FINAL REPORT

Survey 13-184

Rio de la Plata and Puerto Nuevo Topographic Surveys Bayamón, Carolina, Catoña, Dorado, Guaynabo, San Juan, Toa Alta, Toa Baja, & Trujillo Alto Provinces, Puerto Rico

Prepared For:

Jacksonville District USACE
Geomatics Section

Prepared By:

PAR LLC
PRECISION AERIAL RECONNAISSANCE

April, 2014

Table of Contents

Project Management

Project Manager for PAR, LLC was performed by Jeff Lower, the company's president. Mr. Lower was the primary point of contact for PAR, and was responsible for all communication to USACE regarding project status and details. Mr. Lower communicated directly with the USACE POC, Ted Schall. Ted's contact information is:

Theodore N. Schall, CP, GISP
Geodesist
United States Army Corps of Engineers
Jacksonville District
701 San Marco Boulevard
Jacksonville, FL 32207
(904) 232-2214
ted.n.schall@usace.army.mil

Weekly communication and status reporting was provided in the form of weekly reports. There were a total of 30 weekly reports for the Period of Performance (PoP) from October 2013 to April 2014. A copy of the weekly reports is included as **Appendix C** of this report. Additional communication was done through supplemental emails, phone calls and onsite data review at USACE, Jacksonville District.

Our Task Order Project Leads met weekly at a minimum with the technical team to assess and report successes, issues, risks/uncertainties, and concerns to the Project Manager, who raised pertinent ones to USACE. Internal daily communication within the production staff ensured the work being performed in different locations was consistent and transparent as to production location. Our production manager (Ken Comeaux), reported directly to the Project Manager, reviewed technical progress and output weekly to be sure there are were deviations between production locations.

Key Personnel

Project Management Key Personnel Background and Contact Information

NAME: **Jeff Lower, RPP, SP**
President, PAR, LLC
jeff@precisionaerialrecon.com
985-502-6822

ROLE: Project Management, communication with USACE, management of PAR resources
YEARS EXPERIENCE: 20
EDUCATION (DEGREE AND SPECIALIZATION)

- MS / Geography / University of Florida / 1996
- BS / Geography / University of Florida / 1992

CURRENT PROFESSIONAL REGISTRATION (STATE AND DISCIPLINE)

- Surveyor Photogrammetrist in Virginia, #408000065
- Registered Professional Photogrammetrist in OR, #80669RPP

OTHER PROFESSIONAL QUALIFICATIONS (Publications, Organizations, Training, Awards, etc.)
Mr. Lower has 20 years of experience in the geospatial profession in program management, development and implementation of federal, state, and local government projects, resource/time management, project estimating, quality control and assurance, photogrammetric mapping, hydrographic mapping, navigational charting, GIS and cartography. He has performed extensive Federal work, including directing the first S-57 IENC data production in the United States, and directing the largest aerial mapping project in US history (US Border Mapping). He also managed emergency response mapping after Hurricanes Katrina and Rita for USACE and FEMA. Mr. Lower is the current National President of MAPPS.

Data Acquisition and Processing - Key Personnel Background and Contact Information

Key personnel for the data acquisition and processing are:

NAME: **Ken Comeaux, CP, GISP**
Director of Operations, PAR, LLC
ken@precisionaerialrecon.com
985-634-7642

ROLE: Operations Management, Production Management, QA/QC
YEARS EXPERIENCE: 24
CURRENT PROFESSIONAL REGISTRATION (STATE AND DISCIPLINE)

Certified Photogrammetrist (ASPRS) #1485
Certified GIS Professional (GISCI) #00060795

OTHER PROFESSIONAL QUALIFICATIONS (Publications, Organizations, Training, Awards, etc.)

Mr. Comeaux is an ASPRS Certified Photogrammetrist and a GISCI Certified GIS Professional with 24 years of geospatial acquisition and processing experience. He has a wealth of experience working with airborne sensors, data processing, and in the planning of a variety of different types of photogrammetric surveys. Mr. Comeaux provides oversight and direction to our data acquisition field staff and our technical staff.

NAME: **Stephen (Tanner) Farrar**
Chief Pilot, PAR, LLC
Tanner@precisionaerialrecon.com
(405)694-7985

ROLE: Chief Pilot, all flight logistics and coordination, safety of flight crew
YEARS EXPERIENCE: 2
EDUCATION (DEGREE AND SPECIALIZATION)
BA / Science / 2007 /Southwestern OK State University
CURRENT PROFESSIONAL REGISTRATION (STATE AND DISCIPLINE)
FAA Commercial Pilots (License #3358607)
FAA Certified Flight Instructor; Multi Engine Instructor
OTHER PROFESSIONAL QUALIFICATIONS (Publications, Organizations, Training, Awards, etc.)
Member of AOPA – Aircraft Owners and Pilots Association

NAME: **Roy (Trent) Tomlinson**
Sensor Operator and Geospatial Analyst
trent@precisionaerialrecon.com
(870) 904-1144

ROLE: LIDAR Sensor Operator and LIDAR Analyst
YEARS EXPERIENCE: 2
EDUCATION (DEGREE AND SPECIALIZATION)
BS/ 2010 / Geographical Information Science / Louisiana Tech University
OTHER PROFESSIONAL QUALIFICATIONS (Publications, Organizations, Training, Awards, etc.)
ESRI Training, Leica sensor and processing training

Flight Details

Aircraft Description

PAR utilized its Cessna 206 (Tail Number N799AC) for data acquisition for this project. The Cessna 206 is a single engine aircraft. The average fuel consumption for the 206 is between 15 and 20 gallons per hour (depending on headwind and flight conditions).

Sensor Parameters

PAR utilized its Leica ALS70-CM LIDAR sensor for data acquisition (Serial Number 7169). A detailed product specification for the sensor is included as an **Appendix B** to this final report, but the system consists of: the following hardware

- LIDAR unit is a Leica ALS70-CM, serial number 7169
- IMU is a Honeywell MicroIRS, serial number 56038510
- Camera is a Leica RCD30 60Mpixel 4-band camera, serial number 62026 (Not applicable for this task order but part of the system configuration)

Figure 1 - Leica ALS70-CM

Flight Lines and Parameters

Mobilization

The Cessna 206 aircraft mobilized from Shreveport, LA to the Isla Grande Airport in San Juan Puerto Rico on October 25th, 2013. The mobilization was approximately 1750 miles each way. Stops were in South Florida (overnight), and Caicos (for refueling) while in route from South Florida to San Juan.

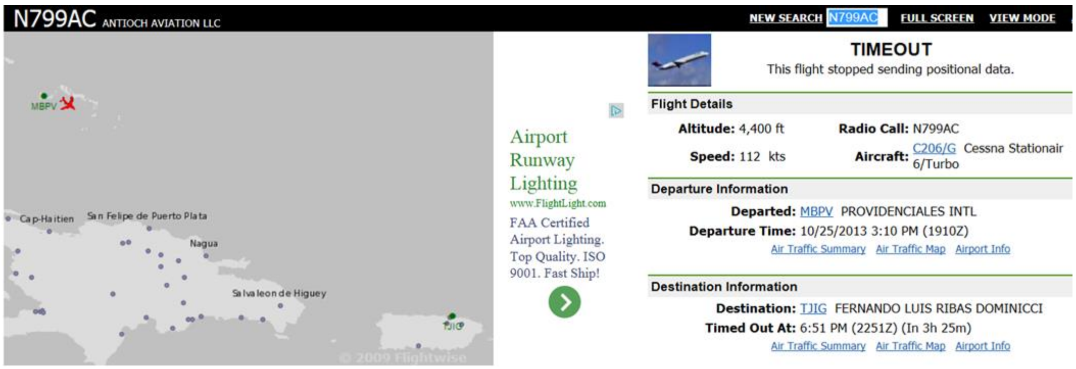


Figure 2 - Flight tracker for mobilization to PR

The base of operation was established at Isla Grande Airport in Puerto Rico upon arrival.

Figure 3 - Base of Operation for Data Collection in Puerto Rico

Based on the block orientation, flight lines were planned the east-west direction across the blocks.

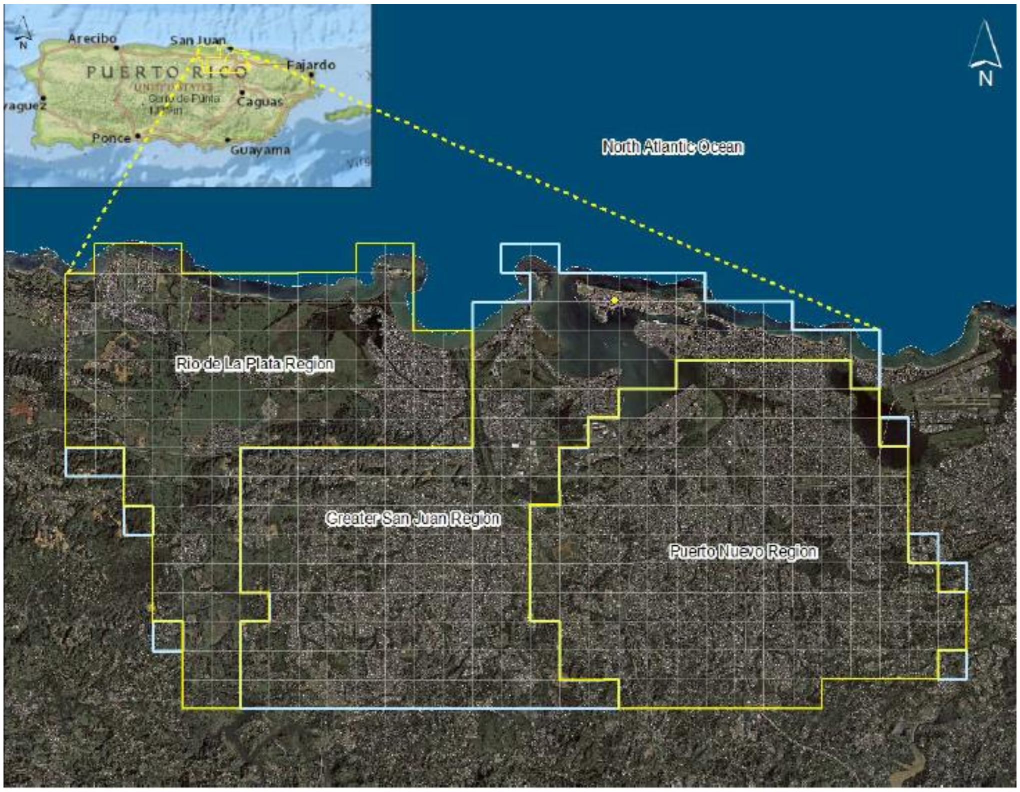


Figure 4 - Project Area; Rio De La Plata is Block 1, Puerto Nuevo is Block 2, and the Greater San Juan Region is Block 3

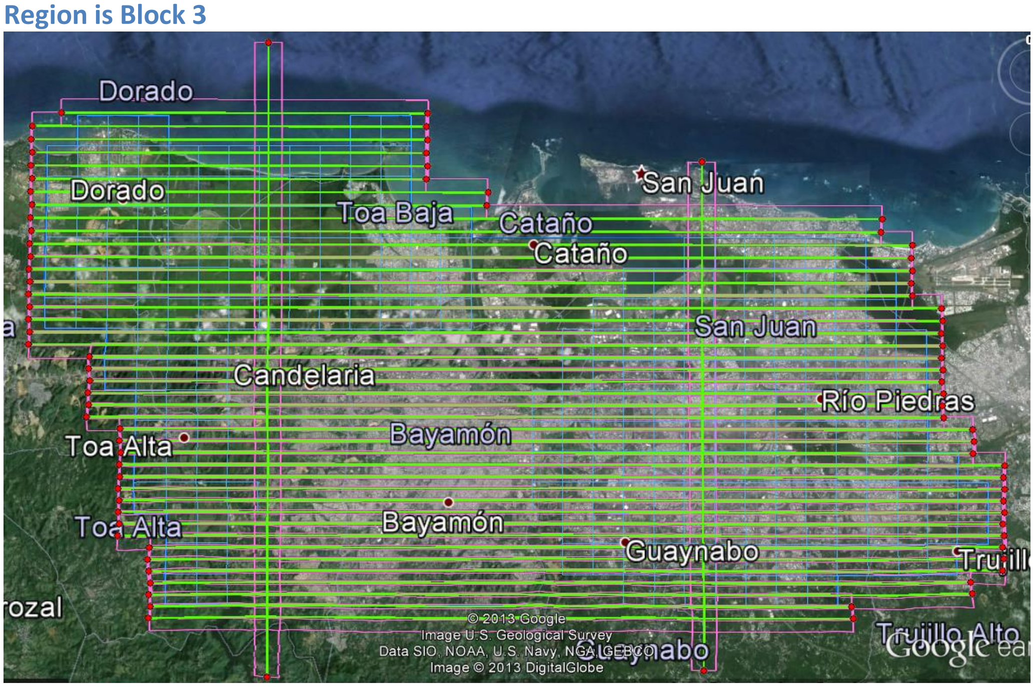


Figure 5 - Planned Flight Lines

As planned, there were 44 flight lines (two of which are tie lines) and a total of approximately 741 miles online. The tie lines were used for calibration of the data, and ground survey control was established along the tie lines and throughout the area of interest. At the base of operations (Isla Grande Airport), we setup a base station to run during collection. An additional base station (CORS) was used as a secondary and backup base. The following are the details for the base stations:

Base Stations

Base station at Airport.
TV1527 DESIGNATION - SAN JUAN SIG APT ARP
TV1527 PID - TV1527
TV1527* NAD 83(2011) POSITION- 18 27 26.32168(N) 066 05 53.59366(W) ADJUSTED
TV1527* NAD 83(2011) ELLIP HT- -40.605 (meters) (06/27/12) ADJUSTED
TV1527* NAD 83(2011) EPOCH - 2010.00
TV1527* PRVD02 ORTHO HEIGHT - 2.317 (meters) 7.60 (feet) ADJUSTED

CORS Base station.
DL7810 CORS - This is a GPS Continuously Operating Reference Station.
DL7810 DESIGNATION - BAYAMON CORS ARP
DL7810 CORS_ID - PRHL
DL7810 PID - DL7810
DL7810* NAD 83(2011) POSITION- 18 22 48.09108(N) 066 09 12.81219(W) ADJUSTED
DL7810* NAD 83(2011) ELLIP HT- -22.539 (meters) (08/??/11) ADJUSTED
DL7810* NAD 83(2011) EPOCH - 2010.00

Flight Parameters

Project Area Size: The original project size was 250 sq. kms, plus 200m buffer on all sides. Block 3 was added in a modification, which increased the size to 404 sq. kms.

Nominal point spacing (1st return): 4.0 pts/m
Flight Plan

- Altitude - 3,800' (1250 meters) above mean terrain
- Lines - 42 plus 2 tie lines
- Line Length - 686 nautical miles (741 miles with tie lines)
- Field of View - 40 Degrees
- Used Scan Rate - 53.4 Hz
- Used Pulse Rate - 435600 kHz
- Speed- 100 knots
- Scan Pattern- Triangle

GPS ANTENNA AND OFFSET ANGLES

N799AC Aircraft Antenna Offsets (GPS Lever Arm Coordinates)
X= 0.051m
Y= 0.340m
Z=-1.220m

IMU Lever Arms
X= 0.450m
Y= 0.159m
Z=-0.169m

IMU Boresight Rotation
Omega= 0.00
Phi=-90.00
Kappa=90.00

User Frame Lever Arms
X=-0.450m
Y= 0.159m
Z=-0.169m

Aircraft to Reference Rotation
Omega= 0.00
Phi=0.00
Kappa=180.00

Sensor Calibration

ALS70-CM Sensor Calibration Certificate can be found in **APPENDIX B**.

Data Collection and Quality Control in the Field

Data for the project area was collected in 6 missions (from 10/27/13 to 11/03/13). The dates and mission names are as follows:

Mission 1 (10/27/2013) – 5 flight lines flown, 3, good, 2 re-flown in mission 7

Mission 2 (10/27/2013) – 14 lines flown, 7 good, 7 re-flown in mission 7

Mission 3 (10/28/2013) – 11 lines flown, 8 good, 3 re-flown in mission 7

Mission 4 (11/01/2013) – 5 lines flown, 4 good, 1 re-flown in mission 6

Mission 5 (11/01/2013) – Mission 5 did not collect any data, clouds rolled in after takeoff

Mission 6 (11/02/2013) – 21 lines flown, 10 good, 11 re-flown in mission 7

Mission 7 (11/03/2013) – 21 lines flown, all good

Mission 1 (10/27/13)

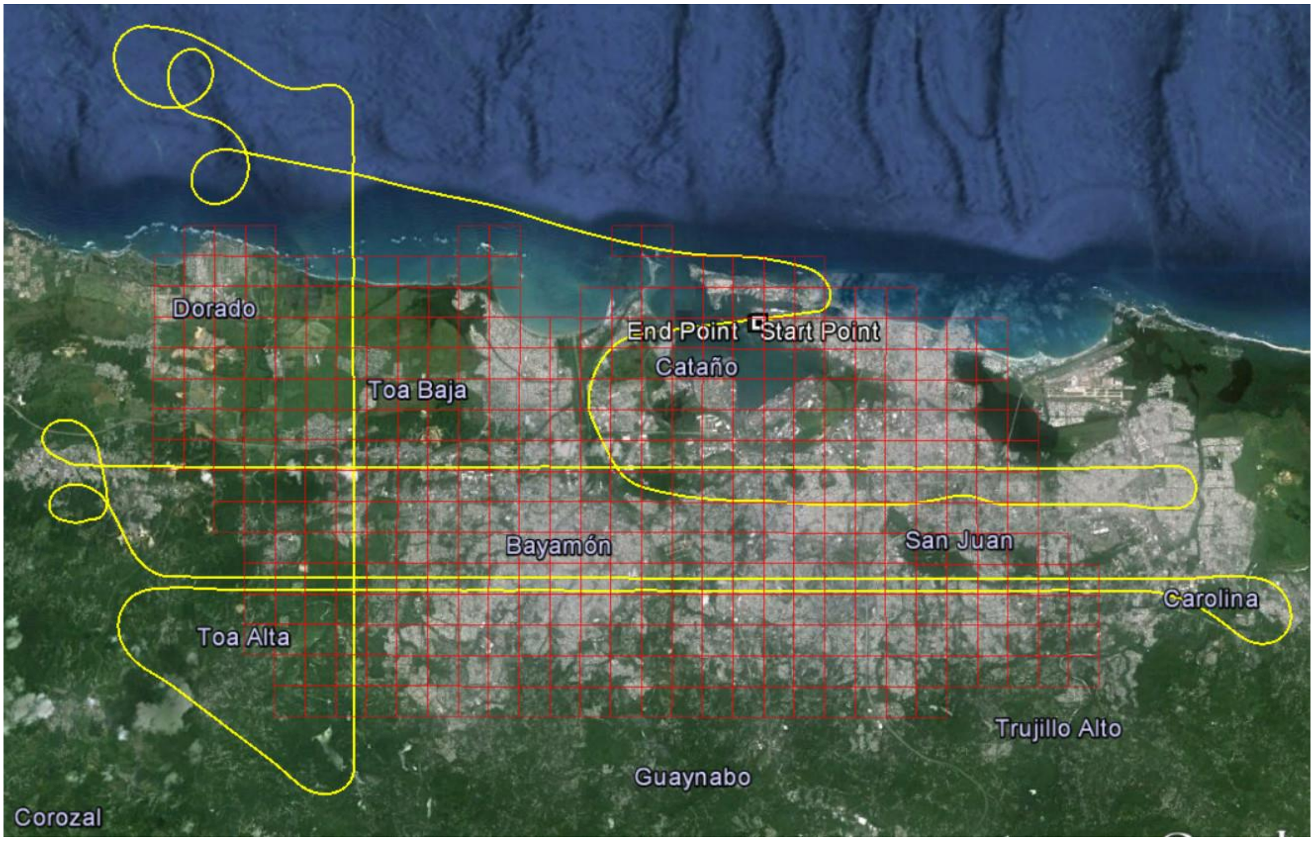


Figure 6 - Trajectory Plot, Mission 1

PAR LLC PRECISION AERIAL RECONNAISSANCE
P.O. Box 72357
Bossier City, LA 72357

LIDAR Daily Log

Field Crew		
	Project #	TBA
	Project Description	PuertoRico
DRIVE A		
	Location	Isle Grande (TJIG)
MISSION 1		

Flight Date (UTC)	Pilot	Operator	Sensor	Aircraft	SENSOR NAVIGATION FILE NAME
10/27/2013	Farrar	Tomlinson	ALS70	N799AC	

Lever Arm

	x	y	z
GPS (m)	-0.110	0.210	-1.220

GPS Information		AGC
Base 1	19823000.T02	
Base 2		Auto
Base3		
Aero 1		

IMU Information	
Start Time	11:56:30
Stop Time	13:24:52

Meteorological Conditions

	Elevation	Temp		Pressure	
Airport	9	23.0°c	296.15°k	29.94 inHg	101388 Pa
@ Altitude	3800AGL	27.0°c	300.15°k	29.92 inHg	101321 Pa
@ Altitude					

GPS Base Station Information

	File Name	RNX File	Ant Hgt	Ant Type
Base 1	19823000.T02		2.05m	Trimble R10
Base 2				
Base 3				

Reflight	Line	Dir	Start	Stop	Total Time	FOV	Scan Rate	Pulse Rate Hz	Roll Comp	Muti Pulse (Y,N)	Altitude ellipsoid (m)	Altitude ellipsoid (ft)	Speed	Nautical Miles Flown	Void "Y"	PDOP	Operator	Conditions/Comments
	PRO43	131027_121934	12:19:51	12:26:14	0:06:23	39.4	53.4	217800	YES	Y	1226	4022					Tomlinson	Cross Line. Had a little clouds at the end, should be good though
	PRO30	131027_122935	12:29:52	12:39:04	0:09:12	39.5	53.4	217800	YES	Y	1106	3629					Tomlinson	good
	PRO29	131027_124156	12:42:12	12:50:49	0:08:37	39.5	53.4	217800	YES	Y	1190	3904					Tomlinson	good
M7	PRO20	131027_125529	12:55:45	13:06:08	0:10:23	39.6	53.4	217800	YES	Y	1137	3730					Tomlinson	Got first 66 frames, then clouds, we'll have to refly line
M7	PRO23	131027_130827	13:08:43	13:09:21	0:00:38	39.6	53.4	217800	YES	Y	1234	4049					Tomlinson	partial line

LIDAR FLIGHT SUMMARY

		Hobbs Start	0
Aircraft IMU Time	1:28:22	Hobbs Stop	0
Sensor Collection Time	0:35:13	Hobbs Total	0.0
Line Miles Flown	0.0	Mission Hobbs	#DIV/0!
Average Flight Lines Speed	#DIV/0!	Reflight Hobbs	#DIV/0!
Average Nautical Line miles Per Mission Hour			#DIV/0!

