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First Order Lidar Metrics:

A supporting document for lidar deliverables

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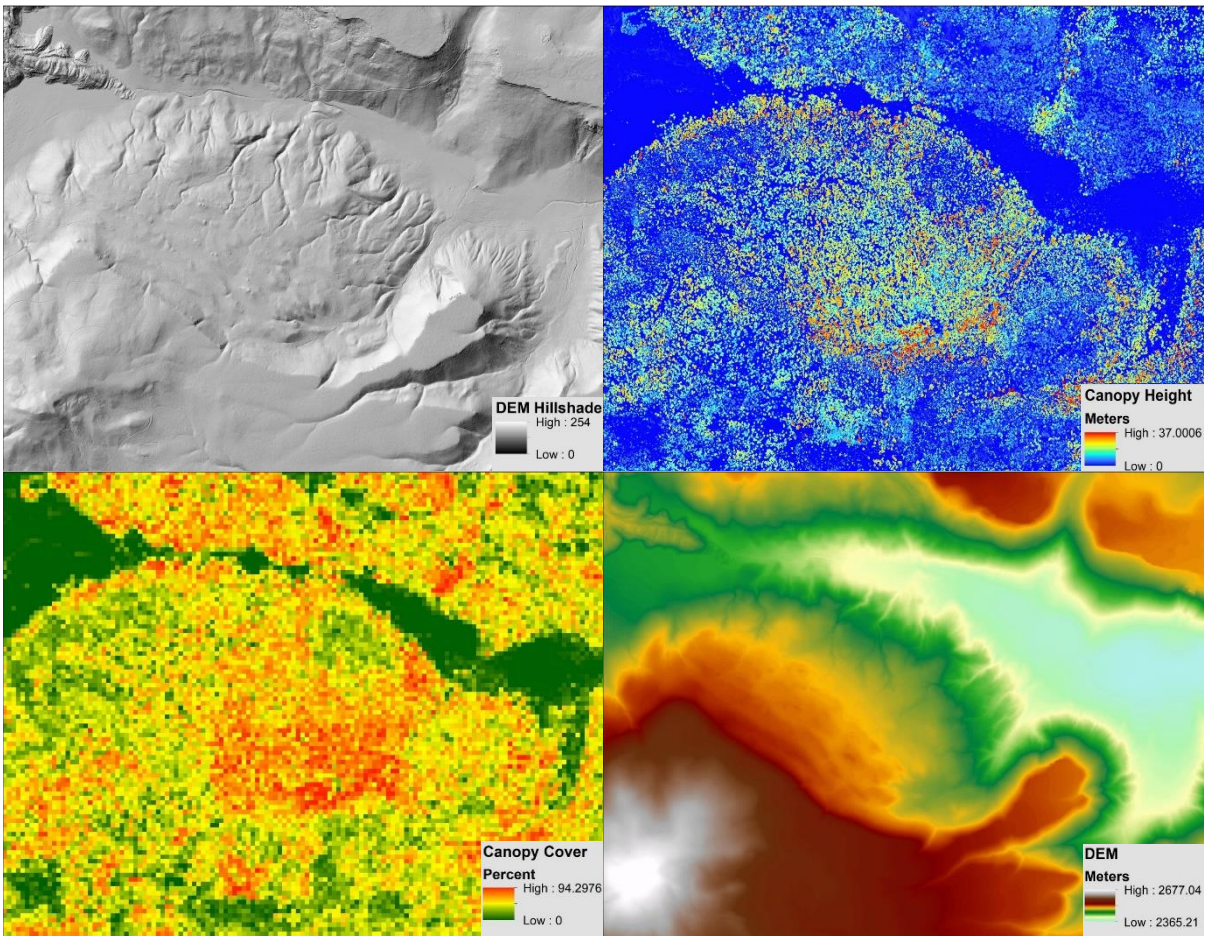

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Purpose

This document was written to ensure that the logic and naming convention of first order lidar metrics produced using FUSION software and the AreaProcessor (AP) processing workflow are understood and applied appropriately.

Lidar Processing and Products

The first order raster layers described in this document are a suite of descriptive statistic raster layers calculated from lidar data. Creating these raster products from the lidar point clouds make the analysis of the information contained in the lidar point cloud easier. Raster products can be more visually representative of the landscape than the raw point cloud, and processing speeds of rasters are far quicker.

These raster products are created using FUSION software and the AP processing workflow, both developed by Bob McGaughey at the Pacific Northwest Research Station. For more information about the FUSION software and the AP lidar processing workflow, please refer to GTAC's Advanced Lidar Processing Tutorial (FSWeb Link: http://fsweb.geotraining.fs.fed.us/www/index.php?lessons_ID=2358 or WWW Link: https://www.fs.fed.us/eng/rsac/lidar_training/Advanced_Lidar_Processing_2018%20-%20Storyline%20output/story.html).

