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Crooked Ochoco Lidar Project, 2013-2014
Lidar QC Report – November 10th, 2014

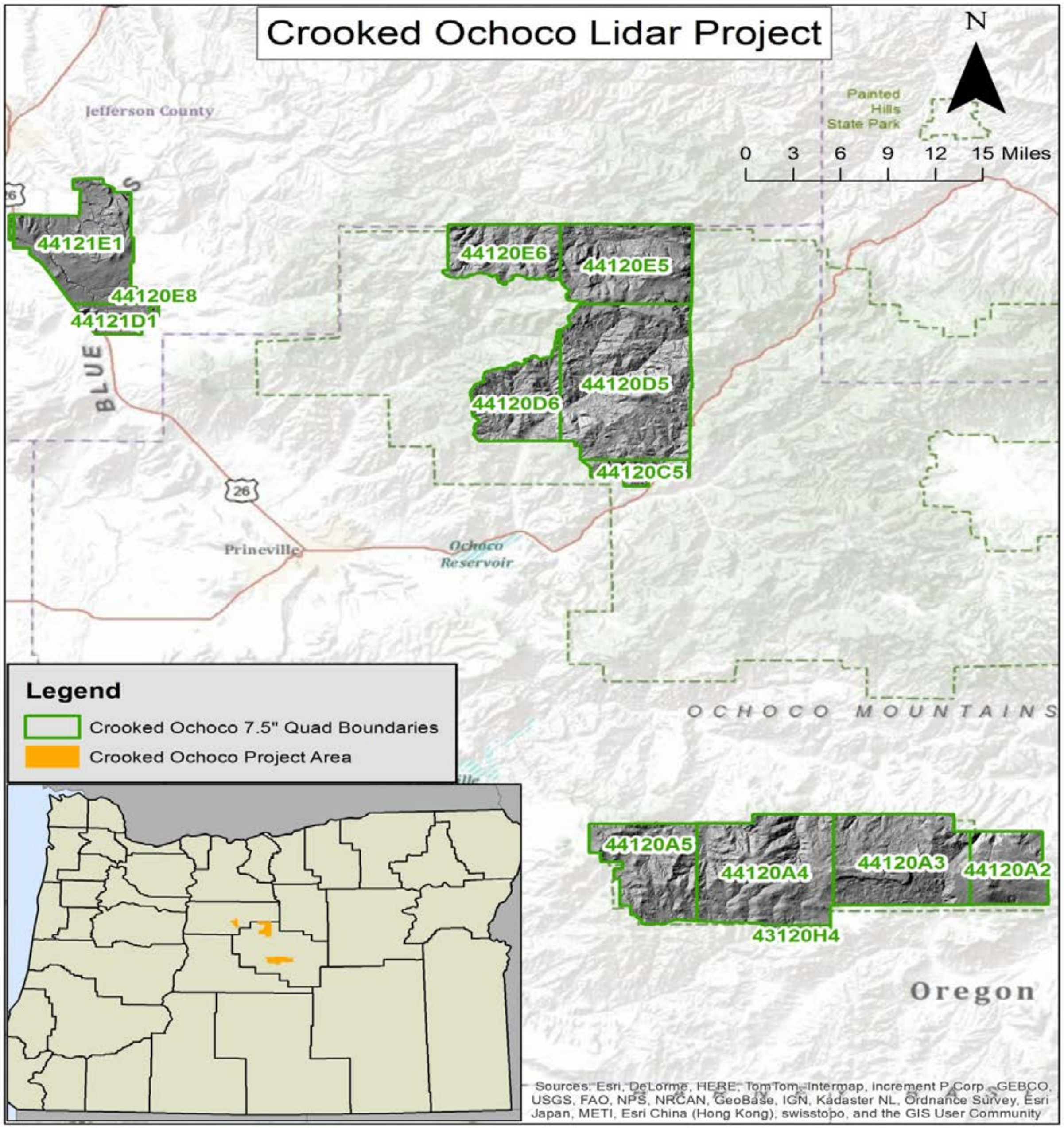

Figure 1. Map featuring the Crooked Ochoco project data extent.

The Oregon Department of Geology & Mineral Industries (DOGAMI) has contracted with Watershed Sciences (WSI) to collect high resolution lidar topographic data for multiple areas within the Pacific Northwest. Areas for lidar data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C of the 2007-2014 Lidar Data Acquisition Price Agreement (OPA #8865, pages 14-23). Data submitted under this price agreement are to be collected at a resolution of at least 8 points per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon the Crooked Ochoco Lidar Project (Figure 1) products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor WSI, all lidar data for Crooked Ochoco were independently reviewed by DOGAMI staff to ensure project specifications were met. All data was inventoried for completeness and checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy. The specific quality control checks are:

- Data Completeness examines all data associated with this delivery to ensure that all required data products are present and function correctly. Quality control review is conducted on every data file delivered to DOGAMI. Lidar ASCII Standard (LAS) point files have been loaded into TerraSolid and ArcGIS to ensure complete and correct lidar data coverage and file integrity. Raster and vector files have been viewed in ArcMap and cross referenced with the delivery area to ensure proper coverage, extent and integrity.
- Spot Diameter Analysis determines the area of ground that is intersected by a laser pulse from the lidar sensor. The spot diameter is a product of the flying height of the aircraft and the beam divergence of the sensor used during acquisition of the data
- Swath Overlap is independently verified by analyzing flight line extents in TerraSolid and making direct measurements of flight line overlap in multiple lidar tiles.
- Swath-to-Swath Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality. Poor calibration leads to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual Analysis is carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The vendor reviews the automated classification to fix misclassifications of point data. The delivered bare earth DEM is then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts. If valid errors are found, data must be corrected and resubmitted.
- Absolute Accuracy Analysis compares the delivered bare-earth DEMs with independent Ground Check Points (GCPs) to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI staff collects independent GCPs with survey-grade GPS, which are then compared against delivered lidar elevation models.

- Metadata Analysis compares the structure of the metadata file against FGDC standards. Metadata content is reviewed by using a visual check as well as analysis by the USGS Geospatial Metadata validation service.

Data Completeness

The northwestern section of the Crooked Ochoco project area was collected between September 27th 2013 through December 11th 2013. The other two sections of the project area were collected between May 3rd 2014 through June 19th 2014 (see figure 4). Total area of delivered data equals 248.86 square miles. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Crooked Ochoco survey collection area (Figure 2):

Delivery: 43120H4, 44120A2, 44120A3, 44120A4, 44120A5, 44120C5, 44120D5, 44120D6, 44120D8, 44120E5, 44120E6, 44120E8, 44121D1, 44121E1, 44121E2

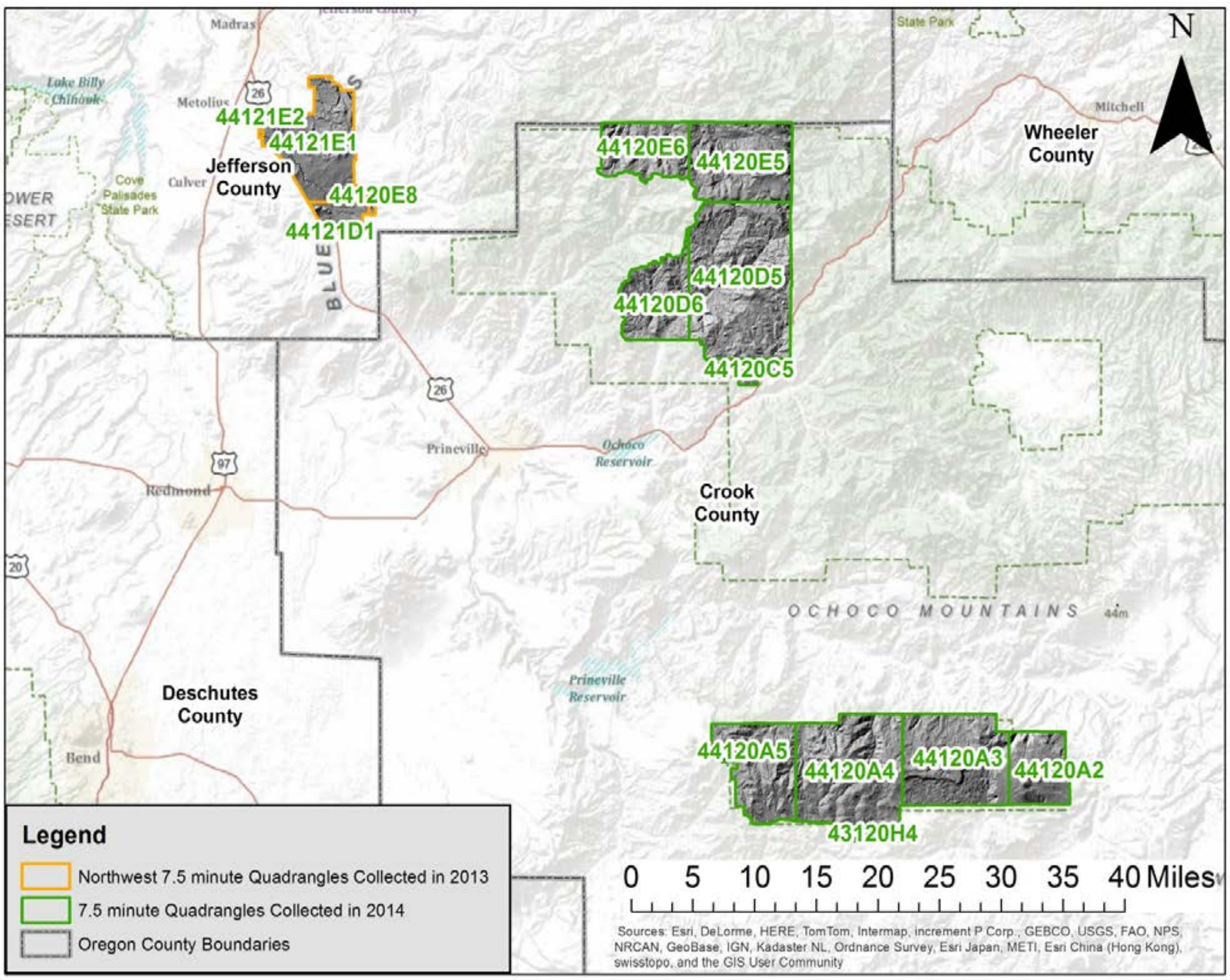

Figure 2. Crooked Ochoco delivery area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Crooked Ochoco collection area.