DATA COLLECTION

Total Lines	0	Project % Complete	#DIV/0!
# Reflight Lines	0	Total Flight Lines	0
Reflight Percent	#DIV/0!	Line Complete	0
Sensor Re-Flight Miles	0.0	Mission Lines	0
Average Nautical Line Miles Per Re-Flight Hour	#DIV/0!		

Comments

Cloud Cover

Clear	X
Fair	
Partly Cloudy	
Cloudy	

Figure 7 - Flight Log, Mission 1

Position Separation Plots - Mission 1

The combined position separation plot is a measure of the difference between the forward run and the backward run solution of the trajectory. The Kalman filter is run in both directions to remove directional specific anomalies. The closer these two solutions match, the better is the overall reliability of the solution. PAR's goal is to maintain a combines Separation Difference of <10cm, often achieving results well below this cap. The spikes in the PDOP graphs are during turn times (no data being collected during these times). The low and high at the beginning and end of the mission is during accent and decent during takeoff and landing.

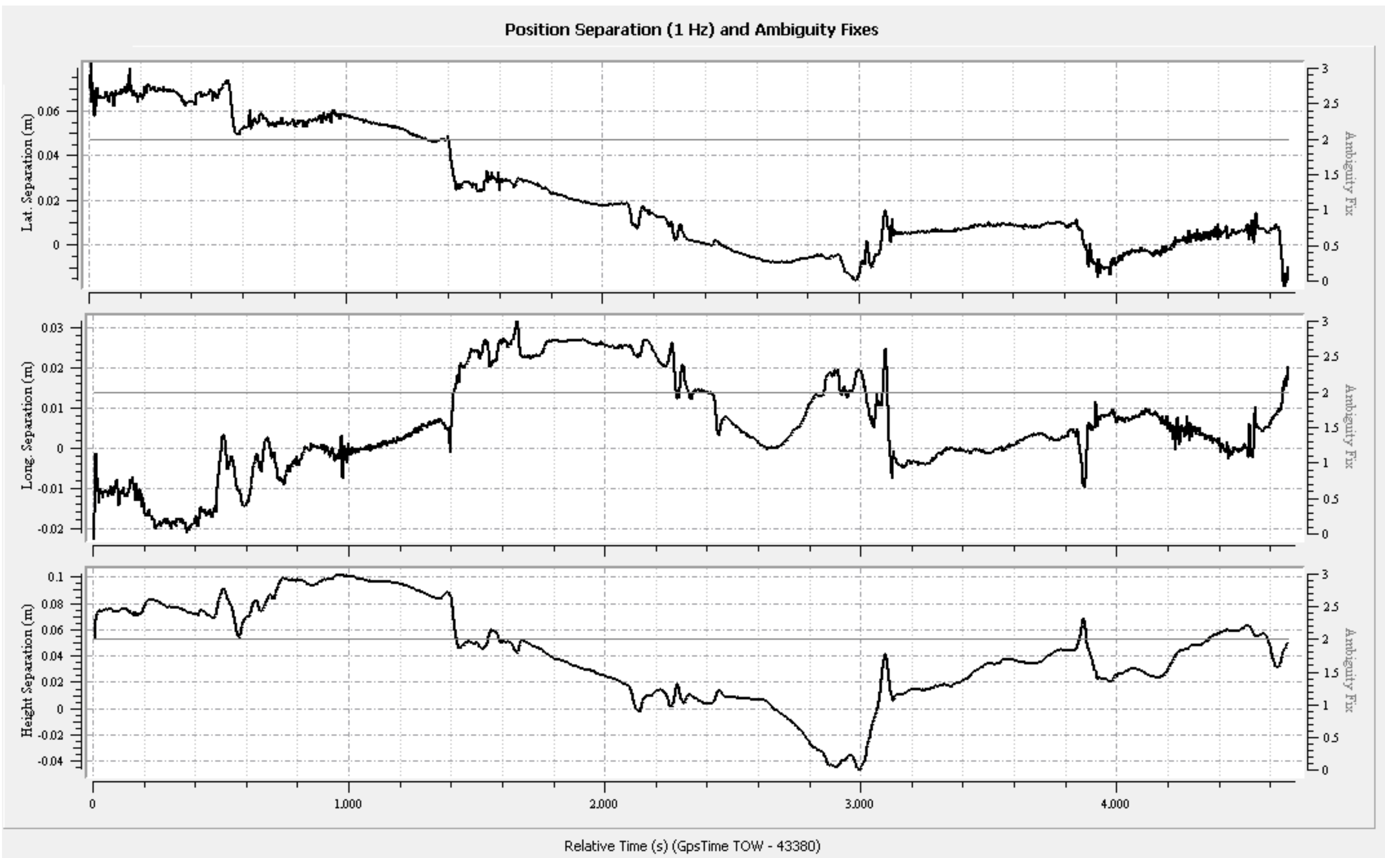


Figure 8 – Position Separation Plot for Mission 1

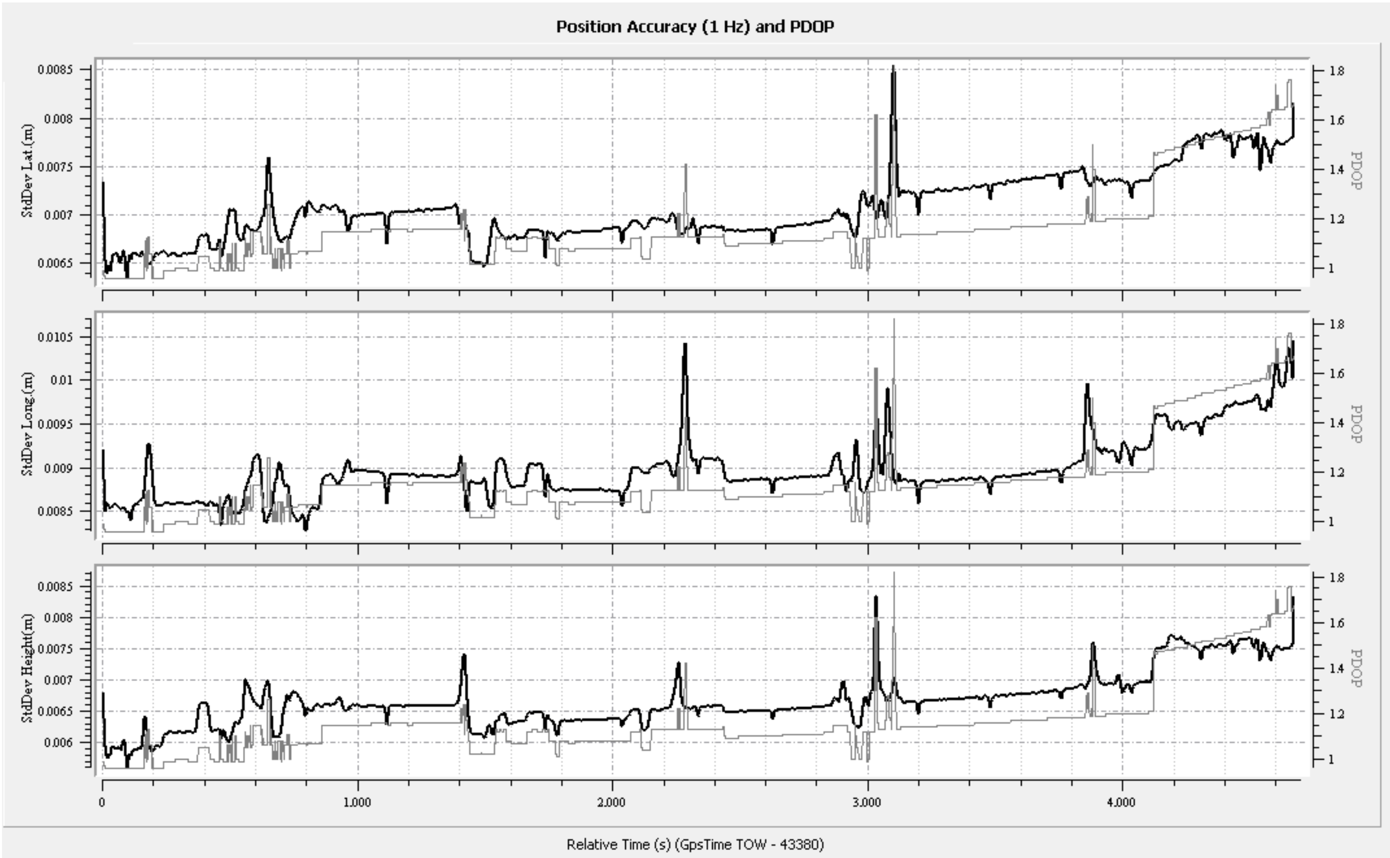


Figure 9 – Position Accuracy Plot and PDOP, Mission 1

Mission 2 (10/27/13)

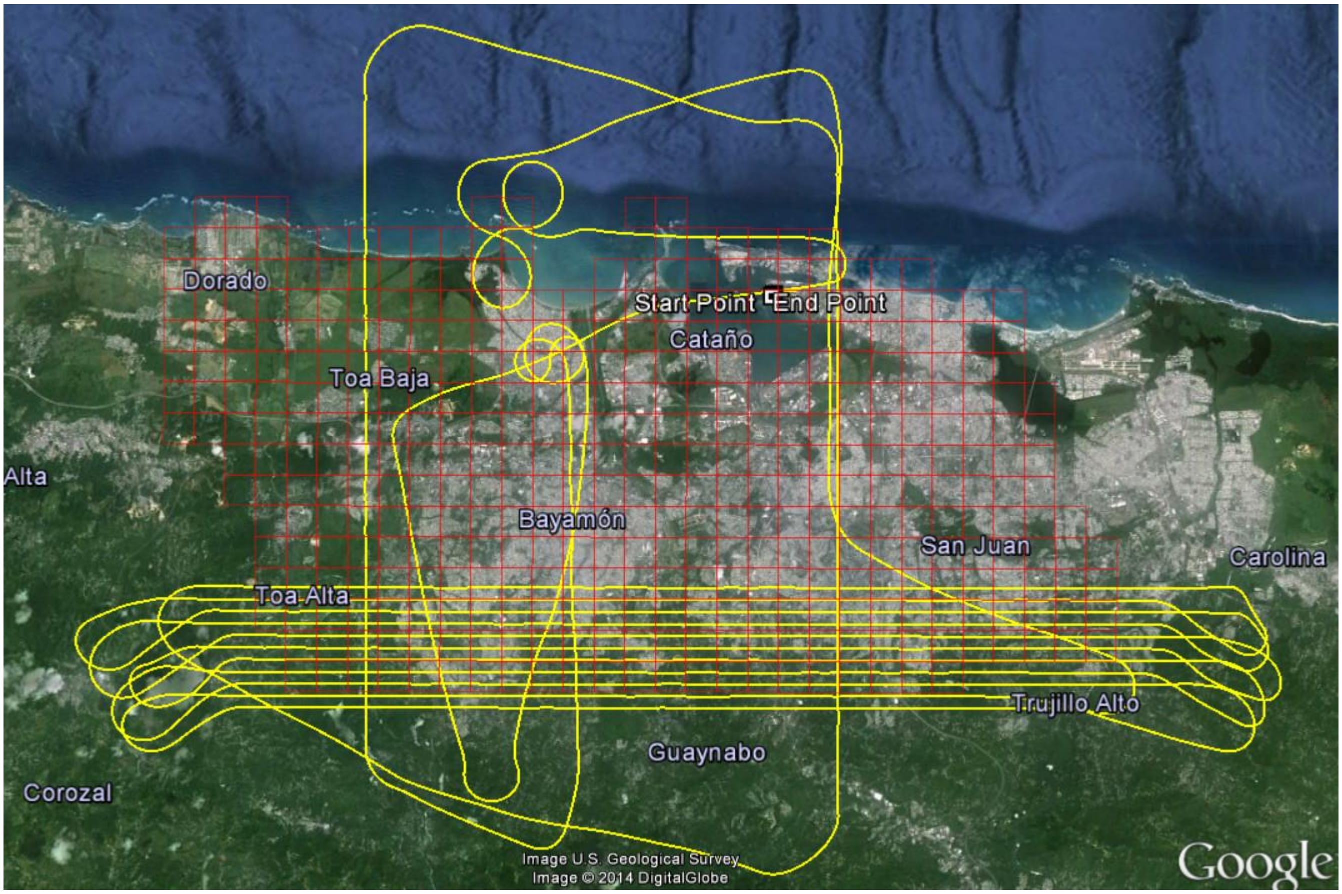


Figure 10 - Trajectory Plot, Mission 2

PAR LLC PRECISION AERIAL RECONNAISSANCE
P.O. Box 72357
Bossier City, LA 72357

LIDAR Daily Log

Field Crew	DRIVE A / MISSION 2
Project #	TBA
Project Description	PuertoRico
Location	Isle Grande (TJIG)
Flight Date (UTC)	10/27/2013
Pilot	Farrar
Operator	Tomlinson
Sensor	ALS70
Aircraft	N799AC
SENSOR NAVIGATION FILE NAME	

Lever Arm	x	y	z
GPS (m)	-0.110	0.210	-1.220

GPS Information		
Base 1	19823001.T02	
Base 2		Auto
Base3		
Aero 1		

IMU Information	
Start Time	23:31:31
Stop Time	2:59:09

Meteorological Conditions					Pressure
Airport	9	23.0'c	296.15'k	29.94 inHg	101388 Pa
@ Altitude	3800AGL	27.0'c	300.15'k	29.92 inHg	101321 Pa
@ Altitude					

GPS Base Station Information	File Name	RNX File	Ant Hgt	Ant Type
Base 1	19823001.T02		2.05m	Trimble R10
Base 2				
Base 3				

Reflight	Line	Dir	Start	Stop	Total Time	FOV	Scan Rate	Pulse Rate Hz	Roll Comp	Muti Pulse (Y,N)	Altitude ellipsoid (m)	Altitude ellipsoid (ft)	Speed	Nautical Miles Flown	Void "Y"	PDOP	Operator	Conditions/Comments
	PRO42	131028_000057	0:01:13	0:08:39	0:07:26	39.6	53.4	217800	YES	Y	1167	3830					Tomlinson	good
	PRO41	131028_001107	0:11:24	0:18:19	0:06:55	39.9	53.4	217800	YES	Y	1156	3792					Tomlinson	good
M7	PRO40	131028_002150	0:22:06	0:30:36	0:08:30	39.7	53.4	217800	YES	Y	1169	3836					Tomlinson	good
M7	PRO39	131028_003323	0:33:39	0:41:38	0:07:59	39.7	53.4	217800	YES	Y	1153	3783					Tomlinson	some cloud(fog) at beginning, will have to check
	PRO38	131028_004420	0:44:37	0:53:31	0:08:54	39.8	53.4	217800	YES	Y	1169	3834					Tomlinson	good
	PRO37	131028_005600	0:56:16	1:04:33	0:08:17	39.7	53.4	217800	YES	Y	1160	3805					Tomlinson	good
	PRO36	131028_010718	1:07:34	1:16:05	0:08:31	39.9	53.4	217800	YES	Y	1164	3819					Tomlinson	good
	PRO35	131028_011902	1:19:18	1:28:02	0:08:44	39.6	53.4	217800	YES	Y	1166	3825					Tomlinson	good
M7	PRO34	131028_013030	1:30:46	1:39:29	0:08:43	39.6	53.4	217800	YES	Y	1182	3877					Tomlinson	check for clouds/fog at end of line
M7	PRO33	131028_014217	1:42:34	1:51:09	0:08:35	39.7	53.4	217800	YES	Y	1165	3823					Tomlinson	check for clouds/fog at beginning
M7	PRO32	131028_015338	1:53:55	2:02:54	0:08:59	39.8	53.4	217800	YES	Y	1170	3838					Tomlinson	check for clouds/fog throughout. Clouds thickening and moving in, goin to get cross lines
M7	PRO44	131028_021107	2:11:23	2:16:50	0:05:27	39.7	53.4	217800	YES	Y	1183	3881					Tomlinson	while over water had clouds, so no worries
M7	PRO43	131028_022124	2:21:40	2:27:14	0:05:34	39.7	53.4	217800	YES	Y	1168	3832					Tomlinson	clouds over where we need tie..communication error, will have to investigate
	UL001	131028_023023	2:30:39	2:32:18	0:01:39	39.7	53.4	217800	YES	Y	1201	3939					Tomlinson	unplanned tie

LIDAR FLIGHT SUMMARY

		Hobbs Start	0
Aircraft IMU Time	3:27:38	Hobbs Stop	0
Sensor Collection Time	1:44:13	Hobbs Total	0.0
Line Miles Flown	0.0	Mission Hobbs	#DIV/0!
Average Flight Lines Speed	#DIV/0!	Reflight Hobbs	#DIV/0!
Average Nautical Line miles Per Mission Hour			#DIV/0!

DATA COLLECTION

Total Lines	0	Project % Complete	#DIV/0!
# Reflight Lines	0	Total Flight Lines	0
Reflight Percent	#DIV/0!	Line Complete	0
Sensor Re-Flight Miles	0.0	Mission Lines	0
Average Nautical Line Miles Per Re-Flight Hour	#DIV/0!		

