

Provincial Lidar Forest Information Product Specifications

Prepared by: The Ministry of Forests, Office of the Chief Forester,
Forest Analysis and Inventory Branch

Version 4.0
Victoria, BC



Table of Contents

Table of Contents	1
Record of Amendments	2
1.0 Introduction	3
2.0 Pre-processing.....	4
3.0 QC Raster Layer Creation	6
4.0 QC Raster Layer Quality Checks	8
5.0 Deliverables and Output Products.....	11
6.0 References	18
Appendix 1-Sample batch code:	19
Appendix 2-Point Cloud Quality Assurance:	20

Record of Amendments

Version	Revised by	Revision Description	Approved by	Date
3.1	Chris Butson & Geoff Quinn	Reduced to only CHM processing conducted at GeoBC, flowchart, ownership, footnote, ministry mark, document formatting		14/03/2024/
3.2	Chris Butson & Geoff Quinn	Change tiling from 1:20,000 mapsheets to 1km tiles, raster QC conducted by FAIB analyst, include BEM processing with buffered tiles, flowchart, update deliverables		19/03/2024
3.3	Geoff Quinn	Edits to appendix		02/04/2024
3.4	Geoff Quinn	included second date to file name structure		17/10/2024
4.0	Spencer Floyd & Geoff Quinn	Changed title to reflect all lidar derived forestry products, added CSM and ITD sections, updated naming conventions to include creation date, and other minor changes		14/08/2026

1.0 Introduction

There are many applications that have benefited from incorporating the highly detailed information inherent in airborne laser scanner data (lidar). Lidar is a survey technology that measures the x,y,z positions of the ground and overlaying surface features. Many purposes leverage the high-resolution digital elevation models (DEM) or bare earth models (BEM) that are produced from lidar point clouds, which are unmatched in precision and productivity relative to other remote survey technologies. With preprocessing strategies lidar point clouds can be manipulated to produce a wealth of information about the forest resource.

This document details the procedural framework that is applied at FAIB to translate lidar point clouds into analysis ready lidar forest products, of which include the modern predictive and enhanced forest inventories. Reference to lidar data throughout the document will refer to one of two data states, a point cloud or raster grid generalizations of those point clouds. The processing objective is to convert the xyz point cloud into a bare earth model/canopy height model (BEM/CHM), individual tree database (ITD), and canopy structure metrics (CSM). It should be noted that wherever brand or trade names are mentioned in this specification, these are meant for example only and are not to be considered as an endorsement or being exclusive of other instruments or procedures that provide similar levels of quality. It should also be noted that the requirements specified in this specification are the minimum ones to be met, which are defined in line with the current lidar technology and quality and availability of the upstream products that are used as inputs for CHM, ITD, and CSM production. These requirements are expected to be updated regularly to reflect the advancement of mapping technology and user demands.

2.0 Pre-processing

2.1 Input Point Cloud

The input data required to generate these forestry products is the classified point cloud, ASPRS LAS version 1.4. Generally, this is classified into ground, default (non-ground) and outlier (noise), classes 2, 1, and 7 respectively. The specifications of the input point cloud must conform to the GeoBC lidar specification document [3]. See appendix 2 for further details on point cloud quality assurance.

2.2 Buffered tiling

Input mapsheet point cloud files are to be retiled to 1000×1000 m tiles with a 0,0 origin. Retiling is intended to eliminate any previous tile clipping errors, duplicate points, to produce manageable files sizes, integer 1m cell dimensions, and to facilitate multi-core processing. The tiling shall include a 20m buffer area that is either added to each tile or used in on-the fly buffering. The buffer data is required to eliminate downstream data artifacts in products, which are caused by edge effects in the triangulated irregular network (TIN) process of the bare earth modeling. Omitting the buffer produces voids in the raster products and interpolation artifacts (Figure 1&2). Buffering is necessary to avoid artifacts in the height normalization process.

Buffered tiling (on raster writing “-use_tile_bb” flag shall be used):

```
lastile64 -i indir*.laz -o "1km_tile_epsg3153" -tile_size 1000 -buffer 20 -flag_as_withheld -tile_ll 0 0 -cores 7 -cpu64 -epsg 3153 -vertical_epsg 9245 -odir outdir -olaz
```

On-The-Fly Buffering can be applied when generating a BEM and for the height normalization:

```
lasheight64 -i indir*.laz -cores 7 -replace_z -buffered 20 -olaz -cpu64 -v -odir outdir -odix "_chm"
```

