Department of Geology & Mineral Industries
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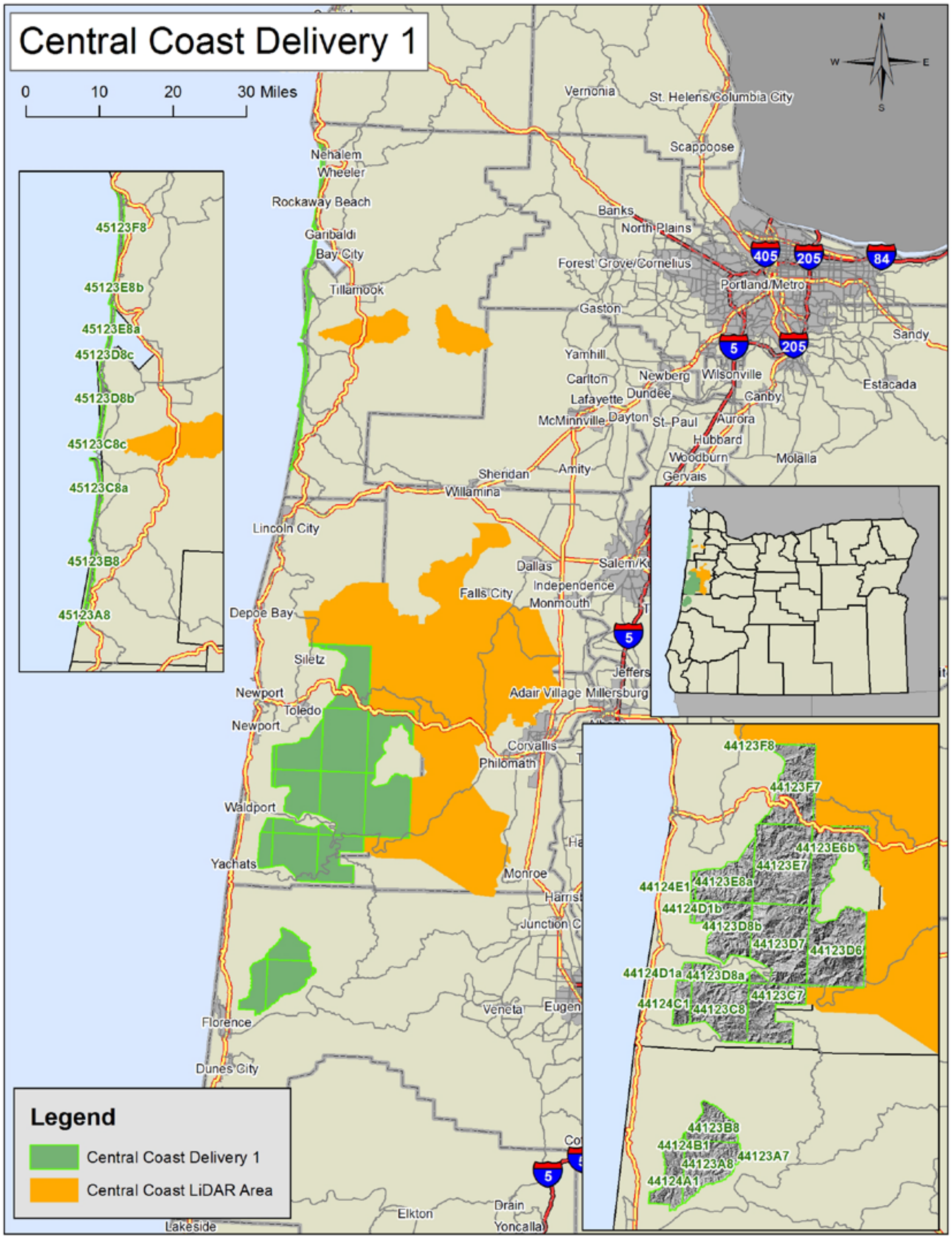
Portland, OR 97232

Central Coast LIDAR Project, 2011 – Delivery 1 QC Analysis

LIDAR QC Report – February 17th, 2012



Map featuring Central Coast Delivery 1 data extent.

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences to collect high resolution lidar topographic data for multiple areas within the State of Oregon. 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 (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is 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 Central Coast Lidar Project – Delivery 1 products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 1 was independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. All data were inventoried for completeness and data were checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual checks are 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 data vendor performs quality control analysis 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 errors are found, data must be resubmitted.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for Central Coast Delivery 1 area were collected between September 2nd and November 22, 2011. Total area of delivered data totals 447.42 square miles. Delivery 1 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point data is delivered in LAS binary format for ground

classified returns as well as the entire lidar point cloud. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Central Coast Survey collection area (Figure 1):

Delivery 1: 44123a7, 44123a8, 44123b8, 44123c7, 44123c8, 44123d6, 44123d7, 44123d8, 44123e6, 44123e7, 44123e8, 44123f7, 44123f8, 44124a1, 44124b1, 44124c1, 44124d1, 44124e1, 45123a8, 45123b8, 45123c8, 45123d8, 45123e8, 45123f8

FINAL Delivery	Resolution	Format	Tiling	
Bare Earth DEMs	3ft	grid	quad	x
Highest Hit DEMs	3ft	grid	quad	x
Trajectory files	1 sec	ascii (TXYZRPH)	flight	x
Intensity Images	1.5ft	tif	100th quad	x
LAS	8pts/m^2	las	100th quad	x
Ground Returns	N/A	las	100th quad	x
Ground Density Raster	3ft	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		dxf or dgn	project	x

Table 1. Deliverable Checklist

All data associated with this delivery has been loaded and viewed to ensure completeness. Raster imagery such as elevation grids and intensity geotifs have been viewed in ArcMap, cross referenced with the delivery area. Las files have been loaded into Terrasolid software to ensure completeness and readability.

Deliverable Descriptions: (All data projected in Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement 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. Data is projected in UTM zone 10, NAD83 (HARN).

- LAS: 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).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- RTK Point Data: Ground GPS Survey data used to correct raw lidar point cloud for vertical offsets.
- Delivery Area Shapefile: Geometry file depicting the geospatial area associated with deliverables.
- Report: Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.

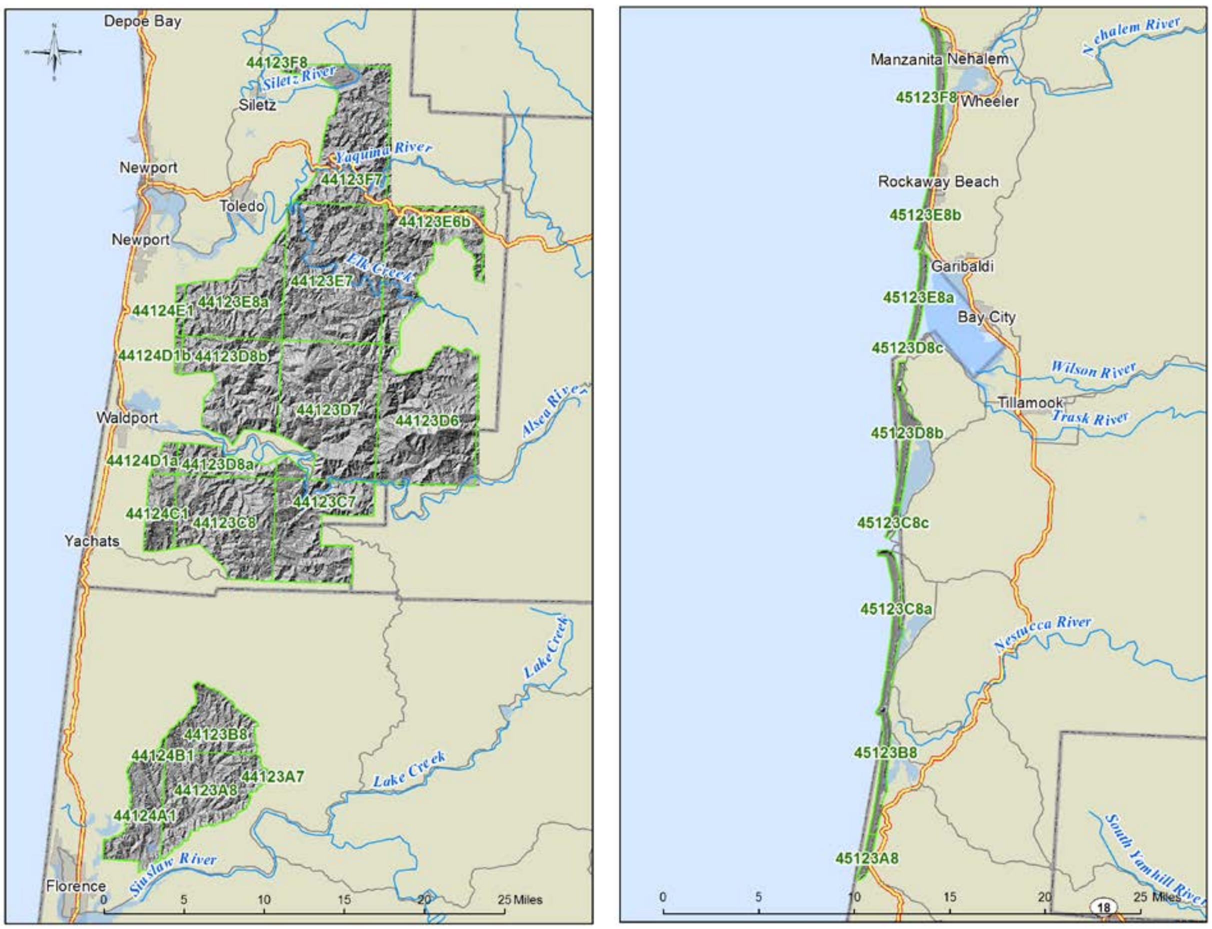


Figure 1. Delivery 1 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Central Coast Survey collection area.

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 2434 delivered data tiles were examined for vertical offset between flight lines. Data tiles with less than 1000 points were not used in analysis. Selection of tiles aimed to evenly sample the delivered spatial extent of data. Each tile measured 750 x 750 meters in size. The average number of points used for flight line comparison was 1,420,464 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meters 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. A total of 846 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	2434
# of Flight Line Sections	846
Avg # of Points	1,420,464
Avg. Magnitude Z error (m)	0.053

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.053	0.173
Standard Error	0.000	0.001
Standard Deviation	0.012	0.041
Sample Variance	0.000	0.001
Range	0.083	0.272
Minimum	0.025	0.082
Maximum	0.108	0.354

Table 2b. Descriptive Statistics for Magnitude Z Error.

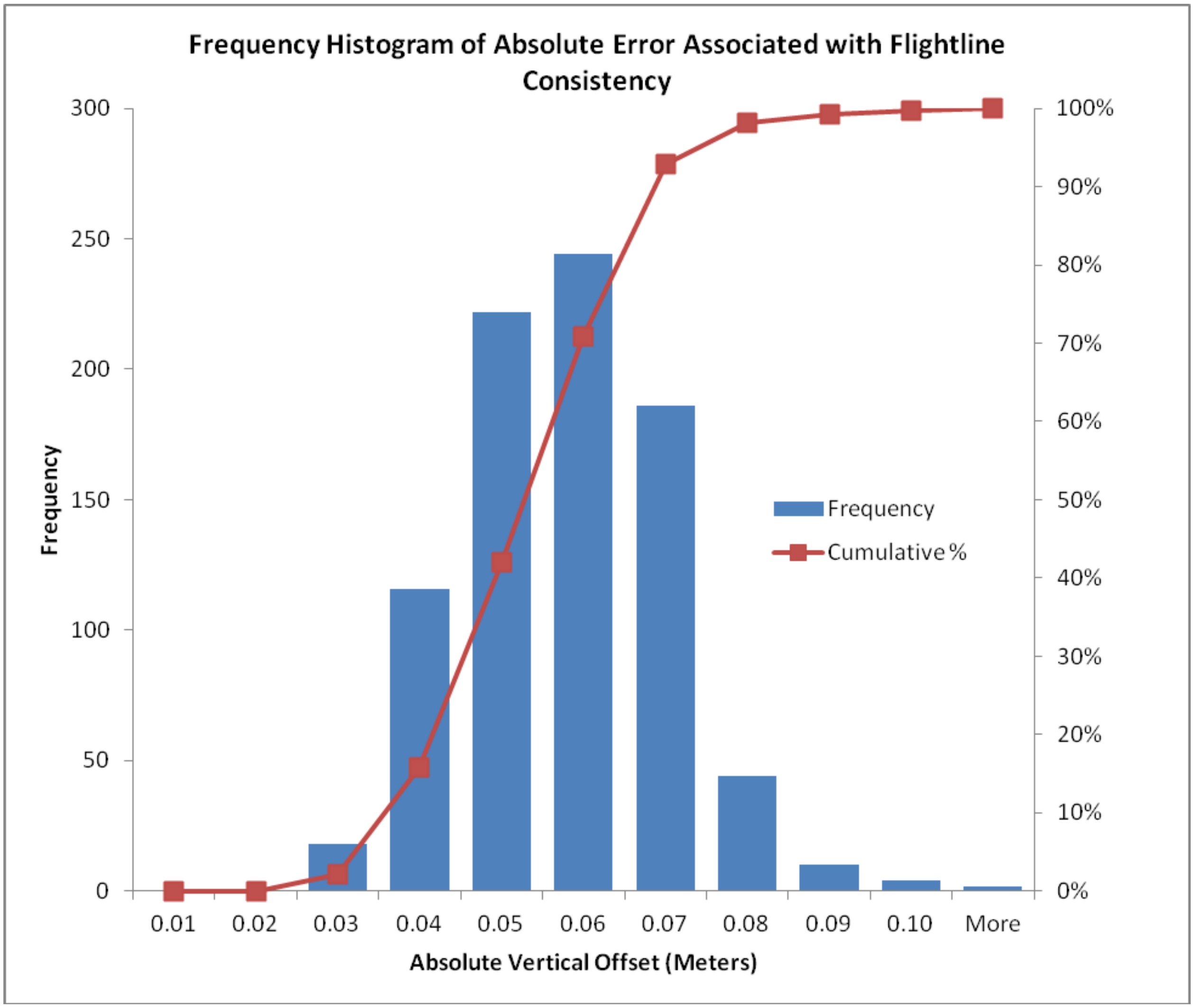


Figure 2.

Results of the consistency analysis found the average flight line offset to be 0.053 meters with a maximum error of 0.108m (Table 2b). Distribution of error showed 92% of all error was less than 0.07m and 99% less than 0.09m (Figure 2). These results show that all data are within tolerances of data consistency according to contract agreement.

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 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning 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 3). 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 5). Birds (high points) typically occur where the laser comes into contact with atmospherics[1].

Errors located during visual analysis were digitized for spatial reference and stored in ESRI shapefile format. Each feature was assigned an ID value and commented to describe the nature of the observed error. The shapefile was delivered to the vendor for locating and fixing errors. Upon receiving the observed error locations, the vendor performed an analysis to conclude whether the error was valid. For all valid errors found, the vendor has reprocessed the data to accommodate fixes. For all observed errors that are found to be false, the vendor has produced an image documenting the nature of the feature in grid and point data format. A readme file was created explaining all edits performed. Corrected data was delivered to DOGAMI. This data were examined to ensure edits were made, and visually inspected for completeness, then combined into the original delivery.

