Municipality Of Anchorage (MOA) Anchorage, Alaska

LiDAR Mapping Report

Prepared by:

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Merrick & Company Job Number: 65218797

EXECUTIVE SUMMARY

Merrick & Company (Merrick) was contracted by the Municipality Of Anchorage (MOA) to perform a LiDAR (**Li**ght **D**etection **A**nd **R**anging) survey in and around the Anchorage, Alaska covering an area of approximately 957 square miles.

The targeted density of the LiDAR point cloud was planned at a minimum of two points per square meter (2ppsm) and four points per square meter (4ppsm). This Nominal Point Spacing (NPS) equates to approximately 2.32' (0.71m).

The vertical accuracy requirements of the LiDAR data meets the following:

- Vertical accuracy
  - 10cm $RMSE_Z$ (Vertical Accuracy = 9.25cm in the interest of meeting a 1 foot contour accuracy specification).

CONTACT INFORMATION

Questions regarding this report should be addressed to:

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Project Completion Report for Muncipality Of Anchorage

The contents of this report summarize the methods used to establish the GPS base station network, perform the LiDAR data collection and post-processing as well as the results of these methods.

LiDAR FLIGHT and SYSTEM REPORT

Project Location

The acquisition area for the Municipality Of Anchorage (MOA) project is defined by the shapefile: AOI_Level_v2.shp.

Duration/Time Period

One LiDAR aircraft, operated by McElhanney, was used to collect the LiDAR data. LiDAR data was collected on May 10, 2015 thru May 31, 2015. Merrill Field Airport (MRI) was used as the airport of operation.

Flight Mission Date and Times

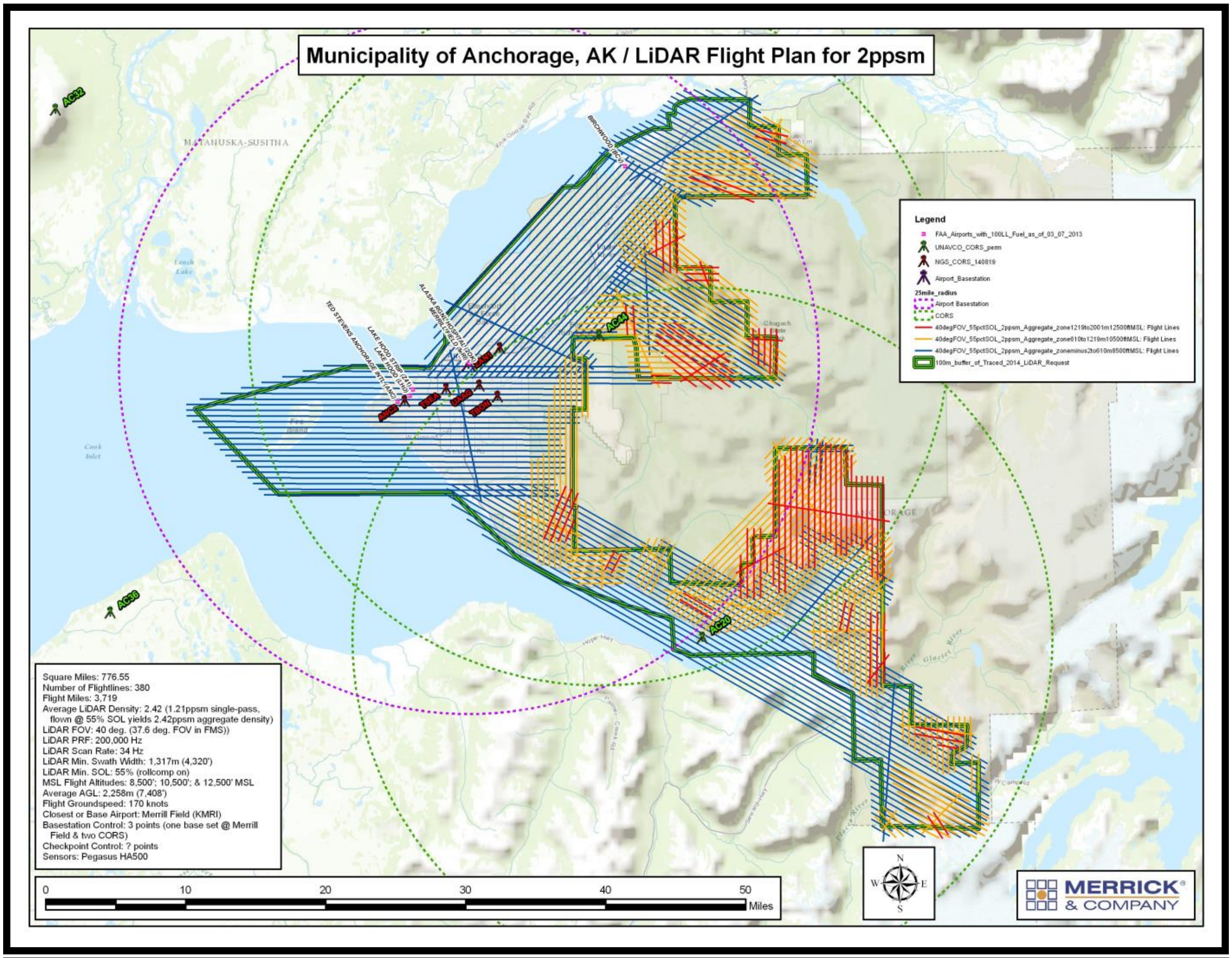
Mission	Date	Sensor	Start Time GPS sec.	End Time GPS sec.	Duration sec.	Number of GNSS Solution Records
150510_A	May 10, 2015	SN7183	67286.5	84348.5	17062.0	34124
150510_B	May 10, 2015	SN7183	86221.5	97818.0	11596.5	23193
150511_A	May 11, 2015	SN7183	151285.5	162801.5	11516.0	23032
150512_A	May 12, 2015	SN7183	238820.0	257481.0	18661.0	37322
150513_A	May 13, 2015	SN7183	259628.5	274773.5	15145.0	30290
150513_B	May 13, 2015	SN7183	319883.0	339589.0	19706.0	39412
150513_C	May 13, 2015	SN7183	342048.5	357472.5	15424.0	30848
150530_A	May 30, 2015	SN7183	584657.0	1058.5 **GPS Week Rollover**	21201.5	42403
150531_A	May 31, 2015	SN7183	3579.5	14849.5	11270.0	22540
150531_B	May 31, 2015	SN7183	61653.5	81570.0	19916.5	39833

Field Work / Procedures

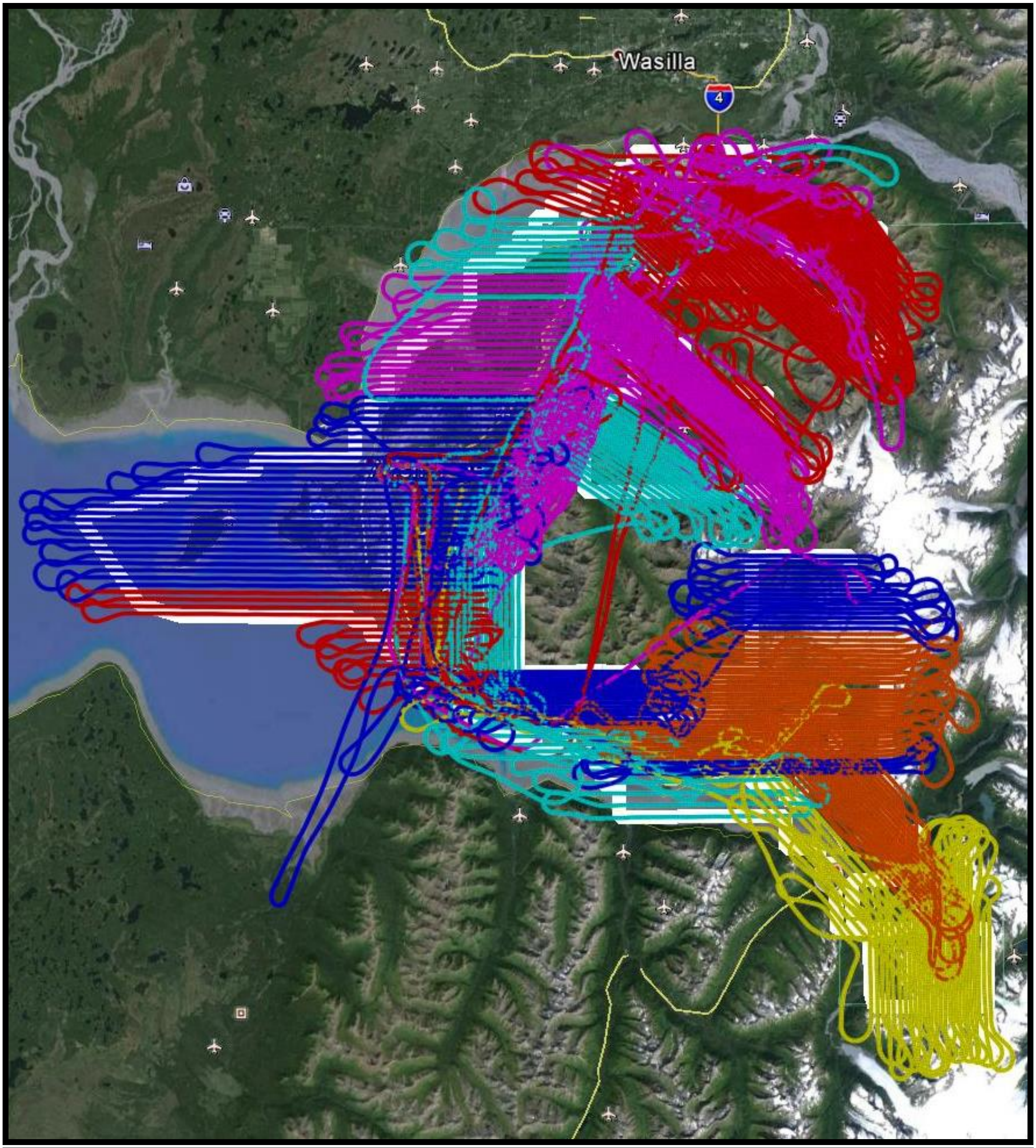
Pre-flight checks such as cleaning the sensor head glass are performed. A five minute INS initialization is conducted on the ground, with the aircraft engines running, prior to the flight mission. To establish fine-alignment of the INS GPS, ambiguities are resolved by flying within ten kilometers of the GPS Base Stations and CORS (Continually Operating Reference Stations). During the data collection, the operator recorded information on log sheets which includes weather conditions, LiDAR operation parameters, and flight line statistics. Near the end of the mission, GPS ambiguities are again resolved by flying within ten kilometers of the GPS Base Stations and CORS (Continually Operating Reference Stations) to aid in post-processing or the Applanix Smart Base processing method is applied utilizing CORS in the vicinity of the flight lines.

During each flight, the system operator monitored all aspects of the LiDAR data capture with the onboard flight control software. PDOP is monitored using the onboard flight management system. Unexpected PDOP spikes are noted and flight lines are re-flown accordingly. The altitude, speed, and attitude of the aircraft are constantly monitored. Real time monitoring of the laser data provides immediate indication of data quality including swath overlap to confirm coverage. In addition, the laser files are checked for validity immediately following the completion of each flight line. In the unlikely event errors are found in the stored laser file, the corresponding flight line is re-flown.

Planned Flight Line Diagram

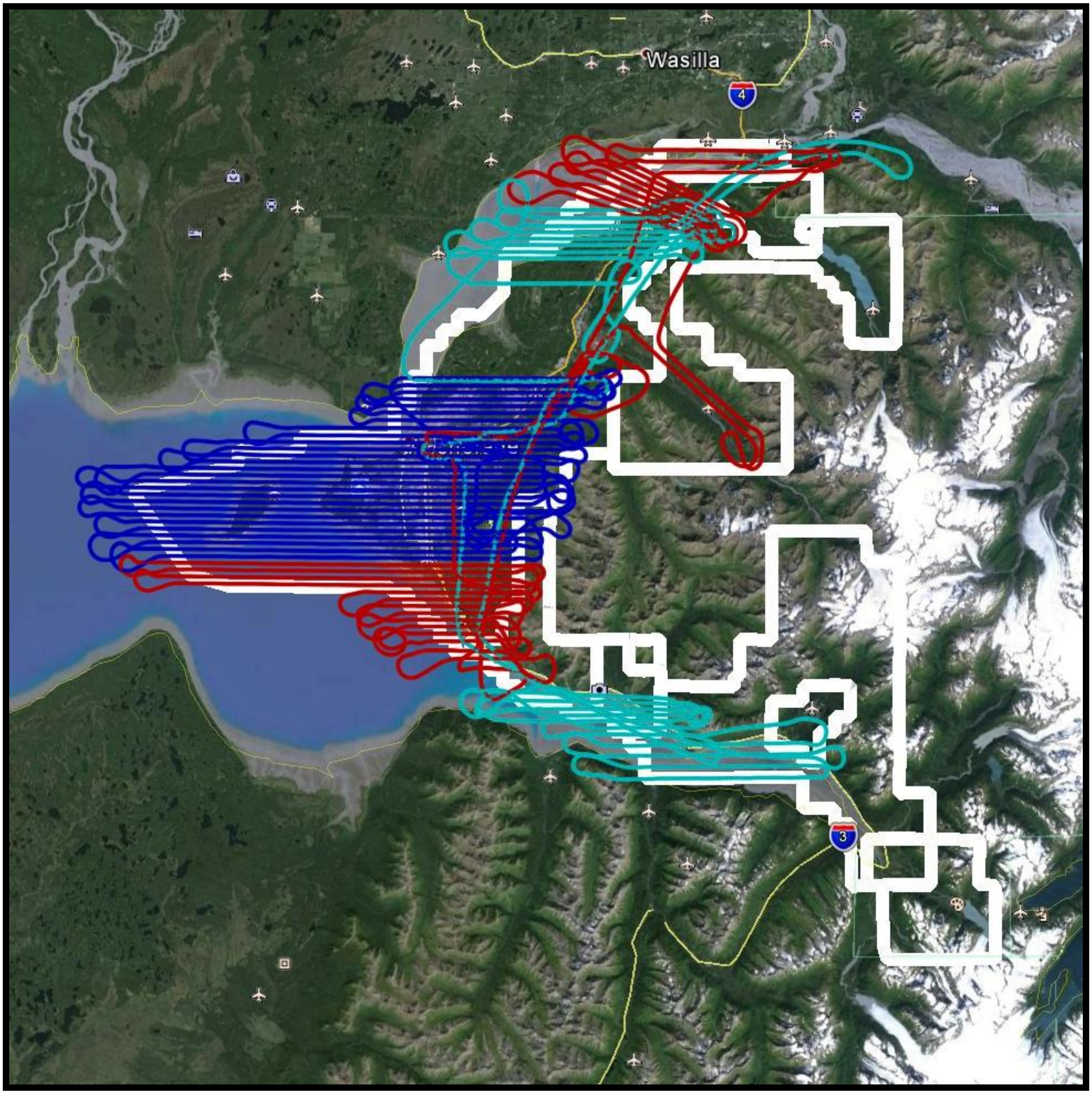


Actual Flight Lines colored mission by mission All



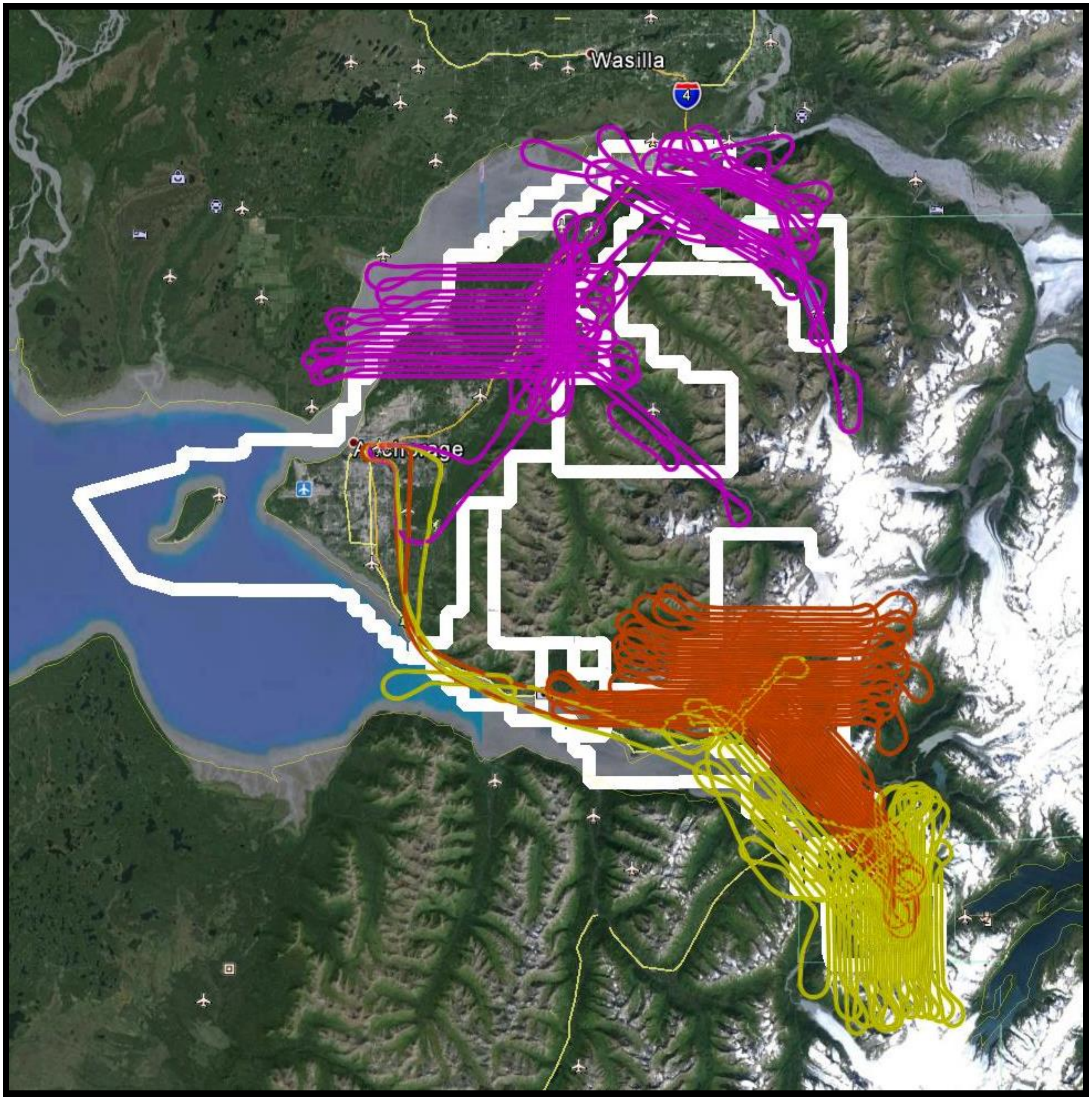
Actual Flight Lines colored mission by mission_Detail_1

Mission	Date	Color
150510_A	May 10, 2015	Blue
150510_B	May 10, 2015	Red
150511_A	May 11, 2015	Cyan



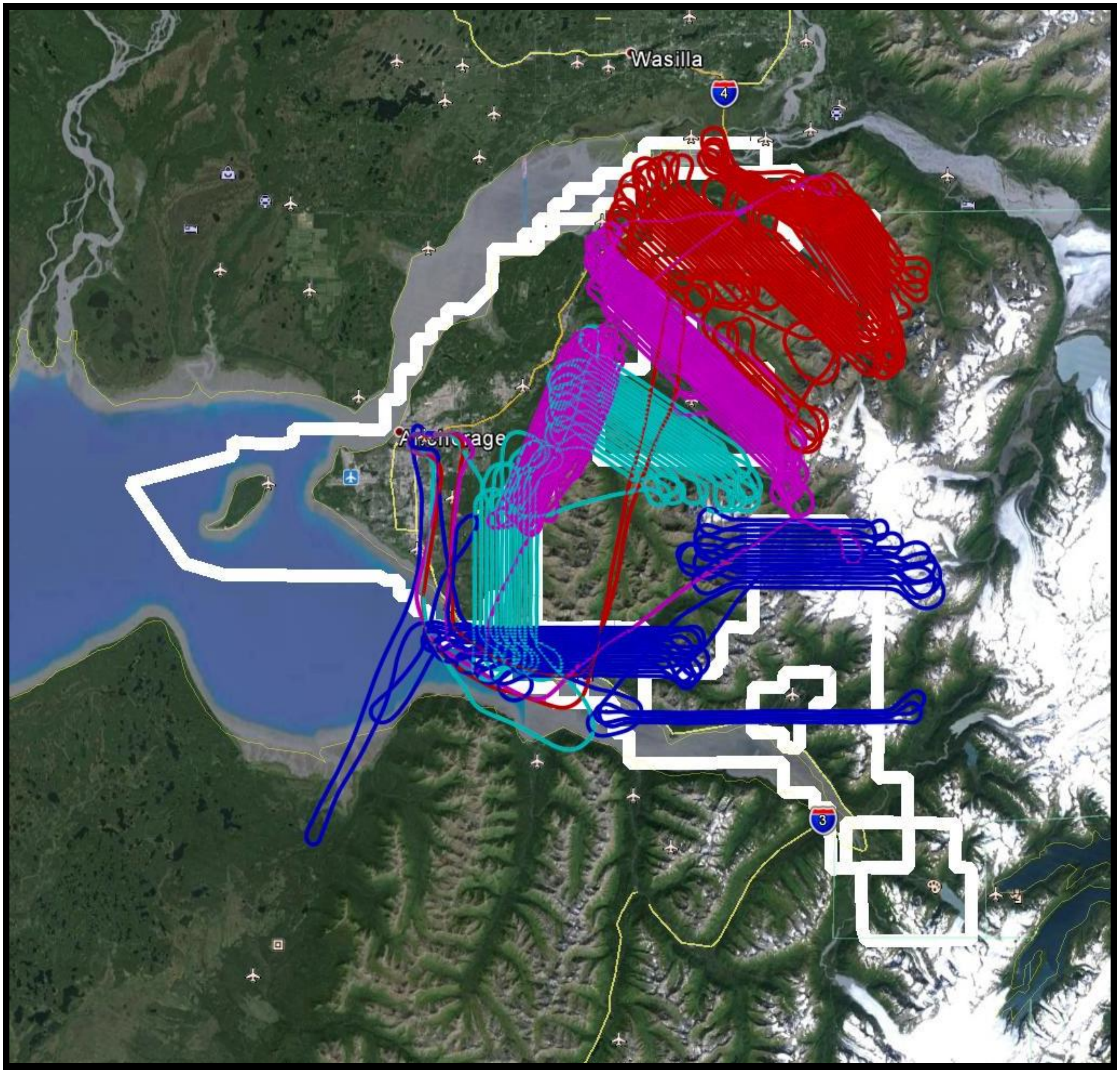
Actual Flight Lines colored mission by mission Detail_2

Mission	Date	Color
150512_A	May 12, 2015	Magenta
150513_A	May 13, 2015	Yellow
150513_B	May 13, 2015	Orange

