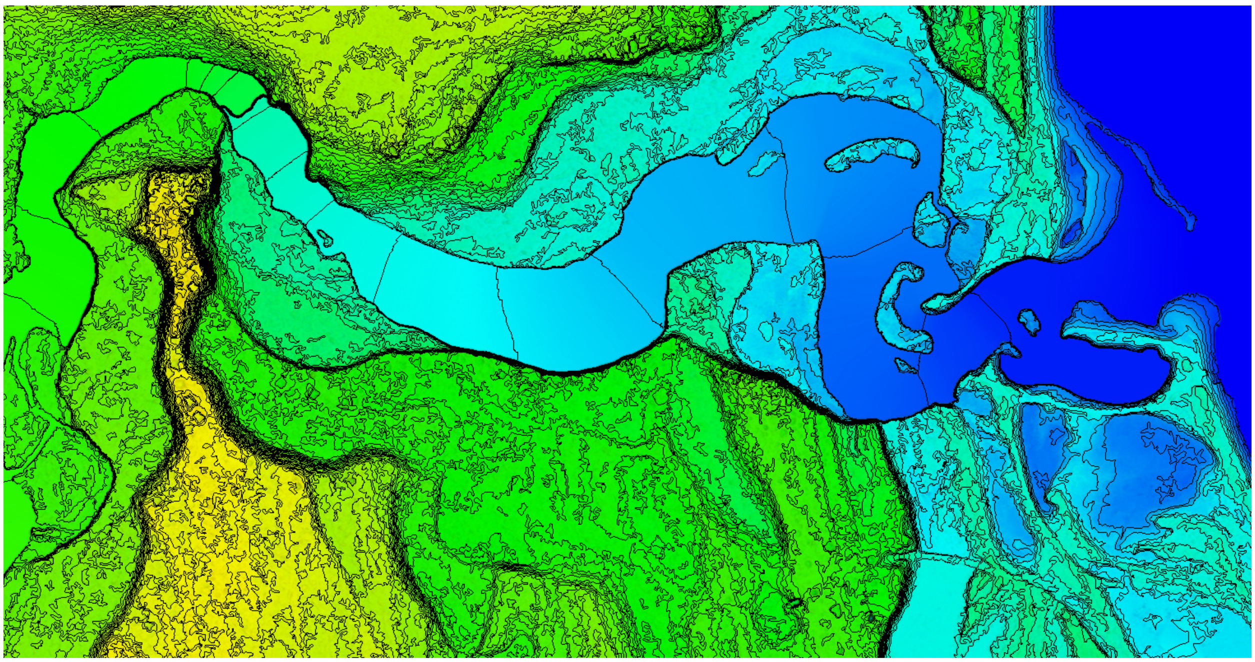
6110901 Brooks Camp Lidar

Acquisition and Processing Report
August 22, 2012



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1 INTRODUCTION

This report contains a summary of the data acquisition and processing for the **BROOKS CAMP LIDAR TASK ORDER.** (Order #G11PD01034)

1.1 Contact Info

Questions regarding the technical aspects of this report should be addressed to:

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1.2 Purpose

The U.S. Geological Survey (USGS) had a requirement for high resolution Lidar needed for mapping the Brooks Camp region of Katmai National Park in Alaska.

Aero-Metric, Inc. (AeroMetric) acquired highly accurate Lidar data for an area that comprises of approximately 17.5 square miles for the USGS. This acquisition was carried out to satisfy the need for high resolution elevation data in the region. AeroMetric's Leica ALS70 Lidar system was used in the collection of data for this project.

1.3 Project Location

The project area is between Lake Brooks and Naknek Lake in Katmai National Park. The project area of interest was defined and supplied by USGS in early 2012.

1.4 Project Scope

This project involves new Lidar data acquisition at an approximate pulse spacing of 0.6 meters. This data was to be calibrated such that all systematic errors were accounted for. The project required bare-earth classification and hydro-enforcement of water bodies for the production of contours and digital elevation models.

Data was to conform to a vertical accuracy of 18.5 cm RMSE in open terrain. The accuracy as tested and published in this report has met vertical accuracy requirements as specified by the client.

1.5 Project Spatial Reference System

The specific spatial reference system for this delivery is as follows:

Horizontal Datum:	NAD83 (CORS96)
Vertical Datum:	NAVD88 (GEOID09)
Projection:	UTM Zone 5 North

1.6 Time Period

Lidar project planning was carried out in early 2012 and concluded by the beginning of May.

Lidar data acquisition was completed between on May 27th, 2012. All data was acquired in a single lift. See Appendix A for individual flight logs.

QC surveys were completed in early June 2012 by GPS, Inc. specifically for this project.

Project delivery was completed in mid-August, 2012.

2 LIDAR ACQUISITION & PROCEDURES

2.1 Acquisition Time Period

Lidar data included in this delivery was acquired on May 27th, 2012.

2.2 Lidar Planning

The Lidar data for this project was collected with AeroMetric's Leica ALS70 Lidar system (Serial Number 7161). All flight planning and acquisition was completed using Leica's FPES, version 10.2.10.5.