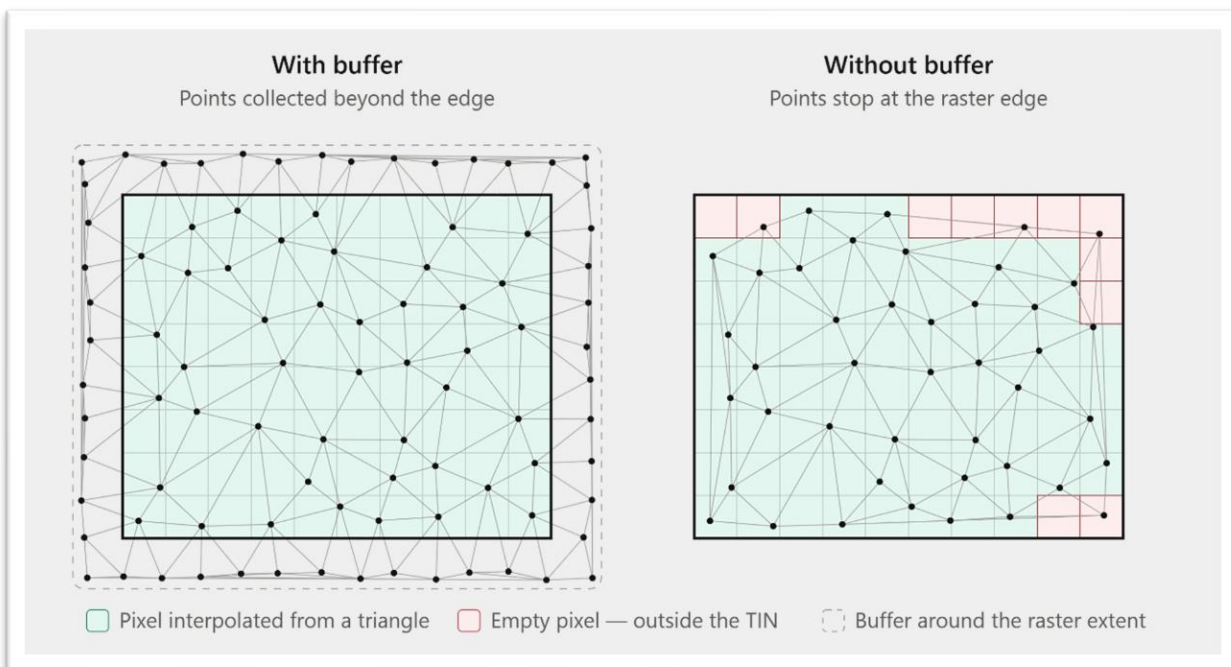


Fig. 1 TIN example with and without buffers

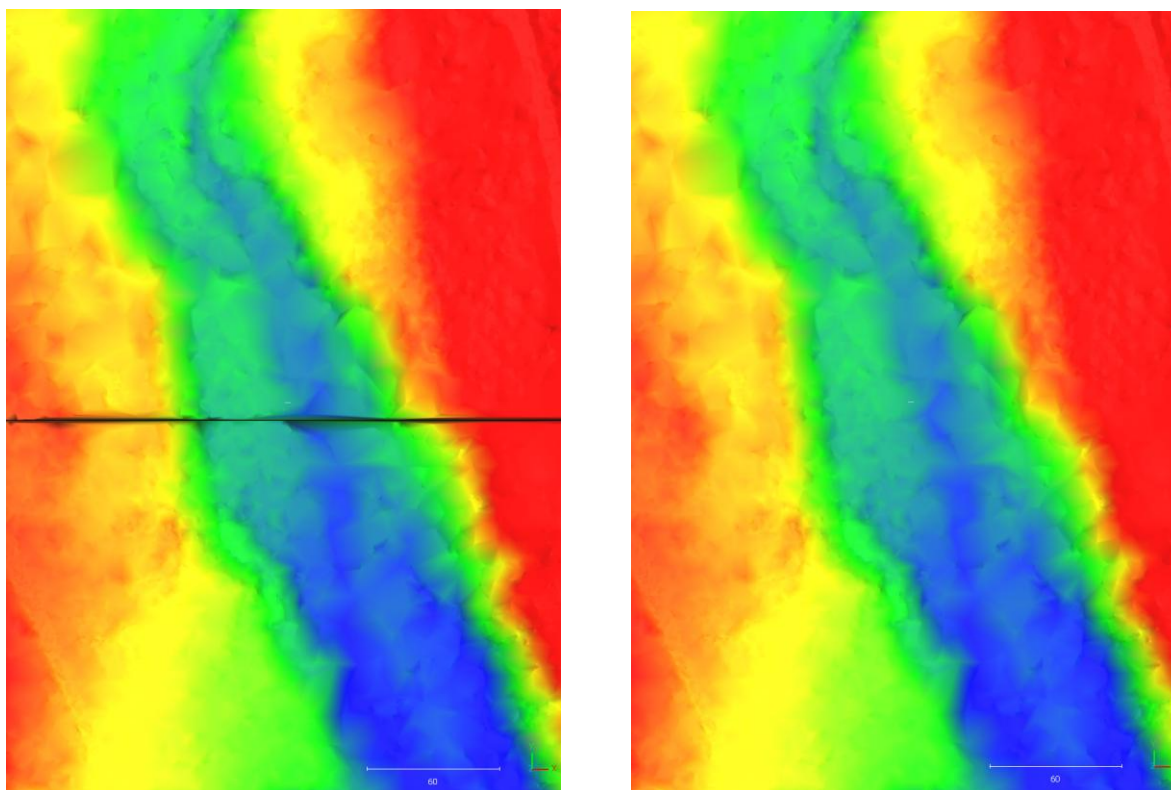


Fig. 2 Interpolation errors and data voids are produced when buffered tiles are not used

3.0 QC Raster Layer Creation

3.1 BEM

A bare earth model (BEM) or lidar derived digital elevation model (DEM) is to be generated at a 1m spatial resolution using class 2 (ground) points only. Raster production must incorporate the mapsheet buffer area, but products must omit the buffer data. Raster derivatives of the BEM are used to evaluate the quality of downstream data products. Hillshade rasters are produced to visualize the quality of the ground classification, large surface interpolations are apparent where ground has been insufficiently classified, a variety of illumination azimuth angles should be used in this process. Slope rasters are produced to evaluate the source of large outliers in the canopy height model. On-the-fly buffering is only possible in LAs tools through the las2dem process, which is limited to tiles with <20M points, therefore buffered tiling is preferred with blast2dem being the process for generating the BEM rasters.

