Illinois Department of Transportation (IDOT)
PTB 156-059
LiDAR Mapping Report
2nd Edition

Pulaski, Massac & part of Johnson Counties

Prepared for (originally- circa March 2012):

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Merrick & Company Job Numbers: 65217216 and 65218069

EXECUTIVE SUMMARY

Merrick & Company (Merrick) was contracted by Illinois Department of Transportation (IDOT) to perform a LiDAR (**Li**ght **D**etection **A**nd **R**anging) survey for approximately 738 square miles located in and around Pulaski, Massac & part of Johnson Counties, Illinois. The main emphasis of the services required is the collection of LiDAR data to support the future generation of a high resolution Digital Terrain Model (DTM) that will be used as base data for regional hydrologic modeling projects and for engineering location studies. The Nominal Point Spacing (NPS) of the LiDAR point cloud was planned to meet one-meter (1m) or less. The LiDAR Fundamental Vertical Accuracy (FVA) will meet or exceed 12.5cm (0.41') $RMSE_Z$ ($Accuracy_Z$ = 24.5cm (0.80') at the 95% confidence level), and assumes well defined open terrain. The Consolidated Vertical Accuracy (CVA) will meet or exceed 18.5cm (0.61') $RMSE_Z$ ($Accuracy_Z$ = 36.3cm (1.19') at the 95% confidence level).

Please note that IDOT provided the LiDAR checkpoint survey. The focus of said survey was xx. No land cover classification checkpoints were surveyed; therefore, neither CVA or SVA (Supplemental Vertical Accuracy) results were not tested for.

The (original) 1st Edition of this report was submitted on March 16, 2012 to IDOT, and reflected the results of the LiDAR acquisition through boresight activities (i.e., pre-classification). The (current) 2nd Edition has been expanded to reflect the results post-classification, and is being submitted to Quantum Spatial (fka AeroMetric).

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 the IDOT project.

LiDAR FLIGHT and SYSTEM REPORT

Project Location

The location for the IDOT project site is defined by shapefile *PTB_156-059_revised110317* further derived from the client-provided shapefiles *D9_3county* and *FEMA_bdy*.

Duration/Time Period

One LiDAR aircraft, a Cessna 402C (tail number N274MR), was used to collect LiDAR data. LiDAR data was collection on February 2, 2012 thru February 17, 2012; the airport of operation was the Barkley Regional Airport (PAH), located west of Paducah City, KY.

Mission Parameters for Cessna 402C (SN62) flown at Altitude 7,500 Feet

LiDAR Sensor	**Leica Geosystems ALS50 Phase 2+**
Nominal Ground Sample Distance	0.97 meters
Field of View (scan angle)	30 deg.
Average Ground Speed	170 Knots
Laser Pulse Rate	105,900 Hertz
Scan Rate	40.5 Hz
Average Altitude (MSL)	7,500 Feet

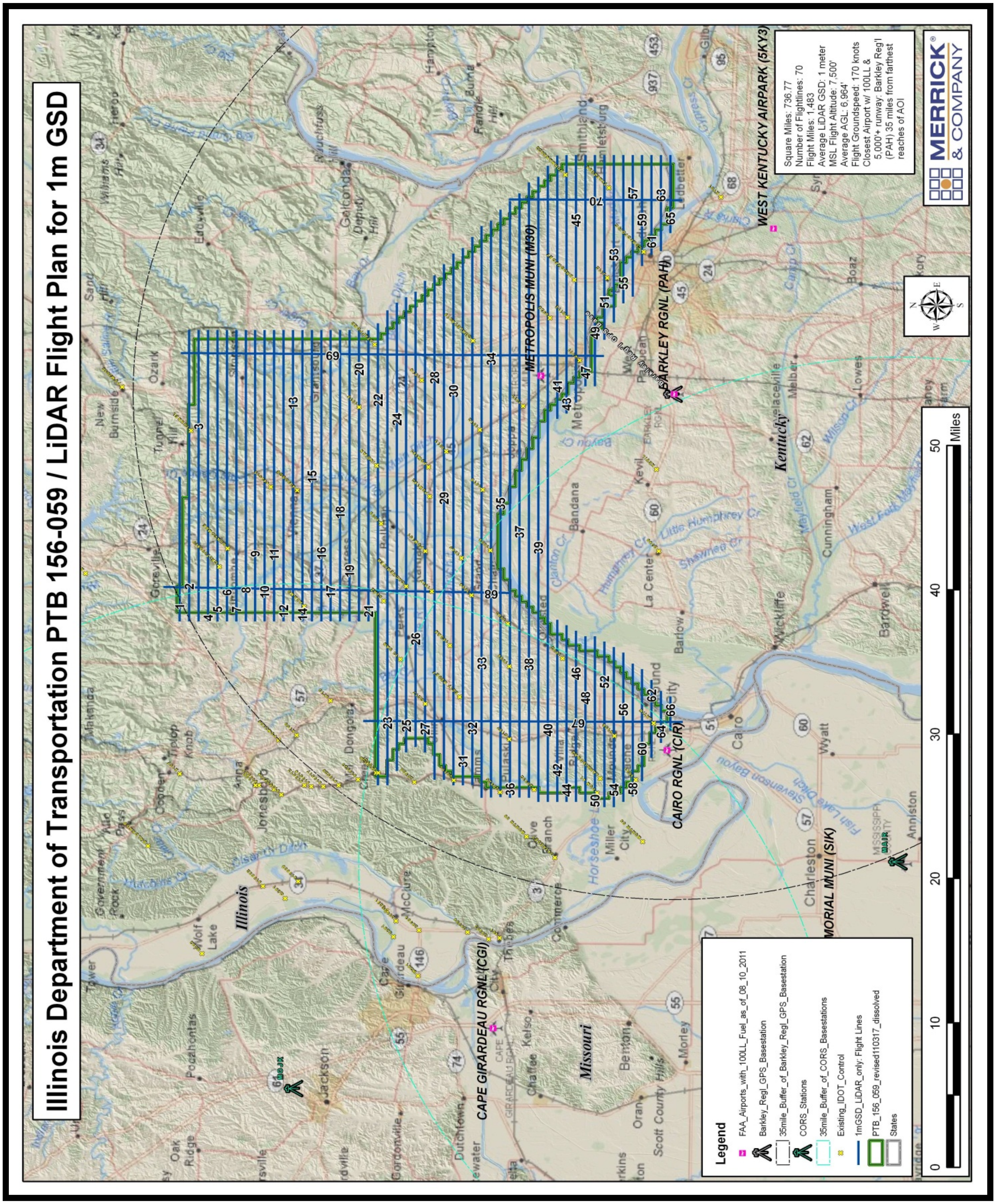
Flight mission Date and Times

Mission	**Date**	**Plane System**	**Start Time GPS sec.**	**End Time GPS sec.**	**Length Time GPS sec.**	**Number of GNSS Solution Records**
120202_A	February 02, 2012	SN62	431200.0	447565.0	16365.0	32730.0
120203_A	February 03, 2012	SN62	488046.5	497571.0	9524.5	19049.0
120206_A	February 06, 2012	SN62	171112.5	189501.5	18389.0	36778.0
120207_A	February 07, 2012	SN62	230156.5	242513.5	12357.0	24714.0
120212_A	February 12, 2012	SN62	55501.0	64440.0	8939.0	17878.0
120217_A	February 17, 2012	SN62	487471.0	490212.0	2741.0	5482.0

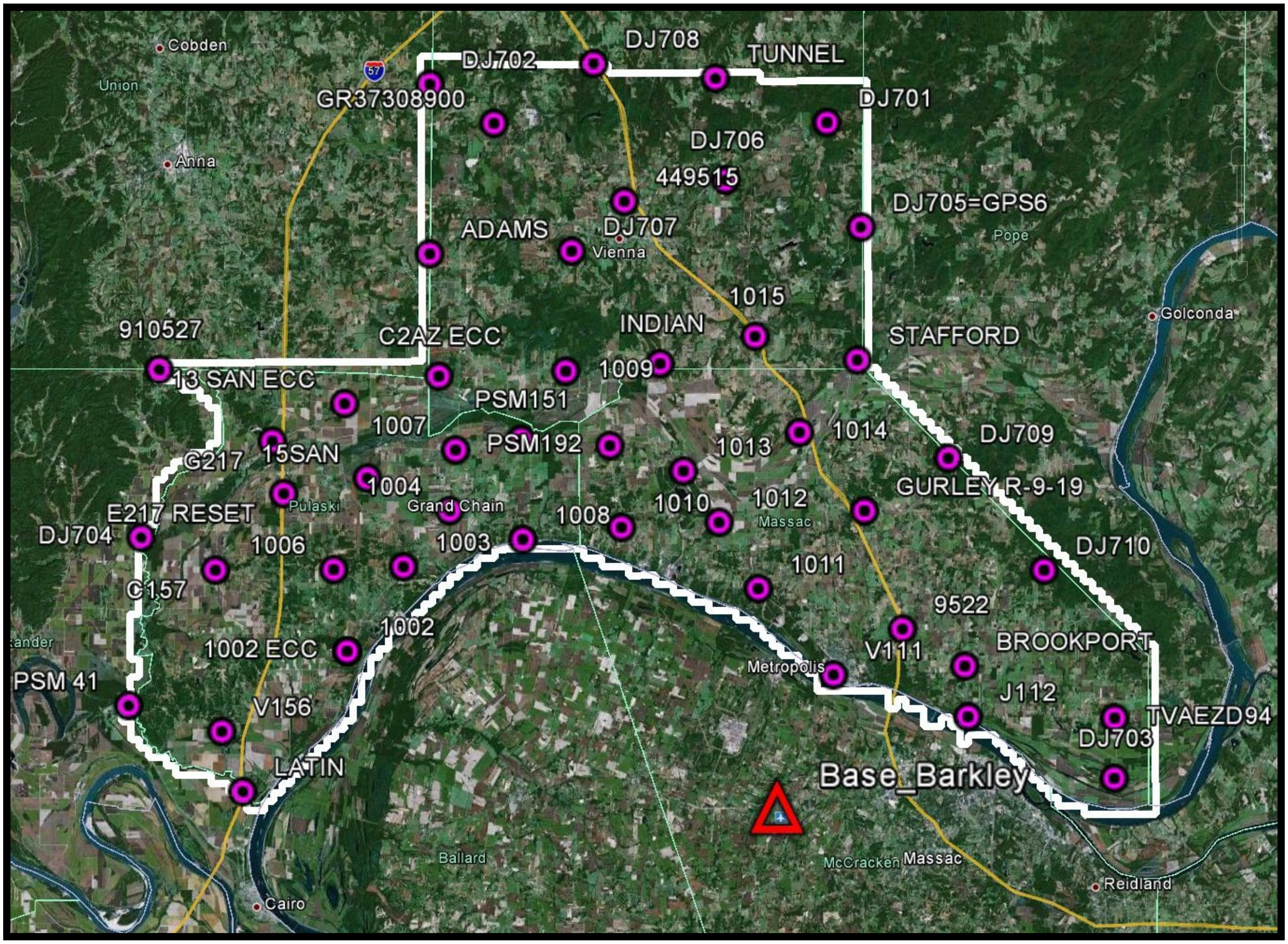
Field Work / Procedures

A ground GPS Base Station (Base_Barkley), for the LiDAR data collection, was set up at the airport of operation every day. 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 Station. 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 Station 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



