Nebraska Iowa Regional Orthophotography Consortium (NIROC)

LiDAR Mapping Report

Prepared by:

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EXECUTIVE SUMMARY

Merrick & Company (Merrick) was contracted by Nebraska Iowa Regional Orthophotography Consortium (NIROC) to perform a LiDAR (**Li**ght **D**etection **A**nd **R**anging) survey for an area located in the eastern part of the State of Nebraska. The purpose of the project is to produce accurate high-resolution data for use in planning, design, and research, utilizing LiDAR. Merrick obtained LiDAR data over approximately 2212 square miles covering an area near Omaha and Lincoln Nebraska. LiDAR accuracy will meet or exceed .3 feet RMSEz at 95% confidence level.

CONTRACT INFORMATION

Questions regarding this report should be addressed to:

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Project Completion

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

LiDAR FLIGHT and SYSTEM REPORT

Project Location

The project location for is defined by the shapefile:
Core_and_WashCo_LIDAR_Request_and_LowerPlatteLiDARClip_dissolved.shp

Duration/Time Period

One LiDAR aircraft, a Cessna 402C (SN53), was used to collect LiDAR Data. The LiDAR data was collection on April 16th, 2010 thru April 28th 2010. The airports of operation were Eppley Airfield, located in Omaha, Lincoln Municipal Airport located in Lincoln, Columbus Municipal Airport located in Columbus, State of Nebraska.

Mission Parameters for Cessna 402C (SN53)

LiDAR Sensor	Leica Geosystems ALS50 Phase 2+
Nominal Ground Sample Distance	1.36 meters
Field of View (scan angle)	35 deg.
Average Airspeed	170 Knots
Laser Pulse Rate	82,700 Hertz
Scan Rate	29 Hz
Average Altitude (MSL)	10,500 Feet

Flight mission Date and Times

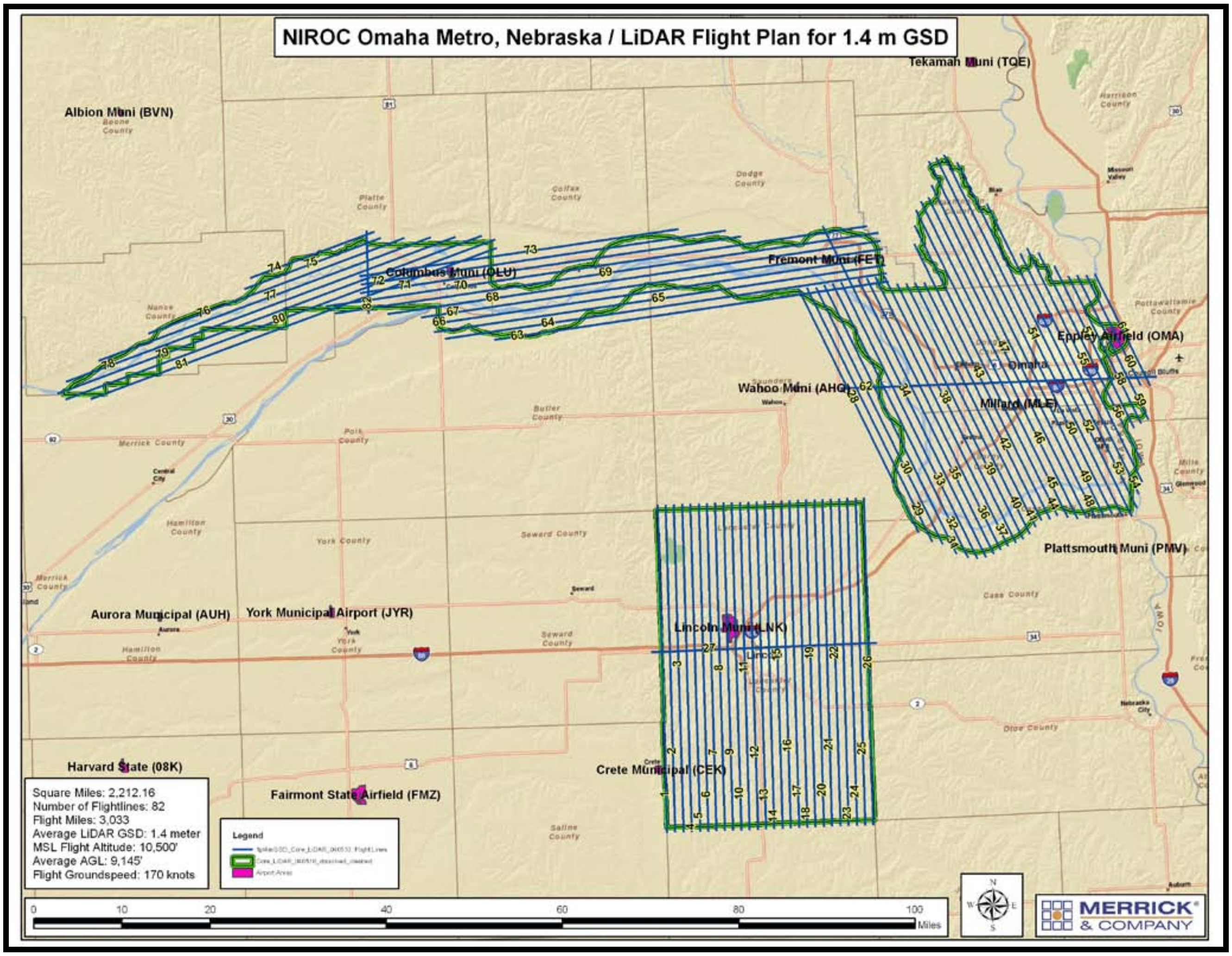
Mission	Date	Plane	Airport of Operation
100416_A	April 16, 2010	SN53	Eppley Airfield Eppley Airfield, located in Omaha
100417_A	April 17, 2010	SN53	Eppley Airfield, located in Omaha Neb.
100417_B	April 17, 2010	SN53	Eppley Airfield, located in Omaha Neb.
100418_A	April 18, 2010	SN53	Lincoln Municipal Airport located in Lincoln Neb.
100418_B	April 18, 2010	SN53	Lincoln Municipal Airport located in Lincoln Neb.
100419_A	April 19, 2010	SN53	Columbus Municipal Airport located in Columbus Neb.
100419_B	April 19, 2010	SN53	Columbus Municipal Airport located in Columbus Neb.
100428_A	April 28, 2010	SN53	Columbus Municipal Airport located in Columbus Neb.

Field Work / Procedures

Two ground GPS Base Stations, for the LiDAR data collection, were set up at the airports of operation. The main GPS Base Station (Base) and the auxiliary GPS Base Station (Aux) used for backup if there are any problems with the main GPS Base Station.

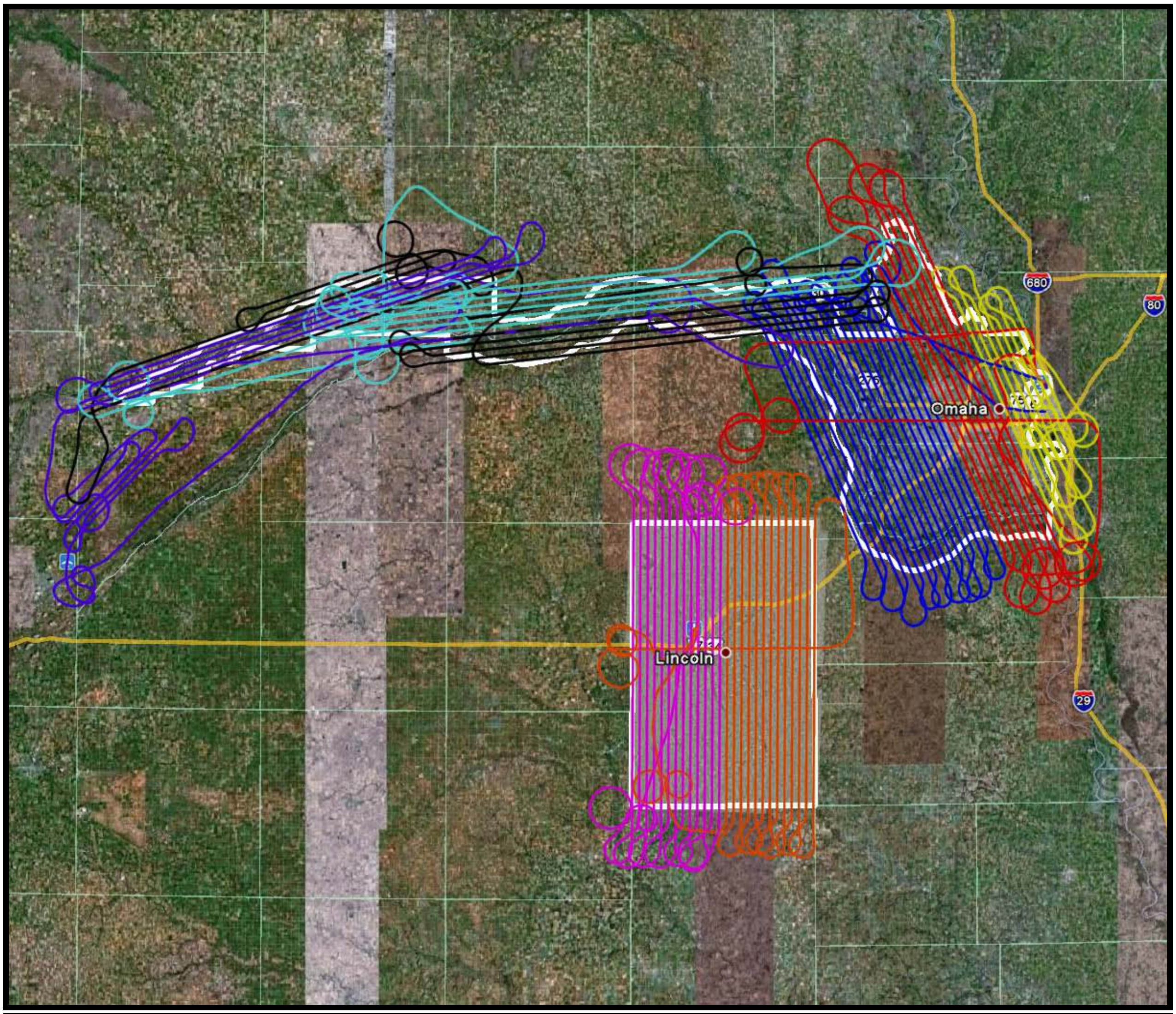
Pre-flight checks such as cleaning the sensor head glass are performed. A five minute INS initialization is conducted on the ground, with the aircraft engines running, prior to the flight mission. To establish fine-alignment of the INS GPS, ambiguities are resolved by flying within ten kilometers of the GPS base stations. 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 were again resolved by flying within ten kilometers of the GPS base stations to aid in post-processing. Data was sent back to the main office and preliminary data processing was performed for quality control of GPS data and to ensure sufficient overlap between flight lines. Any problematic data could then be reflown immediately as required. Final data processing was completed in the Aurora, Colorado office.

