian-spatial-reference-system-csrs/adopted-nad83csrs-epochs/17908); 2002 for all British Columbia excluding Vancouver Island, where epoch 1997 shall be used.

The number of control points required for the project will depend largely on the size and location of the project site(s). It is the responsibility of the vendor to determine the final number of control points needed for each individual project area, however, the number of control points for assessing accuracy of the point cloud shall adhere, at a minimum, to the following requirements:

- For all isolated project areas[1], 10 control points are required, evenly distributed over the area. If a least squares LiDAR strip adjustment is not performed, 30 control points are required.
- Control points used to assess the quality of the point cloud (QC) shall remain within the AOI.

As a guideline, the following should be taken into consideration in the planning and occupation of GCPs for the project site(s):

- GCPs should attempt to cover all project extremities.
- Sky obstructions at the GCPs; observations taken in clear, open areas free from vegetation and overhead obstructions (e.g. trees, buildings, etc.)
- Avoid highly reflective surfaces (e.g. tin roofs or vehicles), and areas with heavy vehicle traffic to mitigate the possibility of multipath.
- Geomagnetic conditions on the day of observations.
- Geometry and number of satellites overhead during the time of observation.
- Baseline lengths to be processed (for differential processing of baselines to known coordinates).

Vendors shall supply a full control report outlining all the minimum requirements listed in Section 7.10; this includes any reports related to processing GCPs (e.g. Post processing, Least Squares Adjustment, etc.).

Vendors using GNSS should refer to "Specifications and Guidelines for Control Surveys Using GPS Technology" [1] for best survey practices.

4.6 Spatial Distribution of Pulses and Planned Area Coverage

The projected collection area – the Area of Interest (AOI) - shall buffer 100 metres outside of the AOI borders to create a Buffered Project Area (BPA). Data collection is obligatory to the full extent of the BPA, and all products shall be generated to the full extent of the BPA.

All collected swaths and all collected returns within each swath shall be delivered as part of the final deliverables. No original points are to be deleted from the LAZ files apart from data that falls outside the BPA.

4.6.1 Spatial Regularity

The spatial distribution of geometrically usable pulses shall be collected uniformly to represent a regular lattice distribution [2]. Although LiDAR instruments do not produce regularly distributed points, collections shall be planned and executed to generate net nominal pulse spacing (*see* Section 6.3.2) that strives to represent a regular lattice of points.

[1] The Branch defines isolated project areas as project areas that are spatially separated in such a way that collected LiDAR swaths will no longer overlap on topographical features. This spatial separation usually occurs when delineated project areas are not continuous (made up of many separated vector polygons) or when there are existing natural features (e.g. large water bodies) preventing LiDAR swaths from overlapping on topographical features.

This regularity of the point pattern and density throughout the dataset should be assessed using a method comparable to the following steps using single return points:

- Generate a density grid with cell sizes equal to twice the required LiDAR Nominal Pulse Spacing (NPS) for the Quality Level (QL) of the project (*see* Section 6.3.2).
- Ensure that 90% of the cells in the grid contain at least one usable LiDAR point that falls within the geometrically usable centre part (typically 95%) of each individual swath.
- Exclude acceptable data voids (*see* Section 4.6.3).

4.6.2 Flight line Overlap and Area Coverage

A daily coverage check shall be performed in the field by loading the cumulatively acquired LiDAR dataset, including data within the BPA, into a capable software package. The data shall be thoroughly examined therein for the following:

- The project area's data coverage;
- Gaps between flight lines (flight line overlap shall be at minimum 30%);
- Data voids, (*see* Section 4.6.3);
- Any other anomalies caused by sensor and/or acquisition errors.

These checks shall be repeated prior to the aircraft leaving the survey area to ensure full coverage to the extent of the BPA. Re-flights shall be planned and completed if data voids exist and/or errors are found to cause gaps. The Branch shall not be held financially responsible for the cost of remobilizing the aircraft for re-acquisition.

4.6.3 Data Voids

Data voids can occur in LiDAR data collection due to various reasons; surface absorbance, scattering, or refraction of the LiDAR pulse. Data voids covering areas larger than $(4 \times NPS)^2$ [3] for single swaths, single return points, are not acceptable, except where caused by the following:

- Waterbodies
- Areas of little Near Infra-Red (NIR) reflectivity (i.e. dark tar-asphalted surfaces).
- Where appropriately filled in by another swath [3].

Object shadowing (e.g. buildings, towers, vertical cliffs) shall be accounted for through subsequent flight lines, unless otherwise stipulated in the project contract.

4.7 Beam Divergence and Laser Pulse Footprint

The Branch defines beam divergence of a LiDAR system as an angular measure (mrad) of the spread of an emitted signal pulse. The emitted signal pulse assumes a 2D Gaussian distribution [4], where the pulse beam diameter in the eyes of the Branch, shall be reported at $1/e^2$.

Unless otherwise specified, LiDAR acquisition shall be planned with a ≤0.35m laser pulse footprint diameter at $1/e^2$.

5.0 DATA PROCESSING AND MANAGEMENT

This section describes expectations of final LiDAR deliverables regarding specific data format properties, classification, tiling, and data delivery.

5.1 Data Format

All LiDAR data shall be delivered in ASPRS LAZ 1.4 format, with point record format 6 [5] unless otherwise specified in the contract. Specific data format properties are discussed here for clarification and emphasis. However, data formatting shall be fully compliant with the ASPRS LAS Specifications unless otherwise specified in this document [5].

5.1.1 Intensity

The intensity value is the numerical representation of the pulse return magnitude and shall always be included for each discrete return. Intensity values shall always be reported as a 16-bit, unsigned value. If the dynamic range of the sensor used is not 16 bits, it shall be converted to a 16-bit value by multiplying the value by 65,536/(intensity dynamic range of the sensor). See the LAS Specification 1.4 for additional information regarding intensity values [5].

5.1.2 GPS Time

GPS time data in the LAS/LAZ files shall be recorded as Adjusted Standard GPS time. All points within a data set deliverable shall have a valid GPS time for each point record. GPS week and GPS time errors will not be accepted by the Branch and is criteria for rejection of the delivered dataset.

5.1.3 Coordinate Reference System

In all projects and files, the coordinate reference system (CRS) used shall be recognized by the European Petroleum Survey Group (EPSG). All files shall contain a CRS that is recognized by current industry standard geographic information systems (GIS) software.

The CRS shall be defined in the LAS/LAZ header in Well Known Text (WKT) format. For the definition of WKT, the Branch refers to the Open Geospatial Consortium (OGC) specifications from 2001 [6]. Additionally, the projection shall be defined as a compound coordinate system, including both the vertical and horizontal CRS. See Appendix C for a sample of an accepted compound CRS in WKT format.

5.1.4 Global Encoding

Global Encoding is a bit field used to indicate certain global properties about a file [5]. The global encoding bit field contains information specifying the type of GPS time and CRS representation in the LAS/LAZ file. If the GPS time is recorded as adjusted standard GPS time and the CRS is represented in WKT format, and no other bits are set, the global encoding value shall be 17 [5]. This is the accepted, default global encoding value for all LAS/LAZ files submitted to the Branch. For additional information on global encoding values, refer to the ASPRS LAS Specification 1.4.

5.1.5 Point Data Record Format

The Point Data Record Format (PDRF) is a standardized encoding by the ASPRS for attributes included for each point record in a LAS file. For all standard LAS/LAZ deliverables, the default PDRF should be 6.

It should be noted that certain circumstances may require a specific PDRF. Selection of an appropriate PDRF should be based on the necessary attributes required to represent the nature of the dataset – choosing the wrong PDRF could result in a loss of meaningful information, or conversely, increase the size of a file unnecessarily.

It is the sole responsibility of the data vendor to select an appropriate PDRF. Data vendors should refer to the latest version of the ASPRS LAS specifications for more information about PDRFs (https://www.asprs.org/).

5.1.6 Global Unique Identifier

The Global Unique Identifier (GUID) is a hexadecimal encoded field in the LAS/LAZ file header that allows users to globally relate a dataset to a single project. Additionally, assigning a GUID ensures preservation of the lineage of a dataset for downstream users. The GUID shall be appropriately set for all LAS/LAZ deliveries, such that it is the same for all files within a project.

All GUID entries shall be derived from the Project Operation Number (PON) assigned by the Branch, in hexadecimal binary encoding. Moreover, the GUID field requires that all GUID entries adhere to the format: 00000000-0000-0000-0000-000000000000. Given these constraints, the following example describes how to correctly generate a GUID for the project:

Project Operation Number:	**L-001-BCT-12**
Project Operation Number in hexadecimal binary:	**4c2d3030312d4243542d31322**
Project Operation Number (GUID formatted):	**4c2d3030-312d-4243-542d-313220000000**

Many free online converters provide an easy method for converting text to hexadecimal binary encoding. However, in the absence of internet access, or in the case that data vendors do not want to use online sources to do this conversion, the Branch shall provide a tool for generating a correct GUID number upon request. For more information about GUIDs, refer to the latest version of the ASPRS LAS specifications (https://www.asprs.org/).

5.1.7 System Identifier

The System Identifier field in the LAS/LAZ file header shall be populated in all delivered files. The field shall be populated with different entries depending on if the LAS/LAZ file is a raw strip of data, or if it is a tile containing overlapping strips of data.

If the file contains raw LiDAR strip data, the System Identifier field shall contain the make and model of the LiDAR system, followed by the serial number of the LiDAR system.

Example: Li-MarkV VQP-15650j; S2223546

If the file contains tiled LiDAR data from overlapping strips, the System Identifier field shall contain the make and model from all sensors used within that tile.

