2018 Yukon
LiDAR
Data Capture and Processing

LiDAR Report

Our File:

2611 19372-01

Submitted To:

Transportation Engineering
Branch Government of the Yukon
Box 2703, Whitehorse, Yukon Y1A 2C6
Tel: (867) 633-7931

Attention: Michael Kearney CLS, P.Eng

Submitted By:
McElhanney Ltd.
100-780 Beatty Street
Vancouver, BC
V6B 2M1
Tel: (604) 424 4784
Fax: (604) 683-4350
Contact: Azadeh Koohzare, Ph.D., P.Eng.

April 5, 2019

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1. Introduction

The scope of this project was to acquire LiDAR and orthophoto mapping of various locations within the Yukon Territory, shown in Figures 1-3.

Coverage	LiDAR	Digital Orthophoto Imagery	Length of Corridor (km)	Area (square kilometres)
Top of the World Highway	Yes	Yes	105.7 km	106 sq. km
Sixty Mile Road	Yes	Yes	14.8 km	18 sq. km
Clinton Creek Road	Yes	Yes	34.0 km	36 sq. km
Klondike Highway	Yes	Yes	10.0 km	10 sq. km
Goldfield Roads	Yes	Yes	133 km	342 sq. km
Freegold_Road	Yes	Yes	81.0 km	194 sq. km
Grizzly valley Subdivision	Yes	Yes	---	4.5 sq. km
Whitehorse Polygons	Yes	No	---	182 sq.km

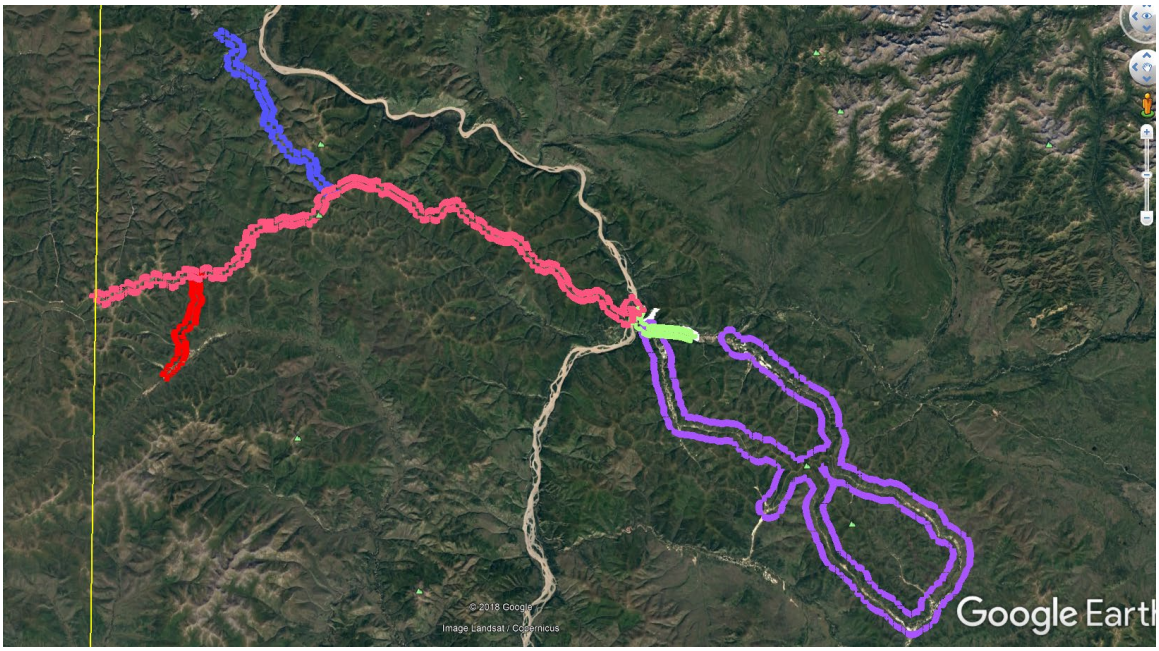

Figure 1– LiDAR Survey Site around Dawson City- Top of the world Hwy., Sixty Mile Rd., Klondike Hwy., Goldfield Rd. and Clinton Creek Rd.

