Central Michigan University
LiDAR Mapping Report

Portions of Bay, Arenac and Iosco Counties, Michigan

Prepared for:

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Merrick & Company Job Number: 02016602

EXECUTIVE SUMMARY

In the spring of 2010, Merrick & Company (Merrick) was contracted by Central Michigan University (CMU) to execute a LiDAR (**Li**ght **D**etection **A**nd **R**anging) survey for portions of Bay, Arenac and Losco Counties, located in east central Michigan west of lake Huron. Please note that Charity Island and Little Charity Island are not included in the project area. The purpose of the project is to produce accurate, high-resolution data for research and analysis. Merrick obtained LiDAR data over approximately 1,400 square miles. The LiDAR was post-processed to meet a relative accuracy for the LiDAR point cloud data of <=7cm RMSEZ within individual swaths; <=10cm RMSEz within swath overlap (between adjacent swaths). Vertical accuracy of NSSDA $RMSE_Z$ = 15cm (NSSDA $Accuracy_Z$ 95% = 30cm) or better; assessment procedures to comply with FEMA guidelines.

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.

LiDAR FLIGHT and SYSTEM REPORT

Project Location

The project location for Central Michigan University is defined by the shapefiles "county_069v9b (Iosco County), county_011v9b (Arenac County) and county_017v9b (Bay County)".

Duration/Time Period

One LiDAR aircraft a Cessna 421C (13RF) was used to collect LiDAR Data. The LiDAR data was collected between May 9th and May 25th, 2010. The airports of operation were Iosco County Airport (ECA) East Tawas, Michigan and the James Clements Municipal Airport (3CM) in Bay City, Michigan. This project was flown and LiDAR data was collected by Digital Aerial Solutions, LLC (DAS) using a Leica ALS60 sensor.

Mission Parameters for Project flown at Altitude 4,333 Meters

LiDAR Sensor	Leica Geosystems ALS60
Nominal Ground Sample Distance	1.78 meters
Field of View (scan angle)	30 deg.
Average Airspeed	170 Knots
Laser Pulse Rate	62,100 Hertz
Scan Rate	24.5 Hz
Average Altitude (MSL)	4,333 Meters

Flight mission Date and Times

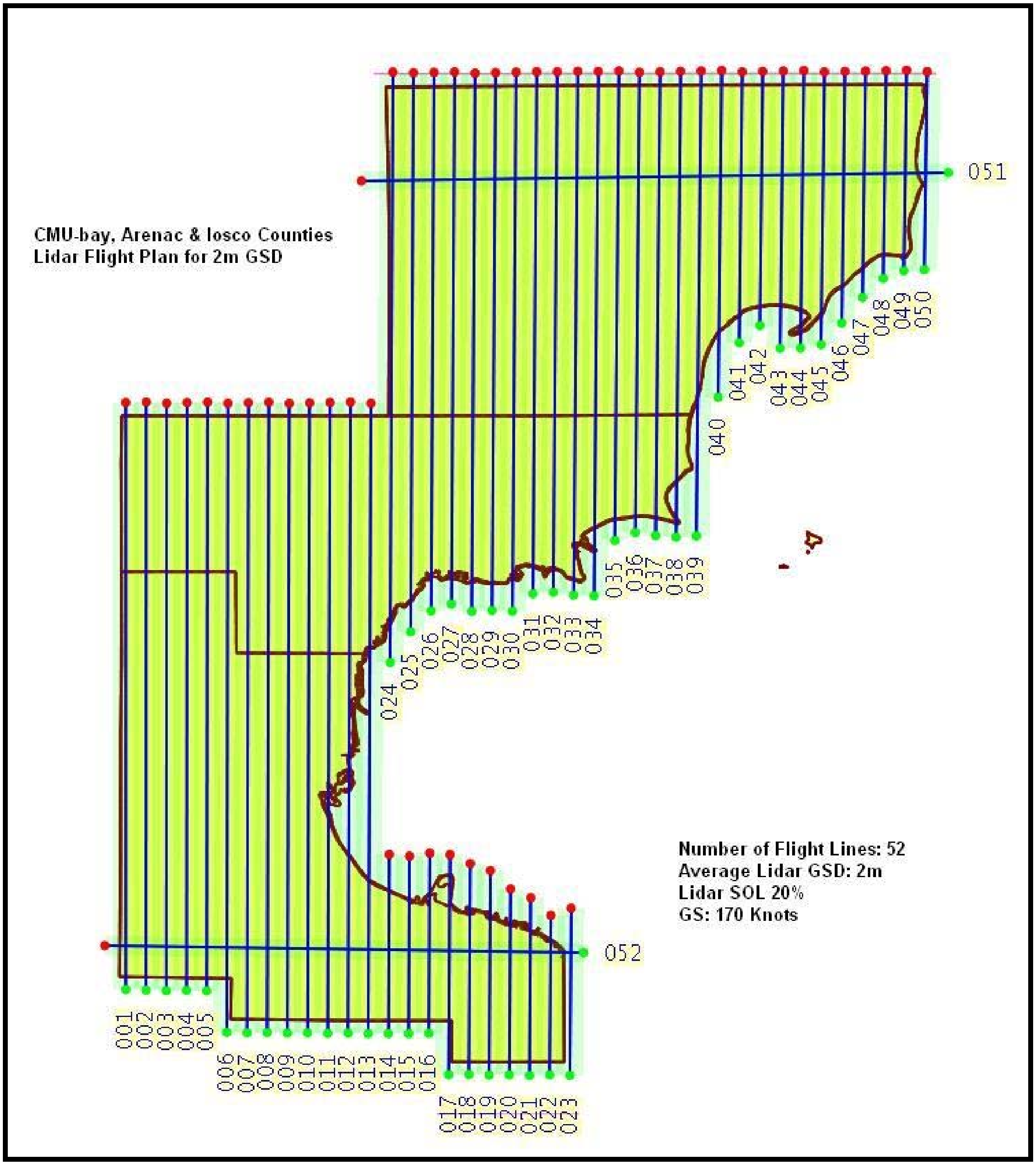
Mission	**Date**	**Plane**	**Start Time GPS sec.**	**End Time GPS sec.**	**Length Time GPS sec.**	**Number of GNSS Solution Records**
100509_A	May 9, 2010	N13RF	48810.5	64739.5	15929.0	31858.0
100510_A	May 10, 2010	N13RF	91200.0	105834.5	14634.5	29269.0
100510_B	May 10, 2010	N13RF	137912.0	153677.5	15765.5	31531.0
100510_C	May 10, 2010	N13RF	155757.0	167734.5	11977.5	23955.0
100510_D	May 10, 2010	N13RF	169768.5	175555.0	5786.5	11573.0
100525_A	May 25, 2010	N13RF	258874.5	263999.5	5125.0	10250.0

Field Work / Procedures

A total of four (4) ground GPS Base Stations were set up up at the airports of operation in support of the LiDAR data collection. The main GPS Base Stations were **Base_Tawaport** and **Base_Clemport**. The auxiliary GPS Base Stations were **Base_Tawaport_Az_Mark** and **Base_Clemport_Az_Mark**). The auxillary Base Stations were used for backup should there be any problems with the main GPS Base Stations.

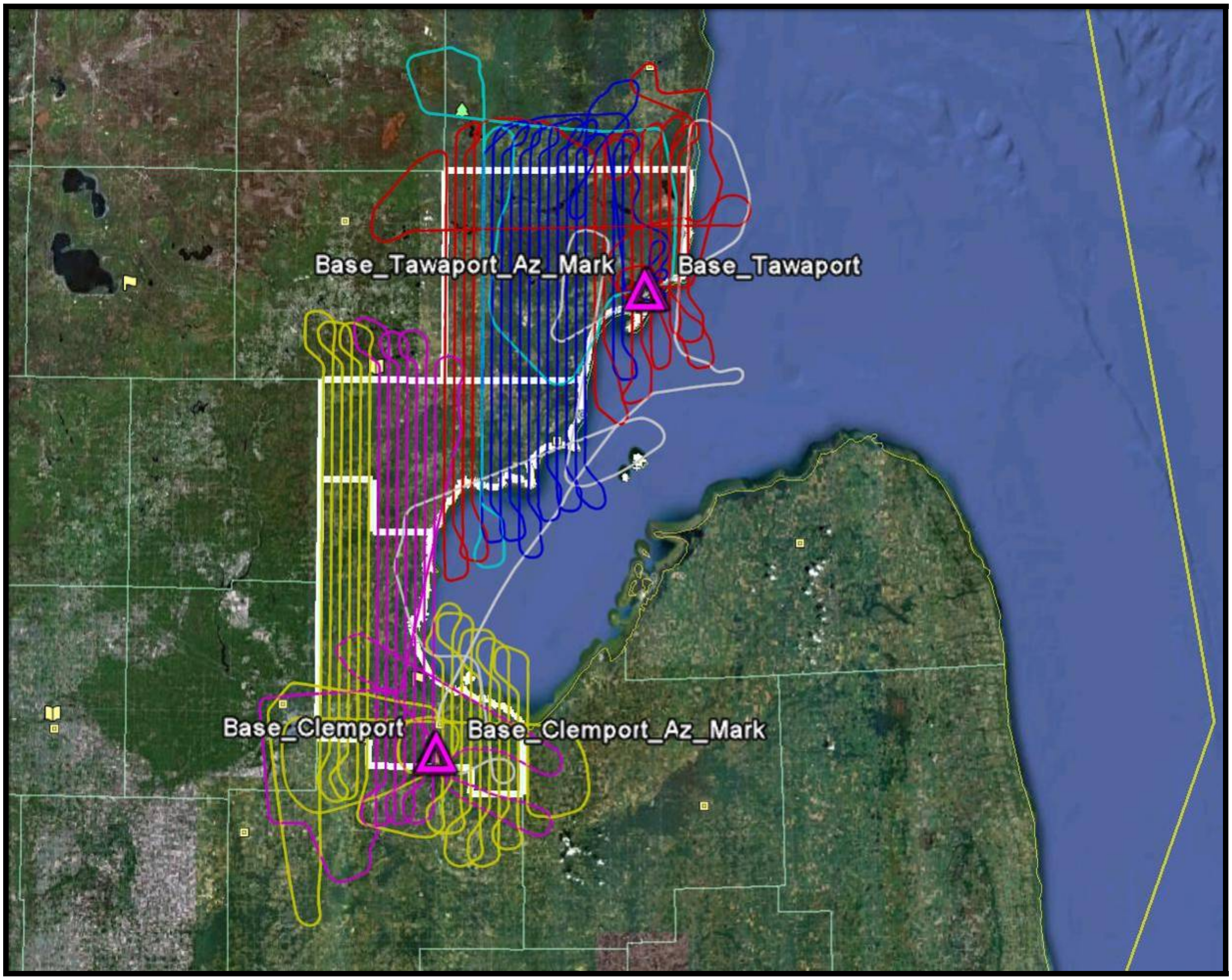
Pre-flight checks such as cleaning the sensor head glass are performed. A five minute INS initialization is conducted on the ground, with the aircraft engines running, prior to the flight mission. To establish fine-alignment of the INS GPS, ambiguities are resolved by flying within ten kilometers of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