Example: SysTech Orion G2000

5.2 Point Cloud Classification

Table 1 is modified from the "ASPRS Standard LiDAR Point Classes" and lists the basic Class Codes that shall be used for LiDAR classification of PDRF 6 through 10 (*see* Section 5.1.5). LiDAR classification assignments for data submitted to the Branch are outlined in the LiDAR Quality Control Report (*see* Section 7.2), unless otherwise specified in the contract.

Outliers, noise points, geometrically unreliable points near the extreme edge of the swath, and other points the vendor deems unusable shall be identified using Class Code 7. This classification applies primarily to unusable points that are identified during pre-processing, through automated post-processing routines, and during manual classification or QA/QC.

Table 1. Modified ASPRS Standard LiDAR Point Classes (PDRF 6-10) [5]

Class Code	Description
0	Created, never classified (raw data)
1	Unclassified[2]

[2] ASPRS refers to classes 0 and 1 as *Unclassified* to maintain compatibility with current popular classification software [packages] [5]

2	Ground
3	Low Vegetation (< 0.3 metre)
4	Medium Vegetation (0.3-1 metre)
5	High Vegetation (> 1 metre)
6	Building
7	Noise (Withheld Point)
8	Reserved
9	Water Body
10	Railroad
11	Road Surface
12	Reserved
13	Wire – Guard (Shield)
14	Wire – Conductor (Phase)
15	Transmission Tower
16	Wire-structure Connector
17	Bridge Deck
18	High Noise
19-63	Reserved
64-255	User Definable

If overlap points are required to be differentiated by the vendor, they must be identified using a method that does not interfere with their classification, such as assigning a classification flag point attribute bit (i.e. OVERLAP), as described in the article on the LAS 1.4 Specification (https://www.asprs.org/wp-content/uploads/2010/12/LAS_Specification.pdf). The technique used to identify these overlap points must be clearly described in the project reports.

When classifying LiDAR in tiles, overlap shall be incorporated whenever classifying ground routines to ensure no errors generated at the edge of the tile are included in that tile. In other words, if running a ground detection routine on a tile, a minimum of 10 metres of data should be temporarily referenced from adjacent tiles to eliminates errors introduced at the edge of the tile. LiDAR data referenced from adjacent tiles shall not be saved as part of the final tile.

Further instructions regarding classification:

- No points in the LAS/LAZ deliverable shall remain in Class Code 0.
- Depending on the project requirements, the Class Code 2 (Ground) may include other flat surfaces (e.g., Roads, Parking lots, Bridge decks) unless otherwise requested in a project contract.
- If only ground and non-ground classes are required, use the Class Code 1 (Unclassified class) to classify non-ground points outside of Class Code 7 (Noise).
- All noise and withheld points shall be stored as Class Code 7 unless otherwise specified.

- All points delivered that are between the AOI and BPA shall be classified according to contract and specification requirements.
- There shall be no ground classified points within large water bodies (8000m^2), inside the AOI or BPA.
- Where break lines are used to delineate water bodies, points within those areas shall be classed to Class Code 9 (water), unless otherwise specified in the project contract.

Point classification shall remain consistent over the entire project, with any variations in the classification between tiles, swaths or lifts being cause for rejection of the deliverable.

5.3 Tiling

All tiles shall be delivered in the British Columbia Geographic System (BCGS) 1:2500 mapsheet grid system, unless otherwise indicated. BCGS tiling shapefiles shall be provided by the Branch. This tiling scheme shall:

- Adhere to the Branch naming convention (Appendix B)
- Use the same coordinate reference system and units as the data.
- Tiled deliverables shall edge-match seamlessly and without gaps.

5.4 Data Handling and Shipping

Data shall be delivered on one or more NTFS format USB 3.0 hard drives, with no less than 2TB of storage. Submitted storage devices shall be labelled with job number/name, collection dates of contained data and a description of contents. Unless stated in the contract, projects consisting of several individual areas on a single hard drive need to be broken down and submitted into area specific directories containing LiDAR data submissions. Where the project covers multiple UTM zones, deliverables in each UTM zone shall be submitted in their own respective UTMZONE# folder (i.e. \UTMZONE9\). Examples of the required folder structure and naming are as follows:

- o <DRIVE>:\UTMZONE#\<SPECIFIC_AREA_NAME>\ACQUISITION_DELIVERABLES
- o <DRIVE>:\UTMZONE#\<SPECIFIC_AREA_NAME>\PRODUCTION_DELIVERABLES\DERIVED_PRODUCTS
- o <DRIVE>:\UTMZONE#\<SPECIFIC_AREA_NAME>\PRODUCTION_DELIVERABLES\LAS_POINT_CLOUD
- o <DRIVE>:\UTMZONE#\<SPECIFIC_AREA_NAME>\PRODUCTION_DELIVERABLES
- o <DRIVE>:\UTMZONE#\<SPECIFIC_AREA_NAME>\ADDITIONAL_INFORMATION

Data must be shipped via courier to the address specified in the contract, and arrive on or before the contract delivery date. The vendor shall notify the Branch that the data has been sent, along with the contents of the shipment, any associated tracking number(s) and/or a faxed or digital copy of the shipping confirmation.

6.0 QUALITY CONTROL PROCEDURES

Quality Control (QC) provides routines and consistent checks to ensure data integrity, correctness, and completeness. Before compiling the deliverables, a quality control procedure shall be implemented to provide confidence of the dataset. *See* Section 7.2 for QC reporting requirements.

6.1 LiDAR Quality and Density Level

The Branch requires the QC of LiDAR data to be evenly assessed over the entire project area. For every project, the Branch will specify which of the five QL requirements the supplier shall adhere to concerning the LiDAR data. QL1 requires the highest accuracy and resolution while QL5 requires the lowest.

Table 2. Vertical Accuracy Requirements per Quality Level

Quality Level	Vertical Accuracy $RMSE_z$ (68% conf.)
QL1	≤ 5.0 cm
QL2	≤ 10 cm
QL3	≤ 20 cm
QL4	≤ 1.0 m
QL5	≤ 3.0 m

Table 3. Nominal Pulse Density (NPD), Nominal Pulse Spacing (NPS) and Achieved Ground Point Density (AGPD) Requirements per Density Level

Density Level	LiDAR NPD (pulse/m^2)	LiDAR NPS (m)	LiDAR AGPD (points/m^2)	LiDAR AGPS (m)
DL1	≥ 12	≤ 0.30	≥ 3.5	≤ 0.53
DL2	≥ 8	≤ 0.35	≥ 3.0	≤ 0.60
DL3	≥ 4	≤ 0.5	≥ 2.0	≤ 0.70
DL4	≥ 2	≤ 0.7	≥ 1.4	≤ 0.84
DL5	≥ 1	≤ 1.0	≥ 1.0	≤ 1.0

The values listed in Table 2 for each QL are defined as follows:

- Vertical Accuracy -> Required maximum non-vegetated elevation Root Mean Squared Error ($RMSE_z$) relating to the measures done on the LiDAR ground surface points and reported at 68% Confidence Level (CL).

The values listed in Table 3 for each DL are defined as follows:

- LiDAR Nominal Pulse Density (NPD) for emitted LiDAR pulse data (minimum)
- LiDAR Nominal Pulse Spacing (NPS) for emitted LiDAR pulse data (maximum)
- LiDAR Achieved Ground Point Density (AGPD) for total net point density of georeferenced, classified ground points (Class 2).

6.2 Absolute Vertical Accuracy: Methodology and Requirements

The absolute vertical accuracy of a LiDAR data set is considered the fundamental measure of point cloud accuracy. Absolute vertical accuracy shall be assessed using orthometric height and reported in accordance with the USGS LiDAR specifications [3].

The required vertical Root Mean Squared Errors ($RMSE_z$) applies to the measures done on the LiDAR point cloud, reported at 68% confidence level. The measures shall be done on expectedly hard and flat surfaces, which ideally produce single LiDAR returns. Moreover, the results of those measurements shall be delivered in an absolute accuracy report. A template indicating acceptable reporting of absolute accuracy is Table 8 found in Appendix A.

An acceptable method of testing absolute accuracy involves comparing the vertical, plumbline difference between ground surveyed control points (e.g. RTK GNSS or total station) and a Triangulated Irregular Network (TIN) surface generated from ground classified LiDAR data. The vertical difference between the control points and the plumbline distance to the planar surface of the TIN model can then be measured and reported in terms of $RMSE_z$.

6.3 Point Density and Point Spacing

LiDAR point density and spatial distribution requirements shall be considered in the mission design and planning process at a particular flying height within specified parameters referred to in this document as 'nominal' pulse density and spacing (NPD and NPS, respectively). The net point density and point spacing of georeferenced, classified LiDAR point cloud data shall be henceforth referred to as 'achieved' ground point density and spacing (AGPD, AGPS).

All of NPS, AGPS, NPD and AGPD include only the geometrically useable part of a swath; excluding acceptable data voids [3] (*see* Section 4.6.3). The merging of flight lines is permitted in the empirical calculation of NPD and NPS, if all precision/accuracy requirements are met, with no thinning of LiDAR datasets.

6.3.1 Nominal Pulse Density

Nominal Pulse Density (NPD) as defined by the Branch refers specifically to the total number of emitted LiDAR pulses through mission planning and design, per square unit of measurement (pulses/m^2). Design of the project NPD shall meet or exceed the requirements listed in Table 3, for the DL assigned to the project.