Comments

Cloud Cover	
Clear	
Fair	X
Partly Cloudy	
Cloudy	

Figure 11 - Flight Log, Mission 2

Position Separation Plots - Mission 2

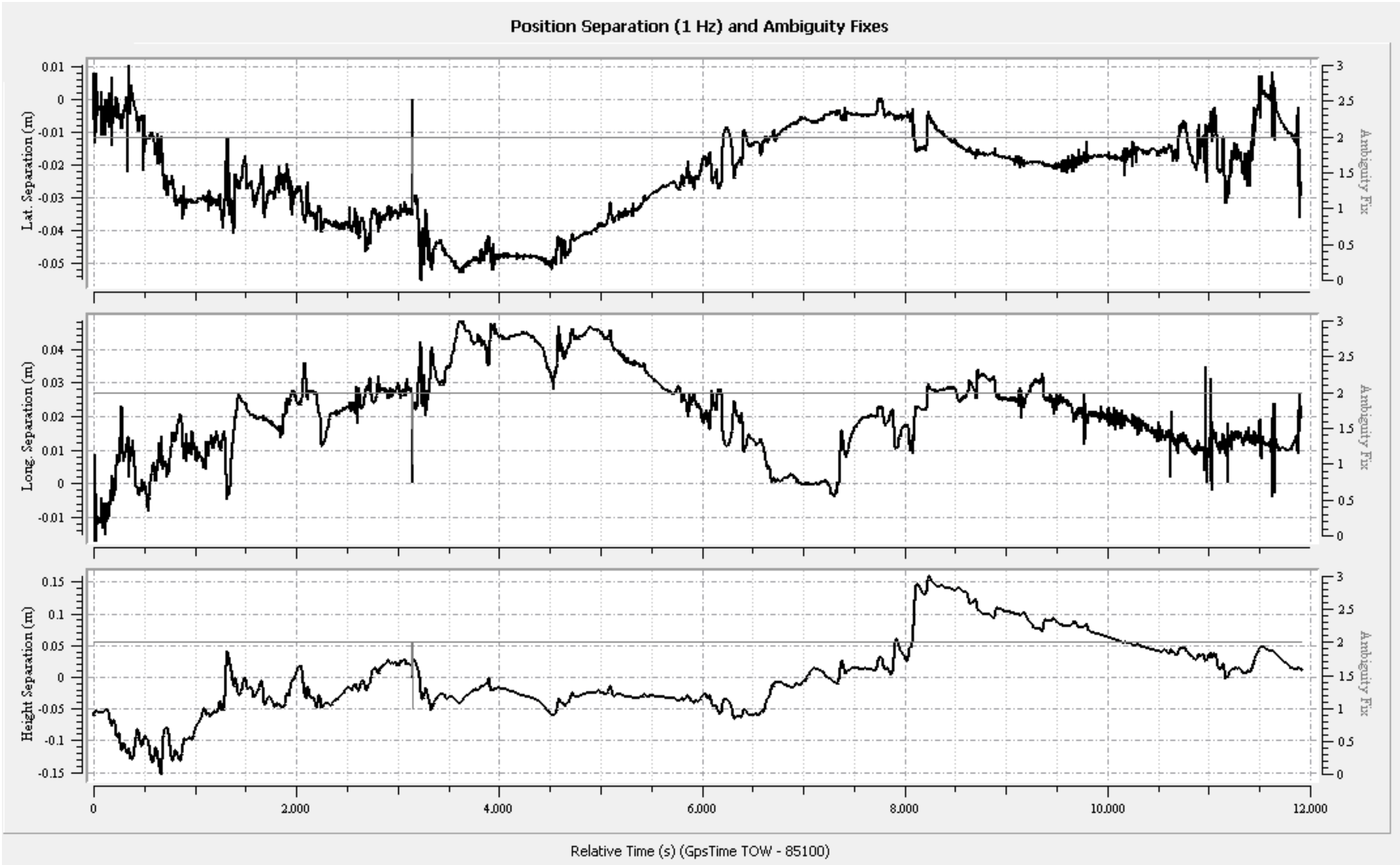


Figure 12 - Position Separation Plot for Mission 2

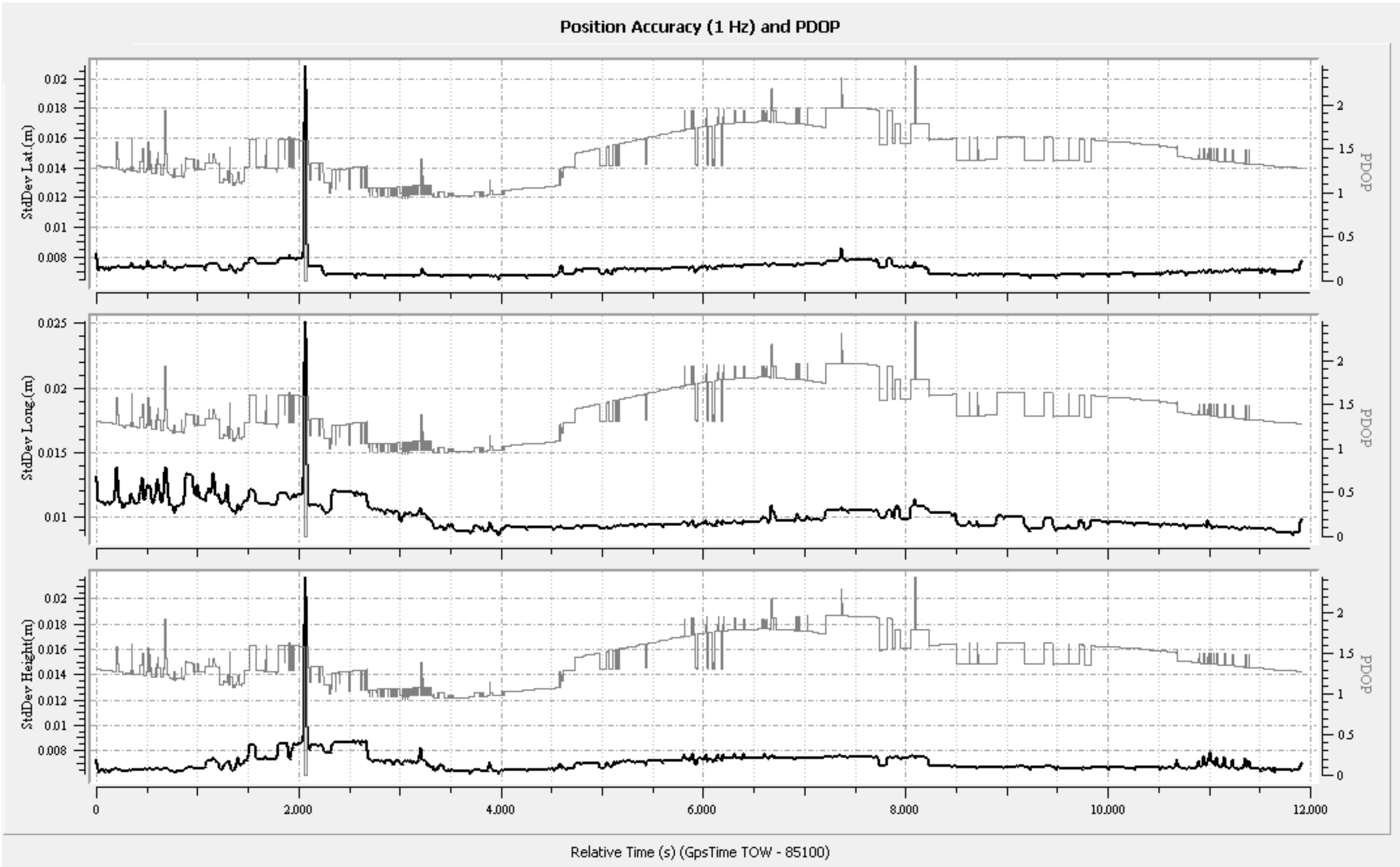


Figure 13 - Position Accuracy Plot and PDOP, Mission 2

Mission 3 (10/28/2013)

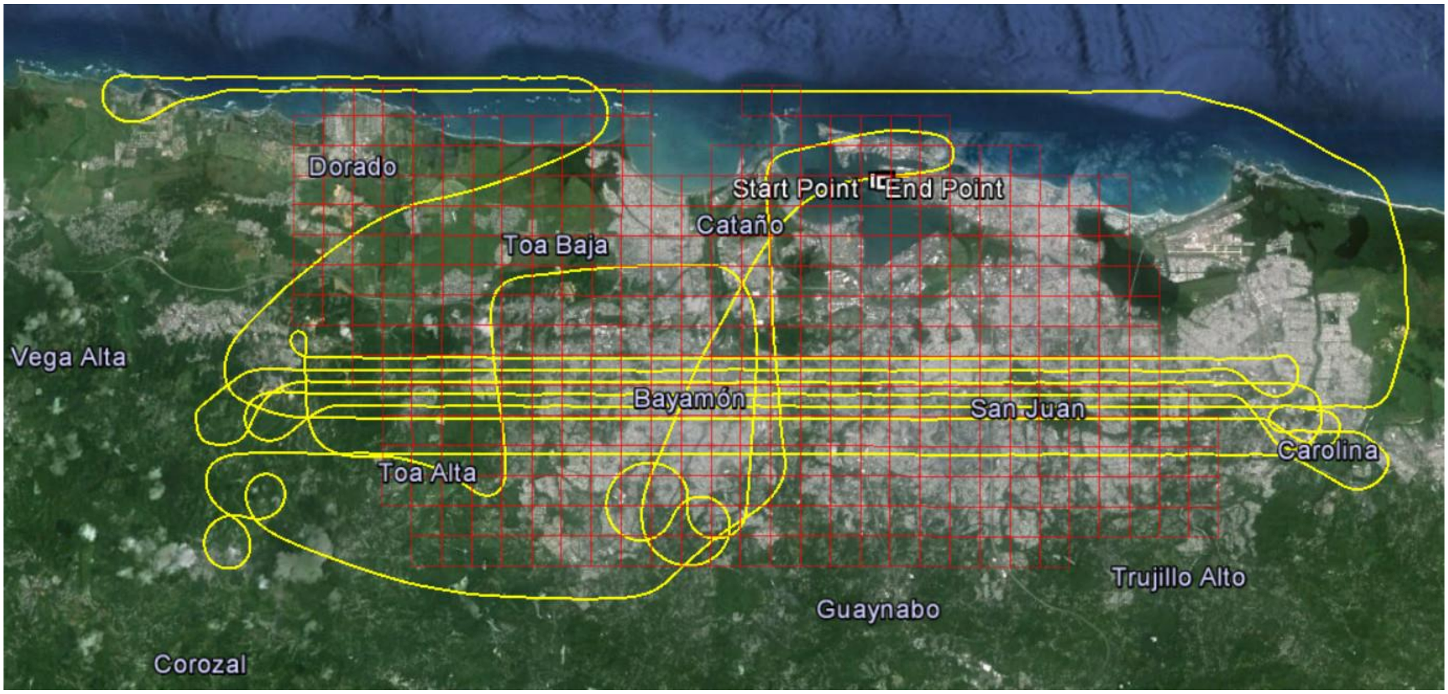


Figure 14 - Trajectory Plot, Mission 3

PAR LLC – PRECISION AERIAL RECONNAISSANCE
P.O. Box 72357
Bossier City, LA 72357

LIDAR Daily Log

Field Crew	DRIVE A
	MISSION 3
Project #	TBA
Project Description	PuertoRico
Location	Isle Grande (TJIG)
Lever Arm GPS (m)	x: -0.110, y: 0.210, z: -1.220

Flight Date (UTC)	Pilot	Operator	Sensor	Aircraft	SENSOR NAVIGATION FILE NAME
10/28/2013	Farrar	Tomlinson	ALS70	N799AC	

GPS Information		
Base 1	19823001.T02	
Base 2		Auto
Base3		
Aero 1		

IMU Information	
Start Time	4:03:21
Stop Time	6:41:42

Meteorological Conditions					Pressure
Airport	9	23.0°c	296.15°k	29.94 inHg	101388 Pa
@ Altitude	3800AGL	27.0°c	300.15°k	29.92 inHg	101321 Pa
@ Altitude					

GPS Base Station Information	File Name	RNX File	Ant Hgt	Ant Type
Base 1	19823001.T02		2.05m	Trimble R10
Base 2				
Base 3				

Reflight	Line	Dir	Start	Stop	Total Time	FOV	Scan Rate	Pulse Rate Hz	Roll Comp	Muti Pulse (Y,N)	Altitude ellipsoid (m)	Altitude ellipsoid (ft)	Speed	Nautical Miles Flown	Void "Y"	PDOP	Operator	Conditions/Comments
	PRO031	131028_042551	4:26:09	4:34:53	0:08:44	39.8	53.4	217800	YES	Y	1166	3824					Tomlinson	GOOD
	PRO002	131028_044322	4:43:40	4:52:02	0:08:22	40.2	53.4	217800	YES	Y	1185	3887					Tomlinson	CLOUDS ONLY OVER WATER
	PRO001	131028_045503	4:55:21	4:58:19	0:02:58	40.3	53.4	217800	YES	Y	1175	3856					Tomlinson	CLOUDS ONLY OVER WATER
	PRO028	131028_050347	5:04:04	5:13:00	0:08:56	40.5	53.4	217800	YES	Y	1180	3871					Tomlinson	SMALL CLOUDS OVER WEST SIDE AOI, STILL HAVE COVERAGE THOUGH
	PRO027	131028_051501	5:15:19	5:24:03	0:08:44	39.9	53.4	217800	YES	Y	1181	3876					Tomlinson	GOOD
	PRO026	131028_052618	5:26:35	5:35:02	0:08:27	40	53.4	217800	YES	Y	1177	3860					Tomlinson	CLOUDS AT START BUT DOESN'T EFFECT LINE
M7	PRO025	131028_053744	5:38:01	5:46:59	0:08:58	40.1	53.4	217800	YES	Y	1174	3853					Tomlinson	HEAVY CLOUDS ON EAST SIDE OF LINE
M7	PRO024	131028_055000	5:50:18	5:58:52	0:08:34	40.2	53.4	217800	YES	Y	1167	3829					Tomlinson	HEAVY CLOUDS IN THE MIDDLE OF THE LINE, CO CLOUDS OVER EITHER AOI
M7	PRO023	131028_060103	6:01:20	6:10:04	0:08:44	40	53.4	217800	YES	Y	1167	3829					Tomlinson	HEAVY CLOUDS ON WEST SIDE OF LINE
	UL001	131028_061405	6:14:23	6:15:38	0:01:15	40	53.4	217800	YES	Y	1154	3787					Tomlinson	GOOD
	UL002	131028_061846	6:19:04	6:20:25	0:01:21	39.8	53.4	217800	YES	Y	1174	3852					Tomlinson	GOOD

LIDAR FLIGHT SUMMARY			
		Hobbs Start	0
Aircraft IMU Time	2:38:21	Hobbs Stop	0
Sensor Collection Time	1:15:03	Hobbs Total	0.0
Line Miles Flown	0.0	Mission Hobbs	#DIV/0!
Average Flight Lines Speed	#DIV/0!	Reflight Hobbs	#DIV/0!
Average Nautical Line miles Per Mission Hour			#DIV/0!

DATA COLLECTION			
Total Lines	0	Project % Complete	#DIV/0!
# Reflight Lines	0	Total Flight Lines	0
Reflight Percent	#DIV/0!	Line Complete	0
Sensor Re-Flight Miles	0.0	Mission Lines	0
Average Nautical Line Miles Per Re-Flight Hour		#DIV/0!	

Comments

Cloud Cover	
Clear	
Fair	X
Partly Cloudy	
Cloudy	

Figure 15 - Flight Log, Mission 3

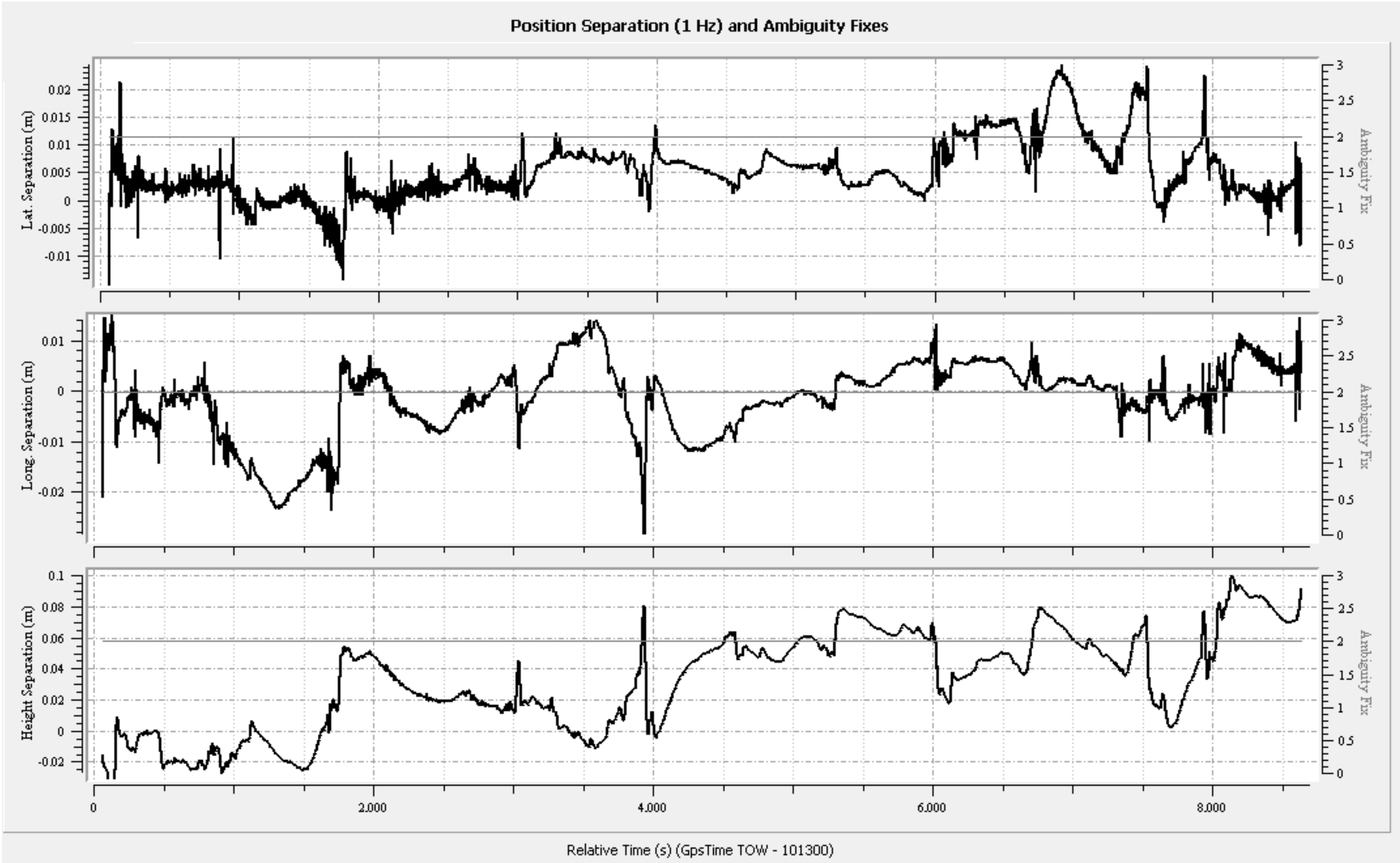


Figure 16 - Position Separation Plot for Mission 3

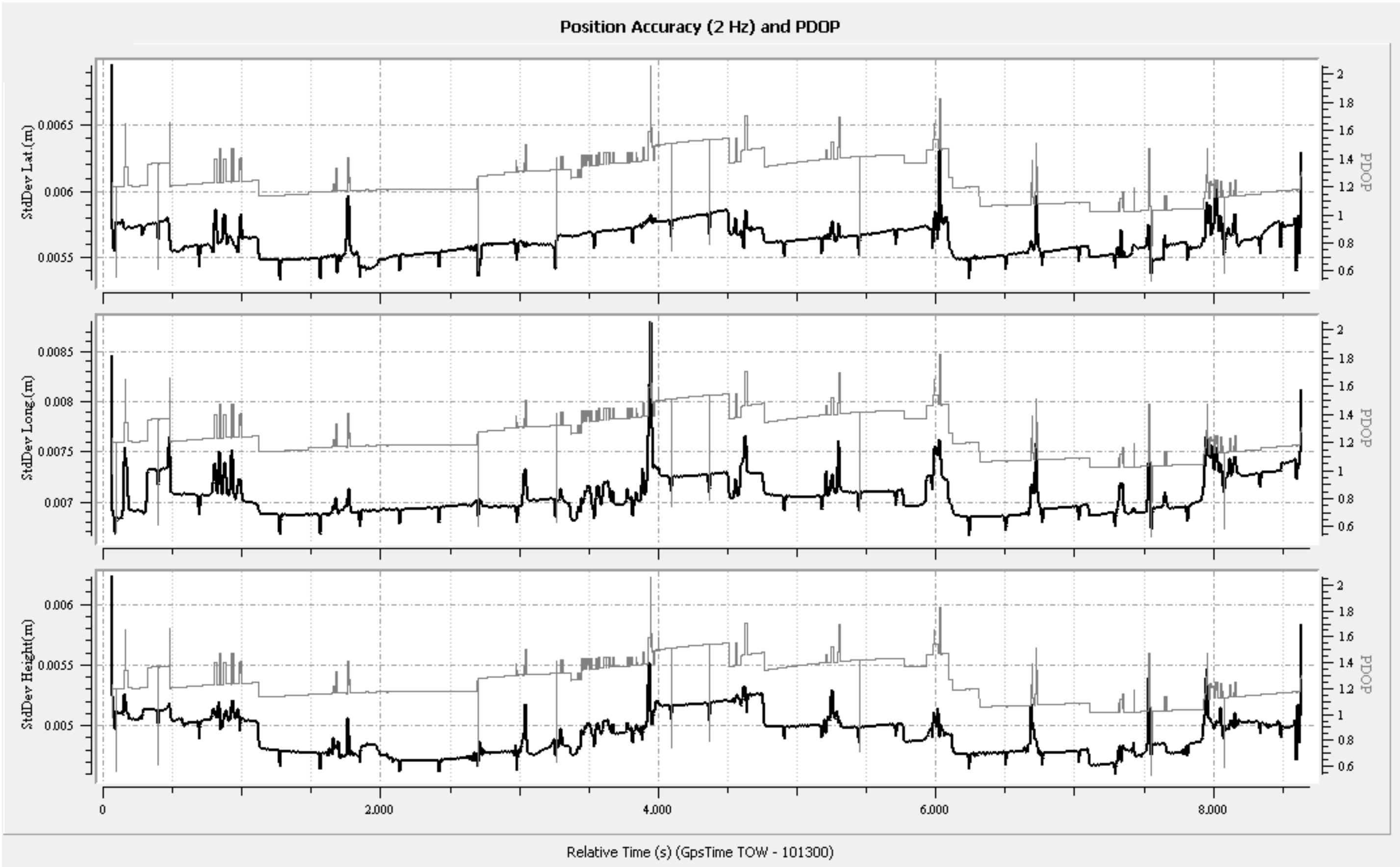


Figure 17 - Position Accuracy Plot and PDOP, Mission 3

Mission 4 (11/01/2013)

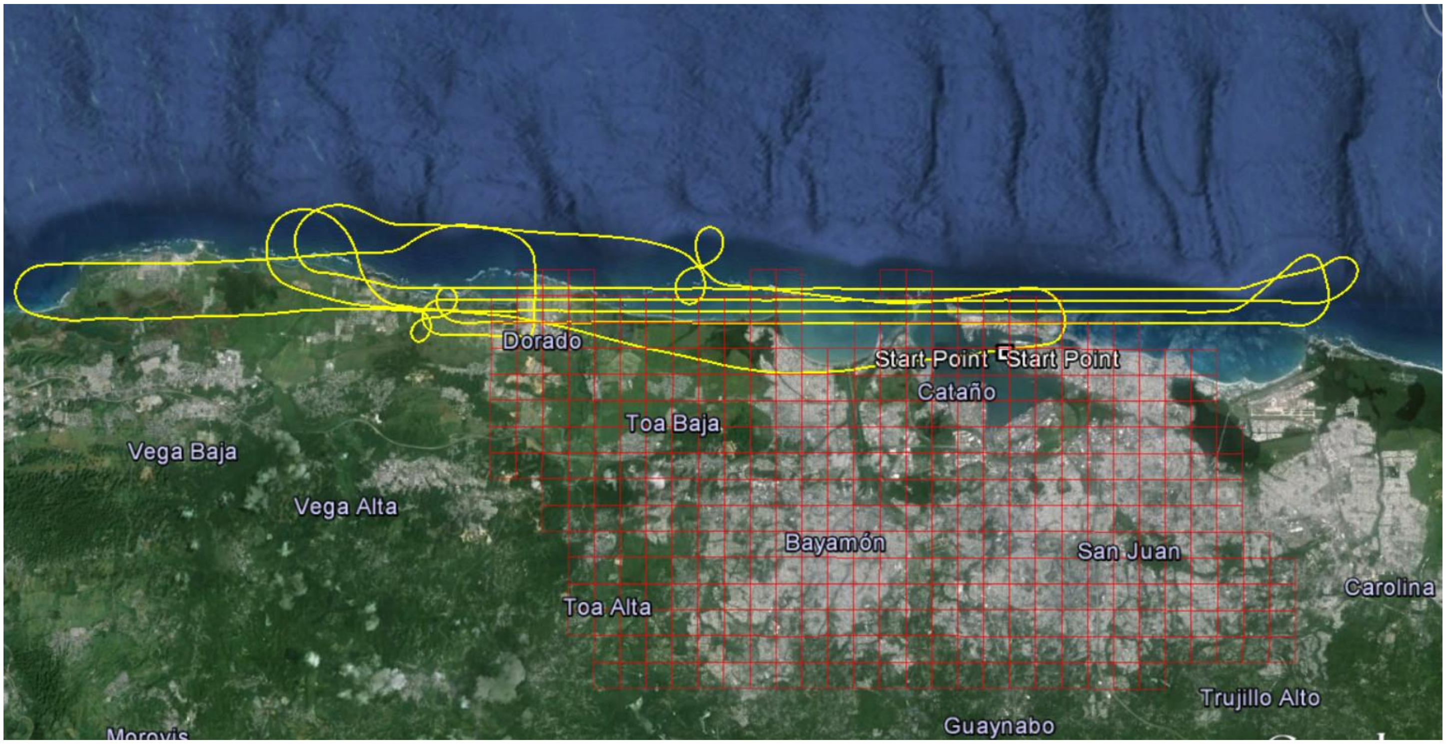


Figure 18 - Trajectory Plot, Mission 4

PAR LLC PRECISION AERIAL RECONNAISSANCE
P.O. Box 72357
Bossier City, LA 72357

LIDAR Daily Log

Field Crew		
DRIVE A	Project #	TBA
MISSION 4	Project Description	PuertoRico
	Location	Isle Grande (TJIG)

Lever Arm	x	y	z
GPS (m)	-0.110	0.210	-1.220

GPS Information		
Base 1	19823050.T02	
Base 2		Auto
Base3		
Aero 1		

IMU Information	
Start Time	13:35:26
Stop Time	15:21:55

Meteorological Conditions					Pressure
Airport	9	23.0°c	296.15°k	29.94 inHg	101388 Pa
@ Altitude	3800AGL	27.0°c	300.15°k	29.92 inHg	101321 Pa
@ Altitude					

GPS Base Station Information	File Name	RNX File	Ant Hgt	Ant Type
Base 1	19823050.T02		2.05m	Trimble R10
Base 2				
Base 3				

Flight Date (UTC)	Pilot	Operator	Sensor	Aircraft	SENSOR NAVIGATION FILE NAME
11/1/2013	Farrar	Tomlinson	ALS70	N799AC	

Reflight	Line	Dir	Start	Stop	Total Time	FOV	Scan Rate	Pulse Rate Hz	Roll Comp	Muti Pulse (Y,N)	Altitude ellipsoid (m)	Altitude ellipsoid (ft)	Speed	Nautical Miles Flown	Void "Y"	PDOP	Operator	Conditions/Comments
	PR003	131101_140445	14:05:01	14:13:45	0:08:44	39.6	53.4	217800	YES	Y	1159	3801					Tomlinson	GOOD
	PR004	131101_141644	14:17:00	14:25:13	0:08:13	39.7	53.4	217800	YES	Y	1179	3868					Tomlinson	GOOD
	UL001	131101_142746	14:28:02	14:28:37	0:00:35	39.7	53.4	217800	YES	Y	1138	3734					Tomlinson	CROSSED LINES 3,4,AND 5
	PR005	131101_143906	14:39:22	14:47:49	0:08:27	39.8	53.4	217800	YES	Y	1150	3773					Tomlinson	MAY HAVE CLOUDS OVER WATER
M6	PR006	131101_145043	14:51:00	14:59:14	0:08:14	40	53.4	217800	YES	Y	1176	3859					Tomlinson	CLOUDS LAST 29 FRAMES. WILL REFLY PART OF LINE.