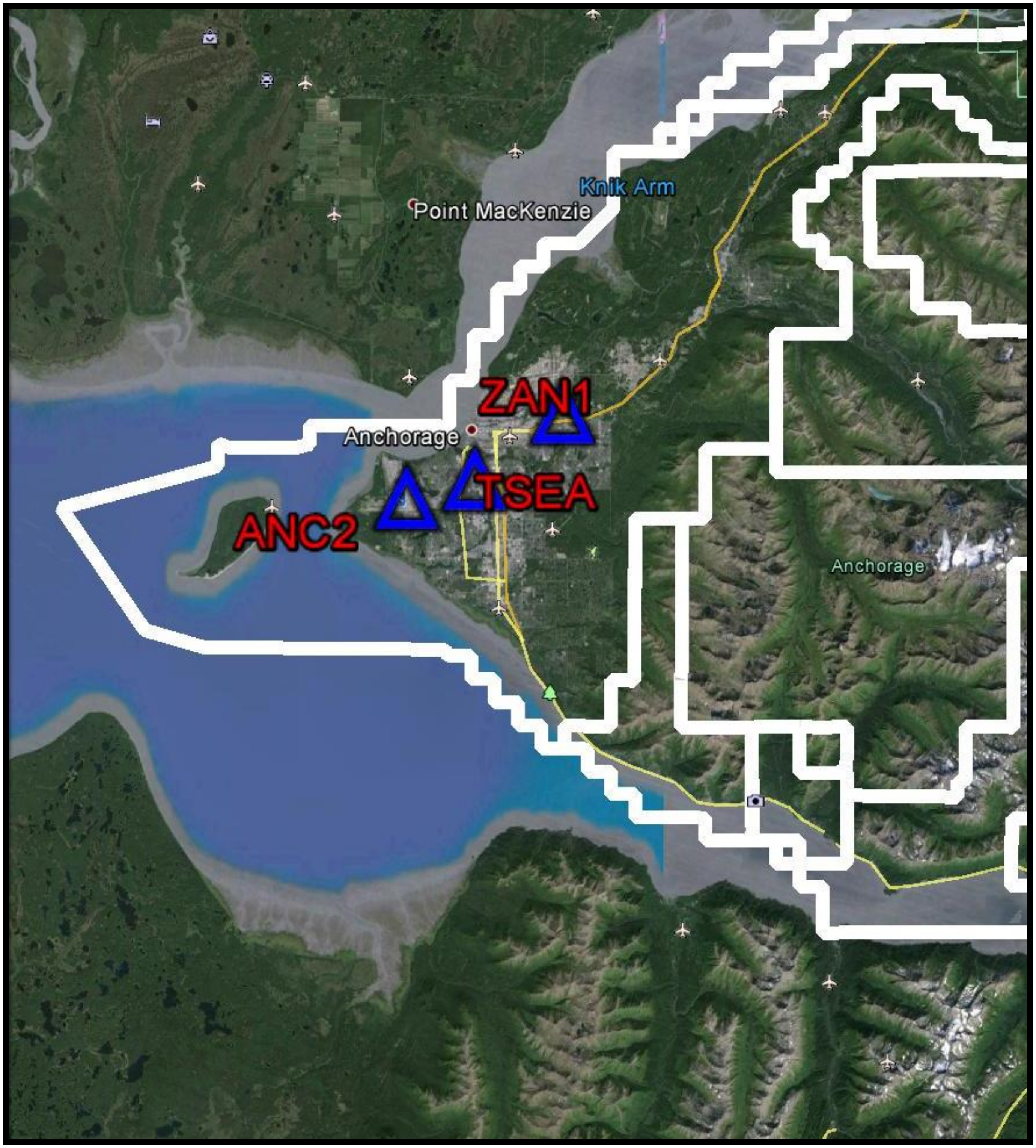


Actual Flight Lines colored mission by mission Detail_3

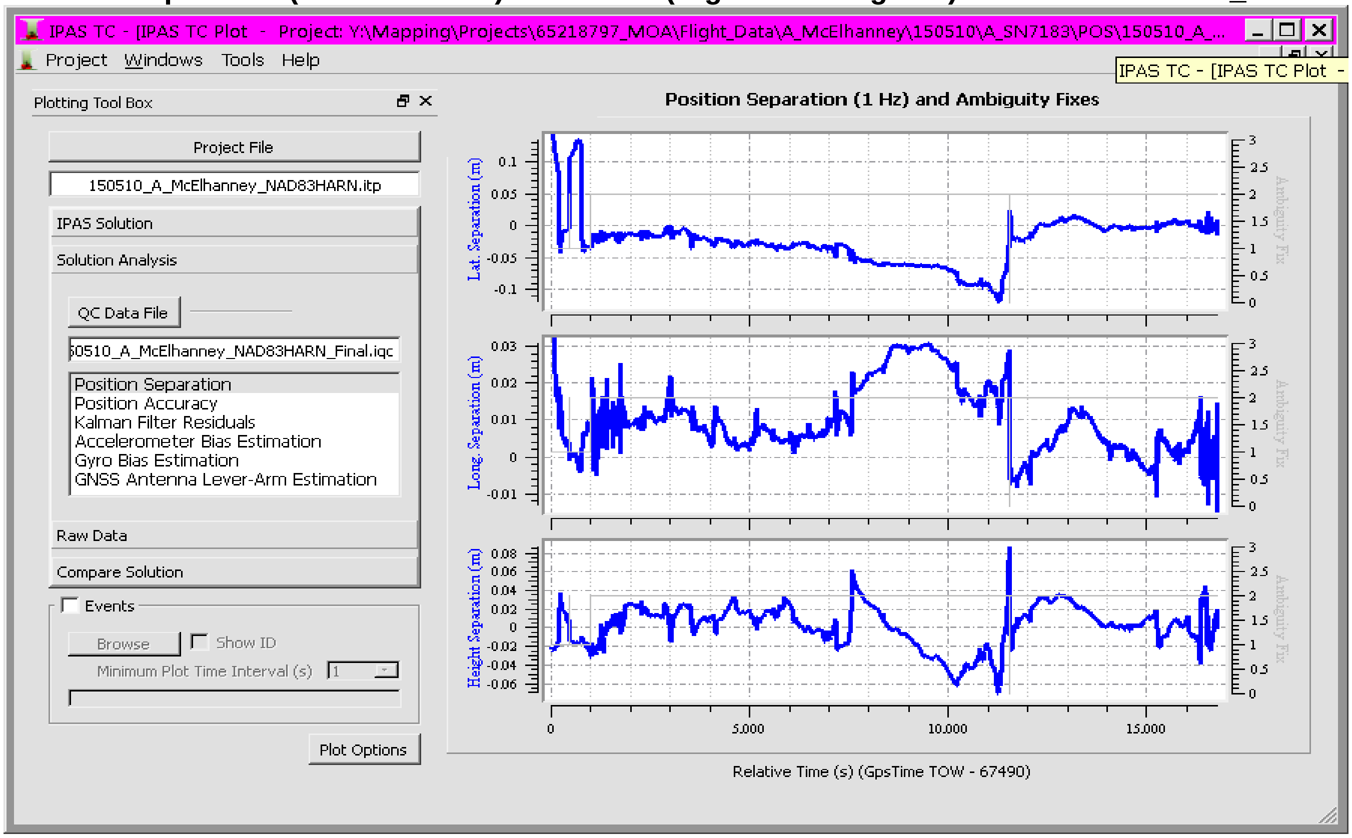
Mission	Date	Color
150513_C	May 13, 2015	Blue
150530_A	May 30, 2015	Red
150531_A	May 31, 2015	Cyan
150531_B	May 31, 2015	Magenta

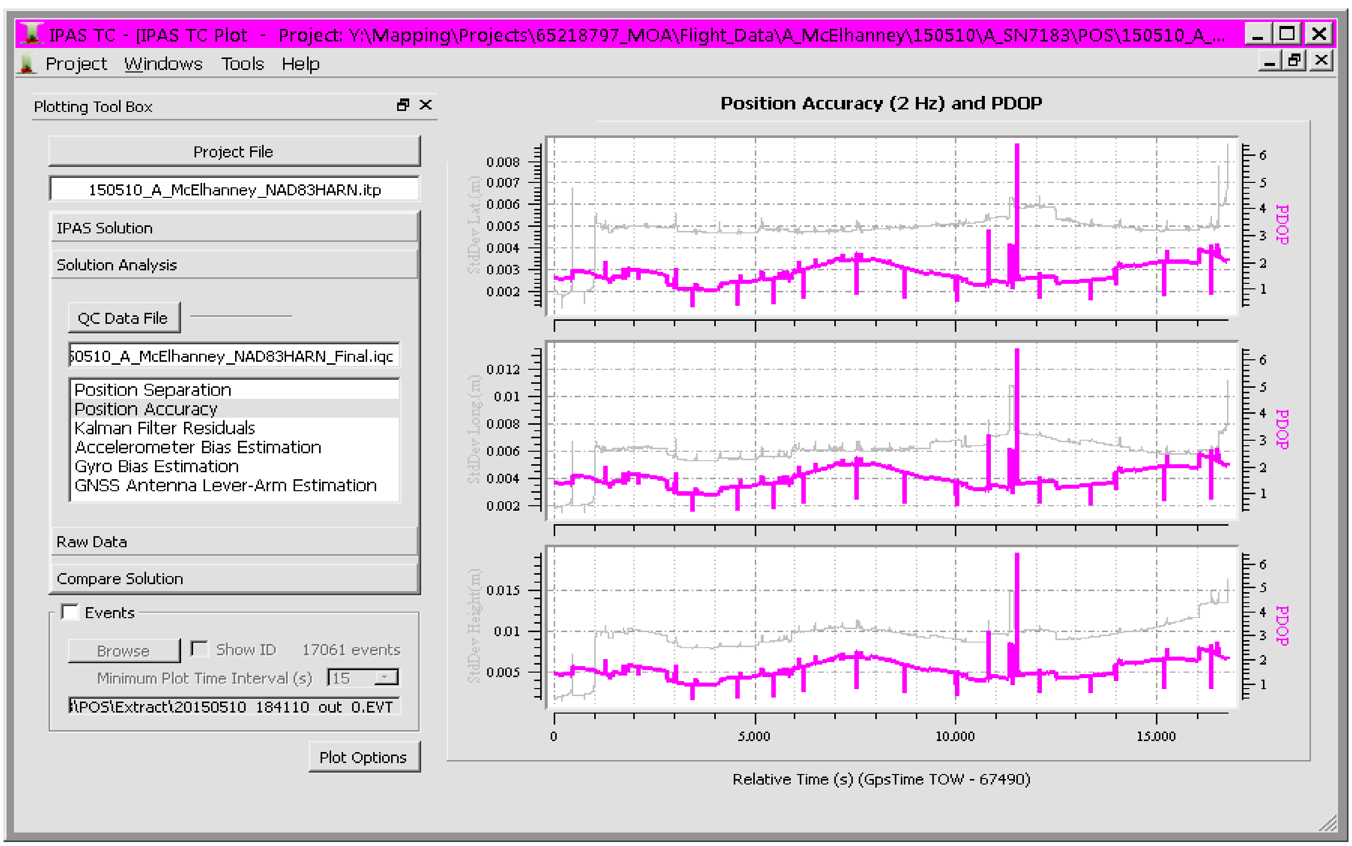


CORS (Continually Operating Reference Stations) used to control the flight lines.
ANC2
TSEA
ZAN1

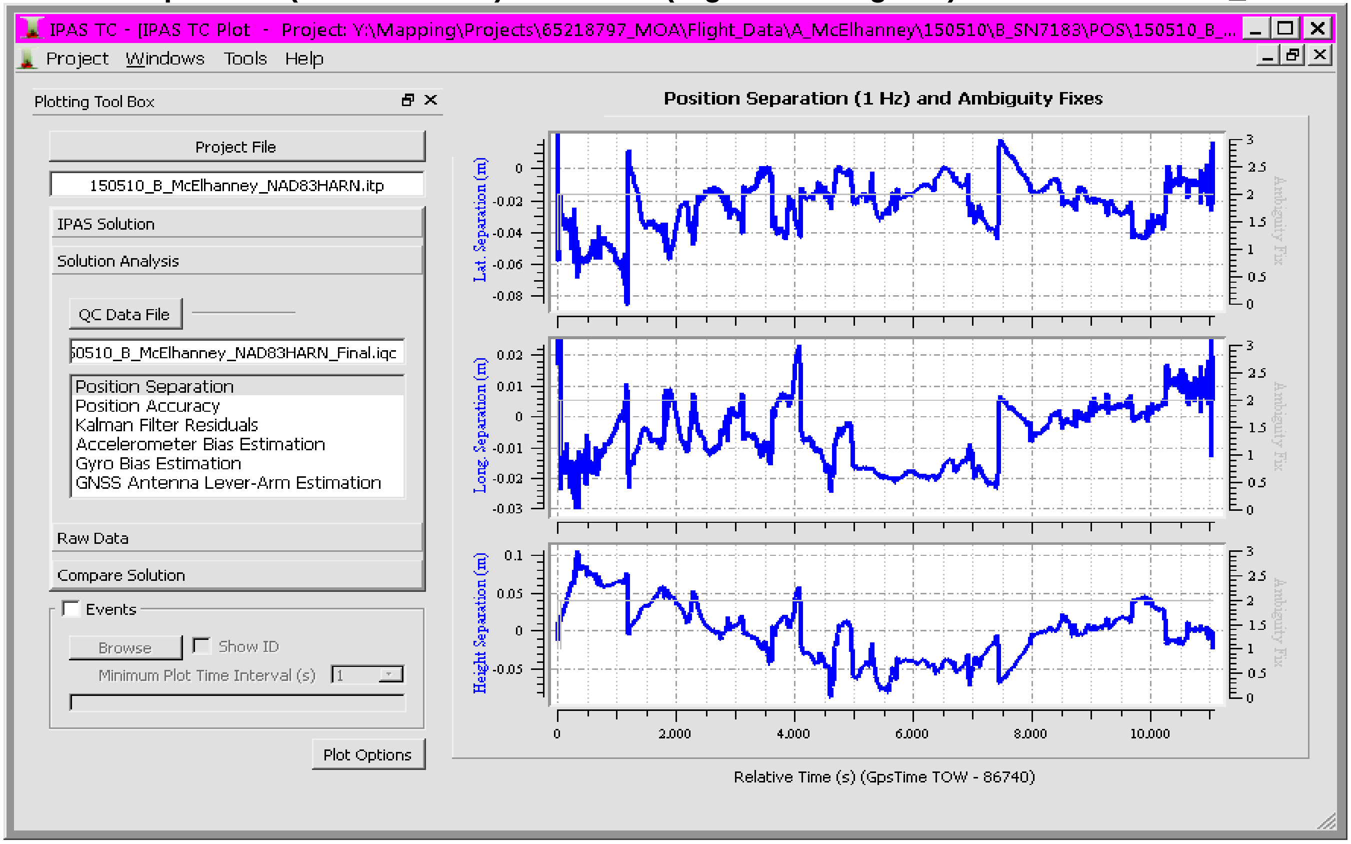


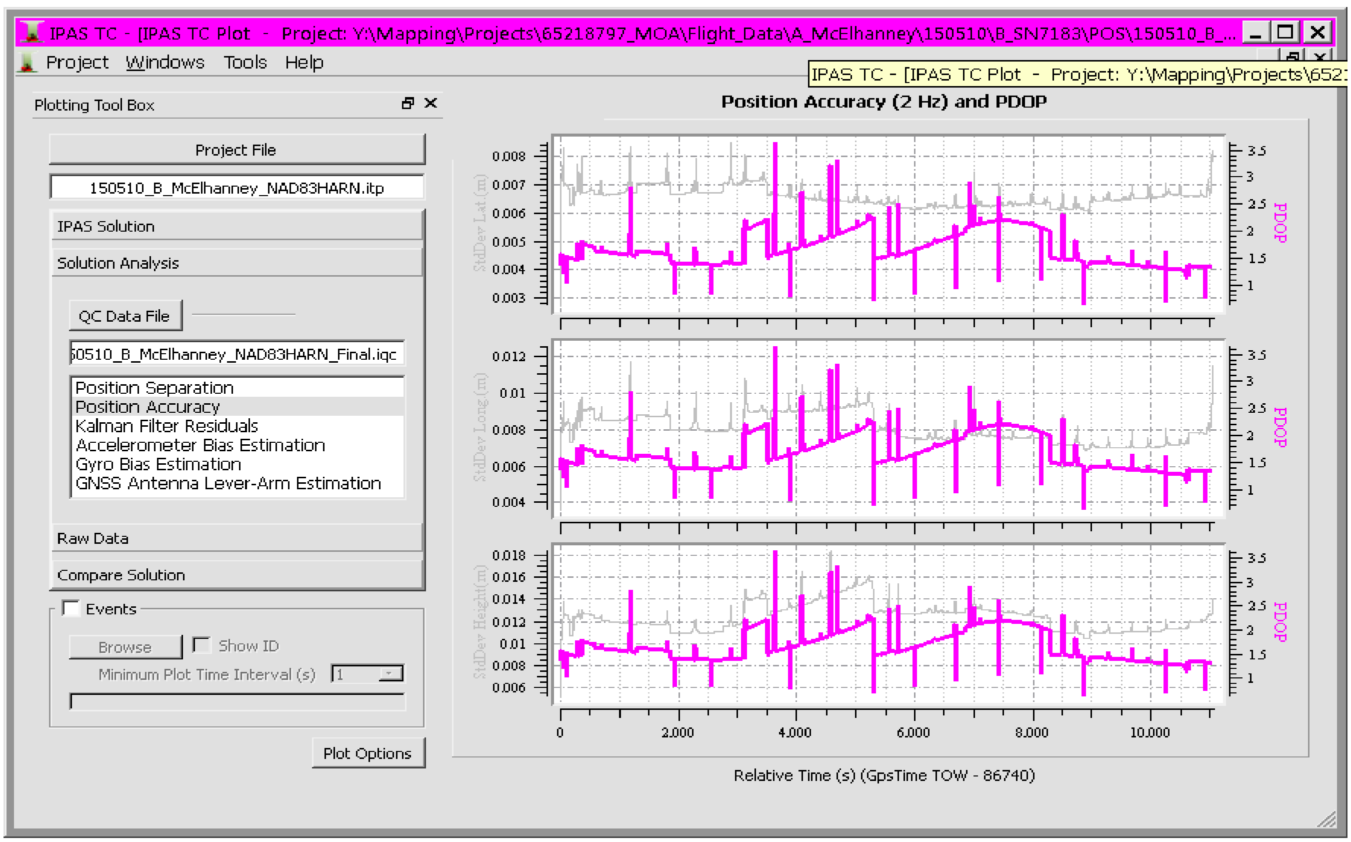
Position Separation (Left Side Blue) and PDOP (Right Side Magenta) for Mission 150510_A



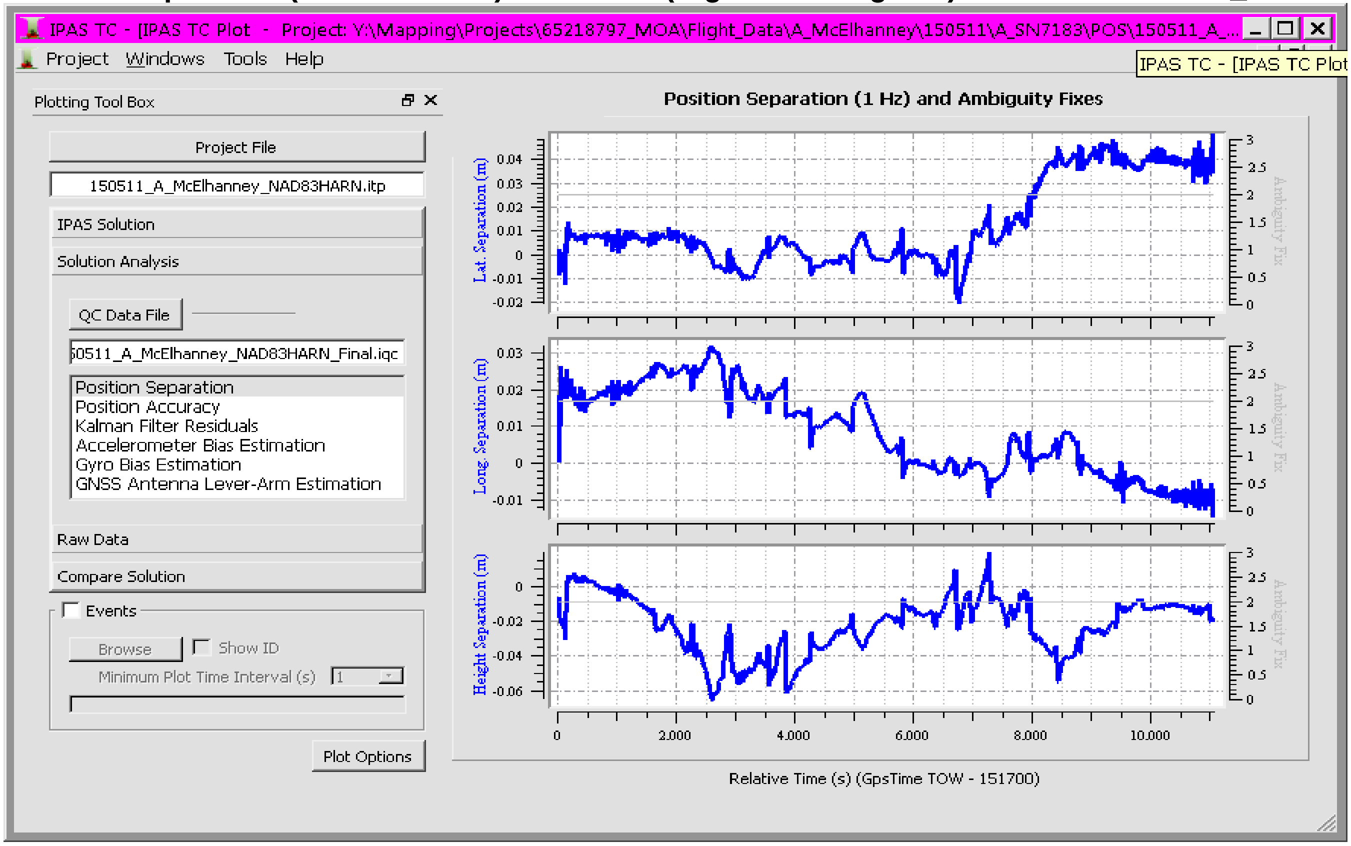


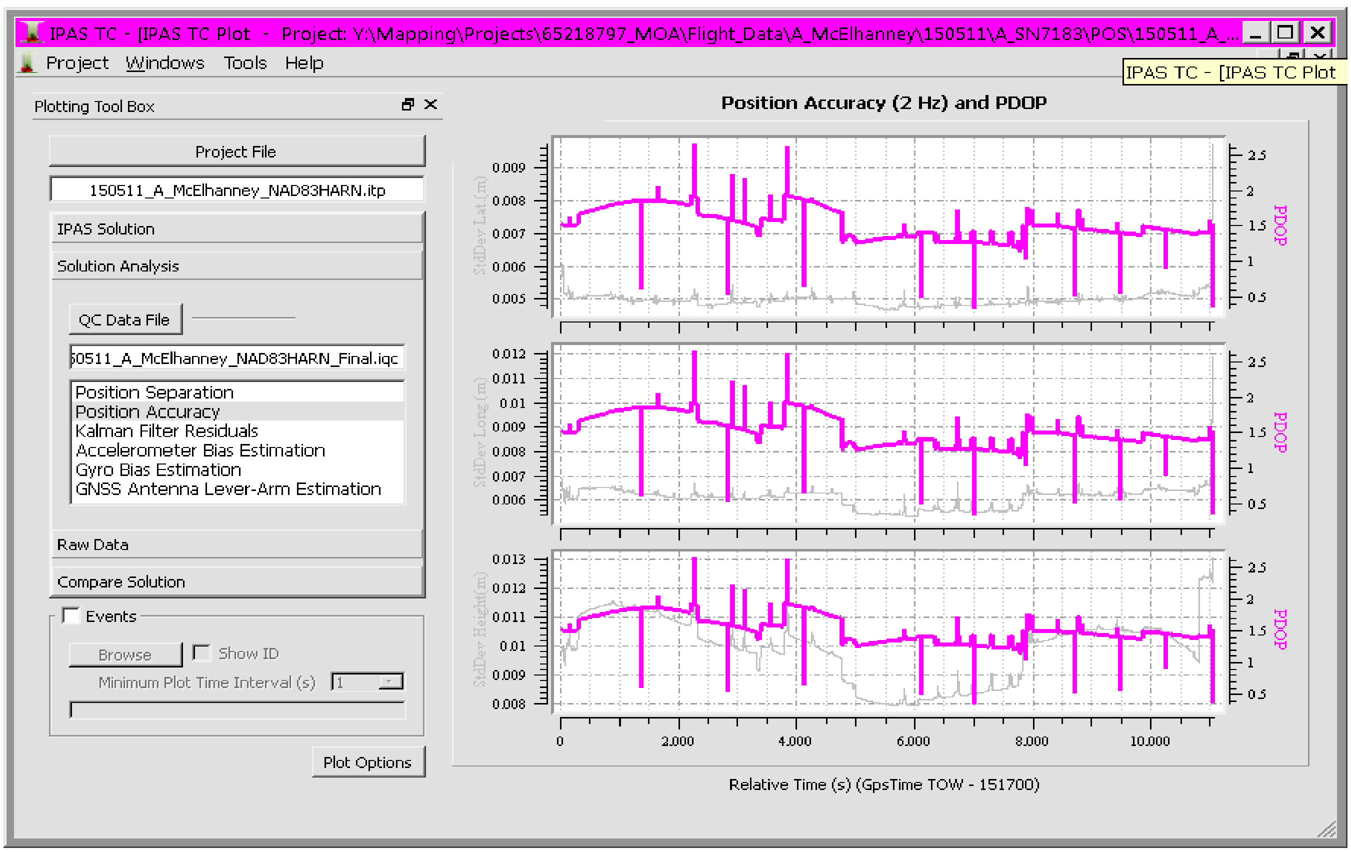
Position Separation (Left Side Blue) and PDOP (Right Side Magenta) for Mission 150510_B