Buffered tiles:

```
blast2dem64 -i indir*.laz -cores 7 -keep_class 2 -step 1 -use_tile_bb -obil -odir outdir  
lasgrid64 -i outdir*.bil -merged -otif -no_kml -no_world_file -o 1m_BEM_mos.tif -odir outdir
```

On-The-Fly buffering (limited to <20M points/tile):

```
las2dem64 -i indir*.laz -cores 7 -buffered 20 -keep_class 2 -step 1 -use_tile_bb -obil -cpu64 -odir outdir  
lasgrid64 -i outdir*.bil -merged -otif -cpu64 -no_kml -no_world_file -o 1m_BEM_mos.tif -odir outdir
```

3.2 CHM

Each point in the dataset must be converted from an orthometric elevation to a height above the ground surface. Height normalization of the point cloud is required for all lidar forest canopy products including the CHM and any downstream products. It also makes it easier for an analyst to find and remove low or high vertical outliers, misclassified points, and other spurious laser returns. Extract the 1m CHM from the terrain normalized point cloud dataset while dropping buffers on writing if applied to buffered tiles. The output raster cells are populated with the maximum height (height above ground) in each pixel where spatial resolutions shall be 1m. The noise filtering and data cleaning is vital due to the point generalization strategy.

The canopy height model in point cloud form is produced by subtracting, from every class 1 (default) point, the elevation of the ground TIN below (figure 3). Because the height normalization process includes the tinning of ground returns the buffered tiles are necessary. This shall be achieved through either buffered tiles or on-the-fly buffering.

Buffered tiles:

```
lasheight64 -i indir*.laz -cores 7 -replace_z -odir outdir -odix "_chm" -olaz  
lasgrid64 -i outdir*.laz -cores 7 -drop_withheld -clamp_z_below 0 -elevation -highest -use_tile_bb -obil -odir outdir
```

On-The-Fly buffering:

```
lasheight64 -i indir*.laz -cores 7 -replace_z -buffered 20 -olaz -v -odir outdir -odix "_chm"  
lasgrid64 -i indir*.laz -cores 7 -drop_class 7 -elevation -highest -use_tile_bb -clamp_z_below 0 -obil -no_kml -no_world_file -v -odir outdir
```

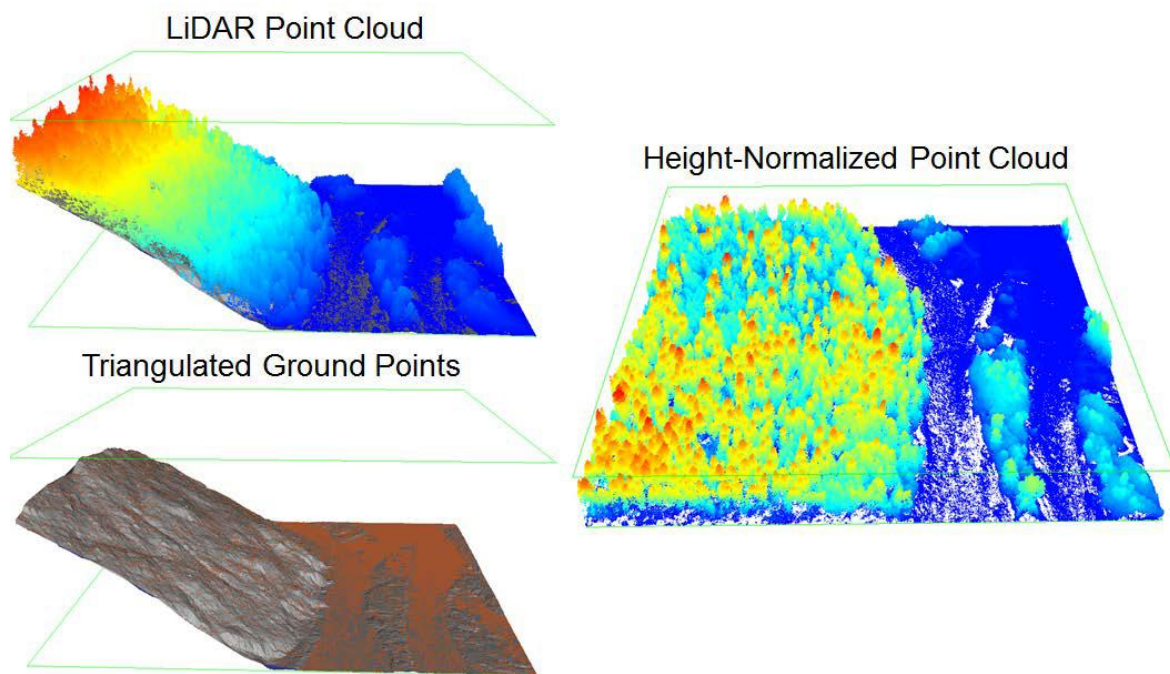


Fig. 3 Point cloud height normalization.

4.0 QC Raster Layer Quality Checks

4.1 Input layers for Quality Check

BEM (plus hillshade) allows for rapid visualization of:

- (a) ground classification errors,
- (b) elevation anomalies (pits and spikes), and
- (c) processing irregularities related to ground-finding parameterization and other types of point filtering.

CHM and slope allows for rapid visualization of:

- (a) height anomalies related to atmospheric reflections, sensor timing errors, misplaced multi-pulse returns, bird hits, etc., and
- (b) canopy distortions related to ground misclassification and steep terrain.

