NRCS Oklahoma 2010
Northern Oklahoma

LiDAR Mapping Report
LiDAR System and Flight Report

Prepared by:

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EXECUTIVE SUMMARY

Merrick & Company (Merrick) was contracted by AMEC Earth & Environmental, Inc., to perform a LiDAR (**Li**ght **D**etection **A**nd **R**anging) survey for a significant area covering 1,733 square miles located in northern Oklahoma. The purpose of the project is to produce accurate high-resolution data for use in planning, design, and research, utilizing LiDAR. All data will meet or exceed standards for both vertical and horizontal accuracy as stated in NDEP, Guidelines for Digital Elevation Data, Version 1.0 for NSSDA of 95% confidence for 2-ft contours and ASPRS Class I Standards.

CONTRACT INFORMATION

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Project Completion - Sub Project 3

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 for the NRCS Oklahoma 2010 project.

LiDAR FLIGHT and SYSTEM REPORT

Project Location

The project location for Project NRCS Oklahoma 2010 is defined by the shapefile: Alt_03_mod_Buffer_N83UTM14m.shp

Duration/Time Period

One LiDAR aircraft, a Cessna 402C (SN53), was used to collect LiDAR Data. The Cessna 402C (SN53) arrived on site December 18, 2010 and the LiDAR data collected December 18, 2010 thru December 22, 2010. The airport of operation was the Perry Municipal Airport (F22).

Mission Parameters for Cessna 402C (SN53) flown at Altitude 11,500 Feet

LiDAR Sensor	Leica Geosystems ALS50 Phase 2+
Nominal Ground Sample Distance	1.38 meters
Field of View (scan angle)	30 deg.
Average Airspeed	165 Knots
Laser Pulse Rate	76,200 Hertz
Scan Rate	28.0 Hz
Average Altitude (MSL)	11,500 Feet

Flight mission Date and Times

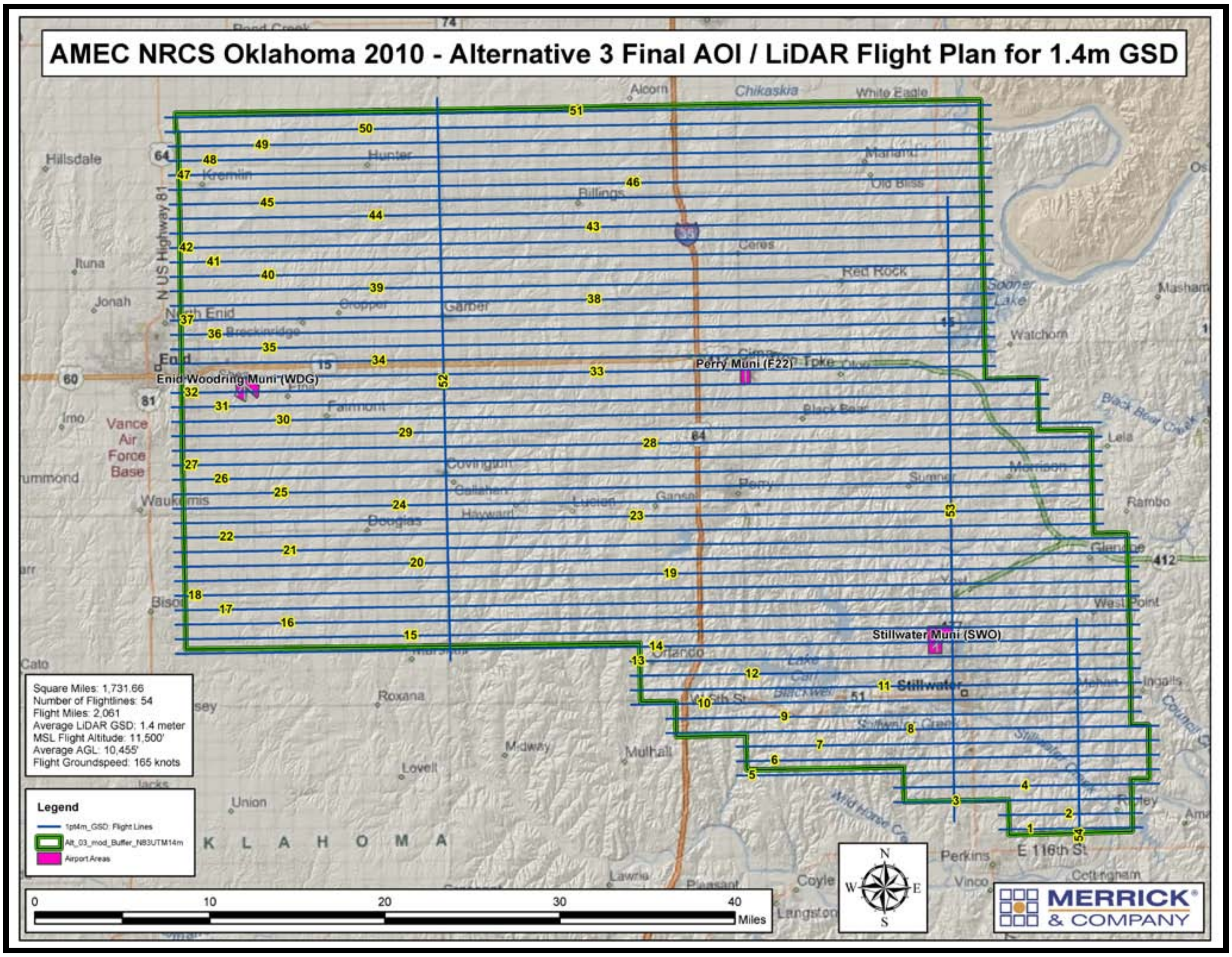
Mission	Date	Plane	Start Time GPS sec.	End Time GPS sec.	Length Time GPS sec.	Number of GNSS Solution Records
101219_A	Dec.19,2010	SN53	65855.5	79980.5	19485.2	28250
101219_B	Dec.19,2010	SN53	89954.0	109438.5	19484.5	38969
101220_A	Dec.20,2010	SN53	141465.5	157538.0	16072.0	32145
101220_B	Dec.20,2010	SN53	162301.5	182257.5	19956.0	39912
101222_A	Dec.22,2010	SN53	311633.5	324819.0	13185.5	26371

Field Work / Procedures

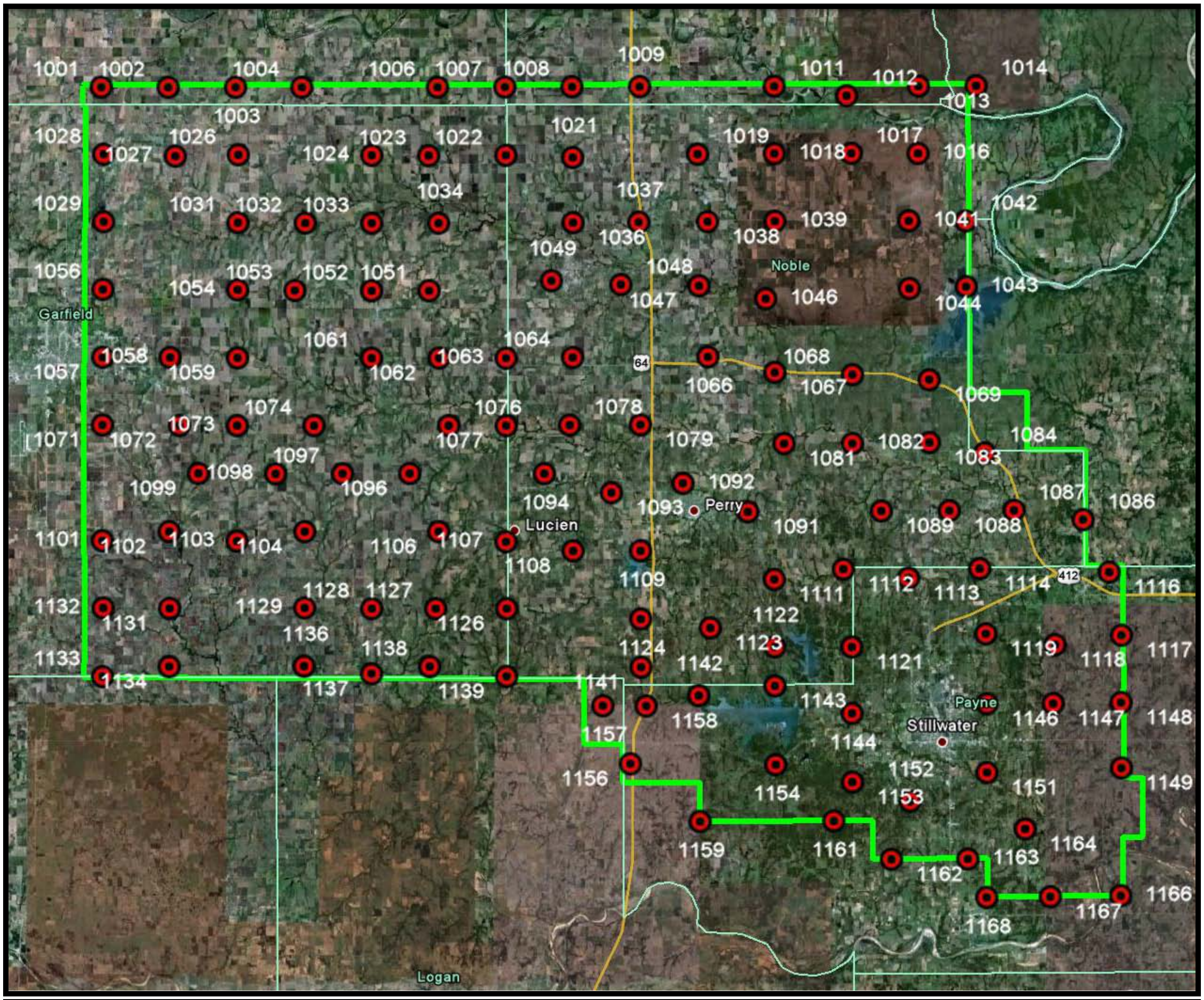
Two ground GPS Base Stations, for the LiDAR data collection, were set up at the airport of operation. The main GPS Base Station (OKL_Base_Main) was used for the LiDAR data collection and the auxiliary GPS Base Station (OKL_Base_Aux) was used for backup if there were any problems with the main GPS Base Station.
See GPS Base Station Locations Diagram Below.

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.