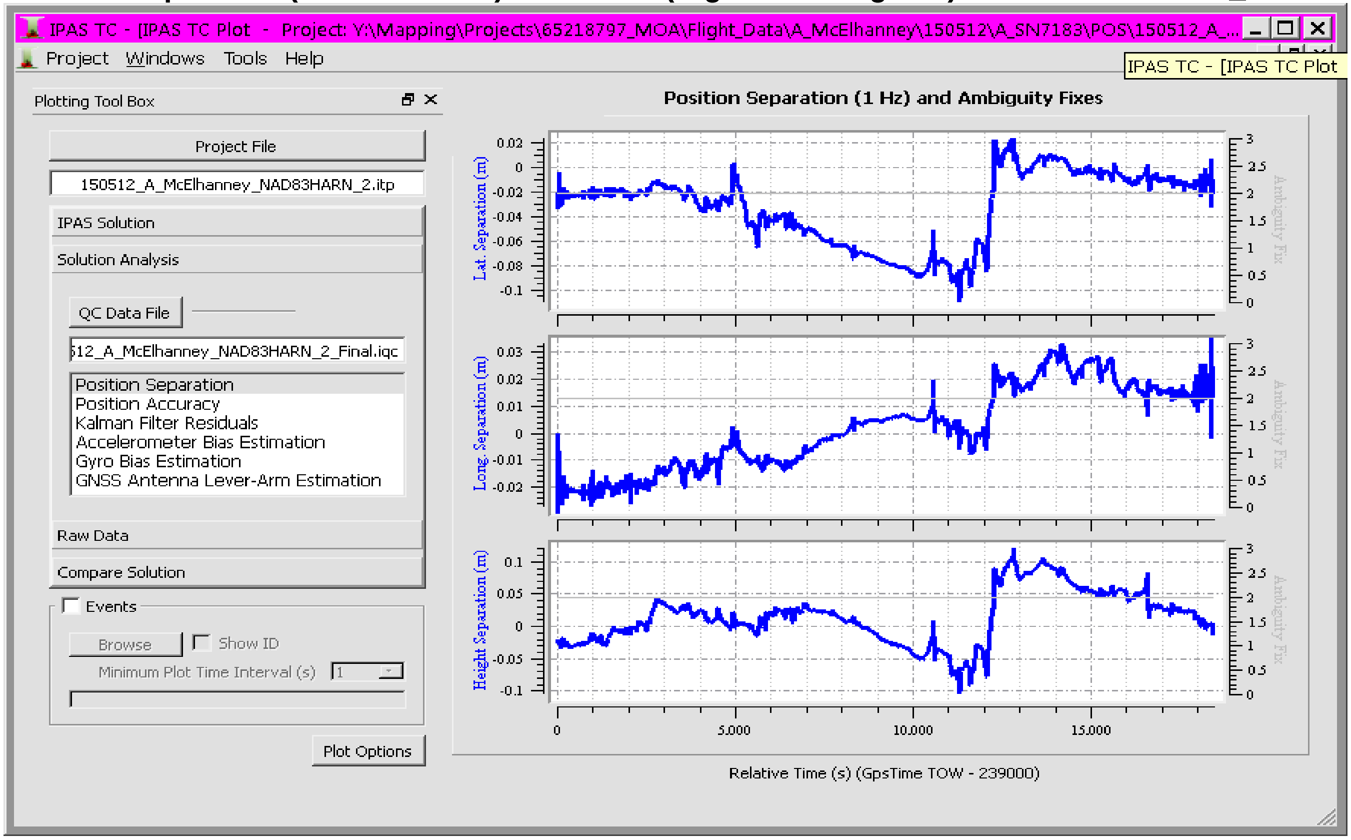


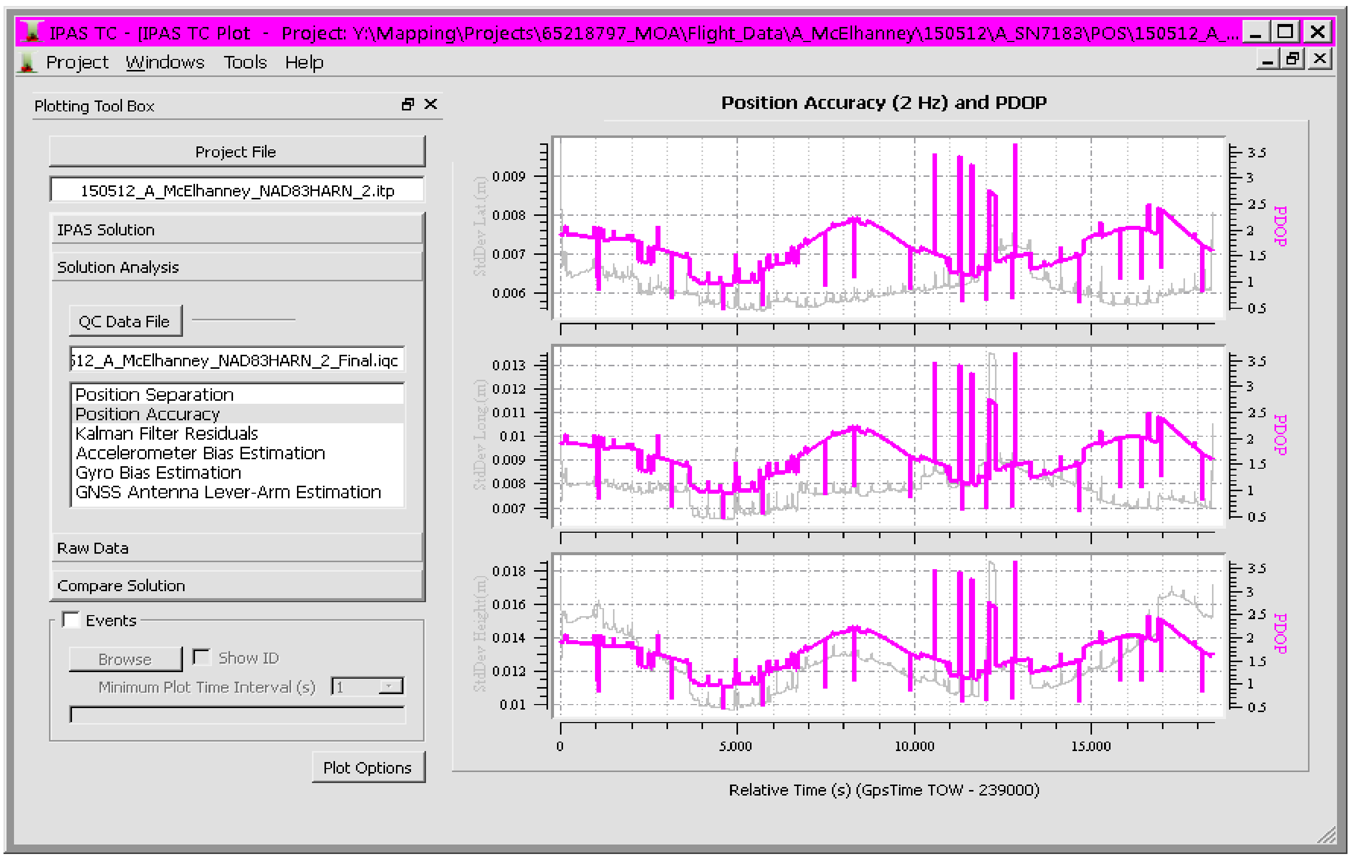
Position Separation (Left Side Blue) and PDOP (Right Side Magenta) for Mission 150511_A



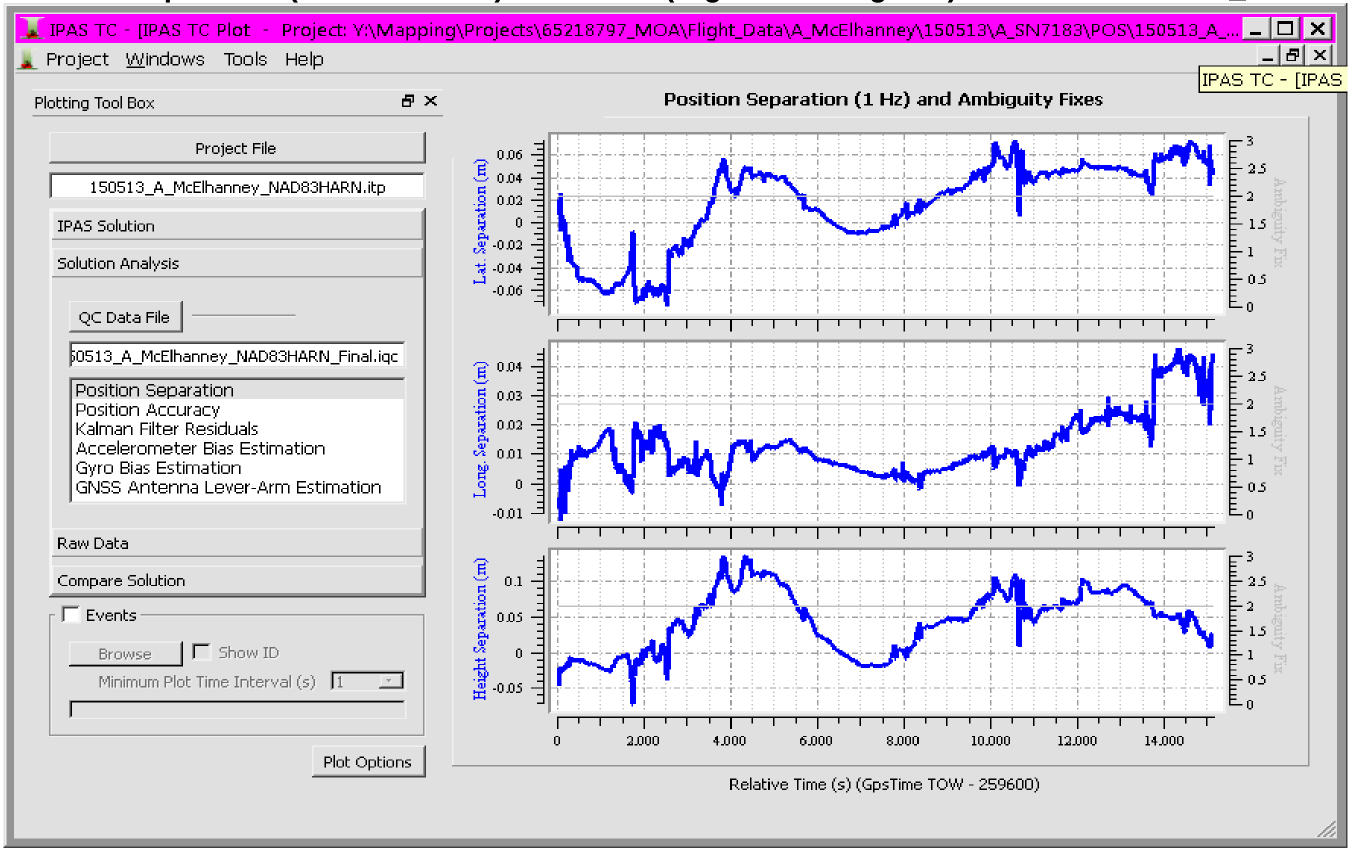


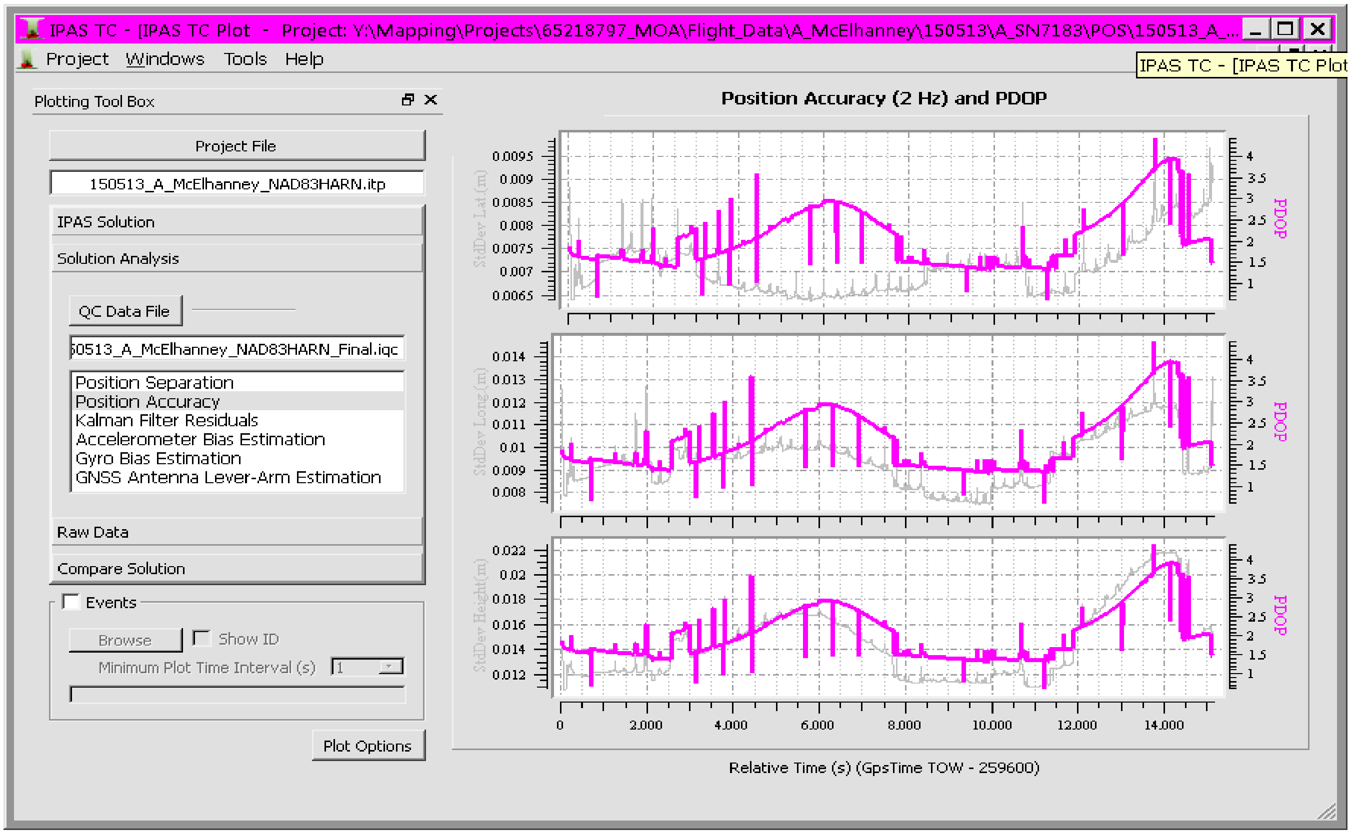
Position Separation (Left Side Blue) and PDOP (Right Side Magenta) for Mission 150512_A



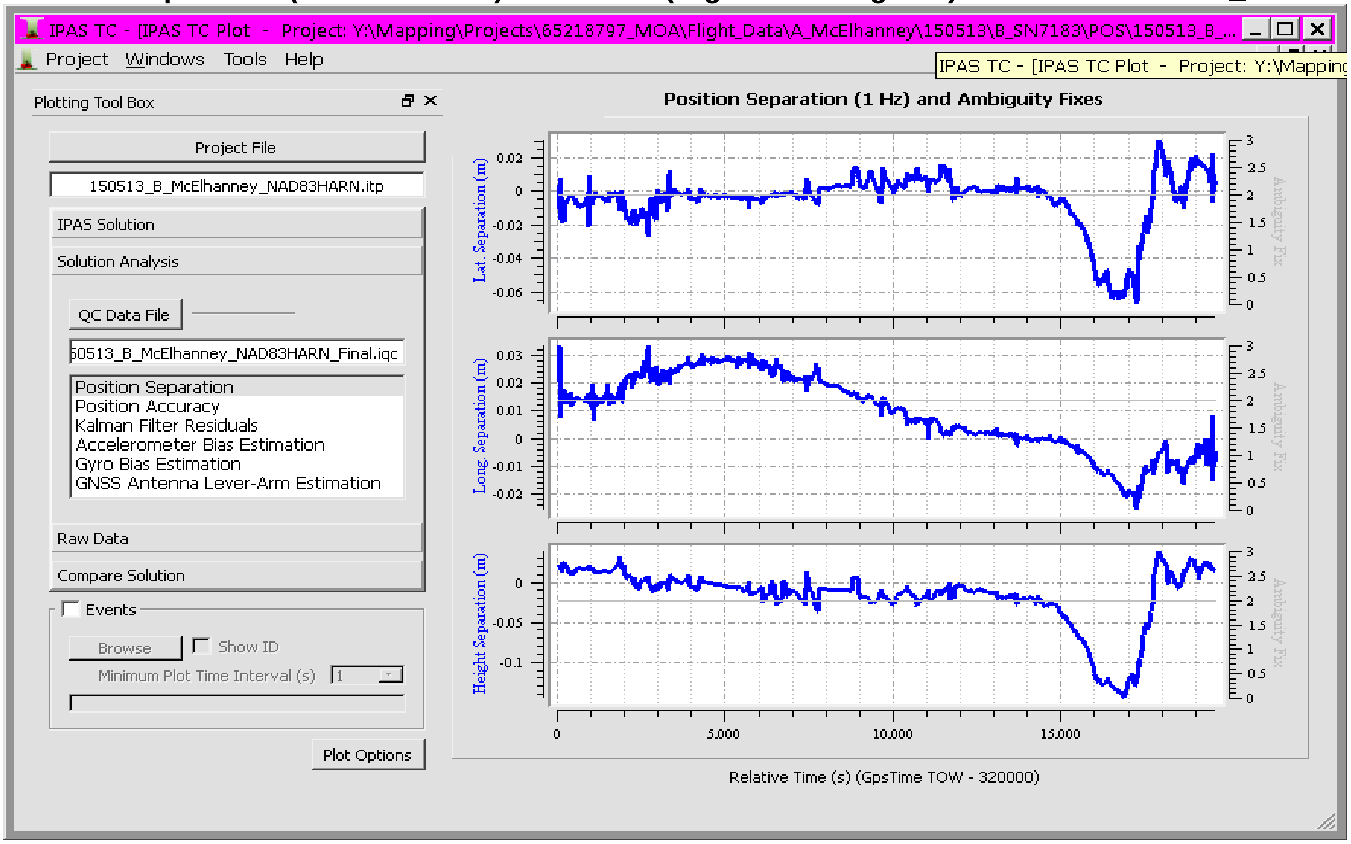


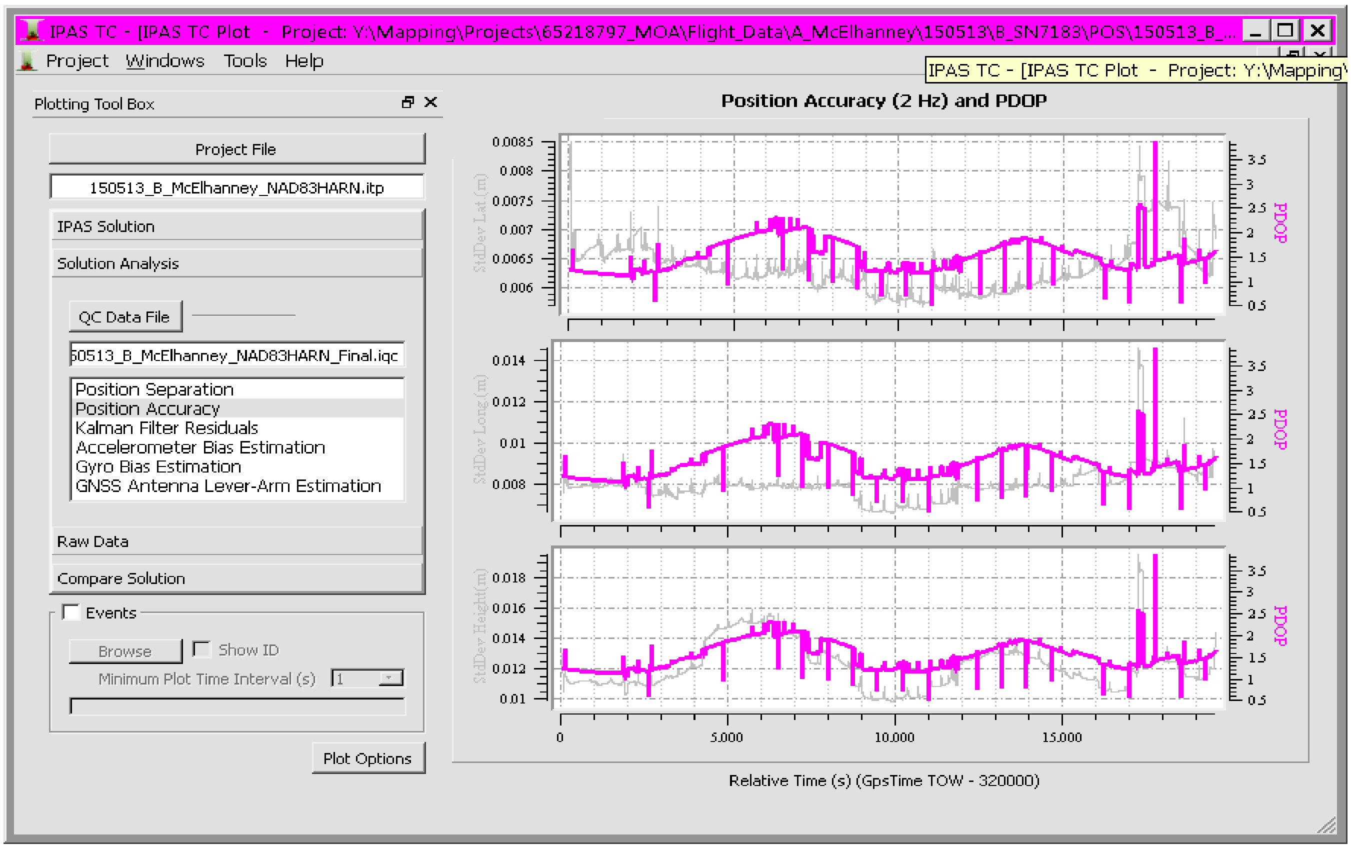
Position Separation (Left Side Blue) and PDOP (Right Side Magenta) for Mission 150513_A



