Lidar Mapping Report for the U.S. Geological Survey

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Work Unit ID: 300729

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WOOLPERT

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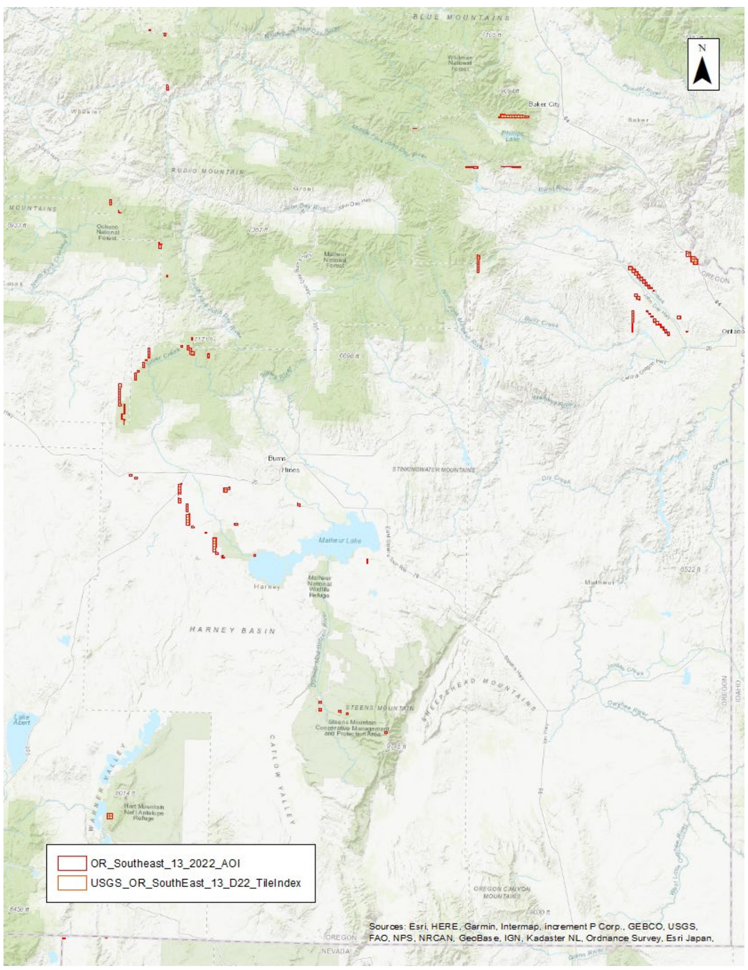
1. Overview

1.1. Description

OR_SouthEast_13_D22, WU 300729 is part of Task order 140G0222F0211.
This Lidar Mapping Report will cover the acquisition, processing, and derivative products of Work Unit 300729. Lidar data was collected to an aggregate nominal pulse spacing (ANPS) of ≤ 0.35-meters and 8-points per square meter (ppsm) covering approximately 46 square miles in southeastern Oregon to meet USGS Quality Level 1 standards. This work unit fills in gaps at the edge of the DPA that needed reflights. In addition to high density lidar data acquisition, new ground control survey data was collected to support lidar data production and accuracy.

Figure 1.1.1 – OR_SouthEast_13_D22



1.2. Purpose

This project will support the 3DEP mission and state and local agencies for stormwater management, urban planning, historic and natural resource preservation, emergency service hazard assessment support and regional planning efforts.

1.3. Specifications

Data and reporting for this task order were acquired and produced to meet the "*USGS Lidar Base Specification v2023 Revision A*", and the American Society of Photogrammetry and Remote Sensing (ASPRS) "*Positional Accuracy Standards for Digital Geospatial Data 2014 (Edition 1, Version 1.0)*".

1.4. Spatial Reference

Geospatial data products were produced using the following spatial data reference system:

- Horizontal Datum: NAD83 (2011)
- Horizontal Projection: UTM 11N
- Horizontal Units: Meters
- Horizontal EPSG Code: 6340
- Vertical Datum: NAVD88
- Geoid Model: 18
- Vertical Units: Meters
- Height Type: Orthometric

1.5. Task Order Deliverables

All data products produced as part of this task order are listed below. All tiled deliverables had a tile size of 1,000-meters x 1,000-meters. The delivery tiles are named in accordance with the US National Grid convention. This delivery's tiled dataset contains a total of 247 tiles.