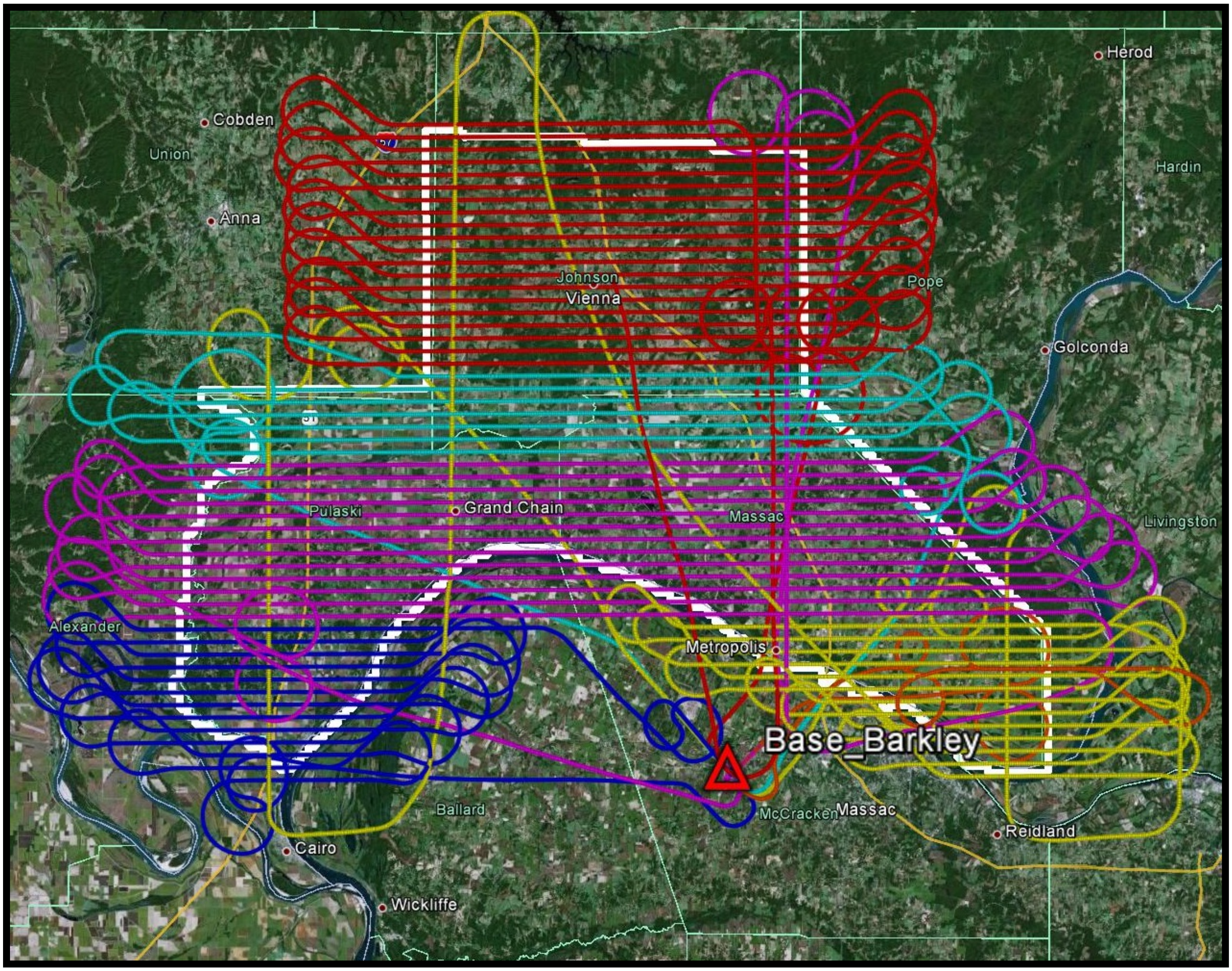
Ground Control Points and Base Station Location



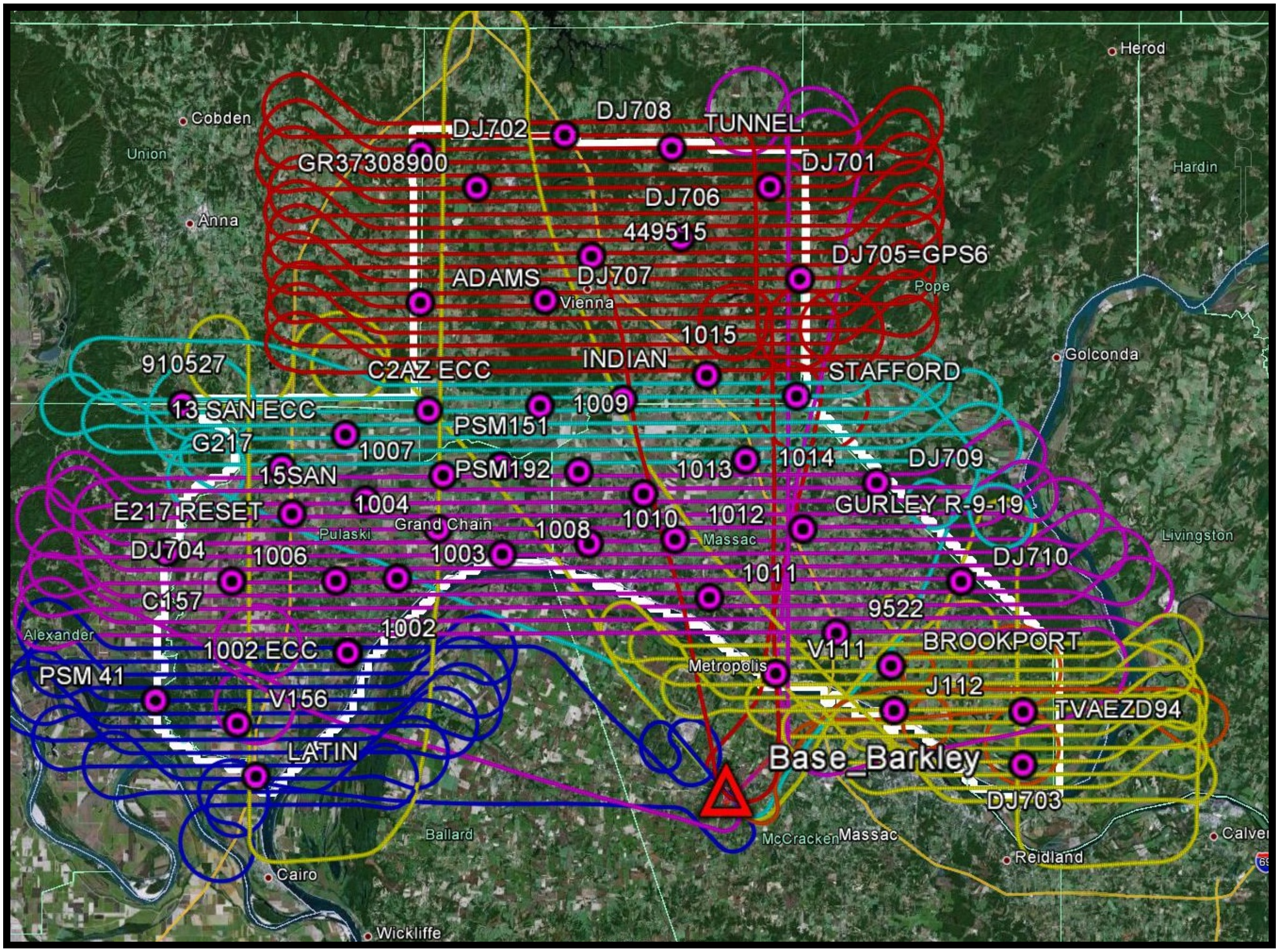
Base Station Location

Actual Flight Lines Shown Mission by Mission and Base Station Location

Mission	Date	Color	Mission	Date	Color
120202_A	February 02, 2012	**Red**	120207_A	February 07, 2012	**Yellow**
120203_A	February 03, 2012	**Cyan**	120212_A	February 12, 2012	**Blue**
120206_A	February 06, 2012	**Magenta**	120217_A	February 17, 2012	**Orange**

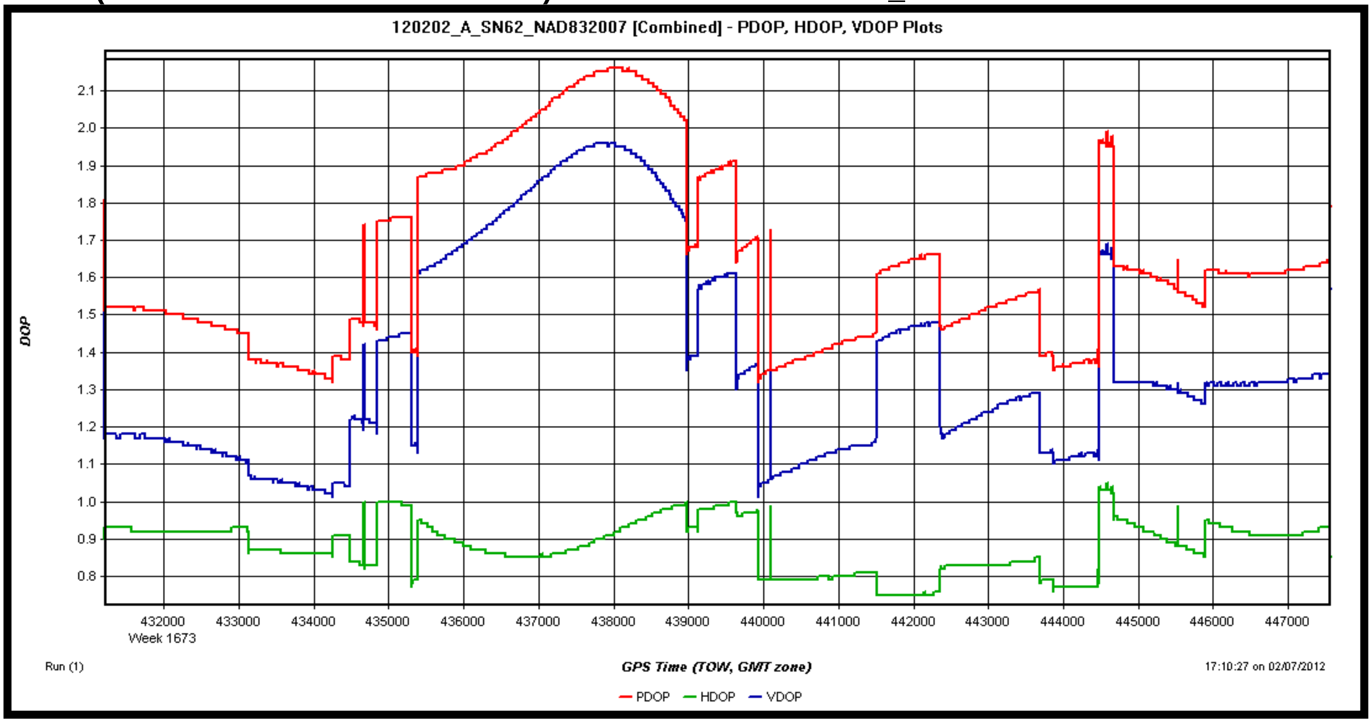


Actual Flight Lines Showing Base Station Location and LiDAR Ground Control

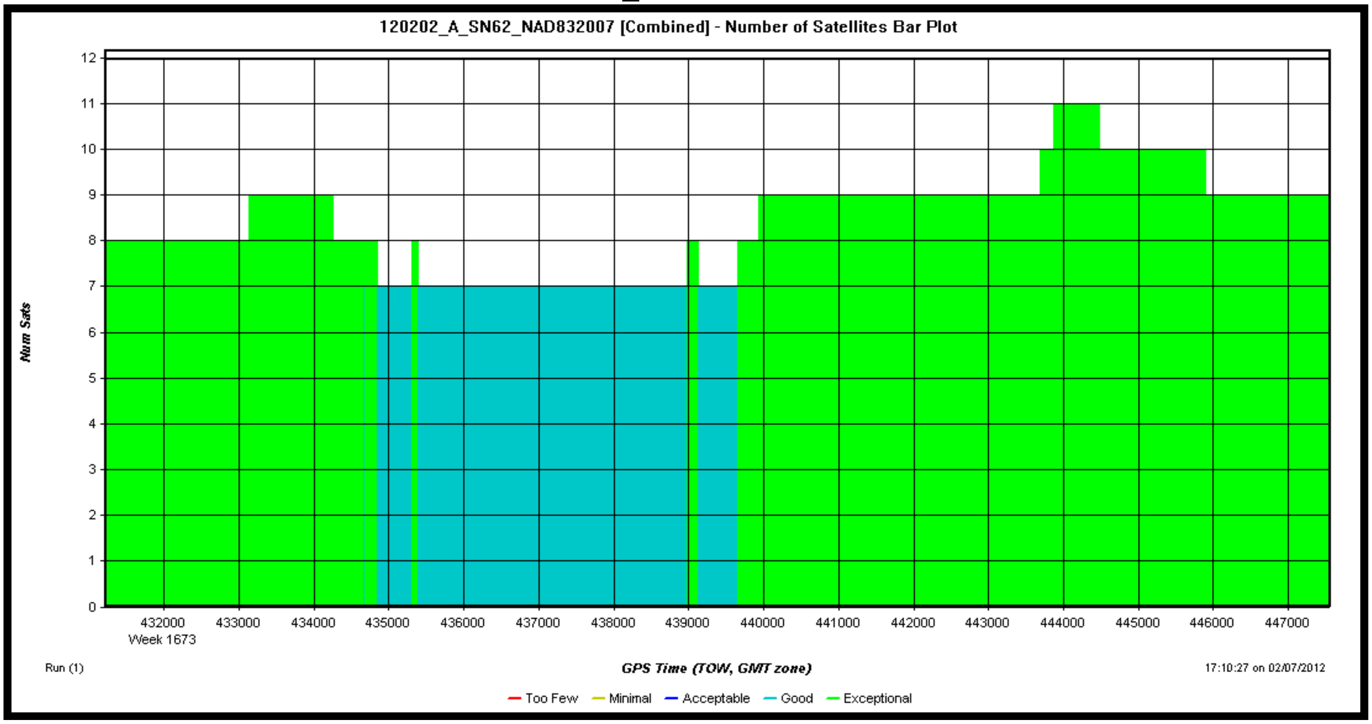


The following graphs show the GPS PDOP (Positional Dilution Of Precision) Plot and Number of Satellites Plot.

