The Reference Library

Spatial Density Distribution

GeoCue Group Support Team
5/28/2015

Quality control and quality assurance checks for LIDAR data continue to evolve as the industry identifies new ways to help ensure that data collections meet desired usage requirements. The U.S. Geological Survey (USGS) LIDAR Base Specification introduced a definition for spatial density distribution and regularity within LIDAR data. The requirement is that the spatial distribution of usable points shall be uniform and regular. LIDAR data by nature is not a gridded surface but a series of random points. To best approximate a uniform surface it is recommended that LIDAR collections should be planned in such a manner as to produce a first return point cloud that comes close to a regular lattice of points. Generally this means having equal downtrack and crosstrack nominal point spacing. This is important since without the requirement it is possible to satisfy the project density requirements, yet still have data that is inconsistent and contains holes, generally in the down track spacing direction due to vehicle movement, allowing for desired features to be missed, or only partially acquired.

The specification goes on to recommend that the point pattern and density within the dataset should be assessed using the following steps as both the pattern and the density within the dataset are important to the overall distribution and regularity:

- Generating a density grid from the data with cell sizes equal to twice the design ANPS and a radius equal to the design ANPS.
- Ensuring at least 90 percent of the cells in the grid contain at least one LIDAR point.
- Using individual (single) swaths, with only the first return points located within the geometrically usable center part (typically 95 percent) of each swath.
- Excluding acceptable data voids previously identified in this specification. [1]

Version 1.2 of the USGS LIDAR base specification defines ANPS as the Aggregate Nominal Pulse Spacing, which is the net overall pulse spacing for the project. In the same manner as Nominal Pulse Spacing (NPS), ANPS includes only the geometrically usable part of the swaths (typically the center 95 percent for oscillating mirror systems), excludes acceptable data voids, and can be empirically calculated by creating a 1 square kilometer polygon that is representative of the overall pulse density of the flight line swath. ANPS can be calculated based off the following equation:

$$\sqrt{Average\ Area\ per\ point}$$

This equation is equivalent to the area of the polygon divided by the number of points contained therein.

---

[1] Heidemann, Hans Karl, 2014, Lidar base specification (ver. 1.2, November 2014): U.S. Geological Survey Techniques and Methods, book 11, chap. B4, 67 p. with appendixes, *http://dx.doi.org/10.3133/tm11B4.*

Spatial Density Distribution

Acceptable data voids are also included within the base specification. A data void is considered any gap within the point cloud, regardless of the cause (for instance refraction of the pulse, instrument anomalies, obstruction of the laser pulse or improper data collection). A data void should be considered if it is greater than or equal to $4(ANPS^2)$, measured using first return points only. Any data voids that exist within a single swath are not accepted, except for the following list:

- Where caused by water bodies,
- Where caused by areas of low near infrared (NIR) reflectivity, such as asphalt or composition roofing, or
- Where appropriately filled in by another swath.

One method of determining spatial density distribution is by generating rasters using the guidelines specified above to determine if 90% of the cells contain at least one point per cell. Two of the products in our product lines, LP360 and TerraScan, may be used to generate the requisite raster images. Subsequent analysis of those images can then be performed to determine if the cut off criteria was met.

Data for Spatial Density

Data used for this example were provided by the Nashville, TN office of the United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS). The data is from Davidson County, Tennessee and was collected using an Optech ALTM 3100 LIDAR sensor. The data was acquired over seven missions between March 16th and March 22nd of 2011.

Point Density Rasters for determining spatial density distribution using any of the options mentioned below should be generated using only first return data that is within the geometrically usable center of the flight line swath. A statistical analysis, using the LP360 Point Cloud Statistics Extractor point cloud task, on the dataset reveals that the minimum and maximum scan angle within the sample dataset is -19° to +19°. Taking into account the 95% of the swath that is considered geometrically useable, according to the USGS specification, results in an acceptable scan angle range between -18° and +18°.

The ANPS for the dataset used in this example is 1.0 meter and the data has an overlap of approximately 30% between swaths. ANPS was obtained from the project report for this dataset, it was verified by running a statistical analysis on the dataset for first return data between the scan angles determined above within LP360. The analysis was run on a one square kilometer area.