LIDAR FLIGHT SUMMARY			
		Hobbs Start	0
Aircraft IMU Time	1:46:29	Hobbs Stop	0
Sensor Collection Time	0:34:13	Hobbs Total	0.0
Line Miles Flown	0.0	Mission Hobbs	#DIV/0!
Average Flight Lines Speed	#DIV/0!	Reflight Hobbs	#DIV/0!
Average Nautical Line miles Per Mission Hour			#DIV/0!

DATA COLLECTION			
Total Lines	0	Project % Complete	#DIV/0!
# Reflight Lines	0	Total Flight Lines	0
Reflight Percent	#DIV/0!	Line Complete	0
Sensor Re-Flight Miles	0.0	Mission Lines	0
Average Nautical Line Miles Per Re-Flight Hour	#DIV/0!		

Comments

Cloud Cover	
Clear	
Fair	X
Partly Cloudy	
Cloudy	

Figure 19 - Flight Log, Mission 4

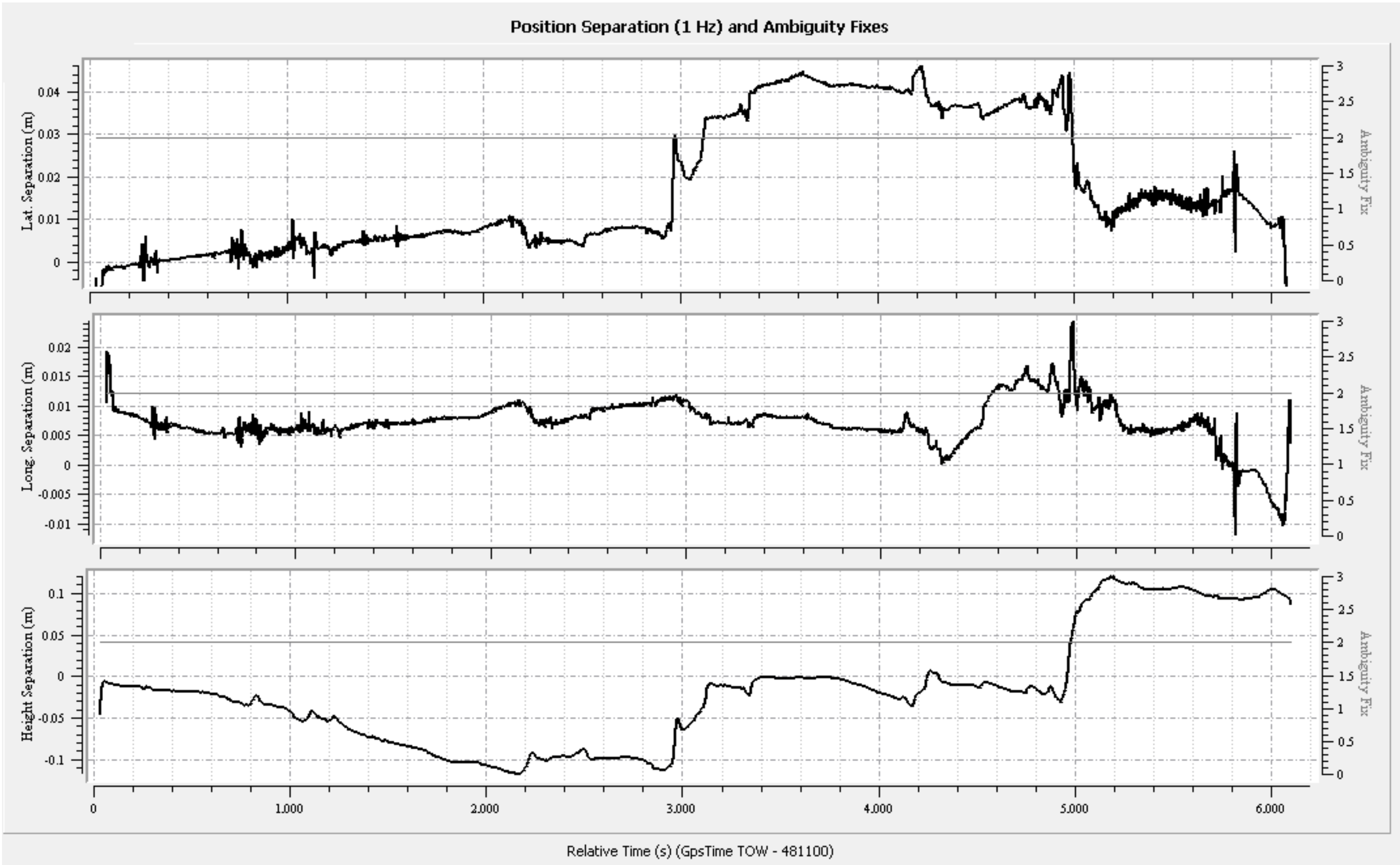


Figure 20 - Position Separation Plot for Mission 4

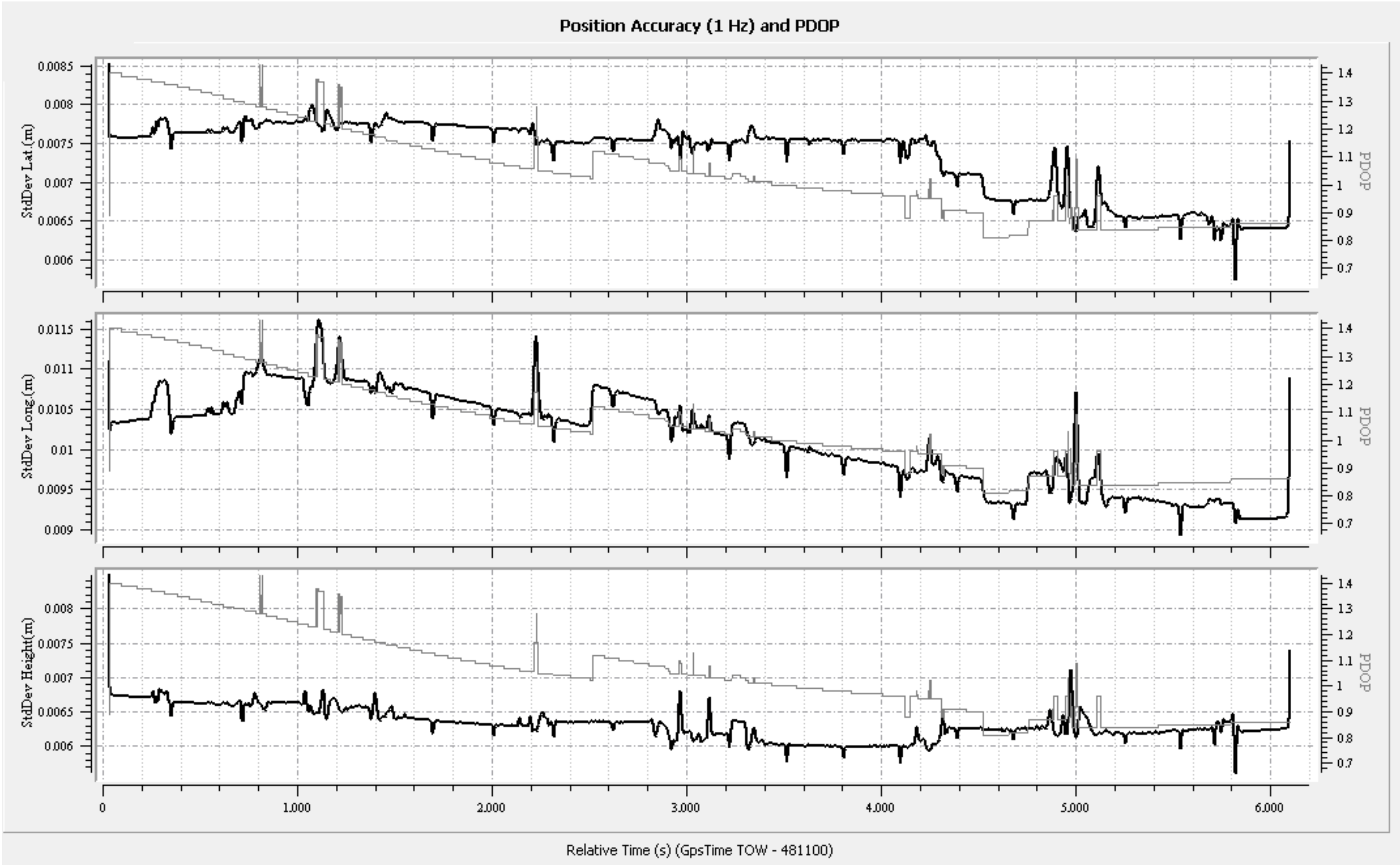


Figure 21 - Position Accuracy Plot and PDOP, Mission 4

Mission 5 (11/1/2013) **–** No data was collected during mission 5. Clouds rolled into the project area after takeoff.

Mission 6 (11/02/2013)

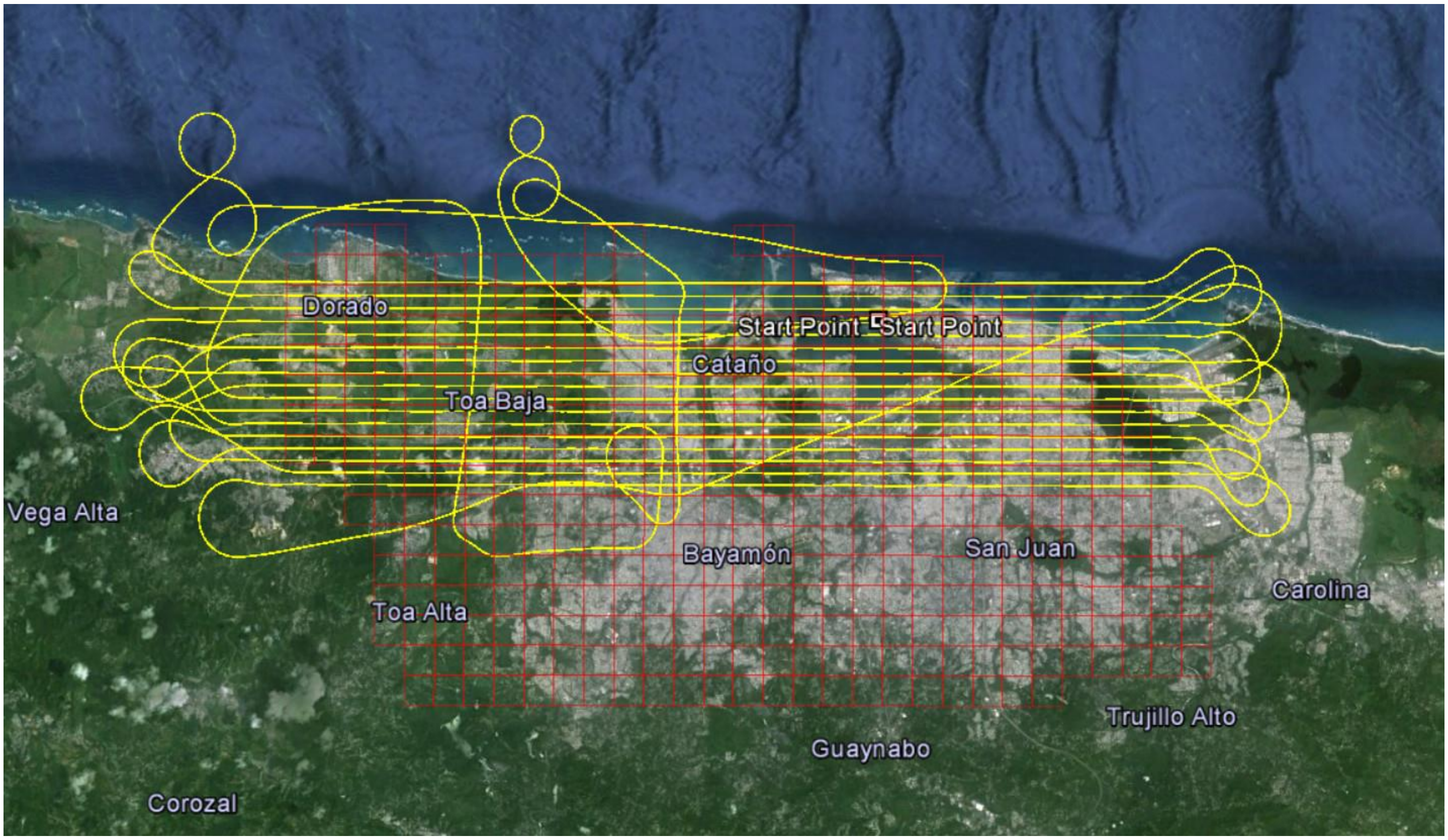


Figure 22 - Trajectory Plot, Mission 6

PAR LLC PRECISION AERIAL RECONNAISSANCE
P.O. Box 72357
Bossier City, LA 72357

LIDAR Daily Log

Field Crew			
DRIVE A	Project #	TBA	
MISSION 6	Project Description	PuertoRico	
	Location	Isle Grande (TJIG)	

Flight Date (UTC)	Pilot	Operator	Sensor	Aircraft	SENSOR NAVIGATION FILE NAME
11/2/2013	Farrar	Tomlinson	ALS70	N799AC	

Lever Arm	x	y	z
GPS (m)	-0.110	0.210	-1.220

GPS Information	
Base 1	19823060.T02
Base 2	
Base3	
Aero 1	

IMU Information	
Start Time	11:39:38
Stop Time	15:49:59

Auto

Meteorological Conditions					Pressure
Airport	9	23.0°c	296.15°k	29.94 inHg	101388 Pa
@ Altitude	3800AGL	27.0°c	300.15°k	29.92 inHg	101321 Pa
@ Altitude					

GPS Base Station Information	File Name	RNX File	Ant Hgt	Ant Type
Base 1	19823060.T02		2.05m	Trimble R10
Base 2				
Base 3				

Reflight	Line	Dir	Start	Stop	Total Time	FOV	Scan Rate	Pulse Rate Hz	Roll Comp	Muti Pulse (Y,N)	Altitude ellipsoid (m)	Altitude ellipsoid (ft)	Speed	Nautical Miles Flown	Void "Y"	PDOP	Operator	Conditions/Comments
	PR006	131102_120047	12:01:05	12:09:54	0:08:49	39.6	53.4	217800	YES	Y	1171	3842					Tomlinson	GOOD
	PR007	131102_121207	12:12:25	12:21:13	0:08:48	39.7	53.4	217800	YES	Y	1174	3851					Tomlinson	GOOD
	PR008	131102_122341	12:23:58	12:32:32	0:08:34	39.8	53.4	217800	YES	Y	1172	3846					Tomlinson	GOOD
M7	PR009	131102_123512	12:35:29	12:35:35	0:00:06	41	53.4	217800	YES	Y	1158	3798					Tomlinson	HAD TO STOP LINE, TOWER ORDERED TO DEVIATE FROM HEADING
	PR022	131102_124445	12:45:03	12:53:09	0:08:06	39.8	53.4	217800	YES	Y	1180	3872					Tomlinson	GOOD
	PR021	131102_125518	12:55:35	13:04:00	0:08:25	39.8	53.4	217800	YES	Y	1184	3884					Tomlinson	GOOD. JUMPING NORTH, CLOUDS MOVING IN FROM SOUTH
M7	PR013	131102_130743	13:08:00	13:16:23	0:08:23	39.8	53.4	217800	YES	Y	1178	3863					Tomlinson	MAY HAVE SMALL CLOUD IN MIDDLE, CHECK
M7	PR012	131102_131857	13:19:15	13:27:48	0:08:33	39.8	53.4	217800	YES	Y	1178	3865					Tomlinson	LITE CLOUDS OVER WATER AND THIN OVER LAND, SHOULD BE GOOD
M7	PR011	131102_133017	13:30:34	13:39:06	0:08:32	39.9	53.4	217800	YES	Y	1177	3862					Tomlinson	LITE SMALL CLOUD IN THE MIDDLE, WILL CHECK
M7	PR010	131102_134133	13:41:50	13:50:24	0:08:34	39.8	53.4	217800	YES	Y	1191	3908					Tomlinson	SMALL LITE CLOUD TOWARDS WEST END. SHOULD BE GOOD. CHECK
M7	PR009	131102_135307	13:53:24	14:01:30	0:08:06	39.9	53.4	217800	YES	Y	1155	3788					Tomlinson	LITE CLOUD, CHECK OVERLAP
M7	PR014	131102_140437	14:04:54	14:13:28	0:08:34	39.8	53.4	217800	YES	Y	1181	3874					Tomlinson	LITE CLOUD, SHOULD BE GOOD. CHECK
M7	PR020	131102_141512	14:15:29	14:24:11	0:08:42	40	53.4	217800	YES	Y	1150	3774					Tomlinson	CLOUDS AT THE LAST 3 FRAMES, QUITE POSSIBLE OUTSIDE AOI
	PR019	131102_142557	14:26:14	14:34:56	0:08:42	40	53.4	217800	YES	Y	1178	3866					Tomlinson	CLOUDS IN FIRST THREE FRAMES BUT MAINLY OVER WATER AND POSSIBLY OUTSIDE AOI
	PR018	131102_143711	14:37:28	14:46:08	0:08:40	40.1	53.4	217800	YES	Y	1179	3869					Tomlinson	GOOD
M7	PR017	131102_144749	14:48:06	14:56:42	0:08:36	40	53.4	217800	YES	Y	1180	3872					Tomlinson	LITE CLOUDS TOWARD WEST END
M7	PR016	131102_145856	14:59:13	15:07:47	0:08:34	40.2	53.4	217800	YES	Y	1168	3831					Tomlinson	E CLOUDS 20 FRAMES IN. THEN HEAVY CLOUD LAST 5 BUT MOSTLY OVER WATER, HAVE CHE
M7	PR015	131102_150951	15:10:08	15:18:37	0:08:29	40	53.4	217800	YES	Y	1187	3894					Tomlinson	HEAVY CLOUDS FIRST 4 FRAMES MOSTLY OVER WATER, will have to check aoi, lite clouds 39 in
	UL001	131102_152230	15:22:47	15:25:10	0:02:23	39.9	53.4	217800	YES	Y	1176	3858					Tomlinson	GOOD
	UL002	131102_152714	15:27:31	15:28:01	0:00:30	40.1	53.4	217800	YES	Y	1168	3832					Tomlinson	HAD TO STOP, TOWER DEVIATE
	UL003	131102_153002	15:30:18	15:31:56	0:01:38	40.3	53.4	217800	YES	Y	1145	3758					Tomlinson	moving to fast, traffic aned clouds don't thik its usable

LIDAR FLIGHT SUMMARY			
		Hobbs Start	0
Aircraft IMU Time	4:10:21	Hobbs Stop	0
Sensor Collection Time	2:29:44	Hobbs Total	0.0
Line Miles Flown	0.0	Mission Hobbs	#DIV/0!
Average Flight Lines Speed	#DIV/0!	Reflight Hobbs	#DIV/0!
Average Nautical Line miles Per Mission Hour			#DIV/0!

