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Subject: U.S. Geological Survey (USGS) Award No. G10AC00117 – Final Technical Report

Title: Processing of 2007 LiDAR Data Acquisition for Lake County, Illinois

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Note – the start date of 04/05/2010 is when Lake County received the signed agreement

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Abstract:

An internal review of the data was done by Lake County GIS staff. The U.S. Geological Survey National Geospatial Program 'LIDAR Guidelines and Base Specification, version 13, dated February 22, 2010' was used as a guide/checklist for the initial review by the county. The main focus of the county's review centered on three areas of the USGS NGP Base LIDAR Specifications: data collection, hydro-flattening, and deliverables. Minor issues were noted during the review, feedback was given back to the vendor and were corrected. Again, any issues were minor and consisted mainly of some classification changes and a few missing breaklines. All issues were corrected by the vendor. The only deviation from the specifications were minor flightline overlaps not at the full 10% required in the specifications. These areas were minimal, had at least some overlap and can be easily explained by supple changes in flight heading due to the prevailing winds on the day of collection.

This report highlights the internal review completed by Lake County, IL GIS staff, see appendix A for the project report prepared by Merrick.

The tiling scheme used by the county for this project is based on the Public Land Survey System (PLSS) and consists of 494 tiles. Merrick began post-processing the 2007 LIDAR data soon after the county accepted and signed the grant contract agreement. A pilot area of 10 tiles was initially processed and delivered to the county for review during the second quarter of this year. The quality of the data was deemed acceptable and Merrick was given the go-ahead to process the remainder of the countywide data.

Internal Quality Assurance / Quality Control Report, Lake County, IL

About Lake County, IL:

Lake County is in the northeast corner of Illinois. It has an area of 301,435 acres, or about 471 square miles, is divided into 18 townships and consists of 494 full or partial PLSS sections. The county is bordered by Cook County on the south, by McHenry County on the west, by Kenosha County, Wisconsin, on the north, and by Lake Michigan on the east.

Physiography, Relief, Drainage, and Natural Resources:

The following description of Lake County, IL is from the 'Soil Survey of Lake County, Illinois', Natural Resources Conservation Service, issued June 2005.

"Lake County consists of moraines, outwash plains, lake plains, kames, stream terraces, flood plains, beaches, and bogs. The county is in the Wheaton Morainal country of the Great Lakes section of the Central Lowland province (Leighton and others, 1948). Relief in Lake County was caused by differences in the thickness of deposits left by the most recent glacier. Generally, the land surface elevation is highest in the northwestern part of the county. The land surface gradually slopes to the south or southeast. The highest point in the county, 957 feet above mean sea level, is located on Gander Mountain in the northwest corner. The lowest point is 580 feet above mean sea level at the Lake Michigan shore near Waukegan. The landscape in Lake County is a mosaic of residential and commercial development, farmland, wetlands, forestland, and natural and constructed bodies of water.

Several moraines run through the county. From east to west, they are the Lake Border Morainic System, the Tinley Moraine, the Valparaiso Morainic System, and the Fox Lake Moraine (Hansel and Johnson, 1996). In general, Lake County has a poorly defined drainage pattern. Many drainageways terminate in depressions and marshes. The land area falls into four major watersheds and 26 drainage basins. The Chicago River, Des Plaines River, Fox River, and Lake Michigan watersheds are all shared with neighboring counties in Illinois and Wisconsin.

The Government Land Office maps and field notes from the 1830s portray the survey area as very sparsely settled, a mixture of forested areas and prairie with extensive wetlands. A study by the Illinois Natural History Survey (Suloway and Hubbell, 1994) estimates that 40 to 61 percent of the county was wetlands. This estimate is based on the large number of hydric soils mapped in the survey area. The word "Lake" in the county's name was very appropriate; even after 160 years of settlement and development, that same study estimated that 6 to 15 percent of the county's original wetlands remained. The Lake County Health Department has inventoried more than 250 lakes with an area of 6 or more acres. The Lake County Wetland Inventory, a cooperative project of Federal and local agencies, has mapped over 8,700 wetland areas. An Advanced

Identification Study (ADID) initiated by the U.S. Environmental Protection Agency and published in 1992 (U.S. Environmental Protection Agency, 1992) listed 203 high-quality wetland sites."

According to the Lake County Wetland Inventory, 2002 and existing GIS data about 22% of the county is water or wetlands

Purpose:

The purpose of the grant is to process countywide LiDAR data captured in 2007. In 2007 Lake County, IL (County) contracted with Merrick & Company (Merrick) to acquire high resolution color aerial imagery. The vendor used an aircraft also equipped with a LiDAR system. On speculation that the data would be processed at a later date, the vendor captured countywide LiDAR suitable for the development of 1' contours. Lake County currently has 2' contours developed in 2002 by the same vendor. While at the time these were of great benefit, they are becoming less useful because of their age and the need to develop higher accuracy models. Small footprint - high density LiDAR such as was captured in 2007, averages 9 points per square meter versus 3 points per square meter in 2002.

It is important to note that the county did not have to pay additional costs for the acquisition of the LiDAR data, as it was captured concurrently with the color aerial imagery; resulting in a cost savings. One of the benefits of this approach is that any LiDAR derived products such as a DEM corresponds to the 2007 imagery and can be used with other GIS layers, the datasets will overlay exactly.

Review Process:

Lake County, IL has been working with Merrick & Co. since 2002. Major projects completed by Merrick include multiple years of orthoimagery acquisition and processing (generally at 1:1200 scale) as well as a major planimetric data collection in 2002. These planimetric data included countywide collections of: building outlines, edge-of-pavement, hydrology, and creation of 2' contours, derived from a LIDAR acquisition.

Lake County, IL is fortunate to have access to a wide assortment of GIS data. These include multiple years of aerial/orthophotography, and the planimetric data which was captured/created in 2002. These data were extensively used during the review process as reference.

The U.S. Geological Survey National Geospatial Program 'LIDAR Guidelines and Base Specification, version 13, dated February 22, 2010' was used as a guide/checklist for the initial review by the county. The main focus of the county's review centered on three areas of the USGS NGP Base LIDAR

Specifications: data collection, hydro-flattening, and deliverables. A pure statistical analysis of the LAS points may indicate higher average GSD. However, due to the physical nature of Lake County this may not reflect the true results. As such, a thorough visual review was completed for the entire dataset.

Collection review included:

- No data voids
- No clustering
- Collection/project area buffer, minimum 100 m
- Flightline overlap of 10% or greater
- No overlap between tiles
- No gap between tiles

Hydro-flattening:

- Lakes/ponds ~2 acre+ (~350’ diameter)
- Stream/rivers – 100’ nominal width

Deliverables:

- Metadata for all products
- QA/QC reports
- Raw point cloud
- Classified point cloud
- Bare earth DEM/DTM
- Breaklines
- Extent of files
- Control shapefile

Results:
All data void areas have been reviewed and no errors were found. The voids have been confirmed to be: water bodies, areas of low near infra-red reflectivity - such as asphalt or composition roofing, and/or highly reflective surface - such as automobiles and glass.

No major clustering of points were found. Minor areas were noticed, however it appears to be from normal operations of flying/collection – due to stronger head winds.

Collection area buffer of ~100 m were confirmed on all land areas. The eastern border of Lake County extends into Lake Michigan and the full ~100 m buffer isn’t necessary.

Flightline overlap of 10% or greater was met or exceeded throughout 95% of the project area. In those cases where it was less than the full 10% were explained by the nature of flying and data capture, noticeably due to head winds/drifting. According to the capture specifications provided by Merrick, the scan angle was 30 degrees, tighter than the 40 degrees indicated in the LIDAR guidelines.

No overlaps or gaps between tiles were noticed.

All lakes/ponds over 2 acres were captured in the breaklines. Merrick was able to capture most water bodies over 1 acre, exceeding the LIDAR guidelines. All streams/rivers over 100’ wide were captured.

Lake County staff also reviewed the classified point cloud to verify correct classes were used.

Merrick also included a ‘LOW COFIDENCE’ shapefile. The county reviewed these areas and found them to be in areas where dense vegetation occurred. These areas were in or near wetlands and were confirmed to be correct.

Lake County also obtained a number of ‘Withheld Control Points’. These withheld points were provided by the county’s Department of Transportation office and the City of Waukegan from GPS points collected in the project area. These GPS points were used in the Merrick Advanced Remote Sensing (MARS®) LiDAR processing and modeling software. The results are listed in table 1 below.

Table 1 – Withheld control points report

Project File		
Project Unit	Feet	
Date	28-Sep-10	
Vertical Accuracy Objective		
Requirement Type	Accuracy(z)	
Accuracy(z) Objective	1	
Confidence Level	95%	
Control Points in Report	189	
Elevation Calculation Method	Interpolated from TIN	
Control Points with LiDAR Coverage	187	
Control Points with Required Accuracy (+/- 1.00)	187	
Percent of Control Points with Required Accuracy (+/- 1.00)	100	
Average Control Error Reported	-0.02	
Maximum (highest) Control Error Reported	0.89	
Median Control Error Reported	-0.07	
Minimum (lowest) Control Error Reported	-0.58	
Standard deviation (sigma) of Z for sample	0.23	
RMSE of Z for sample (RMSE(z))	0.23	PASS
FGDC/NSSDA Vertical Accuracy (Accuracy(z))	0.45	PASS
NSSDA Achievable Contour Interval	0.8	
ASPRS Class 1 Achievable Contour Interval	0.7	
NMAS Achievable Contour Interval	0.8	

Control Point Id	Control Point X (East) USFeet	Control Point Y(North) USFeet	Coverage USFeet	Control Point Z (Elev) USFeet	Z (Elev) from LiDAR USFeet	Z Error USFeet	Minimum Z USFeet	Median Z USFeet	Maximum Z USFeet
P0102	1080214	2069555	Yes	760.743	760.68	-0.06	759.94	760.76	760.85
P0104	1080256	2069871	Yes	768.609	768.46	-0.15	768.25	768.44	768.53
P0105	1080380	2070128	Yes	762.791	762.65	-0.14	762.63	762.64	763.06
P0106	1080214	2069555	Yes	760.749	760.68	-0.07	759.94	760.76	760.85
P0107	1080372	2070657	Yes	752.685	752.57	-0.11	752.4	752.67	752.67
P0108	1080351	2070995	Yes	760.166	760.25	0.08	760.14	760.2	760.36
P0109	1080372	2071270	Yes	769.747	769.59	-0.16	769.38	769.56	769.64
P0110	1080256	2069871	Yes	768.64	768.45	-0.19	768.25	768.44	768.53
P0111	1080380	2070128	Yes	762.933	762.66	-0.27	762.63	762.64	763.06
P0112	1080372	2070657	Yes	752.685	752.58	-0.1	752.4	752.67	752.67
P0113	1080351	2070995	Yes	760.287	760.25	-0.04	760.14	760.2	760.36
P0114	1080372	2071271	Yes	769.797	769.59	-0.21	769.38	769.56	769.64
P0115	1080256	2069871	Yes	768.704	768.45	-0.25	768.25	768.44	768.53
P0116	1080380	2070128	Yes	762.756	762.66	-0.1	762.63	762.64	763.06
P0117	1080372	2070657	Yes	752.615	752.58	-0.03	752.4	752.67	752.67
P0118	1080351	2070995	Yes	760.184	760.25	0.07	760.14	760.2	760.36
P0119	1080372	2071271	Yes	769.756	769.59	-0.17	769.38	769.56	769.64
P0120	1080260	2068916	Yes	756.537	756.43	-0.11	756.03	756.5	756.51
P0121	1080259	2068916	Yes	756.541	756.43	-0.11	756.03	756.5	756.51
P0122	1080260	2068916	Yes	756.529	756.43	-0.1	756.03	756.5	756.51
P0201	1090944	2004905	Yes	663.225	663.16	-0.07	663.13	663.2	663.24
P0202	1091993	2004104	Yes	653.073	653.16	0.09	652.97	653.29	653.34
P0203	1091149	2004405	Yes	662.371	662.36	-0.01	662.35	662.36	662.39
P0204	1090970	2005383	Yes	661.983	661.99	0.01	661.57	661.78	662.04
P0205	1091453	2004189	Yes	662.341	662.53	0.19	662.39	662.4	662.55
P0206	1093136	2004351	Yes	646.761	646.9	0.14	646.87	646.88	646.95
P0207	1093029	2004964	Yes	646.221	647.11	0.89	646.82	647.06	647.35
P0208	1092949	2004970	Yes	646.002	646.11	0.11	646.03	646.09	646.12
P0209	1092473	2004183	Yes	649.209	649.43	0.22	649.32	649.56	649.6
P0210	1094456	2004131	Yes	645.896	646.06	0.16	645.93	646.11	646.18
P0211	1094539	2004101	Yes	645.691	645.98	0.29	645.9	646	646.05
P0212	1094844	2004044	Yes	645.519	645.63	0.11	645.59	645.66	645.7
P0213	1090940	2005086	Yes	664.424	664.32	-0.1	664.23	664.28	664.52
P0214	1090950	2005350	Yes	662.361	662.47	0.11	662.42	662.48	662.64
P0215	1090948	2005359	Yes	662.735	662.61	-0.13	662.47	662.5	662.69
P0216	1092927	2004315	Yes	646.85	646.85	0	646.59	646.76	647.05
P0601	1023421	2054373	Yes	781.53	781.48	-0.05	781.22	782.5	782.56
P0602	1023551	2054262	Yes	784.356	784.3	-0.06	784	784.16	784.53
P0603	1025874	2051722	Yes	777.205	777.07	-0.13	776.5	776.66	777.59
P0604	1025894	2051409	Yes	771.787	771.64	-0.15	771.42	771.65	771.8
P0605	1025889	2051018	Yes	771.3	771.36	0.06	771.27	771.56	771.74
P0606	1025913	2050500	Yes	764.082	764.29	0.21	764.03	764.05	764.54
P0607	1025909	2048890	Yes	770.547	770.64	0.09	770.53	770.64	770.68
P0608	1025683	2052052	Yes	779.807	779.9	0.09	779.83	779.95	779.99
P0609	1025900	2049095	Yes	767.536	767.91	0.37	767.87	767.94	768.05
P0610	1025940	2049095	Yes	769.323	769.2	-0.12	769.1	769.16	769.37
P0611	1025980	2049096	Yes	770.213	770.59	0.38	770.41	770.57	770.75