Planned Flight Line Diagram

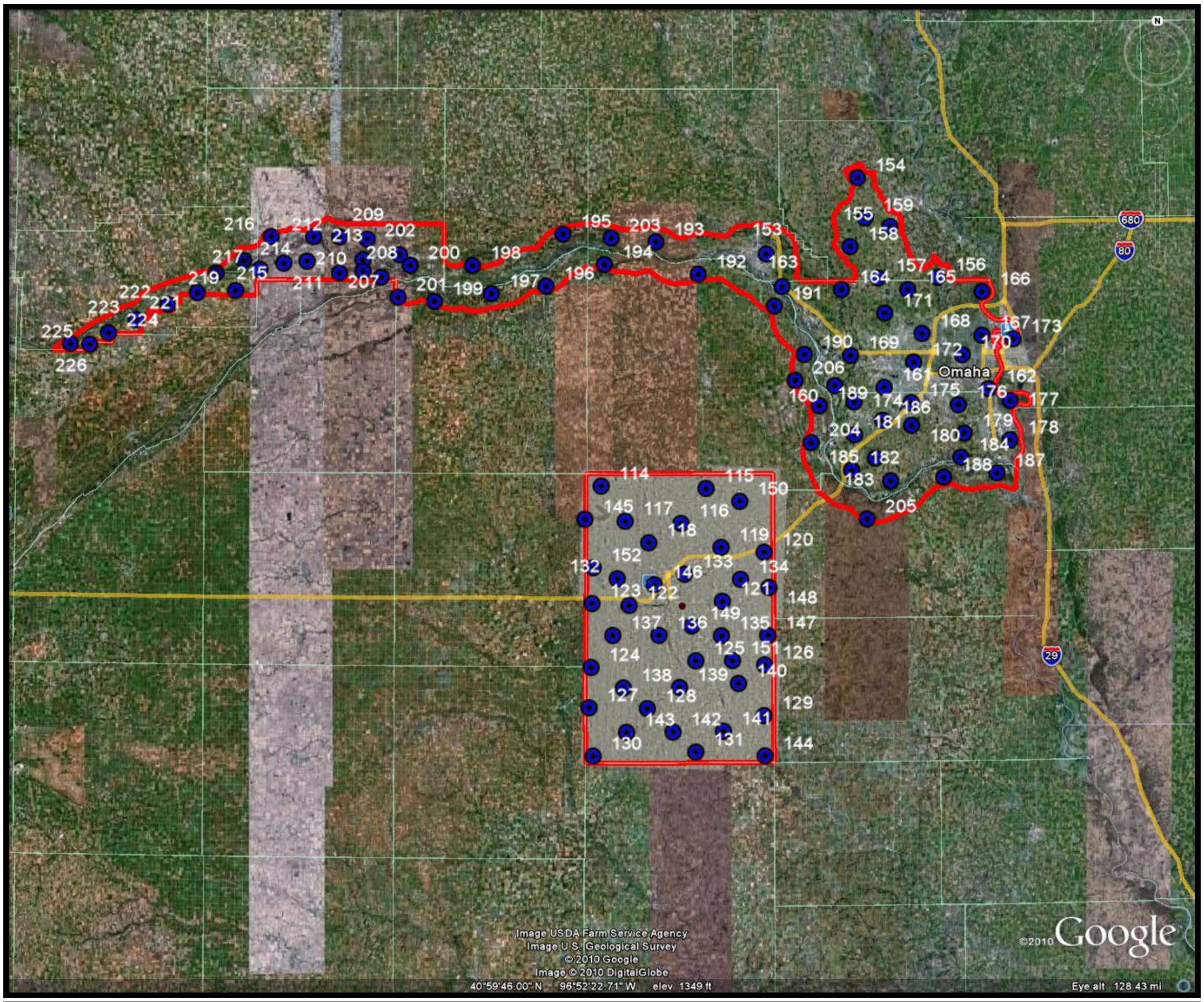


Actual Flight Lines Shown Mission by Mission

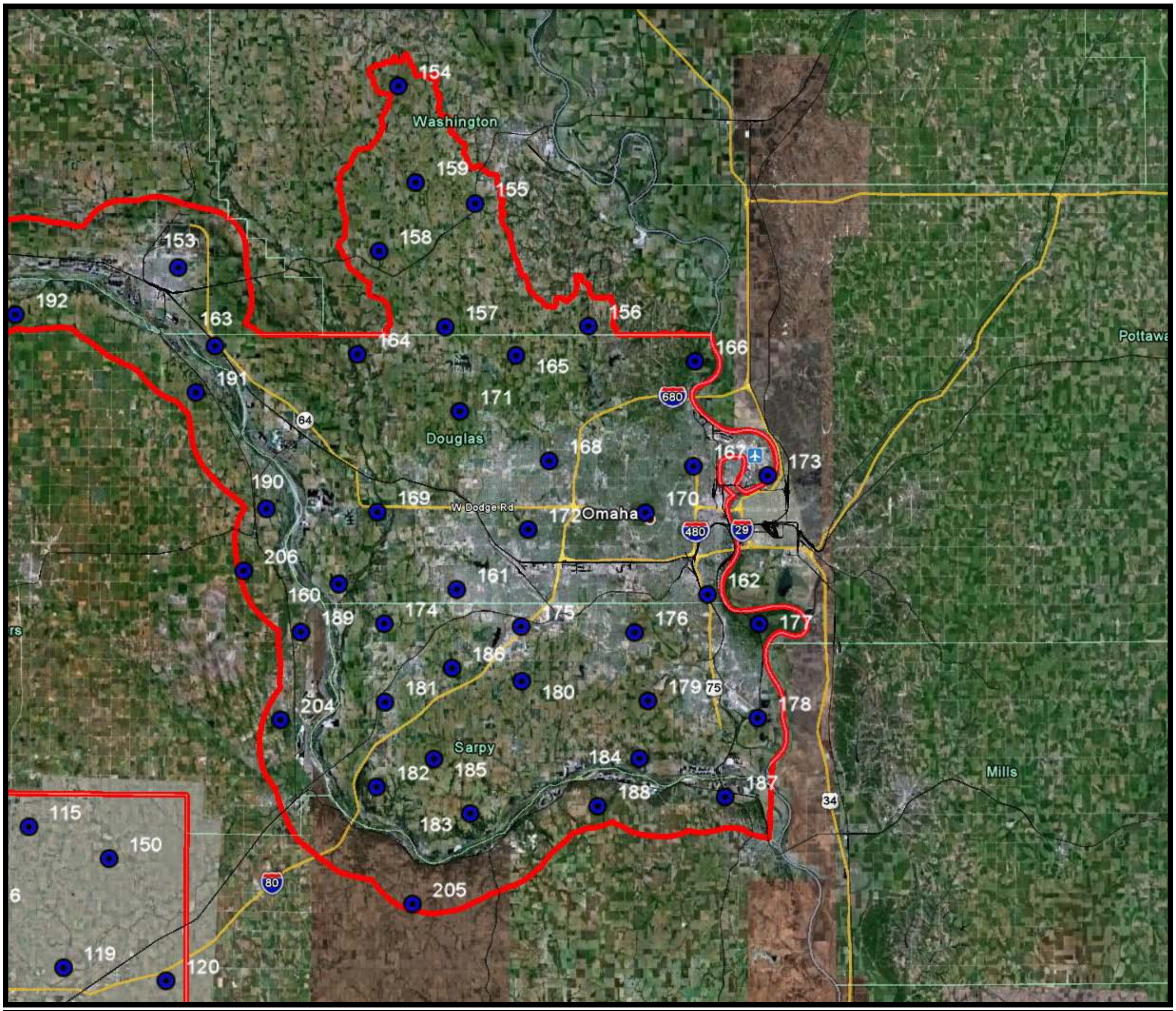
Mission	Color
100416_A	Blue
100417_A	Red
100417_B	Yellow
100418_A	Magenta
100418_B	Orange
100419_A	Cyan
100419_B	Black
100428_A	Purple



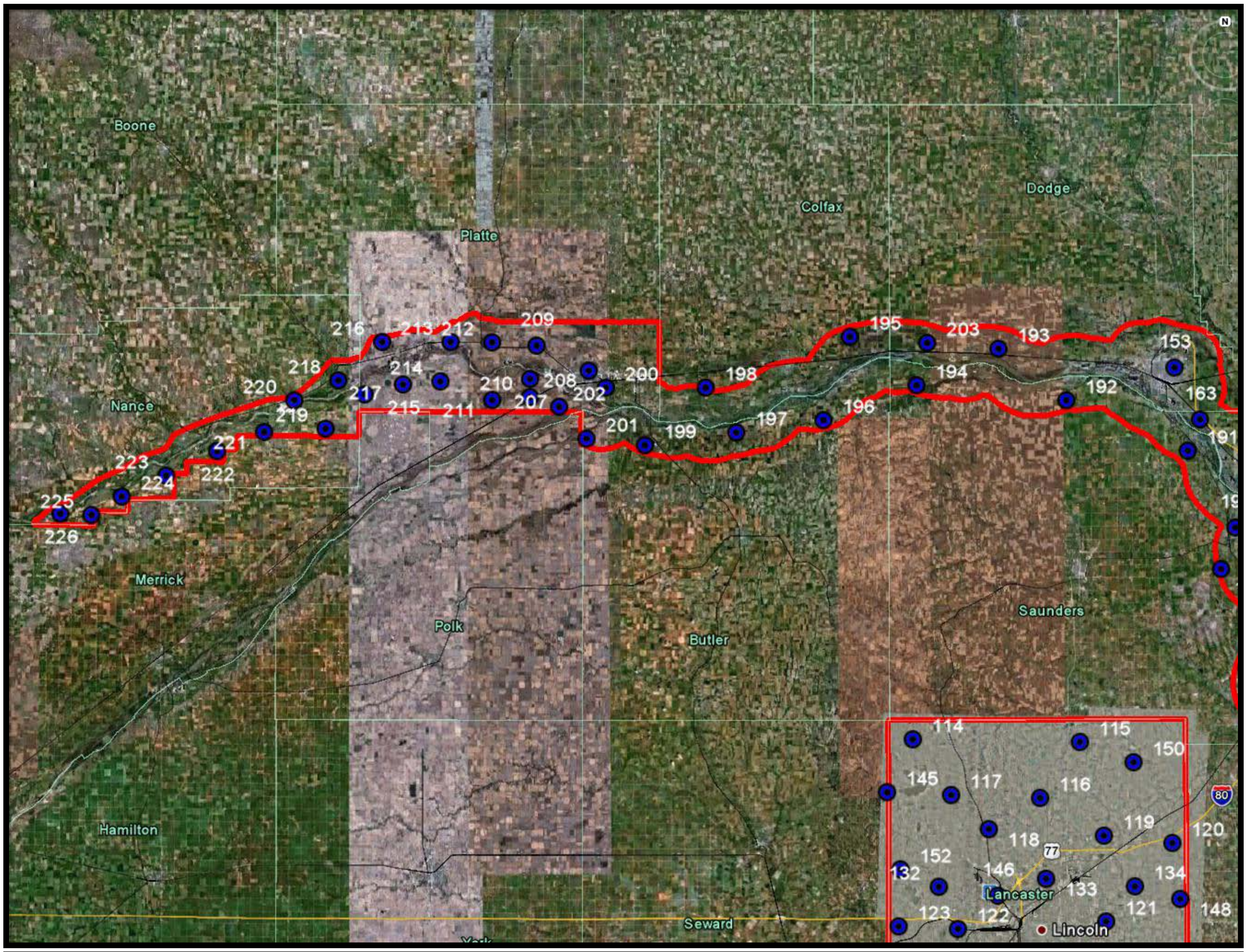
Ground Control LiDAR Check Points All



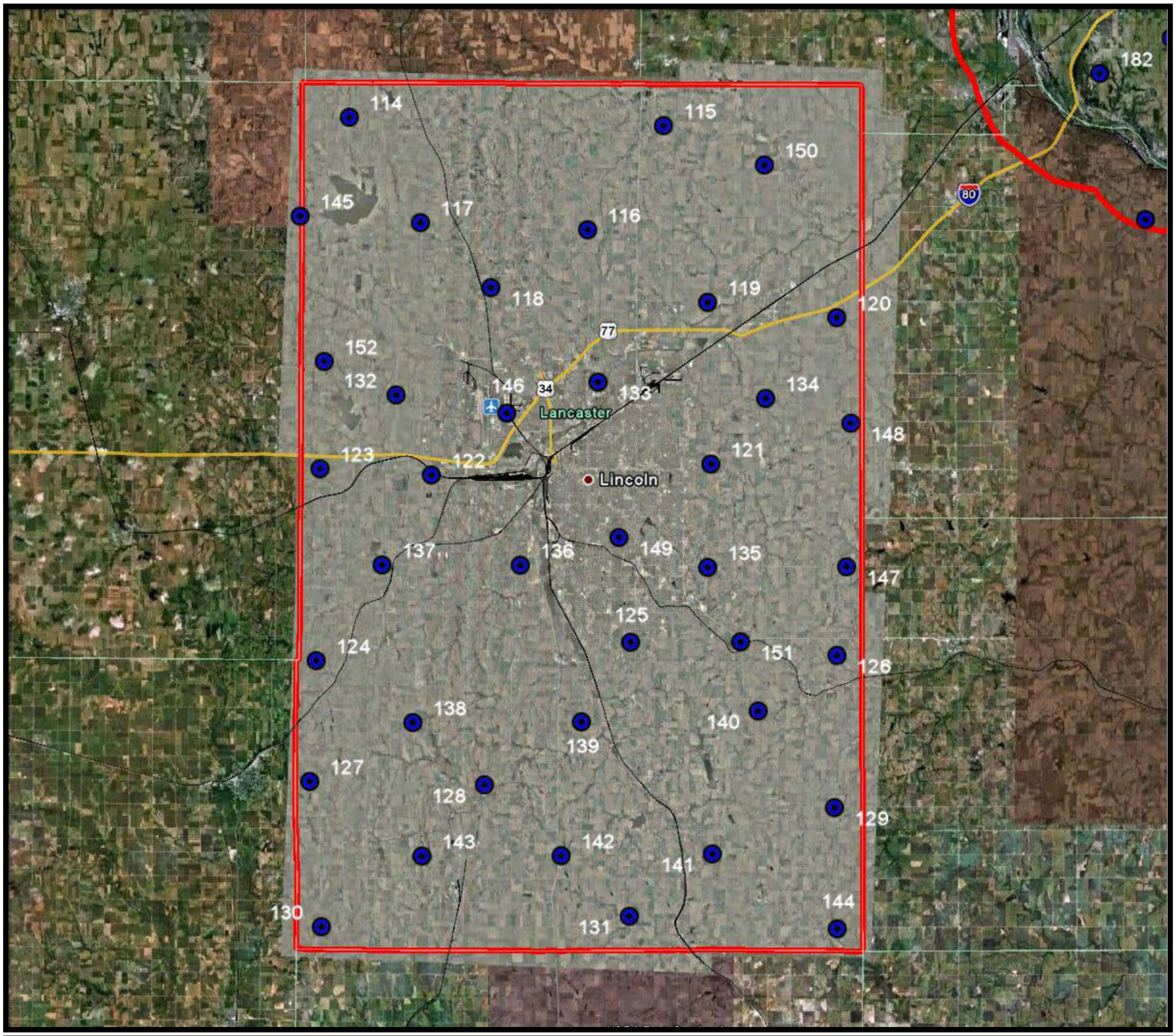
Ground Control LiDAR Check Points Omaha Area



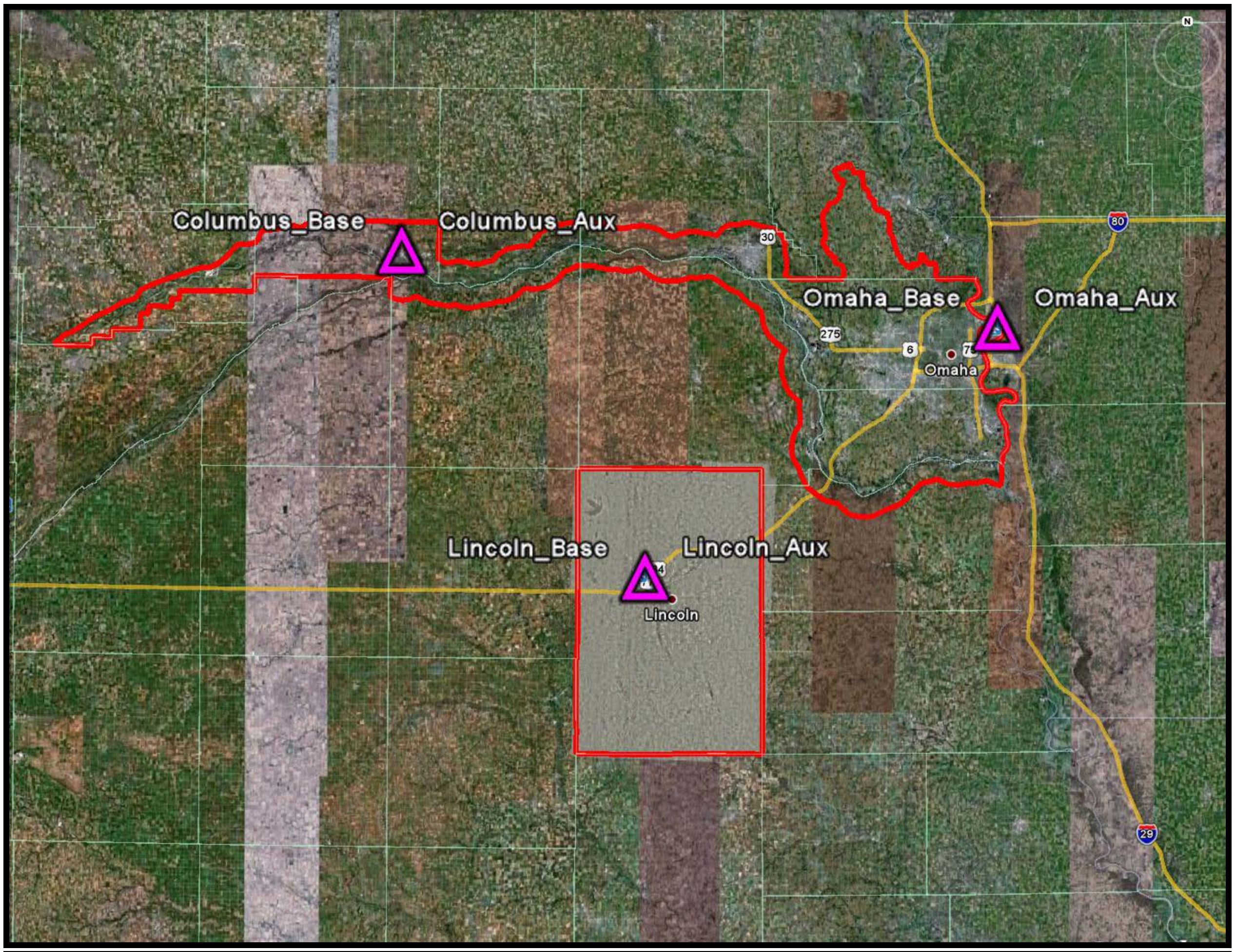
Ground Control LiDAR Check Points Northwest of Omaha Area