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

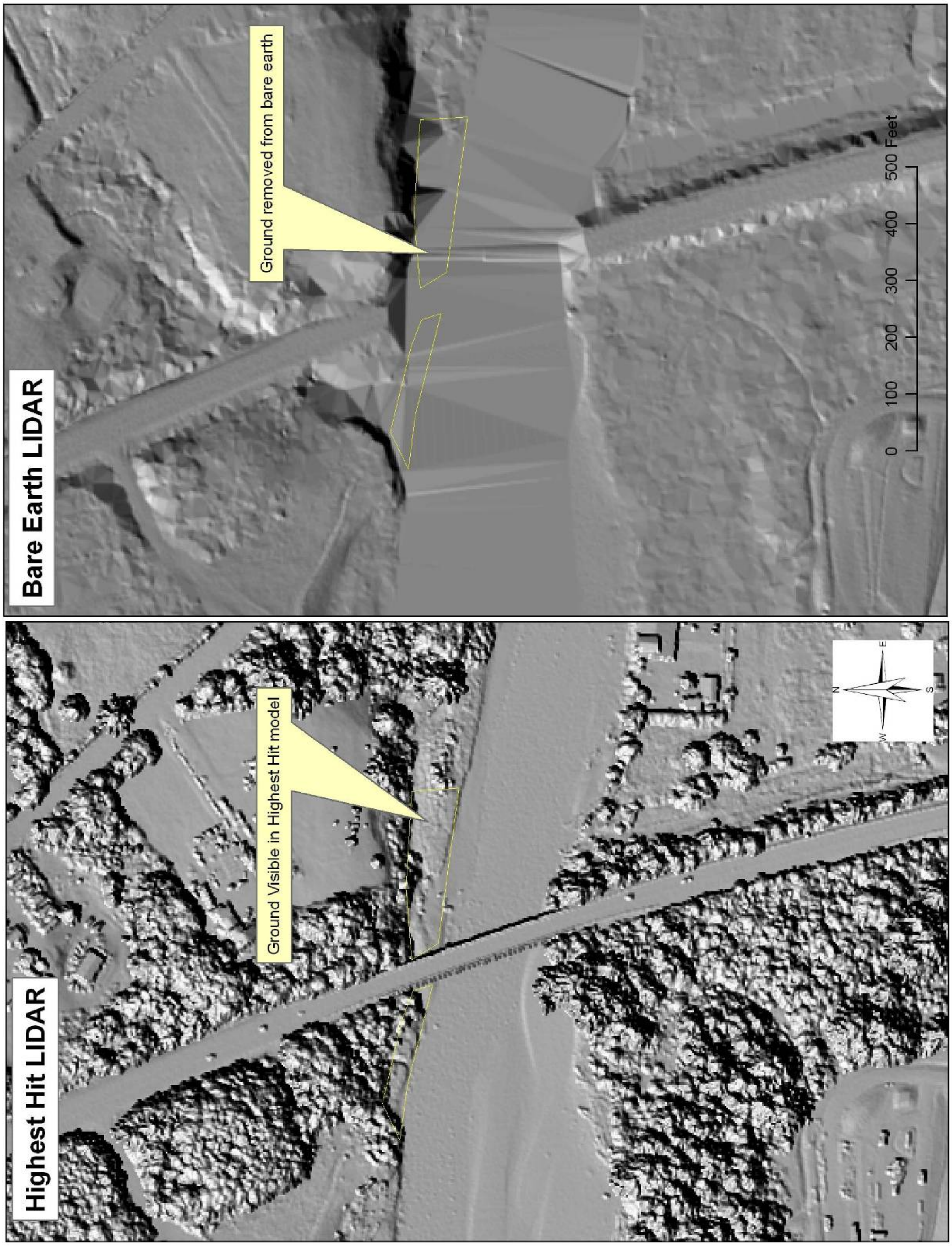


Figure 3. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

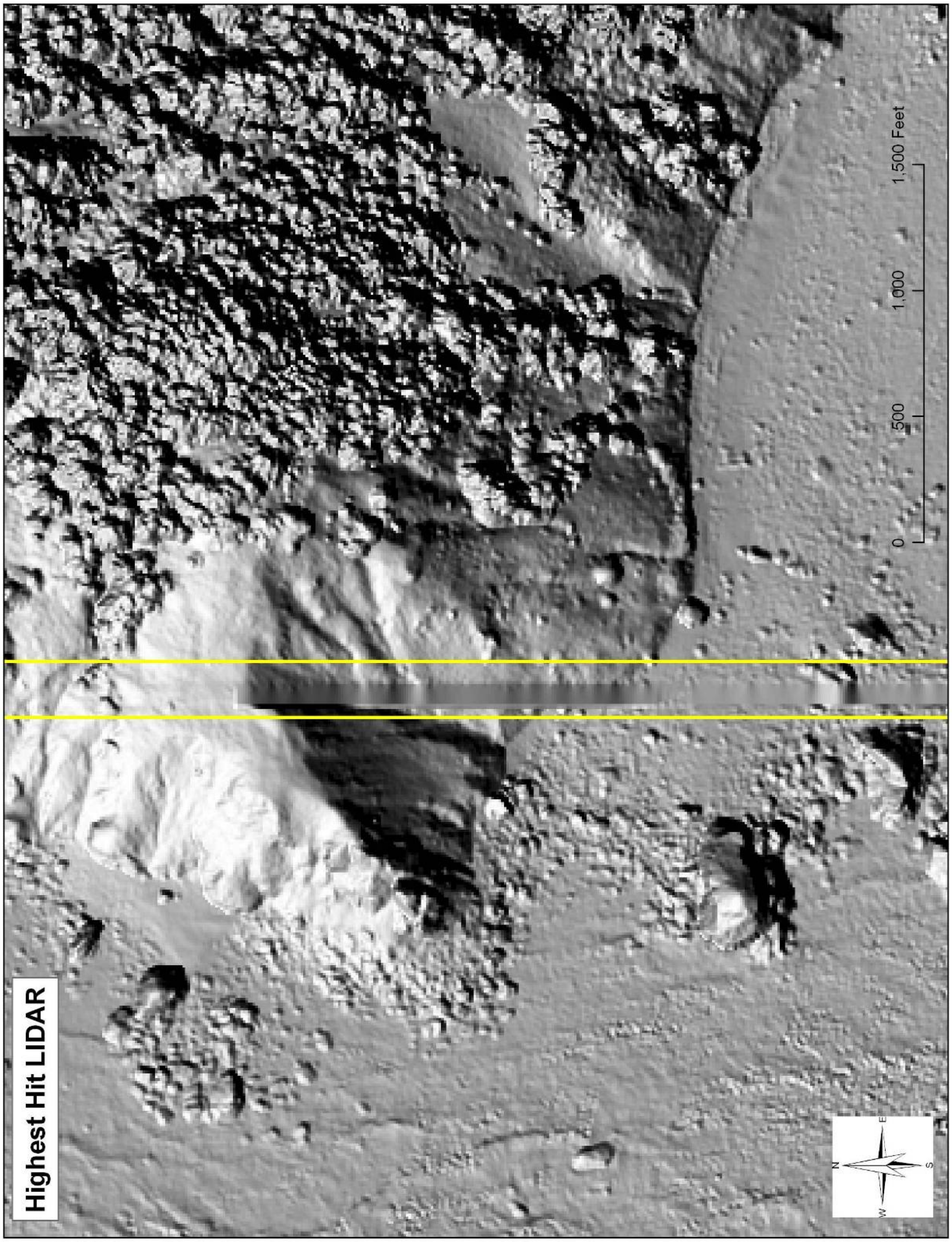


Figure 4. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

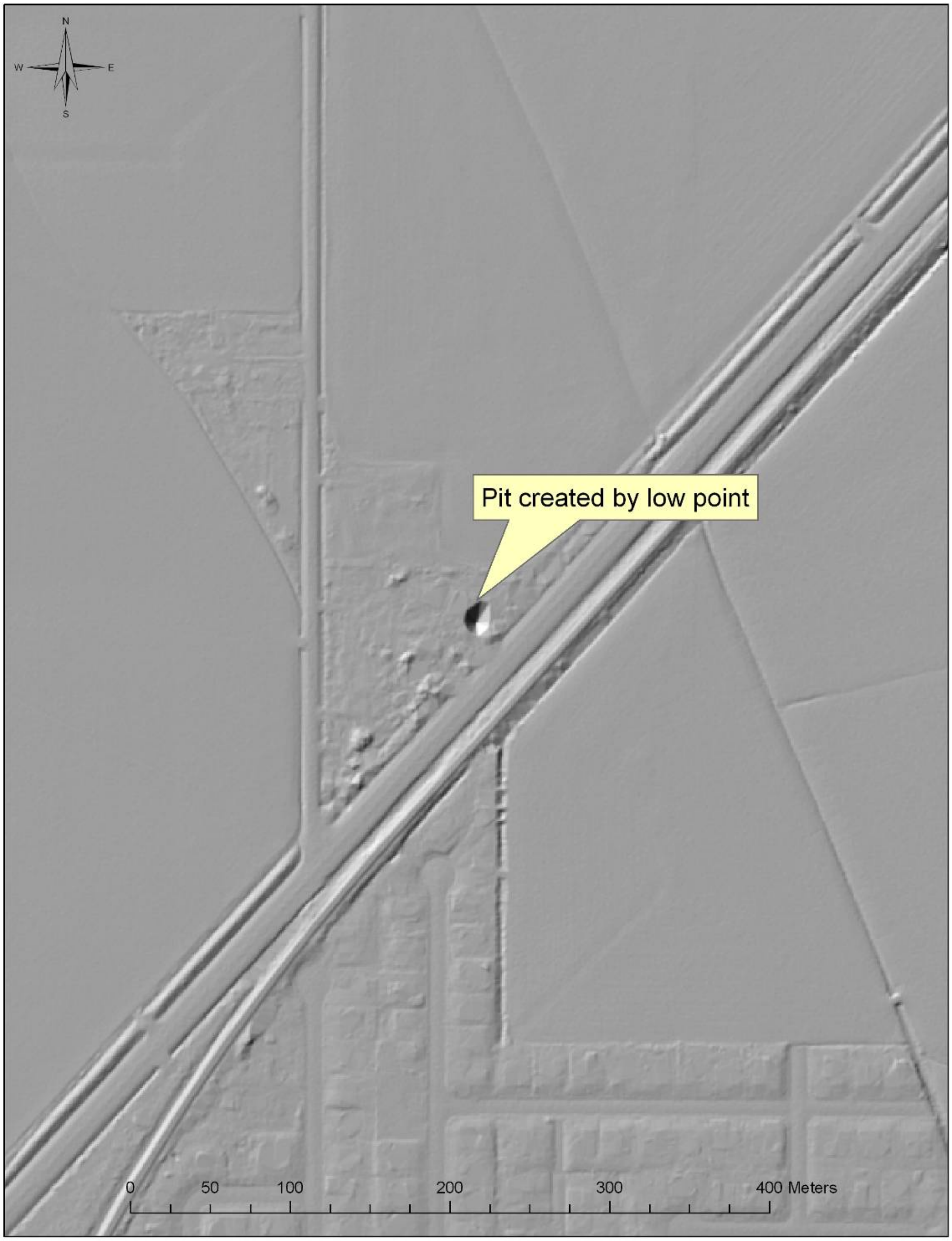


Figure 5. Example of "Pit" caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point elevation is assigned to the grid value

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 5) 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 2.0 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.

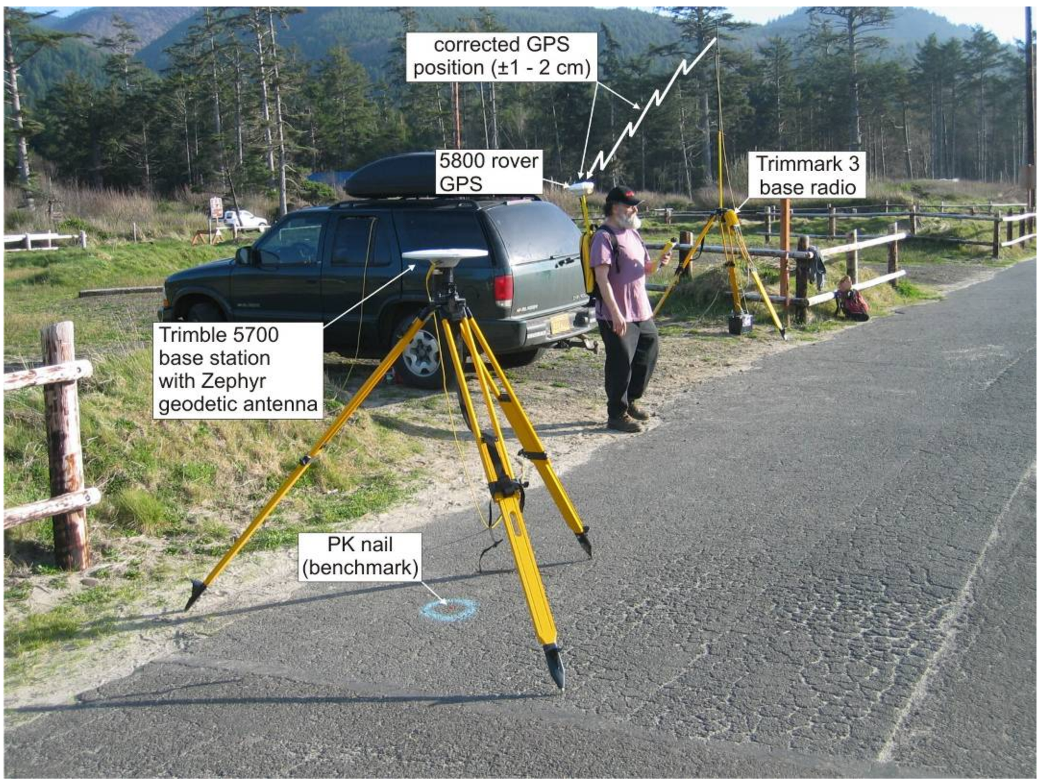


Figure 5. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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 epics).

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.

Vertical accuracy analysis consisted of differencing control data and the delivered 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).

A total of 1137 measured GCP's were obtained in the Delivery 1 region and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of 0.022 meters (0.073 feet) and an RMSE value of 0.068 meters (0.224 ft). Offset values ranged from -0.154 to 0.173meters (Table 3 and Figure 7).

Horizontal accuracies were not specified in agreement since true horizontal accuracy is regarded as a product of the lidar ground foot print. Lidar is referenced to co-acquired GPS base station data that has accuracies far greater than the value of the lidar foot print. The ground footprint is equal to $1/3333^{rd}$ of above ground flying height. Survey altitude for this acquisition was targeted at 900 meters yielding a ground foot print of 0.27 meters. This value exceeds the typical accuracy value of ground control used to reference the lidar data (<0.01m). Project specifications require the lidar foot print to fall within 0.15 and 0.40 meters.