P0612	1025923	2051349	Yes	773.196	773.12	-0.08	773.07	773.12	773.22
P0613	1025924	2051348	Yes	773.198	773.13	-0.07	773.07	773.12	773.22
P0614	1025923	2051347	Yes	773.156	773.16	0	773	773.12	773.26
P0615	1025922	2051348	Yes	773.126	773.16	0.03	773.07	773.12	773.26
P0616	1025920	2051739	Yes	774.829	775.46	0.63	775.02	775.41	775.85
P0617	1025624	2051998	Yes	777.086	777.2	0.11	776.94	777.75	778.19
P0618	1023449	2054396	Yes	780.901	780.76	-0.14	780.67	780.79	781.04
P0619	1023450	2054396	Yes	780.832	780.75	-0.08	780.67	780.86	780.91
P0620	1023450	2054394	Yes	780.94	780.74	-0.2	780.67	781.16	781.21
P0621	1023449	2054394	Yes	780.906	780.91	0	780.67	780.79	781.04
P0803	1101400	2007550	Yes	669.121	668.93	-0.19	668.87	668.91	668.98
P0804	1100699	2008195	Yes	677.554	677.37	-0.18	677.18	677.25	677.76
P0806	1106397	2004015	Yes	680.923	681.11	0.19	680.7	681.01	681.21
P0807	1106364	2004016	Yes	680.502	680.59	0.09	680.4	680.66	680.87
P0808	1106386	2004017	Yes	680.873	680.76	-0.11	680.5	680.85	681.04
P0809	1106393	2004060	Yes	681.172	681.55	0.38	681.14	681.3	681.71
P0810	1106380	2004194	Yes	681.782	681.63	-0.15	681.44	681.61	681.76
P0811	1106373	2004202	Yes	681.543	681.68	0.14	681.66	681.68	681.81
P0812	1106383	2004204	Yes	681.974	681.83	-0.14	681.75	681.84	682.01
P0813	1106398	2004235	Yes	682.839	683.04	0.2	682.92	683.08	683.12
P0814	1106400	2004246	Yes	682.794	682.95	0.16	682.86	682.93	683.23
P0815	1106322	2004336	Yes	681.954	682.01	0.06	681.91	682.02	682.1
P0816	1106316	2004350	Yes	682.06	681.85	-0.21	681.79	682.07	682.15
P0817	1106313	2004369	Yes	682.4	682.13	-0.27	682.09	682.18	682.24
P0818	1106349	2004355	Yes	683.226	683.09	-0.14	683.02	683.14	683.35
P0819	1106359	2004409	Yes	682.778	682.81	0.03	682.75	682.88	682.89
P0820	1106308	2004444	Yes	682.905	682.95	0.05	682.79	682.98	683.12
P0821	1106316	2004448	Yes	682.545	682.46	-0.08	682.37	682.55	682.75
P0822	1106343	2004430	Yes	683.064	683.14	0.08	682.88	683.16	683.29
P0823	1106354	2004445	Yes	682.576	682.64	0.06	682.5	682.74	683
P0824	1106344	2004419	Yes	683.151	683.39	0.24	683.21	683.38	683.48
P0825	1106327	2004397	Yes	683.42	683.49	0.07	683.17	683.4	683.61
P0826	1106332	2004412	Yes	683.508	683.21	-0.3	683.04	683.41	683.57
P0827	1106339	2004422	Yes	683.246	683.26	0.01	683.21	683.36	683.39
P0828	1106334	2004439	Yes	682.892	682.91	0.02	682.77	683.07	683.17
P0829	1106343	2004456	Yes	682.537	682.45	-0.09	682.09	682.6	682.8
P0830	1106351	2004476	Yes	681.556	682.21	0.65	682.05	682.13	682.23
P0831	1106354	2004472	Yes	682.402	682.19	-0.21	682.14	682.16	682.25
P0832	1106345	2004475	Yes	682.313	682.09	-0.22	682.02	682.08	682.13
P0833	1106288	2004410	Yes	682.525	682.65	0.13	682.57	682.61	682.77
P0834	1106279	2004403	Yes	681.973	682.19	0.22	681.98	682.05	682.4
P0835	1106179	2004509	Yes	682.508	682.41	-0.1	682.22	682.39	682.64
P0836	1106190	2004506	Yes	682.638	682.64	0	682.2	682.49	683.17
P0837	1106186	2004517	Yes	682.814	682.82	0.01	682.69	682.8	683.03
P0838	1106052	2004591	Yes	682.367	682.17	-0.2	682.13	682.33	682.48
P0839	1106061	2004599	Yes	682.437	682.33	-0.11	682.3	682.35	682.36
P0840	1106123	2004562	Yes	682.844	682.7	-0.14	682.65	682.72	683.13
P0841	1105774	2004759	Yes	681.054	681.05	0	680.98	681.1	681.4
P0842	1106116	2004558	Yes	682.786	682.7	-0.09	682.51	682.75	682.82
P0843	1106032	2004602	Yes	682.22	682.25	0.03	682.1	682.19	682.31

P0844	1100034	2008932	Yes	666.105	665.9	-0.21	665.8	665.82	666.17
P0845	1099990	2009071	Yes	666.334	666.27	-0.06	666.09	666.14	666.72
P0846	1099955	2009332	Yes	667.078	666.98	-0.1	666.63	666.79	667.04
P0847	1099966	2009347	Yes	666.57	666.37	-0.2	666.2	666.43	666.76
P0848	1099956	2009481	Yes	667.318	667.04	-0.28	666.73	666.91	667.39
P0849	1099961	2009492	Yes	667.189	667	-0.19	666.69	666.79	667.18
P0850	1099956	2009561	Yes	667.502	667.31	-0.19	667.05	667.23	667.32
P0851	1099935	2009816	Yes	668.913	668.58	-0.33	668.16	668.64	668.66
P0852	1099923	2009663	Yes	667.29	666.94	-0.35	666.92	666.93	666.98
P0853	1099933	2009663	Yes	667.247	667.26	0.01	667.11	667.27	667.73
P0854	1099931	2009534	Yes	667.395	667.2	-0.19	667.03	667.25	667.34
P0855	1099921	2009520	Yes	667.062	666.79	-0.27	666.43	666.93	666.98
P0856	1099931	2009383	Yes	667.402	667.1	-0.3	666.65	666.9	667.13
P0857	1099925	2009373	Yes	667.292	666.86	-0.43	666.79	667.02	667.22
P0858	1099932	2009305	Yes	667.539	667.15	-0.39	667.1	667.13	667.33
P0859	1099981	2013856	Yes	660.895	660.76	-0.13	660.64	660.72	660.84
P0860	1099979	2013866	Yes	660.857	660.62	-0.24	660.53	660.68	660.91
P0861	1099979	2013874	Yes	660.882	660.73	-0.15	660.53	660.72	660.84
P0862	1099979	2013920	Yes	661.067	661.18	0.11	660.77	661.11	661.22
P1001	1095784	2054055	Yes	704.793	704.52	-0.27	704.5	704.59	704.68
P1002	1095761	2053741	Yes	700.829	700.88	0.05	700.46	700.89	700.9
P1003	1095024	2051125	Yes	704.091	704.1	0.01	704.01	704.1	704.25
P1004	1095099	2051374	Yes	705.064	705.05	-0.01	704.92	705.04	705.09
P1005	1095697	2053399	Yes	699.445	699.65	0.2	699.4	699.62	699.82
P1006	1094758	2046830	Yes	682.073	681.93	-0.14	681.22	681.94	681.96
P1007	1094716	2049479	Yes	685.874	685.66	-0.21	685.46	685.83	686.09
P1008	1094721	2048977	Yes	686.927	686.76	-0.17	686.2	686.79	686.84
P1009	1094737	2048418	Yes	689.543	689.36	-0.18	689.21	689.23	689.57
P1010	1094807	2047553	Yes	696.172	695.64	-0.53	695.53	695.63	695.92
P1011	1094779	2043953	Yes	698.885	698.56	-0.33	698.5	698.57	698.59
P1012	1094805	2043592	Yes	704.637	704.5	-0.14	704.43	704.49	704.57
P1013	1094782	2043592	Yes	704.99	704.78	-0.21	704.59	704.83	704.85
P1302	1028194	2029689	Yes	743.468	743.6	0.13	743.47	743.58	743.73
P1303	1028738	2026421	Yes	746.143	746.6	0.46	746.39	746.53	746.85
P1304	1028687	2028876	Yes	736.159	735.97	-0.19	735.39	736.02	736.04
P1305	1028727	2029600	Yes	744.25	744.6	0.35	744.43	744.58	744.77
P1306	1028738	2027083	Yes	757.94	758.05	0.11	757.91	757.94	758.14
P1401	1056117	2068453	Yes	802.08	801.86	-0.22	801.75	801.82	801.96
P1402	1056041	2068856	Yes	797.15	797.51	0.36	797.34	797.44	797.57
P1403	1056121	2069438	Yes	798.97	798.81	-0.16	797.7	798.85	798.85
P1404	1056147	2069871	Yes	801.01	800.58	-0.43	800.41	800.53	800.66
W2428	1122838	2077300	Yes	583.768	583.54	-0.23	583.43	583.46	583.6
W1552	1117392	2079219	Yes	651.659	651.6	-0.06	651.47	651.56	651.74
W1914	1117276	2077098	Yes	650.174	650.45	0.28	650.36	650.42	650.56
W1505	1117067	2081939	Yes	659.3	659.21	-0.09	658.75	659.14	659.26
W1809	1119613	2076754	Yes	639.448	639.49	0.04	639.37	639.59	639.71
W1742	1119643	2079223	Yes	637.01	637.36	0.35	637.28	637.31	637.52
W1289	1120479	2084894	Yes	635.427	635.57	0.14	635.48	635.84	635.96
W1393	1119960	2082132	Yes	643.676	644.13	0.45	644.08	644.17	644.22
W2213	1119300	2074032	Yes	655.507	655.34	-0.17	655.15	655.38	655.39

W2535	1121787	2073407	Yes	587.548	587.25	-0.3	587	587.28	587.68
W2628	1119555	2071472	Yes	656.805	656.89	0.09	656.59	656.89	656.9
W2969	1119670	2068962	Yes	640.451	640.3	-0.15	640.22	640.33	640.36
W1995	1116967	2074020	Yes	648.397	648.4	0	648.36	648.4	648.41
W2849	1116665	2068599	Yes	648.586	648.64	0.05	648.45	648.64	648.79
W2775	1117633	2071168	Yes	643.657	643.6	-0.06	643.52	643.53	643.71
W1356	1122481	2079749	Yes	586.47	586.52	0.05	586.4	586.57	586.68
W1134	1117360	2087151	Yes	645.652	645.61	-0.04	645.57	645.6	645.76
W1190	1117339	2083895	Yes	667.196	667.49	0.29	667.14	667.51	667.53
W1090	1119882	2086362	Yes	634.364	634.88	0.52	634.75	634.88	634.89
M9028	1130988	2013843	Yes	670.153	669.57	-0.58	669.44	669.7	669.72
M9021	1090497	2040763	Yes	654.133	653.63	-0.5	653.33	653.59	653.77
M9006	1127452	2106900	Yes	586.357	585.86	-0.5	585.83	585.93	586.15
M9029	1139336	1997790	No	648.595					
M9022	1119967	2044545	Yes	654.096	653.69	-0.41	653.63	653.63	653.75
M9014	1123896	2076860	Yes	586.062	585.72	-0.34	585.61	585.74	585.96
M9025	1020538	2013623	Yes	782.249	781.92	-0.33	781.79	781.83	782.08
M9016	1089546	2060877	Yes	706.918	706.71	-0.21	706.51	706.69	706.88
M9005	1126920	2122499	Yes	589.284	589.08	-0.2	589.05	589.1	589.42
M9026	1058659	2018046	Yes	833.67	833.49	-0.18	833.44	833.49	833.54
M9027	1092592	2018735	Yes	666.911	666.73	-0.18	666.66	666.69	666.84
M9031	1060964	1998834	Yes	780.71	780.54	-0.17	780.33	780.46	780.69
M9023	1123062	2030440	Yes	660.235	660.1	-0.13	660.07	660.26	660.26
M9030	1098639	1998632	Yes	652.144	652.02	-0.12	651.92	652	652.29
M9032	1020452	1998872	Yes	801.065	800.98	-0.09	800.94	801	801.07
M9020	1057117	2039760	Yes	841.173	841.1	-0.07	841.07	841.09	841.12
M9015	1120067	2060557	Yes	589.717	589.65	-0.07	589.21	589.62	589.83
M9018	1020475	2060363	Yes	764.661	764.71	0.05	764.52	764.65	764.77
M9024	1018682	2029658	No	734.536					
M221	1122988	2099595	Yes	593.48	593.55	0.07	593.55	593.59	593.64
M9034	1071901	2089138	Yes	769.237	769.38	0.14	769.31	769.32	769.52
M9010	1020574	2091441	Yes	739.943	740.09	0.15	740	740.14	740.25
M9019	1020968	2045289	Yes	751.308	751.48	0.17	751.38	751.4	751.73
M9001	1020463	2108585	Yes	762.128	762.39	0.26	762.38	762.39	762.41
M9011	1020649	2076851	Yes	752.318	752.59	0.27	752.01	752.42	752.62
M1649	1054174	2060979	Yes	777.003	777.28	0.28	777.24	777.3	777.31
M9012	1055961	2082111	Yes	794.313	794.61	0.3	794.47	794.6	794.63
M9003	1057426	2122832	Yes	826.304	826.6	0.3	826.51	826.66	826.75
M9013	1091314	2081783	Yes	732.272	732.58	0.31	732.53	732.56	732.6
M9004	1094497	2121290	Yes	671.386	671.71	0.32	671.61	671.62	671.81
M9008	1093508	2100257	Yes	670.917	671.28	0.36	670.76	671.12	671.37
M2893	1107324	2094502	Yes	721.291	721.78	0.49	721.71	721.86	722.54

Appendix A - Lake_County_2007_LiDAR_Mapping Report_rev113010, Merrick & Co.

Lake County Department of Information and Technology

LiDAR Mapping Report

Prepared for:

LakeCounty

Mr. Keith J. Caldwell, GISP
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Prepared by:

MERRICK & COMPANY

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Merrick & Company Job Number: 02016551

EXECUTIVE SUMMARY

In spring 2007, Merrick & Company (Merrick) was contracted by the Lake County (IL) Department of Information and Technology (County) to perform a digital aerial photrography acquisition resulting in the creation of color digital orthophotography. As a result of Merrick's ability to simultaneously collect color digital imagery and LiDAR (**Li**ght **D**etection **A**nd **R**anging), Merrick captured a high resolution LiDAR point cloud in the event the County should desire to pursue future development of such. In the spring of 2010, the County procured a USGS grant to help facilitate the development of said LiDAR data to produce accurate high-resolution data and a Digtial Terrain Model (DTM) for use in planning, design, and research. The LiDAR was post-processed to meet NSSDA vertical accuracy of 0.3' $RMSE_z$ (0.6' $Accuracy_z$ at 95% confidence level NSSDA).

CONTRACT INFORMATION

Questions regarding this report should be addressed to:

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Director of Projects
Merrick & Company
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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 Lake County.

LiDAR FLIGHT and SYSTEM REPORT

Project Location

The project location for Lake County is defined by the client-provided shapefile "Lake_County_Layout_Boundary".

Duration/Time Period

One LiDAR aircraft, a Cessna 402C (SN35), was used to collect LiDAR Data. The LiDAR data was collected between April 16th and May 7th, 2007. The airport of operation was Waukegan Regional Airport, located in Waukegan, IL, north of Chicago, IL.