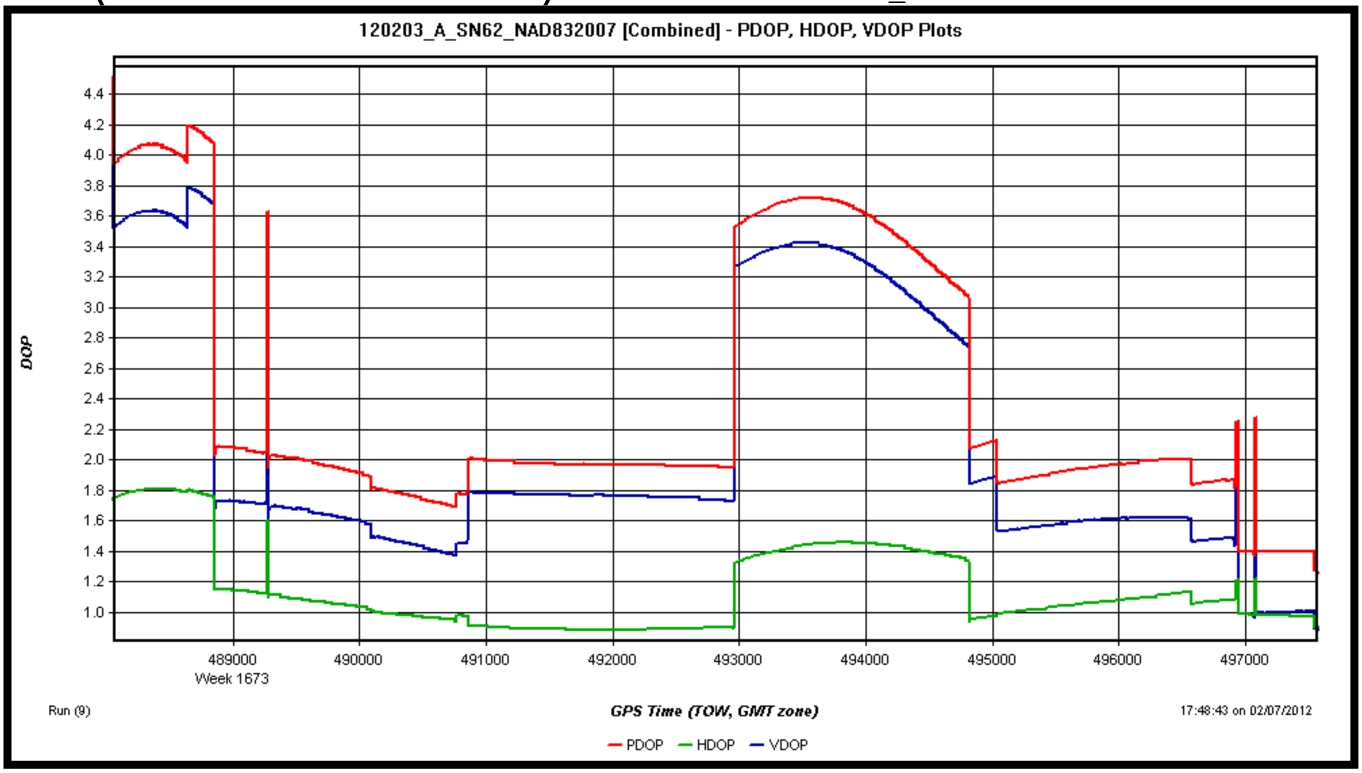
PDOP (Positional Dilution Of Precision) Plot for mission 120202_A



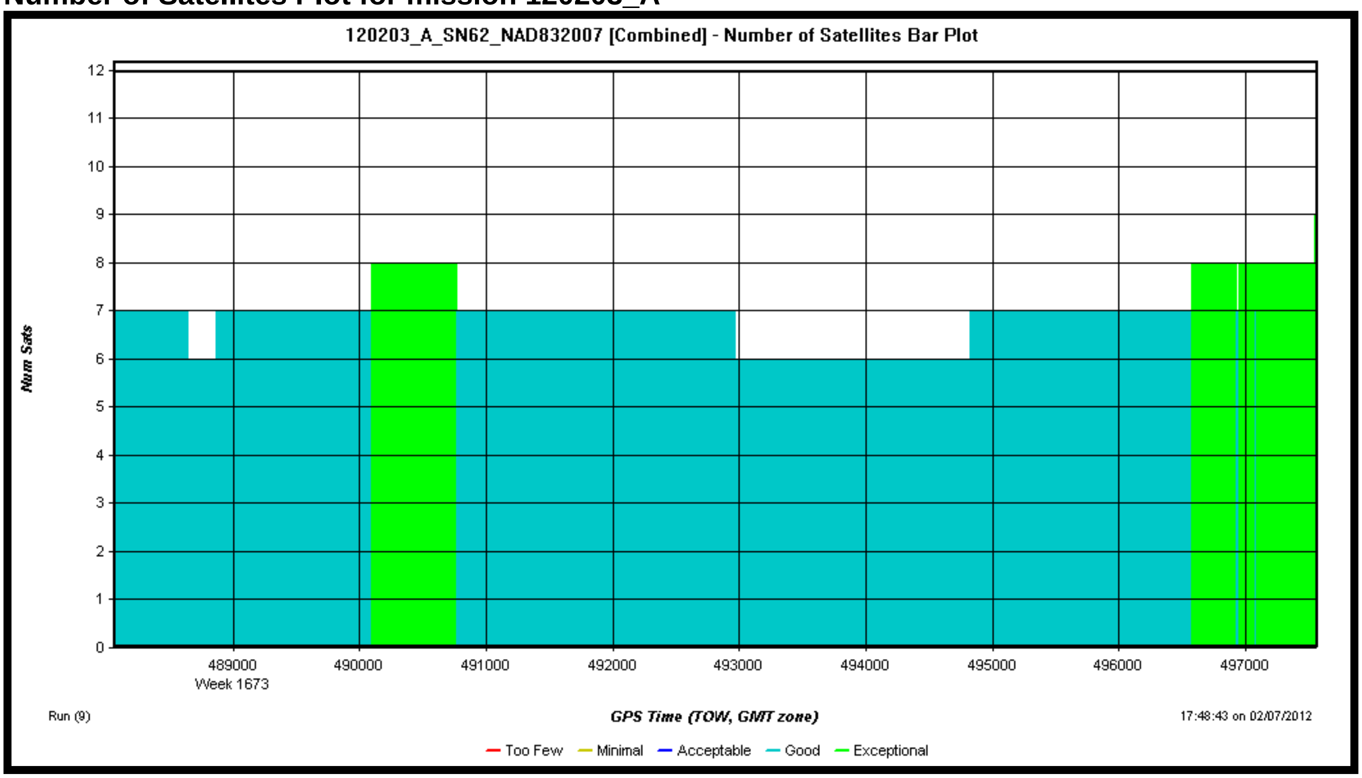
Number of Satellites Plot for mission 120202_A



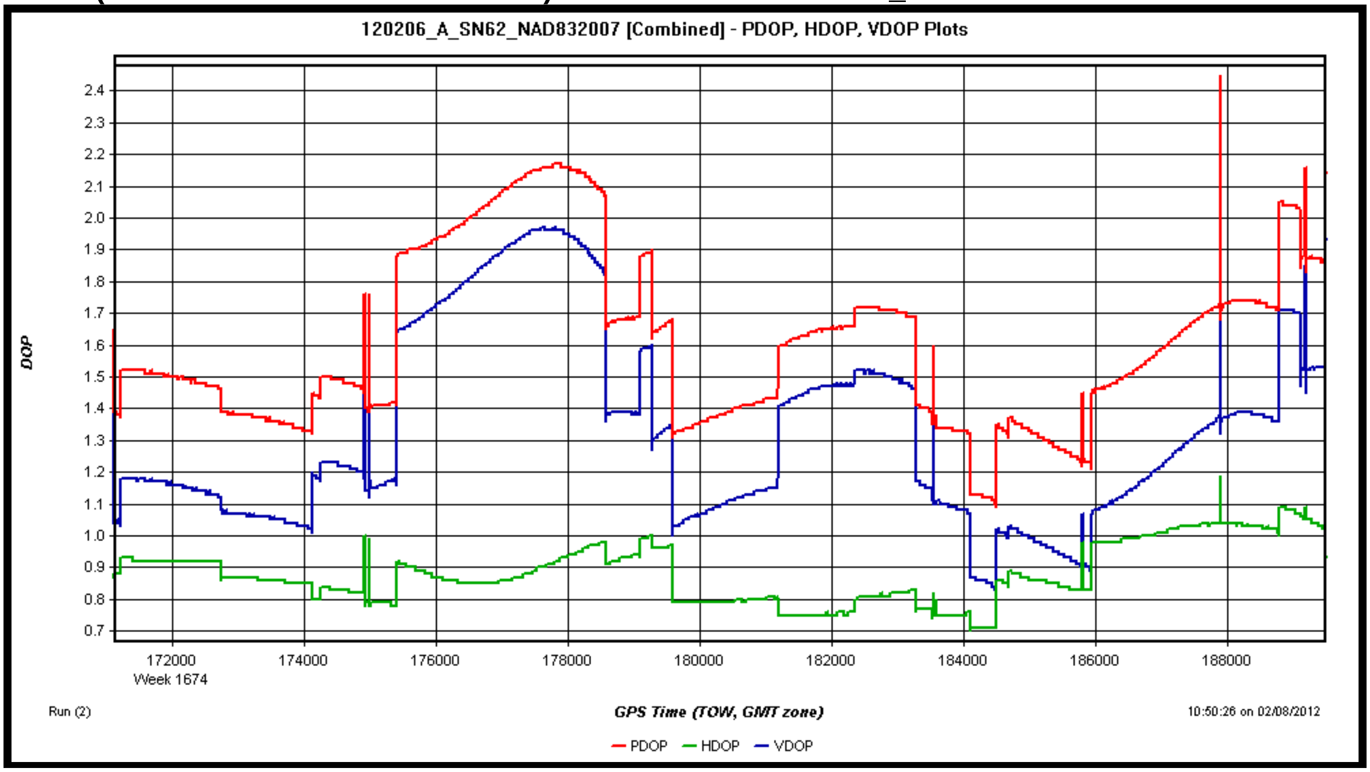
PDOP (Positional Dilution Of Precision) Plot for mission 120203_A