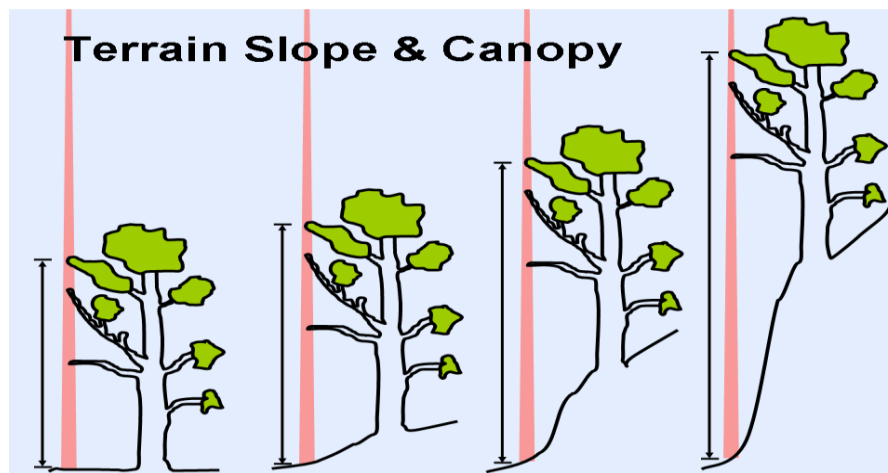


Fig. 4 Steep terrain example as seen in the unrealistic tree heights in the CHM (Source: Martin Isenburg, rapidlasso, GmbH, 2011)

Without a maximum height filter specified in normalization (lasheight) the analyst may evaluate the global maximum of the output for potential ground slope violations. This quality assurance step will be the point where the FAIB analyst needs to decide if the tile/survey needs to be reclassified, or if the errors will be accepted. The analyst shall investigate slope violations in the 1m CHM with reference to the 1m slope raster (figures 4&5). If large errors exist within 4m of terrain slopes less than 70° then the ground classification must be re-evaluated. If the effect appears localized, the analyst shall either manually reclassify the ground anomalies or reclassify ground for the tile or whole AOI.

For the sake of expediency, an analyst may selectively choose a high relief tile for evaluation of maximum terrain slope. The analyst shall produce a vector product for all areas within 4m of the slope threshold. In many cases the slope violation threshold has tended to be within approximately 4m of a terrain slope of 70° and greater.

Once the majority of slope violations tend to occur on steep terrain, the analyst will incrementally query the maximum height until non-slope violation errors are found (true tree heights), these should be evaluated in a point cloud visualization environment (e.g. Cloud Compare) to confirm that the underlying terrain has little influence on the tree height. This maximum tree height is then used as the drop above value in the second iteration of ground normalization (e.g. in the BC interior 80m maybe appropriate where western larch occupy high productive site; coastal areas will be higher still and potentially >100m).

```
lasheight64 -i indir *.laz -cores 7 -replace_z -drop_class 7 -drop_above 80 -odir outdir -odix "_chm" -olaz
```

```
lasgrid64 -i outdir *.laz -cores 7 -drop_withheld -clamp_z_below 0 -elevation -highest -use_tile_bb -otif -odir outdir
```