1.5.1. Lidar Data

- Classified lidar point cloud data in compressed LAZ format:
    - Class 1 – Default / Processed, but not Classified
    - Class 2 – Bare Earth Ground
    - Class 7 – Low Noise
    - Class 9 – Water
    - Class 17 – Bridge Decks
    - Class 18 – High Noise
    - Class 20 – Ignored Ground
    - Class 21 – Snow
    - Class 22 - Temporal

- Breaklines used for hydro-flattening:
    - Rivers 30.5-meters / 100-feet and greater in width as PolylineZ features in Esri geodatabase format.
    - Waterbodies greater than 2-acres as PolygonZ feature classes in Esri geodatabase format.
- Bridges used in DEM generation as PointZ feature classes in Esri .shp format.
- Hydro-flattened bare earth digital elevation model (DEM): 0.5-meter pixel size, 32-bit floating-point with no bridges or overpass structures, in GeoTIFF format.

1.5.2. Metadata

- Tile index: Esri .shp format.
- Swath polygons: Georeferenced, polygonal representation of the detailed extents of each lidar swath as polygon feature class in an Esri file geodatabase format.

- Maximum separation height rasters: 1.0-meter pixel size, 32-bit floating-point, GeoTIFF format.
- Swath separation images: 1.0-meter pixel size, GeoTIFF format.
- Lidar Mapping Report in PDF Format.
- Product level xml metadata.

2. Lidar Data Acquisition

2.1. Planning and Acquisition

Prior to mobilizing to the project site, flight crews coordinated with required air traffic control personnel to ensure airspace access. Lidar data was collected from October 10, 2022 – October 10, 2024, using the specifications listed in lidar info tag. The planned settings are listed but flight height and scan rate may vary between flights.

The following sensors were used:

- TerrainMapper – serial number 91515
- TerrainMapper – serial number 91513
- TerrainMapper – serial number 91511
- Optech Galaxy T2000 – serial number 5060413
- Riegl VQ1560ii – serial number 4890
- Riegl VQ1560iiS – serial number 3546
- Riegl VQ1560iiS – serial number 4046
- Riegl VQ1560iiS – serial number 3061

A total of 48 individual flight lines were collected. The flight logs are contained in Attachment 2: Flight Logs.

Acquisition was planned based on the specifications listed below:

Leica Terrain Mapper:

- Maximum number of returns per pulse: 15
- Nominal post spacing (in meters): 0.35-meters
- Nominal pulse density: 8-ppsm
- Aggregate Nominal Pulse Spacing: 0.35-meters
- Aggregate Nominal Pulse Density: 8-ppsm
- Flying Height for collection: 2,133-meters
- Nominal Flight Speed for collection: 150-knots
- Total Sensor Scan Angle: 40-degrees
- Scan Frequency of scanner: 150-hetrz
- Pulse Rate of scanner: 1,650-kilohertz
- Pulse Duration of scanner: 5-nanoseconds
- Pulse Width: 0.5-meters
- Central Wavelength of the sensor laser: 1,064-nanometers
- Multiple Pulses In Air: 1 (yes)
- Beam Divergence: 0.25-milliradians
- Swath Width on the ground: 1.553-meters

- Nominal Swath Overlap: 25%

Optech Galaxy T2000:

- Maximum number of returns per pulse: 8
- Nominal post spacing (in meters): 0.35-meters
- Nominal pulse density: 8-ppsm
- Aggregate Nominal Pulse Spacing: 0.35-meters
- Aggregate Nominal Pulse Density: 8-ppsm
- Flying Height for collection: 1,645-meters
- Nominal Flight Speed for collection: 135-knots
- Total Sensor Scan Angle: 40-degrees
- Scan Frequency of scanner: 95-hetrz
- Pulse Rate of scanner: 1,100-kilohertz
- Pulse Duration of scanner: 5-nanoseconds
- Pulse Width: 0.23-meters
- Central Wavelength of the sensor laser: 1,064-nanometers
- Multiple Pulses In Air: 1 (yes)
- Beam Divergence: 0.16-milliradians
- Swath Width on the ground: 1.197-meters
- Nominal Swath Overlap: 30%

Riegl VQ1560ii:

- Maximum number of returns per pulse: 15
- Nominal post spacing (in meters): 0.35-meters
- Nominal pulse density: 8-ppsm
- Aggregate Nominal Pulse Spacing: 0.35-meters
- Aggregate Nominal Pulse Density: 8.16-ppsm
- Flying Height for collection: 2,000-meters
- Nominal Flight Speed for collection: 145-knots
- Total Sensor Scan Angle: 58.5-degrees
- Scan Frequency of scanner: 342-hetrz
- Pulse Rate of scanner: 2,800-kilohertz
- Pulse Duration of scanner: 3-nanoseconds
- Pulse Width: 0.36-meters
- Central Wavelength of the sensor laser: 1,064-nanometers
- Multiple Pulses In Air: 1 (yes)
- Beam Divergence: 0.18-milliradians
- Swath Width on the ground: 2,217-meters
- Nominal Swath Overlap: 20%