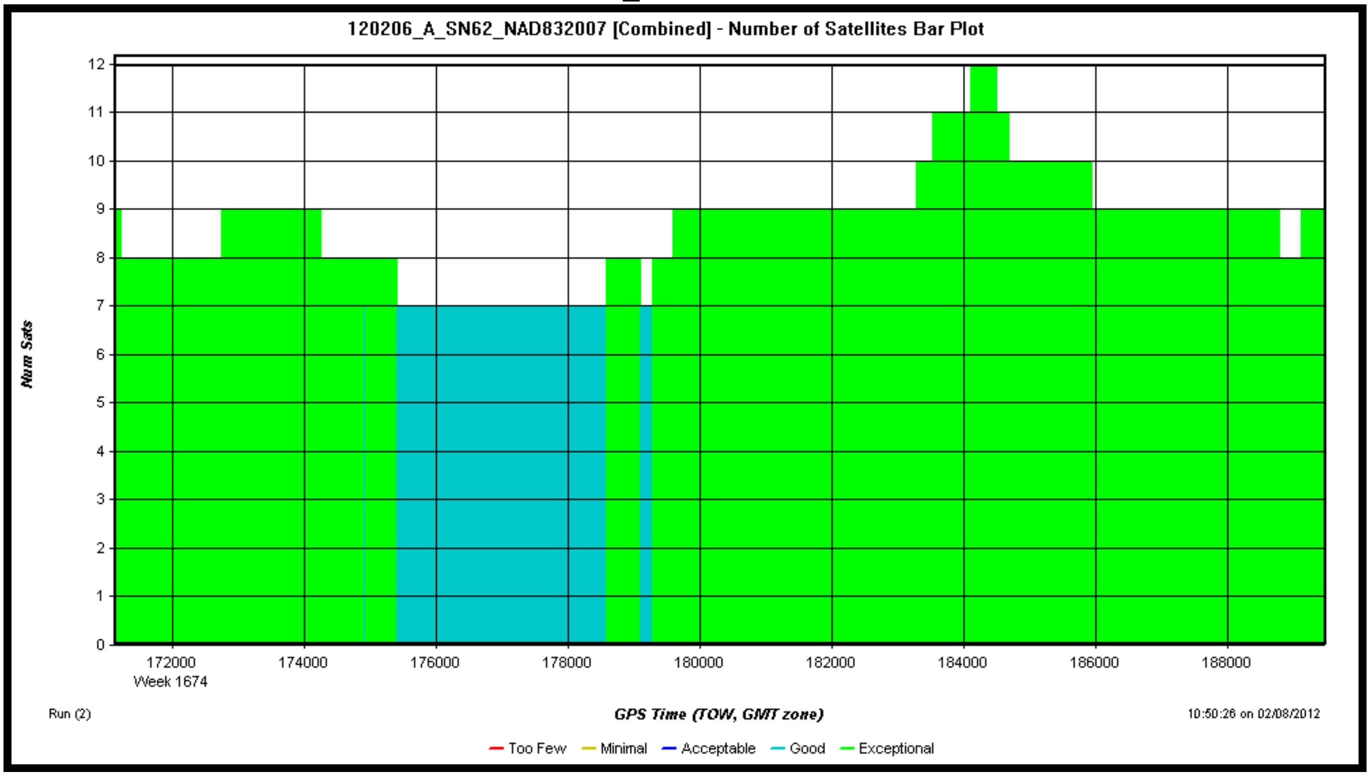
Number of Satellites Plot for mission 120203_A



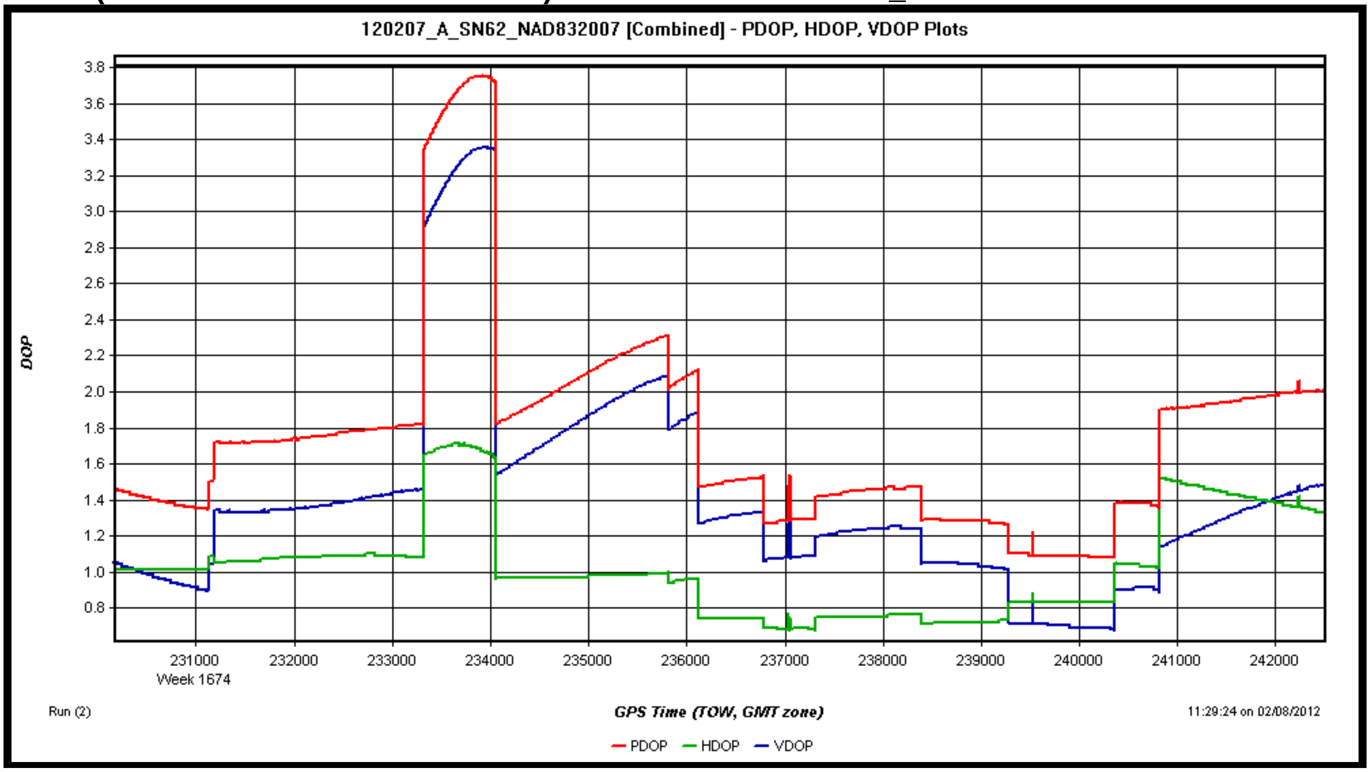
PDOP (Positional Dilution Of Precision) Plot for mission 120206_A



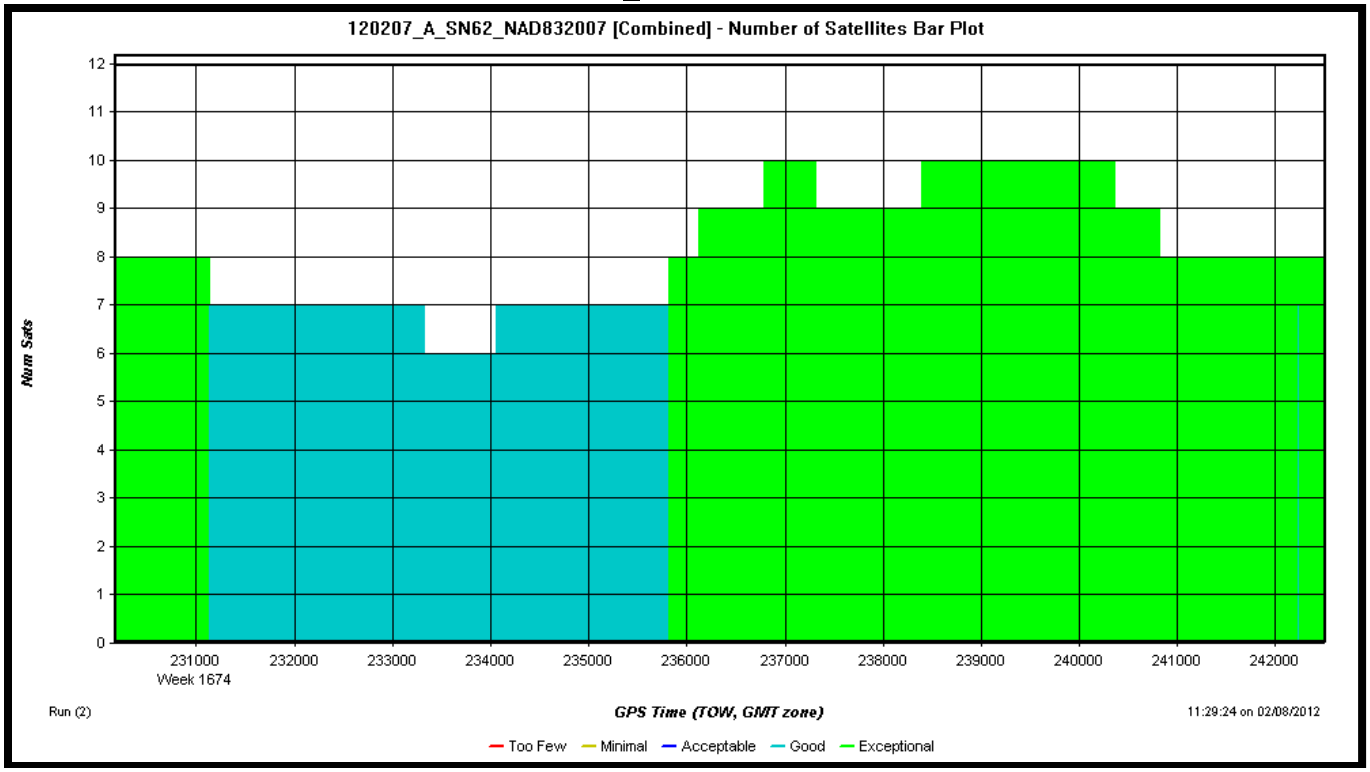
Number of Satellites Plot for mission 120206_A



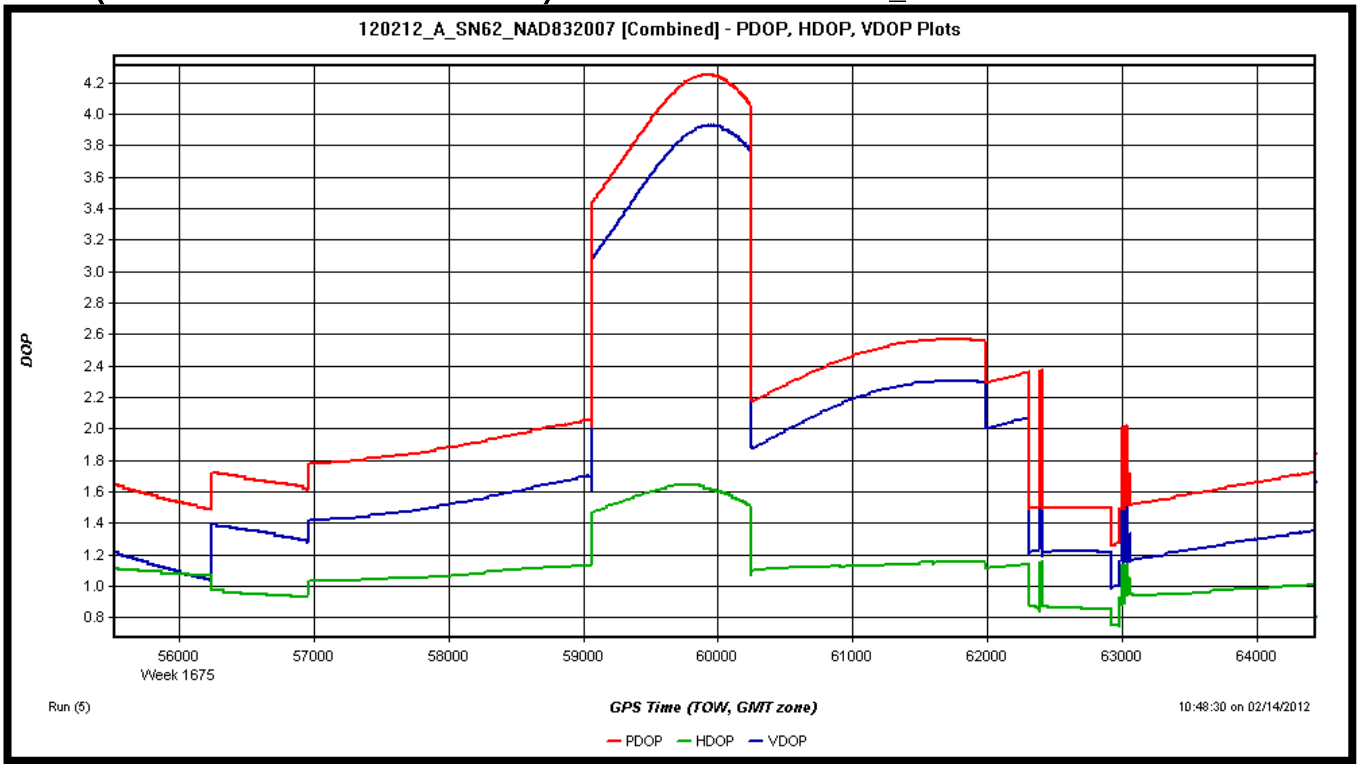
PDOP (Positional Dilution Of Precision) Plot for mission 120207_A