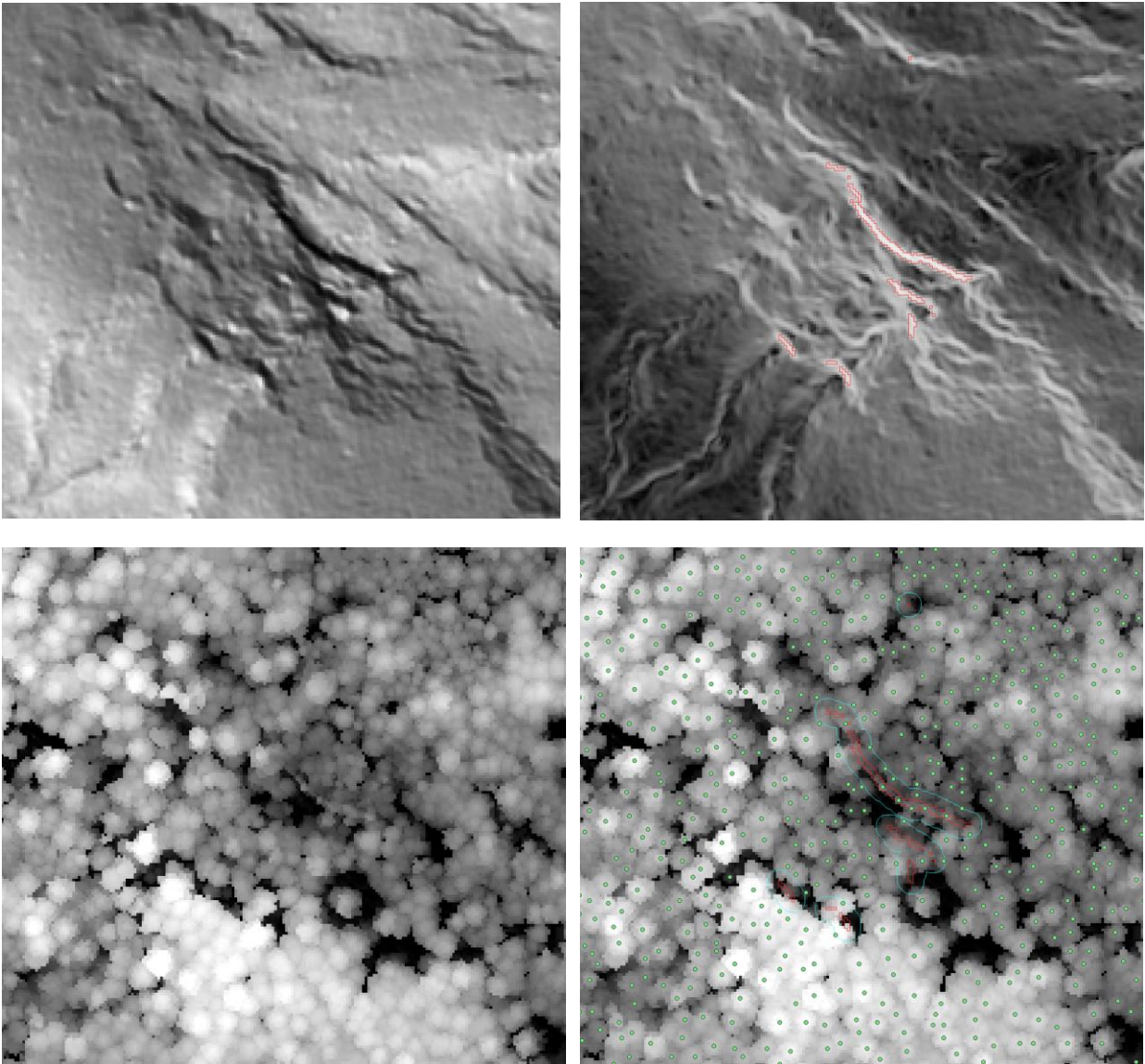


Fig. 5 Rough topography is illustrated in the 1m BEM hillshade zenith 45, azimuth 45 (topleft). Steep slopes are evident in the 1m BEM slope and those greater than 70° are delineated in red (right). The effect of steep terrain on the CHM is the erroneous returns above the ground appearing as though the area is more treed. The delineation of steep slopes with a buffer distance (blue) is used to flag potentially error prone areas in the lidar canopy products (bottom right).

5.0 Deliverables and Output Products

5.1 Bare Earth Model / Canopy Height Model (BEM / CHM) at 1m – TIFF

A raster comprised of two bands, BEM height values and CHM height values respectively. The quality of the product is adversely affected by low point densities, caused by either flight parameters or occlusion, steep slopes, which reduce the effectiveness of ground point classification, isolated air returns and insufficient data buffers in preprocessing. The input is compressed laz files that have been tiled, calibrated, classified, ground normalized and cleaned (no below ground, air hits or MTA zone errors). The process shall either use buffered tiles or on-the-fly buffering especially for the normalization step (lasheight.exe).

Band number	Band name	Description
1	BEM	Elevations taken at the center of each 1m cell calculated using a TIN created using class 2 (ground) points from a non-height normalized point cloud.
2	CHM	Elevations from the highest point in each cell using a height normalized point cloud.

5.1.1 Creation Method

See section 3.1 and 3.2 for the creation methods of BEM and CHM respectively. These outputs are stacked together to create the BEM/CHM tiff product.

5.1.2 Specifications

Raster format: TIFF

Compression type: lossless LZW (6% reduction) or ZIP (up to 20% reduction)

Support digital word order: Mac and PC

32-bit architecture (TIFF)

4 GB file size limit (TIFF)

255+ tags (v6)

Tiling scheme – Provincial standard 1:2500, EPSG= 3153

1m spatial resolution,

bit-depth=float 32-bit

5.1.3 File-naming Convention

[Ownership][Geographic Extent]_x[Acquisition Type][Grid Size]
bcalb[Date1]_[Date2]_bem_chm_[Creation Date].tif

Ownership = 'bc'

Geographic Extent = Geographic BC Map tile (1:2500)

Acquisition Type = 'li' for lidar, 'r' for Radar, and 'rgb' for Photogrammetric

Date1 = earliest collection date (YYYYMMDD)

Date2 = latest collection date (YYYYMMDD)

Creation Date = Date of file creation (YYYYMMDDHHMMSS)

e.g., bc_092L054444_xli_bcalb_20240528_20240619_bem_chm_202505221745.tif

5.2 Individual Tree Database (ITD) – SHP

A vector point representation of the X and Y location of treetops with a height above ground greater than or equal to 4m. Three heights are reported at each XY treetop location shown in the table below.

Attribute	Source	Description
CHM	1m Canopy Height Model	Relative height of the treetop above ground
BEM	1m Bare Earth Model	Absolute ground elevation beneath the treetop
DSM	1m Digital Surface Model	Absolute elevation of the treetop

5.2.1 Creation Method

The treetop X and Y locations are determined using a 3x3 pixel focal binary max convolution filter on a smoothed version of the CHM. At each pixel, the filter compares the centre height value against the eight surrounding values; if the centre pixel is the tallest of the nine, it is flagged as a treetop. The unsmoothed CHM height value is used as the treetop height value. Because a treetop must be the tallest pixel within one pixel in every direction, no two treetops can be detected closer than 2 m apart. This represents the effective minimum stem separation of the method. Detected treetops are subsequently removed when they are located on terrain steeper than 70° (plus a 4 buffer) or within 20 m of a mapped BC transmission line.

See the lidR tutorial on Individual Tree Detection and Segmentation for a similar method.

https://tgoodbody.github.io/lidRtutorial/06_its.html

5.2.2 Specifications

Vector format: SHP

Compression type: None

Support digital word order: Mac and PC

32-bit architecture

Tiling scheme: Provincial standard 1:2500, EPSG = 3153

Average file sizes and compression: 5.82MB (never exceeding 70MB shapefile uncompressed) without proximity and dominance attributes the Esri shapefile sizes are approximately 1MB per map sheet (~34k trees).