Riegl VQ1560iiS:

- Maximum number of returns per pulse: 15

- Nominal post spacing (in meters): 0.35-meters
- Nominal pulse density: 8-ppsm
- Aggregate Nominal Pulse Spacing: 0.35-meters
- Aggregate Nominal Pulse Density: 8.16-ppsm
- Flying Height for collection: 1,600-meters
- Nominal Flight Speed for collection: 150-knots
- Total Sensor Scan Angle: 58.5-degrees
- Scan Frequency of scanner: 304-hetrz
- Pulse Rate of scanner: 2,286-kilohertz
- Pulse Duration of scanner: 3-nanoseconds
- Pulse Width: 0.29-meters
- Central Wavelength of the sensor laser: 1,064-nanometers
- Multiple Pulses In Air: 1 (yes)
- Beam Divergence: 0.18-milliradians
- Swath Width on the ground: 1,774-meters
- Nominal Swath Overlap: 20%

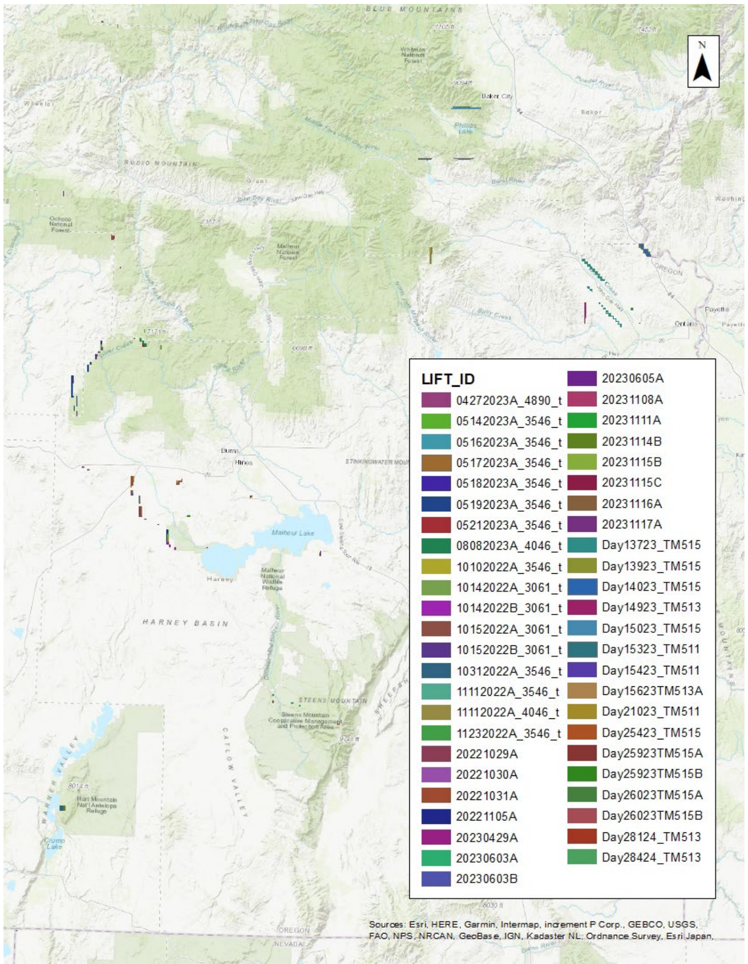
Data was collected based on the criteria listed below:

- Acquisition Conditions:
  - Daytime Acquisition.
  - Leaf-off conditions.
  - Rivers are within their channels at or below their normal levels.
  - Sky is sufficiently clear of clouds, smoke, and atmospheric haze.
- Control: Airborne Global Positioning System (ABGNSS) and Inertial Measurement Unit (IMU) data to be used along with differentially corrected GNSS ground control points.

- Data Voids are not allowed except:
  - Where caused by waterbodies.
  - Where caused by areas of low near infra-red (NIR) reflectivity (i.e. asphalt, composition roofing).
  - Where caused by lidar shadowing from buildings, terrain, or other features.
- Where appropriately filled-in by another swath.

Georeferenced, polygonal representation of the detailed extents of each lidar swath as polygon feature class in an Esri file geodatabase format as shown below.