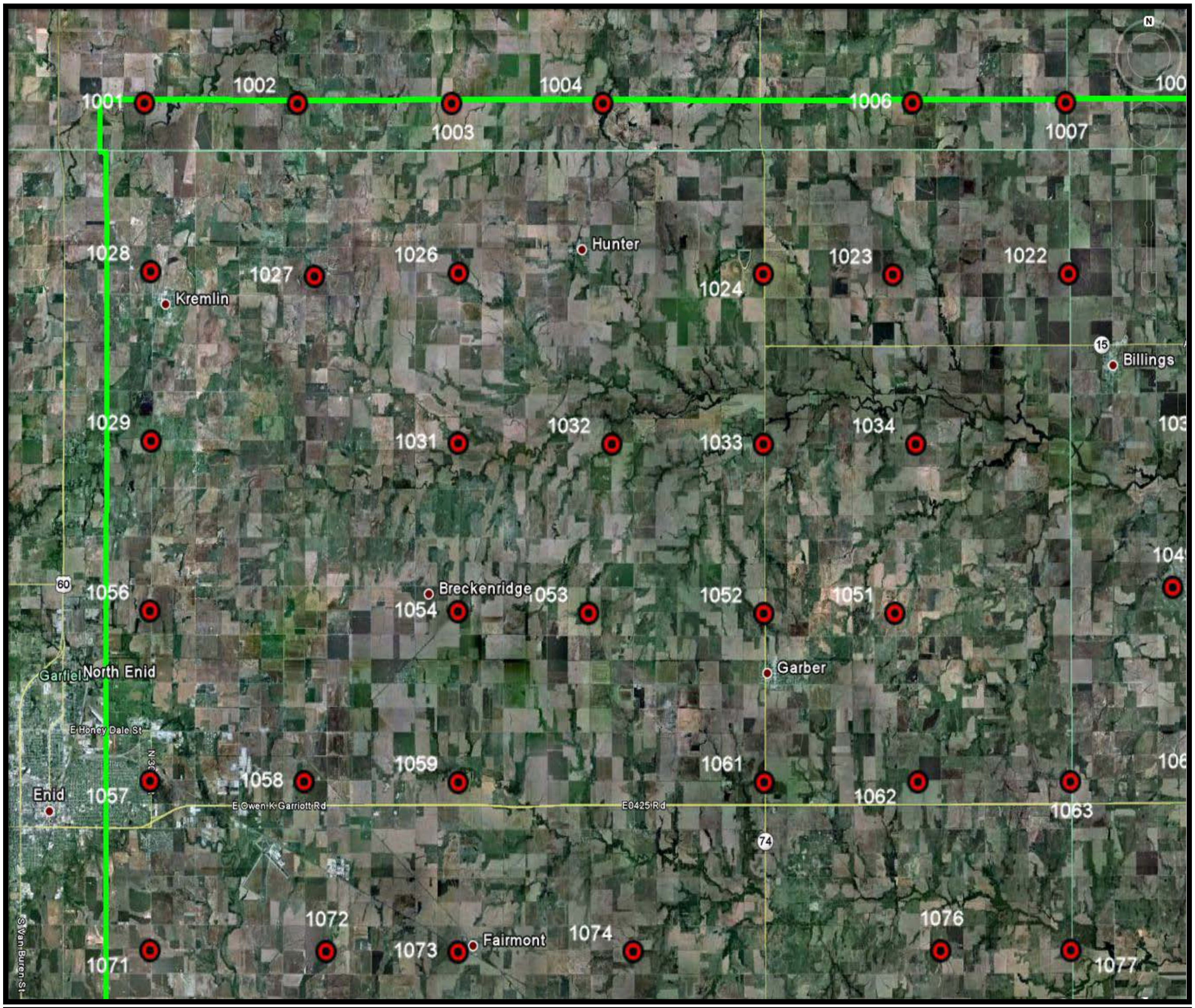
Planned Flight Line Diagram



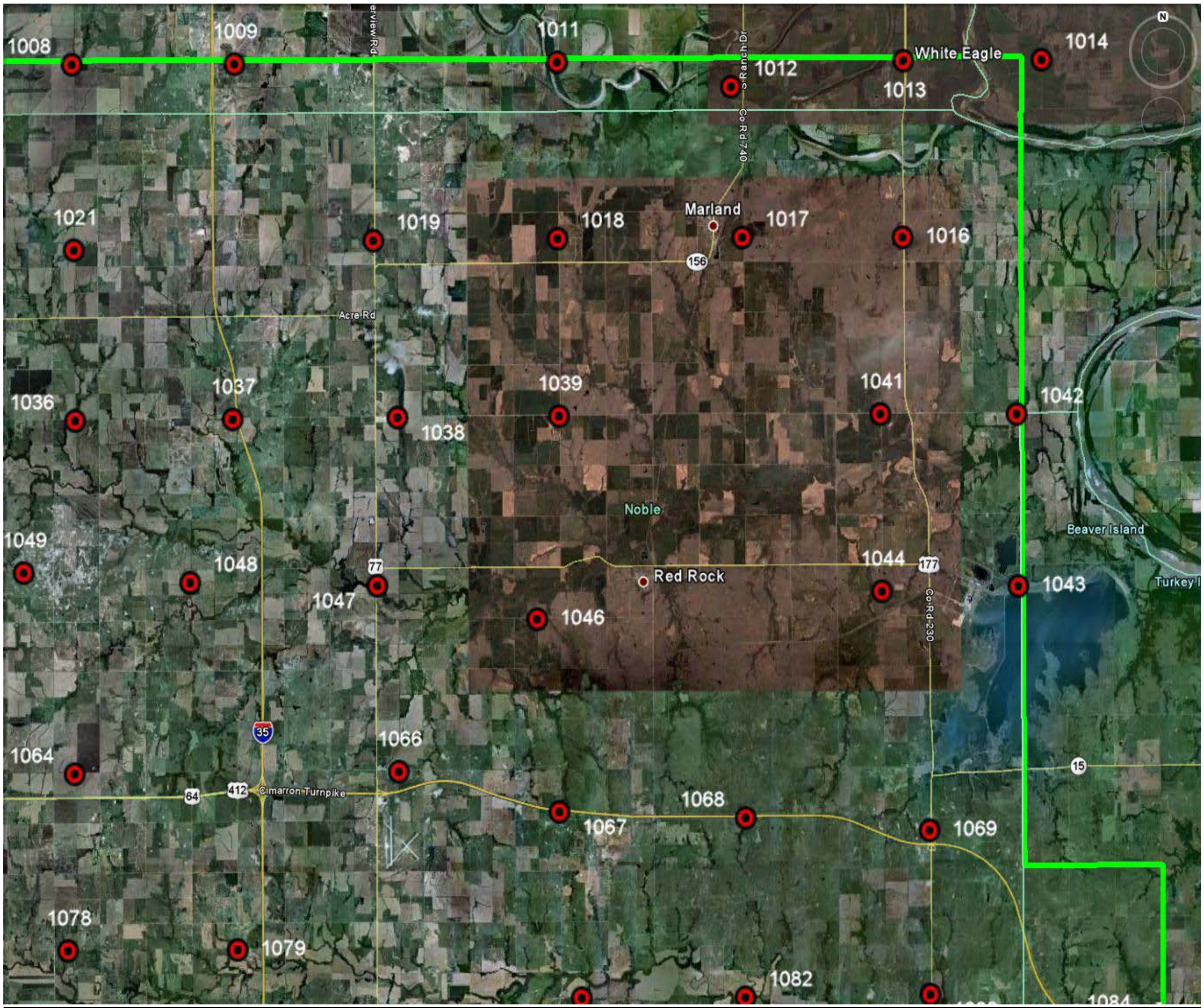
Ground Control Checkpoints All



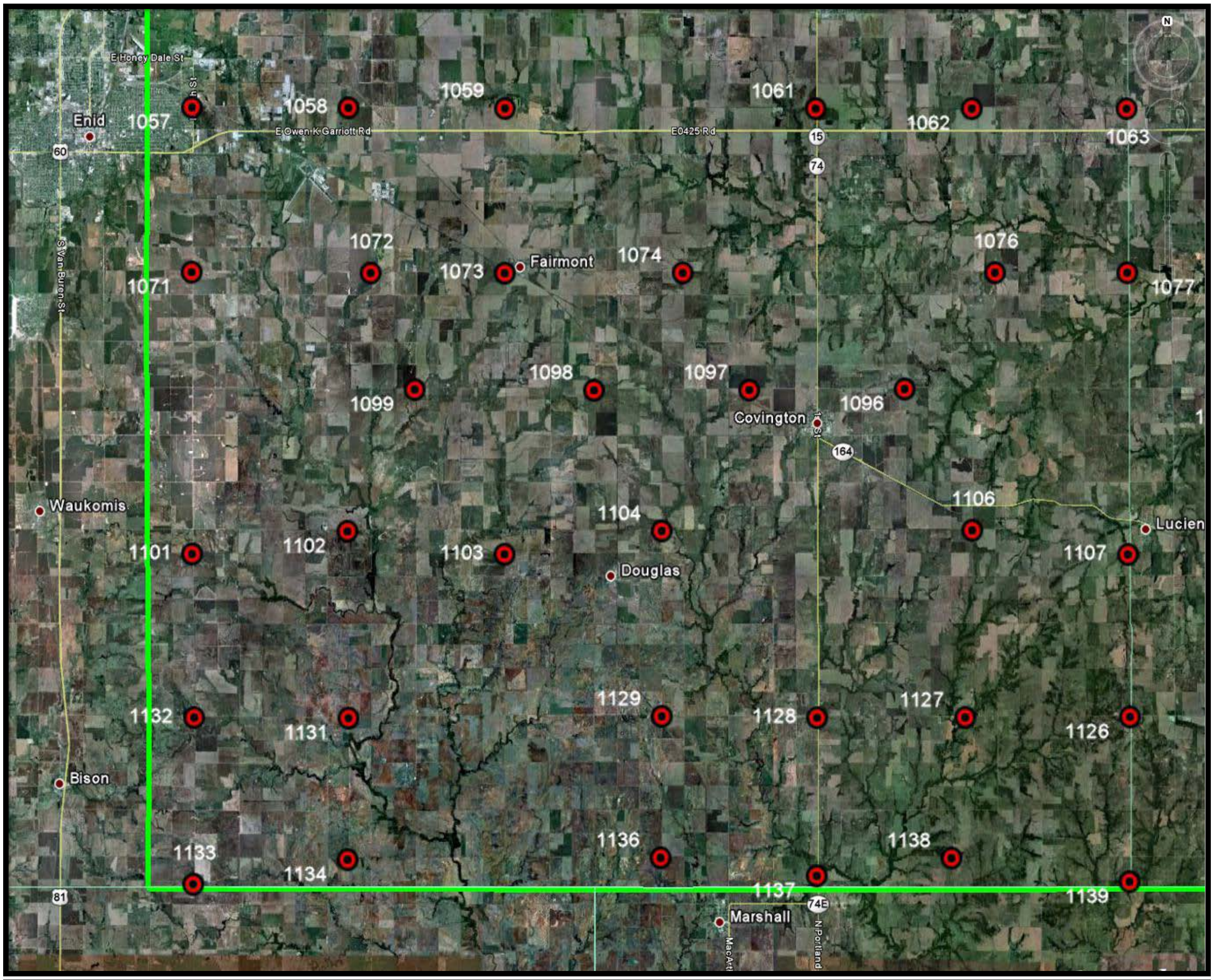
Ground Control Checkpoints Northwest Area



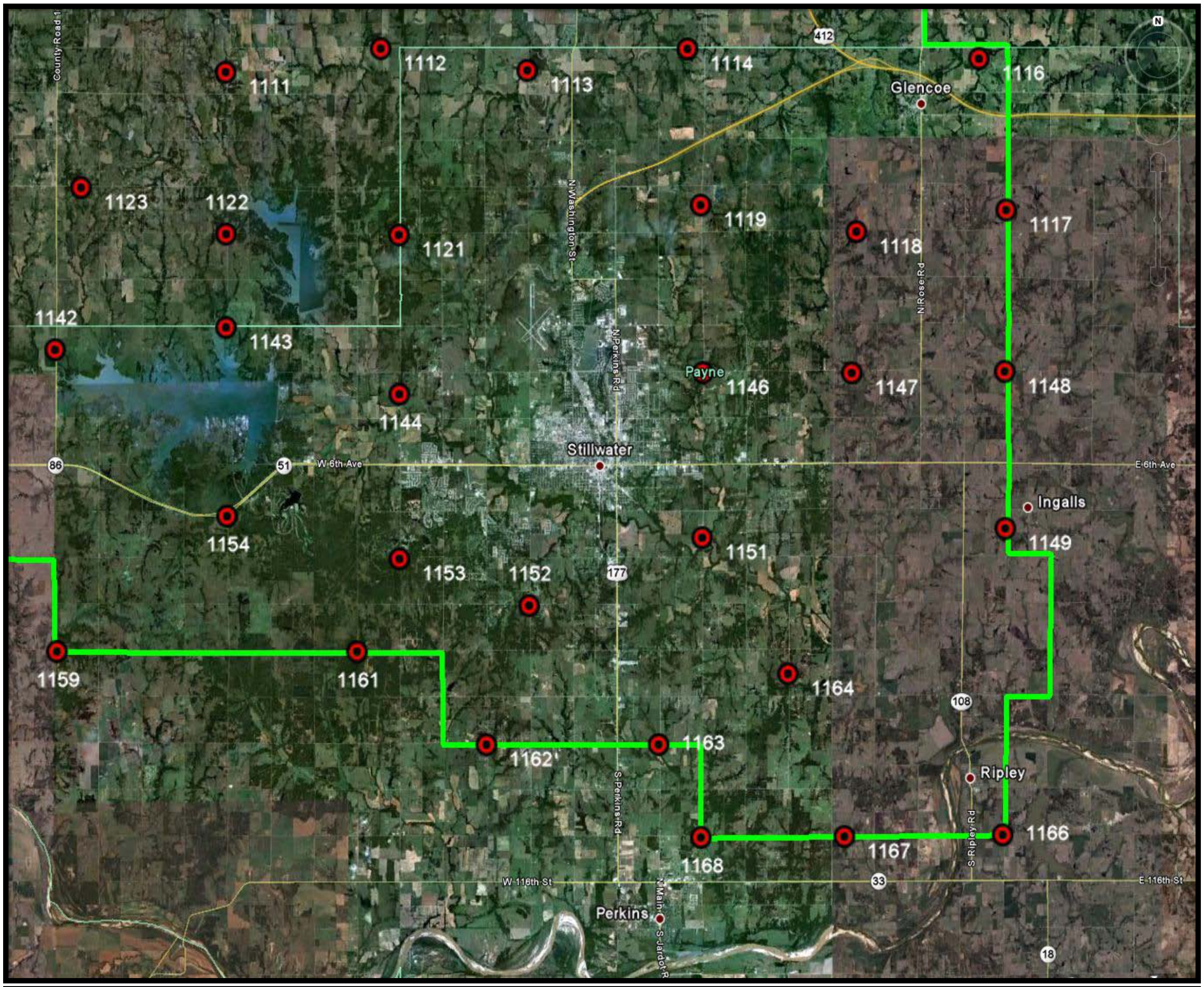
Ground Control Checkpoints Northeast Area