The grid spacing is twice the ANPS, therefore the cell size for the resulting raster file is set to 2m. To ensure a point density of one point per cell, the required density is equal to the inverse of the cell size. With the cell size equal to two, then one point per cell would be half a point per square meter.

Spatial Density Distribution

TerraScan

TerraScan can generate Point Density Rasters three different ways: a TerraScan macro can be created that exports a Lattice Model, Lattice Models can be exported from the project window, or Lattice Models can be output directly from the loaded points in the Main TerraScan window. If exporting Lattice Models from a macro step, or via the project window, be sure to include neighboring points to ensure gaps and anomalies do not occur along tile boundaries.

TerraScan generates the Point Density value for each cell, hence, no categorization needs to be specified during the output process. Figure 1 shows the settings used to generate the point density raster for the example dataset, while Figure 2 shows the resulting raster as displayed in ArcMap. The categorization of the data for display purposes is based upon the fact that the requirement is looking for one point per cell. Hence, the display is set to display in green any cell that is 0.5 point per square meter or higher, while anything in red is lower than the specification and data voids are in white.
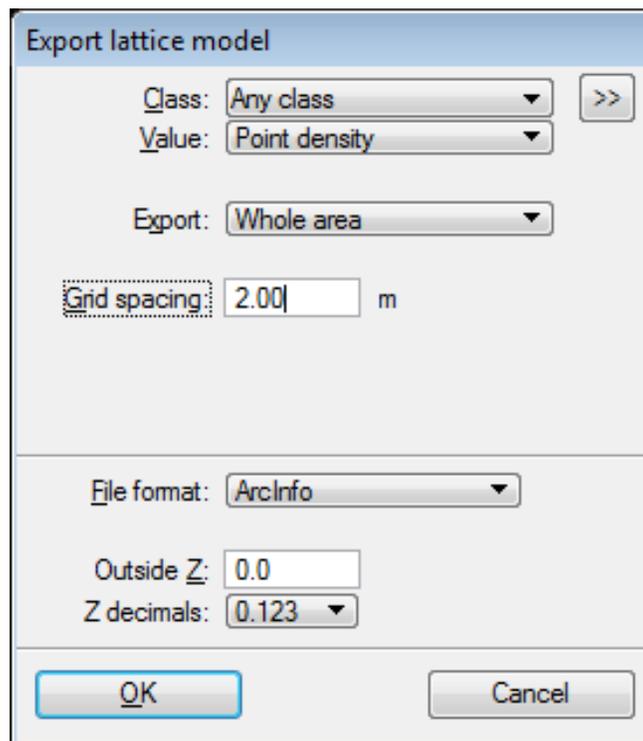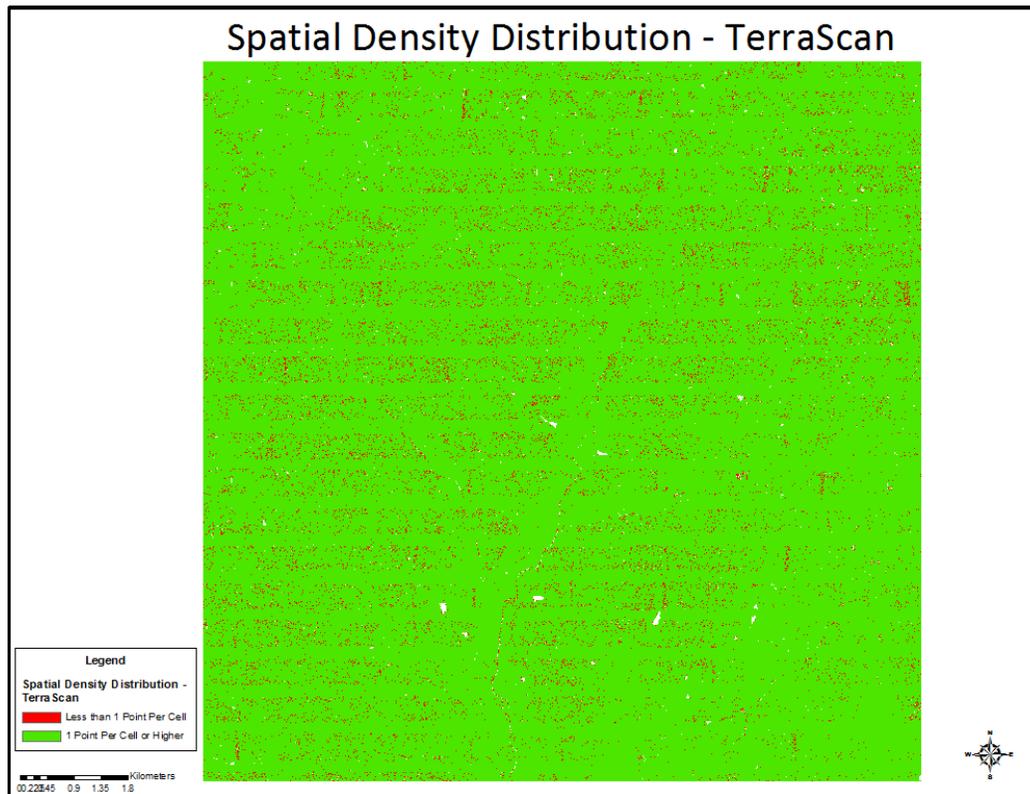