We review data acquisition parameters to ensure WSI has met all data collection requirements outlined in the Lidar Data Acquisition Price Agreement (OPA #8865). DOGAMI staff verifies acquisition specifications by analyzing LAS point data records. Every LAS file (version 1.2 or higher) contains binary data consisting of a header block, variable length record and point data. The header block contains information such as point numbers, coordinate bounds, and GPS time. The variable length record includes information on who created the data and the recorded length of information. The point data records include information on return number, intensity value and scan angle rank. Using the "Create LAS Dataset" tool in the ArcGIS Data Management toolbox, we analyze multiple LAS headers and create statistical information about the collection method for the entire project. Analyzing the LAS files and the information stored within them allows DOGAMI to verify acquisition requirements were met during data collection (Table 1).

Quality Control for Aerial Acquisition Specifications			
Specifications	**Description**	**Checked on this delivery**	**Comments**
Survey Conditions	Lidar data collection shall be conducted in snow-free conditions with the contractor make best effort to acquire data in leaf-off and low stream conditions	Yes	None
Pulse Returns	Lidar sensor used must be capable of recording a minimum of 4 returns per laser pulse, including first and last returns.	Yes	5 return classes
Spot Diameter	Produce an on-ground laser spot diameter no less than 15cm and no greater than 40cm	Yes	None
Horizontal Datum	North American Datum (NAD) 83 (2011) or the most current horizontal datum at the beginning of the survey	Yes	None
Vertical Datum	North American Vertical Datum (NAVD) 88 (Geoid 12A) or the most current Geoid model at the beginning of the survey	Yes	None
Scan Angle	Laser scan angle must not exceed 30 degrees overall (+15 to -15 degrees)	Yes	None
Swath Overlap	Contractor shall plan surveys with 50% sidelap of adjacent swaths. Survey must be designed for 100% double coverage at planned aircraft height above ground.	Yes	None
Design Pulse Density	Aggregate design multi-swath pulse density must be 8.0 pulses per square meter or higher.	Yes	None
Intensity Range	Record intensity range of at least 8 bits	Yes	None
GPS Procedures	At least two dual frequency L1-L2 GPS reference receivers operating during missions at 1 Hz or higher. All GPS measurements must be made with Positional Dilution of Precision (PDOP) less than or equal to 3.0 with at least 6 satellites in view.	Yes	None

Table 1. Acquisition Specifications Checklist

We review each product deliverable's format, resolution and tiling scheme in order to verify content completeness. The Crooked Ochoco lidar project includes data in the format of LAS point files, bare earth grids, highest hit grids, intensity images, trajectory files, ground point density rasters, RTK survey data, a shapefile of the delivery area and the report of survey. Lidar all-return point cloud data is delivered as LAS binary format with all required attribute fields populated (Table 2). Bare earth surface models are created from identified ground points and interpolated via triangulated irregular network into an ArcInfo Grid format with 3ft cell size (Table 3). Highest hit digital elevation models are created from a raster of first-return points that are delivered in ArcInfo Grid format with 3ft cell size (Table 4). Georeferenced intensity images created from first-return points and are supplied in TIF format (Table 5). Supplementary data including trajectory files, ground density rasters, real time kinematic ground survey data (used for absolute vertical adjustment) and delivery area shapefiles are provided in various formats (Table 6). The report of survey is a digital text report, supplied by WSI, that describes lidar data collection methods and processing. The report also provides accuracies associated with calibration, consistency, absolute error and point classification (Table 7).

Quality Control for Delivered All-Return LAS Files			
Specifications	**Description**	**Checked on this delivery**	**Comments**
LAS File Description	Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).	Yes	None
Format	LAS version 1.2 or most commonly distributed LAS format files, as specified in a Purchase Order	Yes	None
Projection	Oregon Statewide Lambert Conformal Conic	Yes	None
Horizontal Datum	NAD 1983 (2011)	Yes	None
Horizontal Units	International Feet	Yes	None
Vertical Datum	NAVD 88 (Geoid 12A)	Yes	None
Vertical Units	International Feet	Yes	None
Classification	Class 1 - Unclassified; Class2 – Ground Classification of ground returns must be as complete as is feasible and without avoidable return misclassification	Yes	None
Return Number	Must list all valid returns – Lidar sensor used must be capable of recording a minimum **of 4 returns per laser pulse**, including first and last returns.	Yes	Up to 5 returns were recorded
Time	GPS Seconds per week Use header information – time should be between 0 and 604800	Yes	None
Attributes	No duplicate entries	Yes	None
Location	Each return contain easting, northing, elevation information reported to nearest 0.01 meter (0.01 feet)	Yes	None

RGB values	All LAS files have RGB values attributed to them where applicable.	Yes	None
Delivery	LAS data must be delivered in 1/100th USGS 7.5 minute quadrangle tiles or specified in Purchase Order	Yes	None
Gaps	Check for Gaps in LAS coverage. (Already part of QC process)	Yes	None

Table 2. Quality Control for LAS Deliverables

Quality Control for Delivered Bare Earth DEMs			
Specifications	**Description**	**Checked on this delivery**	**Comments**
Bare Earth DEM Description	Raster of ground surface, interpolated via triangulated irregular network from identified ground points.	Yes	None
Projection	Oregon Statewide Lambert Conformal Conic	Yes	None
Horizontal Datum	NAD 83 (2011)	Yes	None
Horizontal Units	International Feet	Yes	None
Vertical Datum	NAVD 88 (Geoid 12A)	Yes	None
Vertical Units	International Feet	Yes	None
Format	Esri 32 bit pixel depth floating point grid	Yes	None
Cell Size / Resolution	3 foot (1m if UTM projection specified)	Yes	None
Tiling	Full USGS 7.5-minute quadrangle (7.5 minute by 7.5 minute) tiles, unless otherwise specified in a purchase order	Yes	None
Attributes	No duplicate entries	Yes	None
Gaps	Surface Models must not have tiling artifacts or gaps at tile boundaries or artifacts such as pits, birds, striping or aliasing	Yes	None

Table 3. Quality Control for Bare Earth DEMs

Quality Control for Delivered Highest-Hit DEMs			
Specifications	**Description**	**Checked on this delivery**	**Comments**
Highest Hit Description	Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.	Yes	None

Projection	Oregon Statewide Lambert Conformal Conic	Yes	None
Horizontal Datum	NAD 83 (2011)	Yes	None
Horizontal Units	International Feet	Yes	None
Vertical Datum	NAVD 88 (Geoid 12A)	Yes	None
Vertical Units	International Feet	Yes	None
Format	Esri 32 bit pixel depth floating point grid	Yes	None
Cell Size / Resolution	3 foot (1m if UTM projection specified)	Yes	None
Tiling	Full USGS 7.5-minute quadrangle (7.5 minute by 7.5 minute) tiles, unless otherwise specified in a purchase order	Yes	None
Attributes	No duplicate entries	Yes	None
Gaps	Surface Models must not have tiling artifacts or gaps at tile boundaries or artifacts such as pits, birds, striping or aliasing	Yes	None

Table 4. Quality Control for Highest-Hit DEMs

Quality Control for Delivered Intensity Images			
Specifications	**Description**	**Checked on this delivery**	**Comments**
Intensity Description	TIFF Raster built using returned lidar pulse intensity values gathered from highest hit returns	Yes	None
Horizontal Datum	NAD83 2011	Yes	None
Projection	Oregon Statewide Lambert Conformal Conic	Yes	None
Horizontal Units	International Feet	Yes	None
Format	GEOTIFF	Yes	None
Pixel Depth	8 bit pixel depth gray scale	Yes	16 bit pixel depth – better than required
Cell Size (X, Y)	1.5 foot	Yes	none
Normalized	Intensity shall have been normalized if the sensor or combination of sensors used on the project allow.	Yes	None
Attributes	Intensity file structure conforms to full USGS 7.5 minute quadrangle (7.5 minute by 7.5 minute) tiles	Yes	None
Gaps	Deliverable tiles checked for significant gaps not covered by aerial acquisition checks and/or caused by processing	Yes	None