Planned Flight Line Diagram



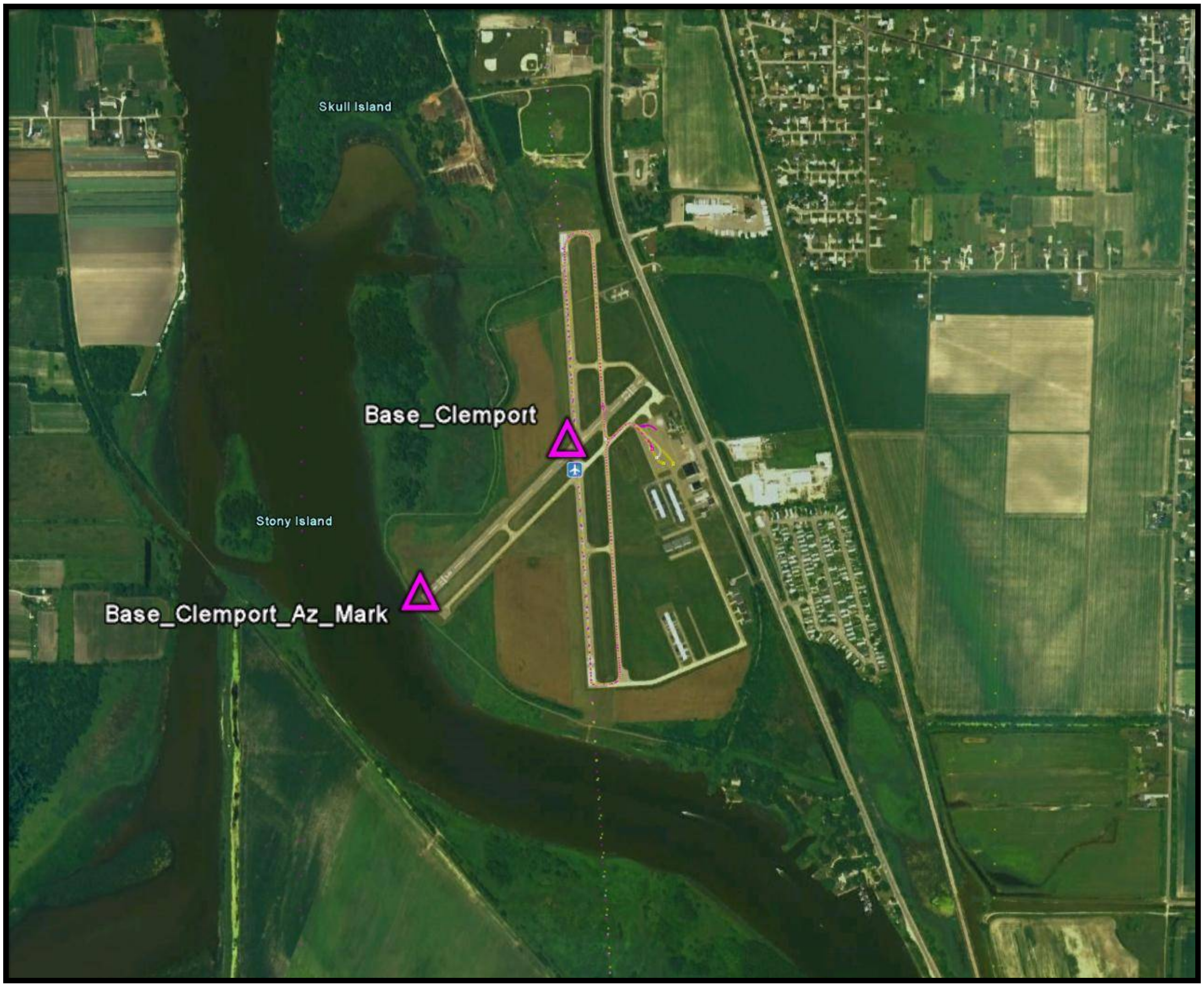
Actual Flight Lines Showing Base Station Location

Mission 100509_A = **Blue**
Mission 100510_A = **Red**
Mission 100010_B = **Yellow**
Mission 100510_C = **Magenta**
Mission 100510_D = **White**
Mission 100525_A = **Cyan**

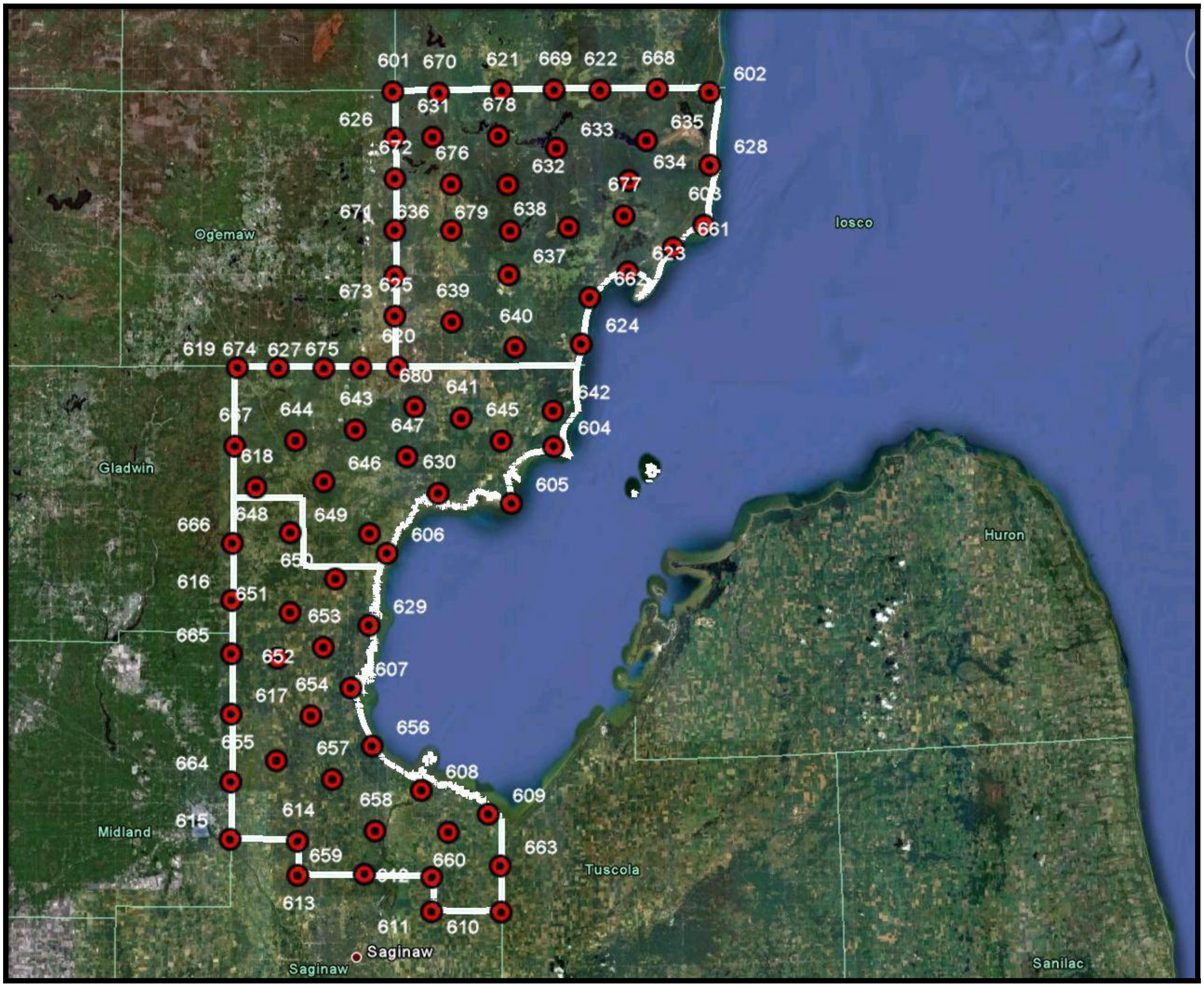


Base Station Locations

Base Station Locations

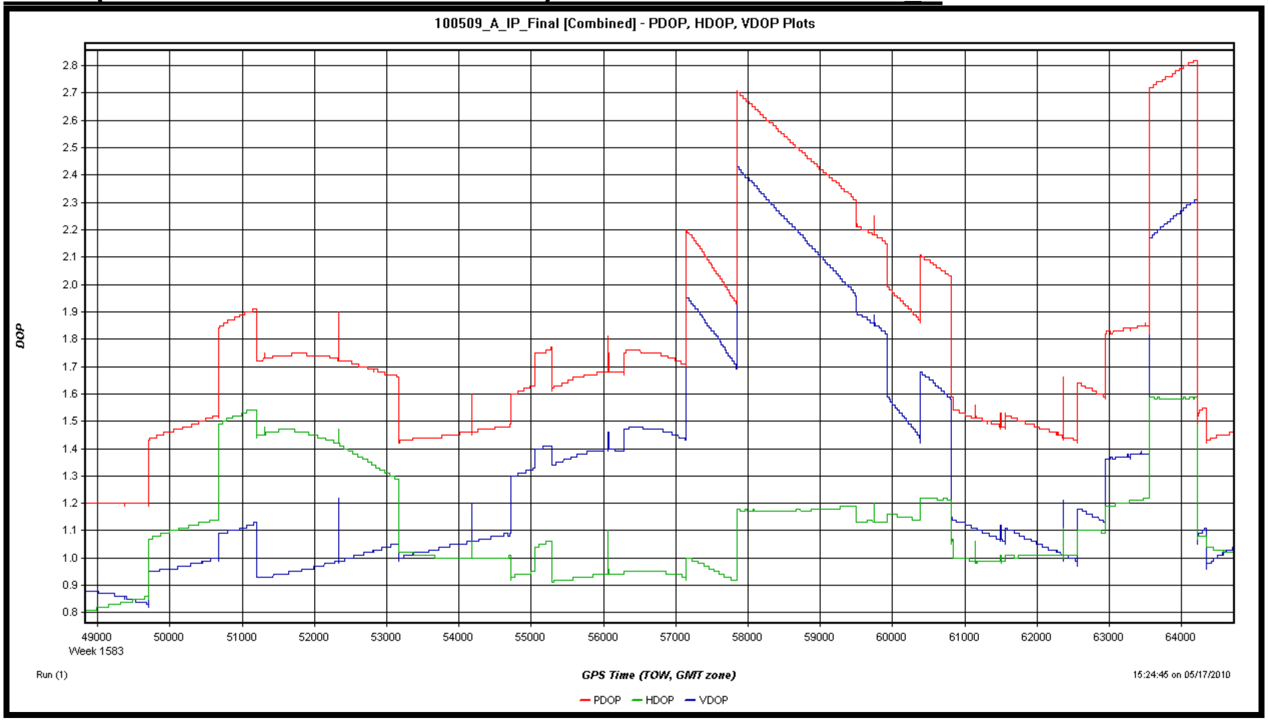


Ground Control LiDAR Points

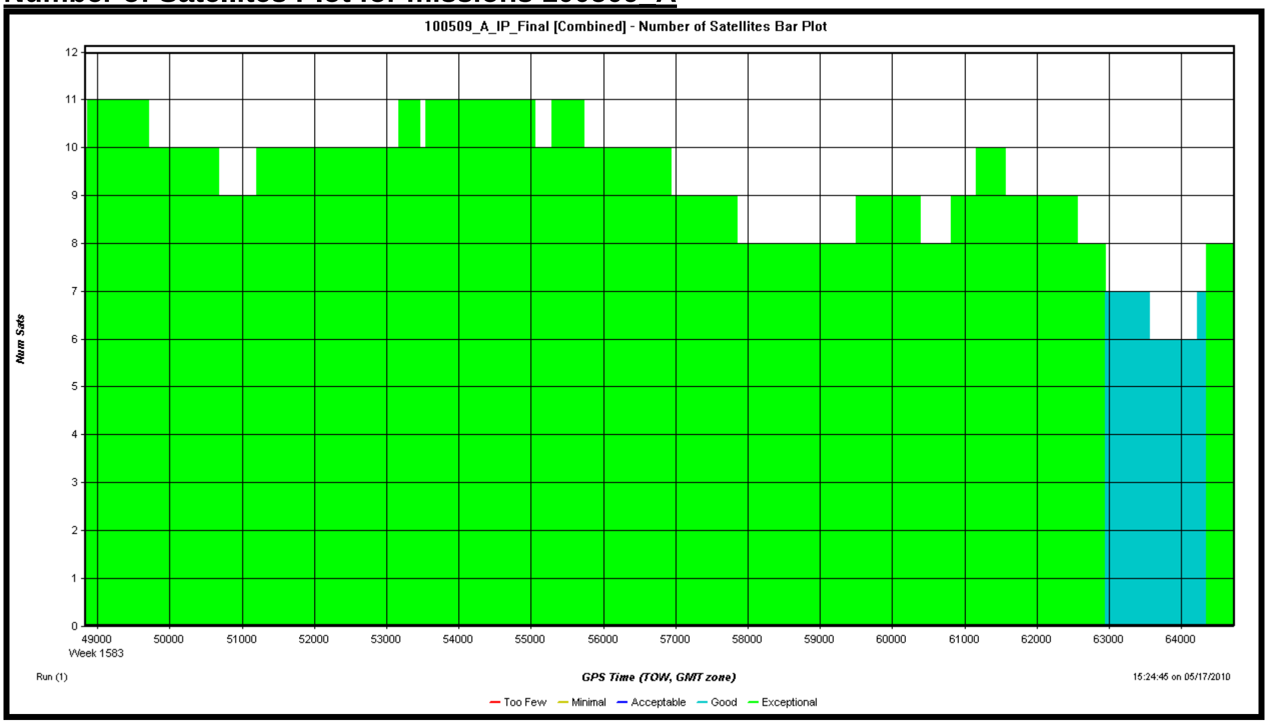


The following graphs show the mission by mission GPS PDOP (Positional Dilution Of Precision) Plot, Number of Satellites Plot.