6.3.2 Nominal Pulse Spacing

Nominal Pulse Spacing (NPS) as defined by the Branch is the predicted value of the spatial distribution of discrete LiDAR points (used as surrogates for pulses) through mission planning and design, represented as units of measurement between adjacent ground surface points (last return). NPS can be predicted using flight planning software or calculated as the square root of the average area per first return points. Design of the project NPS shall meet or exceed the requirements listed in Table 3 for the DL assigned to the project.

$$NPS = 1/\sqrt{NPD}$$

6.3.3 Achieved Ground Point Density

The trend towards achieving the specified NPD for a project through multiple flight passes, overlap greater than [30] percent, multichannel instruments, and multiple instruments on a single collection platform has expanded the industry's options and flexibility in designing LiDAR collection missions [3]. Higher net densities of LiDAR point data are being achieved through this trend; resulting in the creation of the term Achieved Ground Point Density (AGPD) to describe the total net point density of georeferenced, classified ground.

$$AGPD = \sqrt{NPD}$$

Assessment of the AGPD will be made based on a random sampling of areas, 65% of which shall contain a point count greater than or equal to the requirements listed in Table 3, for the DL assigned to the project.

6.3.4 Achieved Ground Point Spacing

Given the irregular nature of LiDAR returns it is nearly impossible to find a point that is equidistant from all other surrounding points, so AGPS should be represented as an average. Therefore, when calculating AGPS, it is necessary to measure between points across (along the scanner swath) and along (between the scanner swaths) the flight path. Measuring point spacing only at the centre of the swath is not an acceptable method for measuring the AGPS.

$$AGPS = 1/\sqrt{AGPD}$$

Assessment of the AGPS shall be made based on a random sampling of areas, 65% of which shall achieve the spacing that complies with the requirements listed in Table 3, for the DL assigned to the project.

6.4 Relative Vertical Accuracy: Methodology and Requirements

Relative vertical accuracy refers to the internal geometric [precision] of a LiDAR dataset without regard to surveyed ground control [3] given multiple flight lines, GNSS conditions, and aircraft attitudes. The Branch considers relative vertical accuracy as the primary measure of the precision of a LiDAR system, as well as a significant indicator of the quality of the LiDAR system calibration. Two primary factors should be considered when testing LiDAR data relative vertical accuracy:

- Smooth surface repeatability (intraswath)
- Overlap consistency (interswath)

6.4.1 Intraswath Accuracy

Intraswath is a measure of the precision of LiDAR quantified in the assessment of variations (noise) from the single return data of one individual swath on a surface that would be expected, ideally, to be flat and without variation.

This assessment shall be conducted on smooth hard surfaces (e.g. parking lots, rooftops, runways) to determine differences in vertical elevation, where a raster subtraction (calculated using the $RMSD_z$) between a raster generated from minimum elevation and another generated from maximum elevation values using that individual swath from single return point data is performed. These values are not to exceed the acceptable limits of smooth surface repeatability listed in Table 4.

The following method is suggested. If a different method is used, it shall be documented and delivered, along with the sample locations and the results.

Sample areas of approximately $50m^2$ will be selected at multiple locations (across and along swath), and shall include areas both at nadir and on the outer swath. The accuracy can then be assessed using a gridded signed difference raster (with cell size equal to 2 times the NPS) derived from the maximum and minimum elevation of the points within each grid cell. The $RMSD_z$ can be calculated using the values of all grid cells of all areas tested.

6.4.2 Interswath Accuracy

Heidemann [3] defines interswath as the "quantified assessment of variations in measurements of a surface that, under ideal theoretical conditions, would be without variation". Swath overlap consistency is a measure of geometric alignment of two overlapping swaths and is a fundamental measure of the quality of the sensor adjustment of the data from each lift; this measure of geometric alignment can also be applied to overlapping lifts and project AOIs.

For internal assessment of interswath accuracy, the Branch refers to its proprietary program LiCAL©. LiCAL© is based on the data quality measures (DQMs) from the ASPRS Guidelines on Geometric Inter-Swath Accuracy and Quality of LiDAR Data [7], while also implementing statistical hypothesis testing for evaluating acceptance or rejection criteria of overlapping LiDAR data. LiCAL© is available to vendors who wish to use it for their own evaluation (ftp://ftp.geobc.gov.bc.ca/sections/outgoing/dis/Aerial-LiDAR/LiCal/).

If any other method(s) of testing overlap consistency are used, the following criteria of assessment shall be considered:

- Multiple locations within adjacent, overlapping, parallel swaths, in non-vegetated areas of only single returns.
- Areas should include surfaces of varying slope and aspect, not only flat surfaces.
- Include cross-tie swaths and the intersecting project swaths.

The actual methodology used in determining the interswath accuracies of a dataset, such as those outlined in the USGS LiDAR Base Specification [3], shall be part of the deliverables and results shall comply with the requirements listed in Table 4.

Table 4. Relative Vertical Accuracy Requirements

Quality Level	Smooth surface repeatability $RMSD_z$ (cm)	Swath overlap difference $RMSD_z$ (cm)	Swath overlap maximum differences allowed (cm)
QL1	≤ 3	≤ 4	± 8
QL2	≤ 6	≤ 8	± 16
QL3	≤ 12	≤ 16	± 32
QL4	≤ 24	≤ 32	± 64
QL5	≤ 48	≤ 64	± 64

6.5 Absolute Horizontal Accuracy

Evaluating absolute horizontal accuracy for LiDAR data presents greater challenges than with vector-based or digital orthophoto products. Structures that are readily visible and identifiable in traditional imagery are more difficult to define in products created from LiDAR data.

While the comparison of overlapping areas for adjacent flight lines provides an idea of the relative horizontal accuracy (precision) of the data, some potential horizontal errors will not be obvious in this comparison of the overlapping area between adjacent flight lines in opposite directions. Furthermore, while major horizontal shifts would almost certainly show up when measuring the absolute vertical accuracy, smaller horizontal errors could be missed if vertical verification is done solely on relatively flat surfaces.

The following Sections 6.5.1 and 6.5.2 outline some methods of measuring absolute horizontal accuracy. Regardless of the strategy used, it should include different planes, not only flat surfaces, and the actual method and results shall be part of the deliverables.

6.5.1 Indirectly Measured Absolute Horizontal Accuracy

Different methods may be used in attempting to measure absolute horizontal accuracies. Meade summarised three such strategies [10], two of these methods are outlined below:

The first method described involves selecting features during a ground control field survey in which horizontal position can be precisely measured and compared with intensity images generated from the LiDAR data. For example, painted strips in parking lots could be used as such control points due to their high reflectivity and contrast to the surrounding asphalt.

The second method to find horizontal shifts is comparing the coincidence of cross-sections measured using ground survey techniques against cross-sections generated from a TIN created with the LiDAR data. Again, the ground survey measurements should be done in areas showing significant slope, not just on flat surfaces, and in different orientations. Roadway ramps, embankment or levees are considered appropriate areas for cross-section measurements.

6.5.2 Directly Measured Absolute Horizontal Accuracy

Directly measured horizontal and vertical LiDAR accuracies can be obtained by using spatially oriented targets or “Control Boxes”. The targets consist of a box (i.e. cardboard) with sidewalls being orthogonal to each other. The target box corners are spatially (3D) aligned with the coordinate axis of the LiDAR data (i.e. UTM coordinate system). LiDAR coordinate differences in ΔX (i.e ΔEasting) can be obtained in subtracting the known coordinate X_{TARGET} (*see* Figure 1) of the Z/Y plane (Elevation/Northing plane of the target sidewall) from a LiDAR coordinate X_{LIDAR}. LiDAR coordinate differences in ΔY (i.e ΔNorthing) can be obtained in subtracting the known coordinate Y_{TARGET} of the Z/X plane (elevation/Easting plane of the target sidewall) and finally LiDAR coordinate differences in ΔZ (i.e ΔElevation) can be obtained in subtracting the known coordinate Z_{TARGET} of the X/Y plane (Easting/Northing plane of the target top wall)Z_L.

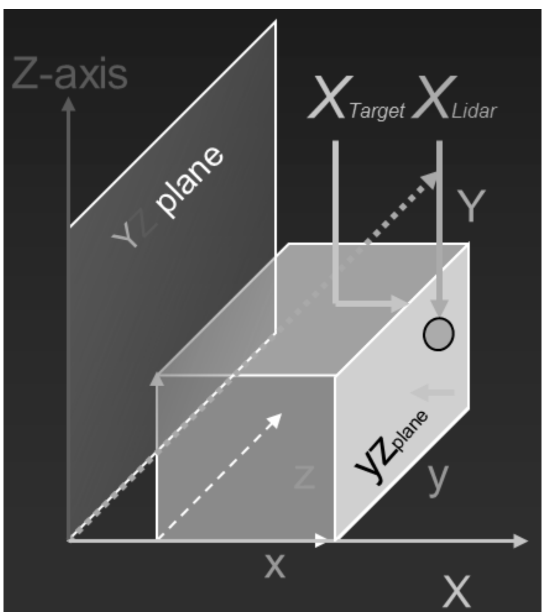

Figure 1. Horizontal accuracy along the X-axis (Easting); coordinate comparison between LiDAR point X_{LiDAR} (Easting) and constant Target plane X_{target} (Easting). Local target plane yz parallel to YZ mapping frame (i.e. UTM).