Figure 2.1.1. - Flight Coverage by Lift



2.2. GNSS and IMU Equipment

Flight navigation during acquisition was performed by Integrated Geospatial Innovations' CCNS (Computer Controlled Navigation System. The pilots are skilled at maintaining their planned trajectory, while holding the aircraft steady and level. If atmospheric conditions were such that the trajectory, ground speed, roll, pitch and/or heading could not be properly maintained, the mission was aborted until suitable conditions occur.

2.3. GNSS-IMU Trajectory Processing

The dataset was corrected for aircraft orientation and movement. This process used airborne inertial, orientation, and GNSS data collected during acquisition along with ground-based GNSS data. The airborne GNSS positions (collected at 1/2-second intervals) were post-processed using Novatel's Inertial Explorer software. A smoothed best estimate of trajectory (SBET) was developed by combining the corrected GNSS positions with 1/500 -second inertial measurement unit (IMU) data, which tracked the plane's roll, pitch, and yaw throughout the flight.

While generating the SBET, several factors are looked at including combined separation, the estimated positional accuracy, and the Positional Dilution of Precision (PDOP).

A Kalman filter was processed in both directions to remove the combined directional anomalies. The data for this task order was processed with a goal to maintain a combined separation difference of less than 10-cm. Estimated positional accuracy plots the standard deviations of the east, north, and vertical directions along a time scale of the trajectory. The plots were reviewed for accuracy better than 5-cm. Lidar data for this task order was processed with a goal to maintain an average PDOP value below 3.0. Brief periods of PDOP over 3.0 are acceptable due to the calibration and control process if other metrics are within specification.

GNSS/IMU graphics are contained in Attachment 2: GNSS IMU Images.

2.4. Acquisition Quality Assurance

Woolpert developed a quality assurance and validation plan to ensure the acquired lidar data meets the USGS Lidar Base Specification. During the initial quality check, the lidar data was processed immediately following acquisition to verify the coverage has appropriate density, distribution, and no unacceptable data voids.

The spatial distribution of the geometrically usable first return lidar points was reviewed for density by verifying the points spaced so that 90% of the cells in a 2*NPS grid placed over the data contain at least one lidar point. The Nominal Point Spacing (NPS) assessment was conducted against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath. The data coverage was reviewed for unacceptable data voids to determine no area greater than or equal to $(4 \times ANPS)^2$ exhibited data coverage gaps.

Accompanying GNSS data was post processed to derive a best estimate of trajectory. The quality of the solution was verified to be consistent with the accuracy requirements of the task order. Any required re-flights were scheduled at the earliest opportunity.

3. Lidar Data Processing

3.1. Processing Summary

Once the lidar data passed initial QC, the dataset was corrected for aircraft orientation and movement. This process used airborne inertial, orientation, and GNSS data collected during acquisition along with ground-based GNSS data. The data was subject to geometric calibration that further corrected each laser point. This calibrated dataset was used to create the LAS point cloud. LAS point data was initially classified into “ground” and “non-ground”, then further refined using the classes specified by the task order. Breaklines were drawn to denote hydrological features. After the hydro-flattening process, the final deliverable products were created.

3.2. Boresight and Geometric Calibration

After the initial phase was complete, a formal reduction process was performed. Boresight calibrations (omega, phi, kappa) are performed, and a block adjustment is made to ensure relative accuracy. The laser point position was then calculated by associating the SBET position to each laser point return time, scan angle, intensity, etc. Raw laser point cloud data was created for the whole project area in LAS format with each point containing the corresponding scan angle, return number (echo), intensity, and x, y, and z information. Automated line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GNSS/IMU drift to test the relative calibration. Calibrations were performed on ground classified points from paired flight lines. Every flight line was used for relative accuracy calibration. Statistical reports were generated for comparison and used to make the necessary adjustments to remove any residual systematic error.

For more information, see the Sensor Calibration Report(s) in Attachment 1: Sensor Calibration Reports. Software used included proprietary software, TerraSolid v24, and Leica CloudPro 1.2.4.

3.3. Density

This project required the aggregate nominal pulse spacing and density to meet the QL1 requirements of ≤0.35 (m) and ≥8.0 (pts/m2) respectively. The density was assessed by creating a raster with a cell size equal to 1 (m) that contained a count of all the points that fell within each cell. The raster was populated with the count of points per raster cell, counting non-withheld, first return points. The results are shown below. Areas with no points are shown as red, up to seven points shown as yellow, and cells containing at least 8 points per square meter, or more are shown as green. The overall density of the project met the required specifications.