Table 5. Quality Assurance of Intensity Images

Quality Control for Supplementary Data					
Specifications	**Description**	**Format**	**Tiling**	**Projection**	**Checked on this delivery**
GCP Shapefile	Ground Control Points used for survey calibration and assessment of absolute vertical accuracy	Esri Shapefile		NAD 1983 UTM Zone 8N (2011), meter	Yes
Trajectory Files	Point location measurements of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting (meters), Northing (meters), Ellipsoid Height (meters) of aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees). Measurements are collected at one second intervals.	ascii point file - (TXYZRPH)	Date and time of acquisition	NAD 1983 UTM Zone 8N (2011), meter	Yes
Trajectory Shapefile	Trajectory data in Esri shapefile format attributed with project name and date of acquisition for each flight line	Esri Shapefile		NAD 1983 UTM Zone 8N (2011), meter	Yes
7.5 minute Quadrangle	Geometry file depicting the geospatial area associated with deliverables.	Esri Shapefile	Full USGS 7.5 minute quadrangle	NAD 1983 Alaska State Plane (2011), US foot	Yes
0.75 minute 1/100th quadrangle	Geometry file depicting the geospatial area associated with deliverables.	Esri Shapefile	1/100th USGS 7.5 minute quadrangle	NAD 1983 Alaska State Plane (2011), US foot	Yes
TerraSolid Processing Bins	DGN file that contains processing bins for all LAS files	DXF or DGN file	1/100th USGS 7.5 minute quadrangle	NAD 1983 Alaska State Plane (2011), US foot	Yes
Delivery Area Shapefile	Geometry file depicting the geospatial area associated with deliverables.	Esri Shapefile	Alaska State Plane NAD 83	NAD 1983 Alaska State Plane (2011), US foot	Yes

Table 6. Quality Control for Supplementary Data

Quality Control of the Report of Survey			
Specifications	**Description**	**Checked on this delivery**	**Comment**
Project Overview	Acquisition information that includes location map, project area, total area flown, acquisition dates and specified coordinate system and datum	Yes	Yes
Aerial Acquisition	Acquisition parameters including information about the aircraft, sensor, flight elevation and a map of flight line trajectories showing dates of collection	Yes	Yes
Report of Ground Survey	A detailed description of GPS procedures used in establishing the reference network and control points for the project. Includes a reference map and table showing monuments used and the location of all GCPs collected.	Yes	Yes
Calibration Report	A report for the systems used in the data acquisition	Yes	More information needed
Relative Accuracy Assessment	Relative accuracy refers to the internal consistency of the data set and is measured as the differential between lidar points collected from different flight lines. Data should be presented as summary statistics and histogram form based on the entire study area.	Yes	Yes
Vertical Accuracy Assessment	Vertical accuracy shall be reported to meet the guidelines of the National Standard for Spatial Data Accuracy (Federal Geographic Data Committee (FGDC), 1998) and ASPRS Guidelines for Vertical Accuracy Reporting for Lidar Data V1.0 (American Society for Photogrammetry and Remote Sensing (ASPRS), 2004). Data shall be presented as both summary statistics and in histogram form.	Yes	Yes
Pulse Density Assessment	Contractor's assessment of pulse density over the project area, including maps showing design pulse density and ground return densities by quarter-quadrangle and histograms of both density parameters.	Yes	Yes
Summary Table	Table of deliverables, listing file formats and total number and data volume of each deliverable.	Yes	Table of deliverables not listed

Table 7. Quality Control of the Report of Survey

Spot Diameter Analysis

Horizontal accuracy is not specified in the price agreement since true horizontal accuracy is regarded as a product of the lidar spot diameter (SD). The lidar spot diameter is the area of ground that is intersected by a single pulse from the lidar sensor. SD is a function of range and beam divergence. The range is calculated as the distance between the laser aperture and the detected surface. The reported range value is given as above ground level flying height (AGL) of the sensor during collection. Beam divergence (γ) is the degree by which the light pulse emitted from the sensor fans out from a straight line. Beam divergence is measured in radians, with 1 radian = 57.3 degrees. The lidar SD is calculated by multiplying AGL and beam divergence, SD = AGL * γ

Crooked Ochoco data was collected using Leica ALS50, ALS60 and ALS70 lidar sensors flown at 900 meters AGL. The Leica ALS60 and ALS70 specification sheet reports a beam divergence value of 0.22 milliradians @ $1/e^2$, meaning that ~85% of the laser energy falls within this divergence. The Leica ALS50 specification sheet reports a beam divergence value of 0.33 milliradians @ $1/e^2$, meaning that ~85% of the laser energy falls within this divergence.

The range of spot diameters for the Crooked Ochoco project is between 0.198 meters and 0.297 meters. This equals an average spot diameter of 0.248 meters for these deliveries, which is within the project specification tolerance of 0.15 meter to 0.40 meter for SD.

Swath Overlap

Swath overlap is independently verified by measuring the amount of flight line overlap in multiple lidar tiles. This is accomplished by importing the all-return LAS files into a CAD software called TerraSolid™. Each LAS file contains header information that includes the trajectory number or flight line that was flown during its acquisition. The LAS files are assigned a color value based on the flight line number so that multiple swaths can be displayed and percent overlap can be measured (Figure 3). 8 out of 80 all-return LAS files (10%) were loaded into TerraSolid and direct measurements were made in multiple locations. All 8 all-return LAS files contained ≥ 50% sidelap of adjacent swaths. These results show that all data are within specification.

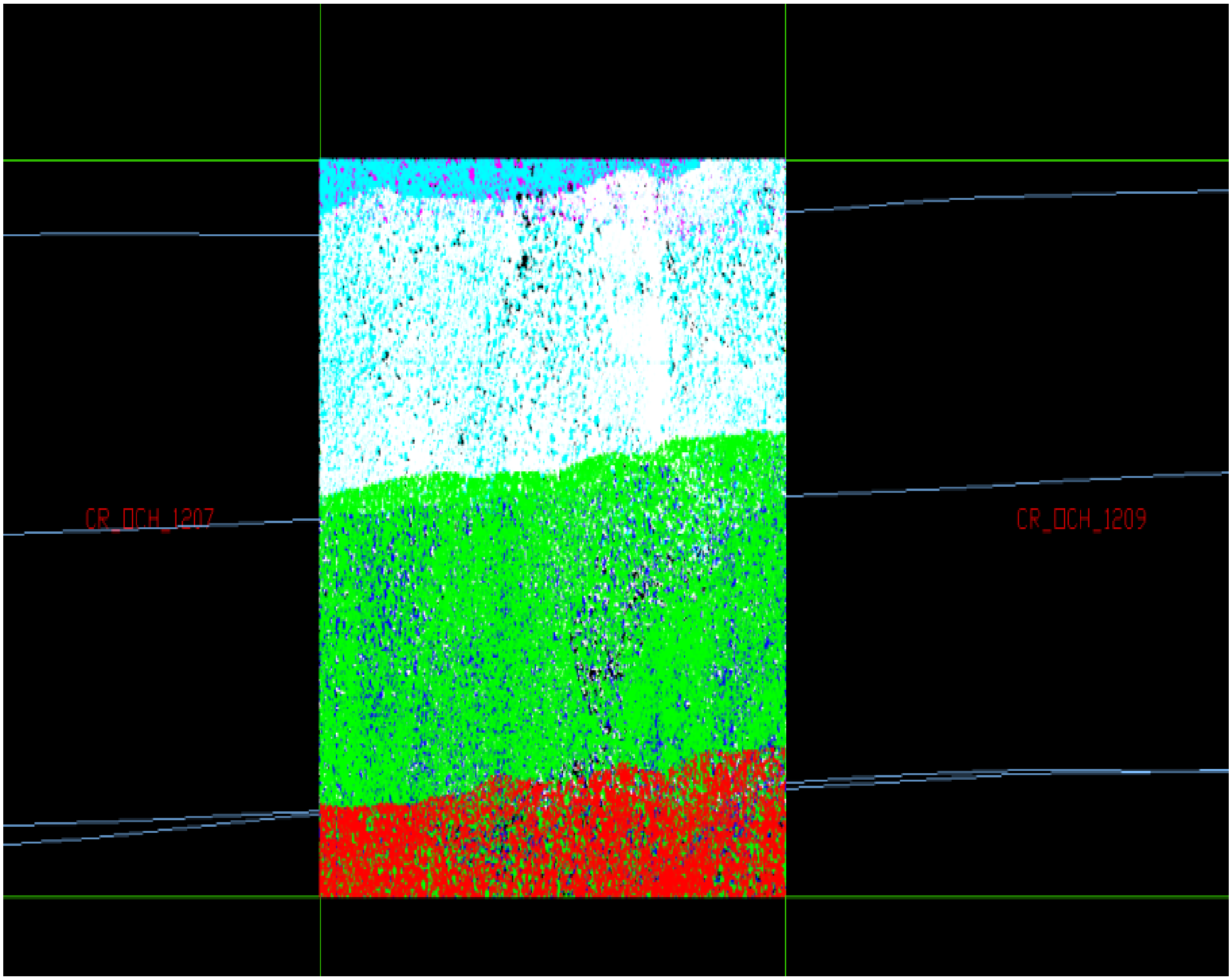

Figure 3. Lidar points colored by flight line in the 0.75 minute 1/100th quadrangle 44122A8119.

Swath-to-Swath Consistency Analysis

DOGAMI has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between flight lines. DOGAMI measures consistency offsets throughout delivered datasets to ensure that project specifications are met.