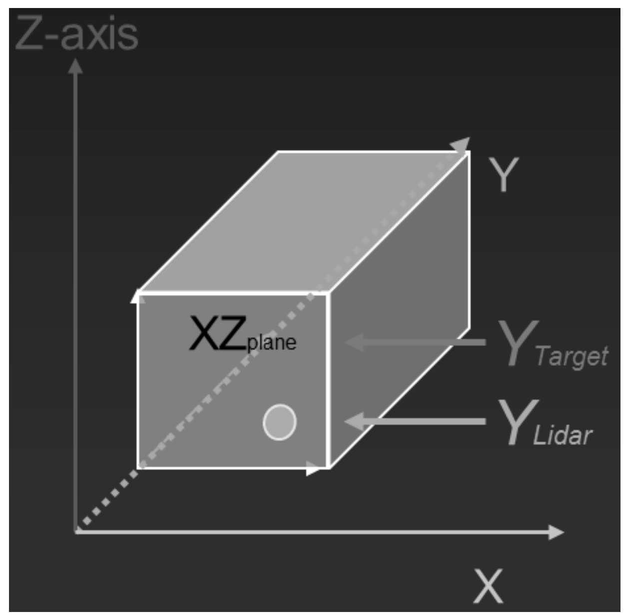

Figure 2. Horizontal accuracy along the Y-axis (Northing); coordinate comparison between LiDAR point Y_{LiDAR} and constant Target plane Y_{Target}. Local target plane XZ parallel to XZ frame (i.e. UTM).

Depending on the number of LiDAR points falling on a specific plane, the RMSE for each coordinate axis can be obtained according to:

$$\boldsymbol{RMSE_{coordinate}} = \sqrt{\sum \frac{(N_{plane} - N_i')^2}{n}} \quad \text{(1dRMSE, at 68\% probability)}$$

where:

N_{Plane} is the specific measured target box coordinate for a target sidewall, plane specific

N_i' is the *i-th* corresponding LiDAR point coordinate of the sidewall plane being evaluated, plane specific

i is an integer ranging from 1 to n and

n the number of LiDAR point hits on a specific sidewall (plane)

6.5.3 Linear Horizontal Error Propagation Model

In addition to the above methods, the Branch suggests the following linear error propagation model to estimate the LiDAR a priori horizontal accuracy:

$$\boldsymbol{RMSEr} = \sqrt{(\theta_{laser}\ x\ AGL)^2 + \left(\sigma_{GNSS_{xy}}\right)^2 + \left(\sigma_{IMUrp}\ x\ AGL\right)^2}$$

where:

RMSEr = Horizontal LiDAR point accuracy over flat terrain (metres) at 63% probability

θ_{laser} = Laser beam divergence (mrad)

AGL = Aircraft altitude above ground level at Nadir position (metres)

$\sigma_{GNSS_{xy}}$ ≅ $RMSE_r$ = Average 2D positional precision of the GNSS system (metres) at 63% probability

σ_{IMUrp} = Average 3D angular accuracy of the drift corrected IMU in roll and pitch orientation (mrad)

6.6 LiDAR Point Cloud Classification Accuracy and Errors

Testing of the classification accuracy shall be done on random portions of the project AOI. Vendors should pay special attention to areas which are susceptible to classification errors (i.e. sudden changes in terrain behavior where input classification parameters have not been adjusted accordingly), searching for points that have demonstrable errors in the classification value. Table 5 is presented as a guideline regarding what the Branch considers an acceptable amount of classification error with respect to various quality levels. Exceeding the values shown in Table 5 may be considered by the Branch as grounds for rejection of the entire dataset.

Table 5. Classification errors per QL

Quality Level	% Errors allowed per km^2
QL1	≤ 0.5%
QL2	≤ 1.0%
QL3	≤ 2.0%
QL4 and QL5	≤ 5.0%

Furthermore, the following classification errors shall result in an automatic rejection of the dataset unless circumstances are identified and are accepted by the Branch:

- An excess of points remaining in Class Code 1 (Default) that should be classified in any other required Class Code
- Artificial ground ridges between blocks, artifacts/divots (points returned from vegetation, structures or noise that are mistakenly classified as ground points)
- Areas where no ground points were classified due to uneven terrain.
- Duplicated points within the LiDAR datasets (2 or more points with the same XYZ coordinates).
- Aggressively thinned, interpolated, "smoothed" or artificial points unless specified otherwise in a project contract.
- Ground points within waterbodies larger than $8000m^2$.
- Noticeable inconsistency in character, texture, density or quality of the classification between tiles, swaths, lifts, or other non-natural divisions of data.

7.0 LIDAR PROJECT DELIVERABLES AND SUPPLEMENTARY REPORTS

In Section 7.1 and 7.2 typical LiDAR deliverables and supporting documents are presented in a table as a guideline of what the Branch expects during milestones in a LiDAR project. All contents of the tables in Sections 7.1 and 7.2 are subject to change depending on the project. It is the responsibility of the vendor to ensure products are delivered as they pertain to the project contract.

7.1 LiDAR Data Submission and Reporting Table

A kickoff meeting shall be held before data acquisition to ensure that the project requirements and schedule are understood. The Quality Control Report found in Section 7.2 is mandatory for all projects.

<table>
<tr><th colspan="7">1. Planning Deliverables</th></tr>
<tr><th>Milestone</th><th>Section</th><th>Product</th><th>Format</th><th># of Copies</th><th>Completion Date</th><th>Additional Notes</th></tr>
<tr><td rowspan="3">Prior to Acquisition</td><td>7.3</td><td>LiDAR system Calibration Report</td><td>DOC/PDF</td><td>1</td><td><Insert Date></td><td>Acquisition shall not begin until review and approval of calibration report</td></tr>
<tr><td>7.5</td><td>Mission Planning Report</td><td>DOC/PDF</td><td>1</td><td><Insert Date></td><td>Acquisition shall not begin until review and approval of Mission Planning Report</td></tr>
<tr><td>4.3</td><td>LiDAR Calibration Data (raw)</td><td>LAZ</td><td>1</td><td><Insert Date></td><td>Acquisition shall not begin until review and approval of LiDAR Calibration outcome</td></tr>
<tr><th colspan="7">2. Flight Reporting</th></tr>
<tr><th>Milestone</th><th>Section</th><th>Product</th><th>Format</th><th># of Copies</th><th>Completion Date</th><th>Additional Notes</th></tr>
<tr><td>During Acquisition</td><td>7.6</td><td>Online Acquisition Reporting System</td><td>Web based GIS map</td><td>N/A</td><td><Insert Date></td><td>Updated Daily</td></tr>
<tr><th colspan="7">3. Acquisition Deliverables</th></tr>
<tr><th>Milestone</th><th>Section</th><th>Product</th><th>Format</th><th># of Copies</th><th>Completion Date</th><th>Additional Notes</th></tr>
<tr><td rowspan="3">Six Weeks Past Acquisition</td><td>N/A</td><td>Trajectories (SBET)</td><td>OUT/CSV/TXT</td><td>1</td><td><Insert Date></td><td></td></tr>
<tr><td>7.2</td><td>Raw Unclassified LiDAR Strips</td><td>LAZ</td><td>1</td><td><Insert Date></td><td></td></tr>
<tr><td>7.7</td><td>Last Return Density Grid</td><td>ESRI ASCII</td><td>1</td><td><Insert Date></td><td></td></tr>
</table>

	7.8	LiDAR Swath Polygons	Shapefile	1	<Insert Date>	Refer to Appendix B for naming convention
	7.9	LiDAR Acquisition Date Extent Polygons	Shapefile	1	<Insert Date>	Refer to Appendix B for naming convention
	7.10	Ground Control Report	DOC/PDF	1	<Insert Date>	
	4.5	Ground Control Points	Shapefile	1	<Insert Date>	
4. Production Deliverables						
Milestone	Section	Product	Format	# of Copies	Completion Date	Additional Notes
Four Weeks Prior to Project Deadline	N/A	Digital Elevation Model	ESRI ASCII/ GeoTIFF	2	<Insert Date>	See GeoBC DEM Specifications for further detail
	7.2	Classified LiDAR Point Cloud	LAZ	2	<Insert Date>	
	N/A	Digital Surface Model	GeoTIFF	2	<Insert Date>	
	N/A	Shoreline Delineation	Shapefile	1	<Insert Date>	Based on LiDAR intensity Data
	7.11	Data Adjustment Report	DOC/PDF	1	<Insert Date>	
	7.4	Metadata Reporting	XML/PDF	1	<Insert Date>	Two different reports; one XML and one PDF file
5. Post-Production Deliverables						
Milestone	Section	Product	Format	# of Copies	Completion Date	Additional Notes
Post Production	7.12	Final Project Report	DOC/PDF	1	<Insert Date>	Refer to Section 7.12

7.2 Quality Control (QC) Report

The Quality Control Report provides links to the various sections in this document outlining the minimum requirements for QC relating to Branch specifications. The vendor shall complete the Quality Control Report at different stages of the data production. For example, the "Raw Unclassified LiDAR Strips" section shall be completed and delivered with the acquisition deliverables only - referenced in the Deliverables Table (Section 7.1). Then, the remainder of the report shall be completed and delivered with the production deliverables from Section 7.1.