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 vender and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

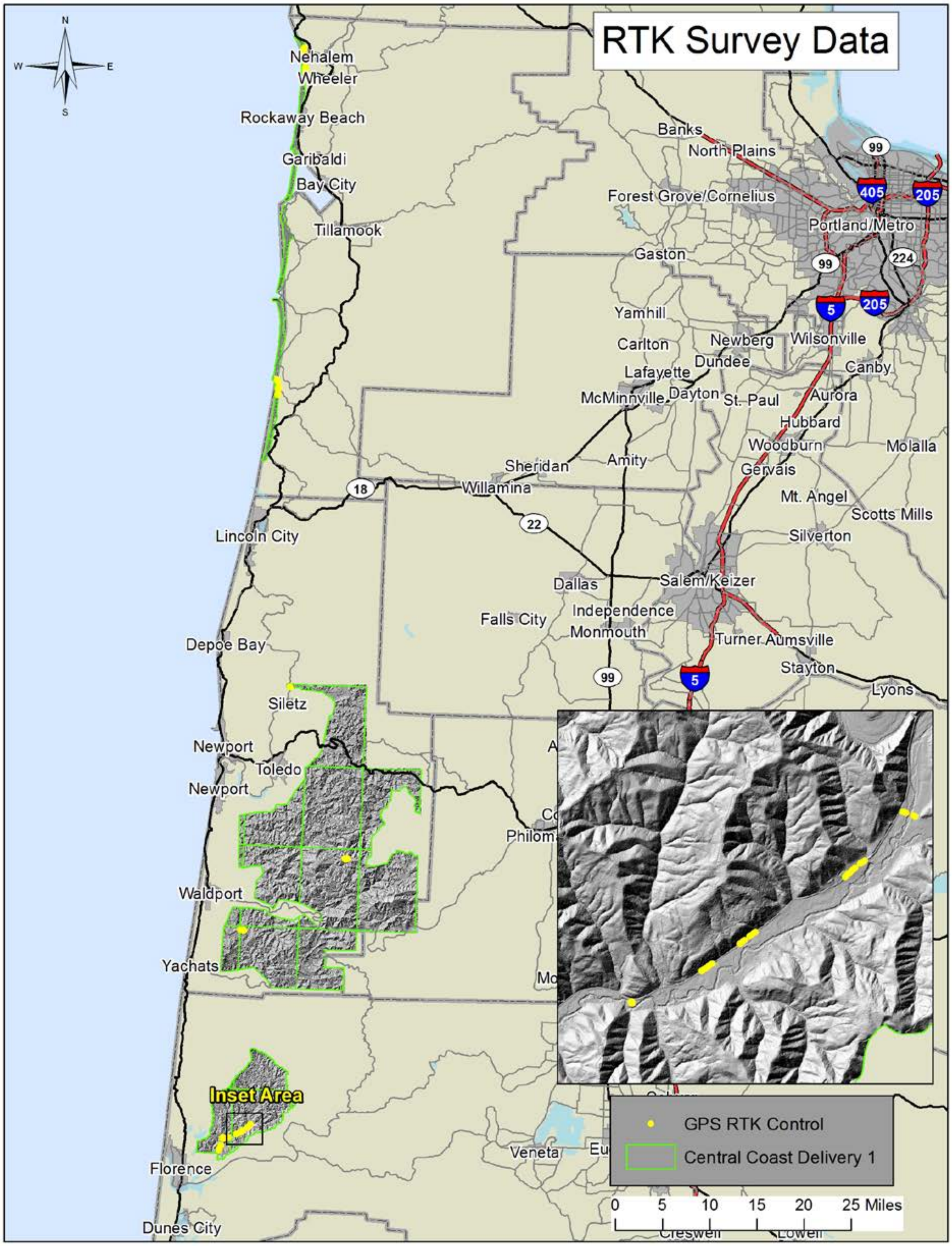


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Central Coast lidar survey within the Delivery 1 extent.

	Meters	*Feet*
Mean	0.022	0.073
Standard Error	0.002	0.006
Standard Deviation	0.065	0.212
Range	0.327	1.072
Minimum	-0.154	-0.505
Maximum	0.173	0.567
RMSE	0.068	0.224

Table 3. Descriptive Statistics for absolute value vertical offsets.

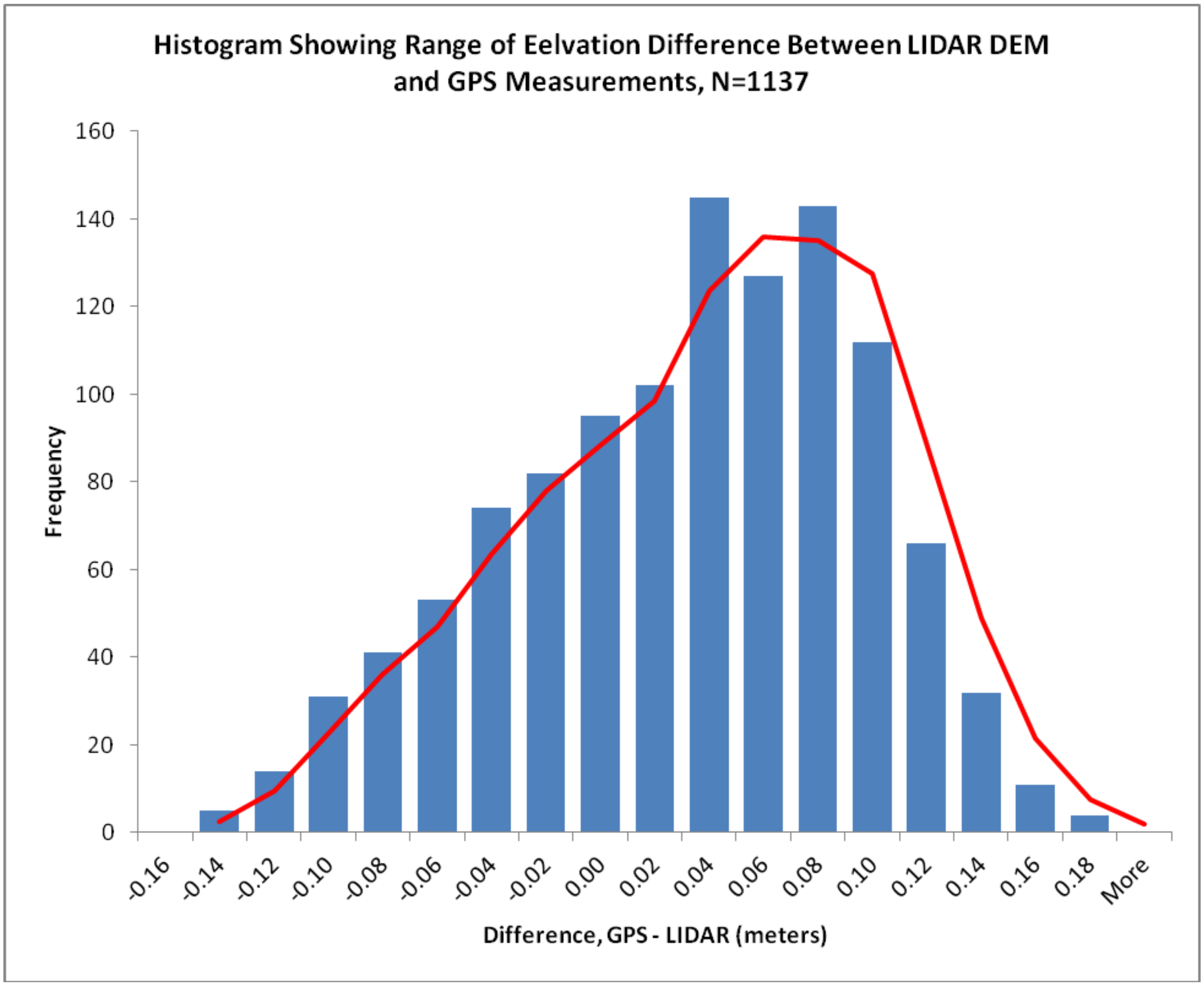


Figure 7. Histogram of absolute vertical accuracy

Acceptance

The data described in this report meets and exceeds project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of February 17th, 2012. 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 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

______________________________ Date: 4/16/2012

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

______________________________ Date: 4/16/2012

John English
Lidar Database Coordinator – Department of Geology & Mineral Industries

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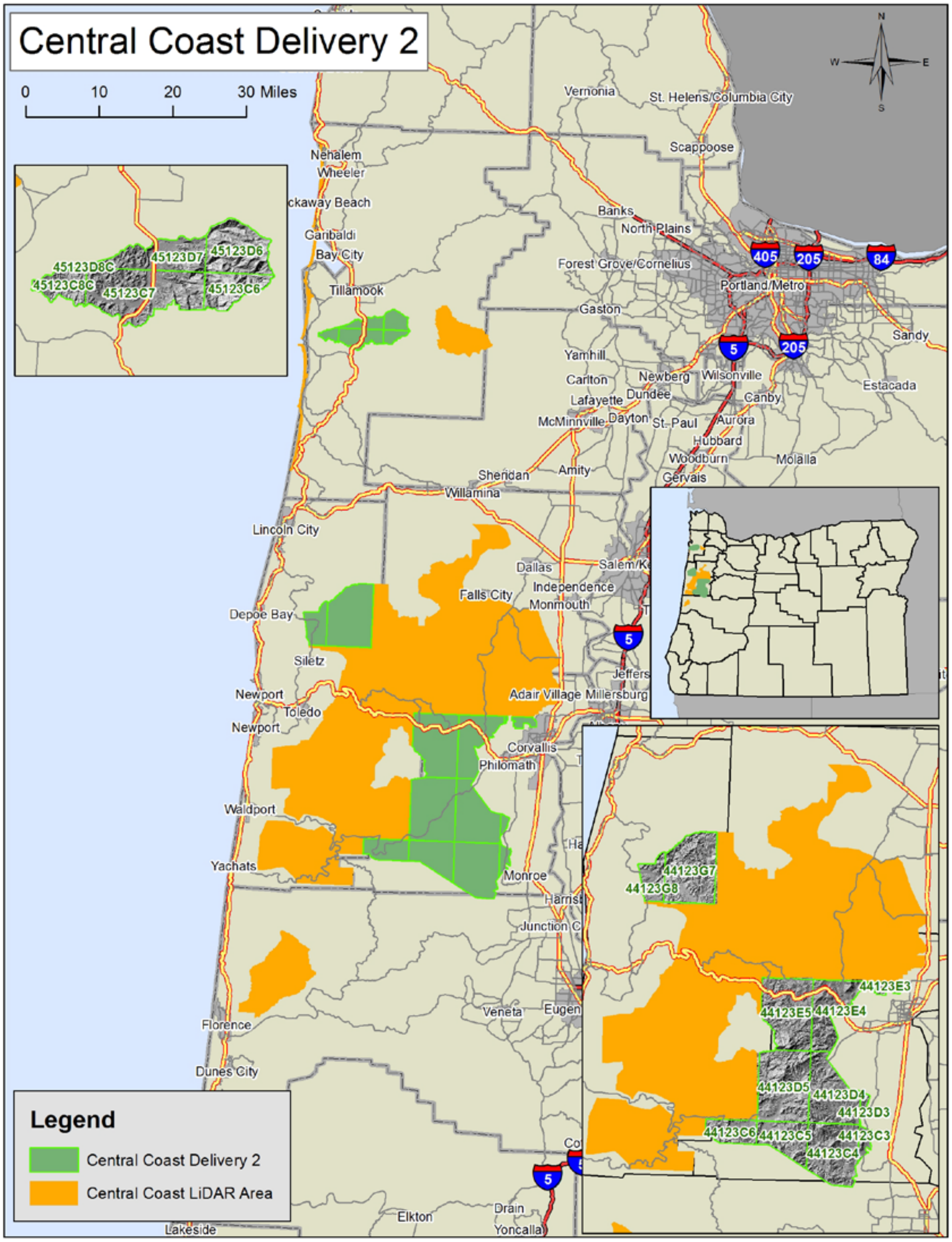
Central Coast LIDAR Project, 2012 – Delivery 2 QC Analysis

LIDAR QC Report – April 16th, 2012



Map featuring Central Coast Delivery 2 data extent.

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences to collect high resolution lidar topographic data for multiple areas within the State of Oregon. 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 (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is 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 Central Coast Lidar Project – Delivery 2 products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 2 was independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. All data were inventoried for completeness and data were checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual checks are 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 data vendor performs quality control analysis 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 errors are found, data must be resubmitted.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for Central Coast Delivery 2 area were collected between September 4th, 2011 and February 3rd, 2012. Total area of delivered data totals 366.82 square miles. Delivery 2 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point data is delivered in LAS binary format for ground

classified returns as well as the entire lidar point cloud. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Central Coast Survey collection area (Figure 1):

Delivery 2: 44123c3, 44123c4, 44123c5, 44123c6, 44123d3, 44123d4, 44123d5, 44123e3, 44123e4, 44123e5, 44123g7, 44123g8, 45123c6, 45123c7, 45123c8, 45123d6, 45123d7, 45123d8

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LAS	8pts/m^2	las	100th quad	x
Ground Returns	N/A	las	100th quad	x
Ground Density Raster	3ft	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		dxf or dgn	project	x

Table 1. Deliverable Checklist

All data associated with this delivery has been loaded and viewed to ensure completeness. Raster imagery such as elevation grids and intensity geotifs have been viewed in ArcMap, cross referenced with the delivery area. Las files have been loaded into Terrasolid software to ensure completeness and readability.

Deliverable Descriptions: (All data projected in Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement 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. Data is projected in UTM zone 10, NAD83 (HARN).

- LAS: 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).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
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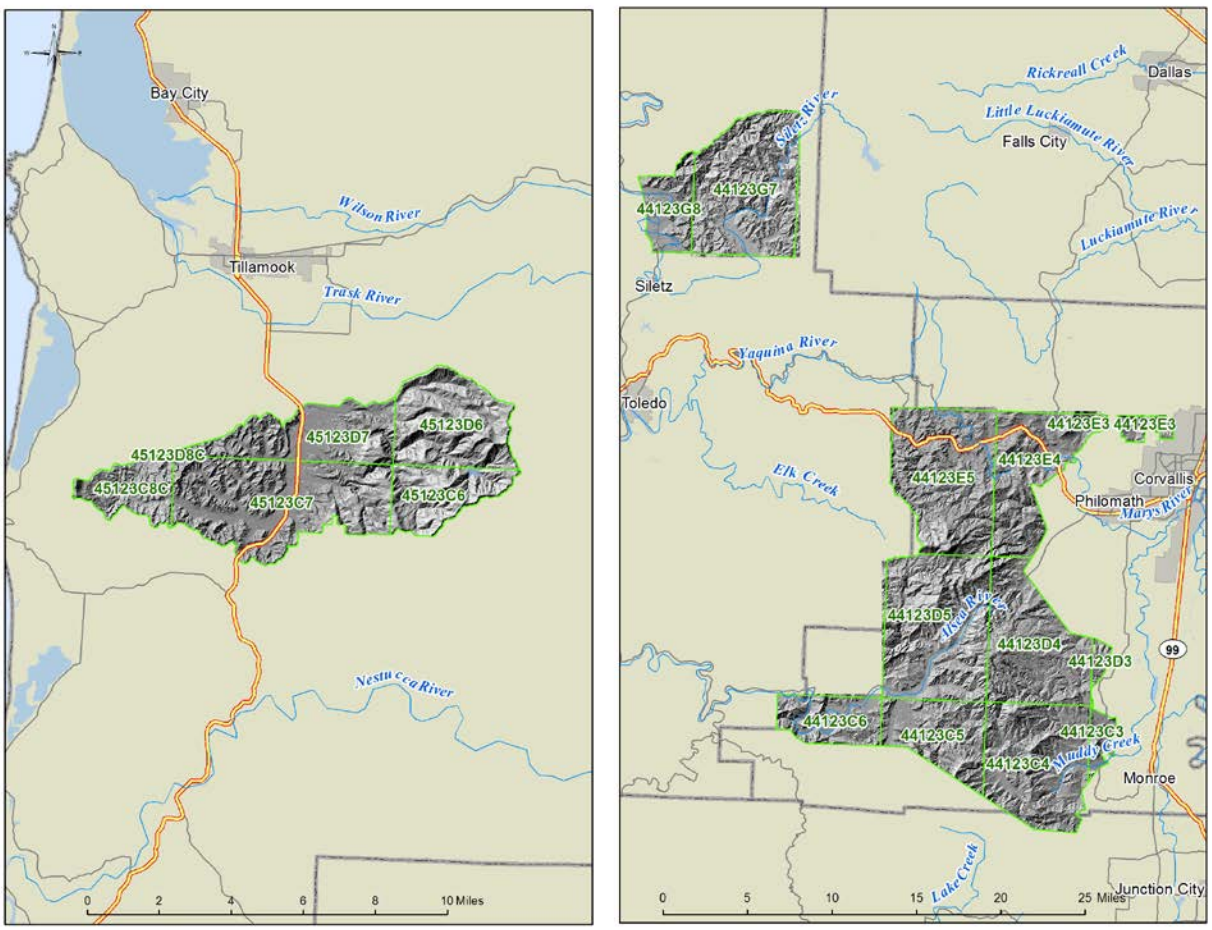

Figure 1. Delivery 2 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Central Coast Survey collection area.