Figure 1 - TerraScan Lattice Model Settings

Figure 2-Red and White Areas in the Point Density Image represent Areas of Interest

LP360

In LP360, the Point Density images are generated from the active LAS Layer using the Export Wizard. Figure 3 and Figure 4 represent the settings used within the Export Wizard to generate Point Density images for this example. Using the specifications mentioned above for this dataset the cell size is two and the point density is half a meter. For this example any cell that is showing up in the TIFF image as red does not meet the Point Density Requirement, any cells in black indicate data voids. Green cells are those above the one point per cell threshold and can be considered meeting the minimum criteria.
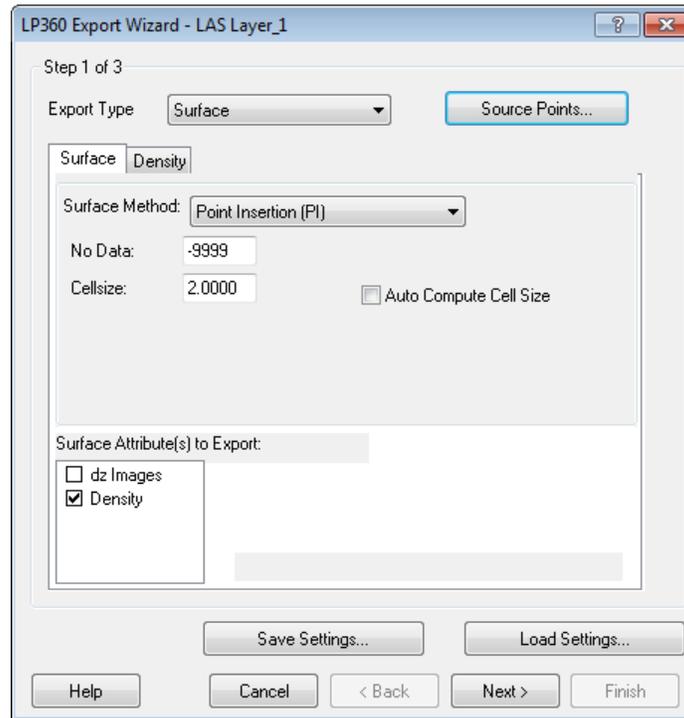
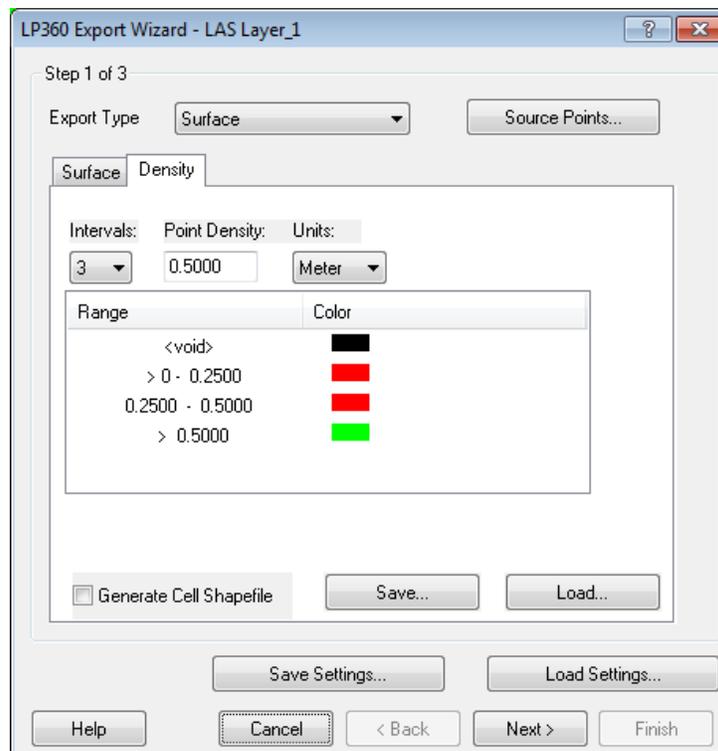# Spatial Density Distribution