DATA COLLECTION			
Total Lines	0	Project % Complete	#DIV/0!
# Reflight Lines	0	Total Flight Lines	0
Reflight Percent	#DIV/0!	Line Complete	0
Sensor Re-Flight Miles	0.0	Mission Lines	0
Average Nautical Line Miles Per Re-Flight Hour	#DIV/0!		

Comments

Cloud Cover	
Clear	
Fair	X
Partly Cloudy	
Cloudy	

Figure 23 - Flight Log, Mission 6

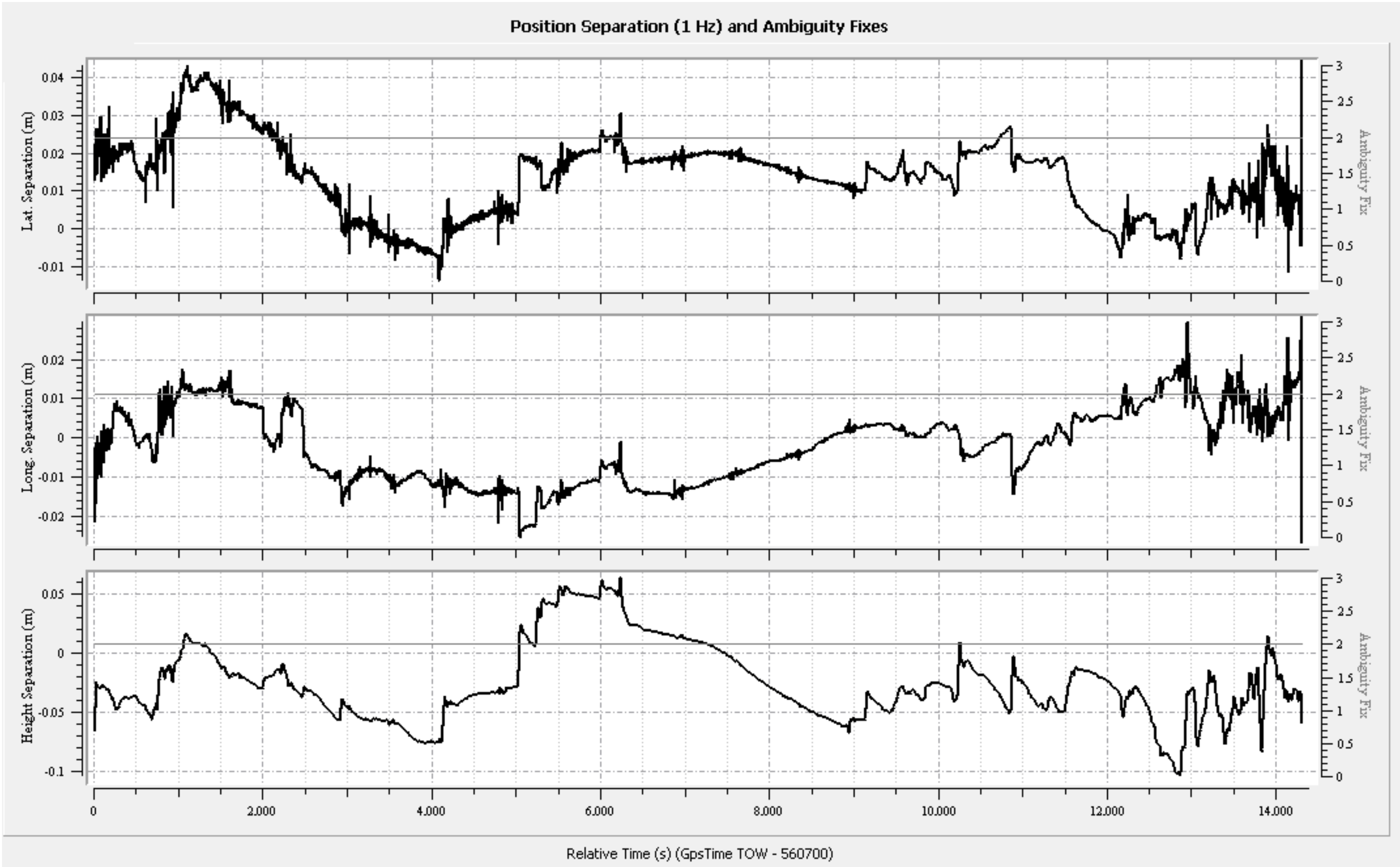


Figure 24 -Position Separation Plot for Mission 6

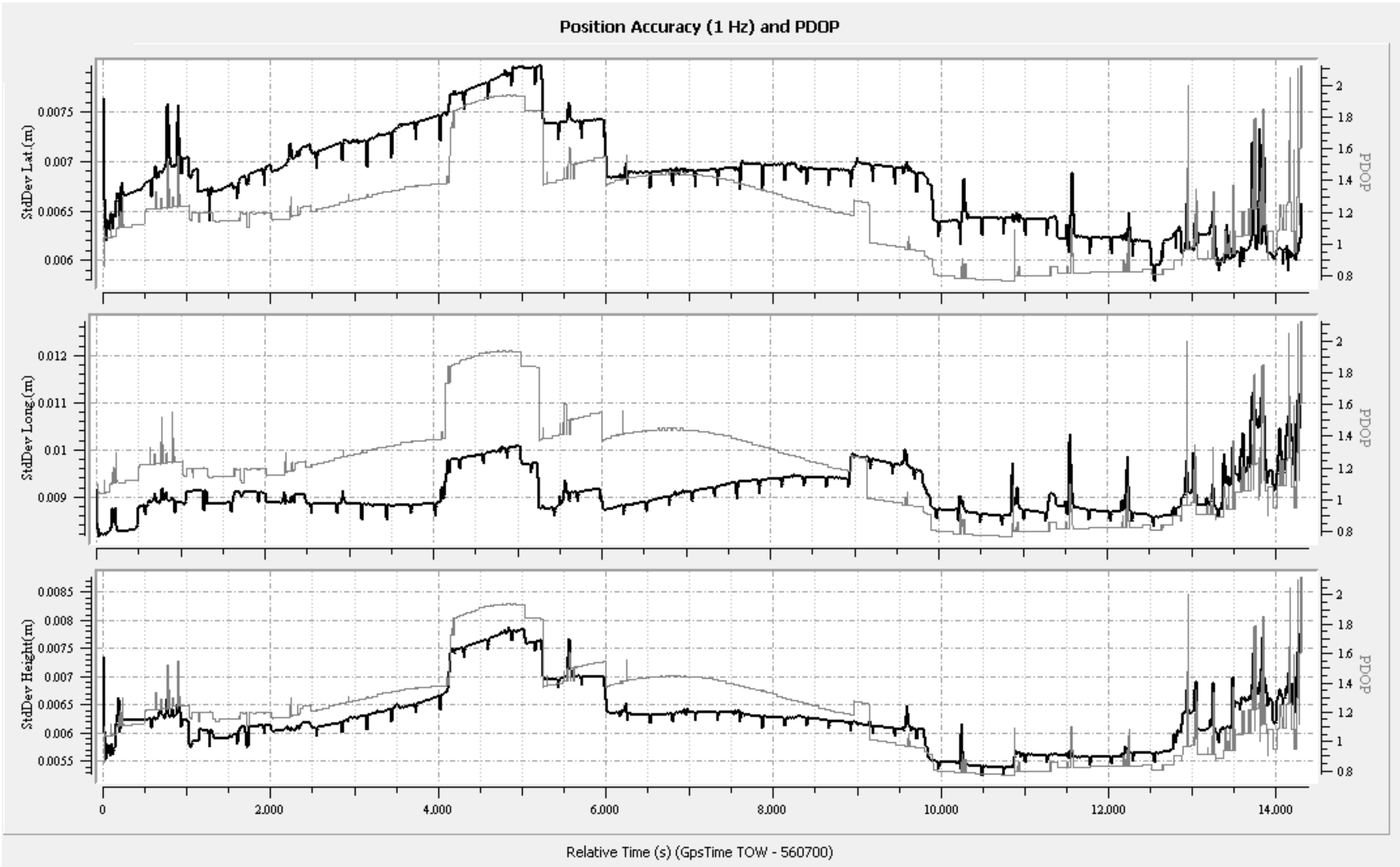


Figure 25 - Position Accuracy Plot and PDOP, Mission 6

Mission 7 (11/03/2013)

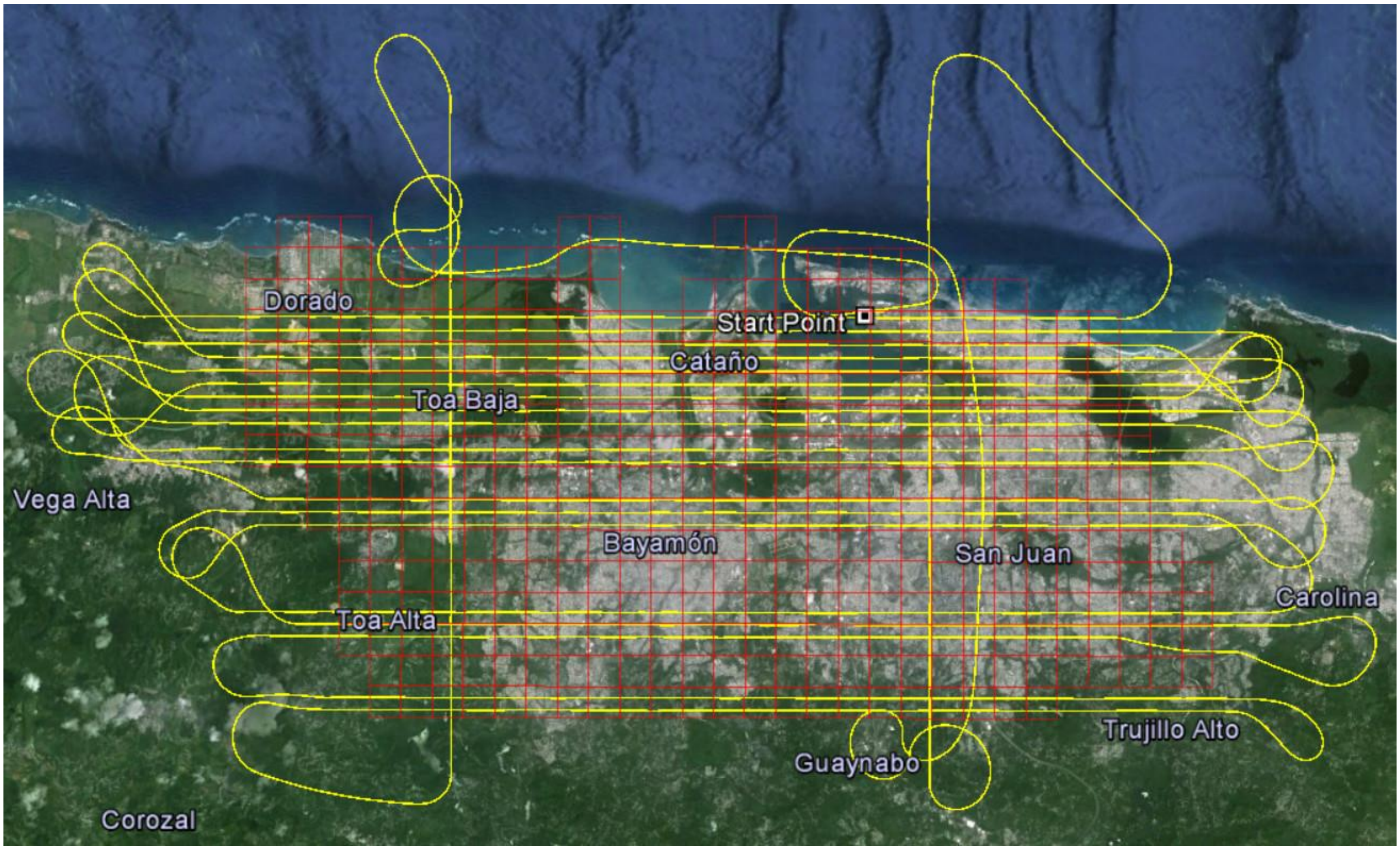


Figure 26 - Trajectory Plot, Mission 7

PAR LLC PRECISION AERIAL RECONNAISSANCE
P.O. Box 72357
Bossier City, LA 72357

LIDAR Daily Log

Field Crew		Project #	TBA
DRIVE A		Project Description	PuertoRico
MISSION 7		Location	Isle Grande (TJIG)

Lever Arm	x	y	z
GPS (m)	-0.110	0.210	-1.220

Flight Date (UTC)	Pilot	Operator	Sensor	Aircraft	SENSOR NAVIGATION FILE NAME
11/3/2013	Farrar	Tomlinson	ALS70	N799AC	

GPS Information		
Base 1	19823070.T02	
Base 2		Auto
Base3		
Aero 1		

IMU Information	
Start Time	0:39:46
Stop Time	5:09:47

Meteorological Conditions					Pressure
Airport	9	23.0°c	296.15°k	29.94 inHg	101388 Pa
@ Altitude	3800AGL	27.0°c	300.15°k	29.92 inHg	101321 Pa
@ Altitude					

GPS Base Station Information	File Name	RNX File	Ant Hgt	Ant Type
Base 1	19823070.T02		2.05m	Trimble R10
Base 2				
Base 3				

Reflight	Line	Dir	Start	Stop	Total Time	FOV	Scan Rate	Pulse Rate Hz	Roll Comp	Muti Pulse (Y,N)	Altitude ellipsoid (m)	Altitude ellipsoid (ft)	Speed	Nautical Miles Flown	Void "Y"	PDOP	Operator	Conditions/Comments
	PR043	131103_010000	1:00:18	1:05:41	0:05:23	39.7	53.4	217800	YES	Y	1160	3806					Tomlinson	GOOD
	PR040	131103_010836	1:08:54	1:16:41	0:07:47	39.7	53.4	217800	YES	Y	1158	3799					Tomlinson	GOOD
	PR039	131103_011849	1:19:07	1:26:45	0:07:38	39.8	53.4	217800	YES	Y	1163	3816					Tomlinson	GOOD
	PR034	131103_012840	1:28:58	1:36:07	0:07:09	39.8	53.4	217800	YES	Y	1168	3832					Tomlinson	Got west side, the east side had clouds, cut line short...will need to combine with L34 from M2
	PR033	131103_013955	1:40:13	1:48:31	0:08:18	39.8	53.4	217800	YES	Y	1155	3789					Tomlinson	Flown for west side, east has clouds...will need to combine with L33 from M2
	PR032	131103_015123	1:51:41	2:00:04	0:08:23	39.8	53.4	217800	YES	Y	1160	3806					Tomlinson	GOOD
	PR025	131103_020152	2:02:09	2:10:08	0:07:59	39.9	53.4	217800	YES	Y	1169	3835					Tomlinson	GOOD
	PR024	131103_021232	2:12:49	2:21:06	0:08:17	39.9	53.4	217800	YES	Y	1168	3832					Tomlinson	GOOD
	PR023	131103_022351	2:24:09	2:32:12	0:08:03	39.9	53.4	217800	YES	Y	1181	3875					Tomlinson	GOOD
	PR020	131103_023557	2:36:14	2:45:22	0:09:08	39.8	53.4	217800	YES	Y	1169	3835					Tomlinson	GOOD
	PR019	131103_024813	2:48:31	2:57:06	0:08:35	39.8	53.4	217800	YES	Y	1157	3796					Tomlinson	GOOD
	PR017	131103_030102	3:01:19	3:10:03	0:08:44	39.8	53.4	217800	YES	Y	1169	3835					Tomlinson	GOOD
	PR016	131103_031232	3:12:49	3:21:18	0:08:29	39.8	53.4	217800	YES	Y	1163	3816					Tomlinson	GOOD
	PR015	131103_032440	3:24:58	3:33:44	0:08:46	39.9	53.4	217800	YES	Y	1163	3816					Tomlinson	GOOD
	PR014	131103_033607	3:36:24	3:44:37	0:08:13	39.9	53.4	217800	YES	Y	1166	3825					Tomlinson	GOOD
	PR013	131103_034714	3:47:32	3:56:03	0:08:31	39.8	53.4	217800	YES	Y	1159	3802					Tomlinson	GOOD
	PR012	131103_035850	3:59:07	4:07:39	0:08:32	39.9	53.4	217800	YES	Y	1172	3845					Tomlinson	GOOD
	PR011	131103_041022	4:10:40	4:18:58	0:08:18	39.9	53.4	217800	YES	Y	1156	3793					Tomlinson	GOOD
	PR010	131103_042123	4:21:41	4:29:56	0:08:15	39.8	53.4	217800	YES	Y	1163	3816					Tomlinson	GOOD
	PR009	131103_043234	4:32:52	4:41:07	0:08:15	39.9	53.4	217800	YES	Y	1159	3802					Tomlinson	GOOD
	PR044	131103_044503	4:45:20	4:50:52	0:05:32	39.8	53.4	217800	YES	Y	1171	3842					Tomlinson	GOOD

LIDAR FLIGHT SUMMARY			
		Hobbs Start	0
Aircraft IMU Time	4:30:01	Hobbs Stop	0
Sensor Collection Time	2:48:15	Hobbs Total	0.0
Line Miles Flown	0.0	Mission Hobbs	#DIV/0!
Average Flight Lines Speed	#DIV/0!	Reflight Hobbs	#DIV/0!
Average Nautical Line miles Per Mission Hour			#DIV/0!

DATA COLLECTION			
Total Lines	0	Project % Complete	#DIV/0!
# Reflight Lines	0	Total Flight Lines	0
Reflight Percent	#DIV/0!	Line Complete	0
Sensor Re-Flight Miles	0.0	Mission Lines	0
Average Nautical Line Miles Per Re-Flight Hour	#DIV/0!		