5.2.3 File-naming Convention

[Ownership]_[Geographic Extent]_x[Acquisition Type]
bcalb[Date1]_[Date2]_treetops_[Creation_Date].shp

Ownership = 'bc'

Geographic Extent = Geographic BC Map tile (1:2500)

Acquisition Type = 'li' for lidar, 'r' for Radar, and 'rgb' for Photogrammetric

Date1 = earliest collection date (YYYYMMDD)

Date2 = latest collection date (YYYYMMDD)

Creation Date = Date of file creation (YYYYMMDDHHMMSS)

e.g., bc_092L054444_xli_bcalb_20240528_20240619_treetops_202505221746.shp

5.3 Canopy Structure Metrics (CSM) at 20m - TIFF

A raster stack representation of the vertical and horizontal structure of the forest canopy including the standard univariate statistical measures, height quantiles and density profiles at a 20m spatial resolution. Metrics are stored as bands in the TIFF file format (1,2,3...n). These metrics are directly related to forest inventory attributes and are the basis for the area-based approach to lidar forest inventories. The standardized metrics produced are listed in the table below.

https://github.com/LAStools/LAStools/blob/master/bin/lascanopy_README.md

Band number	Band name	Source	Range	Description
1	chm_b02	point cloud	0-1	proportion of points within the pixel that fall within the first 2% of the height distribution within the pixel - interpret as crown closure at a lower canopy position
2	chm_b05	point cloud	0-1	as chm_b02 but 3% higher in vertical canopy position
3	chm_b10	point cloud	0-1	as above
4	chm_b15	point cloud	0-1	as above
5	chm_b20	point cloud	0-1	as above
6	chm_b25	point cloud	0-1	as above
7	chm_b30	point cloud	0-1	as above
8	chm_b40	point cloud	0-1	as above
9	chm_b50	point cloud	0-1	as above
10	chm_b60	point cloud	0-1	as above
11	chm_b70	point cloud	0-1	as above
12	chm_b75	point cloud	0-1	as above
13	chm_b80	point cloud	0-1	as above
14	chm_b85	point cloud	0-1	as above
15	chm_b90	point cloud	0-1	as above
16	chm_b95	point cloud	0-1	as above
17	chm_b98	point cloud	0-1	as above

Band number	Band name	Source	Range	Description
18	chm_all	point cloud	0-inf	the total number of lidar returns in the given pixel
19	chm_avg	point cloud	0-inf	the average height of lidar returns
20	chm_kur	point cloud	3-inf	height distribution shape metric of the lidar returns; describes how heavy the tails are; i.e. higher values represent sharp peaks (leptokurtic); lower values represent more uniform (platykurtic)
21	chm_max	point cloud	0-inf	the maximum height of the lidar returns
22	chm_min	point cloud	0-inf	the minimum height of the lidar returns
23	chm_qav	point cloud	0-inf	the quadratic average of the lidar returns; taller points have more weight
24	chm_ske	point cloud	0-inf	height distribution shape metric of the lidar returns; describes how asymmetrical the distribution is; i.e. higher positive values long tail into higher values; lower negative values represent longer tail into lower values
25	chm_std	point cloud	0-inf	the standard deviation of heights of the lidar returns
26	cov_gap	point cloud	0-1	canopy cover metric calculated as the fraction of first returns above 1.3m relative to the total number of first returns
27	dns_gap	point cloud	0-1	canopy cover metric calculated as the fraction of all returns above 1.3m relative to the total number of all returns
28	chm_p02	point cloud	0-inf	the height below which 2% of all returns within the pixel fall
29	chm_p05	point cloud	0-inf	as above
30	chm_p10	point cloud	0-inf	as above
31	chm_p15	point cloud	0-inf	as above
32	chm_p20	point cloud	0-inf	as above
33	chm_p25	point cloud	0-inf	as above
34	chm_p30	point cloud	0-inf	as above
35	chm_p40	point cloud	0-inf	as above
36	chm_p50	point cloud	0-inf	as above
37	chm_p60	point cloud	0-inf	as above
38	chm_p70	point cloud	0-inf	as above

Band number	Band name	Source	Range	Description
39	chm_p75	point cloud	0-inf	as above
40	chm_p80	point cloud	0-inf	as above
41	chm_p85	point cloud	0-inf	as above
42	chm_p90	point cloud	0-inf	as above
43	chm_p95	point cloud	0-inf	as above
44	chm_p98	point cloud	0-inf	as above
45	TTall	treetops	0-inf	the total number of detected treetops in the given pixel
46	TTavg	treetops	4-inf	the average height of detected treetops
47	TTkur	treetops	0-inf	height distribution shape metric of the detected treetops; describes how heavy the tails are; i.e. higher values represent sharp peaks (leptokurtic); lower values represent more uniform (platykurtic)
48	TTmax	treetops	4-inf	the maximum height of the detected treetops
49	TTmin	treetops	4-inf	the minimum height of the detected treetops
50	TTp25	treetops	4-inf	the detected treetop height below which 25% of all detected treetops within the pixel fall
51	TTp50	treetops	4-inf	as above
52	TTp75	treetops	4-inf	as above
53	TTp85	treetops	4-inf	as above
54	TTqav	treetops	16-inf	the quadratic average of the lidar detected treetops; taller trees have more weight
55	TTske	treetops	inf	height distribution shape metric of the detected treetops; describes how asymmetrical the distribution is; i.e. higher positive values long tail into higher values; lower negative values represent longer tail into lower values
56	TTstd	treetops	0-inf	the standard deviation of heights of the detected treetops
57	chm_vc0	point cloud	0-1	Shannon entropy; measure of vertical complexity with a vertical bin size of 1m; higher values represent representation across many heights; lower values suggest canopy concentrated in few height bins
58	chm_vc1	point cloud	0-1	as above with 5m vertical bins
59	chm_vc2	point cloud	0-1	as above with 10m vertical bins
60	chm_vc3	point cloud	0-1	as above with 15m vertical bins