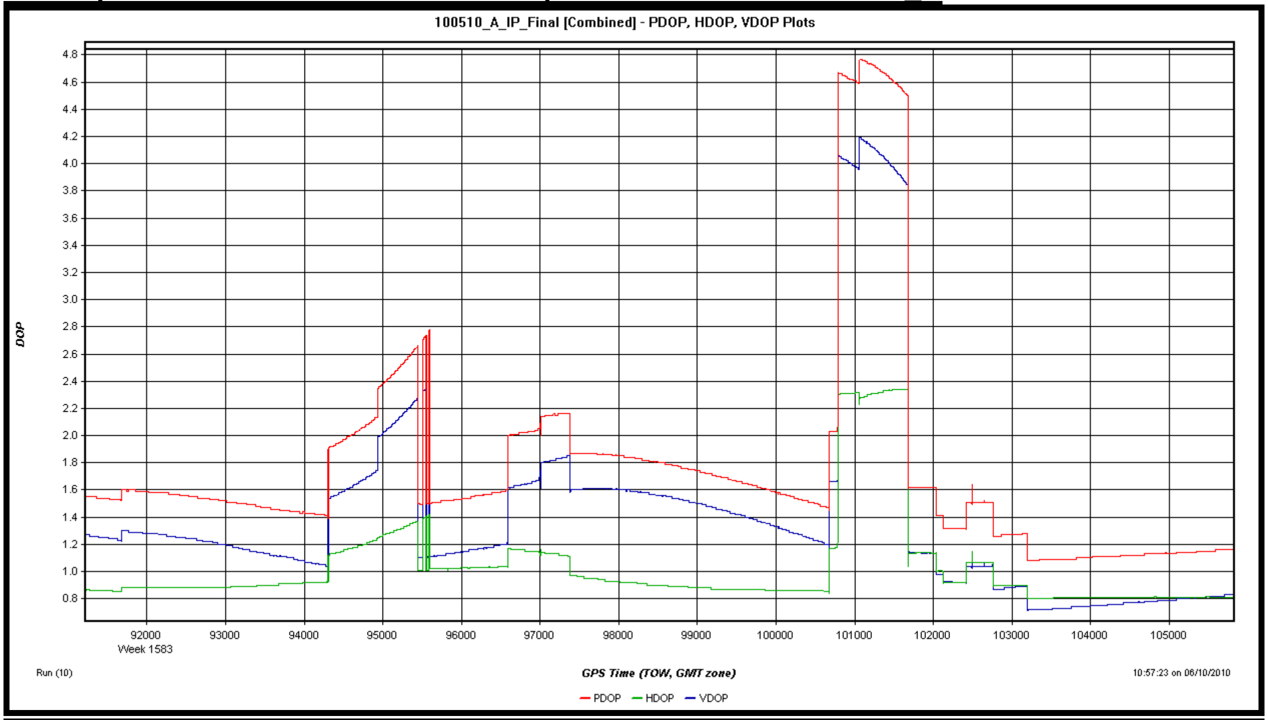
PDOP (Positional Dilution Of Precision) Plot for missions 100509_A



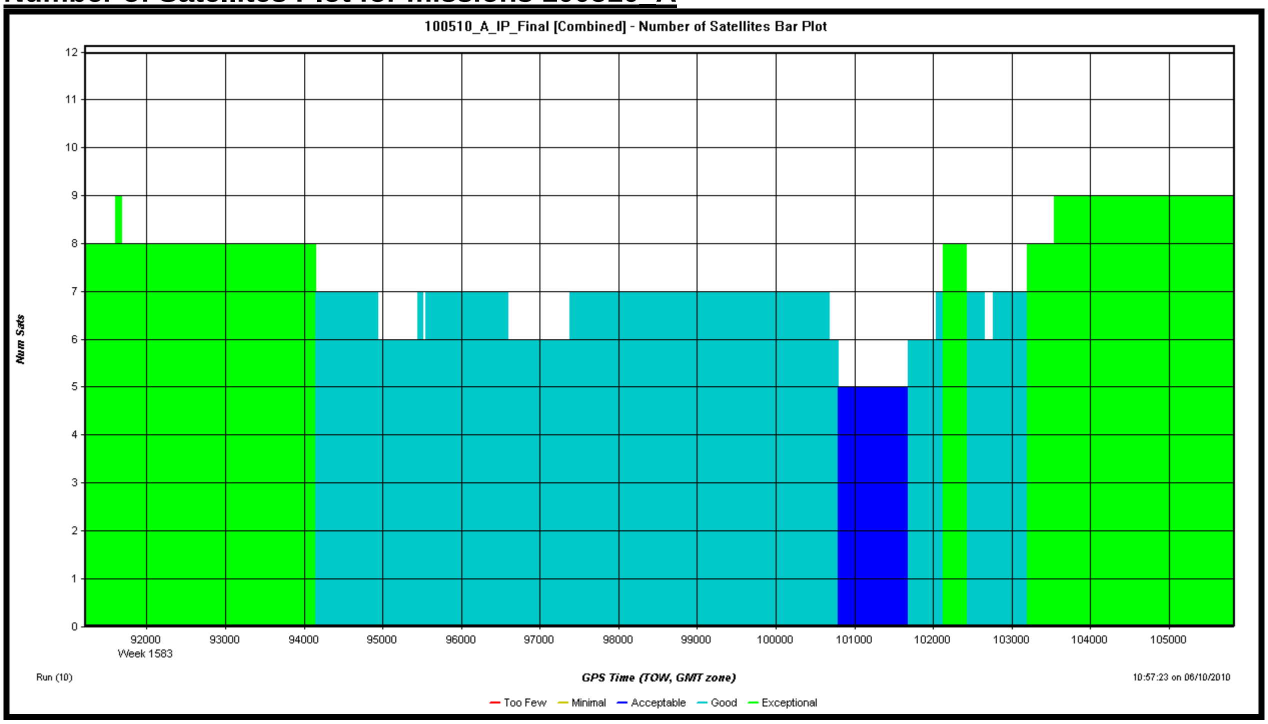
Number of Satellites Plot for missions 100509_A



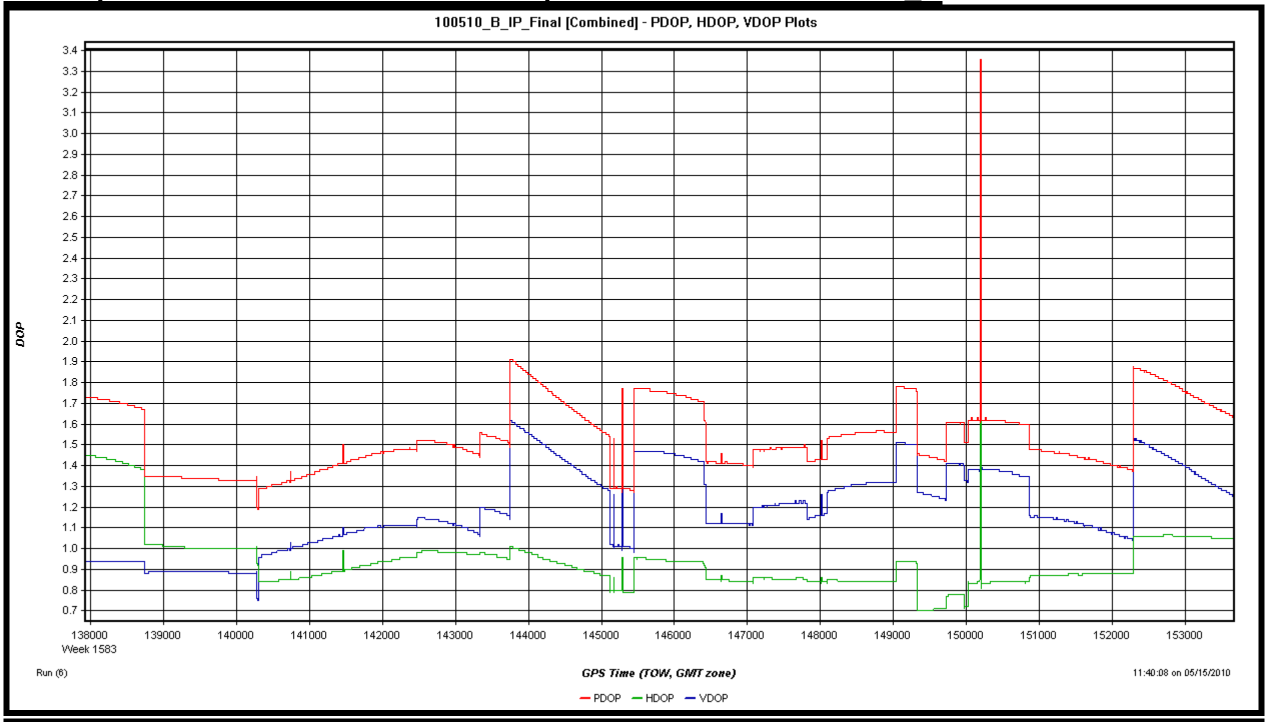
PDOP (Positional Dilution Of Precision) Plot for missions 100510_A



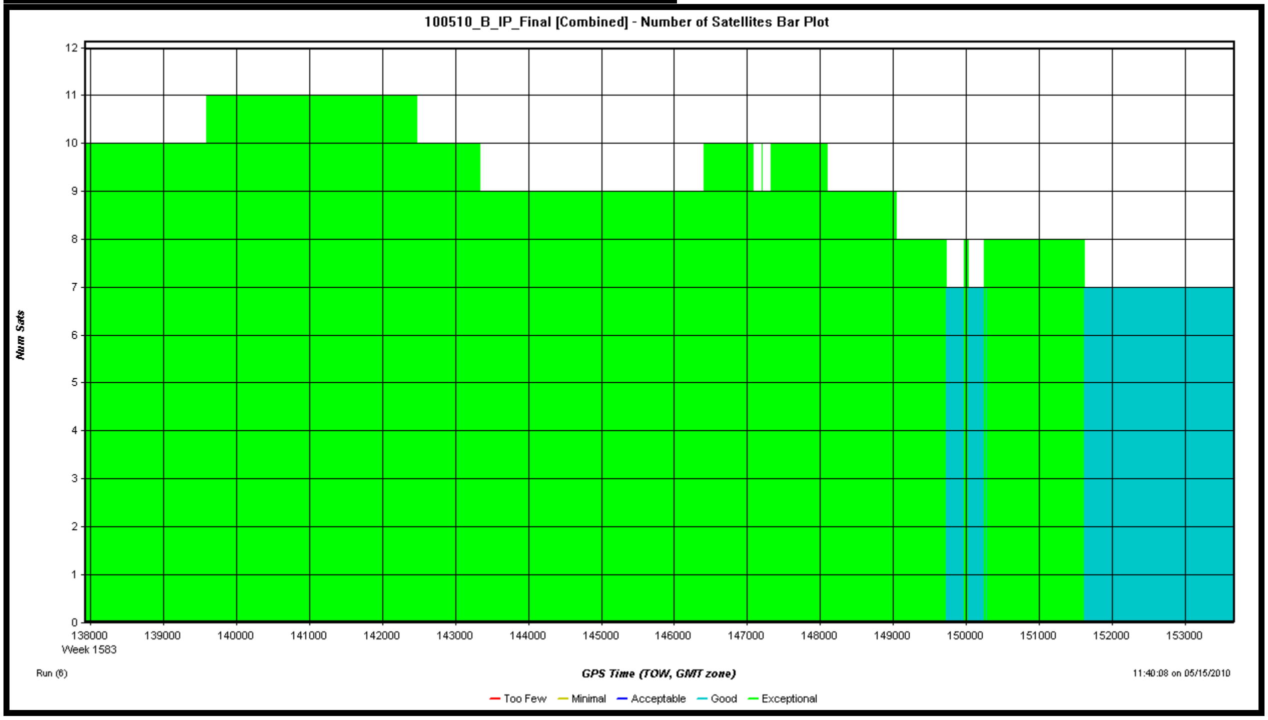
Number of Satellites Plot for missions 100510_A