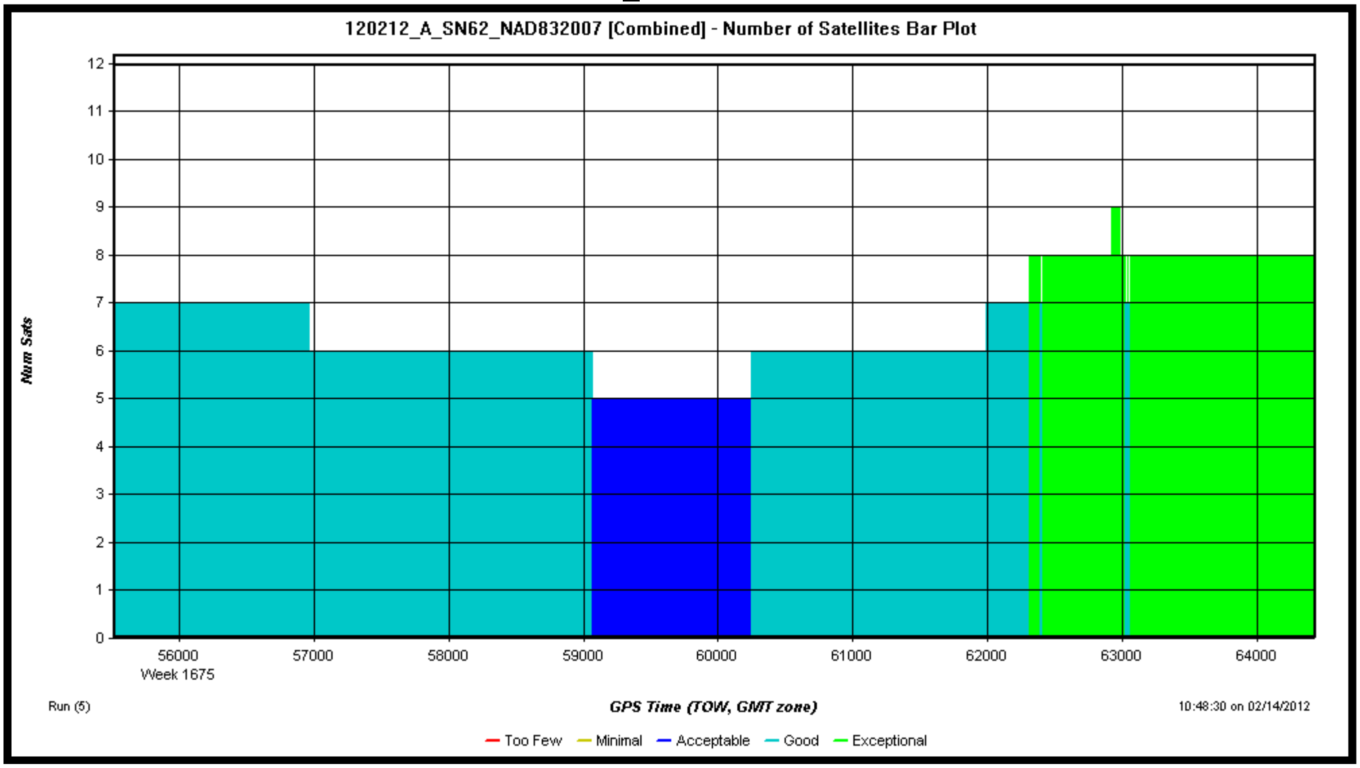
Number of Satellites Plot for mission 120207_A



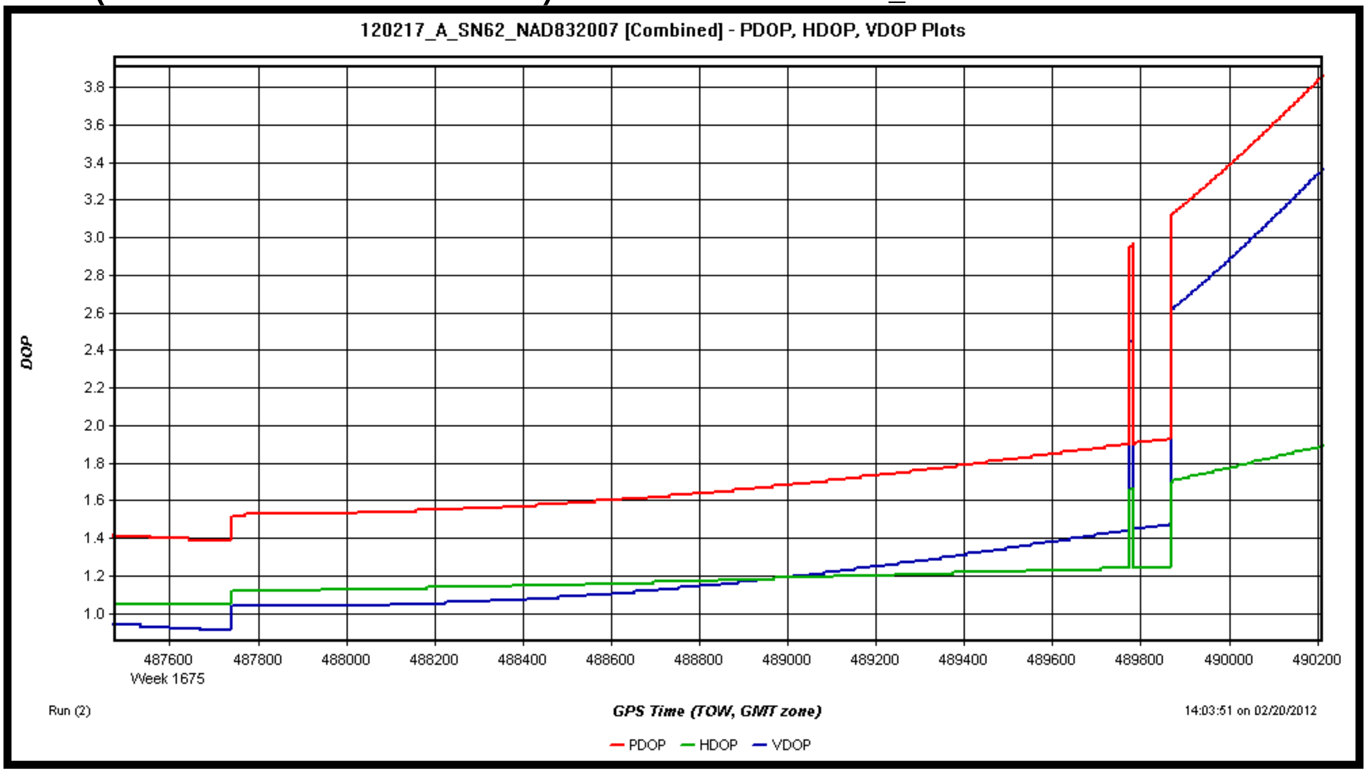
PDOP (Positional Dilution Of Precision) Plot for mission 120212_A



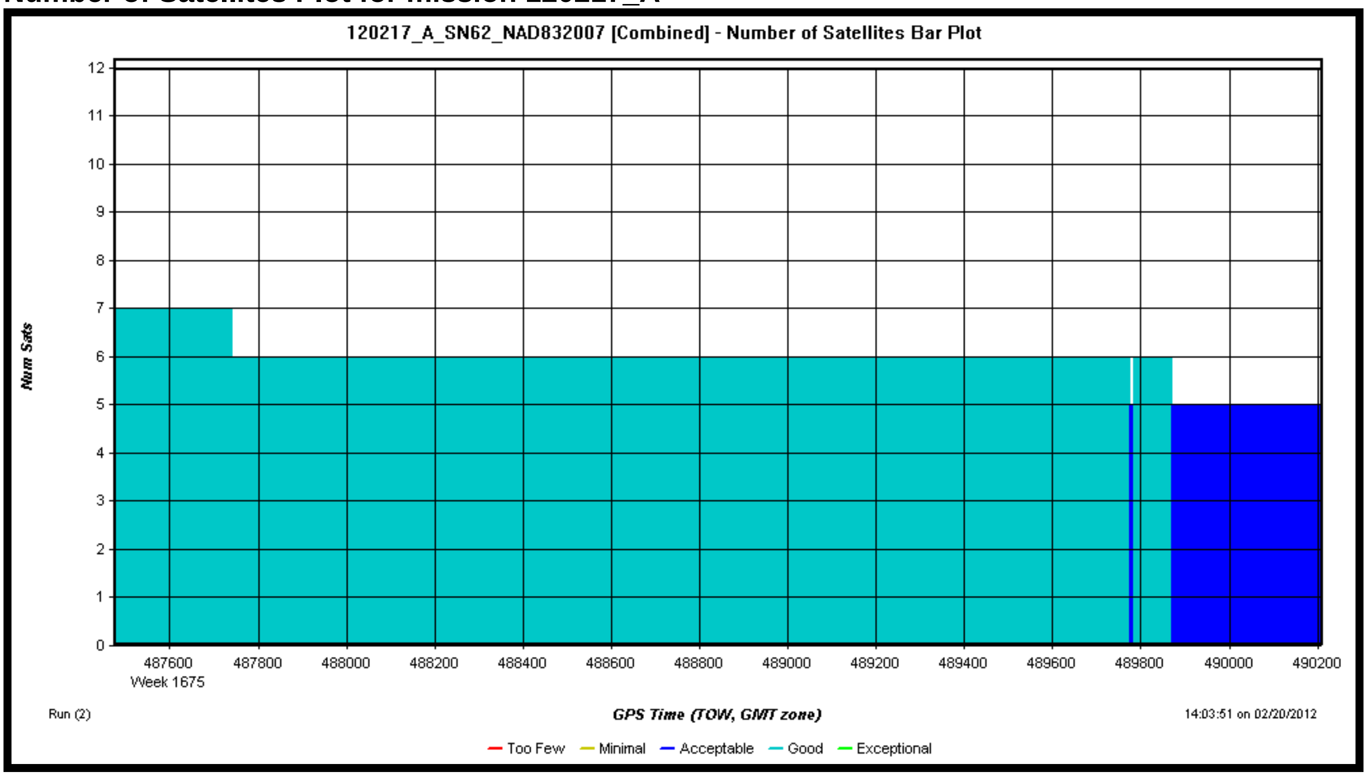
Number of Satellites Plot for mission 120212_A



PDOP (Positional Dilution Of Precision) Plot for mission 120217_A



Number of Satellites Plot for mission 120217_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.

Nominal Pulse Spacing (NPS) and Point Density Results

The following table illustrates the actual NPS / LiDAR density vs. the targeted requirements of 1m NPS based on first-return LiDAR points in the tiled LAS data (as reported in Part 1.4 of the *65218069 AeroMetric - IDOT PTB 156-059 Detailed LiDAR QA/QC Report* provided under separate cover):

Average NPS (m)	Average Density (ppsm)
1.05	0.91

The significant amount of standing water – especially in the southern portion of the project area – negatively impacted the density results. This coupled with partially filled tiles all along the project boundary further skews these results suggesting NPS was achieved when using the more accurate and realistic method of testing the boresighted LiDAR swath / point cloud.

GPS Controls

A ground GPS Base Station (Base_Barkley) was set up and observed daily at the airport of operation.

Project: IDOT
Job#: 65217216
Date: Feb. 2012

Coordinate System: Illinois State Plane
Zone: Illinois East and Illinois West
Horizontal Datum: NAD83(2007)
Vertical Datum(Geoid):NAVD 88 (Geoid 09)
Units: US Feet

Pt#	NAD83(2007)	NAD83(2007)	Ellipsoid	Code	Desc
Name	Latitude	Longitude	Height		
	North	West	Geoid(09)		
	Deg Min Sec	Deg Min Sec	US FEET		
Base_Barkley	37°04’02.09740”N	88°46’33.43350”W	298.20	Monument Set	Barkley Airport

Pt#	Ill. State Plane East Zone	Ill. State Plane East Zone	NAVD 88	Code	Desc
Name	Northing	Easting	Elevation		
	Y	X	Z		
	US FEET	US FEET	US FEET		
Base_Barkley	146145.540	855107.270	391.33	Monument Set	Barkley Airport

Ground Control Parameters

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 adjusted using the National Spatial Reference System of 2007 (NAD 83 / NSRS 2007).
Coordinate System: Illinois State Plane East Zone (and West Zone).
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD 88)
Geoid Model: GEOID09 (GEOID09 was used to convert ellipsoid heights to orthometric heights).
Units: Horizontal units are in US Survey Foot, Vertical units are in US Survey Foot.

