Texas Desert Mountains Topographic Lidar Project

Lot 6 - Block 1 Report

March 12, 2020

Prepared for:

United States Geological Survey,
National Geospatial Technical Operations Center

Prepared by:

Optimal GEO, Inc.

CONTRACT: G17PC00007

TASK ORDER: 140G0219F0017

Contents

Contents

Introduction

Precision Aerial Reconnaissance (PAR) was tasked by the United States Geological Survey to acquire and process QL2 topographic LiDAR data for 4,528 square miles in Texas, including the partial counties of: El Paso and Hudspeth. These LiDAR data will be used to produce a high-resolution bare earth Digital Elevation Model of the entire project area. This report describes the data acquisition, ground survey, data processing, quality control, and data validation activities related to producing the final deliverables for this project.

The LiDAR data were processed in accordance with this task order's Statement of Work, as well as the USGS' NGP Lidar Base Specification version 1.3 (February 2018).

This contract has been novated from PAR to Optimal GEO, Inc. Under this task order, Optimal GEO assumed full responsibilities of the data handling, from acquisition to delivery.

Project Team

Optimal GEO, Inc., serving as the prime contractor of this task order, was responsible for managing all project related activities. Optimal GEO was directly responsible for the topographic lidar post acquisition QA/QC, initial automated classification, manual editing of the lidar data and breakline generation and performing QA/QC on all final deliverables. All ground survey activities required to collect ground control and accuracy checkpoints were performed by Flora Bama Geospatial Solutions, LLC. The data acquisition and calibration were performed by Quantum Spatial.

Coordinate Reference System

The lidar data and derived products were delivered in the following reference system.

Horizontal Datum: North American Datum 1983, 2011 adjustment (NAD83 (2011))
Vertical Datum: North American Vertical Datum of 1988, (NAVD88)
Coordinate System: Universal Transverse Mercator (UTM) Zone 13 North
Units: Horizontal units are in meters to 2 decimal places; Vertical units are in meters to 2 decimal places.
Geoid Model: Geoid12B (used to convert ellipsoid heights to orthometric heights)

Lidar Vertical Accuracy

The tested RMSEz of the classified lidar data for checkpoints in non-vegetated terrain is 5.9 cm, within the 10 cm specification. The NVA of the classified lidar data computed using RMSEz x 1.96 is 11.6 cm, within the 19.6 cm specification.

The tested VVA of the classified lidar data computed using the 95th percentile is equal to 23.1 cm, compared to the 30 cm specification.

Project Deliverables

The deliverables for the project are as follows:

1. Classified Point Cloud Data (Tiled)
2. Bare Earth Surface (Raster DEM – GeoTIFF, 32-bit floating-point format)
3. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
4. Breakline Data (ESRI GDB Feature Class Format)
5. Independent Survey Checkpoint Data (Report, Photos, & Points)
6. Calibration Points
7. Metadata
8. Project Report (Acquisition, Processing, QC)
9. Project Extents

Lidar Acquisition

Quantum Spatial planned 158 passes for the TX Desert Mountains project area containing cross ties for the purposes of quality control. To reduce any margin for error in the flight plan, Quantum Spatial followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Teledyne Optech Mission Management flight design software for direct integration into the aircraft flight navigation system.
- Planned flight lines; flight line numbers; and coverage area.
- Lidar coverage extended by a predetermined margin (100m) beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.
- Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, Quantum Spatial filed their flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Quantum Spatial monitored weather and atmospheric conditions and conducted lidar missions only when no conditions exist below the sensor that will affect the collection of data. These conditions include leaf-off for hardwoods, no snow, rain, fog, smoke, mist and low clouds. lidar systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. Quantum Spatial accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection to position our sensor to maximize successful data acquisition.

Within 72-hours prior to the planned day(s) of acquisition, Quantum Spatial closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, our aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

The lidar survey was conducted between September 11, 2019 and October 20, 2019.

Lidar System Parameters

Quantum Spatial operated a Cessna 310 (twin-piston) (Tail # N7516Q) outfitted with an Optech Galaxy Prime LiDAR system during the collection of the study area.

Table 1 lists Quantum Spatial's system parameters for lidar acquisition on this project.

Item	Parameter
System	Optech Galaxy Prime
Altitude (AGL meters)	2825
Approx. Flight Speed (knots)	170
Scanner Pulse Rate (kHz)	500
Scan Frequency	69
Pulse Duration of the Scanner (nanoseconds)	3
Pulse Width of the Scanner (m)	0.71
Swath width (m)	1945
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Beam Divergence (milliradians)	0.25
Nominal Swath Width on the Ground (m)	1945
Swath Overlap (%)	30
Total Sensor Scan Angle (degree)	38
Nominal Pulse Spacing (single swath), (m)	0.71
Nominal Pulse Density (single swath) (ppsm), (m)	2.94
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.71
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	2.94
Maximum Number of Returns per Pulse	8

Table 1. Quantum Spatial's lidar system parameters.

Acquisition Status Report and Flight Lines

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. The Acquisition Manager contacted air traffic control and coordinated flight pattern requirements. Lidar acquisition began immediately upon notification that control base stations were in place. During flight operations, the flight crew monitored weather and atmospheric conditions. Lidar missions were flown only when no condition existed below the sensor that would affect the collection of data. The pilot constantly monitored the aircraft course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the sensor, the status of PDOPs, and performed the first Q/C review during acquisition. The flight crew constantly reviewed weather and cloud locations. Any flight lines (Figure 1) impacted by unfavorable conditions were marked as invalid and re-flown immediately or at an optimal time.

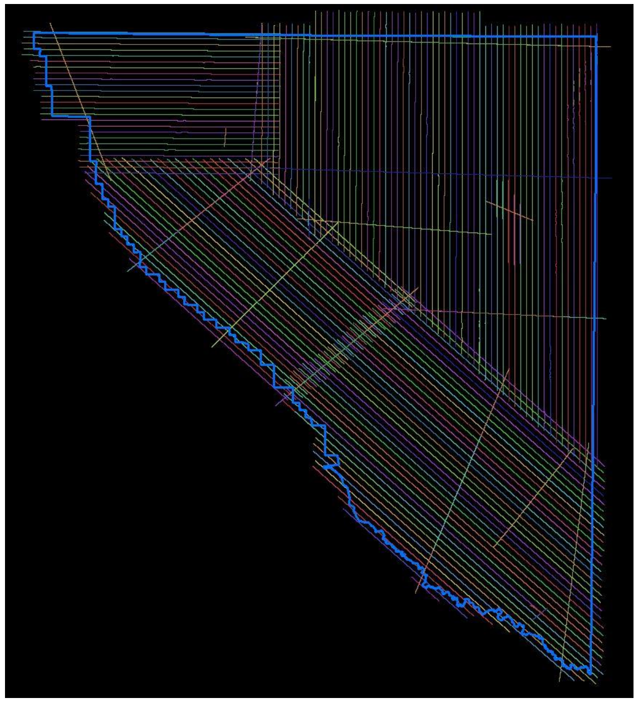


Figure 1. Trajectories as flown.

Lidar Ground Control

One LiDAR acquisition base station (Table 2) was used to control the lidar acquisition for the TX Desert Mountains project area. The Trimble R10 GNSS receiver and a Trimble R7 GNSS receiver were both used during the survey collection, logging at 2 Hertz affixed to a 2-meter range, pole served as base stations during acquisition. The coordinates of all used base station positions are provided in Table 2.

Name	NAD83 (2011) UTM 15		Ellipsoidal Ht (m)	Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)		
LIDAR BASE	369917.999	3518745.270	1179.004	1204.176

Table 2. Listing of NGS monuments used for ground control of the lidar data.

Airborne GPS Kinematic and Flightlogs

Applanix + POSPac Mobile Mapping Suite software was used for post-processing of airborne GPS and inertial data (IMU), which is critical to the positioning and orientation of the LiDAR sensor during all flights. POSPac combines aircraft raw trajectory data with stationary GPS base station data yielding a "Smoothed Best Estimate Trajectory (SBET) necessary for additional post processing software to develop the resulting geo-referenced point cloud from the LiDAR missions.

During the sensor trajectory processing (combining GPS & IMU data sets) certain statistical graphs and tables are generated within the Applanix POSPac processing environment which are commonly used as indicators of processing stability and accuracy. This data for analysis include: Max horizontal / vertical GPS variance, separation plot, altitude plot, PDOP plot, base station baseline length, processing mode, number of satellite vehicles, and mission trajectory.

Flight logs, GPS, and IMU processing reports are included in the Acquisition report: Appendix A.

Generation and Calibration of Laser Points

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete.

Point clouds were then created using Optech LMS software. The generated point cloud is the mathematical three-dimensional composite of all returns from all laser pulses as determined from the aerial mission. Laser point data are imported into GeoCue, a distributive processing software, which allows for a more manageable file size to be created in a LAS tile format.

On a project level, a supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.

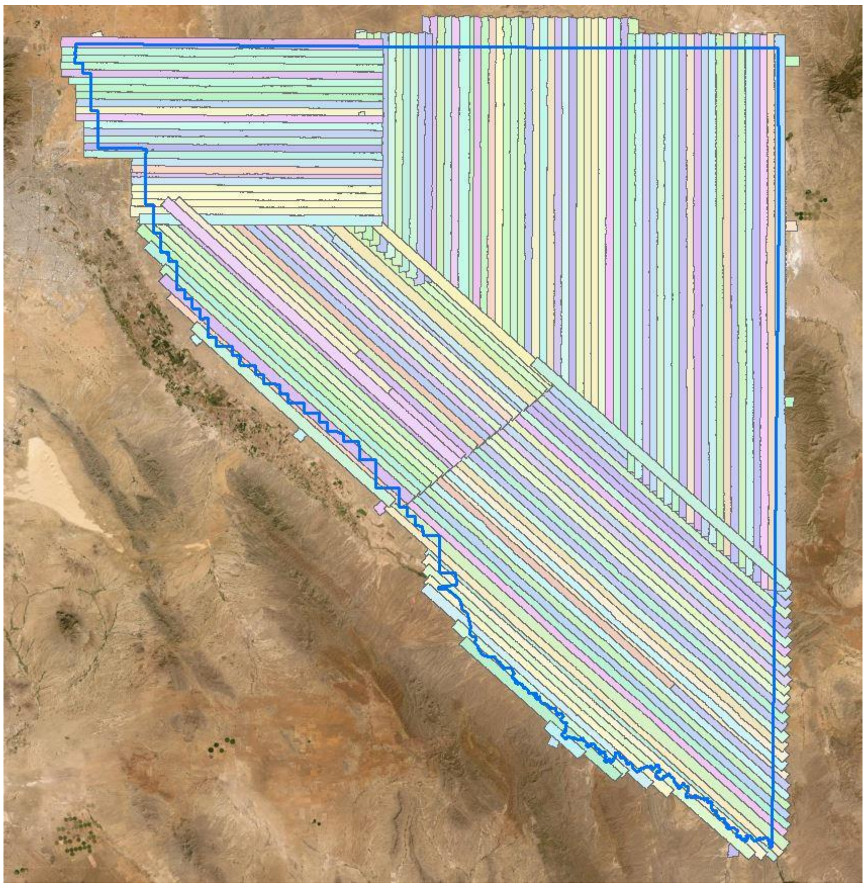


Figure 2. Lidar Swath output showing complete coverage.

Boresight and Relative Accuracy

The initial points for each mission calibration are inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the lidar unit or GPS. Roll, pitch and scanner scale are optimized during the calibration process until the relative accuracy is met.

Relative accuracy and internal quality are checked using at least 3 regularly spaced QC blocks in which points from all lines are loaded and inspected. Vertical differences between ground surfaces of each line are displayed. Color scale is adjusted so that errors greater than the specifications are flagged. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement. An example of this review is illustrated in Figure 3.

For this project the specifications used are as follows:
Relative accuracy ≤ 6 cm maximum differences for smooth surface repeatability and ≤8 cm RMSDz between adjacent and overlapping swaths.

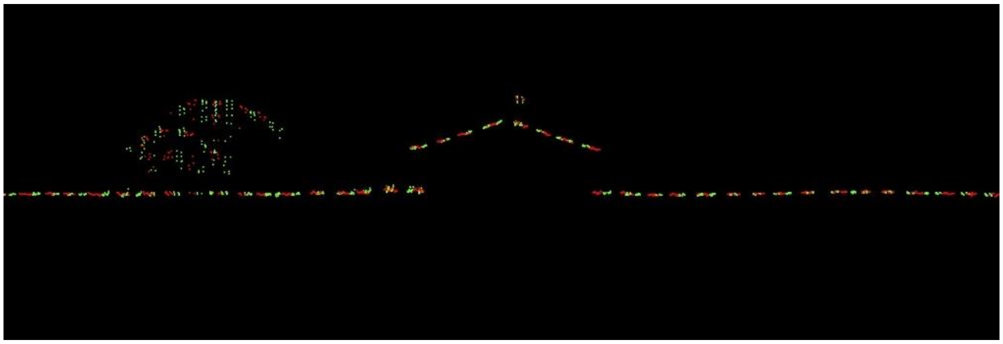


Figure 3. Profile view showing correct roll and pitch adjustments.

Lidar Processing & Quantitative Assessment

Initial Processing

Optimal GEO performed several validations on the dataset prior to starting full-scale production on the project. These validations include vertical accuracy of the swath data, inter-swath (between swath) relative accuracy validation, intra-swath (within a single swath) relative accuracy validation, verification of horizontal alignment between swaths, and confirmation of point density and spatial distribution. This initial assessment allows Optimal GEO to determine if the data are suitable for full-scale production. Addressing issues at this stage allows the data to be corrected while imposing the least disruption possible on the overall production workflow and overall schedule.

Final Swath Vertical Accuracy Assessment

Optimal GEO tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Vertical accuracy of the swath data was tested using seventy-five (75) non-vegetated (open terrain and urban) independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the lidar point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete lidar point. Optimal GEO utilized MicroStation/TerraScan software to test the classified lidar vertical accuracy, and ESRI's ArcMap to test the DEM vertical accuracy so that two different software programs are used to validate the vertical accuracy for each project. Project specifications require a NVA of 19.6 cm based on the $RMSE_z$ (10 cm) x 1.96.

The dataset for the TX Desert Mountains Lidar QL2 Project satisfies these criteria. This raw lidar swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy tested to be $RMSE_z$ = 6.1 cm, equating to ± 11.9 cm at 95% confidence level. Table 3 shows all calculated statistics for the raw swath data.

Table 3: NVA at 95% Confidence Level Raw Calibrated Data.

# of Points	RMSE	RMSEz @ 95% CI	Mean (m)	Median (m)	Skew (m)	Std Dev (m)	Min (m)	Max (m)
75	0.061	0.119	-0.014	-0.007	-0.411	0.059	-0.163	0.097

Inter-Swath Relative Accuracy

Optimal GEO verified inter-swath or between swath relative accuracy of the dataset by creating Delta-Z (DZ) orthomosaics. According to the SOW, USGS Lidar Base Specifications v1.3, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL2 data must meet inter-swath relative accuracy of 8 cm RMSDz or less with maximum differences less than 16 cm. These measurements are to be taken in non-vegetated and flat open terrain using single or only returns from all classes.

Measurements are calculated in the DZ orthos on 1-meter pixels or cell sizes. Areas in the dataset where overlapping flight lines are within 8 cm of each other within each pixel are colored white, areas in the dataset where overlapping flight lines have elevation differences in each pixel between 8 cm to 16 cm are colored red or blue dependent on which line is above or below the overlapping line, and as the DZ values approach 16 cm and greater, the intensity of that color increases. Pixels that do not contain points from overlapping flight lines are colored white as well. Areas of vegetation and steep slopes (slopes with 16 cm or more of valid elevation change across 1 linear meter) are expected to appear yellow or red in the DZ orthos. If the project area is heavily vegetated, Optimal GEO may also create DZ Orthos from the initial ground classification only, while keeping all other parameters consistent. This allows Optimal GEO to review the ground classification relative accuracy beneath vegetation and to ensure flight line ridges or other issues do not exist in the final classified data.

Flat, open areas are expected to be white in the DZ orthos. Large or continuous sections of blue or red pixels can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the utility of the data, especially when these blue/red sections follow the flight lines and not the terrain or areas of vegetation. The DZ orthos for the TX Desert Mountain QL2 Lidar Project are shown in Figure 4; this project meets inter-swath relative accuracy specifications.

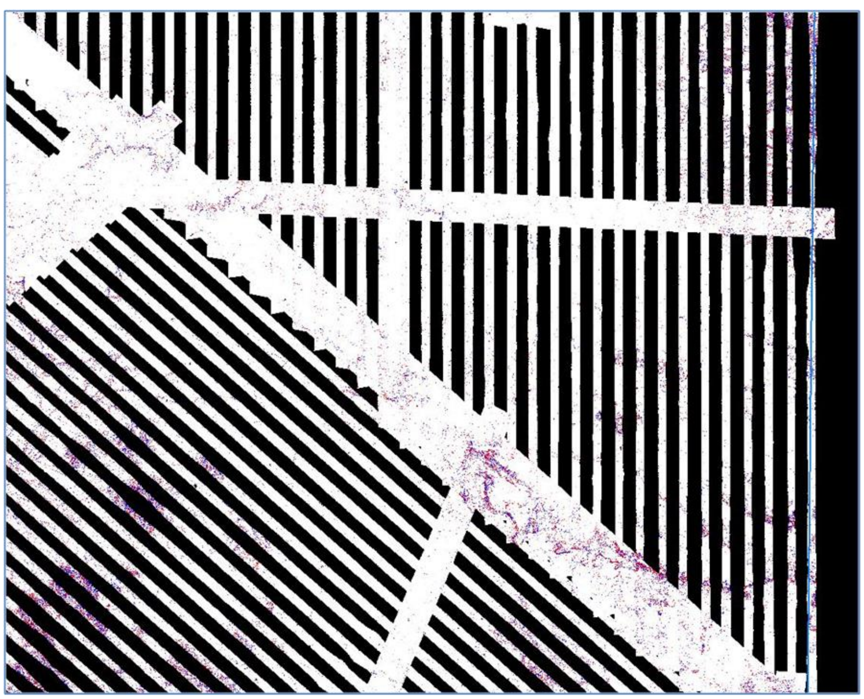


Figure 4. Delta-Z orthoimage raster generated to test inter-swath relative accuracy. Areas in the dataset where overlapping flight lines are within 8 cm of each other within each pixel are colored white, areas in the dataset where overlapping flight lines have elevation differences in each pixel between 8 cm to 16 cm are colored red or blue dependent on which line is above or below the overlapping line, and as the DZ values approach 16 cm and greater, the intensity of that color increases. The bright red or blue areas in this image are attributed to vegetation or steep slopes.

Intra-Swath Relative Accuracy

Optimal GEO verifies the intra-swath or within swath relative accuracy by LAStools scripting and visual reviews. QTM scripting is used to calculate the maximum difference of all points within each 1-meter pixel/cell size of each swath. Optimal GEO analysts then identify planar surfaces acceptable for repeatability testing and analysts review the results in those areas. According to the SOW, USGS Lidar Base Specifications v1.3, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL2 data must meet intra-swath relative accuracy of 6 cm maximum difference or less. Figure 5 shows examples of the intra-swath relative accuracy of the TX Desert Mountain QL2 lidar data; this project meets intra-swath relative accuracy specifications.

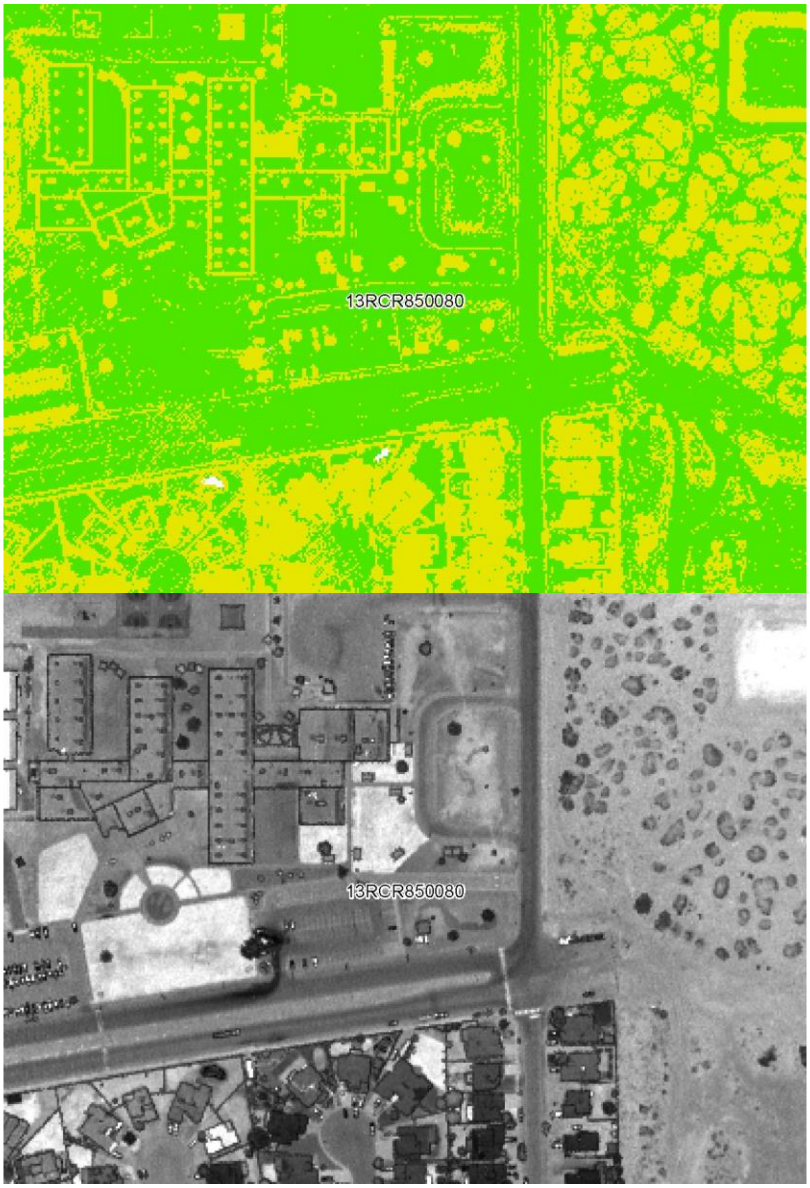


Figure 5. Intra-swath relative accuracy. The top image shows a close up of the project area; flat, open areas are colored green as they are within 6 cm whereas sloped terrain is colored yellow because it exceeds 6 cm maximum difference, as expected, due to actual slope/terrain change. The bottom image is a close-up of a flat area. Except for vegetated areas and around buildings (shown as yellow speckling/mottling as the elevation/height difference in vegetated areas will exceed 6 cm), this open flat area is acceptable for repeatability testing. Intra-swath relative accuracy passes specifications.

Horizontal Alignment

To ensure horizontal alignment between adjacent or overlapping flight lines, Optimal GEO uses LAStools scripting and visual reviews. LAStools scripting is used to create files similar to DZ orthos for each swath but this process highlights planar surfaces, such as roof tops. Horizontal shifts or misalignments between swaths on roof tops and other elevated planar surfaces are highlighted. Visual reviews of these features, including additional profile verifications, are used to confirm the results of this process. Figure 6 shows an example of the horizontal alignment between swaths for the TX Desert Mountain lidar data.

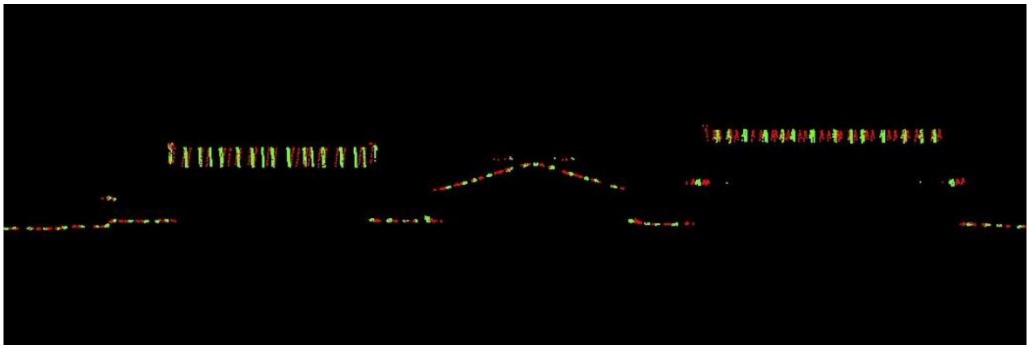


Figure 6. Profile of a lidar point cloud cross section of a buildings. Points are colorized by flight line number.

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.71 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 2 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics, the project area was determined to have an ANPS less than 0.71 meters or an ANPD greater than 2 points per square meter which satisfies the project requirements.

The spatial distribution of points must be uniform and free of clustering. This specification is tested by creating a grid with cell sizes equal to the design NPS*2. LAStools scripting is then used to calculate the number of first return points of each swath within each grid cell. At least 90% of the cells must contain 1 lidar point, excluding acceptable void areas such as water or low NIR reflectivity features, i.e. some asphalt and roof composition materials.