Descriptions of raster products and how they are derived will be given in the document below. For additional descriptions of lidar height and density metrics created by FUSION, please refer to the documentation for the GridMetrics command in the FUSION manual, which will be in the doc folder of your FUSION download.

FUSION and AP Processing Considerations

When an AP run is started, the user will need to manually set some parameters regarding which points to include in vegetation metrics. These parameters will be recorded in the naming convention of the metrics output by the AP. This section of the document will discuss several of those parameters and considerations to take when setting them.

Height and Cover Cutoffs

Depending on the study area, separate runs of the AP processing workflow may be required in order to generate metrics appropriate for describing unique vegetation types with significantly different canopy structure characteristics. Creating lidar metrics for specific vegetation types can help to ensure that canopy height distribution and density statistics are reasonably calculated. Multiple AP runs with different height and canopy cover threshold parameters may be needed in study areas spanning

multiple forest types, where tree species differ significantly in terms of canopy height and growth pattern.

Expert knowledge of the forest vegetation types of interest should inform the threshold parameters that are used. For example, higher height and cover cutoff threshold values are typically applied where forest canopies are dominated by taller tree species and lower cutoff values are often used in forest canopies dominated by smaller stature species. Refer to Figure 1 for a comparison of how two plots in different example vegetation types appear in the lidar point cloud. In this example, metrics applicable to the taller vegetation type (mixed-conifer forest) were processed with higher height and cover cutoff values. Owing to characteristically small stature of the second (woodland) vegetation type, a lower height and cover cutoff value were used. Vegetation type specific metrics are typically generated wall-to-wall for the study area with the understanding that additional information describing forest type will be considered to guide their appropriate application in inventory modeling and/or in support of management activities. The same suite of metrics are generally generated for the different vegetation types, the key difference being the height and cover thresholds used for height statistics and density calculations.

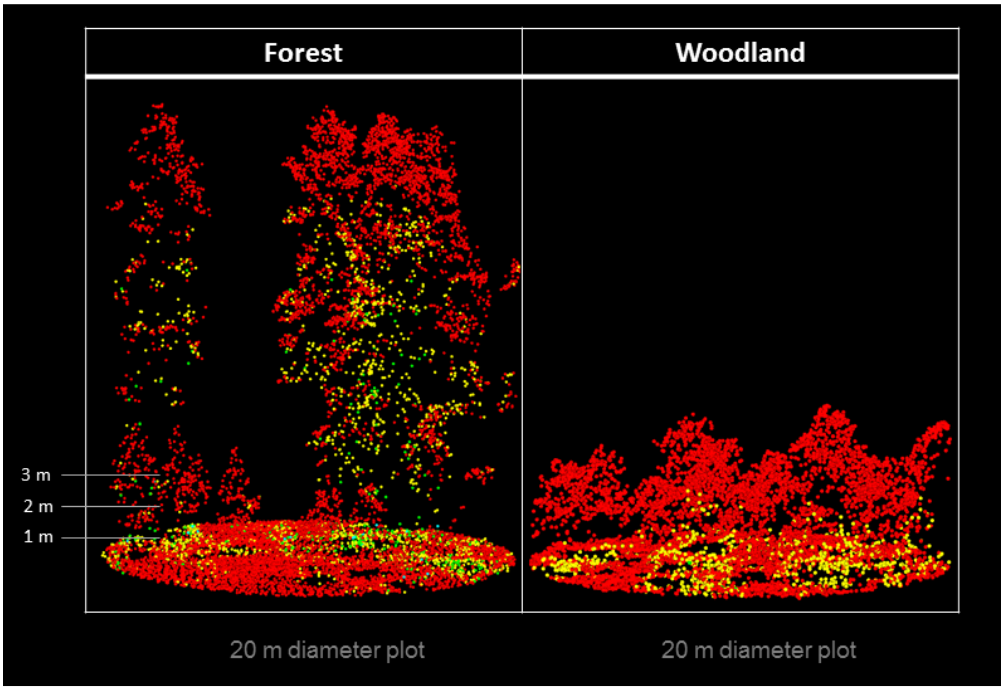


Figure 1: Comparison of point cloud views of plots representing two distinct forest types. Points are colored according to their return number, first returns are shown in red, second, third and fourth returns are shown in yellow, green and blue. The plot in figure A on the left is in a mixed-conifer forest type that is dominated by taller tree species. In this forest type (mixed-conifer), the canopy cover cutoff of 3 meters was used for the calculation of the cover statistics and a height cutoff value of 2 meters was used for calculating height statistics. Figure B on the right shows a pinyon-juniper woodland plot with smaller stature trees. In this case, a lower height and cover cutoff value of 1 meter was used to account for the smaller stature.

