Airborne LiDAR Report

AK Yukon Kuskokwim QL2 Lidar

Contract Number: G16PC00022
Task Number: G16PD00650

Contractor: Woolpert, Inc.
Woolpert Project # 76769

April 2017

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Section 1: Overview

TASK ORDER NAME: AK Yukon Kuskokwim QL2 Lidar

Project: # 76769

This report contains a comprehensive outline of the AK Yukon Kuskokwim QL2 Lidar Processing task order for the United States Geological Survey (USGS). This task is issued under USGS Contract No. G16PC00022, Task Order No. G16PD00650. This task order requires lidar data to be acquired within the Yukon-Kuskokwim River delta between the communities of Chevak and Newtok in Western Alaska. Additional satellite areas of interest are located near the communities of Emmonak, Scammon Bay, and Mekoryuk, Alaska. (Approximately 1,667 square miles) collected at a nominal pulse spacing (NPS) of 0.7 meters. The NPS assessment is made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.

- A Riegl LMS Q780 airborne lidar sensor mounted inside a Cessna 182 aircraft was utilized to acquire point cloud data at a nominal pulse spacing (NPS) of 0.7 meters The aerial lidar was collected at the following sensor specifications:

Table 1.1:Riegl Specifications – Kodiak Mapping	
Post Spacing	0.70 m
AGL (Above Ground Level) average flying height	2100m
Average Ground Speed:	110 knots
Field of View (full)	60 degrees
Pulse Rate	400 kHz
variable	variable
Side Lap	50%

LiDAR data was produced in NAD 1983 UTM Zone 3 North, NAVD88 Geoid12B meters. A secondary LAS delivery was processed and delivered in WGS84 (G1674) UTM Zone 3 North with ellipsoidal heights (GRS 80).

Figure 1.1: AK Yukon Kuskokwim QL2 Lidar Task Order AOI

Section 2: Acquisition

The lidar data was acquired by Kodiak Mapping, Inc (KMI) using a Riegl LMS Q780 airborne lidar sensor mounted inside a Cessna 182 aircraft. The LiDAR data was collected in ten (10) missions, flown as close together as the weather permitted, to ensure consistent ground conditions across the project area. An initial quality control process was performed immediately on the LiDAR data to review the data coverage, airborne GPS data, and trajectory solution.

Prior to mobilizing to the project site, flight crews coordinated with the necessary Air Traffic Control personnel to ensure airspace access.

Ground based GPS+GLONASS capable stations were operated onsite for the duration of all missions. Trajectory data was processed utilizing a tightly coupled GPS-IMU methodology with reference to the ground stations.

Table 2.1: Airborne Lidar Acquisition Flight Summary

Date of Mission	Lines Flown	Mission Time (UTC) Wheels Up/ Wheels Down
August 30, 2016_A	**YKD001-YKD010**	**8:40 – 12:08**
August 30, 2016_B	**YKD021-YKD039**	**2:24 – 7:11**
August 31, 2016	**YKD011-YKD020, YKD114-YKD121**	**11:50 – 7:02**
September 1, 2016_A	**YKD040-YKD047**	**11:46 – 2:16**
September 1, 2016_B	**YKD094-YKD113**	**4:56 - 7:39**
September 2, 2016	**YKD082-YKD093**	**10:40 – 12:24**
October 14, 2016_A	**SCM001-SCM005, YKD048-YKD051**	**9:55 – 11:46**
October 14, 2016_B	**YKD052-YKD063**	**2:00 – 5:42**
October 15, 2016	**EMK001-EMK010, YKD064-YKD081**	**3:56 – 11:32**
October 16, 2016	**MYU001-MYU005**	**9:08 – 9:40**

Figure 2.1: LiDAR Flight Layout, AK Yukon Kuskokwim QL2 Lidar

Section 3: LiDAR Data Processing

Applications and Work Flow Overview

1. Resolved kinematic corrections for three subsystems: inertial measurement unit (IMU), sensor orientation information and airborne GPS data. Developed a blending post-processed aircraft position with attitude data using Kalman filtering technology or the smoothed best estimate trajectory (SBET).
2.Calculated laser point position by associating the SBET position to each laser point return time, scan angle, intensity, etc. Created raw laser point cloud data for the entire survey in LAS format. Automated line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift.
3.Imported processed LAS point cloud data into the task order tiles. Resulting data were classified as ground and non-ground points with additional filters created to meet the task order classification specifications. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data. Based on the statistical analysis, the lidar data was then adjusted to reduce the vertical bias when compared to the survey ground control.
4.The LAS files were evaluated through a series of manual QA/QC steps to eliminate remaining artifacts from the ground class.