To perform this test, Optimal GEO generated a Spatial Distribution raster grid from first return lidar points. This grid was generated for all tiles that intersect the project area. Optimal GEO did not identify any tiles where less than 90% of the cells did not contain at least one lidar point excluding acceptable void areas. Figure 7 below illustrates spatial distribution below.

Optimal GEO did identify voids in the lidar data that were larger than USGS' tolerance for acceptable data voids as defined in the task order. According to the USGS Lidar Base Specification, data voids are gaps in point cloud coverage greater or equal to $(4*ANPS)^2$ measured using only first returns within a single swath. The voids were identified using a density raster. Each void identified was assessed against the latest imagery in Google Earth. The types of voids found in the dataset occurred from naturally occurring dark surfaces present on piles of tires in the desert, on a football field with black paint that absorbed the laser, on dark tarpaulin sheets that outlined retention ponds, and finally a tall rock formation on a cliff that obscured underlying data. An example of these voids are shown on the pages following in Figures 8, 9, 10, and 11 respectively.

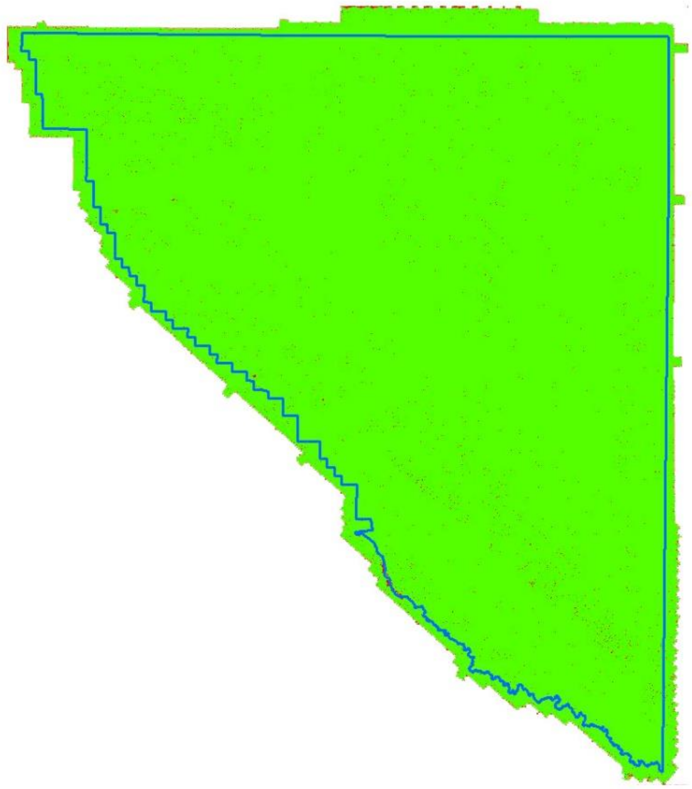


Figure 7. Spatial distribution raster generated from first return lidar pulses of the lidar data. Green pixels are areas with a count of 1 point or greater. Red pixels contain no data. The red areas are attributed to small ponds or variations in aircraft pitch that occurred during the acquisition.

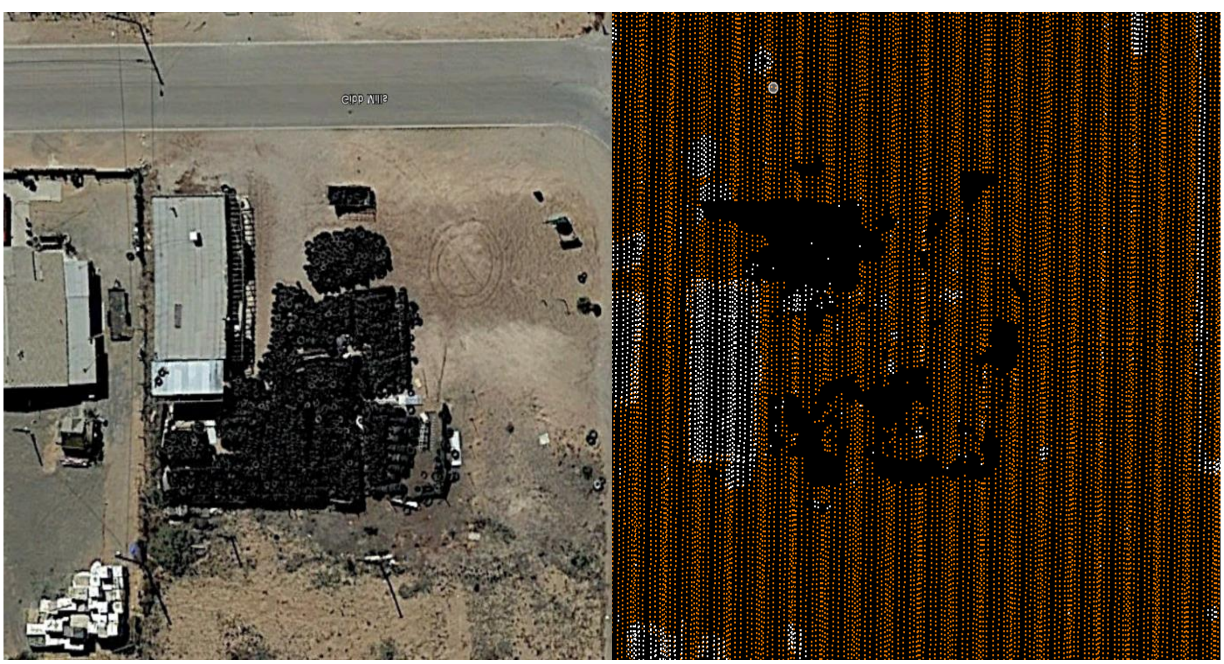


Figure 8. Tire pile voids. The laser was absorbed due to the material and color of the piles.

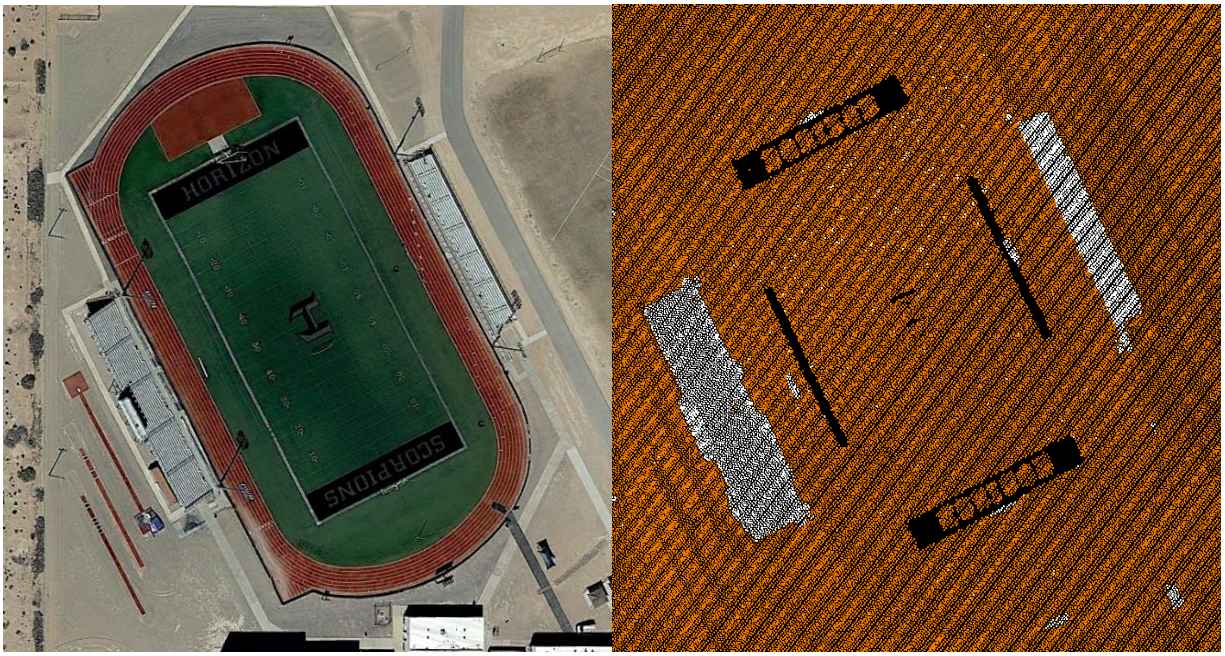


Figure 9. Shows a football field painted black that absorbed the laser returns.

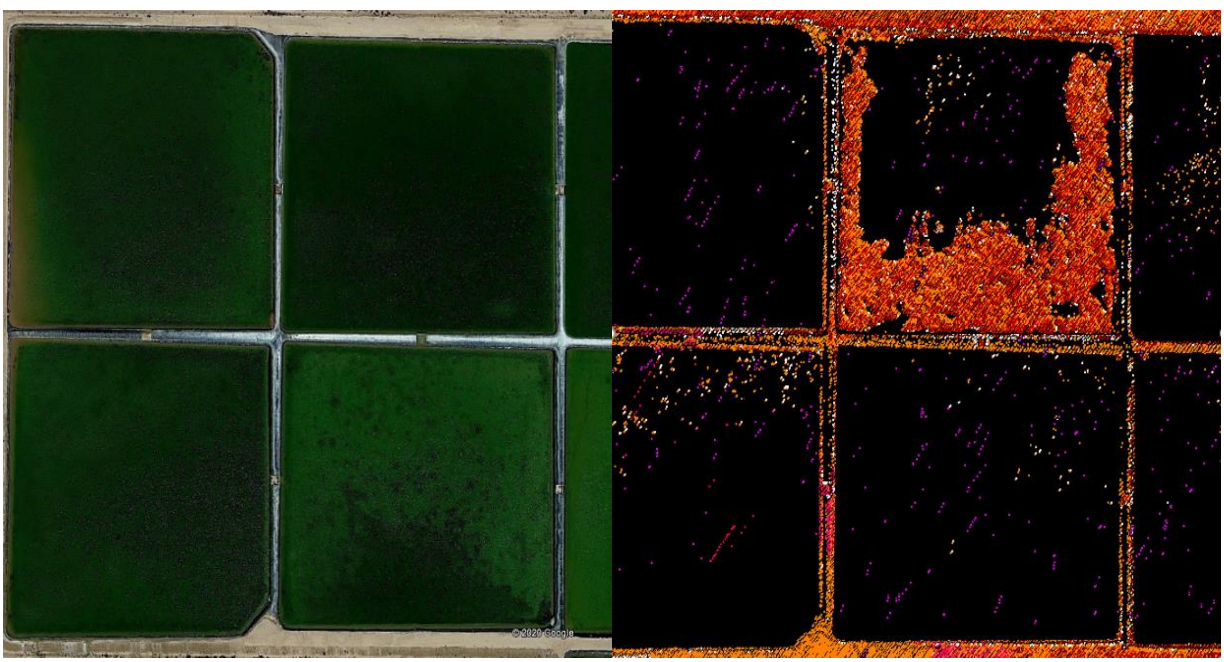


Figure 10. Voids around retention ponds due to laser absorption on the dark surfaces.

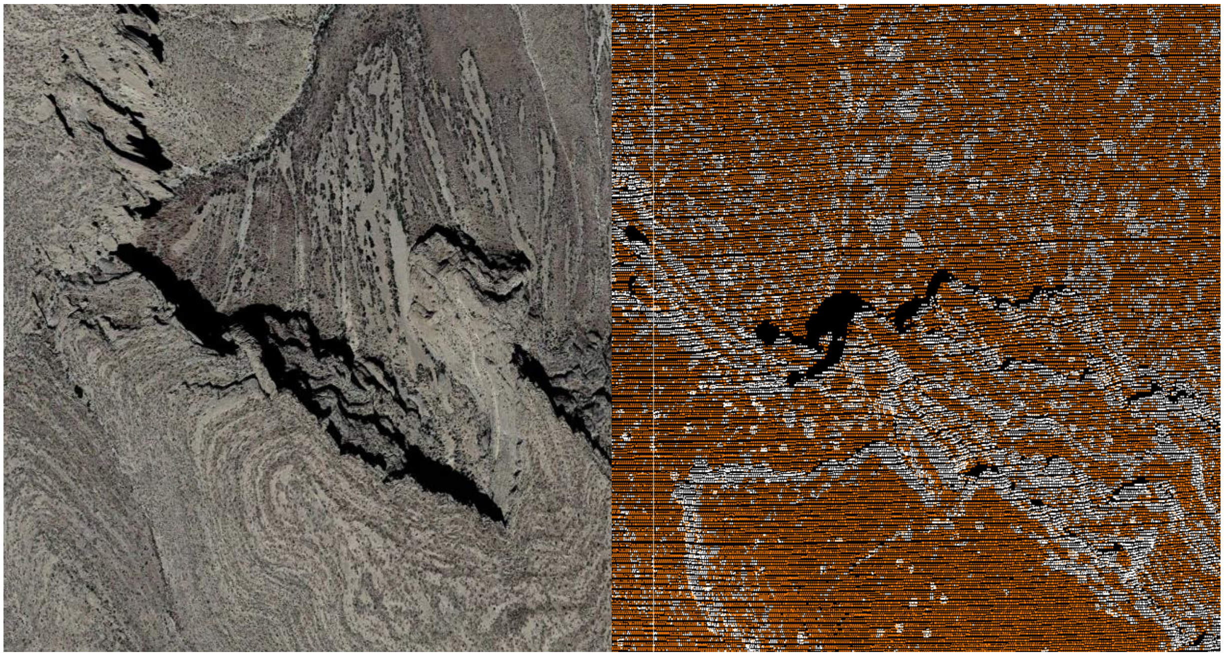


Figure 11. Steep rock formations obscuring underlying ground.

Data Classification and Editing

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data was confirmed, Optimal GEO utilized a variety of software suites for data processing. The data was processed using TerraScan software. The initial step is the setup of the TerraScan project, which is done by importing a project defined tile boundary index encompassing the entire project area. The acquired 3D laser point clouds, in LAS binary format, were imported into the TerraScan project and tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classifies any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. Points along flight line edges that are geometrically unusable are identified as withheld and classified to a separate class so that they will not be used in the initial ground algorithm. After points that could negatively affect the ground are removed from class 1, the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model.

This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated, and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model.

Each tile was then imported into TerraScan and a surface model was created to examine the ground classification. Optimal GEO analysts visually reviewed the ground surface model and corrected errors in the ground classification such as vegetation, buildings, and bridges that were present. Optimal GEO analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points are removed from the ground classification. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilizes breaklines compiled to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water. During this water classification routine, points that are within 1x NPS or less of the hydrographic features are moved to class 20, an ignored ground due to breakline proximity. Overage points are then identified and used in TerraScan to set the overlap bit for the overage points and the withheld bit is set on the withheld points previously identified before the ground classification routine was performed.

The lidar tiles were classified to the following classification schema:

- Class 1 = Unclassified, used for all other features that do not fit into the Classes 2, 7, 9, 17, 18, 20, 21, or 22, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- Class 7 = Low Noise
- Class 9 = Water, points located within collected breaklines
- Class 17 = Bridge Decks
- Class 18 = High Noise
- Class 20 = Ignored Ground due to breakline proximity
- Class 21 = Snow
- Class 22 = Temporal Exclusion

After manual classification, the LAS tiles were peer reviewed and then underwent a final QA/QC. After the final QA/QC and corrections, all headers, appropriate point data records, and variable length records, including spatial reference information, are updated in TerraScan software and then verified using proprietary Optimal GEO tools.

Lidar Qualitative Assessment

Optimal GEO's qualitative assessment utilizes a combination of statistical analysis and interpretative methodology or visualization to assess the quality of the data for a bare-earth digital terrain model (DTM). This includes creating pseudo image products such as lidar orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models as well as reviewing the actual point cloud data. This process looks for anomalies in the data, areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model, and other classification errors. This report will present representative examples where the lidar and post processing had issues as well as examples of where the lidar performed well.

Formatting

After the final QA/QC is performed and all corrections have been applied to the dataset, all lidar files are updated to the final format requirements and the final formatting, header information, point data records, and variable length records are verified using Optimal GEO's proprietary tools. Table 4 lists some of the main lidar header fields that are updated and verified.

Classified Lidar Formatting		
Parameter	**Requirement**	**Pass/Fail**
LAS Version	1.4	Pass
Point Data Format	Format 6	Pass
Coordinate Reference System	NAD83 (2011) Universal Transverse Mercator (UTM) Zone 13 North, meters and NAVD88 (Geoid 12B), meters in WKT Format	Pass
Global Encoder Bit	Should be set to 17 for Adjusted GPS Time	Pass
Time Stamp	Adjusted GPS Time (unique timestamps)	Pass
System ID	Should be set to the processing system/software and is set to TerraScan	Pass
Multiple Returns	The sensor shall be able to collect multiple returns per pulse and the return numbers are recorded	Pass
Intensity	16-bit intensity values are recorded for each pulse	Pass
Classification	Required Classes include: Class 1: Unclassified Class 2: Ground Class 7: Low Noise Class 9: Water Class 17: Bridge Decks Class 18: High Noise Class 20: Ignored Ground Class 21: Snow Class 22: Temporal Exclusion	Pass, class 21 and 22 were not utilized
Overlap and Withheld Points	Overlap (Overage) and Withheld points are set to the Overlap and Withheld bits	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Table 4. Classified Lidar Formatting.

Lidar Positional Accuracy

Background

Optimal GEO quantitatively tested the dataset by testing the vertical accuracy of the lidar. The vertical accuracy is tested by comparing the discreet measurement of the survey checkpoints to that of the interpolated value within the three closest lidar points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the lidar data is actually tested. However, there is an increased level of confidence with lidar data due to the relative accuracy. This relative accuracy in turn is based on how well one lidar point "fits" in comparison to the next contiguous lidar measurement and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy. Typically, ESRI ArcMap is used to test the swath lidar vertical accuracy, TerraScan software to test the classified lidar vertical accuracy, and ESRI ArcMap to test the DEM vertical accuracy so that two different software programs are used to validate the vertical accuracy for each project.

Survey Vertical Accuracy Checkpoints

For the final vertical accuracy assessment, one hundred and twenty-six (126) check points were surveyed for the project and are located within bare earth/open terrain, grass/weeds/crops, and forested/fully grown land cover categories. Please see the included survey report found in the survey folder of the deliverables structure which details and validates how the survey was completed for this project.

Checkpoints were evenly distributed throughout the project area to cover as many flight lines as possible using the “dispersed method” of placement.

Table 5 lists the location of the QA/QC checkpoints used to test the positional accuracy of the dataset.

Table 5. Ground Surveyed Vertical Accuracy Check Points.

Point ID	NAD83(2011), UTM Zone 15N		Elevation (m; NAVD88 Geoid12B
	Easting X (m)	Northing Y (m)	
2001	373424.403	3538502.435	1220.471
2002	386325.645	3536880.481	1241.721
2003	397571.072	3532933.492	1317.310
2004	404091.700	3533675.913	1430.560
2005	414105.663	3539748.565	1632.319
2006	427465.152	3534550.813	1522.262
2007	436169.150	3534711.982	1463.927
2008	443285.714	3533962.512	1511.284
2009	453404.395	3531687.848	1390.539
2010	469455.918	3532831.980	1256.690
2011	477674.988	3533686.404	1153.174
2012	485892.786	3533680.376	1111.583
2013	495891.465	3531959.700	1106.787
2014	494133.898	3528944.272	1102.775
2015	485925.689	3528575.019	1109.287
2016	477676.646	3526864.401	1155.493
2017	467969.378	3526804.729	1252.766

Table 5. Ground Surveyed Vertical Accuracy Check Points continued.

2018	454446.478	3521744.881	1333.447
2019	454477.925	3518974.102	1342.681
2020	436091.218	3526018.698	1425.921
2021	426001.312	3523729.484	1604.260
2022	411718.635	3525705.572	1593.904
2023	408116.228	3523248.992	1579.717
2025	383447.103	3527968.913	1230.276
2027	386427.783	3517091.704	1227.772
2028	396050.580	3516157.437	1248.163
2029	404043.279	3515280.394	1337.859
2030	415869.110	3515931.500	1561.343
2031	425171.619	3519075.458	1582.984
2032	440801.262	3512032.122	1390.730
2033	447569.909	3515019.384	1339.253
2034	457668.174	3515623.058	1322.177
2035	467882.497	3516265.111	1241.913
2036	478195.828	3512394.939	1228.169
2037	489191.351	3512182.942	1140.428
2038	492727.320	3517960.819	1112.799
2039	497037.550	3504594.907	1106.870
2040	500844.716	3497010.149	1104.343
2041	484581.510	3498455.209	1270.296
2042	477493.766	3491875.212	1298.606
2043	481684.320	3502148.621	1227.829
2044	472655.279	3503994.231	1249.592
2045	464812.607	3501981.541	1298.379
2046	456681.910	3507391.191	1325.698
2047	445863.309	3506609.589	1372.040
2048	435823.597	3505301.740	1450.069
2049	426857.524	3506626.139	1516.135
2050	417077.993	3502444.531	1348.390
2051	405222.142	3506254.092	1256.438
2052	397668.060	3505620.416	1236.379
2053	387601.590	3506494.882	1230.091
2054	396036.185	3497576.106	1236.359
2055	405221.068	3497251.466	1232.873
2056	415220.709	3495094.821	1282.236
2057	425002.214	3497524.443	1416.699
2058	449336.319	3497930.582	1383.742
2059	458706.948	3492540.100	1332.149
2060	468139.348	3494040.595	1276.769

Table 5. Ground Surveyed Vertical Accuracy Check Points continued.

2062	483920.321	3484833.404	1348.675
2063	477583.131	3482934.703	1356.885
2064	465188.636	3484571.013	1323.097
2065	453420.037	3483504.384	1441.667
2066	445422.043	3485855.003	1452.239
2067	436371.003	3484187.317	1544.909
2068	424030.108	3482911.930	1294.945
2069	414650.284	3488240.919	1239.266
2071	398012.845	3485499.719	1195.698
2072	409918.460	3477544.807	1187.994
2073	415336.544	3474855.911	1177.611
2075	434320.959	3474453.098	1305.956
2076	447830.313	3474709.542	1499.949
2077	458689.601	3475712.936	1399.514
2079	477955.490	3474378.704	1377.488
2080	490464.643	3476887.242	1448.273
2121	440003.713	3494021.712	1511.978
3001	373395.413	3538462.006	1221.140
3002	389813.601	3534461.838	1240.848
3003	400295.948	3531997.159	1355.918
3004	414318.751	3540102.751	1622.740
3006	439772.825	3532269.809	1465.585
3007	448453.185	3533789.807	1457.024
3008	467790.001	3532320.588	1245.032
3009	478595.839	3533696.941	1145.667
3010	492259.795	3531970.773	1107.357
3011	499406.471	3532003.053	1110.658
3012	496694.465	3525928.366	1105.577
3013	498000.927	3506500.927	1102.823
3014	488749.505	3519771.276	1113.362
3015	480919.795	3525210.603	1130.748
3016	464560.339	3519750.963	1264.290
3017	457037.086	3515757.641	1318.047
3018	438928.746	3519967.768	1417.283
3019	427540.184	3523042.272	1561.731
3020	413245.566	3521646.646	1562.362
3021	399302.448	3519160.567	1273.842
3022	392855.639	3521517.719	1243.045
3023	377485.044	3524641.057	1213.305
3024	388783.037	3506292.471	1225.043
3025	405205.754	3506143.476	1255.668

Table 5. Ground Surveyed Vertical Accuracy Check Points continued.

3026	417410.576	3503610.296	1358.758
3027	422884.014	3508998.222	1445.772
3028	440828.157	3512380.789	1382.356
3029	454431.617	3508292.679	1331.027
3031	479454.602	3512384.717	1226.846
3032	493737.431	3511550.377	1118.247
3033	497875.346	3498035.564	1114.779
3034	484761.275	3496651.450	1295.249
3035	476104.501	3495722.072	1267.235
3036	464832.565	3497082.824	1279.338
3037	453958.115	3499020.667	1342.611
3038	434576.605	3499011.044	1505.535
3039	426406.821	3502720.757	1450.542
3040	413662.440	3493834.136	1265.848
3041	407751.513	3497316.817	1244.162
3042	391237.732	3498306.610	1212.459
3044	419982.409	3486339.628	1267.510
3045	429024.678	3482263.255	1313.284
3046	438617.984	3486711.044	1528.001
3047	454011.080	3485974.900	1455.253
3048	466687.397	3480378.207	1329.228
3049	474629.957	3488595.799	1314.159
3050	484249.996	3485625.566	1351.512
3052	498036.594	3473527.253	1607.783
3057	436060.493	3474508.612	1320.909
3058	429565.225	3474739.899	1264.242
3059	416527.331	3474810.666	1177.864

Vertical Accuracy Test Procedures

Non-vegetated Vertical Accuracy

NVA (Non-vegetated Vertical Accuracy) is determined with check points located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) and urban areas, where there is a very high probability that the lidar sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The NVA determines how well the calibrated lidar sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error (RMSEz) of the checkpoints x 1.9600. For the TX Desert Mountain Lidar Project, vertical accuracy must be 19.6 cm or less based on an RMSEz of 10 cm x 1.9600.

Vegetated Vertical Accuracy

VVA (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95^{th} percentile error for all checkpoints in all vegetated land cover categories combined. Desert Mountain's QL2 lidar project VVA standard is 30 cm based on the 95^{th} percentile. Here, $Accuracy_z$ differs from VVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas VVA assumes lidar errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid. The relevant testing criteria are summarized in Table 6.

