DPH-9.1 Report on Overlap Consistency (interswath)

The USGS Lidar Base Specification 2021 rev. A states: "Overlap consistency will be assessed at multiple locations within overlap in nonvegetated areas of only single returns and with slopes of less than 10 degrees. To the degree that the data allow, test areas should be located such that the full width of the overlap is represented. The overlap areas that will be tested are those between the following:

- adjacent, overlapping parallel swaths within a project,
- cross-tie swaths and a sample of intersecting project swaths in both flight directions; and
- adjacent, overlapping lifts.

Each overlap area will be evaluated using a signed difference raster with a cell size equal to the ANPS, rounded up to the next integer, then doubled (Cellsize=CEILING(ANPS)×2). The difference rasters will be statistically summarized to verify that RMSDz values do not exceed the limits set forth in table 2 for the QL of information that is being collected."

Table 2. Relative vertical accuracy for light detection and ranging swath data.

[QL, quality level; $RMSD_z$, root mean square difference in the *z* direction; m, meter; ≤, less than or equal to]

Quality level	Smooth surface repeatability, $RMSD_z$ (m)	Swath overlap difference, $RMSD_z$ (m)
QL0	≤0.03	≤0.04
QL1	≤0.06	≤0.08
QL2	≤0.06	≤0.08
QL3	≤0.12	≤0.16

The purpose of this section is to show two separate mosaicked versions of a thematically rendered map of swath separation for all of the data processed.

For the first – known as a Measurable Flightline Separation Raster (FSR) - processing has been done to isolate measurements to clusters of single returns and is limited to areas of < 10 degree slope. The colors are gradated by the selected QL's swath overlap difference RMSDz limits. Only swath overlap areas are shown in the raster. The color is overlaid on a lidar intensity background to show land cover features. A frequency distribution chart of RMSDz raster values can be found on the page following the raster graphic.

For the second raster – known as a Swath Separation Image and found at the end of this test section – there are no limitations on slope angles and return types are user defined. The colors are gradated by the selected QL's swath overlap difference RMSDz limits. Only swath overlap areas are shown in the RGB raster. The color is overlaid on a lidar intensity background to show land cover features. Tiled GeoTIFFs of this mosaicked raster can be found in the output folder for this test.

DPH-9.1 Report on Overlap Consistency (interswath) - Measurable FSR

Description of the process that generates the Measurable Flightline Separation Raster (FSR):

a. Areas of swath overlap are determined within each delivery tile.

b. A TIN is created for the overlap areas of each swath within a tile, and a Grid is overlaid on those TINs. Grid cell sizes are 3x the aggregate nominal pulse spacing (ANPS) as shown in Table 1 of the USGS Lidar Base Specification 2021 rev. A. ANPS varies depending on the Quality Level of the data.