LiDAR Data Processing

When the sensor calibration, data acquisition, and GPS processing phases were complete, the formal data reduction processes by Woolpert lidar specialists included:

- Processed individual flight lines to derive a raw “Point Cloud” LAS file. Matched overlapping flight lines, generated statistics for evaluation comparisons, and made the necessary adjustments to remove any residual systematic error.
- Calibrated LAS files were imported into the task order tiles and initially filtered to create a ground and non-ground class. Then additional classes were filtered as necessary to meet client specified classes.
- Once all project data was imported and classified, survey ground control data was imported and calculated for an accuracy assessment. As a QC measure, Woolpert has developed a routine to generate accuracy statistical reports by comparisons against the TIN and the DEM using surveyed ground control of higher accuracy. The lidar is adjusted accordingly to meet or exceed the vertical accuracy requirements.
- The lidar tiles were reviewed using a series of proprietary QA/QC procedures to ensure it fulfills the task order requirements. A portion of this requires a manual step to ensure anomalies have been removed from the ground class.
- The lidar LAS files are classified into the Default (Class 1), Ground (Class 2), Low Noise (Class 7), Water (Class 9), Ignored Ground (Class 10), Bridge Decks (Class 17) and High Noise (Class 18) classifications.
- Although hydro flattening was a requirement for this task order no hydro features satisfied the USGS LBS version 1.2 criteria for hydro collection. Bridge breaklines were also compiled in efforts to generate an accurate DEM product. The bridge breakline product was delivered in ESRI shapefile format and was also used in the processing of the DEM deliverable.
- FGDC Compliant metadata was developed for the task order in .xml format per product.

The horizontal datum used for the task order was referenced to NAD83(2011) UTM 3N meters. The vertical datum used for the task order was referenced to NAVD 1988, meters, GEOID12B. A secondary LAS delivery was processed and delivered in WGS84 (G1674) UTM Zone 3N with ellipsoidal heights (GRS 80).

Section 4: Hydrologic Flattening

HYDROLOGIC FLATTENING OF LIDAR DEM DATA

AK Yukon Kuskokwim QL2 Lidar processing task order required the compilation of breaklines defining water bodies and rivers. The breaklines were used to perform the hydrologic flattening of water bodies, and gradient hydrologic flattening of double line streams and rivers. Lakes, reservoirs and ponds, at a minimum size of 2-acre or greater, were compiled as closed polygons. The closed water bodies were collected at a constant elevation. Rivers and streams, at a nominal minimum width of 30 meters (100 feet), were compiled in the direction of flow with both sides of the stream maintaining an equal gradient elevation.

LIDAR DATA REVIEW AND PROCESSING

Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing lidar data.

The compilation procedure included use of lidar intensity, bare earth surface model, point cloud data, and open source imagery in an effort to perform a primarily threshold-based object oriented semi-automated feature extraction to compile hydrologic features in a 2-d environment. The automated process does not provde as refined a hydrologic breakline as a manual effort, however in this type of terrain, the automated approach is the most practical. Following the compilation phase, a separate process was used to adjust the breakline data to best match the water level at the time of the lidar collection. Any ponds and/or lakes were adjusted to be at or just below the bank and to be at a constant elevation. Any streams were adjusted to be at or just below the bank and to be monotonic. Bridge breaklines were also compiled in an effort to generate an accurate DEM product. The final hydrologic and bridge breakline product was delivered in ESRI shape file format and was also used in the processing of the DEM deliverable. It is understood that due to the complexity of water features located witin the Kuskokwim Alaska project area, the breakline process as described, was necessary and will likely yield accuracy that is less than typically expected of breakline features on a 3DEP lidar project. Due to temporal issues related to tidally influenced streams within the AOI, water heights found in the interior of the project are occasionally higher than heights found along the coast. Occasionally, this will be evident in the digital elevation model.

The lakes, reservoirs and ponds, at a minimum size of 2-acre or greater and streams at a minimum size of 30 meters (100 feet) nominal width, were compiled to meet task order requirements. **Figure 4.1** illustrates an example of 30 meters (100 feet) nominal streams identified and defined with hydrologic breaklines. The breaklines defining rivers and streams, at a nominal minimum width of 30 meters (100 feet), were draped with both sides of the stream maintaining an equal gradient elevation.

All ground points were reclassified from inside the hydrologic feature polygons to water, class nine (9).

All ground points were reclassified from within a buffer along the hydrologic feature breaklines to buffered ground, class ten (10).

The lidar ground points and hydrologic feature breaklines were used to generate a new digital elevation model (DEM).

Figure 4.1: Example Hydrologic Breaklines

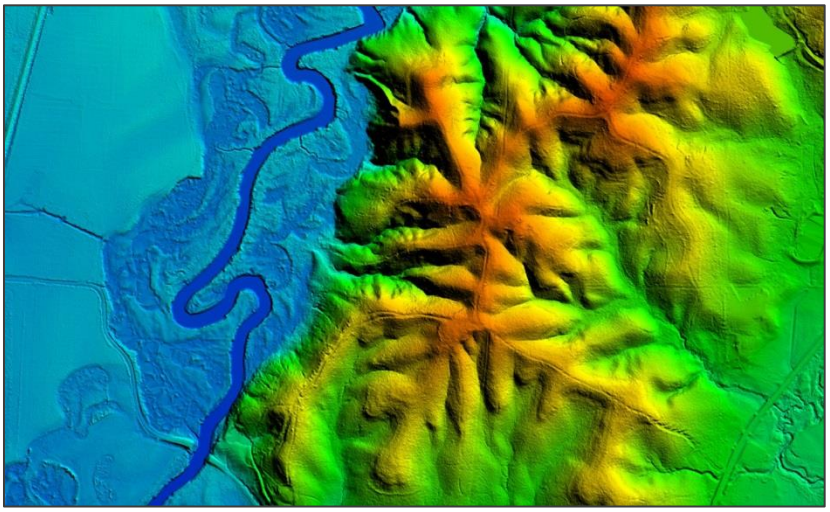


Figure 4.2 reflects a DEM generated from original lidar bare earth point data prior to the hydrologic flattening process. Note the "tinning" across the lake surface.