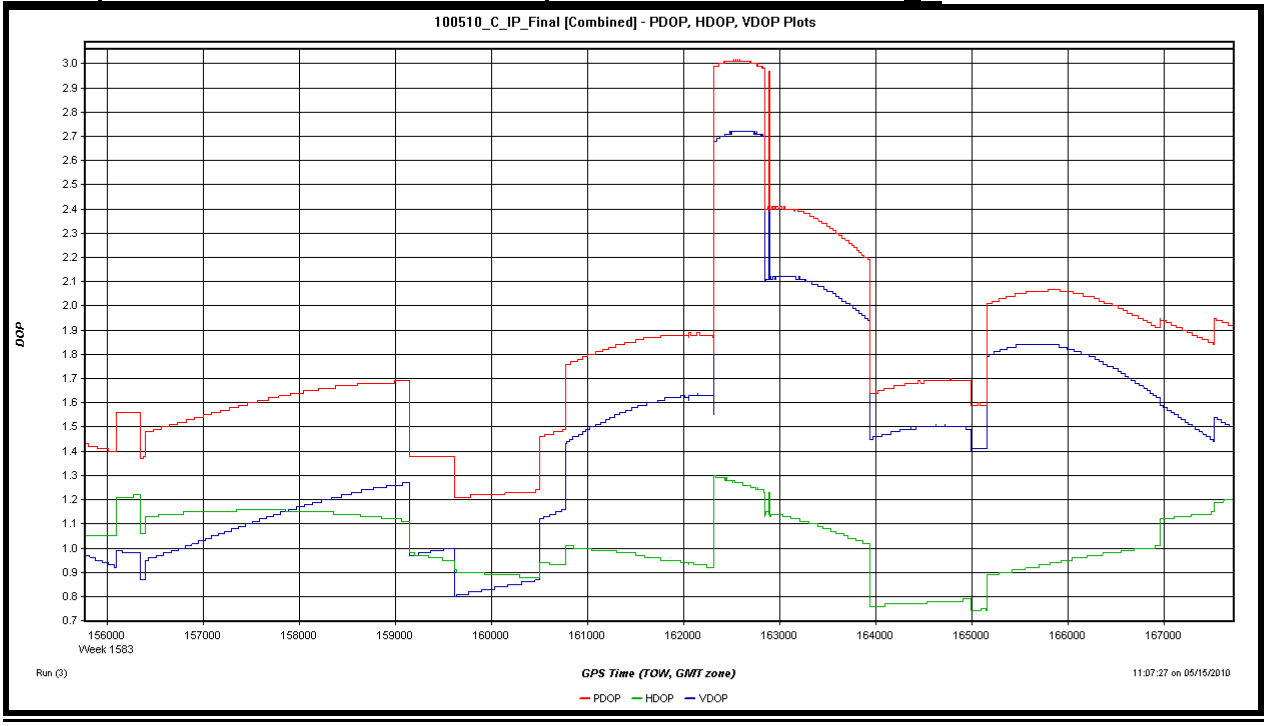
PDOP (Positional Dilution Of Precision) Plot for missions 100510_B



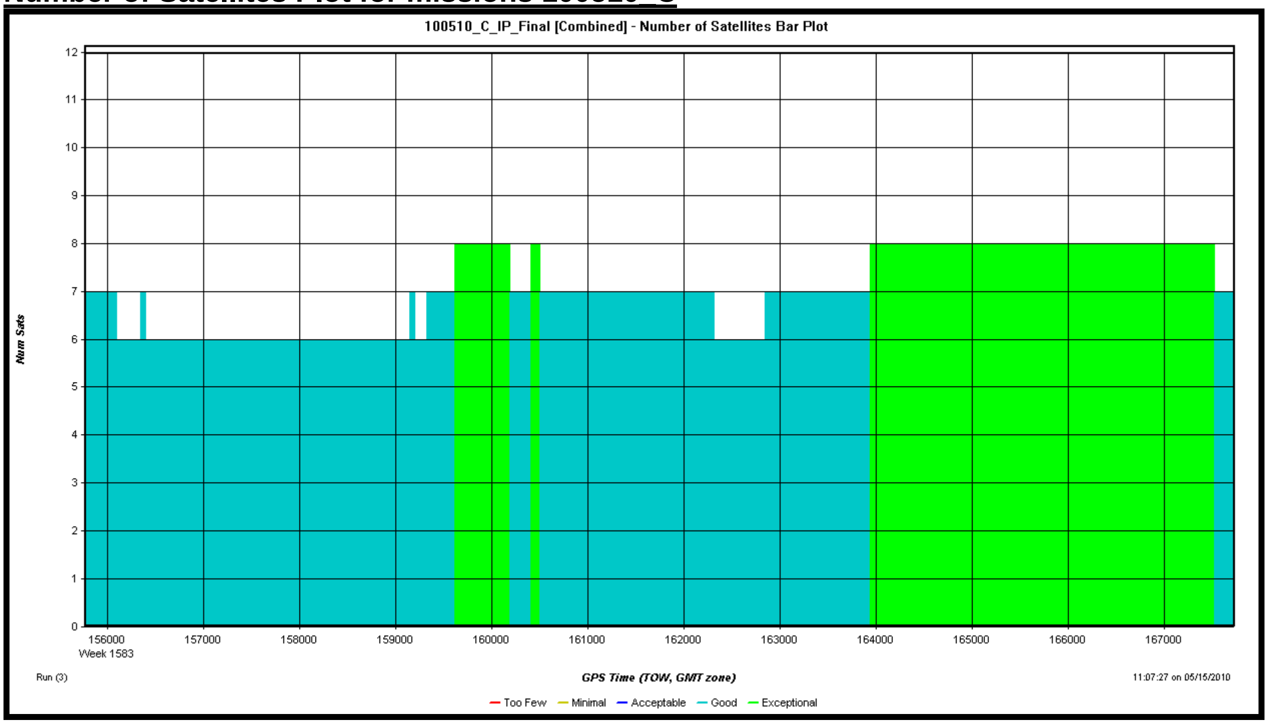
Number of Satellites Plot for missions 100510_B



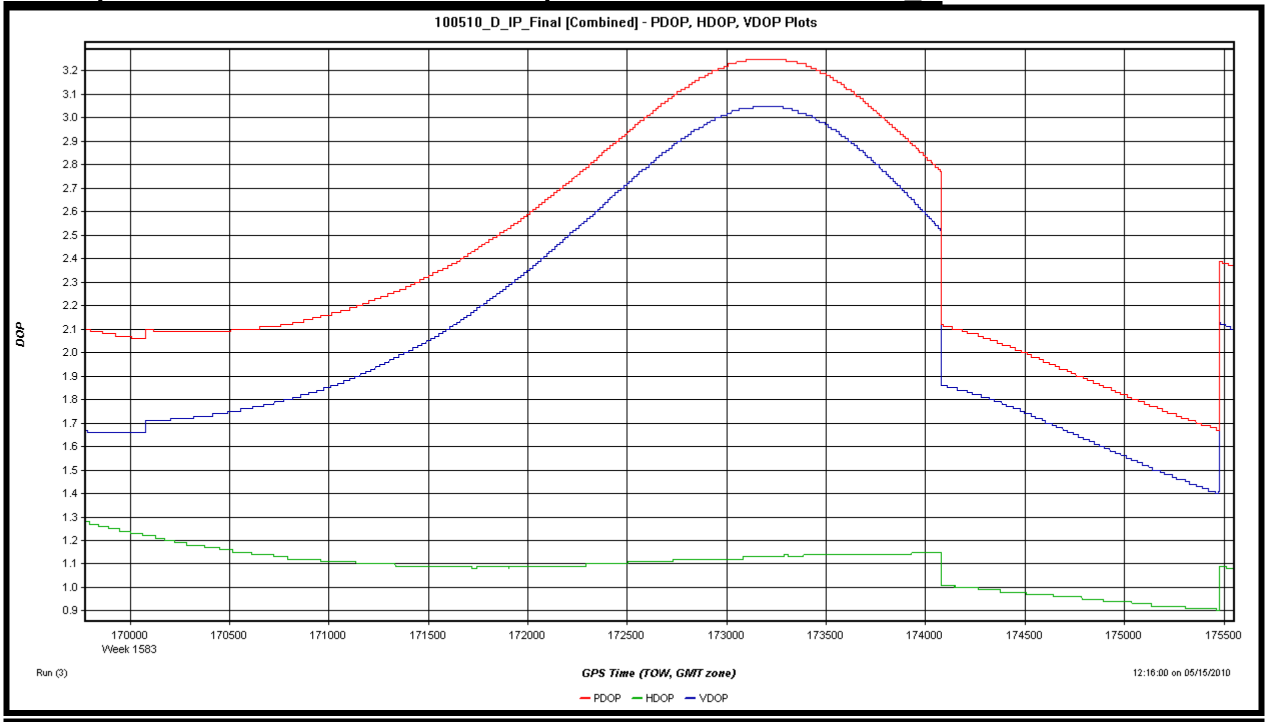
PDOP (Positional Dilution Of Precision) Plot for missions 100510_C



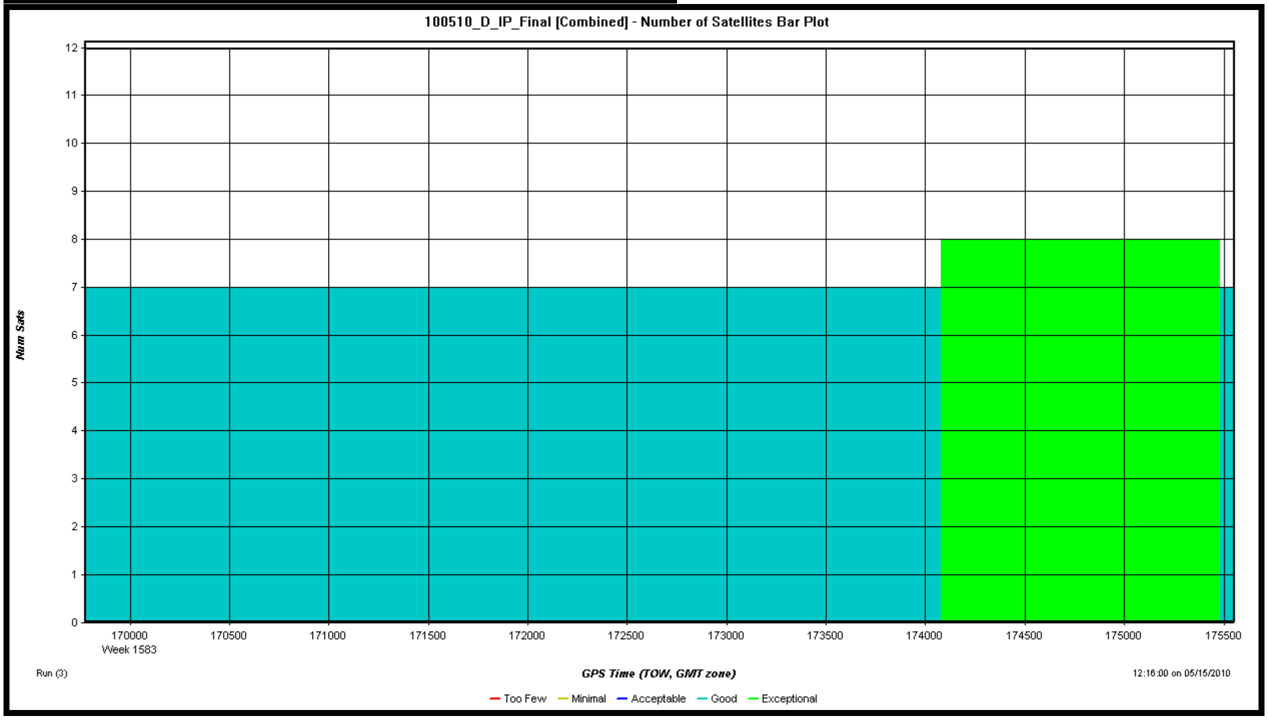
Number of Satellites Plot for missions 100510_C



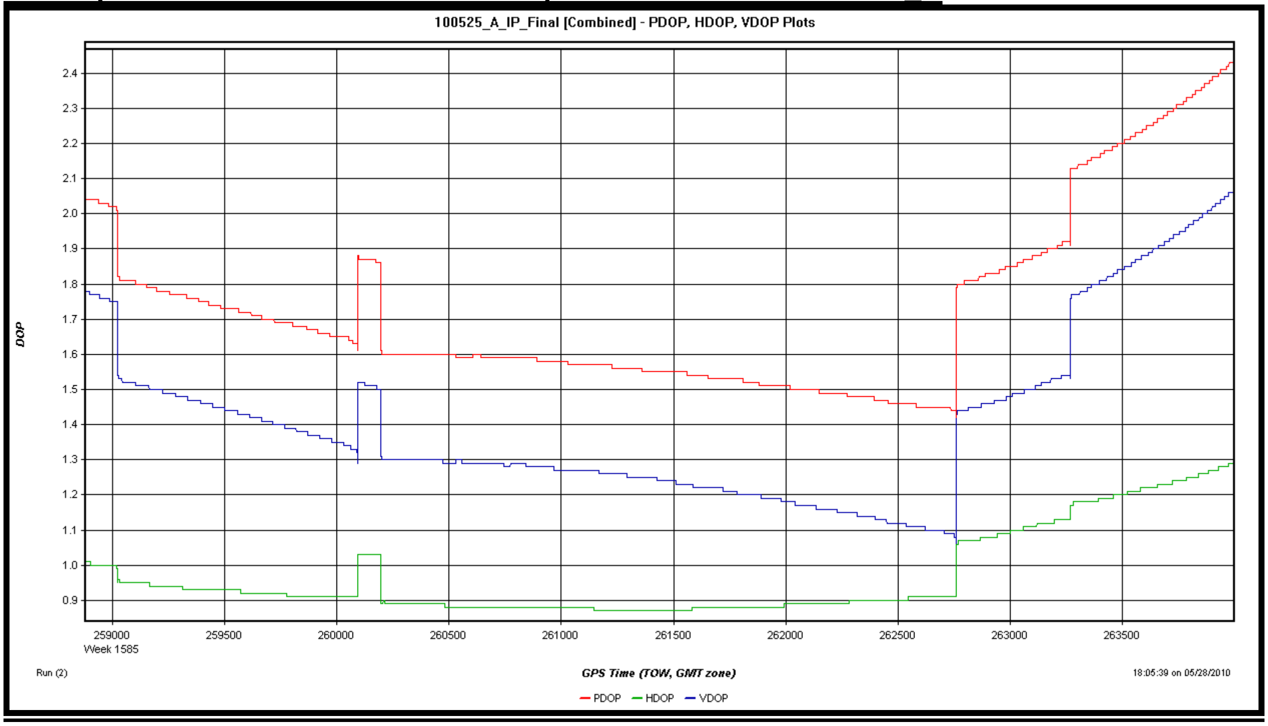
PDOP (Positional Dilution Of Precision) Plot for missions 100510_D