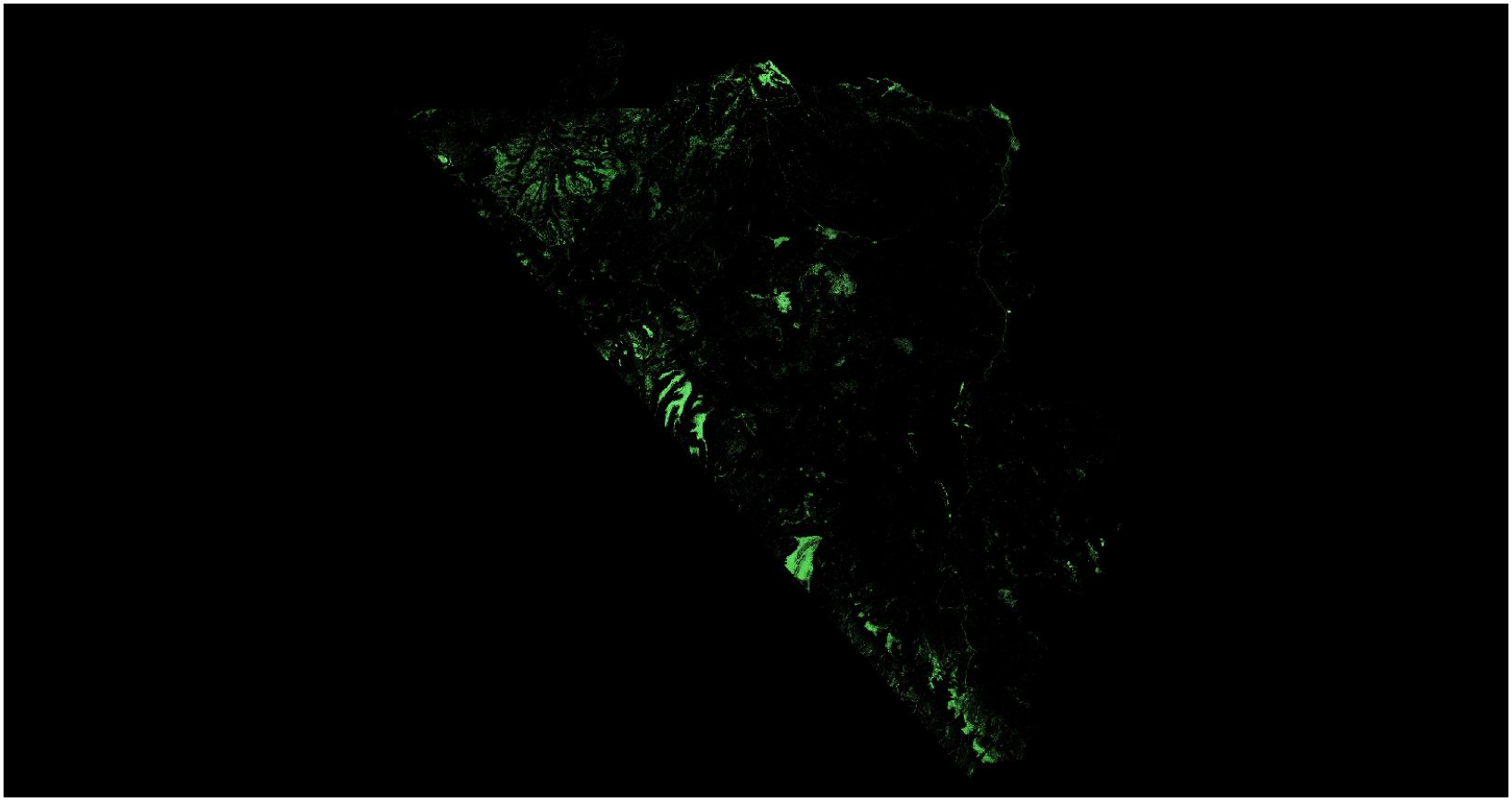
c. The grid cells are populated with the vertical separation values between the underlying TINs as measured at the centroid of each grid cell. When three or more swaths coincide with a cell, the value is set to the difference between the maximum and minimum of all elevations. Only areas of slope < 10 degrees are measured. Points flagged as Withheld, including those points classed as High or Low Noise, are excluded from this analysis.

d. The Measurable FSR uses a pre-filtering algorithm that selects only clusters of single returns for use in the RMSDz analysis. The algorithm's purpose is to find areas for measurement that are in the open, away from roof edges, trees, etc. - it is not designed to find ground below vegetation canopy. By using only clusters of single returns (at a minimum distance from any multiple returns) and ignoring cells with NODATA values, reliable RMSDz values are produced.

e. A vertical separation cut-off is used to remove values that are not appropriate for separation measurements (e.g., trees, moving objects, etc.). This cut-off is set to 10 times the color gradation interval value.

f. The tiled rasters are mosaicked into a single project-wide flight separation raster. A single, aggregate RMSDz is calculated from this complete grid, and the final thematic raster is generated. This raster graphic is found on the following page.