Consistency refers to lidar elevation differences between overlapping flight lines. Consistency errors are created by poor lidar system calibration settings associated with sensor platform mounting. Errors in consistency manifest as vertical offsets between individual flight lines. Consistency offsets were measured using the “Find Match” tool within the TerraMatch© software toolset. This tool uses aircraft trajectory information linked to the lidar point cloud to quantify flight line-to-flight line offsets.

To quantify the magnitude of this error 662 of 695 delivered data tiles (98%) were examined for vertical offset between flight lines. Data tiles with less than 1000 points were not used in analysis. Each tile measured 750 x 750 meters in size (Figure 4). The average number of points used for flight line comparison was 12,387,804 per tile (Table 8a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meter in the horizontal plane and 0.2 meters in the vertical plane. Each flight line was compared to adjacent flight lines, and the average magnitude of vertical error was calculated. 410 flight lines out of 442 total flight lines (93%) were sampled and compared for consistency.

Results of the consistency analysis found the average flight line offset to be 0.034 meters with a maximum error of 0.069 meters (Table 8b). Distribution of error showed 98% of all error was less than 0.05 meters and 100% less than 0.07m (Figure 5). These results show that all data are within specification.

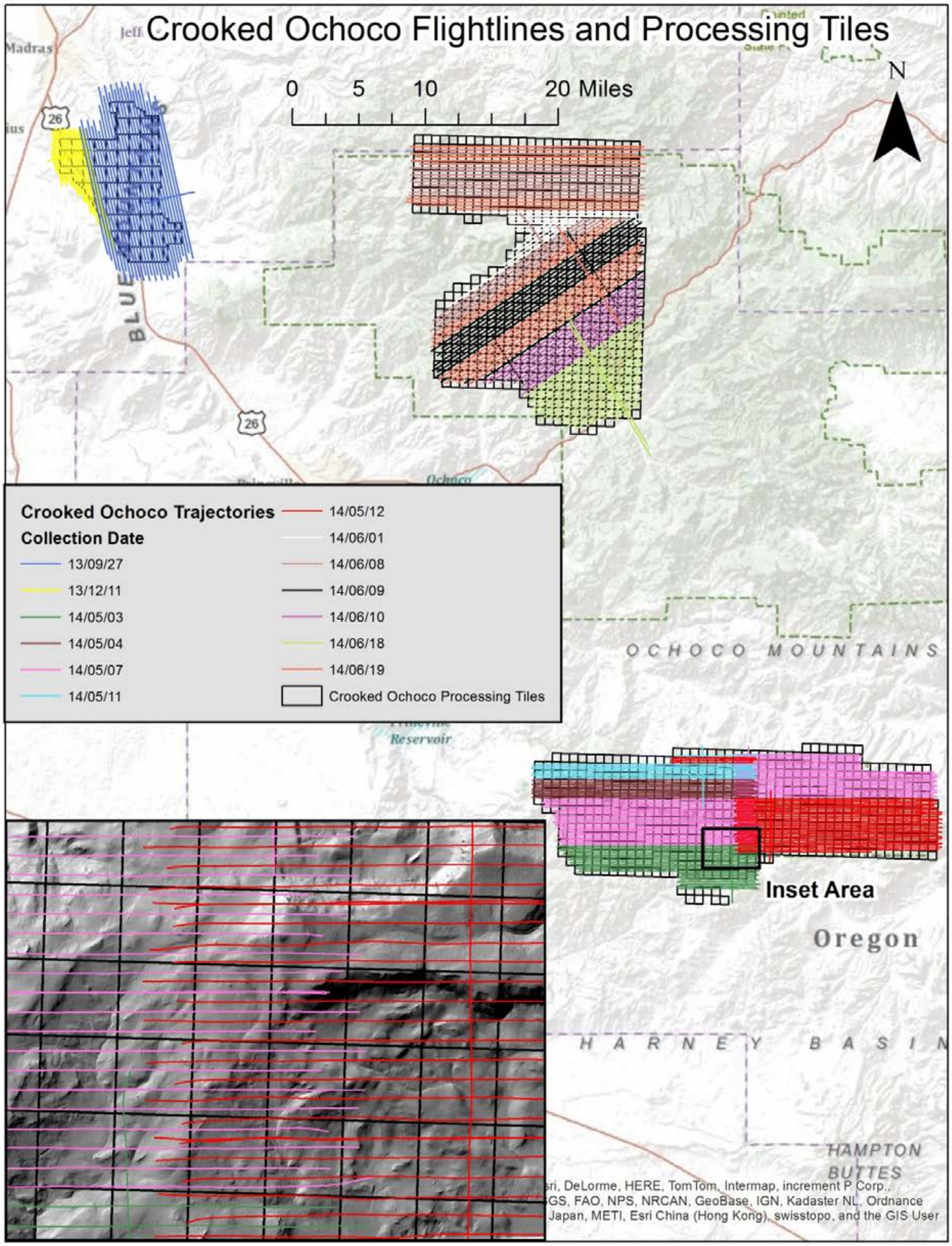

Figure 4. Spatial distribution of flight lines and processing tiles used in the consistency analysis.

Table 8a. Summary Results of Consistency Analysis

Summary Statistics	
# of Tiles	662
# of Flight Line Sections	410
Avg. # of Points	1,439,310
Avg. Magnitude Z error	0.034 meters

Table 8b. Descriptive Statistics for Magnitude Z Error.

Descriptive Statistics	Meters	Feet
Mean	0.034	0.111
Standard Error	0.000	0.001
Standard Deviation	0.010	0.034
Sample Variance	0.000	0.000
Range	0.059	0.193
Minimum	0.001	0.032
Maximum	0.069	0.225