Ground Control Checkpoints Southwest Area

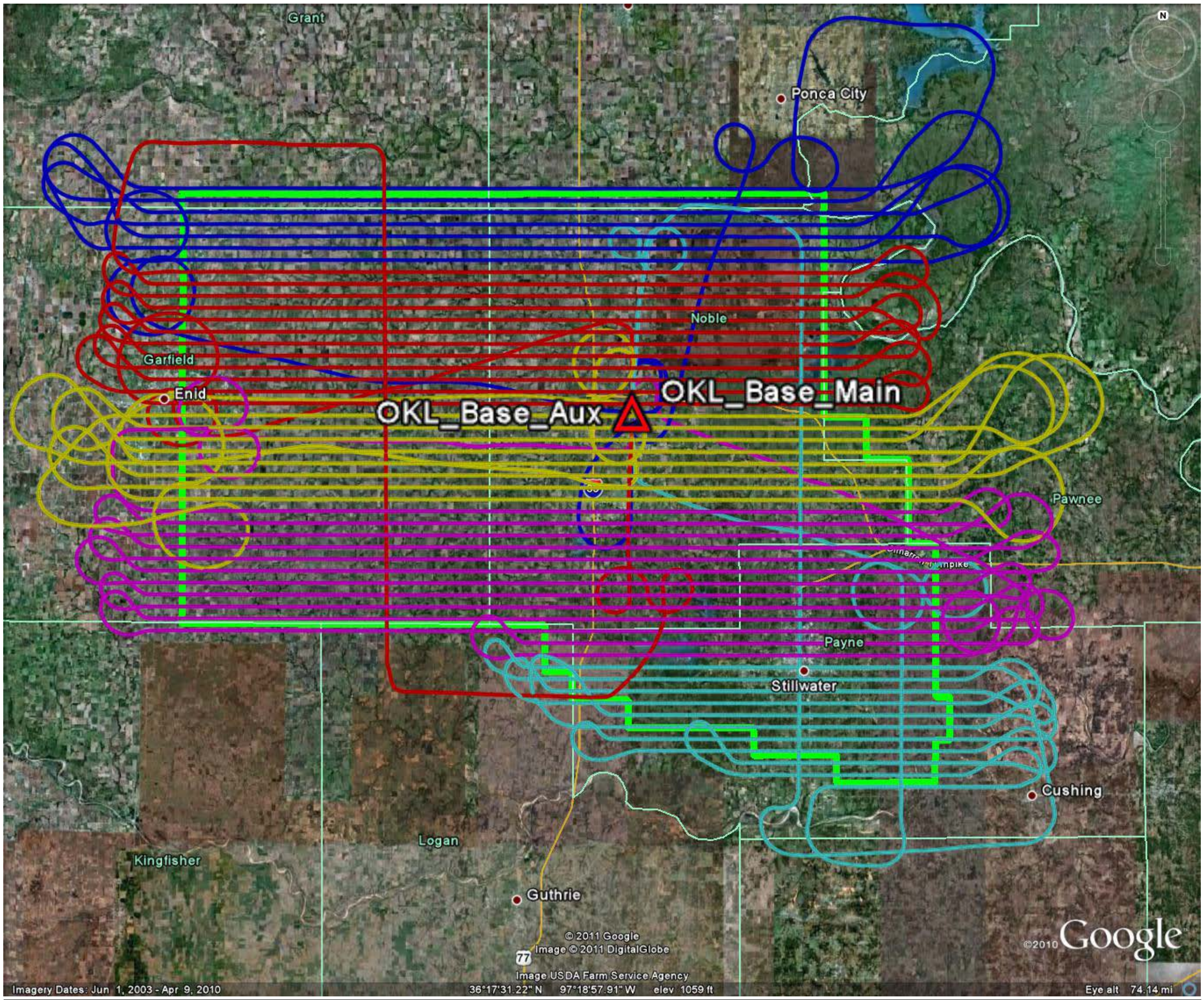


Ground Control Checkpoints Southeast Area

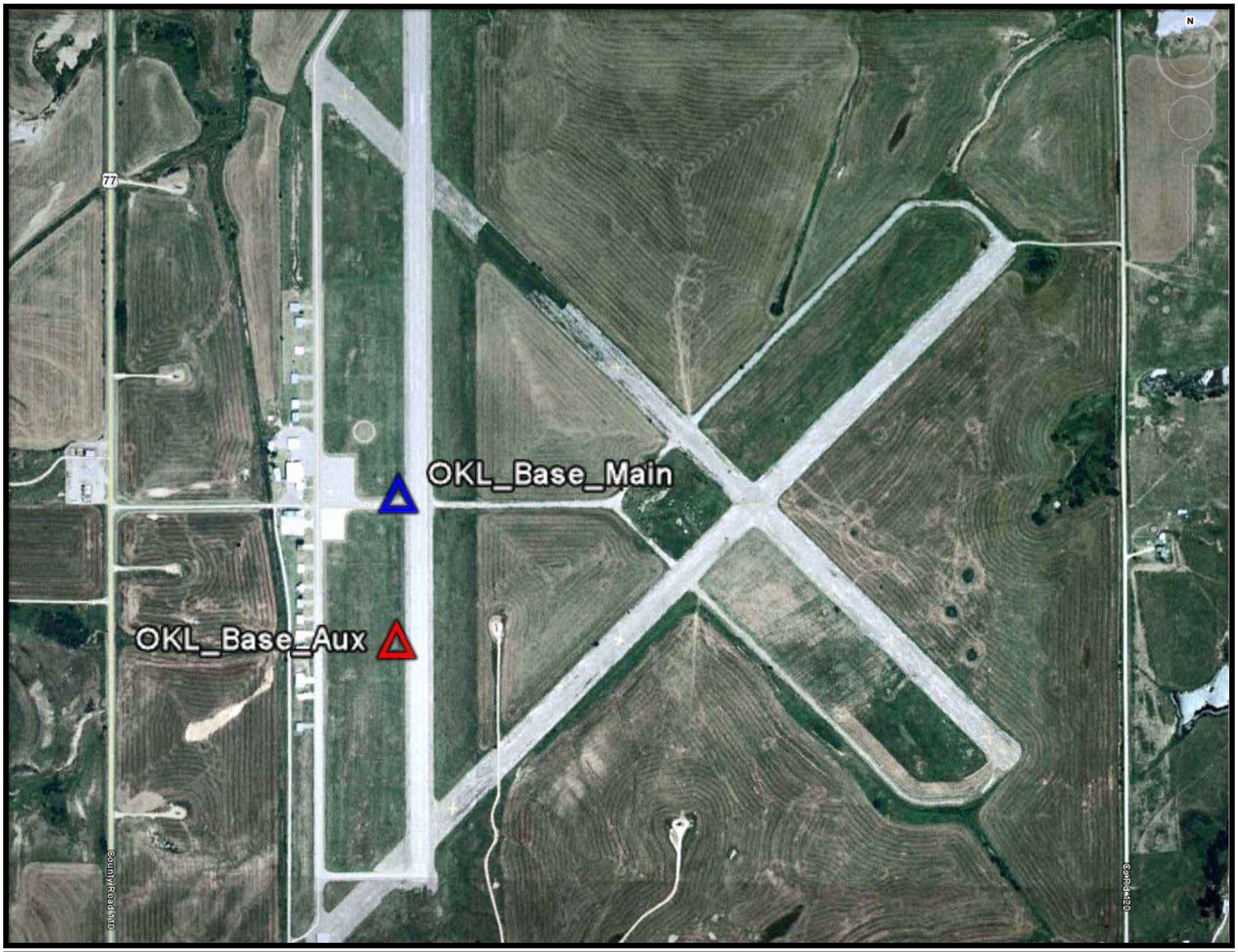


Actual Flight Lines Showing Base Station Locations and colored mission by mission

Blue = 101219_A
Red = 101219_B
Yellow = 101220_A
Magenta = 101220_B
Cyan =101222_A

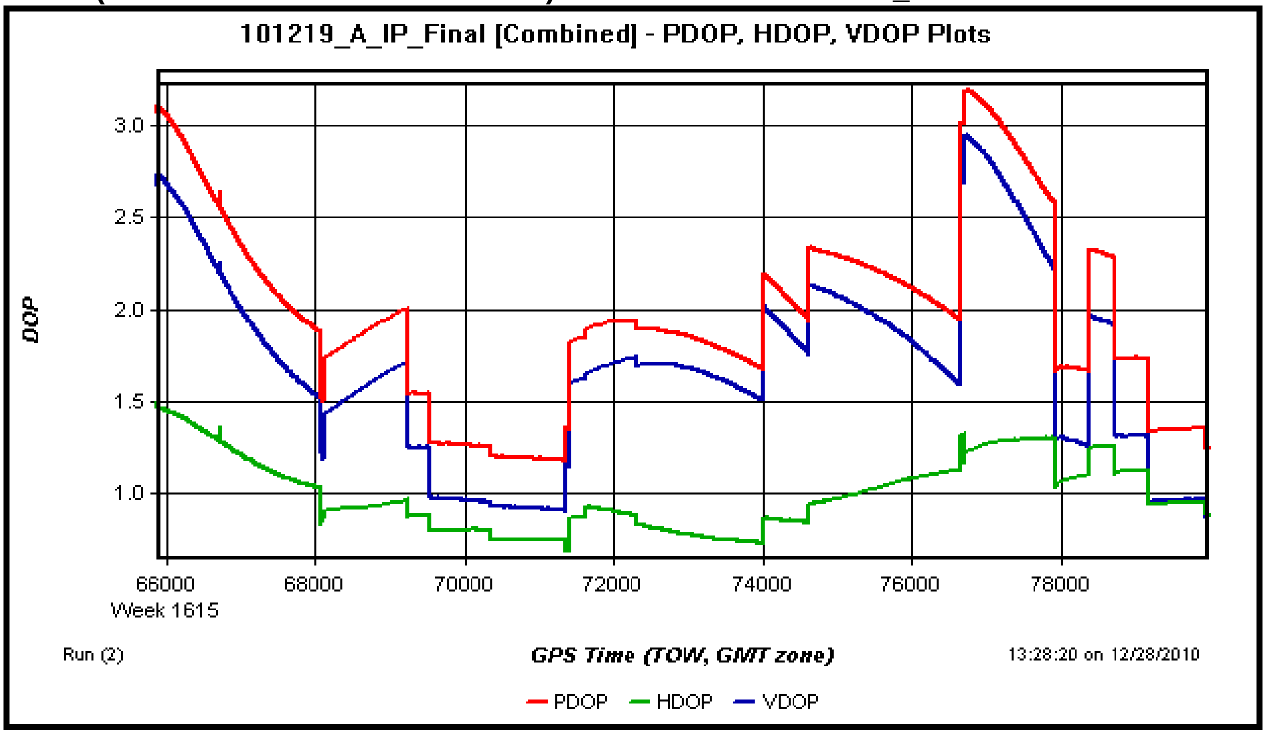


Base Stations Location at Airport

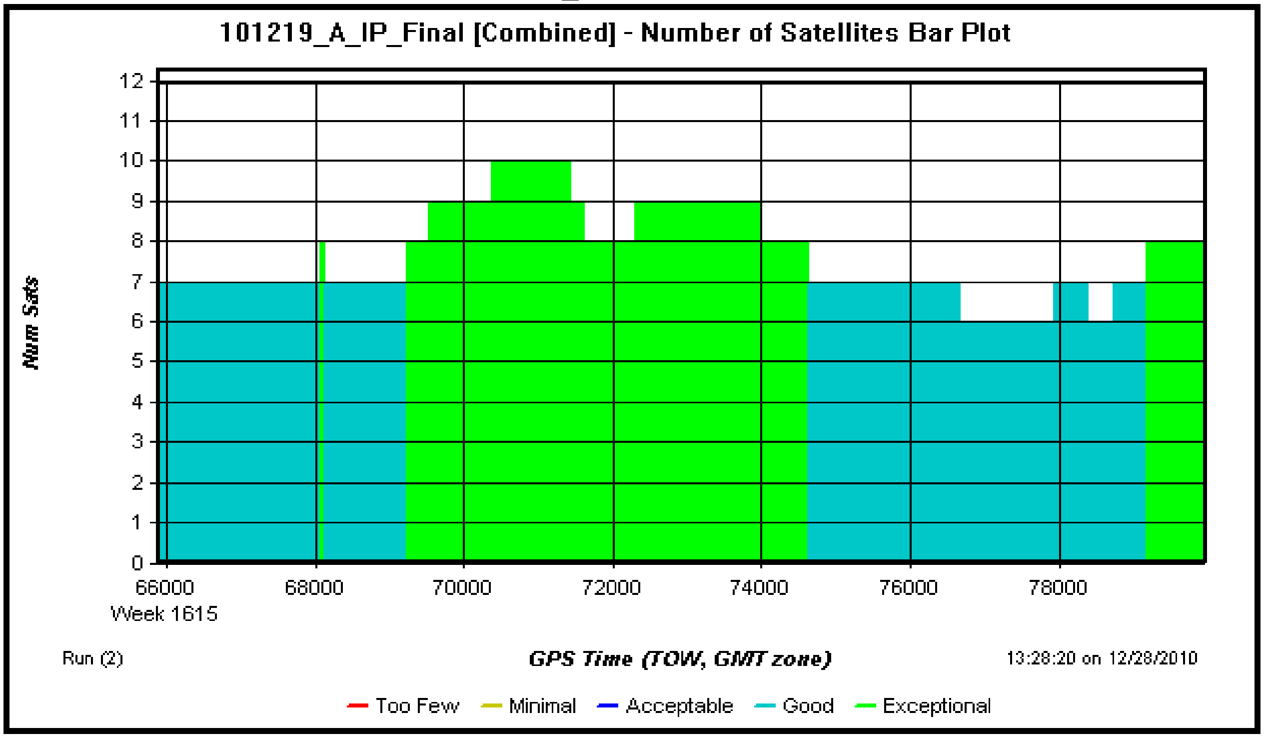


The following graphs show the mission by mission GPS PDOP (Positional Dilution Of Precision) Plots and the Number of Satellite Plots.