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using $RMSE_z$ *1.9600	19.6 cm (based on $RMSE_z$ (10 cm) * 1.9600)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined at the 95% confidence level	30 cm (based on 95^{th} percentile)

Table 6. Acceptance Criteria

The primary QA/QC vertical accuracy testing steps used by Optimal GEO are summarized as follows:

1. The ground team surveyed QA/QC vertical checkpoints in accordance with the project's specifications.
2. Next, Optimal GEO interpolated the bare-earth lidar DTM to provide the z-value for every checkpoint.
3. Optimal GEO then computed the associated z-value differences between the interpolated z-value from the lidar data and the ground truth survey checkpoints and computed NVA, VVA, and other statistics.
4. The data were analyzed by Optimal GEO to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by the scope of work. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. This report provides tables, graphs and figures to summarize and illustrate data quality.

Vertical Accuracy Results

Table 7 summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the fully classified lidar LAS files.

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm NVA
NVA	75	11.6 cm	
VVA	51		23.1 cm

Table 7. Tested NVA and VVA

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =5.9 cm, equating to ± 11.6 cm at 95% confidence level. Actual VVA accuracy was found to be ± 23.1 cm at the 95th Percentile.

Table 8 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) @95% CL	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)
NVA	75	0.116	-0.013	-0.007	-0.305	0.058	-0.141	0.097
VVA	51	N/A	0.041	0.037	0.205	0.100	-0.257	0.315

Table 8. Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Optimal GEO, the lidar dataset for the TX Desert Mountains QL2 Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

Breakline Production & Qualitative Assessment Report

Breakline Production Methodology

Optimal GEO digitized the project's hydrographic breaklines from the lidar utilizing the TIN and intensity for visualization and placement. This technique enables Optimal GEO to produce accurate 3D hydrographic breaklines for features that are consistent with the lidar data at the time of airborne survey. All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are at a constant elevation where the water body has been captured at the lowest elevation. Bridge deck breaklines are compiled directly from the project's DEMs. Bridge Breaklines are used where necessary to enforce the terrain beneath bridge decks and to prevent bridge saddles in the bare earth DEMs. All features were compiled in accordance with the project's Data Dictionary.

Breakline Qualitative Assessment

Completeness and horizontal placement are verified through visual reviews against lidar intensity imagery. Automated checks are applied on all breakline features to validate topology, including the 3D connectivity of features, enforced monotonicity on linear hydrographic breaklines, and flatness on water bodies. After all corrections and edits to the breakline features, the breaklines are imported into the final GDB and verified for correct formatting.

Breakline Data Dictionary

The following data dictionary was used for this project.

Horizontal and Vertical Datum

The horizontal datum shall be North American Datum of 1983, 2011 adjustment (NAD83 2011), Units in Meters. The vertical datum shall be referenced to the North American Vertical Datum of 1988, Units in Meters. Geoid12B shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to Universal Transverse Mercator (UTM) Zone 13 North, Horizontal Units in Meters and Vertical Units in Meters.

Inland Streams and Rivers

Feature Class: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will depict linear hydrographic features with a width greater than 100 feet.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Streams and Rivers	Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 100 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project.	Capture features showing dual line (one on each side of the feature). Average width shall be greater than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity. Generally, both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present. The banks of the stream must be captured at the same elevation to ensure flatness of the water feature. If the elevation of the banks appears to be different see the task manager or PM for further guidance. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Every effort should be made to avoid breaking a stream or river into segments. Dual line features shall break at road crossings (culverts). In areas where a bridge is present the dual line feature shall continue through the bridge. Islands: The double line stream shall be captured around an island if the island is greater than 1 acre. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature.

Inland Ponds and Lakes

Feature Class: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will depict closed water body features that are at a constant elevation.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Ponds and Lakes	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features 2 acres in size or greater. “Donuts” will exist where there are islands within a closed water body feature.	Water bodies shall be captured as closed polygons with the water feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. An Island within a Closed Water Body Feature that is 1 acre in size or greater will also have a “donut polygon” compiled. These instructions are only for docks or piers that follow the coastline or water’s edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water’s edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

DEM Production & Qualitative Assessment

DEM Production Methodology

Optimal GEO generates a project wide DEM using ESRI ArcGIS software. Once the DEM is created, it is reviewed in ArcGIS for any issues requiring corrections, including remaining lidar misclassifications, erroneous breakline elevations, poor hydro-flattening or hydro-enforcement, and processing artifacts. After corrections are applied, the DEM is then split into individual tiles in accordance with the project tiling scheme. The tiles are verified for final formatting and then loaded into Global Mapper to ensure no missing or corrupt tiles and to ensure seamlessness across tile boundaries.

DEM Qualitative Assessment

Optimal GEO performed a comprehensive qualitative assessment of the bare earth DEM deliverables to ensure that all tiled DEM products were delivered with the proper extents, were free of processing artifacts, and contained the proper referencing information. This process was performed in ArcGIS software with the use of a tool set Optimal GEO has developed to verify that the raster extents match those of the tile grid and contain the correct projection information. The DEM data was reviewed at a scale of 1:5000 to review for artifacts caused by the DEM generation process and to review the hydro-flattened features. To perform this review Optimal GEO creates hillshade models and overlays a partially transparent colorized elevation model to review for these issues. All corrections are completed using Optimal GEO’s proprietary correction workflow. Upon completion of the corrections, the DEM data is loaded into Global Mapper for its second review and to verify corrections. Once the DEMs are tiled out, the final tiles are again loaded into Global Mapper to ensure coverage, extents, and that the final tiles are seamless.

DEM Vertical Accuracy Results

One hundred and twenty-six (126) checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products. Accuracy results may vary between the source lidar and final DEM deliverable. DEMs are created by averaging several lidar points within each pixel which may result in slightly different elevation values at each survey checkpoint when compared to the source LAS, which does not average several lidar points together but may interpolate (linearly) between three points to derive an elevation value. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations. Optimal GEO typically uses TerraScan software to test the swath lidar vertical accuracy, to test the classified lidar vertical accuracy, and ESRI ArcMap to test the DEM vertical accuracy so that two different software programs are used to validate the vertical accuracy for each project.

Table 10 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=30 cm
NVA	75	13.3 cm	
VVA	51		22.5 cm

Table 10. DEM tested NVA and VVA

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =6.8 cm, equating to +/- 13.3 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 22.5 cm at the 95th percentile.

Table 11 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) @95% CL	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)
NVA	75	0.133	-0.017	-0.006	-0.962	0.066	-0.271	0.087
VVA	51	N/A	0.045	0.026	0.685	0.106	-0.257	0.400

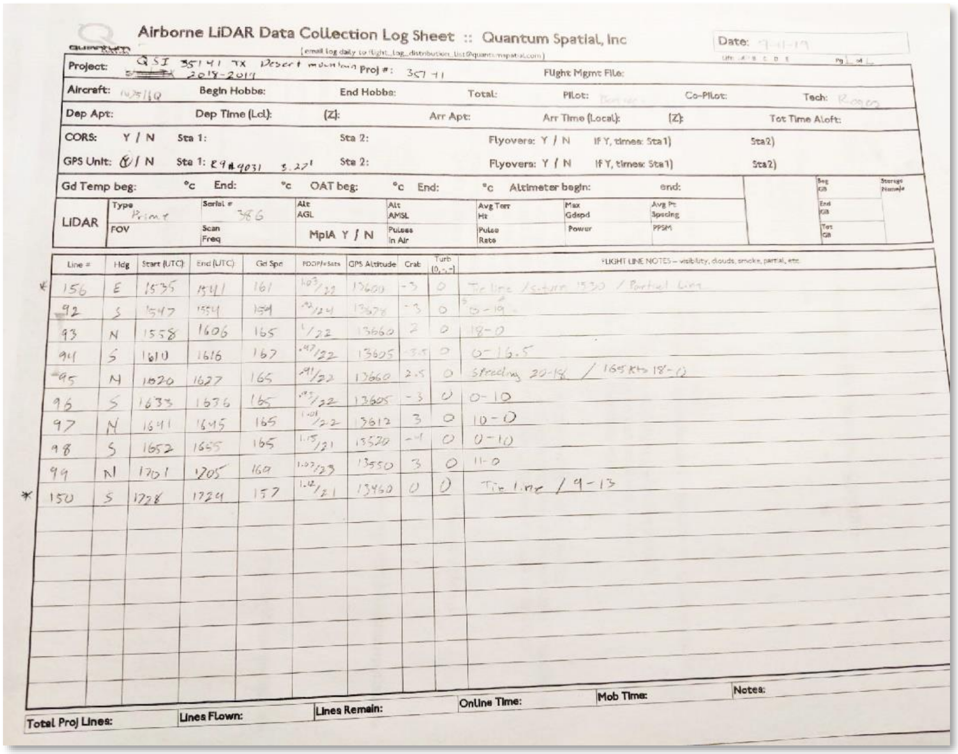
Table 11. Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Optimal GEO, the DEM dataset for the TX Desert Mountains QL2 Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

Appendix A: Flightlogs, IMU, and GPS Processing Reports

Mission 1 (20190911A)

Flight Log



Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

Date:

Project: QSI 35141 TX Desert mountains 2018-2019 | Proj #: 35141 | Flight Mgmt File:

Aircraft: | Begin Hobbs: | End Hobbs: | Total: | Pilot: | Co-Pilot: | Tech:

Dep Apt: | Dep Time (Lcl): | (Z): | Arr Apt: | Arr Time (Local): | (Z): | Tot Time Aloft:

CORS: Y / N | Sta 1: | Sta 2: | Flyovers: Y / N | If Y, times: Sta1) | Sta2)

GPS Unit: Y / N | Sta 1: E9 #9031 5.271 | Sta 2: | Flyovers: Y / N | If Y, times: Sta1) | Sta2)

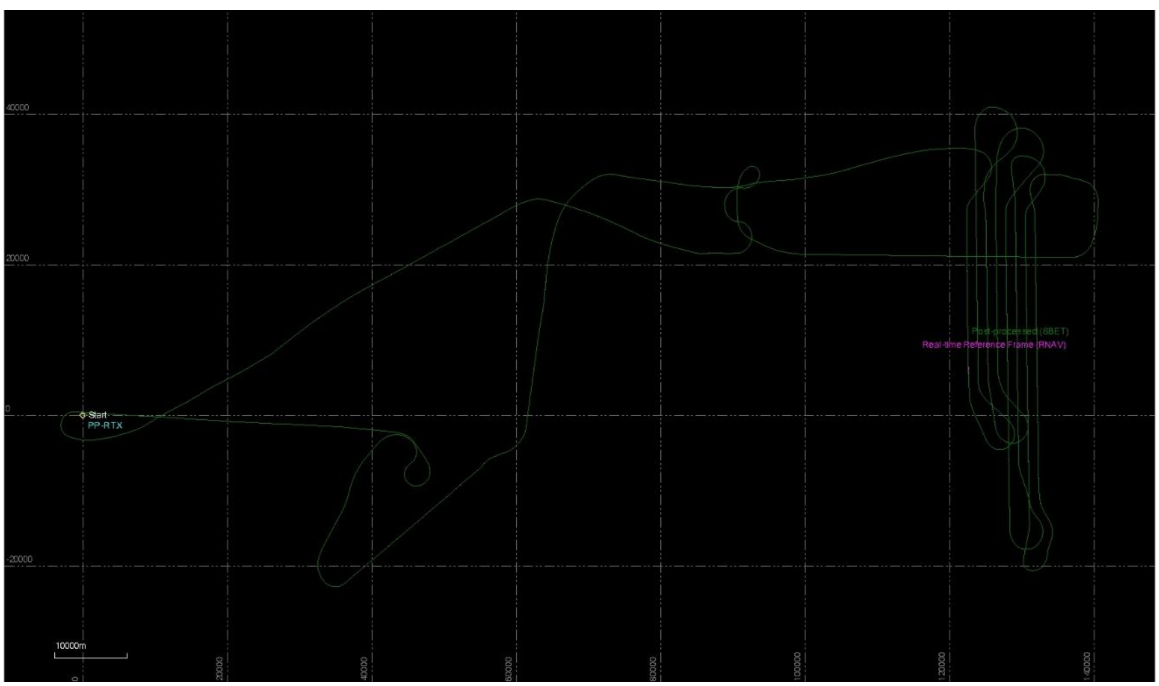
Gd Temp beg: °c | End: °c | OAT beg: °c | End: °c | Altimeter begin: | end:

LIDAR | Type: Prime | Serial #: 386 | Alt AGL | Alt AMSL | Avg Terr Ht | Max Gdspd | Avg Pt Spacing | FOV | Scan Freq | MpiA Y / N | Pulses in Air | Pulse Rate | Power | PPSM

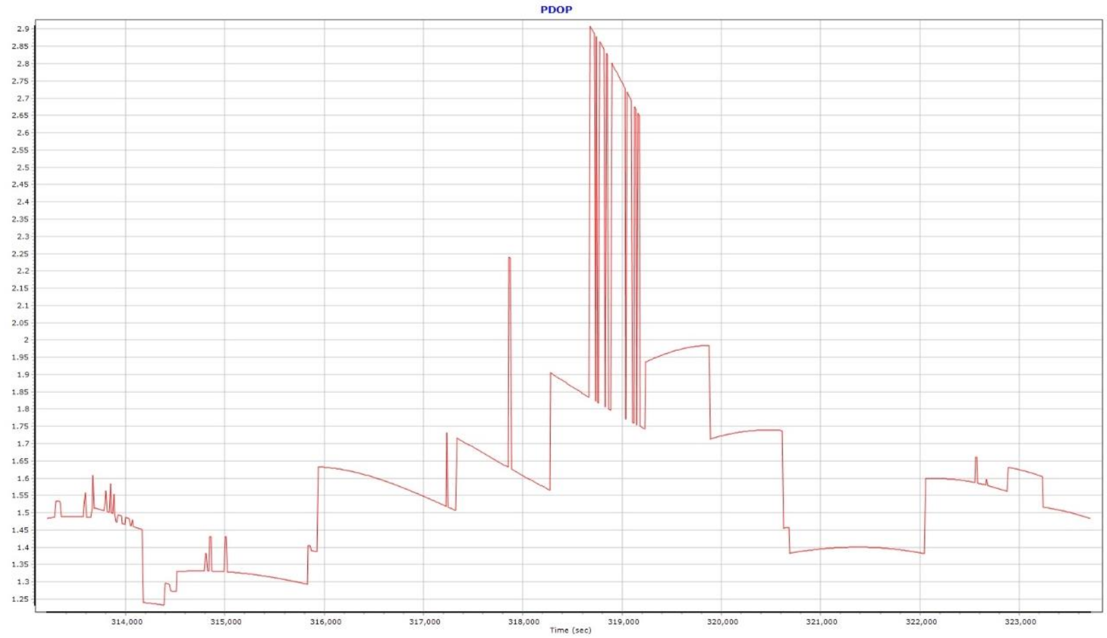
Line #	Hdg	Start (UTC)	End (UTC)	Gd Spd	PDOP/#Sats	GPS Altitude	Crab	Turb (0,-,+)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
* 156	E	1535	1541	161	1.03/22	13600	-3	0	Tie line / return 1530 / Partial Line
92	S	1547	1554	159	.92/24	13678	-3	0	5-19
93	N	1558	1606	165	1/22	13660	2	0	18-0
94	S	1610	1616	167	.97/22	13605	-3.5	0	0-16.5
95	N	1620	1627	165	.91/22	13660	2.5	0	Speeding 20-18 / 165 Kts 18-0
96	S	1633	1636	165	.95/22	13605	-3	0	0-10
97	N	1641	1645	165	1.01/22	13612	3	0	10-0
98	S	1652	1655	165	1.15/21	13520	-4	0	0-10
99	N	1701	1705	169	1.07/23	13550	3	0	11-0
* 150	S	1728	1729	157	1.12/21	13460	0	0	Tie line / 9-13

Total Proj Lines: | Lines Flown: | Lines Remain: | Online Time: | Mob Time: | Notes:

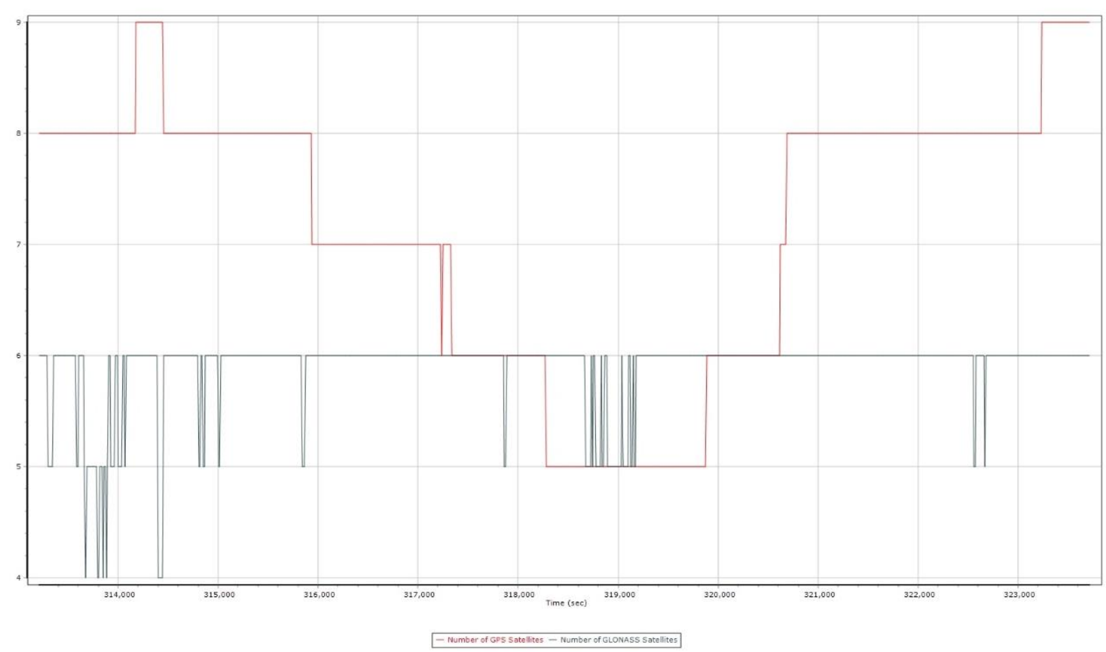
Mission Trajectory



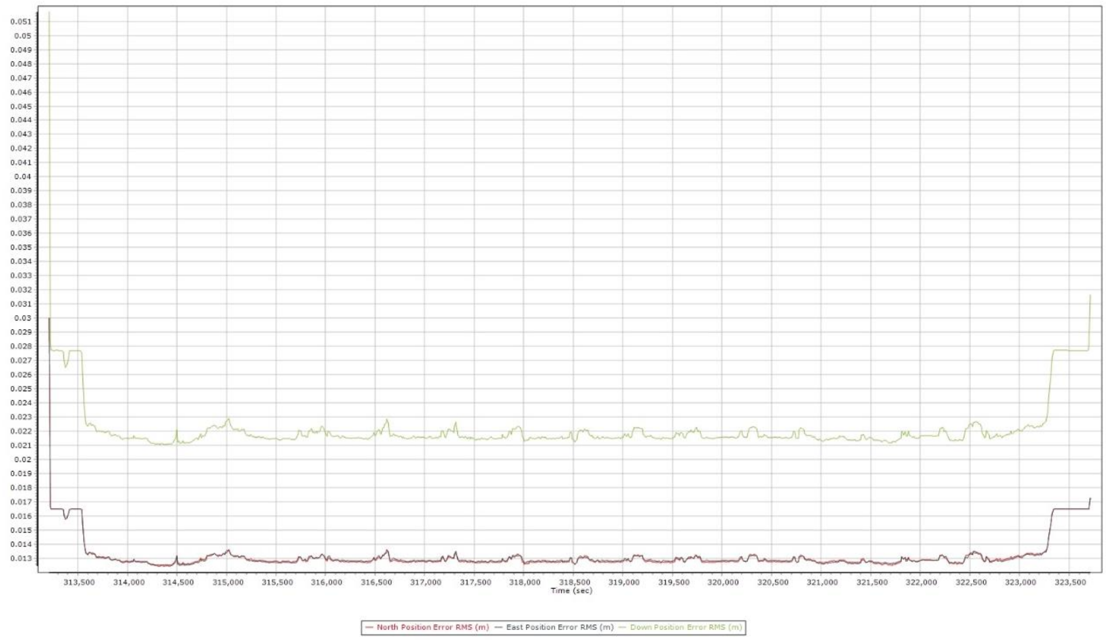
PDOP



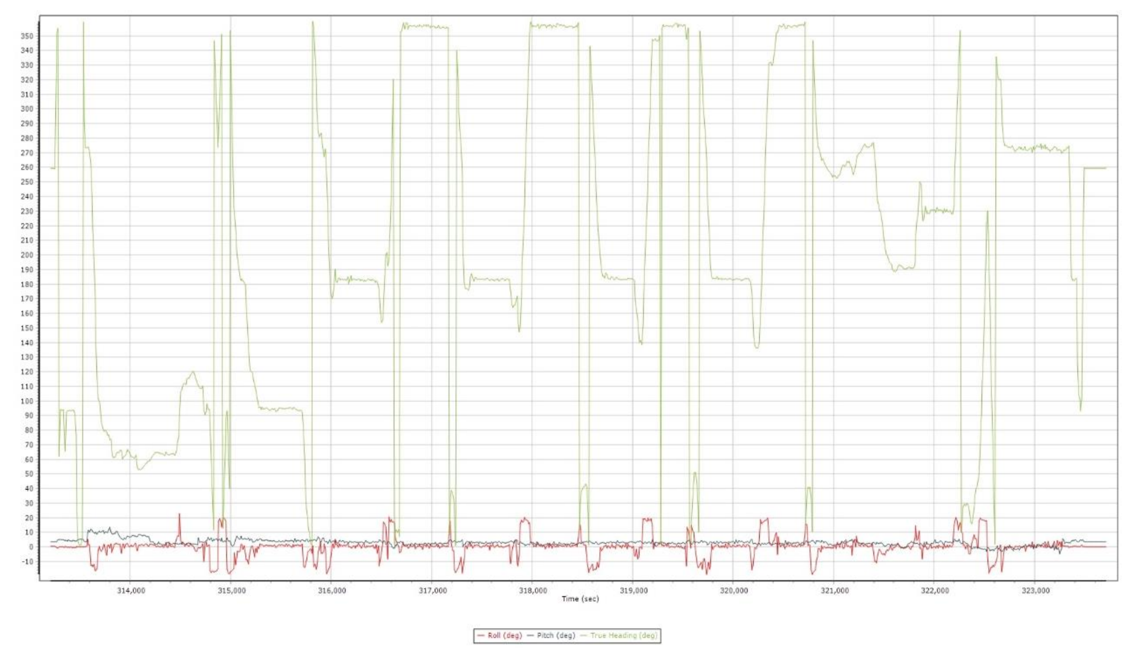
Satellites



RMS (m)

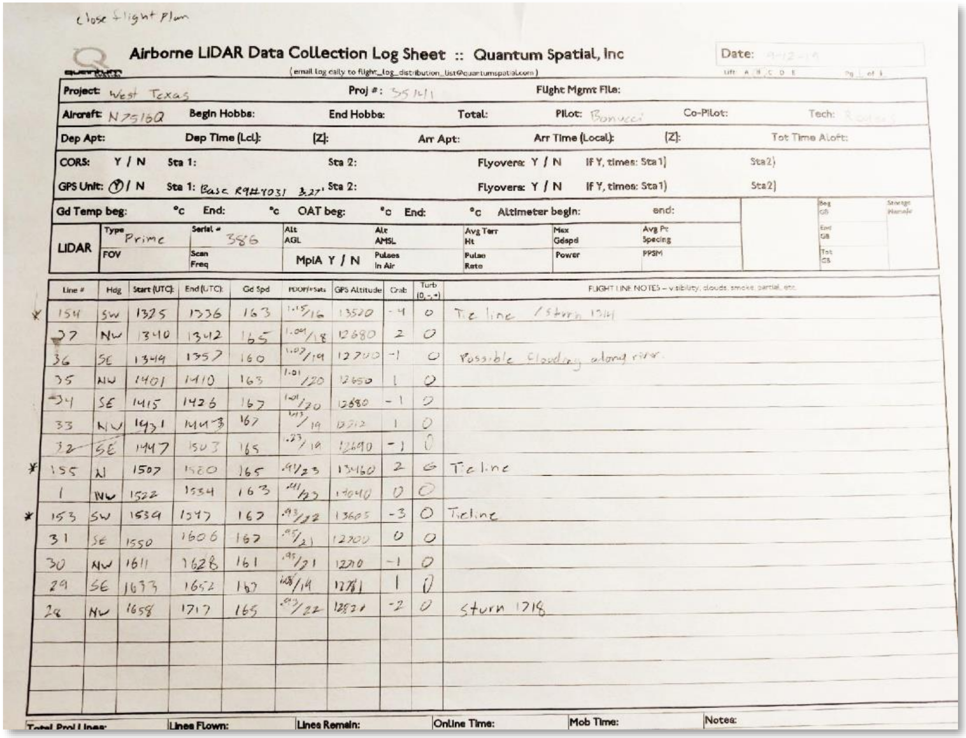

Time (sec)
North Position Error RMS (m) — East Position Error RMS (m) — Down Position Error RMS (m)