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 1900 delivered data tiles were examined for vertical offset between flight lines. Data tiles with less than 1000 points were not used in analysis. Selection of tiles aimed to evenly sample the delivered spatial extent of data. Each tile measured 750 x 750 meters in size. The average number of points used for flight line comparison was 3,705,061 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meters 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. A total of 494 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	1900
# of Flight Line Sections	494
Avg # of Points	3,705,061
Avg. Magnitude Z error (m)	0.049

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.049	0.161
Standard Error	0.001	0.002
Standard Deviation	0.013	0.042
Sample Variance	0.000	0.001
Range	0.066	0.216
Minimum	0.028	0.090
Maximum	0.093	0.306

Table 2b. Descriptive Statistics for Magnitude Z Error.

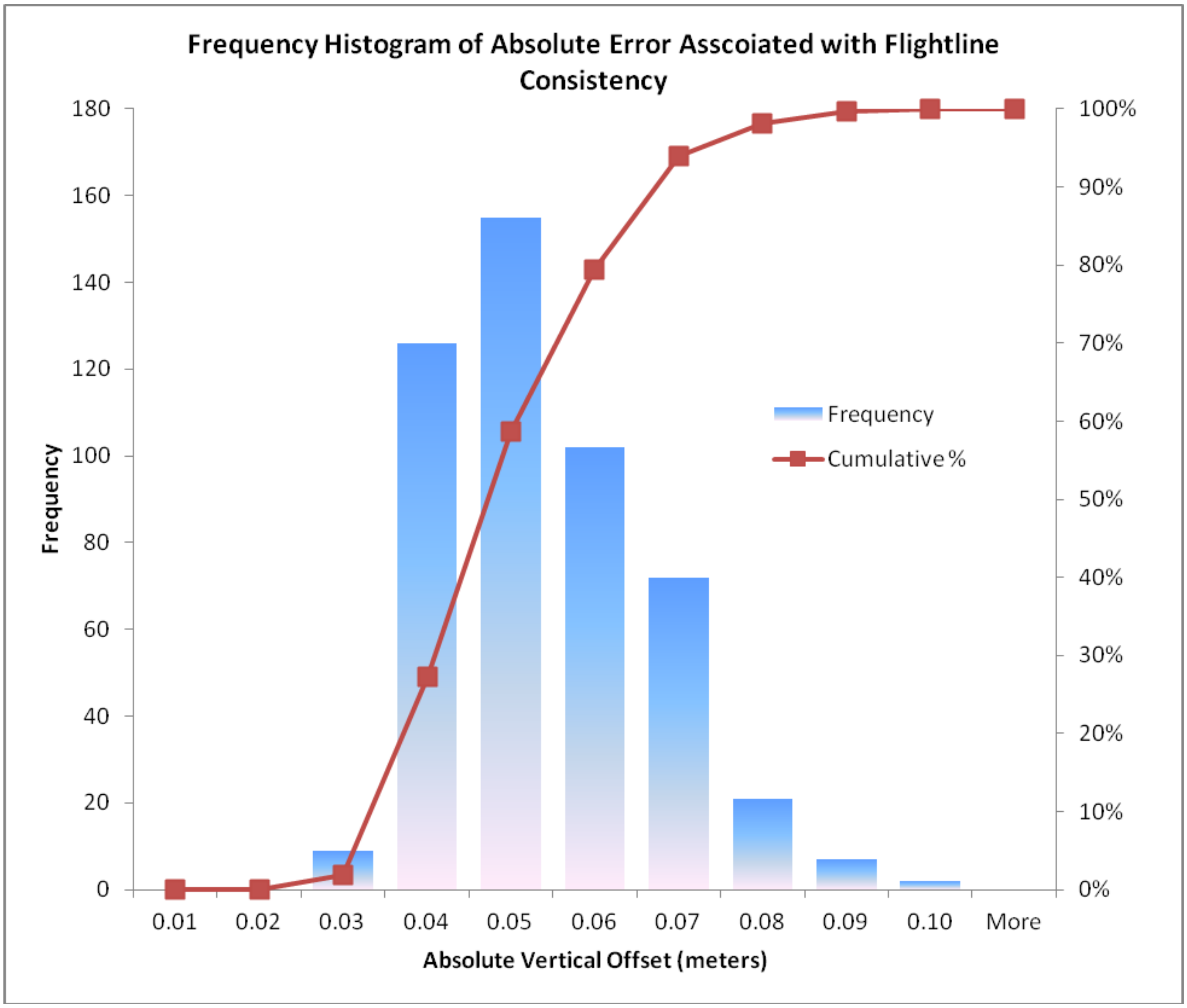

Figure 2.

Results of the consistency analysis found the average flight line offset to be 0.049 meters with a maximum error of 0.093m (Table 2b). Distribution of error showed 93% of all error was less than 0.07m and 99% less than 0.09m (Figure 2). These results show that all data are within tolerances of data consistency according to contract agreement.

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 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand

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Errors located during visual analysis were digitized for spatial reference and stored in ESRI shapefile format. Each feature was assigned an ID value and commented to describe the nature of the observed error. The shapefile was delivered to the vendor for locating and fixing errors. Upon receiving the observed error locations, the vendor performed an analysis to conclude whether the error was valid. For all valid errors found, the vendor has reprocessed the data to accommodate fixes. For all observed errors that are found to be false, the vendor has produced an image documenting the nature of the feature in grid and point data format. A readme file was created explaining all edits performed. Corrected data was delivered to DOGAMI. This data were examined to ensure edits were made, and visually inspected for completeness, then combined into the original delivery.

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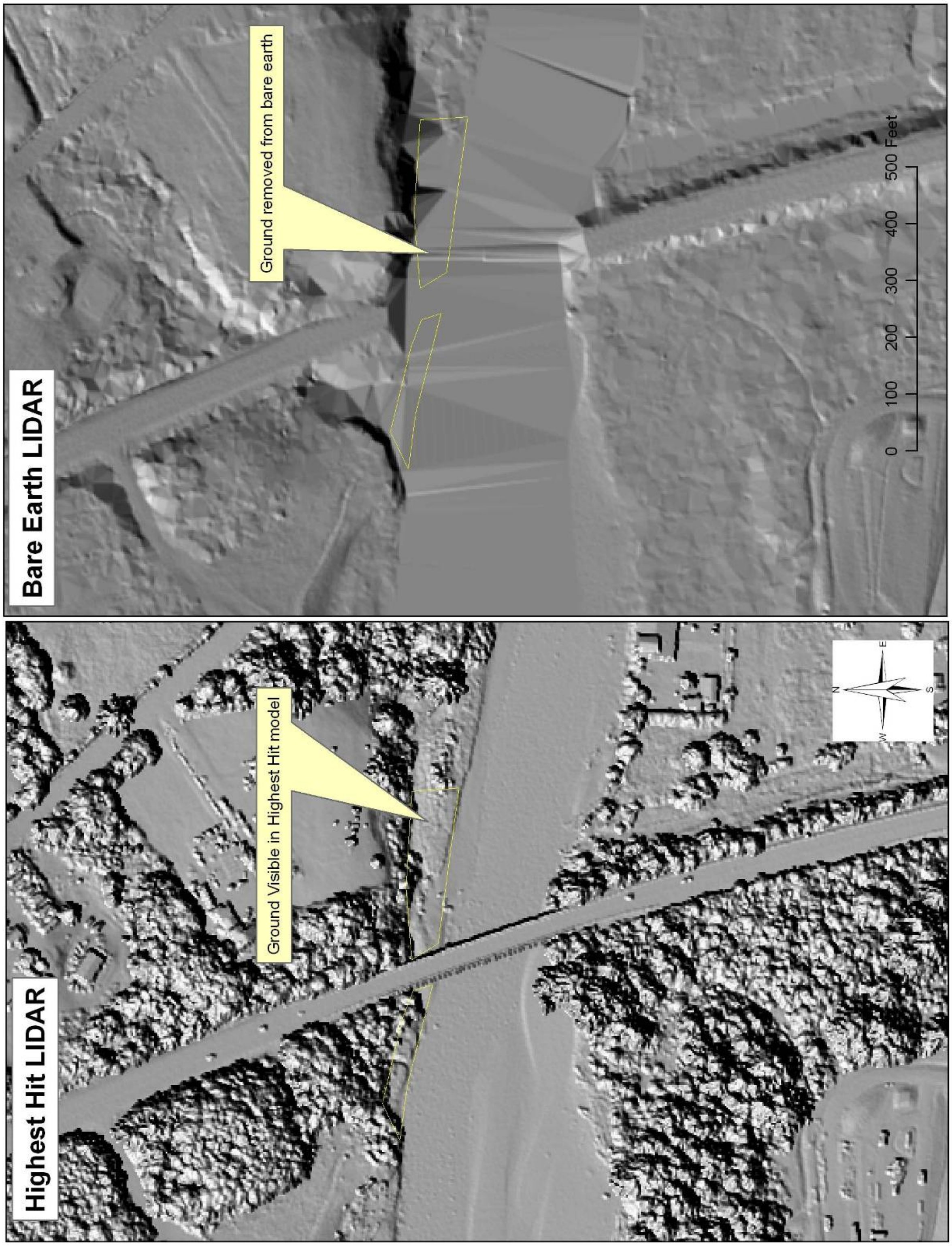