DPH-9.1 Report on Overlap Consistency (interswath) - Area 1 - Measurable



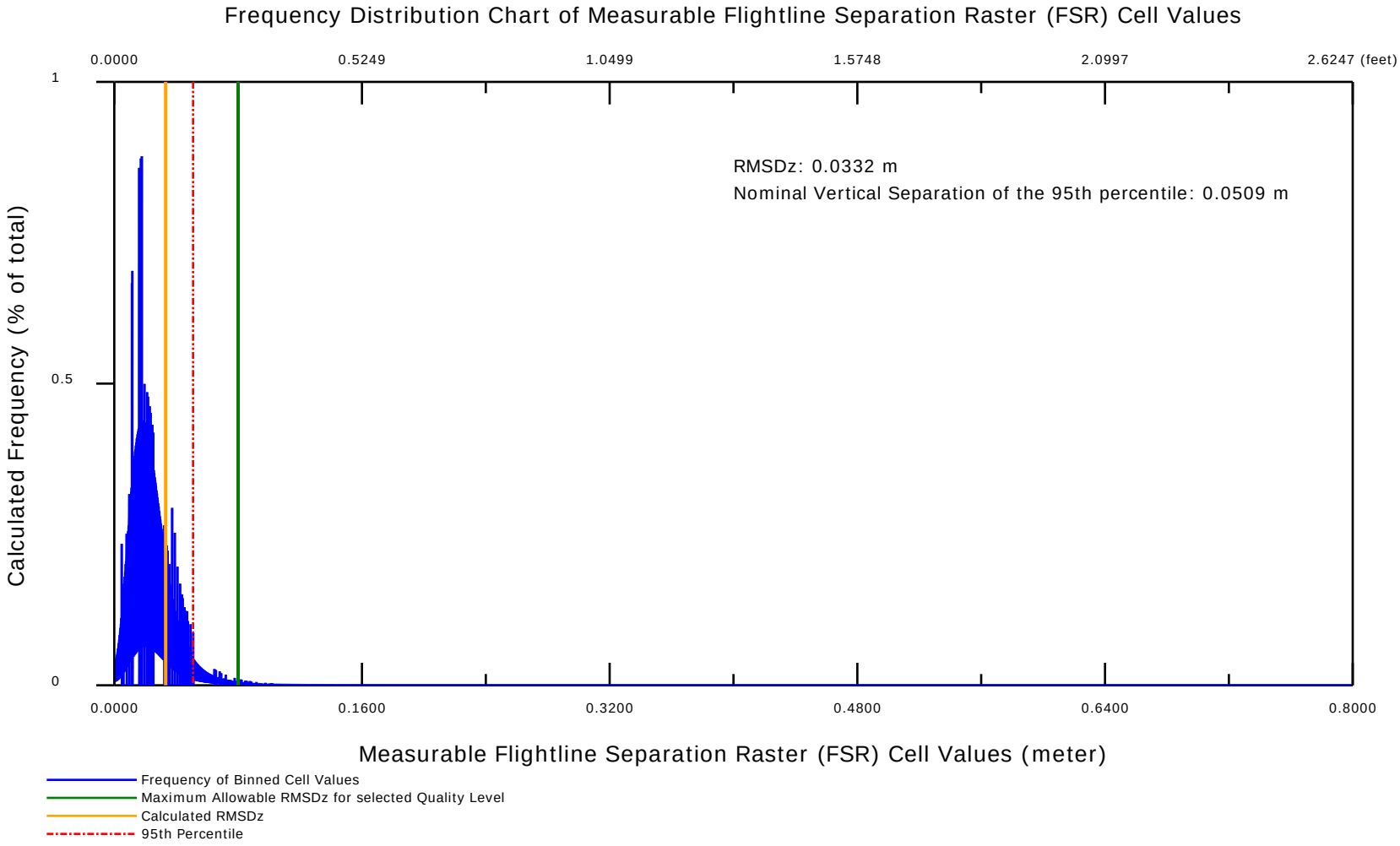
0	0.080	0.160	0.240	0.800 (Meter)
0	0.262	0.525	0.787	2.625 (Feet)

A maximum vertical separation cutoff has been applied to this graphic for the purpose of masking out disruptive features that do not show calibration issues between flight lines (e.g., trees, moving cars, etc.).