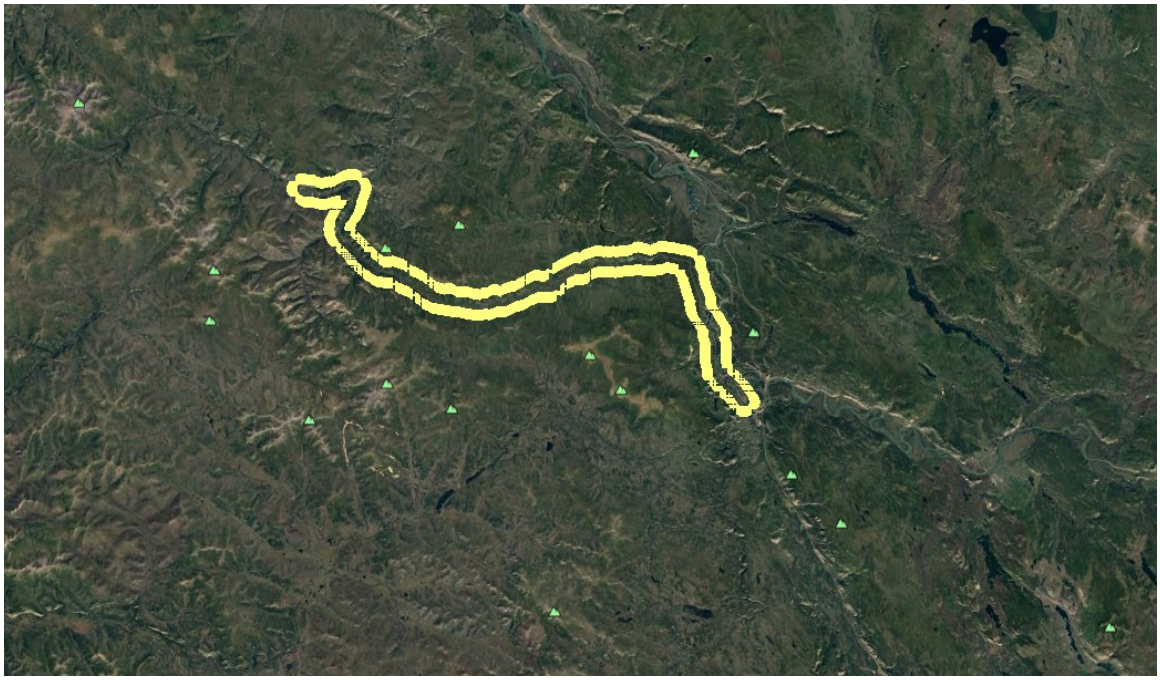

Figure 2- LiDAR Survey Site -Freegold Rd.