Figure 4.3 reflects a DEM generated from lidar with breaklines compiled to define the hydrologic features. This figure illustrates the results of adding the breaklines to hydrologically flatten the DEM data. Note the smooth appearance of the lake surface in the DEM.

Figure 4.2

Figure 4.3

Terrascan was used to add the hydrologic breakline vertices and export the lattice models. The hydrologically flattened DEM data was provided to USGS in ERDAS .IMG format.

The hydrologic breaklines compiled as part of the flattening process were provided to the USGS as an ESRI Geodatabase The breaklines defining the water bodies greater than 2-acre and for the gradient flattening of all rivers and streams at a nominal minimum width of 30 meters (100 feet) were provided as a Polygon-Z and Polyline-Z shape file, respectively.

DATA QA/QC

Initial QA/QC for this task order was performed in Global Mapper v15, by reviewing the grids and hydrologic breakline features. Additionally, ESRI software and proprietary methods were used to review the overall connectivity of the hydrologic breaklines.

Edits and corrections were addressed individually by tile. If a water body breakline needed to be adjusted to improve the flattening of the DEM data, the area was cross referenced by tile number, corrected accordingly, a new DEM file was regenerated and reviewed.

Section 5: ACCURACY ASSESSMENT

Accuracy Assessment

The vertical accuracy statistics were calculated by comparison of all lidar points to the ground surveyed QC points.

Table 5.1: Overall Vertical Accuracy Statistics		
Average error	+0.015	Meter
Minimum error	-0.167	Meter
Maximum error	+0.098	Meter
Average magnitude	0.035	Meter
Root mean square	0.044	Meter
Standard deviation	0.042	Meter

Table 5.2: RAW Swath Quality Check Point Analysis NVA

Point ID	Easting (Meter)	Northing (Meter)	Elevation (Meter)	TIN Elevation (Meter)	Dz (Meter)
1104	469675.972	6857030.965	3.596	3.600	0.004
1110	469989.640	6856890.776	3.768	3.720	-0.048
1112	470099.774	6856841.924	4.499	4.490	-0.009
1114	470104.548	6856753.975	4.717	4.710	-0.007
1122	469942.259	6856949.373	3.647	3.690	0.043
1124	469769.653	6857026.207	3.561	3.600	0.039
1126	469649.232	6857080.509	3.640	3.660	0.020
1128	469517.143	6857138.371	3.617	3.640	0.023
1130	469319.224	6857203.515	3.457	3.480	0.023
1132	469424.002	6857141.038	3.573	3.640	0.067
1134	469498.217	6857107.252	3.566	3.570	0.004
1136	469545.606	6856747.968	7.543	7.640	0.097
1140	469774.815	6856560.880	11.723	11.730	0.007
1142	469918.189	6856548.737	17.185	17.150	-0.035
1148	470210.033	6856405.277	38.507	38.510	0.003
1150	470176.183	6856319.890	42.903	42.910	0.007
1152	470124.326	6856392.452	40.847	40.770	-0.077
1154	470043.090	6856437.457	38.490	38.430	-0.060
1156	470038.791	6856423.013	40.042	40.030	-0.012
1158	470058.426	6856471.463	38.749	38.730	-0.019
2204	439456.418	6821160.445	3.298	3.200	-0.098
2208	441172.848	6821986.733	7.021	7.040	0.019