Figure 3 - Density Surface

Figure 4 - Point Density Values

Spatial Density Distribution

Determining 90% Percent

Once the rasters have been generated, it's time to determine if the project meets the requirement that at least 90% of the cells have at least 1 point per cell.

If we look at Figure 5 as an example of a Point Density Raster, you will notice that it is colored red to show all areas less than 1 point per cell, and data void areas are in black. These cells are the areas of interest with respect to calculating the specification.
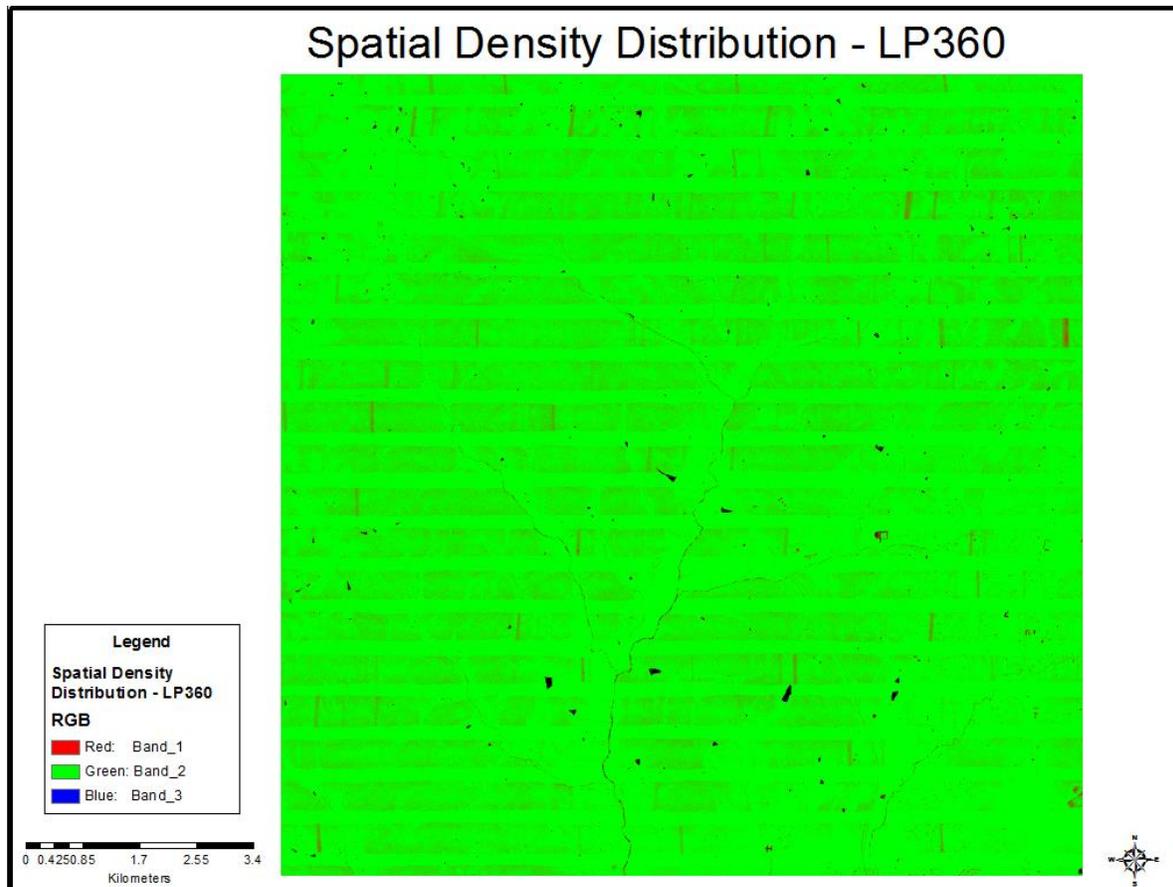