First Order Metrics Descriptions, Naming Conventions, and Examples

For each AP run completed, there will be a corresponding set of canopy structure statistics images. These are named according to the type of structure statistic and the threshold values used in the calculation. Custom naming can be implemented by editing the batch file used to name the output layers in the AP processing workflow, for more information please refer to the Advanced Lidar Processing Tutorial referenced in the previous sections. The examples below provide explanations for the raster naming conventions that describes each layer by specifying the information outlined in the filename. In general, first order lidar metrics names follow the form:

<type of metric>_<how it was calculated>_<threshold cutoff value>_<cell size & units>.<file type>

Metrics that do not follow that naming convention are covered later in this document.

Height Metrics

Naming Convention

The canopy height metrics produced by the AP all have the prefix, *elev* in the filename. The examples below show that the elev prefix specify the type of metric:
*<**type of metric**>_<how it was calculated>_<threshold cutoff value>_<cell size & units>.<file type>*

***elev**_P95_2plus_20METERS.img*

***elev**_mean_2plus_20METERS.img*.

The next part of the file name describes the calculation that was used to create the raster. Explanations of all of the calculations can be found in the Fusion manual, in the GridMetrics section. The two examples below show that second part of the filename specifies the calculation used for the metric:
*<type of metric>_<**how it was calculated**>_<threshold cutoff value>_<cell size & units>.<file type>*

*elev_**P95**_2plus_20METERS.img – Pixel represents height of the 95th percentile of returns in the pixel.*

*elev_**mean**_2plus_20METERS.img*. – Pixel represents the mean height of returns in the pixel.

The third part of the file name specifies the height cutoff that was used for the raster. Canopy height metrics are calculated using all the returns in the lidar point cloud (i.e., first, second, third and fourth returns are all considered). The only points not included in the height metrics are points which fall below the specified height cutoff value, which the user sets in the basic_setup.bat file. The two examples below show how the third part of the filename specifies the height cutoff for the raster:
*<type of metric>_<how it was calculated>_<**threshold cutoff value**>_<cell size & units>.<file type>*

*elev_P95_**2plus**_20METERS.img – Only returns more than 2 meters above ground surface are used.*

*elev_mean_**2plus**_20METERS.img. – Only returns more than 2 meters above ground surface are used.*

The final part of the file name specifies the raster cell size (the spatial resolution) of the image. The cell size and the units are defined by the user in the basic_setup.bat file and in the AP interface.

*<type of metric>_<how it was calculated>_<threshold cutoff value>_<**cell size & units**>.<file type>*

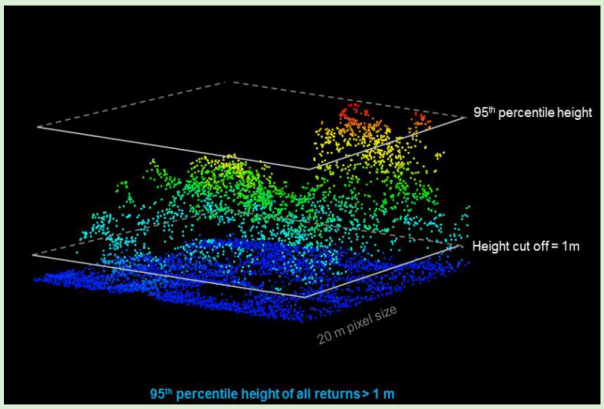
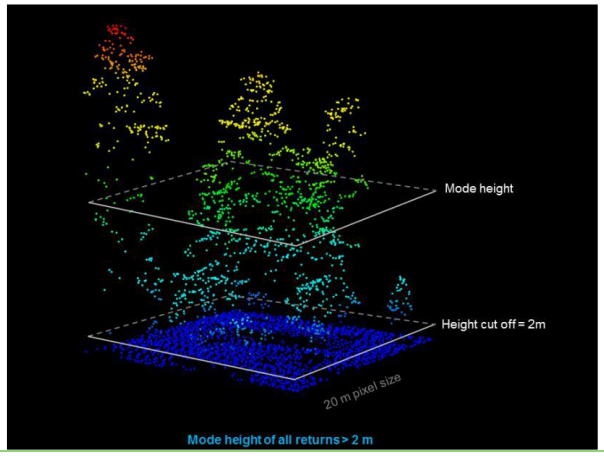
*elev_P95_2plus_**20METERS**.img – Raster has a 20 meter spatial resolution.*

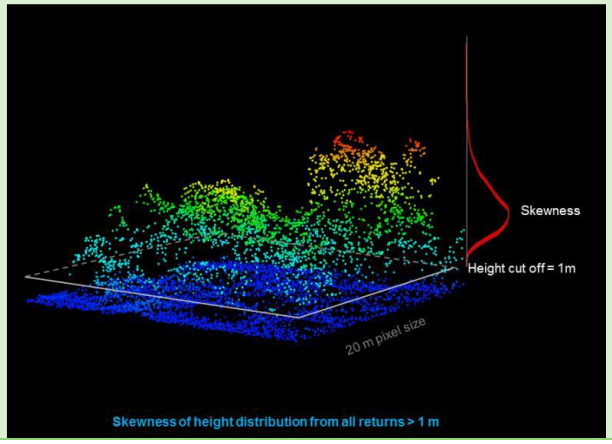
*elev_mean_2plus_**20METERS**.img. – Raster has a 20 meter spatial resolution.*

These metrics include basic distribution statistics such as the mean, mode, variance, maximum height values, and height values of a range of percentiles. The metrics also include statistics describing the shape of the point cloud height distributions including measurements of skewness, kurtosis, and linear (L) moments. Refer to the FUSION manual for a technical description of these metrics.