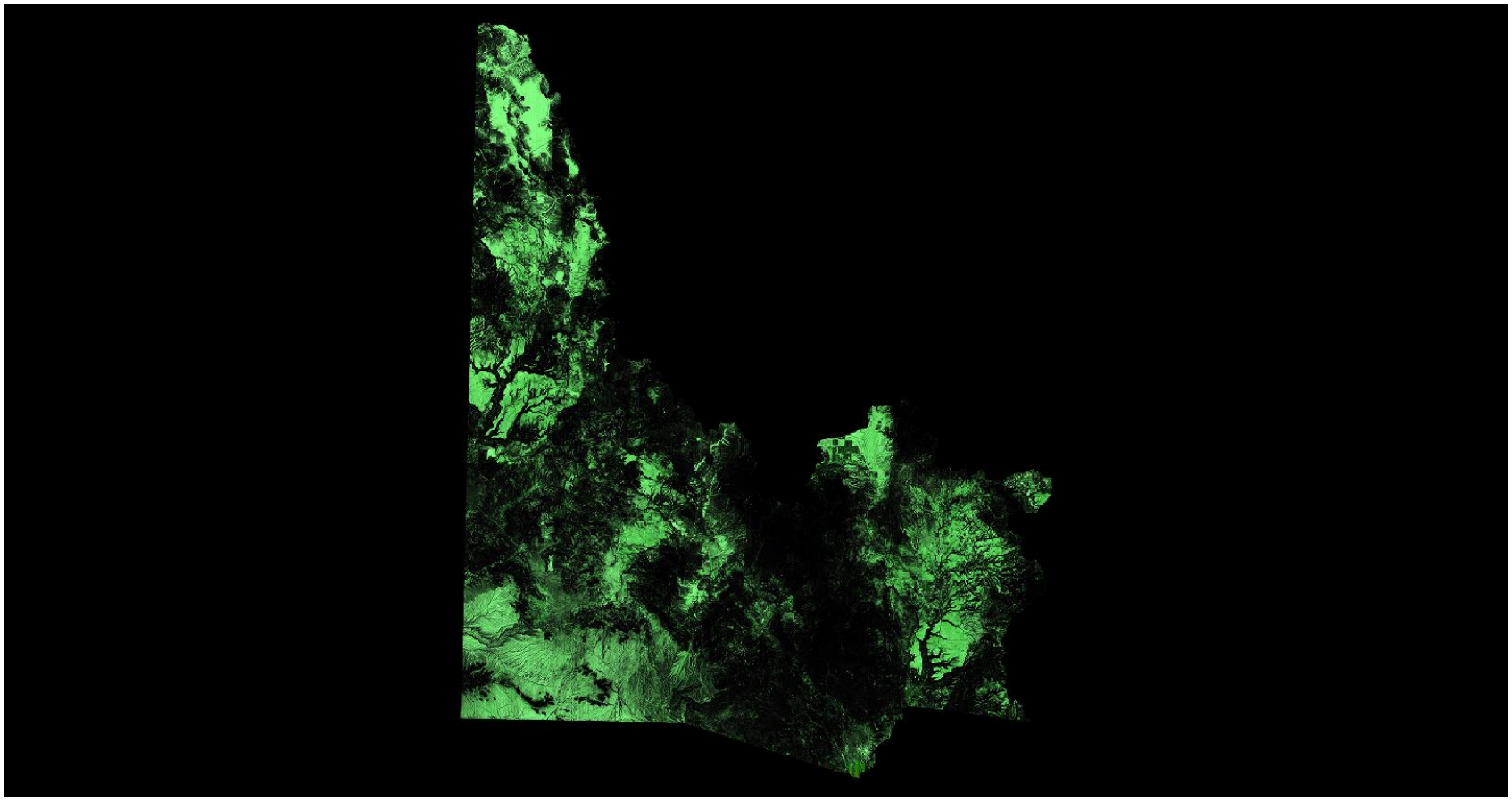
DPH-9.1 Report on Measurable RMSDz

The purpose of this section is to show a frequency distribution chart of pixel values (RMSDz) for the entire dataset.