2214	441282.093	6821860.175	6.661	6.610	-0.051
2218	441353.424	6821747.189	5.280	5.270	-0.010
2222	441435.716	6821612.265	5.529	5.470	-0.059
2228	441576.369	6821623.532	6.356	6.310	-0.046
2232	441069.294	6822086.504	8.815	8.850	0.035
2236	440903.052	6821984.630	7.316	7.300	-0.016
2240	439373.645	6821289.215	4.095	4.040	-0.055
2244	439336.330	6821302.932	4.292	4.290	-0.002
2248	439367.495	6821249.757	4.282	4.220	-0.062
2252	439326.261	6821258.166	4.408	4.340	-0.068
2260	439216.398	6821270.174	4.277	4.110	-0.167
2304	467899.524	6822913.151	14.965	15.000	0.035
2308	467993.030	6823055.313	16.151	16.210	0.059
2314	468056.469	6823150.046	16.929	16.970	0.041
2320	468027.121	6823169.770	17.048	17.100	0.052
2324	467964.853	6823074.156	16.280	16.350	0.070
2328	467901.732	6822979.592	15.420	15.470	0.050
2336	467858.953	6822833.764	14.494	14.580	0.086
2402	467988.234	6822719.308	13.244	13.280	0.036
2406	468009.725	6822553.646	9.856	9.890	0.034
2412	468031.306	6822434.042	12.318	12.360	0.042
2416	468053.943	6822304.209	16.428	16.500	0.072
2422	468085.960	6822085.232	20.294	20.320	0.026
2426	468116.376	6821925.504	20.480	20.550	0.070
2504	519675.589	6755793.289	7.356	7.420	0.064
2508	519645.279	6755807.911	7.719	7.790	0.071
2512	519627.144	6755739.749	7.601	7.650	0.049
2524	519582.864	6755798.535	7.351	7.430	0.079
2528	519578.973	6755826.895	7.395	7.490	0.095
2532	519552.643	6755853.510	7.252	7.350	0.098
2536	519538.129	6755881.080	7.116	7.170	0.054
2544	519483.062	6755978.104	6.440	6.530	0.090
2604	519525.884	6755922.716	6.832	6.870	0.038
2608	519471.402	6756020.006	6.341	6.380	0.039
2614	519398.065	6756152.327	5.554	5.600	0.046
2620	519339.457	6756234.581	4.869	4.900	0.031
2624	519385.060	6756154.161	5.392	5.460	0.068
2630	519452.711	6756034.131	6.205	6.230	0.025
2700	525746.231	6961049.176	5.786	5.800	0.014
2704	525793.373	6960961.464	5.858	5.890	0.032
2708	525871.904	6960872.134	5.378	5.420	0.042

2714	525800.281	6960814.612	6.112	6.140	0.028
2718	525724.762	6960908.005	5.832	5.880	0.048
2722	525735.353	6960953.712	5.905	5.950	0.045
2804	525916.853	6961094.138	5.877	5.900	0.023
2808	525998.172	6961210.491	5.975	6.000	0.025
2814	525991.021	6961416.917	5.693	5.700	0.007
2820	526026.864	6961527.531	5.698	5.700	0.002
2824	526036.189	6961401.719	5.650	5.660	0.010
2828	526043.035	6961280.396	5.731	5.750	0.019
2834	526049.036	6961127.140	5.789	5.800	0.011
2840	525737.592	6960780.013	5.926	5.960	0.034
2844	525740.517	6960727.685	5.911	5.940	0.029
2900	514495.753	6950573.859	6.567	6.590	0.023
2904	514438.189	6950656.772	6.090	6.120	0.030
2910	514243.330	6950752.586	6.033	6.060	0.027
2916	514203.784	6950864.351	6.015	6.000	-0.015
2920	514201.993	6950752.781	5.894	5.870	-0.024
2924	514202.378	6950641.959	5.936	5.950	0.014
2930	514201.856	6950565.244	5.973	5.950	-0.023
2936	514400.649	6950584.393	5.371	5.350	-0.021
3000	514248.500	6950578.285	5.874	5.900	0.026
3004	514244.623	6950449.250	5.907	5.910	0.003
3008	514243.691	6950332.993	5.966	5.930	-0.036
3014	514243.385	6950159.163	5.932	5.970	0.038
3018	514203.690	6950041.856	5.996	5.960	-0.036
3024	514203.471	6950159.103	5.936	5.960	0.024
3028	514203.716	6950275.101	5.953	5.940	-0.013
3034	514203.944	6950391.035	5.991	5.950	-0.041
3040	514203.539	6950507.451	5.930	5.910	-0.020
3102	430347.867	6693832.532	15.930	15.940	0.010
3106	430253.025	6693853.933	16.077	16.100	0.023
3108	430276.211	6693797.707	15.712	15.730	0.018
3110	430304.423	6693744.213	15.307	15.270	-0.037
3112	430258.339	6693718.321	15.388	15.410	0.022
3114	430106.632	6693664.029	15.119	15.100	-0.019
3122	430222.675	6693657.492	15.432	15.470	0.038
3128	430379.122	6693730.010	15.432	15.440	0.008
3130	430452.192	6693759.006	15.289	15.310	0.021
3138	430396.432	6693770.490	15.605	15.620	0.015
3140	430341.852	6693754.279	15.565	15.570	0.005
3202	430344.480	6693890.172	15.634	15.670	0.036

3208	430519.666	6693909.432	15.214	15.220	0.006
3210	430577.305	6693915.422	14.980	14.990	0.010
3214	430699.374	6693943.604	14.703	14.740	0.037
3216	430758.672	6693960.654	14.806	14.830	0.024
3218	430815.816	6693972.470	14.946	14.960	0.014
3220	430874.192	6693965.171	15.294	15.320	0.026
3224	430855.084	6693974.277	15.373	15.400	0.027
3226	430796.028	6693975.210	15.045	15.060	0.015
3232	430620.361	6693926.612	14.809	14.840	0.031
3234	430561.188	6693919.752	15.087	15.110	0.023
3236	430503.604	6693912.570	15.456	15.510	0.054
3240	430443.570	6693907.280	15.544	15.540	-0.004
3244	430329.498	6693891.102	15.915	15.920	0.005

VERTICAL ACCURACY CONCLUSIONS

Raw Swath Non-Vegetated Vertical Accuracy (NVA) Tested 0.086 Meters Non vegetated vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported against 117 NVA points using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the TIN using all lidar points.