3.4. Lidar Data Classification

LAS data was initially classified as ground and non-ground points "first and only" as well as "last of many" lidar returns. In determining ground classification, steps were utilized to classify points to low noise in order to derive the best ground model. Not all points that theoretically could be bare earth get classified to ground class at the risk of impacting the surface model in the form of pits or spikes. Additional filters were created to meet the task order classification specifications. Statistical absolute accuracy was assessed by direct comparisons of ground classified points to ground RTK survey data. Based on the statistical analysis, the lidar data was then adjusted to reduce the vertical bias when compared to the survey ground control of higher accuracy.

The bare-earth (Class 2 - Ground) lidar points were subject to a manual quality control step to verify the quality of the Digital Elevation Model (DEM) as well as a peer-based review. This included a review of the DEM surface to remove artifacts and ensure topographic quality. After the bare-earth surface was finalized, it was used to generate all hydro-breaklines through a semi-automated process.

All Ground (Class 2) lidar data inside of the Lake Pond and Double Line Drain hydrological flattening breaklines were then classified to Water (Class 9) using TerraSolid/LP360 algorithms. A buffer of 0.35-meters was also used around each hydro-flattened feature to classify these Ground (Class 2) points to Ignored Ground (Class 20). All Lake Pond Island and Double Line Drain Island features were checked to ensure that the Ground (Class 2) points were reclassified to the correct classification after the automated classification was completed.

Sensor noise was reviewed using the normalized digital surface points that exceeded the average canopy height for this project overlayed on the maximum surface height raster's (MSHRs). A manual review was performed to also look for noise patterns falling below this threshold. All noise points were classified as Class 7 or Class 18 and flagged as withheld.

All data was manually reviewed, and any remaining artifacts were removed. Industry-standard LAS files were then created. Final statistical analysis was performed per tile on the LAS files classes to verify final classification metrics and full LAS header information. Those classes include:

- Class 1 – Default / Processed, but not Classified
- Class 2 – Bare Earth Ground
- Class 7 – Low Noise
- Class 9 – Water
- Class 17 – Bridge Decks
- Class 18 – High Noise
- Class 20 – Ignored Ground
- Class 21 – Snow

- Class 22 – Temporal

Classified LAZ files were evaluated through a series of manual quality control steps as well as a peer-based review to eliminate remaining artifacts from the Ground class. This included a review of the DEM surface to remove artifacts and ensure topographic quality. The LAS were generated in point record format 6 and delivered in LAZ 1.4 format.

Software used included proprietary software, LAStools 240220, GeoCue LP360, TerraSolid v24, and Global Mapper v25.

3.5. Hydrologic Flattening and Breakline

The lidar task order required compilation of breaklines defining the following types of waterbody features:

- Lakes, reservoirs, and ponds:
  - Minimum of 2-acres or greater
  - Compiled as closed polygons collected at a constant elevation.

- Rivers and streams:
  - Nominal width of 30.5-meters / 100-feet
  - Compiled in direction of flow, with both sides maintaining an equal elevation gradient.

Woolpert used the following steps to hydrologically flatten the waterbodies and for gradient hydrologic flattening of the double line streams within the existing lidar data:

- Newly acquired lidar data was used to manually compile the hydrologic features in a 2D environment using the lidar intensity and bare earth surface. Open-Source imagery was used as reference as necessary.
- An integrated software approach combined the lidar data and 2D breaklines. This process “draped” the 2D breaklines onto the 3D lidar surface model to assign an elevation. A monotonic process was performed to ensure the streams flowed consistently in a downhill gradient. A secondary step within the program verified an equally matching elevation of both stream edges. The breaklines that characterize the closed waterbodies were draped onto the 3D lidar surface and assigned a constant elevation at or just below ground elevation.
- All classified ground points inside the hydrologic feature polygons were reclassified to Water (Class 9).
- All classified Ground points were reclassified from within a buffer along the hydrologic feature breaklines to Buffered/Ignored Ground (Class 20). The buffer distance was approximately the task order designed Nominal Pulse Spacing distance.
- Breaklines used for bridge removal during the hydrologic flattening were included with the hydrologic breakline geodatabase deliverable. These breaklines produce a more aesthetically pleasing DEM appearance.
- The lidar ground points and breaklines were used to generate a DEM.
- Quality control was performed by reviewing the hydrologically flattened DEM and hydrologic breakline features. An approach combining commercial off the shelf software and proprietary methods reviewed the overall connectivity of the hydrologic breaklines.