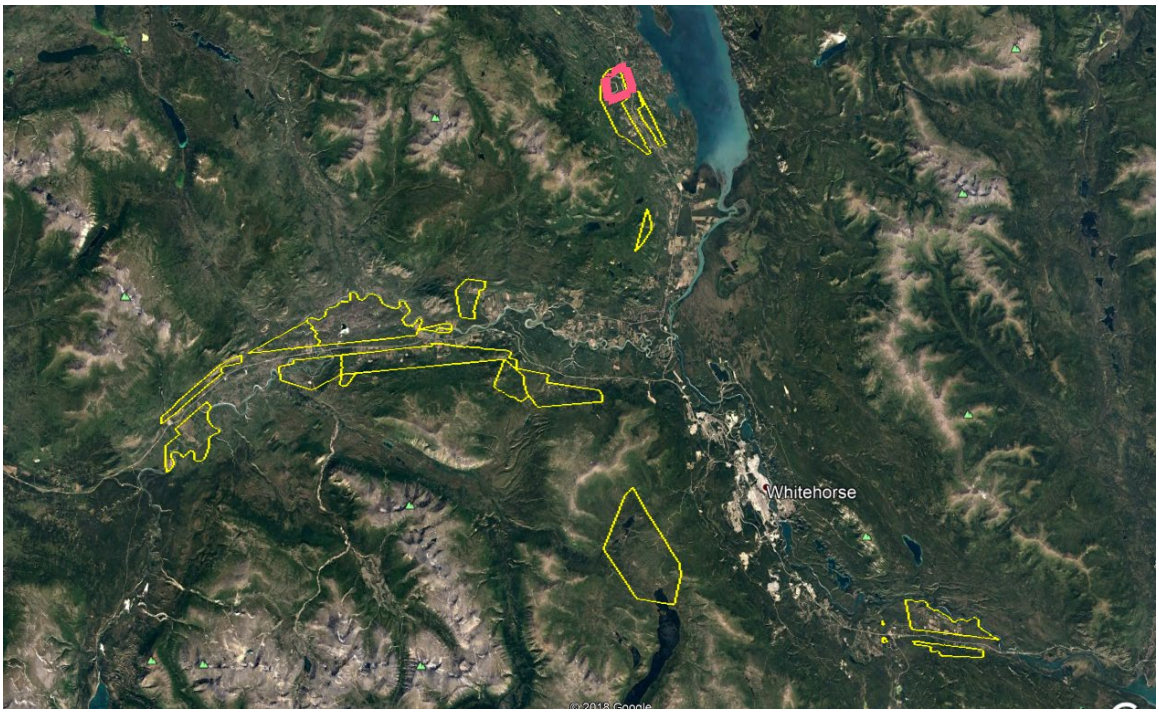

Figure 3- LiDAR Survey Site around Whitehorse

The sites were flown from September 19th, 2018 to September 29th, 2018. This report describes the acquisition, post-processing and quality control methodology used to produce the final elevation models.

2. Mission Plan

Project: 2018 Yukon LiDAR
Date: September 19th, 2018-September 29th, 2018
Location: Yukon
Topography: Various

3. LiDAR Acquisition

McElhanney utilized the Optech Galaxy system (Figure 4).
For Product Specifications of Optech Galaxy please see
http://www.teledyneoptech.com/index.php/product/optech-altm-galaxy/
The Galaxy was mounted on Piper Apache fixed wing Aircraft.

Figure 4 – Optech Galaxy components

4. Flight Plan

The following tables show the flight paratemets based on different missions (lift):

20180919

Strip ID	Start [s]	Stop [s]	Duration [s]	PRF [kHz]	Scan Frequency [Hz]	Scan Swath [deg]	Speed Avg [m/s]	Height Avg [m]
1	341889.8	342066.7	176.9	600	66	44	72.7	2023.5
2	342162.3	342336.4	174.1	600	66	44	78.1	2016.2
3	342446	342638.8	192.8	600	66	44	71	2025.9
4	342760.6	343000	239.4	600	66	44	77.3	2057.5
5	343140.4	343312.7	172.3	600	66	44	76	2089.7
6	343452.2	343511.5	59.3	600	66	44	72.1	2152.4
7	343621.1	343726.2	105	600	66	44	79.6	2160.9
8	343828.3	343948.3	120	600	66	44	74.2	2151.9
9	344058.9	344176	117.2	600	66	44	76.8	2141
10	344305.3	344408.4	103.2	600	66	44	73.9	2129.1
11	344684.2	345038.4	354.2	600	66	44	73.5	2310
12	345234.8	345778.6	543.7	600	66	44	77.2	2262.4
13	345878.9	346460.9	582	600	66	44	75	2264.7

20180921

Strip ID	Start [s]	Stop [s]	Duration [s]	PRF [kHz]	Scan Frequency [Hz]	Scan Swath [deg]	Speed Avg [m/s]	Height Avg [m]
1	502371.5	502947.8	576.4	600	66	44	77.1	2249.1
2	503066.8	503644.1	577.3	600	66	44	77.5	2239.9