Ground Control LiDAR Check Points Lincoln Area



Base Station Locations



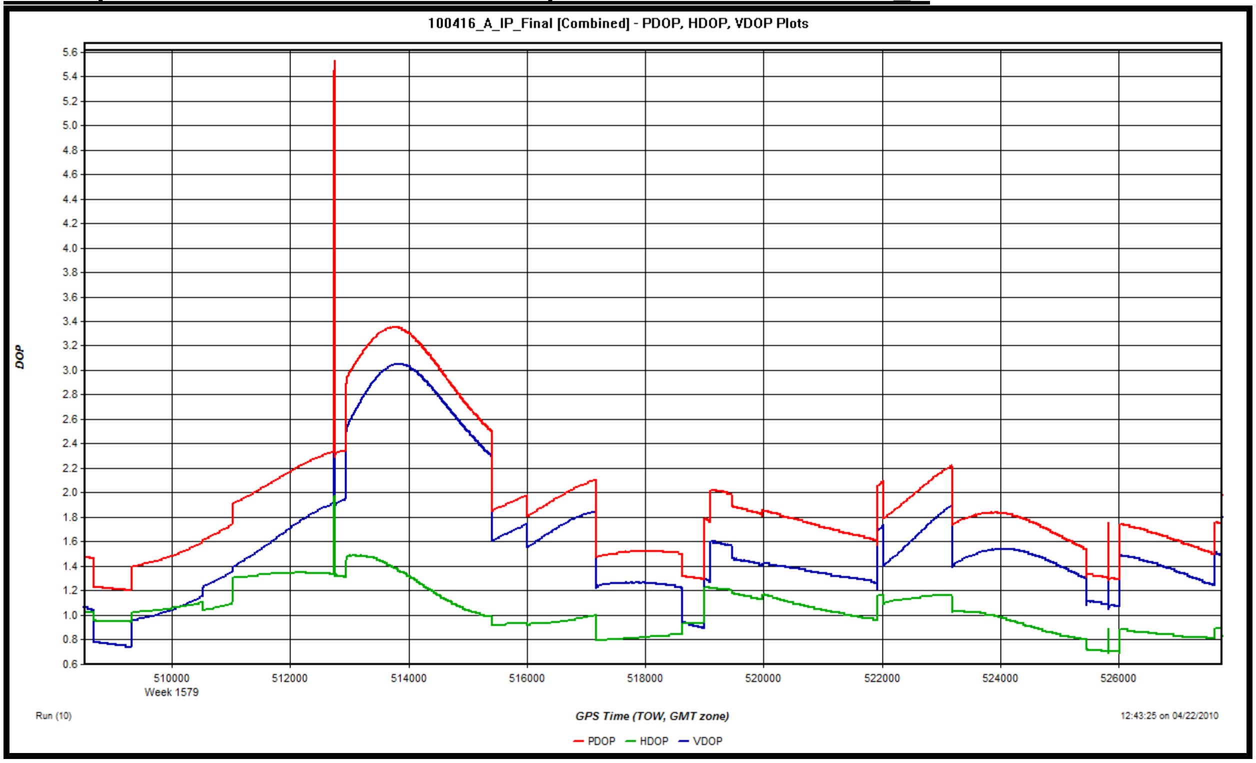
Base Station Locations Omaha

Base Station Locations Lincoln

Base Station Locations Columbus

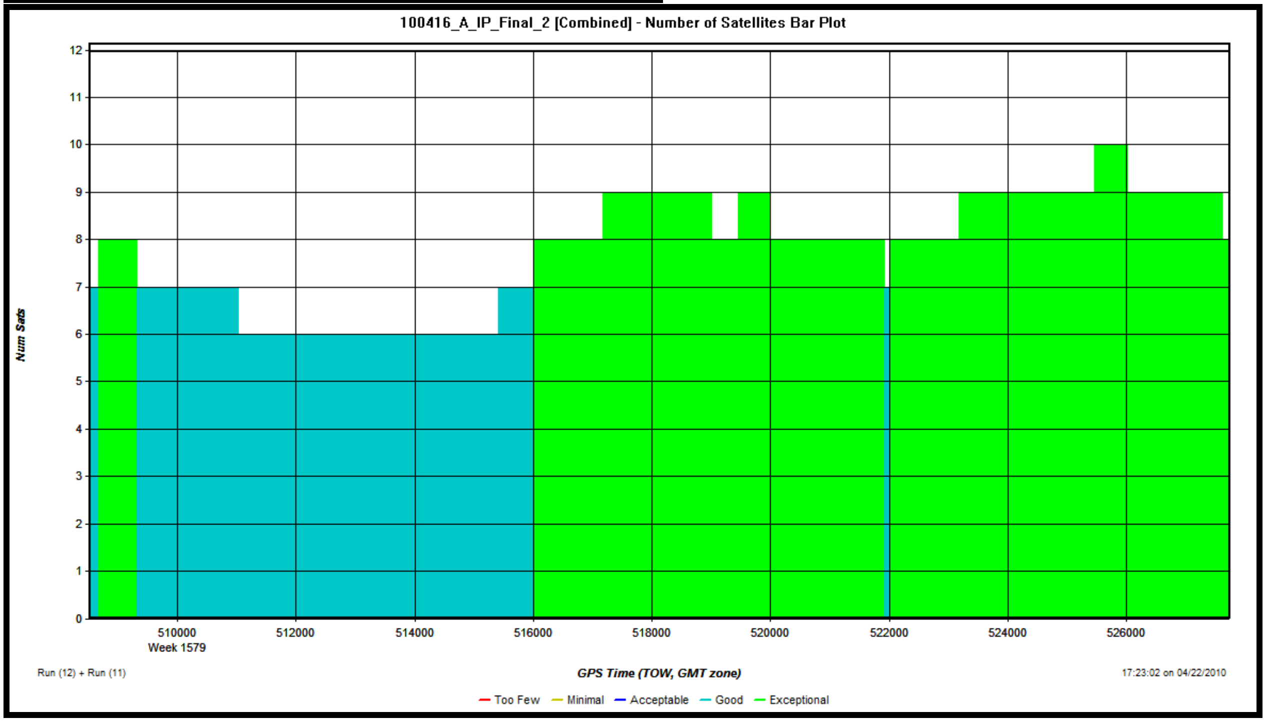
The following graphs show the mission by mission GPS PDOP (Positional Dilution Of Precision) Plot and Number of Satellites Plot.

PDOP (Positional Dilution Of Precision) Plot for mission 100416_A

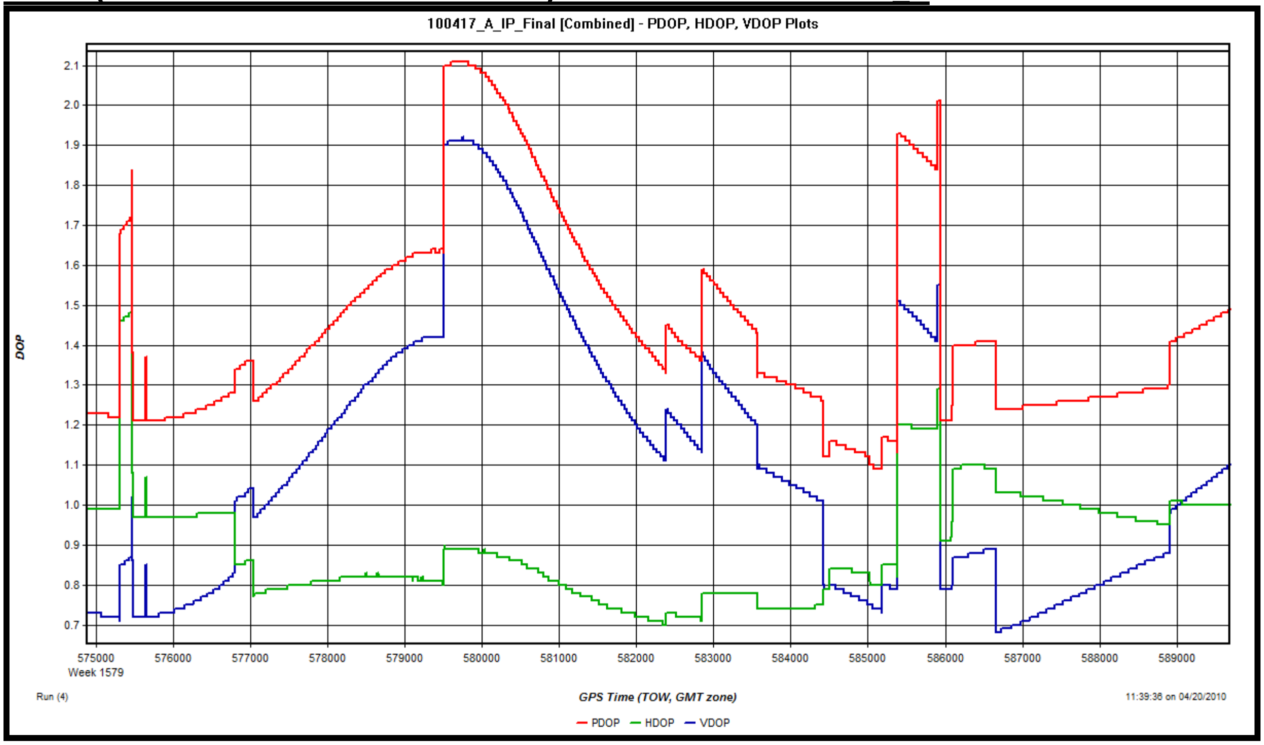


Note: PDOP Spike at GPS Time 512750 seconds occurs during a turn and not during a flight line

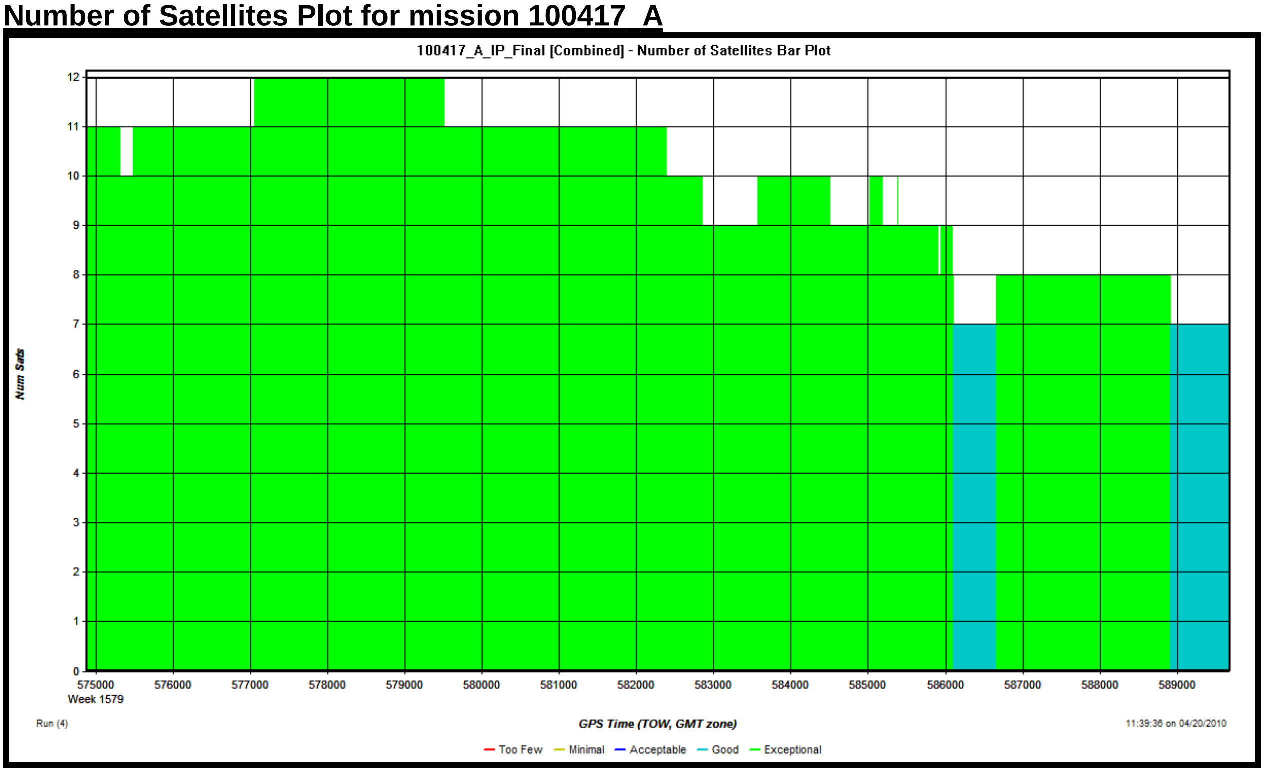
Number of Satellites Plot for mission 100416_A



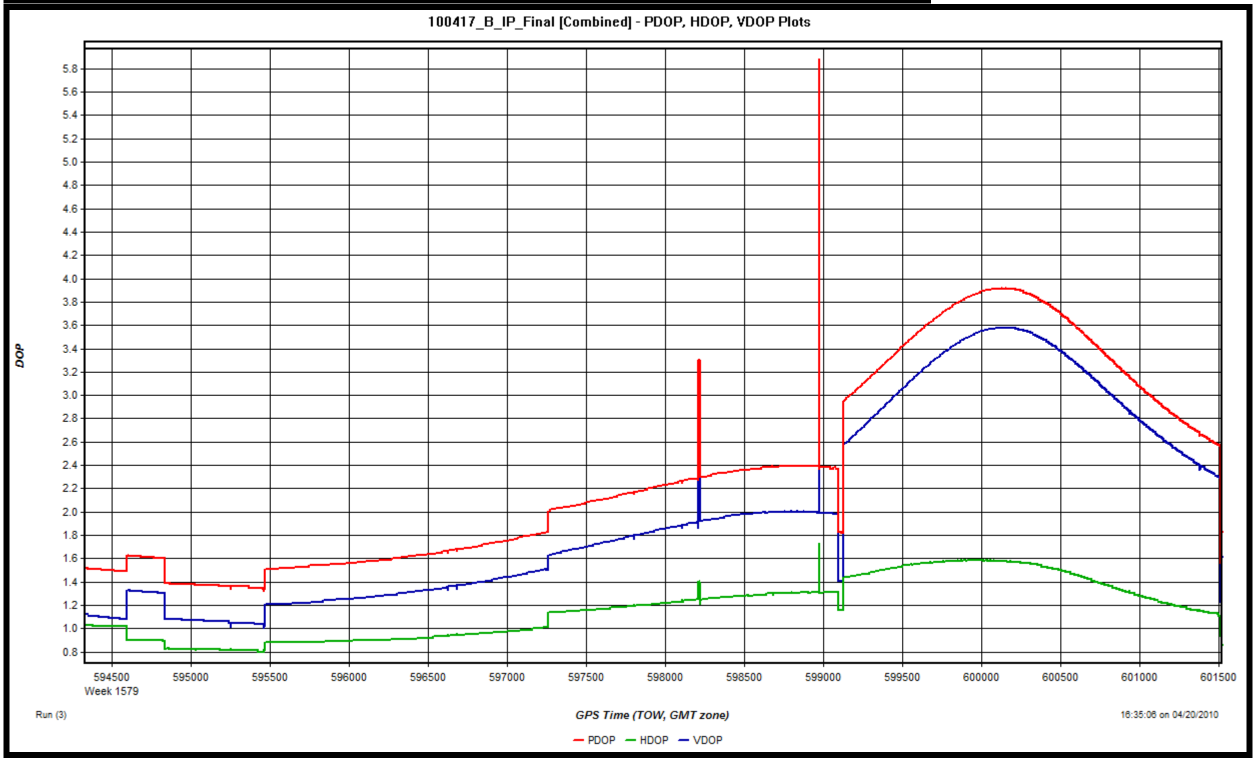
PDOP (Positional Dilution Of Precision) Plot for mission 100417_A