Figure 3. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

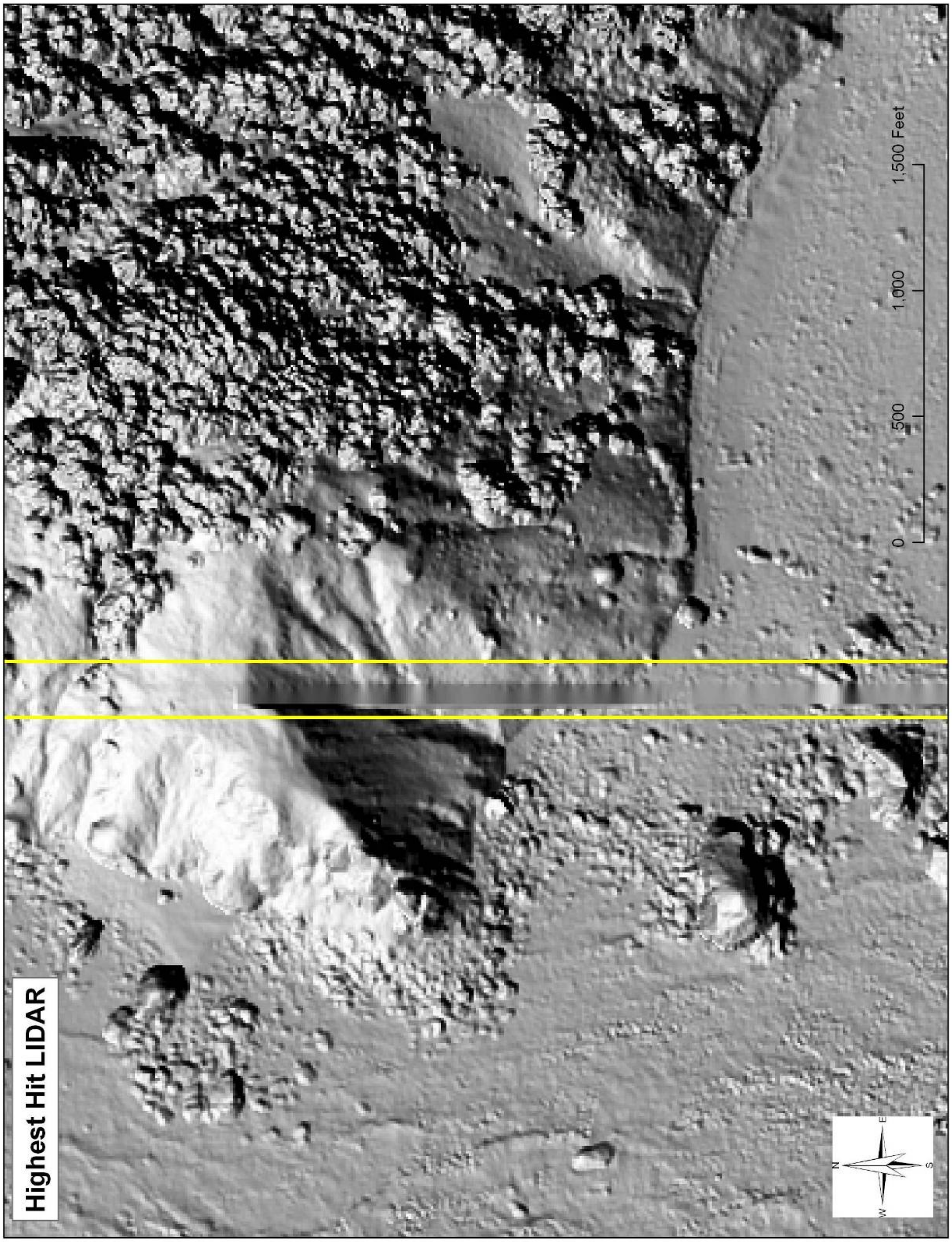


Figure 4. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

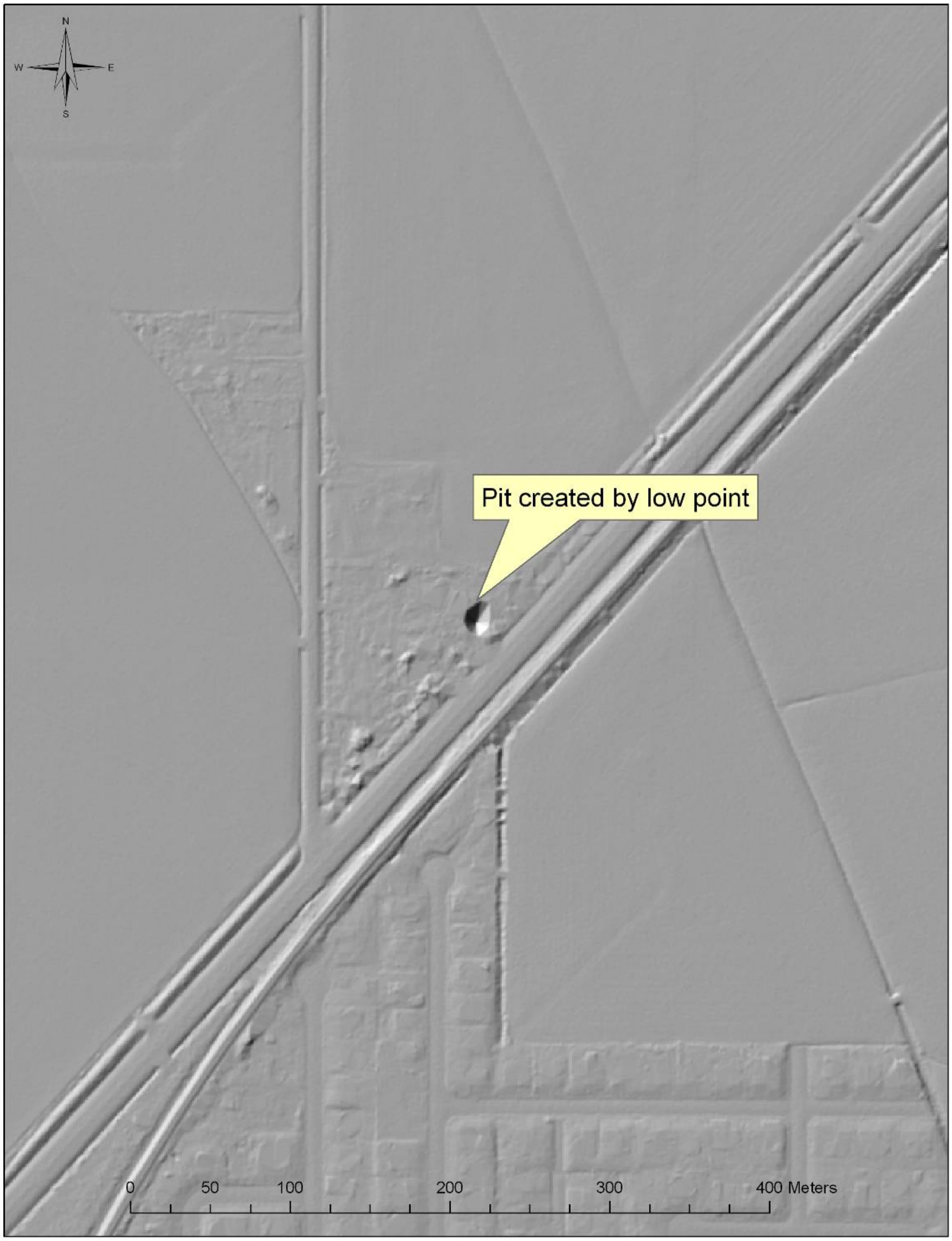


Figure 5. Example of “Pit” caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point elevation is assigned to the grid value

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 5) 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 2.0 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.

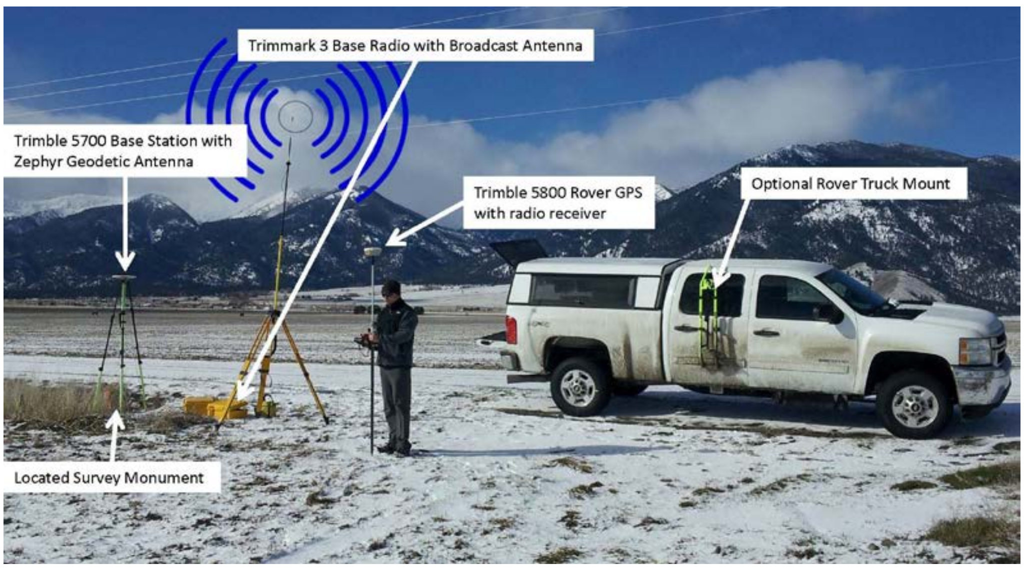


Figure 5. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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.

Vertical accuracy analysis consisted of differencing control data and the delivered 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).

A total of 2348 measured GCP's were obtained in the Delivery 2 region and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of -0.005 meters (-0.018 feet) and an RMSE value of 0.072 meters (0.238 ft). Offset values ranged from -0.208 to 0.228 meters (Table 3 and Figure 7).

Horizontal accuracies were not specified in agreement since true horizontal accuracy is regarded as a product of the lidar ground foot print. Lidar is referenced to co-acquired GPS base station data that has accuracies far greater than the value of the lidar foot print. The ground footprint is equal to 1/3333rd of above ground flying height. Survey altitude for this acquisition was targeted at 900 meters yielding a ground foot print of 0.27 meters. This value exceeds the typical accuracy value of ground control used to reference the lidar data (<0.01m). Project specifications require the lidar foot print to fall within 0.15 and 0.40 meters.

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 vender and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

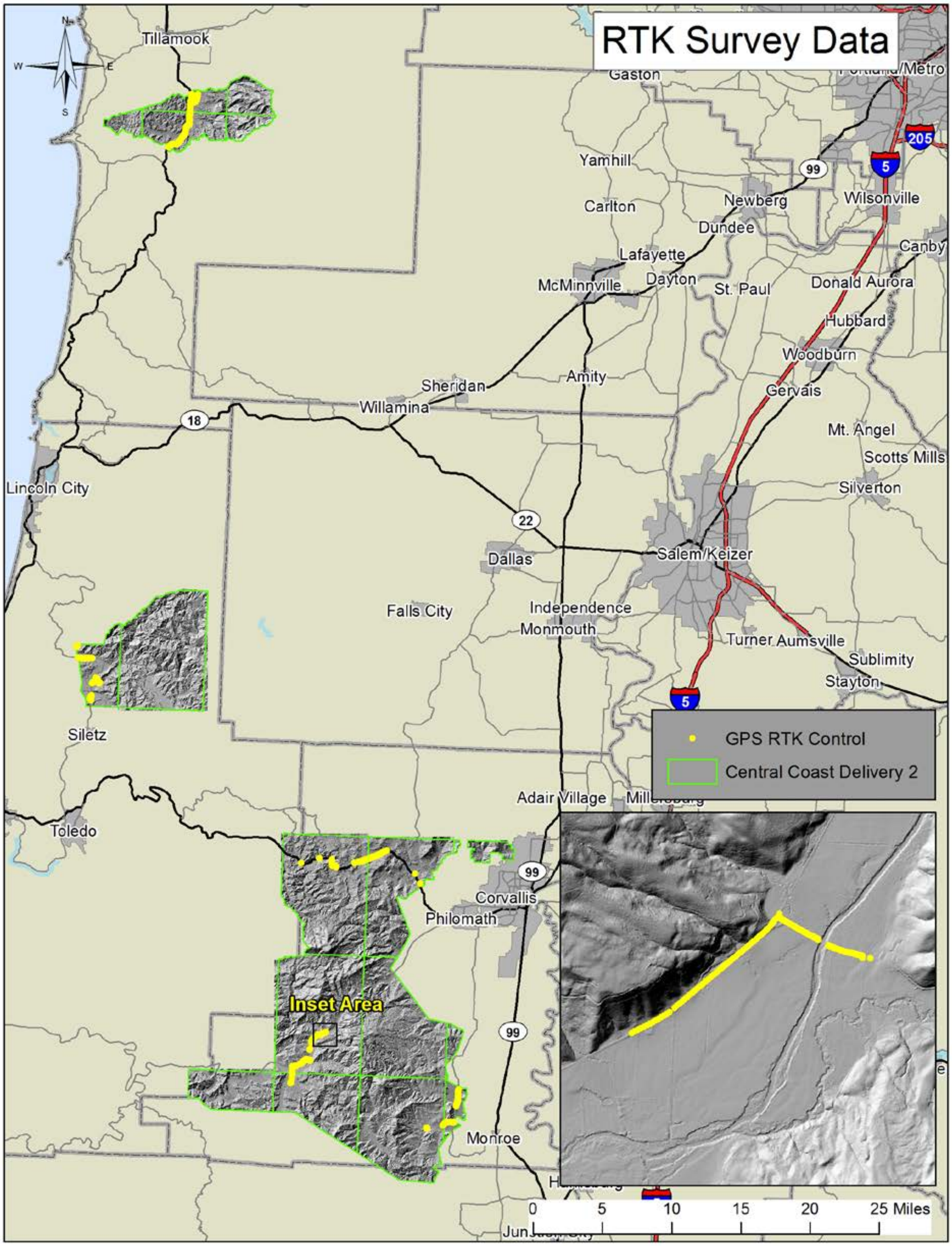


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Central Coast lidar survey within the Delivery 2 extent.

	Meters	*Feet*
Mean	-0.005	-0.018
Standard Error	0.001	0.005
Standard Deviation	0.072	0.237
Range	0.436	1.431
Minimum	-0.208	-0.683
Maximum	0.228	0.748
RMSE	0.072	0.238

Table 3. Descriptive Statistics for absolute value vertical offsets.

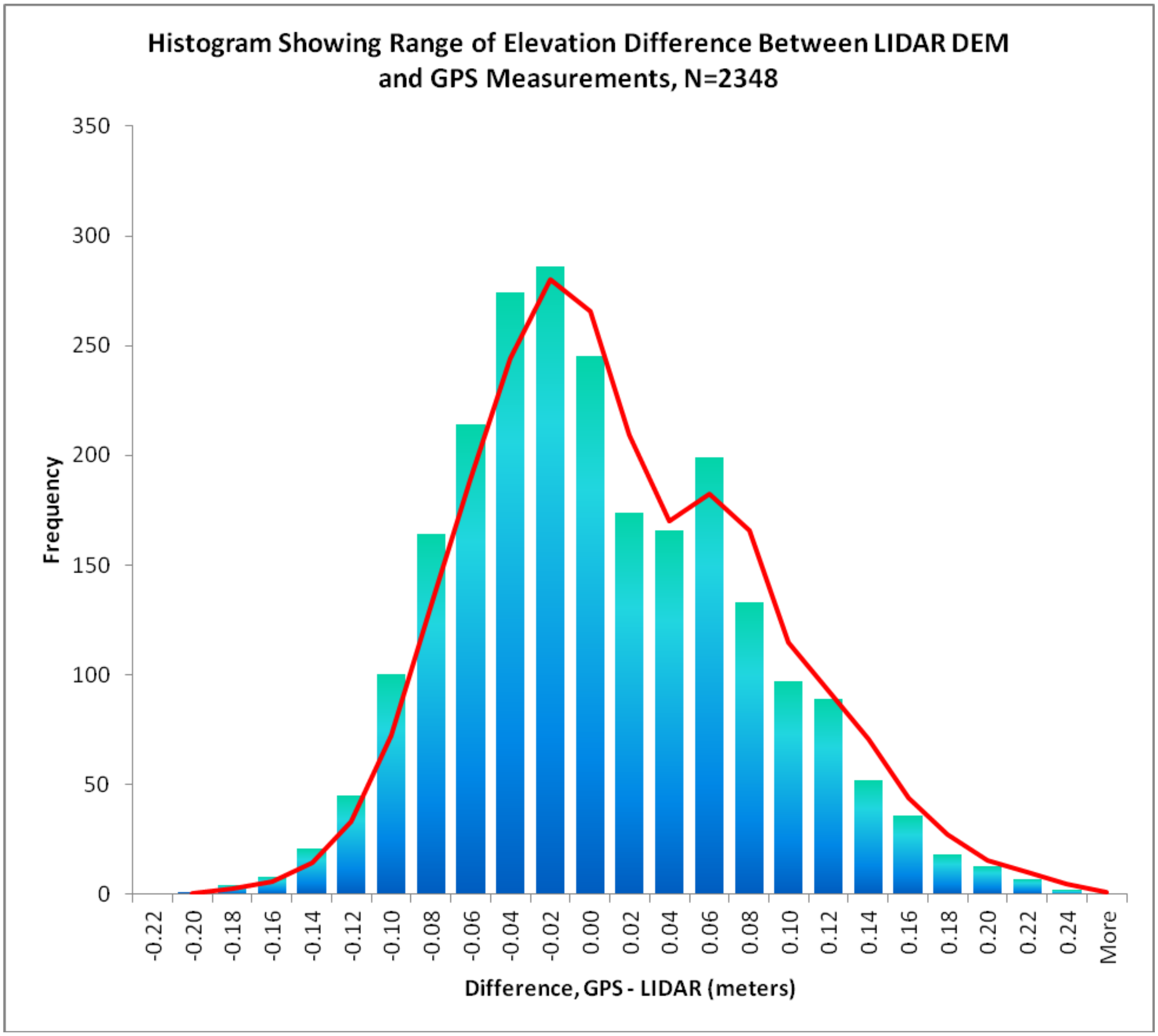


Figure 7. Histogram of absolute vertical accuracy

Acceptance

The data described in this report meets and exceeds project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of April 16th, 2012. 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 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