3	503749.1	504328.3	579.2	600	66	44	76.5	2238.9
4	504879.3	504989.1	109.7	600	66	44	71.2	2168.3
5	505082.8	505206.5	123.7	600	66	44	76.5	2159.4
6	505318	505488.4	170.4	600	66	44	70.6	2192.5
7	505594.3	505706.8	112.5	600	66	44	76.4	2149.3
8	505806.1	505919.6	113.5	600	66	44	69.8	2174.2
9	506136.5	506229.5	92.9	600	66	44	78.5	2307.9
10	506327.9	506434.8	106.9	600	66	44	71.7	2277.5
11	506527.6	506620.5	92.9	600	66	44	77.6	2287.2
12	506701.2	506801.6	100.4	600	66	44	68.2	2309.6
13	506900	506985.5	85.5	600	66	44	74.3	2327.5
14	507186.6	507343.9	157.3	600	66	44	76.8	2167.2
15	507541.2	507739.6	198.4	600	66	44	72.8	2219.8
Strip ID	**Start [s]**	**Stop [s]**	**Duration [s]**	**PRF [kHz]**	**Scan Frequency [Hz]**	**Scan Swath [deg]**	**Speed Avg [m/s]**	**Height Avg [m]**
1	523365.6	523508	142.4	600	66	44	69.9	1985.6
2	523736.2	523843.1	106.9	600	66	44	75.3	1911.1
3	523991	524151.1	160.1	450	66	36	74	1944.5
4	524261.6	524430.1	168.5	450	66	36	75.1	1881.7
5	524554.7	524727.9	173.2	450	66	36	74.9	1886.5
6	525177.2	525686.4	509.2	450	66	36	76.7	2200.5
7	525833.4	526365.9	532.5	450	66	36	74	2180.9
Strip ID	**Start [s]**	**Stop [s]**	**Duration [s]**	**PRF [kHz]**	**Scan Frequency [Hz]**	**Scan Swath [deg]**	**Speed Avg [m/s]**	**Height Avg [m]**
1	509275.6	509615.9	340.2	600	66	44	74.1	2225.5
2	509716.1	509987.3	271.2	600	66	44	76.2	2175.6
Strip ID	**Start [s]**	**Stop [s]**	**Duration [s]**	**PRF [kHz]**	**Scan Frequency [Hz]**	**Scan Swath [deg]**	**Speed Avg [m/s]**	**Height Avg [m]**
1	511568.4	511902.1	333.7	100	40	50	74.6	2167.7
2	512008.9	512324.9	316	600	66	44	74.7	2135.1
3	512406.5	512691.7	285.2	600	66	44	73.9	2098.8
4	512804.1	512996	191.9	600	66	44	76.2	2083.2
5	513210.1	513269.4	59.3	600	66	44	77.7	2323.7
6	513361.3	513468.2	106.9	600	66	44	68.8	2231.5