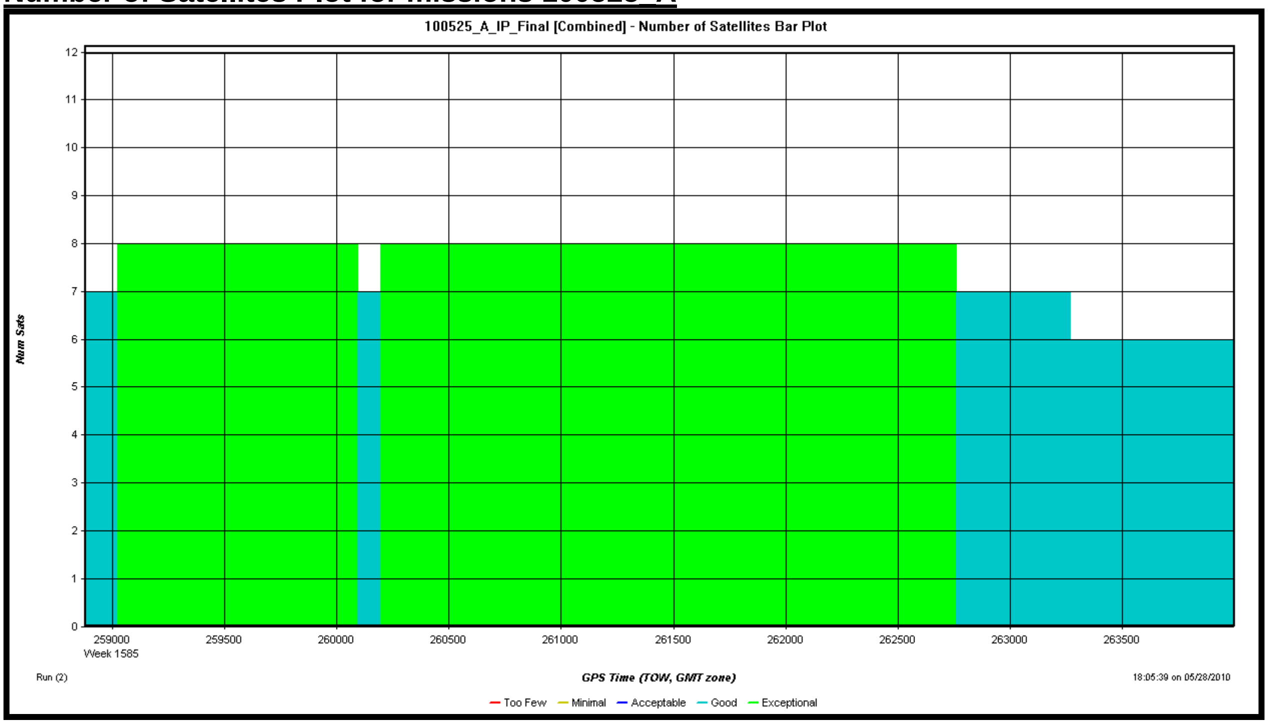
Number of Satellites Plot for missions 100510_D



PDOP (Positional Dilution Of Precision) Plot for missions 100525_A



Number of Satellites Plot for missions 100525_A



LiDAR Data Processing

The airborne GPS data was post-processed using Leica IPAS Pro version 1.35 and Novatel GrafNav version 8.1. 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 version 1.35. The Smoothed Best Estimated Trajectory (SBET) and refined attitude data are then utilized in the ALS Post Processor to compute the laser point-positions – the trajectory is combined with the attitude data and laser range measurements to produce the 3-dimensional coordinates of the mass points. Up to four return values are produced within the ALS Post Processor software for each pulse which ensures the greatest chance of ground returns in a heavily forested area.

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

GPS Controls

A total of four (4) ground GPS Base Stations were set up up at the airports of operation in support of the LiDAR data collection. The main GPS Base Stations were **Base_Tawaport** and **Base_Clemport**. The auxiliary GPS Base Stations were **Base_Tawaport_Az_Mark** and **Base_Clemport_Az_Mark**). The auxillary Base Stations were used for backup should there be any problems with the main GPS Base Stations. Leica GPS receivers (500 and 1200 series) were used for the Base Stations, and were checked with OPUS solutions from NGS (National Geodetic Survey).

See Below for NGS Airborne GPS Base Station information.

```
PK0341  DESIGNATION -  TAWAPORT
PK0341  PID         -  PK0341
PK0341  STATE/COUNTY-  MI/IOSCO
PK0341  USGS QUAD   -  EAST TAWAS (1989)
PK0341
PK0341                        *CURRENT SURVEY CONTROL
PK0341  ___________________________________________________________________
PK0341* NAD 83(2007)-  44 18 45.16126(N)    083 25 20.34737(W)     NO CHECK
PK0341* NAVD 88     -       184.0    (meters)     604.     (feet)  GPS OBS
PK0341  ___________________________________________________________________
PK0341  EPOCH DATE  -        2002.00
PK0341  X           -     523,653.618 (meters)                     COMP
PK0341  Y           -  -4,541,298.940 (meters)                     COMP
PK0341  Z           -   4,433,111.162 (meters)                     COMP
PK0341  LAPLACE CORR-           0.22  (seconds)                    DEFLEC09
PK0341  ELLIP HEIGHT-         148.697 (meters)          (02/10/07) NO CHECK
PK0341  GEOID HEIGHT-         -35.17  (meters)                     GEOID09
PK0341
PK0341  ------- Accuracy Estimates (at 95% Confidence Level in cm) --------
PK0341  Type    PID    Designation                      North   East  Ellip
PK0341  -------------------------------------------------------------------
PK0341  NETWORK PK0341 TAWAPORT                          0.69   0.65   1.86
PK0341  -------------------------------------------------------------------
PK0341.This mark is at Iosco County Airport (6D9)
PK0341.The horizontal coordinates were established by GPS observations
PK0341.and adjusted by the National Geodetic Survey in February 2007.
PK0341.The datum tag of NAD 83(2007) is equivalent to NAD 83(NSRS2007).
PK0341.See National Readjustment for more information.
PK0341.No horizontal observational check was made to the station.
PK0341.The horizontal coordinates are valid at the epoch date displayed above.
PK0341.The epoch date for horizontal control is a decimal equivalence
PK0341.of Year/Month/Day.
PK0341.The orthometric height was determined by GPS observations and a
PK0341.high-resolution geoid model.
PK0341.The X, Y, and Z were computed from the position and the ellipsoidal ht.
PK0341.The Laplace correction was computed from DEFLEC09 derived deflections.
PK0341.The ellipsoidal height was determined by GPS observations
PK0341.and is referenced to NAD 83.
PK0341.The geoid height was determined by GEOID09.
PK0341
PK0341;                    North         East     Units Scale Factor Converg.
PK0341;SPC MI C     -   111,102.210 6,075,340.069   MT  0.99997289   +0 40 01.5
PK0341;SPC MI C     -   364,508.56 19,932,218.07   iFT  0.99997289   +0 40 01.5
PK0341;UTM  17      - 4,909,441.088   306,813.671   MT  1.00005900   -1 41 33.7
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PK0342  DESIGNATION -  TAWAPORT AZ MK
PK0342  PID         -  PK0342
PK0342  STATE/COUNTY-  MI/IOSCO
PK0342  USGS QUAD   -  EAST TAWAS (1989)
PK0342
PK0342                         *CURRENT SURVEY CONTROL
PK0342  ___________________________________________________________________
PK0342* NAD 83(1994)-  44 18 49.80746(N)    083 24 50.74919(W)     ADJUSTED
PK0342* NAVD 88     -       183.7    (meters)     603.     (feet)  GPS OBS
PK0342  ___________________________________________________________________
PK0342  X           -     524,293.759 (meters)                     COMP
PK0342  Y           -  -4,541,124.041 (meters)                     COMP
PK0342  Z           -   4,433,213.597 (meters)                     COMP
PK0342  LAPLACE CORR-           0.15  (seconds)                    DEFLEC09
PK0342  ELLIP HEIGHT-         148.436 (meters)          (07/17/02) ADJUSTED
PK0342  GEOID HEIGHT-         -35.17  (meters)                     GEOID09
PK0342  HORZ ORDER  -  FIRST
PK0342  ELLP ORDER  -  FOURTH    CLASS I
PK0342
PK0342.This mark is at Iosco County Airport (6D9)
PK0342
PK0342.The horizontal coordinates were established by GPS observations
PK0342.and adjusted by the National Geodetic Survey in February 1997.
PK0342
PK0342.The orthometric height was determined by GPS observations and a
PK0342.high-resolution geoid model.
PK0342
PK0342.The X, Y, and Z were computed from the position and the ellipsoidal ht.
PK0342
PK0342.The Laplace correction was computed from DEFLEC09 derived deflections.
PK0342
PK0342.The ellipsoidal height was determined by GPS observations
PK0342.and is referenced to NAD 83.
PK0342
PK0342.The geoid height was determined by GEOID09.
PK0342
PK0342;                    North         East     Units Scale Factor Converg.
PK0342;SPC MI C     -   111,253.277 6,075,994.284   MT  0.99997264   +0 40 22.4
PK0342;SPC MI C     -   365,004.19 19,934,364.45   iFT  0.99997264   +0 40 22.4
PK0342;UTM  17      - 4,909,565.100   307,473.606   MT  1.00005587   -1 41 13.1
```

```
OJ1097  DESIGNATION -  CLEMPORT
OJ1097  PID         -  OJ1097
OJ1097  STATE/COUNTY-  MI/BAY
OJ1097  USGS QUAD   -  BAY CITY (1973)
OJ1097
OJ1097                         *CURRENT SURVEY CONTROL
OJ1097  ___________________________________________________________________
OJ1097* NAD 83(2007)-  43 32 51.65848(N)    083 53 42.86988(W)     NO CHECK
OJ1097* NAVD 88     -       177.2    (meters)     581.     (feet)  GPS OBS
OJ1097  ___________________________________________________________________
OJ1097  EPOCH DATE  -        2002.00
OJ1097  X           -     492,421.942 (meters)                     COMP
OJ1097  Y           -  -4,604,089.312 (meters)                     COMP
OJ1097  Z           -   4,371,901.404 (meters)                     COMP
OJ1097  LAPLACE CORR-          -1.27  (seconds)                    DEFLEC09
OJ1097  ELLIP HEIGHT-         142.727 (meters)          (02/10/07) NO CHECK
OJ1097  GEOID HEIGHT-         -34.44  (meters)                     GEOID09
```

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 OJ1097
 OJ1097  ------- Accuracy Estimates (at 95% Confidence Level in cm) --------
 OJ1097  Type    PID    Designation                          North   East  Ellip
 OJ1097  -------------------------------------------------------------------
 OJ1097  NETWORK OJ1097 CLEMPORT                              2.08   1.37   6.39
 OJ1097  -------------------------------------------------------------------
 OJ1097
 OJ1097.This mark is at James Clement Municipal Airport (3CM)
 OJ1097
 OJ1097.The horizontal coordinates were established by GPS observations
 OJ1097.and adjusted by the National Geodetic Survey in February 2007.
 OJ1097
 OJ1097.The datum tag of NAD 83(2007) is equivalent to NAD 83(NSRS2007).
 OJ1097.See National Readjustment for more information.
 OJ1097.No horizontal observational check was made to the station.
 OJ1097.The horizontal coordinates are valid at the epoch date displayed above.
 OJ1097.The epoch date for horizontal control is a decimal equivalence
 OJ1097.of Year/Month/Day.
 OJ1097
 OJ1097.The orthometric height was determined by GPS observations and a
 OJ1097.high-resolution geoid model.
 OJ1097
 OJ1097.The X, Y, and Z were computed from the position and the ellipsoidal ht.
 OJ1097
 OJ1097.The Laplace correction was computed from DEFLEC09 derived deflections.
 OJ1097
 OJ1097.The ellipsoidal height was determined by GPS observations
 OJ1097.and is referenced to NAD 83.
 OJ1097
 OJ1097.The geoid height was determined by GEOID09.
 OJ1097
 OJ1097;                    North         East     Units Scale Factor Converg.
 OJ1097;SPC MI S     -   227,565.697 4,038,096.074   MT  0.99997376   +0 19 14.9
 OJ1097;SPC MI S     -   746,606.62 13,248,346.70   iFT  0.99997376   +0 19 14.9
 OJ1097;UTM  17      - 4,825,710.004   266,115.225   MT  1.00027291   -1 59 44.2
```