LiDAR Quality Control Report					
Project:	<Insert Project Name>				
Date:	<Insert Date>				
Produced by:	<Insert Name of Project Manager>				
Product	Section	Check	Requirement	Achieved	Remarks
Raw Unclassified LiDAR strips	4.6.2	Swath Overlap	≥ 30%		
	4.6	Buffered Project Area (BPA)	≥ 100m		
	5.1	Format	LAZ 1.4		
		Flight line Numbers	Present and unique for all flight lines		
	5.1.2	GPS Time	Present in all points		Adjusted Standard GPS Time
	5.1.3	CRS Information	Projection		
			Horizontal Datum: NAD83 (CSRS)		
			Vertical Datum: CGVD2013		
			Geoid Model: CGG2013		
			Georeferencing information in LiDAR file headers		Compound WKT format (Horizontal and vertical datum)
	5.1.6	GUID			Consistent and appropriate values set for every tile delivered

	5.1.4	Global Encoding value	17		Consistent and appropriate values set for every tile delivered
	5.1.7	System ID			Consistent and appropriate values set for every tile delivered
	Appendix B	Naming Convention	Compliant with GeoBC Naming Conventions		
Product	Section	Check	Requirement	Achieved	Remarks
Classified LiDAR Point Cloud	5.1.5	Return Fields	Conforming to ASPRS Point Record Formats [5]		Unless otherwise specified in project contract
	5.2	Classification Assignments	Classes: 1, 2, 7, 9		Unless otherwise specified in project contract
	5.1.3	CRS Information	Projection:		
			Horizontal Datum: NAD83 (CSRS)		
			Vertical Datum: CGVD2013		
			Geoid Model: CGG2013		
			Georeferencing information in LiDAR file headers		Compound WKT format (Horizontal and vertical datum)
	Appendix B	Naming Convention	Compliant with GeoBC Naming Conventions		
	5.3	Tile Size	1:2500 BCGS		
	5.1	Format	LAZ 1.4		

	5.1.4	Global Encoding value	17		Consistent and appropriate values set for every tile delivered
	5.1.6	GUID			Consistent and appropriate values set for every tile delivered
	5.1.7	System ID			Consistent and appropriate values set for every tile delivered
	6.2	Vertical Accuracy[3]	≤ 10cm at $RMSE_z$		Provide number of control points
	6.4.1	Smooth Surface Repeatability[4]	≤ 6cm at $RMSD_z$		Provide flight line numbers tested
	6.4.2	Swath Overlap Difference[4]	≤ 8cm $RMSD_z$		Provide flight line numbers tested

7.3 LiDAR System Calibration Report

A LiDAR system calibration report is required to provide details on the airborne survey equipment proposed for the project. For projects utilizing multiple scanning systems and multiple aircrafts, a LiDAR system calibration report is required for each system installation in each aircraft. Any sensor changes, failures or replacements prior to or during the data collection shall be reported. For LiDAR system calibration guidelines, go to Section 4.3.

At a minimum, the document shall include the information listed below:

[3] Value references QL2 in Table 2, and is subject to change dependent on project Quality Level.
[4] Values reference QL2 in Table 4, and are subject to change dependent on project Quality Level.

Components	Requirements
Sensor Instrument – LiDAR System	▪ Manufacturer ▪ Year ▪ Model ▪ Ownership ▪ Serial number ▪ Calibration Site ▪ Processing/logging software
Airborne GNSS System	▪ Manufacturer ▪ Year ▪ Model ▪ Processing software ▪ Processing solution/method ▪ Epoch and datum transformation ▪ Lever arm distances
IMU	▪ Manufacturer ▪ Year ▪ Model
Ground control points (for the purpose of calibration)	▪ Ground Survey Methods ▪ Ground control points coordinates ▪ LiDAR data comparison to control
Calibration	▪ Calibration procedure ▪ Lever arm offsets ▪ Laser channel offsets ▪ Roll, pitch, yaw, and scanner scale factors ▪ Least squares adjustment report (if applicable) o Variance-covariance matrix of calibration parameters o Flight line ID and best estimated trajectory o Adjustment parameters

7.4 Metadata Reporting (XML & PDF)

Two different metadata reports shall be provided to the vendor, an XML metadata coversheet, and a PDF metadata summary. The XML template (LiDAR_Metadata_FilledIn.xml) will include descriptions of each field. The PDF document (LiDAR_Metadata_Summary.pdf) shall include all fields as below:

LiDAR Metadata Summary	
Owner:	
Project Name:	
Date of Data Submission:	
Project Location:	
Sign-off:	

License:		
Acquisition Parameters	**Parameter**	**Value**
	Specifications:	
	Sensor Model:	
	Max Returns:	
	Max Scan Angle:	
	Pulse Rate:	
	Beam Divergence:	
	Flying Height (AGL):	
	Swath Overlap:	
	Target Density:	
	Project Units:	
	Range of Acquisition Dates:	
Format	**Parameter**	**Value**
	LAS Version:	
	LAS Point Record Format:	
	Global Encoding:	
Accuracy	**Parameter**	**Value**
	Non-Vegetated Vertical Accuracy (95% [1.96*RMSE$_Z$]):	
	Number of Control Points:	
	Interswath Accuracy (RMSD):	
	Number of flight line pairs tested:	
	Intraswath Accuracy (RMSD):	
	Number of flight lines tested:	
Class	**Parameter**	**Value**
	Classified (Yes/No):	
	Class Codes Used:	
Reference System	**Parameter**	**Value**
	Horizontal Datum:	
	Projection System:	
	Vertical Datum:	
	Geoid Model:	
Derived Products	**Product**	
	Derived Product 1	
	Derived Product 2	
	Derived Product 3	
Notes:		

7.5 Mission Planning Report

The following indicates the minimum content of the mission planning report:

- Important project dates:
    - Start of collection
    - Vegetation conditions (leaf-on/off)
    - Deliverable timelines
    - Project final deadline
- Aircraft information
- Airport staging information
- Assessment of controlled airspaces where special permits may be required (if applicable)
- Calibration plan
- Flight Planning
    - Maps which include:
        - Planned survey area and buffer
        - Flight line locations
    - Flight line overlap
    - Flight height above ground
    - Flying speed
    - Scan Rate
    - Scan Field of View
    - Point density and spacing estimations
- Planned GNSS stations and control points
- Planned fieldwork procedure
- Planned procedure for re-flights
- Planning to account for weather, land cover, and terrain
- Tidal considerations (if applicable)

7.6 Flight Reporting

Project information and flight logs shall be reported in the Online Acquisition Reporting System (OARS) provided by the data supplier. Content required is listed below and shall be updated daily:

- Date of collection
- Pilot/Operator names
- Aircraft make/model and tail number
- Extent of collection
- Weather conditions

- Ground conditions
- Any problems encountered

The OARS provided shall include visual representations including but not limited to:

- Planned acquisition flight lines
- Accepted acquired flight lines
- Flight lines requiring re-flight
- BCGS map tiles delivered to date

7.7 LiDAR Density Grid

A density grid shall be delivered with acquisition deliverables and will be used to verify:

- Data acquisition and area coverage
- Project density requirements have been met

All density grids delivered shall be in gridded raster format and generated using first or last return data only. Each cell value shall be calculated as the number of points per 1 square metre (points/m^2) and the product shall be delivered at a resolution of 5 metres.

7.8 LiDAR Swath Extent Polygon

For each LiDAR swath collected, a georeferenced polygon (shapefile) representation of the swath extents shall be delivered. Each polygon shall generally follow the overall shape of the swath. Bounding box rectangles and other simplified rectangles are not acceptable.

Each polygon shall be delivered in shapefile format using the same projection and name as the acquired LiDAR data it bounds (*See* Appendix B). Additionally, each polygon shall contain the attributes listed in Table 6.

Table 6. LiDAR Swath Extent Polygon Attributes

LIDAR_SYSTEM	SYSTEM_SERIAL_NUMBER	ACQUISITION_DATE	AGL	PRF
Name of the LiDAR System used to acquire the data. (e.g. Riegl VQ-780i)	Serial Number of the LiDAR System used to acquire the data.	The date of data acquisition in the format YYYYMMDD. (e.g. 20200225)	Flying height Above Ground Level (AGL) during acquisition.	Effective Pulse Rate Frequency during data collection.

7.9 LiDAR Acquisition Date Extent Polygon

The individual swath extent polygons (*See* Section 7.8) shall also be dissolved by the ACQUISITION_DATE attribute and provided to the Branch as a georeferenced polygon (shapefile) to indicate the full LiDAR extents for each day of acquisition. Bounding box rectangles and other simplified rectangles are not acceptable. Each swath extent polygon shall be named according to Appendix B and shall contain the attributes in Table 7.

Table 7. LiDAR Acquisition Date Extent Polygon

LIDAR_SYSTEM_1	LIDAR_SYSTEM_2	ACQUISITION_DATE
Name of the LiDAR System used to acquire the data. (e.g. Riegl VQ-780i)	Name of other LiDAR systems used to collect the data (if multiple were used). (e.g. Riegl VQ-1560i)	The date of data acquisition in the format YYYYMMDD. (e.g. 20200225)

7.10 Ground Control Reports

Ground control reports shall include:

- Instrumentation
  - Instrument model
  - Manufacturer precisions
  - Instrument calibration results (if applicable)
- CRS information
  - Horizontal and vertical datum, including horizontal epoch references
  - Geoid model
  - Projection
- Control point information
  - Coordinates
  - Final obtained accuracies (horizontal and vertical) in RMSE
  - Type of reference station used (i.e. CBN or CACS)
  - Reference station coordinates
- Detailed explanation of methodology (i.e. Precise Point Positioning or Differential Processing)
- Processing report
  - Software or application used
  - All input parameters
  - Full output results
  - All default reports generated by the software used for processing
- Adjustment report (if applicable)
  - Software or application used
  - All input parameters (i.e. precision weighting, a-priori scale

factor, etc.)
    - Full output results
    - All default reports generated by the software used for adjustment
- Signature by a designated professional

7.11 LiDAR Data Adjustment Report (if applicable)

If any data adjustments are performed, the vendor shall submit a data adjustment report which includes the following:

- Software or application used
- Detailed explanation of methodology
- All input parameters
- Full output results

7.12 Project Report

A Project Report shall be delivered no more than two weeks after products are delivered at the end of the LiDAR project. The project report serves as the master report for the entire project.