________________________ Date: 4/16/2012

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

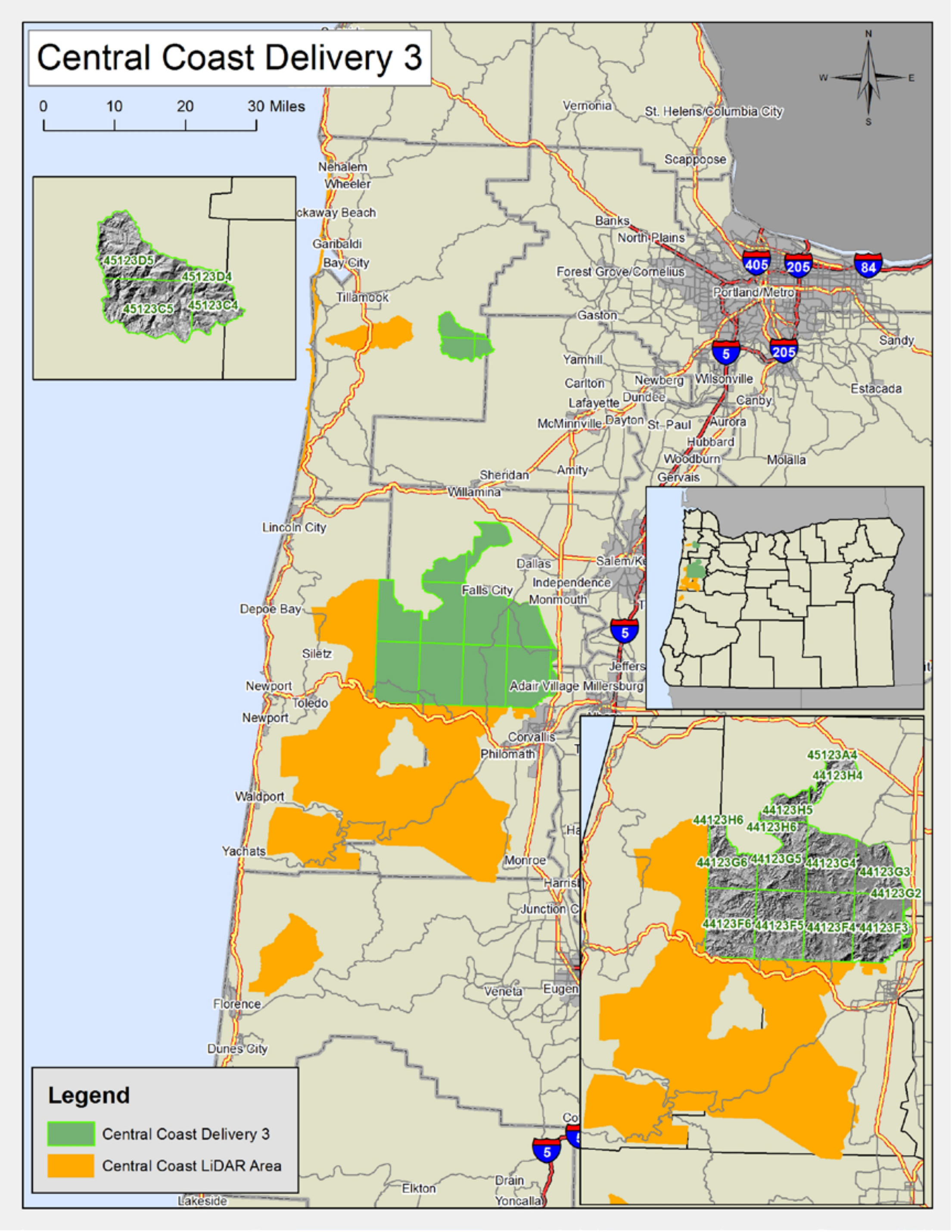
________________________ Date: 4/16/2012

John English
Lidar Database Coordinator – Department of Geology & Mineral Industries

Department of Geology & Mineral Industries
800 NE Oregon St, Suite 965
Portland, OR 97232

Central Coast LIDAR Project, 2012 – Delivery 3 QC Analysis

LIDAR QC Report – August 16th, 2012



Map featuring Central Coast Delivery 3 data extent.

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences to collect high resolution lidar topographic data for multiple areas within the State of Oregon. 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 (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is 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 Central Coast Lidar Project – Delivery 3 products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 3 was independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. All data were inventoried for completeness and data were checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual checks are 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 data vendor performs quality control analysis 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 errors are found, data must be resubmitted.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for Central Coast Delivery 3 area were collected between September 4th, 2011 and May 11th, 2012. Total area of delivered data totals 445.55 square miles. Delivery 3 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point data is delivered in LAS binary format for ground

classified returns as well as the entire lidar point cloud. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Central Coast Survey collection area (Figure 1):

Delivery 3: 44123f2, 44123f3, 44123f4, 44123f5, 44123f6, 44123g2, 44123g3, 44123g4, 44123g5, 44123g6, 44123h3, 44123h4, 44123h5, 44123h6, 45123a4, 45123c4, 45123c5, 45123d4, 45123d5

FINAL Delivery	Resolution	Format	Tiling	
Bare Earth DEMs	3ft	grid	quad	x
Highest Hit DEMs	3ft	grid	quad	x
Trajectory files	1 sec	ascii (TXYZRPH)	flight	x
Intensity Images	1.5ft	tif	100th quad	x
LAS	8pts/m^2	las	100th quad	x
Ground Returns	N/A	las	100th quad	x
Ground Density Raster	3ft	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		dxf or dgn	project	x

Table 1. Deliverable Checklist

All data associated with this delivery has been loaded and viewed to ensure completeness. Raster imagery such as elevation grids and intensity geotifs have been viewed in ArcMap, cross referenced with the delivery area. Las files have been loaded into Terrasolid software to ensure completeness and readability.

Deliverable Descriptions: (All data projected in Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement 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. Data is projected in UTM zone 10, NAD83 (HARN).

- LAS: 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).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- RTK Point Data: Ground GPS Survey data used to correct raw lidar point cloud for vertical offsets.
- Delivery Area Shapefile: Geometry file depicting the geospatial area associated with deliverables.
- Report: Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.

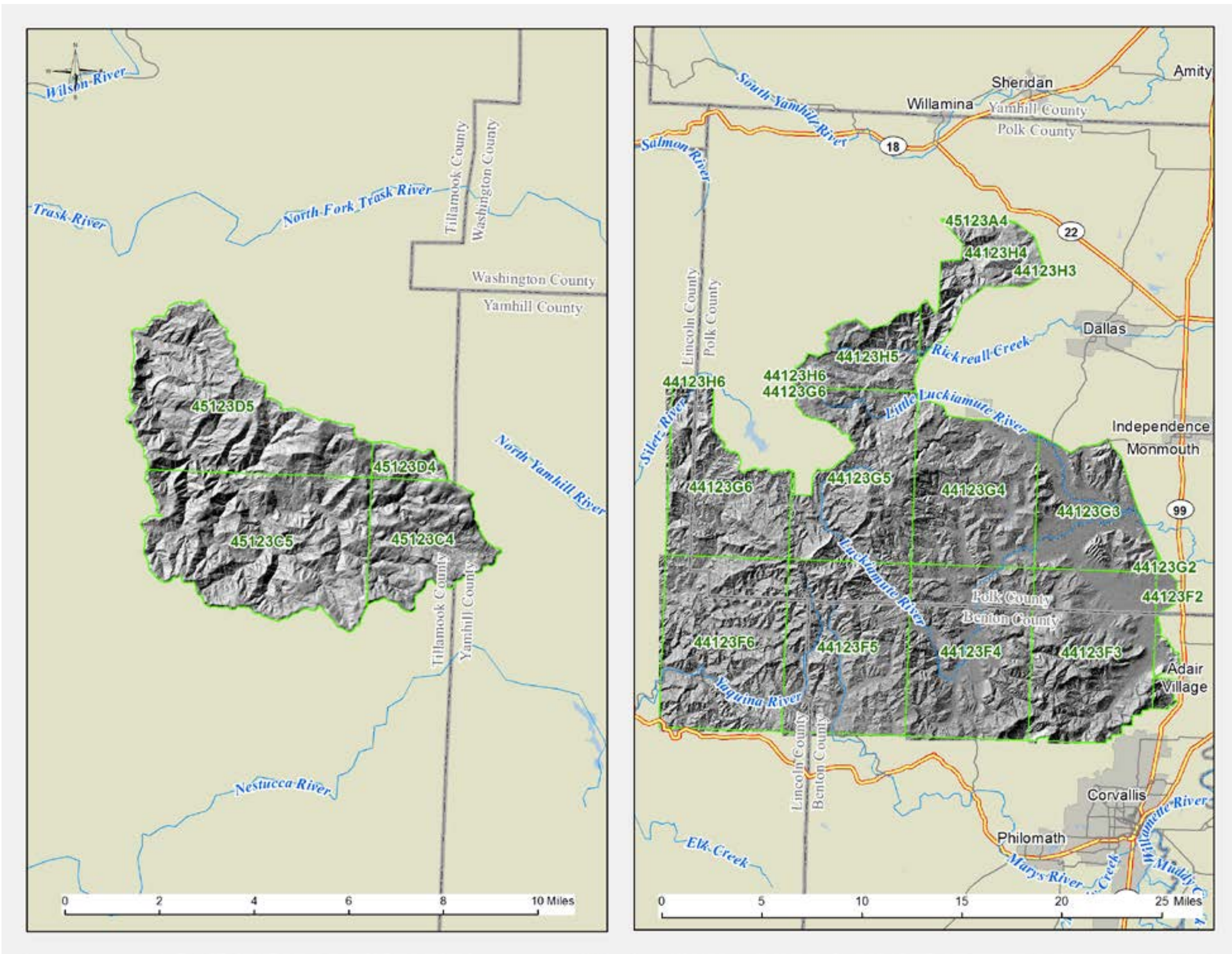


Figure 1. Delivery 3 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Central Coast Survey collection area.

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 2231 delivered data tiles were examined for vertical offset between flight lines. Data tiles with less than 1000 points were not used in analysis. Selection of tiles aimed to evenly sample the delivered spatial extent of data. Each tile measured 750 x 750 meters in size. The average number of points used for flight line comparison was 6,416,512 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meters 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. A total of 553 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	2231
# of Flight Line Sections	494
Avg # of Points	6,416,512
Avg. Magnitude Z error (m)	0.050

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.050	0.163
Standard Error	0.001	0.002
Standard Deviation	0.012	0.038
Sample Variance	0.000	0.000
Range	0.071	0.234
Minimum	0.024	0.079
Maximum	0.096	0.314

Table 2b. Descriptive Statistics for Magnitude Z Error.

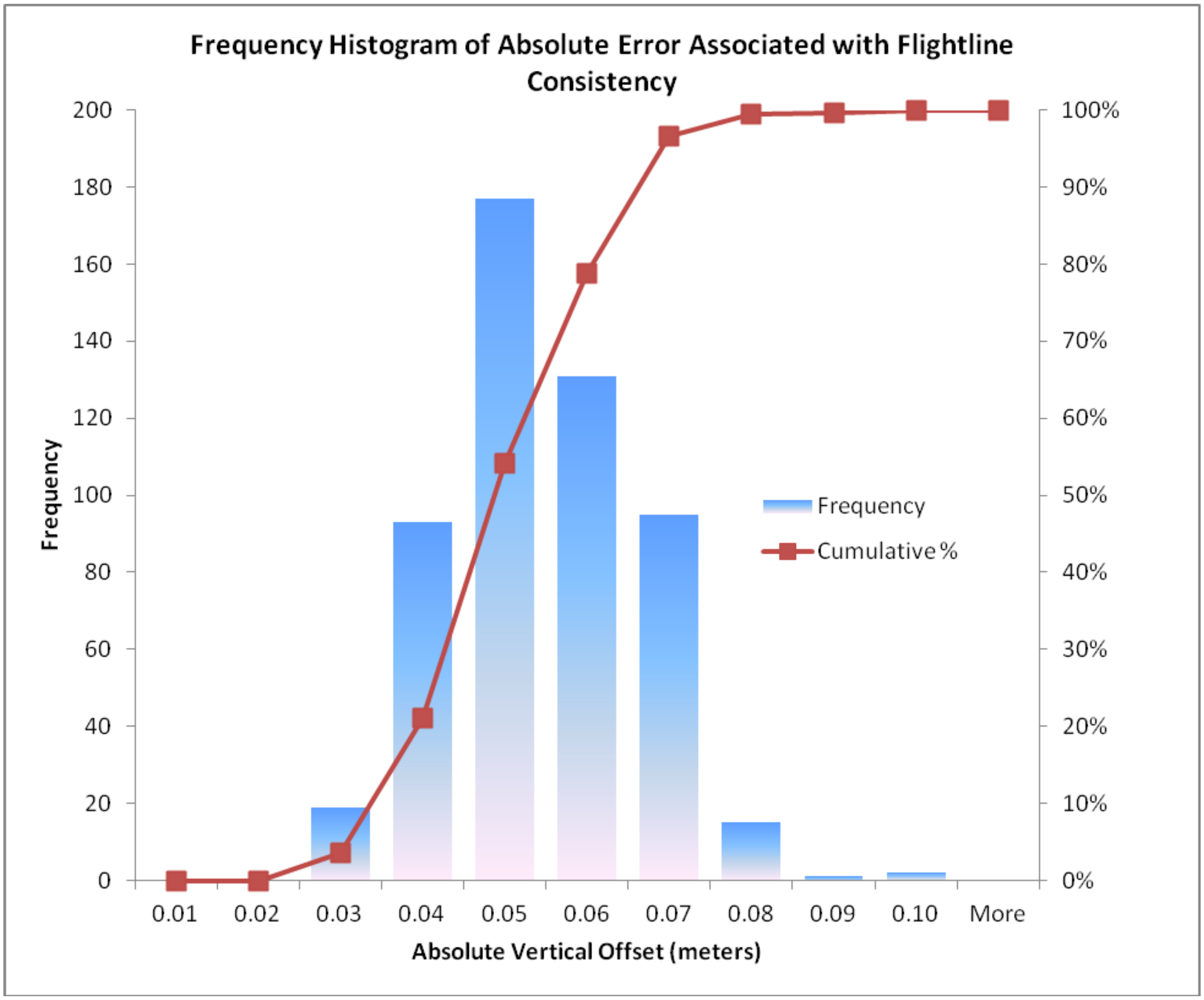


Figure 2. Flight line Consistency Analysis Results

Results of the consistency analysis found the average flight line offset to be 0.050 meters with a maximum error of 0.096m (Table 2b). Distribution of error showed 96% of all error was less than 0.07m (Figure 2). These results show that all data are within tolerances of data consistency according to contract agreement.

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 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning 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 3). 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 5). Birds (high points) typically occur where the laser comes into contact with atmospherics[1].