```
OJ1098  DESIGNATION -  CLEMPORT AZ MK
 OJ1098  PID         -  OJ1098
 OJ1098  STATE/COUNTY-  MI/BAY
 OJ1098  USGS QUAD   -  BAY CITY (1973)
 OJ1098
 OJ1098                         *CURRENT SURVEY CONTROL
 OJ1098  ___________________________________________________________________
 OJ1098* NAD 83(1994)-  43 32 39.06038(N)    083 53 59.46329(W)     ADJUSTED
 OJ1098* NAVD 88     -       176.7    (meters)     580.     (feet)  GPS OBS
 OJ1098  ___________________________________________________________________
 OJ1098  X           -     492,080.014 (meters)                     COMP
 OJ1098  Y           -  -4,604,395.206 (meters)                     COMP
 OJ1098  Z           -   4,371,619.533 (meters)                     COMP
 OJ1098  LAPLACE CORR-          -1.35  (seconds)                    DEFLEC09
 OJ1098  ELLIP HEIGHT-         142.651 (meters)         (07/17/02) ADJUSTED
 OJ1098  GEOID HEIGHT-         -34.43  (meters)                     GEOID09
 OJ1098  HORZ ORDER  -  FIRST
 OJ1098  ELLP ORDER  -  FOURTH    CLASS I
 OJ1098
 OJ1098.This mark is at James Clement Municipal Airport (3CM)
 OJ1098
 OJ1098.The horizontal coordinates were established by GPS observations
 OJ1098.and adjusted by the National Geodetic Survey in February 1997.
 OJ1098
```

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OJ1098.The orthometric height was determined by GPS observations and a
OJ1098.high-resolution geoid model.
OJ1098
OJ1098.The X, Y, and Z were computed from the position and the ellipsoidal ht.
OJ1098
OJ1098.The Laplace correction was computed from DEFLEC09 derived deflections.
OJ1098
OJ1098.The ellipsoidal height was determined by GPS observations
OJ1098.and is referenced to NAD 83.
OJ1098
OJ1098.The geoid height was determined by GEOID09.
OJ1098
OJ1098;                    North         East     Units Scale Factor Converg.
OJ1098;SPC MI S     -   227,174.834 4,037,725.756   MT  0.99997306   +0 19 03.7
OJ1098;SPC MI S     -   745,324.26 13,247,131.75   iFT  0.99997306   +0 19 03.7
OJ1098;UTM  17      - 4,825,334.316   265,729.296   MT  1.00027514   -1 59 55.2
```

Ground Control Parameters

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 (NAD83).
Coordinate System: UTM Zone 17
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Geiod Model: Geoid 2009 (Geoid 09 used to convert ellipsoid heights to orthometric heights).
Units: Horizontal units are in Meters, Vertical units are in Meters.

GROUND CONTROL REPORT / CHECK POINT SURVEY RESULTS

Ground Survey Control Report

The following listing shows the ground control, collected for LiDAR check points. The existing ground control points (checkpoints) were surveyed in April 2010 by Atwell, LLC.

Ground Control

Project: Central Michigan University
Job#: 02016602
Date: May 2010

Coordinate System: UTM17
Zone: 17N
Horizontal Datum: NAD83
Vertical Datum(Geoid09): NAVD88
Units: Meters

Pt#	Geodetic		Ellipsoid	UTM17		NAVD88
Name	Latitude	Longitude	Height	Northing	Easting	Elevation
	North	West	Geoid	Y	X	Z
	Deg Min Sec	Deg Min Sec	Meters	Meters	Meters	Meters
601	44°30'32.82999N	83°53'16.94873W	275.562	4932479.69	270441.21	310.645
602	44°30'26.44630N	83°19'48.37517W	150.405	4930866.01	314784.26	185.863
603	44°20'24.66019N	83°20'27.45257W	143.439	4912322.56	313390.11	178.627
604	44°03'47.19855N	83°36'18.64709W	145.646	4882182.50	291351.10	180.674
605	43°59'30.49570N	83°40'44.97781W	144.067	4874452.48	285168.25	179.036
606	43°55'44.63462N	83°53'45.09019W	142.731	4868071.53	267546.85	177.666
607	43°45'36.51943N	83°57'30.26965W	142.636	4849487.45	261854.08	177.324
608	43°37'54.21480N	83°50'09.37292W	143.763	4834879.20	271225.03	178.347
609	43°36'06.93523N	83°43'11.32855W	142.986	4831255.79	280484.59	177.513
610	43°28'43.87289N	83°41'52.13322W	150.171	4817528.73	281816.47	184.570
611	43°28'44.90650N	83°49'05.56168W	144.850	4817883.39	272080.14	179.271
612	43°31'20.91153N	83°49'03.73983W	145.825	4822694.99	272284.14	180.290
613	43°31'27.05325N	84°03'01.35558W	158.246	4823548.18	253486.63	192.540
614	43°34'01.75442N	84°03'03.34223W	156.285	4828322.65	253617.29	190.644
615	43°34'08.35611N	84°10'05.21013W	156.020	4828880.67	244161.07	190.242
616	43°52'09.72629N	84°10'00.27857W	182.217	4862239.75	245547.43	216.876
617	43°43'35.35264N	84°10'01.10150W	164.276	4846370.44	244921.32	198.753
618	44°00'41.09885N	84°07'30.99506W	204.325	4877890.51	249477.34	239.198
619	44°09'41.98157N	84°09'32.59927W	215.704	4894682.28	247410.35	250.640
620	44°09'45.37352N	83°52'41.60792W	202.425	4893961.96	269869.11	237.539
621	44°30'37.28242N	83°41'45.61642W	225.016	4932095.21	285710.18	260.242
622	44°30'38.70339N	83°31'21.69013W	212.308	4931698.94	299487.34	247.645
623	44°16'54.23773N	83°28'28.59383W	144.130	4906143.17	302539.99	179.308

624	44°11'29.35718N	83°33'23.46753W	145.051	4896319.69	295691.74	180.194
625	44°13'36.31418N	83°52'59.22604W	209.802	4901101.20	269727.96	244.921
626	44°27'02.80344N	83°53'02.93877W	239.580	4925988.28	270521.78	274.661
627	44°09'39.96511N	84°00'25.51422W	208.241	4894164.09	259559.38	243.299
628	44°24'56.16981N	83°19'48.12547W	143.285	4920675.11	314499.34	178.562
629	43°50'19.52895N	83°55'37.66002W	143.221	4858129.56	264681.22	178.022
630	44°00'16.31131N	83°48'24.05378W	143.686	4876206.32	274990.67	178.711
631	44°27'06.38237N	83°49'03.44888W	247.917	4925914.12	275818.76	283.037
632	44°23'30.68052N	83°41'06.94693W	215.927	4918904.15	286131.64	251.096
633	44°26'15.65174N	83°35'59.34050W	214.434	4923774.63	293098.89	249.659
634	44°23'48.04206N	83°28'19.82949W	156.646	4918905.12	303119.52	191.884
635	44°26'48.83942N	83°26'28.76132W	183.304	4924409.88	305743.06	218.599
636	44°20'04.10462N	83°47'03.36020W	219.418	4912793.75	278029.59	254.557
637	44°16'42.86647N	83°41'01.19771W	183.609	4906316.96	285846.65	218.777
638	44°20'16.30477N	83°34'42.23624W	204.667	4912633.02	294454.14	239.857
639	44°13'09.79273N	83°46'59.47446W	173.043	4900007.39	277681.79	208.195
640	44°11'15.08416N	83°40'20.96845W	154.419	4896174.32	286409.09	189.573
641	44°05'55.35623N	83°45'59.94201W	151.337	4886558.58	278551.50	186.443
642	44°06'27.76073N	83°36'21.98476W	149.308	4887138.78	291433.72	184.387
643	44°05'01.90381N	83°57'06.53034W	172.043	4885424.49	263671.05	207.107
644	44°04'12.49709N	84°03'23.25463W	208.253	4884206.00	255236.00	243.243
645	44°04'11.83158N	83°41'47.86860W	144.142	4883178.36	284051.55	179.210
646	44°01'07.56546N	84°00'23.62660W	174.247	4878352.95	259023.55	209.239
647	44°03'00.79240N	83°51'41.77540W	154.908	4881432.60	270763.74	189.981
648	43°57'16.64227N	84°03'53.55680W	170.537	4871400.37	254084.58	205.415
649	43°57'13.70939N	83°55'35.70940W	151.642	4870906.81	265177.74	186.602
650	43°53'48.67926N	83°59'08.56199W	153.039	4864750.99	260204.58	187.896
651	43°51'16.14339N	84°03'53.27892W	161.759	4860277.52	253677.80	196.495
652	43°47'49.68205N	84°05'11.28767W	161.660	4853972.39	251698.30	196.300
653	43°48'39.27280N	84°00'23.84341W	150.779	4855265.78	258177.65	185.501
654	43°43'29.84421N	84°01'40.18602W	153.916	4845781.28	256122.65	188.515
655	43°40'05.97777N	84°05'16.44019W	151.107	4839670.13	251049.63	185.580
656	43°41'14.00941N	83°55'16.37076W	143.476	4841282.01	264562.59	178.096
657	43°38'42.70687N	83°59'26.10841W	147.879	4836813.39	258802.92	182.403
658	43°34'49.72739N	83°54'58.31004W	145.777	4829411.85	264550.19	180.272
659	43°31'34.07284N	83°56'04.71444W	143.609	4823428.02	262847.63	178.027
660	43°34'44.87056N	83°47'21.48402W	144.718	4828910.04	274791.00	179.243
661	44°18'43.09799N	83°23'41.85946W	146.341	4909313.31	308993.70	181.515
662	44°14'59.58836N	83°32'30.53775W	146.003	4902769.74	297067.57	181.176
663	43°32'12.46981N	83°41'56.56334W	145.028	4823967.45	281925.81	179.479
664	43°38'28.59927N	84°10'02.02959W	164.684	4836907.07	244538.84	199.034
665	43°48'08.29209N	84°10'00.94320W	166.089	4854791.29	245247.14	200.662
666	43°56'27.34048N	84°09'57.54577W	201.142	4870185.71	245913.31	235.894
667	44°03'46.52227N	84°09'46.10000W	200.867	4883726.38	246688.64	235.751
668	44°30'42.04335N	83°25'18.31951W	152.862	4931559.16	307513.27	188.270
669	44°30'40.19697N	83°36'13.08761W	218.212	4931946.93	293055.03	253.497
670	44°30'26.78771N	83°48'26.06629W	231.625	4932069.30	276857.41	266.784

671	44°20'04.69641N	83°53'00.70285W	230.413	4913085.77	270116.61	265.516
672	44°23'58.42684N	83°53'01.72292W	241.332	4920298.34	270348.05	276.421
673	44°16'36.49773N	83°53'00.38488W	203.064	4906661.60	269897.65	238.178
674	44°09'42.62905N	84°05'14.15920W	208.347	4894484.05	253151.32	243.351
675	44°09'42.57011N	83°56'32.29967W	216.494	4894056.94	264742.22	251.582
676	44°23'32.63414N	83°47'05.15071W	223.147	4919229.28	278208.77	258.277
677	44°21'08.95351N	83°28'52.61140W	148.972	4914018.41	302245.56	184.181
678	44°27'12.28432N	83°42'06.20309W	221.634	4925784.93	285046.50	256.821
679	44°20'00.92422N	83°40'51.56538W	205.981	4912420.98	286260.04	241.148
680	44°06'46.07680N	83°50'52.54870W	164.563	4888345.52	272099.72	199.671

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.