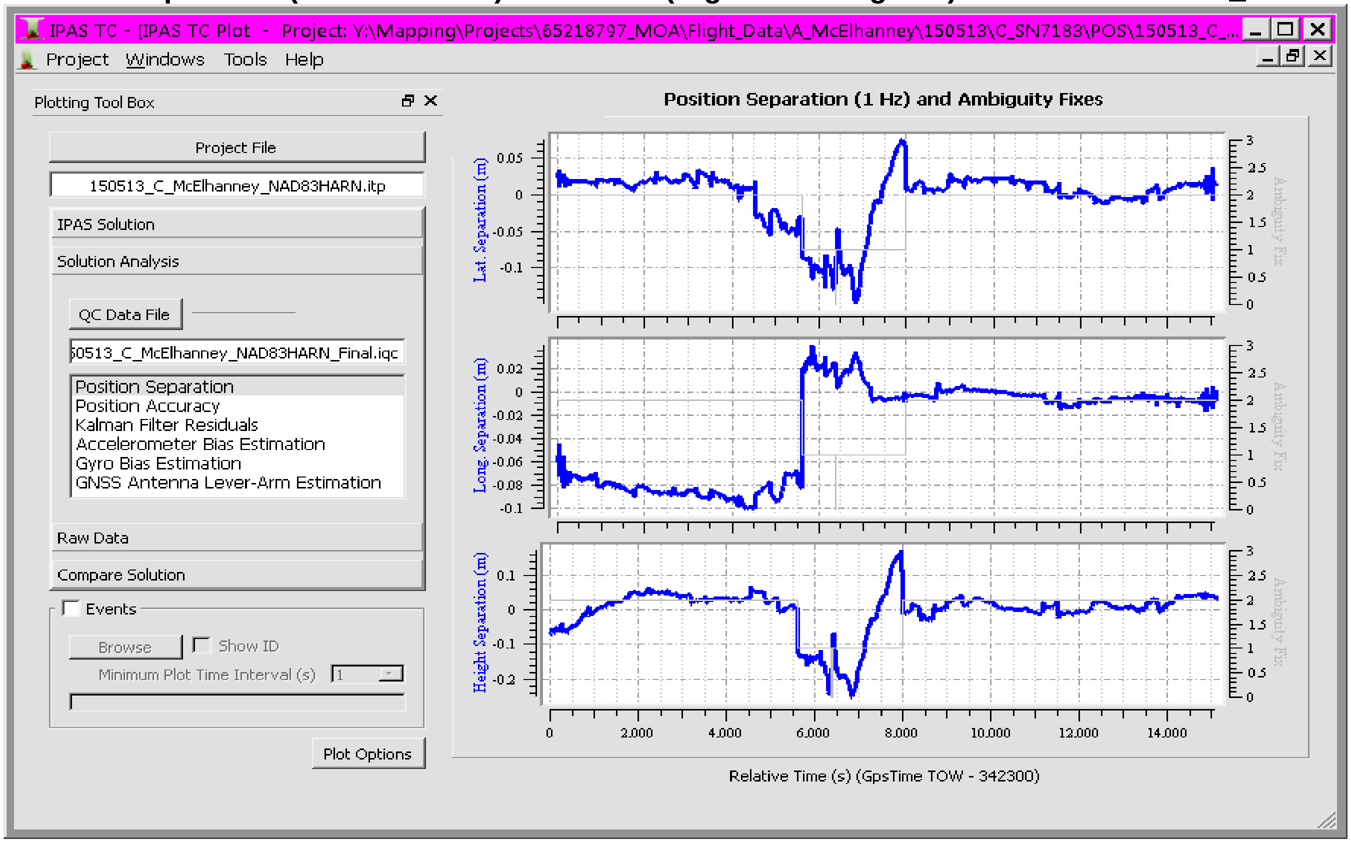


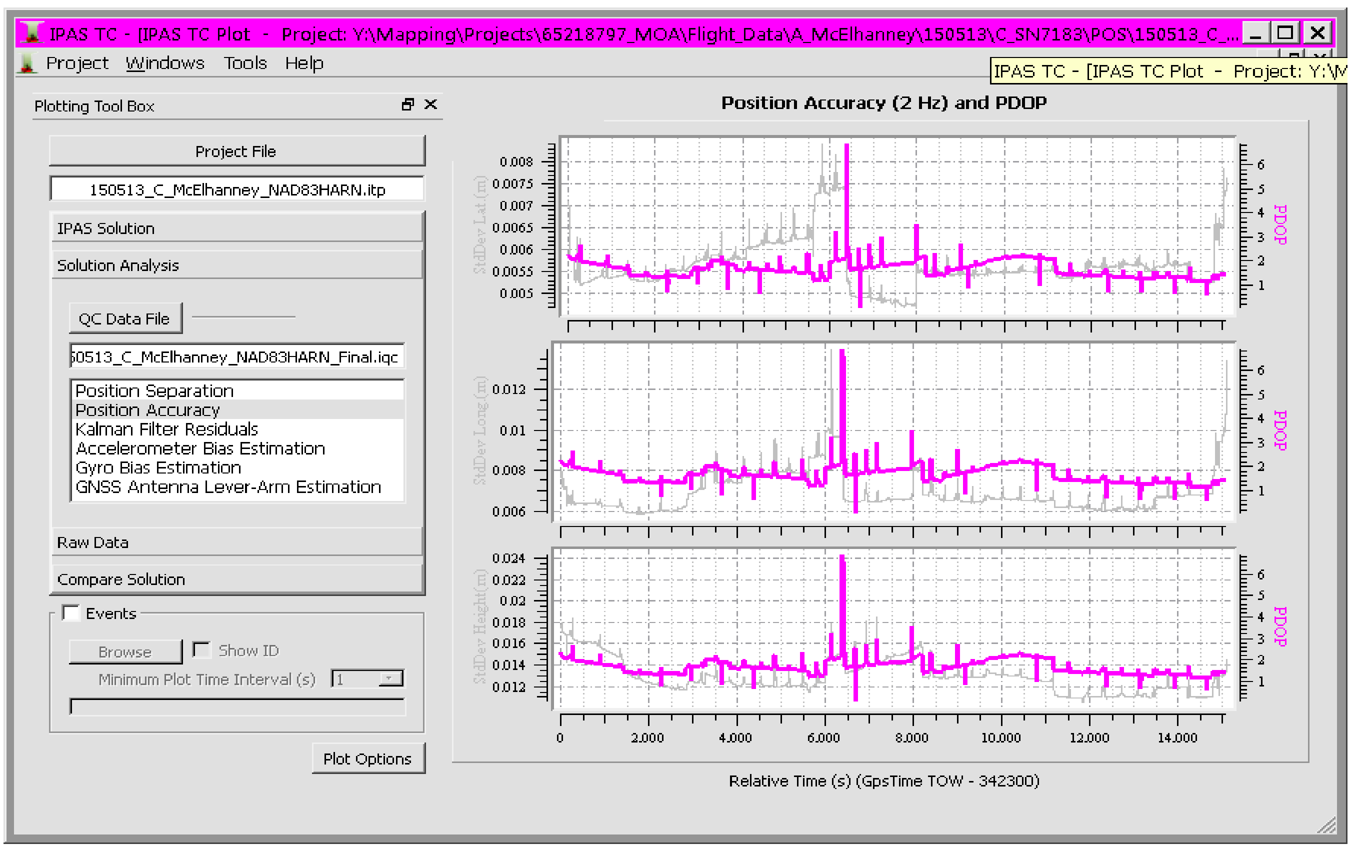
Position Separation (Left Side Blue) and PDOP (Right Side Magenta) for Mission 150513_B



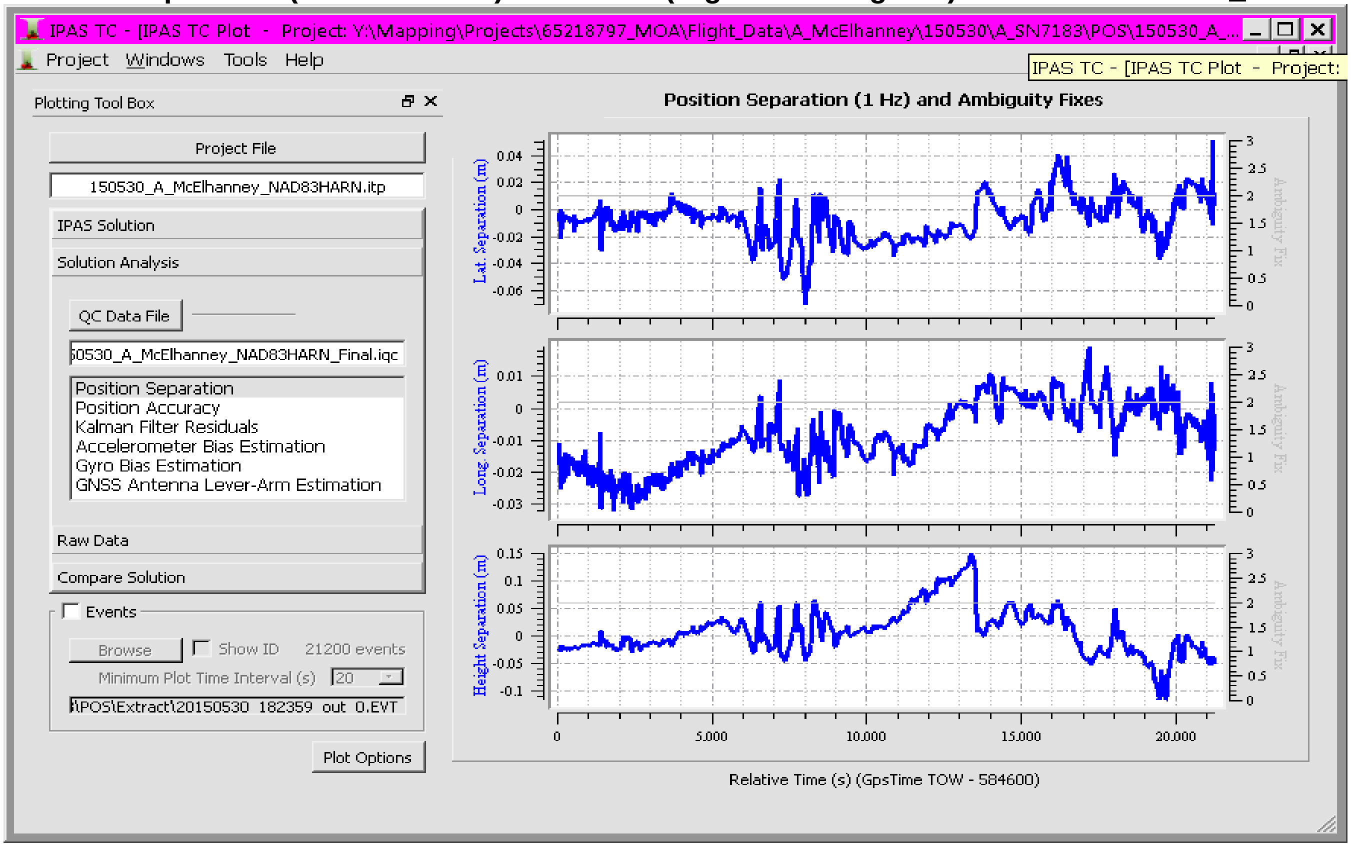


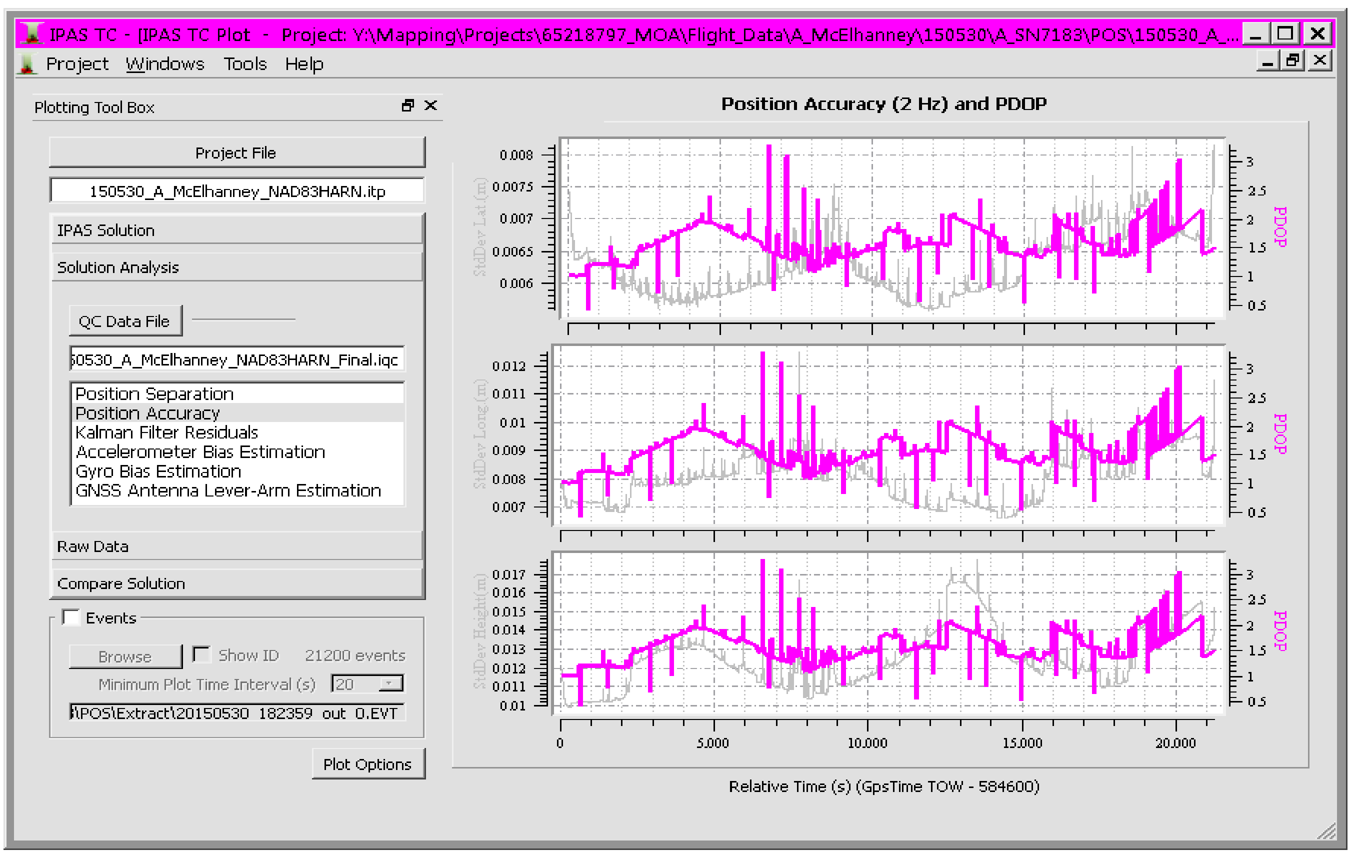
Position Separation (Left Side Blue) and PDOP (Right Side Magenta) for Mission 150513_C



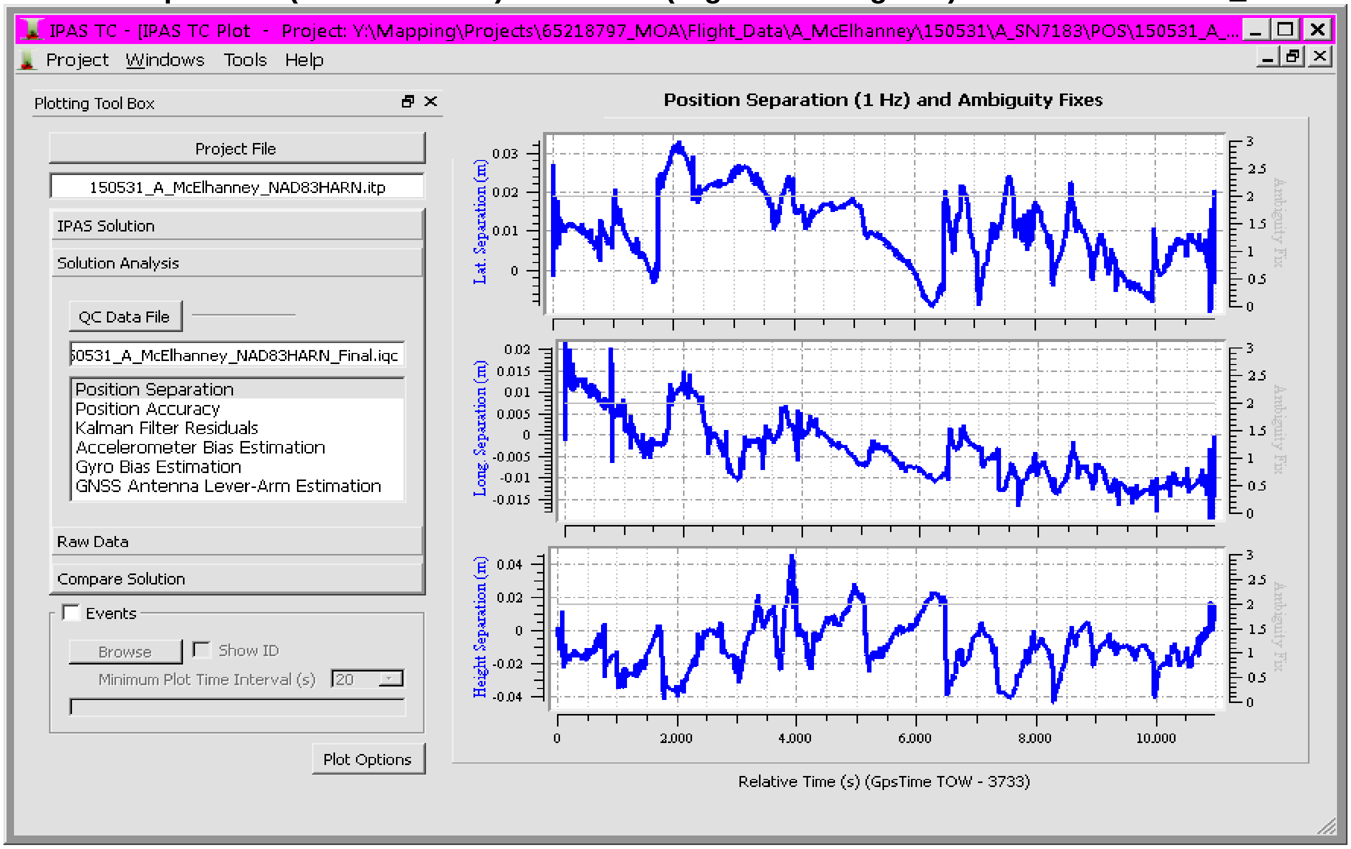


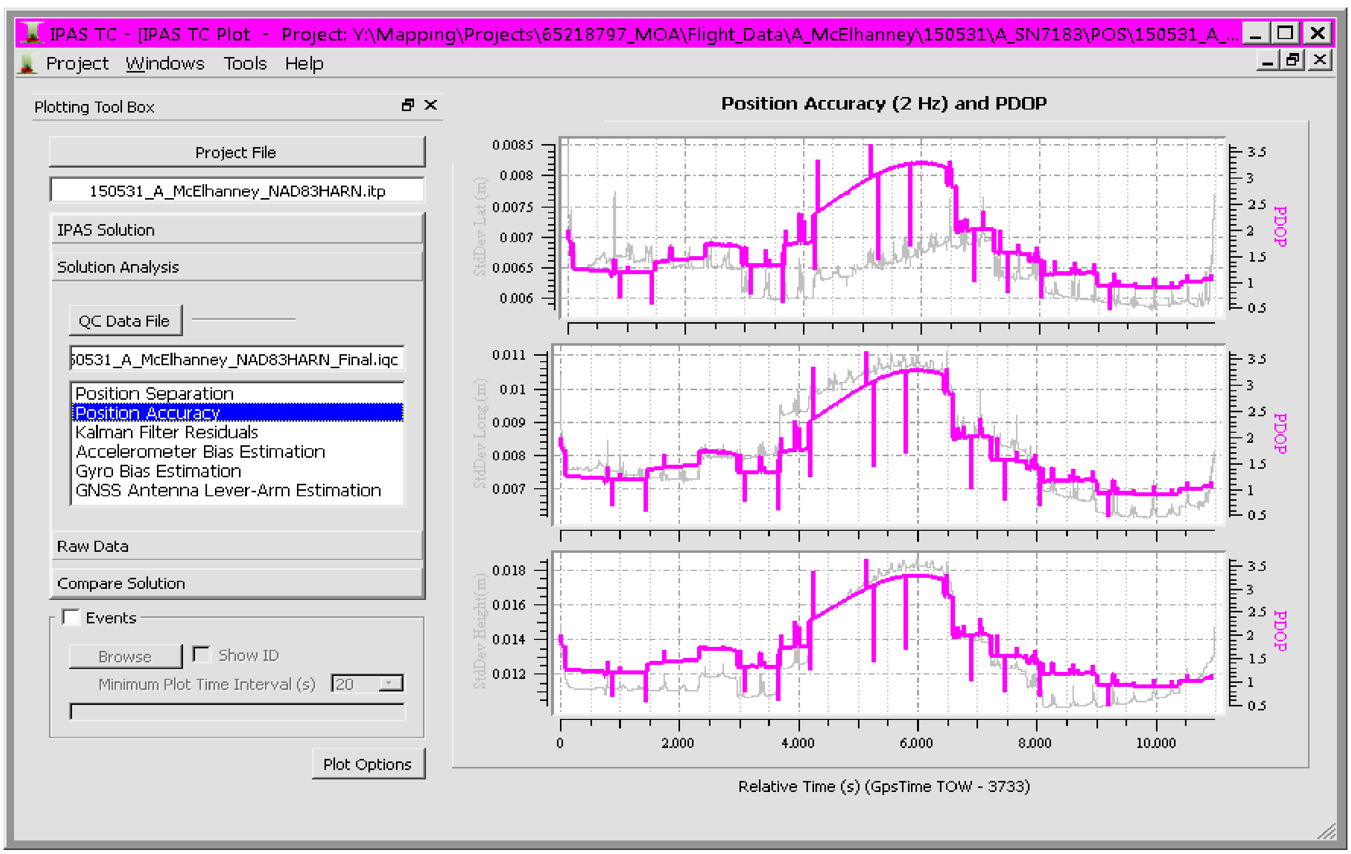
Position Separation (Left Side Blue) and PDOP (Right Side Magenta) for Mission 150530_A