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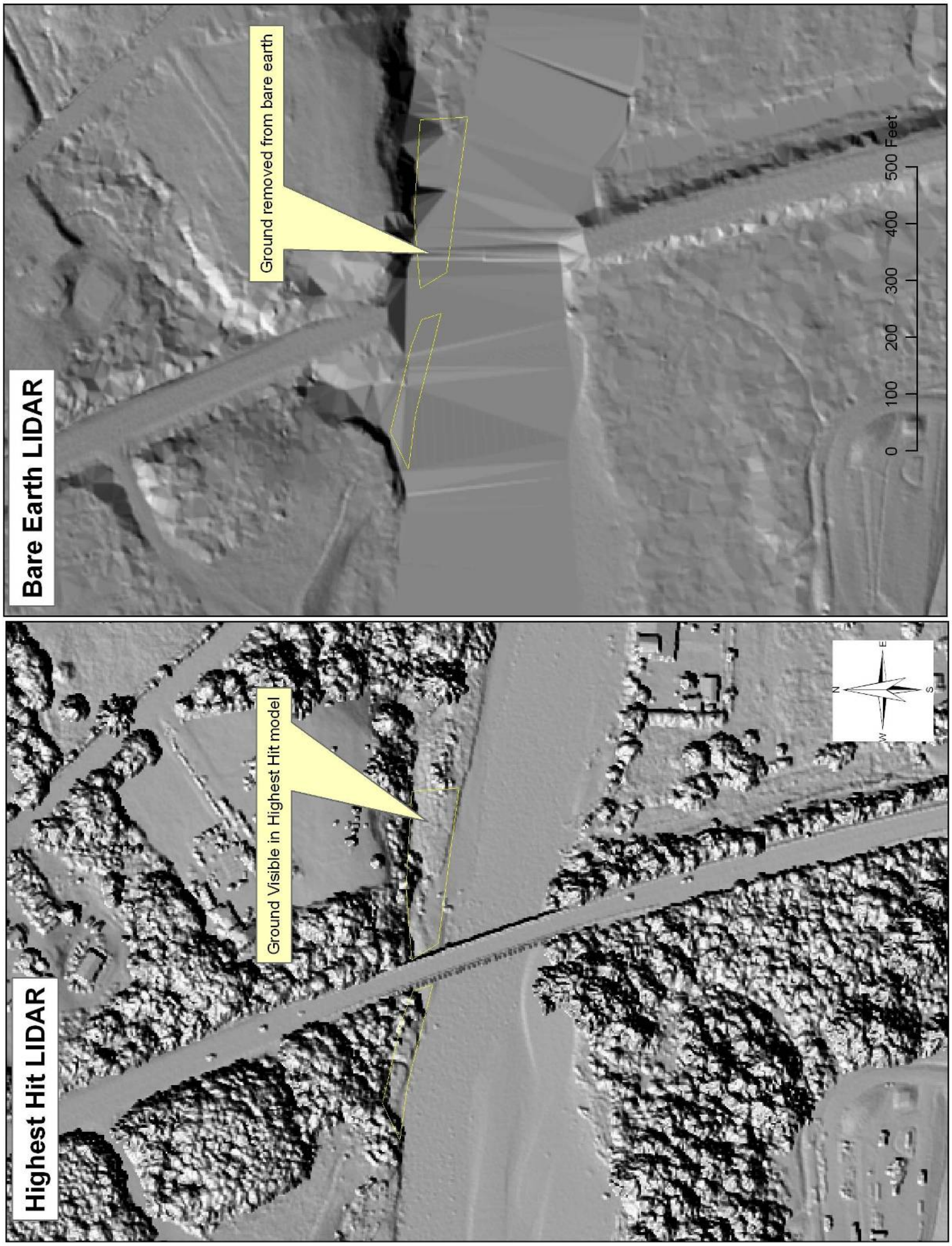
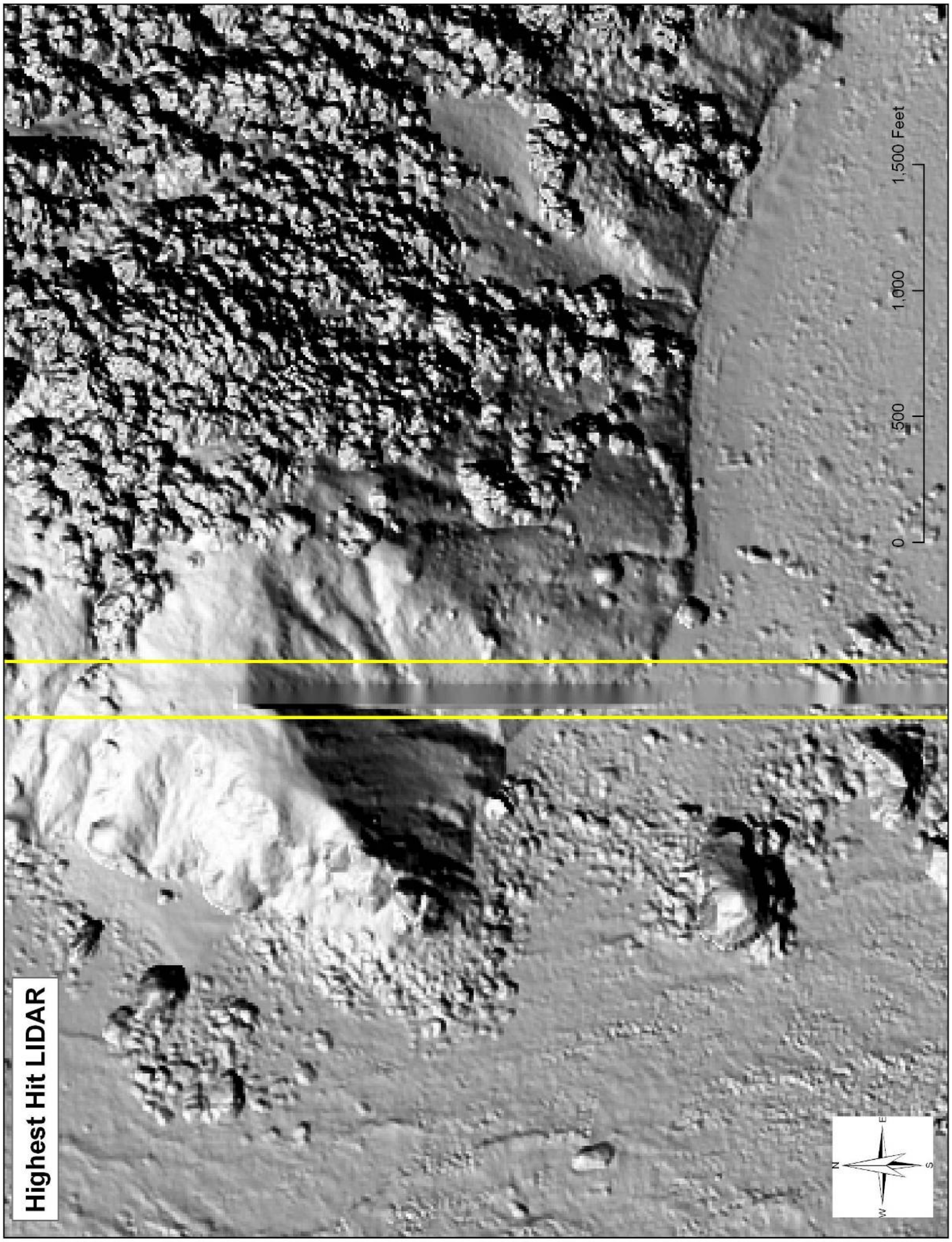


Figure 3. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.



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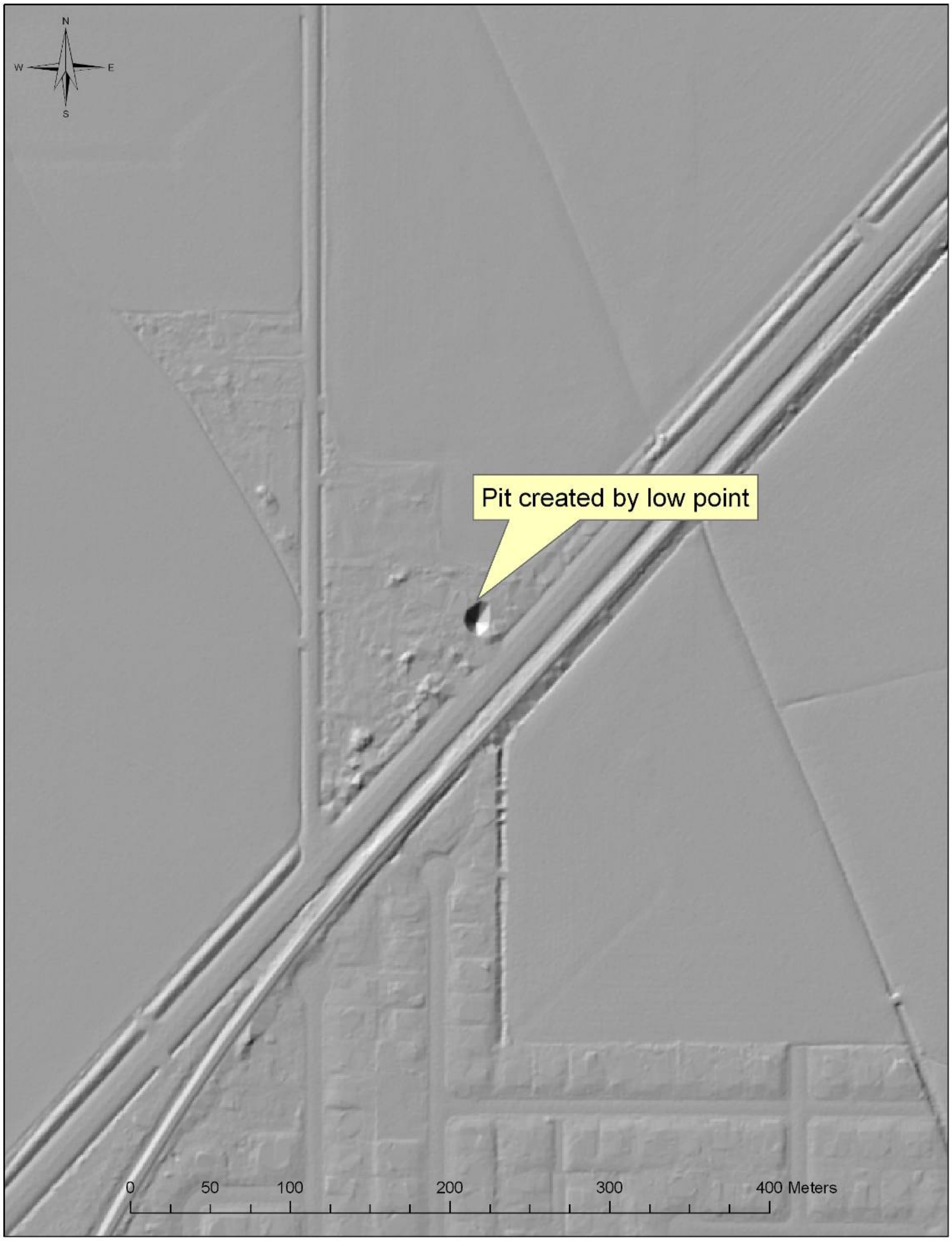

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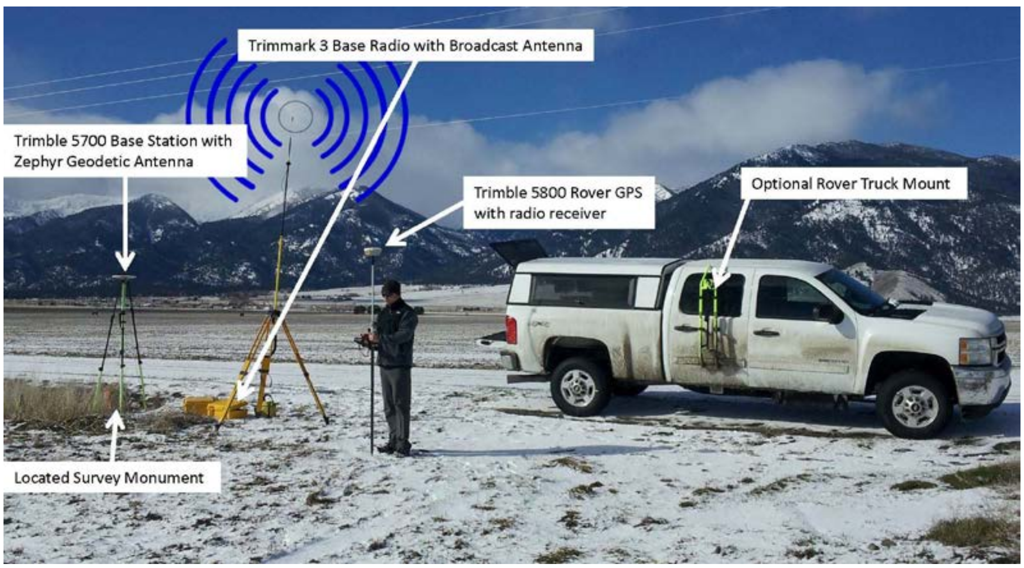

Figure 5. The Trimble 5700 base station antenna located over a known reference point at Cove, OR. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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).

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Vertical accuracy analysis consisted of differencing control data and the delivered 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).

A total of 916 measured GCP's were obtained in the Delivery 3 region and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of -0.053 meters (-0.175 feet) and an RMSE value of 0.082 meters (0.270 ft). Offset values ranged from -0.178 to 0.142 meters (Table 3 and Figure 7).

Horizontal accuracies were not specified in agreement since true horizontal accuracy is regarded as a product of the lidar ground foot print. Lidar is referenced to co-acquired GPS base station data that has accuracies far greater than the value of the lidar foot print. The ground footprint is equal to 1/3333rd of above ground flying height. Survey altitude for this acquisition was targeted at 900 meters yielding a ground foot print of 0.27 meters. This value exceeds the typical accuracy value of ground control used to reference the lidar data (<0.01m). Project specifications require the lidar foot print to fall within 0.15 and 0.40 meters.

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 vender and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

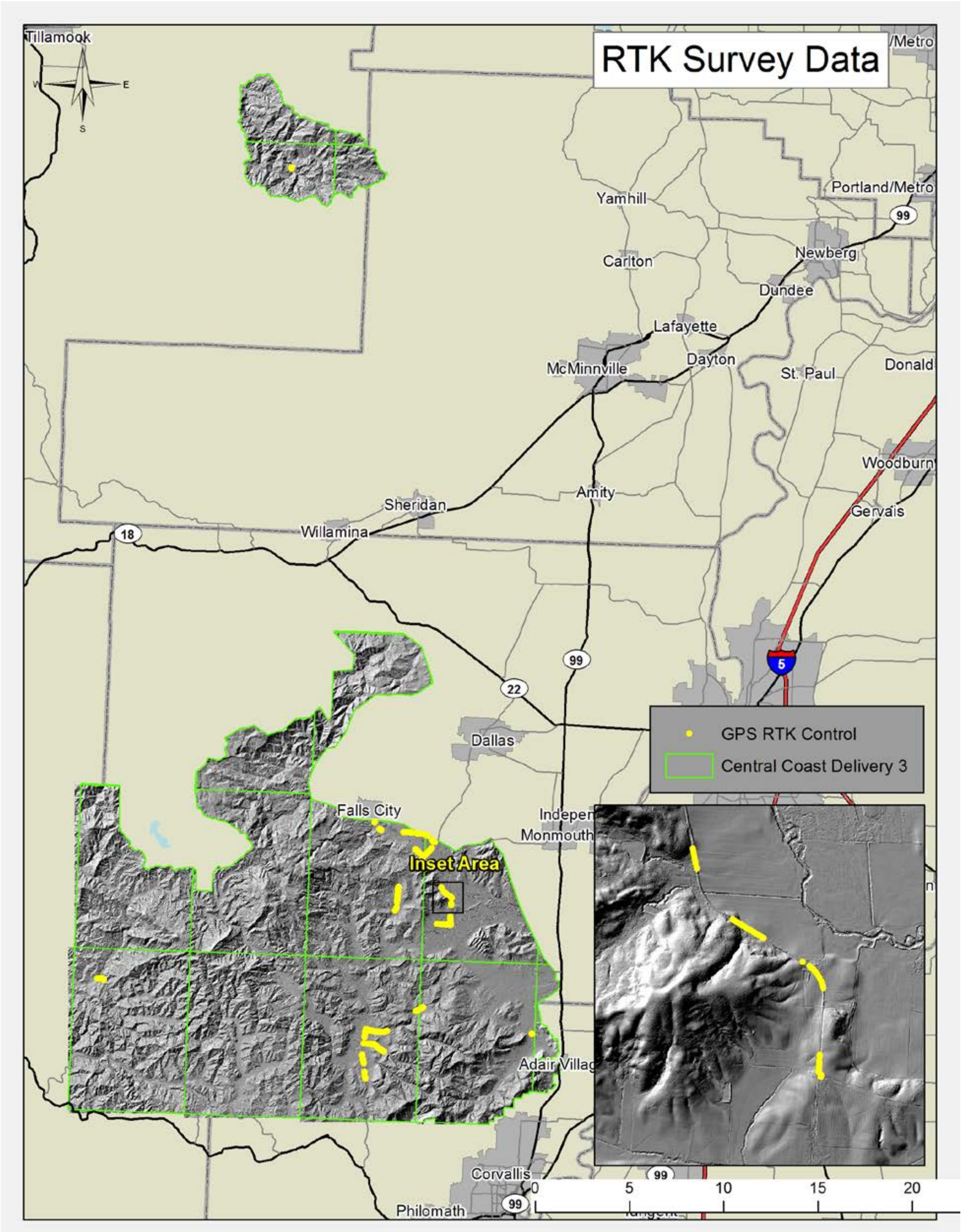

Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Central Coast lidar survey within the Delivery 3 extent.