Breaklines defining waterbodies greater than 2-acres were provided as a PolygonZ feature class. All lake breaklines compiled as part of the flattening process were provided in an Esri file geodatabase. Breaklines used for DEM generation were provided in Esri shapefile format.

Software used included TerraSolid v24, Esri ArcMap v10.8, and GeoCue LP360, GDAL 3.8.1 and LAStools 240220.

3.6. Digital Elevation Model (DEM)

TerraSolid was used to add the hydrologic breakline vertices and export the lattice models using triangulated model-z interpolation method. Ground lidar points in conjunction with the hydro breaklines and bridge breaklines were used to create 0.5-meter hydro-flattened bare-earth raster DEM files. Automated routines in ArcMap generated a 32-bit floating point raster GeoTIFF file for each tile. Each surface was checked for surface anomalies or incorrect elevations found within the surface.

Software used included TerraSolid v24, GDAL 3.8.1, Esri ArcMap v10.8, and Global Mapper v25, and LAStools 240220.

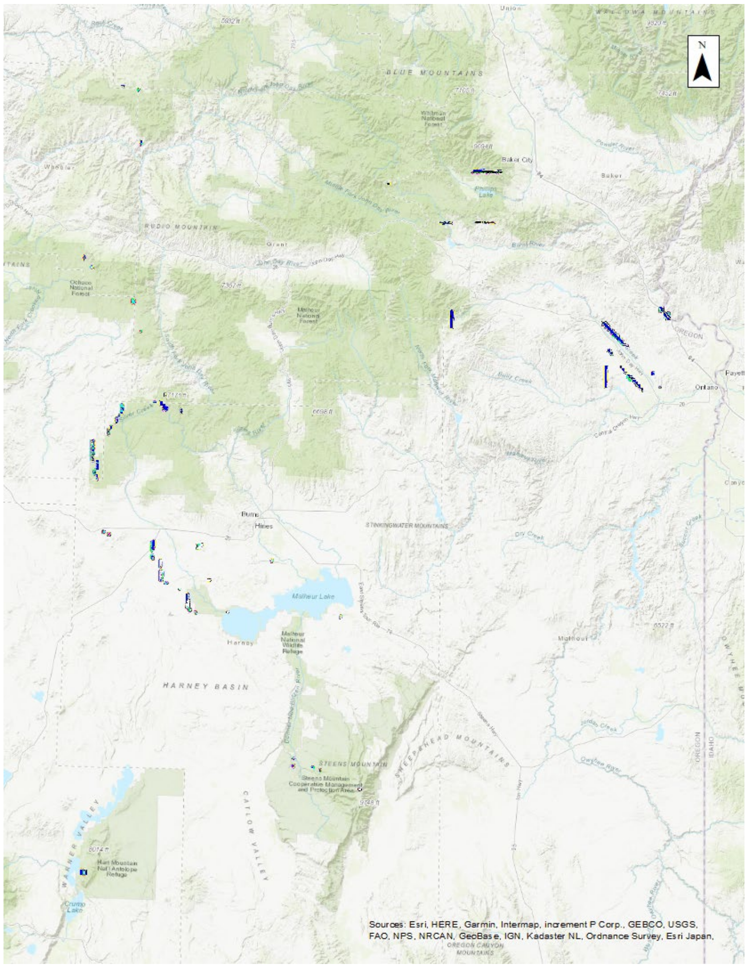
3.7. Swath Separation Image (SSI)

The Swath Separation Image (SSI) was generated to visualize the DZ between the overlapping areas of the flight lines. The SSI is generated with a point insertion gridding method from lidar last return points, excluding points classified as noise and/or flagged as withheld. For non-excluded last return points that fall within a given cell, the point with the lowest Z value from each flight line is selected; the separation value for that cell is then computed as the maximal vertical distance (dZ) between the selected points. A GeoTIFF was generated, and the color ramp is based on a QL1 data product. Intensity values were modulated to 50% to ensure that there is no oversaturation of intensities values throughout the surface. The GSD for the raster is 1 meter, which is two times the DEM post spacing.
Software used was LAStools 240220.