LAS Swath Non-Vegetated Vertical Accuracy (NVA) Tested 0.076 Meters Non vegetated vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported against 117 NVA points using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the TIN using ground lidar points.

Table 5.3: NVA Check Point Analysis DEM

Point ID	Easting (Meter)	Northing (Meter)	Elevation (Meter)	DEM Elevation (Meter)	Dz (Meter)
1104	469675.972	6857030.965	3.596	3.570	-0.026
1110	469989.640	6856890.776	3.768	3.750	-0.018
1112	470099.774	6856841.924	4.499	4.460	-0.039
1114	470104.548	6856753.975	4.717	4.710	-0.007
1122	469942.259	6856949.373	3.647	3.670	0.023
1124	469769.653	6857026.207	3.561	3.580	0.019
1126	469649.232	6857080.509	3.640	3.650	0.010
1128	469517.143	6857138.371	3.617	3.640	0.023
1130	469319.224	6857203.515	3.457	3.510	0.053
1132	469424.002	6857141.038	3.573	3.610	0.037
1134	469498.217	6857107.252	3.566	3.610	0.044
1136	469545.606	6856747.968	7.543	7.640	0.097
1140	469774.815	6856560.880	11.723	11.730	0.007
1142	469918.189	6856548.737	17.185	17.250	0.065

1148	470210.033	6856405.277	38.507	38.480	-0.027
1150	470176.183	6856319.890	42.903	42.900	-0.003
1152	470124.326	6856392.452	40.847	40.840	-0.007
1154	470043.090	6856437.457	38.490	38.480	-0.010
1156	470038.791	6856423.013	40.042	39.970	-0.072
1158	470058.426	6856471.463	38.749	38.730	-0.019
2204	439456.418	6821160.445	3.298	3.230	-0.068
2208	441172.848	6821986.733	7.021	7.060	0.039
2214	441282.093	6821860.175	6.661	6.560	-0.101
2218	441353.424	6821747.189	5.280	5.220	-0.060
2222	441435.716	6821612.265	5.529	5.480	-0.049
2228	441576.369	6821623.532	6.356	6.300	-0.056
2232	441069.294	6822086.504	8.815	8.800	-0.015
2236	440903.052	6821984.630	7.316	7.310	-0.006
2240	439373.645	6821289.215	4.095	4.060	-0.035
2244	439336.330	6821302.932	4.292	4.260	-0.032
2248	439367.495	6821249.757	4.282	4.240	-0.042
2252	439326.261	6821258.166	4.408	4.350	-0.058
2260	439216.398	6821270.174	4.277	4.190	-0.087
2304	467899.524	6822913.151	14.965	15.030	0.065
2308	467993.030	6823055.313	16.151	16.180	0.029
2314	468056.469	6823150.046	16.929	16.980	0.051
2320	468027.121	6823169.770	17.048	17.080	0.032
2324	467964.853	6823074.156	16.280	16.320	0.040
2328	467901.732	6822979.592	15.420	15.470	0.050
2336	467858.953	6822833.764	14.494	14.580	0.086
2402	467988.234	6822719.308	13.244	13.250	0.006
2406	468009.725	6822553.646	9.856	9.920	0.064
2412	468031.306	6822434.042	12.318	12.330	0.012
2416	468053.943	6822304.209	16.428	16.450	0.022
2422	468085.960	6822085.232	20.294	20.290	-0.004
2426	468116.376	6821925.504	20.480	20.550	0.070
2504	519675.589	6755793.289	7.356	7.430	0.074
2508	519645.279	6755807.911	7.719	7.810	0.091
2512	519627.144	6755739.749	7.601	7.610	0.009
2524	519582.864	6755798.535	7.351	7.410	0.059
2528	519578.973	6755826.895	7.395	7.490	0.095
2532	519552.643	6755853.510	7.252	7.340	0.088
2536	519538.129	6755881.080	7.116	7.180	0.064
2544	519483.062	6755978.104	6.440	6.570	0.130
2604	519525.884	6755922.716	6.832	6.880	0.048