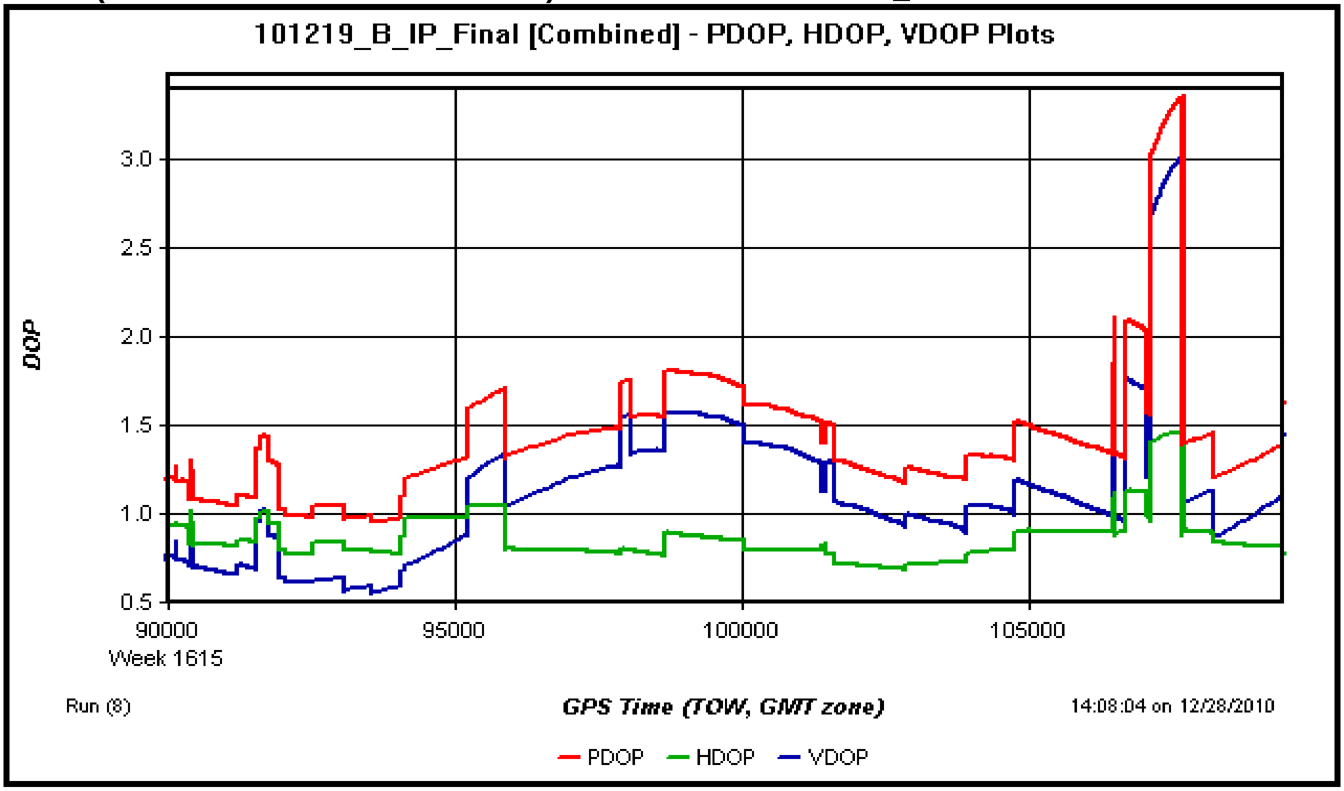
PDOP (Positional Dilution Of Precision) Plot for mission 101219_A



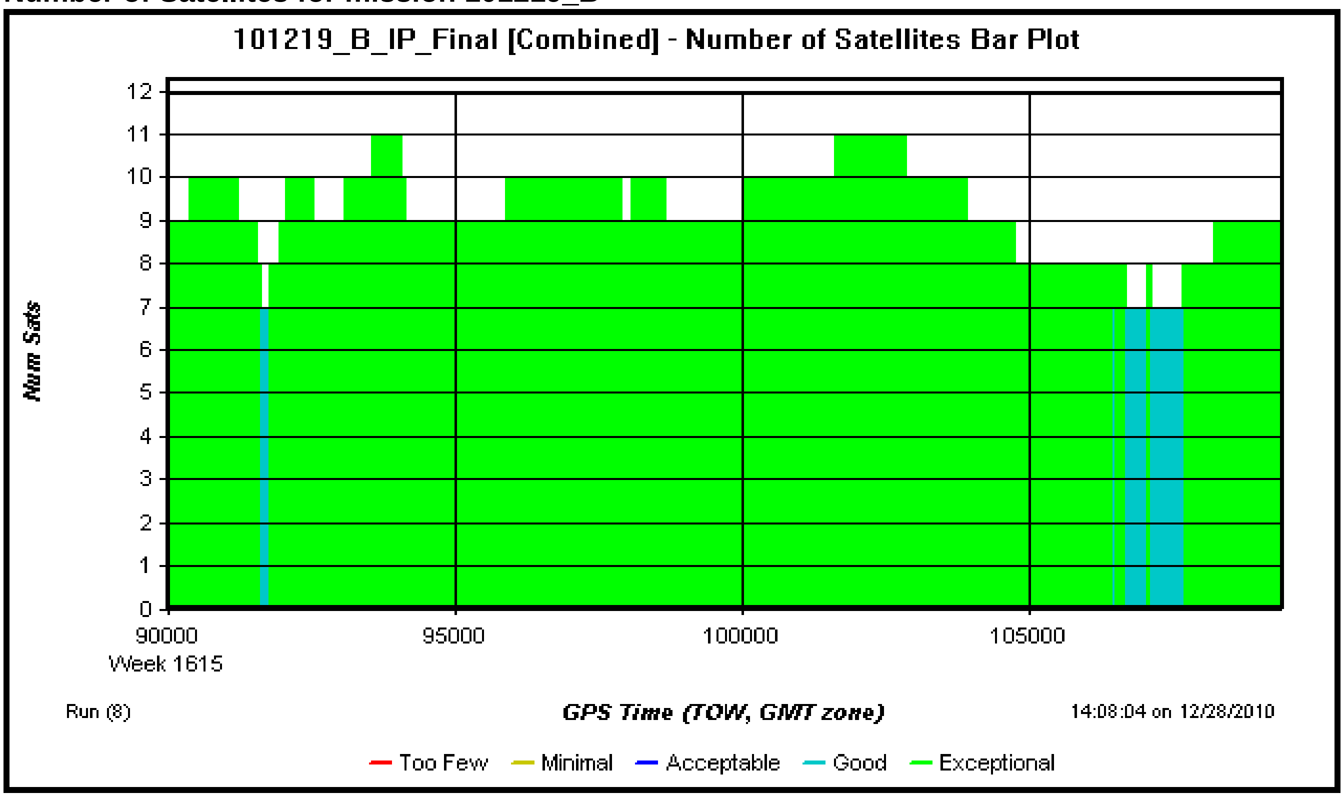
Number of Satellites for mission 101219_A



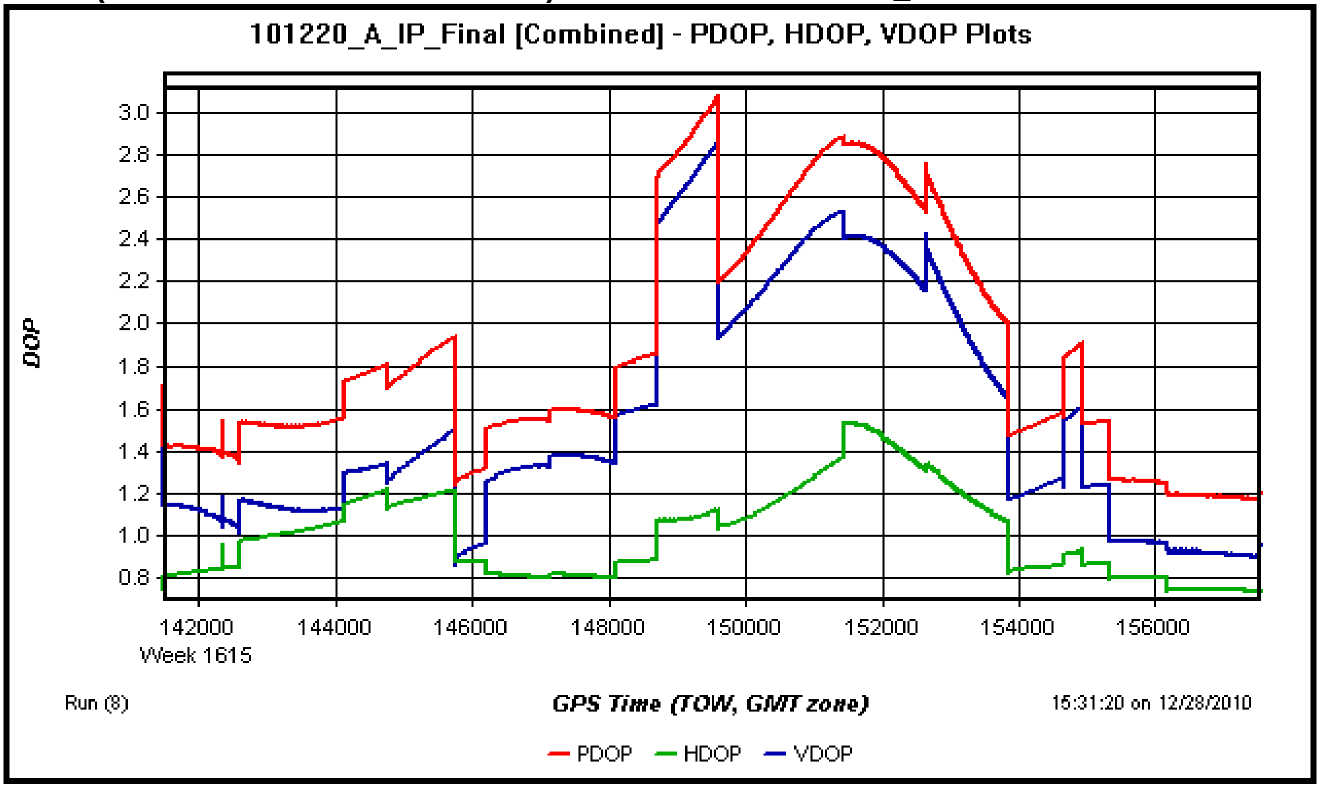
PDOP (Positional Dilution Of Precision) Plot for mission 101219_B



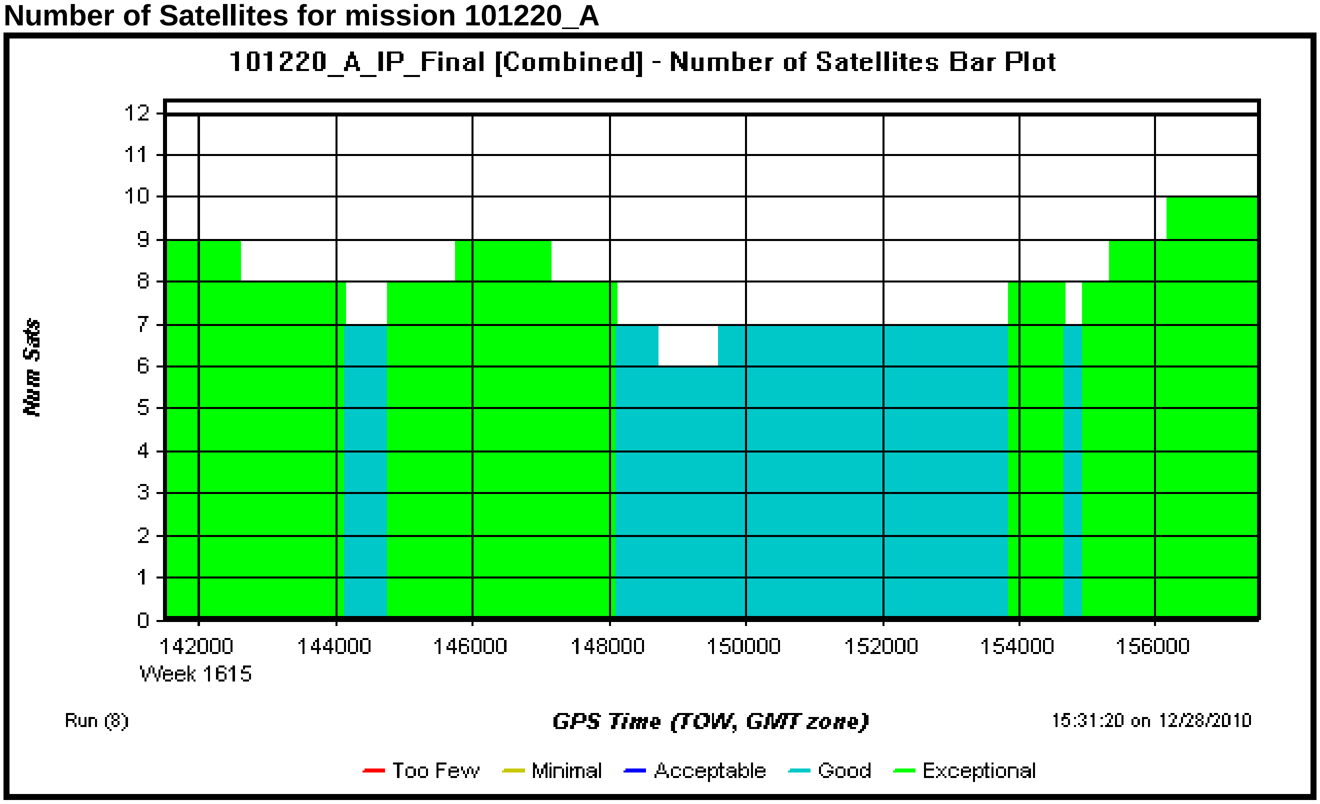
Number of Satellites for mission 101219_B