GROUND CONTROL SURVEY AND CONTROL REPORT

Ground Control Survey: Illinois East Zone Values

The following listing shows the established GPS Ground Control points, collected for the LiDAR checkpoints. The ground control points were established and surveyed by IDOT surveyors.
Note: Points in **Red Font** were duplicate points and not used as ground control points.
Point (13 SAN ECC) replaced Point (13 SAN).
Point (ADAMS) replaced Point (ADAMS ECC).
Point (C2AZ ECC) replaced Point (C2AZ).

IDOT DISTRICT 9	**JOHNSON, MASSAC PULASKI COUNTIES**	**NAD 83 (2007)**
2/1/2012	**CONTROL**	**NAVD 88**
STATIC + RTK GPS	**EAST ZONE FINAL**	**GEOID 09**

MONUMENT NOTES:
NGS = NATIONAL GEODETIC SURVEY MONUMENT
IDOT = ILLINOIIS DEPARTMENT OF TRANSPORTATION MONUMENT
DI = DEPARTMENT OF INTERIOR MONUMENT
CK PT = LiDAR CHECKPOINT

ORTHO HEIGHT NOTES:
RUN = BASED ON AN IDOT DIFFERENTIAL LEVEL CIRCUIT
GPS = BASED ON A GPS OBSERVED ORTHOMETRIC HEIGHT
NGS = PUBLISHED NGS ORTHOMETRIC HEIGHT

G.S. = DISTANCE ABOVE OR BELOW TOP OF MONUMENT TO SURROUNDING GROUND SURFACE

Point ID	Northing	Easting	Ortho Ht.	GPS/Run	Mon.	G. S.	Ground
13 SAN	237472.08	758914.98	340.372	RUN	DI	FLUSH	340.37
13 SAN ECC	237100.20	758928.39	340.257	RUN	CK PT	FLUSH	340.26
15SAN	220456.83	763928.98	353.133	RUN	NGS	FLUSH	353.13
1002	181874.31	759163.32	347.194	RUN	IDOT	FLUSH	347.19
1002 ECC	181878.95	759188.66	347.984	RUN	CK PT	FLUSH	347.98
1003	200657.14	771914.41	478.733	RUN	IDOT	+0.1'	478.63
1004	213098.97	782355.84	426.053	RUN	IDOT	FLUSH	426.05
1006	200115.28	756286.56	466.634	RUN	IDOT	FLUSH	466.63
1007	226622.73	783751.61	343.447	RUN	IDOT	FLUSH	343.45
1008	206578.86	798722.33	358.085	RUN	IDOT	FLUSH	358.09
1009	244032.98	808553.10	443.683	GPS	IDOT	FLUSH	443.68
1010	209166.57	820827.88	396.245	RUN	IDOT	FLUSH	396.25
1011	195327.05	851406.25	386.767	RUN	IDOT	FLUSH	386.77
1012	210163.10	842724.33	344.616	RUN	IDOT	FLUSH	344.62
1013	221641.15	834790.02	338.690	RUN	IDOT	FLUSH	338.69
1014	230097.21	860850.02	343.425	RUN	IDOT	FLUSH	343.43
1015	251557.37	851015.94	540.456	RUN	IDOT	FLUSH	540.46
9522	186147.25	883684.31	374.789	RUN	IDOT	FLUSH	374.79
449515	281833.16	821874.78	505.109	GPS	IDOT	FLUSH	505.11
910527	244932.47	717336.03	387.149	GPS	IDOT	FLUSH	387.15

ADAMS	270377.45	778187.22	606.626	GPS	NGS	+0.4'	606.23
ADAMS ECC	270402.18	778280.58	605.256	GPS	CK PT	FLUSH	605.26
BROOKPORT	177809.98	897625.05	378.008	GPS	NGS	FLUSH	378.01
C2AZ	243106.09	780213.58	489.035	RUN	NGS	+0.3'	488.74
C2AZ ECC	243086.98	780103.97	484.405	RUN	CK PT	FLUSH	484.41
C157	200127.50	729685.62	342.345	NGS	NGS	+0.2'	342.15
E217 RESET	217102.37	745140.52	339.061	RUN	NGS	-0.1'	339.16
G217	228817.71	742636.59	339.133	NGS	NGS	FLUSH	339.13
GR37308900	299401.15	792749.76	400.325	GPS	NGS	-0.5'	400.83
GURLEY R-9-19	212551.90	875313.10	476.377	RUN	NGS	-0.3'	476.68
HOHMAN R 9 22	180862.55	936013.57	468.083	GPS	NGS	-0.4'	468.48
INDIAN	245588.22	829695.17	576.312	RUN	NGS	FLUSH	576.31
J112	166505.02	898333.36	339.596	NGS	NGS	+0.3'	339.30
LATIN	150644.75	735526.13	330.558	GPS	NGS	FLUSH	330.56
PSM 41	170004.20	710000.45	333.283	RUN	IDOT	FLUSH	333.28
PSM151	228885.31	798442.97	342.956	RUN	IDOT	FLUSH	342.96
PSM192	227383.64	818327.73	348.882	RUN	IDOT	FLUSH	348.88
STAFFORD	246176.49	873903.57	358.055	GPS	NGS	-0.7'	358.76
TUNNEL	309122.64	842438.44	761.194	RUN	NGS	FLUSH	761.19
TVAEZD94	165996.34	931241.89	342.471	GPS	DI	FLUSH	342.47
V111	176018.92	868159.24	344.635	NGS	NGS	FLUSH	344.64
V156	164093.42	730902.86	329.848	NGS	NGS	+0.6'	329.25
DJ701	299168.66	867373.27	763.887	GPS	IDOT	FLUSH	763.89
DJ702	308187.39	778479.28	480.408	GPS	CK PT	FLUSH	480.41
DJ703	152523.97	931114.42	329.380	RUN	IDOT	FLUSH	329.38
DJ704	207508.89	713073.06	338.472	RUN	CK PT	FLUSH	338.47
DJ705=GPS6	275793.30	874907.43	542.327	GPS	NGS	FLUSH	542.33
DJ706	286411.58	844628.57	513.474	GPS	IDOT	FLUSH	513.47
DJ707	270803.34	810004.50	456.950	GPS	CK PT	FLUSH	456.95
DJ708	312556.92	815180.13	715.218	GPS	CK PT	FLUSH	715.22
DJ709	224168.14	894145.77	566.412	GPS	CK PT	FLUSH	566.41
DJ710	199082.61	915561.48	454.287	GPS	CK PT	FLUSH	454.29

Ground Control Survey: Illinois West Zone Values

The following listing shows the established GPS Ground Control points, collected for the LiDAR checkpoints. The ground control points were established and surveyed by IDOT surveyors.
Note: Points in **Red Font** were duplicate points and not used as ground control points.
Point (13 SAN ECC) replaced Point (13 SAN).
Point (ADAMS) replaced Point (ADAMS ECC).
Point (C2AZ ECC) replaced Point (C2AZ).

IDOT DISTRICT 9	**JOHNSON, MASSAC PULASKI COUNTIES**	-	**NAD 83 (2007)**
2/1/2012	**CONTROL**		**NAVD88**
STATIC + RTK GPS	**West ZONE FINAL**		**GEOID 09**

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G.S. = DISTANCE ABOVE OR BELOW TOP OF MONUMENT TO SURROUNDING GROUND SURFACE

Point ID	Northing	Easting	Ortho Ht.	GPS/Run	Mon.	G. S.	Ground
13 SAN	238264.14	2604397.62	340.37	RUN	DI	FLUSH	340.37
13 SAN ECC	237892.58	2604418.24	340.26	RUN	CK PT	FLUSH	340.26
15SAN	221348.96	2609740.66	353.13	RUN	NGS	FLUSH	353.13
1002	182680.65	2605722.51	347.19	RUN	IDOT	FLUSH	347.19
1002 ECC	182685.78	2605747.75	347.98	RUN	CK PT	FLUSH	347.98
1003	201707.07	2618108.24	478.73	RUN	IDOT	+0.1'	478.63
1004	214349.21	2628307.23	426.05	RUN	IDOT	FLUSH	426.05
1006	200862.86	2602493.44	466.63	RUN	IDOT	FLUSH	466.63
1007	227898.10	2629440.75	343.45	RUN	IDOT	FLUSH	343.45
1008	208146.91	2644797.83	358.09	RUN	IDOT	FLUSH	358.09
1009	245787.23	2653901.41	443.68	GPS	IDOT	FLUSH	443.68
1010	211162.38	2666850.87	396.25	RUN	IDOT	FLUSH	396.25
1011	197915.84	2697694.82	386.77	RUN	IDOT	FLUSH	386.77
1012	212582.89	2688726.23	344.62	RUN	IDOT	FLUSH	344.62
1013	223906.38	2680570.13	338.69	RUN	IDOT	FLUSH	338.69
1014	232867.13	2706464.55	343.43	RUN	IDOT	FLUSH	343.43
1015	254135.30	2696214.55	540.46	RUN	IDOT	FLUSH	540.46
9522	189360.80	2730149.25	374.79	RUN	IDOT	FLUSH	374.79
449515	283842.32	2666487.21	505.11	GPS	IDOT	FLUSH	505.11
910527	244916.36	2562682.13	387.15	GPS	IDOT	FLUSH	387.15
ADAMS	271538.45	2623027.80	606.63	GPS	NGS	+0.4'	606.23

ADAMS ECC	271565.00	2623120.67	605.26	GPS	CK PT	FLUSH	605.26
BROOKPORT	181293.16	2744251.08	378.01	GPS	NGS	FLUSH	378.01
C2AZ	244310.48	2625583.53	489.04	RUN	NGS	+0.3'	488.74
C2AZ ECC	244289.24	2625474.31	484.41	RUN	CK PT	FLUSH	484.41
C157	200360.30	2575897.31	342.35	NGS	NGS	+0.2'	342.15
E217 RESET	217631.07	2591020.50	339.06	RUN	NGS	-0.1'	339.16
G217	229295.67	2588290.01	339.13	NGS	NGS	FLUSH	339.13
GR37308900	300841.39	2637023.59	400.33	GPS	NGS	-0.5'	400.83
GURLEY R-9-19	215602.81	2721267.15	476.38	RUN	NGS	-0.3'	476.68
HOHMAN R 9 22	185087.97	2782581.49	468.08	GPS	NGS	-0.4'	468.48
INDIAN	247752.66	2675011.22	576.31	RUN	NGS	FLUSH	576.31
J112	170001.87	2745177.84	339.60	NGS	NGS	+0.3'	339.30
LATIN	151000.37	2582692.69	330.56	GPS	NGS	FLUSH	330.56
PSM 41	169862.99	2556798.77	333.28	RUN	IDOT	FLUSH	333.28
PSM151	230445.21	2644086.31	342.96	RUN	IDOT	FLUSH	342.96
PSM192	229329.24	2663997.98	348.88	RUN	IDOT	FLUSH	348.88
STAFFORD	249199.05	2719205.60	358.06	GPS	NGS	-0.7'	358.76
TUNNEL	311529.89	2686517.78	761.19	RUN	NGS	FLUSH	761.19
TVAEZD94	170128.89	2778096.91	342.47	GPS	DI	FLUSH	342.47
V111	178932.59	2714820.42	344.64	NGS	NGS	FLUSH	344.64
V156	164357.13	2577810.80	329.85	NGS	NGS	+0.6'	329.25
DJ701	302062.28	2711645.10	763.89	GPS	IDOT	FLUSH	763.89
DJ702	309348.41	2622583.98	480.41	GPS	CK PT	FLUSH	480.41
DJ703	156653.49	2778229.58	329.38	RUN	IDOT	FLUSH	329.38
DJ704	207418.56	2559145.47	338.47	RUN	CK PT	FLUSH	338.47
DJ705=GPS6	278834.42	2719633.94	542.33	GPS	NGS	FLUSH	542.33
DJ706	288863.10	2689150.04	513.47	GPS	IDOT	FLUSH	513.47
DJ707	272582.80	2654832.67	456.95	GPS	CK PT	FLUSH	456.95
DJ708	314432.61	2659194.97	715.22	GPS	CK PT	FLUSH	715.22
DJ709	227583.82	2739874.38	566.41	GPS	CK PT	FLUSH	566.41
DJ710	202912.97	2761776.21	454.29	GPS	CK PT	FLUSH	454.29

LiDAR Control Report

The following listing shows the accuracy results of the LiDAR data compared to the IDOT ground control coordinates. 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 checkpoints. The results suggest the LiDAR data meets 0.25' $RMSE_Z$ ($Accuracy_Z$ = 0.49' at 95% confidence).