Data Source - Y:\Mapping\Projects\65221006_AZ_Yavapai\Production\Final_Client_Deliverables\Projectwide\point_cloud\tilecls



DPH-9.1 Report on Overlap Consistency (interswath) - Area 2 - Measurable



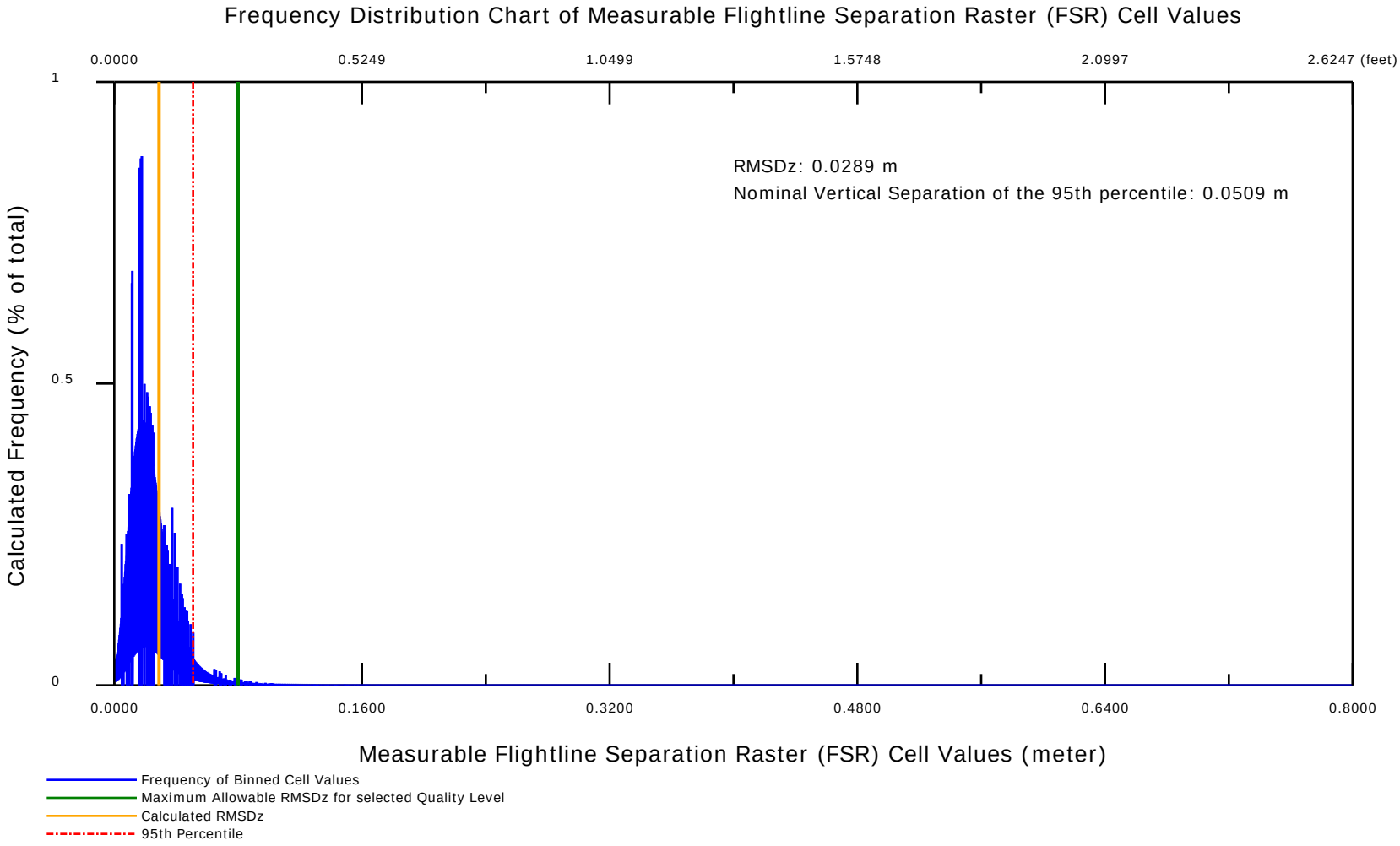
0	0.080	0.160	0.240	0.800 (Meter)
0	0.262	0.525	0.787	2.625 (Feet)

A maximum vertical separation cutoff has been applied to this graphic for the purpose of masking out disruptive features that do not show calibration issues between flight lines (e.g., trees, moving cars, etc.).