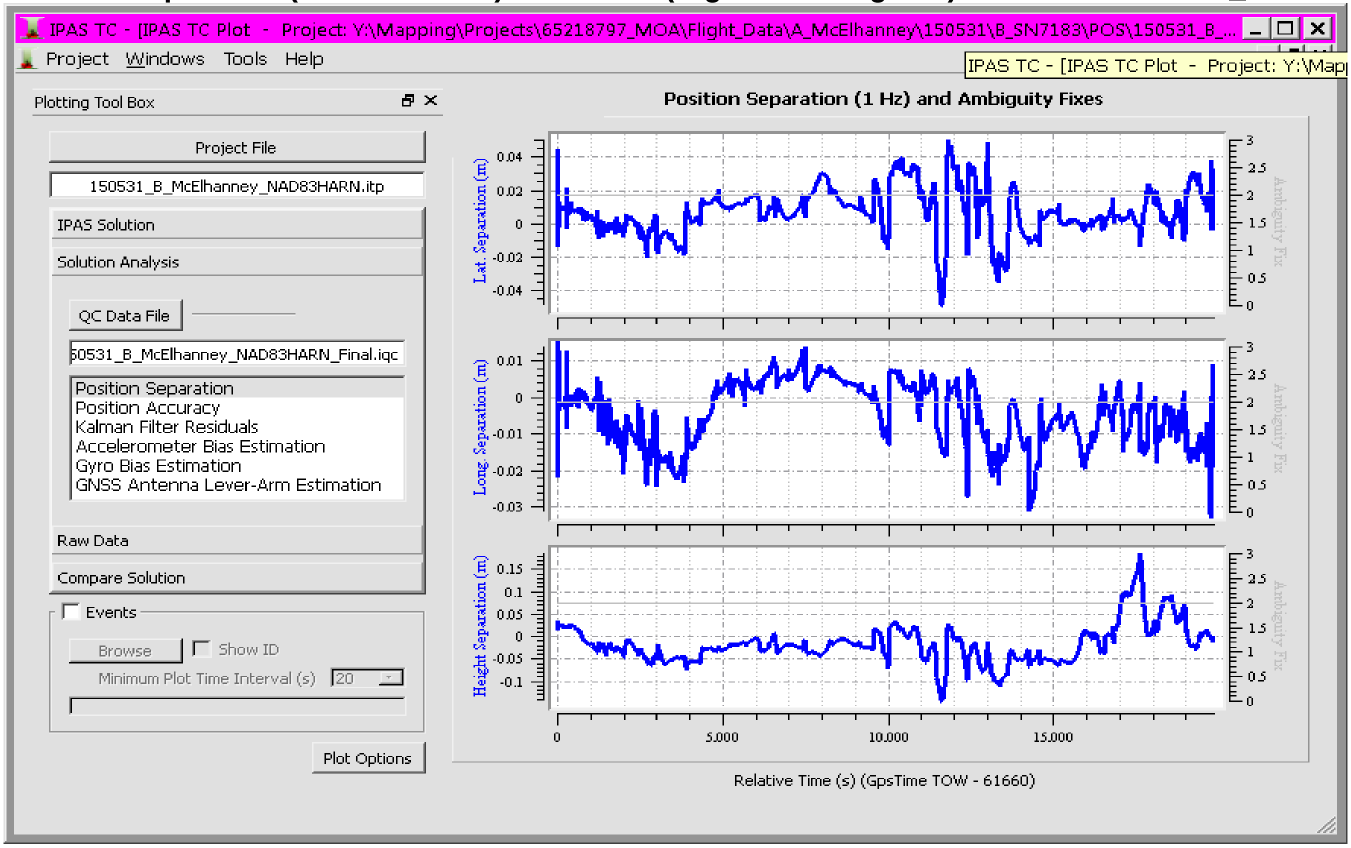


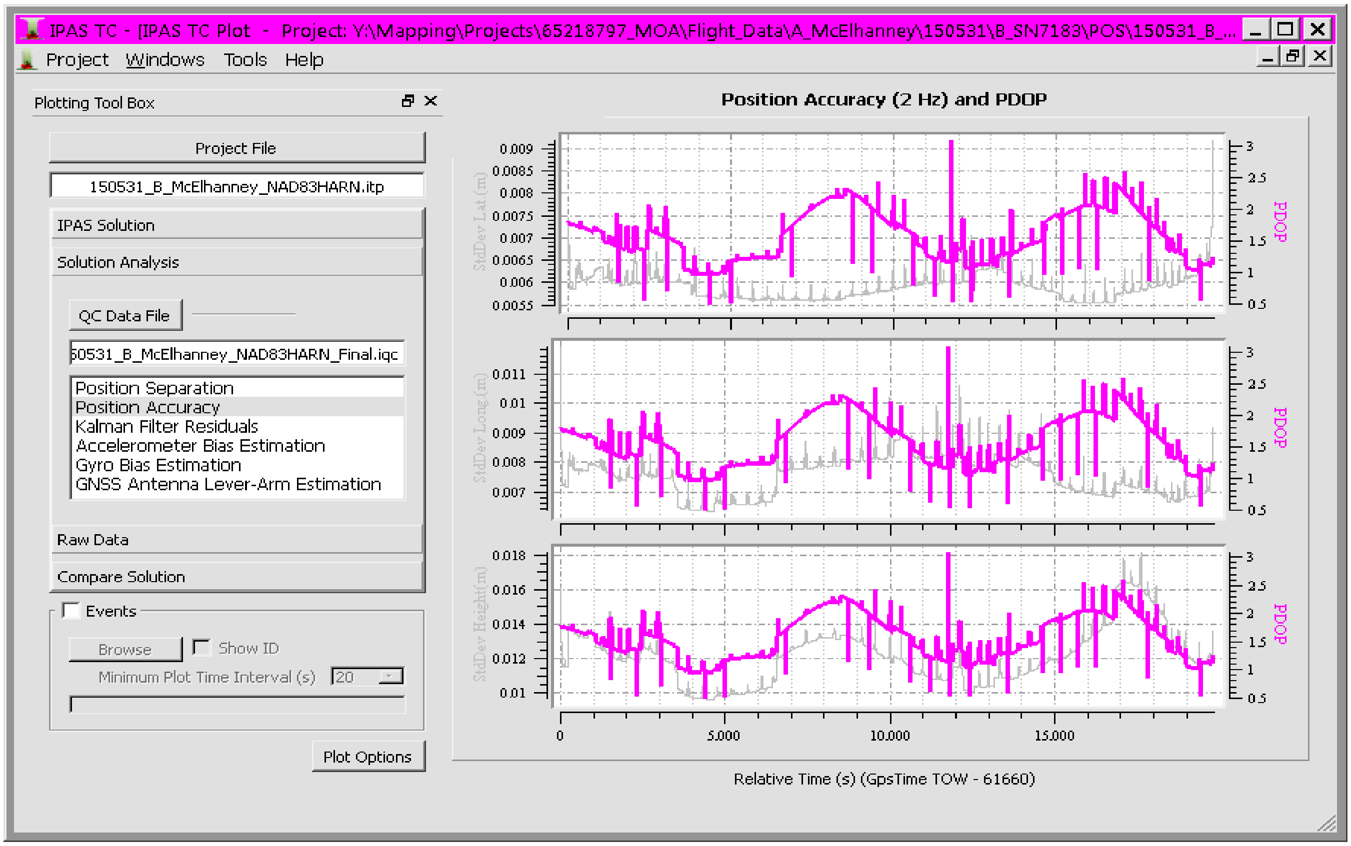
Position Separation (Left Side Blue) and PDOP (Right Side Magenta) for Mission 150531_A





Position Separation (Left Side Blue) and PDOP (Right Side Magenta) for Mission 150531_B





LiDAR Data Processing

The airborne GPS data was post-processed using Leica IPAS TC GNSS/INS Processor version 3.20. A fixed-bias carrier phase solution was computed in both the forward and reverse chronological directions. Whenever practical, LiDAR acquisition was limited to periods when the PDOP (**P**ositional **D**ilution **O**f **P**recision) was less than 4.0. PDOP indicates satellite geometry relating to position. Generally PDOP's of 4.0 or less result in a good quality solution, however PDOP's between 4.0 and 5.0 can still yield good results most of the time. PDOP's over 6.0 are of questionable results and PDOP's of over 7.0 usually result in a poor solution. Usually as the number of satellites increase the PDOP decreases. Other quality control checks used for the GPS include analyzing the Position Separation of the forward and reverse GPS processing and the Position Accuracy. The Position Separation Plot (See Plots) shows the position separation between forward and reverse IPAS TC solutions. If both forward and reverse solutions are based on fixed ambiguity solutions, then the separation should be small (0.00 meters to +/- 0.10 meters) and result in a good positional accuracy.

The GPS trajectory was combined with the raw IMU data and post-processed using Leica IPAS TC GNSS/INS Processor version 3.20. The smoothed best estimated trajectory (SBET) and refined attitude data are then utilized in the ALS Post Processor to compute the laser point-positions – the trajectory is combined with the attitude data and laser range measurements to produce the 3-dimensional coordinates of the mass points. Up to four return values are produced within the ALS Post Processor software for each pulse which ensures the greatest chance of ground returns in a heavily forested area.

Laser point classification was completed using Merrick Advanced Remote Sensing (MARS®) LiDAR processing and modeling software. Several algorithms are used when comparing points to determine the best automatic ground solution. Each filter is built based on the projects terrain and land cover to provide a surface that is 90% free of anomalies and artifacts. After the auto filter has been completed the data sets are then reviewed by an operator utilizing MARS® to remove any other anomalies or artifacts not resolved by the automated filter process. During these final steps the operator also verifies that the datasets are consistent and complete with no data voids.

Ground Control Parameters

Coordinate System: State Plane Alaska Zone 4.
Horizontal Datum: The horizontal datum for the project is North American Datum of 1983, adjusted to the 1992 system (NAD83 /1992).
Vertical Datum: The Vertical datum for the project is MOA72 (MOA 1972 Adjustment) and the North American Vertical Datum of 1988 (NAVD88) (USGS).
Units: Horizontal units are in US Survey Feet, Vertical units are in US Survey Feet.

Ground Control LiDAR- Checkpoints

The following listing shows the points that were used as LiDAR checkpoints. Some of the ground control points (LiDAR checkpoints) were established and surveyed by R&M Consultants, Inc. For most of the ground control points, no field survey was performed for this project. Identified points were compiled from existing data collected or recorded since 2003. R&M researched past survey projects and extracted control points recovered or set with NAD83 State Plane Zone 4 values that best met the project requirements. Points that had leveled MOA72 vertical elevations were extracted wherever possible. In some cases where State Plane coordinates were not previously used for a project but high quality GPS data was collected at the time of survey, that data was reprocessed and adjusted to fit the purpose of this project.

Project: Municipality Of Anchorage (MOA) Alaska

Project Number: 65218797

Date: May 2015

Project Coordinates are NAD83 (HARN1992) Alaska State Plane Zone 4 coordinates, Expressed in U.S. Survey Feet.

The Vertical Datum is NGVD 1929 - M.O.A. 1972 Adjustment. The elevations of all Photo Control Points were determined by static GPS observations. The elevations of Points No. 607 to 616, along Eklutna Lake Road, Eagle River Road and Hiland Road, are based on M.O.A. Bench Marks E-17 and E-32. The elevations of Points No. 603 and 604, along Crow Creek Road in Girdwood, are based on Points No. 3130, 3141 and 3182 shown as Points No. 66, 552 and 6 on the Record of Survey, Survey Control Diagram, Seward Highway: Right-of-Way Study, recorded as Plat No. 2014-32 in the Anchorage Recording District.

Name	Northing USFeet	Easting USFeet	Point Elev. MOA72 USFeet	Panel Elev. MOA72 USFeet	Desc.	Ground to Monument Relationship
603	2555874.93	1800401.51	**541.27**	**542.0**	Panel	Set 2" ALCAP 0.7' below ground
604	2568149.40	1799309.89	**1359.23**	**1359.8**	Panel	Set 2" ALCAP 0.6' below ground
607	2652870.01	1735235.71	**1871.17**	**1871.4**	Panel	Set 2" ALCAP 0.2' below ground
608	2644180.30	1768720.59	**530.30**	**531.1**	Panel	Set 2" ALCAP 0.7' below ground
609	2664214.20	1742808.12	**406.79**	**406.8**	Panel	Set 2" ALCAP flush with ground
610	2639871.35	1740308.08	**2327.02**	**2327.6**	Panel	Set 2" ALCAP 0.6' below ground
611	2732292.79	1789099.01	**36.20**	**36.8**	Panel	Set 2" ALCAP 0.6' below ground
614	2708597.50	1789643.44	**1007.93**	**1008.1**	Panel	Set 2" ALCAP 0.2' below ground
615	2723818.67	1767496.93	**1290.69**	**1290.8**	Panel	Set 2" ALCAP 0.1' below ground

616	2725629.71	1753443.65	**45.66**	**46.1**	Panel	Brass Cap 0.1' (0.4')below ground

Name	Northing USFeet	Easting USFeet	Point Elev. NAVD88G12 USFeet	Ground Elev NAVD88G12 USFeet	Desc.	Ground to Monument Relationship
603	2555874.93	1800401.51	548.40	549.10	Panel	Set 2" ALCAP 0.7' below ground
604	2568149.40	1799309.89	1366.36	1366.96	Panel	Set 2" ALCAP 0.6' below ground
607	2652870.01	1735235.71	1877.69	1877.89	Panel	Set 2" ALCAP 0.2' below ground
608	2644180.30	1768720.59	536.82	537.52	Panel	Set 2" ALCAP 0.7' below ground
609	2664214.20	1742808.12	413.31	413.31	Panel	Set 2" ALCAP flush with ground
610	2639871.35	1740308.08	2333.54	2334.14	Panel	Set 2" ALCAP 0.6' below ground
611	2732292.79	1789099.01	42.72	43.32	Panel	Set 2" ALCAP 0.6' below ground
614	2708597.50	1789643.44	1014.45	1014.65	Panel	Set 2" ALCAP 0.2' below ground
615	2723818.67	1767496.93	1297.22	1297.32	Panel	Set 2" ALCAP 0.1' below ground
616	2725629.71	1753443.65	52.18	52.28	Panel	Brass Cap 0.1' (0.4')below ground

Name	NAD83(1992) N.Latitude	NAD83(1992) W.Longitude)	Ellip. Mon USFeet	Ellip. Ground USFeet	Desc.	Ground to Monument Relationship
603	N60°59'34.06401"	W149°05'55.89843"	582.85	583.55	Panel	Set 2" ALCAP 0.7' below ground
604	N61°01'35.07960"	W149°06'14.62650"	1401.30	1401.90	Panel	Set 2" ALCAP 0.6' below ground
607	N61°15'36.27444"	W149°27'41.01966"	1906.81	1907.01	Panel	Set 2" ALCAP 0.2' below ground
608	N61°14'07.50747"	W149°16'18.31507"	569.40	570.10	Panel	Set 2" ALCAP 0.7' below ground
609	N61°17'27.34636"	W149°25'04.11140"	443.01	443.01	Panel	Set 2" ALCAP flush with ground
610	N61°13'27.84735"	W149°25'59.60431"	2363.58	2364.18	Panel	Set 2" ALCAP 0.6' below ground
611	N61°28'32.71512"	W149°08'58.51371"	76.13	76.73	Panel	Set 2" ALCAP 0.6' below ground
614	N61°24'39.32699"	W149°08'53.67536"	1048.44	1048.64	Panel	Set 2" ALCAP 0.2' below ground
615	N61°27'11.84416"	W149°16'25.21485"	1328.97	1329.07	Panel	Set 2" ALCAP 0.1' below ground
616	N61°27'31.13342"	W149°21'13.98092"	82.55	82.65	Panel	Brass Cap 0.1' (0.4')below ground

Ground Control Data compiled from existing data collected or recorded since 2003

Name	North USF Alaska Zone4	East USF Alaska Zone4	Elev USF MOA72	Elev USF NAVD88
3	2610429.45	1665830.99	147.47	153.99
10	2626228.14	1664066.59	110.99	117.51
91	2609041.07	1648948.91	88.65	95.17
93	2611806.28	1648877.32	118.74	125.26
554	2582745.39	1671654.30	17.32	23.84
559	2589418.68	1669614.01	150.68	157.20
672	2620892.95	1658434.41	120.29	126.81
839	2594529.76	1685593.24	950.77	957.29
850	2640405.84	1687421.62	270.62	277.14
975	2626214.53	1668402.16	172.92	179.44
1802	2615600.97	1651552.36	92.86	99.38
3003	2636909.12	1660593.25	106.27	112.79
3004	2636905.05	1660322.30	105.90	112.42
3008	2629751.47	1671395.97	133.59	140.11
3026	2623494.47	1667348.01	137.78	144.30
3027	2632508.04	1674252.89	139.61	146.13
3028	2632829.19	1674246.90	141.78	148.30
3029	2633648.11	1674248.60	145.96	152.48
3030	2618199.18	1669041.41	153.01	159.53
3031	2616896.39	1659925.02	107.76	114.28
3040	2628377.25	1663614.51	109.44	115.96
3045	2638790.72	1660585.51	16.94	23.46
3047	2598276.56	1661229.76	122.83	129.35
3048	2598270.20	1659961.74	113.39	119.91
3052	2604811.11	1649962.40	55.23	61.75
3053	2604533.04	1650023.62	56.63	63.15
3054	2604972.38	1650461.31	59.92	66.44
3055	2633544.52	1689910.03	282.78	289.30
3056	2633279.25	1689440.53	282.62	289.14
3057	2633542.22	1689439.42	280.18	286.70
3058	2633536.49	1689310.07	277.79	284.31
3061	2639439.12	1674721.49	163.45	169.97
3080	2707254.03	1730206.75	168.29	174.81
3081	2705254.06	1735618.09	277.89	284.41
3085	2624518.28	1688017.28	328.17	334.69
3086	2624394.99	1687704.14	325.26	331.78

3087	2624251.78	1687601.09	323.94	330.46
3088	2629796.55	1661833.36	106.58	113.10
3089	2605793.94	1647761.77	53.24	59.76
3090	2605929.29	1648002.26	48.10	54.62
3091	2605982.66	1648241.61	48.50	55.02
3092	2615352.63	1646929.03	114.83	121.35
3093	2614581.48	1646929.57	125.95	132.47
3101	2673923.66	1721427.46	592.68	599.20
3107	2591915.58	1672122.98	274.80	281.32
3108	2599532.10	1675007.57	419.11	425.63
3109	2588033.20	1675148.84	384.77	391.29
3112	2618485.37	1673141.78	183.41	189.93
3113	2618546.41	1673859.89	184.12	190.64
3123	2534721.26	1790121.39	27.58	34.10
3124	2538172.93	1784274.42	29.83	36.35
3125	2536945.34	1779758.79	26.09	32.61
3126	2535797.15	1775522.16	25.33	31.85
3127	2535147.55	1769218.93	26.30	32.82
3128	2534241.87	1764687.76	23.50	30.02
3129	2536650.80	1752239.35	26.54	33.06
3130	2545457.26	1739628.70	72.37	78.89
3131	2547563.94	1736680.92	75.03	81.55
3132	2548041.24	1734463.49	62.31	68.83
3133	2548584.75	1733428.36	108.31	114.83
3134	2552593.48	1728297.96	52.95	59.47
3135	2552028.10	1717307.71	43.34	49.86
3136	2563574.02	1687295.73	37.62	44.14
3137	2563941.54	1686759.46	33.52	40.04
3138	2564496.30	1686104.64	36.21	42.73
3139	2573738.09	1677845.56	33.56	40.08
3140	2541269.98	1743785.34	79.47	85.99
3141	2532161.51	1756770.21	62.80	69.32
3143	2551518.20	1723027.59	54.54	61.06
3144	2551979.02	1709999.63	46.97	53.49
3152	2610429.45	1665830.99	147.47	153.99
3163	2594398.09	1666275.02	145.80	152.32
3164	2595687.69	1665430.03	145.08	151.60
3172	2688019.62	1723309.44	480.99	487.51

Ground Control Data compiled from existing data collected or recorded since 2003 Latitude and Longitude