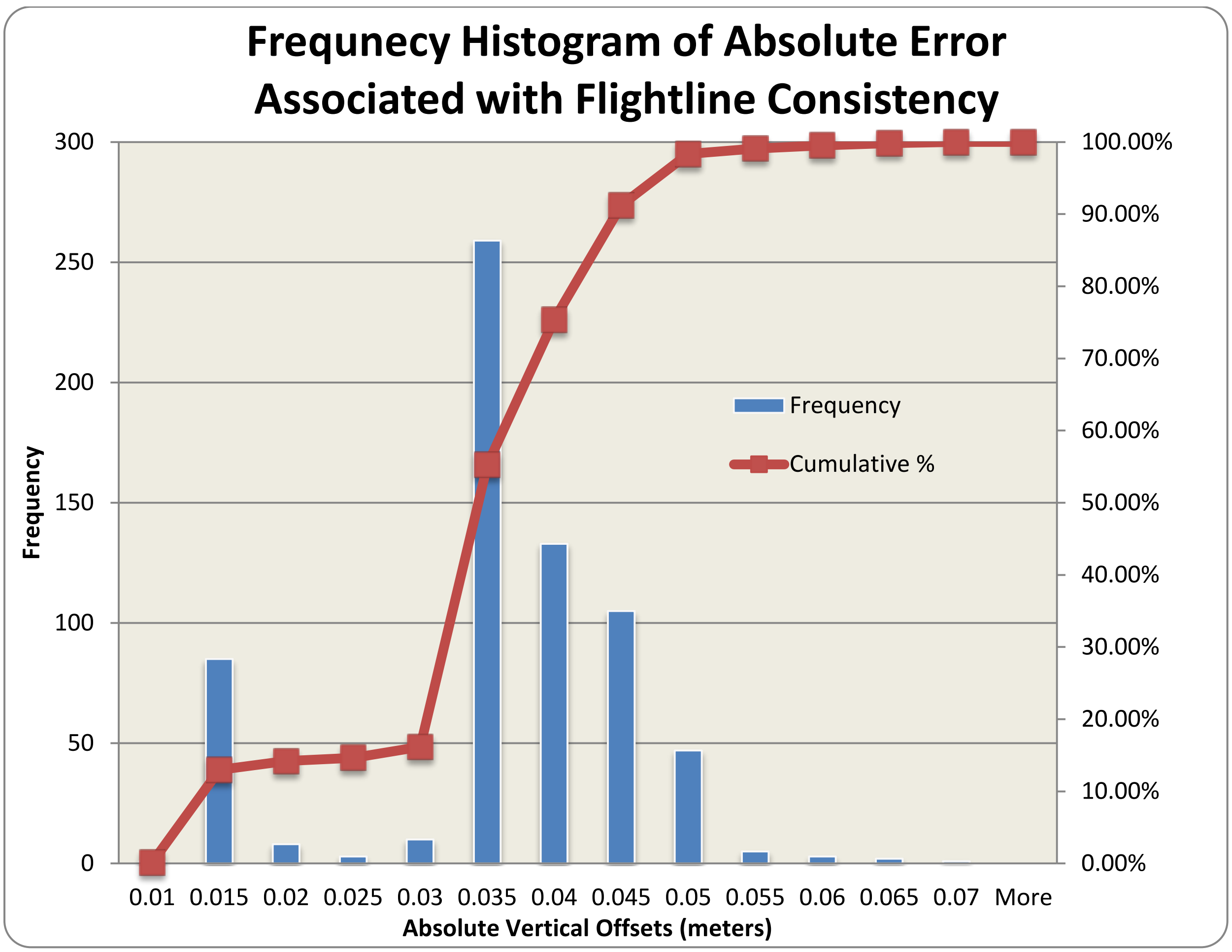

Figure 5. Flight line Consistency Histogram in meters

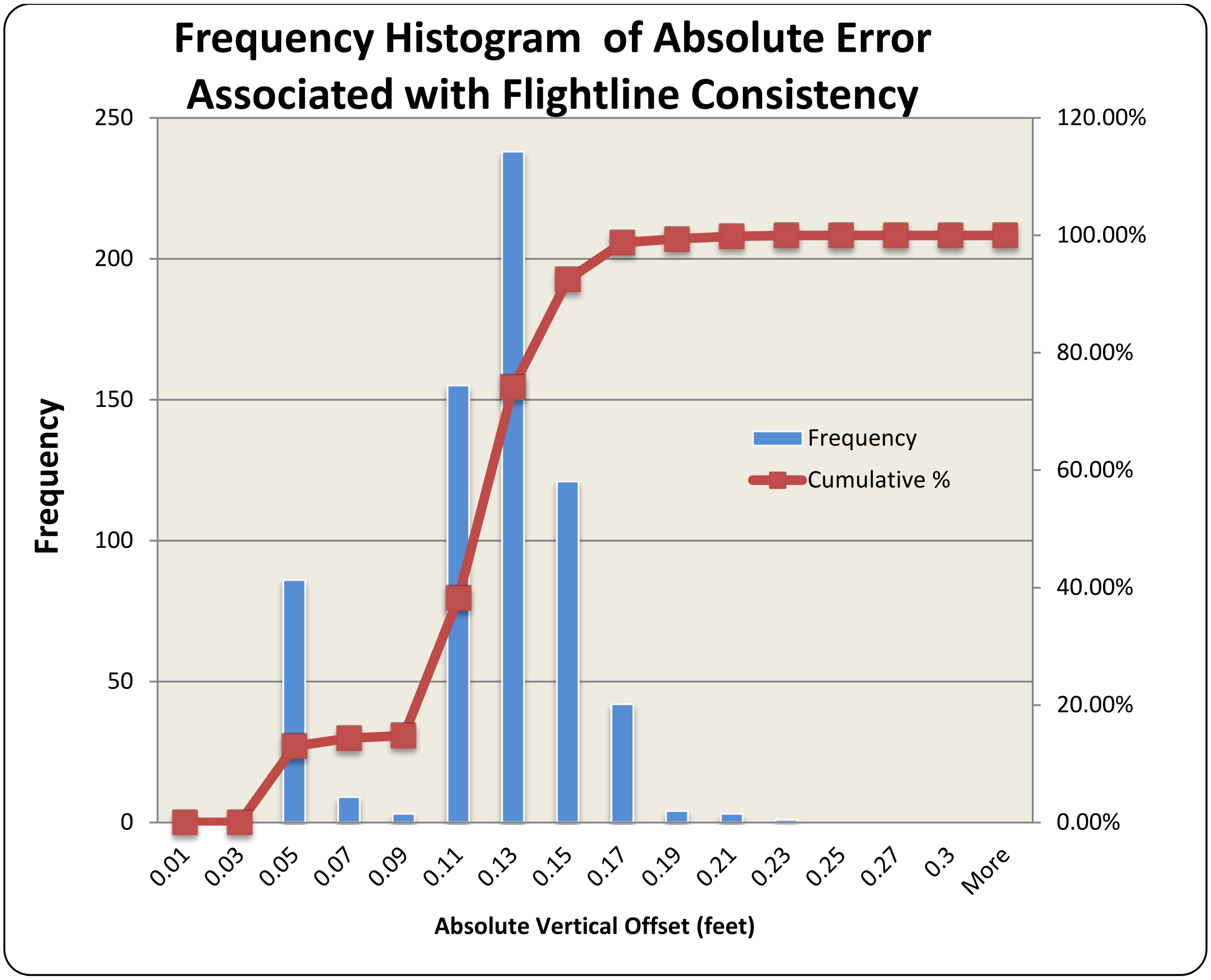

Figure 6. Flight line Consistency Histogram in feet

Visual Analysis

Lidar 3ft grids were loaded into ArcGIS software for visual analysis. Data were examined through slope and hillshade models of bare-earth returns. Hillshades of the highest hit models were used to identify areas of missing ground (Figure 7). Both bare-earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 8), seam line offsets, pits (Figure 9), and birds.

Calibration offsets typically are visualized as a corduroy-like pattern within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in highest hit models than bare earth. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as linear features typically 1-2 grid cells in width, and are present in both the highest hit and bare earth models (e.g. Figure 7). Seam line offsets occur where two distinct days of lidar data overlap. Errors occur as a result of improper absolute vertical error adjustments. These errors are typically visualized as a linear stair step running along the edge of connecting flight lines. Pits and birds refer to uncommonly high or low points that are the result of atmospheric and sensor noise. Pits (low points) typically occur where the laser comes in contact with water on the ground (Figure 9). Birds (high points) typically occur where the laser comes into contact with atmospherics[1].

During visual analysis of Crooked Ochoco raster data, 110 observed errors were digitized for spatial reference and stored in Esri shapefile format. Each feature was assigned an ID value and included a brief description of the observed error. The shapefile was then delivered to WSI for locating and fixing errors. Upon receiving the observed error locations, WSI performed an analysis to conclude whether the error was valid and provided comments on how the data was adjusted. 91 out of the 110 observed errors (82.7%) were adjusted and the data was reprocessed to accommodate fixes. Errors that were not fixed by WSI were reviewed by DOGAMI staff to ensure justification was valid. Final sets of lidar 3 ft grids were loaded into ArcGIS software and examined to ensure edits were made and visually inspected an additional time for completeness (figure 12).

[1]Atmospherics include clouds, rain, fog, or virga.