DPH-9.1 Report on Measurable RMSDz

The purpose of this section is to show a frequency distribution chart of pixel values (RMSDz) for the entire dataset.

Data Source - Y:\Mapping\Projects\65221006_AZ_Yavapai\Production\Final_Client_Deliverables\Projectwide\point_cloud\tilecls



DPH-9.1 USGS Swath Separation Image

Image creation:

a. All returns, single returns, or last returns, shall be used to create the images.
b. All point classes and flags shall be enabled when creating the images and points flagged as withheld or classified as noise shall be excluded.
c. Elevation values and differences shall not be subjected to a threshold or otherwise clipped so all differences are represented.
d. The images will be derived from TINs to reduce the number of false difference values on slopes; however, other algorithms are acceptable.
e. The images shall consist of a 50 percent transparent RGB layer overlaying the lidar intensity image.
f. The images shall use at least three color levels wherever two or more swaths overlap within a pixel.
g. Where two or more swaths overlap within a pixel (based on point source ID),
   i. pixel color shall be based on vertical difference of swaths using the following breaks (based on multiples of the Swath Overlap Difference for the QL, table 2):

   For QL1 or QL2 data the breaks are:
   1. 0-8 cm: GREEN;
   2. 8-16 cm: YELLOW;
   3. > 16 cm or > last additional color ramp bin value: RED (for example, addition of ORANGE pixels for the range of 16-24 cm would require red pixels to represent > 24 cm).

   For QL0 data the breaks are:
   1. 0-4 cm: GREEN;
   2. 4-8 cm: YELLOW;
   3. > 8 cm or > last additional color ramp bin value: RED (for example, addition of ORANGE pixels for the range of 8-12 cm would require red pixels to represent > 12 cm).

   ii. color choice of GREEN, YELLOW, and RED is suggested but not required.
   iii. no pixel shall remain uncolored (transparent) in the overlap areas.
h. Where swaths do not overlap, pixel values shall be intensity alone.

Image file formats and version control:

a. Swath difference image format may be delivered as GeoTIFF or JPEG (with world file) by tile or as a single compressed JPEG 2000 (JP2) image mosaic.
b. The point cloud geometry and intensity data delivered shall be identical to the point cloud geometry and intensity data used to create the difference images. Changes in the point cloud geometry or intensity requires recreation of the difference images.