7	513576	513673.6	97.6	600	66	44	78.6	2159.1
8	513790.7	513970.4	179.7	600	66	44	69.4	2168.2
9	514065	514167.3	102.3	600	66	44	77.9	2225.9
10	514379.6	514456.6	77	600	66	44	77.6	2333.3
11	514669.8	514802.9	133.1	600	66	44	81.2	1930.1
12	514902.3	515142.6	240.4	600	66	44	75.4	1959.2
13	515235.5	515506.6	271.2	600	66	44	71.2	1980
14	515620.9	515886.5	265.6	600	66	44	75.7	1999.9
15	516009.2	516267.3	258.1	600	66	44	78.4	2003.4
16	516443.2	516628.5	185.3	600	66	44	75.5	2014.6
17	516969.6	517190.4	220.8	600	66	44	82.7	2090.8
18	517482	517623.5	141.4	600	66	44	75.7	1994.6
19	517738.7	517890.4	151.7	600	66	44	78.1	1959.2
20	518002.8	518249.7	246.9	600	66	44	68.1	1973.4
21	518364	518527.9	163.9	600	66	44	77.5	1975.1
22	518628.2	518736.9	108.8	600	66	44	72.6	2008.4
23	518878.3	518882.5	4.3	600	66	44	88.8	1773
24	518953.9	518958.1	4.2	600	66	44	81	1591.5
20180929-a								
Strip ID	**Start [s]**	**Stop [s]**	**Duration [s]**	**PRF [kHz]**	**Scan Frequency [Hz]**	**Scan Swath [deg]**	**Speed Avg [m/s]**	**Height Avg [m]**
1	593395.2	593453.6	58.4	600	66	46	78.8	1712
2	593535.2	593679.5	144.3	600	66	46	71.7	1723.6
3	593769.5	593909.1	139.6	600	66	46	75.9	1721
4	594005.6	594120	114.4	600	66	46	70.4	1723.6
5	594212.8	594229.1	16.3	600	66	46	75.3	1725.4
20180929-b								
Strip ID	**Start [s]**	**Stop [s]**	**Duration [s]**	**PRF [kHz]**	**Scan Frequency [Hz]**	**Scan Swath [deg]**	**Speed Avg [m/s]**	**Height Avg [m]**
9	594592.7	594687.5	94.8	600	66	46	76.7	1726.4
10	594798	594870.4	72.4	600	66	46	75.1	1720.7
11	595202.2	595248.4	46.2	600	68	46	78	2270.7
12	595379.5	595647.9	268.4	600	68	46	77	2028.5
13	595751	596033.4	282.4	600	68	46	73.3	2046.2
14	596212.1	596452.5	240.4	600	68	46	76.9	2264.2
15	596554.6	596675.5	120.9	600	68	46	79.3	2331.5
16	596781.4	596887.4	106	600	68	46	78.8	2293
17	597065.1	597122.6	57.5	600	68	46	76.1	2320.3
18	597314.4	597497.8	183.4	600	66	46	79.7	2328.2

19	597645.7	597848.7	203	600	66	46	76.1	2327.9
20	597944.3	598139.9	195.6	600	66	46	78.8	2320.3
21	598285	598472.2	187.2	600	66	46	74.3	2322.2
22	598702.2	598795.2	92.9	600	66	46	80.8	2325.7
23	598981.3	599043.4	62.1	600	66	46	84.4	2299.3
24	599210	599428.9	218.9	600	66	46	77	2141.9
25	599514.2	599722	207.7	600	66	46	77.9	2154.3
26	599835.3	599953.4	118.1	600	66	46	76.4	2163.9
27	600057.4	600123.3	65.9	600	66	46	73.4	2292.1
28	600219.8	600518.1	298.3	600	66	46	78.7	2318.7
29	600609	600934.4	325.3	600	66	46	73.3	2330.5
30	601031.9	601336.6	304.8	600	66	46	78.4	2316.3
31	601439.7	601641.8	202.1	600	66	46	72.8	2328.9
32	601905.5	602031.1	125.6	600	66	46	72.6	2329.5
33	602126.7	602250.4	123.7	600	66	46	77.9	2325.6
34	602471.1	602639.6	168.5	600	66	46	75.5	2366.3
35	602736.1	602930.8	194.6	600	66	46	75	2382
36	603046	603242.5	196.5	600	66	46	75.9	2362.5
37	603361.5	603548.7	187.2	700	66	46	75.4	2323.6
38	603815.1	603913.6	98.5	600	66	46	75.5	2474.9
39	604085.8	604593.1	507.3	450	66	36	78.7	2207.3
40	604715.8	605247.4	531.6	450	66	36	76.3	2222
41	605363.5	605881.1	517.6	450	66	36	78.2	2198.6
42	606178.3	606260	81.7	450	66	36	76	2305.9

20180922								
Strip ID	**Start [s]**	**Stop [s]**	**Duration [s]**	**PRF [kHz]**	**Scan Frequency [Hz]**	**Scan Swath [deg]**	**Speed Avg [m/s]**	**Height Avg [m]**
1	589241.7	589342.1	100.4	600	66	46	72.5	2476.2
2	589501.2	589590.4	89.2	600	66	46	81.9	2432
3	589723.3	589828.4	105.1	600	66	46	72.5	2410.9
4	589906.2	590024.4	118.1	600	66	46	83.1	2444.1
5	590095.7	590258.6	162.9	600	66	46	63.3	2414.8
6	590316.9	590473.3	156.4	600	66	46	66.8	2402
7	590544.7	590697.3	152.7	600	66	46	66	2415.7
8	590760.3	590915.7	155.5	600	66	46	64.7	2391
9	591010.4	591127.6	117.2	600	66	46	74.4	2417.1
10	591285.7	591333.9	48.1	600	66	46	89.6	2185.5
11	591503.2	591647.5	144.2	600	66	46	72.1	2165