Comments	Cloud Cover	
	Clear	
	Fair	X
	Partly Cloudy	
	Cloudy	

Figure 27 - Flight Log, Mission 7

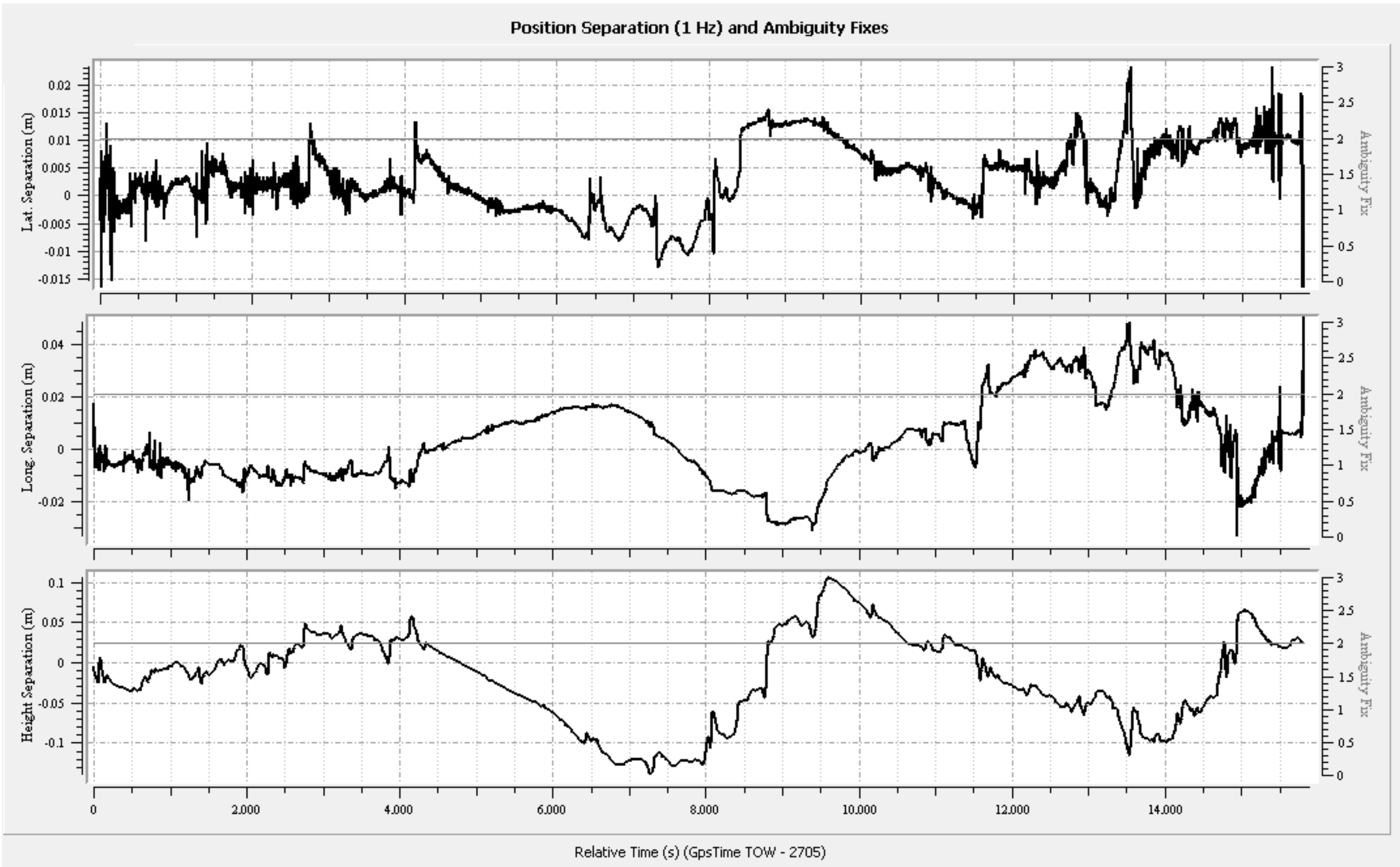


Figure 28 - Position Separation Plot for Mission 7

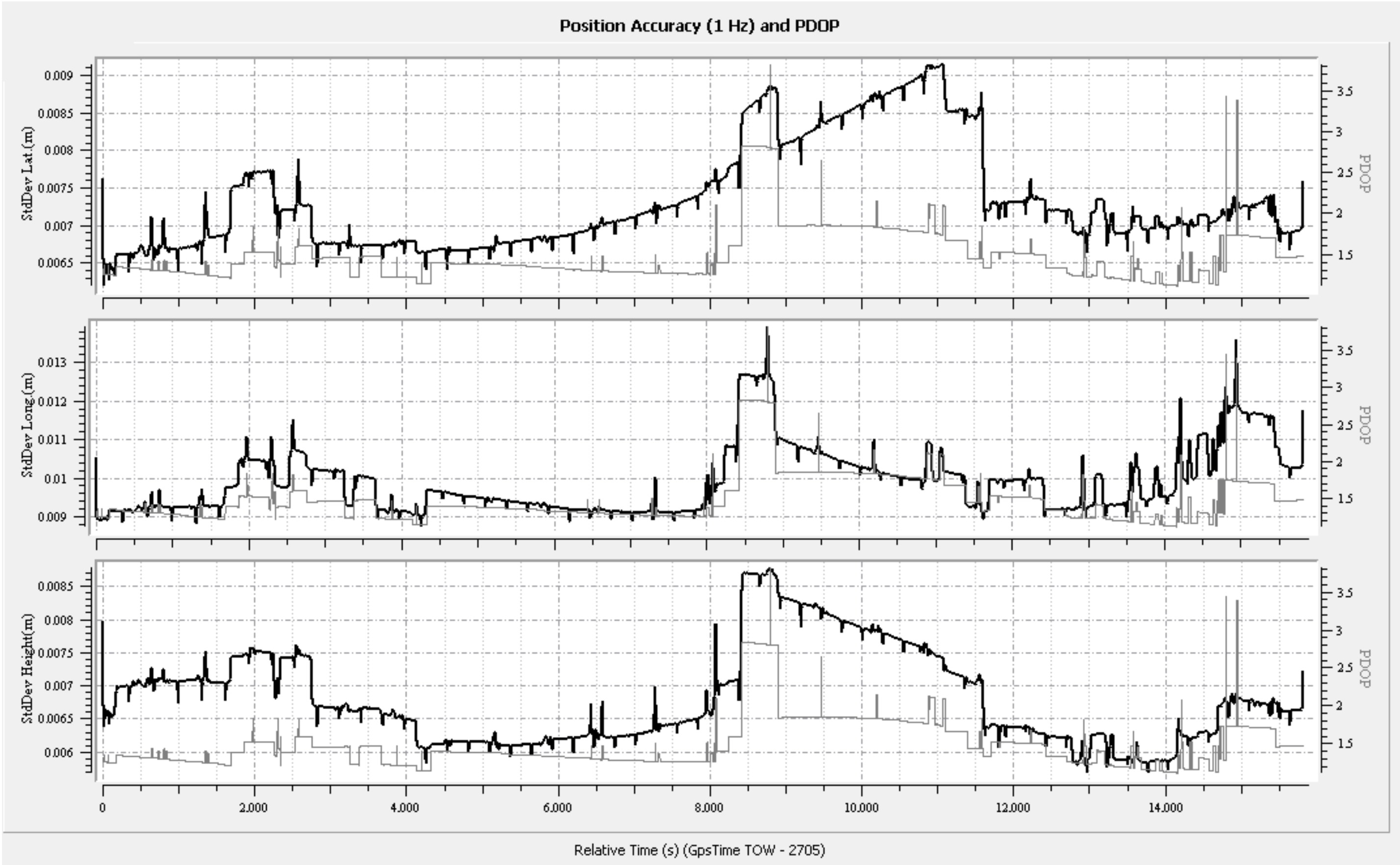


Figure 29 - Position Accuracy Plot and PDOP, Mission 7

Field QC and Data Shipping

Acquired data was shipped on a regular interval using commercial shippers. The aircraft remained at the project site until collected data was validated in the office as good. The Pilot filed the appropriate flight plan daily, and remained in constant communication with Air Traffic Control (ATC) while airborne.

In preparation for and execution of flying a mission, i.e. data capture, the following procedures were followed:

- Checked weather conditions at the Project site and/or AOI
- Selected an appropriate capture area according to current project progress and environmental conditions
- Filed flight plan with ATC
- Preflight inspection of aircraft per Standard Operating Procedures (SOP)
- Prepared and tested sensor per SOP
  - Insert or attach data storage device(s)
  - Load Flight Plan
- Flew mission per SOP
- Downloaded data
  - Upon completion, all log files, data, etc. were taken from the sensor on data storage devices
  - The data was downloaded on two devices; a backup device and a ship device
    - PAR always retains redundant data; the sensor data storage device is not cleaned until the processors have confirmed successful receipt, download and archive
    - Shipped data to processing center, no less frequently than 3 days

- Field QC of data
  - The raw data was processed at the hotel and reviewed by the sensor operator prior to the next day's mission.
    - Checked for artifacts caused by clouds
    - Checked for desired post spacing
    - Checked for gaps caused by extreme terrain or missed lines, check quality of GPS data

Airborne Data Post Processing

Processing Summary

IPAS-TC software was used to compute Inertial SOL file to process the final LiDAR LAS files. The method works by integrating Inertial Navigation Solution by processing IMU data and the simultaneously collected GPS data from SPAN System *(Position and Orientation System/Airborne Vehicle)* along with observables of locally positioned GPS base station on the ground. It computes a carrier phase GPS solution and then blends it with inertial data.

The IMU report depicted healthy data.

POSGNSS Processing Summary

The raw airborne kinematic GPS data was processed along with ground GPS data observables. The North American Datum of 1983, 2011 Realization (NAD83/2001) and Ellipsoidal Heights referenced to the Geodetic Reference System of 1908 (GRS80).

The accuracy of the processed Airborne GPS data is 12cm or better as shown in the combined forward/reverse separation plots. M2 had a time of 15cm separation but the lines were re-flown on missions6 & 7.

Program: IPAS-TC

Version: 3.20

Solution Type: Combined

Position Standard Deviation Percentages:

0.0 - 0.10 m: 99.9%

0.10 – 0.15 m: .01%

0.10 - 0.30 m: 0.0 %

0.30 - 1.00 m: 0.0 %

1.00 - 5.00 m: 0.0 %

5.00 m + over: 0.0 %

Data Processing

Key Personnel for data processing were Ken Comeaux and Trent Tomlinson (Background described above).

The full study area of approximately 404 square km was processed. The tiles are 1,000 x 1,000m in size and Final deliverables were provided as geographic coordinates referenced to the North American Datum of 1983/2011 Realization (NAD83/2011) and as projected coordinates referenced to the State Plane Coordinate System, Puerto Rico Virgin Islands FIPS Zone 5200, NAD83/2011, vertical PRVD02 orthometric height. Vertical information associated with the geographic coordinates was reported as ellipsoid heights referenced to the Geodetic Reference System of 1980 (GRS80).

Airborne Survey Processing

Airborne GPS was extracted and computed to give the best possible positional accuracies. The IMU data was then analyzed and the lever arms corrected to achieve consistent airborne data. Upon the creation of the SOL file, the LAS files were computed using Leica's proprietary post-processing software.

The Quality Assurance (QA) analyst did a thorough review for any quality issues with the data. This could include data voids, high and low points, and data gaps. The data voids or high points could be the result of any high elevation point returns, including clouds, steam from industrial plants, flocks of birds, or any other anomaly.

The LiDAR data was reviewed at the flight line level in order to verify sufficient flight line overlap as required to ensure there are no data gaps between usable portions of the swath. Each line was also assessed to fully address the data's overall accuracy, quality, coverage and point density. Within this Quality Assurance/Quality Control (QA/QC) process, four fundamental questions were addressed:

- Did the LiDAR system perform to specifications?
  - Result - Yes
- Did the data have any discrepancies or anomalies?
  - Result - No
- If there are any discrepancies or anomalies, are they addressed accordingly?
  - Result - NA
- Was the data complete?
  - Result – Yes

Preliminary Intensity Images were generated and provided to USACE for validation of data collection.

Flight line Calibration

The LiDAR data set was calibrated using suitable test sites identified throughout the project area within the raw point cloud. The sensor misalignment angles (heading, roll, and pitch) and mirror scale were then adjusted based on measurements taken between adjacent flight swaths within the point cloud at the test site locations.

This project's data was processed in strip form, meaning each flight line was processed independently. Processing the lines individually provides the data analyst with the ability to QC the overlap between lines.

Each strip was imported into a project using TerraScan (Terrasolid, Ltd.) By creating a project the various flight lines are combined while breaking the dataset as a whole into manageable pieces. This process also converts the dataset from Geographic Coordinate System (NAD 83, 2011) to NAD83, 2011 Puerto State Plane. The ellipsoid height values will be converted to PRVD02, Meters, orthometric values using Geoid 12A, provided by National Geodetic Survey (NGS).

Individual lines were checked against adjacent lines and intersecting control lines to ensure a cohesive dataset. All overlapping areas will be checked to ensure that the relative accuracy meets the 5cm accuracy specs. The Figures 30 and 31 below demonstrate the pre- and post-calibration data.

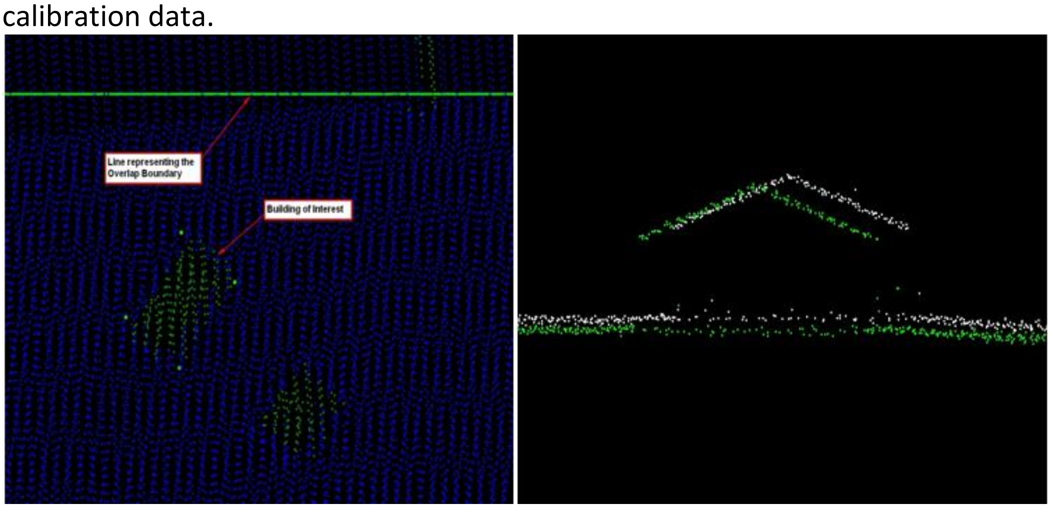


Figure 30 - a horizontal offset in the overlapping region between two swaths (before calibration)

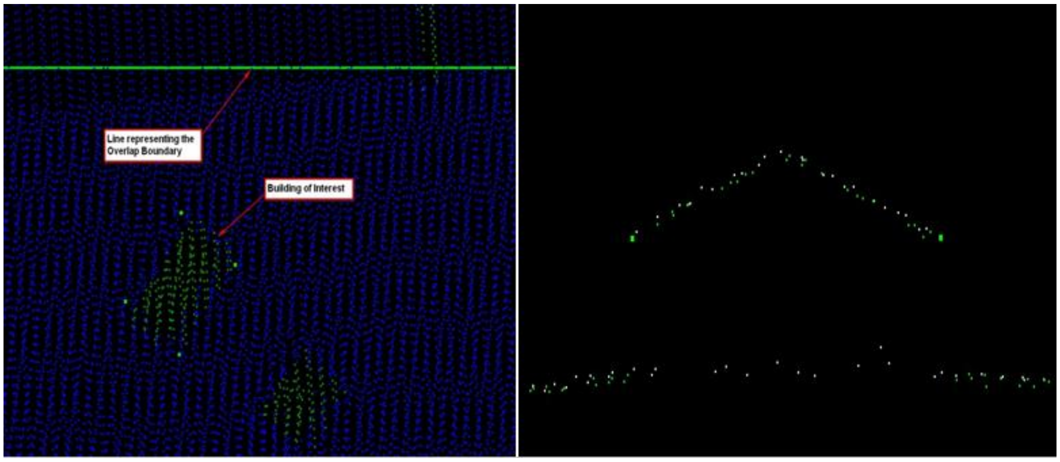


Figure 31 - showing the offset as corrected after calibration values are applied

Once the misalignment angle adjustments are applied to the point cloud, it is compared to the ellipsoidal heights of the surveyed ground control points. Based on the Z-bias given, the data is adjusted to an average delta-Z value to meet or exceed the specified requirements. A geoid model is then created and applied to the point cloud. These final datasets are now quality checked against the orthometric heights of the surveyed ground control points to ensure that they are fully compliant with Statement of Work accuracy specs.

The raw point cloud data was then tiled into 1000m by 1000m tiles which are stored in LAS format version 1.2, with point format 1. The populated tiles were then quality checked to ensure that tiles which lie completely within the project area are complete to tile edges and that tiles which lie partially outside the project boundary are complete to the project boundary and include enough overlap beyond the project boundary to ensure that no parts of the project are omitted.

Point Classification

After calibration, the data was cut into 1000m by 1000m tiles, per the scope of work. The tiles are contiguous, do not overlap, and are suitable for seamless topographic data mosaics that include no "no data" areas.

The tiles were based on the following scheme:

PR_ yyyy_PROJECTED_TILE_llxlly.las

Where PR indicates LiDAR tiles belonging to the Commonwealth of Puerto Rico, yyyy is the calendar year of the data acquisition, llx is the first three digits of the lower left tile corner X State Plane Coordinate, and lly is the first three digits of the lower left tile corner Y State Plane Coordinate.

The NAD83/2011 geodetic products were delivered as individual LAS files representing the geographic extent of each uniquely identified and acquired flight line or lift. The geodetic LAS files are named based on the following scheme:

PR_ yyyy_GEOGRAPHIC_LIFT_xxxa.las

Where PR indicates LiDAR tiles belonging to the Commonwealth of Puerto Rico, yyyy is the calendar year of the data acquisition, xxx is a three digital numeric identifier indicator of each unique lift (e.g., 001, 002, 003…), and a is a alphabetic character indicating lifts that have been cut into multiple sections in order to limit the LAS file size (e.g., 001A, 001B, 001C…)

Ground classification algorithms were then applied. The data is automatically classified into the following classes:

- Class 1 – Unclassified
- Class 2 – Ground
- Class 9 – Water
- Class 12 – Overlap (not in original scope but added based on request to USACE)

Class 1 was used for feature points that are not in Classes 2, 9, or 12. These typically represent returns from man-made structures, vegetation etc.

Class 2 was used for feature points that represent the bare-earth.

Class 9 was used for all water points.

Class 12 was used for LiDAR points in a small portion of the overlap between flight lines

Each tile is reviewed by an experienced LiDAR analyst to verify the results of the automated ground filters. Points are manually reclassified when necessary. Hydro flattening breaklines are collected, per the project specification, which results in the point classifications for Classes 9 (Water)

For this project, significant classification work was required in the coastal and floodplain regions in areas with tall grass vegetation. Initial deliveries to USACE were not filtered aggressively enough in blocks 1 and 2 in these areas. Even though the LIDAR was collected at a very high density (~10-16 ppm), these areas showed very few ground points. Manual editing and very aggressive vegetative filtering was required in these areas to classify the vegetation as class 1. Source data provided by USACE (Stereo Imagery and Ortho Imagery) were also used to help determine ground trends and to help identify areas of concern for vegetation. These areas of tall grass should be considered low confidence in terms of true representation of the ground. Most of these areas are predominantly flat, which helps considering the aggressive filtering left very few ground points in the thick vegetation.

Methodology for Breakline Collection and Hydro-flattening

Breaklines are collected manually, based on the LiDAR surface model in TerraModeler version 013. The classification of points as either water or ground is determined based on a combination of factors in the data: point density, voids in data returns, and flatness of the surface, and intensity value. Auxiliary information, such as the imagery provided by USACE, as well as ESRI's Hydro layer is used as an additional aid in decision making.

When an area has sufficient voids in returns, i.e. the point density is sparse due to absorption, and the area when viewed in cross-section appears to be flat with no apparent vegetation growth, then it is determined to be water. There are cases where a significantly sized body of water has returns on the surface of the water, but based on it being completely flat in cross-section and existing point return voids in close proximity within the bounds of the feature, the area is classified as water.

Along smaller streams and lakes, if there are sufficient point returns that are similar in density to the surrounding ground data, those points are determined to be likely ground returns as well. It is not possible to verify or determine with 100% certainty whether dense point returns within water bodies are actual ground or floating plant debris/algae mats on the water surface. Block 2 (Puerto Nuevo) had such floating vegetation and needed to be edited after initial delivery to place the breakline at the water body edge vs. along the edge of the floating vegetation.

Inland ponds and lakes are given a single, constant elevation via hydro flattening breaklines. This elevation value is determined by reviewing multiple cross sectional views of the point data at various locations around the feature in order to identify the elevation of point returns on the surface of the water.

Sloped inland stream and river breaklines have a gradient longitudinally and are flat and level, bank-to-bank, perpendicular to the apparent flow centerline. This is accomplished by setting benchmark heights along the breakline feature at each endpoint and at intervals as needed. These heights are determined by viewing cross sections at each benchmark, identifying the elevation. The feature is then sloped using linear interpolation to set the vertex heights between the benchmarks. The sloped feature is then checked at multiple places to verify the fit to the point data. At any given point along the sloped breakline, the water surface should be at or just below the adjacent ground data.

After the manual point classification edits and breakline collection process, the tiles went through a final round of QC by our most experienced analysts. Point classifications, breakline collection, and breakline heights are verified. After all data passes the final round of QC, the Bare Earth LiDAR products are generated from the classified LAS tiles. For this project, even our most experienced analysts had difficulty reviewing and editing the areas with thick tall grass vegetation.

Figure 32 - An example of the tall grass vegetation in the coastal and flood plain area. LIDAR points on the ground were minimal in these areas.

Product Generation - Raw Point Cloud Data, LAS format

Following calibration, all raw swaths are evaluated to ensure that the data meets all deliverable requirements. The point cloud is verified to the extent of the AOI and that all points meet LAS 1.2 requirements. GPS times are set to 'Adjusted GPS Time' to allow each return to have a unique timestamp.

Long swaths resulting in a LAS file larger than 2GB are split into segments no greater than 2GB each, without splitting point "families" (i.e. groups of returns belonging to a single source laser pulse). Each segment is subsequently regarded as a unique swath and is assigned a unique File Source ID and each point given a Point Source ID equal to its File Source ID. Georeference information is added and verified. Intensity values are in native radiometric resolution. All swaths are included in this deliverable.

Following calibration and correct naming convention application, the raw point cloud is organized and structured per swath as the first deliverable.

Product Generation - Classified Point Cloud Tiles, LAS format

Following calibration, the data was cut into 1000m by 1000m tiles, and ground classification algorithms are applied. The data was reviewed by experienced LiDAR analysts, on a tile by tile basis, and ground classifications were manually corrected, as needed. The classified tiles go through one round of quality control and point classification edits, using experienced LiDAR analysts. A second round of QC is performed by our most experienced analysts, which sometimes involves minor edits to the point classifications. The "Ground" class for all classified point cloud tiles is loaded into TerraScan version 013 to verify completeness of the dataset.

Product Generation - Breaklines, ESRI Shapefile format

All breaklines were collected in MicroStation v8 DGN format then combined into a single master DGN file. Breakline collection adheres to the project specification for feature size and hydro flattening requirements. Breaklines are collected alongside the Quality Control and manual point classification of the LiDAR point data while viewing a surface model of a single tile of data.

Inland ponds and lakes are given a single, constant elevation via hydro flattening breaklines. Inland stream and river breaklines are sloped using a proprietary macro, which interpolates the vertex heights between the established benchmark heights.

The master DGN is then converted to ESRI Shapefile format, as 3D polylines. All breaklines used to modify the surface for the purpose of DEM creation are considered a data deliverable.

Software

The section below outlines the software and workflow that will be used for each data set from initial processing to the final product development.

- GPS Computation (Leica IPAS-TC)
- IMU data processing (Leica IPAS-TC)
- Creation of the SOL (Smooth Best Estimated Trajectory) (IPAS-TC)
- Laser data file creation (Leica - ALSPP)
- Calibration of LiDAR data (TerraScan, TerraMatch)
- LiDAR data edits and classification (TerraScan, TerraModeler)
- Breakline creation (TerraScan)
- LiDAR data quality control (TerraScan, TerraModeler)
- Report generation

Specific Area of Interest Data Processing Issues and Solutions Encountered During this Project

Calibration

Calibration took significantly longer than anticipated for this project. Calibration was expected to take approximately three weeks, and ended up taking closer to two months. The end result of the calibration process produced great results, but issues were encountered in Leica's **Registration** and IBRC (Intensity Based Range Correction) files. PAR teamed with Leica to optimize the files to produce better calibration results. In the Registration file, it was determined that an offset hardcoded in the file was not needed and was causing calibration issues. The adjustments (tweaks) in the IBRC resulted in better intensity range values, which tightened the relative accuracy between points and lines.

Tall Grass/Crops and Brush/Low Trees

The density of the vegetation in these two classes resulted in significant edits, filtering and re-edit to the point cloud. Initial deliveries for blocks 1 and 2 were not filtered and edited aggressively enough to remove vegetation that was inaccurately classified as ground. USACE provided additional source data (stereo and ortho imagery) to be used to look at ground trends and feature types. This supplemental source data was used to define areas to re-edit. Aggressive ground filtering and manual edits in these areas resulted in ground points that were 10's and 100's meters apart. The accuracy tables (in the Accuracy Assessment Section of this Report) show that without detail ground representation in these areas, target vertical accuracies were not achieved.

Breaklines Near floating vegetation

Other area needing special attention during editing was floating vegetation. In some areas, the floating vegetation was so thick near the water's edge that it was mistaken as ground. The supplemental source data provided by USACE was useful in determining areas to review and edit. Breaklines were moved from the floating vegetation to the bank.