Illustrated Examples

This section provides example illustrations of metrics and a discussion of the corresponding filenames for a small, representative sample of first order lidar metrics generated in the AP. In the tables below, the metric filenames are described from left to right. While only a small subset of the total metrics generated by the AP are covered, the hope is that deciphering these names will foster sufficient understanding to make sense any of the other metrics included in a set of final deliverables.

Height Metric and Explanation	Illustration
elev_P95_1plus_20METERS.img ○ **elev**: specifies a height metric ○ P95: Indicates that the metric represents the **95th** percentile height value of points in the cell above the height cutoff ○ **1plus**: designates that a height cutoff of 1 meter was used when calculating the height percentile ○ **20METERS**: designates the cell size and units at which the metric was calculated Logic: *The 95th percentile height for all returns > height cutoff*	
elev_mode_2plus_20METERS.img ○ **elev**: specifies a height metric ○ **mode**: Indicates that the metric represents the mode height value of points in the cell above the height cutoff ○ **2plus**: designates that a height cutoff of 2 meters was used when calculating the mode height ○ **20METERS**: The cell size and units at which the metric was calculated Logic: *The mode height for all returns > height cutoff*	

Height Metric and Explanation	Illustration
elev_skewness_1plus_20METERS.img ○ **elev**: specifies a height metric ○ **skewness**: indicates that the metric represents the skewness value for the cell ○ **1plus**: designates that a height cutoff of 1 meter was used when calculating the skewness ○ **20METERS**: designates the cell size at which the metric was calculated Logic: *The 'skewness' of the distribution of all points above the height cutoff*	

Cover Metrics

Another large group of calculated metrics collectively represent different aspects of canopy cover and canopy density. The various metrics in this group are all computed as ratios of lidar returns above a specified height threshold to the total returns as described in the generic equation below:

Equation 1:

$$Cover = \left(\frac{\#\ returns > cover\ cutoff}{Total\ \#\ Returns}\right) * 100$$

The many different cover and density metrics generated by the AP differ according to the type of lidar returns (first returns or all returns) used in the numerator and/or denominator of the expression above, and by the height cutoff value, which determines the number of returns in the numerator.

In general, metrics calculated using only the first returns from each lidar pulse represent measures of canopy cover, while those considering all returns represent the overall density of the canopy.

Naming Convention

In the cover metrics naming convention, the first and sometimes the second position in the filename describe which points are used in the numerator and denominator of the cover equation (Equation 1). This is shown in the illustrations in the next section and explained in the examples below:
***1st**_cover_above_mean_20METERS.img – first returns above the cover cutoff are used in the numerator, while total first returns are used in the denominator of the cover equation. If only one set of returns is indicated, the values for the numerator and denominator were both derived from that set of returns.*

***all_1st**_cover_above1_20METERS.img – all returns above the cover cutoff are used in the numerator of the cover equation, while total first returns are used in the denominator. With two sets of returns indicated, the first represents the returns used in the numerator and the second represents the returns used in the denominator.*

Following the file naming convention, these metrics all contain the word, ***cover***, in the third or fourth position in the filename. Unlike the height metrics, the cover specification is not in the first position in the file name. The examples below show how "cover" specifies the type of metric:
*<**type of metric**>_<threshold cutoff value>_<cell size & units>.<file type>*

*1st_**cover**_above_mean_20METERS.img*

*all_1st_**cover**_above1_20METERS.img*

The next part of the filename specifies what cover cutoff was used for the metric. This may be easier to understand in the illustrations below, but the following examples show how the filename describes which points get included in the numerator of the cover equation (Equation 1).
*<type of metric>_<**threshold cutoff value**>_<cell size & units>.<file type>*

*1st_cover_**above_mean**_20METERS.img – specifies that only first returns above the mean height for the given pixel are used in this cover metric.*