5.3.1 Creation Method

The following four commands are run to produce four separate geotiff files. They are combined into a single geotiff file which contain all 60 bands of information listed above.

```
lascanopy64 -i *.laz -cores 8 -keep_class 1 3 4 5 -drop_withheld -epsg 3153 -vertical_cgvd2013 -  
clamp_z_below 0 -drop_z_above 90 -all -min -max -avg -std -ske -kur -qav -grid_ll 0 0 -otif-no_kml -  
no_world_file -v -odir outdir
```

```
lascanopy64 -i *.laz -cores 8 -keep_class 1 3 4 5 -drop_withheld -epsg 3153 -vertical_cgvd2013 -  
clamp_z_below 0 -drop_z_above 90 -cov -dns -gap -p 2 5 10 15 20 25 30 40 50 60 70 75 80 85 90 95 98 -  
fractions -grid_ll 0 0 -otif-no_kml -no_world_file -v -odir outdir
```

```
lascanopy64 -i *.laz -cores 8 -keep_class 1 3 4 5 -drop_withheld -epsg 3153 -vertical_cgvd2013 -  
clamp_z_below 0 -drop_z_above 90 -height_cutoff 0 -b 2 5 10 15 20 25 30 40 50 60 70 75 80 85 90 95 98 -  
-fractions -grid_ll 0 0 -otif-no_kml -no_world_file -v -odir outdir
```

```
lascanopy64 -i *.laz -cores 8 -keep_class 1 3 4 5 -drop_withheld -epsg 3153 -vertical_cgvd2013 -  
clamp_z_below 0 -drop_z_above 90 -vci 1 5 10 15 -grid_ll 0 0 -otif-no_kml -no_world_file -v -odir  
outdir
```

5.3.2 Specifications

Raster format: TIFF or BIGTIFF (64-bit, >4GB files), multi-band
Compression type: lossless LZW (6% reduction) or ZIP (up to 20% reduction)
Support digital word order: Mac and PC
32-bit architecture (TIFF)
4 GB file size limit (TIFF)
255+ tags (v6)
Tiling scheme – Provincial standard 1:2500, EPSG = 3153
20m spatial resolution,
bit-depth=float 32-bit,
average file size: 900KB.

5.3.3 File-naming Convention

[Ownership]_[Geographic Extent]_x[Acquisition Type][Grid Size]
bcalb[Date1]_[Date2]_csm_[Creation Date].tif

Ownership = 'bc'

Geographic Extent = Geographic BC Map tile (1:2500)

Acquisition Type = 'li' for lidar, 'r' for Radar, and 'rgb' for Photogrammetric

Grid Size = cell size in metres, shall be an integer number (e.g., 20m).

Date1 = earliest collection date (YYYYMMDD)

Date2 = latest collection date (YYYYMMDD)

csm = Canopy Structure Metrics

Creation Date = Date of file creation (YYYYMMDDHHMMSS)

e.g., bc_092L054444_xli_bcalb_20231031_20231031_csm_20260617005238.tif

6.0 References

- [1] H. K. Heidemann, "Lidar Base Specification, Version 1.3," United States Geological Survey (USGS), February 2018. [Online]. Available: <https://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf>.
- [2] International Organization for Standardization, "Multi-Lingual Glossary of Terms," 2020. [Online]. Available: <https://isotc211.geolexica.org/concepts/>.
- [3] Specifications for Airborne Lidar for the Province of British Columbia, 2023.[Online]. Available: https://www2.gov.bc.ca/assets/gov/data/geographic/digital-imagery/specifications_for_airborne_lidar_for_the_province_of_british_columbia_53.pdf