Name	North USF	East USF	Lat	Long
	Alaska Zone4	Alaska Zone4	Deg	Deg
3	2610429.45	1665830.99	61.14496975	-149.85616457
10	2626228.14	1664066.59	61.18819850	-149.86596709
91	2609041.07	1648948.91	61.14123954	-149.95171643
93	2611806.28	1648877.32	61.14880415	-149.95211014
554	2582745.39	1671654.30	61.06919838	-149.82362925
559	2589418.68	1669614.01	61.08746842	-149.83505393
672	2620892.95	1658434.41	61.17363153	-149.89793387
839	2594529.76	1685593.24	61.10130990	-149.74466988
850	2640405.84	1687421.62	61.22678650	-149.73327895
975	2626214.53	1668402.16	61.18813472	-149.84139613
1802	2615600.97	1651552.36	61.15917866	-149.93694789
3003	2636909.12	1660593.25	61.21743504	-149.88554582
3004	2636905.05	1660322.30	61.21742518	-149.88708281
3008	2629751.47	1671395.97	61.19778933	-149.82437536
3026	2623494.47	1667348.01	61.18070070	-149.84740632
3027	2632508.04	1674252.89	61.20530809	-149.80813345
3028	2632829.19	1674246.90	61.20618667	-149.80816206
3029	2633648.11	1674248.60	61.20842685	-149.80813879
3030	2618199.18	1669041.41	61.16620392	-149.83788586
3031	2616896.39	1659925.02	61.16269200	-149.88952818
3040	2628377.25	1663614.51	61.19408003	-149.86850473
3045	2638790.72	1660585.51	61.22258230	-149.88557100
3047	2598276.56	1661229.76	61.11174959	-149.88232937
3048	2598270.20	1659961.74	61.11173821	-149.88949843
3052	2604811.11	1649962.40	61.12966591	-149.94600094
3053	2604533.04	1650023.62	61.12890508	-149.94565589
3054	2604972.38	1650461.31	61.13010592	-149.94317785
3055	2633544.52	1689910.03	61.20798864	-149.71932630
3056	2633279.25	1689440.53	61.20726847	-149.72199513
3057	2633542.22	1689439.42	61.20798786	-149.72199511
3058	2633536.49	1689310.07	61.20797368	-149.72272877
3061	2639439.12	1674721.49	61.22426461	-149.80535930
3080	2707254.03	1730206.75	61.40894896	-149.48753489
3081	2705254.06	1735618.09	61.40335857	-149.45674702
3085	2624518.28	1688017.28	61.18331881	-149.73027095
3086	2624394.99	1687704.14	61.18298506	-149.73204821

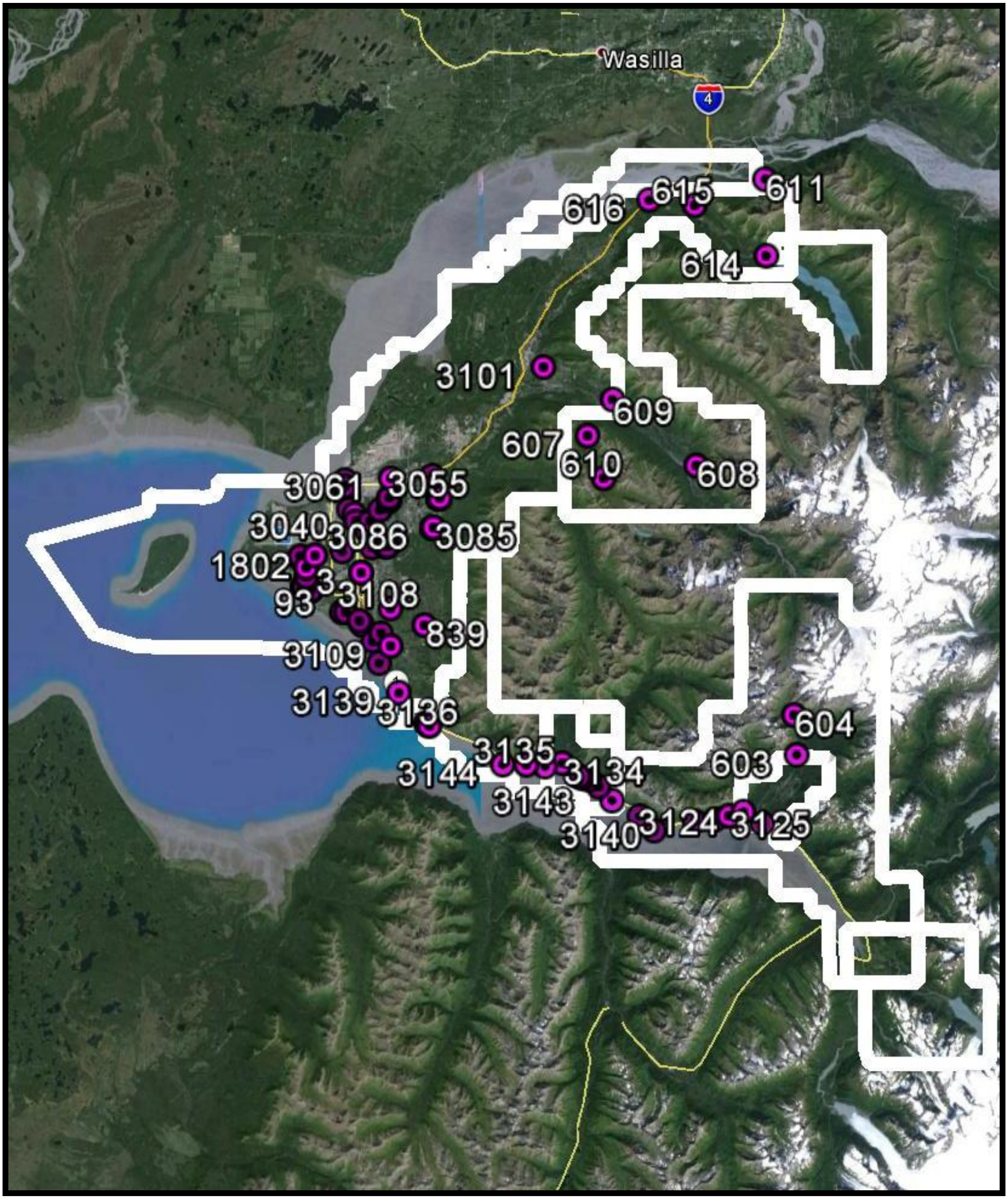
3087	2624251.78	1687601.09	61.18259446	-149.73263544
3088	2629796.55	1661833.36	61.19797205	-149.87858605
3089	2605793.94	1647761.77	61.13235894	-149.95844611
3090	2605929.29	1648002.26	61.13272878	-149.95708507
3091	2605982.66	1648241.61	61.13287433	-149.95573071
3092	2615352.63	1646929.03	61.15850895	-149.96312672
3093	2614581.48	1646929.57	61.15639940	-149.96312615
3101	2673923.66	1721427.46	61.31795598	-149.53898288
3107	2591915.58	1672122.98	61.09428090	-149.82084135
3108	2599532.10	1675007.57	61.11509401	-149.80441327
3109	2588033.20	1675148.84	61.08363653	-149.80380938
3112	2618485.37	1673141.78	61.16695702	-149.81465930
3113	2618546.41	1673859.89	61.16711835	-149.81059126
3123	2534721.26	1790121.39	60.93530685	-149.15828772
3124	2538172.93	1784274.42	60.94494993	-149.19091877
3125	2536945.34	1779758.79	60.94174205	-149.21639513
3126	2535797.15	1775522.16	60.93873770	-149.24029264
3127	2535147.55	1769218.93	60.93715593	-149.27577303
3128	2534241.87	1764687.76	60.93481301	-149.30130285
3129	2536650.80	1752239.35	60.94174746	-149.37115717
3130	2545457.26	1739628.70	60.96615019	-149.44164793
3131	2547563.94	1736680.92	60.97198081	-149.45813873
3132	2548041.24	1734463.49	60.97333605	-149.47059805
3133	2548584.75	1733428.36	60.97484559	-149.47640023
3134	2552593.48	1728297.96	60.98592078	-149.50510953
3135	2552028.10	1717307.71	60.98458703	-149.56701827
3136	2563574.02	1687295.73	61.01660896	-149.73575391
3137	2563941.54	1686759.46	61.01762026	-149.73876844
3138	2564496.30	1686104.64	61.01914494	-149.74244729
3139	2573738.09	1677845.56	61.04450778	-149.78883706
3140	2541269.98	1743785.34	60.95459686	-149.41846542
3141	2532161.51	1756770.21	60.92934569	-149.34593133
3143	2551518.20	1723027.59	60.98308490	-149.53483063
3144	2551979.02	1709999.63	60.98457860	-149.60817134
3152	2610429.45	1665830.99	61.14496975	-149.85616457
3163	2594398.09	1666275.02	61.10111182	-149.85385415
3164	2595687.69	1665430.03	61.10464472	-149.85861411
3172	2688019.62	1723309.44	61.35647759	-149.52769314

Description of Ground Control Data compiled from existing data collected or recorded since 2003

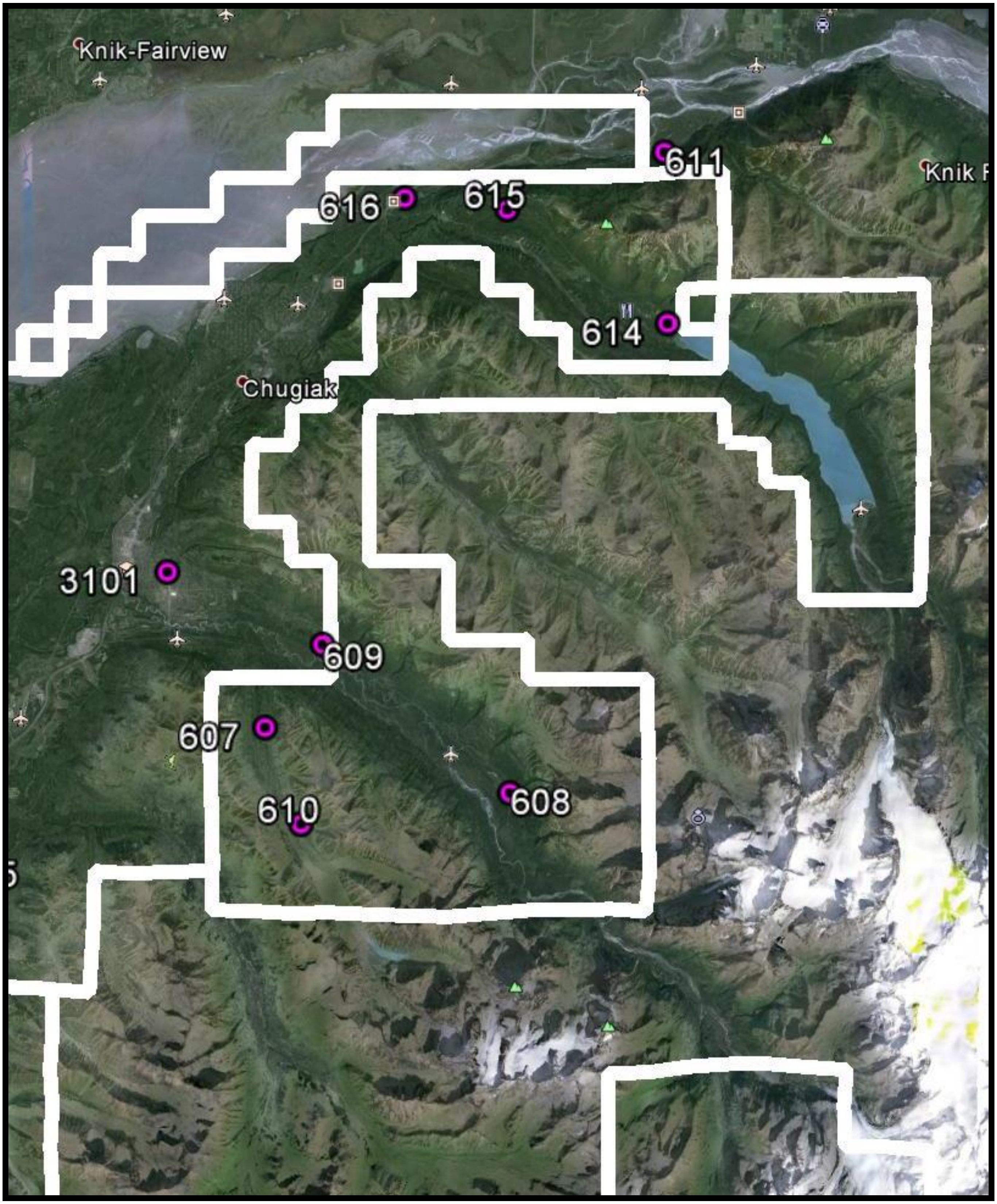
Name	Description
	Note: points in red were removed from ground control
3	SET ROD/AC: SW-3 OPDMSW
10	RBR/PC[DOT]: SW-10 SEW/36TH
91	RBR/PC[DOT]:TS JL-1 JEWEL LK/88TH
93	RBR/PC[DOT]: TS JL-3
554	FD BC[NGS] GPS POTTER
559	FD BC[NGS]: GPS GREG
672	FD BC/BX: 1/4 S36|S31 *T13N R4|3W
839	RBR/PC: TS RCH-19 HILL/DEARM
850	BC/CONC[DOT]--GPS OPMDGL
975	RBR/PC[DOT]: TS 36A
1802	FD BC/Bx[DOT]: C 1/4 S2 *T12N R4W
3003	RBR/PC[USKH]: CP-3
3004	RBR/PC[USKH]: CP-4
3008	BC[DOWLHKM]: GPS HSIP-8 2009
3026	AM[DOWL]: NW St. Mary's Greatland Subd
3027	BC[DOWLHKM]: GPS HSIP-9 2009
3028	BC[DOWLHKM]: GPS HSIP-10 2009
3029	BC[DOWLHKM]: GPS HSIP-11 2009
3030	BC[DOWLHKM]: GPS HSIP-1 2009
3031	AM[1654-S]: Lot 2 1983
3040	BC[WHP]: S36X-40
3045	AC[LS6915]: 2 1/2 ALCAP in asphalt naer CL 1st Ave
3047	AC[4723-S]: 10+00 1991
3048	AC[5232-S]: Radius PT W 121st Cir 1996
3052	RBR[]: Intersection Kachemak Cir and Kachemak Place
3053	RBR[]: Intersection Kachemak Place and Amber Bay Loop
3054	RBR[]: NE Lot 26 Blk 5 Unit no 1 Bayshore West Subdv
3055	RBR/AC[]: Intersection Turf Ct and Early View Dr
3056	RBR/AC[]: Radius Pt Moss Ct
3057	RBR/AC[]: Radius Pt Turf Ct
3058	RBR[]: NW Lot 9 Blk 6 Foothills East Subd
3061	RBR/AC[R&M]: GBI 5
3080	BC[MOA]: MOA BM E-17
3081	BC[MOA]: MOA BM R-83 Reset 2010 NE abutment pedestrian bridge over Peters Creek
3085	IP[]: CL Ressurection Drive
3086	IP[]: CL Ressurection Drive

3087	IP[]: CL Ressurection Drive
3088	BC[DOT]: FW-3A 2001 NW Lot 6A Blk 2 Smith Subd
3089	AC/BX[MOA]: West INTX Northpoint Dr & Tahoe Dr LS-5122 1995
3090	AC/BX[MOA]: CL Northpoint Dr
3091	RBR/BX[]: East INTX of Northwood Dr & Tahoe Dr
3092	AM[]: SW Lot 4 Blk 1 Tall Birch Subd
3093	RBR/AC[]: SE Lot 19 Blk 1 Tall Birch Subd
3101	RBR/AC[DOT]: 1/4 S12 LS-10383 2012
3107	BC[MOA]: BM MOA-31 1988
3108	BC[MOA]: BM MOA-23 1988
3109	BC[MOA]: BM MOA-33 1988
3112	RBR/AC[DOT]: Dowling Rd PC in median 0.2 mi west of Elmore Rd
3113	RBR/AC[DOT]: Dowling Rd PT 3ft south of median 280ft west of Elmore Rd
3123	RBR/PC[DOT]: CP 1
3124	RBR/PC[DOT]: CP 8
3125	RBR/PC[DOT]: CP 13
3126	RBR/PC[DOT]: CP 18
3127	RBR/PC[DOT]: CP 25
3128	Fd Rbr/AC[DOT]: CP 30
3129	Set Rbr/PC[DOT]: CP 48
3130	Set Rbr/PC[DOT]: CP 66
3131	Set Rbr/PC[DOT]: CP 69
3132	Set Rbr/PC[DOT]: CP 71
3133	Set Rbr/PC[DOT]: CP 72
3134	Set Rbr/PC[DOT]: CP 78
3135	Set Rbr/PC[DOT]: CP 90
3136	Set Rbr/PC[DOT]: CP 125
3137	Set Rbr/PC[DOT]: CP 126
3138	Fd Rbr/PC[DOT]: CP 127 (CP 136 TS IP-??)
3139	Set Rbr/PC[DOT]: CP 139
3140	ROD w/ DATUM POINT: BIRD 1W
3141	BC/ROD[DOT]: GPS SWH 96.1
3143	BC[NGS]: GPS INDIAN
3144	BC[NGS] GPS 24
3152	AD/Rod[LS-6912]: OPDMSW 1994
3163	BC[DOT]: OSH-1 2011
3164	BC[DOT]: OSH-3 2011
3172	ROD[USCGS]: MOA BM L-83 1964

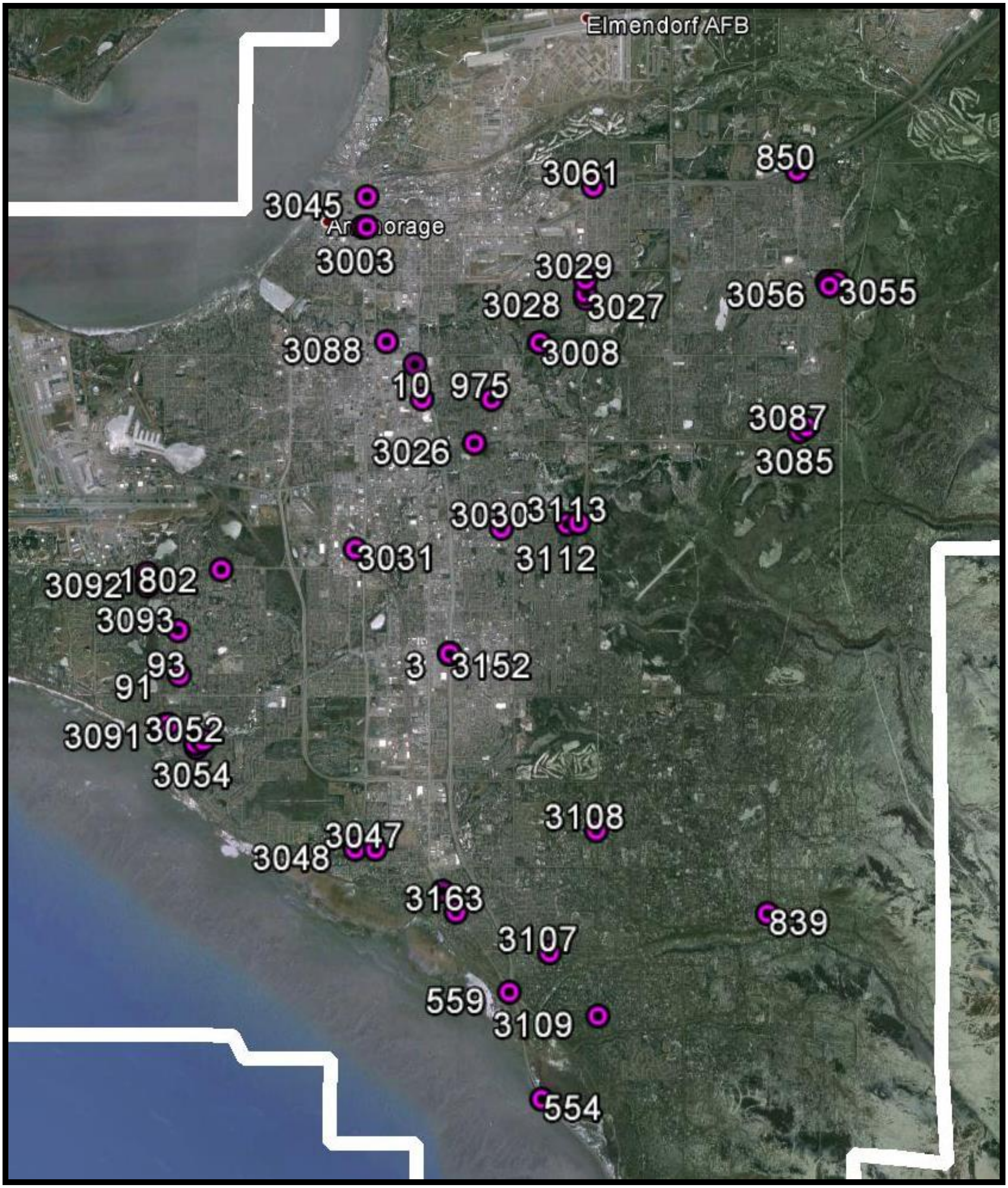
LiDAR Control Points (Checkpoints) All



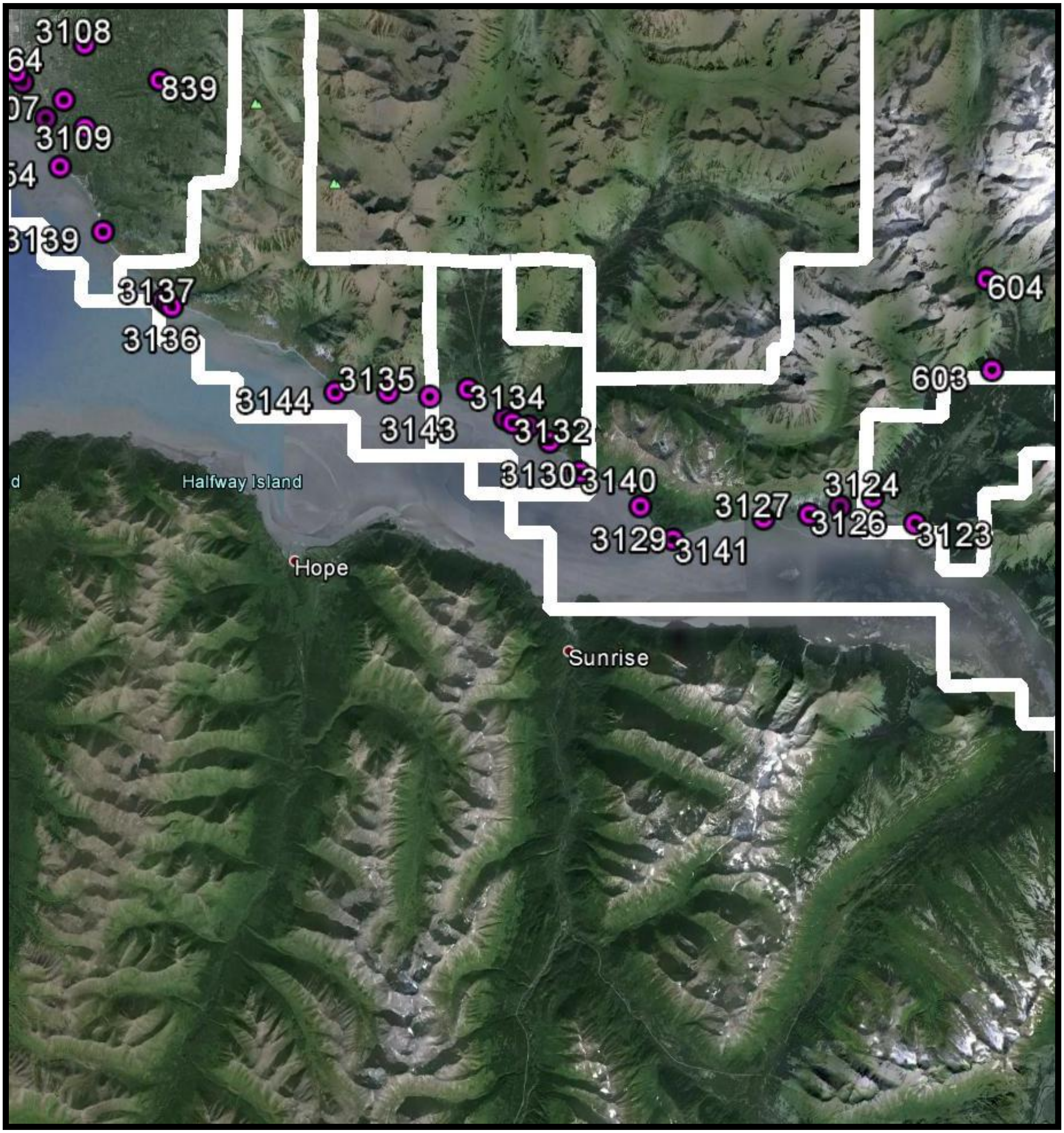
LiDAR Control Points (Checkpoints) Detail 1



LiDAR Control Points (Checkpoints) Detail 2



LiDAR Control Points (Checkpoints) Detail 3



LiDAR Accuracy Report

The following tables illustrate the results of the LiDAR data compared to the LiDAR checkpoints. The listing is sorted by the **Z Error** column showing, in ascending order, the vertical difference between the LiDAR points and the surveyed ground control points.