Number of Satellites Plot for mission 100417_A

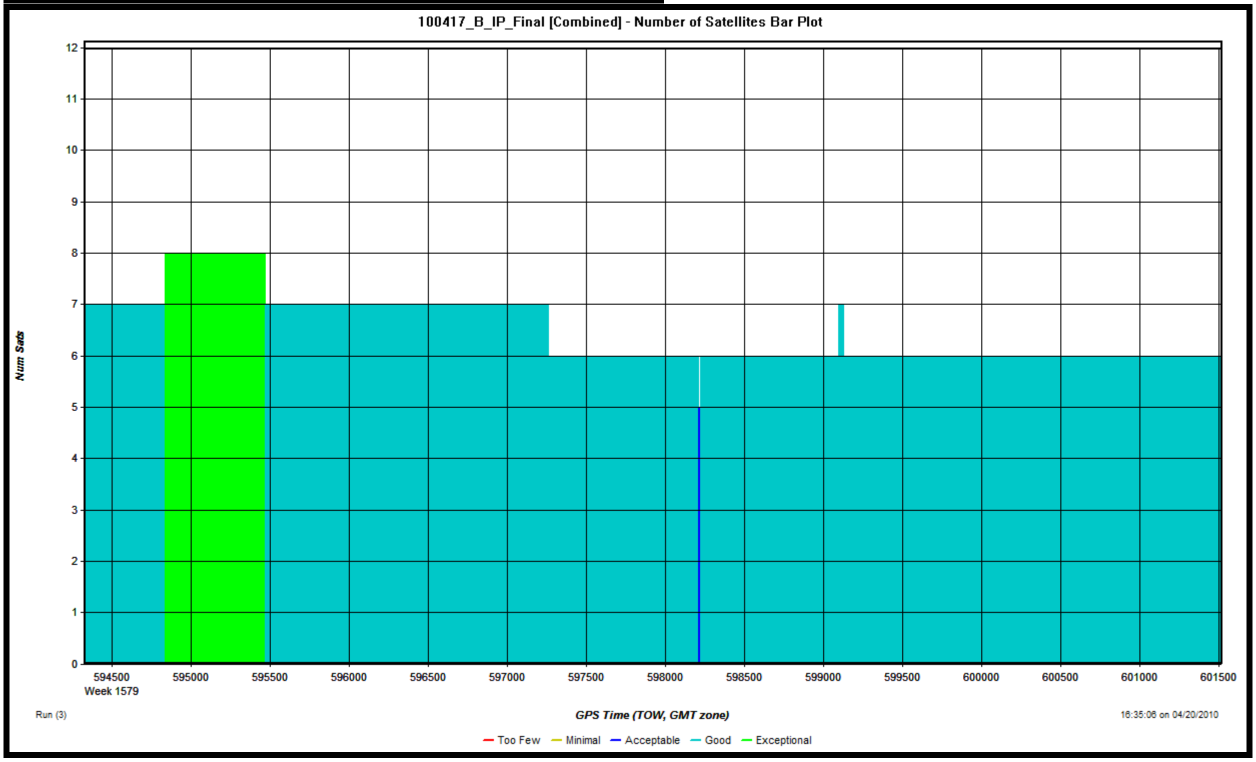


PDOP (Positional Dilution Of Precision) Plot for mission 100417_B

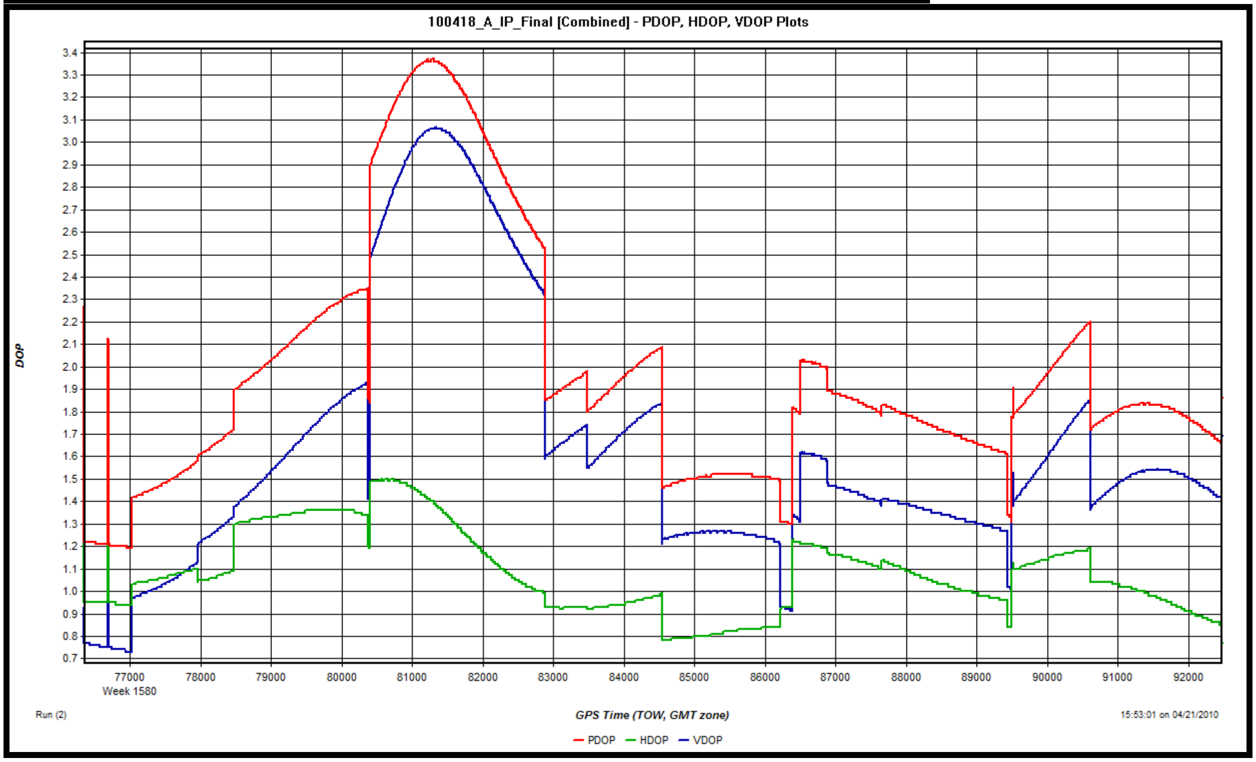


Note: PDOP Spike at GPS Time 598970 seconds occurs during a turn and not during a flight line

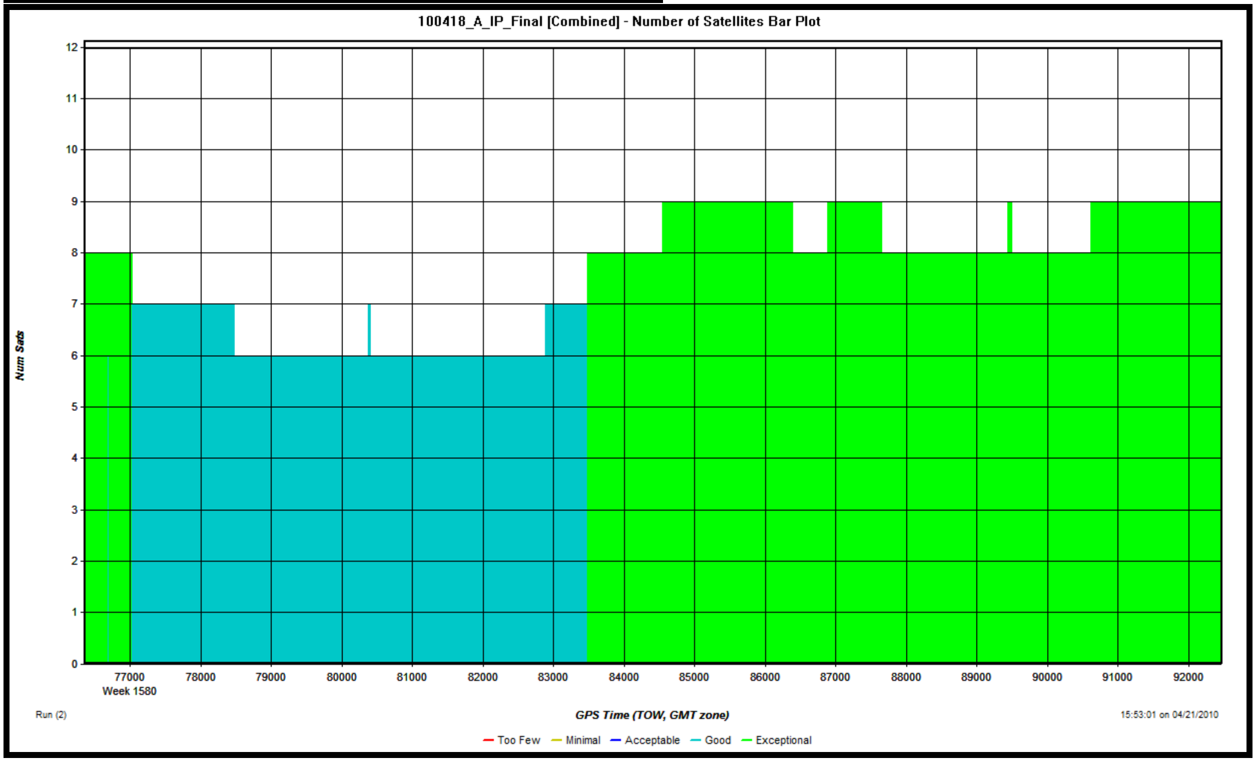
Number of Satellites Plot for mission 100417_B



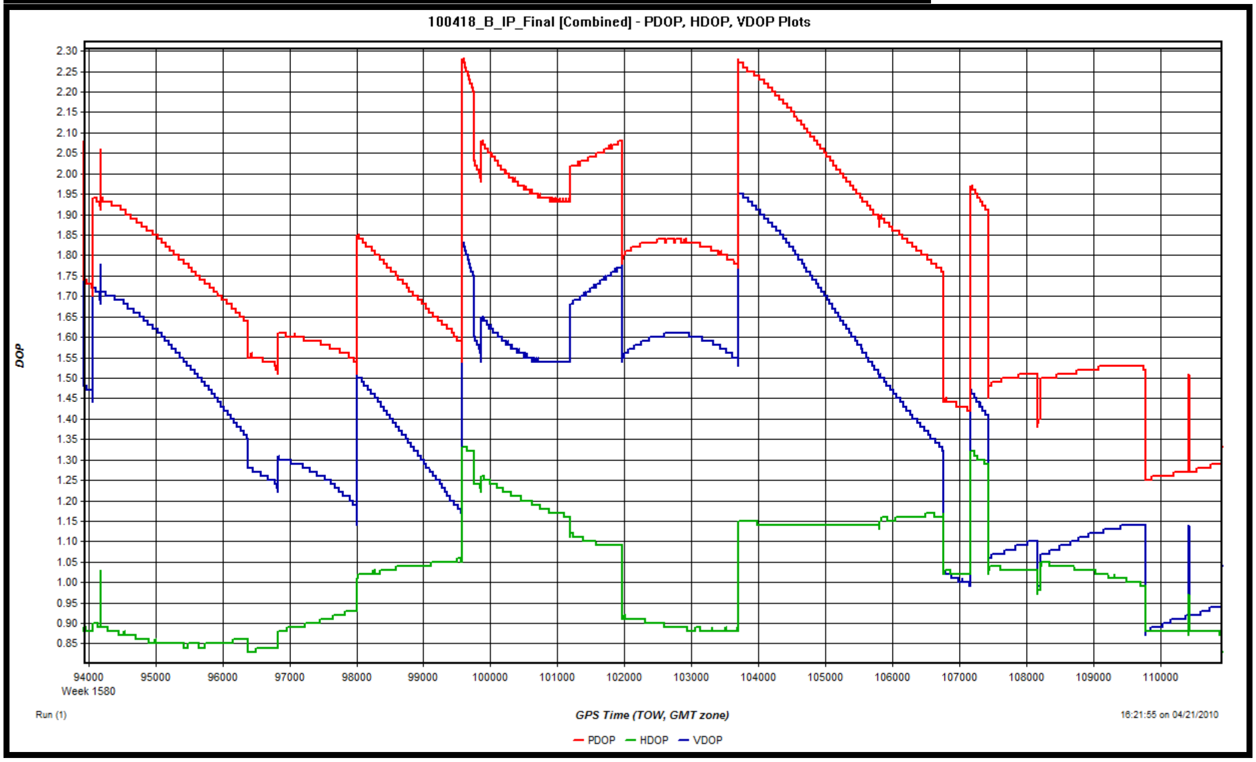
PDOP (Positional Dilution Of Precision) Plot for mission 100418_A



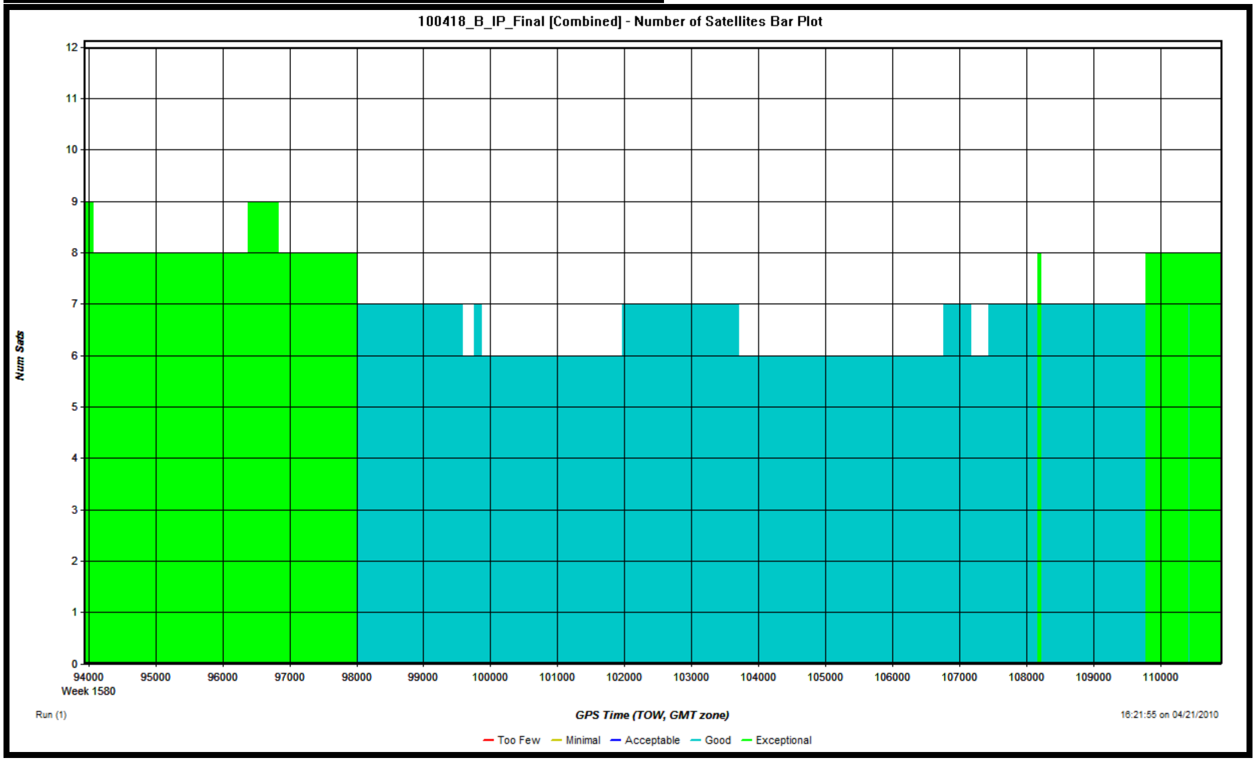
Number of Satellites Plot for mission 100418_A