The following are the acquisition settings for all missions:

- Flying Height (Above Ground): 1500 meters
- Laser Pulse Rate: 70 kHz
- Mirror Scan Frequency: 62 Hz
- Scan Angle (+/-): 11°
- Side Lap: 54 %
- Ground Speed: 150 kts
- Nominal Point Spacing: 0.687 meters

2.3 Lidar Acquisition

The lidar data for this project was acquired in a single mission. See Appendix A of this report for the flight log. Precise airborne GPS and IMU data was collected during acquisition for use in determining the sensor's position.

The May 27th mission lasted approximately 4 hours. Before take-off, the Lidar system and the Airborne GPS and IMU system were initiated for a period of five minutes and then again after landing for another five minutes.

The mission involved the acquisition of all planned project lines and cross flights. The cross flights were flown perpendicular to the planned flight lines and their data used in the in-situ calibration of the sensor.

2.4 ABGPS and IMU Processing

Leica IPAS-TC v 3.1 software was used to determine both the ABGPS trajectory and the blending of inertial data. GPS, Inc. was operating a GPS base station on location during the acquisition of this data. The position of the base station and raw GPS data were provided to AeroMetric by GPS, Inc. for use in processing.

IPAS-TC is designed to post-process GPS and IMU data simultaneously in a "tightly-coupled" fashion using a rigorous Kalman filter. IPAS-TC can be used in either precise point positioning (PPP) mode or in the more traditional differential GPS mode using reference stations on the ground. To achieve the accuracies required for this project, the processing was carried out in differential mode using the reference station provided by GPS, Inc.

Tightly-Coupled Processing Results

Resultant metrics from the airborne processing are shown below. The plots in IPAS-TC are separation into 3 individual plots for Easting, Northing, and Elevation. Blue markers indicate laser-on times. The residuals from the Kalman filter used in processing are shown, in addition to the "combined separation".

While processing, IPAS-TC estimates the trajectory both from beginning to end and from end to beginning, providing two independent trajectories. The combined separation values are computed by taking the differences between these two trajectories, making this a valuable tool for estimating the overall accuracy of the processing. The final trajectory will be a smoothed combination of these results.

Kalman Filter Residuals for the May 27th flight:

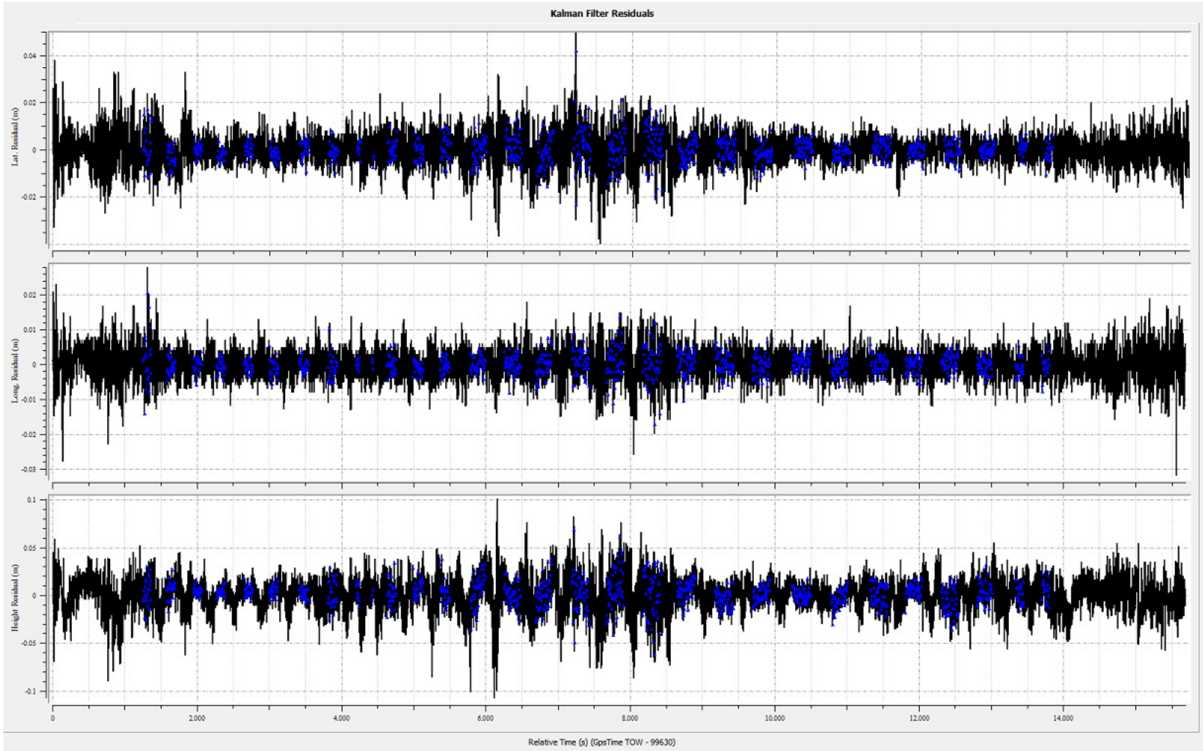


Figure 1 - Kalman Filter Residuals Within +/-0.05m

Combined Separation Results for the May 27th flight:

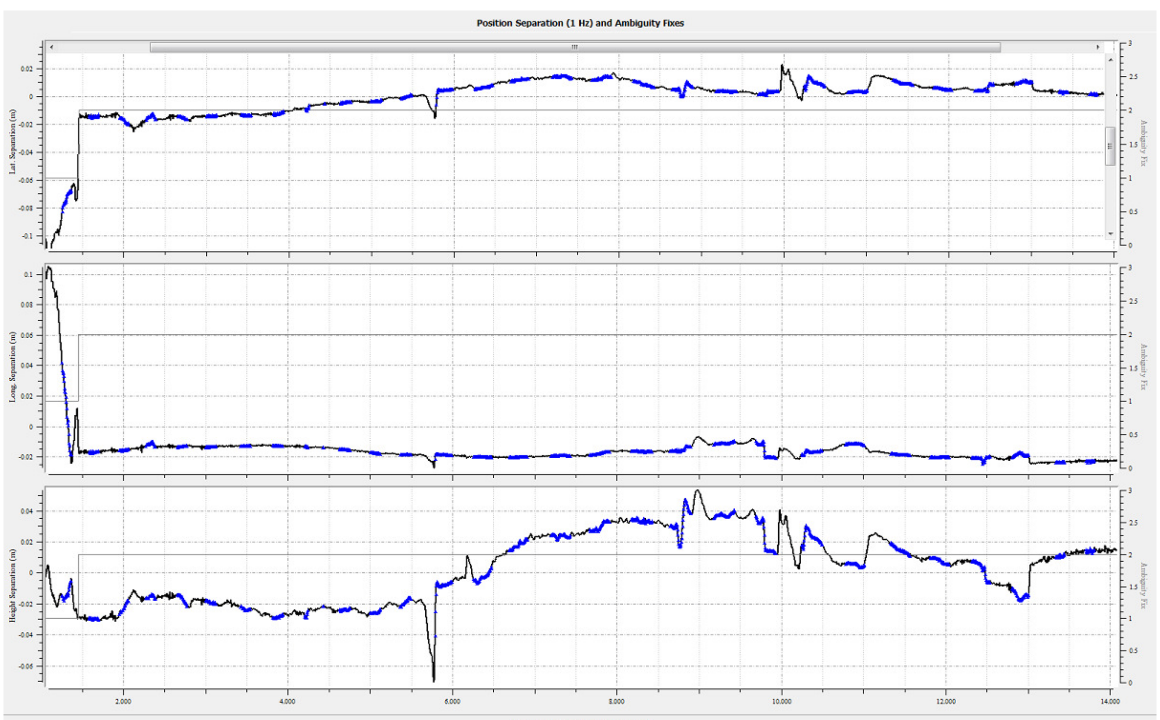


Figure 2 - Combined Separation Results Within +/-0.08m

2.5 Lidar "Point Cloud" Generation

The ABGPS/IMU post processed data along with the Lidar raw measurements were processed using Leica's ALS Post-Processor v. 2.74. This software was used to match the raw Lidar measurements with the computed ABGPS/IMU positions and attitudes of the Lidar sensor. The result was a "point cloud" of Lidar measured points referenced to the ground control system. One LAS 1.2 file was generated per flightline

2.6 Lidar Calibration

Introduction

The purpose of the Lidar system calibration is to refine the system parameters in order for the post-processing software to produce a "point cloud" that best fits relatively from swath to swath. If the results of the calibration are good, then adjusting the calibrated point cloud to ground control should provide a data set that is an optimal representation of the terrain for the given data's resolution.

Calibration Procedures

AeroMetric routinely performs two types of calibrations on its Leica ALS70 Lidar system. The first calibration, system calibration, is performed whenever the Lidar system is installed in the aircraft. This calibration is performed to define the system parameters affected by the physical misalignment of the system versus aircraft. The second calibration, in-situ calibration, is performed for each mission using that missions data. This calibration is performed to refine the system parameters that are affected by the on site conditions as needed.

System Calibration and Correction Software

AeroMetric utilizes an array of specialty software packages for computing and evaluating its Lidar calibration parameters. For this project, TerraSolid's TerraMatch v 12.001 (TMatch) package was the primary tool utilized in the computation and correction of systematic errors. This software has tools for correcting fine-alignment errors in the orientation of the sensor, as well as other system parameters such as mirror scale.

In-situ Calibration

The in-situ calibration is performed as needed using the mission's data. This calibration is performed to refine the system parameters that may change slightly with time, as well as to correct for any additional swath-to-swath errors.

For each mission, planned lines are flown parallel to each other, with some perpendicular cross flights. The processed data of the crossing lines is compared using TMatch software to determine if any systematic errors are present.

In TerraSolid's TerraScan v 12.003 (TerraScan), points can be viewed by offset from overlapping flightlines. This is done by generating independent TINs of each flightline and computing distances from those TINs. This provides a useful tool for visualizing and identifying systematic calibration errors. See below example.