Mission Parameters for Cessna 402C (SN35) flown at Altitude 5,500 USFeet

LiDAR Sensor	Leica Geosystems ALS50 Phase 2+
Nominal Ground Sample Distance	0.91 meters
Field of View (scan angle)	30 deg.
Average Airspeed	120 Knots
Laser Pulse Rate	61,000 Hertz
Scan Rate	28 Hz
Average Altitude (MSL)	5,500 US Survey Feet

Flight mission Date and Times

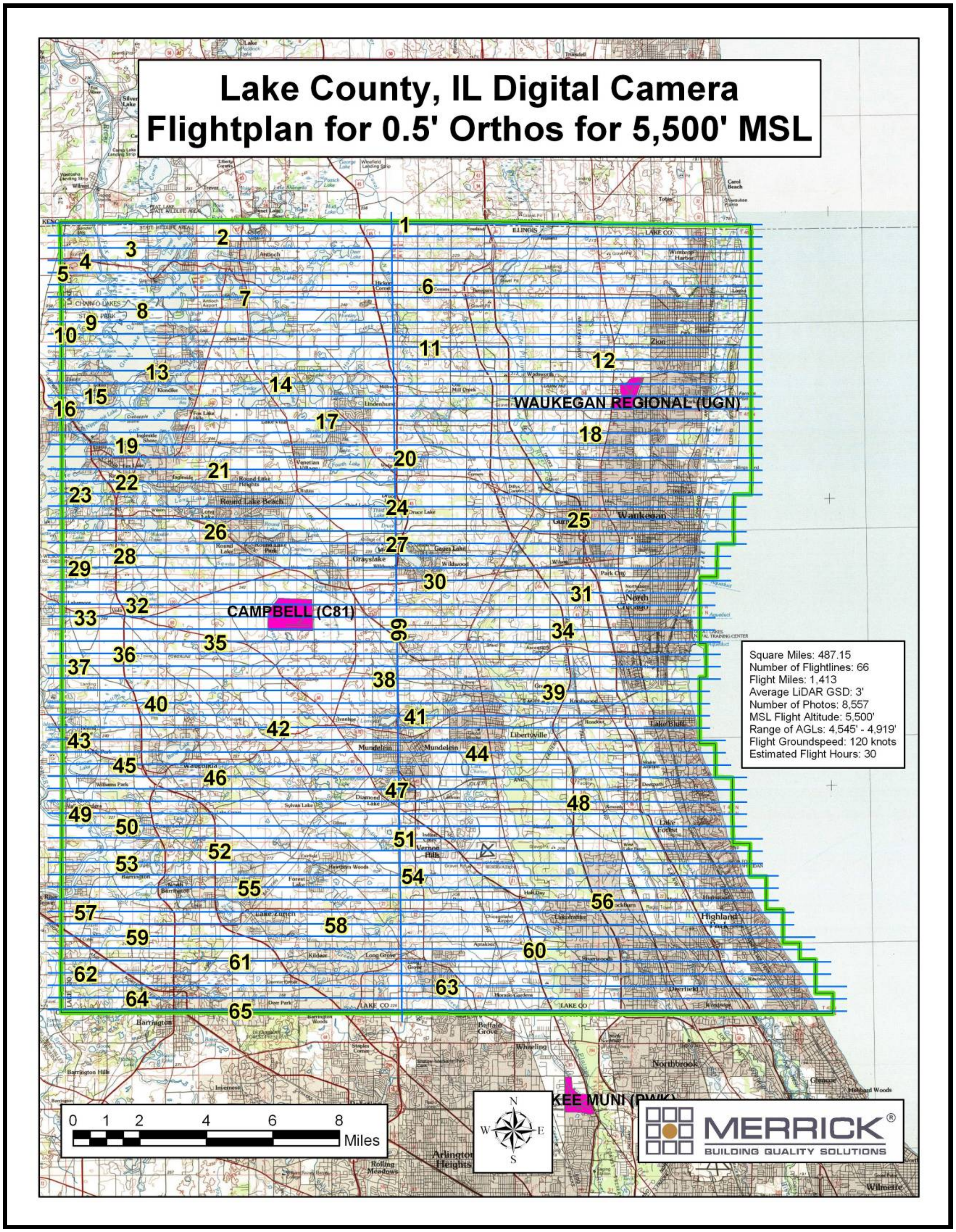
Mission	Date	Plane	Start Time GPS sec.	End Time GPS sec.	Length Time GPS sec.	Number of GNSS Solution Records
070416_A	April 16, 2007	SN35	145629.0	162590.0	16961.0	33921
070419_A	April 19, 2007	SN35	407150.5	421941.0	14790.5	29581
070420_A	April 20, 2007	SN35	490503.0	508944.0	18441.0	36884
070424_A	April 24, 2007	SN35	229707.0	237298.0	7591.0	15182
070428_A	April 28, 2007	SN35	572600.0	580173.0	7573.0	15146
070502_A	May 02, 2007	SN35	319973.0	338006.5	18033.5	36067
070507_B	May 07, 2007	SN35	157007.0	162302.0	5295.0	10590

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 (Airborne Base: LAK131 1A) and the auxiliary GPS Base Station (AUX Point), used for backup if there are any problems with the main GPS Base Station.

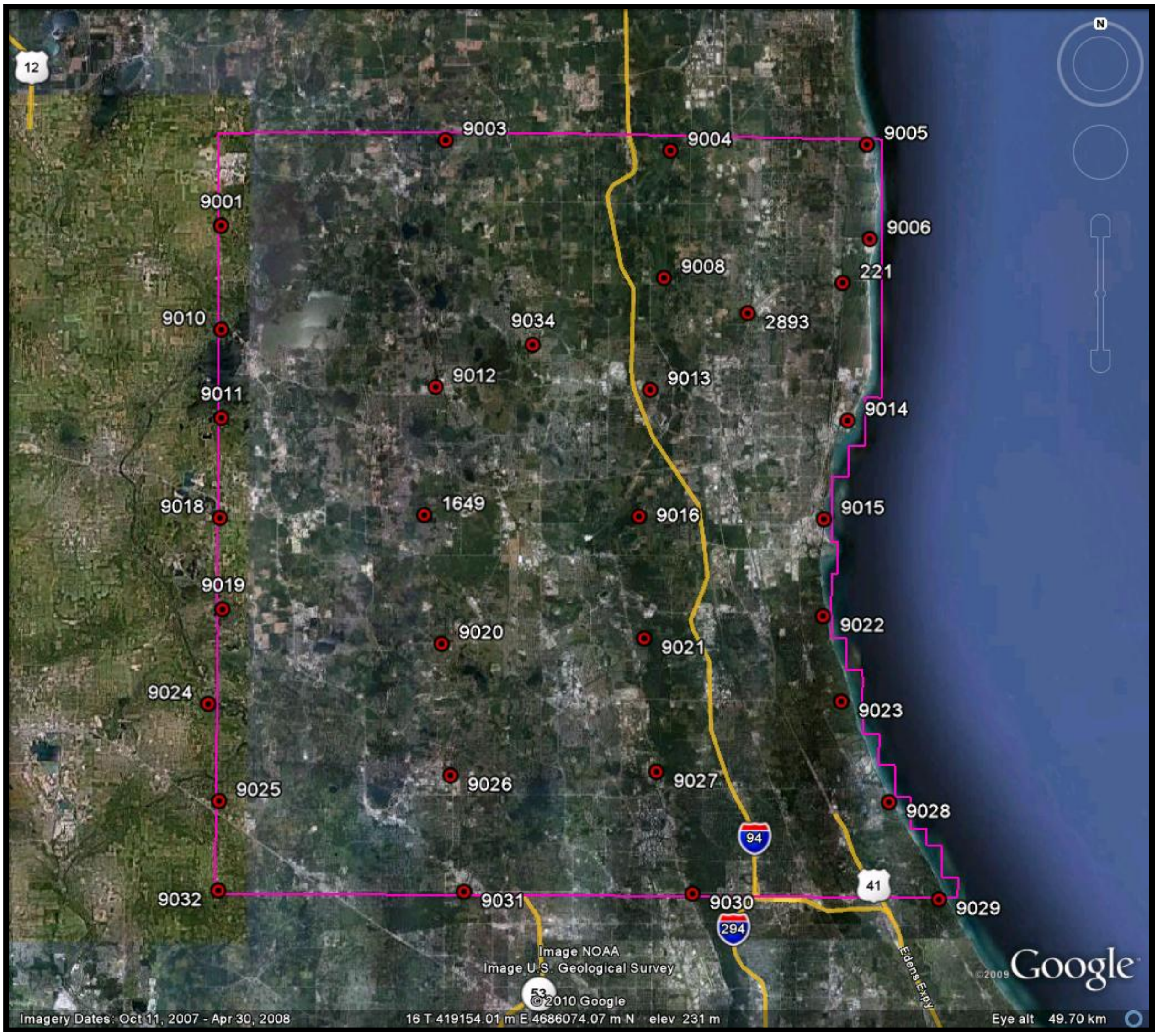
Pre-flight checks such as cleaning the sensor head glass are performed. A five minute INS initialization is conducted on the ground, with the aircraft engines running, prior to the flight mission. To establish fine-alignment of the INS GPS, ambiguities are resolved by flying within ten kilometers of 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



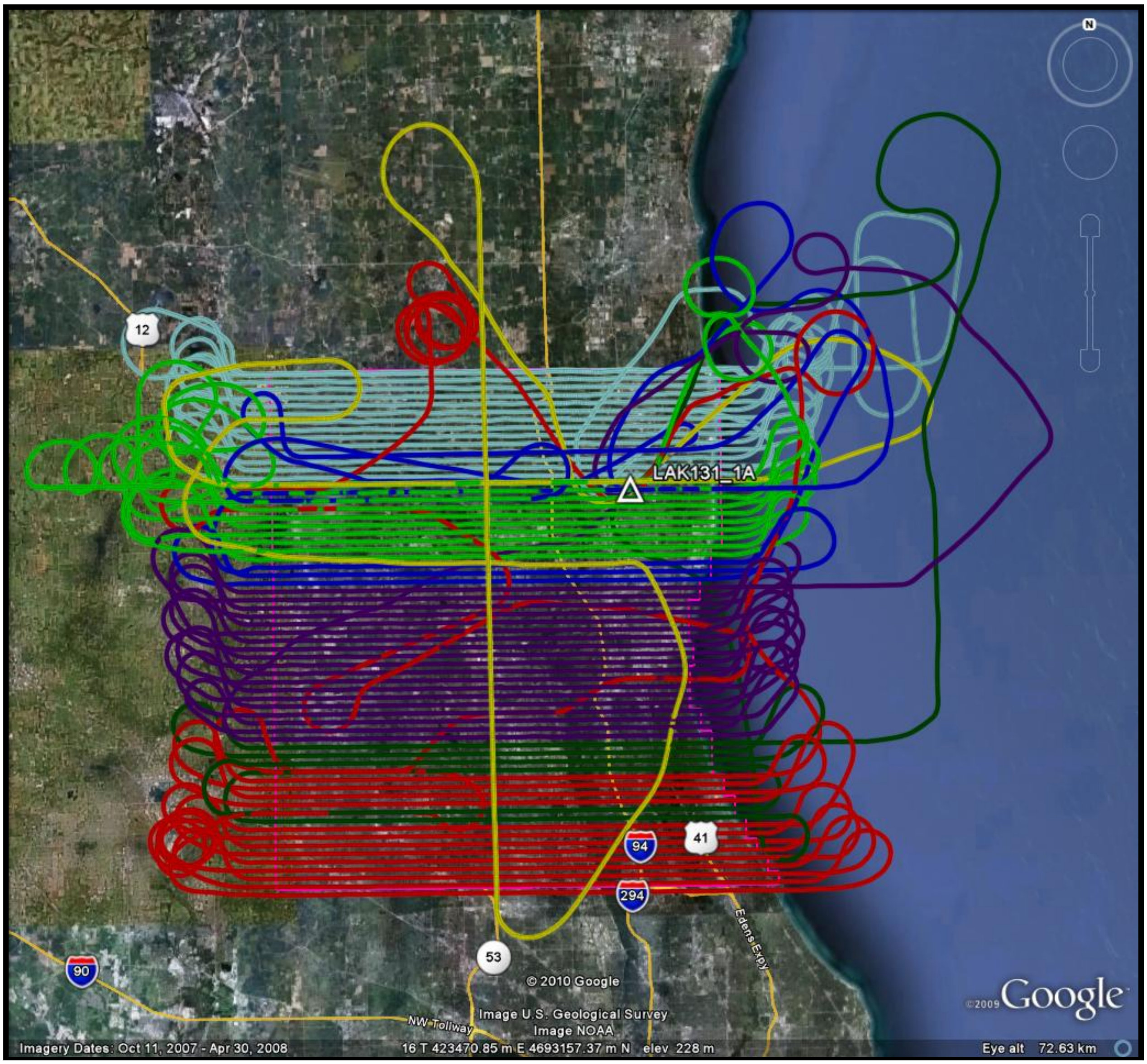
Note: The references to "feet" (') in the diagram above reflect US Survey Feet.

Ground Control LiDAR Points



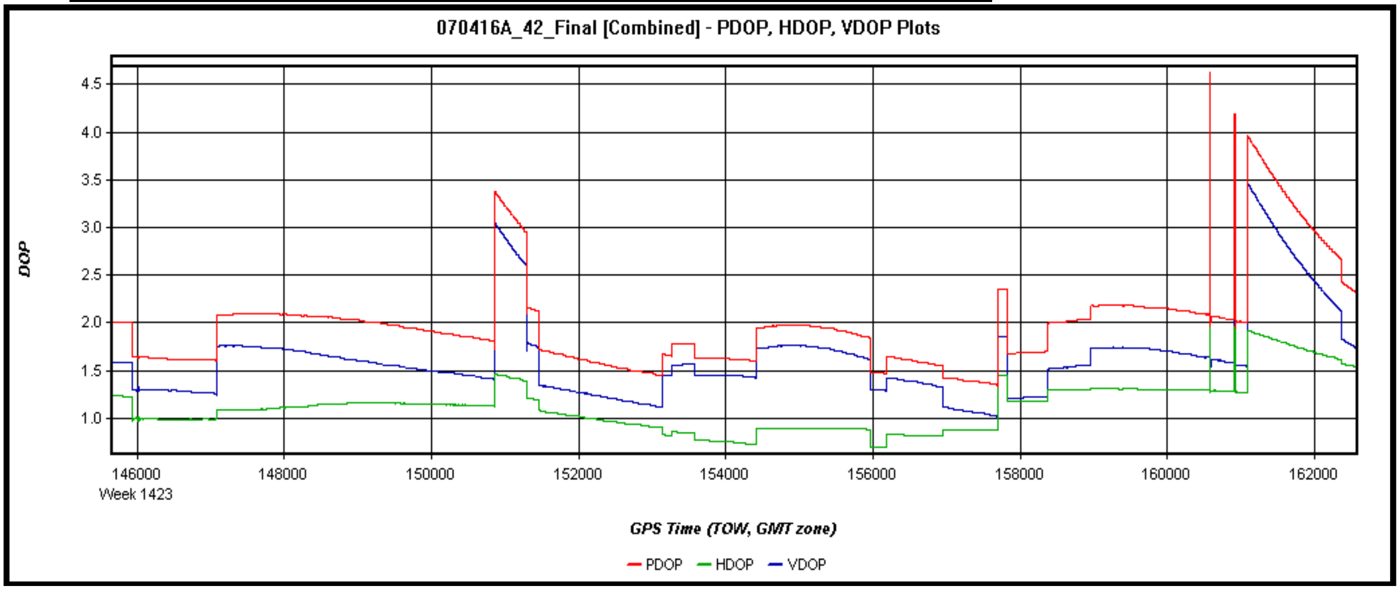
Actual Flight Lines Showing Base Station Location

Mission 070416 = **Cyan**
Mission 070419 = **Light Green**
Mission 070420 = **Purple**
Mission 070424 = **Dark Green**
Mission 070428 = **Blue**
Mission 070502 = **Red**
Mission 070507 = **Yellow**

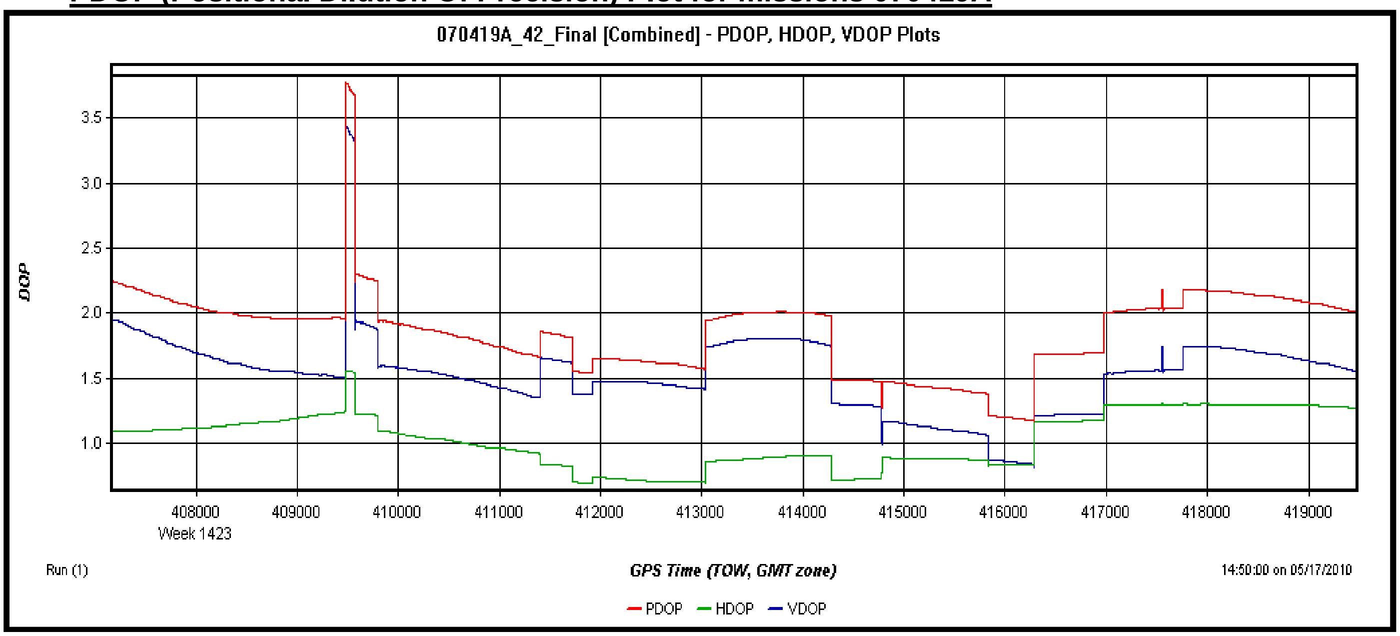


The following graphs show the mission by mission GPS PDOP (Positional Dilution Of Precision) Plot, Number of Satellites Plot, Forward-Reverse Plot