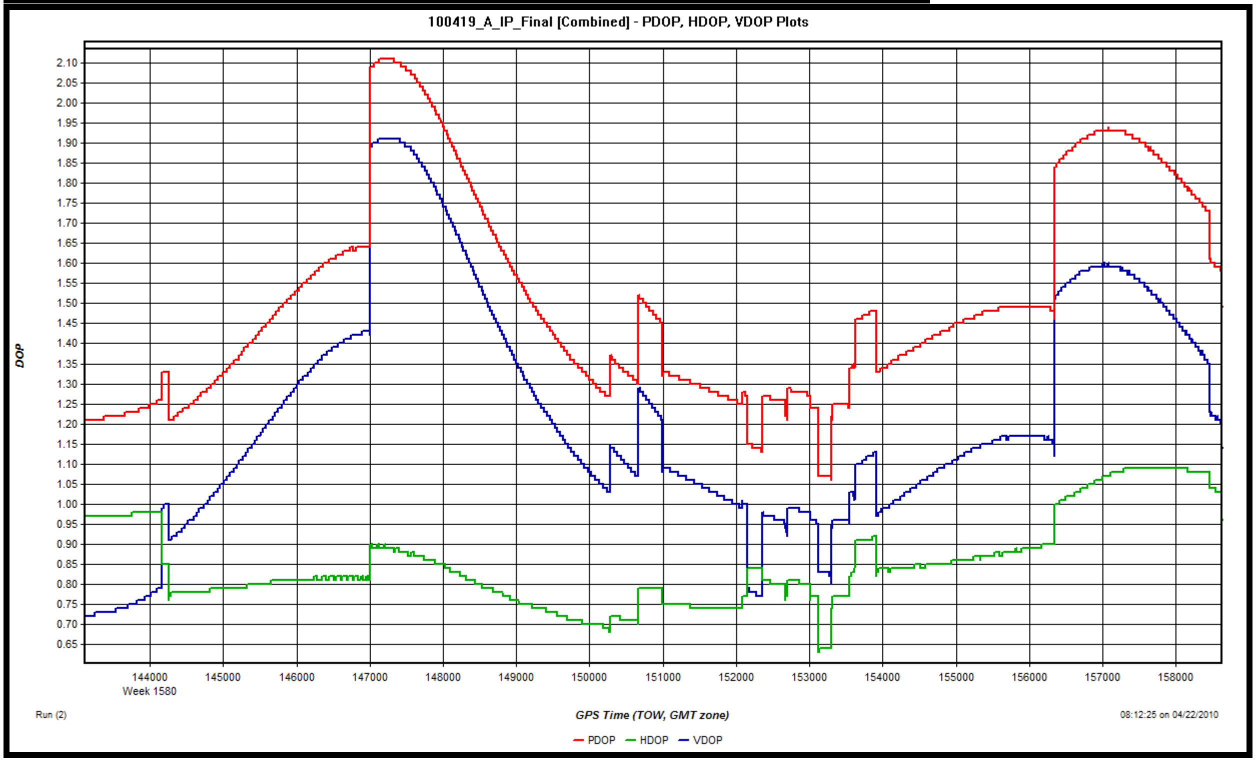
PDOP (Positional Dilution Of Precision) Plot for mission 100418_B



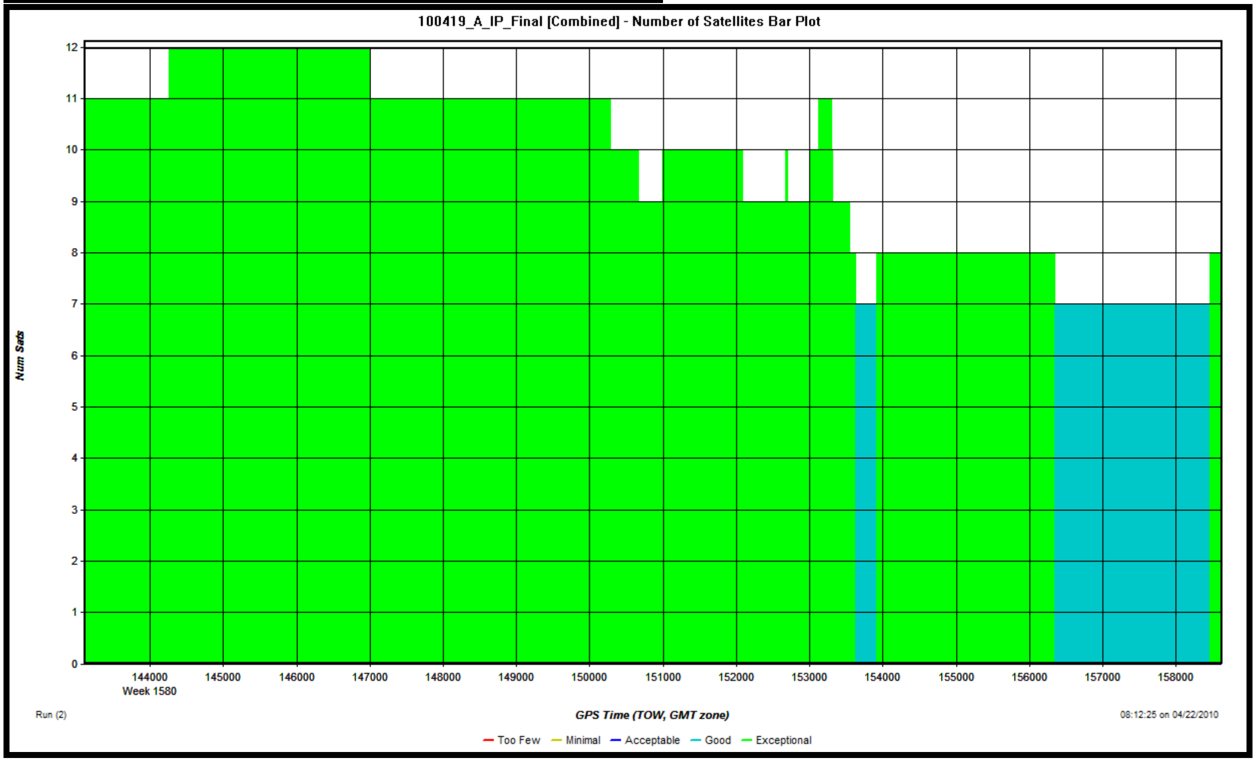
Number of Satellites Plot for mission 100418_B



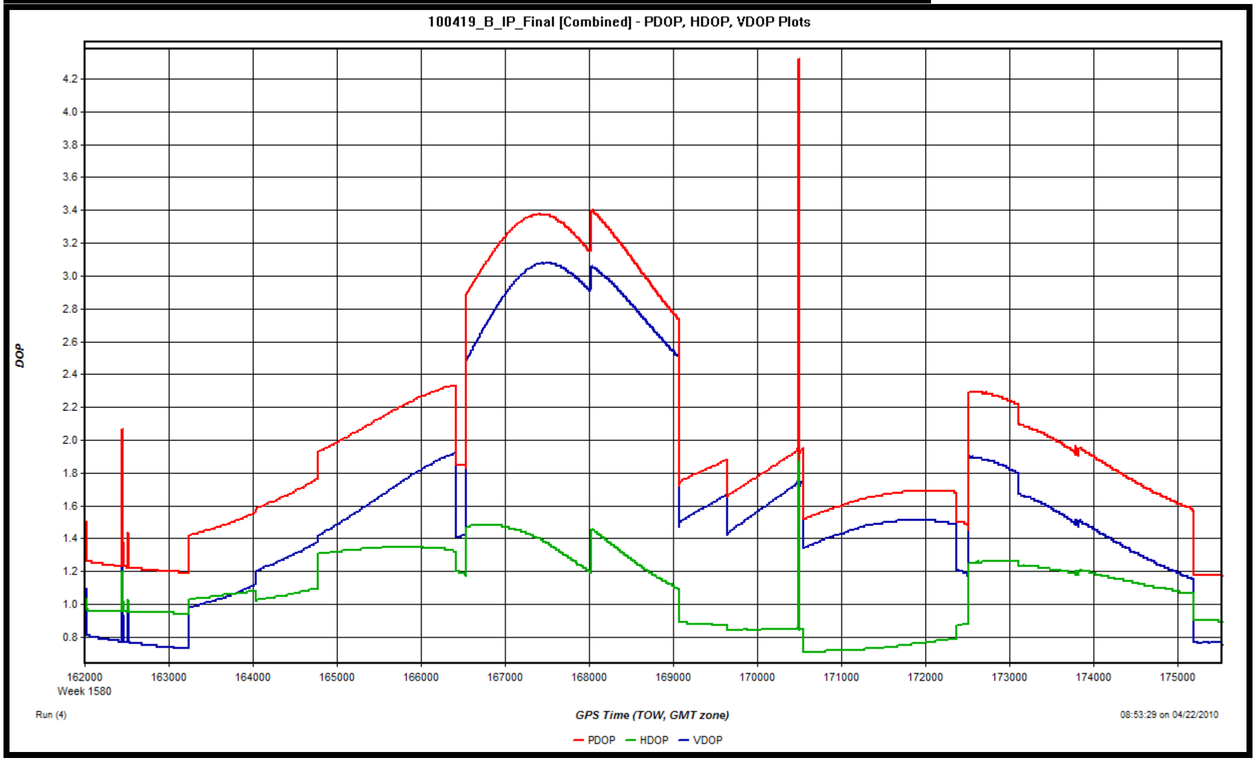
PDOP (Positional Dilution Of Precision) Plot for mission 100419_A



Number of Satellites Plot for mission 100419_A

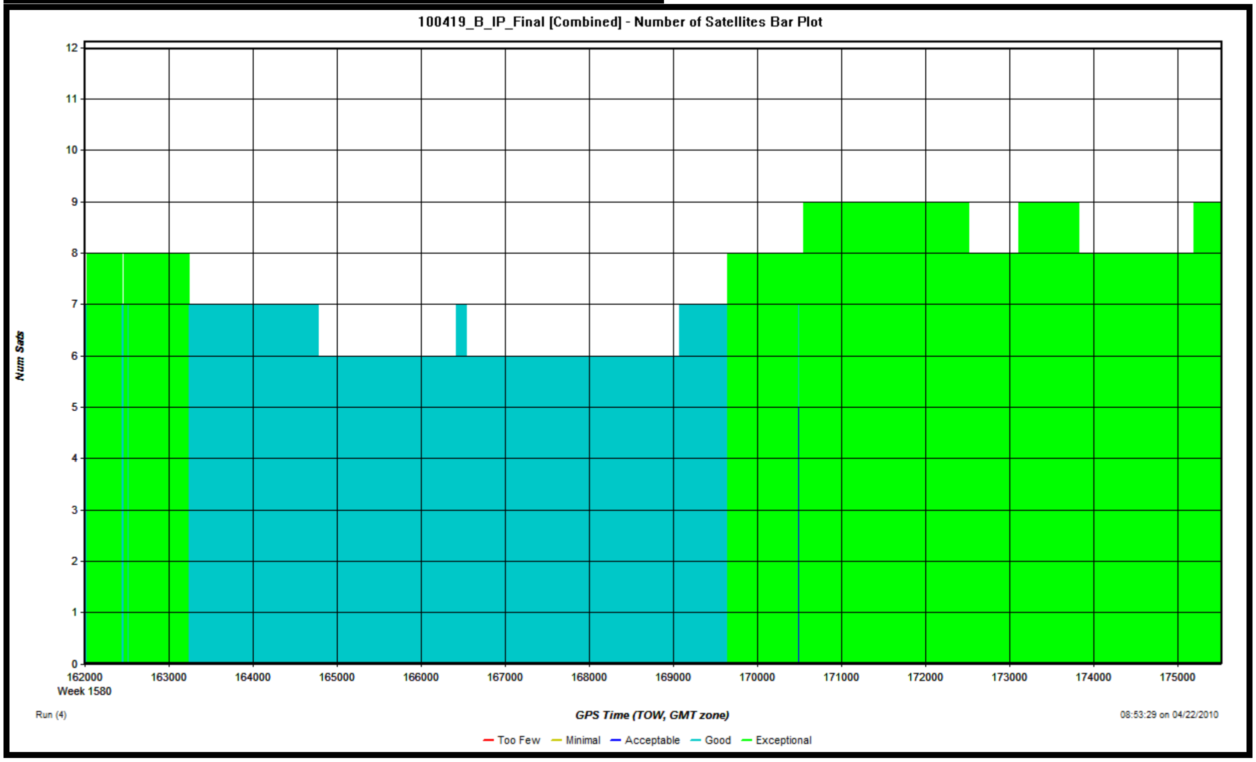


PDOP (Positional Dilution Of Precision) Plot for mission 100419_B

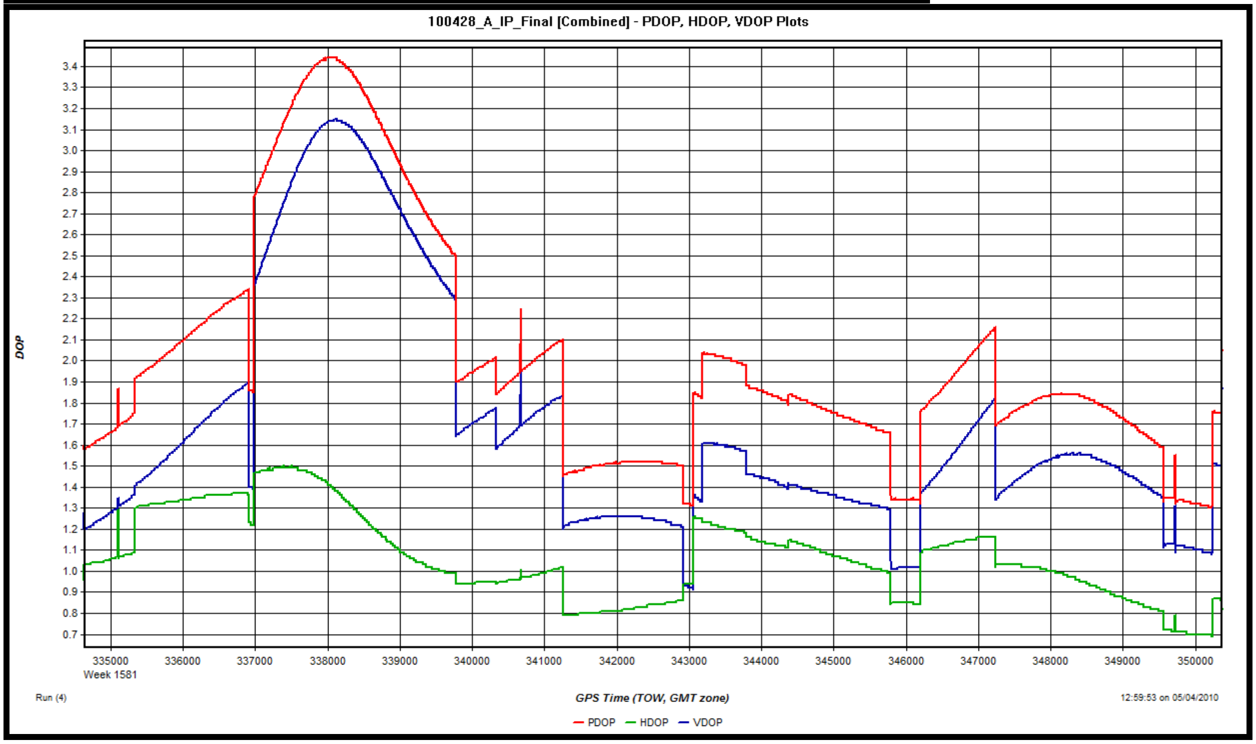


Note: PDOP Spike at GPS Time 170490 seconds occurs during a turn and not during a flight line