12	591736.5	591890.1	153.6	600	66	46	71.5	2187.6
13	591961.5	592119.7	158.2	600	66	46	69.5	2206.8
14	592212.5	592328.8	116.2	600	66	46	71	2234.1
15	592675.5	592756.3	80.8	600	66	46	65.1	2066.6
16	592864.9	593143.6	278.7	600	66	46	76.8	2073.7
17	593254.1	593586.9	332.8	600	66	46	65.8	2050.7
18	593724.5	593980.8	256.3	600	66	46	75.2	2063.8
19	594124	594427.9	303.8	600	66	46	65.8	2056.4
20	594536.6	594829.2	292.6	600	66	46	75.2	2054
21	594941.6	595275.4	333.7	600	66	46	65.3	2062.1
22	595371	595624.4	253.4	600	66	46	77.1	2052.4
23	595737.8	596008	270.3	600	66	46	65.8	2049.3
24	596124.2	596323.5	199.3	600	66	46	78.1	2055.9
25	596448.1	596662.3	214.2	600	66	46	65.9	2060.8
26	596864.3	596998.3	134	600	66	46	69	2049.5
27	597285.2	597330.6	45.3	600	66	46	63.2	2053.1
28	597449.5	597544.3	94.8	600	66	46	75.9	2071.2
29	597699.7	597815.9	116.3	600	66	46	63.2	2065.4
30	597923.7	598011	87.3	600	66	46	79.5	2084.9
31	598111.3	598221	109.7	600	66	46	61.9	2094.4
32	598335.3	598487	151.7	600	66	46	77.9	2100
33	598598.5	598780.1	181.6	600	66	46	62.9	2141.3
34	598893.4	598983.5	90.1	600	66	46	71.6	2065.8
35	599464.6	599531.4	66.8	600	66	46	75.6	2151.7
36	599639.2	599735.8	96.6	600	66	46	55.1	2217.7
37	599933.1	600001.8	68.7	600	66	46	81	2333.2
38	600278.5	600339.7	61.2	600	66	46	78.3	2055.3
39	600918.8	601027.5	108.8	600	66	46	68.1	2132.9
40	601142.8	601355.1	212.4	600	66	46	53.2	2078.2
41	601465.7	601630.5	164.8	600	66	46	69.3	2057.9
42	601748.5	601878.8	130.2	600	66	46	70	2045.5
43	601978.1	602091.6	113.5	600	66	46	70.7	2067.6
44	602239.4	602296	56.5	600	66	46	61.9	2061.3
45	602334.6	602396.8	62.1	600	66	46	53.1	2112.7
46	602554.9	602633.8	78.9	600	66	46	75.6	2039.9
20180924								
Strip ID	**Start [s]**	**Stop [s]**	**Duration [s]**	**PRF [kHz]**	**Scan Frequency [Hz]**	**Scan Swath [deg]**	**Speed Avg [m/s]**	**Height Avg [m]**
1	158152.1	158273	120.9	600	66	46	76.4	2143.2
2	158353.7	158509.2	155.5	600	66	46	65.9	2081