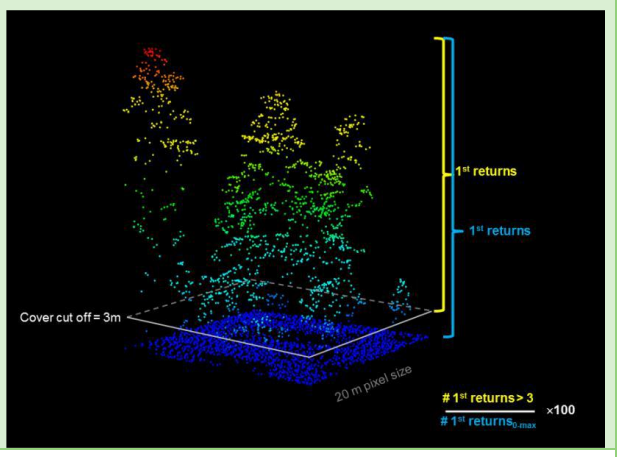
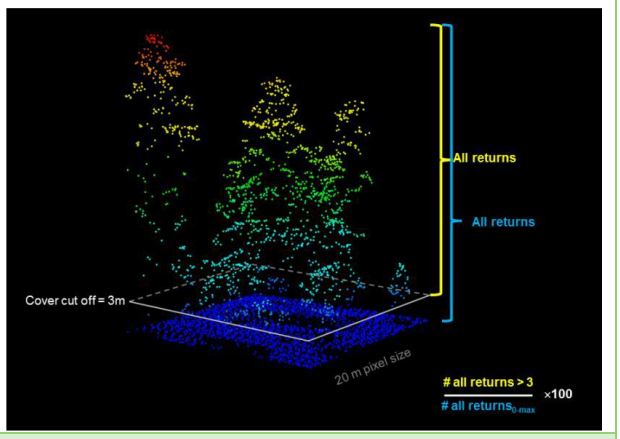
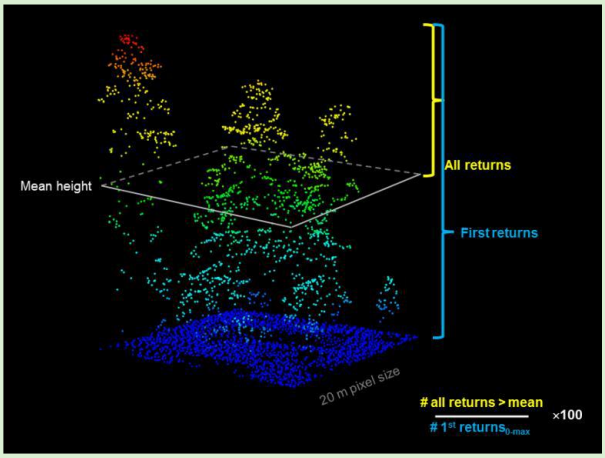
*all_1st_cover_**above1**_20METERS.img - specifies that all returns above 1 meter (cover cutoff) are used in this cover metric.*

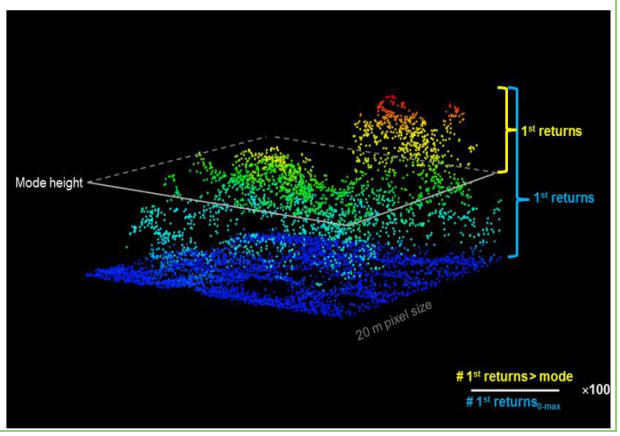
Just like with the height metrics, the final position in the filename describes the cell size and the units of the rasters. In both of the examples below, the rasters have a 20 meter spatial resolution. The cell size and the units are defined by the user in the basic_setup.bat file and in the AP interface.
*1st_cover_above_mean_**20METERS**.img*

*all_1st_cover_above1_**20METERS**.img*

Illustrated Examples

This section provides example illustrations of cover metrics and a discussion of the corresponding filenames for a small, representative sample of first order lidar metrics generated in the AP. In the tables below, the metric filenames are described from left to right. While only a small subset of the total metrics generated by the AP are covered, the hope is that deciphering these names will foster sufficient understanding to make sense any of the other metrics included in a set of final deliverables.

Cover Metric and Explanation	Illustration
1st_cover_above3_20METERS.img ○ **1st**: designates first returns are used in the numerator and the denominator of the cover ratio ○ **cover**: designates that it is a cover ratio ○ **above3**: designates that a cover cutoff of 3 meters was used when calculating the cover ratio ○ **20METERS**: designates the cell size at which the metric was calculated Logic: *((# of first returns > 3 meters) / (total # of first returns in the pixel)) * 100*	
all_cover_above3_20METERS.img ○ **all**: designates all returns are used in the numerator and the denominator of the cover ratio ○ **cover**: designates that it is a cover ratio ○ **above3**: designates that a cover cutoff of 3 meters was used when calculating the cover ratio ○ **20METERS**: designates the cell size at which the metric was calculated Logic: *((# of all returns > 3 meters) / (total # of all returns in the pixel)) * 100*	
all_1st_cover_above_mean_20METERS.img ○ **all**: designates that all returns above the mean are used in the numerator of the cover ratio ○ **1st**: designates that only first returns are used in the denominator of the cover ratio ○ **cover**: designates that it is a cover ratio ○ **above_mean**: designates that the mean height was used as the cover cutoff when calculating the cover ratio ○ **20METERS**: designates the cell size at which the metric was calculated *Logic:* *((# of all returns > mean height) / (total # of first returns in the pixel)) * 100*	