Checkpoint Accuracy Report for Illinois East Zone (post-classification)*

Project Units	US Survey Foot	
Date	Thursday, October 31, 2013	
Total LAS Files	5094	
Vertical Accuracy Objective		
Requirement Type	RMSE(z)	
RMSE(z) Objective	0.41	
Control Points in Report	48	
Elevation Calculation Method	Interpolated from TIN	
Control Points with LiDAR Coverage	47	
Average Control Error Reported	-0.004	
Maximum (highest) Control Error Reported	0.473	
Median Control Error Reported	0.017	
Minimum (lowest) Control Error Reported	-0.537	
Standard deviation (sigma) of Error for sample	0.255	
RMSE of Error for sample (RMSE(z))	0.252	PASS
NSSDA Achievable Contour Interval	0.9	
ASPRS Class 1 Achievable Contour Interval	0.8	
NMAS Achievable Contour Interval	0.9	

Control Point Id	Control Point X	Control Point Y	Coverage	Control Point Z	Z from LiDAR	Z Error	Minimum Z	Median Z	Maximum Z
TUNNEL	842438.44	309122.64	Yes	761.19	760.66	-0.54	760.63	760.67	760.84
STAFFORD	873903.57	246176.49	Yes	358.76	358.26	-0.50	357.88	358.57	359.02
DJ703	931114.42	152523.97	Yes	329.38	328.91	-0.47	328.83	328.90	329.07
DJ702	778479.28	308187.39	Yes	480.41	479.98	-0.43	479.52	479.74	480.03
DJ701	867373.27	299168.66	Yes	763.89	763.48	-0.40	763.45	763.54	763.58
DJ707	810004.50	270803.34	Yes	456.95	456.56	-0.39	456.52	456.63	456.93
DJ705=GPS6	874907.43	275793.30	Yes	542.33	541.97	-0.36	541.91	541.99	542.02
GR37308900	792749.76	299401.15	Yes	400.83	400.55	-0.27	400.38	400.66	400.79
1007	783751.61	226622.73	Yes	343.45	343.19	-0.26	342.98	343.31	343.35
1002 ECC	759188.66	181878.95	Yes	347.98	347.73	-0.25	347.70	347.71	347.85
DJ709	894145.77	224168.14	Yes	566.41	566.20	-0.21	566.13	566.31	566.37
1010	820827.88	209166.57	Yes	396.25	396.06	-0.19	395.71	395.93	396.22
J112	898333.36	166505.02	Yes	339.30	339.16	-0.14	339.07	339.21	339.22
DJ704	713073.06	207508.89	Yes	338.47	338.35	-0.13	338.24	338.36	338.51

1002	759163.32	181874.31	Yes	347.19	347.07	-0.12	347.02	347.07	347.24
1009	808553.10	244032.98	Yes	443.68	443.61	-0.07	443.50	443.65	443.85
1015	851015.94	251557.37	Yes	540.46	540.39	-0.07	539.96	540.39	540.46
910527	717336.03	244932.47	Yes	387.15	387.09	-0.06	386.48	387.36	387.48
13 SAN ECC	758928.39	237100.20	Yes	340.26	340.21	-0.05	340.15	340.16	340.30
1004	782355.84	213098.97	Yes	426.05	426.03	-0.03	425.76	425.93	426.37
449515	821874.78	281833.16	Yes	505.11	505.09	-0.02	505.03	505.08	505.21
DJ710	915561.48	199082.61	Yes	454.29	454.27	-0.02	453.98	454.23	454.42
PSM151	798442.97	228885.31	Yes	342.96	342.95	-0.01	342.37	343.04	343.09
DJ706	844628.57	286411.58	Yes	513.47	513.49	0.02	513.48	513.53	513.54
1011	851406.25	195327.05	Yes	386.77	386.80	0.03	386.76	386.85	386.91
PSM192	818327.73	227383.64	Yes	348.88	348.93	0.05	348.73	348.85	349.06
PSM 41	710000.45	170004.20	Yes	333.28	333.37	0.08	333.34	333.36	333.39
C2AZ ECC	780103.97	243086.98	Yes	484.41	484.49	0.08	484.23	484.53	484.58
INDIAN	829695.17	245588.22	Yes	576.31	576.41	0.09	576.16	576.43	576.56
GURLEY R-9-19	875313.10	212551.90	Yes	476.68	476.80	0.13	476.72	477.25	477.40
G217	742636.59	228817.71	Yes	339.13	339.28	0.15	338.86	339.31	339.44
ADAMS	778187.22	270377.45	Yes	606.23	606.38	0.16	606.35	606.37	606.44
15SAN	763928.98	220456.83	Yes	353.13	353.31	0.18	353.26	353.40	353.42
1013	834790.02	221641.15	Yes	338.69	338.87	0.18	338.80	338.81	339.15
TVAEZD94	931241.89	165996.34	Yes	342.47	342.67	0.20	342.59	342.64	342.73
E217 RESET	745140.52	217102.37	Yes	339.16	339.37	0.21	339.22	339.38	339.45
V111	868159.24	176018.92	Yes	344.64	344.85	0.21	344.72	344.84	345.13
9522	883684.31	186147.25	Yes	374.79	375.01	0.22	374.91	375.01	375.12
1006	756286.56	200115.28	Yes	466.63	466.87	0.23	466.73	466.96	467.07
1003	771914.41	200657.14	Yes	478.63	478.88	0.25	478.85	478.85	478.93
1008	798722.33	206578.86	Yes	358.09	358.33	0.25	358.14	358.20	358.47
C157	729685.62	200127.50	Yes	342.15	342.40	0.26	342.33	342.41	342.52
V156	730902.86	164093.42	Yes	329.25	329.54	0.29	329.38	329.55	329.65
BROOKPORT	897625.05	177809.98	Yes	378.01	378.34	0.33	378.16	378.37	378.52
1012	842724.33	210163.10	Yes	344.62	344.97	0.36	344.67	344.77	345.17
LATIN	735526.13	150644.75	Yes	330.56	330.93	0.37	330.63	330.77	331.37
1014	860850.02	230097.21	Yes	343.43	343.90	0.47	343.78	343.87	343.99
DJ708	815180.13	312556.92	No	715.22					

*Accuracy assessment not performed on West Zone coordinates as results would be the same.

LiDAR CALIBRATION

Note: All figures represented on the following pages are for general illustration purposes, and are not examples derived from actual IDOT project 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 laser scanning systems, 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 flight lines 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.

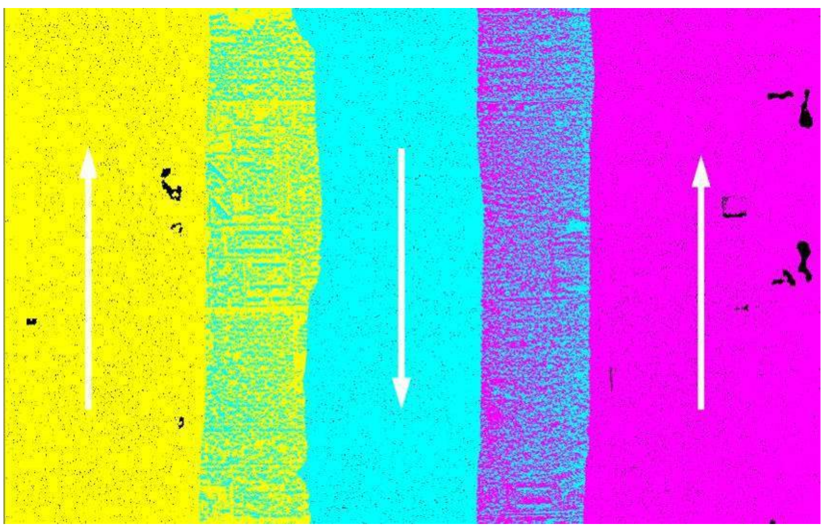

Figure 1: Flight pattern required for calibration

Correcting for Pitch and Heading Biases

There are many settings in the ALS post processor that can be used to adjust 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.

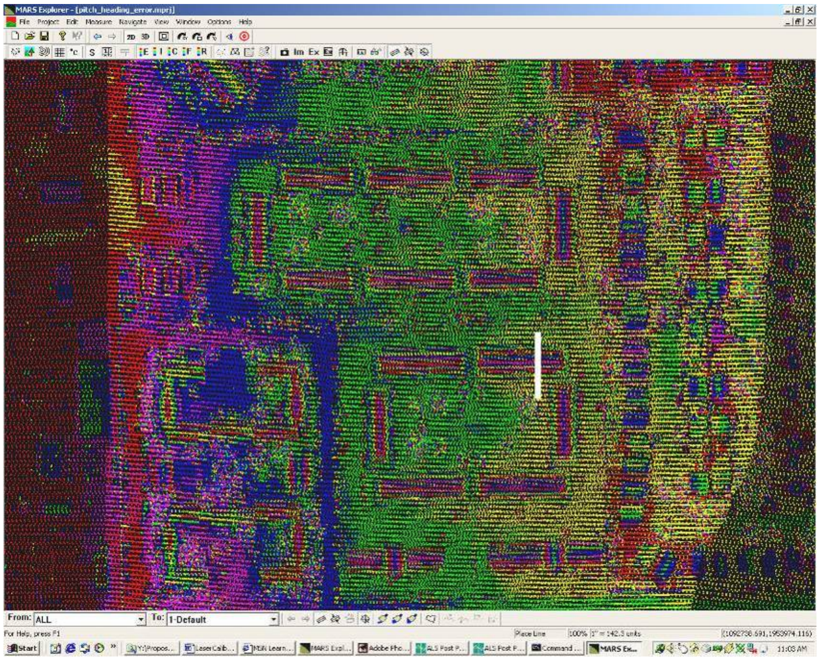

Figure 2: Orthographic view with profile line

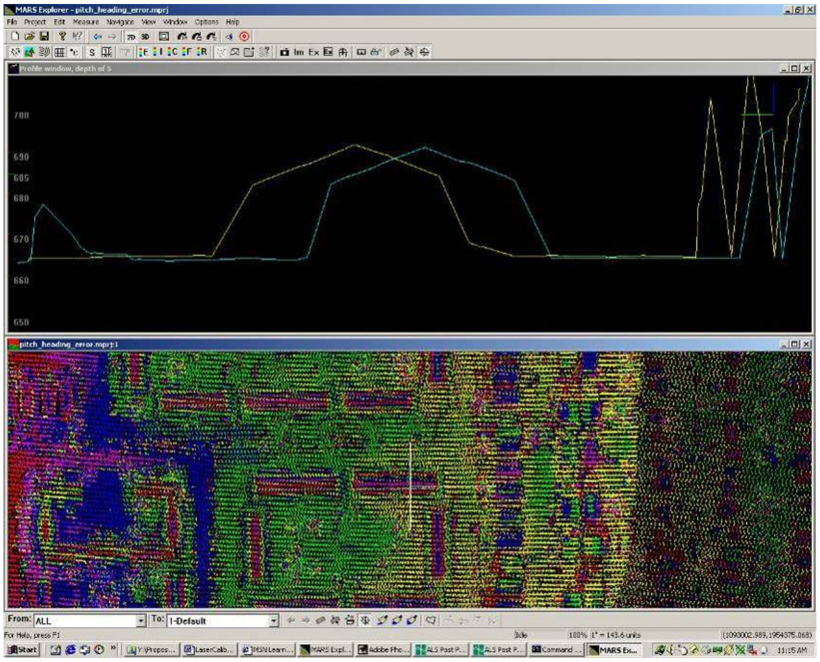

Figure 3: Profile view of misalignment

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).