Filtered Control Report for LiDAR Checkpoints MOA_72 Data

Project File: MOA (MOA72)
Project Unit: US Feet
Date: OCT. 2015
Vertical Accuracy Objective:
Requirement Type: RMSE(z)
RMSE(z) Objective: 0.3
Control Points in Report: 79
Elevation Calculation Method: Interpolated from TIN
Control Points with LiDAR Coverage: 78
Average Control Error Reported: -0.02
Maximum (highest) Control Error Reported: 0.576
Median Control Error Reported: -0.042
Minimum (lowest) Control Error Reported: -0.56
Standard deviation (sigma) of Error for sample: 0.3
RMSE of Error for sample (RMSE(z)): 0.299: PASS
NSSDA Achievable Contour Interval: 1
ASPRS Class 1 Achievable Contour Interval: 0.9
NMAS Achievable Contour Interval: 1

Control Point Id	Control Pt X (East) USFeet	Control Pt Y (North) USFeet	Coverage	Control Pt Z (Elev) USFeet	Z from LiDAR USFeet	**Z Error USFeet**	Min. Z USFeet	Median Z USFeet	Max. Z USFeet
616	1753443.65	2725629.71	Yes	46.10	45.54	**-0.56**	45.44	45.54	45.58
3101	1721427.46	2673923.66	Yes	592.68	592.14	**-0.54**	592.09	592.12	592.22
608	1768720.59	2644180.30	Yes	531.10	530.58	**-0.52**	530.52	530.58	530.62
615	1767496.93	2723818.67	Yes	1290.80	1290.32	**-0.48**	1290.24	1290.41	1290.59
614	1789643.44	2708597.50	Yes	1008.10	1007.63	**-0.47**	1007.55	1007.63	1007.71
3057	1689439.42	2633542.22	Yes	280.18	279.75	**-0.43**	279.65	279.80	279.84
3	1665830.99	2610429.45	Yes	147.47	147.08	**-0.39**	146.35	146.89	147.24
3152	1665830.99	2610429.45	Yes	147.47	147.08	**-0.39**	146.35	146.89	147.24
3163	1666275.02	2594398.09	Yes	145.80	145.42	**-0.38**	145.14	145.53	145.57
3144	1709999.63	2551979.02	Yes	46.97	46.60	**-0.37**	46.35	46.54	46.71
3056	1689440.53	2633279.25	Yes	282.62	282.25	**-0.37**	282.17	282.21	282.27
610	1740308.08	2639871.35	Yes	2327.60	2327.24	**-0.36**	2327.22	2327.23	2327.35
3045	1660585.51	2638790.72	Yes	16.94	16.59	**-0.35**	16.50	16.59	16.66

3040	1663614.51	2628377.25	Yes	109.44	109.09	**-0.35**	109.06	109.08	109.16
3055	1689910.03	2633544.52	Yes	282.78	282.46	**-0.32**	282.39	282.42	282.47
3008	1671395.97	2629751.47	Yes	133.59	133.27	**-0.32**	133.24	133.27	133.32
975	1668402.16	2626214.53	Yes	172.92	172.62	**-0.30**	172.53	172.59	172.69
3164	1665430.03	2595687.69	Yes	145.08	144.80	**-0.28**	144.79	144.80	144.90
3003	1660593.25	2636909.12	Yes	106.27	105.99	**-0.28**	105.86	106.11	106.15
3087	1687601.09	2624251.78	Yes	323.94	323.67	**-0.27**	323.63	323.64	323.82
3085	1688017.28	2624518.28	Yes	328.17	327.90	**-0.27**	327.78	327.92	327.94
3004	1660322.30	2636905.05	Yes	105.90	105.64	**-0.26**	105.62	105.64	105.75
3029	1674248.60	2633648.11	Yes	145.96	145.71	**-0.25**	145.65	145.71	145.76
3027	1674252.89	2632508.04	Yes	139.61	139.37	**-0.24**	139.28	139.40	139.41
3028	1674246.90	2632829.19	Yes	141.78	141.55	**-0.23**	141.51	141.62	141.62
93	1648877.32	2611806.28	Yes	118.74	118.51	**-0.23**	118.45	118.57	118.60
3061	1674721.49	2639439.12	Yes	163.45	163.23	**-0.22**	163.20	163.29	163.42
3088	1661833.36	2629796.55	Yes	106.58	106.38	**-0.20**	106.36	106.40	106.43
10	1664066.59	2626228.14	Yes	110.99	110.81	**-0.18**	110.52	110.79	110.82
3058	1689310.07	2633536.49	Yes	277.79	277.64	**-0.15**	277.45	277.49	277.75
607	1735235.71	2652870.01	Yes	1871.40	1871.26	**-0.14**	1870.68	1871.16	1871.87
3126	1775522.16	2535797.15	Yes	25.33	25.20	**-0.14**	25.18	25.26	25.29
850	1687421.62	2640405.84	Yes	270.62	270.49	**-0.13**	270.35	270.42	270.56
3053	1650023.62	2604533.04	Yes	56.63	56.53	**-0.10**	56.22	56.60	56.65
3112	1673141.78	2618485.37	Yes	183.41	183.33	**-0.08**	183.29	183.41	183.51
554	1671654.30	2582745.39	Yes	17.32	17.25	**-0.07**	17.12	17.30	17.34
3086	1687704.14	2624394.99	Yes	325.26	325.21	**-0.05**	325.11	325.21	325.35
3048	1659961.74	2598270.20	Yes	113.39	113.34	**-0.05**	113.33	113.35	113.52
3089	1647761.77	2605793.94	Yes	53.24	53.20	**-0.04**	53.10	53.16	53.35
609	1742808.12	2664214.20	Yes	406.80	406.76	**-0.04**	406.57	406.75	406.90
91	1648948.91	2609041.07	Yes	88.65	88.62	**-0.03**	88.34	88.72	88.75
839	1685593.24	2594529.76	Yes	950.77	950.74	**-0.03**	950.48	950.72	950.99
3129	1752239.35	2536650.80	Yes	26.54	26.55	**0.01**	26.39	26.66	26.67
3140	1743785.34	2541269.98	Yes	79.47	79.50	**0.03**	79.48	79.53	79.60
3113	1673859.89	2618546.41	Yes	184.12	184.16	**0.04**	184.10	184.14	184.26
3141	1756770.21	2532161.51	Yes	62.80	62.85	**0.05**	62.82	62.88	62.89
3047	1661229.76	2598276.56	Yes	122.83	122.89	**0.06**	122.84	122.89	123.06
3026	1667348.01	2623494.47	Yes	137.78	137.87	**0.09**	137.38	138.24	138.32
3090	1648002.26	2605929.29	Yes	48.10	48.21	**0.11**	47.90	48.15	48.25
3134	1728297.96	2552593.48	Yes	52.95	53.09	**0.14**	53.02	53.03	53.13
3143	1723027.59	2551518.20	Yes	54.54	54.69	**0.15**	54.66	54.66	54.85
3133	1733428.36	2548584.75	Yes	108.31	108.46	**0.15**	108.12	108.58	108.63
1802	1651552.36	2615600.97	Yes	92.86	93.01	**0.15**	92.96	93.00	93.08
3030	1669041.41	2618199.18	Yes	153.01	153.17	**0.16**	153.09	153.09	153.21

3093	1646929.57	2614581.48	Yes	125.95	126.12	**0.17**	126.05	126.11	126.16
3091	1648241.61	2605982.66	Yes	48.50	48.70	**0.20**	48.51	48.70	48.76
3135	1717307.71	2552028.10	Yes	43.34	43.54	**0.20**	43.40	43.45	43.98
3092	1646929.03	2615352.63	Yes	114.83	115.05	**0.22**	114.99	115.05	115.07
603	1800401.51	2555874.93	Yes	542.00	542.22	**0.22**	542.12	542.15	542.65
3054	1650461.31	2604972.38	Yes	59.92	60.16	**0.24**	59.98	60.27	60.28
604	1799309.89	2568149.40	Yes	1359.80	1360.06	**0.26**	1360.01	1360.06	1360.07
3136	1687295.73	2563574.02	Yes	37.62	37.89	**0.27**	37.64	37.86	37.91
3127	1769218.93	2535147.55	Yes	26.30	26.58	**0.28**	26.45	26.49	26.76
3131	1736680.92	2547563.94	Yes	75.03	75.31	**0.28**	75.25	75.27	75.34
3124	1784274.42	2538172.93	Yes	29.83	30.11	**0.28**	30.06	30.13	30.21
3130	1739628.70	2545457.26	Yes	72.37	72.67	**0.30**	72.60	72.69	72.71
3031	1659925.02	2616896.39	Yes	107.76	108.11	**0.35**	107.97	108.11	108.12
559	1669614.01	2589418.68	Yes	150.68	151.04	**0.36**	150.81	151.03	151.06
3138	1686104.64	2564496.30	Yes	36.21	36.58	**0.37**	36.40	36.66	36.72
3109	1675148.84	2588033.20	Yes	384.77	385.14	**0.37**	384.80	385.02	385.23
3125	1779758.79	2536945.34	Yes	26.09	26.46	**0.37**	26.01	26.20	26.59
3132	1734463.49	2548041.24	Yes	62.31	62.70	**0.39**	62.47	62.73	62.94
3108	1675007.57	2599532.10	Yes	419.11	419.57	**0.46**	419.41	419.46	419.62
3107	1672122.98	2591915.58	Yes	274.80	275.28	**0.48**	275.23	275.29	275.45
3139	1677845.56	2573738.09	Yes	33.56	34.05	**0.49**	33.70	33.81	34.50
3123	1790121.39	2534721.26	Yes	27.58	28.08	**0.50**	28.06	28.09	28.10
3137	1686759.46	2563941.54	Yes	33.52	34.03	**0.51**	33.96	34.00	34.22
3052	1649962.40	2604811.11	Yes	55.23	55.81	**0.58**	55.62	55.78	55.88
611	1789099.01	2732292.79	No	36.80					

Filtered Control Report for LiDAR Checkpoints NAVD88 Data

Project File: MOA (NAVD88)
Project Unit: US Feet
Date: Oct. 2015
Vertical Accuracy Objective:
Requirement Type: RMSE(z)
RMSE(z) Objective: 0.3
Control Points in Report: 79
Elevation Calculation Method: Interpolated from TIN
Control Points with LiDAR Coverage: 78
Average Control Error Reported: -0.03
Maximum (highest) Control Error Reported: 0.576
Median Control Error Reported: -0.05
Minimum (lowest) Control Error Reported: -0.54
Standard deviation (sigma) of Error for sample: 0.295
RMSE of Error for sample (RMSE(z)): 0.295: PASS
NSSDA Achievable Contour Interval: 1
ASPRS Class 1 Achievable Contour Interval: 0.9
NMAS Achievable Contour Interval: 1

Control Point Id	Control Pt X (East) USFeet	Control Pt Y (North) USFeet	Coverage	Control Pt Z (Elev) USFeet	Z from LiDAR USFeet	**Z Error USFeet**	Min. Z USFeet	Median Z USFeet	Max. Z USFeet
3101	1721427.46	2673923.66	Yes	599.20	598.66	**-0.54**	598.61	598.64	598.74
614	1789643.44	2708597.50	Yes	1014.65	1014.15	**-0.50**	1014.07	1014.15	1014.23
615	1767496.93	2723818.67	Yes	1297.32	1296.84	**-0.48**	1296.76	1296.93	1297.11
3057	1689439.42	2633542.22	Yes	286.70	286.27	**-0.43**	286.17	286.32	286.36
608	1768720.59	2644180.30	Yes	537.52	537.10	**-0.42**	537.04	537.10	537.14
3152	1665830.99	2610429.45	Yes	153.99	153.60	**-0.39**	152.87	153.41	153.76
3	1665830.99	2610429.45	Yes	153.99	153.60	**-0.39**	152.87	153.41	153.76
3163	1666275.02	2594398.09	Yes	152.32	151.94	**-0.38**	151.66	152.05	152.09
610	1740308.08	2639871.35	Yes	2334.14	2333.76	**-0.38**	2333.74	2333.75	2333.87
604	1799309.89	2568149.40	Yes	1366.96	1366.58	**-0.38**	1366.53	1366.58	1366.59
3056	1689440.53	2633279.25	Yes	289.14	288.77	**-0.37**	288.69	288.73	288.79
3144	1709999.63	2551979.02	Yes	53.49	53.12	**-0.37**	52.87	53.06	53.23
603	1800401.51	2555874.93	Yes	549.10	548.74	**-0.36**	548.64	548.67	549.17
3045	1660585.51	2638790.72	Yes	23.46	23.11	**-0.35**	23.02	23.11	23.18
3040	1663614.51	2628377.25	Yes	115.96	115.61	**-0.35**	115.58	115.60	115.68
3055	1689910.03	2633544.52	Yes	289.30	288.98	**-0.32**	288.91	288.94	288.99
3008	1671395.97	2629751.47	Yes	140.11	139.79	**-0.32**	139.76	139.79	139.84
975	1668402.16	2626214.53	Yes	179.44	179.14	**-0.30**	179.05	179.11	179.21

3164	1665430.03	2595687.69	Yes	151.60	151.32	**-0.28**	151.31	151.32	151.42
3003	1660593.25	2636909.12	Yes	112.79	112.51	**-0.28**	112.38	112.63	112.67
3087	1687601.09	2624251.78	Yes	330.46	330.19	**-0.27**	330.15	330.16	330.34
3085	1688017.28	2624518.28	Yes	334.69	334.42	**-0.27**	334.30	334.44	334.46
3004	1660322.30	2636905.05	Yes	112.42	112.16	**-0.26**	112.14	112.16	112.27
3029	1674248.60	2633648.11	Yes	152.48	152.23	**-0.25**	152.17	152.23	152.28
3027	1674252.89	2632508.04	Yes	146.13	145.89	**-0.24**	145.80	145.92	145.93
3028	1674246.90	2632829.19	Yes	148.30	148.07	**-0.23**	148.03	148.14	148.14
93	1648877.32	2611806.28	Yes	125.26	125.03	**-0.23**	124.97	125.09	125.12
616	1753443.65	2725629.71	Yes	52.28	52.06	**-0.22**	51.96	52.06	52.10
3061	1674721.49	2639439.12	Yes	169.97	169.75	**-0.22**	169.72	169.81	169.94
3088	1661833.36	2629796.55	Yes	113.10	112.90	**-0.20**	112.88	112.92	112.95
10	1664066.59	2626228.14	Yes	117.51	117.33	**-0.18**	117.04	117.31	117.34
3058	1689310.07	2633536.49	Yes	284.31	284.16	**-0.15**	283.97	284.01	284.27
3126	1775522.16	2535797.15	Yes	31.85	31.72	**-0.14**	31.70	31.78	31.81
850	1687421.62	2640405.84	Yes	277.14	277.01	**-0.13**	276.87	276.94	277.08
607	1735235.71	2652870.01	Yes	1877.89	1877.78	**-0.11**	1877.20	1877.68	1878.39
3053	1650023.62	2604533.04	Yes	63.15	63.05	**-0.10**	62.74	63.12	63.17
3112	1673141.78	2618485.37	Yes	189.93	189.85	**-0.08**	189.81	189.93	190.03
554	1671654.30	2582745.39	Yes	23.84	23.77	**-0.07**	23.64	23.82	23.86
3086	1687704.14	2624394.99	Yes	331.78	331.73	**-0.05**	331.63	331.73	331.87
3048	1659961.74	2598270.20	Yes	119.91	119.86	**-0.05**	119.85	119.87	120.04
3089	1647761.77	2605793.94	Yes	59.76	59.72	**-0.04**	59.62	59.68	59.87
91	1648948.91	2609041.07	Yes	95.17	95.14	**-0.03**	94.86	95.24	95.27
609	1742808.12	2664214.20	Yes	413.31	413.28	**-0.03**	413.09	413.27	413.42
839	1685593.24	2594529.76	Yes	957.29	957.26	**-0.03**	957.00	957.24	957.51
3129	1752239.35	2536650.80	Yes	33.06	33.07	**0.01**	32.91	33.18	33.19
3140	1743785.34	2541269.98	Yes	85.99	86.02	**0.03**	86.00	86.05	86.12
3113	1673859.89	2618546.41	Yes	190.64	190.68	**0.04**	190.62	190.66	190.78
3141	1756770.21	2532161.51	Yes	69.32	69.37	**0.05**	69.34	69.40	69.41
3047	1661229.76	2598276.56	Yes	129.35	129.41	**0.06**	129.36	129.41	129.58
3026	1667348.01	2623494.47	Yes	144.30	144.39	**0.09**	143.90	144.76	144.84
3090	1648002.26	2605929.29	Yes	54.62	54.73	**0.11**	54.42	54.67	54.77
3134	1728297.96	2552593.48	Yes	59.47	59.61	**0.14**	59.54	59.55	59.65
3143	1723027.59	2551518.20	Yes	61.06	61.21	**0.15**	61.18	61.18	61.37
3133	1733428.36	2548584.75	Yes	114.83	114.98	**0.15**	114.64	115.10	115.15
1802	1651552.36	2615600.97	Yes	99.38	99.53	**0.15**	99.48	99.52	99.60
3030	1669041.41	2618199.18	Yes	159.53	159.69	**0.16**	159.61	159.61	159.73
3093	1646929.57	2614581.48	Yes	132.47	132.64	**0.17**	132.57	132.63	132.68
3091	1648241.61	2605982.66	Yes	55.02	55.22	**0.20**	55.03	55.22	55.28
3135	1717307.71	2552028.10	Yes	49.86	50.06	**0.20**	49.92	49.97	50.50

3092	1646929.03	2615352.63	Yes	121.35	121.57	**0.22**	121.51	121.57	121.59
3054	1650461.31	2604972.38	Yes	66.44	66.68	**0.24**	66.50	66.79	66.80
3136	1687295.73	2563574.02	Yes	44.14	44.41	**0.27**	44.16	44.38	44.43
3127	1769218.93	2535147.55	Yes	32.82	33.10	**0.28**	32.97	33.01	33.28
3131	1736680.92	2547563.94	Yes	81.55	81.83	**0.28**	81.77	81.79	81.86
3124	1784274.42	2538172.93	Yes	36.35	36.63	**0.28**	36.58	36.65	36.73
3130	1739628.70	2545457.26	Yes	78.89	79.19	**0.30**	79.12	79.21	79.23
3031	1659925.02	2616896.39	Yes	114.28	114.63	**0.35**	114.49	114.63	114.64
559	1669614.01	2589418.68	Yes	157.20	157.56	**0.36**	157.33	157.55	157.58
3138	1686104.64	2564496.30	Yes	42.73	43.10	**0.37**	42.92	43.18	43.24
3109	1675148.84	2588033.20	Yes	391.29	391.66	**0.37**	391.32	391.54	391.75
3125	1779758.79	2536945.34	Yes	32.61	32.98	**0.37**	32.53	32.72	33.11
3132	1734463.49	2548041.24	Yes	68.83	69.22	**0.39**	68.99	69.25	69.46
3108	1675007.57	2599532.10	Yes	425.63	426.09	**0.46**	425.93	425.98	426.14
3107	1672122.98	2591915.58	Yes	281.32	281.80	**0.48**	281.75	281.81	281.97
3139	1677845.56	2573738.09	Yes	40.08	40.57	**0.49**	40.22	40.33	41.02
3123	1790121.39	2534721.26	Yes	34.10	34.60	**0.50**	34.58	34.61	34.62
3137	1686759.46	2563941.54	Yes	40.04	40.55	**0.51**	40.48	40.52	40.74
3052	1649962.40	2604811.11	Yes	61.75	62.33	**0.58**	62.14	62.30	62.40
611	1789099.01	2732292.79	No	43.32					

LiDAR CALIBRATION

Note: All figures represented on the following pages are for general illustration purposes, and are not examples derived from actual MOA data.

Introduction

A LiDAR calibration or 'boresight' is performed on every mission to determine and eliminate systemic biases that occur within the hardware of the Leica ALS70 laser scanning system, the inertial measurement unit (IMU), and because of environmental conditions which affect the refraction of light. The systemic biases that are corrected for include roll, pitch, and heading.

Calibration Procedures

In order to correct the error in the data, misalignments of features in the overlap areas of the LiDAR flightlines must be detected and measured. At some point within the mission, a specific flight pattern must be flown which shows all the misalignments that can be present. Typically, Merrick flies a pattern of at least three opposing direction and overlapping lines, three of which provide all the information required to calibrate the system.

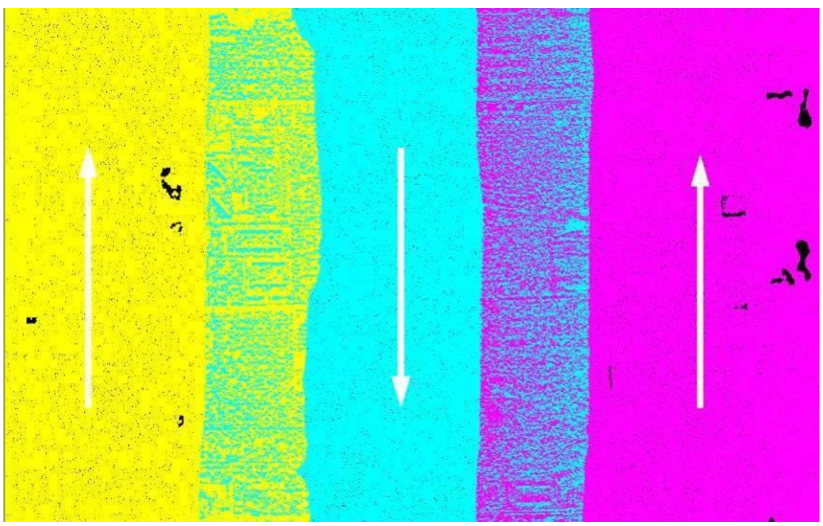


Figure 1: Flight pattern required for calibration

Correcting for Pitch and Heading Biases

There are many settings in the ALS post processor that can be used to manipulate the data; six are used for boresighting. They are roll, pitch, heading, torsion, range and atmospheric correction. The order in which each is evaluated is not very important and may be left to the discretion of the operator. For this discussion, pitch and heading will be evaluated first. It is important to remember that combinations of error can be very confusing, and this is especially true with pitch and heading. They affect the data in similar ways, so error attributed to pitch may be better blamed on heading and vice versa. To see a pitch/heading error, one must use the profile tool to cut along the flight path at a pitched roof or any elevation feature that is perpendicular to the flight path. View the data by elevation to locate these scenarios.