Cover Metric and Explanation	Illustration
1st_cover_above_mode_20METERS.img ○ **1st**: designates first returns were used as the numerator and denominator of the cover ratio ○ **cover**: designates that it is a cover ratio ○ **above_mode**: designates that the mode height was used as the cover cutoff when calculating the cover ratio ○ **20METERS**: designates the cell size at which the metric was calculated *Logic:* *((# of first returns > mode height of all returns) / (total # of first returns in the pixel)) * 100*	

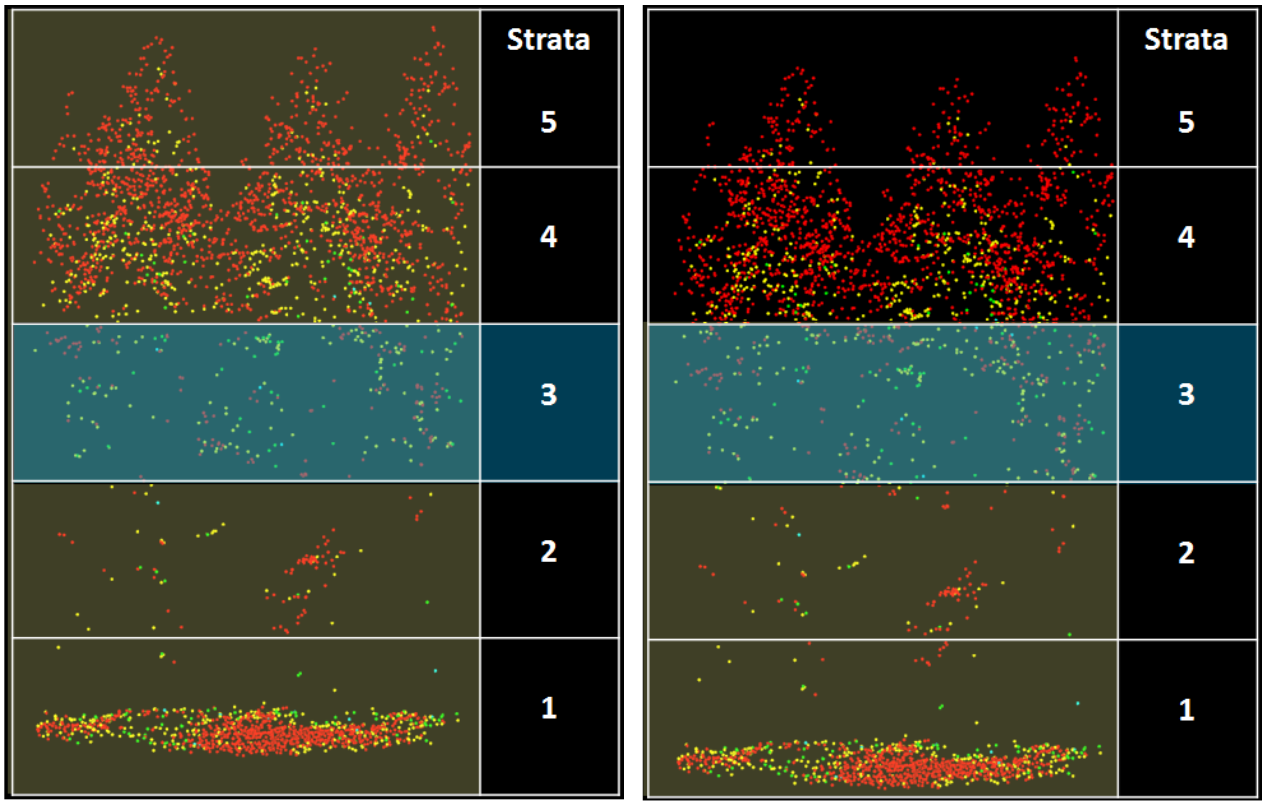
STRATA METRICS (Optional)

In addition to the height and density metrics we can produce to describe the entire canopy, density metrics representing specific height strata can be created as an optional output of the AP processing workflow. Height strata can be conceptualized as 'slices', or horizontal cross-sections through the lidar point cloud. These facilitate the description of canopy structure for specific vertical portions of the canopy (see Figure 2 for an example illustration). In the basic_setup batch file, the user will need to set the DOSTRATA variable to TRUE, set the number of strata layers, and define the strata heights. The example in Figure 2 shows 5 strata layers, but those are defined by the user, who can select as few or as many as necessary. Like the height and cover cutoff values, height strata will need to be defined with the help of prior knowledge of the vegetation and according to the information needs of the project.