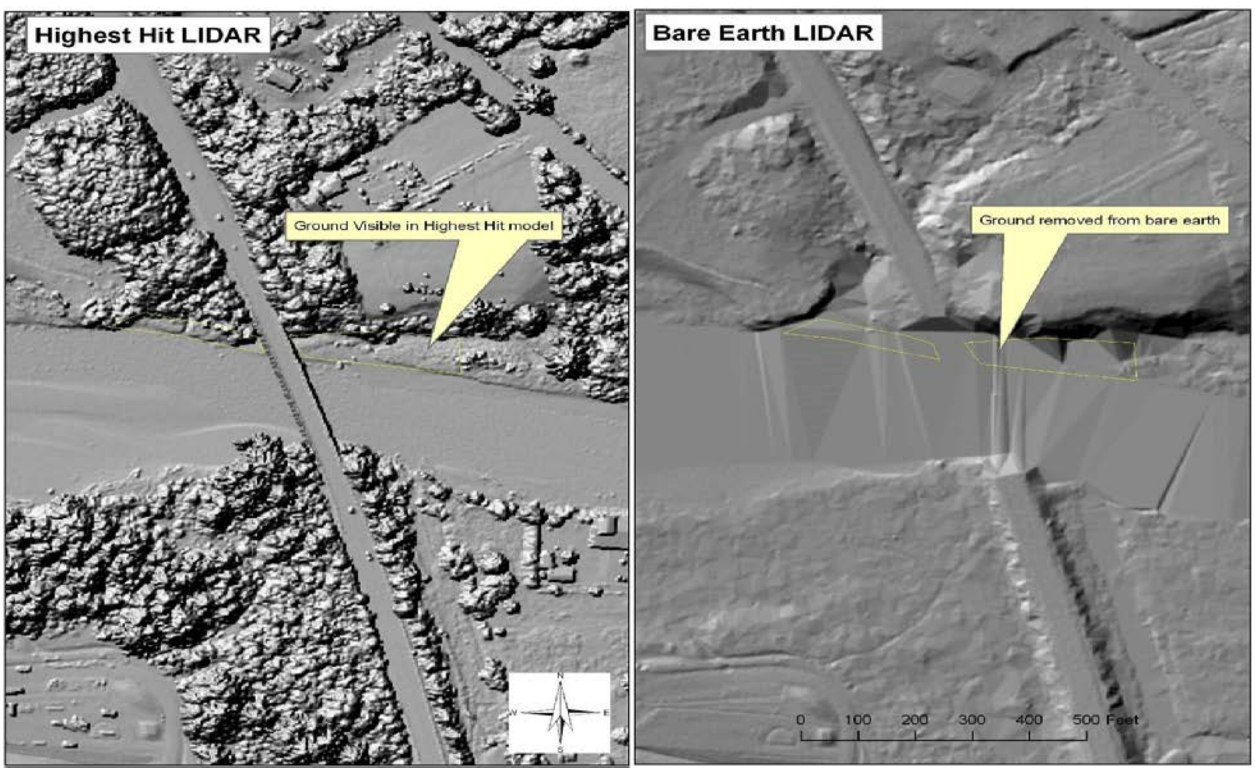

Figure 7. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features

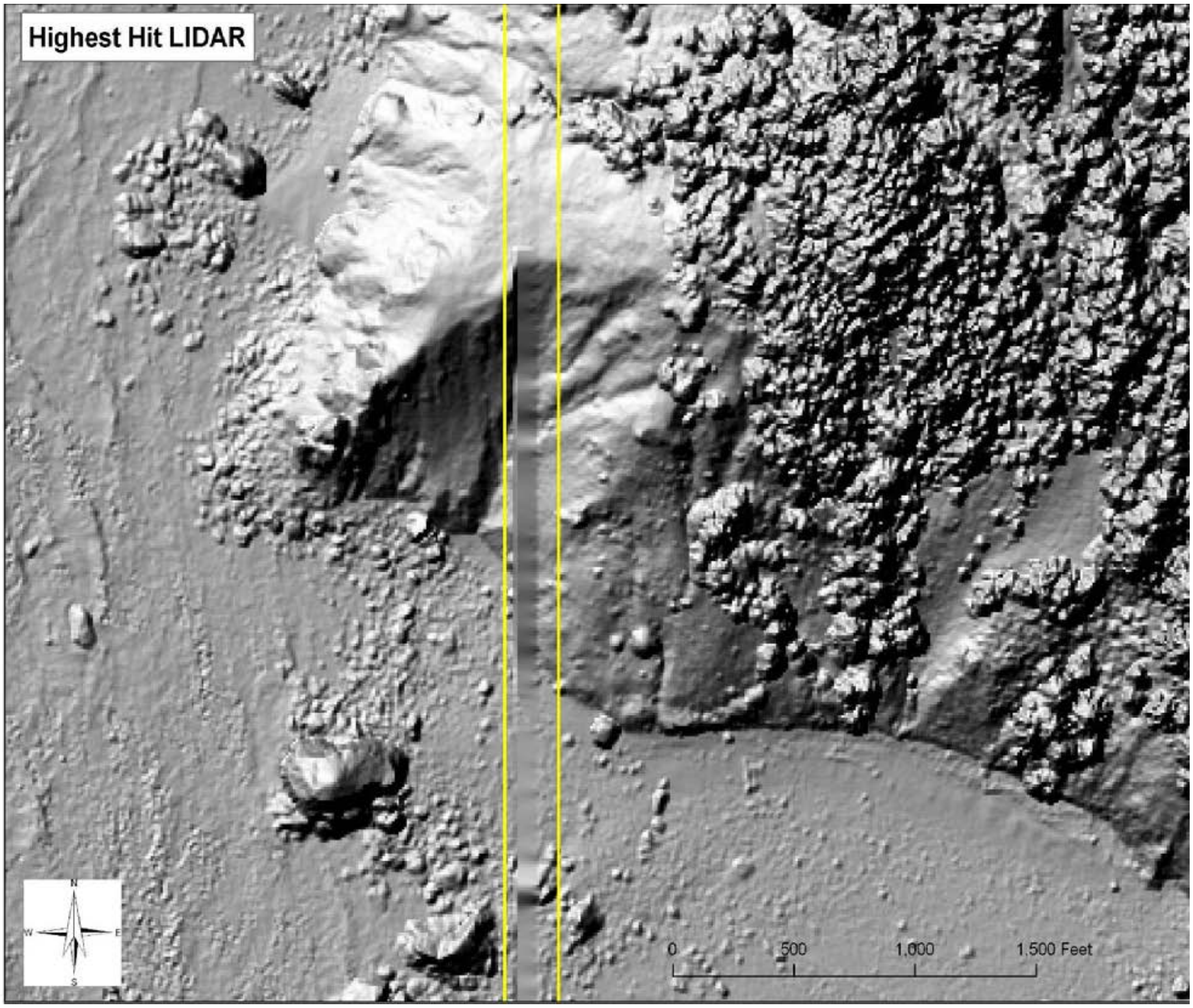

Figure 8. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

Figure 9. Example of "Pit" caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point elevation is assigned to the grid value.

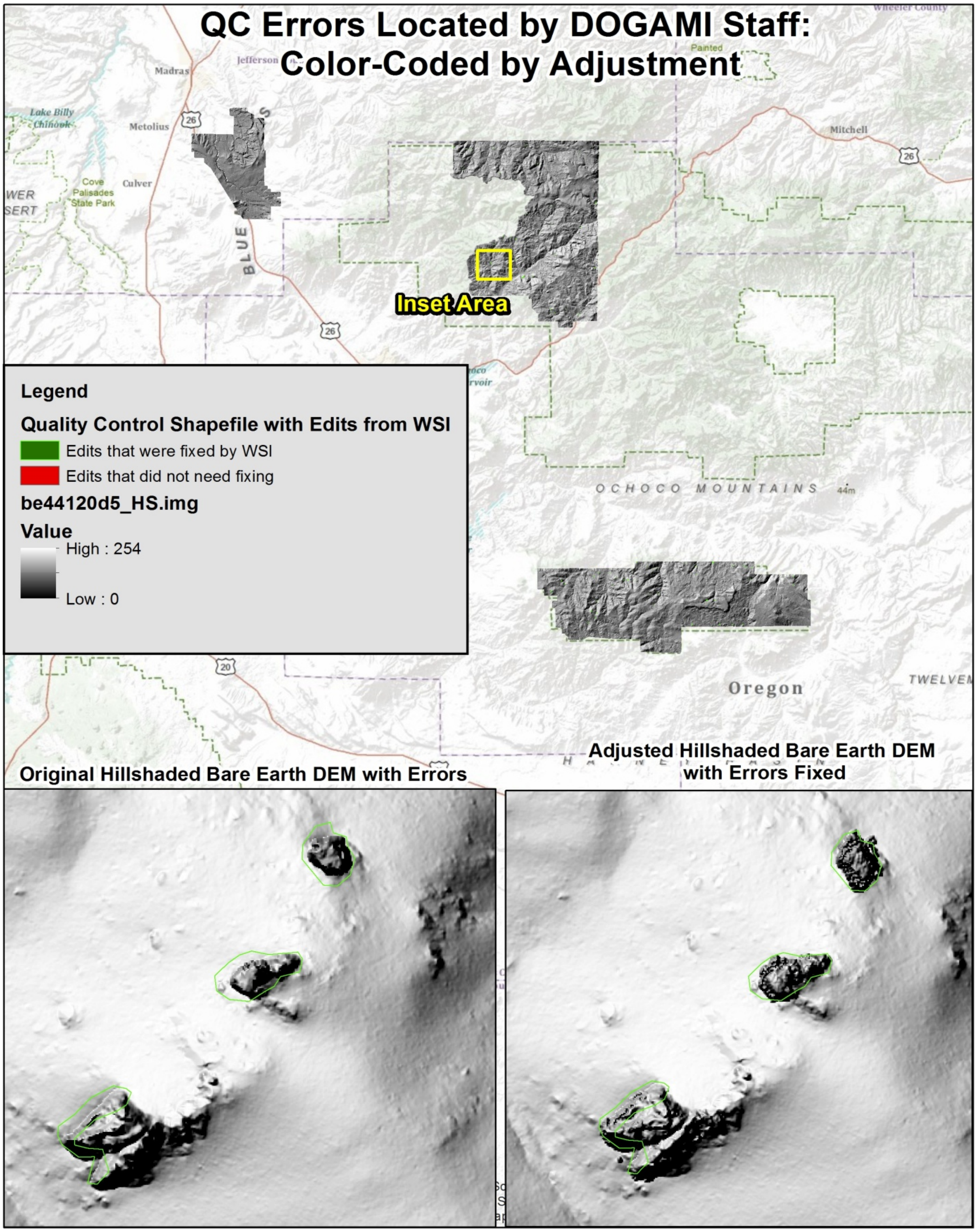

Figure 10. Spatial distribution of visual QC errors located by DOGAMI staff.

Absolute Accuracy Analysis

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used a Trimble™ 5700/5800 Total Station GPS surveying system (Figure 11) to measure GCP's. This system consisted of a GPS base station (5700 unit), Zephyr Geodetic antenna, Trimmark 3 radio, and 5800 "rover". The 5700 base station was mounted on a fixed height (typically 1.8 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately ±1-cm + 1ppm (parts per million * the baseline length) and ±2-cm in the vertical (TrimbleNavigationSystem, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties.

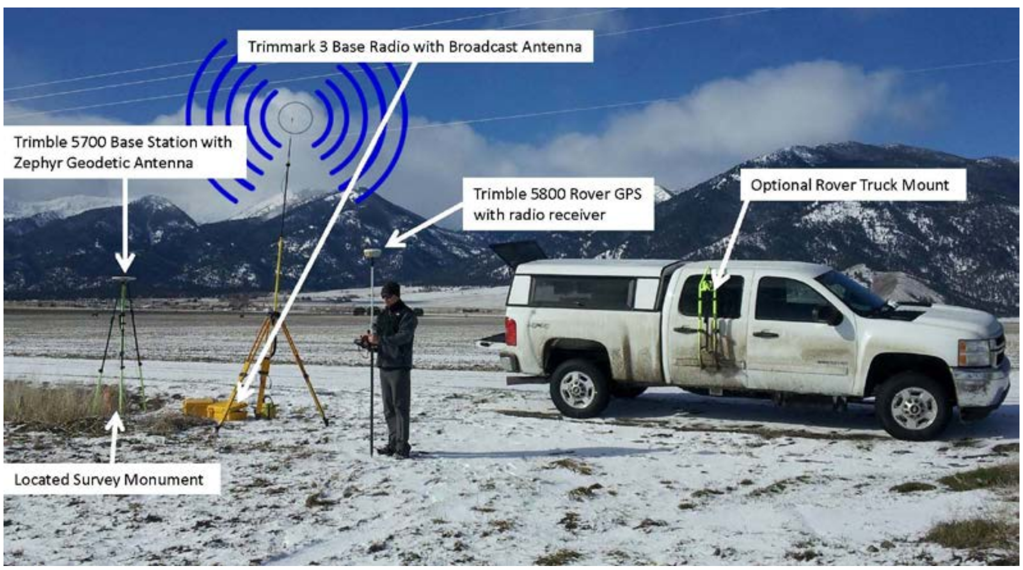

Figure 11. The Trimble 5700 base station antenna located over a known reference point outside Baker City. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

The approach adopted for DOGAMI lidar surveys was comprised of two components:

1) Verify the horizontal and vertical coordinates established by Watershed Sciences for a select number of survey monuments used to calibrate the lidar survey. These surveys typically involved a minimum of two hours of GPS occupation over a known point. The collected data were then submitted to the National Geodetic Survey (NGS) Online

Positioning User Service (OPUS) for post-processing against several Continuously Operating Reference Stations (CORS) operated by the NGS.