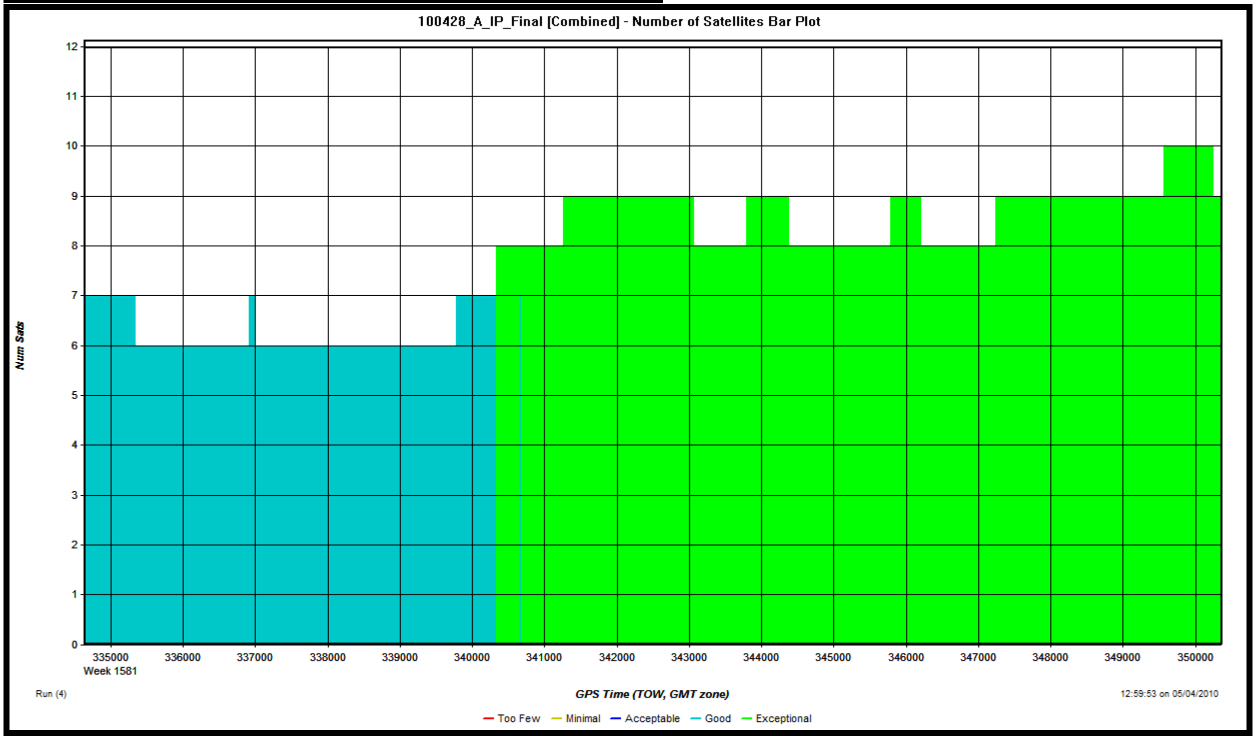
Number of Satellites Plot for mission 100419_B



PDOP (Positional Dilution Of Precision) Plot for mission 100428_A



Number of Satellites Plot for mission 100428_A



LiDAR Data Processing

The airborne GPS data was post-processed using Leica IPAS Pro GNSS/INS Processor version 1.35. 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 (Positional Dilution Of Precision) 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 combined separation of the forward and reverse GPS processing from one base station and the results of the combined separation when processed from two different base stations. Basically this is the difference between the two trajectories. An analysis of the number of satellites, present during the flight and data collection times, is also performed.

The GPS trajectory was combined with the raw IMU data and post-processed using Leica IPAS Pro GNSS/INS Processor version 1.35. 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.

GPS Controls

Two ground GPS Base Stations, for the LiDAR data collection, were set up at the airports of operation. The main GPS Base Station (Base) and the auxiliary GPS Base Station (Aux) used for backup if there are any problems with the main GPS Base Station. Trimble GPS receivers were used for the Base Stations and tied directly to each other by post processing using Trimble Geomatics Office Software version 1.63 and checked with OPUS solutions from NGS (National Geodetic Survey).

Project: NIROC Nebraska Iowa Regional Orthophotography Consortium
Job#: 02016472
Date: May 2010

Coordinate System: Nebraska State Plane
Zone: Nebraska
Horizontal Datum: NAD83
Vertical Datum(Geoid): NAVD88 (Geoid09)
Units: USFeet

Pt#	Geodetic		Height	Description
Name	Latitude	Longitude	Ellip	Code
	North	West	Geoid09	
	Deg Min Sec	Deg Min Sec	US Feet	
Omaha_Base	41°18'13.90317"N	95°53'01.24181"W	891.24	Omaha_Base
Omaha_Aux	41°18'15.14635"N	95°53'02.22933"W	890.91	Omaha_Aux
Lincoln_Base	40°50'50.19479"N	96°44'44.56875"W	1105.35	Lincoln_Base
Lincoln_Aux	40°50'54.21429"N	96°44'44.51367"W	1106.03	Lincoln_Aux
Columbus_Base	41°26'41.84465"N	97°20'31.89987"W	1358.58	Columbus_Base
Columbus_Aux	41°26'39.61341"N	97°20'32.53662"W	1357.30	Columbus_Aux

Pt#	State Plane Nebraska		NAVD88	Description
Name	Northing	Easting	Elevation	Code
	Y	X	Z	
	USFeet	USFeet	USFeet	
Omaha_Base	562558.39	2770618.94	982.30	Omaha_Base
Omaha_Aux	562680.45	2770537.69	981.98	Omaha_Aux
Lincoln_Base	386279.53	2540318.21	1191.27	Lincoln_Base
Lincoln_Aux	386686.08	2540307.14	1191.96	Lincoln_Aux
Columbus_Base	598237.93	2368741.05	1441.86	Columbus_Base
Columbus_Aux	598010.78	2368699.54	1440.49	Columbus_Aux

Ground Control Parameters

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 (NAD 83).
Coordinate System: Nebraska State Plane (single zone).
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Geiod Model: Geoid09 (Geoid 09 will be used to convert ellipsoid heights to orthometric heights).
Units: Horizontal units are in USFeet, Vertical units are in USFeet.

GROUND CONTROL REPORT / CHECK POINT SURVEY RESULTS

Ground Survey Control Report

The following listing shows the newly established GPS ground control, collected for LiDAR check points and ground cover check points. The new ground control points were established and surveyed by Pixxures and Merrick and Company surveyors.

Photo_Number	EastUSF_NebNAD83	NorthUSF_NebNAD83	ElevUSF_NAVD88
114	2502999.55	449929.93	1433.38
115	*2572242.66*	*450883.83*	*1275.78*
116	2556470.24	427320.67	1297.35
117	2519608.41	427421.25	1230.38
118	2535677.51	413793.45	1195.73
119	2583509.50	412475.13	1120.38
120	2612066.82	410264.90	1154.81
121	2585645.83	377031.13	1218.10
122	2524238.36	372183.42	1180.48
123	2499684.56	372564.53	1292.37
124	2500551.37	330480.86	1451.09
125	2569548.13	337275.78	1264.93
126	2615058.27	336218.52	1273.84
127	2500175.18	303939.98	1480.40
128	2538639.37	304730.94	1297.71
129	2615861.27	302839.12	1377.91
130	2503959.44	272156.33	1460.78
131	2571672.54	277206.76	1341.25
132	2515761.59	389406.81	1360.22
133	2560092.15	393996.48	1154.41
134	2597110.05	391910.74	1271.24
135	2585837.28	354355.48	1356.40
136	2544590.29	353185.19	1219.19
137	2514176.31	352040.31	1254.54
138	2522353.49	317749.03	1386.58
139	2559430.67	319386.43	1287.22
140	2598219.16	323355.89	1316.21
141	2589404.47	291599.80	1400.60
142	2556143.03	289903.68	1434.49
143	2525491.92	288561.06	1373.35
144	2617534.22	276278.81	1315.10
145	2493047.30	427799.73	1306.15
146	2540281.75	386418.49	1191.73

147	2616401.17	355733.52	1352.73
148	2616091.24	387231.02	1214.76
149	2566066.08	360126.76	1285.97
150	2594810.11	443150.18	1138.86
151	2593728.35	338332.51	1425.39
152	2499666.12	396115.96	1385.49
153	2606579.38	606529.00	1182.91
154	2665133.52	659162.21	1274.84
155	2687825.36	627775.97	1177.36
156	2720633.61	595512.08	1152.33
157	2681171.83	593456.45	1165.31
158	2661908.32	613513.48	1263.28
159	2671117.66	632836.46	1243.59
160	2654971.03	521558.11	1103.93
161	2687606.48	521577.92	1218.13
162	2756848.86	523329.31	1110.92
163	2617788.31	585455.94	1175.12
164	2657213.71	584928.07	1142.65
165	2701017.59	586568.11	1247.04
166	2750482.84	587214.97	1002.11
167	2751346.34	558377.98	1042.77
168	2711475.49	558033.58	1050.61
169	2664705.05	541799.45	1114.96
170	2738697.02	545016.15	1091.88
171	2686250.88	570491.86	1267.48
172	2706559.20	538933.52	1158.49
173	2772019.29	556775.66	984.52
174	2668021.72	511275.50	1281.60
175	2705867.77	512202.91	1095.54
176	2737188.78	511998.87	1094.62
177	2771461.33	515929.29	968.54
178	2772276.09	490039.98	963.82
179	2741736.83	493398.05	1183.82
180	2706680.78	497208.03	1205.03
181	2669201.38	489733.31	1249.20
182	2667967.91	466307.90	1226.94
183	2694134.03	460183.86	1142.79
184	2740127.14	477438.38	1113.18
185	2683415.88	474740.39	1211.11
186	2687308.77	499935.87	1211.39
187	2764287.32	467947.13	969.71
188	2729183.32	463837.05	1145.64

189	2645102.93	507899.65	1093.35
190	2634023.30	541350.94	1128.24
191	2613101.72	572395.47	1254.10
192	2562099.33	591589.53	1304.10
193	2533369.58	611856.85	1260.03
194	2499895.14	595739.23	1304.35
195	2471827.08	614817.33	1334.09
196	2461915.11	580100.91	1364.87
197	2426104.34	573881.56	1397.43
198	2412959.43	592005.32	1388.15
199	2388667.91	567477.86	1436.69
200	2371840.37	590693.29	1435.26
201	2364501.92	569419.39	1445.20
202	2364529.94	597398.31	1443.57
203	2503804.13	613330.48	1288.38
204	2640550.73	483507.52	1072.35
205	2679291.46	434597.44	1175.23
206	2628593.93	524034.57	1199.76
207	2340470.78	593291.16	1468.07
208	2352820.12	582214.94	1454.07
209	2342722.76	607065.24	1479.18
210	2340731.35	585815.47	1474.45
211	2325166.52	584118.33	1522.00
212	2324358.09	607826.55	1491.96
213	2307233.09	607472.62	1508.91
214	2303515.33	591107.18	1516.29
215	2288129.96	589396.37	1541.37
216	2279032.72	606576.65	1559.72
217	2272431.19	584784.85	1552.66
218	2261458.87	590213.56	1558.61
219	2256802.86	570176.26	1593.12
220	2243485.66	581463.30	1572.90
221	2231438.97	568022.82	1662.67
222	2212291.68	559592.92	1623.29
223	2191482.44	548817.10	1648.75
224	2173329.63	539660.71	1675.50
225	2161021.00	531657.13	1693.17
226	2148139.60	531773.68	1697.96

LiDAR Control Report

The following listing shows the results of the LiDAR data compared to the GPS ground survey control data. 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.