The report shall include the following content:

- Project Summary
    - Provide summary of location, area size and coverage, and dates.
- Acquisition
    - Provide summary of aircraft, system information and system installations.
- Calibration
    - Provide summary of calibration site, methodology and processing details.
    - Full calibration report in the appendix
- GNSS/Inertial Processing
    - Provide summary detailing the GNSS/IMU processing, software and methodology.
- Post Processing
    - Provide summary of adjustment methodology, software, and results.
- Production
    - Provide summary of tile scheme, data acquired and derived products.
- Ground Control
    - Provide summary of equipment, method of collection, data processing, datum, projection, and geoid.
    - Include full ground control report (*see* Section 7.10)
- Density QC

    - Final last return and ground point density statistics (including histogram plot)
    - Gridded last return and ground density raster plot (including color ramp and values associated with the color ramp)
- Accuracy QC
    - Absolute accuracy: Provide summary of accuracy testing methodology (i.e. point to point or point to plane comparison), and results achieved. Include "Accuracy Report for LiDAR Data" (Table 8) found in Appendix A.
    - Relative accuracy: Provide summary of methodology and results from testing.

REFERENCES

[1] Province of British Columbia (GeoBC), Specifications and Guidelines for Control Surveys Using GPS Technology, 2010.

[2] Natural Resources Canada, Public Safety Canada, Federal Airborne LiDAR Data Acquisition Guideline, Government of Canada, 2017.

[3] H. Heidemann, "LiDAR Base Specification - Ver. 1.3," in *U.S. Geological Survey Techniques and Methods*, USGS, 2014, p. Chapter 4.

[4] F. Rohrbach, "LiDAR Footprint Diameter," 13 November 2015. [Online]. Available: https://felix.rohrba.ch/en/2015/lidar-footprint-diameter/. [Accessed March 2020].

[5] American Society for Photogrammetry and Remote Sensing, "LAS Specification 1.4," ASPRS, 2013.

[6] Open GIS Consortium, "OpenGIS Implementation Specification: Coordinate Transformation Services," *OGC 01-009,* 2001.

[7] "ASPRS Guidelines on Geometric Inter-Swath Accuracy and Quality of LiDAR Data," in *Photogrammetric Engineering & Remote Sensing*, American Society for Photogrammetry and Remote Sensing, 2018, pp. 117-128.

[8] A. Behan, "On the Matching Accuracy of Rasterized Scanning Laser Altimeter Data," *IAPRS, Vol. 33, Part 2,* 2000.

[9] H. Maas, "Least-squares Matching with Airborne Laser Scanning Data in a TIN Structure," *International Archives of Photogrammetry and Remote Sensing 33 (Part 3A),* pp. 548-555, 2000.

[10] M. Meade, From the Ground Up: Horizontal Accuracy Assessment in LiDAR, 2008.

[11] ISO, "Geographic Information/Geomatics Terminology; Multi-Lingual Glossary of Terms," in *ISO/TC 211*, 2015, p. Glossary.

APPENDIX A: ACCURACY REPORTING

Table 8 shall be used by the vendor to report the horizontal and vertical accuracies of the LiDAR data (Modified from ASPRS, 2013 [5]).

Equations used to calculate the values in the reports:

Residual Errors $\Delta = \frac{\sum(N_i - N_i')}{n}$

where:
- N_i is the i^{th} measured coordinate being evaluated, in the specified direction
- N_i' is the corresponding checkpoint i^{th} coordinate for the points being evaluated, in the specified direction
- i is an integer ranging from 1 to n and
- n the number of control points

Mean Error $\bar{\Delta} = \frac{\sum \Delta_i}{n}$

where:
- Δ_i is the i^{th} residual error in the specified direction
- i is an integer ranging from 1 to n and
- n the number of control points

Standard Deviation $\sigma = \sqrt{\frac{\sum(\Delta_i - \bar{\Delta})^2}{(n-1)}}$

where:
- Δ_i is the i^{th} residual error in the specified direction
- $\bar{\Delta}$ is the mean error in the specified direction
- i is an integer ranging from 1 to n and
- n the number of control points

Root Mean Square Error $RMSE_N = \sqrt{\sum \frac{(N_i - N_i')^2}{n}}$ (1dRMSE, at 68% probability)

where:
- N_i is the i^{th} measured coordinate being evaluated, in the specified direction
- N_i' is the corresponding checkpoint i^{th} coordinate for the points being evaluated, in the specified direction
- i is an integer ranging from 1 to n and
- n the number of control points

Radial Horizontal Accuracy $RMSE_r = \sqrt{(RMSE_x^2 + RMSE_y^2)}$ (1d$RMSE_r$, at 63% probability)

where:
- $RMSE_x$ is the RMSE in the x direction, and
- $RMSE_y$ is the RMSE in the y direction

Table 8. Accuracy Report for LiDAR data

Point ID	Measured Values (LiDAR) [metres]	Survey Control Point Values [metres]			Measured Error [metres]
	Elevation (z)	Easting (x)	Northing (y)	Elevation (z)	Δ_Z Elevation
GCP1					0.000
GCP2					0.000
GCP3					0.000
GCP4					0.000
GCP5					0.000
GCP6					0.000
GCP7					0.000
GCP8					0.000
GCP9					0.000
GCP10					0.000
GCP11					0.000
GCP12					0.000
GCP13					0.000
GCP14					0.000
GCP15					0.000
GCP16					0.000
GCP17					0.000
GCP18					0.000
GCP19					0.000
GCP20					0.000
Number of control points					20
Mean Error					0.000
Standard Deviation					0.000
Root Mean Square Error RMSE, 1dRMSE at 68% Confidence Level					0.000

APPENDIX B: FILE NAMING CONVENTIONS[6]

For LiDAR products delivered in LAS/LAZ file format:

[Ownership]_[Geographic Extent]_x[Classification]_[Nominal Pulse Density]_[Projection]_[Date].[file type]

Ownership = BC (i.e. bc_)
Geographic Extent = Geographic BC Map tile
Classification = yes or no
Nominal Pulse Density = the project design pulse density in points per square metre, shall be an integer number (i.e. 5) or a decimal number denoted by 'p' (i.e. 7p03)
Projection = Data projection (i.e. bcalb for BC Albers or utm10 for Universal Transverse Mercator Zone 10)
Date = year of acquisition

i.e. bc_092b081_1_1_3_xyes_8_utm10_2016.laz

For raw LiDAR data strips (LAS/LAZ format):

[File Source ID]_[GPS Day]_[Year]_[System Serial Number]_[Tail Number].[file type]

File Source ID = the raw strip equivalent to the original FL number assigned to the file, ranging from 1 through to 65,535 (2 byte unsigned short); according to the LAS 1.4 Specifications [5]
GPS Day = Day of year wherein January 1st is considered '001', in increasing increments through to day 365 (December 31st)
Year = year of data collection
System Serial Number = serial number of acquisition system (Laser)
Tail Number = identification number of aircraft used in data collection

i.e. 00001_001_234_2020_####_G-CHJI.laz

For LiDAR Swath Extent Polygons (shapefile):

Note: The naming convention follows the same as raw LiDAR data strips, with a shapefile extension (.shp) rather than LAS/LAZ (i.e. .laz).

[File Source ID]_[GPS Day]_[Year]_[System Serial Number]_[Tail Number].[file type]

File Source ID = the raw strip equivalent to the original FL number assigned to the file, ranging from 1 through to 65,535 (2 byte unsigned short); according

[6] There shall be no uppercase letters, spaces or special characters in any file or folder names on the submitted drives. File and folder names shall only contain lowercase letters, numbers and underscores as separators.

to the LAS 1.4 Specifications [5]
GPS Day = Day of year wherein January 1st is considered '001', in increasing increments through to day 365 (December 31st)
Year = year of data collection
System Serial Number = serial number of acquisition system (Laser)
Tail Number = identification number of aircraft used in data collection

i.e. 00001_001_234_2020_####_G-CHJI.shp

For Acquisition Date Extent Polygons (shapefile):

[Project-Name/Contract#]_LiDAR_Acquisition_[Date of Acquisition].shp

Project-Name/Contract# = Contract number (i.e. OP20BMC078)
LiDAR Acquisition = "LiDAR Acquisition"
Date of Acquisition = YYYYMMDD

i.e. OP20BMC078_LiDAR_Acquisition_20200402.shp

APPENDIX C: EXAMPLE OF WKT COMPOUND COORDINATE SYSTEM

Compound CRS: [EPSG (2955 + 6647): NAD83 UTM Zone 11 (CSRS) + CGVD 2013 height]

```
OGC WKT :
COMPD_CS["CGVD2013 height + NAD83(CSRS) / UTM zone 11N",
    VERT_CS["CGVD2013 height",
        VERT_DATUM["Canadian Geodetic Vertical Datum of 2013",2005,
            AUTHORITY["EPSG","1127"]],
        UNIT["metre",1,
            AUTHORITY["EPSG","9001"]],
        AXIS["Up",UP],
        AUTHORITY["EPSG","6647"]],
    PROJCS["NAD83(CSRS) / UTM zone 11N",
        GEOGCS["NAD83(CSRS)",
            DATUM["NAD83_Canadian_Spatial_Reference_System",
                SPHEROID["GRS 1980",6378137,298.257222101,
                    AUTHORITY["EPSG","7019"]],
                TOWGS84[0,0,0,0,0,0,0],
                AUTHORITY["EPSG","6140"]],
            PRIMEM["Greenwich",0,
                AUTHORITY["EPSG","8901"]],
            UNIT["degree",0.0174532925199433,
                AUTHORITY["EPSG","9122"]],
            AUTHORITY["EPSG","4617"]],
        PROJECTION["Transverse_Mercator"],
        PARAMETER["latitude_of_origin",0],
        PARAMETER["central_meridian",-117],
        PARAMETER["scale_factor",0.9996],
        PARAMETER["false_easting",500000],
        PARAMETER["false_northing",0],
        UNIT["metre",1,
            AUTHORITY["EPSG","9001"]],
        AXIS["Easting",EAST],
        AXIS["Northing",NORTH],
        AUTHORITY["EPSG","2955"]]]
```