The color ramp for the swath separation image is as follows:

- Less than 8-cm: Green
- 8 to 16-cm: Yellow
- 16 to 24-cm: Orange
- Greater than 24-cm: Red

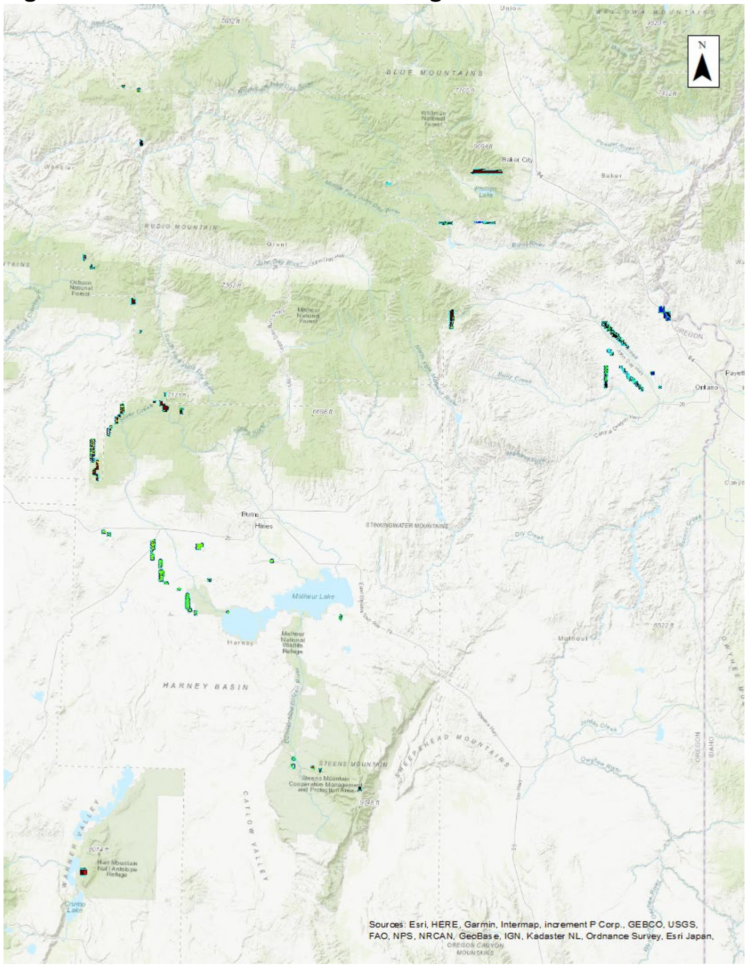
Figure 3.7.1 - Swath Separation Image



3.8. Maximum Surface Height Raster (MSHR)

The Maximum Surface Height Raster is a proof of performance check using all lidar returns excluding points flagged as withheld to show that the withheld bit flag was used properly in the point cloud. The MSHR is generated as a 32-bit floating-point GeoTIFF with each pixel being generated as highest-hit elevation and is visually reviewed for anomalies that might indicate improperly classified noise. Any issues encountered are then corrected in the point cloud and a new/updated raster is generated. The GSD for the raster is 1 meter, which is two times the DEM post spacing.
Software used included LAStools 240220.

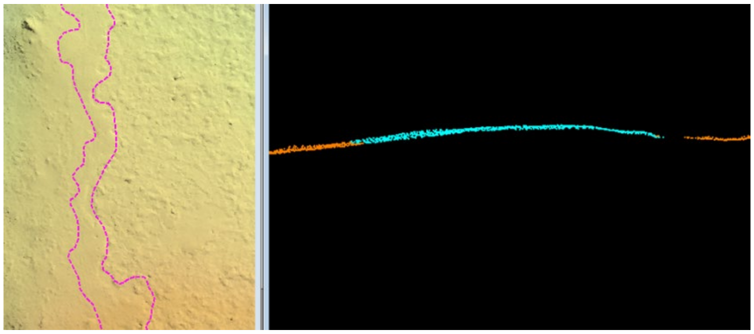
Figure 3.8.1 - Maximum Surface Height Raster



3.9. Snow Polygons

Snow polygons are provided to indicate areas where Class 21 (snow) is present, identifiable, and is needed to form a continual surface from adjacent non-snow surface in the DEM. The snow class was used in areas where snow can be distinguished from the adjacent ground surface using a combination of sources to identify snow signatures such as smoothness of surface, bright intensity, historical imagery. The screenshot below shows a snow polygon; the snow has a smoother appearance in the DEM than the surrounding ground class.