RPH (deg)


Time (sec)
Roll (deg) — Pitch (deg) — True Heading (deg)

Mission 2 (20190912B)

Flight Log



Close flight plan

Airborne LIDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 9-12-19

Project: West Texas | Proj #: 55141 | Flight Mgmt File:

Aircraft: N7516Q | Begin Hobbs: | End Hobbs: | Total: | Pilot: Bonucci | Co-Pilot: | Tech: [illegible]

Dep Apt: | Dep Time (Lcl): | (Z): | Arr Apt: | Arr Time (Local): | (Z): | Tot Time Aloft:

CORS: Y / N | Sta 1: | Sta 2: | Flyovers: Y / N | If Y, times: Sta1) | Sta2)

GPS Unit: (Y) / N | Sta 1: Base R9#4031 3.27' | Sta 2: | Flyovers: Y / N | If Y, times: Sta1) | Sta2)

Gd Temp beg: °c | End: °c | OAT beg: °c | End: °c | Altimeter begin: | end:

LIDAR | Type: Prime | Serial #: 386 | Alt AGL: | Alt AMSL: | Avg Terr Ht: | Max Gdspd: | Avg Pt Spacing:

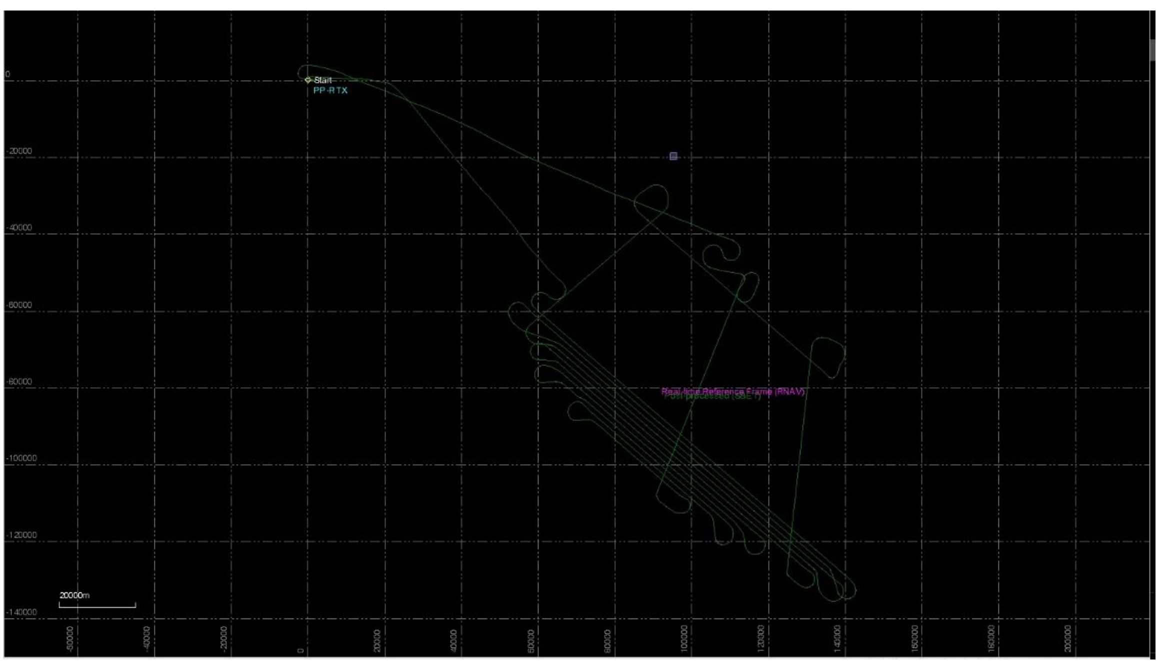
FOV: | Scan Freq: | MpIA Y / N | Pulses in Air: | Pulse Rate: | Power: | PPSM:

Beg GB: | End GB: | Tot GB: | Storage Name:

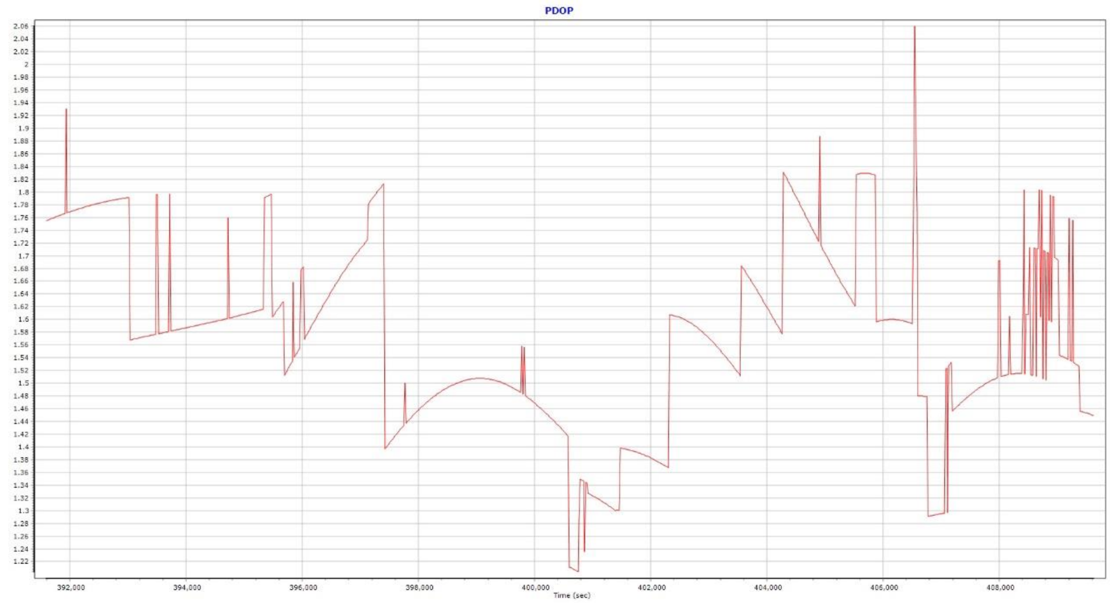
	Line #	Hdg	Start (UTC)	End (UTC)	Gd Spd	PDOP/#sats	GPS Altitude	Crab	Turb (0, -, +)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
*	154	SW	1325	1336	163	1.15/16	13520	-4	0	Tie line / Sturn 1314
	37	NW	1340	1342	165	1.04/18	12680	2	0	
	36	SE	1349	1357	160	1.07/19	12700	-1	0	Possible flooding along river.
	35	NW	1401	1410	163	1.01/20	12650	1	0	
	34	SE	1415	1426	167	1.01/20	12680	-1	0	
	33	NW	1431	1443	167	1.13/19	12712	1	0	
	32	SE	1447	1503	165	1.23/19	12690	-1	0	
*	155	N	1507	1520	165	.91/23	13460	2	0	Tieline
	1	NW	1522	1534	163	.41/23	14040	0	0	
*	153	SW	1539	1547	162	.93/22	13605	-3	0	Tieline
	31	SE	1550	1606	162	.95/21	12700	0	0	
	30	NW	1611	1628	161	.95/21	12710	-1	0	
	29	SE	1633	1652	162	1.08/14	12781	1	0	
	28	NW	1658	1717	165	.93/22	12821	-2	0	Sturn 1718

Total Proj Lines: | Lines Flown: | Lines Remain: | Online Time: | Mob Time: | Notes:

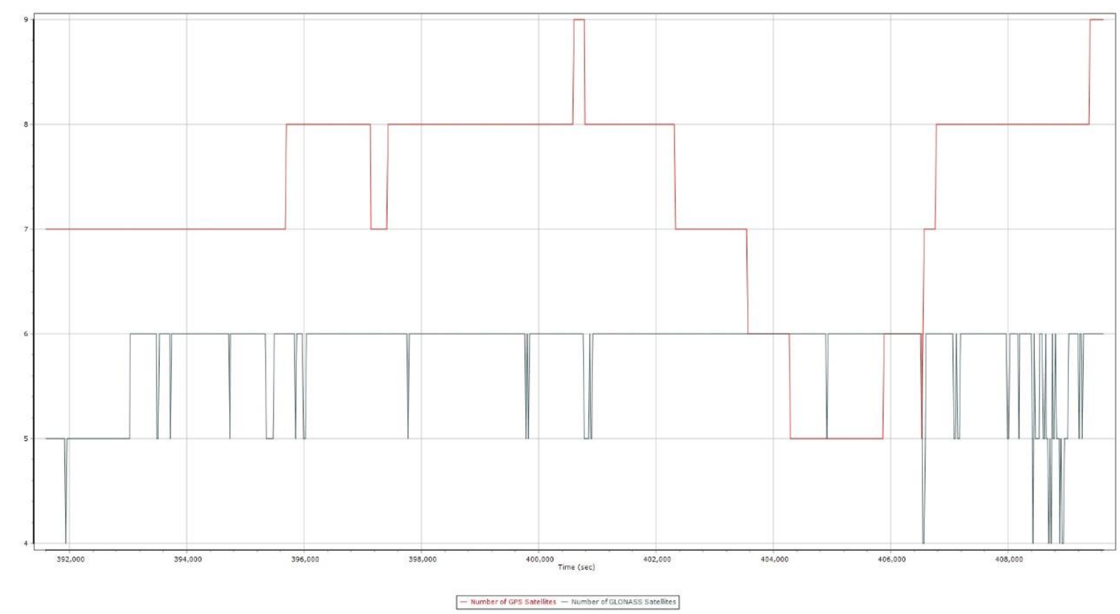
Mission Trajectory



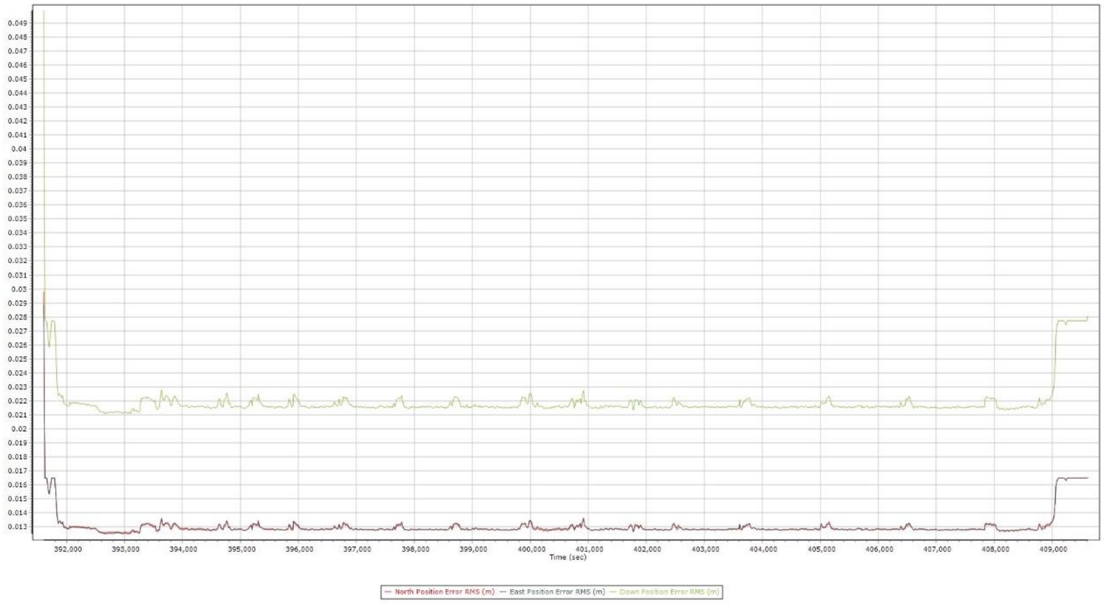
PDOP



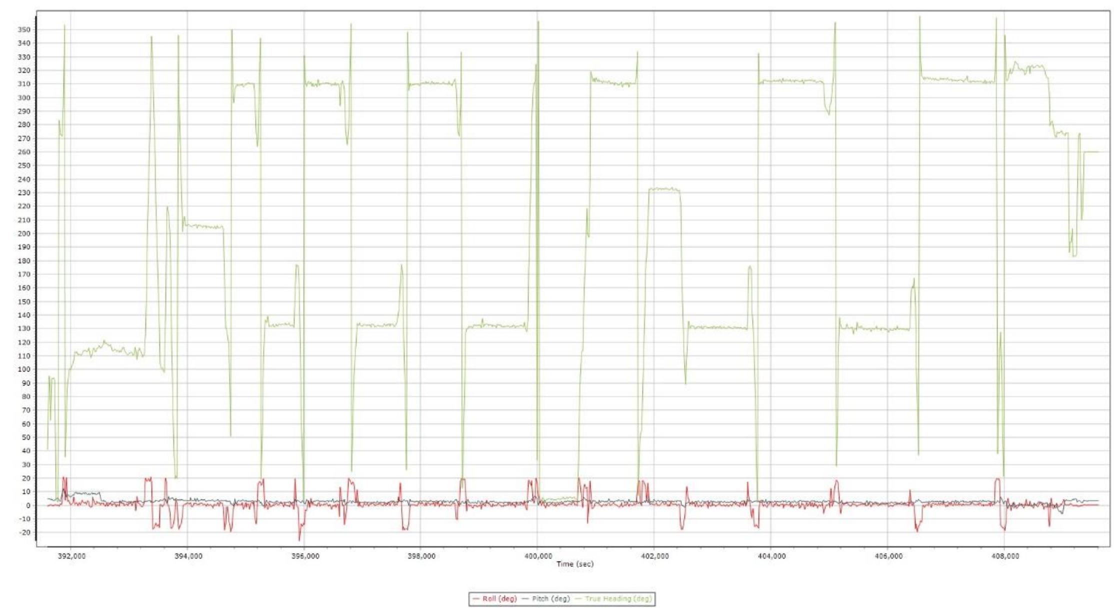
Satellites



RMS (m)

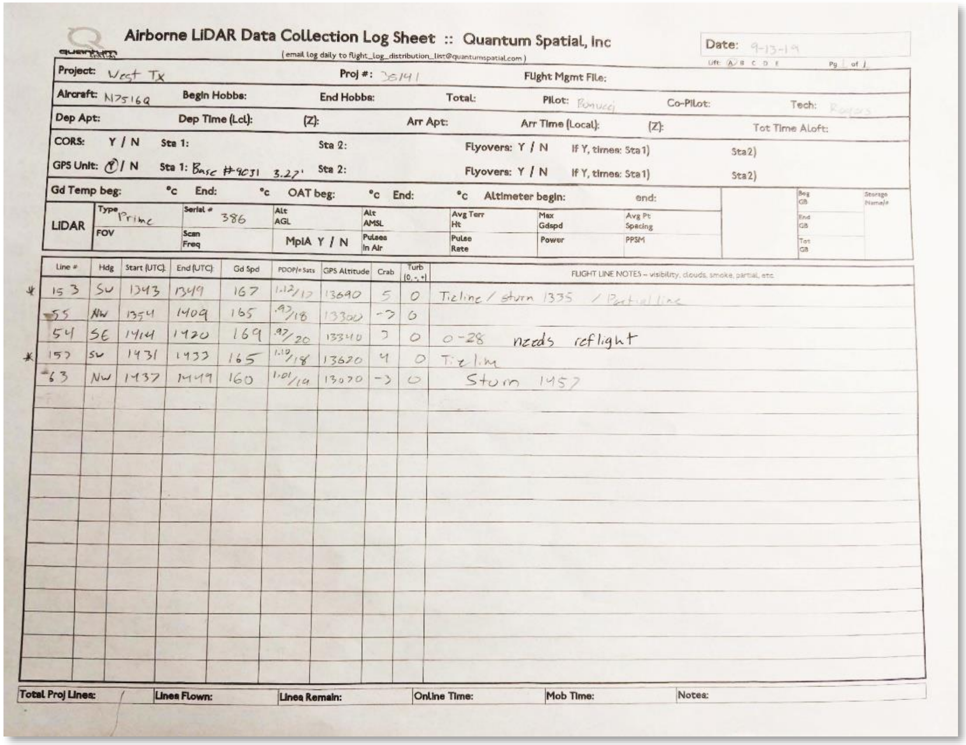

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 3 (20190913A)

Flight Log



Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc
(email log daily to flight_log_distribution_list@quantumspatial.com)

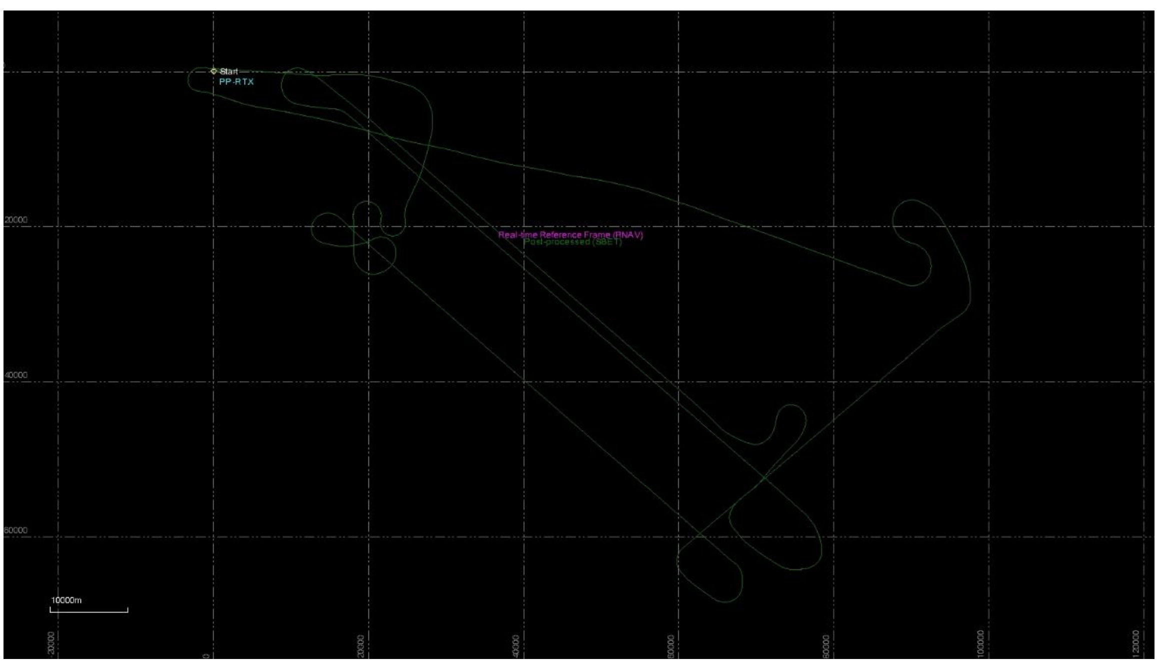
Date: 9-13-19

Project: West Tx | Proj #: 35141 | Flight Mgmt File:
Aircraft: N7516Q | Begin Hobbs: | End Hobbs: | Total: | Pilot: Bonucci | Co-Pilot: | Tech: Rogers
Dep Apt: | Dep Time (Lcl): | (Z): | Arr Apt: | Arr Time (Local): | (Z): | Tot Time Aloft:
CORS: Y / N | Sta 1: | Sta 2: | Flyovers: Y / N | If Y, times: Sta 1) | Sta 2)
GPS Unit: (Y) / N | Sta 1: Base #9031 3.27' | Sta 2: | Flyovers: Y / N | If Y, times: Sta 1) | Sta 2)
Gd Temp beg: °c | End: °c | OAT beg: °c | End: °c | Altimeter begin: | end:
LIDAR: Type Prime | Serial # 386 | Alt AGL | Alt AMSL | Avg Terr Ht | Max Gdspd | Avg Pt Spacing
FOV | Scan Freq | MpIA Y / N | Pulses In Air | Pulse Rate | Power | PPSM

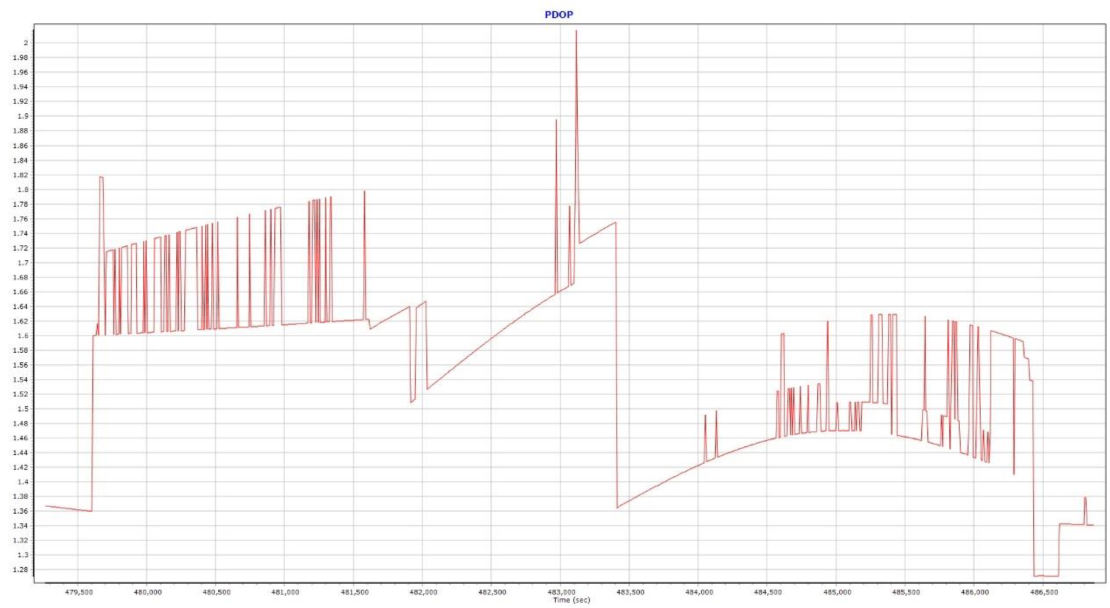
	Line #	Hdg	Start (UTC)	End (UTC)	Gd Spd	PDOP/# Sats	GPS Altitude	Crab	Turb (0, -, +)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
*	153	SW	1343	1349	167	1.12/17	13690	5	0	Tieline / sturn 1335 / Partial line
	55	NW	1354	1409	165	.93/18	13300	-7	0	
	54	SE	1414	1420	169	.97/20	13340	7	0	0-28 needs reflight
*	157	SW	1431	1433	165	1.10/18	13620	4	0	Tie line
	63	NW	1437	1449	160	1.01/14	13070	-3	0	Sturn 1457

Total Proj Lines: | Lines Flown: | Lines Remain: | Online Time: | Mob Time: | Notes:

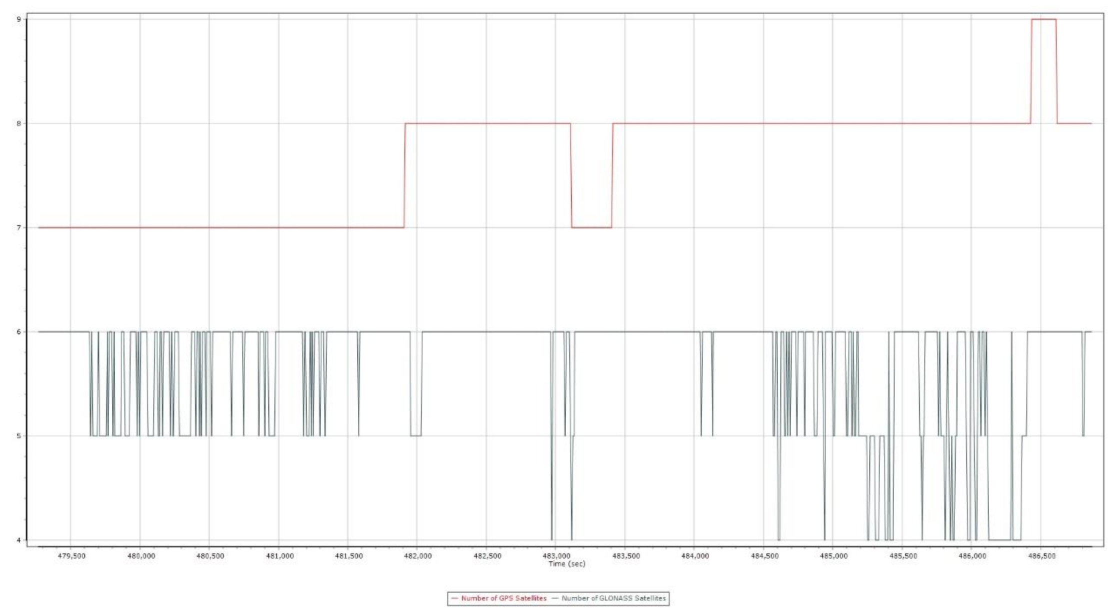
Mission Trajectory



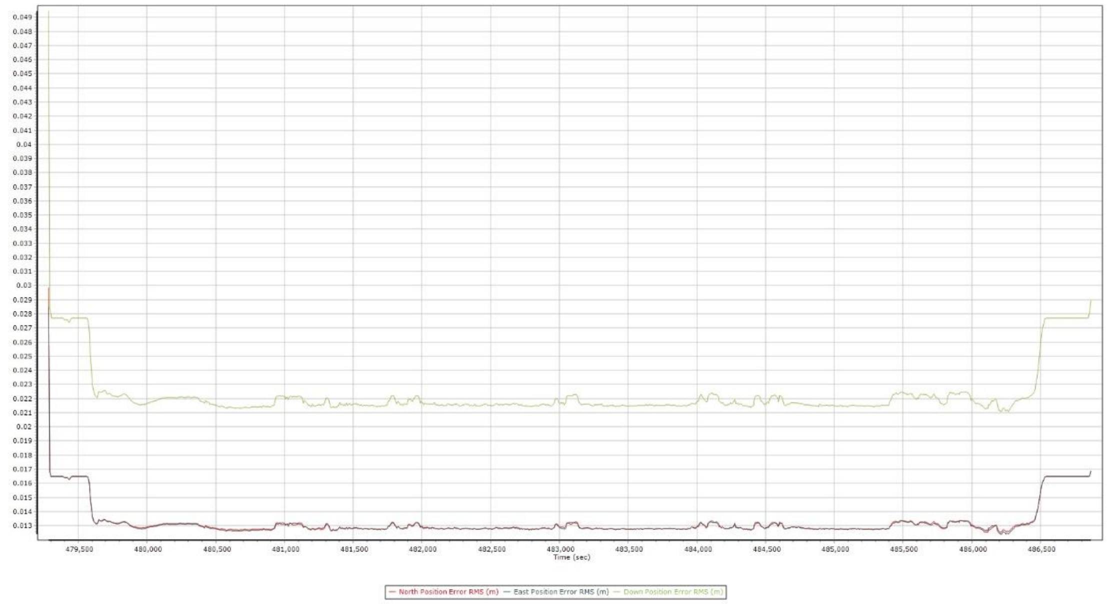
PDOP



Satellites

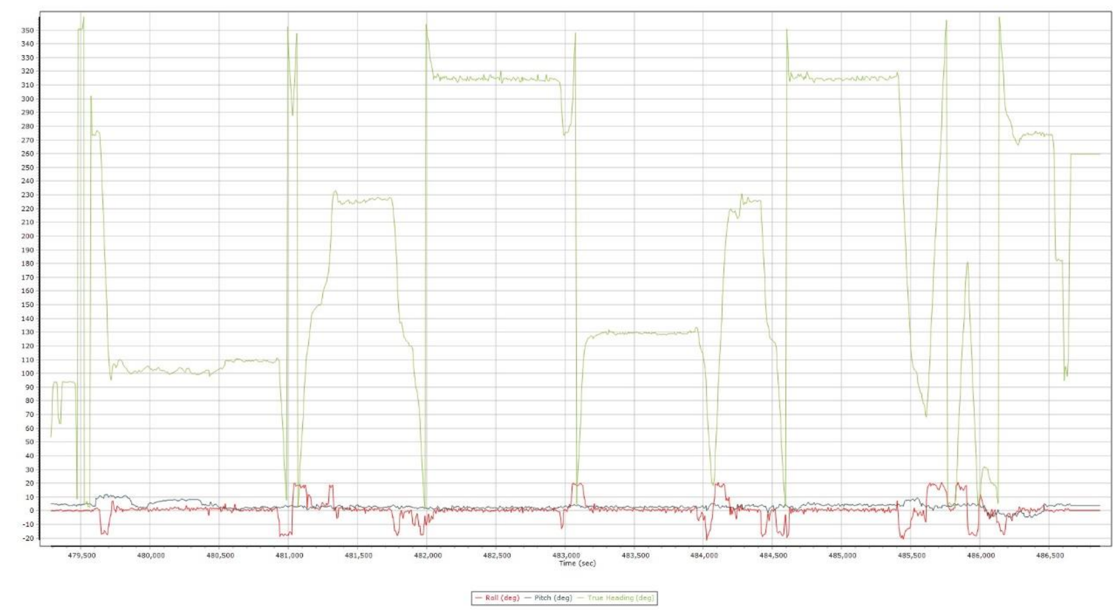


RMS (m)



0.049
0.048
0.047
0.046
0.045
0.044
0.043
0.042
0.041
0.04
0.039
0.038
0.037
0.036
0.035
0.034
0.033
0.032
0.031
0.03
0.029
0.028
0.027
0.026
0.025
0.024
0.023
0.022
0.021
0.02
0.019
0.018
0.017
0.016
0.015
0.014
0.013
479,500
480,000
480,500
481,000
481,500
482,000
482,500
483,000
483,500
484,000
484,500
485,000
485,500
486,000
486,500
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

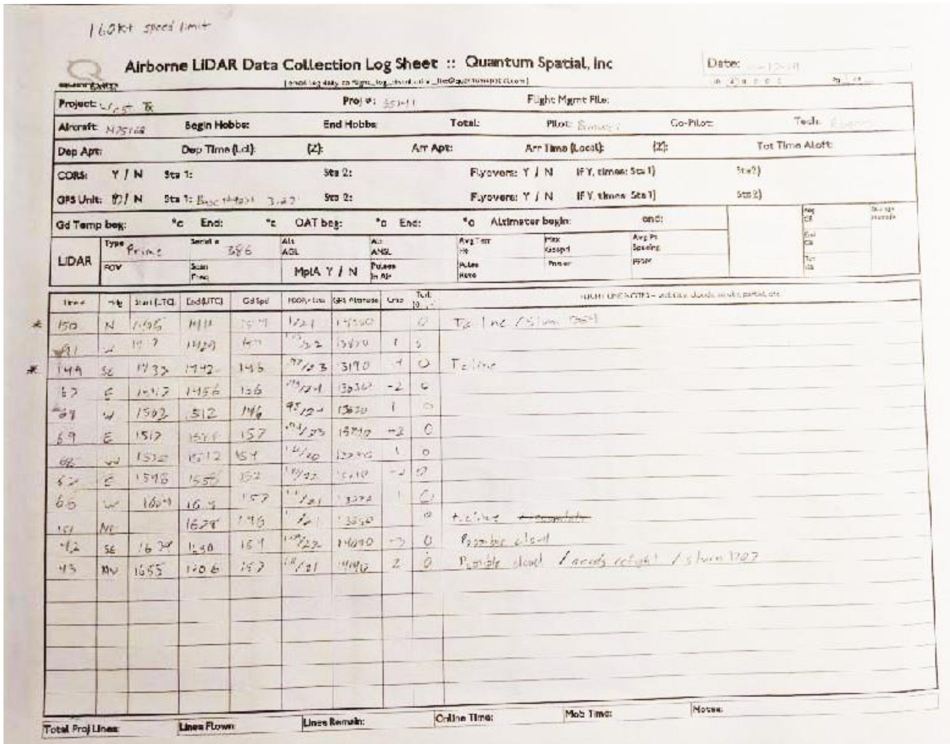
RPH (deg)



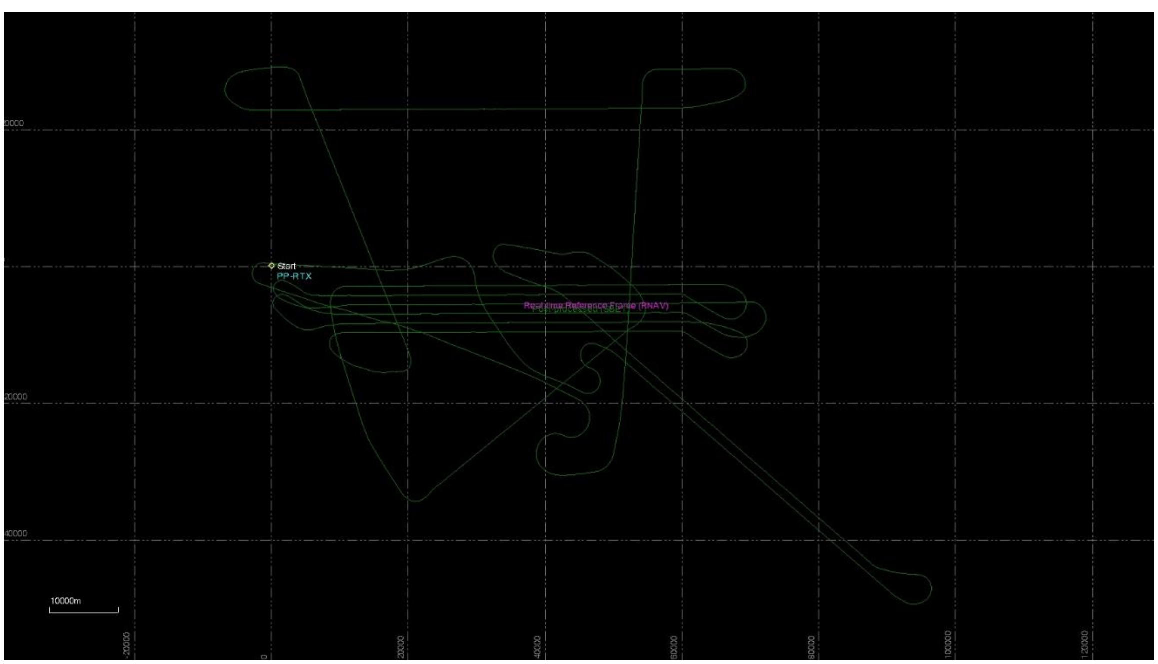
350
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
479,500
480,000
480,500
481,000
481,500
482,000
482,500
483,000
483,500
484,000
484,500
485,000
485,500
486,000
486,500
Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 4 (20190917A)

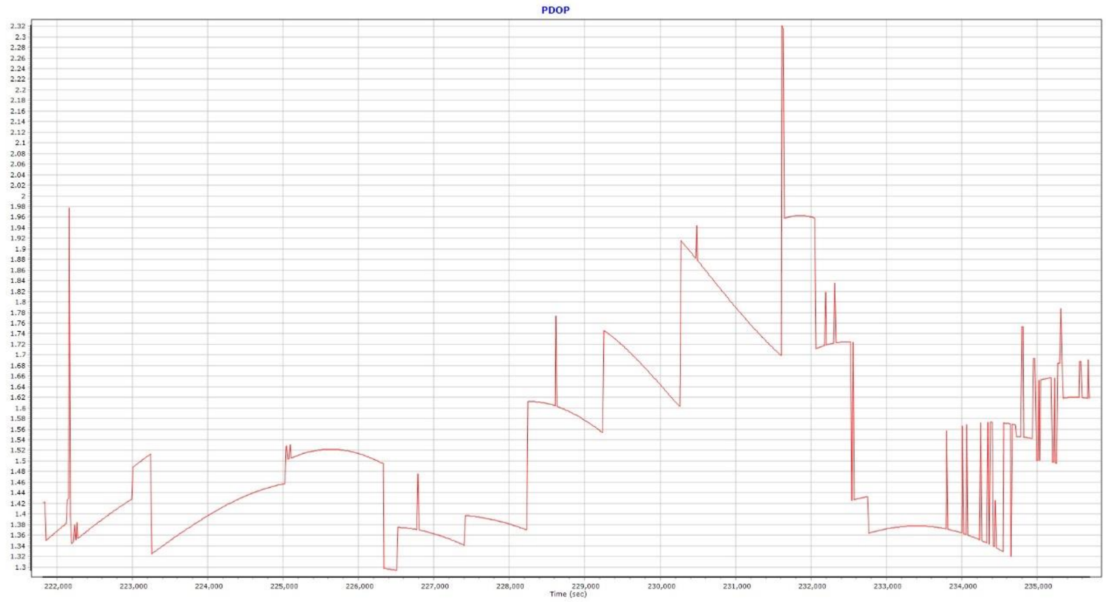
Flight Log



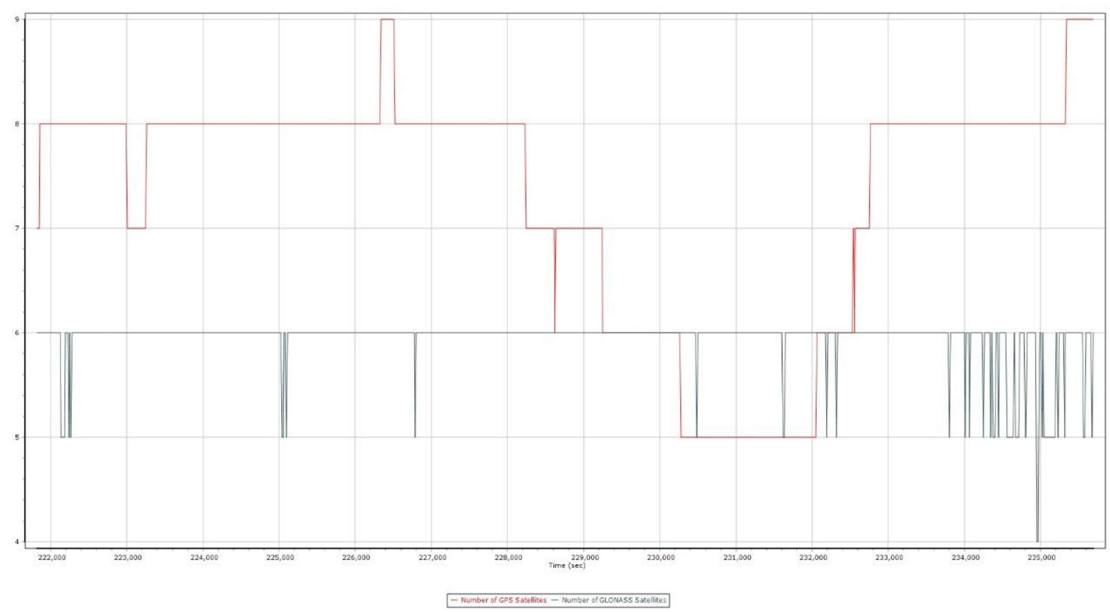
Mission Trajectory



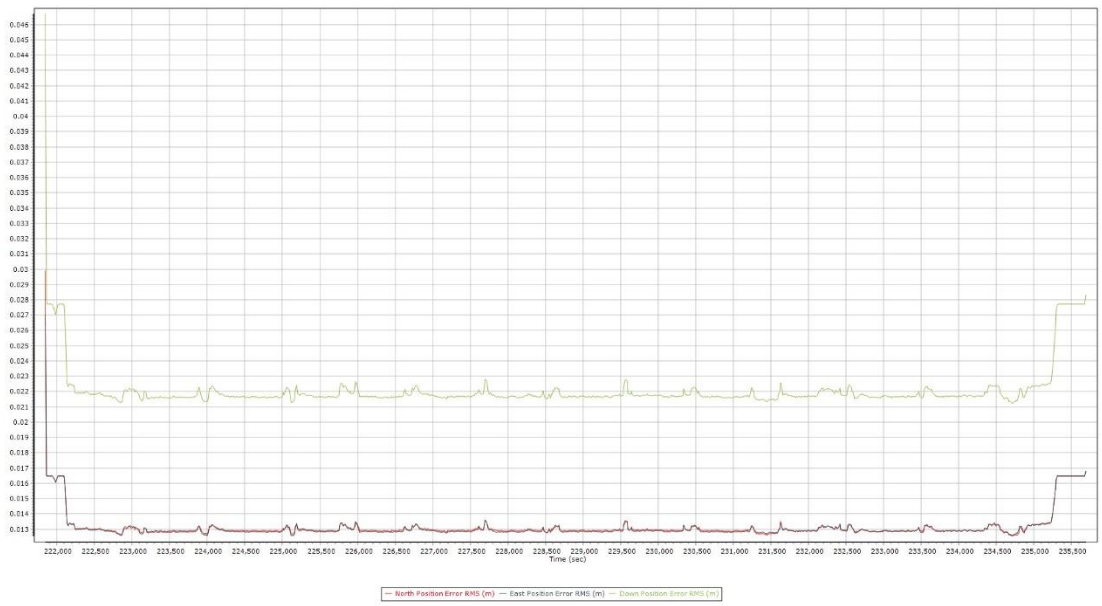
PDOP



Satellites

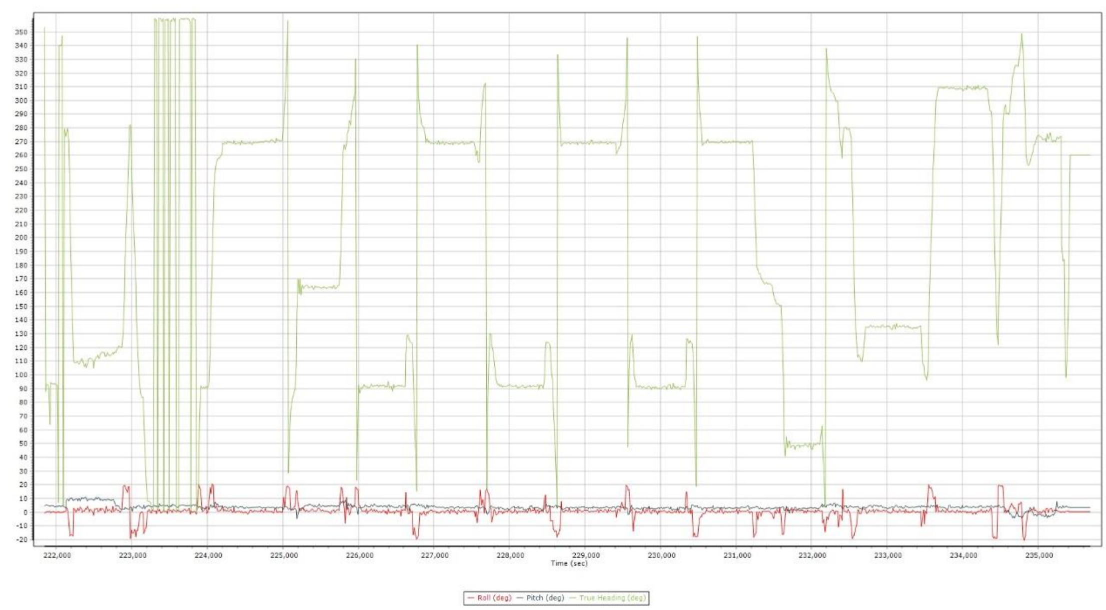


RMS (m)



Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

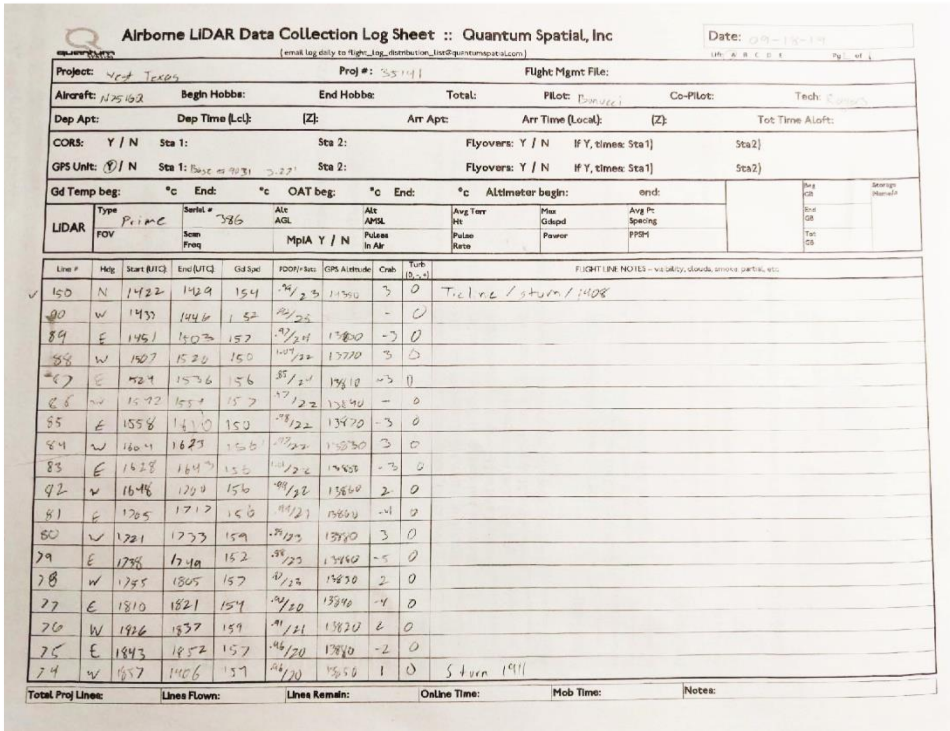
RPH (deg)



Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 5 (20190918A)

Flight Log



Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 09-18-19

Project: West Texas | Proj #: 35141 | Flight Mgmt File:

Aircraft: N25162 | Begin Hobbs: | End Hobbs: | Total: | Pilot: Bonucci | Co-Pilot: | Tech:

Dep Apt: | Dep Time (Lcl): | (Z): | Arr Apt: | Arr Time (Local): | (Z): | Tot Time Aloft:

CORS: Y / N | Sta 1: | Sta 2: | Flyovers: Y / N | If Y, times: Sta1) | Sta2)

GPS Unit: (Y) / N | Sta 1: Base at 9031 3.27' | Sta 2: | Flyovers: Y / N | If Y, times: Sta1) | Sta2)

Gd Temp beg: °c End: °c OAT beg: °c End: °c Altimeter begin: end:

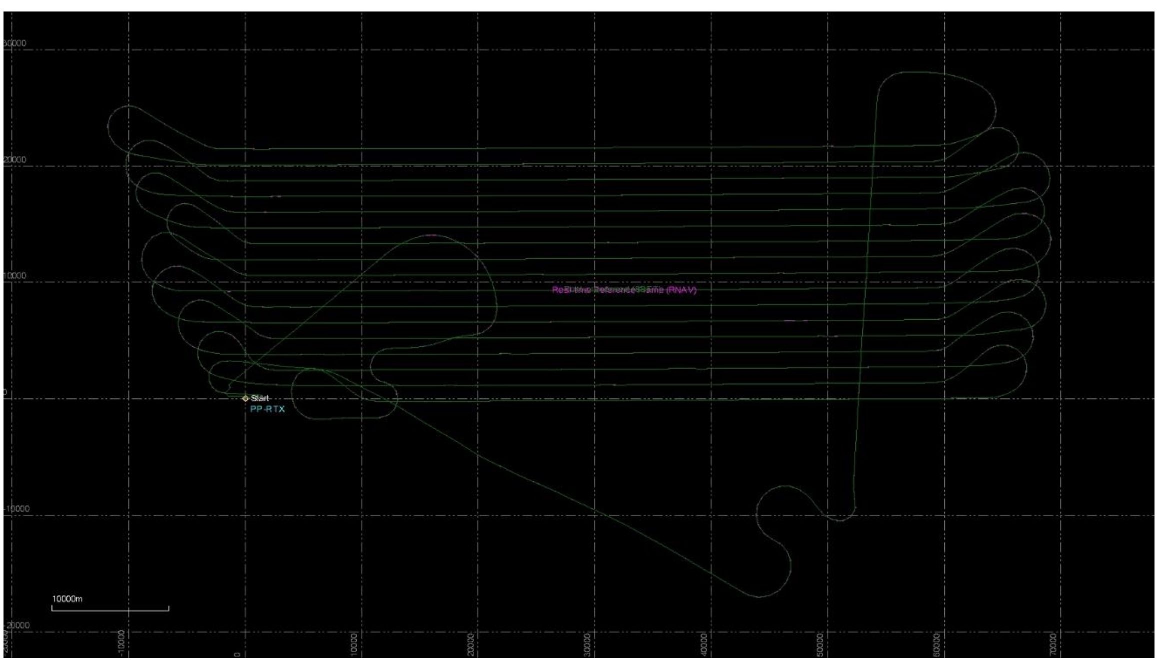
LIDAR | Type: Prime | Serial #: 386 | Alt AGL | Alt AMSL | Avg Terr Ht | Max Gdspd | Avg Pt Spacing