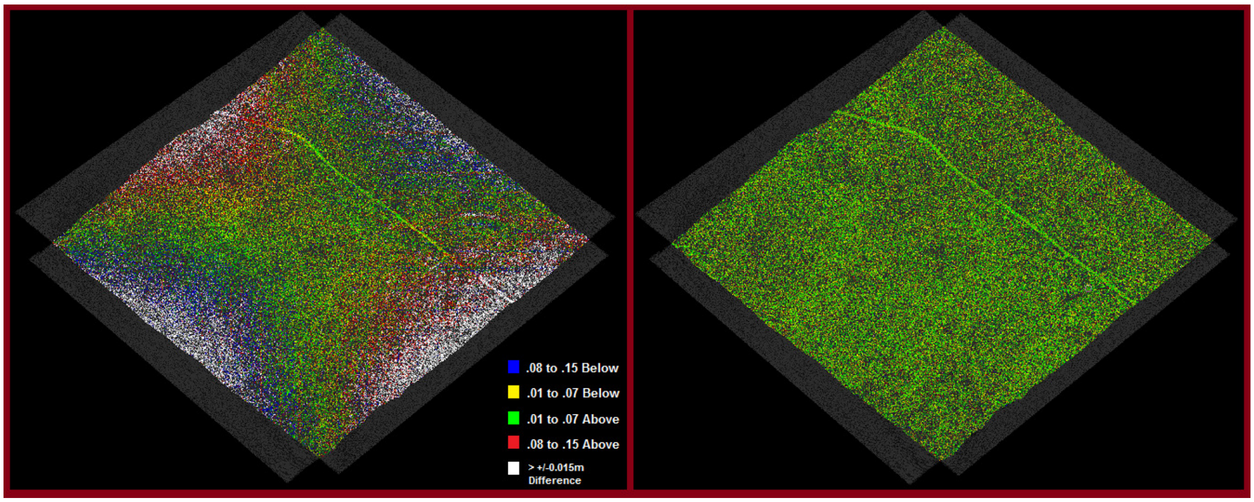


Figure 3 - Perpendicular Lines Colored by Offset Before and After Systematic Corrections are Applied

2.7 Lidar Processing

LAS files were imported and parsed into manageable, tiled grids using GeoCue version 7.0.34.0. GeoCue allows for ease of data management and process tracking.

The first step after the data has been processed and calibrated is to perform a relative accuracy assessment of the flight lines. To perform this assessment, Aero-Metric uses GeoCue to create Orthophotos colored by elevation differences. These images provide a visual interpretation of how well flight lines match, and are a useful tool in determining either the success or need to re-evaluate the in-situ calibration procedure.

The following figure shows the results of the flightline difference orthophotos. The color scheme is as follows: Green = +/-0.07m, Yellow +/-0.08-0.15m, Orange = +/-0.16-0.23m, Red = > +/-0.23m. It is generally understood that flightlines should be matched tightly in areas of open, moderate terrain, and will not match as well in steeper areas.

These results are also affected by the presence of thick vegetation in certain areas. A dense canopy will cause the terrain to be modeled by fewer points, sometimes causing the differences between flightlines to appear greater than they actually are.

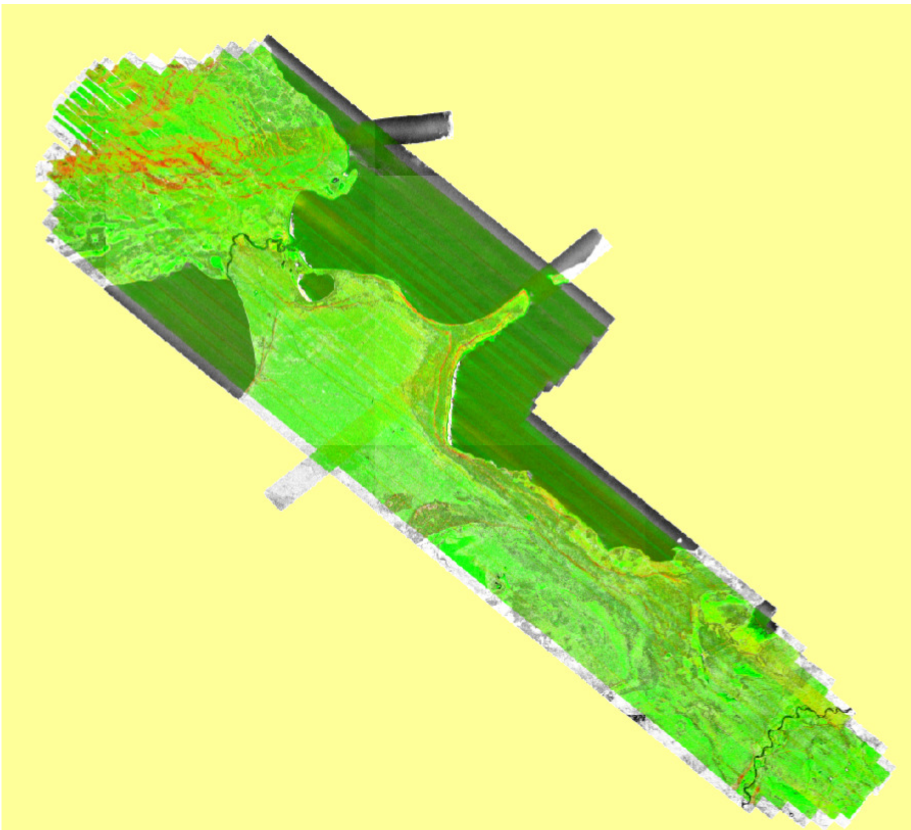


Figure 4 - Difference Imagery for Brooks Camp

Once the calibration results have been verified, the point cloud data is then “auto-classified”. This process involves running multi-step ground and error classification routines on the entire project. The goal of these routines is to automatically identify and classify atmospheric noise, and more importantly, the apparent ground surface. These routines are often tested and tweaked in an attempt to optimize their effectiveness for a given project’s terrain.