2608	519471.402	6756020.006	6.341	6.350	0.009
2614	519398.065	6756152.327	5.554	5.590	0.036
2620	519339.457	6756234.581	4.869	4.900	0.031
2624	519385.060	6756154.161	5.392	5.500	0.108
2630	519452.711	6756034.131	6.205	6.230	0.025
2700	525746.231	6961049.176	5.786	5.790	0.004
2704	525793.373	6960961.464	5.858	5.880	0.022
2708	525871.904	6960872.134	5.378	5.440	0.062
2714	525800.281	6960814.612	6.112	6.130	0.018
2718	525724.762	6960908.005	5.832	5.810	-0.022
2722	525735.353	6960953.712	5.905	5.940	0.035
2804	525916.853	6961094.138	5.877	5.900	0.023
2808	525998.172	6961210.491	5.975	5.990	0.015
2814	525991.021	6961416.917	5.693	5.700	0.007
2820	526026.864	6961527.531	5.698	5.710	0.012
2824	526036.189	6961401.719	5.650	5.650	0.000
2828	526043.035	6961280.396	5.731	5.720	-0.011
2834	526049.036	6961127.140	5.789	5.790	0.001
2840	525737.592	6960780.013	5.926	5.960	0.034
2844	525740.517	6960727.685	5.911	5.950	0.039
2900	514495.753	6950573.859	6.567	6.550	-0.017
2904	514438.189	6950656.772	6.090	6.090	0.000
2910	514243.330	6950752.586	6.033	6.030	-0.003
2916	514203.784	6950864.351	6.015	5.960	-0.055
2920	514201.993	6950752.781	5.894	5.850	-0.044
2924	514202.378	6950641.959	5.936	5.910	-0.026
2930	514201.856	6950565.244	5.973	5.940	-0.033
2936	514400.649	6950584.393	5.371	5.360	-0.011
3000	514248.500	6950578.285	5.874	5.880	0.006
3004	514244.623	6950449.250	5.907	5.910	0.003
3008	514243.691	6950332.993	5.966	6.000	0.034
3014	514243.385	6950159.163	5.932	5.960	0.028
3018	514203.690	6950041.856	5.996	5.960	-0.036
3024	514203.471	6950159.103	5.936	5.940	0.004
3028	514203.716	6950275.101	5.953	5.920	-0.033
3034	514203.944	6950391.035	5.991	5.950	-0.041
3040	514203.539	6950507.451	5.930	5.910	-0.020
3102	430347.867	6693832.532	15.930	15.920	-0.010
3106	430253.025	6693853.933	16.077	16.090	0.013
3108	430276.211	6693797.707	15.712	15.720	0.008
3110	430304.423	6693744.213	15.307	15.250	-0.057

3112	430258.339	6693718.321	15.388	15.390	0.002
3114	430106.632	6693664.029	15.119	15.000	-0.119
3122	430222.675	6693657.492	15.432	15.470	0.038
3128	430379.122	6693730.010	15.432	15.430	-0.002
3130	430452.192	6693759.006	15.289	15.280	-0.009
3138	430396.432	6693770.490	15.605	15.620	0.015
3140	430341.852	6693754.279	15.565	15.570	0.005
3202	430344.480	6693890.172	15.634	15.650	0.016
3208	430519.666	6693909.432	15.214	15.230	0.016
3210	430577.305	6693915.422	14.980	15.000	0.020
3214	430699.374	6693943.604	14.703	14.740	0.037
3216	430758.672	6693960.654	14.806	14.820	0.014
3218	430815.816	6693972.470	14.946	14.960	0.014
3220	430874.192	6693965.171	15.294	15.300	0.006
3224	430855.084	6693974.277	15.373	15.370	-0.003
3226	430796.028	6693975.210	15.045	15.010	-0.035
3232	430620.361	6693926.612	14.809	14.850	0.041
3234	430561.188	6693919.752	15.087	15.110	0.023
3236	430503.604	6693912.570	15.456	15.490	0.034
3240	430443.570	6693907.280	15.544	15.520	-0.024
3244	430329.498	6693891.102	15.915	15.900	-0.015

VERTICAL ACCURACY CONCLUSIONS

Bare-Earth DEM Non-Vegetated Vertical Accuracy (NVA) Tested 0.086 Meters Non-Vegetated vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported against 117 NVA points using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM.

Table 5.4: VVA Quality Check Point Analysis DEM

Point ID	Easting (Meter)	Northing (Meter)	Elevation (Meter)	DEM Elevation (Meter)	Dz (Meter)
1106	469682.001	6857005.204	3.022	3.050	0.028
1118	470275.864	6856755.251	3.715	3.800	0.085
1120	470112.936	6856875.122	4.405	4.400	-0.005
1138	469565.489	6856748.700	5.087	5.160	0.073
1146	470102.646	6856494.589	27.745	27.830	0.085
2212	441242.021	6821908.899	7.396	7.520	0.124
2224	441457.734	6821602.032	5.544	5.600	0.056
2256	439231.324	6821368.828	4.803	4.840	0.037
2258	439160.468	6821348.239	5.081	5.070	-0.011
2262	439243.633	6821220.163	4.092	4.090	-0.002