FOV | Scan Freq | MpIA Y / N | Pulses In Air | Pulse Rate | Power | PPSM

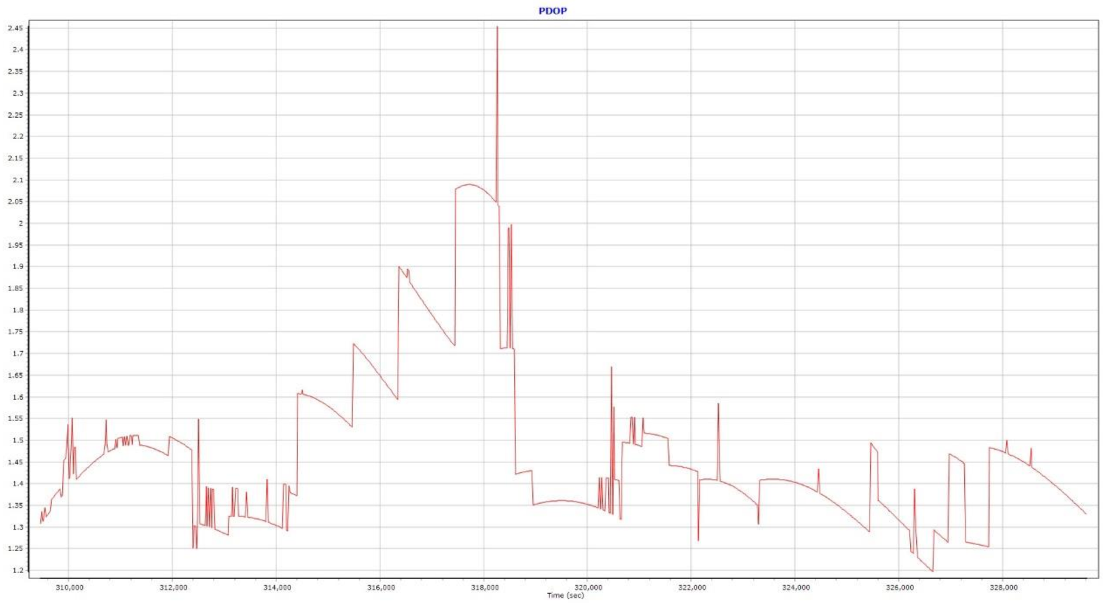
Line #	Hdg	Start (UTC)	End (UTC)	Gd Spd	PDOP/#Sats	GPS Altitude	Crab	Turb (0,-,+)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
✓ 150	N	1422	1429	154	.94/23	14390	3	0	Tieline / sturn / 1408
90	W	1433	1446	157	.93/25		-	0	
89	E	1451	1503	157	.97/24	13800	-3	0	
88	W	1507	1520	150	1.07/22	13770	3	0	
87	E	1524	1536	156	.85/24	13810	-3	0	
86	W	1542	1554	157	.97/22	13840	–	0	
85	E	1558	1610	150	.98/22	13870	-3	0	
84	W	1604	1623	156	.97/22	13830	3	0	
83	E	1628	1643	155	1.01/22	13850	-3	0	
82	W	1648	1700	156	.99/22	13860	2	0	
81	E	1705	1717	156	.99/21	13860	-4	0	
80	W	1721	1733	159	.94/23	13880	3	0	
79	E	1738	1749	152	.98/23	13860	-5	0	
78	W	1755	1805	157	.92/23	13830	2	0	
77	E	1810	1821	154	.94/20	13840	-4	0	
76	W	1826	1837	159	.91/21	13820	2	0	
75	E	1843	1852	157	.96/20	13880	-2	0	
74	W	1857	1906	157	.96/20	13850	1	0	S turn 1911

Total Proj Lines: | Lines Flown: | Lines Remain: | Online Time: | Mob Time: | Notes:

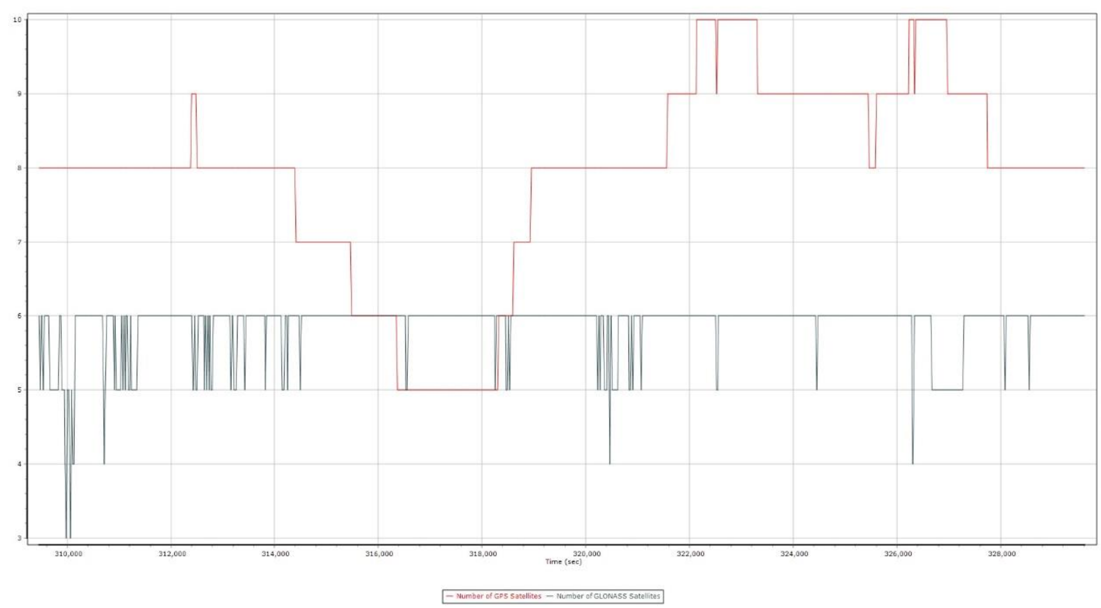
Mission Trajectory



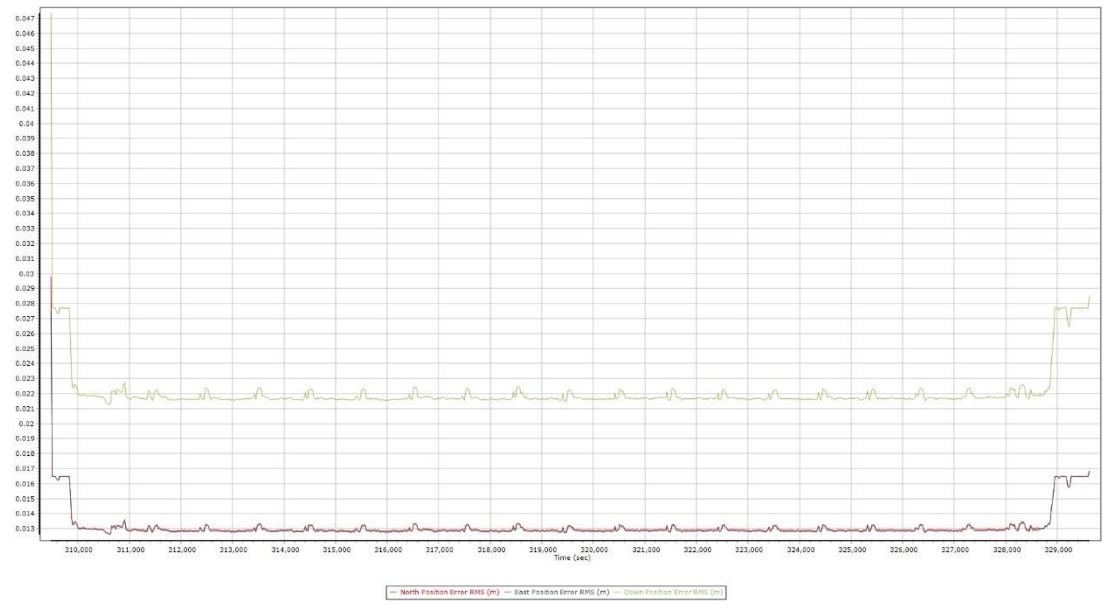
PDOP



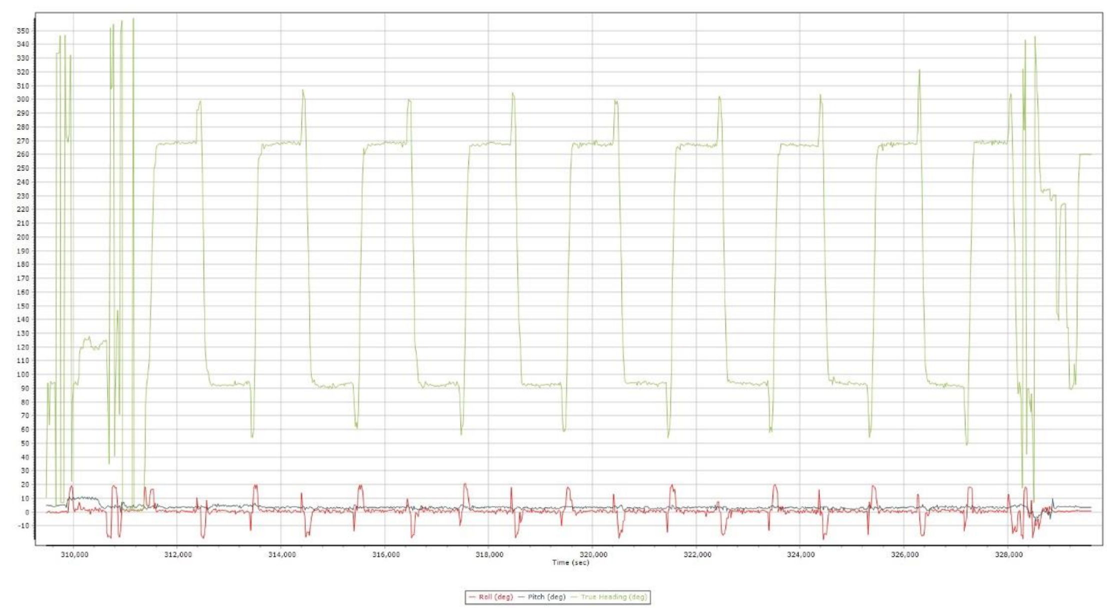
Satellites



RMS (m)

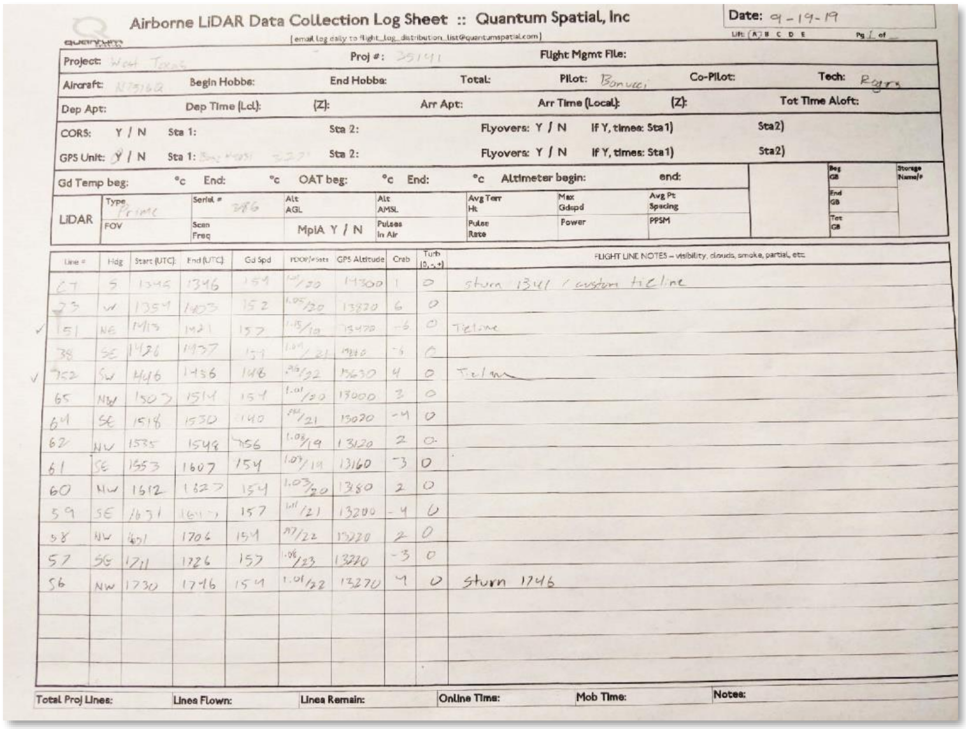

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 6 (20190919A)

Flight Log



Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

[email log daily to flight_log_distribution_list@quantumspatial.com]

Date: 9-19-19

Lift: (A) B C D E   Pg 1 of

Project: West Texas   Proj #: 35141   Flight Mgmt File:

Aircraft: N7516Q   Begin Hobbs: End Hobbs: Total: Pilot: Bonucci   Co-Pilot: Tech: Rogers

Dep Apt: Dep Time (Lcl):   (Z):   Arr Apt: Arr Time (Local):   (Z):   Tot Time Aloft:

CORS: Y / N   Sta 1:   Sta 2:   Flyovers: Y / N   If Y, times: Sta 1)   Sta 2)

GPS Unit: Y / N   Sta 1: [illegible]   Sta 2:   Flyovers: Y / N   If Y, times: Sta 1)   Sta 2)

Gd Temp beg: °c   End: °c   OAT beg: °c   End: °c   Altimeter begin: end:

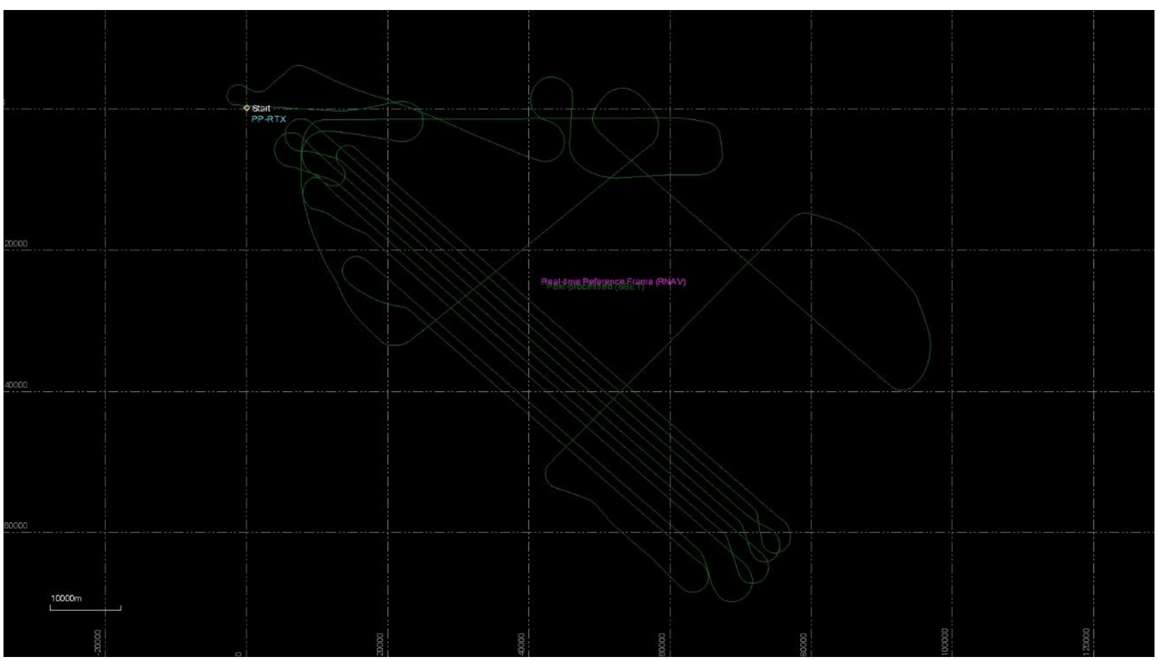
LiDAR: Type Prime   Serial # 386   Alt AGL   Alt AMSL   Avg Terr Ht   Max Gdspd   Avg Pt Spacing   Beg GB   Storage Name/#

FOV   Scan Freq   MpiA Y / N   Pulses In Air   Pulse Rate   Power   PPSM   End GB   Tot GB

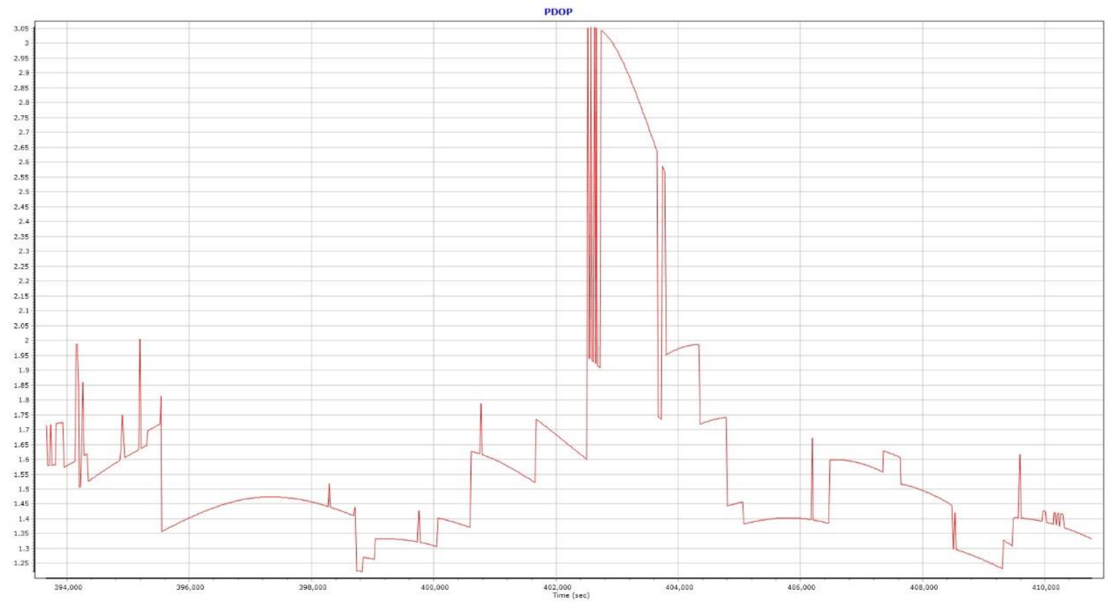
Line #	Hdg	Start (UTC)	End (UTC)	Gd Spd	PDOP/#Sats	GPS Altitude	Crab	Turb (0, -, +)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
CT	S	1345	1346	154	1.01/20	14300	1	0	sturn 1341 / custom tieline
73	W	1354	1403	152	1.05/20	13820	6	0	
151	NE	1413	1421	157	1.15/19	13470	-6	0	Tieline
38	SE	1426	1437	154	1.04/21	13410	-6	0	
152	SW	1446	1456	148	.96/22	13630	4	0	Tieline
65	NW	1503	1514	154	1.01/20	13000	3	0	
64	SE	1518	1530	140	.94/21	13020	-4	0	
62	NW	1535	1548	156	1.03/19	13120	2	0	
61	SE	1553	1607	154	1.07/19	13160	-3	0	
60	NW	1612	1627	154	1.03/20	1380	2	0	
59	SE	1631	1647	157	1.11/21	13200	-4	0	
58	NW	1651	1706	154	.97/22	13220	2	0	
57	SE	1711	1726	157	1.06/23	13220	-3	0	
56	NW	1730	1746	154	1.01/22	13270	4	0	sturn 1746

Total Proj Lines: Lines Flown: Lines Remain: Online Time: Mob Time: Notes:

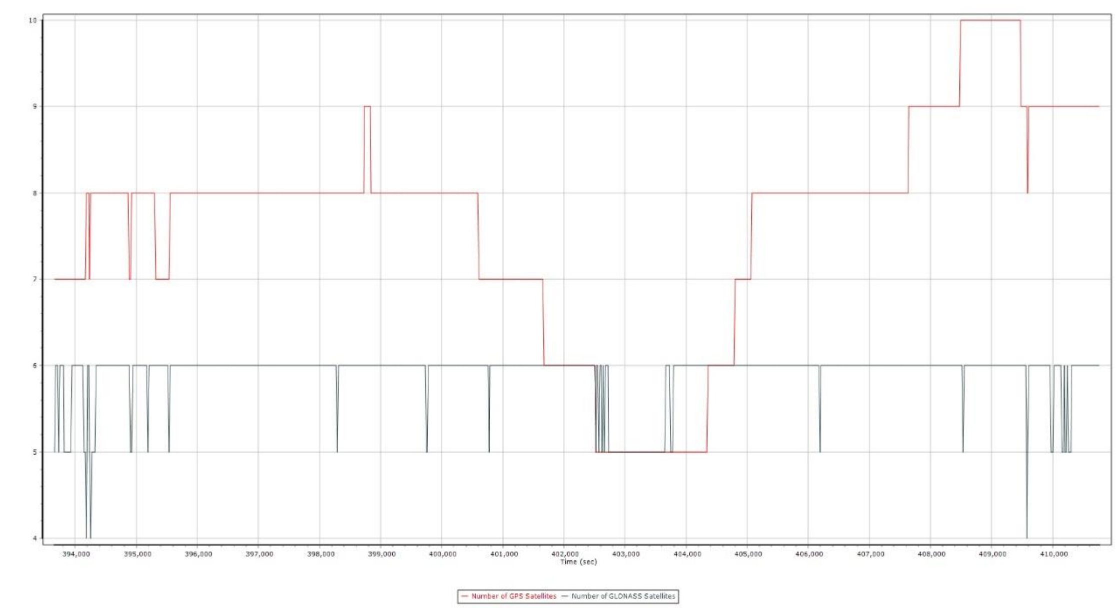
Mission Trajectory



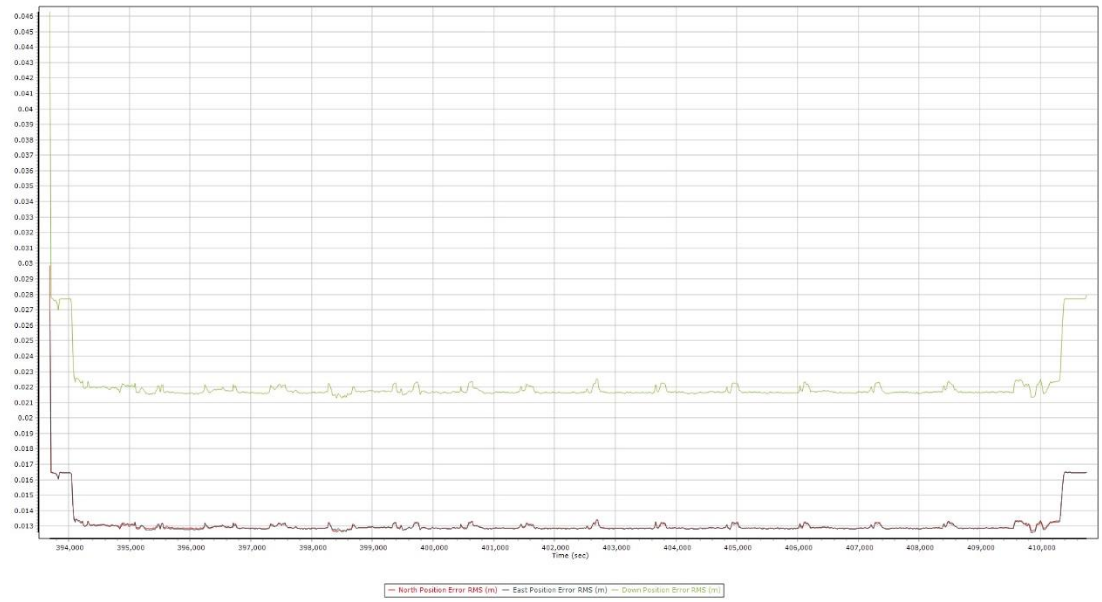
PDOP



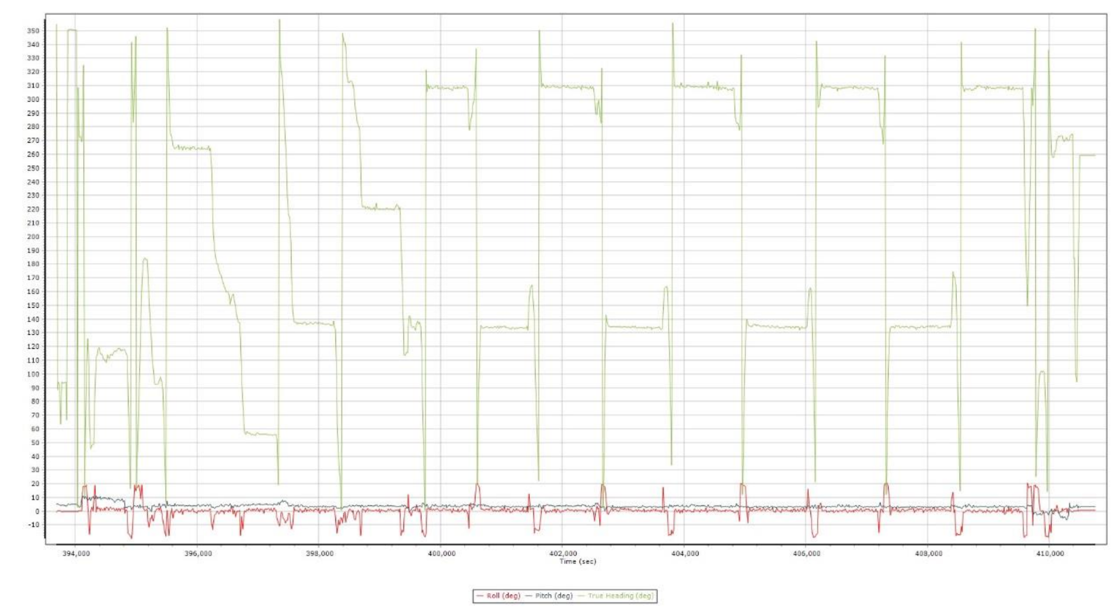
Satellites



RMS (m)