3	158587	158727.6	140.5	600	66	46	69.4	2092.9
4	158808.3	158943.2	134.9	600	66	46	68.4	2160.4
5	159026.6	159114	87.3	600	66	46	74.6	2212.8
6	159302	159382.8	80.8	600	66	46	65.5	2136.3
7	159501.7	159506.9	5.2	600	66	46	92.3	1763.6
20180925								
Strip ID	**Start [s]**	**Stop [s]**	**Duration [s]**	**PRF [kHz]**	**Scan Frequency [Hz]**	**Scan Swath [deg]**	**Speed Avg [m/s]**	**Height Avg [m]**
1	252183.6	252472.5	288.9	600	66	46	77.3	1924
2	252561.6	252859.8	298.3	600	66	46	77.7	1914.8
3	252963.8	253270.5	306.6	600	66	46	76.7	1913.4
4	253360.5	253666.2	305.7	600	66	46	77.8	1931
5	253740.4	254029.3	288.9	600	66	46	76.1	1985.8
6	254264.9	254344.8	79.8	600	66	46	75.5	2076.5
7	254455.3	254560.4	105	600	66	46	80.2	1928.3
8	254974.3	255102.6	128.4	500	66	36	78.2	2498.3
9	255234.7	255547.8	313.2	500	66	36	78.3	2214.2
10	255652.8	255966	313.2	500	66	36	78.7	2213.5
11	256138.1	256552.1	414	500	66	36	79.7	2178.7
12	256655.2	256970.3	315.1	500	66	36	76.8	2204.5
13	257069.6	257324.9	255.3	500	66	36	77.6	2191.8
14	257411.2	257591.9	180.6	500	66	36	74.9	2228.9
15	257775.2	257846.7	71.4	500	66	36	74	2337.9
16	258055.2	258310.5	255.3	550	60	40	75.3	2364.4
17	258409	258654	245.1	550	60	40	81.7	2361.5
18	259086.6	259152.4	65.8	600	66	46	72.6	2250.3
19	259250.8	259337.2	86.4	600	66	46	81.2	2179.5
20	259443.1	259579	135.8	600	66	46	75.6	2023.7
21	259667.1	259770.3	103.2	600	66	46	75.9	2111.9
22	259879.9	259995.2	115.3	600	66	46	67.4	2269.9
23	260161.8	260294.8	133	550	66	40	72	2179.4
24	260390.4	260528.2	137.7	550	66	40	73.9	2183.4
25	260616.3	260754	137.7	550	66	40	75.8	2163.9
26	260868.3	261003.2	134.9	550	66	40	75.9	2141.1
27	261109.1	261235.6	126.5	550	66	40	77.4	2120.7
28	261465.7	261752.7	287	550	60	40	79.8	2373
29	261853	262133.5	280.5	550	60	40	71.8	2407.9
30	262231.9	262471.4	239.5	550	60	40	77.8	2452
31	262579.1	262761.7	182.5	550	60	40	71.7	2514.9
32	262908.6	262985.7	77	550	60	40	76	2533.1

33	263226	263468.2	242.2	550	60	40	82.5	2364
20180926								
Strip ID	**Start [s]**	**Stop [s]**	**Duration [s]**	**PRF [kHz]**	**Scan Frequency [Hz]**	**Scan Swath [deg]**	**Speed Avg [m/s]**	**Height Avg [m]**
1	336905.9	337075.3	169.5	600	66	44	77.8	2154.6
2	337151.3	337327.3	176	600	66	44	80.2	2111.9
3	337425.7	337618.5	192.8	600	66	44	73.7	2130
4	337696.4	337854.7	158.2	600	66	44	77.8	2089.6
5	337990.4	338050.7	60.3	600	66	44	72.3	2117.3
6	339812.3	339902.4	90.1	600	66	44	78.8	2342.9
7	339987.8	340088.1	100.4	600	66	44	82.2	2323.5
8	340179.1	340287.9	108.8	600	66	44	74.6	2340.9
9	340394.7	340492.3	97.6	600	66	44	78.4	2390.4
10	340628	340688.3	60.2	600	66	44	75.7	2341.5

5. Data Processing

All GPS and IMU data was processed using PostPac MMS 8.2 software. The laser data was extracted using Teledyne Optech LMS software. The GPS antenna position in the airplane was calculated by post–processing the raw data at 1 second intervals for the entire flight.

We have post-processed the airborne trajectory using Whitehorse ACP and Precise Point Positining (PPP).

The airborne positions were combined with the post–processed platform attitude information to generate a time tagged position and orientation solution.

The standard deviation of the airborne GPS solution for using KAR (Kinematics Ambiguity Resolution) was estimated to be 0.03, 0.04 and 0.05m in East, North and height directions, respectively.