Field Survey Acquisition and Processing

A detailed **GROUND SURVEY REPORT (APPENDIX A)** is provided as a separate report to accompany this overall project report. Below is a summary of the personnel and plan for the ground survey.

Key personnel involved in the ground control survey were:

NAME: **Ryan Fowler, PSM**
SurvTech Solutions, Inc.
rfowler@survtechsolutions.com
386-624-2930

Role: Supervision of ground control survey
Years of Experience: 12
EDUCATION (Degree and Specialization)
State University of New York at Cortland BS in Geology and Env. Science, Pursuit MEng, GIS Remote Sensing
OTHER PROFESSIONAL QUALIFICATIONS (Publications, Organizations, Training, Awards, etc.)
Mr. Fowler is a Professional Land Surveyor licensed in the State of Florida. He has field and office experience working for the USACE since 2007. USACE projects include: topographic, hydrographic (Singlebeam and Multibeam), boundary and cadastral surveying. Other qualifications include: Leica High Density Scanning & Cyclone Training, Trained in data acquisition of terrestrial LiDAR , Certified 29 CFR 1910 HTRW; 40 Hour HAZWOPER Certified Competent Person; GIS Graduate Certificate in GIS from the University of Colorado at Denver.

NAME: **David J. O'Brien Jr., PSM, CFedS**
SurvTech Solutions, Inc.
dobrien@survtechsolutions.com
813-621-4929

ROLE: Principle at SurvTech, management of survey resources for ground control
YEARS OF EXPERIENCE: 18
EDUCATION (Degree and Specialization)
BS, Surveying Engineering
University of Maine – Orono, Maine
CURRENT PROFESSIONAL REGISTRATION (State and Discipline)
Professional Surveyor – AL, FL, GA, KY, LA, MS, NC, SC, TN & TX
Certified Federal Surveyor (CFedS) #1244

OTHER PROFESSIONAL QUALIFICATIONS (Publications, Organizations, Training, Awards, etc.)
Mr. O'Brien has 18 years of experience working on and adjacent to military installations, including boundary surveys of small to large facilities. He has performed as Project Surveyor on numerous DOD, NAVFAC and USACE Projects. His expertise includes boundary surveying, specifically federal lands, Indian lands and the Public Land Survey System (PLSS). He is one of only a handful of professional surveyors in the Southeast United States who is a Certified Federal Surveyor (CFedS) and certified by the Bureau of Land Management (BLM) to survey Indian Trust and Federal lands.

NAME: **Lyman Hill**
Party Chief, SurvTech
ROLE: Party Chief
YEARS OF EXPERIENCE: 30
OTHER PROFESSIONAL QUALIFICATIONS (Publications, Organizations, Training, Awards, etc.)
Mr. Hill has over 30 years in the surveying profession. He is OSHA 40 Hour Hazwoper Certified; MSHA New Miner & Phosphate Certified; CPR & First Aid Certified; and background checked. He is extremely competent in boundary retracement and data collection techniques, including RTK (real time kinematic) GPS, conventional surveying instruments, GPR (ground penetrating radar), hydrographic surveying and 3D laser scanning.

Survey Equipment

1. **RTK GPS**
    a. Trimble R6 RTK GPS Receiver using Puerto Rico VRS/RTK Network
2. **Total Station**
    a. Topcon GPT 1030 Total Station
    b. Nikkon DTM 352 Total Station
3. **Data Collectors**
    a. Carlson Surveyor (Total Station)
    b. Trimble TSC2 (RTK)

Methodology

Survey check points were collected in the following two areas: Rio de la Plata (West Area) and Puerto Nuevo Project (East Area). Spread across each area 15-20 survey check points for each of the following classes were collected. The five classes were:

	DESCRIPTION	FEATURE CODE
a.	Open/Low Grass	OLG
b.	Tall Grass/Crops	TGC
c.	Brush/Low Trees	BLT
d.	Forest	FOR
e.	Wetlands	WET

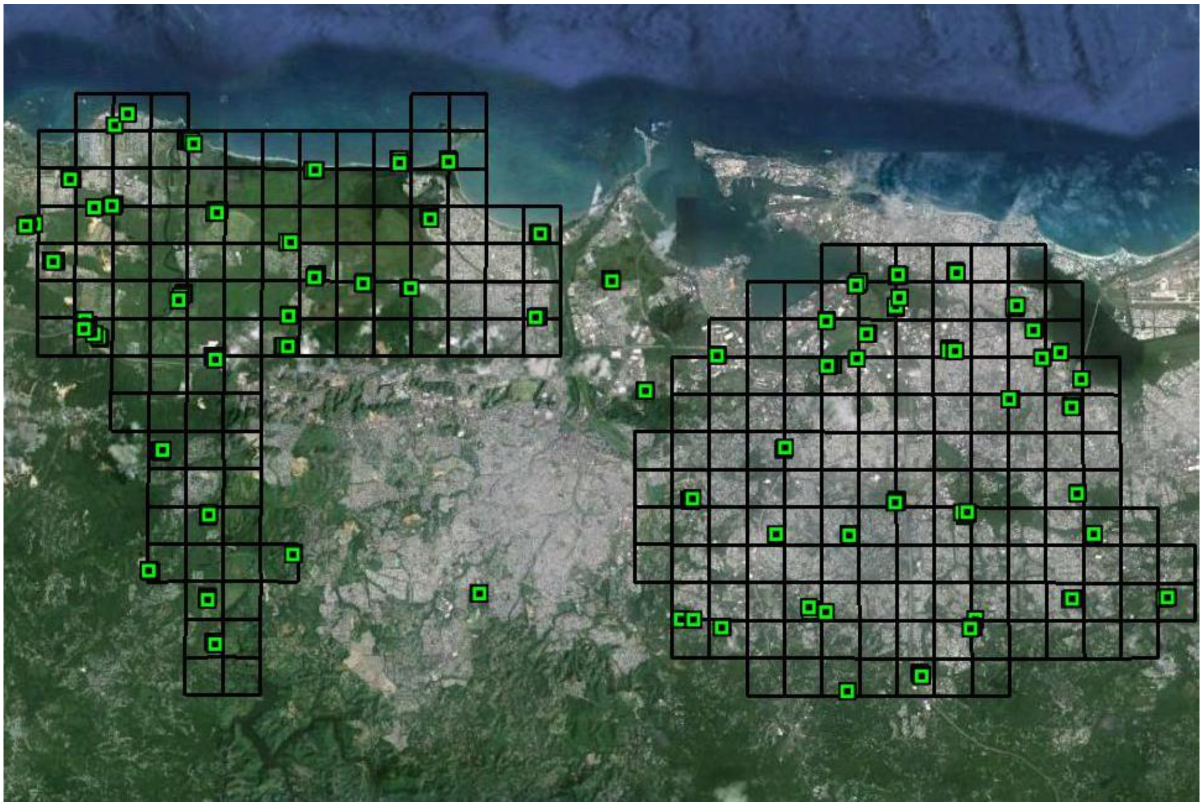


Figure 33 -The figure above illustrates the distribution and location of each ground survey point. Each survey point is represented by a green box

Overall, 201 points were collected as described in the table below (This tables includes landscape class points, but does not include the additional points collected for vertical and horizontal control). The additional points and accuracy calculations are provided in the accuracy assessment portion of this report.

Ground Survey Point Summary

Class	AREA 1	AREA2	AREA3	Total
OLG	25	23	2	50
TGC	26	16	2	44
BLT	26	18	0	44
FOR	22	21	3	46
WET	7	9	1	17
Total	106	87	8	**201**

Survey Notes

1. Horizontal Datum: North American Datum of 1983, 2011 Realization (NAD83/2011) State Plane Coordinate System, Puerto Rico Virgin Islands FIPS Zone 5200, NAD83/2011 Meters
2. Vertical Datum: Ellipsoid heights reference Geodetic Reference System of 1980 (GRS80), State Plane Coordinates reference Puerto Rico Vertical Datum of 2002 (PRVD02) Meters
3. Conversions: Trimble Business Center (v. 2.81) utilized Geoid12A to perform the conversion between the orthometric elevations and ellipsoidal heights
4. A1 = Area 1 -Rio de La Plata Region (West Area)
5. A2 = Area 2 -Puerto Nuevo Region (East Area)
6. A3 = Area between Area 1 and Area 2 (Greater San Juan Region)
7. BLT = Brush/ Low Trees
8. FOR = Forest
9. OLG = Open/Low Grass
10. TGC = Tall Grass Crops
11. WET = Wetland

Accuracy Assessment

Methodology

Check points were surveyed by a subcontractor (SurvTech Solutions) using RTK GPS/Static techniques. The method of collection and accuracies are detailed in the Survey Report for this project (**APPENDIX A**). In total 358 check points were collected on open/low grass, Tall Grass/Crops, Brush/Low Trees, Forrest, Wetland, Vertical Control, and Horizontal Control and.

The classification codes for the control survey are:

Landscape Class	Code
Open/Low Grass	OLG
Tall Grass/Crops	TGC
Brush/Low Trees	BLT
Forest	FOR
Wetland	WET
Vertical Control	VC

A comparison of the check points to the LiDAR TIN surface was then made to determine the Δz, from which accuracy statistics were generated to report the fundamental, supplemental and consolidated vertical accuracy of the LiDAR data. The software used for the accuracy statistics was the accuracy reporting tool from Terrascan

The survey required the LiDAR data meet the following standards:

- EM 1110-0-1005 Topographic Surveying
- EM 1110-1-1000 Photogrammetric Mapping
- EM 1110-1-1002 Survey Markers and Monumentation
- EM 1110-1-1003 NAVSTAR Global Positioning System Surveying
- EM 1110-1-1004 Geodetic and Control Surveying
- EM 1110-1-2909 Geospatial Data and Systems
- EM 1110-2-2907 Remote Sensing
- EM 385-1-1 Safety and Health Requirements
- ASPRS Guidelines: Vertical Accuracy Reporting for LiDAR Data
- ASPRS LAS Specification Version 1.2
- FGDC-STD-007-1998 Geospatial Positioning Accuracy Standards
- FGDC-STD-001-1998 Content Standard for Digital Geospatial Metadata
- FGDC-STD-012-2002 Content Standard for Digital Geospatial Metadata: Extensions for Remote Sensing Metadata

The accuracy for each landscape class (as defined in the scope) was:

Landscape Class Accuracy (RMSE in centimeters)
Open/Low Grass = 10 cm
Tall Grass/Crops = 10 cm
Brush/Low Trees = 15 cm
Forest = 20 cm
Wetland = N/A

$RMSE_z$ is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. If those differences are normally distributed and average zero, 95 percent of any sufficiently large sample should be less than 1.96 times the $RMSE_z$. $Accuracy_z$ of any DEM is defined as 1.96 times the $RMSE_z$ of linearly interpolated elevations in the DEM, as compared with known elevations from high-accuracy test points.

The Fundamental Vertical Accuracy (FVA) of the dataset was determined using check points located only in open, non-vegetated terrain where there is a very high probability that the sensor will have detected the ground surface. For this project, one of the ground cover classes (OLG) was used in addition to vertical control (VC) to calculate the fundamental vertical accuracy. The vertical control points were not a ground cover classification, but were captured to be used in the calibration and editing of the data. The fundamental accuracy is calculated at the 95-percent confidence level as a function of $RMSE_z$ and is specified at a higher level of accuracy than other land cover categories. The FVA is calculated using the same formula as $Accuracy_z$.

Results

After delivery of all tiles to USACE, an additional edit was performed on the highly vegetated areas. The purpose of this edit was an attempt to improve the accuracy of these areas to be approximately 20 cm. The following screen shot shows the areas identified as highly vegetated. These are the Forrest (FOR), Brush/Low Tree (BLT) and Tall Grass/Crops (TGC) feature categories. It should be noted that this shapefile is also provided to USACE to identify areas of low confidence. The vegetation in these areas was so thick that minimal ground points were present in the final LAS files.

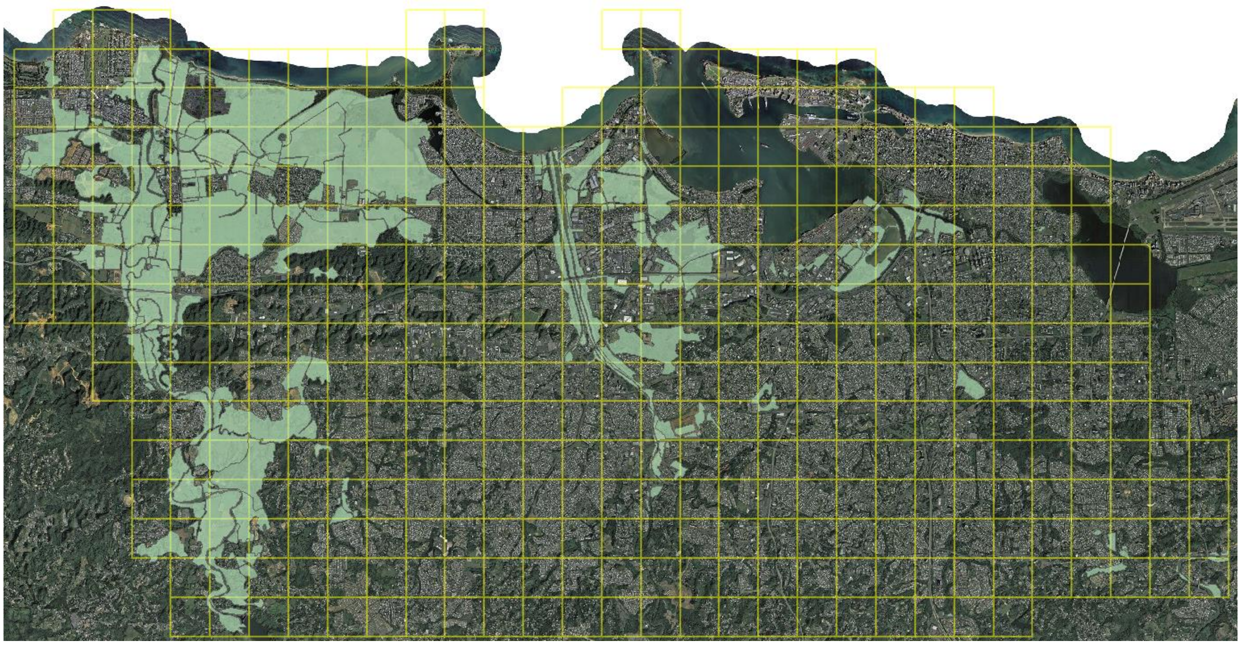


Figure 34 - Highly Vegetated Areas, Considered Low Confidence.

The results of the Accuracy Assessment are shown below:

The favorable result the comparison to the check points in the Fundamental Vertical Accuracy classes, provides an overall confidence that the LiDAR system was operating properly during data collection.

The two landscape classes with dense tall grass vegetation (Brush/low trees and Tall Grass/Crops) tested at higher than the target accuracy. Based on the thick vegetation, the LIDAR points that got to the ground in these areas were minimal, and aggressive filtering and manual edits were required in order to remove the dense vegetation from the ground point classification. As a result, the ground points in these areas were sometimes tens to hundreds of meters apart. The distance of the ground points in these locations resulted in a triangulated test surface that may not represent the small terrain variations around the control survey points. The tested results of all classifications are included in the tables below.

Although a particular LiDAR point cannot be tested, accuracy statements can be made about the performance of the ABGPS, IMU and LiDAR sensors. The ABGPS data are quality controlled by solutions from base stations. On this project, these solutions all agreed to better than 5 cm horizontally. The IMU sensor combines the post-processed GPS data with the raw inertial data to produce a best estimate of trajectory. Automated quality control checks will not allow the IMU solution to be of a lower accuracy than the provided input from the GPS solution. The altitude of the ALS70-CM sensor (S/N 7169) on this project was 1250-meters AGL providing a spot size of 29 cm in diameter. Each return is located somewhere within the spot on the ground, meaning the location of the point is located within 14.5 cm of the center of the spot.

Accuracy Tables

Vertical Accuracy

A Microsoft Excel version of the accuracy calculations is provided as a deliverable for this project. The following is a summary of the results of the accuracy analysis.

VERTICAL ACCURACY

		Before Final Vegetation Edit	After Final Vegetation Edit	Improvement After Edit
	# Points	**RMSEz (M)**	**RMSEz (M)**	**RMSEz (M)**
Vertical Control	44	0.059	0.059	0.000
Open/Low Grass	91	0.061	0.060	0.002
Consolidated Fundamental	135	0.059	0.059	0.000
Brush/Low Trees	66	0.191	0.146	0.045
Forest	74	0.157	0.123	0.033
Tall Grass/Crops	83	0.330	0.241	0.089
Wet	34	0.443	0.442	0.002
Consolidated Supplemental	223	0.244	0.181	0.062
Consolidated	358	0.196	0.146	0.050

The following tables show the accuracy statistics for each land cover class. These statistics are for the final datasets (after the final focused vegetation edits). The accuracy of each land cover class before the edits is included in the Excel file (with each tab names 'ORIG' for the land cover class.

OLG	**US Feet**	**Meters**
Average Δz =	-0.04	-0.01
Minimum Δz =	-0.61	-0.19
Maximimum Δz =	0.47	0.14
Average Magnitude =	0.15	0.05
$RMSE_z$ =	0.20	0.060
Standard Deviation =	0.19	0.06
Mean =	-0.04	-0.01
Median =	-0.06	-0.02
Skew =	1.17	0.36
Tested supplemental vertical accuracy at 95th percentile in high open/low grass =	**0.41**	**0.12**
Target $Accuracy_z$	**0.64**	**0.196**
	PASS	

Figure 35 - Open Low Grass Accuracy (OLG)

FOR	US Svy Ft	Meters
Average Δz =	-0.04	-0.01
Minimum Δz =	-1.01	-0.31
Maximum Δz =	1.51	0.46
Average Magnitude =	0.30	0.09
$RMSE_z$ =	0.40	0.123
Standard Deviation =	0.40	0.12
Mean =	-0.04	-0.01
Median =	-0.07	-0.02
Skew =	1.99	0.61
Tested supplemental vertical accuracy at 95th percentile in forest =	**0.87**	**0.27**
$Target Accuracy_z$	**1.29**	**0.392**
	PASS	

Figure 36 - Forest Accuracy (FOR)

BLT	US Feet	Meters
Average Δz =	0.28	0.08
Minimum Δz =	-0.57	-0.17
Maximum Δz =	1.21	0.37
Average Magnitude =	0.36	0.11
$RMSE_z$ =	0.48	0.146
Standard Deviation =	0.39	0.12
Mean =	0.28	0.08
Median =	0.17	0.05
Skew =	1.05	0.32
Tested supplemental vertical accuracy at 95th percentile in brush/low trees =	**0.90**	**0.28**
$Target Accuracy_z$	**0.96**	**0.294**
	Over Target	

Figure 37 - Brush/ Low Trees (BLT) Accuracy

TGC	US Feet	Meters
Average Δz =	0.57	0.18
Minimum Δz =	-0.27	-0.08
Maximimum Δz =	2.73	0.83
Average Magnitude =	0.61	0.18
$RMSE_z$ =	0.79	0.241
Standard Deviation =	0.54	0.16
Mean =	0.57	0.18
Median =	0.45	0.14
Skew =	3.63	1.11
Tested supplemental vertical accuracy at 95th percentile in high tall grass/crops =	**1.49**	**0.46**
Target Accuracy$_z$	**0.64**	**0.196**
	Over Target	

Figure 38 - Tall Grass/Crops (TGC) Accuracy

Consolidated Fundamental	US Feet	Meters
Average Δz =	-0.06	-0.02
Minimum Δz =	-0.61	-0.19
Maximimum Δz =	0.47	0.14
Average Magnitude =	0.16	0.05
$RMSE_z$ =	0.20	0.06
Standard Deviation =	0.19	0.06
Mean =	-0.06	-0.02
Median =	-0.08	-0.02
Skew =	1.74	0.53
Tested consolidated vertical accuracy at 95th percentile in open terrain, high grass and trees =	**0.40**	**0.12**
Target Accuracy$_z$	**0.64**	**0.196**
	PASS	

Figure 39 - Consolidated Fundamental (includes VC and OLG)

BLT and TGC	US Feet	Meters
Average Δz =	0.44	0.13
Minimum Δz =	-0.57	-0.17
Maximimum Δz =	2.73	0.83
Average Magnitude =	0.50	0.15
$RMSE_z$ =	0.67	0.204
Standard Deviation =	0.50	0.15
Mean =	0.44	0.13
Median =	0.37	0.11
Skew =	3.48	1.06
Tested supplemental vertical accuracy at 95th percentile in brush/low trees =	**1.28**	**0.39**
Target $Accuracy_z$	**0.96**	**0.294**
	Over Target	

Figure 40 - Combined BLT and TGC

Consolidated Supplemental	US Feet	Meters
Average Δz =	0.28	0.09
Minimum Δz =	-1.01	-0.31
Maximimum Δz =	2.73	0.83
Average Magnitude =	0.43	0.13
$RMSE_z$ =	0.60	0.181
Standard Deviation =	0.52	0.16
Mean =	0.28	0.09
Median =	0.19	0.06
Skew =	2.84	0.87
Tested supplemental vertical accuracy at 95th percentile in brush/low trees =	**1.23**	**0.38**

Figure 41 - Consolidated Supplemental (includes BLT, FOR and TGC)

Horizontal Accuracy

Expected horizontal accuracy for the Leica ALS70-cm sensor, as determined from system studies and other methods, is 1/5500th of the flight height, which, in the instance of this particular project was 3,800-feet AGL (1250m), giving a horizontal tolerance of less than 0.691 US survey feet (0.211 m).