Once the data has been auto-classified, it is reviewed thoroughly in TerraScan. Manual classification techniques are then utilized to re-classify features as necessary. This can involve adding data to the ground class where the automated routines did not, or removing low features from the ground class that are not in fact ground.

2.8 Breakline Acquisition

For this project, river and lake features were digitized in Microstation v 8.05.02.27 while the point cloud data was loaded using TerraScan. The lake breakline features were set to the lowest elevation along the shoreline.

“XBars”, or crossing lines at a fixed elevation, were used to drape the river breakline features. Setting XBars along the length of a river at fixe intervals of elevation change ensures a constant flow. Additional XBars can be set between intervals to fix the draping of island features and other abnormalities.

Unique to this project was the famous mini-waterfall where bears frequently fish. To model this waterfall, breaklines were placed along the top and bottom in a way that provided smooth flow of the surface through the transition.

Once all breakline features were collected, lidar points near the surface within the breaklines were classified as water, which keeps them from being used in the generation of deliverable products such as contours and DEMs. This process was done to satisfy the hydro-flattening requirements for this project, which called for the flattening of lakes whose area was equal to or greater than 2 acres, and rivers with a nominal width of 100’ or greater.

3 QC PROCEDURES

3.1 QC Summary

AeroMetric performs various QC checks throughout its processing of Lidar data. Those associated with calibration have already been described above. Other QC procedures involve manually reviewing the work completed in classification and breakline creation. This typically involves a more senior lidar analyst reviewing the work completed to ensure quality practices were utilized.

Further QC procedures involve comparison with field-survey data to “adjust” the point cloud to best match the actual ground surface. This process involves statistically comparing the lidar “bare-earth” surface to collected survey data, determining and applying a vertical offset, and generating final statistics to determine the vertical accuracy of the data.

3.2 Bias Adjustments

GPS, Inc. acquired RTK-GPS data within the project area and provided it to AeroMetric for use in determining the vertical bias in the lidar data. The vertical bias was found to be 0.187 meters, and all lidar points were translated down by this amount to match the profile data.

3.3 Fundamental Vertical Accuracy

The required Fundamental Vertical Accuracy (FVA) requirement for this project was equal to or less than 0.245m at the 95% confidence interval, based upon an RMSE of 0.125m in open terrain.

GPS, Inc. acquired 105 RTK GPS check points throughout the project area. The computed $RMSE_z$ based on these check points was 0.029 meters, which equates to an $RMSE_z$ of 0.057 meters at the 95% confidence interval, meeting this project's specifications.

An additional 20 check points were collected in "open terrain" and are provided in this delivery for the client's use. These points were not included in any of AeroMetric's QC processes or calculations.