Control Report

Project File: Central Michigan University
Project Unit: Meter
Date: Wednesday: June 02: 2010
Vertical Accuracy Objective
Requirement Type: RMSE(z)
RMSE(z) Objective: 0.15
Control Points in Report: 80
Elevation Calculation Method: Interpolated from TIN
Control Points with LiDAR Coverage: 80
Average Control Error Reported: 0.00
Maximum (highest) Control Error Reported: 0.28
Median Control Error Reported: 0.01
Minimum (lowest) Control Error Reported: -0.2
Standard deviation (sigma) of Z for sample: 0.10
RMSE of Z for sample (RMSE(z)): 0.10: PASS
NSSDA Achievable Contour Interval: 0.4
ASPRS Class 1 Achievable Contour Interval: 0.4
NMAS Achievable Contour Interval: 0.4

Control	Control Pt.	Control Pt.	Coverage	Control Pt.	from LiDAR	**Z Error**	Min Z	Median Z	Max Z
Point Id	X(East)	Y(North)		Z(Elev)	Z(Elev)				
	Meter	Meter		Meter	Meter	**Meter**	Meter	Meter	Meter
664	244538.84	4836907.07	Yes	199.03	198.83	**-0.20**	198.79	198.83	198.84
644	255236.00	4884206.00	Yes	243.24	243.05	**-0.19**	243.03	243.07	243.09
616	245547.43	4862239.75	Yes	216.88	216.69	**-0.19**	216.68	216.68	216.69
615	244161.07	4828880.67	Yes	190.24	190.07	**-0.17**	190.02	190.06	190.10
666	245913.31	4870185.71	Yes	235.89	235.73	**-0.16**	235.68	235.78	235.81
618	249477.34	4877890.51	Yes	239.20	239.04	**-0.16**	239.03	239.04	239.08
646	259023.55	4878352.95	Yes	209.24	209.10	**-0.14**	209.10	209.12	209.13
653	258177.65	4855265.78	Yes	185.50	185.37	**-0.13**	185.36	185.37	185.38
667	246688.64	4883726.38	Yes	235.75	235.63	**-0.12**	235.61	235.67	235.67

655	251049.63	4839670.13	Yes	185.58	185.47	**-0.11**	185.46	185.47	185.49
652	251698.30	4853972.39	Yes	196.30	196.19	**-0.11**	196.10	196.22	196.23
665	245247.14	4854791.29	Yes	200.66	200.55	**-0.11**	200.49	200.55	200.55
651	253677.80	4860277.52	Yes	196.50	196.40	**-0.10**	196.35	196.41	196.41
617	244921.32	4846370.44	Yes	198.75	198.66	**-0.09**	198.63	198.67	198.72
658	264550.19	4829411.85	Yes	180.27	180.18	**-0.09**	180.14	180.19	180.21
654	256122.65	4845781.28	Yes	188.52	188.44	**-0.08**	188.40	188.42	188.48
650	260204.58	4864750.99	Yes	187.90	187.82	**-0.08**	187.79	187.86	187.88
678	285046.50	4925784.93	Yes	256.82	256.74	**-0.08**	256.68	256.81	256.87
657	258802.92	4836813.39	Yes	182.40	182.32	**-0.08**	182.27	182.32	182.34
648	254084.58	4871400.37	Yes	205.42	205.34	**-0.08**	205.32	205.33	205.40
627	259559.38	4894164.09	Yes	243.30	243.22	**-0.08**	243.19	243.21	243.25
636	278029.59	4912793.75	Yes	254.56	254.49	**-0.07**	254.44	254.61	254.62
670	276857.41	4932069.30	Yes	266.79	266.72	**-0.07**	266.68	266.71	266.76
639	277681.79	4900007.39	Yes	208.20	208.14	**-0.06**	208.06	208.18	208.20
607	261854.08	4849487.45	Yes	177.32	177.26	**-0.06**	177.24	177.26	177.28
659	262847.63	4823428.02	Yes	178.03	177.97	**-0.06**	177.87	177.93	177.98
629	264681.22	4858129.56	Yes	178.02	177.97	**-0.05**	177.93	177.98	178.00
611	272080.14	4817883.39	Yes	179.27	179.23	**-0.04**	179.17	179.25	179.25
645	284051.55	4883178.36	Yes	179.21	179.17	**-0.04**	179.17	179.17	179.29
677	302245.56	4914018.41	Yes	184.18	184.14	**-0.04**	184.13	184.14	184.16
668	307513.27	4931559.16	Yes	188.27	188.24	**-0.03**	188.15	188.27	188.32
619	247410.35	4894682.28	Yes	250.64	250.61	**-0.03**	250.60	250.60	250.62
624	295691.74	4896319.69	Yes	180.19	180.16	**-0.03**	180.12	180.16	180.17
621	285710.18	4932095.21	Yes	260.24	260.21	**-0.03**	260.21	260.22	260.23
609	280484.59	4831255.79	Yes	177.51	177.48	**-0.03**	177.45	177.47	177.49
614	253617.29	4828322.65	Yes	190.64	190.62	**-0.02**	190.55	190.65	190.65
674	253151.32	4894484.05	Yes	243.35	243.33	**-0.02**	243.15	243.31	243.35
613	253486.63	4823548.18	Yes	192.54	192.54	**0.00**	192.53	192.54	192.56
660	274791.00	4828910.04	Yes	179.24	179.24	**0.00**	179.22	179.24	179.25
641	278551.50	4886558.58	Yes	186.44	186.44	**0.00**	186.41	186.43	186.50
630	274990.67	4876206.32	Yes	178.71	178.72	**0.01**	178.68	178.74	178.77
676	278208.77	4919229.28	Yes	258.28	258.30	**0.02**	258.19	258.30	258.31
612	272284.14	4822694.99	Yes	180.29	180.31	**0.02**	180.29	180.30	180.34
608	271225.03	4834879.20	Yes	178.35	178.37	**0.02**	178.28	178.38	178.41
632	286131.64	4918904.15	Yes	251.10	251.13	**0.03**	251.12	251.14	251.17
640	286409.09	4896174.32	Yes	189.57	189.60	**0.03**	189.55	189.60	189.62
663	281925.81	4823967.45	Yes	179.48	179.51	**0.03**	179.48	179.50	179.56
638	294454.14	4912633.02	Yes	239.86	239.89	**0.03**	239.88	239.89	239.93
656	264562.59	4841282.01	Yes	178.09	178.13	**0.04**	178.09	178.10	178.13

642	291433.72	4887138.78	Yes	184.39	184.43	**0.04**	184.30	184.32	184.44
669	293055.03	4931946.93	Yes	253.50	253.54	**0.04**	253.47	253.51	253.58
649	265177.74	4870906.81	Yes	186.60	186.64	**0.04**	186.64	186.64	186.66
679	286260.04	4912420.98	Yes	241.15	241.20	**0.05**	241.17	241.24	241.27
610	281816.47	4817528.73	Yes	184.57	184.62	**0.05**	184.62	184.63	184.66
662	297067.57	4902769.74	Yes	181.18	181.23	**0.05**	181.20	181.30	181.40
605	285168.25	4874452.48	Yes	179.04	179.11	**0.07**	179.04	179.11	179.17
643	263671.05	4885424.49	Yes	207.11	207.18	**0.07**	207.14	207.15	207.20
623	302539.99	4906143.17	Yes	179.31	179.38	**0.07**	179.36	179.38	179.40
634	303119.52	4918905.12	Yes	191.88	191.95	**0.07**	191.93	191.96	191.99
626	270521.78	4925988.28	Yes	274.66	274.73	**0.07**	274.71	274.74	274.80
633	293098.89	4923774.63	Yes	249.66	249.73	**0.07**	249.68	249.76	249.79
606	267546.85	4868071.53	Yes	177.66	177.74	**0.08**	177.72	177.76	177.82
637	285846.65	4906316.96	Yes	218.78	218.87	**0.09**	218.84	218.84	218.94
622	299487.34	4931698.94	Yes	247.64	247.73	**0.09**	247.71	247.73	247.84
602	314784.26	4930866.01	Yes	185.86	185.96	**0.10**	185.91	185.97	185.99
601	270441.21	4932479.69	Yes	310.65	310.76	**0.11**	310.71	310.74	310.81
672	270348.05	4920298.34	Yes	276.42	276.53	**0.11**	276.52	276.56	276.61
603	313390.11	4912322.56	Yes	178.63	178.75	**0.12**	178.72	178.73	178.76
628	314499.34	4920675.11	Yes	178.56	178.68	**0.12**	178.63	178.65	178.73
661	308993.70	4909313.31	Yes	181.51	181.64	**0.13**	181.59	181.62	181.67
604	291351.10	4882182.50	Yes	180.67	180.81	**0.14**	180.77	180.77	180.83
647	270763.74	4881432.60	Yes	189.98	190.12	**0.14**	190.06	190.10	190.18
675	264742.22	4894056.94	Yes	251.58	251.72	**0.14**	251.68	251.72	251.72
680	272099.72	4888345.52	Yes	199.67	199.82	**0.15**	199.74	199.76	199.86
671	270116.61	4913085.77	Yes	265.52	265.67	**0.15**	265.64	265.69	265.75
631	275818.76	4925914.12	Yes	283.04	283.20	**0.16**	283.14	283.17	283.21
625	269727.96	4901101.20	Yes	244.92	245.09	**0.17**	245.05	245.11	245.12
673	269897.65	4906661.60	Yes	238.18	238.37	**0.19**	238.35	238.37	238.48
620	269869.11	4893961.96	Yes	237.54	237.76	**0.22**	237.65	237.67	237.77
635	305743.06	4924409.88	Yes	218.60	218.88	**0.28**	218.87	218.88	218.92

LiDAR CALIBRATION

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

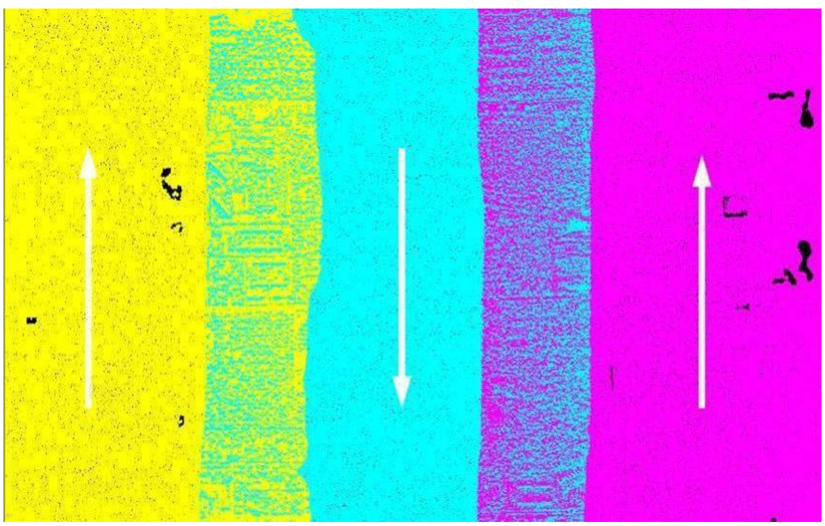


Figure 1: Flight pattern required for calibration

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.

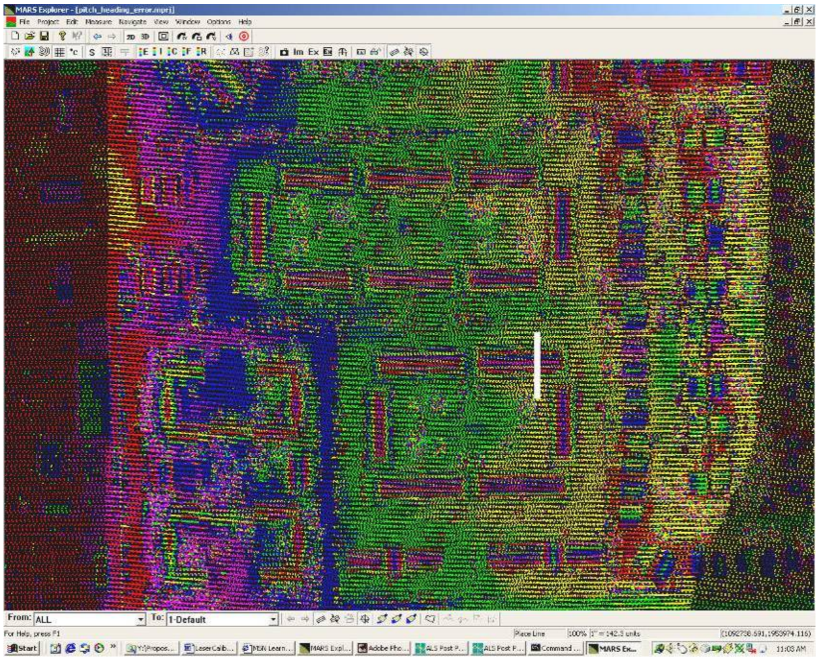


Figure 2: Orthographic view with profile line

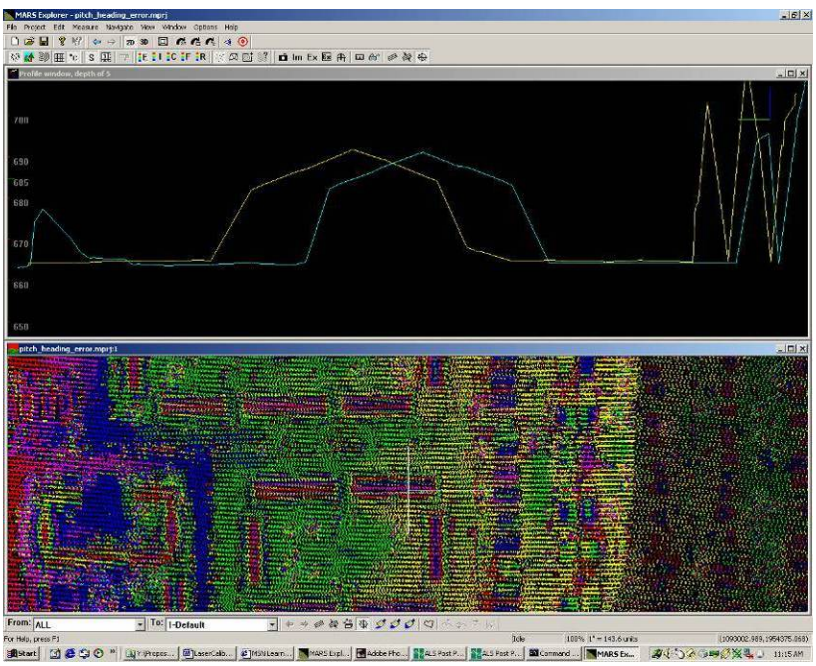


Figure 3: Profile view of misalignment

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).