2) Collect GCP's along relatively flat surfaces (roads, paths, parking lots etc.). This step involved the collection of both continuous measurements (from a vehicle as well as from a backpack) as well as static measurements (typically 5 epochs).

Having collected the GCP data, the GPS data was post-processed using Trimble's Geomatic Office software. Data post-processing typically involved calibrations against at least three CORS stations as well as from local site calibrations performed in the field using those benchmarks that had been independently verified. Data is post processed to refine measurements so that horizontal and vertical errors are less than 0.02 meters (0.065 feet). Horizontal accuracy of data is tested by reoccupying a sample subset of survey monuments used for processing of lidar data. Each occupation's x and y coordinates are compared with the vendor coordinates for offsets (Figure 9).

DOGAMI collected GCP points on May 23rd 2014 and June 18th 2014. Ground conditions were good every day of collection with no snow and no inclement weather on either collection dates. The base stations used in the GCP data collection for Crooked Ochoco were located on monuments Crooked 05 and Crooked 06 which were established by WSI (See Report of Survey). Accuracy assessments of survey monuments are provided in the form of an OPUS solution from NGS, below is the OPUS solution for monument Crooked 05.

NAV FILE: brdc1340.14n		OBS USED: 4004 / 4256 : 94%	
ANT NAME: TRM41249.00 SCIT		AMB: 36 / 44 : 82%	
ARP HEIGHT: 1.800		OVERALL RMS: 0.311(m)	
REF FRAME: NAD_83(2011) (EPOCH:2010.0000)		IGS08 (EPOCH:2014.36447)	
X: -2350535.280(m)	0.006(m)	-2350536.145(m)	0.006(m)
Y: -3905873.117(m)	0.066(m)	-3905871.898(m)	0.066(m)
Z: 4447281.317(m)	0.048(m)	4447281.323(m)	0.048(m)
LAT: 44 29 2.96146	0.006(m)	44 29 2.97518	0.006(m)
E LON: 238 57 38.43860	0.035(m)	238 57 38.37663	0.035(m)
W LON: 121 2 21.56140	0.035(m)	121 2 21.62337	0.035(m)
EL HGT: 926.287(m)	0.074(m)	925.864(m)	0.074(m)
ORTHO HGT: 947.055(m)	0.075(m)	[NAVD88 (Computed using GEOID12A)]	

		UTM COORDINATES UTM (Zone 10)	STATE PLANE COORDINATES SPC (3602 OR S)
Northing (Y)	[meters]	4927518.911	90985.026
Easting (X)	[meters]	655912.243	2457098.097
Convergence	[degrees]	1.37414600	-0.38248005

Point Scale	0.99989895	0.99996543
Combined Factor	0.99975357	0.99982022

DOGAMI was able to test the horizontal accuracy of survey monuments used to reference the lidar data while conducting vertical control measurements. For internal purposes only, the XY coordinates of survey monuments surveyed by DOGAMI were compared to the survey monuments provided by the vendor. The average horizontal accuracy for all monument locations occupied by DOGAMI during GCP data collection is 0.007 meters Northing and 0.031 meters Easting (Table 9). The average root mean square error (RMSE) for positional accuracy for all monument locations occupied by DOGAMI during GCP data collection is 0.211 meters.

Table 9. Average accuracy values for occupied monuments

Occupied Monuments	***meters***	feet
Avg. Northing accuracy	0.007	0.023
Avg. Easting accuracy	0.031	0.102
Avg. RMSE for positional accuracy	0.211	0.692

Vertical accuracy analysis of delivered lidar data consisted of differencing collected GCP data and the lidar Digital Elevation Models (DEM) to expose offsets. These offsets were used to produce a mean vertical error and vertical RMSE value for the entire delivered data set. Project specifications list the maximum acceptable mean vertical offset to be 0.20 meters (0.65 feet) and the maximum vertical RSME to not exceed 0.0925 meters (0.303 feet).

A total of 1489 measured GCP's were obtained in the Crooked Ochoco project area and were compared with the lidar elevation grids (Figure 12). The data delivered to DOGAMI was found to have a mean vertical offset of 0.007 meters (0.025 feet) and an RMSE value of 0.055 meters (0.181 feet). Offset values ranged from -0.207 meters to 0.169 meters (Table 10 and Figure 13 and 14).

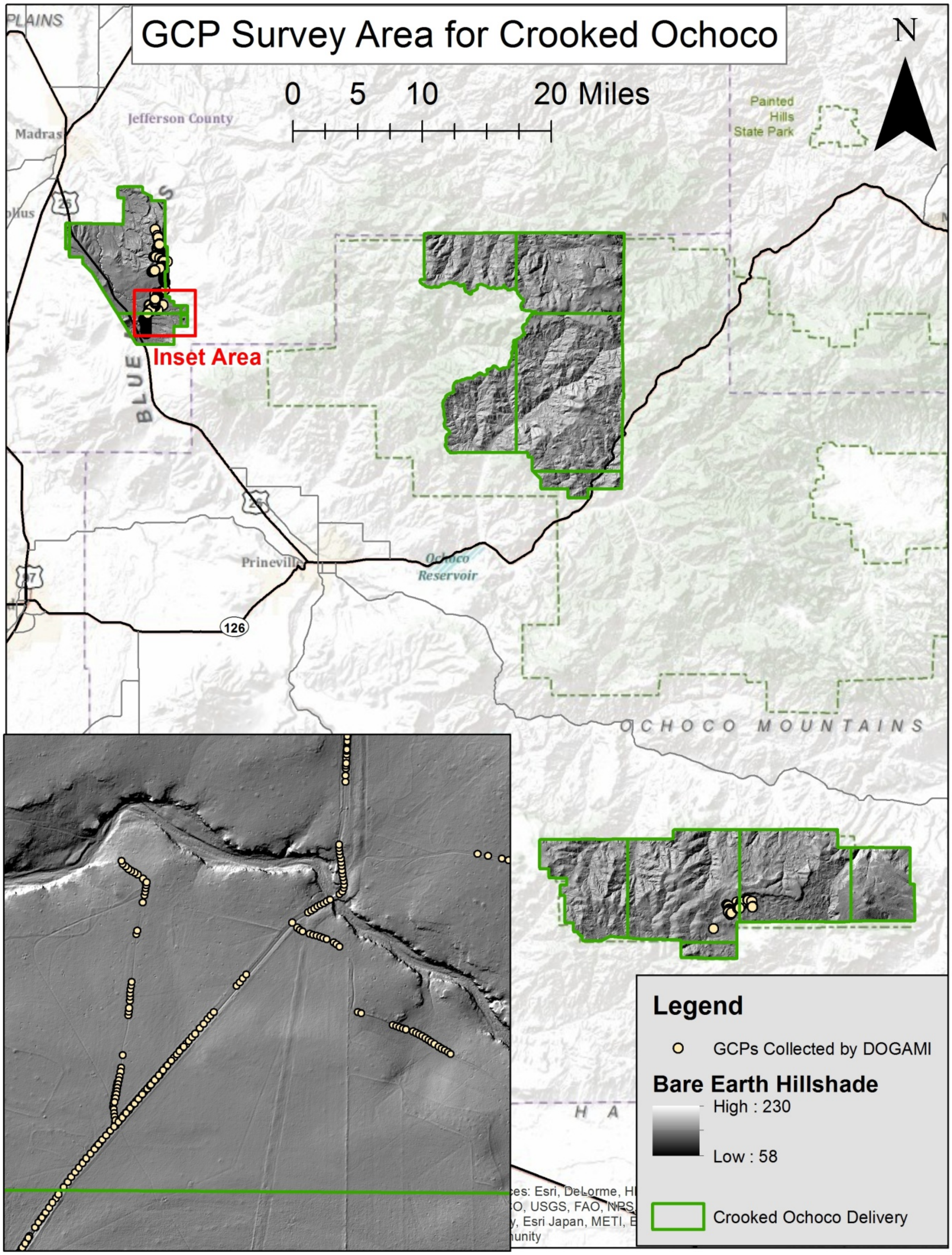

Figure 12. Locations of GCPs surveyed by DOGAMI staff. Data was used to test absolute accuracy for the Crooked Ochoco project areas.

Table 10. Descriptive Statistics for absolute value vertical offsets.