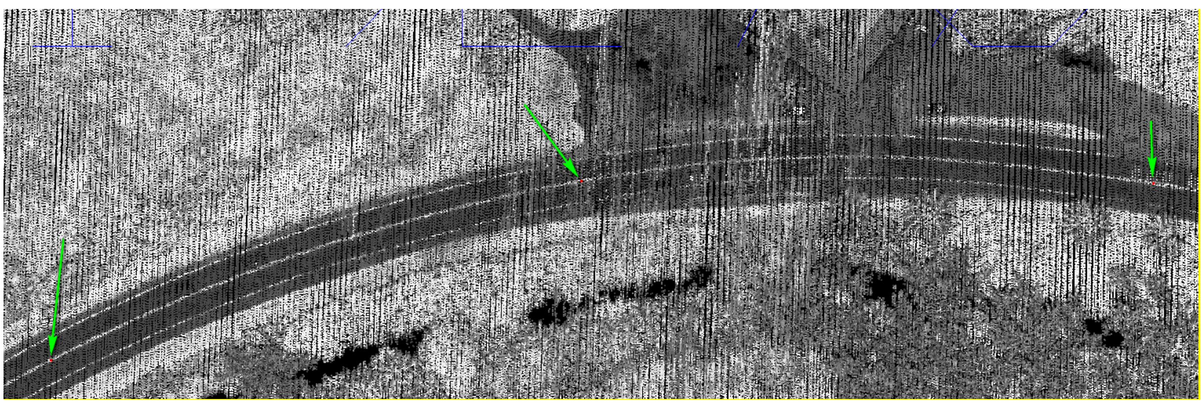


Figure 42 - Red dots are horizontal control check points, they were collected on white stripes in the roadway. In these screen shots they are overlaid on the LIDAR intensity image

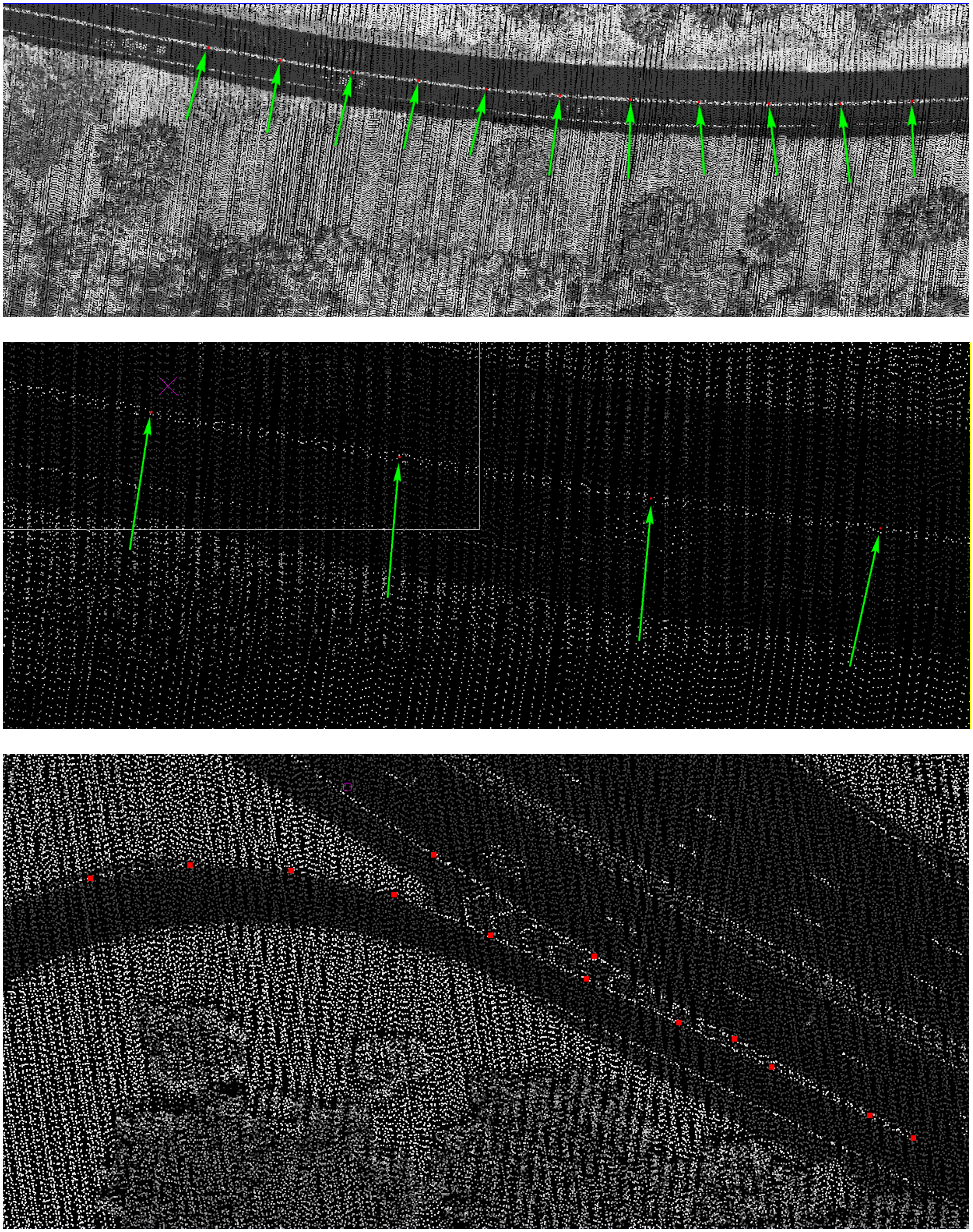
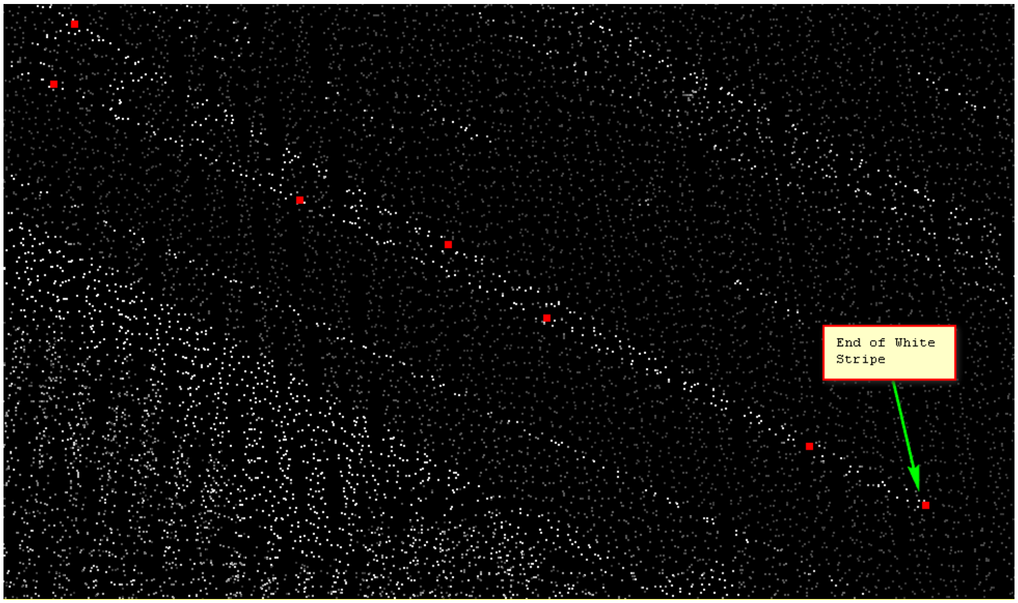


Figure 43 - Red dots are horizontal control check points, they were collected on white stripes in the roadway. In these screen shots they are overlaid on the LIDAR intensity image



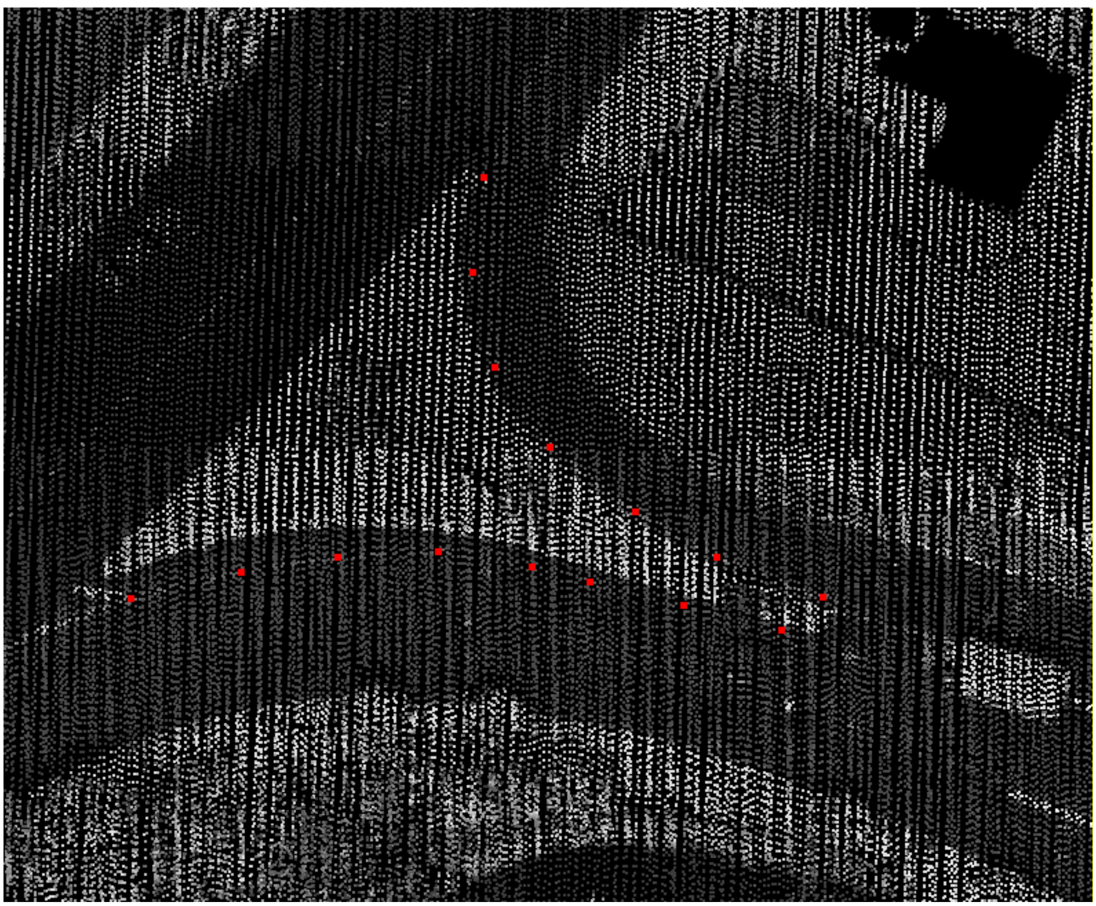
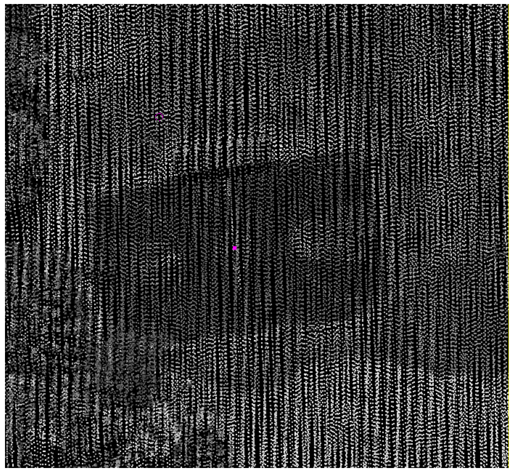
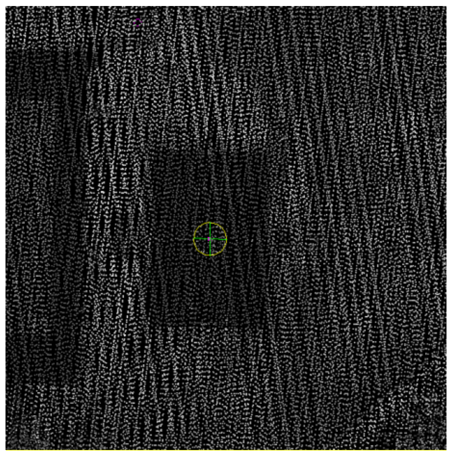


Figure 44 - Red dots are horizontal control check points, they were collected on white stripes in the roadway. In these screen shots they are overlaid on the LIDAR intensity image





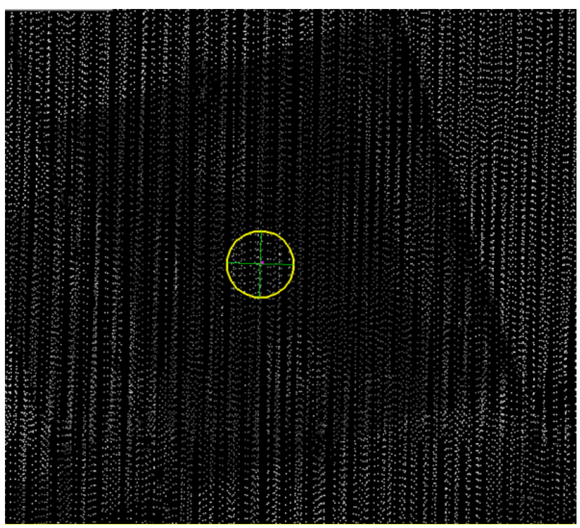


Figure 45 - The following table contains measurements taken from these horizontal control points. These are from basketball courts in tiles 226258, 228266 and 242257

Horizontal Accuracy Computation

Point	x_{ri}	x_{mi}	error in x dimension = reference - map	error in x dimension squared	variance of e_{xi}	y_{ri}	y_{mi}	error in y dimension = reference - map	error in x dimension squared	variance of e_{yi}	sum of squared errors
ID	LiDAR	Control	$(x_{ri} - x_{mi}) = e_{xi}$	$(x_{ri} - x_{mi})^2 = e_{xi}^2$	$(\|e_{xi}\|-RSME_x)^2$	reference	(map)	$(y_{ri} - y_{mi}) = e_{yi}$	$(y_{ri} - y_{mi})^2 = e_{yi}^2$	$(\|y_i\|-RSME_y)^2$	$e_{xi}^2 + e_{yi}^2$
1520	226799.051	226798.972	0.079	0.006241	0.00	258724.449	258724.457	-0.008	0.000064	0.00	0.00630
2046	242819.316	242819.409	-0.093	0.008649	0.00	257939.087	257939.127	-0.04	0.001600	0.00	0.01025
2031	228351.178	228351.195	-0.017	0.000289	0.00	266043.918	266043.866	0.052	0.002704	0.00	0.00299
		Sum	-0.031	0.015179	0				0.004368	0	0

$RMSE_x$	0.07	$RMSE_y$	0.04
S^2_x	0.00	S^2_y	0.00
S_x	0.04	S_y	0.02
S_{RMSEx}	0.024	S_{RMSEy}	0.014

Definitions	X Dimension Equations	X Dimension Values
Estimated Root Mean Square of the population of errors	$RMSE_x = \sqrt{\sum_i^n (e_{xi})^2 / n}$	0.07
Estimated Variance of the populatiuon of errors	$S^2{}_x = \sum_i^n (\lvert e_{xi} \rvert - RMSE_x)^2 / (n-1)$	0.00
Esimated Standard Deviation of the population of errors	$S_x = \sqrt{\sum_i^n (\lvert e_{xi} \rvert - RMSE_x)^2 / (n-1)}$	0.04
Esimated Standard Deviation of the population of RSMEs	$S_{RMSE_x} = \sqrt{S_x{}^2 / n}$	0.02
Greenwalt & Schultz CMAS Standard normal (Ƶ) interval of the population of errors at 95% probability	$1.96 * S_x$	0.08
Greenwalt & Schultz CMAS Standard normal (Ƶ) interval of the population of errors at 90% probability	$1.645 * S_x$	0.07
NSSDA Statistic	$1.96 * RMSE_x$	0.14
Confidence interval on the estimate of RMSE$_x$ at 95% probability	$RMSEx + 1.96 * S_{RMSE} > e_{xi} > RMSEx - 1.96 * S_{RMSE}$	0.02 to 0.12

Definitions	Y Dimension Equations	Y Dimension Values
Estimated Root Mean Square of the population of errors	$RMSE_y = \sqrt{\sum_i^n (e_{yi})^2 / n}$	0.04
Estimated Variance of the populatiuon of errors	$S^2{}_y = \sum_i^n (\lvert e_{yi} \rvert - RMSE_y)^2 / (n-1)$	0.00
Esimated Standard Deviation of the population of errors	$S_y = \sqrt{\sum_i^n (\lvert e_{yi} \rvert - RMSE_y)^2 / (n-1)}$	0.02
Esimated Standard Deviation of the population of RSMEs	$S_{RMSE_y} = \sqrt{S_y{}^2 / n}$	0.01
Greenwalt & Schultz CMAS Standard normal (Ƶ) interval of the population of errors at 95% probability	$1.96 * S_y$	0.05
Greenwalt & Schultz CMAS Standard normal (Ƶ) interval of the population of errors at 90% probability	$1.645 * S_y$	0.04
NSSDA Statistic	$1.96 * RSME_y$	0.07
Confidence interval on the estimate of RMSE$_x$ at 95% probability	$RMSEy + 1.96 * S_{RMSE} > e_{yi} > RMSEy - 1.96 * S_{RMSE}$	0.01 to 0.06

Definitions	Circular Equations	Circular Values
Estimated Root Mean Square of the populations of errors	$RMSE_h = \sqrt{\sum_i^n (e_{hi})^2 / n}$	0.08
Esimated Standard Deviation of the population of errors	$S_h = (S_x + S_y)/2$	0.03
Esimated Standard Deviation of the population of RSMEs	$S_{RMSE_h} = S_h / \sqrt{n}$	0.02
Greenwalt & Schultz CMAS Standard normal (Ƶ) interval of the population of errors at 95% probability	$2.4477 * S_h$	0.08
Greenwalt & Schultz CMAS Standard normal (Ƶ) interval of the population of errors at 90% probability	$2.1460 * S_h$	0.07
NSSDA$_{circular}$ Statistic	$1.7308 * RMSE_h$	0.14
NSSDA$_{eliptical}$ Statistic	$2.4477 * .5 * (RMSEx + RMSEy)$	0.13
Confidence interval on the estimate of RMSE at 95% probability	$RMSE_h + 1.96 * S_{RMSE} > e_{hi} > RMSE_h - 1.96 * S_{RMSE}$	0.04 to 0.12

Deliverables

Data production and deliverable creation was led by Ken Comeaux. The following is a list and description of each deliverable.

1. **Project Plan –** Was delivered at the beginning of the project
2. **Status Reports Weekly throughout the project –** Weekly status reports will be sent by PAR to USACE on each Monday. There were a total of 30 reports for the PoP from October 2013 to April 2014. These reports are included with this final report as **Appendix C**
3. **LiDAR Data -** Two complete sets of LiDAR point cloud data, one containing geodetic coordinates and the other projected coordinates, were delivered as ASPRS LAS files formatted as v1.2 – Point Data Record Format 1. As specified in the scope, PAR also delivered all breaklines in ESRI 3-D line feature format. The data processing section of this document describes the methodology to produce the deliverables and quality control procedures.
4. **Final Survey Data & Report –** PAR also delivered final field survey data and a comprehensive FINAL Survey Report. The data and report included any ground control, base station observations, and aircraft/sensor positioning data, along with a detailed report documenting the survey methods employed to complete the project. The survey report contained all relevant aspects of the aerial and ground surveys, including but not necessarily limited to equipment and personnel lists, field log books, the actual flight line trajectories, description of the survey methods, survey control locations and observations, base station locations and observations, LiDAR processing methodology, digital photographs of each surveyed location, project timeline, weather and site conditions, quality control procedures, among others. This report is authored as a narrative of how PAR carried out each step of the project, the results of each aspect of the survey, and the methods employed to ensure the quality of the deliverables and a successful completion of the project. The report is delivered in PDF format. In addition to the Final Report document, all relevant spatial data, such as the actual flight lines, ground control, base station location(s), field photographs, etc., were delivered as ESRI GeoDatabase Feature Classes with appropriate Federal Geodetic Data Committee (FGDC) compliant metadata attached.
5. **USACE Review & Acceptance –** With all deliverables sent to USACE, PAR understands the review period for USACE (30 days) to review and accept each deliverable

All deliverables were sent the USACE Project Manager and Point to Contact, Ted Schall:

Theodore N. Schall, CP, GISP, LSP
United States Army Corps of Engineers
Jacksonville District
701 San Marco Boulevard
Jacksonville, FL 32207
(904) 232-2214
ted.n.schall@usace.army.mil

Resource Personnel and Associated Tasks

Below is a list of the personnel types assigned to work on this project and the roles for each personnel category as it relates to execution of the work

Geospatial/LiDAR-Data Processing		**Tasks**
0001	Project Manager Jeff Lower, PAR Ken Comeaux, PAR	Overall project management, serve as quality manager, perform QC checks, project reports, weekly status
0007	CADD/Civil Engineering Technician Trent Tomlinson, PAR Ryan Comeaux, Magnolia River Ben Beckman, Magnolia River	Data processing (calibration, break lines, editing, deliverable production)
Geospatial/LiDAR- Acquisition		
0001	Project Manager Jeff Lower, PAR Bob Hamilton, PAR Ken Comeaux, PAR	Coordination of all flight logistics, flight permissions from ATC, implementation of collection plan including base stations, review of collected data for QA/QC
0012	LiDAR Aerial Survey (Flight Crew, Sensor, Single engine Aircraft, excluding fuel) Tanner Farrar, PAR Trent Tomlinson, PAR	Mobilization to Puerto Rico, all flights for data collection, includes pilot and sensor operator
0019	Aircraft Standby (Flight Crew) Tanner Farrar, PAR Trent Tomlinson, PAR	Standby for downtime due to weather delays and/or delays from water conditions on the ground
Geospatial/LiDAR-Field Survey		
0001	Project Manager - Coordinate with Survey Company Ken Comeaux, PAR Ryan Fowler, SurvTech	Management of survey crew, post processing of survey data, quality control checks, reports
0036	2-Person GPS RTK Survey Party Lyman Hill, SurvTech Ben Stinson, SurvTech	Onsite data collection of survey ground control