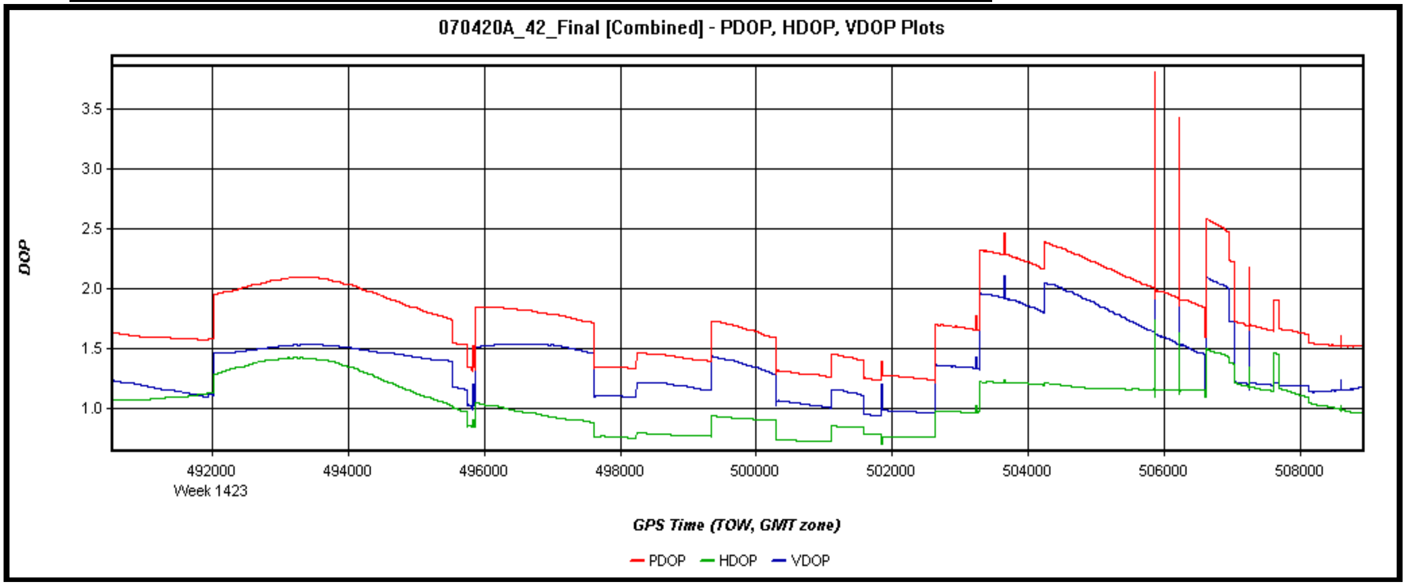
PDOP (Positional Dilution Of Precision) Plot for missions 070416A



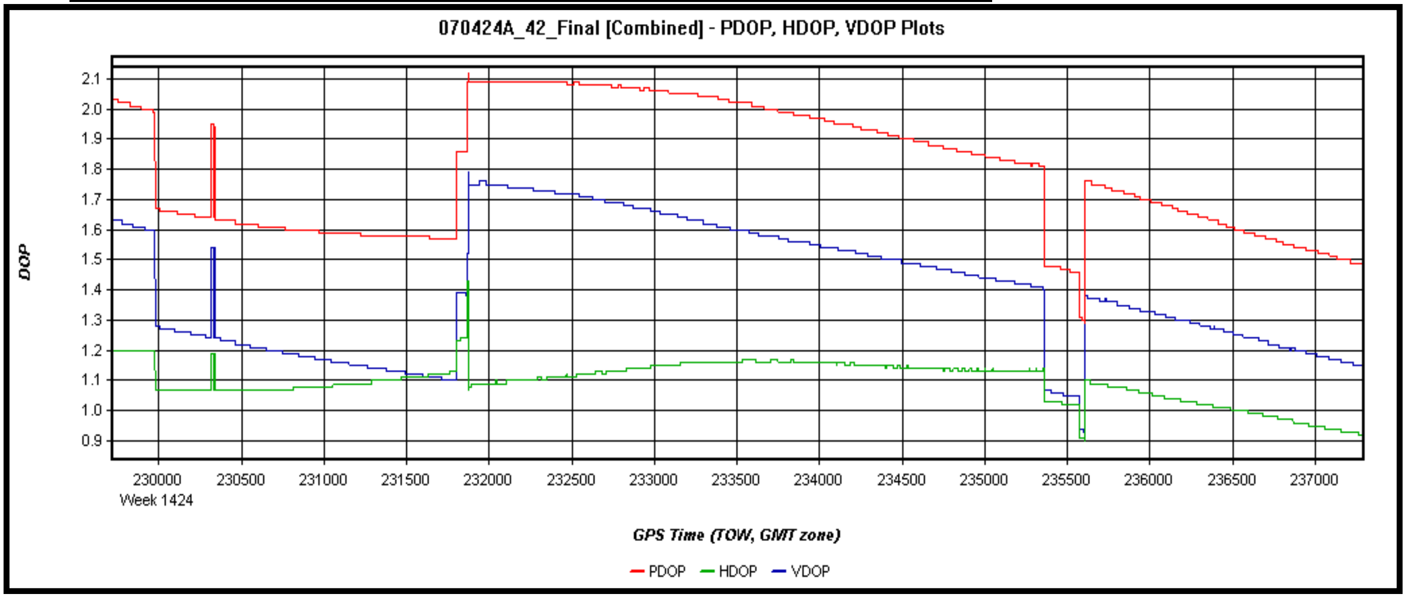
PDOP (Positional Dilution Of Precision) Plot for missions 070419A



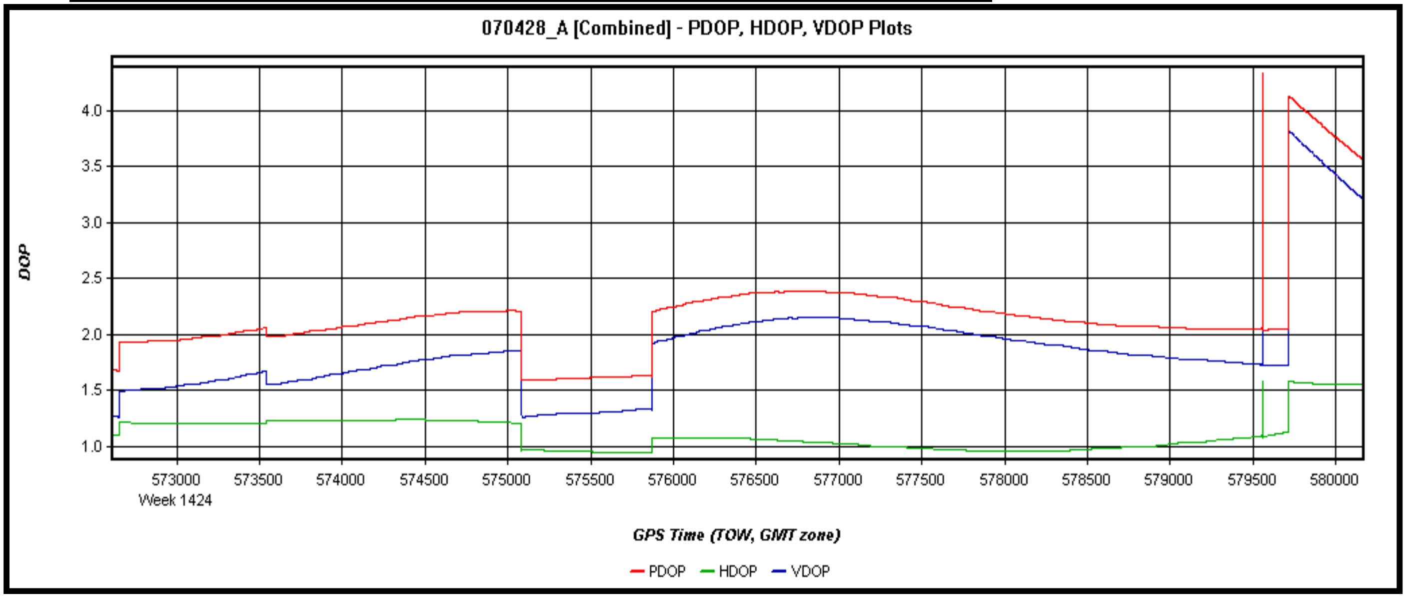
PDOP (Positional Dilution Of Precision) Plot for missions 070420A



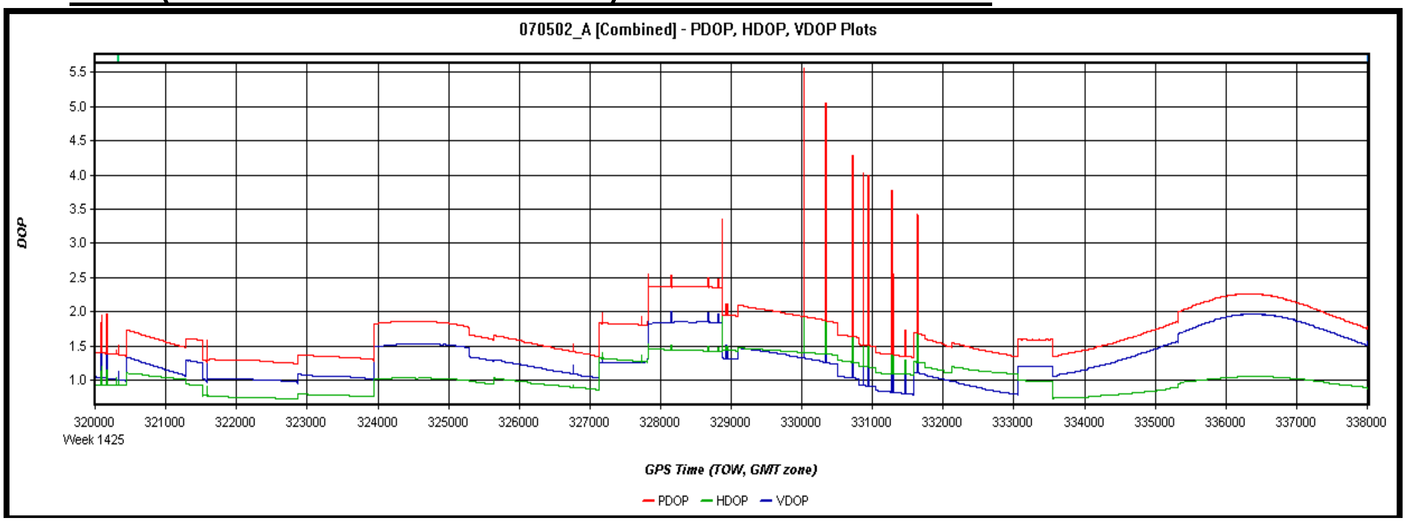
PDOP (Positional Dilution Of Precision) Plot for missions 070424A



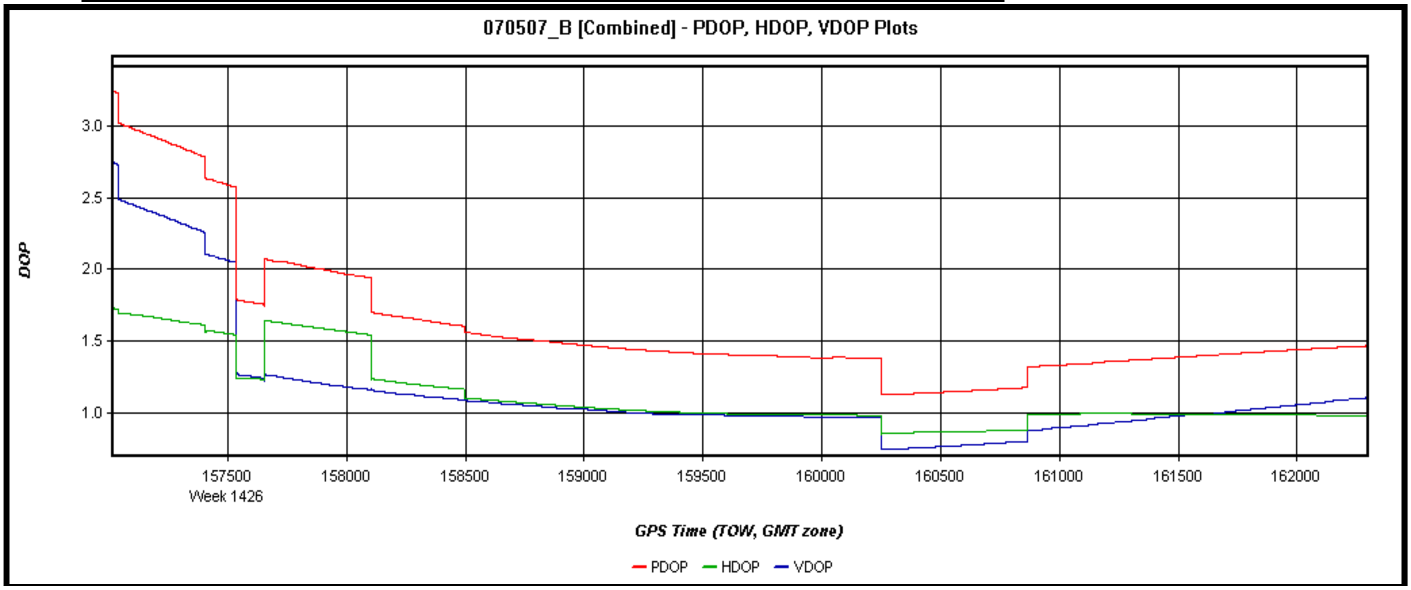
PDOP (Positional Dilution Of Precision) Plot for missions 070428A