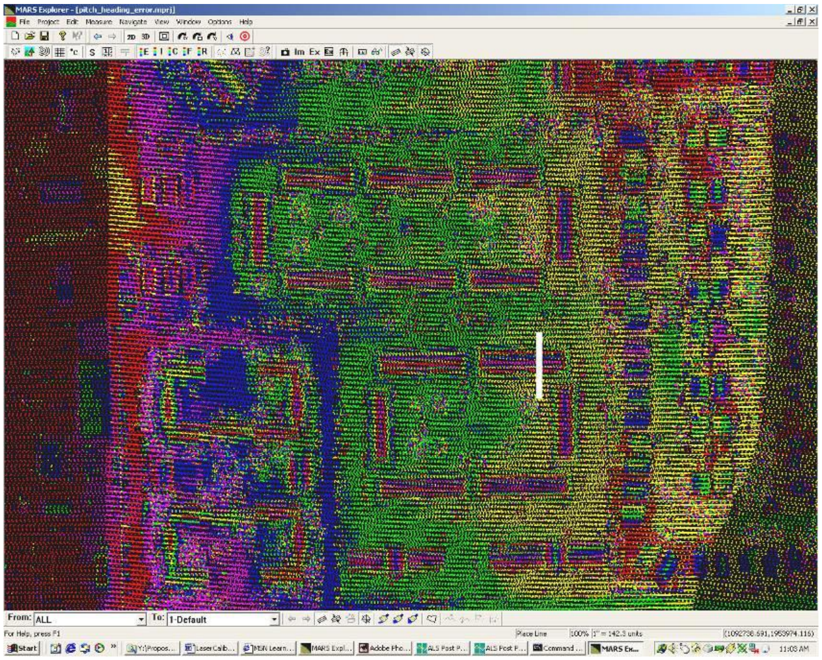


Figure 2: Orthographic view with profile line

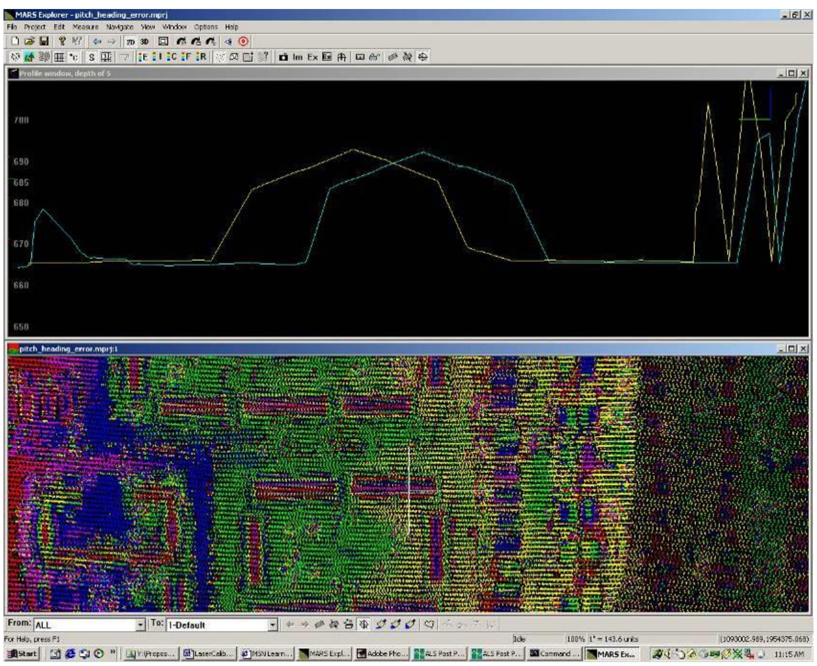


Figure 3: Profile view of misalignment

The profile line in Figures 2 and 3 has an additional thin line perpendicular to the cut that shows the direction of the view. In this case, the line is pointing to the right, or east. In the profile window, we are looking through two separate TINs, so there are two lines showing the location of the same building. The yellow line is from the flight line on the left (flown north); the light blue line is from the flight line in the middle (flown south).

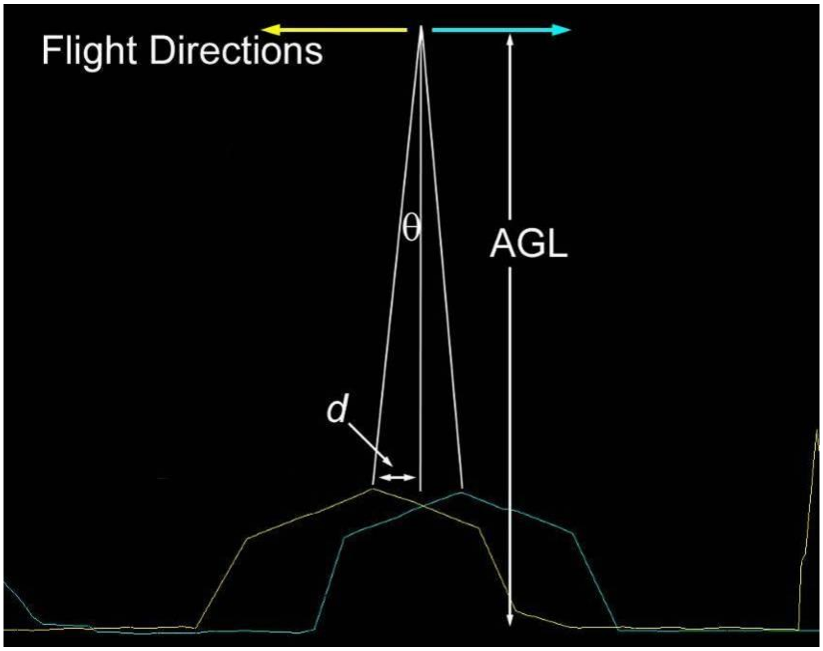


Figure 4: Adjusting pitch

The top arrows represent each respective flight direction. We are looking east, the yellow flight line was flown north, and the blue line is flown south. Adjusting pitch changes the relationship between the pitch from the IMU and the actual pitch of the plane. Increasing pitch sends the nose of the plane up and the data ahead in the flight direction. Lowering pitch does the opposite. In this example, pitch needs to decrease in order to bring these two roof lines together. The angle theta□ must be expressed in radians. The formula to arrive at this angle is…

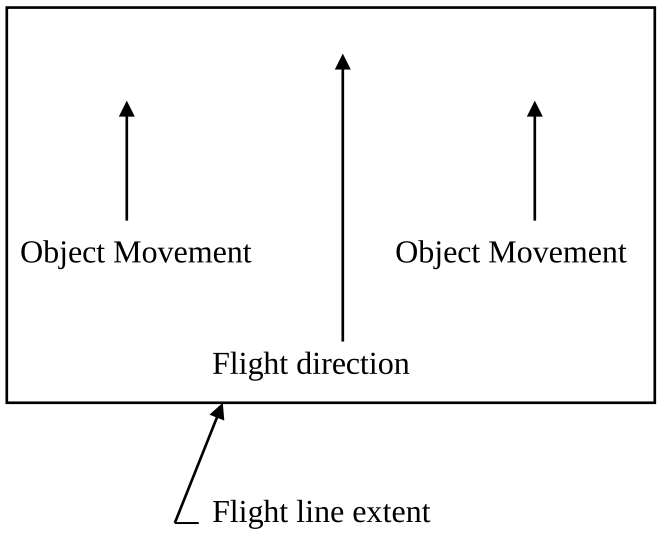
$$\theta = \frac{\arctan\left(\frac{d}{AGL}\right)}{57.2958}$$

where *d* is the distance from nadir (directly under the plane) to the peak of the roof and AGL is the 'above ground level' of the plane. The conversion from degrees to radians is one radian equals 57.2958 degrees. This number is then subtracted from the pitch value that was used to create the data.

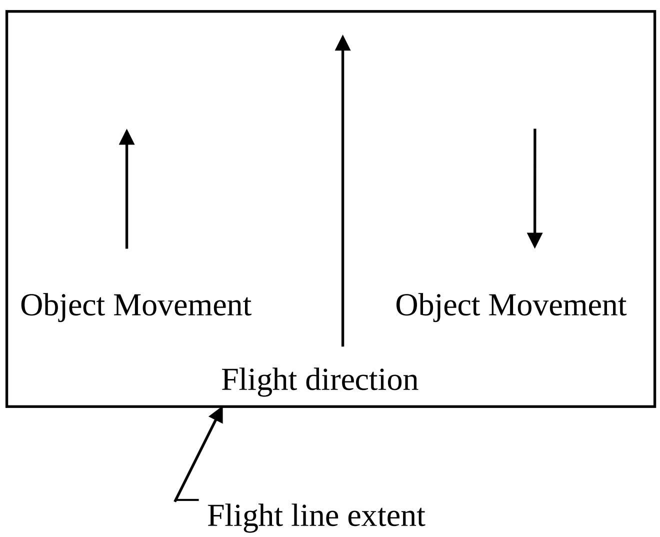
The next issue to resolve, before actually changing the pitch value, is to determine if this shift is at all due to an incorrect heading value, since heading will move data in the direction of flight also. The difference is that heading rotates the data, meaning that when heading is changed, objects on opposite sides of the swath move in opposite directions.

Figures 5 and 6: Pitch and Heading movement.

Pitch increases, objects throughout the data move forward.



Heading increases, objects move clockwise.



When heading changes, objects on the sides of the flight line move in opposite directions. If heading is increased, objects in the flight line move in a clockwise direction. If heading is decreased, objects move in a counter-clockwise direction.

To find out if heading is correct, a similar profile line must be made in the overlap area between the middle flight line and the one to the east, or right side. If the distance *d* (see Figure 4) is different on the right verses the left, then heading is partially responsible for the error. If the distance *d* is the same on both sides then heading *or* pitch is fully responsible.

Correcting for the Roll Bias

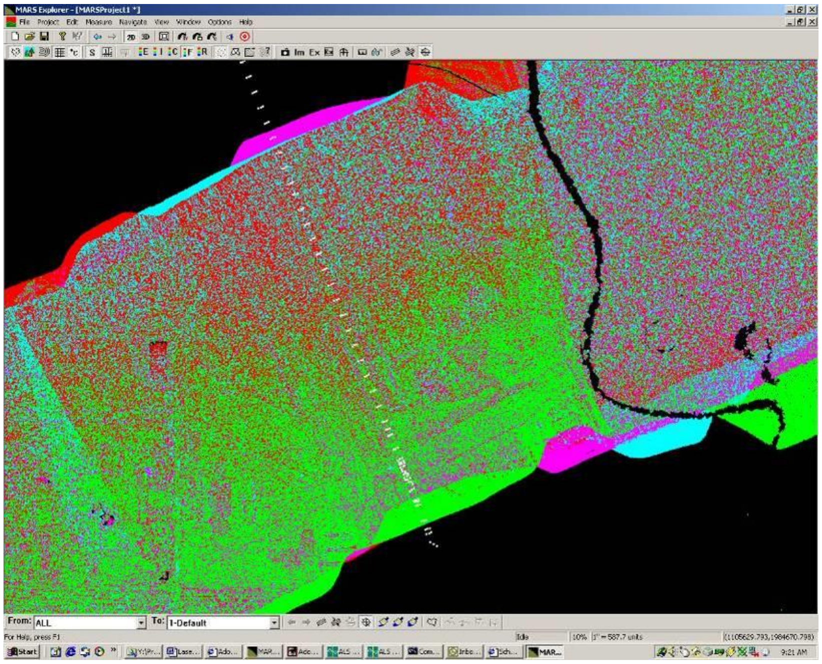


Figure 7: The truth survey

Each pair of flight lines was flown in opposite directions, and in this case the red and blue lines were flown east and the green and magenta lines were flown west. The first step is to make a profile line across the survey. Once the profile is created, exaggeration of the elevation by 100 times is necessary to see the pattern. (Figure 8)

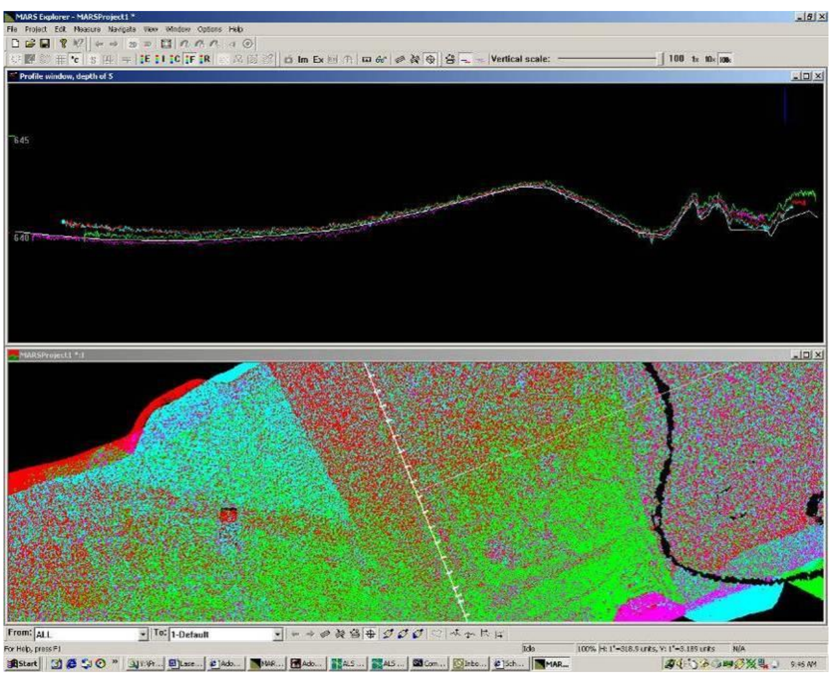


Figure 8: Profile view of calibration flight lines

Even without zooming in, a pattern is already apparent. The two east flown lines, red and blue, are high on the left compared to the west flown lines, and low on the right. Since the profile line was created with the view eastward, it is easiest to think about what the east lines are doing. The east lines are low on the right, which means the relationship between the IMU and the right wing of the plane must be adjusted up. As in heading adjustments, sending the data in a clockwise direction is positive. If the axis of the clock is the tail/nose axis of the plane, then it is obvious this data must go in a counter clock-wise, or negative direction. The method for determining the magnitude of the adjustment is similar to determining the magnitude of the adjustment for the pitch. The only difference is how the triangles are drawn in relationship to the data. (Figures 9 and 10)

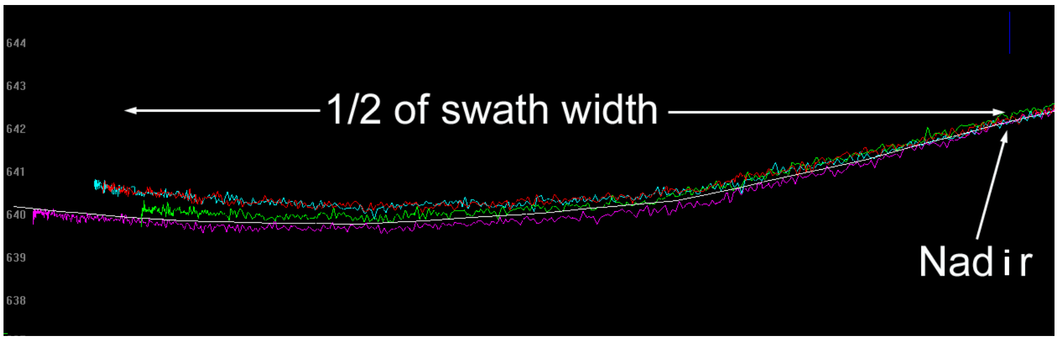


Figure 9: Half of calibration profile

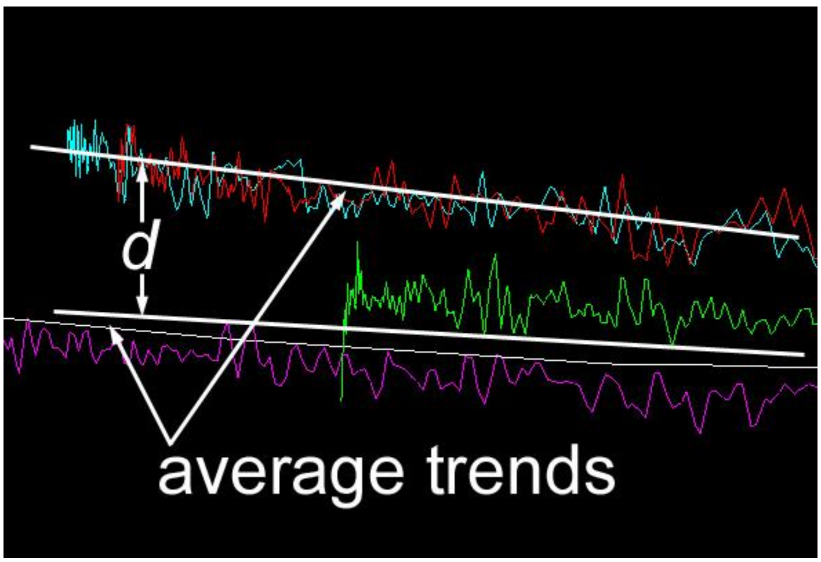


Figure 10: Differences in average roll trends

The important measurements for this formula are the distance from nadir to the edge of the swath, or ½ swath width, and d, the distance from the two average trend lines for each group. Since any adjustments made to roll effect both east and west lines, we are really interested in ½ d; this will give the value that will bring both sets of lines together. The formula is:

$$\theta = \frac{\arctan\left(\dfrac{d/2}{EdgeToNadir}\right)}{57.2958}$$

Correcting the Final Elevation

The next step is to ensure that all missions have the same vertical offset. Two techniques are used to achieve this. The first is to compare all calibration flight lines and shift the missions appropriately. The second is to fly an extra 'cross flight' which touches all flight lines in the project. Each mission's vertical differences can then be analyzed and corrected. However, the result of this exercise is only proof of a high level of relative accuracy. Since many of the calibration techniques affect elevation, project wide GPS control must be utilized to place the surface in the correct location. This can be achieved by utilizing the elevation offset control in the post processor or by shifting the data appropriately in MARS®. The control network may be pre-existing or collected by a licensed surveyor. This is always the last step and is the only way to achieve the high absolute accuracy that is the overall goal.

LIDAR CLASSIFICATION

Auto-Filter (automated)

Merrick uses customizable software to classify an automated bare-earth (i.e., ground / Class 2) solution from the LiDAR point cloud. The software uses several different algorithms combined in a macro to determine the classification for each point. Filter parameters are adjusted based on the terrain and land cover for each project to produce the best ground result and to minimize hand-filter. Merrick's automated filters typically classify 85- to 90-percent of the ground.

Hand-Filter (manual editing)

The remaining 10- to 15-percent of the points resulting from the automated filtering techniques are possibly misclassified and require final editing. Using the MARS® software, Merrick has several manual edit tools which allow us to re-classify these features to the appropriate class. All the data within the project extent is viewed by an operator to ensure all artifacts are removed, and that we are meeting project specifications. Once it is deemed the best ground solution is met, Merrick performs a final auto-filter to classify all points to meet the ASPRS LAS 1.4 specification. During this process all non-ground points are classified to Class 1 (Unclassified), and following this is a height-from-surface (≥5' below) auto-filter is run to re-class noise to Class 7.

The following table represents the ASPRS LAS 1.4 classifications used for the Municipality Of Anchorage:

- Class 1 – Processed, but unclassified
- Class 2 – Bare-earth ground
- Class 7 – Noise (low or high, manually identified, if needed)
- Class 9 – Water
- Class 10 – Ignored Ground (Breakline Proximity)
- Class 17- Bridge Decks

Hydro-enforcing breaklines are captured by Merrick compilers. These features are appropriately turned in to polygons and are used in MARS® to reclassify ground points in water to Water (Class 9). The LiDAR points around the breaklines are reclassified to Ignored Ground (Class 10) based on a five-foot (5') buffer.

Important to note, Merrick preserves the integrity of overlap points (i.e., typically Class 12) in the final ground class for the following reasons:

1. Overlap points increase the density of ground features enabling:
   a. Better vegetation penetration
   b. Better ground classifications
   c. Better ability to place breaklines as needed
2. Overlap points often fill in LiDAR shadows caused by buildings and other occlusive features that impede the laser's path to the ground thus modeling the ground better.
3. The overlap points are included in statistical calculations to determine average GSD and point density at both the planning stage and the delivery stage.
4. Overlap points are calibrated to the same accuracy specifications as the rest of the LiDAR swath.

DATA COLLECTION

Breaklines

Merrick uses a methodology that directly interacts with the LiDAR bare-earth data to collect drainage breaklines. To determine the alignment of a drainage way, the technician first views the area as a TIN of bare-earth points using a color ramp to depict varying elevations. In areas of extremely flat terrain, the technician may need to determine the direction of flow based on measuring LiDAR bare-earth points at each end of the drain. The operator will then use the color ramped TIN to digitize the drainage centerline in 2D with the elevation being attributed directly from the bare-earth .LAS data. All drainage breaklines are collected in a downhill direction. For each point collected, the software uses a 5' search radius to identify the lowest point within that proximity. Within each radius, if a bare-earth point is not found that is lower than the previous point, the elevation for subsequent point remains the same as the previous point. This forces the drain to always flow in a downhill direction. Waterbodies that are embedded along a drainage way are validated to ensure consistency with the downhill direction of flow.

This methodology may differ from those of other vendors in that Merrick relies on the bare-earth data to attribute breakline elevations. As a result of our methodology, there is no mismatch between LiDAR bare-earth data and breaklines that might otherwise be collected in stereo 3D as a separate process. This is particularly important in densely vegetated areas where breaklines collected in 3D from imagery will most likely not match (either horizontally or vertically), the more reliable LiDAR bare-earth data.

Merrick has the capability of “draping” 2D breaklines to a bare-earth elevation model to attribute the “z” as opposed to the forced downhill attribution methodology described above. However, the problem with this process is the “pooling”effect or depressions along the drainage way caused by a lack of consistent penetration in densely vegetated areas.

Waterbodies

Waterbodies are digitized from the color ramped TIN, similar to the process described above. The elevation attribute is determined as a post-process using the lowest determined bare-earth point within the polygon.

Digital Terrain Model (DTM)

Merrick combines the Ground (Class 2) with aforementioned breaklines to create the DTM. Merrick conditions the ground by removing ground points in waterbodies and a five-foot (5') buffer around each breakline to mitigate “noise”.