Two sets of strata specific density metrics can be created: 1) the *overall relative density* that describes the proportion of points in each height stratum relative to the total points within each cell (FUSION) and; 2) the *normalized relative density* that describes the 'normalized' relative proportion of points in each stratum, which is the ratio of the number of points in a given strata with respect to the total number of points at and below the specified strata height (additional raster processing required).

A. Overall Relative Strata Density

B. Normalized Relative Strata Density



$$ORD\ Stratum_3 = \frac{\#\ returns\ in\ stratum_3}{\sum_{i=1}^{5}(\#\ returns\ in\ stratum_i)}$$

$$NRD\ Stratum_3 = \frac{\#\ returns\ in\ stratum_3}{\sum_{i=1}^{3}(\#\ returns\ in\ stratum_i)}$$

Figure 2: Comparison of how the two sets of strata-specific density metrics are calculated. The figure on the left (A) shows how the overall proportion of points is calculated by dividing the number of points in each stratum by the total number of points in the grid cell. The figure on the right (B) illustrates how influences of upper canopy characteristics are normalized by omitting points in the upper strata from the density calculation. Normalized strata density metrics are calculated by dividing the number of points in each stratum by all the points within and below the stratum of interest. Points are colored according to their return number: first returns are shown in red; second, third, and fourth returns are shown in blue and green.

Overall Relative Density

The first set of strata density metrics are the overall relative density. These are created using the gridmetrics command within the AP processing workflow. The additional *strata* argument (or switch as they are termed in FUSION) is specified in order to create these metrics. Including the additional strata argument and specifying strata ranges results in the creation of the additional suite of strata statistic layers, point counts, and return proportions for points in each stratum of each cell in the output raster. Because point counts vary as a function of lidar scan angle, side-lap between flight lines, etc., only the proportion metrics are appropriate for comparison among areas or summary across the acquisition. Proportion layers created by the gridmetrics function represent the total number of points in each

defined stratum divided by the total number of points in all the strata for a given grid cell size (see Equation 2: below and Figure 2a).

Equation 2:

$$\textit{Overall Relative Density in } \boldsymbol{Stratum_x} = \frac{\#\ \boldsymbol{returns\ in\ stratum_x}}{\sum_{i=1}^{n}(\#\ \boldsymbol{returns\ in\ stratum_i})}$$

Normalized Relative Density

The second set of strata density metrics, the normalized relative density, is created through an additional raster-math processing step implemented in an external GIS or raster processing software; they are not created in FUSION. These are created by a series of raster math calculations that include dividing the number of points in each stratum by the total number of points below and including the stratum of interest (see Equation 3: below and Figure 2b on the next page).

Equation 3:

$$\boldsymbol{Normalized\ Relative\ Density}\ \textit{in}\ \boldsymbol{Stratum_x} = \frac{\#\ \boldsymbol{returns\ in\ stratum_x}}{\sum_{i=1}^{x}(\#\ \boldsymbol{returns\ in\ stratum_i})}$$

The key difference between overall relative density and the normalized relative density is in how the points above each stratum are treated in the calculation of the relative proportion. This additional normalization step is taken to help remove potential bias introduced by inconsistencies in the relative proportion of points in the upper canopy strata. Bias in strata density arises because each lidar pulse contains a finite amount of energy and the potential for each pulse to penetrate to lower canopy strata is likely reduced where there is a significant amount of canopy structure in the strata of the upper canopy. Refer to Figure 2 for an example illustration and comparison of how these overall and normalized relative strata proportions are calculated.

Naming Convention

The overall density strata metrics created as part of the AP processing workflow are named as follows where the key word, ***Rel***, is present only for the normalized relative density strata metrics (relative metrics were created after the AP process using an external and are not default outputs from the AP process):