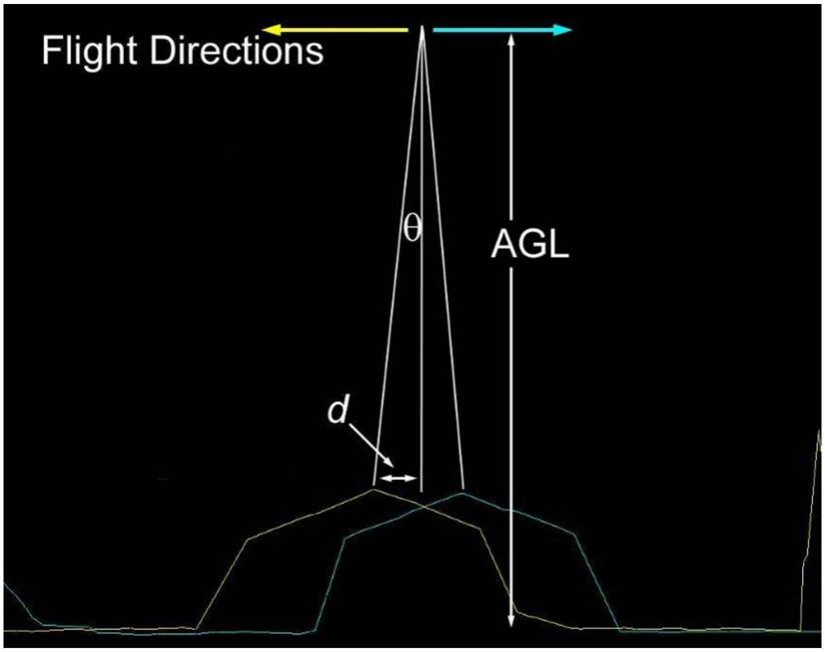


Figure 4: Adjusting pitch

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

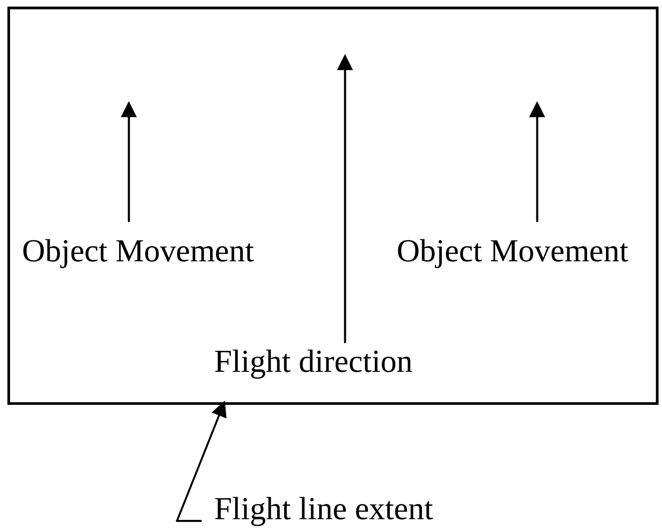
$$\theta = \frac{\arctan\left(\frac{d}{AGL}\right)}{57.2958}$$

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

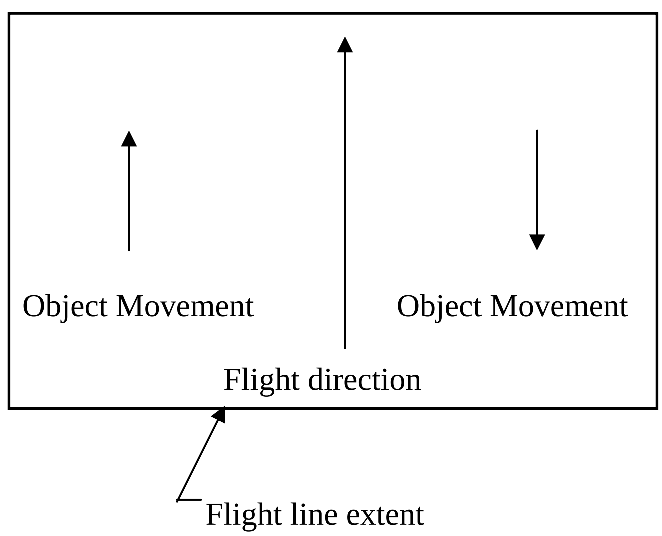
The next issue to resolve, before actually changing the pitch value, is to determine if this shift is at all due to an incorrect heading value, since heading will move data in the direction of flight also. The difference is that heading rotates the data, meaning that when heading is changed, objects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

Figures 5 and 6: Pitch and Heading movement.

Pitch increases, objects throughout the data move forward.



Heading increases, objects move clockwise.



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

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

Correcting for the Roll Bias

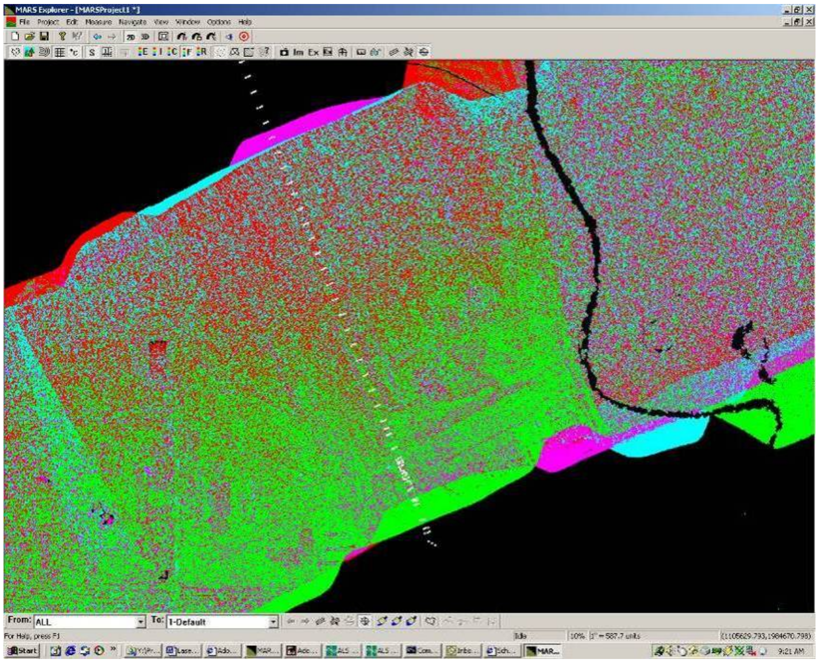


Figure 7: The truth survey

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

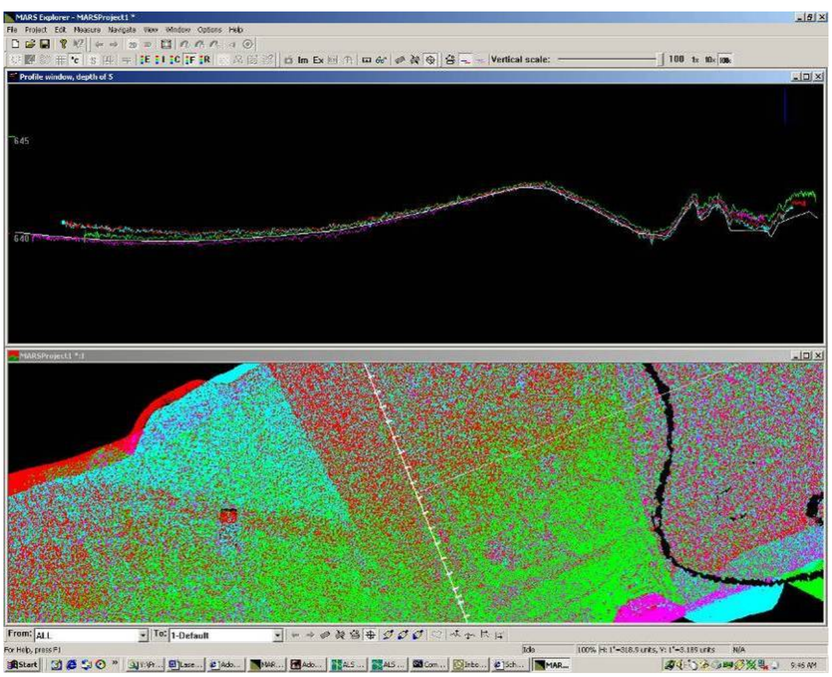


Figure 8: Profile view of calibration flight lines

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

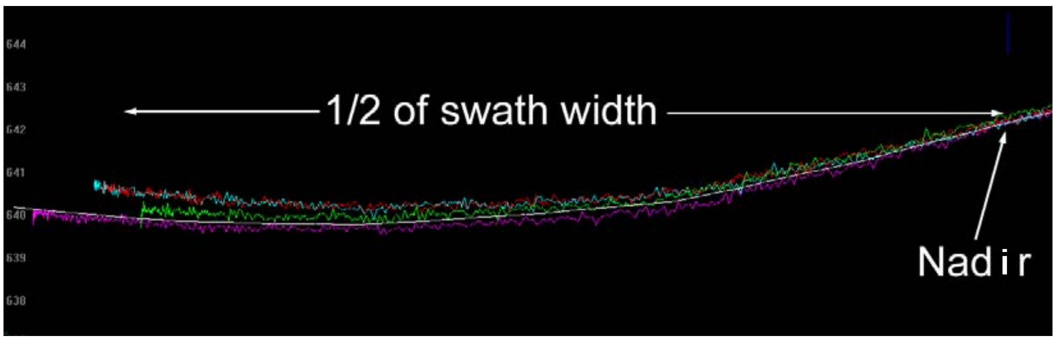


Figure 9: Half of calibration profile

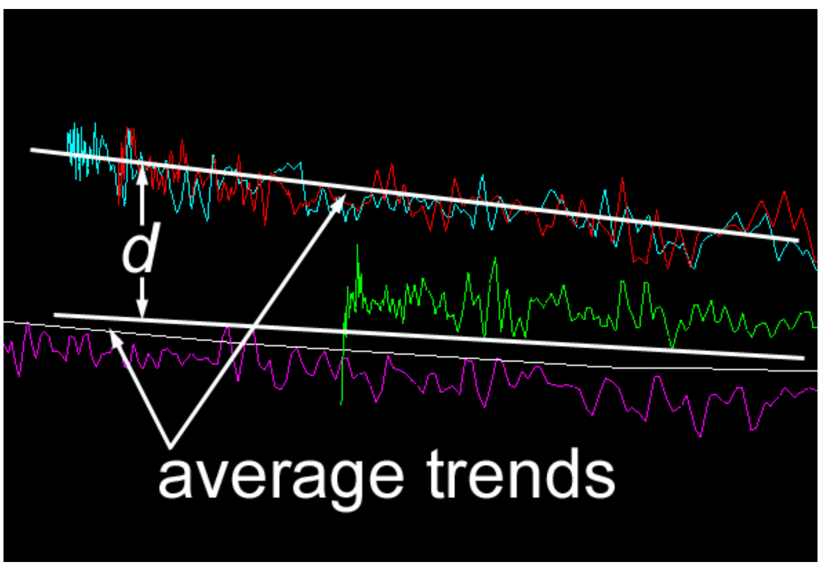


Figure 10: Differences in average roll trends

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

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

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

Per contract requirements, Merrick did NOT perfrom any LiDAR classification.

DIGITAL ELEVATION MODEL (DEM)

Per contract requirements, Merrick did NOT perfrom any DEM development.

BREAKLINE COLLECTION

Per contract requirements, Merrick did NOT perfrom any breakline collection.