Post-filter Control Report for

Project File: NIROC

Project Unit: US Feet

Date: Wednesday: July 21: 2010

Vertical Accuracy Objective

Requirement Type: RMSE(z)

RMSE(z) Objective: 0.30

Control Points in Report: 113

Elevation Calculation Method: Interpolated from TIN

Control Points with LiDAR Coverage: 113

Average Control Error Reported: 0.00

Maximum (highest) Control Error Reported: 0.37

Median Control Error Reported: -0.01

Minimum (lowest) Control Error Reported: -0.36

Standard deviation (sigma) of Error for sample: 0.15

RMSE of Error for sample (RMSE(z)): 0.15: PASS

NSSDA Achievable Contour Interval: 0.6

ASPRS Class 1 Achievable Contour Interval: 0.5

NMAS Achievable Contour Interval: 0.5

Control Point Id	Control Pt. X(East) USFeet	Control Pt. Y(North) USFeet	Coverage	Control Pt. Z(Elev) USFeet	from LiDAR Z(Elev) USFeet	**Z Error USFeet**	Min Z USFeet	Median Z USFeet	Max Z USFeet
222	2212291.68	559592.92	Yes	1623.29	1622.93	**-0.36**	1622.90	1622.94	1623.10
219	2256802.86	570176.26	Yes	1593.12	1592.78	**-0.34**	1592.54	1592.80	1592.80
192	2562099.33	591589.53	Yes	1304.10	1303.79	**-0.31**	1303.64	1303.72	1303.82
172	2706559.20	538933.52	Yes	1158.49	1158.20	**-0.29**	1158.14	1158.27	1158.28
196	2461915.11	580100.91	Yes	1364.87	1364.59	**-0.28**	1364.49	1364.66	1364.68
139	2559430.67	319386.43	Yes	1287.22	1286.98	**-0.24**	1286.92	1286.98	1286.98
187	2764287.32	467947.13	Yes	969.71	969.48	**-0.23**	969.36	969.50	969.53
224	2173329.63	539660.71	Yes	1675.50	1675.27	**-0.23**	1675.25	1675.25	1675.29
157	2681171.83	593456.45	Yes	1165.31	1165.09	**-0.22**	1164.66	1165.11	1165.20

136	2544590.29	353185.19	Yes	1219.19	1218.98	**-0.21**	1218.84	1219.02	1219.23
138	2522353.49	317749.03	Yes	1386.58	1386.38	**-0.20**	1386.21	1386.30	1386.46
225	2161021.00	531657.13	Yes	1693.17	1692.97	**-0.20**	1692.86	1692.90	1693.06
170	2738697.02	545016.15	Yes	1091.88	1091.68	**-0.20**	1091.58	1091.62	1091.80
144	2617534.22	276278.81	Yes	1315.10	1314.91	**-0.19**	1314.83	1314.87	1314.96
171	2686250.88	570491.86	Yes	1267.48	1267.30	**-0.18**	1267.24	1267.36	1267.43
169	2664705.05	541799.45	Yes	1114.96	1114.79	**-0.17**	1114.75	1114.77	1115.05
179	2741736.83	493398.05	Yes	1183.82	1183.66	**-0.16**	1183.63	1183.69	1183.74
226	2148139.60	531773.68	Yes	1697.96	1697.81	**-0.15**	1697.75	1697.80	1697.86
197	2426104.34	573881.56	Yes	1397.43	1397.28	**-0.15**	1396.99	1397.37	1397.38
161	2687606.48	521577.92	Yes	1218.13	1217.98	**-0.15**	1217.90	1217.94	1218.21
175	2705867.77	512202.91	Yes	1095.54	1095.39	**-0.15**	1095.22	1095.40	1095.56
126	2615058.27	336218.52	Yes	1273.84	1273.70	**-0.14**	1273.41	1273.71	1273.96
154	2665133.52	659162.21	Yes	1274.84	1274.70	**-0.14**	1274.36	1274.58	1274.80
206	2628593.93	524034.57	Yes	1199.76	1199.63	**-0.13**	1199.47	1199.61	1199.76
167	2751346.34	558377.98	Yes	1042.77	1042.64	**-0.13**	1042.40	1042.66	1042.69
142	2556143.03	289903.68	Yes	1434.49	1434.37	**-0.12**	1434.20	1434.27	1434.49
163	2617788.31	585455.94	Yes	1175.12	1175.00	**-0.12**	1174.82	1174.98	1175.18
165	2701017.59	586568.11	Yes	1247.04	1246.92	**-0.12**	1246.64	1246.87	1246.94
124	2500551.37	330480.86	Yes	1451.09	1450.98	**-0.11**	1450.86	1450.93	1451.02
199	2388667.91	567477.86	Yes	1436.69	1436.58	**-0.11**	1436.43	1436.55	1436.62
190	2634023.30	541350.94	Yes	1128.24	1128.13	**-0.11**	1128.11	1128.18	1128.29
176	2737188.78	511998.87	Yes	1094.62	1094.52	**-0.10**	1094.44	1094.53	1094.78
203	2503804.13	613330.48	Yes	1288.38	1288.29	**-0.09**	1288.22	1288.32	1288.44
135	2585837.28	354355.48	Yes	1356.40	1356.31	**-0.09**	1356.10	1356.22	1356.56
174	2668021.72	511275.50	Yes	1281.60	1281.51	**-0.09**	1281.49	1281.49	1281.54
215	2288129.96	589396.37	Yes	1541.37	1541.28	**-0.09**	1541.16	1541.22	1541.52
221	2231438.97	568022.82	Yes	1662.67	1662.58	**-0.09**	1662.22	1662.57	1662.63
117	2519608.41	427421.25	Yes	1230.38	1230.30	**-0.08**	1230.18	1230.30	1230.43
220	2243485.66	581463.30	Yes	1572.90	1572.82	**-0.08**	1572.74	1572.76	1572.84
184	2740127.14	477438.38	Yes	1113.18	1113.10	**-0.08**	1112.80	1113.14	1113.24
115	2572242.66	450883.83	Yes	1275.78	1275.71	**-0.07**	1275.59	1275.70	1275.74
223	2191482.44	548817.10	Yes	1648.75	1648.68	**-0.07**	1648.50	1648.63	1648.79
218	2261458.87	590213.56	Yes	1558.61	1558.54	**-0.07**	1558.53	1558.69	1558.83
182	2667967.91	466307.90	Yes	1226.94	1226.88	**-0.06**	1226.82	1226.90	1227.01
122	2524238.36	372183.42	Yes	1180.48	1180.43	**-0.05**	1180.21	1180.46	1180.55
166	2750482.84	587214.97	Yes	1002.11	1002.07	**-0.04**	1001.89	1002.06	1002.20
151	2593728.35	338332.51	Yes	1425.39	1425.35	**-0.04**	1425.28	1425.38	1425.45
140	2598219.16	323355.89	Yes	1316.21	1316.17	**-0.04**	1316.13	1316.15	1316.38
143	2525491.92	288561.06	Yes	1373.35	1373.32	**-0.03**	1373.23	1373.28	1373.37

129	2615861.27	302839.12	Yes	1377.91	1377.88	**-0.03**	1377.70	1377.92	1377.93
133	2560092.15	393996.48	Yes	1154.41	1154.38	**-0.03**	1154.28	1154.39	1154.57
173	2772019.29	556775.66	Yes	984.52	984.50	**-0.02**	984.49	984.50	984.58
120	2612066.82	410264.90	Yes	1154.81	1154.79	**-0.02**	1154.75	1154.86	1154.89
164	2657213.71	584928.07	Yes	1142.65	1142.63	**-0.02**	1142.62	1142.70	1142.70
185	2683415.88	474740.39	Yes	1211.11	1211.10	**-0.01**	1210.72	1210.89	1211.13
149	2566066.08	360126.76	Yes	1285.97	1285.96	**-0.01**	1285.86	1286.05	1286.24
121	2585645.83	377031.13	Yes	1218.10	1218.09	**-0.01**	1217.87	1218.18	1218.21
180	2706680.78	497208.03	Yes	1205.03	1205.03	**0.00**	1204.83	1205.02	1205.10
130	2503959.44	272156.33	Yes	1460.78	1460.79	**0.01**	1460.67	1460.75	1460.82
125	2569548.13	337275.78	Yes	1264.93	1264.94	**0.01**	1264.85	1264.95	1265.27
137	2514176.31	352040.31	Yes	1254.54	1254.55	**0.01**	1254.21	1254.88	1254.93
123	2499684.56	372564.53	Yes	1292.37	1292.39	**0.02**	1292.20	1292.49	1292.52
131	2571672.54	277206.76	Yes	1341.25	1341.28	**0.03**	1341.20	1341.35	1341.40
150	2594810.11	443150.18	Yes	1138.86	1138.89	**0.03**	1138.81	1138.84	1139.00
213	2307233.09	607472.62	Yes	1508.91	1508.94	**0.03**	1508.82	1508.95	1509.04
183	2694134.03	460183.86	Yes	1142.79	1142.82	**0.03**	1142.77	1142.81	1142.93
134	2597110.05	391910.74	Yes	1271.24	1271.27	**0.03**	1271.23	1271.39	1271.47
168	2711475.49	558033.58	Yes	1050.61	1050.65	**0.04**	1050.56	1050.62	1050.68
191	2613101.72	572395.47	Yes	1254.10	1254.15	**0.05**	1254.11	1254.15	1254.21
118	2535677.51	413793.45	Yes	1195.73	1195.78	**0.05**	1195.54	1195.78	1195.83
201	2364501.92	569419.39	Yes	1445.20	1445.26	**0.06**	1445.23	1445.24	1445.31
155	2687825.36	627775.97	Yes	1177.36	1177.42	**0.06**	1177.08	1177.36	1177.64
148	2616091.24	387231.02	Yes	1214.76	1214.82	**0.06**	1214.64	1214.74	1214.92
114	2502999.55	449929.93	Yes	1433.38	1433.45	**0.07**	1432.92	1433.49	1433.54
127	2500175.18	303939.98	Yes	1480.40	1480.47	**0.07**	1480.44	1480.44	1480.59
216	2279032.72	606576.65	Yes	1559.72	1559.79	**0.07**	1559.72	1559.84	1559.92
181	2669201.38	489733.31	Yes	1249.20	1249.28	**0.08**	1249.17	1249.34	1249.38
210	2340731.35	585815.47	Yes	1474.45	1474.53	**0.08**	1474.44	1474.55	1474.74
147	2616401.17	355733.52	Yes	1352.73	1352.82	**0.09**	1352.81	1352.82	1352.84
177	2771461.33	515929.29	Yes	968.54	968.63	**0.09**	968.52	968.63	968.65
141	2589404.47	291599.80	Yes	1400.60	1400.69	**0.09**	1400.46	1400.68	1400.79
153	2606579.38	606529.00	Yes	1182.91	1183.00	**0.09**	1182.99	1183.02	1183.13
186	2687308.77	499935.87	Yes	1211.39	1211.48	**0.09**	1211.42	1211.48	1211.54
128	2538639.37	304730.94	Yes	1297.71	1297.80	**0.09**	1297.44	1297.78	1297.91
132	2515761.59	389406.81	Yes	1360.22	1360.32	**0.10**	1360.01	1360.35	1360.54
152	2499666.12	396115.96	Yes	1385.49	1385.59	**0.10**	1385.53	1385.55	1385.73
205	2679291.46	434597.44	Yes	1175.23	1175.34	**0.11**	1175.25	1175.38	1175.42
209	2342722.76	607065.24	Yes	1479.18	1479.30	**0.12**	1479.18	1479.26	1479.43
217	2272431.19	584784.85	Yes	1552.66	1552.78	**0.12**	1552.70	1552.82	1552.85

211	2325166.52	584118.33	Yes	1522.00	1522.13	**0.13**	1522.11	1522.19	1522.21
158	2661908.32	613513.48	Yes	1263.28	1263.41	**0.13**	1263.37	1263.50	1263.50
208	2352820.12	582214.94	Yes	1454.07	1454.20	**0.13**	1454.01	1454.36	1454.42
146	2540281.75	386418.49	Yes	1191.73	1191.87	**0.14**	1191.63	1191.75	1191.97
189	2645102.93	507899.65	Yes	1093.35	1093.49	**0.14**	1093.34	1093.50	1093.52
159	2671117.66	632836.46	Yes	1243.59	1243.76	**0.17**	1243.45	1243.81	1243.96
145	2493047.30	427799.73	Yes	1306.15	1306.32	**0.17**	1306.19	1306.37	1306.42
212	2324358.09	607826.55	Yes	1491.96	1492.13	**0.17**	1492.02	1492.10	1492.23
119	2583509.50	412475.13	Yes	1120.38	1120.55	**0.17**	1120.24	1120.60	1120.79
160	2654971.03	521558.11	Yes	1103.93	1104.11	**0.18**	1104.08	1104.14	1104.14
195	2471827.08	614817.33	Yes	1334.09	1334.27	**0.18**	1334.18	1334.18	1334.55
188	2729183.32	463837.05	Yes	1145.64	1145.82	**0.18**	1145.50	1145.57	1146.03
214	2303515.33	591107.18	Yes	1516.29	1516.48	**0.19**	1516.16	1516.54	1516.54
204	2640550.73	483507.52	Yes	1072.35	1072.54	**0.19**	1072.53	1072.54	1072.56
162	2756848.86	523329.31	Yes	1110.92	1111.12	**0.20**	1111.03	1111.12	1111.17
207	2340470.78	593291.16	Yes	1468.07	1468.28	**0.21**	1468.25	1468.28	1468.41
193	2533369.58	611856.85	Yes	1260.03	1260.24	**0.21**	1260.17	1260.24	1260.30
198	2412959.43	592005.32	Yes	1388.15	1388.38	**0.23**	1388.37	1388.39	1388.40
178	2772276.09	490039.98	Yes	963.82	964.05	**0.23**	963.95	963.98	964.09
202	2364529.94	597398.31	Yes	1443.57	1443.81	**0.24**	1443.55	1443.94	1444.10
200	2371840.37	590693.29	Yes	1435.26	1435.50	**0.24**	1435.45	1435.62	1435.65
156	2720633.61	595512.08	Yes	1152.33	1152.62	**0.29**	1152.51	1152.63	1152.82
116	2556470.24	427320.67	Yes	1297.35	1297.67	**0.32**	1297.60	1297.69	1297.75
194	2499895.14	595739.23	Yes	1304.35	1304.72	**0.37**	1304.66	1304.73	1304.80

LiDAR CALIBRATION

Note: All figures represented on the following pages are for general illustration purposes, and are not examples derived from actual NIROC 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 ALS50 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.

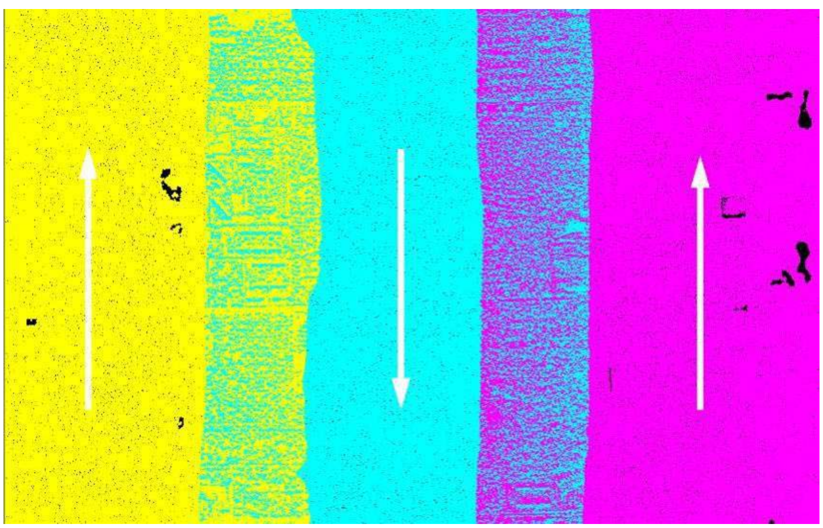


Figure 1: Flight pattern required for calibration

Correcting for Pitch and Heading Biases

There are many settings in the ALS40/50 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.