	Meters	Feet
Mean	-0.053	-0.175
Standard Error	0.002	0.007
Standard Deviation	0.063	0.205
Range	0.320	1.050
Minimum	-0.178	-0.585
Maximum	0.142	0.465
RMSE	0.082	0.270

Table 3. Descriptive Statistics for absolute value vertical offsets.

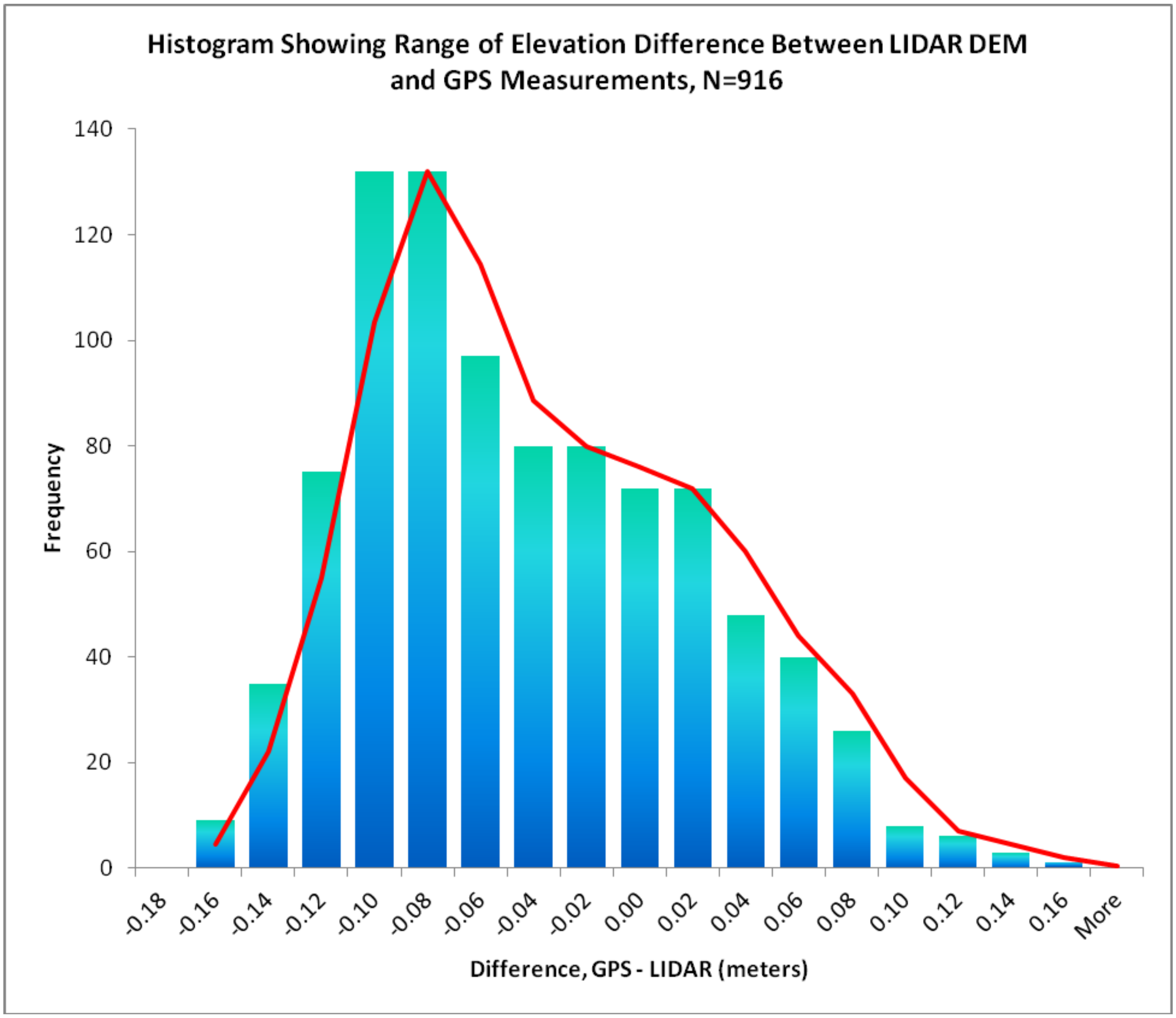

Figure 7. Histogram of absolute vertical accuracy

FEMA Vertical and Horizontal Accuracy Reporting

A total of 256 square miles of the Central Coast lidar project was acquired through FEMA funds and requires vertical and horizontal accuracy reporting subject to FEMA guidelines. The FEMA area of the Central Coast lidar project was delivered in three sections described as "Delivery 1", "Delivery 2", and "Delivery 3". This section of the report describes accuracy statistics for the entirety of the FEMA area of the project.

DOGAMI acquired 39 GCPs between November 28th and December, 2nd, 2011 and April 10th -13th, 2012 to compare with lidar intensity imagery to establish horizontal accuracy (Figure 8). DOGAMI collected GCPs in specific locations where reflective surfaces show up in intensity imagery and additionally provide a quality check for horizontal accuracy. For example GCPs were collected at parking lot spaces, intermittent road centerlines, and stop lines at road junctions (See Figure 6). Intensity images have a resolution of 0.5 meters. GCPs were collected in manner that aimed to provide the widest distribution of data as possible. The result of this comparison was an $RMSE_r$ of 0.843 meters (2.767 feet) and an $Accuracy_r$ of 1.460 meters (4.789 feet) (Table 4).

Vertical accuracy analysis consisted of differencing control data and the delivered 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).

A total of 1793 measured GCP's were obtained in the Delivery region and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of 0.000 meters (0.001 feet) and an RMSE value of 0.082 meters (0.269 ft). Offset values ranged from -0.184 to 0.260 meters (Table 5 and Figure 9).

In addition to DOGAMI's independent vertical accuracy analysis, survey locations provided by the LiDAR vendor (Watershed Sciences Inc.) have been used to assess FEMA specific vertical accuracy reporting. Watershed Sciences collected survey points in land classes described as: short-grass, tall-grass, farmland planted, and shrub land. These classes along with DOGAMI's vertical control have been used to calculate Fundamental Vertical Accuracy (FVA), Supplemental Vertical Accuracy (SVA), and Consolidated Vertical Accuracy (CVA). See Table 6 and figure 9 for results.

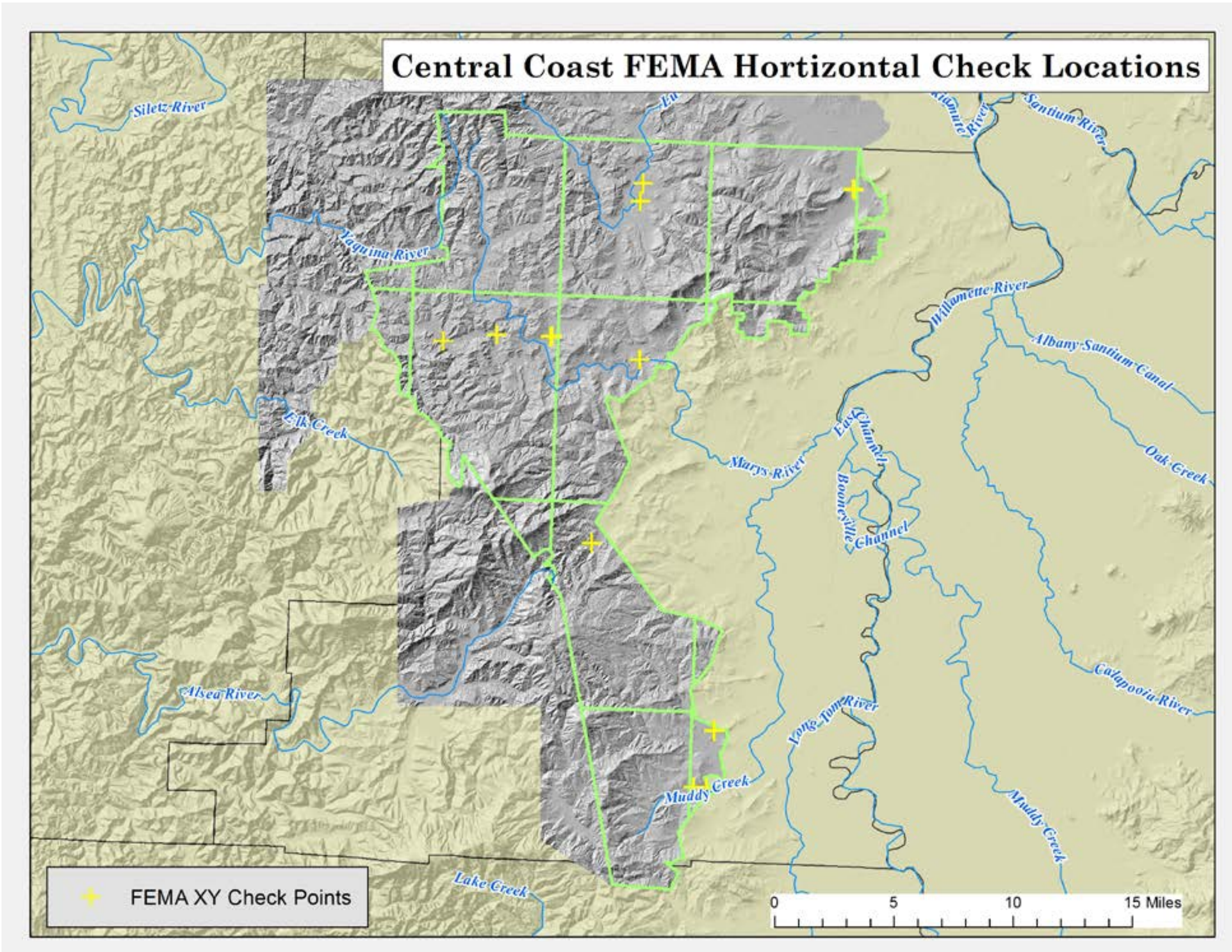

Figure 8. Locations of GPS points used in horizontal accuracy analysis.

	X meters	Y meters
Mean	-0.131	0.099
RMSE	0.293	0.315
RMSE 95%	0.574	0.618

	meters	feet
$RMSE_r$	0.843	2.767
$Accuracy_r$	1.460	4.789

Table 4. Horizontal Accuracy Reporting comparing GPS points to intensity imagery

	Meters	*Feet*
Mean	0.000	0.001
Standard Error	0.003	0.008
Standard Deviation	0.082	0.269
Range	0.444	1.455
Minimum	-0.184	-0.604
Maximum	0.260	0.852
RMSE	0.082	0.269

Table 5. Descriptive statistics for absolute value vertical offsets.

	RMSE (m)	RMSE 95% (m)	RMSE 95% (ft)	n
FVA	0.082	0.160	0.526	1048
CVA	0.100	0.196	0.642	1793
SVA Farm	0.099	0.195	0.639	213
SVA Forest	0.121	0.236	0.775	210
SVA Grass	0.069	0.136	0.447	74
SVA Low Res	0.103	0.201	0.659	123
SVA Shrub	0.177	0.347	1.138	130

Table 6. FEMA vertical accuracy statistics summary table.

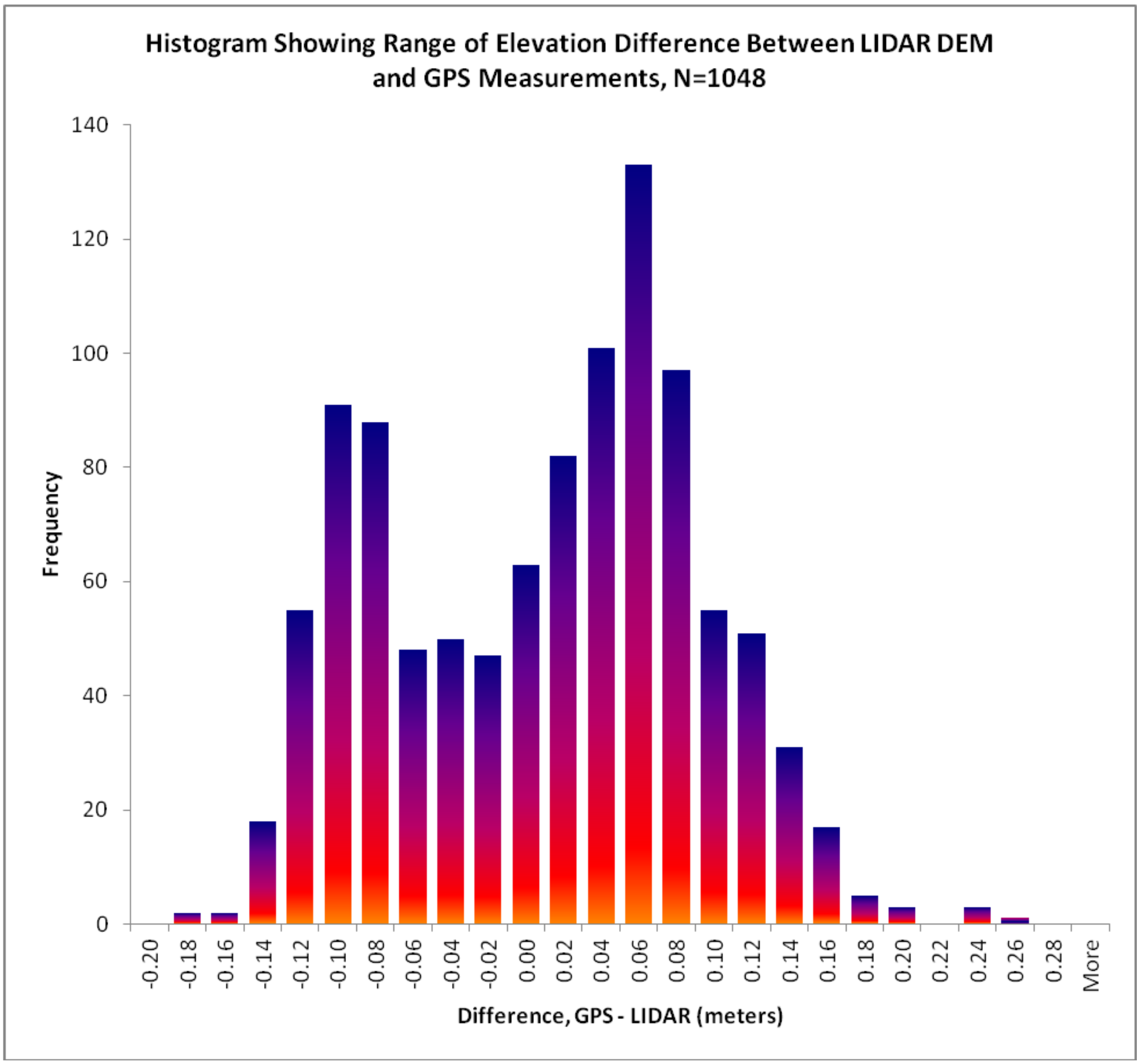

Figure 9. Histogram of Fundamental Vertical Accuracy Distribution.

Acceptance

The data described in this report meets and exceeds project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of August 16th, 2012. 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 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

______________________________ Date: 8/16/2012

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

______________________________ Date: 8/16/2012

John English
Lidar Database Coordinator – Department of Geology & Mineral Industries