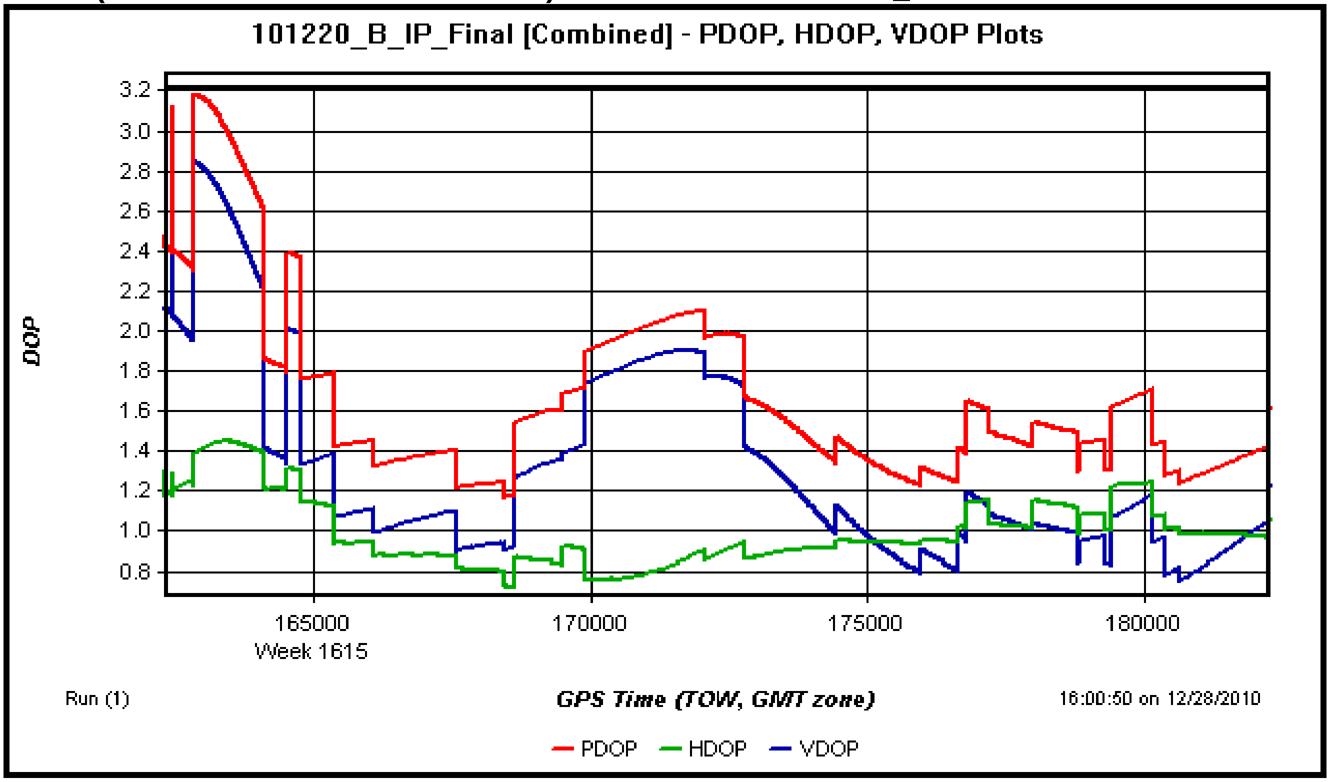
PDOP (Positional Dilution Of Precision) Plot for mission 101220_A



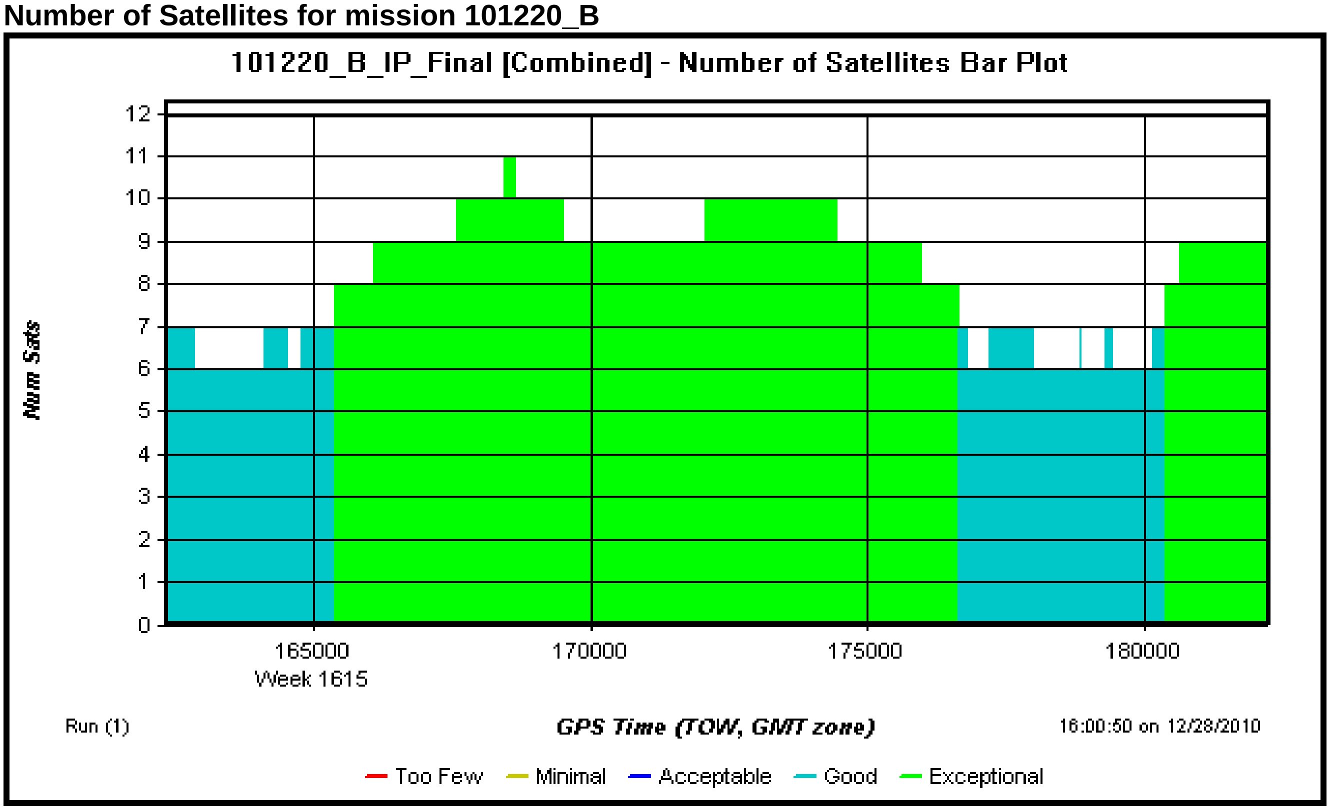
Number of Satellites for mission 101220_A



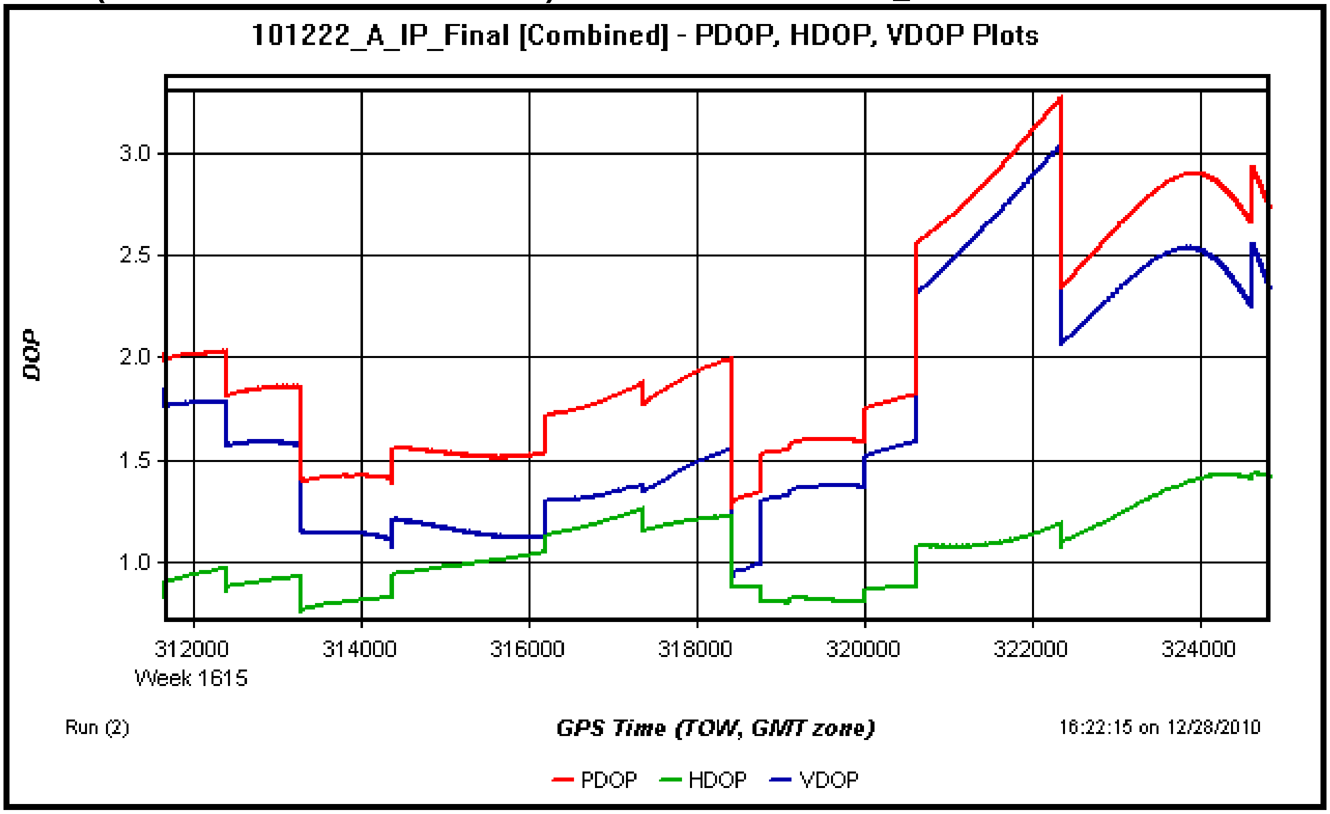
PDOP (Positional Dilution Of Precision) Plot for mission 101220_B



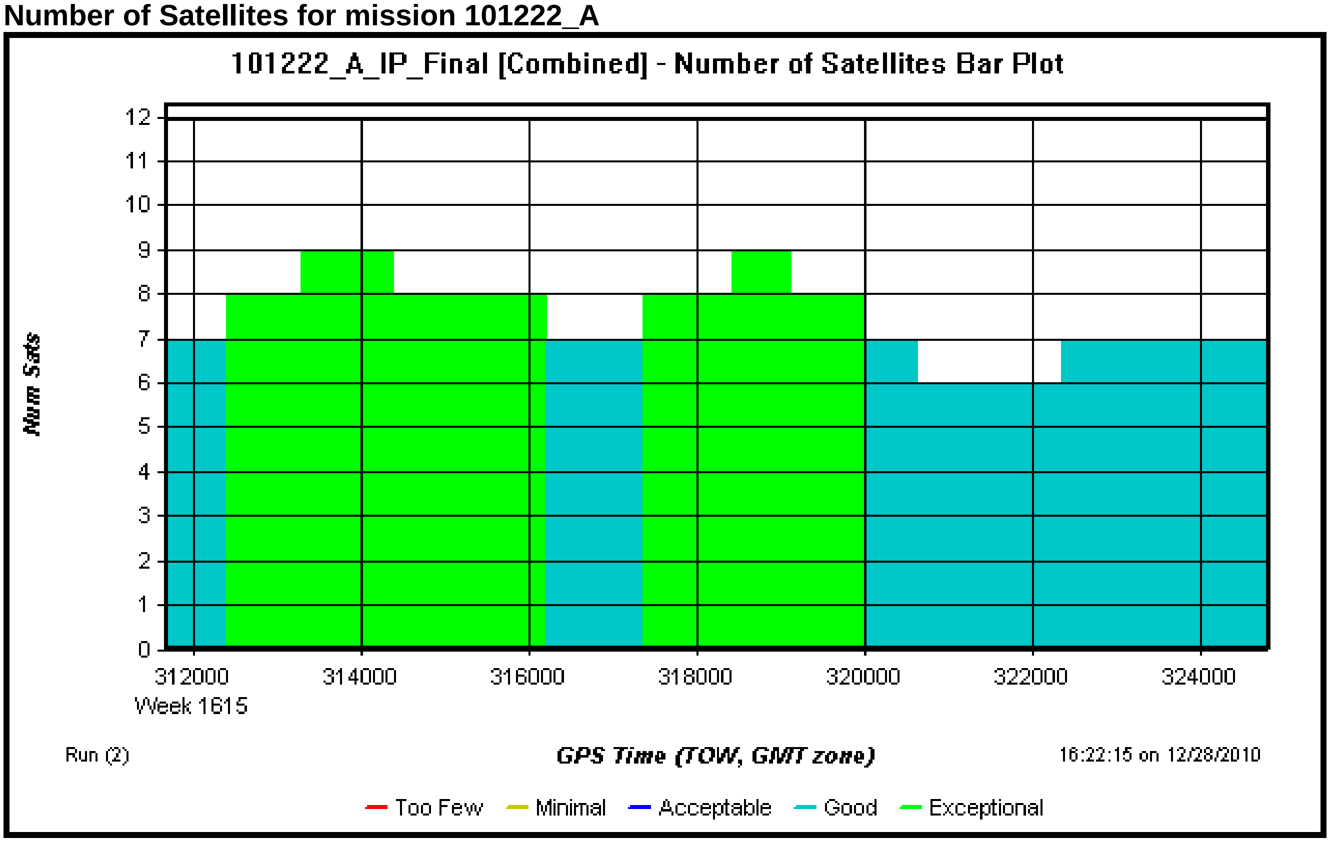
Number of Satellites for mission 101220_B



PDOP (Positional Dilution Of Precision) Plot for mission 101222_A



Number of Satellites for mission 101222_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 (**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 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 airport of operation. The main GPS Base Station (OKL_Base_Main) was used for the LiDAR data collection and the auxiliary GPS Base Station (OKL_Base_Aux) was used for backup if there were 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).
See Spreadsheet Below for Airborne GPS Base Station information.