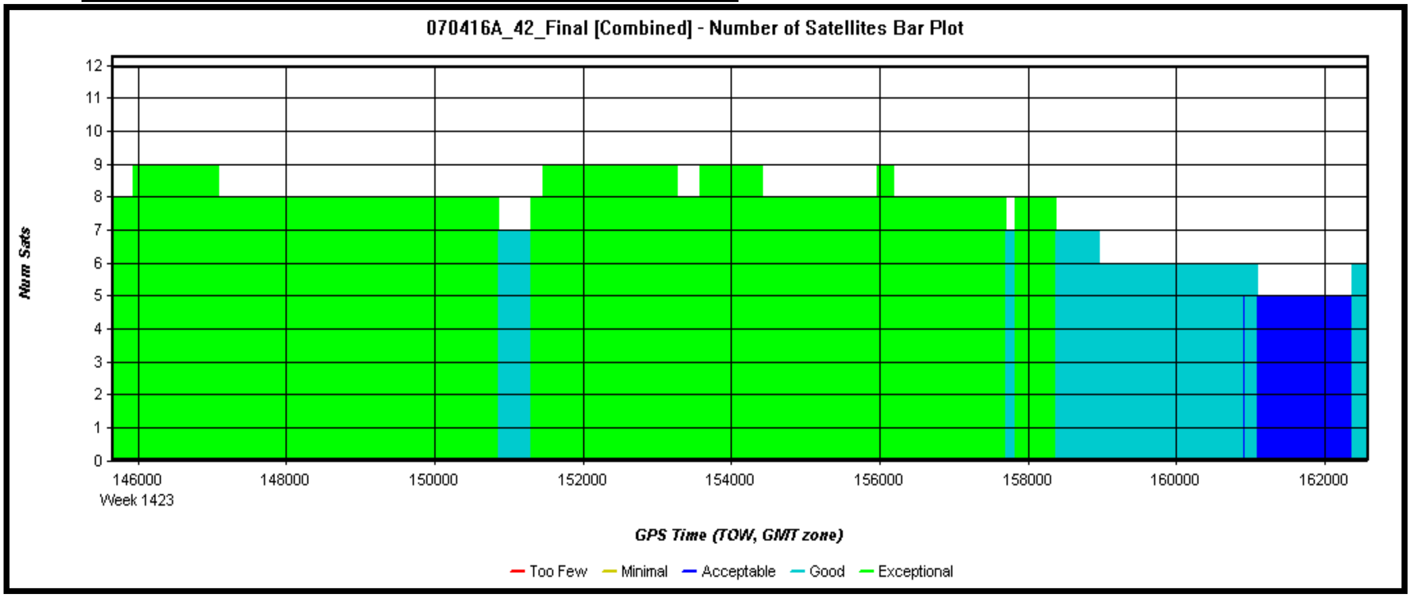
PDOP (Positional Dilution Of Precision) Plot for missions 070502A



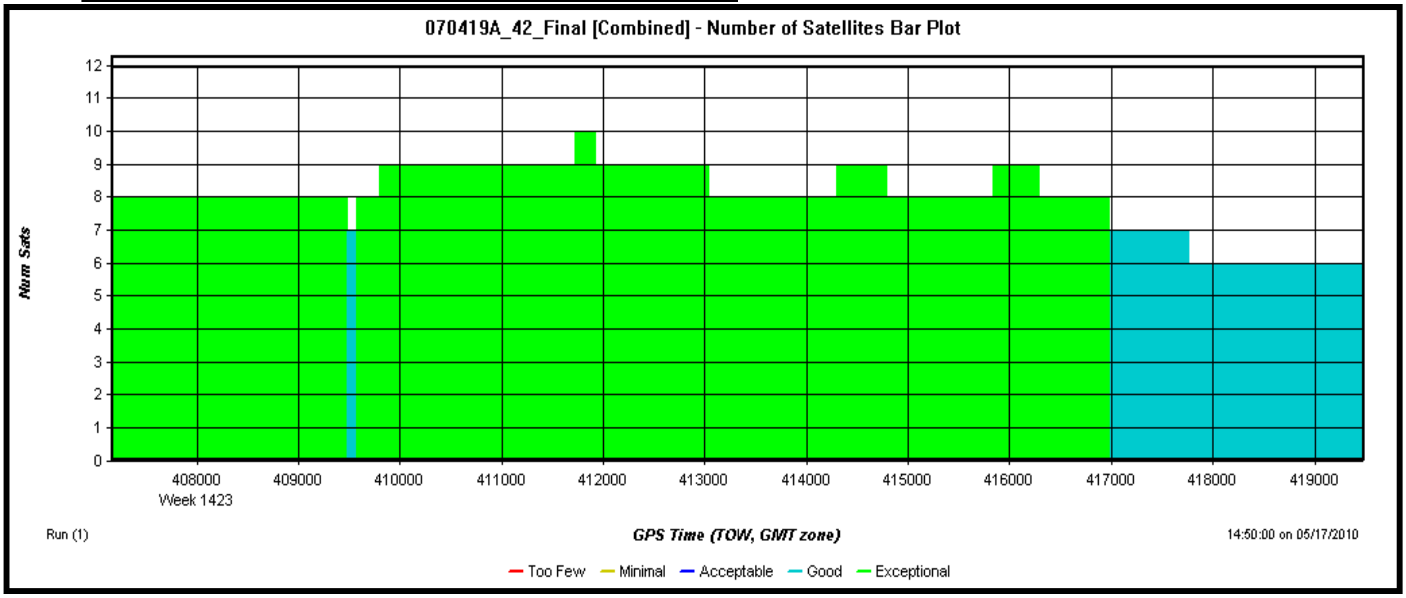
PDOP (Positional Dilution Of Precision) Plot for missions 070507B



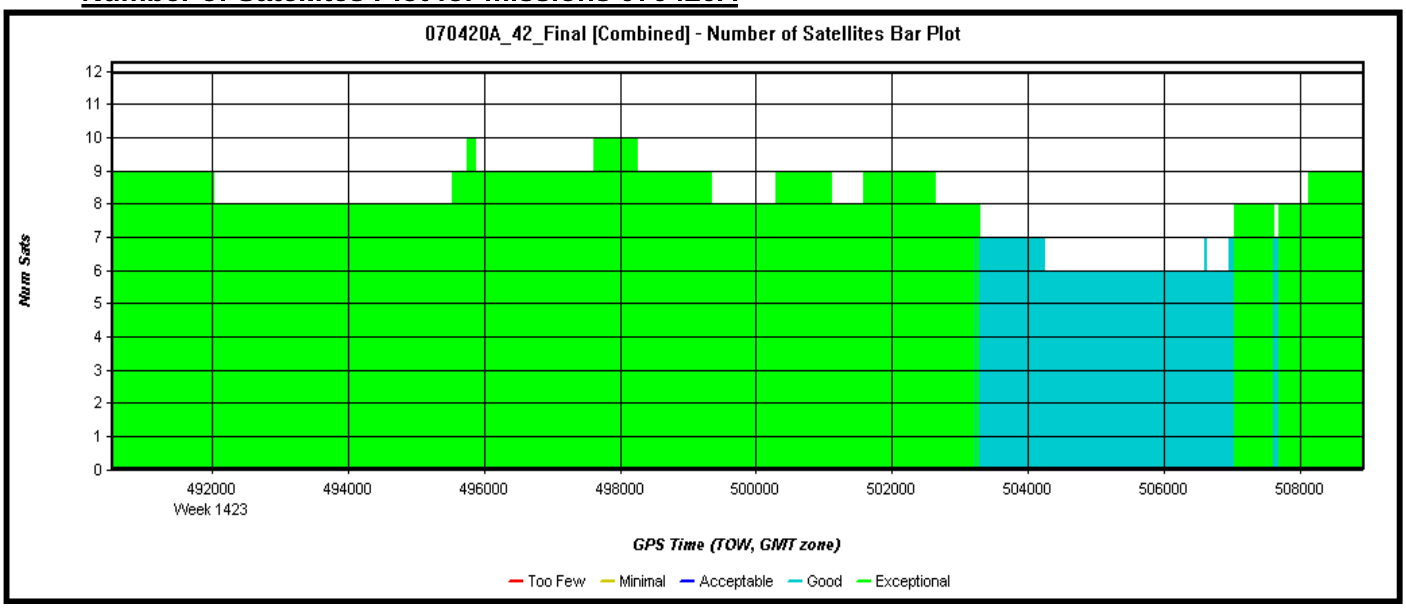
Number of Satellites Plot for missions 070416A



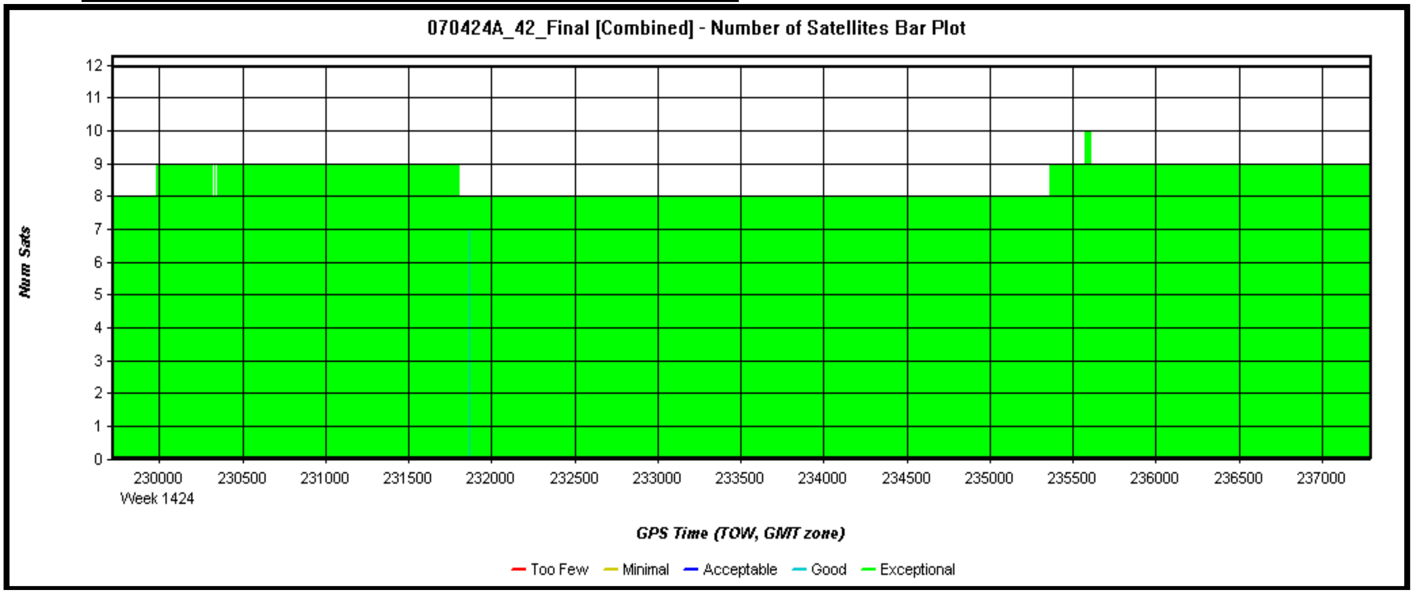
Number of Satellites Plot for missions 070419A



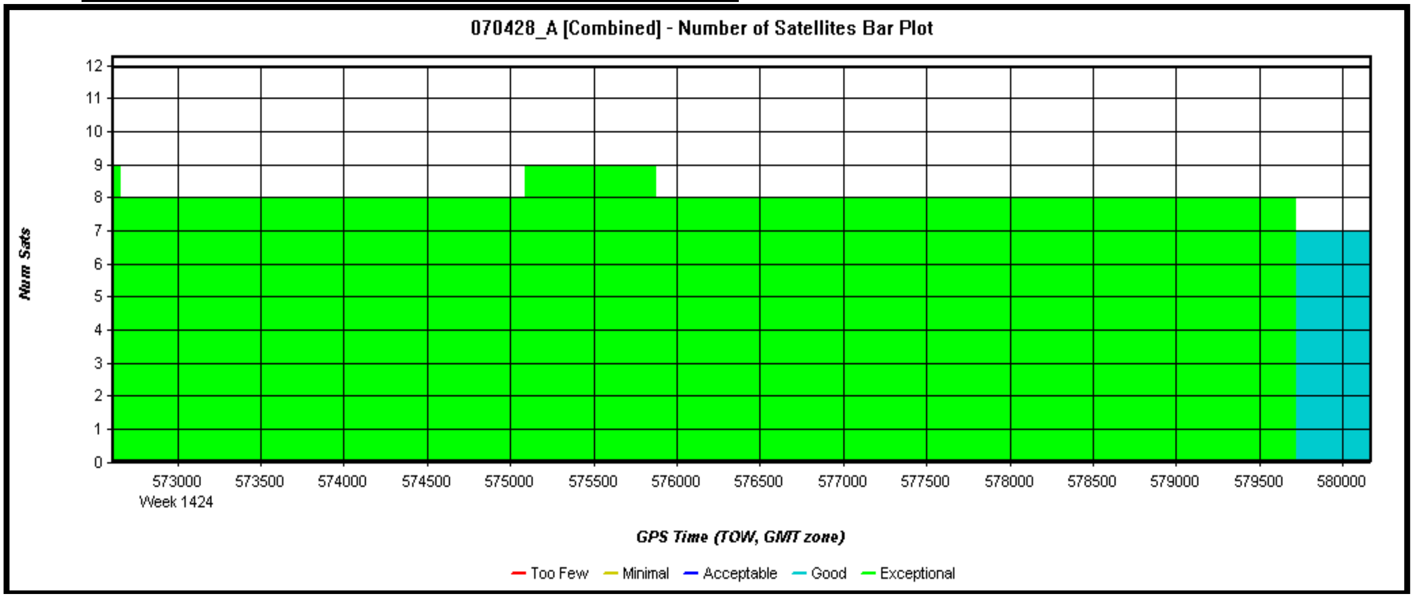
Number of Satellites Plot for missions 070420A



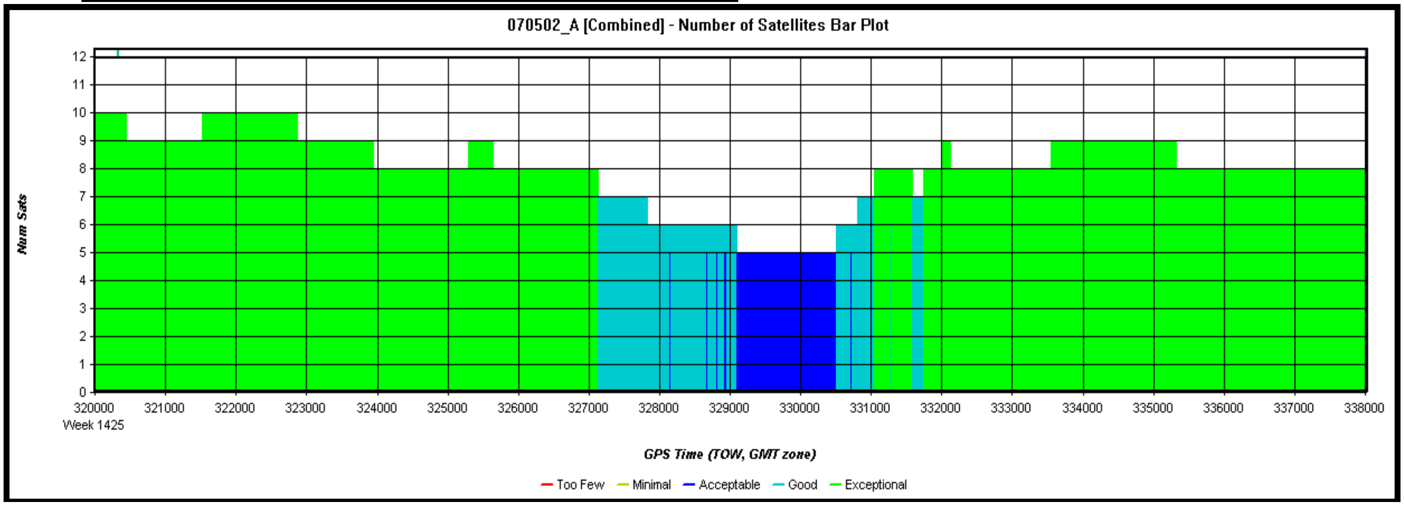
Number of Satellites Plot for missions 070424A