2312	468050.558	6823122.447	14.591	14.660	0.069
2318	468041.312	6823234.207	15.954	16.000	0.046
2334	467825.521	6822879.395	13.712	13.820	0.108
2410	468037.702	6822466.251	10.269	10.300	0.031
2420	468060.849	6822158.318	19.610	19.690	0.080
2428	468115.437	6821871.504	19.071	19.140	0.069
2516	519619.912	6755716.609	6.517	6.590	0.073
2518	519634.179	6755747.514	7.047	7.070	0.023
2520	519584.236	6755771.628	6.224	6.370	0.146
2522	519593.877	6755779.306	7.377	7.410	0.033
2538	519521.477	6755877.991	5.450	5.450	0.000
2540	519508.892	6755912.165	5.609	5.650	0.041
2610	519452.946	6756071.916	5.273	5.400	0.127
2626	519399.783	6756100.312	4.068	4.210	0.142
2710	525880.051	6960822.696	4.720	4.760	0.040
2724	525721.361	6960900.272	5.040	5.140	0.100
2810	525980.308	6961283.970	4.676	4.660	-0.016
2816	525979.721	6961462.812	4.541	4.630	0.089
2832	526099.131	6961185.690	4.270	4.410	0.140
2836	526059.684	6961083.315	5.257	5.400	0.143
2848	525753.352	6960629.698	4.345	4.510	0.165
2906	514337.301	6950624.238	4.518	4.640	0.122
2912	514252.170	6950800.606	4.546	4.640	0.094
2928	514195.440	6950582.131	4.650	4.600	-0.050
2932	514302.516	6950578.768	4.370	4.290	-0.080
2938	514415.057	6950578.994	4.639	4.470	-0.169
3010	514259.299	6950283.418	3.191	3.240	0.049
3022	514163.076	6950094.572	3.113	3.220	0.107
3032	514193.653	6950361.440	4.238	4.170	-0.068
3038	514194.035	6950480.516	4.477	4.570	0.093
3118	430133.514	6693612.692	14.796	14.810	0.014
3120	430191.204	6693637.714	14.678	14.750	0.072
3126	430312.458	6693690.773	14.644	14.720	0.076
3136	430401.083	6693795.639	15.110	15.200	0.090
3212	430638.430	6693915.059	14.137	14.430	0.293
3222	430907.245	6693945.448	14.523	14.550	0.027
3230	430678.571	6693952.593	14.740	14.740	0.000
3238	430504.100	6693939.607	15.179	15.180	0.001
1106	469682.001	6857005.204	3.022	3.050	0.028
1118	470275.864	6856755.251	3.715	3.800	0.085
1120	470112.936	6856875.122	4.405	4.400	-0.005

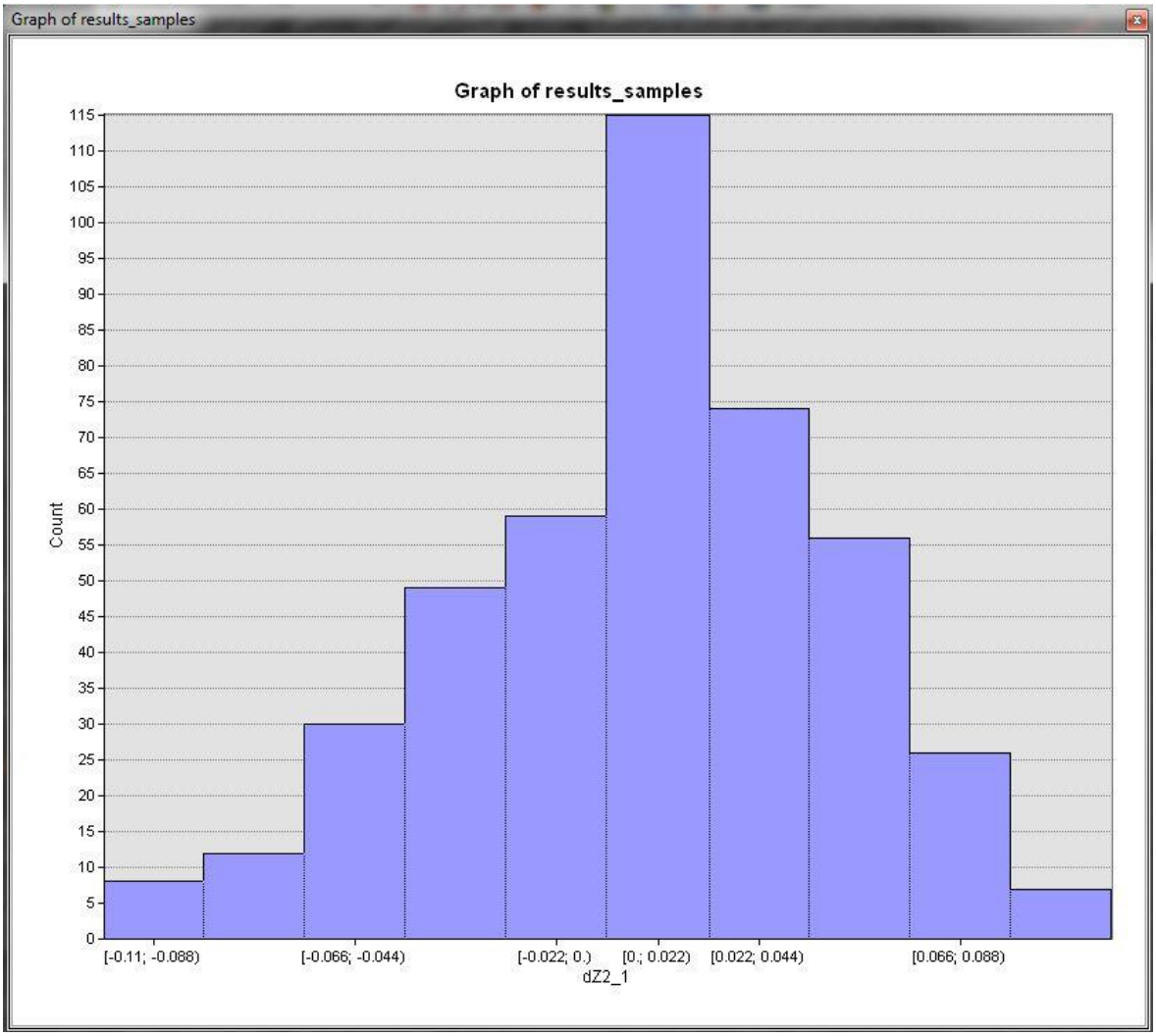
1138	469565.489	6856748.700	5.087	5.160	0.073
1146	470102.646	6856494.589	27.745	27.830	0.085
2212	441242.021	6821908.899	7.396	7.520	0.124
2224	441457.734	6821602.032	5.544	5.600	0.056
2256	439231.324	6821368.828	4.803	4.840	0.037
2258	439160.468	6821348.239	5.081	5.070	-0.011
2262	439243.633	6821220.163	4.092	4.090	-0.002
2312	468050.558	6823122.447	14.591	14.660	0.069
2318	468041.312	6823234.207	15.954	16.000	0.046
2334	467825.521	6822879.395	13.712	13.820	0.108
2410	468037.702	6822466.251	10.269	10.300	0.031
2420	468060.849	6822158.318	19.610	19.690	0.080
2428	468115.437	6821871.504	19.071	19.140	0.069
2516	519619.912	6755716.609	6.517	6.590	0.073
2518	519634.179	6755747.514	7.047	7.070	0.023
2520	519584.236	6755771.628	6.224	6.370	0.146
2522	519593.877	6755779.306	7.377	7.410	0.033
2538	519521.477	6755877.991	5.450	5.450	0.000
2540	519508.892	6755912.165	5.609	5.650	0.041
2610	519452.946	6756071.916	5.273	5.400	0.127
2626	519399.783	6756100.312	4.068	4.210	0.142
2710	525880.051	6960822.696	4.720	4.760	0.040
2724	525721.361	6960900.272	5.040	5.140	0.100
2810	525980.308	6961283.970	4.676	4.660	-0.016
2816	525979.721	6961462.812	4.541	4.630	0.089
2832	526099.131	6961185.690	4.270	4.410	0.140
2836	526059.684	6961083.315	5.257	5.400	0.143
2848	525753.352	6960629.698	4.345	4.510	0.165
2906	514337.301	6950624.238	4.518	4.640	0.122
2912	514252.170	6950800.606	4.546	4.640	0.094
2928	514195.440	6950582.131	4.650	4.600	-0.050
2932	514302.516	6950578.768	4.370	4.290	-0.080
2938	514415.057	6950578.994	4.639	4.470	-0.169
3010	514259.299	6950283.418	3.191	3.240	0.049
3022	514163.076	6950094.572	3.113	3.220	0.107
3032	514193.653	6950361.440	4.238	4.170	-0.068
3038	514194.035	6950480.516	4.477	4.570	0.093
3118	430133.514	6693612.692	14.796	14.810	0.014
3120	430191.204	6693637.714	14.678	14.750	0.072
3126	430312.458	6693690.773	14.644	14.720	0.076
3136	430401.083	6693795.639	15.110	15.200	0.090