Ground Control Parameters

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 (NAD 83).
Coordinate System: Universal Transverse Mercator (UTM), Zone 14 North
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 Meters, Vertical units are in Meters.

NRCS Oklahoma 2010 Base Stations				
PT#	UTM NAD 83	UTM NAD 83	ELEV.	DESCRIPTION
	ZONE 14 NORTH	ZONE 14 NORTH	NAVD 88	
	NORTHING	EASTING	Z	
	METERS	METERS	METERS	
Base Main	4027931.011	654489.515	302.685	OKL Base Main
Base Aux	4027700.054	654491.269	303.611	OKL Base Aux
PT#	NAD 83	NAD83	ELLIPSOID	DESCRIPTION
	LATITUDE	LONGITUDE	MATCH	
	North	West	GEOID 09	
	Deg-Min-Sec	Deg-Min-Sec	METERS	
Base Main	36 23 02.79763	97 16 39.23858	274.234	OKL Base Main
Base Aux	36 22 55.30424	97 16 39.33349	275.162	OKL Base Aux

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. The new ground control points (checkpoints) were established and surveyed by AMEC Earth & Environmental, Inc.

Name	NorthM_UTM14NAD83	EastM_UTM14NAD83	ElevM_NAVD88	Code
1001	4052007.488	603759.609	325.723	NG
1002	4052063.814	609366.800	327.902	NG
1003	4052142.722	615012.009	329.494	NG
1004	4052223.219	620546.203	318.098	NG
1006	4052403.286	631881.631	321.882	NG
1007	4052500.958	637505.824	301.159	NG
1008	4052607.535	643103.553	324.894	NG
1009	4052710.347	648755.830	297.308	NG
1011	4052930.245	659988.942	285.314	NG
1012	4052234.980	666055.502	298.056	NG
1013	4053143.251	672044.071	289.176	NG
1014	4053251.164	676866.960	280.587	NG
1016	4047532.165	672092.477	306.819	NG
1017	4047445.328	666511.291	308.663	NG
1018	4047316.645	660086.320	303.723	NG
1019	4047163.206	653679.050	310.438	NG
1021	4046713.718	643260.608	312.519	NG
1022	4046807.706	637679.902	312.350	NG
1023	4046681.496	631242.604	323.879	NG
1024	4046635.346	626494.661	330.553	NG
1026	4046511.292	615344.620	341.110	NG
1027	4046331.926	610076.047	349.267	NG
1028	4046413.933	604073.169	335.411	NG
1029	4040786.968	604177.403	356.471	NG
1031	4040870.708	615410.939	334.666	NG
1032	4040921.738	621033.944	317.756	NG
1033	4040990.742	626579.154	309.261	NG
1034	4041075.185	632160.857	316.197	NG
1036	4041304.350	643375.976	290.810	NG
1037	4041427.349	648857.170	296.559	NG
1038	4041562.864	654595.760	296.264	NG
1039	4041688.078	660216.697	298.588	NG

1041	4041914.625	671402.070	275.803	NG
1042	4041979.885	676153.304	263.884	NG
1043	4036519.568	676287.270	286.717	NG
1044	4036284.777	671534.057	282.192	NG
1046	4035234.483	659546.576	287.928	NG
1047	4036219.127	653967.941	280.746	NG
1048	4036221.118	647449.899	292.963	NG
1049	4036449.108	641649.100	311.440	NG
1051	4035451.670	631465.458	329.113	NG
1052	4035375.966	626666.254	342.358	NG
1053	4035299.907	620261.243	348.916	NG
1054	4035286.266	615482.766	360.597	NG
1056	4035154.176	604217.869	383.660	NG
1057	4029513.967	604296.789	374.771	NG
1058	4029572.797	609935.201	362.377	NG
1059	4029627.909	615570.839	353.136	NG
1061	4029779.509	626758.954	346.779	NG
1062	4029869.048	632388.187	342.941	NG
1063	4029949.730	637975.697	341.414	NG
1064	4030092.288	643522.162	313.482	NG
1066	4030330.038	654799.334	292.758	NG
1067	4029128.851	660403.222	305.694	NG
1068	4029034.883	666885.153	315.746	NG
1069	4028720.464	673296.798	303.588	NG
1071	4023889.320	604364.051	356.099	NG
1072	4023946.417	610811.432	349.326	NG
1073	4024001.289	615641.109	360.416	NG
1074	4024103.094	622044.795	344.490	NG
1076	4024271.165	633296.418	331.367	NG
1077	4024342.387	638076.660	318.575	NG
1078	4024478.048	643363.219	324.099	NG
1079	4024592.601	649268.813	302.260	NG
1081	4023222.401	661262.401	285.111	NG
1082	4023326.450	666965.939	279.121	NG
1083	4023507.624	673402.891	288.229	NG
1084	4022715.724	678051.615	298.348	NG
1086	4017307.747	686356.215	302.093	NG
1087	4017983.361	680564.899	287.444	NG
1088	4017875.403	675149.847	283.930	NG
1089	4017761.609	669474.752	300.672	NG

1091	4017510.464	658333.235	314.356	NG
1092	4019788.441	652883.683	318.213	NG
1093	4018919.637	646933.443	322.280	NG
1094	4020416.968	641317.914	329.679	NG
1096	4020251.049	630090.243	345.150	NG
1097	4020135.195	624493.818	352.916	NG
1098	4020050.789	618905.509	358.601	NG
1099	4019987.832	612450.133	342.223	NG
1101	4014266.966	604508.163	334.807	NG
1102	4015119.374	610090.510	324.921	NG
1103	4014409.486	615760.085	340.392	NG
1104	4015285.678	621410.880	332.773	NG
1106	4015459.329	632589.228	365.561	NG
1107	4014712.582	638212.000	344.518	NG
1108	4014040.454	643815.967	346.809	NG
1109	4014135.846	649436.675	335.985	NG
1111	4011938.700	660632.249	321.317	NG
1112	4012870.795	666374.238	326.854	NG
1113	4012227.013	671826.394	289.949	NG
1114	4013098.049	677762.773	298.078	NG
1116	4012977.425	688597.570	301.070	NG
1117	4007745.783	689713.650	308.842	NG
1118	4006877.234	684160.373	310.692	NG
1119	4007685.864	678359.811	301.438	NG
1121	4006425.517	667178.622	310.072	NG
1122	4006330.292	660757.179	305.859	NG
1123	4007828.738	655348.910	348.427	NG
1124	4008475.027	649539.769	351.571	NG
1126	4009166.535	638361.508	368.218	NG
1127	4009063.937	632432.835	325.729	NG
1128	4008984.285	627095.441	330.316	NG
1129	4008956.208	621497.489	338.871	NG
1131	4008735.770	610211.719	315.836	NG
1132	4008680.720	604656.792	331.919	NG
1133	4002983.364	604694.237	331.224	NG
1134	4003901.847	610245.442	326.747	NG
1136	4004122.267	621522.020	325.991	NG
1137	4003575.603	627159.730	308.365	NG
1138	4004250.447	632009.331	341.113	NG
1139	4003532.604	638435.470	344.346	NG

1141	4004477.582	649632.545	336.405	NG
1142	4002197.485	654477.681	299.171	NG
1143	4003094.092	660818.088	301.625	NG
1144	4000910.279	667298.771	274.038	NG
1146	4001877.617	678561.490	279.863	NG
1147	4001978.986	684089.215	277.829	NG
1148	4002148.884	689779.963	267.765	NG
1149	3996702.652	689906.740	291.251	NG
1151	3996158.638	678649.316	259.953	NG
1152	3993675.898	672266.305	282.687	NG
1153	3995199.154	667424.255	294.572	NG
1154	3996552.782	660991.578	319.259	NG
1156	3996440.664	648873.309	346.065	NG
1157	4001231.138	646501.012	329.295	NG
1158	4001261.925	650102.781	313.133	NG
1159	3991731.683	654761.932	299.553	NG
1161	3991948.694	665915.447	302.212	NG
1162	3988821.955	670781.652	299.913	NG
1163	3988948.619	677171.955	276.786	NG
1164	3991499.355	681932.791	272.149	NG
1166	3986063.012	690030.318	268.575	NG
1167	3985893.305	684138.135	292.807	NG
1168	3985757.994	678810.405	272.178	NG

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

Project File: NRCS
Project Unit: Meter
Date: Tuesday: March 08: 2011
Vertical Accuracy Objective
Requirement Type: RMSE(z)
RMSE(z) Objective: 0.667
Control Points in Report: 134
Elevation Calculation Method: Interpolated from TIN
Control Points with LiDAR Coverage: 134
Average Control Error Reported: -0.004
Maximum (highest) Control Error Reported: 0.312
Median Control Error Reported: -0.023
Minimum (lowest) Control Error Reported: -0.234
Standard deviation (sigma) of Error for sample: 0.108
RMSE of Error for sample (RMSE(z)): 0.108: PASS
NSSDA Achievable Contour Interval: 0.4
ASPRS Class 1 Achievable Contour Interval: 0.4
NMAS Achievable Contour Interval: 0.4

Control	Control Pt.	Control Pt.	Coverage	Control Pt.	from LiDAR	**Z Error**	Min Z	Median Z	Max Z
Point Id	X(East)	Y(North)		Z(Elev)	Z(Elev)				
	Meters	Meters		Meters	Meters	**Meters**	Meters	Meters	Meters
1069	673296.798	4028720.464	Yes	303.588	303.354	**-0.234**	303.257	303.310	303.376
1119	678359.811	4007685.864	Yes	301.438	301.209	**-0.229**	301.171	301.176	301.230
1017	666511.291	4047445.328	Yes	308.663	308.484	**-0.179**	308.455	308.485	308.553
1128	627095.441	4008984.285	Yes	330.316	330.154	**-0.162**	330.084	330.181	330.191
1121	667178.622	4006425.517	Yes	310.072	309.914	**-0.158**	309.894	309.938	310.000
1117	689713.650	4007745.783	Yes	308.842	308.684	**-0.158**	308.677	308.678	308.704
1124	649539.769	4008475.027	Yes	351.571	351.422	**-0.149**	351.314	351.343	351.478
1011	659988.942	4052930.245	Yes	285.314	285.170	**-0.144**	285.127	285.169	285.289
1148	689779.963	4002148.884	Yes	267.765	267.622	**-0.143**	267.615	267.616	267.626
1137	627159.730	4003575.603	Yes	308.365	308.226	**-0.139**	308.162	308.266	308.326
1089	669474.752	4017761.609	Yes	300.672	300.533	**-0.139**	300.497	300.505	300.647
1014	676866.960	4053251.164	Yes	280.587	280.458	**-0.129**	280.454	280.463	280.469

1083	673402.891	4023507.624	Yes	288.229	288.116	**-0.113**	288.102	288.138	288.158
1114	677762.773	4013098.049	Yes	298.078	297.974	**-0.104**	297.953	297.966	298.091
1037	648857.170	4041427.349	Yes	296.559	296.459	**-0.100**	296.417	296.505	296.572
1103	615760.085	4014409.486	Yes	340.392	340.292	**-0.100**	340.269	340.301	340.317
1116	688597.570	4012977.425	Yes	301.070	300.975	**-0.095**	300.951	300.982	301.027
1062	632388.187	4029869.048	Yes	342.941	342.848	**-0.093**	342.823	342.858	342.868
1112	666374.238	4012870.795	Yes	326.854	326.763	**-0.091**	326.701	326.773	326.811
1138	632009.331	4004250.447	Yes	341.113	341.022	**-0.091**	340.962	341.032	341.040
1053	620261.243	4035299.907	Yes	348.916	348.827	**-0.089**	348.746	348.847	348.981
1044	671534.057	4036284.777	Yes	282.192	282.105	**-0.087**	282.091	282.104	282.106
1046	659546.576	4035234.483	Yes	287.928	287.843	**-0.085**	287.699	287.846	287.876
1006	631881.631	4052403.286	Yes	321.882	321.800	**-0.082**	321.772	321.795	321.862
1012	666055.502	4052234.980	Yes	298.056	297.975	**-0.081**	297.952	297.954	298.010
1086	686356.215	4017307.747	Yes	302.093	302.014	**-0.079**	301.986	302.007	302.059
1091	658333.235	4017510.464	Yes	314.356	314.278	**-0.078**	314.207	314.269	314.330
1088	675149.847	4017875.403	Yes	283.930	283.852	**-0.078**	283.815	283.836	283.912
1052	626666.254	4035375.966	Yes	342.358	342.282	**-0.076**	342.209	342.279	342.294
1073	615641.109	4024001.289	Yes	360.416	360.346	**-0.070**	360.244	360.351	360.353
1141	649632.545	4004477.582	Yes	336.405	336.337	**-0.068**	336.336	336.337	336.343
1013	672044.071	4053143.251	Yes	289.176	289.109	**-0.067**	289.103	289.127	289.138
1041	671402.070	4041914.625	Yes	275.803	275.738	**-0.065**	275.721	275.751	275.758
1087	680564.899	4017983.361	Yes	287.444	287.380	**-0.064**	287.252	287.428	287.430
1033	626579.154	4040990.742	Yes	309.261	309.198	**-0.063**	309.151	309.185	309.209
1096	630090.243	4020251.049	Yes	345.150	345.087	**-0.063**	345.041	345.094	345.103
1068	666885.153	4029034.883	Yes	315.746	315.683	**-0.063**	315.583	315.635	315.692
1094	641317.914	4020416.968	Yes	329.679	329.617	**-0.062**	329.582	329.616	329.639
1016	672092.477	4047532.165	Yes	306.819	306.758	**-0.061**	306.753	306.767	306.777
1008	643103.553	4052607.535	Yes	324.894	324.837	**-0.057**	324.773	324.861	324.922
1118	684160.373	4006877.234	Yes	310.692	310.636	**-0.056**	310.616	310.626	310.673
1084	678051.615	4022715.724	Yes	298.348	298.292	**-0.056**	298.167	298.311	298.313
1098	618905.509	4020050.789	Yes	358.601	358.545	**-0.056**	358.534	358.542	358.604
1143	660818.088	4003094.092	Yes	301.625	301.573	**-0.052**	301.533	301.588	301.593
1034	632160.857	4041075.185	Yes	316.197	316.147	**-0.050**	316.114	316.137	316.170
1126	638361.508	4009166.535	Yes	368.218	368.168	**-0.050**	368.156	368.158	368.171
1043	676287.270	4036519.568	Yes	286.717	286.668	**-0.049**	286.597	286.650	286.675
1061	626758.954	4029779.509	Yes	346.779	346.730	**-0.049**	346.672	346.735	346.749
1074	622044.795	4024103.094	Yes	344.490	344.448	**-0.042**	344.409	344.437	344.448
1092	652883.683	4019788.441	Yes	318.213	318.171	**-0.042**	318.149	318.185	318.206
1047	653967.941	4036219.127	Yes	280.746	280.707	**-0.039**	280.555	280.654	280.728
1127	632432.835	4009063.937	Yes	325.729	325.691	**-0.038**	325.598	325.644	325.767