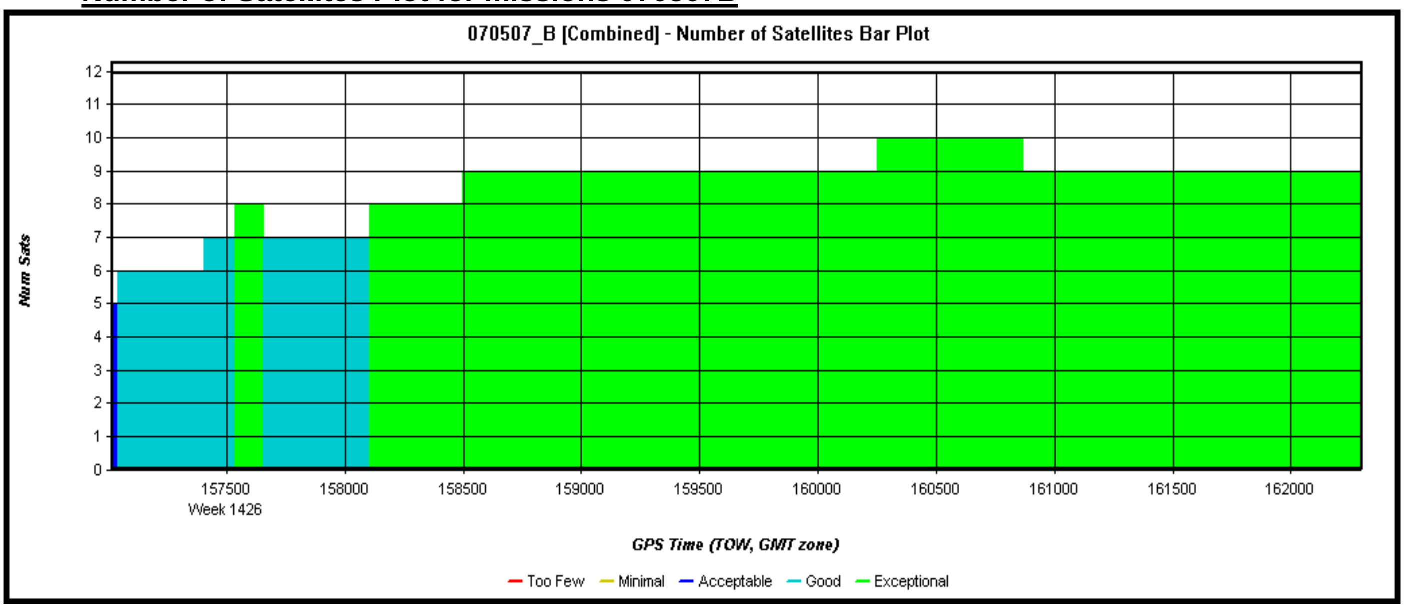
Number of Satellites Plot for missions 070428A



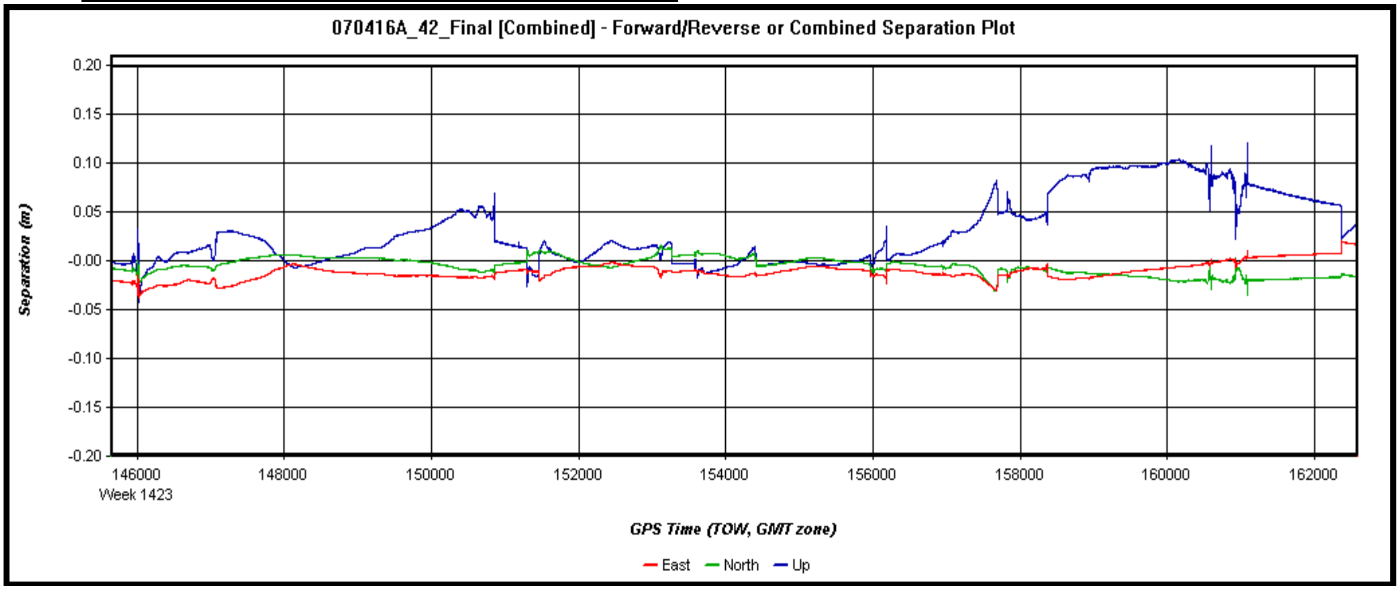
Number of Satellites Plot for missions 070502A



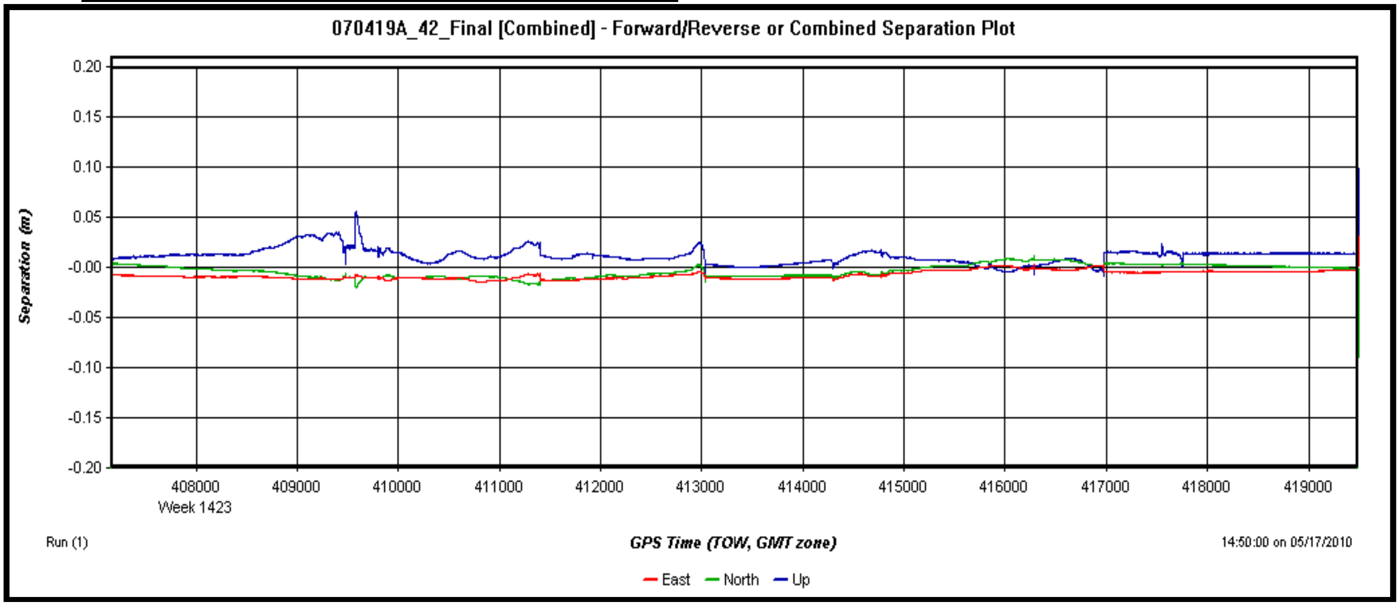
Number of Satellites Plot for missions 070507B



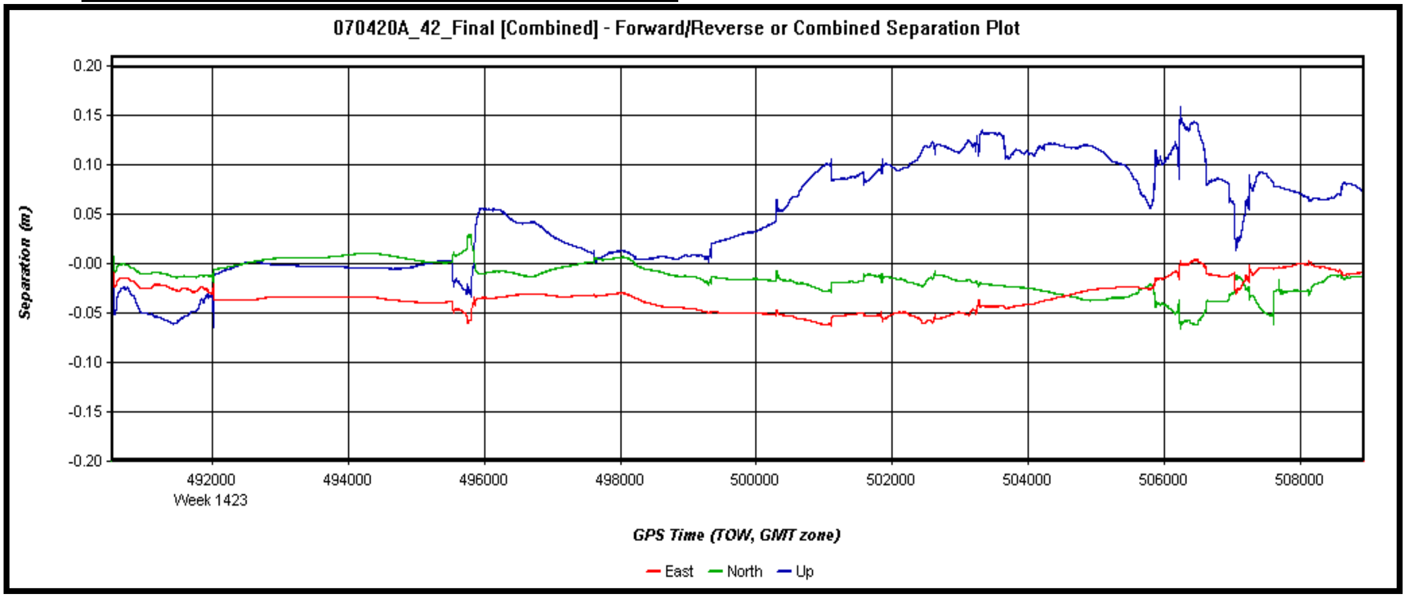
Forward-Reverse Plot for mission 070416A



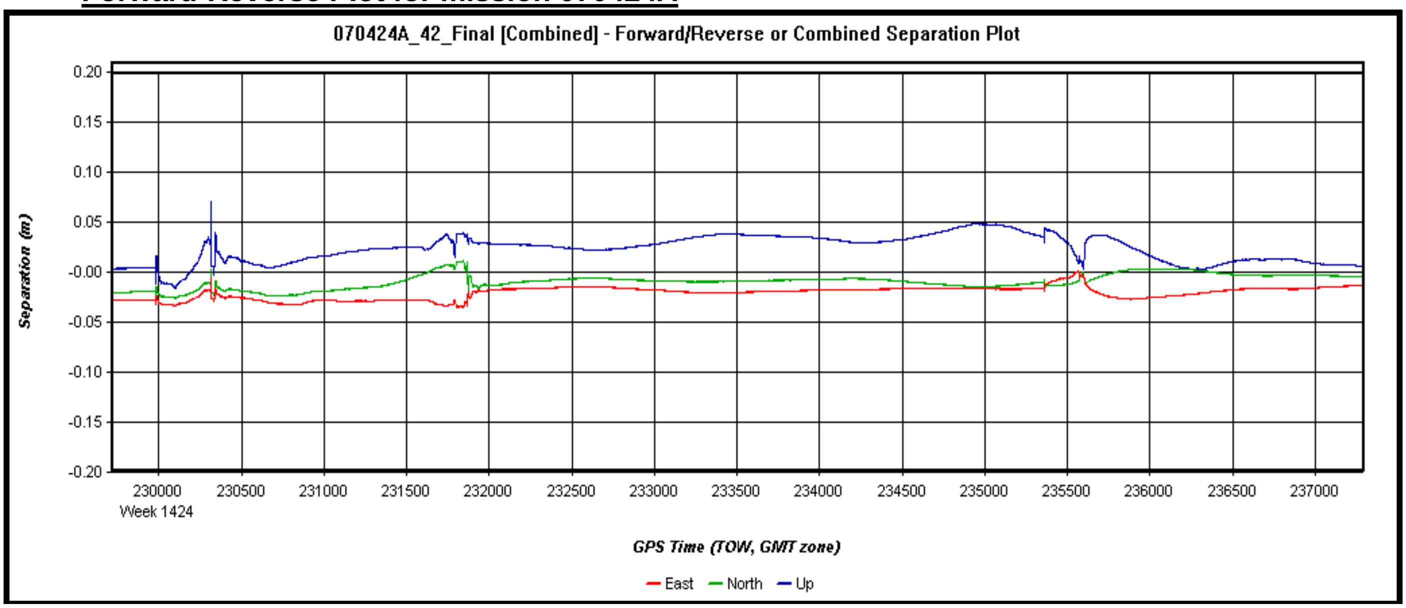
Forward-Reverse Plot for mission 070419A



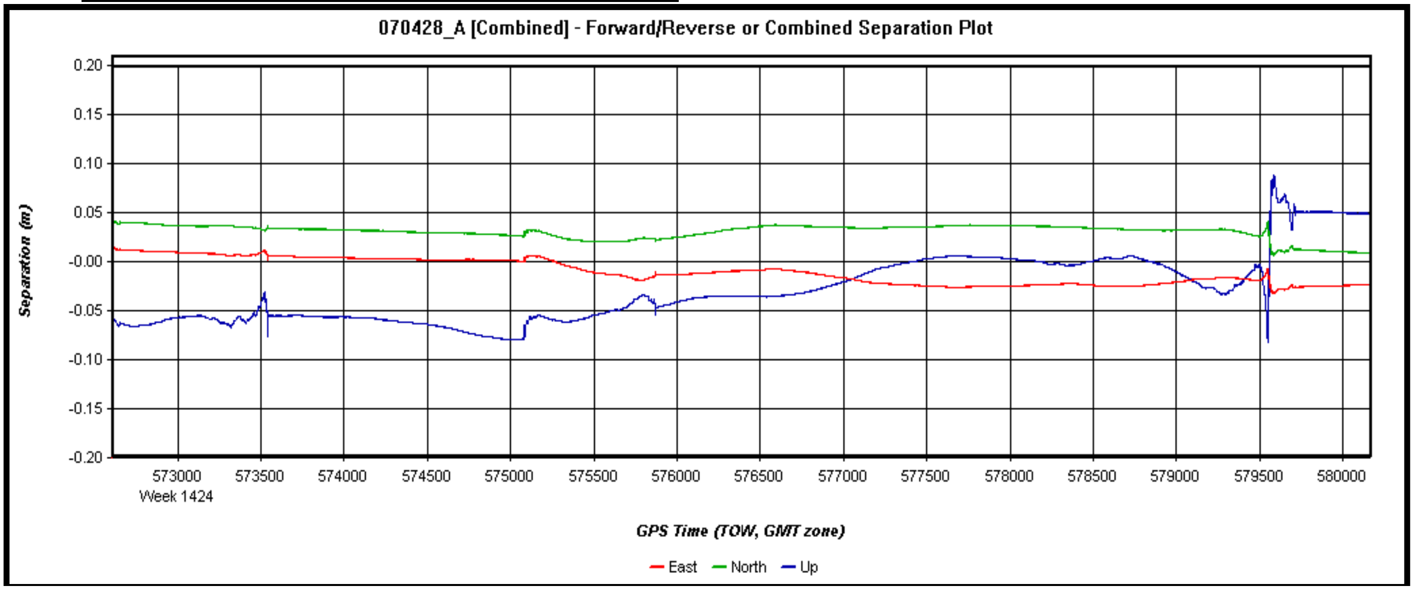
Forward-Reverse Plot for mission 070420A