3212	430638.430	6693915.059	14.137	14.430	0.293
3222	430907.245	6693945.448	14.523	14.550	0.027
3230	430678.571	6693952.593	14.740	14.740	0.000
3238	430504.100	6693939.607	15.179	15.180	0.001

VERTICAL ACCURACY CONCLUSIONS

Vegetated Vertical Accuracy (VVA) Tested 0.167 Meters at the 95th percentile reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM using 48 VVA points. VVA Errors larger than 95th percentile include:
Point 2938, Easting 514415.057, Northing 6950578.994, Z-Error 0.169 Meters
Point 3212, Easting 430638.430, Northing 6693915.059, Z-Error 0.293 Meters

Figure 5.1: LIDAR Relative Accuracy Histogram



RELATIVE ACCURACY ASSESSMENT AND CONCLUSION

Relative accuracy also known as "between swath" accuracy was tested through a series of well distributed flight line overlap locations. The relative accuracy for the AK Yukon Kuskokwim QL2 Lidar measured at 0.042 Meter RMSDz.

Approved by:	Name	Signature	Date
Associate Member, Lidar Specialist Certified Photogrammetrist #1381	Qian Xiao		April 2017

Section 6: Final Deliverables

The final lidar deliverables are listed below.

- LAS v1.4 classified point cloud
- LAS v1.4 raw unclassified point cloud flight line strips.
- Hydro Breaklines as ESRI Geodatabase
- Bridge Breaklines as ESRI Geodatabase
- Digital Elevation Model in ERDAS .IMG format
- Digital Model Elevation Mosaic in ERDAS .IMG format
- 8-bit gray scale intensity images in .TIF format
- Tile layout provided as ESRI shapefile
- Control Points provided as ESRI shapefile
- FGDC compliant metadata per product in XML format
- Lidar processing report in pdf format
- Survey report in pdf format