LIST OF ACRONYMS

AGL	Above Ground Level (from aircraft at Nadir position)
AOI	Area of Interest
ALS	Airborne LiDAR Scanning
AGPD	Achieved Ground Point Density
AGPS	Achieved Ground Point Spacing
ASPRS	American Society for Photogrammetry and Remote Sensing
BCGS	British Columbia Geographic System
CACS	Canadian Active Control System
CBN	Canadian Base Network
CGG2013	Canadian Geoid 2013
CGVD	Canadian Geodetic Vertical Datum
CL	Confidence Level
CRS	Coordinate Reference System
CSRS	Canadian Spatial Reference System
DEM	Digital Elevation Model
DL	Density Level
DQM	Data Quality Measures
DSM	Digital Surface Model
EPSG	European Petroleum Survey Group
FGDC	Federal Geographic Data Committee
FL	Flight line
FOV	Field of View
GCM	Geodetic Control Monument
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GUID	Global Unique Identifier
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
LAS	LASer file format exchange
LAZ	LASzip
LiDAR	Light Detection and Ranging
LSM	Least Squares Matching
NIR	Near Infra-Red
NPD	Nominal Pulse Density

NPS	Nominal Pulse Spacing
NRCan	Natural Resources Canada
NTFS	New Technology File System
OARS	Online Acquisition Reporting System
OGC	Open Geospatial Consortium
PDOP	Position Dilution of Precision
PDRF	Point Data Record Format
PON	Project Operation Number
PPP	Precise Point Positioning
QA	Quality Assurance
QC	Quality Control
QL	Quality Level
RGB	Red-Green-Blue
RMSD	Root Mean Square Difference
$RMSD_z$	Vertical (z) Root Mean Squared Difference
$RMSE_r$	Horizontal (radial) Root Mean Squared Error
$RMSE_x$	Horizontal (x) Root Mean Squared Error
$RMSE_y$	Horizontal (y) Root Mean Squared Error
$RMSE_z$	Vertical (z) Root Mean Squared Error
RTK	Real-time Kinematic
SBET	Smoothed Best Estimate Trajectory
TIN	Triangular Irregular Network
USB	Universal Serial Bus
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WKT	Well-Known Text
XML	eXtensible Markup Language

GLOSSARY OF TERMS[7]

Accuracy - The closeness of an estimated value (measured or computed) to a standard or accepted (true) value of a particular quantity. Related to the source data and DEM products quality. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value.

- **Absolute accuracy** - A measure that accounts for all systematic and random errors in a dataset. Absolute accuracy is stated with respect to a defined datum or reference system.
- **Horizontal accuracy** - Positional accuracy of a dataset with respect to a horizontal datum at a specified confidence level or percentile.
- **Measurement accuracy** - Closeness of agreement between a test result or measurement result and the true value.
- **Positional accuracy** - The accuracy of the position of features, including horizontal and vertical positions, with respect to horizontal and vertical datums.
- **Relative accuracy -** A measure of variation in point-to-point accuracy in a dataset. In light detection and ranging (LiDAR), this term may also specifically mean the positional agreement between points within a swath, adjacent swaths within a lift, adjacent lifts within a project, or between adjacent projects.

Achieved Ground Point Density – A measure of the calculated net overall point density of classified and georeferenced LiDAR points on the ground (typically last returns) resulting from multiple passes of the LiDAR instrument, within the geometrically usable portion of the swath.

$$AGPD = \sqrt{NPD}$$

See also: Nominal Pulse Density

Achieved Ground Point Spacing – A measure of the calculated net overall point spacing of classified and georeferenced LiDAR points on the ground (typically last returns) resulting from multiple passes of the LiDAR instrument, within the geometrically usable portion of the swath.

$$AGPS = 1/\sqrt{AGPD}$$

See also: Nominal Pulse Spacing

[7] Source: modified from Heidemann (2014) [3] and ISO/TC 211 (2015) [11]

Active sensor - Sensor that generates the energy that it uses to perform the sensing.

Altitude – A height measured with respect to the underlying ground surface, meaning above mean sea level.

Bare earth (bare-earth) - Terrain free from vegetation, buildings, and other man-made structures. Elevations of the ground.

Beam divergence – The beam divergence of a LiDAR system is an angular measure of the spread of an emitted signal pulse with distance from the source. Measured in milliradians (mrad).

Bias – A systematic error inherent in measurements due to some deficiency in the measurement process or subsequent processing.

Blunder – A mistake resulting from inattention, carelessness or negligence.

Calibration (LiDAR Systems) – Calibration is the process of quantitatively defining a system's responses to known, controlled signal inputs. For LiDAR systems, calibration refers to the process of identifying and correcting for systematic errors in the sensor configuration (alignment), hardware, software and/or procedures. Calibration falls into three main categories:

- **Sensor Adjustment:** the calibration of a LiDAR system considering straight, and level flight of an aircraft equipped with an IMU and GNSS to determine the accurate position of the sensor in 'x, y, z' with respect to the GNSS and orientation (roll, pitch, yaw) of a LiDAR instrument.

- **Lever Arm offsets:** Lever arm components are estimated relative to the antenna phase centre and determine the sensor-to-GNSS-antenna offset vectors. These offset vector components are redetermined each time the sensor or aircraft GNSS antenna are moved or repositioned. The components are often field calibrated for each new project to determine corrections to the roll, pitch, yaw, and scale calibration parameters.

- **Instrument calibration:** A factory calibration including radiometric and geometric calibration unique to the manufacturer's hardware and tuned to meet the performance specifications for the model being calibrated. Only assessed and corrected by the instrument manufacturer.

Classification (of LiDAR) - The classification of LiDAR point clouds in accordance with a classification scheme to identify the type of target from which each LiDAR return is reflected. The process allows future differentiation between bare-earth terrain points, water, noise, vegetation, buildings, other manmade features and objects of interest.

Confidence level - The percentage of points within a dataset that is estimated to meet the stated accuracy. For example, accuracy reported at the 95%

confidence level means that 95% of the positions in the dataset will have an error on true ground position that is equal to or smaller than the reported accuracy value.

Control point - A surveyed point used to adjust a dataset geometrically to establish its positional accuracy relative to the real world. Control points are independent of, and may never be used as, checkpoints on the same project.

Coordinates – A group of 3D numbers that define a point in 3D space. Traditionally, a vertical coordinate would be defined as a 3D coordinate, that is, an x/y coordinate with an associated z-value.

Correction - Compensation for an estimated systematic error.

Data product specification - Detailed description of a dataset or dataset series, together with additional information that will enable it to be created, supplied to and used by another party.

Dataset - Identifiable collection of data.

Datum - A set of reference points on the Earth's surface from which position measurements are made and (usually) an associated model of the shape of the Earth (reference ellipsoid) to define a geographic coordinate system. Horizontal datums are used for describing a point on the Earth's surface, in latitude and longitude or another coordinate system. Vertical datums are used to measure elevations or depths.

Easting - Distance in a coordinate system, eastwards (positive) or westwards (negative) from a north-south reference line.

Elevation - The distance measured upward along a plumb line between a point and the geoid. The elevation of a point is normally the same as its orthometric height, defined as H in the equation:

$$H = h - N$$

where h is equal to the ellipsoid height and
N is equal to the geoid height

Error - Measured quantity value minus a reference quantity value.

First return - First reflected signal that is detected by a 3D imaging system, for a given sampling position and a given emitted pulse. Associated with the highest feature in the landscape like a treetop or top of a building.

Format - Language construct that specifies the representation, in character form, of data objects in a record, file, message, storage device, or transmission channel.

Geographic Coordinate System (GCS) - A 2D coordinate system defined by latitude and longitude, based on a reference ellipsoid approximation of the earth. Latitude and longitude are based on the angle from the equator and prime meridian respectively.

Geographic Information System (GIS) - A system of spatially referenced information, including computer programs that acquire, store, manipulate, analyse, and display spatial data.

Geoid - The equipotential surface that coincides with the mean ocean surface of the Earth. A smooth but highly irregular surface, known by gravitational measurements, to which the force of gravity is everywhere perpendicular.

Georeferencing - Geopositioning an object using a Correspondence Model derived from a set of points for which both ground and image coordinates are known.

Geospatial data - Information that identifies the geographic location and characteristics of natural or constructed features and boundaries of the earth. This information may be derived from remote sensing, mapping, and surveying technologies.

Global Positioning System (GPS) - A system of radio-emitting and -receiving satellites used to determine positions on the earth. Orbiting satellites transmit signals that allow a GPS receiver to calculate its location through trilateration (determining position with respect to two other points by measuring the distance between all three points).

Global Unique Identifier (GUID) - A hexadecimal encoded field in the LAS/LAZ file header that allows users to globally relate a dataset to a single project.

Ground Control Point (GCP) - Newly established, GNSS occupied on-site survey points used for geometric adjustment of the LiDAR point cloud; no previously existing marker.

Ground Surface Points – Refers to LiDAR point data that reaches the earth's surface. Not the same as georeferenced, classified ground points.

Inertial Measurement Unit (IMU) - The combination of a 3-axis accelerometer combined with a 3-axis gyro. An onboard processor, memory, and temperature sensor may be included to provide a digital interface, unit conversion and to apply a sensor calibration model. The IMU by itself does not provide any kind of navigation solution (position, velocity, attitude), it only actuates as a sensor.

Inertial Navigation System (INS) – A self-contained navigation system comprised of several subsystems: IMU, navigation computer, power supply, interface, etc. Uses measured accelerations and rotations to estimate velocity, position and orientation. An unaided INS loses accuracy over time, due to gyro drift.