Appendix 1-Sample batch code:

```
rem--The barebones process for pre-FAIB work is below. execute with:
D:\temp\GeoBC_test_set\scripts\FAIB_LAZ_PROCESSING_REDUCED_V0.bat >>
D:\temp\GeoBC_test_set\outdir\FAIB_ALS_LOG_%date:~0,4%%date:~5,2%%date:~8,2%%time:~0,
2%%time:~3,2%%time:~6,2%.txt 2>&1

set datloc=F:\lidar\500m_Tiled\LAZ\
set indir=F:\temp\indir\
set outdir=D:\temp\GeoBC_test_set\reduced\
set lastools=D:\lastools\bin\

rem—index original data to enable parallel multi-core processing
%lastools%\lasindex.exe -i %datloc%*.laz -cores 7 -cpu64

rem—create buffered tiles
%lastools%\lastile.exe -i %datloc%*.laz -o "1km_tile_epsg3153" -tile_size 1000 -tile_ll 0 0 -buffer 20 -
flag_as_withheld -cores 7 -cpu64 -epsg 3153 -vertical_epsg 9245 -odir %indir% -olaz
%lastools%\lasindex.exe -i %indir%*.laz -cores 7 -cpu64

rem—generate BEM raster
md %outdir%\bem\
%lastools%\blast2dem.exe -i %indir%*.laz -cores 7 -keep_class 2 -step 1 -cores 7 -obil -odir %outdir%\bem\ -epsg
3153 -use_tile_bb -vertical_cgvd2013 -no_kml -no_world_file
%lastools%\lasgrid.exe -i %outdir%\bem%.bil -merged -otif -cpu64 -no_kml -no_world_file -epsg 3153 -
vertical_cgvd2013 -o %outdir%\bem\1m_bem_mos.tif
del %outdir%\bem%.bil
del %outdir%\bem%.blw
del %outdir%\bem%.prj
del %outdir%\bem%.hdr
del %outdir%\bem%.stx

rem--generate CHM point cloud
md %outdir%\chm\
md %outdir%\chm\laz\
%lastools%\lasheight.exe -i %indir%*.laz -cores 7 -replace_z -drop_class 7 -odir %outdir%\chm\laz\ -odix "_chm" -
olaz -cpu64
%lastools%\lasindex.exe -i %outdir%\chm\laz%*.laz -cores 7 -cpu64

rem--generate CHM rasters
%lastools%\lasgrid.exe -i %outdir%\chm\laz%*.laz -cores 7 -drop_withheld -clamp_z_below 0 -elevation -highest -
use_tile_bb -obil -odir %outdir%\chm\ -cpu64 -no_kml -no_world_file
%lastools%\lasgrid.exe -i %outdir%\chm%.bil -merged -epsg 3153 -vertical_epsg 9245 -otif -o
%outdir%\chm\1m_chm_mos.tif
del %outdir%\chm%.bil
del %outdir%\chm%.blw
del %outdir%\chm%.prj
del %outdir%\chm%.hdr
del %outdir%\chm%.stx
```

Appendix 2-Point Cloud Quality Assurance:

Point Cloud Quality Assurance:

This section describes the quality assurance checks that should be performed on the point cloud data prior to generating the lidar canopy products. Many of these items shall be thoroughly defined in the ALS acquisition contract between the vendor and data recipient. These quality control items are summarized below with lastools examples:

1) **Raw point files must conform to specification.**

Data must be delivered in las version 1.4 and in compressed LAZ format, the point data type must have adjusted standard GPS time and therefore must not be types 0, 2 or 4, data must be delivered in the requested map projection. To avoid ambiguity, specify the EPSG code, the vertical datum should be specified (i.e. CGVD2013), data must adhere to the ASPRS classification regime, global encoding must be 17 (adjusted standard GPS time, CRS in WKT), first return density (alternatively last return density) must be greater than or equal to 8pnts/m², scan angles must not exceed +/- 30°. All files must retain point source id as unique flightline identifier to facilitated recompiling flightline data. Lidar file format is assured through the lasinfo utility.

```
%lastools%lasinfo.exe -i %datloc%*.laz* -odir %datloc%las_info\ -odix "_info" -cd -gw -repair -otxt -cores 7
```

2) **Point classification accuracy.**

The minimum permissible point classification is 1,2,7 for unclassified, ground and noise respectively. Large interpolation triangulated irregular network facets should not be evident in bare earth models (exception being open water bodies and courses), particular attention should be given to high relief areas and slope crests where morphological ground classification algorithms tend to fail based on the assumed TIN distance and terrain angle parameters. Air hits should also be captured in class 7. Large interpolations in the bare earth model and noise in classes 1:5 are grounds for failing quality assurance. At a very minimum a random sample of 10% of the tiles should be manually evaluated. Evaluation should start with the 1m CHM and anomalies checked with point cloud visualization software (e.g. Cloud Compare). Any noise identified in the point cloud data must be retained in the point cloud and classified appropriately. Multi-time around (MTA) zone errors, which can be detected through a 5m range raster (all classes), should be dealt with properly through one of three strategies: by reassigning erroneous data to the appropriate MTA zone in pre-processing (preferred), by re survey, or finally by GPS timing clipping only if minimum point density specifications are maintained.

3) **Data gaps** –The data coverage within each 1:2500 tile must be complete and not contain any gaps between flight lines (post scan angle clipping +/-29°). Data gaps are evaluated though the lasboundary and/or lasoverlap utility. For a given mapsheet to be processed there must be at least 20m of buffer data available outside the extent of the mapsheet (the

exception being overlapping water features and provincial ALS extent boundaries). Point cloud data delivered to FAIB must include, at minimum the outermost 20m buffer beyond all mapsheets delivered.

*lasboundary64 -i indir *.laz -cores 7 -concavity 10 -disjoint -odir outdir -odix "_conc10" -oshp*

- 4) **Point cloud statistics** – Point cloud statistics are evaluated through the initial lasinfo utility (point density last only per square meter) and/or through lasgrid 1m point density raster production. GeoBC provincial specifications for provincial lidar must meet quality level 2 specifications: nominal point density of $\geq 8 \text{ pnts/m}^2$ first or last return excluding sidelap (with sidelap specification density must be greater than 13.2 pnts/m^2), area outside density specification must not exceed 5%, nominal point spacing $\leq 35 \text{ cm}$, with the exclusion of low reflecting targets voids $\geq (4 * \text{NPS})^2 = 2 \text{ m}^2$ are not acceptable, sidelap shall be greater than 30% and flightline alignment shall be better than $\pm 16 \text{ cm}$.

*lasgrid64 -i indir *.laz -cores 7 -drop_withheld -drop_class 7 -last_only -point_density - use_tile_bb -obil -odir outdir*

- 5) **Processing artifacts** – Data artifacts like atmospheric noise and air hits, AOI edge and flightline matching and various point filtering are very common in ALS collections and must be minimized whenever possible. These data need to be properly classified potentially by manual classification so that they can be filtered out as to not be included in the subsequent data products.