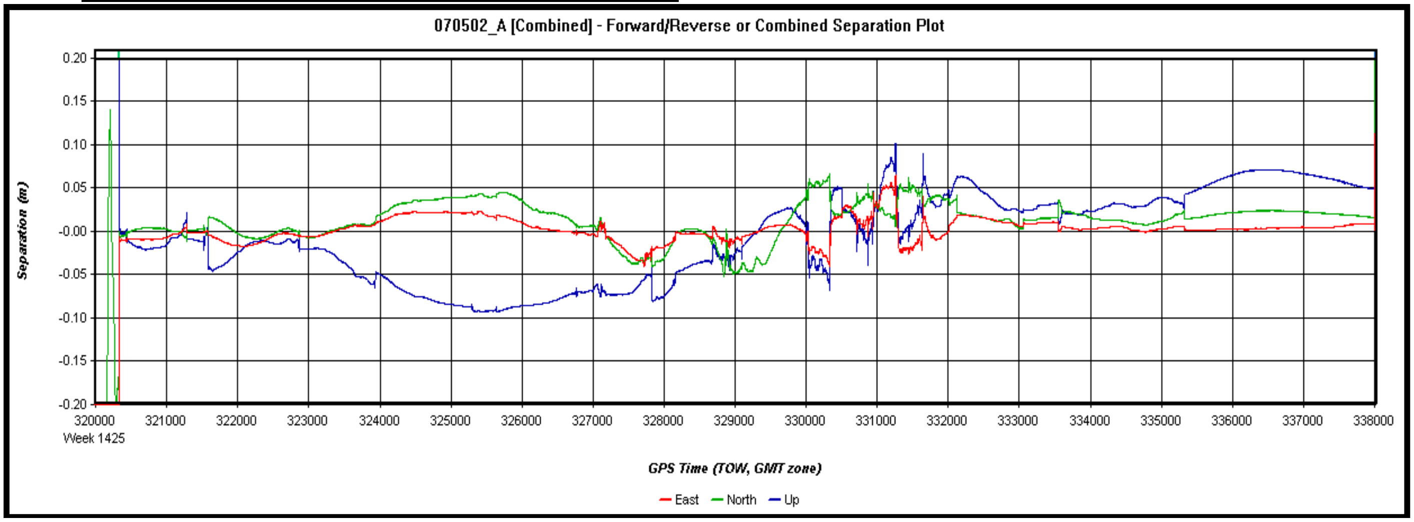
Forward-Reverse Plot for mission 070424A



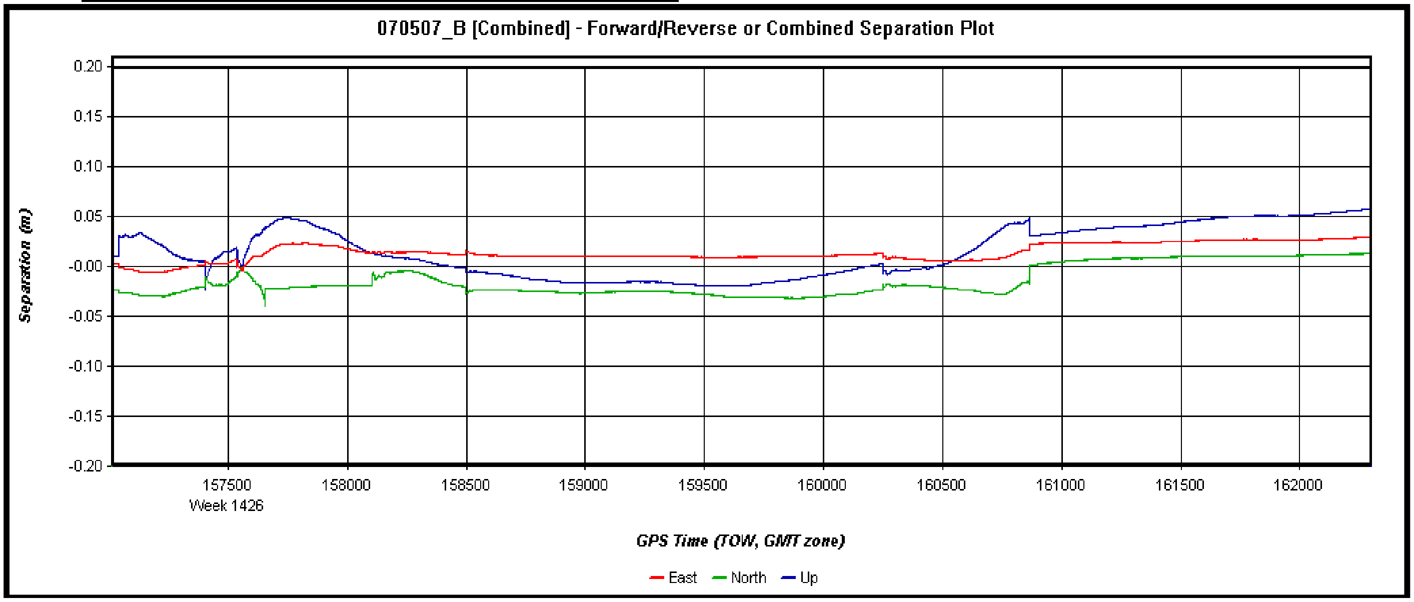
Forward-Reverse Plot for mission 070428A



Forward-Reverse Plot for mission 070502A



Forward-Reverse Plot for mission 070507B



LiDAR Data Processing

The airborne GPS data was post-processed using Novatel GrafNav 7.8. 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 Applanix POSPac version 4.2. 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 (Airborne Base: LAK131 1A) and the auxiliary GPS Base Station (AUX Point), 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 1.62 and checked with OPUS solutions from NGS (National Geodetic Survey).

See Spreadsheet Below for Airborne GPS Base Station information.

Lake County, IL Base Stations				
PT#	SPCS NAD 83(1997)	SPCS NAD 83(1997)	ELEV.	DESCRIPTION
	Illinois East-1201	Illinois East-1201	NAVD 88	
	NORTHING	EASTING	Z	
	US Survey Feet	US Survey Feet	US Survey Feet	
BASE	2094502.45	1107324.04	721.32	NGS STATION LAK131 1A
AUX	2094695.01	1110098.27	703.74	Auxillary Point
PT#	NAD 83(1997)	NAD83(1997)	ELLIPSOID	DESCRIPTION
	LATITUDE	LONGITUDE	MATCH	
	North	West	GEOID 03	
	Deg-Min-Sec	Deg-Min-Sec	US Survey Feet	
BASE	42°24'57.44976"N	87°52'39.22931"W	608.47	NGS STATION LAK131 1A
AUX	42°24'59.20314"N	87°52'02.23160"W	590.87	Auxillary Point

Ground Control Parameters

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983, 1997 adjustment (NAD83/97).
Coordinate System: State Plane Coordinate System (SPCS), Illinois East Zone 1201
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Geiod Model: Geoid 2003 (Geoid 03 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 existing ground control, collected for LiDAR check points. The existing ground control points (checkpoints) were confirmed and/or established and surveyed in April 2007 by American Surveying Consultants, P.C. (ASC), which is now known as American Surveying & Engineering, P.C. (ASE).

Project: Lake County LiDAR
Job#: 02016551
Date: May 2010

Coordinate System: Illinois State Plane
Zone: East -1201
Project Datum: NAD 1983(97)
Vertical Datum: NAVD88
Units: US Survey feet

Pt#	SPCS IL East	SPCS IL East	NAVD88	Description
Name	Northing	Easting	Elevation	
	Y	X	Z	
	USFeet	USFeet	USFeet	
221	1122988.45	2099595.25	593.48	Lake Control
1649	1054173.99	2060979.37	777.00	Lake Control
2893	1107324.04	2094502.45	721.29	Lake Control
9001	1020462.67	2108585.13	762.13	Lake Control
9003	1057426.05	2122831.58	826.30	Lake Control
9004	1094496.54	2121290.06	671.39	Lake Control
9005	1126920.12	2122499.24	589.28	Lake Control
9006	1127451.84	2106900.14	586.36	Lake Control
9008	1093508.17	2100256.81	670.92	Lake Control
9010	1020574.45	2091440.57	739.94	Lake Control
9011	1020648.77	2076851.40	752.32	Lake Control
9012	1055961.03	2082110.54	794.31	Lake Control
9013	1091314.22	2081783.34	732.27	Lake Control
9014	1123895.99	2076859.87	586.06	Lake Control
9015	1120066.78	2060557.12	589.72	Lake Control
9016	1089546.23	2060876.56	706.92	Lake Control
9018	1020474.60	2060363.29	764.66	Lake Control
9019	1020968.22	2045289.25	751.31	Lake Control
9020	1057117.41	2039759.86	841.17	Lake Control
9021	1090497.40	2040762.51	654.13	Lake Control
9022	1119967.32	2044545.00	654.10	Lake Control

9023	1123061.57	2030440.11	660.24	Lake Control
9024	1018682.06	2029658.10	734.54	Lake Control
9025	1020538.26	2013623.44	782.25	Lake Control
9026	1058658.94	2018046.34	833.67	Lake Control
9027	1092591.87	2018735.20	666.91	Lake Control
9028	1130987.91	2013843.01	670.15	Lake Control
9029	1139336.50	1997789.72	648.60	Lake Control
9030	1098638.51	1998632.37	652.14	Lake Control
9031	1060964.19	1998833.63	780.71	Lake Control
9032	1020452.00	1998872.09	801.07	Lake Control
9034	1071901.00	2089137.73	769.24	Lake Control

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 Lake County

Project File: Lake County, IL
Project Unit: USFeet
Date: Tuesday, May 18, 2010
Vertical Accuracy Objective
Requirement Type:Accuracy(z)
Accuracy(z) Objective: 0.6
Confidence Level: 0.95
Control Points in Report: 32
Elevation Calculation Method:Interpolated from TIN
Control Points with LiDAR Coverage: 32
Control Points with Required Accuracy (+/- 0.60): 32
Percent of Control Points with Required Accuracy (+/- 0.60): 100
Average Control Error Reported: -0.03
Maximum (highest) Control Error Reported: 0.49
Median Control Error Reported: -0.07
Minimum (lowest) Control Error Reported: -0.58
Standard deviation (sigma) of Z for sample:0.3
RMSE of Z for sample (RMSE(z)): 0.29 PASS
FGDC/NSSDA Vertical Accuracy (Accuracy(z)): 0.57 PASS
NSSDA Achievable Contour Interval: 1
ASPRS Class 1 Achievable Contour Interval: 0.9
NMAS Achievable Contour Interval: 1

Control Point Id	Control Pt. X(East) USFeet	Control Pt. Y(North) USFeet	Coverage USFeet	Control Pt. Z(Elev) USFeet	from LiDAR Z(Elev) USFeet	**Z Error** USFeet	Min Z USFeet	Median Z USFeet	Max Z USFeet
9028	1130987.91	2013843.01	Yes	670.15	669.57	-0.58	669.44	669.70	669.72
9006	1127451.84	2106900.14	Yes	586.36	585.86	-0.50	585.83	585.93	586.15
9021	1090497.40	2040762.51	Yes	654.13	653.63	-0.50	653.33	653.59	653.77
9029	1139336.50	1997789.72	Yes	648.60	648.11	-0.49	647.88	648.24	648.33
9022	1119967.32	2044545.00	Yes	654.10	653.69	-0.41	653.63	653.63	653.75
9014	1123895.99	2076859.87	Yes	586.06	585.72	-0.34	585.61	585.74	585.96
9025	1020538.26	2013623.44	Yes	782.25	781.92	-0.33	781.79	781.83	782.08
9016	1089546.23	2060876.56	Yes	706.92	706.71	-0.21	706.51	706.69	706.88
9005	1126920.12	2122499.24	Yes	589.28	589.08	-0.20	589.05	589.10	589.42
9026	1058658.94	2018046.34	Yes	833.67	833.49	-0.18	833.44	833.49	833.54

9027	1092591.87	2018735.20	Yes	666.91	666.73	-0.18	666.66	666.69	666.84
9031	1060964.19	1998833.63	Yes	780.71	780.54	-0.17	780.33	780.46	780.69
9023	1123061.57	2030440.11	Yes	660.24	660.10	-0.13	660.07	660.26	660.26
9030	1098638.51	1998632.37	Yes	652.14	652.02	-0.12	651.92	652.00	652.29
9032	1020452.00	1998872.09	Yes	801.07	800.98	-0.09	800.94	801.00	801.07
9015	1120066.78	2060557.12	Yes	589.72	589.65	-0.07	589.21	589.62	589.83
9020	1057117.41	2039759.86	Yes	841.17	841.10	-0.07	841.07	841.09	841.12
9018	1020474.60	2060363.29	Yes	764.66	764.71	0.05	764.52	764.65	764.77
9024	1018682.06	2029658.10	Yes	734.54	734.59	0.05	734.49	734.52	734.66
221	1122988.45	2099595.25	Yes	593.48	593.55	0.07	593.55	593.59	593.64
9034	1071901.00	2089137.73	Yes	769.24	769.38	0.14	769.31	769.32	769.52
9010	1020574.45	2091440.57	Yes	739.94	740.09	0.15	740.00	740.14	740.25
9019	1020968.22	2045289.25	Yes	751.31	751.48	0.17	751.38	751.40	751.73
9001	1020462.67	2108585.13	Yes	762.13	762.39	0.26	762.38	762.39	762.41
9011	1020648.77	2076851.40	Yes	752.32	752.59	0.27	752.01	752.42	752.62
1649	1054173.99	2060979.37	Yes	777.00	777.28	0.28	777.24	777.30	777.31
9003	1057426.05	2122831.58	Yes	826.30	826.60	0.30	826.51	826.66	826.75
9012	1055961.03	2082110.54	Yes	794.31	794.61	0.30	794.47	794.60	794.63
9013	1091314.22	2081783.34	Yes	732.27	732.58	0.31	732.53	732.56	732.60
9004	1094496.54	2121290.06	Yes	671.39	671.71	0.32	671.61	671.62	671.81
9008	1093508.17	2100256.81	Yes	670.92	671.28	0.36	670.76	671.12	671.37
2893	1107324.04	2094502.45	Yes	721.29	721.78	0.49	721.71	721.86	722.54

LiDAR Relative Accuracy Assessment and LiDAR Spatial Points Distribution Assessment

LiDAR Density

- An array with cell size equal to Nominal Point Spacing (NPS) multiplied by 2 will be laid over the data. The NPS for Lake County is 3 feet (0.91 meters), resulting in a 6 foot (1.83 meter) cell size. At least 90% of cells will contain one (1) first-return LiDAR point.
- The MARS® approach: Used the LiDAR Spatial Distribution Verification Grid with a cell size of 6 feet (i.e., 36 square feet) using only first-return data, on all classifications. The grid was clipped to the project boundary. The resultant number: 96.57% of cells contained at least one (1) LiDAR point.

Relative Accuracy

- Elevation difference between flightlines in the areas of overlap shall be ≤ 0.10m RMSEz.

The MARS® approach: Used the Flightline Separation Grid with a cell size of 3 feet (0.91 meters) using ground classified data. The grid was clipped to the project boundary. The maximum vertical separation between two or more flightlines was determined at the X,Y of the pixel centroid. This comparison was done between the TIN facet (plane) of each flightline. This distance was stored in a float grid and an overall RMSEz was calculated from all pixels in areas of flightline overlap. The resultant number: 0.0816 meters RMSEz (0.2677 feet RMSEz).

LiDAR CALIBRATION

Note: All figures represented on pages 25-30 are for general illustration purposes, and are not examples derived from actual Lake County 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.