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

Interpolation – Procedure used to estimate the z-values at a point with x/y coordinates at locations lacking sampled points and is based on the principles of spatial autocorrelation, which assumes that closer points are more similar compared to farther ones.

Last return - Last reflected signal that is detected by a 3D imaging system, for a given sampling position and a given emitted pulse. Not always a return of the true ground surface.

Least Squares LiDAR Strip Adjustment – Adjustment of overlapping LiDAR strips using least squares matching, in order to detect and correct for geometric errors in the data.

Lift – Duration of time between a single take-off and landing of an aircraft. Often, a single day of acquisition will include multiple lifts. Also referred to as 'session' or 'flight'.

Light Detection and Ranging (LiDAR) - An instrument that measures the distance to a reflecting object by emitting timed pulses of light and measuring the time difference between the emission of a laser pulse and the reception of the pulse's reflection(s). The measured time interval for each reflection is converted to distance. This distance conversion, combined with position and attitude information from GNSS, INS and the instrument itself, allows the derivation of the 3D point location of the reflecting target's location.

Measurement error - Measured quantity value minus a reference quantity value.

Measurement precision - Closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions.

Metadata - Any information that is descriptive or supportive of a geospatial dataset, including formally structured and formatted metadata files. For example, eXtensible Markup Language (XML), formatted Federal Geographic Data Committee (FGDC) metadata, reports (collection, processing, Quality Assurance/Quality Control (QA/QC)), and other supporting data (i.e., survey points, shapefiles).

Model - Abstraction of some aspects of reality.

Noise - Unwanted signal which can corrupt the measurement of irrelevant or meaningless cells that exist due to poor scanning or imperfections in the original source document.

Nominal Pulse Density (NPD) - A common measure of the density of a LiDAR dataset; NPD is the typical or average number of points occurring in a specified areal unit. The NPD is typically expressed as points per square metre (pts/m^2). This value can be predicted in mission planning and empirically calculated from the collected data, using only the first (or last) return points as surrogates for pulses. The merging of flight lines is permitted in the empirical calculation of NPD, if all precision/accuracy requirements are met, with no thinning of LiDAR datasets. Assuming metres are being used in both expressions, NPD can be calculated from NPS using the formula:

$$NPD = 1/NPS^2$$

See also: Achieved Ground Point Density, Nominal Pulse Spacing

Nominal Pulse Spacing (NPS) - As a common measure of the density of a LiDAR dataset, NPS is the typical or average lateral distance between points, typically expressed in metres and most simply calculated as the square root of the average area per first return points. This value can be predicted in mission planning and empirically calculated from the collected data, using first (or last) return points as surrogates for pulses; merging of flight lines is permitted in the empirical calculation for NPS if all precision/accuracy requirements are met, with no thining of LiDAR datasets. Assuming metres are being used in both expressions, NPS can be calculated from Nominal Point Density (NPD) using the formula:

$$NPS = 1/\sqrt{NPD}$$

See also: Achieved Ground Point Spacing, Nominal Pulse Density

Northing - Distance in a coordinate system, northwards (positive) or southwards (negative) from an east-west reference line.

Orthometric Height – The height, as measured along the plumbline, between the geoid and a point on the Earth’s surface, taken positive upwards from the geoid.

Pitch - Vehicles that are free to operate in three dimensions, such as an aircraft, can change their attitude and rotation about the three orthogonal axes centred on the vehicle’s centre of gravity — the longitudinal, vertical, and horizontal axes. Motion about the lateral axis is called pitch and it is a measure of how far an aircraft’s nose is tilted up or down.

Platform - Structure which supports a sensor, or sensors.

Plumbline - A line that corresponds to the direction of gravity at a point on the earth's surface; the line along which an object will fall when dropped.

Positioning system – A system of instrumental and computational components for determining position.

Precision - Measure of the repeatability of a set of measurements. The closeness with which measurements agree with each other, even though they may all contain a systematic bias. Related to the source data and DEM products quality.

Primary Geodetic Control – Refers to Canadian Active Control System (CACS) or GNSS occupied on passive Canadian Base Network (CBN) stations.

Projected coordinate reference system - A method used to represent the curved, 3D surface of the Earth on a 2D plane. Essentially, the conversion of location data from a sphere approximation to a planar surface (i.e., UTM).

Pulse Density – Measured as total pulses that reach the reflecting surface per square metre, as a function of flying height and laser PRF (pulse repetition frequency – number of pulses per second).

Quality - Degree to which a set of inherent characteristics fulfils requirements. Accuracy (exactitude) and precision (repeatability) are the means used to evaluate the quality of the source data and DEM products.

Quality Assurance (QA) - Set of activities for ensuring quality in the processes by which products are developed. In particular, the measures taken to ensure the quality of the source data, before and during acquisition of the data.

Quality Control (QC) - Set of activities for ensuring quality in products. The activities focus on identifying defects in the actual products produced. The verification of the quality of the deliverables is part of the QC.

Raster - Set of regularly spaced, continuous cells with, in the case here, bare-earth elevation values attached to the centre of each cell and the value for a cell is assumed to be valid for the whole cell area.

Remote sensing - Collection and interpretation of information about an object without being in physical contact with the object.

Return (laser pulse): The reflected signal that is detected by a 3D imaging system, for a given sampling position and a given emitted pulse. For every laser pulse emitted a discrete return sensor can record multiple measurements within the footprint. Additional returns indicate whether a return is single or one of multiple (i.e. first, second, third (etc), and last).

Roll - Vehicles that are free to operate in three dimensions, such as an aircraft, can change their attitude and rotation about the three orthogonal axes centred on the vehicle's centre of gravity — the longitudinal, vertical, and horizontal axes. Motion about the longitudinal axis is called roll and it determines how much the wings of the aircraft are banked.

Root Mean Square Difference (RMSD) - The square root of the average of the set of squared differences between two dataset coordinate values taken at identical locations. RMSD differentiates from root mean square error (RMSE) because neither dataset is known to be more or less accurate than the other, and the differences cannot be regarded as errors. RMSD is used in LiDAR when assessing relative accuracy, both intraswath and interswath. *See* root mean square error.

$RMSD_z$ The vertical root mean square difference in the z direction (elevation)

$$\sqrt{\frac{\sum(z_e - z_o)^2}{n}}$$

Where:
z_e is the expected z value,
z_o is the observed z value,
n is the total number of z values

Root Mean Square Error (RMSE) - The square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The RMSE is used to estimate the absolute accuracy of both horizontal ($RMSE_x$ and $RMES_y$) and vertical ($RMSE_z$) coordinates where standard or accepted values are known, as with GNSS-surveyed checkpoints of higher accuracy than the data being tested.

The standard equations for calculating horizontal and vertical RMSE are provided here:

$RMSE_x$ The horizontal root mean square error in the x direction (Easting):

$$\sqrt{\sum\frac{(X_i - X_i')^2}{n}}$$

where:
X_i is the set of n x coordinates being evaluated,
X_i' is the corresponding set of checkpoint *x* coordinates for the points being evaluated,
n is the number of x coordinate checkpoints, and
i is the identification number of each checkpoint from 1 through n.

$RMSE_y$ The horizontal root mean square error in the y direction (Northing):

$$\sqrt{\sum\frac{(Y_i - Y_i')^2}{n}}$$

where:
Y_i is the set of n y coordinates being evaluated,
Y_i' is the corresponding set of checkpoint y coordinates for the points being evaluated,
n is the number of y coordinate checkpoints, and
i is the identification number of each checkpoint from 1 through n.

$RMSE_r$ The horizontal root mean square error in the radial direction that includes both x and y coordinate errors:

$$\sqrt{(RMSE_X^2 + RMSE_Y^2)}$$

where:
$RMSE_x$ is the RMSE in the x direction, and
$RMSE_y$ is the RMSE in the y direction.

$RMSE_z$ The vertical root mean square error in the z direction (elevation):

$$\sqrt{\sum \frac{(Z_i - Z_i')^2}{n}}$$

where:
Z_i is the set of n z values (elevations) being evaluated,
Z_i' is the corresponding set of checkpoint elevations for the points being evaluated,
n is the number of z checkpoints, and
i is the identification number of each checkpoint from 1 through n.

Secondary Geodetic Control - GNSS occupied on an existing provincial monumentation (i.e. brass cap, GCM, etc.), where new coordinates shall be independently produced (i.e. published coordinates of the monument are not to be used).

Sensor - Element of a measuring system that is directly affected by a phenomenon, body, or substance carrying a quantity to be measured.

Swath (or strip) – The extent on the ground of the FOV of a laser scan line from a single flight line; a function of scanning angle and flying height AGL.

Vendor - Organization or person that provides a product.

Vertical accuracy - The measure of the positional accuracy of a dataset with respect to a specified vertical datum, at a specified confidence level or percentile. Vertical accuracy is an indicator of quality for geospatial products.

Triangulated Irregular Networks (TINs) – A set of adjacent, non-overlapping triangles computed from irregularly spaced points with x/y coordinates and z-values. The TIN model stores the topological relationship between triangles and their adjacent neighbours. The TIN data structure allows for the efficient generation of surface models for the analysis and display of terrain and other types of surfaces. TINs are able to capture critical points that define terrain discontinuities and are topologically encoded so that adjacency and proximity analyses can be performed.

Yaw - Vehicles that are free to operate in three dimensions, such as an aircraft, can change their attitude and rotation about the three orthogonal axes centred on the vehicle’s centre of gravity — the longitudinal, vertical, and horizontal axes. Motion about the perpendicular axis is called yaw, and it determines which direction the nose of the aircraft is pointed. (Note: Aircraft do not necessarily fly in the same direction as the nose is pointed if there are significant winds.)

LIST OF TABLES

LIST OF FIGURES