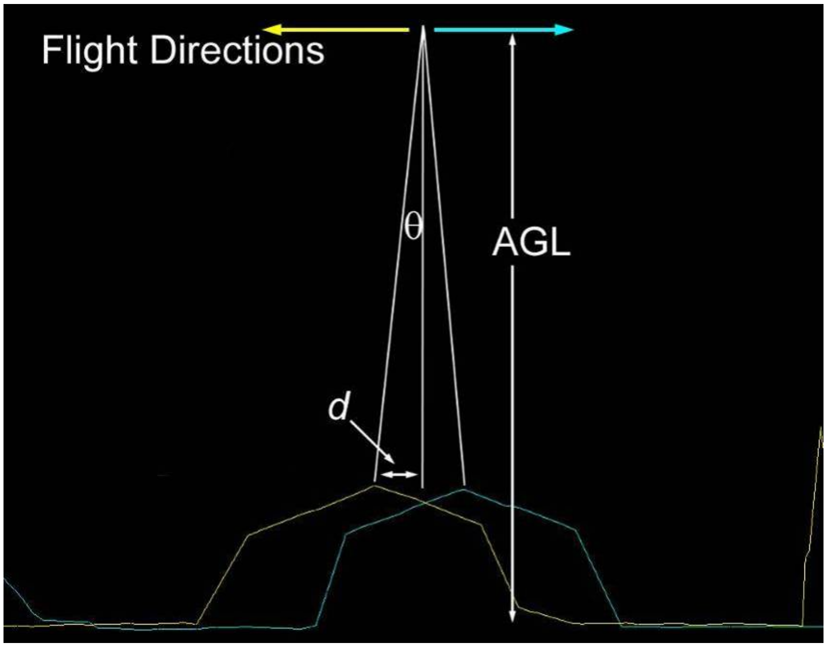

Figure 4: Adjusting pitch

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 (θ) 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.

Pitch increases, objects throughout the data move forward.

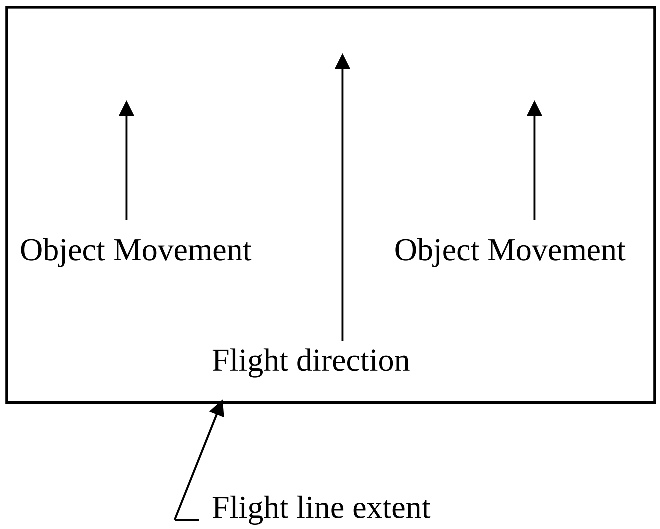

Figure 5: Pitch movement.

Heading increases, objects move clockwise.

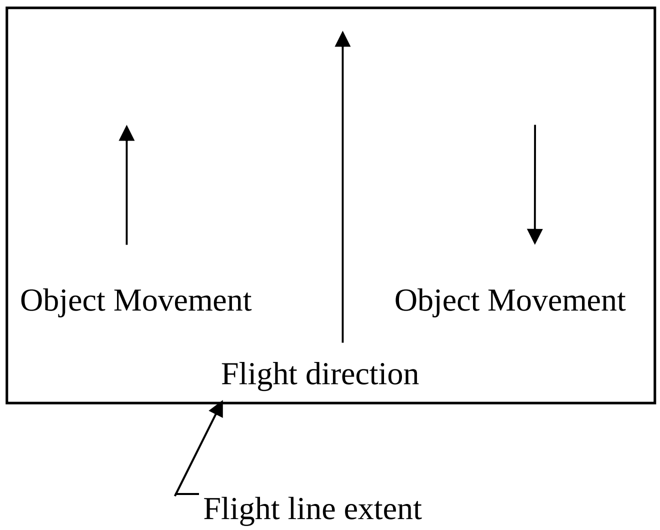

Figure 6: Heading movement.

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

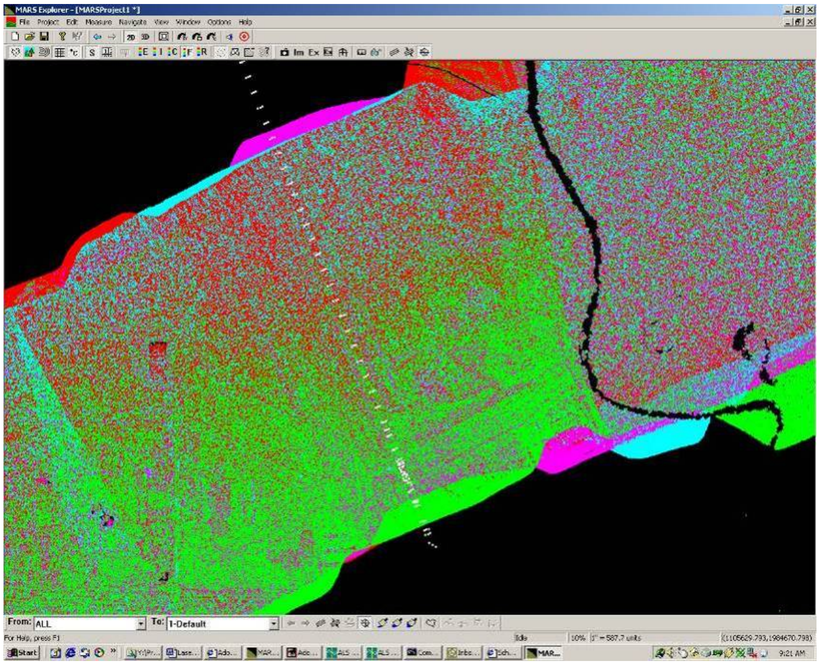

Figure 7: The truth survey

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)

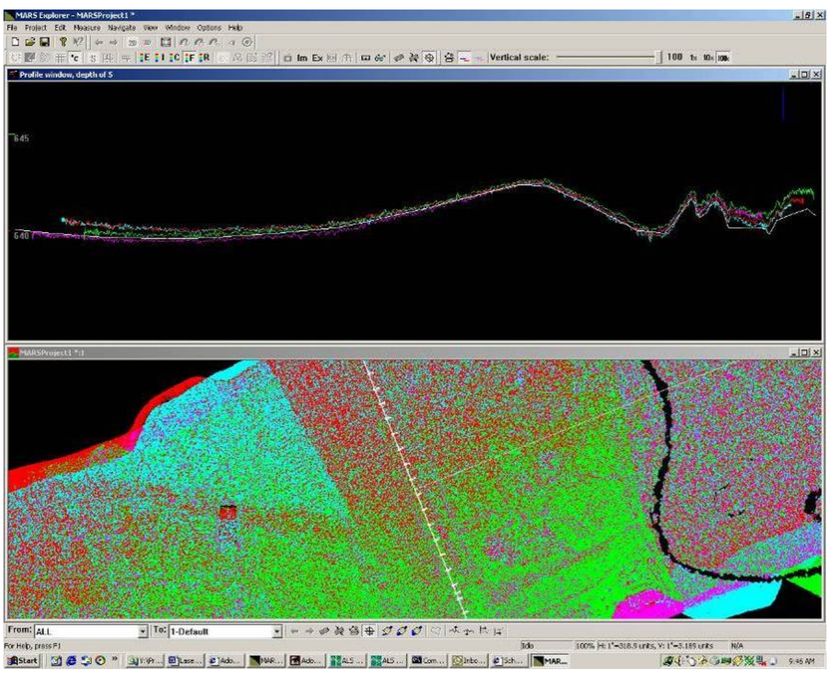

Figure 8: Profile view of calibration flight lines

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)

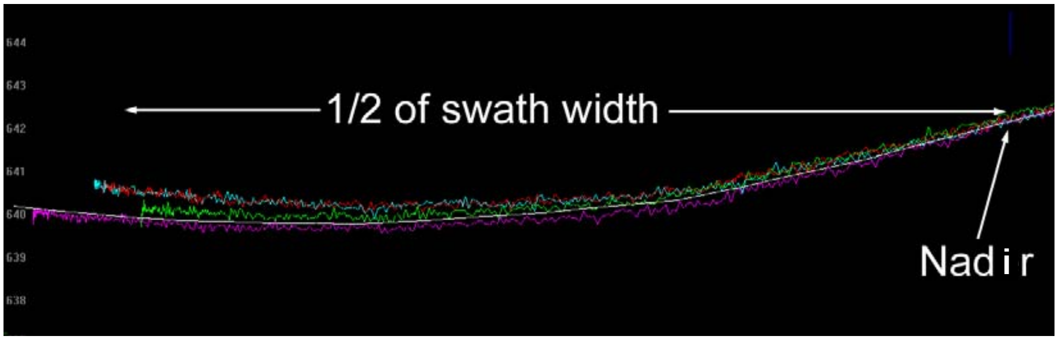

Figure 9: Half of calibration profile

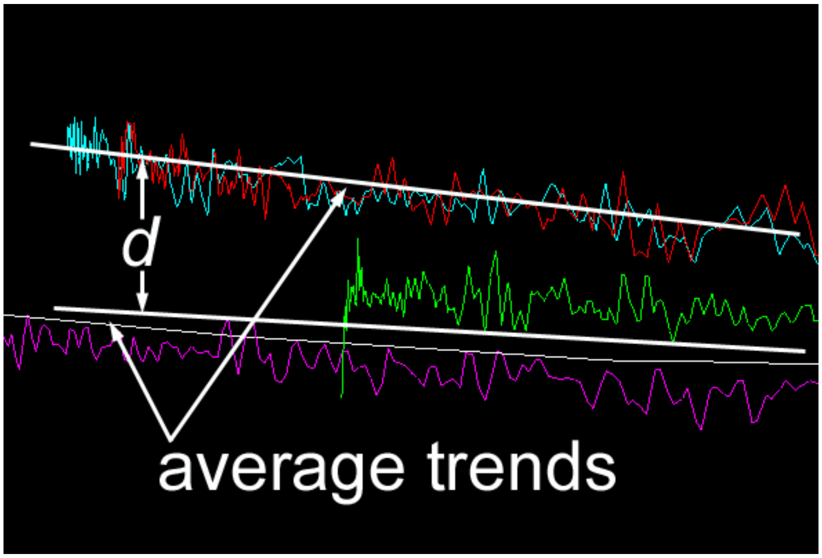

Figure 10: Differences in average roll trends

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 an 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 Class 2 (Ground), and following this a height above / below surface (≤-1m / ≥160m) auto-filter is run to classify Class 7 (Noise). The Model Keypoint Filter creates a new, thinned dataset from Class 2 (Ground) points by searching for the highest and lowest points in a user-defined area based on specific tolerances. Those points classified as Class 8 (Model Keypoints) and should resemble a more consistent representation of the 1m NPS that was required per the project specifications.

The following table represents the ASPRS LAS 1.2 classifications used for IDOT:

- Class 1 = Unclassified
- Class 2 = Ground
- Class 3 = Low Vegetation
- Class 4 = Medium Vegetation
- Class 5 = High Vegetation
- Class 6 = Building
- Class 7 = Low point (noise)
- Class 8 = Model Keypoint (mass point)
- Class 9 = Water
- Class 10 = Ignored Ground (Breakline Proximity)

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.

HYDRO-FLATTENING BREAKLINE COLLECTION (*per NGP-USGS Base LiDAR Specifications, Version 1.0*)

Linear hydrographic features

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 Intensity 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.

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 drainageway caused by a lack of consistent penetration in densely vegetated areas.

Criteria of linear hydrographic breaklines are as follows:

- Linear hydrographic features (e.g., visible streams, rivers, shorelines, canals, etc.) greater than one hundred feet (100') wide will be captured as a double-lined polygon
  - linear hydrographic features must be flat and level bank-to-bank (perpendicular to the apparent flow centerline) with gradient following the immediately surrounding terrain
  - water surface edge must be at or just below the immediately surrounding terrain
  - streams should break at road crossings (e.g., culverts), and streams and rivers should not break at bridges

Waterbodies
Waterbodies are digitized from the color ramped TIN, similar to the process described above. Intensity 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.

Criteria of waterbody breaklines are as follows:

- Water bodies (e.g., lakes, ponds, reservoirs) greater than two (2) acres in size are surrounded by a water breakline (i.e., closed polygon)
  - water bodies must be flat and level with a single elevation for every bank vertex
  - water surface edge must be at or just below the immediately surrounding terrain
  - long impoundments, such as reservoirs or inlets, whose water surface elevations drop when moving downstream should be treated as rivers

DIGITAL ELEVATION MODEL (DEM)

Raster Grid Development
Merrick exports the Class 2 (ground) LiDAR points along with the breaklines to create a 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.