1003	615012.009	4052142.722	Yes	329.494	329.457	**-0.037**	329.443	329.453	329.478
1024	626494.661	4046635.346	Yes	330.553	330.517	**-0.036**	330.466	330.513	330.534
1093	646933.443	4018919.637	Yes	322.280	322.244	**-0.036**	322.132	322.242	322.303
1029	604177.403	4040786.968	Yes	356.471	356.437	**-0.034**	356.404	356.441	356.442
1057	604296.789	4029513.967	Yes	374.771	374.737	**-0.034**	374.718	374.774	374.791
1147	684089.215	4001978.986	Yes	277.829	277.795	**-0.034**	277.723	277.783	277.828
1081	661262.401	4023222.401	Yes	285.111	285.078	**-0.033**	285.032	285.069	285.102
1019	653679.050	4047163.206	Yes	310.438	310.405	**-0.033**	310.402	310.406	310.437
1059	615570.839	4029627.909	Yes	353.136	353.104	**-0.032**	353.090	353.113	353.155
1106	632589.228	4015459.329	Yes	365.561	365.531	**-0.030**	365.527	365.530	365.547
1123	655348.910	4007828.738	Yes	348.427	348.397	**-0.030**	348.372	348.429	348.476
1139	638435.470	4003532.604	Yes	344.346	344.317	**-0.029**	344.259	344.310	344.335
1002	609366.800	4052063.814	Yes	327.902	327.874	**-0.028**	327.860	327.876	327.900
1071	604364.051	4023889.320	Yes	356.099	356.075	**-0.024**	355.944	356.010	356.117
1007	637505.824	4052500.958	Yes	301.159	301.136	**-0.023**	301.073	301.165	301.212
1042	676153.304	4041979.885	Yes	263.884	263.862	**-0.022**	263.830	263.848	263.884
1067	660403.222	4029128.851	Yes	305.694	305.673	**-0.021**	305.644	305.675	305.690
1063	637975.697	4029949.730	Yes	341.414	341.393	**-0.021**	341.351	341.370	341.411
1097	624493.818	4020135.195	Yes	352.916	352.896	**-0.020**	352.885	352.907	352.933
1082	666965.939	4023326.450	Yes	279.121	279.102	**-0.019**	279.091	279.103	279.112
1113	671826.394	4012227.013	Yes	289.949	289.930	**-0.019**	289.918	289.933	289.936
1054	615482.766	4035286.266	Yes	360.597	360.579	**-0.018**	360.564	360.610	360.628
1036	643375.976	4041304.350	Yes	290.810	290.794	**-0.016**	290.771	290.796	290.890
1039	660216.697	4041688.078	Yes	298.588	298.572	**-0.016**	298.531	298.547	298.592
1109	649436.675	4014135.846	Yes	335.985	335.973	**-0.012**	335.947	335.959	336.028
1157	646501.012	4001231.138	Yes	329.295	329.284	**-0.011**	329.259	329.265	329.302
1018	660086.320	4047316.645	Yes	303.723	303.713	**-0.010**	303.688	303.706	303.744
1064	643522.162	4030092.288	Yes	313.482	313.473	**-0.009**	313.447	313.466	313.488
1122	660757.179	4006330.292	Yes	305.859	305.852	**-0.007**	305.782	305.876	305.892
1028	604073.169	4046413.933	Yes	335.411	335.405	**-0.006**	335.379	335.406	335.410
1031	615410.939	4040870.708	Yes	334.666	334.662	**-0.004**	334.659	334.660	334.671
1026	615344.620	4046511.292	Yes	341.110	341.107	**-0.003**	341.084	341.089	341.126
1158	650102.781	4001261.925	Yes	313.133	313.130	**-0.003**	313.031	313.044	313.156
1099	612450.133	4019987.832	Yes	342.223	342.222	**-0.001**	342.216	342.219	342.236
1131	610211.719	4008735.770	Yes	315.836	315.836	**0.000**	315.823	315.842	315.857
1129	621497.489	4008956.208	Yes	338.871	338.872	**0.001**	338.862	338.871	338.957
1048	647449.899	4036221.118	Yes	292.963	292.964	**0.001**	292.933	292.959	293.017
1072	610811.432	4023946.417	Yes	349.326	349.329	**0.003**	349.307	349.313	349.340
1078	643363.219	4024478.048	Yes	324.099	324.102	**0.003**	323.986	324.019	324.117
1142	654477.681	4002197.485	Yes	299.171	299.175	**0.004**	299.150	299.174	299.194

1107	638212.000	4014712.582	Yes	344.518	344.522	**0.004**	344.489	344.528	344.543
1049	641649.100	4036449.108	Yes	311.440	311.447	**0.007**	311.290	311.392	311.481
1032	621033.944	4040921.738	Yes	317.756	317.763	**0.007**	317.675	317.775	317.797
1004	620546.203	4052223.219	Yes	318.098	318.106	**0.008**	318.085	318.120	318.123
1051	631465.458	4035451.670	Yes	329.113	329.123	**0.010**	329.115	329.127	329.161
1009	648755.830	4052710.347	Yes	297.308	297.318	**0.010**	297.309	297.356	297.356
1133	604694.237	4002983.364	Yes	331.224	331.242	**0.018**	331.215	331.257	331.316
1038	654595.760	4041562.864	Yes	296.264	296.285	**0.021**	296.242	296.274	296.300
1066	654799.334	4030330.038	Yes	292.758	292.779	**0.021**	292.681	292.772	292.803
1136	621522.020	4004122.267	Yes	325.991	326.016	**0.025**	326.005	326.010	326.103
1056	604217.869	4035154.176	Yes	383.660	383.687	**0.027**	383.621	383.684	383.716
1077	638076.660	4024342.387	Yes	318.575	318.607	**0.032**	318.582	318.603	318.609
1058	609935.201	4029572.797	Yes	362.377	362.414	**0.037**	362.401	362.416	362.437
1134	610245.442	4003901.847	Yes	326.747	326.787	**0.040**	326.694	326.787	326.818
1001	603759.609	4052007.488	Yes	325.723	325.766	**0.043**	325.734	325.774	325.778
1023	631242.604	4046681.496	Yes	323.879	323.928	**0.049**	323.887	323.931	323.950
1104	621410.880	4015285.678	Yes	332.773	332.823	**0.050**	332.787	332.813	332.865
1111	660632.249	4011938.700	Yes	321.317	321.369	**0.052**	321.353	321.394	321.401
1027	610076.047	4046331.926	Yes	349.267	349.324	**0.057**	349.273	349.310	349.352
1132	604656.792	4008680.720	Yes	331.919	331.978	**0.059**	331.959	331.975	332.021
1021	643260.608	4046713.718	Yes	312.519	312.583	**0.064**	312.517	312.569	312.649
1108	643815.967	4014040.454	Yes	346.809	346.890	**0.081**	346.811	346.874	346.897
1079	649268.813	4024592.601	Yes	302.260	302.344	**0.084**	302.336	302.349	302.463
1102	610090.510	4015119.374	Yes	324.921	325.014	**0.093**	324.969	325.001	325.028
1076	633296.418	4024271.165	Yes	331.367	331.464	**0.097**	331.447	331.484	331.490
1022	637679.902	4046807.706	Yes	312.350	312.451	**0.101**	312.422	312.427	312.457
1154	660991.578	3996552.782	Yes	319.259	319.412	**0.153**	319.385	319.417	319.503
1144	667298.771	4000910.279	Yes	274.038	274.238	**0.200**	274.172	274.193	274.338
1149	689906.740	3996702.652	Yes	291.251	291.458	**0.207**	291.437	291.489	291.717
1167	684138.135	3985893.305	Yes	292.807	293.024	**0.217**	292.973	293.026	293.133
1162	670781.652	3988821.955	Yes	299.913	300.136	**0.223**	300.126	300.131	300.189
1153	667424.255	3995199.154	Yes	294.572	294.797	**0.225**	294.735	294.803	294.837
1152	672266.305	3993675.898	Yes	282.687	282.916	**0.229**	282.827	282.911	282.966
1151	678649.316	3996158.638	Yes	259.953	260.186	**0.233**	260.170	260.178	260.189
1156	648873.309	3996440.664	Yes	346.065	346.303	**0.238**	346.256	346.313	346.323
1161	665915.447	3991948.694	Yes	302.212	302.457	**0.245**	302.451	302.461	302.487
1159	654761.932	3991731.683	Yes	299.553	299.798	**0.245**	299.757	299.784	299.862
1164	681932.791	3991499.355	Yes	272.149	272.401	**0.252**	272.355	272.389	272.468
1146	678561.490	4001877.617	Yes	279.863	280.119	**0.256**	280.026	280.108	280.159
1163	677171.955	3988948.619	Yes	276.786	277.057	**0.271**	277.028	277.044	277.104

1101	604508.163	4014266.966	Yes	334.807	335.111	**0.304**	335.086	335.120	335.168
1168	678810.405	3985757.994	Yes	272.178	272.490	**0.312**	272.488	272.492	272.534

LiDAR CALIBRATION

Note: All figures represented on the following pages are for general illustration purposes, and are not examples derived from actual NRCS Oklahoma 2010 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.

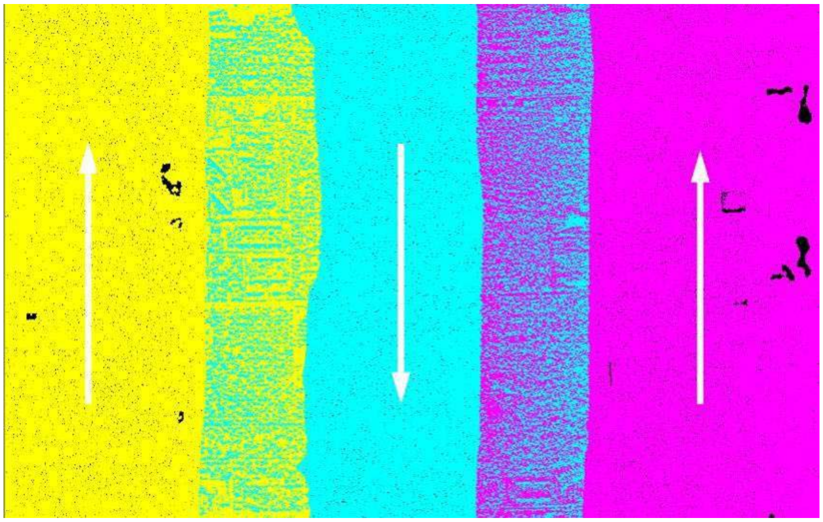


Figure 1: Flight pattern required for calibration

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.