Figure 5 – Red and Black Areas represent the Area of Interest

The following is just one way that the tools within ArcMap can be used to determine if 90% of the project has at least 1 point per cell. All the steps are accomplished using Model Builder, with the exception of the manual QA/QC process for step 5.

1) Categorization
   a. **LP360 Only**: Add the three separate RGB bands to Model Builder. Use the raster calculator to subtract the three bands from one another and produce an Integer Based Raster with three values: 0 (voids), -255 (meets specification) and +255 (below specification)

      b. **TerraScan Only**: Use the Spatial Analyst → Reclass → Reclassify to reclassify the density classes into two classes. No Data values become class 0, anything above a half meter becomes class 1 and anything below 0.5 meters becomes class 2.

2) Use Analysis Tools → Statistics → Frequency
      a. Frequency Fields → Count
3) Use Data Management Tools → Fields → Add Field
      a. Add a field called Percent
4) Open the DBF file in Excel and calculate Percent Total
5) Load the Reclass or Combo, TerraScan or LP360 produced, raster file into ArcGIS and overlay any hydrology datasets that exist which represent void areas. Verify that these areas are representative of the void areas shown within the raster outputs.
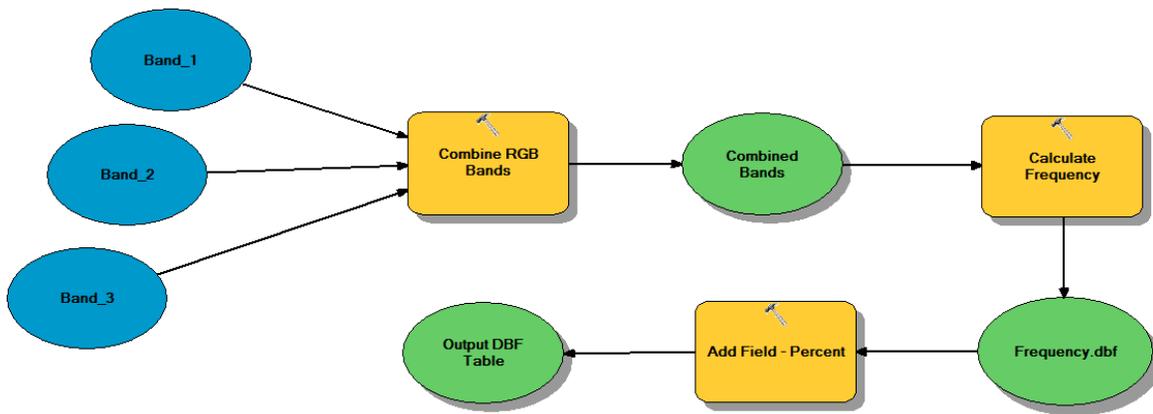