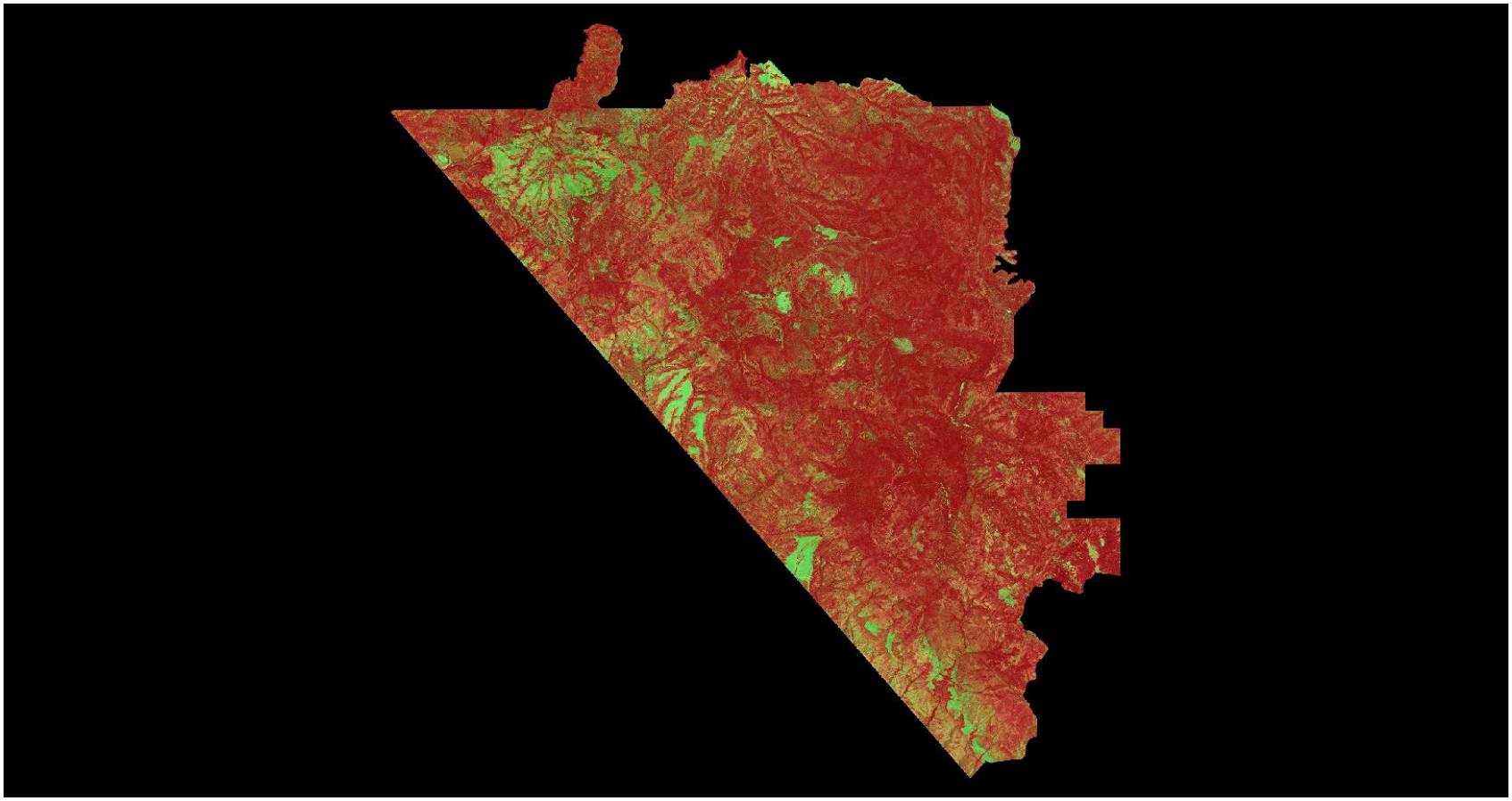
Spatial extent and coordinate reference system:

a. Spatial resolution (pixel dimension) of the images shall be no greater than 4 times the Nominal Pulse Spacing (2-4 x NPS) in the project's linear unit (meters or feet).
b. The difference images must be representative of the associated data delivery.
c. The images shall be in the same CRS as the point cloud data to ensure alignment with the point cloud.