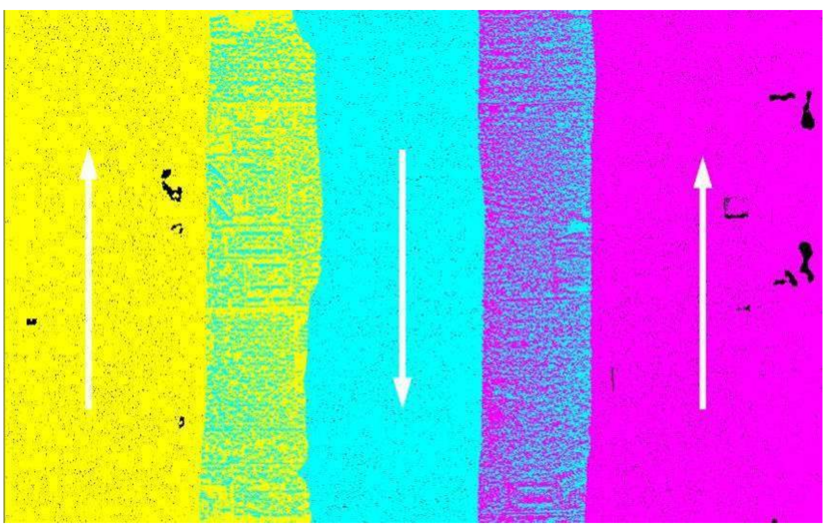


Figure 1: Flight pattern required for calibration

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.

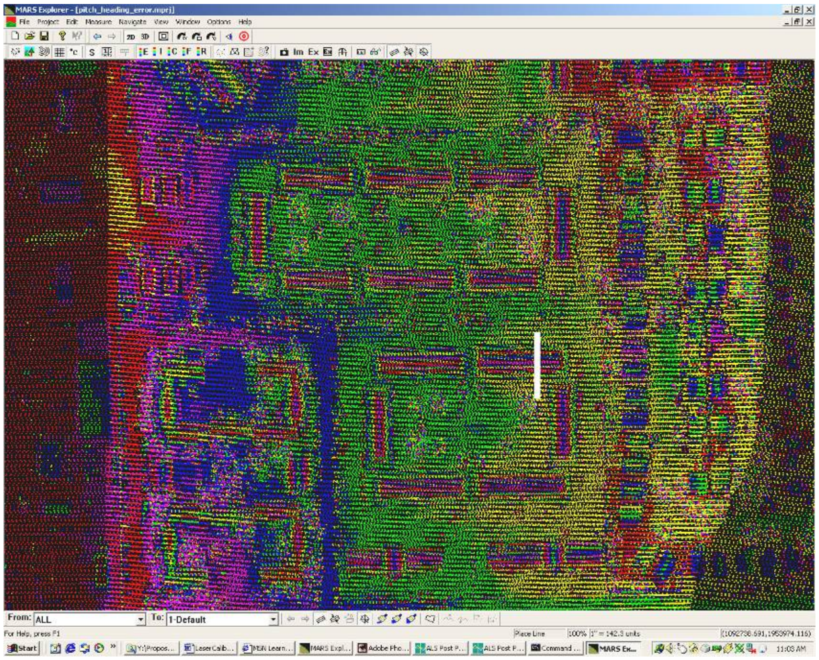


Figure 2: Orthographic view with profile line

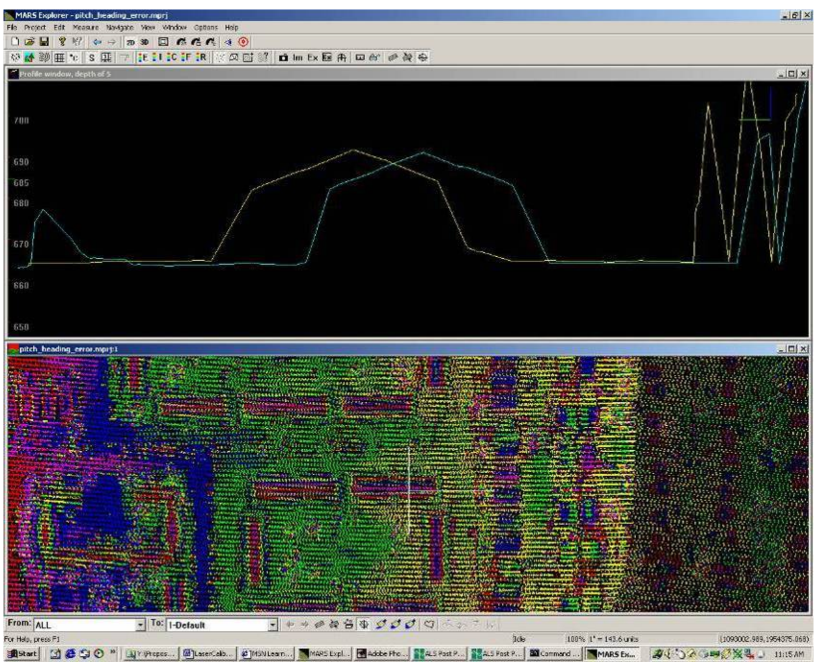


Figure 3: Profile view of misalignment

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).

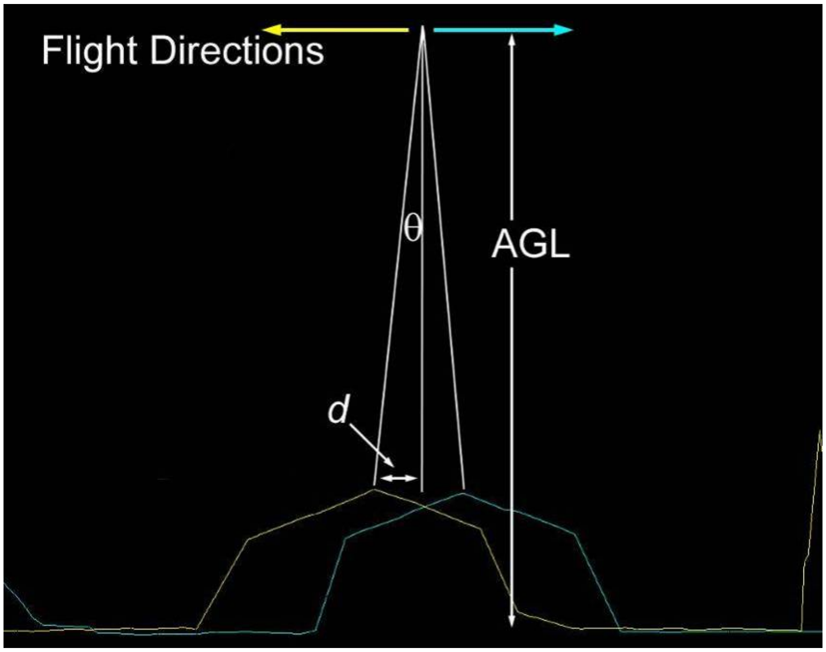


Figure 4: Adjusting pitch

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…

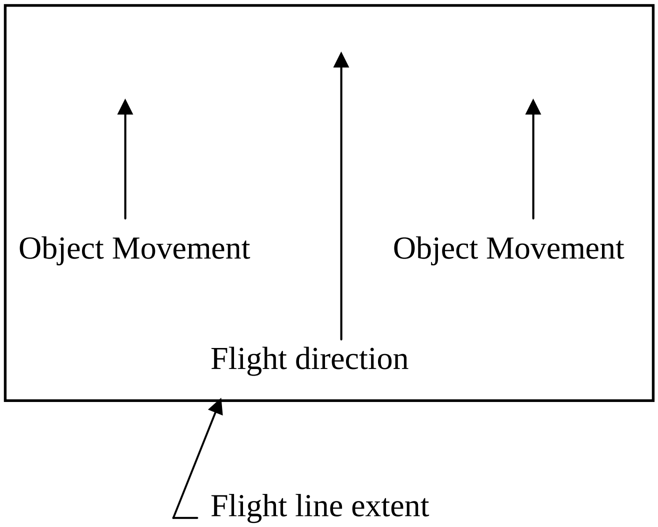
$$\theta = \frac{\arctan\left(\frac{d}{AGL}\right)}{57.2958}$$

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.

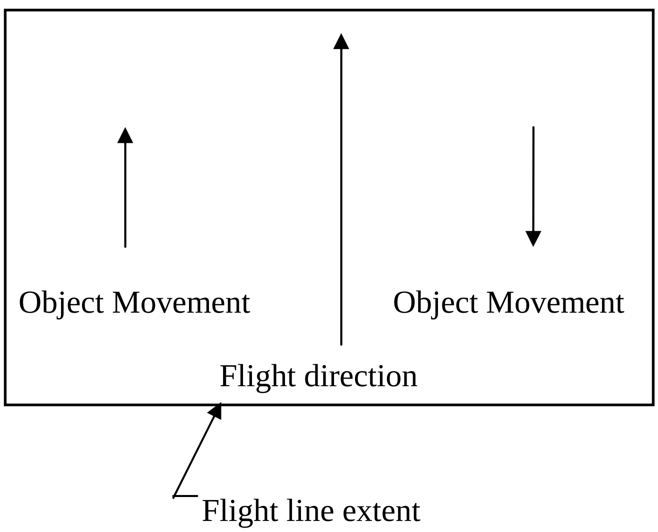
The next issue to resolve, before actually changing the pitch value, is to determine if this shift is at all due to an incorrect heading value, since heading will move data in the direction of flight also. The difference is that heading rotates the data, meaning that when heading is changed, objects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

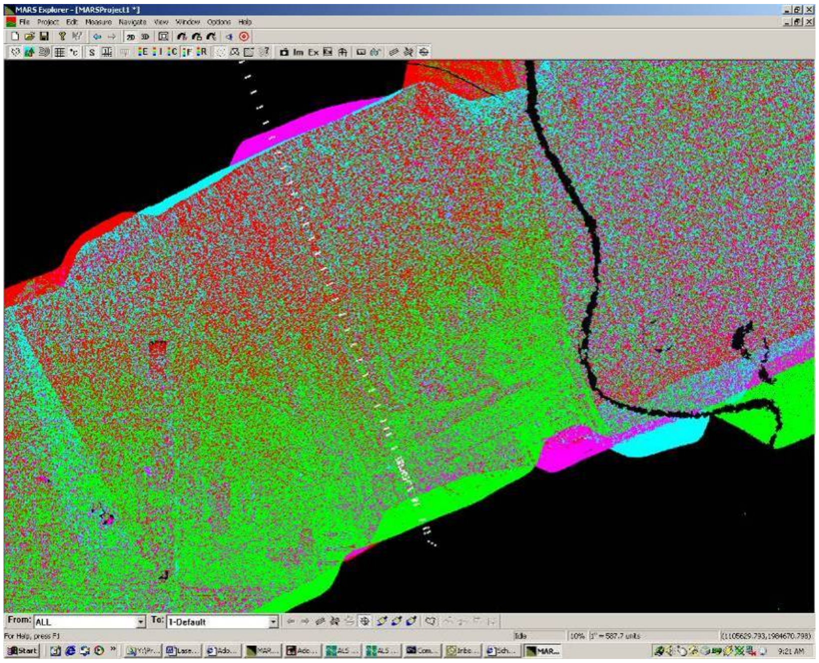


Figure 7: The truth survey

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)

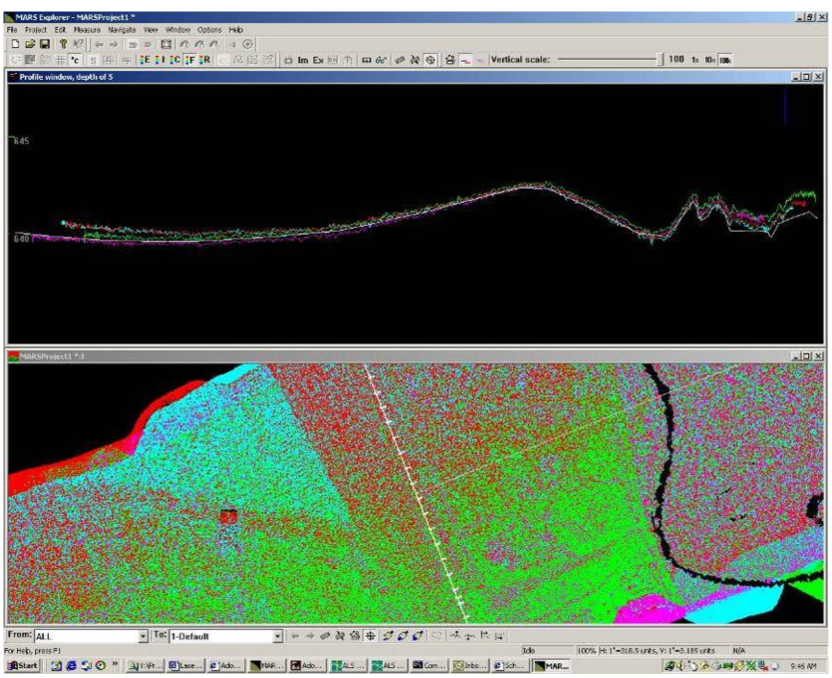


Figure 8: Profile view of calibration flight lines

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)

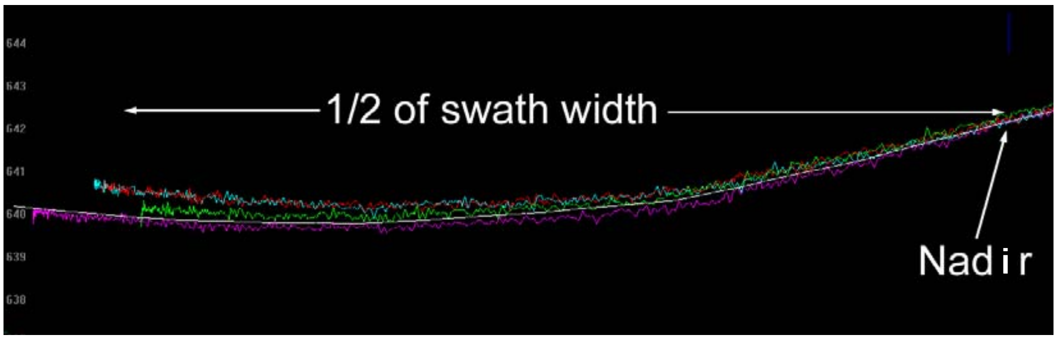


Figure 9: Half of calibration profile

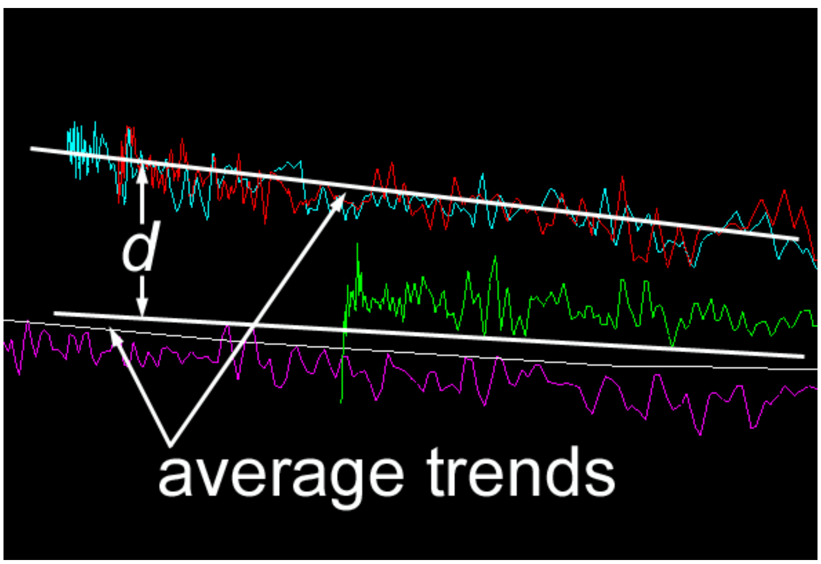


Figure 10: Differences in average roll trends

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:

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

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-from-surface (≥0' below) auto-filter is run to re-class noise to Class 7.

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

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

DIGITAL ELEVATION MODEL (DEM)

Raster Grid Development

Merrick exports the Class 2 (ground) LiDAR points 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.

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.

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

Waterbodies

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