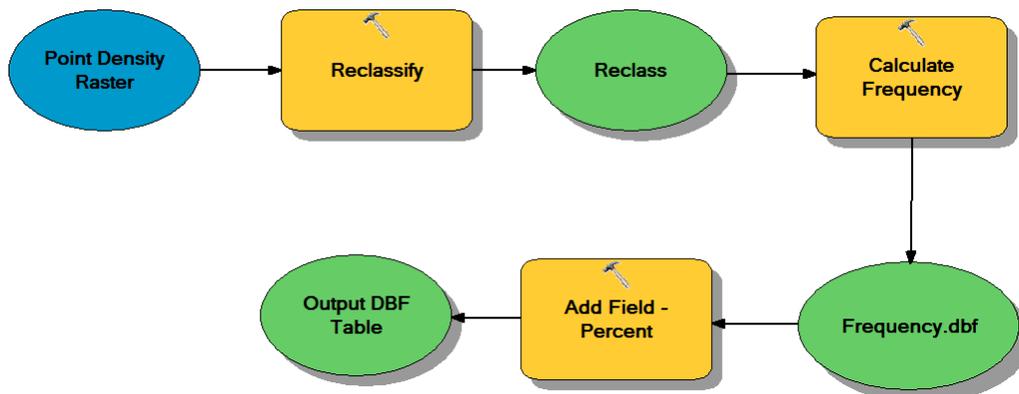*Figure 6-Model Builder Using LP360 Generated Point Density Image*

Figure 7-Model Builder Using TerraScan Generated Point Density Image

Spatial Density Distribution

VALUE	COUNT	PERCENT
0	129122	0.36%
255	1226198	3.41%
-255	34644680	96.24%

Table 1-Total Percentage for cells with at least 1 point per cell LP360

VALUE	COUNT	PERCENT
0	129124	0.36%
1	1226196	3.41%
2	34644680	96.24%

Table 2-Total Percentage for cells with at least 1 point per cell TerraScan
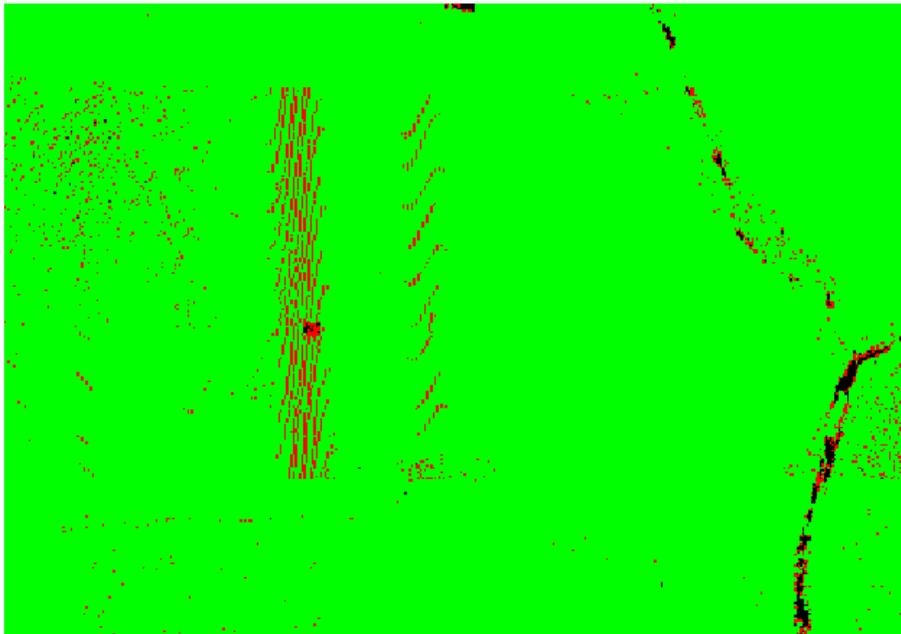

Figure 8 - Example of density distribution below specifications

The resulting tables (Table 1 and Table 2) and image samples (Figure 8) can be included as part of the metadata accompanying the LIDAR elevation dataset. Since LIDAR data is inherently a random point cloud and not a gridded dataset, then by demonstrating that the collection meets the density distribution and regularity requirements one can assure the dataset will be suitable for the intended purposes. By following the suggested workflows for Spatial Density Distribution, using either LP360 or TerraScan, one can then successfully demonstrate having met the USGS LIDAR Base Specification for their LIDAR data collection. If you have any questions or comments on the suggested workflows please comment below this post on our knowledge base, or contact our GeoCue Group Support Team.