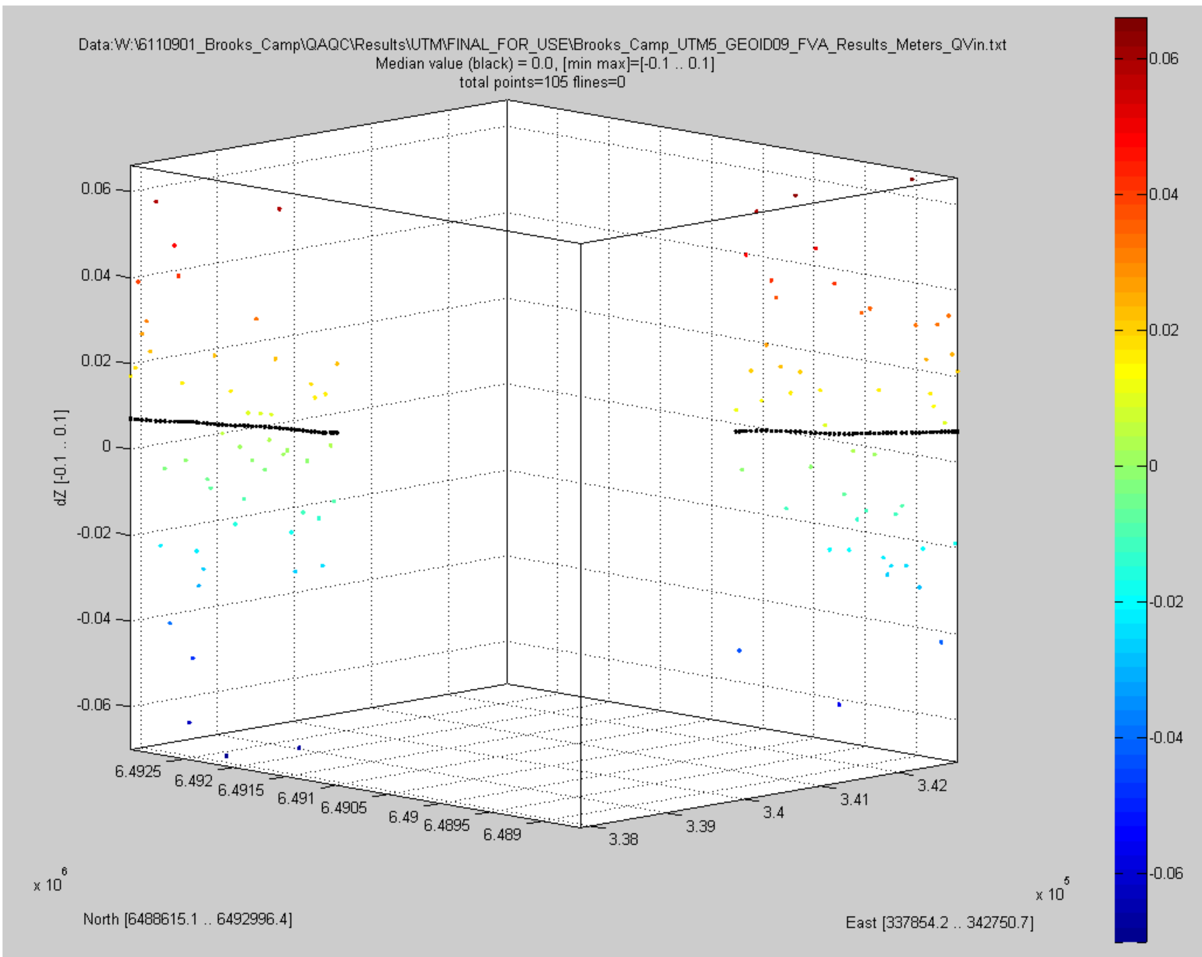


Figure 5 - Final Fundamental Vertical Accuracy Results

A statistical summary of these FVA results has been compiled and can be found in Appendix B.

4 DELIVERABLES

4.1 Delivered Products

All deliverables listed below use the spatial reference listed in the project specifications which is as follows:

Horizontal Reference – NAD83 (CORS96)
Projection / Units – UTM Zone 5, Meters
Vertical Reference – NAVD88 (GEOID09), meters

Raw Point Cloud Data – Provided in LAS 1.2 format with adjusted GPS timestamps and georeference tags in file headers; 1 file per swath.

Classified Point Cloud Data – Provided in LAS 1.2 format with adjusted GPS timestamps and georeference tags in file headers. Delivery is tiled in accordance with the included layout and follows the provided classification scheme of:

Code 1 – Processed, but unclassified
Code 2 – Bare-earth ground
Code 7 – Noise
Code 9 – Water
Code 10 – Ignored Ground (Breakline Proximity)

Bare Earth DEMs – Provided in USGS DEM format in accordance with the included tile layout. DEM resolution is 1m.

Intensity Imagery – Provided in 8-bit gray scale GeoTiff format in accordance with the included tile scheme.

ESRI Terrain Object – Provided in Arc Geodatabase format.

Breaklines – Provided in ESRI Shapefile format.

Contours – Provided in ESRI Shapefile format in accordance with the included tile scheme. Contour interval is 0.30m.

Metadata – Provided as FGDC compliant project level Metadata in .xml format, per deliverable.

Tile Index – Provided in ESRI shapefile format. Tiles are 1500 meters x 1500 meters, except where extending beyond the project boundary. In these cases, tiles are complete to the project boundary plus 100 meters buffer as per the project specifications

Processing Report – Provided as this document, outlining acquisition, processing, and QC procedures, and all other relevant project information.

4.2 Deliverable Generation Methodology

Raw Point Cloud Data – Generated from calibrated LAS data; data was extracted to “strips” by flight ID with all points classified as Code 0 using TerraScan. Georeference tags and Adjusted GPS Timestamps were added to files using proprietary in-house software.

Classified Point Cloud Data – Generated in GeoCue, classified in TerraScan. Georeference tags and Adjusted GPS Timestamps were added to files using proprietary in-house software.

Bare-Earth DEMs – Generated from classified LAS data and breaklines utilizing QCoherent’s LP360.

Intensity Imagery – Generated from LAS data utilizing TerraScan. Output in 8-bit gray scale GeoTiff format.

ESRI Terrain Object – Built from bare-earth keypoints and densified breakline points with 3 pyramid levels. Used the Z Tolerance method with tolerances of 0.15, 0.3, and 0.6 meters.

Breaklines – Digitized in Microstation and draped utilizing classified LAS data in TerraScan. Converted to ESRI Shapefile format using Global Mapper v 13.

Contours – Classified LAS data was run through a “contour keypoints” routine with settings appropriate for the generation of 30cm contours. The resultant keypoints were used to generate 30cm contours in ESRI Shapefile format using proprietary in-house software.

5 CONCLUSION

This delivery satisfies the requests for the Brooks Camp Lidar Task Order by providing high quality Lidar derived products. The required data accuracies have been met, and the procedures used align with the guidelines provided by the USGS.

All requested deliverable products have been generated and formatted to meet the specifications provided by the USGS, and are included in this submission. Any further information regarding these data or the status of this project can be requested from AeroMetric at any time by the USGS.