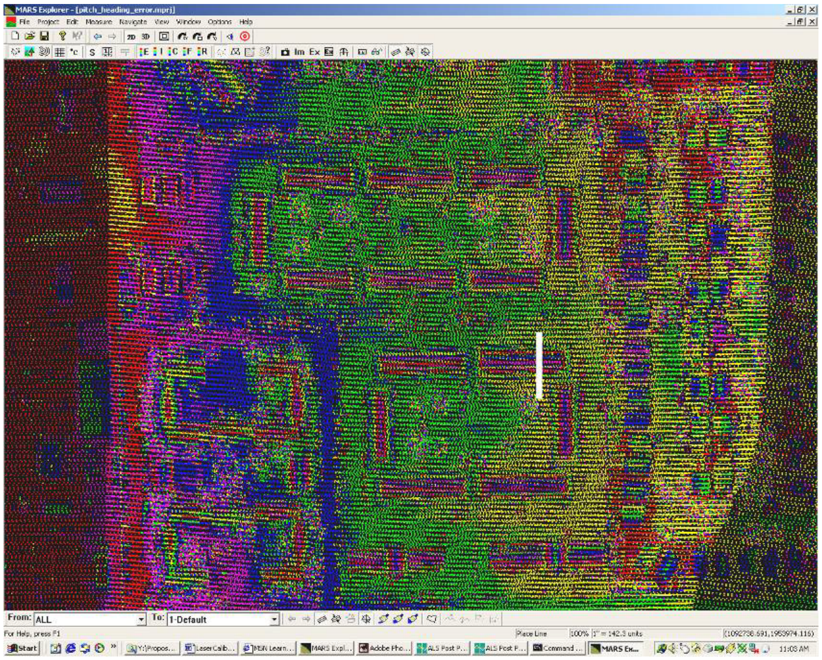


Figure 2: Orthographic view with profile line

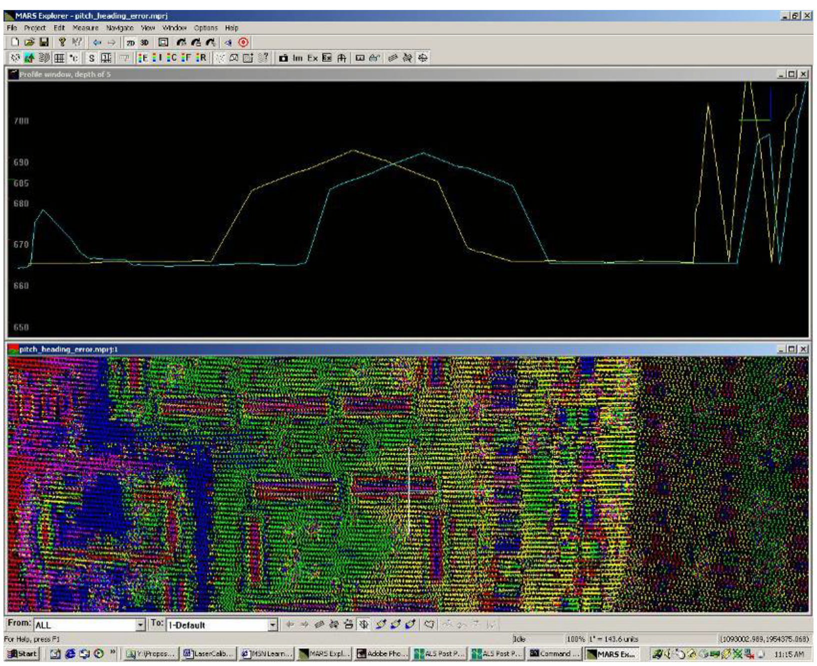


Figure 3: Profile view of misalignment

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).

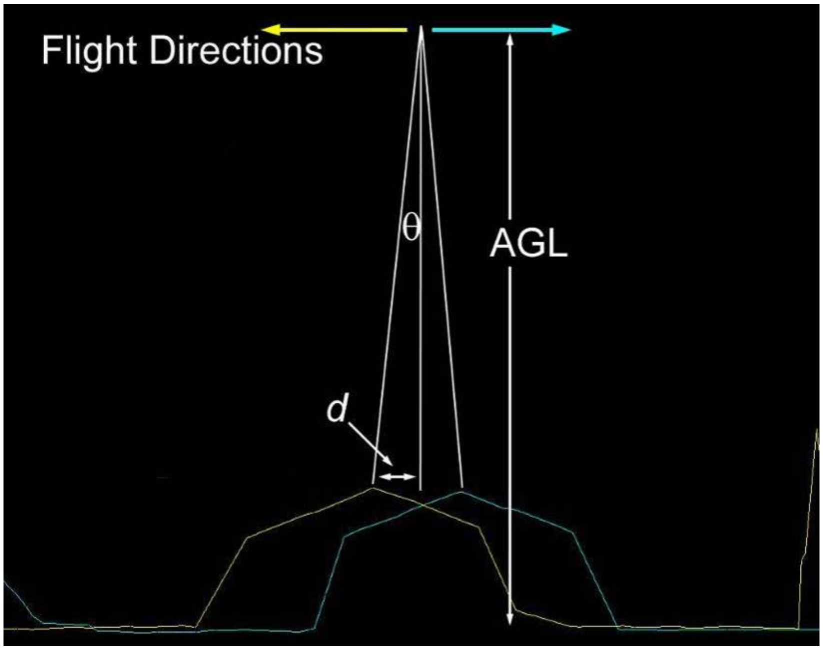


Figure 4: Adjusting pitch

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

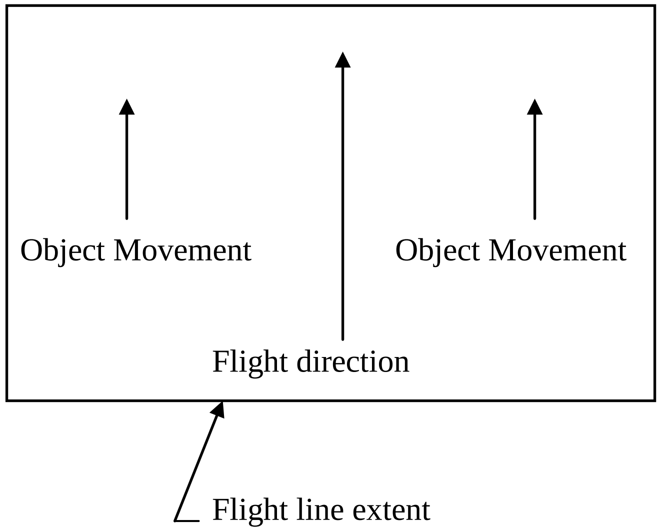
$$\theta = \frac{\arctan\left(\frac{d}{AGL}\right)}{57.2958}$$

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.

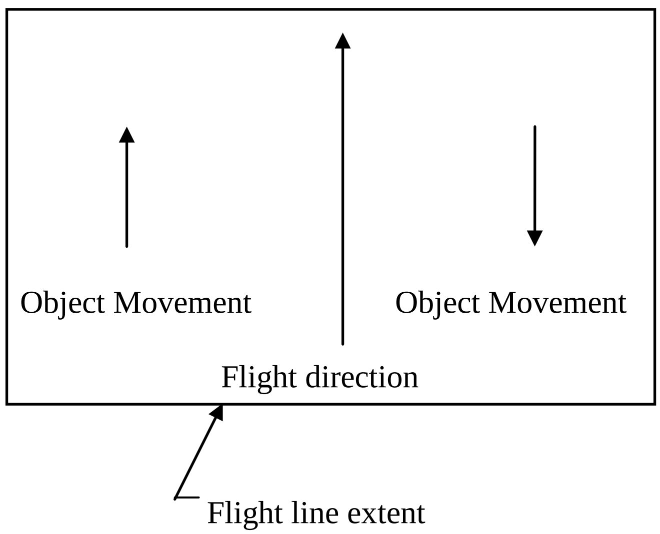
The next issue to resolve, before actually changing the pitch value, is to determine if this shift is at all due to an incorrect heading value, since heading will move data in the direction of flight also. The difference is that heading rotates the data, meaning that when heading is changed, objects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

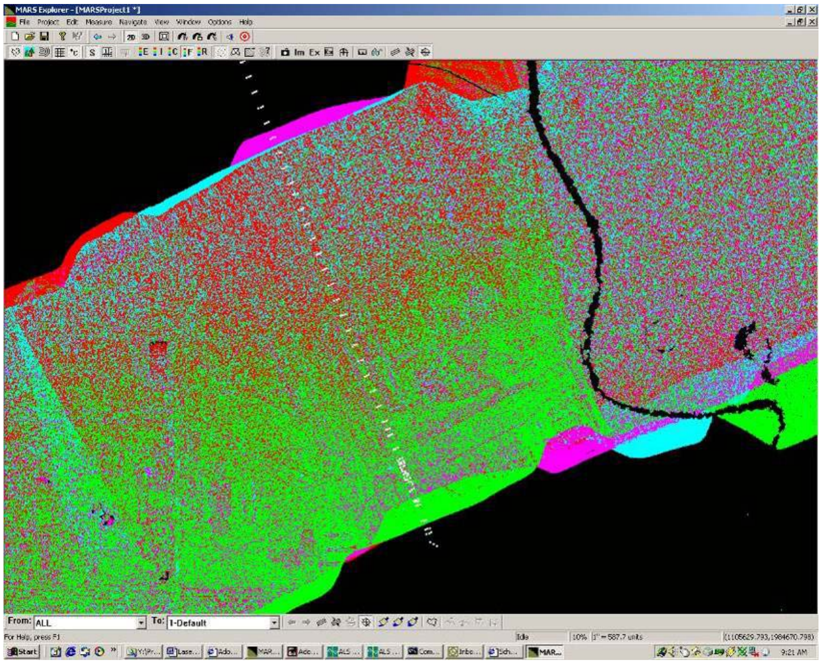


Figure 7: The truth survey

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)

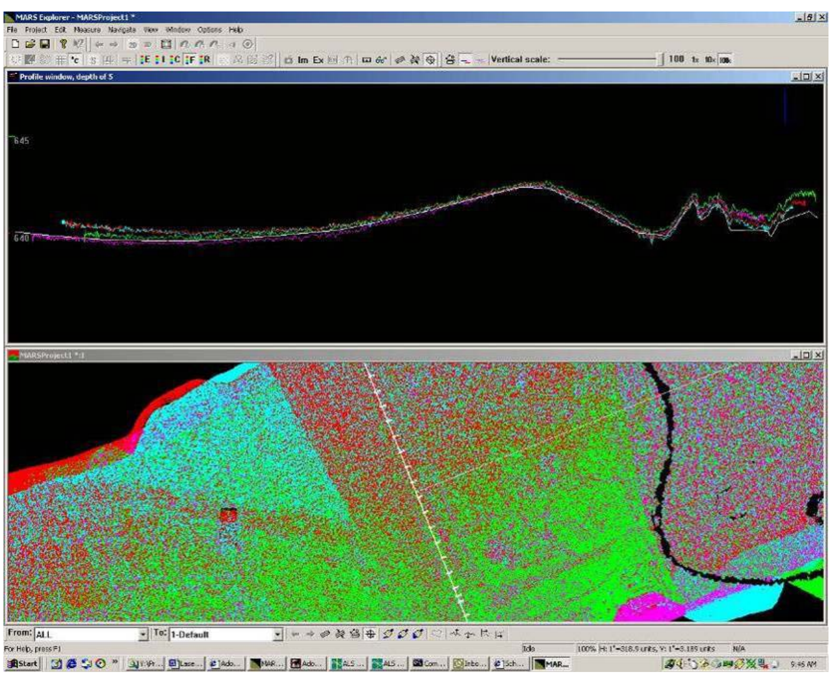


Figure 8: Profile view of calibration flight lines

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)

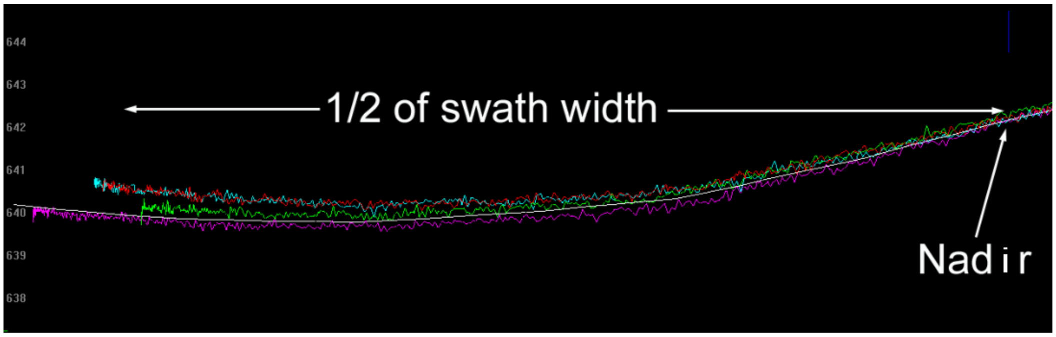


Figure 9: Half of calibration profile

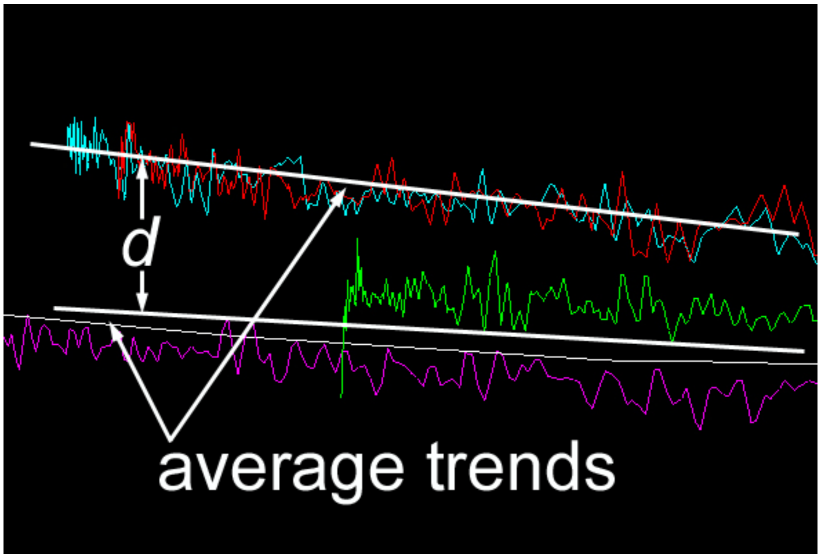


Figure 10: Differences in average roll trends

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 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 following this is a height-above-surface (+/-2’) auto-filter is run to re-class noise to Class 7.

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 ELEVATION MODEL (DEM)

Raster Grid Development

Merrick exports the Class 2 (ground) LiDAR point to an one-meter (1m) cell size ESRI floatgrid (.flt) using MARS®. These floatgrids are formatted to the project tiling scheme. Using the ArcInfo Workstation floatgrid command, the floatgrids are imported and converted to ESRI raster grids (1m resolution). The result is a seamless (tile edge to tile edge) DEM in ArcGrid (i.e., ESRI grid) floating point format. Projection information is applied that reflects the classified LAS / project requirements