Figure 3.9.1 – Snow Polygons

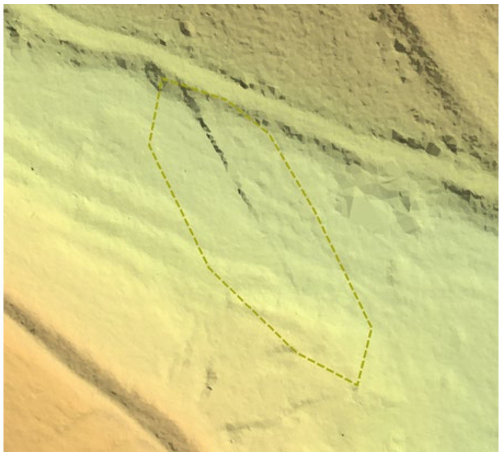


3.10. Temporal Polygons

Due to time difference between initial collection and reflights for the gap sections, there are temporal differences exhibited in the dataset. We have delineated the type of temporal affect into the following categories.

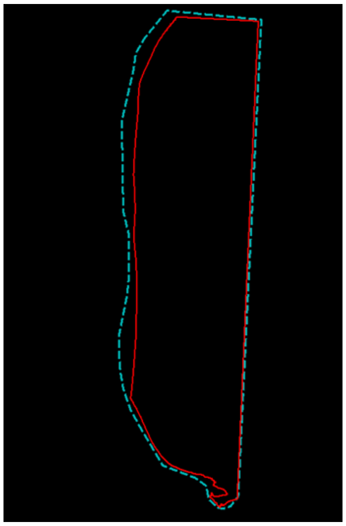
- Temporal General – because of the large time difference between collects, temporal differences were found in various terrains where ground surface could change significantly over time. The following images shows a dry drainage bed that has likely changed over time due to multiple periods of water flow present and therefore changing the underlying surface.

Figure 3.10.1 – Temporal General



- Temporal Hydro – Differing water levels were observed and priority was given to lower water level since it revealed the most ground as well as avoid any floating of hydro breaklines above adjacent ground surfaces. This caused a greater than normal degree of breaklines "digging" below adjacent surfaces. These hydro features were marked with corresponding temporal polygon to denote this occurrence.

Figure 3.10.2 – Temporal Hydro



- Temporal Snow – When snow is present but does not represent lowest surface in the DEM, and identifiable as temporal differences in areas of overlapping flightlines. Classified to Class 22 (Temporal Exclusion) to denote higher snow surface. Instead of snow polygons for this situation, a generalized temporal polygon is being provided. The screenshot below shows a temporal polygon where the higher, smoother line was identified as snow but put in Class 22 because of the line with valid ground to be used in the DEM underneath. The DEM shows the same ground variation as the surrounding surface.

Figure 3.10.3 – Temporal Snow

3.11. Metadata

FGDC CSDGM/USGS MetaParser-compliant metadata was produced in XML format. The metadata includes a complete description of the task order client information, contractor information, project purpose, lidar acquisition and ground survey collection parameters, lidar acquisition and ground survey collection dates, spatial reference system information, data processing including acquisition quality assurance procedures, GNSS and base station processing, geometric calibration, lidar classification, hydrologic flattening, and final product development. Product level metadata was created for the following deliverables:

- Classified LAS
- Bare Earth DEM
- Hydro Geodatabase
- SSI
- MSHR

4. Accuracy

4.1. Relative Accuracy: Interswath (Overlap) Consistency

This work unit is comprised of tiles that required reflights and are adjacent to the following work units: OR_SouthEast_2_D22, OR_SouthEast_6_D22, OR_SouthEast_8_D22, OR_SouthEast_9_D22, and OR_SouthEast_10_D22. Given the scattered nature of these tiles, it was not possible to run the normal accuracy tests as an independent work unit.

4.2. Relative Accuracy: Intraswath Precision

This work unit is comprised of tiles that required reflights and are adjacent to the following work units: OR_SouthEast_2_D22, OR_SouthEast_6_D22, OR_SouthEast_8_D22, OR_SouthEast_9_D22, and

OR_SouthEast_10_D22. Given the scattered nature of these tiles, it was not possible to run the normal accuracy tests as an independent work unit.

4.3. Horizontal Accuracy

This work unit is comprised of tiles that required reflights and are adjacent to the following work units: OR_SouthEast_2_D22, OR_SouthEast_6_D22, OR_SouthEast_8_D22, OR_SouthEast_9_D22, and OR_SouthEast_10_D22. Given the scattered nature of these tiles, it was not possible to run the normal accuracy tests as an independent work unit.

4.4. Classified Point Cloud

The LAS data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 1 (2014) for a 10-cm $RMSE_V$ Vertical Accuracy Class.

4.5. Digital Elevation Model

The Bare-Earth DEM data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 1, Version 1 (2014) for a 10-cm RMSEV Vertical Accuracy Class.