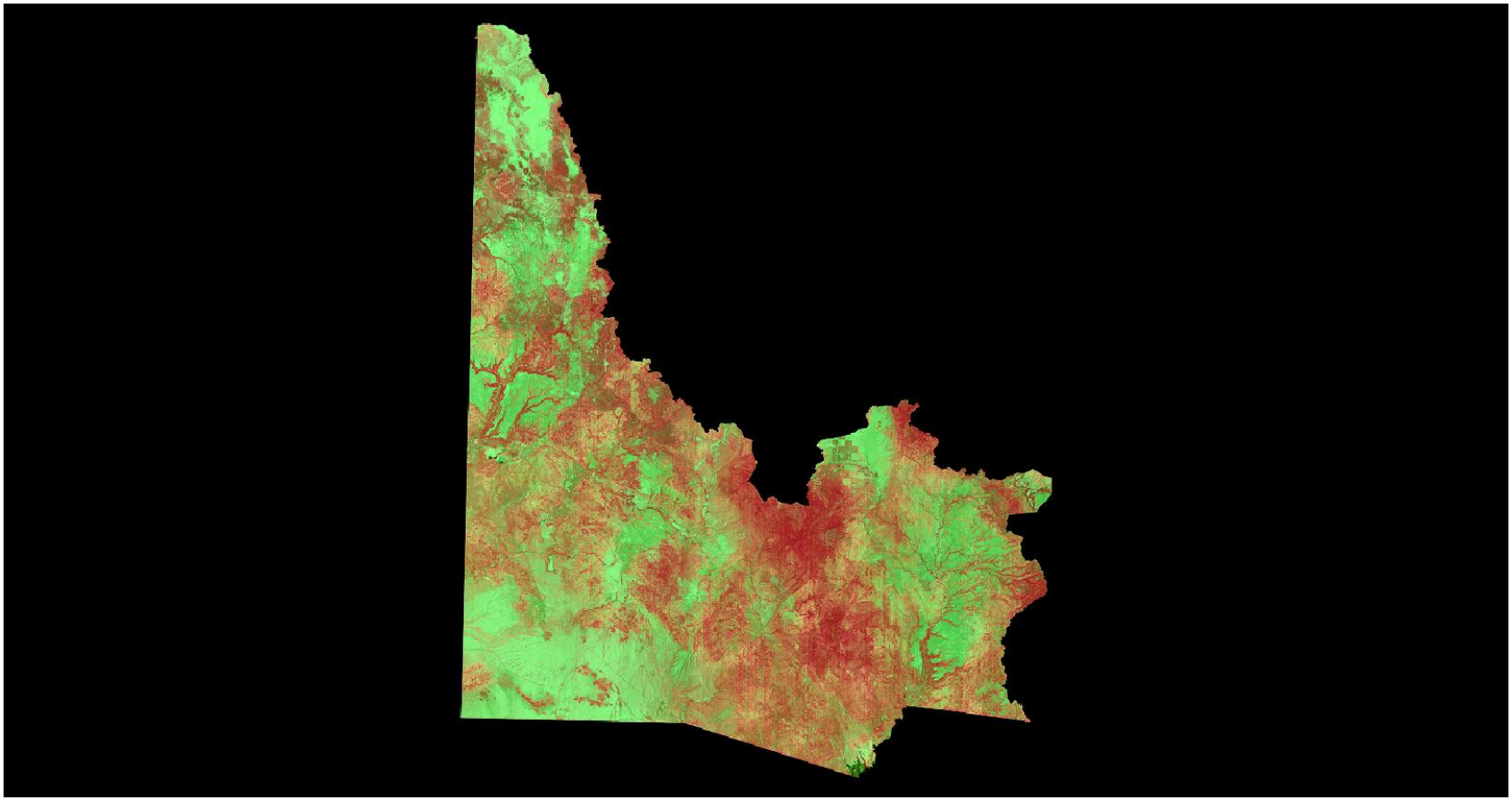
Description of the process that generates the Swath Separation Image:

a. Areas of swath overlap are determined within each delivery tile.
b. A Grid is created for each overlap area. Grid cell sizes are 3x the aggregate nominal pulse spacing (ANPS) as shown in Table 1 of the USGS Lidar Base Specification 2021 rev. A. ANPS varies depending on the Quality Level of the data. The grid cells are then populated with the maximum vertical separation values of the underlying points. Points flagged as Withheld, including those points classed as High or Low Noise, are excluded from this analysis.
c. No vertical separation cut-off is used for this raster.
d. The tiled rasters are mosaicked into a single project-wide swath separation raster, with the grid cells colored based on the separation values. For QL1 and QL2, a green cell indicates an elevation difference of 8 cm or less, yellow indicates greater than 8 cm but LTE 16 cm, orange indicates greater than 16 cm but LTE 24 cm, and red is any value greater than 24 cm. The mosaicked raster graphic is found on the following page, and tiled GeoTIFFs of the complete project can be found in the output folder for this test.

DPH-9.1 USGS Swath Separation Image - Area 1 - continued



DPH-9.1 USGS Swath Separation Image - Area 2 - continued



0	0.080	0.160	0.240	9999.000 (Meter)
0	0.262	0.525	0.787	32805.052 (US Survey Feet)