Descriptive Statistics	Meters	Feet
Mean	0.007	0.025
Standard Error	0.001	0.005
Standard Deviation	0.055	0.179
Range	0.375	1.231
Minimum	-0.207	-0.678
Maximum	0.169	0.553
RMSE	0.055	0.181

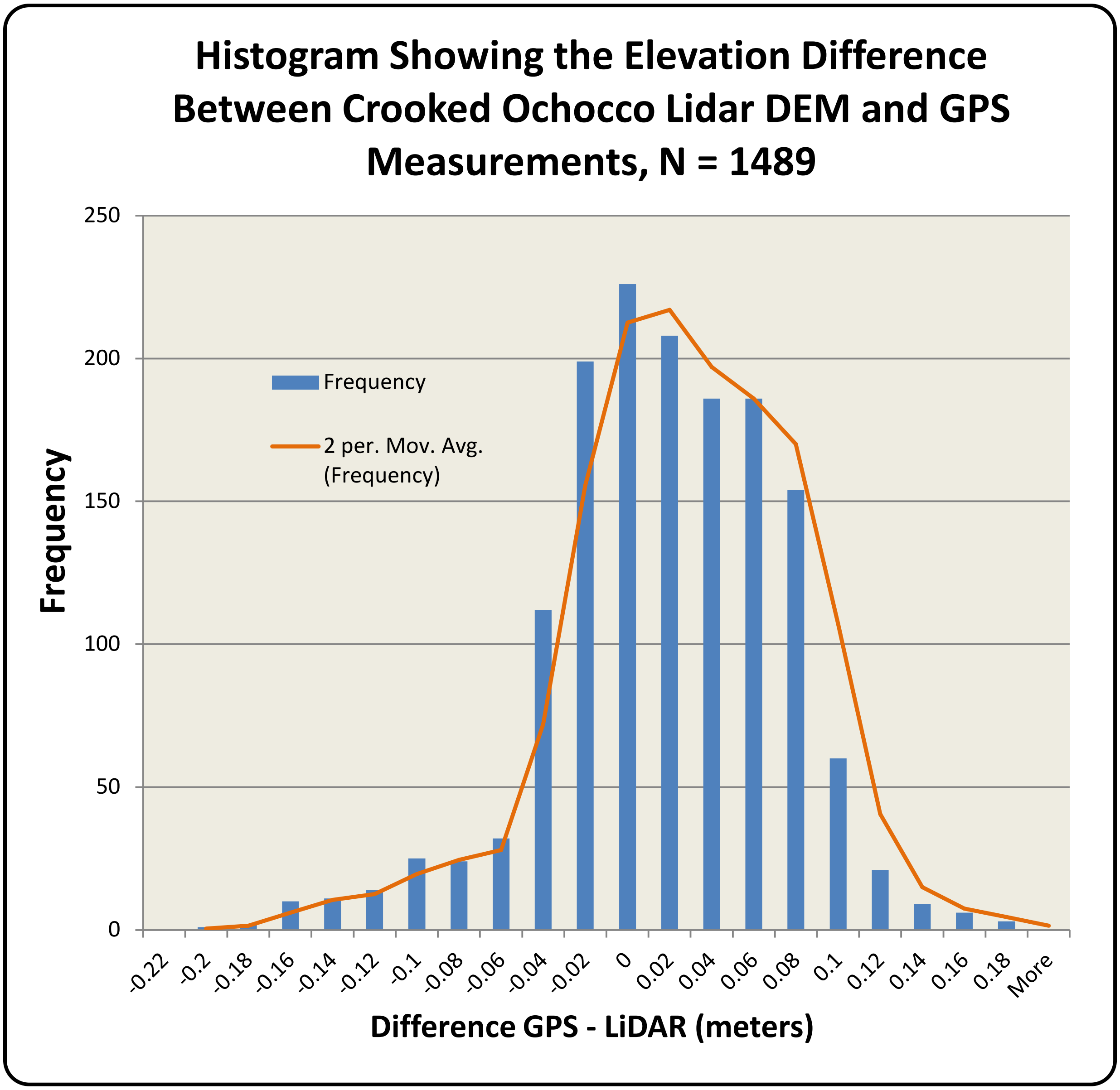

Figure 13. Histogram of absolute vertical accuracy in meters.

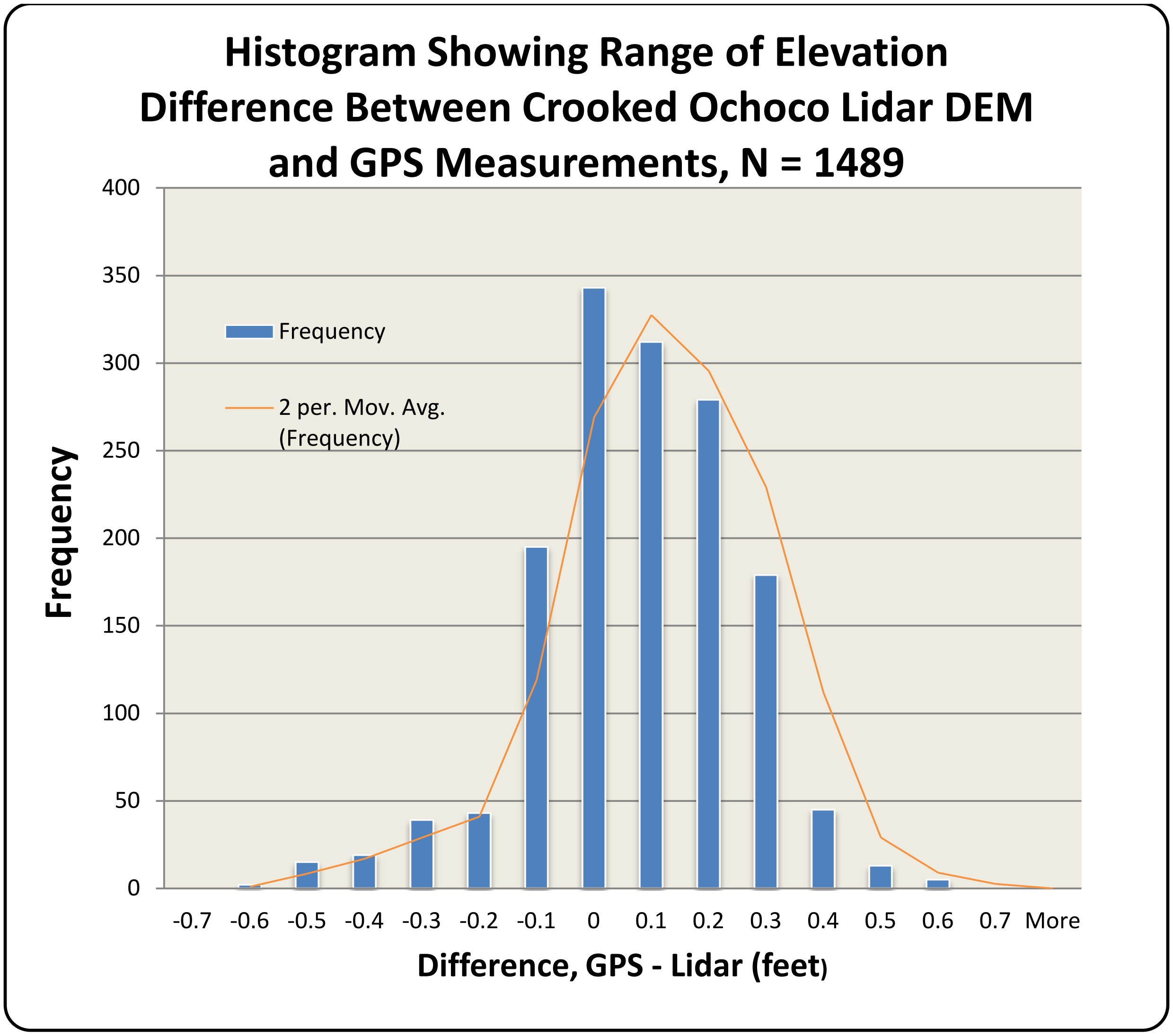

Figure 14. Histogram of absolute vertical accuracy in feet.

Metadata Analysis

Metadata analysis compared the structure of the metadata file against FGDC standards. Metadata content was reviewed by using a visual check in Esri ArcCatalog as well as analysis by the USGS Geospatial Metadata validation service: http://geo-nsdi.er.usgs.gov/validation/. 5 metadata files, representing 25% of all metadata associated with this delivery were viewed by DOGAMI staff. No structure issues were found when validating the compliance of metadata to FGDC standards.

Acceptance

The data described in this report meet and exceed project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of November 7th, 2014. Quality control has confirmed that all delivered data is within specification and function correctly. Quality Assurance has evaluated acquisition parameters to confirm that data was collected within project design scope. Consistency analysis has concluded that all data contains flight line to flight line vertical offset less than the threshold of 0.15 meters as specified in the agreement. The vendor has adequately responded to all fixable errors identified as part of the visual analysis. Perceived grid errors identified by DOGAMI that were found to be false have been documented by the vendor and explained to the satisfaction of DOGAMI reviewers. Absolute accuracy analysis of the data has concluded that absolute vertical error of lidar data is less than the specified tolerance of 0.20 meters as specified in the data standards agreement.

Approval Signatures

[signature] Date: 11/13/2014

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

[signature] Date: 11/13/2014

Jacob Edwards
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