APPENDIX A – FLIGHT LOG

LIDAR FLIGHT L G

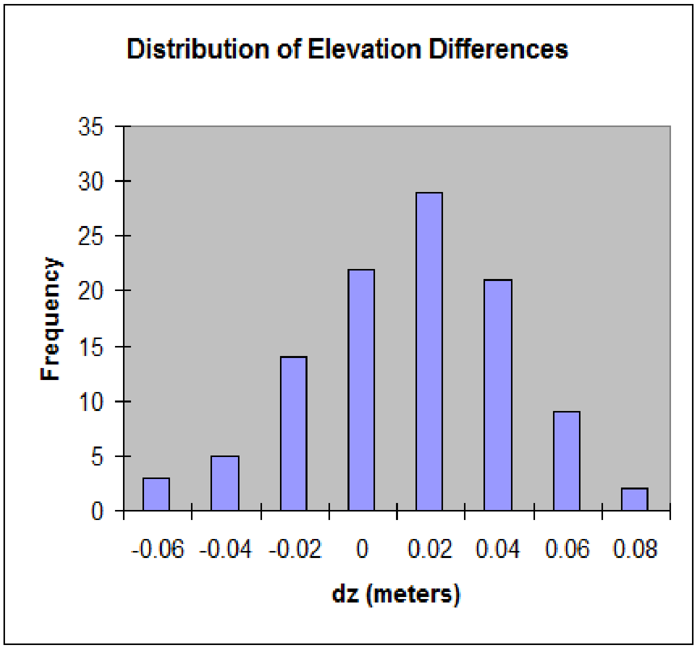
ALTM 1

MISSION: 20120528_033453	DATE: 5/27/12		
PILOT: WENGER	OPERATOR: PESTRIKOFF / POWELL	AIRCRAFT: 12 TB	

PROJECT NUMBER	LINE NO. & Hdg	GND SPEED (KTS)	SCAN FREQ	SCAN ANGLE	PRF	ALT (m)	TIME START	TIME STOP	Laser Time	TZPK	REMARKS
6110901							19:43				TAKE OFF / HOBBS 1468.0
							19:18	0:09			TERRA POS
	1 E	146	57	22	194	4844	20:01	20:03			
	2 W	154				4844	20:06	20:08			
	3 E	156				4842	20:12	20:14			
	4 W	150				4842	20:18	20:20			
	5 E	153				4842	20:24	20:26			
	6 W	155				4845	20:30	20:32			
	7 E	148				4844	20:37	20:39			Terrain too high for eye min
	8 W	153				4844	20:43	20:45			
	9 E	151				4844	20:50				NOT RECORDING
	9 E	154				4844	20:57	20:59			RE-FLY
						~~4844~~	20:54	20:54			TEST LINE
	10 W	155				4844	21:03	21:05			
	11 E	157				4844	21:09	21:11			
	12 W	162				4841	21:16	21:20			
	13 E	154				4841	21:24	21:28			
	14 W	163				4841	21:31	21:35			
	15 E	158				4841	21:39	21:44			
	16 W	166				4841	21:48	21:52			

STATUS	TOTAL LINES	FLOWN	LEFT	AIRCRAFT SITE	AIRCRAFT FERRY	STATIC	START:	STOP:	NOTES:
) _033453	28	28	0	3.5	1.0				
) FERRY MRI->AKN 5/26					2.0	[illegible]			
) FERRY AKN MRI 5/28					2.0				

APPENDIX B – STATISTICAL FVA SUMMARY



Statistical Summary		
Mean:	0.005	meters
Median:	0.007	meters
Mode:	0.016	meters
Kurtosis:	0.048	
	-	
Skew:	0.265	
Minimum:	-0.07	meters
Maximum:	0.066	meters
Range:	0.136	meters
Count:	105	
RMSE:	0.029	
RMSE*1.96 (95% CI - NSSDA)	0.057	

Number	Easting	Northing	Known Z	Laser Z	Dz	Dz^2
7125	338241.2	6492353	41.87	41.8	-0.07	0.0049
7143	338527.1	6491859	47.057	46.99	-0.067	0.004489
7115	338122.5	6492626	33.453	33.39	-0.063	0.003969
7029	341891.1	6489123	59.356	59.3	-0.056	0.003136
7116	338144.6	6492607	37.618	37.57	-0.048	0.002304
7050	341338.6	6489681	55.644	55.6	-0.044	0.001936
7005	342633.1	6488686	72.502	72.46	-0.042	0.001764
7110	338013.5	6492732	29.91	29.87	-0.04	0.0016
7118	338158.1	6492559	39.991	39.96	-0.031	0.000961
7011	342463.3	6488770	68.329	68.3	-0.029	0.000841
7119	338171.5	6492523	40.277	40.25	-0.027	0.000729
7142	338517.7	6491889	47.026	47	-0.026	0.000676
7018	342240.2	6488915	62.176	62.15	-0.026	0.000676
7149	338589.2	6491675	47.244	47.22	-0.024	0.000576
7017	342270.1	6488900	63.074	63.05	-0.024	0.000576
7014	342370	6488829	66.074	66.05	-0.024	0.000576
7117	338154.7	6492576	40.323	40.3	-0.023	0.000529
7108	337970.1	6492791	29.012	28.99	-0.022	0.000484
7019	342210.6	6488932	61.822	61.8	-0.022	0.000484
7031	341838.3	6489175	58.47	58.45	-0.02	0.0004
7027	341952.2	6489072	60.14	60.12	-0.02	0.0004
7010	342489.3	6488756	69.12	69.1	-0.02	0.0004
7001	342734.3	6488627	74.409	74.39	-0.019	0.000361
7141	338507.1	6491921	46.817	46.8	-0.017	0.000289