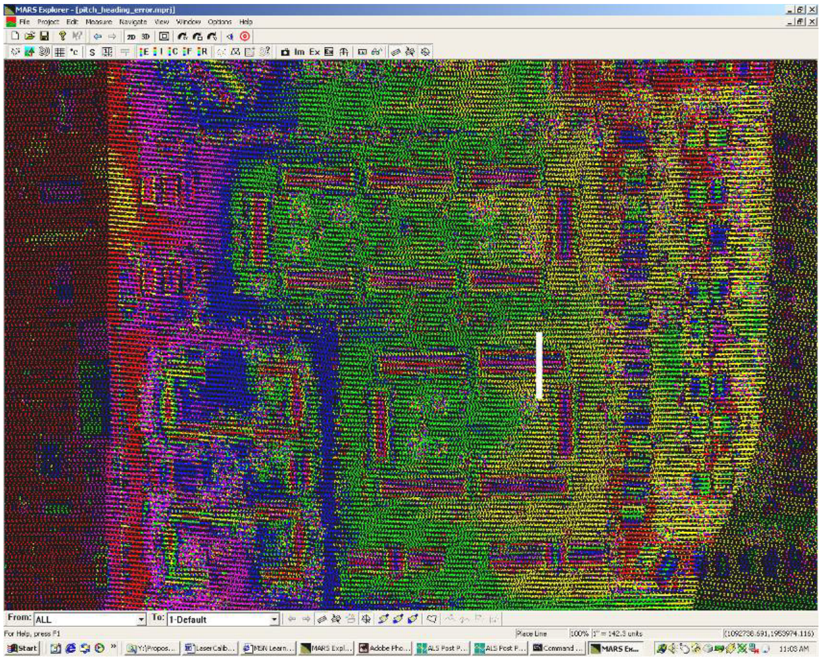


Figure 2: Orthographic view with profile line

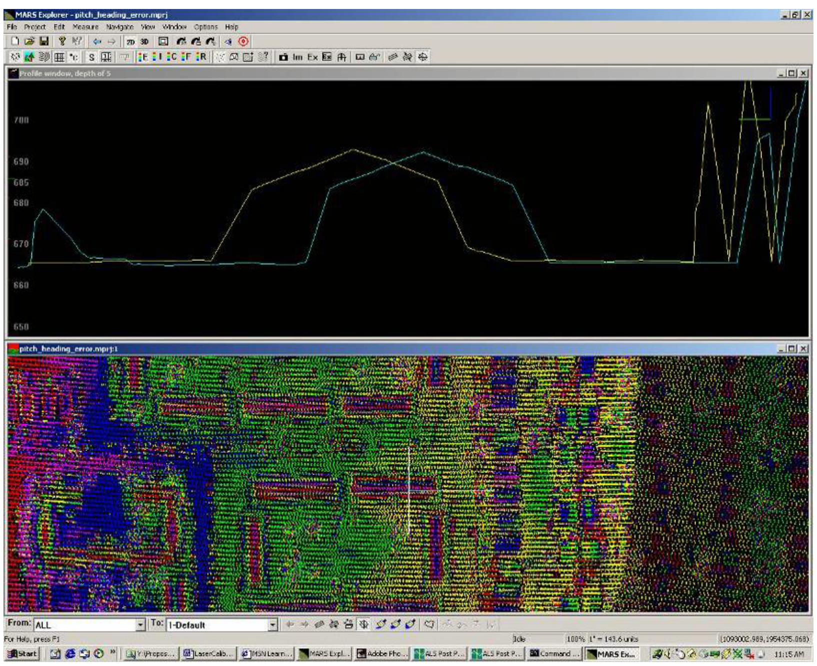


Figure 3: Profile view of misalignment

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).

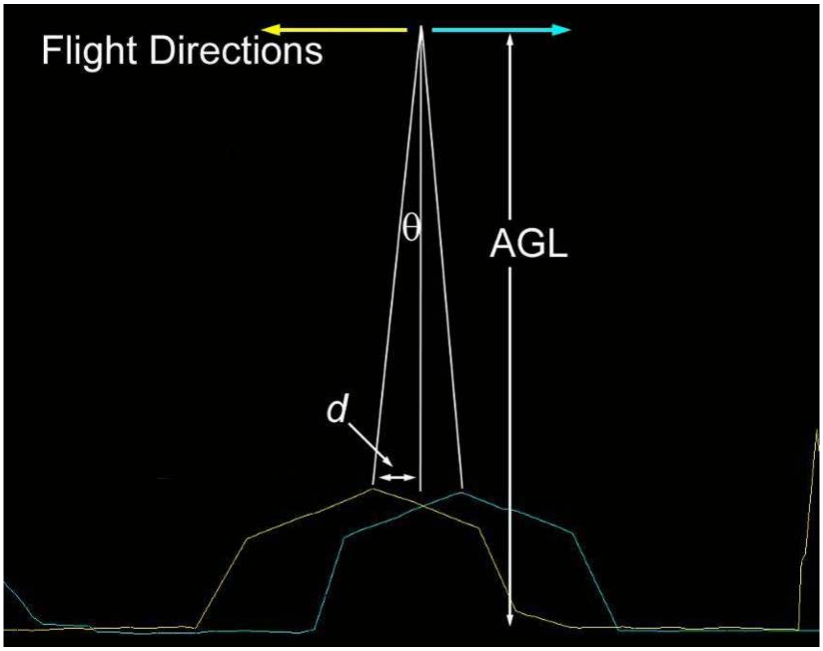


Figure 4: Adjusting pitch

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 thetạ must be expressed in radians. The formula to arrive at this angle is…

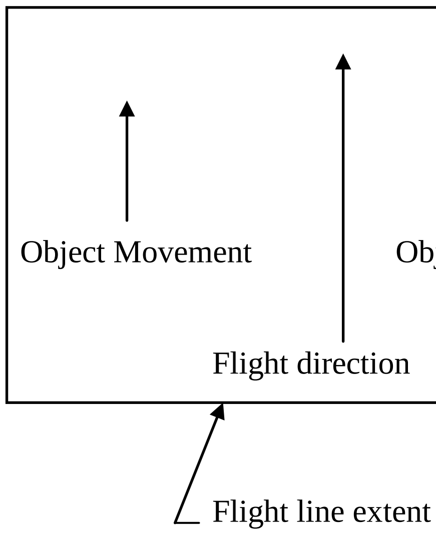
$$\theta = \frac{\arctan\left(\frac{d}{AGL}\right)}{57.2958}$$

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.

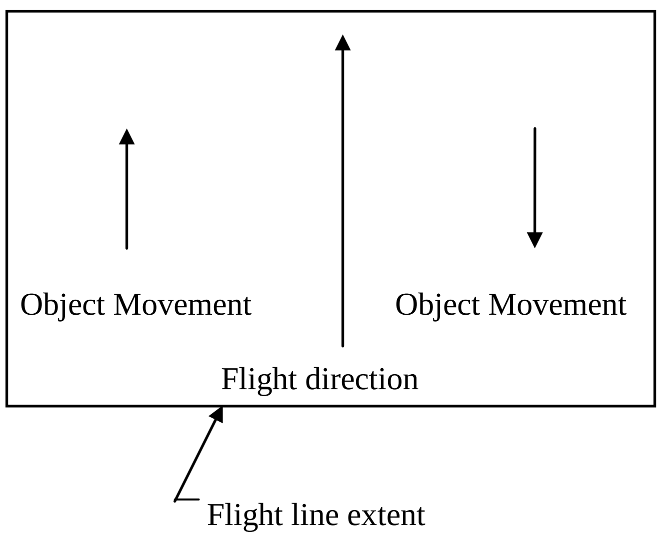
The next issue to resolve, before actually changing the pitch value, is to determine if this shift is at all due to an incorrect heading value, since heading will move data in the direction of flight also. The difference is that heading rotates the data, meaning that when heading is changed, objects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

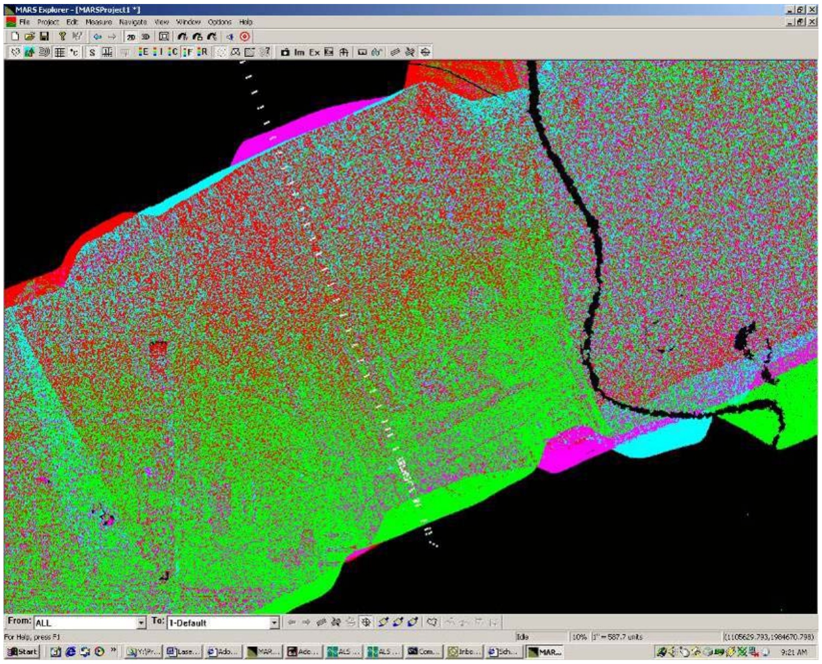


Figure 7: The truth survey

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)

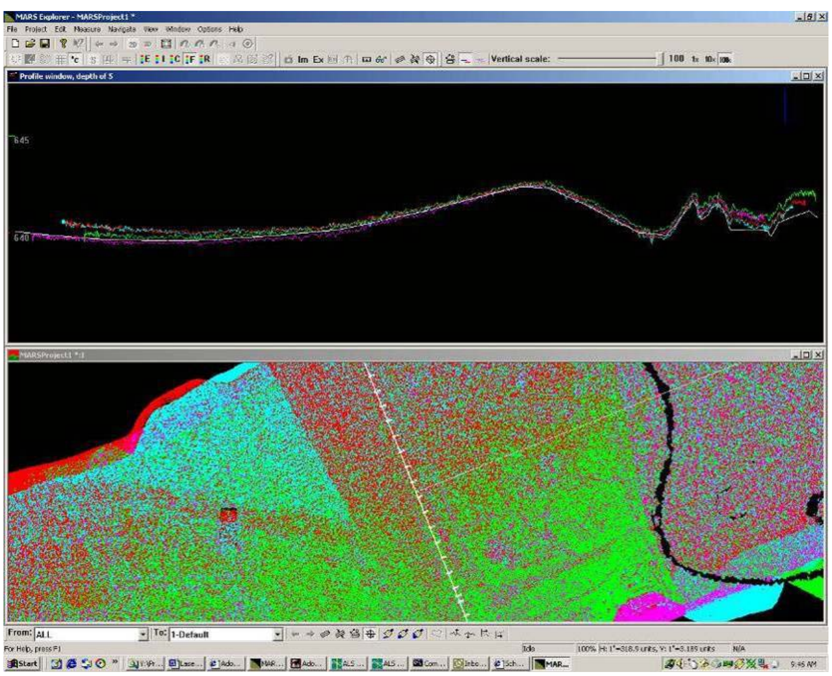


Figure 8: Profile view of calibration flight lines

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)

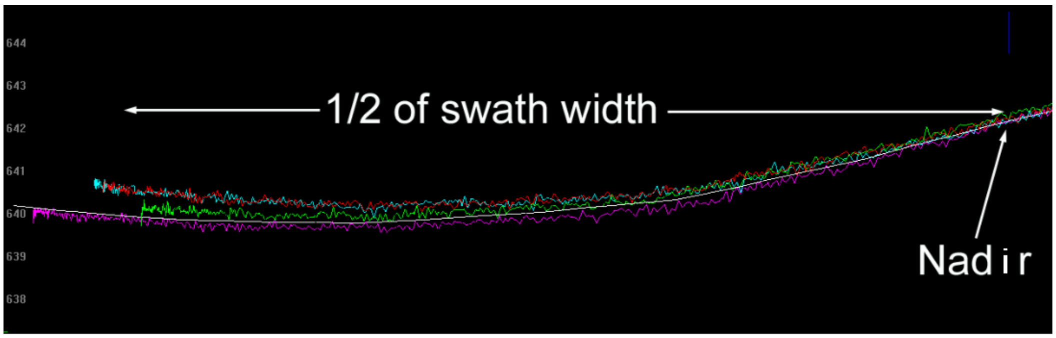


Figure 9: Half of calibration profile

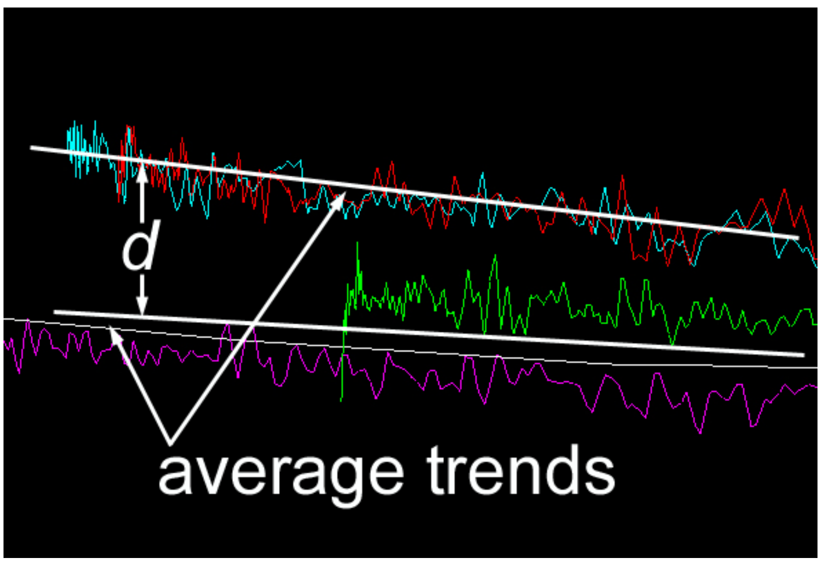


Figure 10: Differences in average roll trends

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:

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

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 its proprietary software MARS® 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 1.2 specification. During this process all non-ground points are classified to Class 1 (Unclassified), and water points are classified to Class 9 (Water).

Important to note, Merrick preserves the integrity of overlap points (i.e., 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. Many other companies cannot perform this task to the same level therefore reclassify these points into a non-ground class to prevent inaccurate data deliveries. Merrick has no need to do this since all points are boresighted accurately.

DIGITAL TERRAIN MODEL (DTM)

Raster Grid Development

Merrick exports the Class 2 (ground) and LiDAR point and the breaklines to a 4 foot cell size ERDAS .IMG using MARS®. These rasters are formatted to the project tiling scheme and assigned projection information. The result is a seamless (tile edge to tile edge) DTM in ERDAS .IMG format.

BREAKLINE COLLECTION

Drainage Breaklines

Merrick uses a methodology that directly interacts with the LiDAR bare-earth data to collect drainage breaklines. To determine the alignment of a drainageway, 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. Merrick's proprietary MARS® software has the capability of "flipping" views between the TIN and ortho imagery, as necessary, to further assist in the determination of the drainage centerline. All drainage breaklines are collected in a downhill direction. For each point collected, the software uses a five-foot (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 drainageway 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.

Waterbodies

Waterbodies are digitized from the color ramped TIN, similar to the process described above. Ortho imagery is also used, as necessary, to determine the waterbody outline.

The elevation attribute is determined as a post-process using the lowest determined bare-earth point within the polygon.