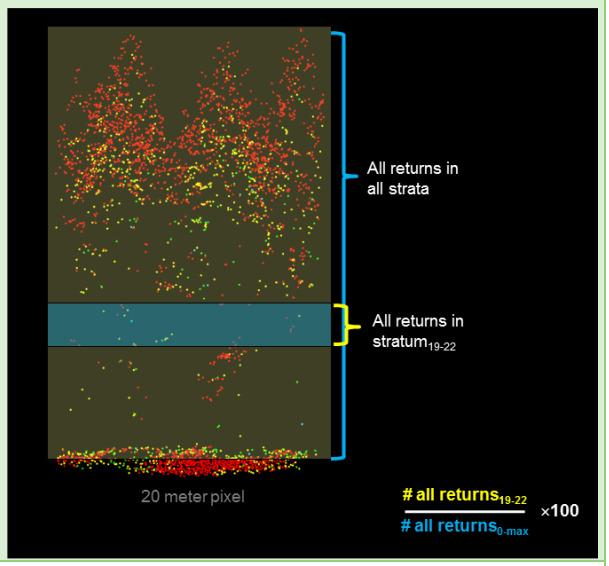
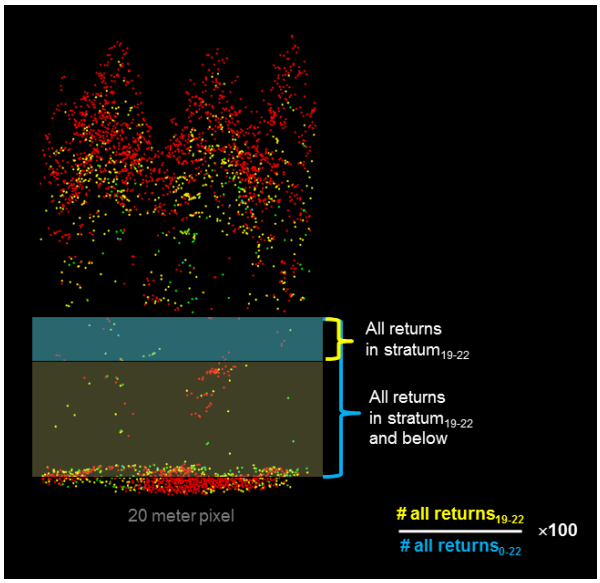
[Rel_]strata_1to2M_return_proportion_20METERS.img

For example, the metric, *Rel_strata_1to2M_return_proportion_20METERS.img*, is the normalized relative density of points within the user specified height range of strata 2. The abbreviation, ***Rel***, at the beginning of the filename indicates that the metric is normalized (i.e., calculated using Equation 3:).

Recall that only the relative density metrics for each stratum should be used since absolute point counts are influenced by variable factors related to the acquisition of the data. Stratum count metrics are

created during the run, but as they are, they should not be used in inventory modeling or management activities. Count metrics have the keywords, ***strata_1to2M_return_cnt***, in the filename as well as a number range and unit after the word **strata** to specify the vertical range of the stratum (e.g., *strata_**1to2M**_total_return_cnt_20METERS.img).*

Illustrated Examples

Strata Metric and Explanation	Illustration
strata_1to2M_return_proportion_20METERS.img ○ **strata:** specifies the layer is a strata metric ○ **1to2M:** vertical height range of stratum ○ **return_proportion**: indicates a relative density ratio of the point count in the specified stratum to the total points considered in each cell ○ **20METERS**: designates the cell size at which the metric was calculated Logic: *((# of points in the stratum) / (total # points in all) * 100*	
Rel_strata_1to2M_return_proportion_20METERS.img ○ **Rel**: designates a *normalized* relative density ○ **strata**: specifies the layer is a strata metric ○ **1to2M**: vertical height range of stratum ○ **return_proportion**: indicates a relative density ratio of the point count in the specified stratum to the total points considered in each cell ○ **20METERS**: designates the cell size at which the metric was calculated Logic: *((# of points in the strata) / (total # points in the specified strata and below strata in the cell)) * 100*	

Other Metrics

This document only goes into detail on height, density, and strata metrics. The AP, however, provides other metrics not covered in as much detail here. A brief overview of some of these metrics are described below. If you'd like to use these metrics and require a more detailed explanation, see McGaughey, 2013, 2016.

FIRST_RETURNS

Beginning in FUSION version 3.60 the user is given the option to output all of the metrics created using only the first returns. These metrics will follow the same naming convention described above, but will have the prefix FIRST_RETURNS.

Intensity Metrics

A lidar return can contain information about the intensity of the returned pulse. Intensity metrics are created using the return intensity, instead of the vertical position of any of the returns in a pulse. For most data, intensity metrics computed using only first returns may be the most useful. The naming convention of the intensity metrics is similar to the elevation metrics described above, but the prefix will be "int".

Return Counts

The return count metrics are simply a count of the number of returns from all the pulses within a cell. FUSION recognizes up to 10 returns for each pulse and builds output layers for the first 7 returns. The prefix "cnt" defines the return count metrics.

Topographic Metrics

FUSION has the ability to create surface metrics, not just raster metrics. For a description of the difference between surface and raster products see McGaughey, 2016. Topographic metrics are produced using the bare ground surfaces. The metrics are raster products that describe the topography in a cell and can include measurements like slope and aspect. The metrics are defined with the prefix "topo" in the filename.

References

McGaughey, R. 2013. FUSION/LDV: software for lidar data analysis and visualization. Version 3.41. Seattle, WA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station [online]. Available http://forsys.cfr.washington.edu/fusion/fusionlatest.html.

McGaughey, R. J. 2016. LiDAR Processing With FUSION: First Order Product Descriptions. Version 3.50+. Seattle, WA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.