7127	338285.3	6492300	44.466	44.45	-0.016	0.000256
7148	338576	6491704	47.003	46.99	-0.013	0.000169
7025	342024.5	6489047	60.083	60.07	-0.013	0.000169
7144	338536.6	6491828	47.022	47.01	-0.012	0.000144
7016	342301.1	6488880	64.422	64.41	-0.012	0.000144
7040	341646.9	6489455	57.691	57.68	-0.011	0.000121
7023	342099.3	6489015	60.681	60.67	-0.011	0.000121
7129	338338.3	6492253	45.72	45.71	-0.01	0.0001
7015	342342.7	6488849	65.43	65.42	-0.01	0.0001
7152	338662.5	6491621	47.749	47.74	-0.009	0.000081
7121	338191.3	6492468	40.638	40.63	-0.008	0.000064
7028	341920.8	6489095	59.847	59.84	-0.007	0.000049
7120	338182.1	6492494	40.346	40.34	-0.006	0.000036
7109	337989.6	6492764	29.504	29.5	-0.004	0.000016
7134	338433.1	6492121	45.923	45.92	-0.003	0.000009
7114	338099.6	6492643	31.662	31.66	-0.002	0.000004
7049	341364.3	6489673	55.922	55.92	-0.002	0.000004
7131	338371	6492199	45.841	45.84	-0.001	0.000001
7035	341757.3	6489297	57.431	57.43	-0.001	0.000001
7145	338547.1	6491795	47.17	47.17	0	0
7139	338487.3	6491984	46.549	46.55	0.001	0.000001
7128	338316.6	6492277	45.448	45.45	0.002	0.000004
7140	338497.1	6491952	46.548	46.55	0.002	0.000004
7021	342152.3	6488975	61.418	61.42	0.002	0.000004
7026	341989.6	6489059	60.197	60.2	0.003	0.000009
7135	338448.2	6492090	45.996	46	0.004	0.000016
7151	338639.9	6491635	47.556	47.56	0.004	0.000016
7124	338226.5	6492381	41.295	41.3	0.005	0.000025
7123	338213.6	6492407	41.133	41.14	0.007	0.000049
7036	341736.7	6489338	57.323	57.33	0.007	0.000049
7032	341815.8	6489204	58.351	58.36	0.009	0.000081
7004	342659.6	6488670	73.291	73.3	0.009	0.000081
7130	338352.9	6492224	45.52	45.53	0.01	0.0001
7133	338414.2	6492148	45.92	45.93	0.01	0.0001
7136	338454.7	6492076	46.04	46.05	0.01	0.0001
7051	341309.5	6489691	55.498	55.51	0.012	0.000144
7007	342573.6	6488715	71.187	71.2	0.013	0.000169
7045	341511.7	6489594	56.936	56.95	0.014	0.000196
7126	338260.1	6492326	43.155	43.17	0.015	0.000225
7147	338566.5	6491734	47.255	47.27	0.015	0.000225
7113	338077.6	6492660	31.624	31.64	0.016	0.000256
7150	338605.2	6491660	47.454	47.47	0.016	0.000256
7039	341669.3	6489429	57.554	57.57	0.016	0.000256
7008	342545.5	6488727	70.384	70.4	0.016	0.000256
7101	337854.2	6492996	25.423	25.44	0.017	0.000289
7033	341793.8	6489235	57.943	57.96	0.017	0.000289
7020	342180.8	6488952	61.533	61.55	0.017	0.000289
7146	338557	6491764	47.332	47.35	0.018	0.000324
7102	337872.4	6492961	26.291	26.31	0.019	0.000361
7047	341434.8	6489640	56.319	56.34	0.021	0.000441

7037	341715.1	6489371	57.649	57.67	0.021	0.000441
7000	342750.7	6488615	74.439	74.46	0.021	0.000441
7041	341618.6	6489488	57.588	57.61	0.022	0.000484
7106	337924.6	6492858	28.467	28.49	0.023	0.000529
7122	338201.4	6492438	41.037	41.06	0.023	0.000529
7137	338466.8	6492045	46.167	46.19	0.023	0.000529
7153	338685.2	6491606	47.887	47.91	0.023	0.000529
7009	342515.2	6488742	69.616	69.64	0.024	0.000576
7002	342713.2	6488640	74.325	74.35	0.025	0.000625
7104	337890.1	6492911	28.573	28.6	0.027	0.000729
7044	341541.4	6489569	56.823	56.85	0.027	0.000729
7105	337912.2	6492884	28.41	28.44	0.03	0.0009
7132	338391.6	6492174	46.078	46.11	0.032	0.001024
7012	342437.5	6488787	67.368	67.4	0.032	0.001024
7006	342603.1	6488702	71.728	71.76	0.032	0.001024
7003	342686.6	6488654	73.886	73.92	0.034	0.001156
7024	342062.2	6489034	60.335	60.37	0.035	0.001225
7022	342123.9	6488997	61.004	61.04	0.036	0.001296
7042	341595.6	6489513	57.122	57.16	0.038	0.001444
7103	337881.7	6492941	26.141	26.18	0.039	0.001521
7112	338056.3	6492681	31.389	31.43	0.041	0.001681
7043	341569.5	6489542	57.028	57.07	0.042	0.001764
7030	341862.6	6489148	58.628	58.67	0.042	0.001764
7111	338035.9	6492704	30.712	30.76	0.048	0.002304
7048	341397	6489659	56.312	56.36	0.048	0.002304
7034	341774.6	6489265	57.48	57.53	0.05	0.0025
7107	337945.6	6492817	28.722	28.78	0.058	0.003364
7138	338477.2	6492014	46.412	46.47	0.058	0.003364
7046	341477	6489618	56.552	56.61	0.058	0.003364
7038	341692.9	6489399	57.618	57.68	0.062	0.003844
7013	342411.3	6488804	66.734	66.8	0.066	0.004356