The estimated values for the GPS antenna position were used with the laser ranges and platform angles to compute all the individual X, Y, and Z coordinates for each laser return in each flight line. The result is a processed point cloud containing all measured points.

6. Point Density

Bare earth point density varies with canopy closure, understory density and topographic features. Mean density of the Full Feature (FF) and Bare Earth (BE) for different area were measured.

Freegold Point density: FF: 11.5 pts/m² BE: 3.8 pts/m²	**Top of the world hwy, Sixy Mile Rd., Clinton Creek Rd., Klondike Hwy and Goldfield Rds** Point density: FF: 10.7 pts/m² BE: 4.1 pts/m²
Whitehorse and Grizzly Point density: FF: 10.1 pts/m² BE: 4.2 pts/m²	**Datlaska** Point density: FF: 10 pts/m² BE: 4.6 pts/m²
Takhini Point density: FF: 11.3 pts/m² BE: 4.1 pts/m²	

7. Calibration

System: Optech ALTM Galaxy S/N 5060392
LiDAR Calibration flight: 20180808_springbank

Calibration Date: 2018-08-08 Location: Springbank, AB

The LiDAR system calibration was flown over Springbank, AB. The lever arms (offset between GPS antenna IMU and Laser Mirror), were measured as:

Lever Arms

GPS Lever arms in (m):
x: 0.75 y: -0.48 z: -1.192

IMU Lever arms in (m): x: 0 y: 0 z: 0

There were a total number of 13 flight lines for calibration: 12 basic orthogonal lines for LMS software analysis and 1 redundant line for better accuracy. The lines were planned as follow:
Flight line direction: 5 lines north – south and 7 lines east – west and 1 line NW-SE

All GPS and IMU data was processed using POSPac Applanix software v.8.0. and the laser data was extracted using LMS v.4.2.0. The GPS antenna position in the airplane was calculated by post–processing the raw data at 1 second intervals for the entire flight. We have used Chilliwack ACP for the airborne GPS processing, and the coordinates were calculated in NAD83-CSRS. The boresight correction are as follow:

```
imu_ex: 0.046134033025998535 rad
imu_ey:-0.04690775593678837 rad
imu_ez:-0.13995240064194475 rad
```

8. Quality Control

The LiDAR data consistencies have been checked between the flight lines using Terrascan software. We compared the 2018 LiDAR data vs older LiDAR data in the area with ground survey points and adjust the 2018 LiDAR to match with the old data where there were overlap.

Comparison of Bare Earth LiDAR data with Ground Survey Values

According to ASPRS guidelines, the vertical accuracy of LiDAR is as follows:

$$RMSE_z = Sqrt[\sum (Z_{Lidar(i)} - Z_{check(i)})^2 / n] = 0.14 \text{ m}$$

Where the ”Check” refers to the ground truth (In this project, we used survey points which are at least three times more accurate than the individual LiDAR points) and *n* is

the number of check points. We have 1146 Kinematics GPS ground survey points from 2014 survey work for check.

Average dz -0.064 m
Minimum dz -0.517 m
Maximum dz +0.511 m
Average magnitude 0.110 m
Root mean square 0.141 m
Std deviation 0.126 m

9. Deliverables

Final output data is provided in NAD83-CSRS UTM and the elevations are based on CGVD28- Ht2 geoid model. The deliverables include:

- Digital Terrain Model 1 m contour (AUTOCAD).
- Bare Earth terrain files in DWG
- Metadata for each road
- Orthophotography with 15 cm resolution ECW format andGeoTiff
- Intensity images files in ECW and Tiff formats for areas with no orthophoto
- Classified Bare Earth and Non-Bare Earth LAS and ASCII XYZfiles
- Model Key Point files consisting of filtered LAS files used tocreate a tin model of the classified Bare Earth provided in andASCII XYZ file format.
- LiDAR derived feature extraction of road centrelines, shoulders,ditch lines, treelines and edges of waterbodies.
- Shape files with the orthophoto image footprints in pdf format,labelled with km posts and imagery file names.
- Technical report