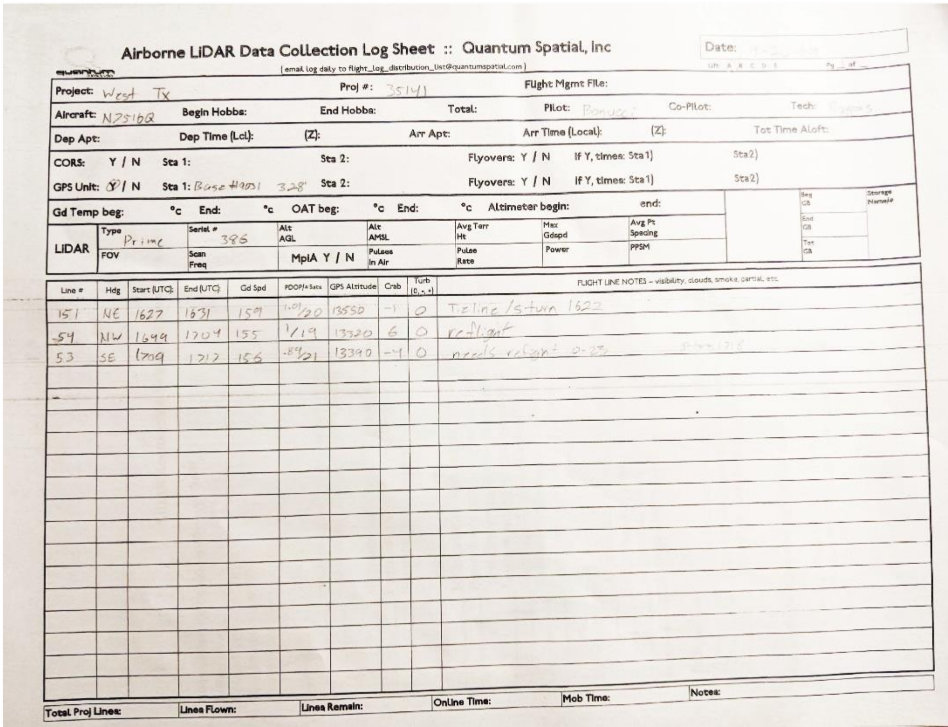

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 7 (20190920A)

Flight Log



Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date:

Project: West Tx | Proj #: 35141 | Flight Mgmt File:

Aircraft: N7516Q | Begin Hobbs: | End Hobbs: | Total: | Pilot: Bonucci | Co-Pilot: | Tech:

Dep Apt: | Dep Time (Lcl): | (Z): | Arr Apt: | Arr Time (Local): | (Z): | Tot Time Aloft:

CORS: Y / N | Sta 1: | Sta 2: | Flyovers: Y / N | If Y, times: Sta1) | Sta2)

GPS Unit: (Y) / N | Sta 1: Base #9031 3.28' | Sta 2: | Flyovers: Y / N | If Y, times: Sta1) | Sta2)

Gd Temp beg: °c | End: °c | OAT beg: °c | End: °c | Altimeter begin: | end:

LIDAR | Type: Prime | Serial #: 386 | Alt AGL | Alt AMSL | Avg Terr Ht | Max Gdspd | Avg Pt Spacing

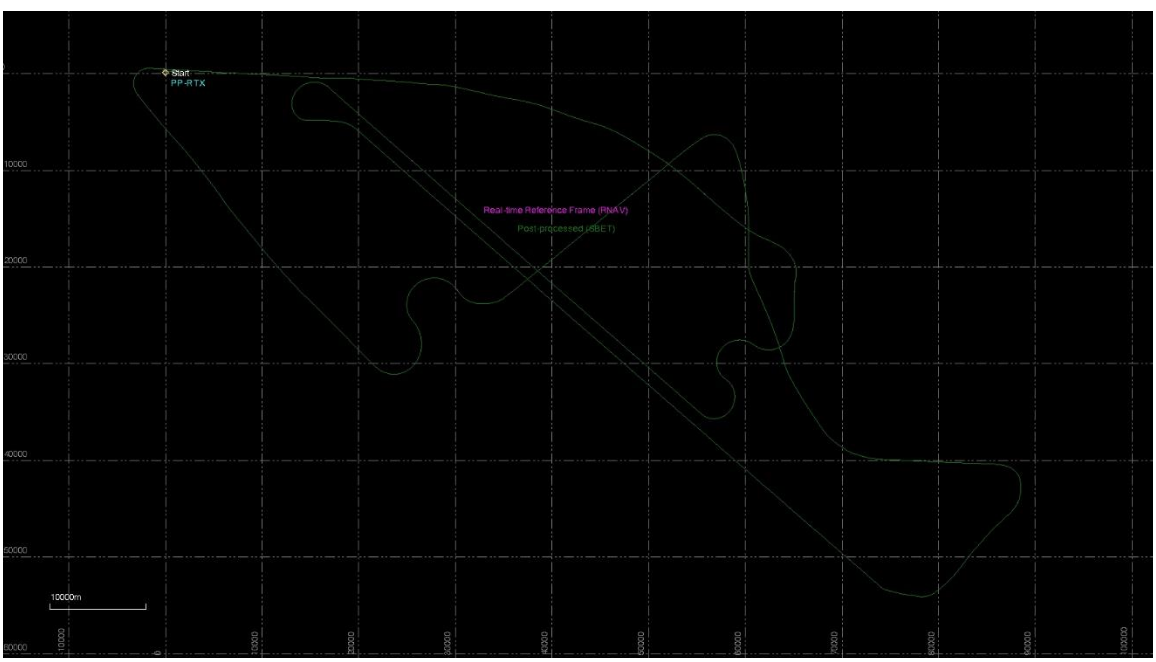
FOV | Scan Freq | MplA Y / N | Pulses In Air | Pulse Rate | Power | PPSM

Beg GB | End GB | Tot GB | Storage Name/#

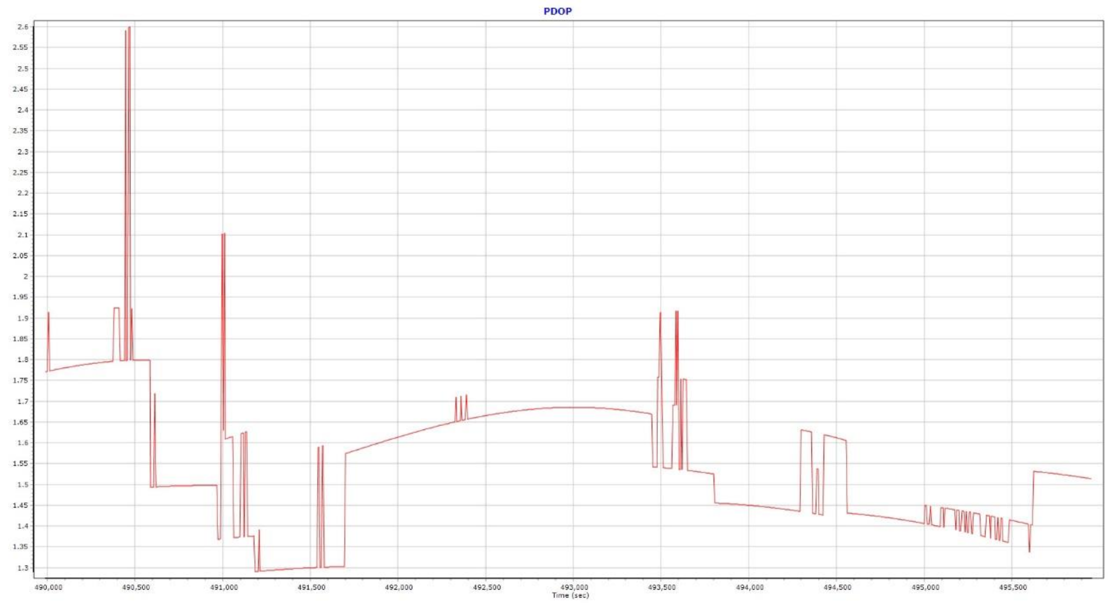
Line #	Hdg	Start (UTC):	End (UTC)	Gd Spd	PDOP/# Sats	GPS Altitude	Crab	Turb (0, -, +)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc
151	NE	1627	1631	159	1.01/20	13550	-1	0	Tieline /s-turn 1622
54	NW	1649	1704	155	1/19	13320	6	0	reflight
53	SE	1709	1717	156	.84/21	13390	-4	0	needs reflight 0-23

Total Proj Lines: | Lines Flown: | Lines Remain: | Online Time: | Mob Time: | Notes:

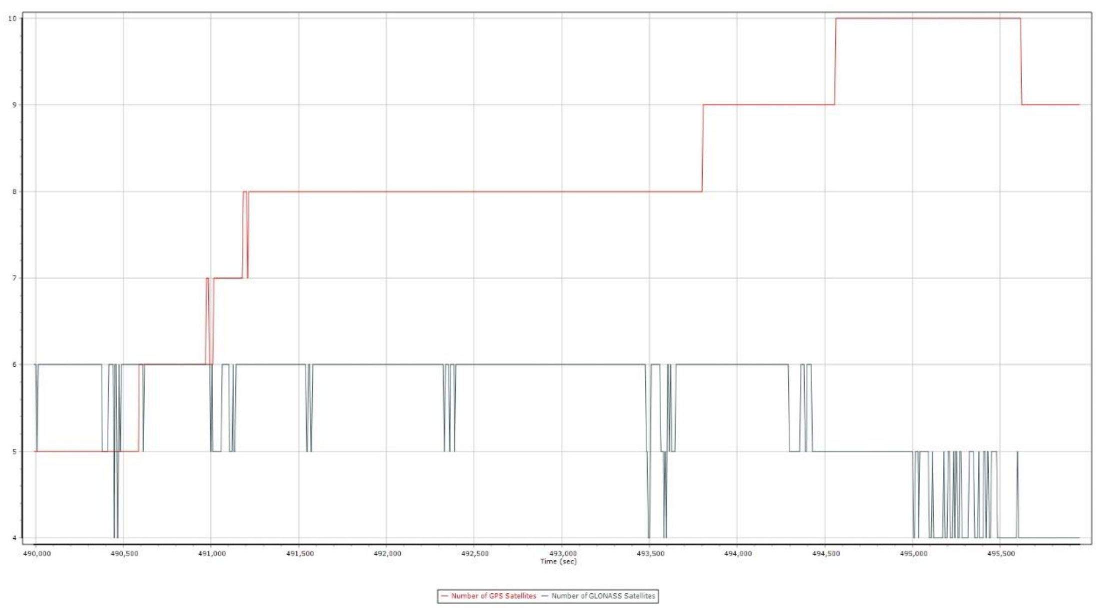
Mission Trajectory



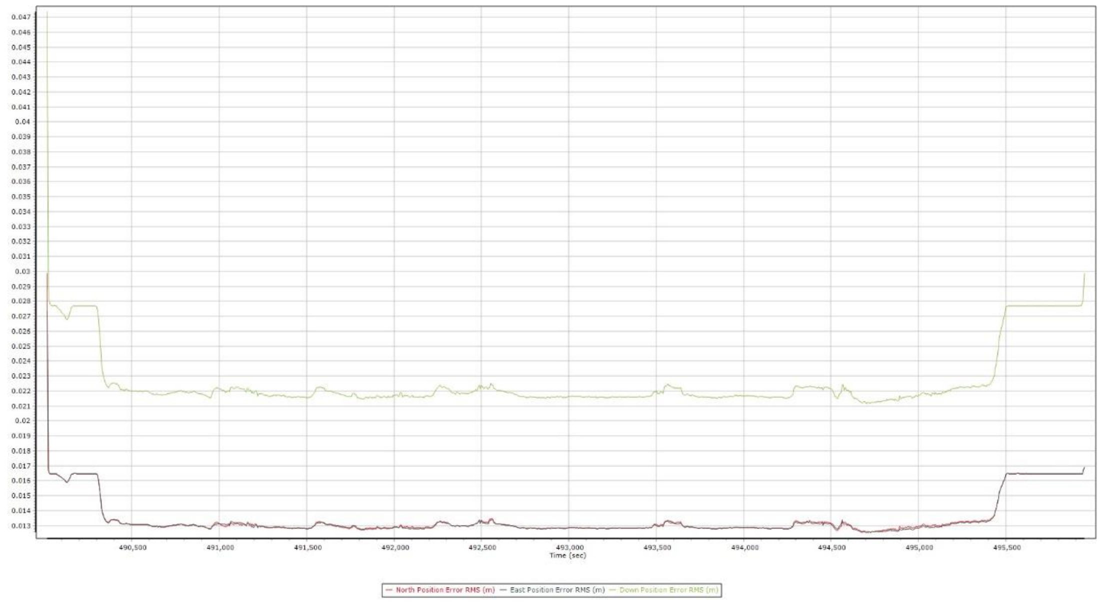
PDOP



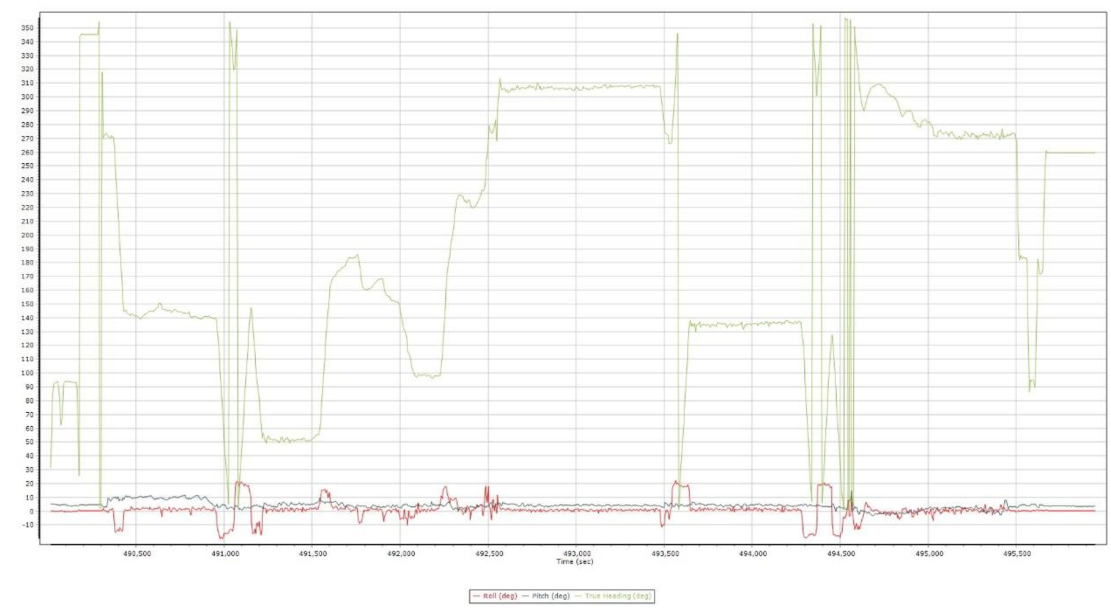
Satellites



RMS (m)

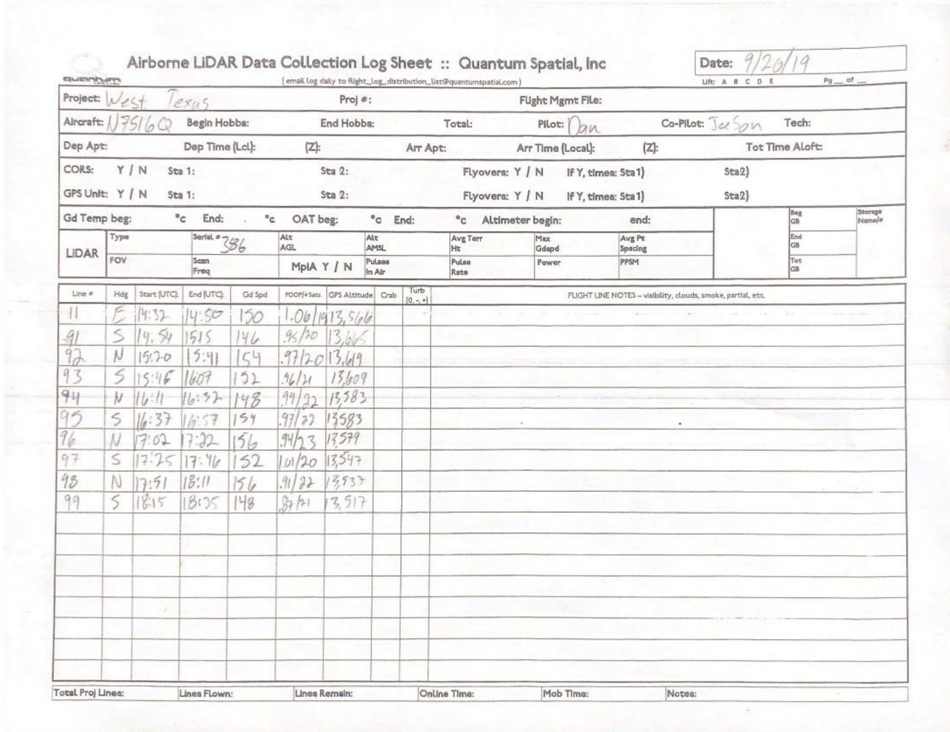

490,500
491,000
491,500
492,000
492,500
493,000
493,500
494,000
494,500
495,000
495,500
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


490,500
491,000
491,500
492,000
492,500
493,000
493,500
494,000
494,500
495,000
495,500
Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 8 (20190926B)

Flight Log



Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 9/26/19

Lift: A B C D E Pg __ of __

Project: West Texas Proj #: Flight Mgmt File:

Aircraft: N7516Q Begin Hobbs: End Hobbs: Total: Pilot: Dan Co-Pilot: Jerson Tech:

Dep Apt: Dep Time (Lcl): (Z): Arr Apt: Arr Time (Local): (Z): Tot Time Aloft:

CORS: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

GPS Unit: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

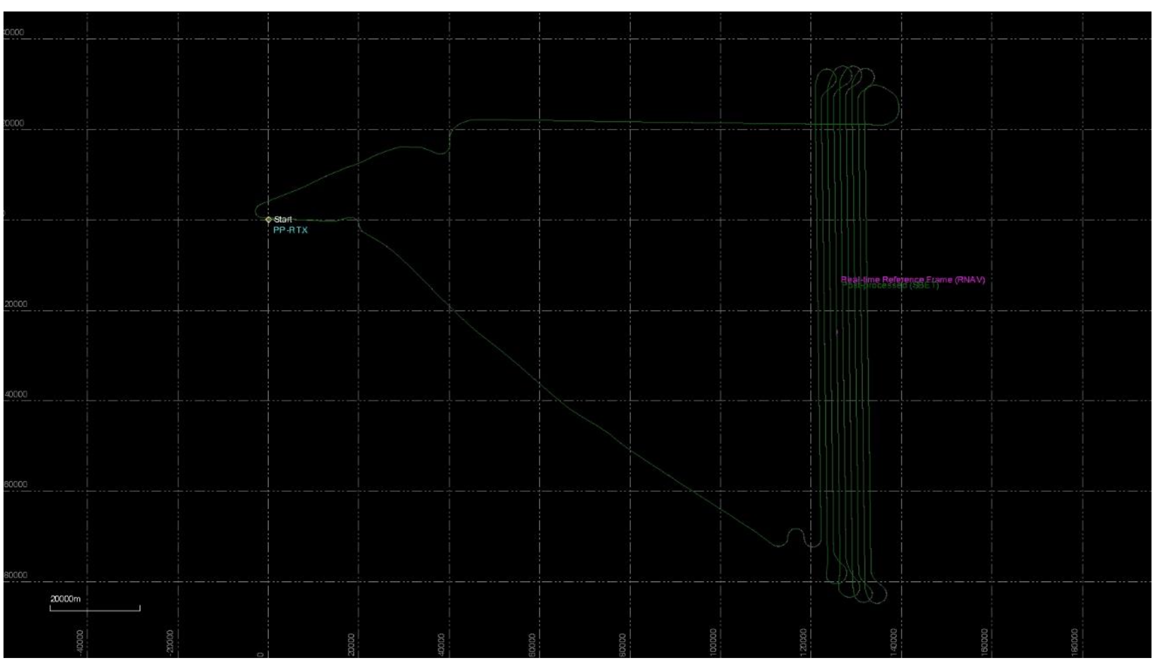
Gd Temp beg: °c End: °c OAT beg: °c End: °c Altimeter begin: end:

LiDAR — Type: Serial #: 386 Alt AGL: Alt AMSL: Avg Terr Ht: Max Gdspd: Avg Pt Spacing: FOV: Scan Freq: MpIA Y / N Pulses In Air: Pulse Rate: Power: PPSM: Beg GB: End GB: Tot GB: Storage Name/#:

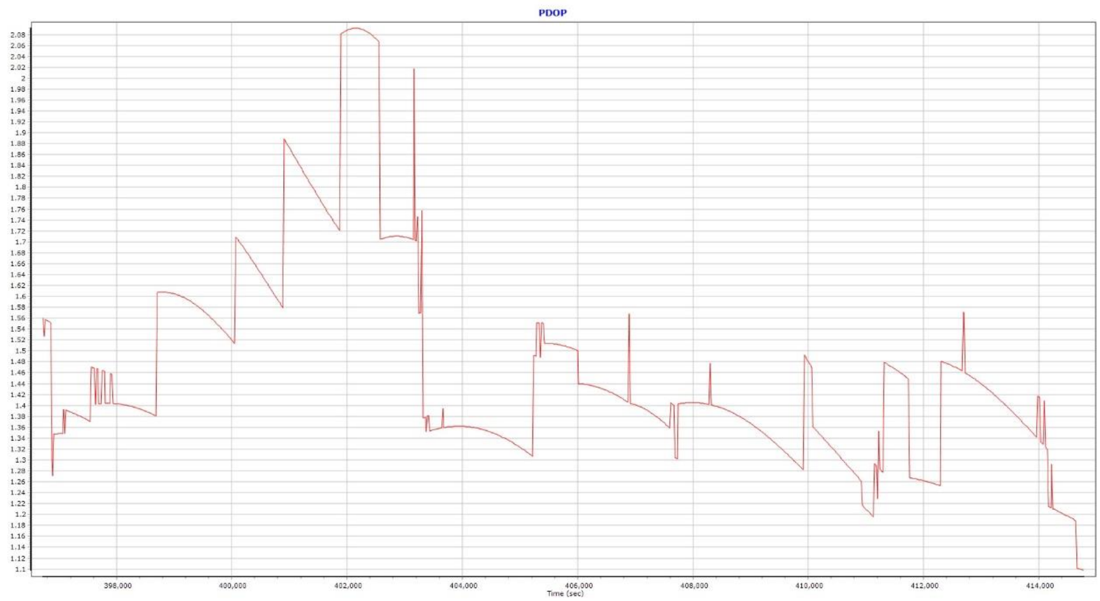
Line #	Hdg	Start (UTC)	End (UTC)	Gd Spd	PDOP/# Sats	GPS Altitude	Crab	Turb (0, -, +)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
11	E	14:32	14:50	150	1.06/19	13,566			
91	S	14:54	1515	146	.95/20	13,665			
92	N	15:20	15:41	154	.97/20	13,619			
93	S	15:46	1607	152	.96/21	13,609			
94	N	16:11	16:32	148	.99/22	13,583			
95	S	16:37	16:57	154	.97/22	13,583			
96	N	17:02	17:22	156	.94/23	13,579			
97	S	17:25	17:46	152	1.01/20	13,547			
98	N	17:51	18:11	156	.91/22	13,537			
99	S	18:15	18:35	148	.87/21	13,517			

Total Proj Lines: Lines Flown: Lines Remain: Online Time: Mob Time: Notes:

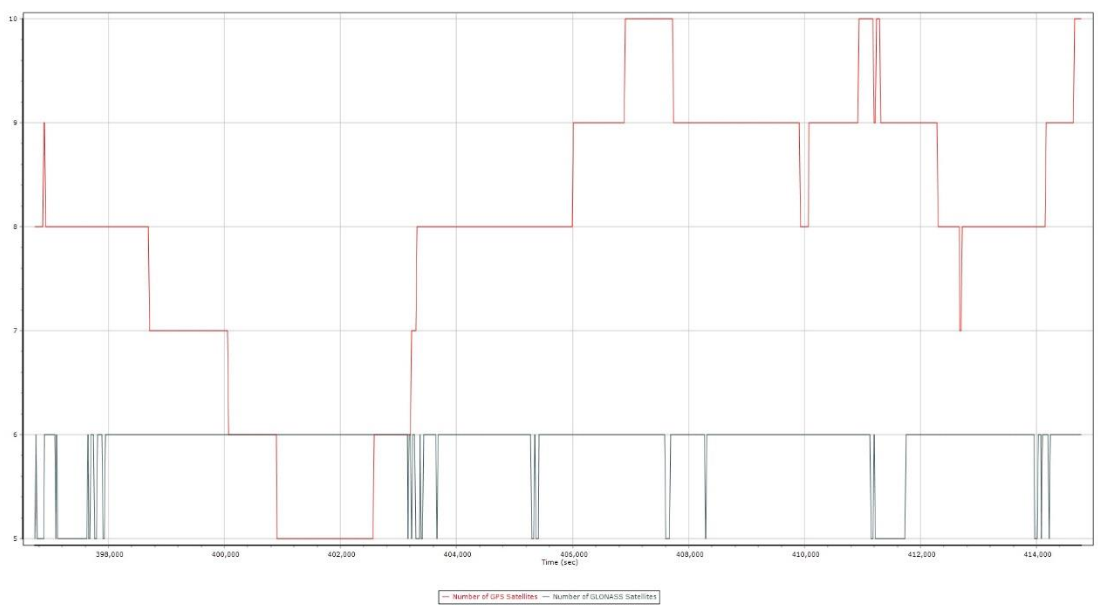
Mission Trajectory



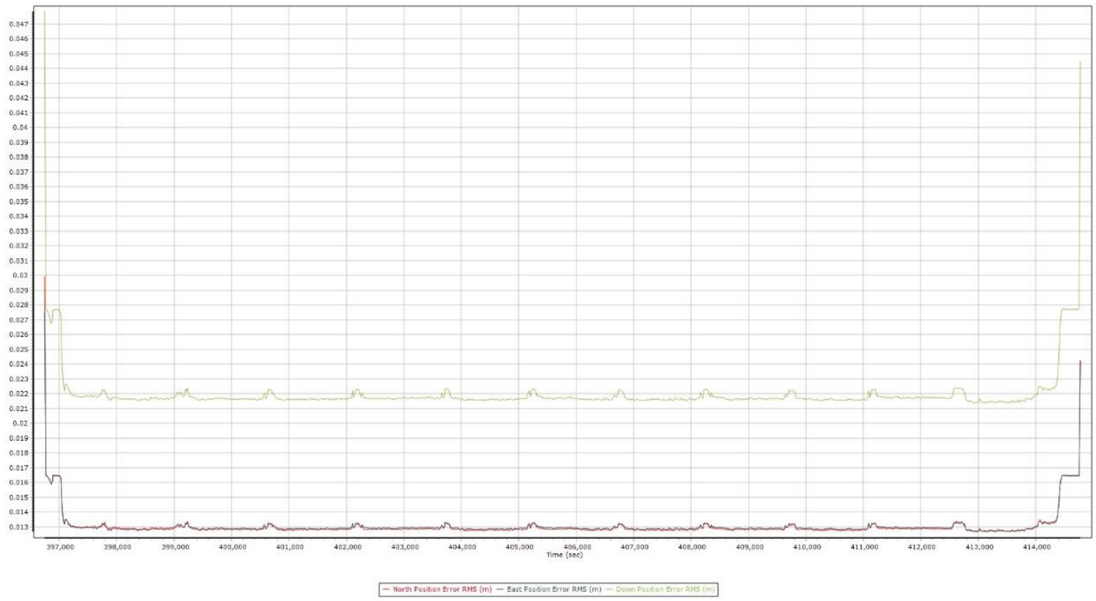
PDOP



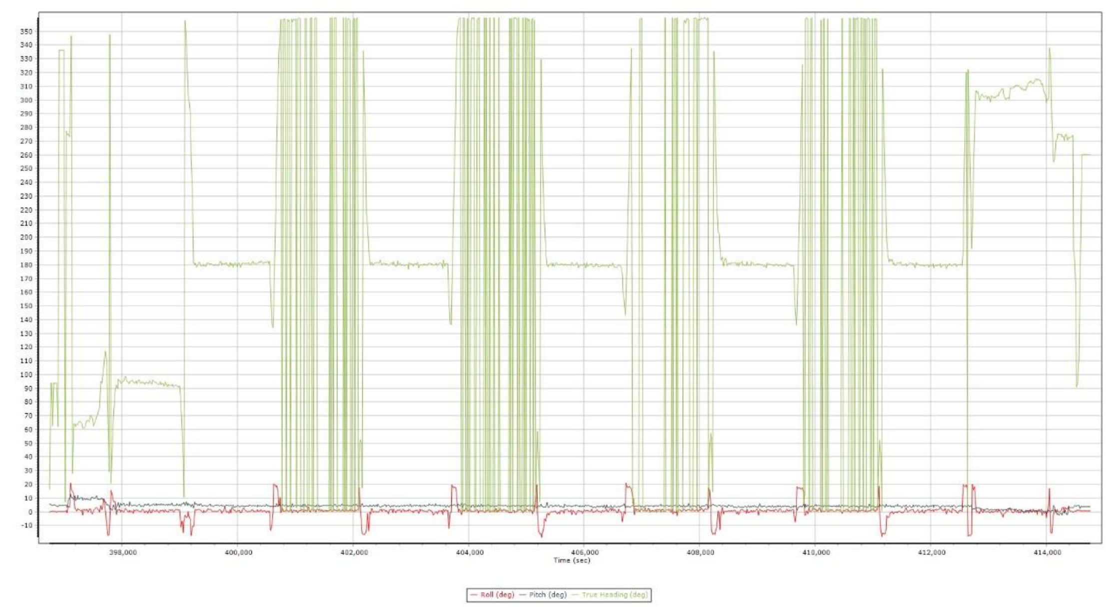
Satellites



RMS (m)

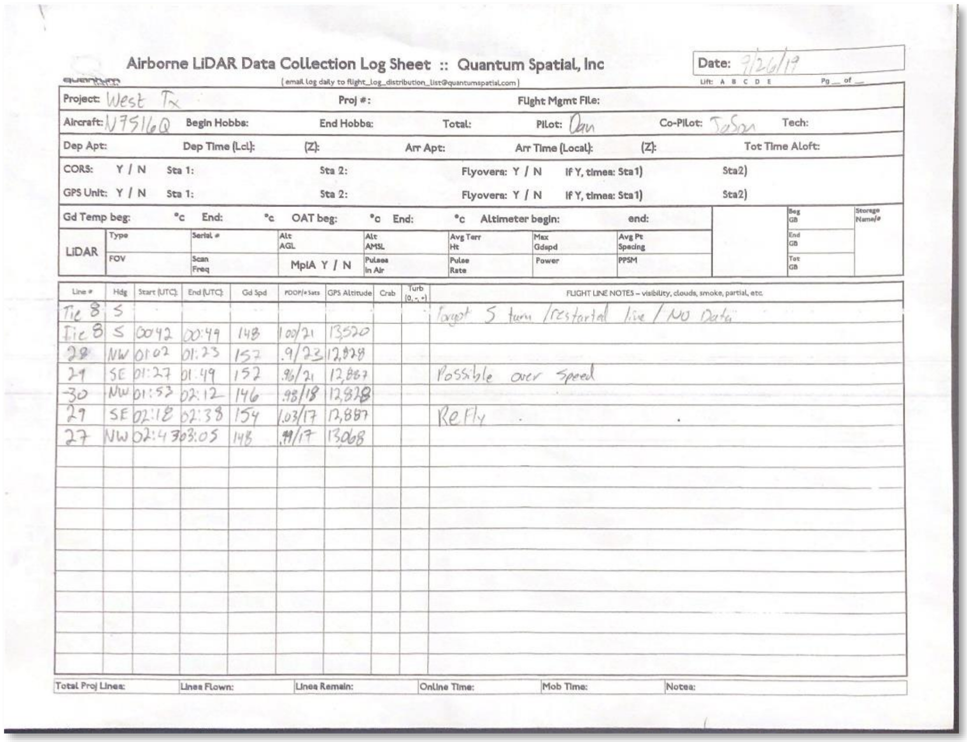

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 9 (20190926C)

Flight Log



Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 9/26/19

Project: West Tx | Proj #: | Flight Mgmt File:

Aircraft: N7516Q | Begin Hobbs: | End Hobbs: | Total: | Pilot: Dan | Co-Pilot: JaSon | Tech:

Dep Apt: | Dep Time (Lcl): | (Z): | Arr Apt: | Arr Time (Local): | (Z): | Tot Time Aloft:

CORS: Y / N | Sta 1: | Sta 2: | Flyovers: Y / N | If Y, times: Sta1) | Sta2)

GPS Unit: Y / N | Sta 1: | Sta 2: | Flyovers: Y / N | If Y, times: Sta1) | Sta2)

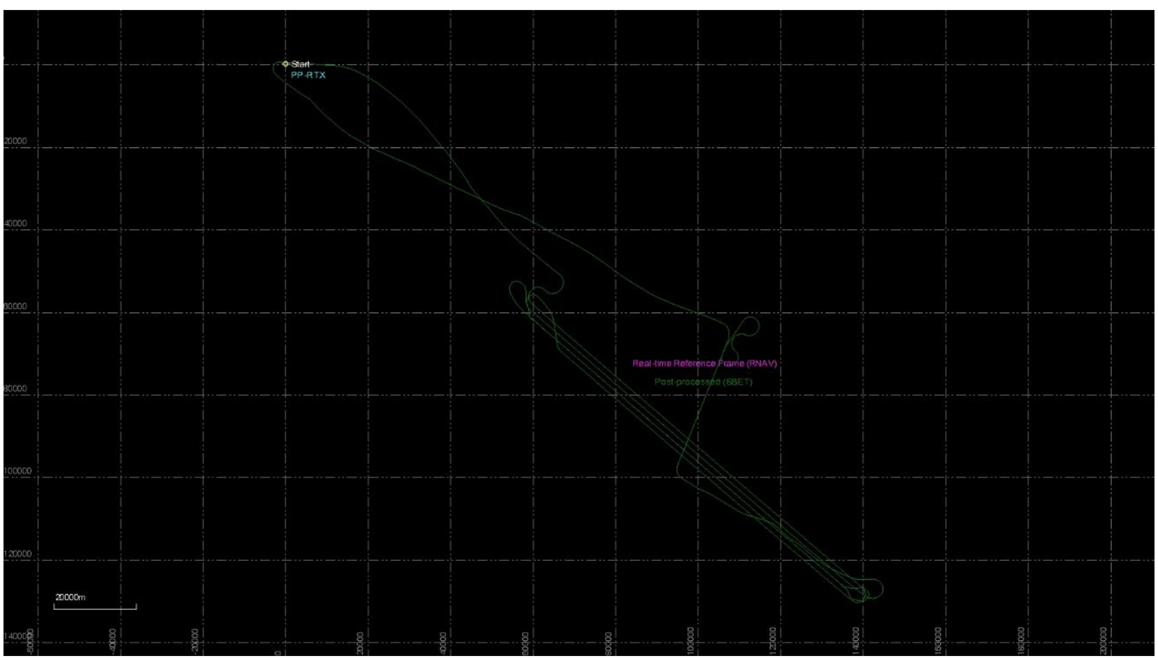
Gd Temp beg: °c | End: °c | OAT beg: °c | End: °c | Altimeter begin: | end:

LiDAR: Type | Serial # | Alt AGL | Alt AMSL | Avg Terr Ht | Max Gdspd | Avg Pt Spacing | FOV | Scan Freq | MplA Y / N | Pulses in Air | Pulse Rate | Power | PPSM | Beg GB | End GB | Tot GB | Storage Name/#

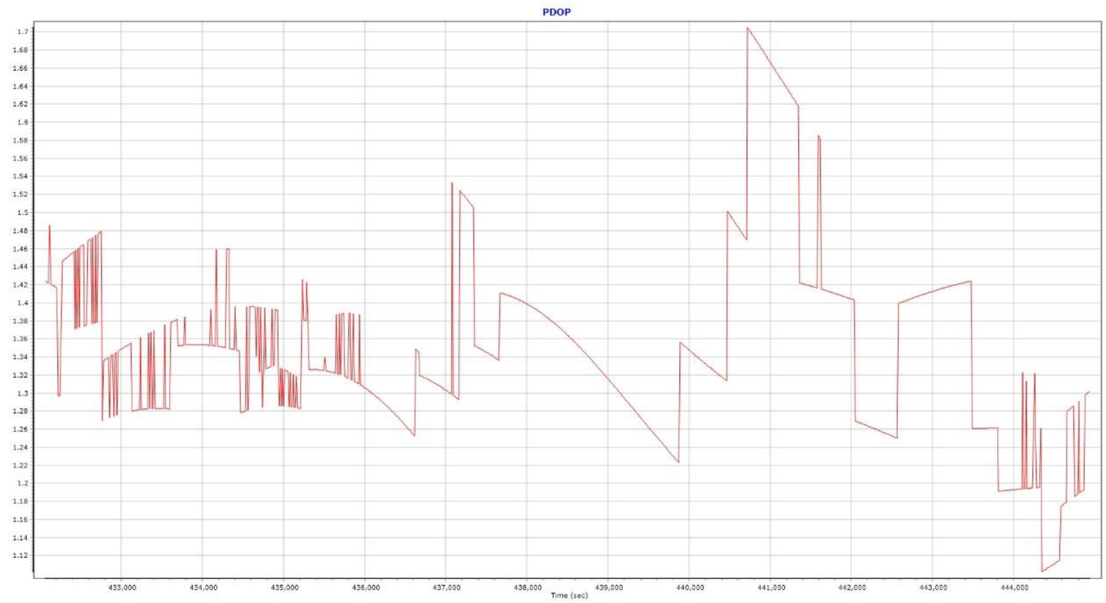
Line #	Hdg	Start (UTC)	End (UTC)	Gd Spd	PDOP/#Sats	GPS Altitude	Crab	Turb (0, -, +)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
Tie 8	S								forgot S turn / restarted line / NO Data
Tie 8	S	00:42	00:49	148	1.00/21	13,520			
28	NW	01:02	01:23	157	.9/23	12,828			
29	SE	01:27	01:49	152	.96/21	12,887			Possible over speed
30	NW	01:53	02:12	146	.98/18	12,828			
29	SE	02:18	02:38	154	1.03/17	12,887			ReFly
27	NW	02:43	03:05	148	.99/17	13,068			

Total Proj Lines: | Lines Flown: | Lines Remain: | Online Time: | Mob Time: | Notes:

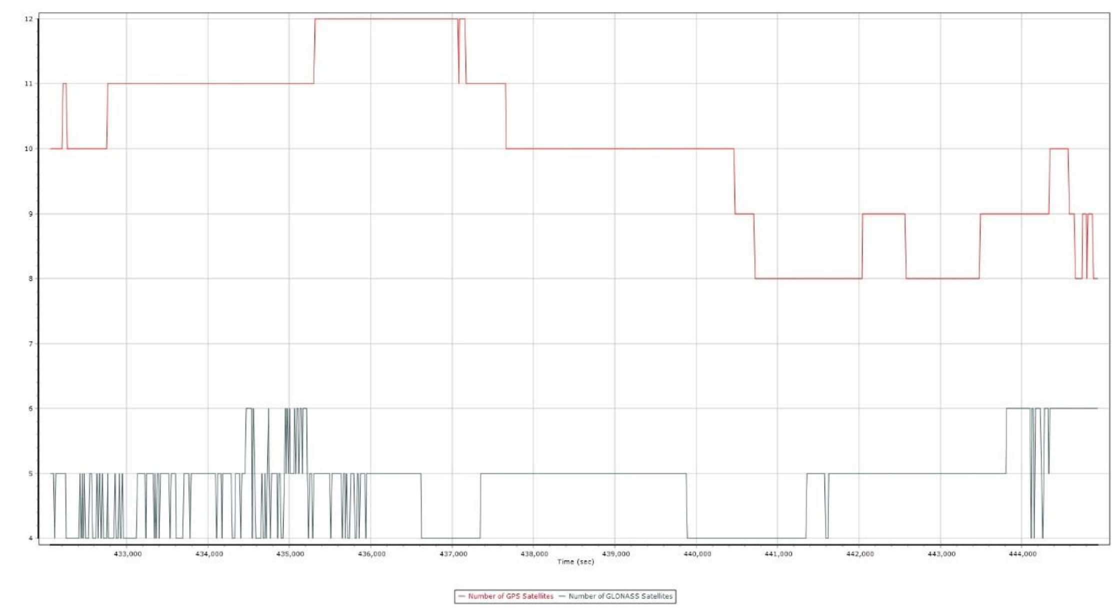
Mission Trajectory



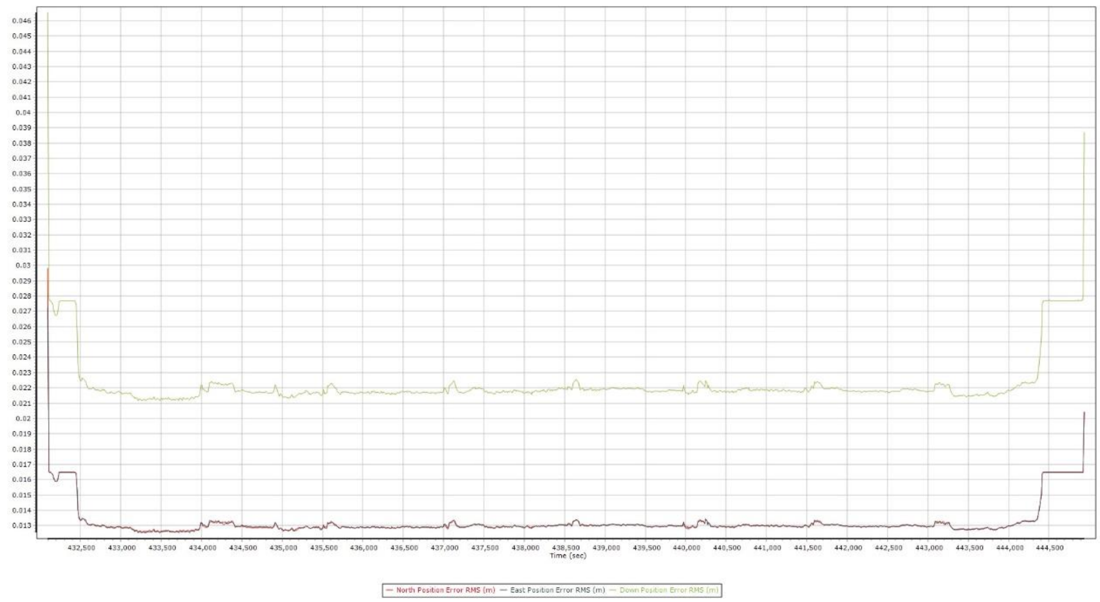
PDOP



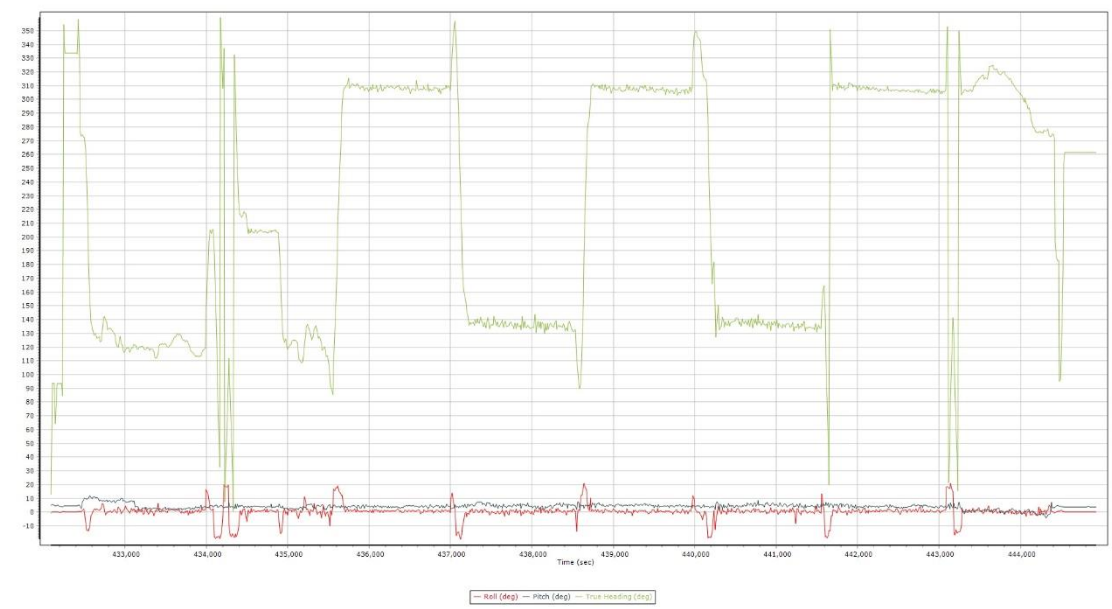
Satellites



RMS (m)

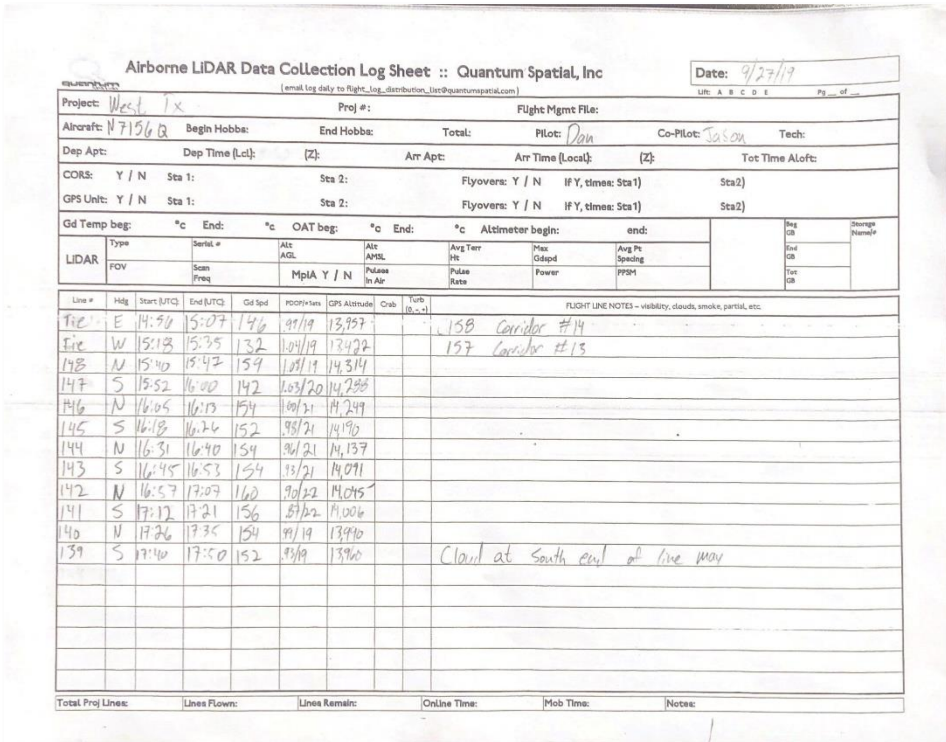

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 10 (20190927A)

Flight Log



Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 9/27/19

Lift: A B C D E   Pg __ of __

Project: West Tx   Proj #:   Flight Mgmt File:

Aircraft: N7156Q   Begin Hobbs: End Hobbs: Total: Pilot: Dan   Co-Pilot: Jason   Tech:

Dep Apt: Dep Time (Lcl):   (Z):   Arr Apt: Arr Time (Local):   (Z):   Tot Time Aloft:

CORS: Y / N   Sta 1:   Sta 2:   Flyovers: Y / N   If Y, times: Sta1)   Sta2)

GPS Unit: Y / N   Sta 1:   Sta 2:   Flyovers: Y / N   If Y, times: Sta1)   Sta2)

Gd Temp beg: °c   End: °c   OAT beg: °c   End: °c   Altimeter begin: end:

LIDAR   Type   Serial #   Alt AGL   Alt AMSL   Avg Terr Ht   Max Gdspd   Avg Pt Spacing

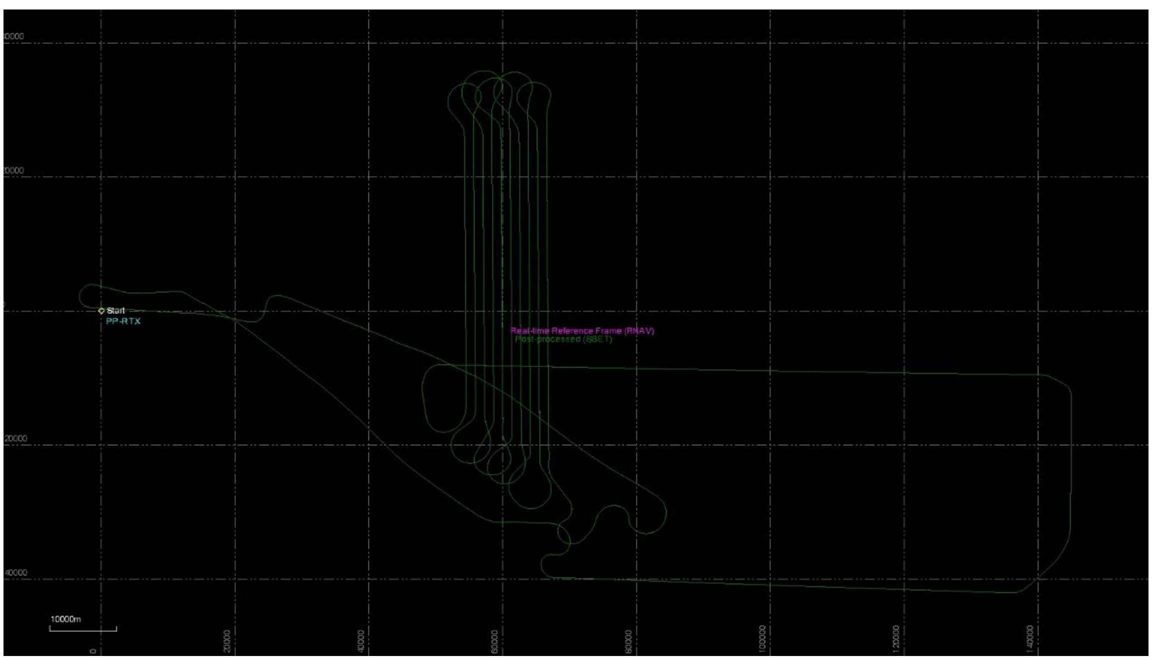
FOV   Scan Freq   MpIA Y / N   Pulses In Air   Pulse Rate   Power   PPSM

Beg GB   End GB   Tot GB   Storage Name/#

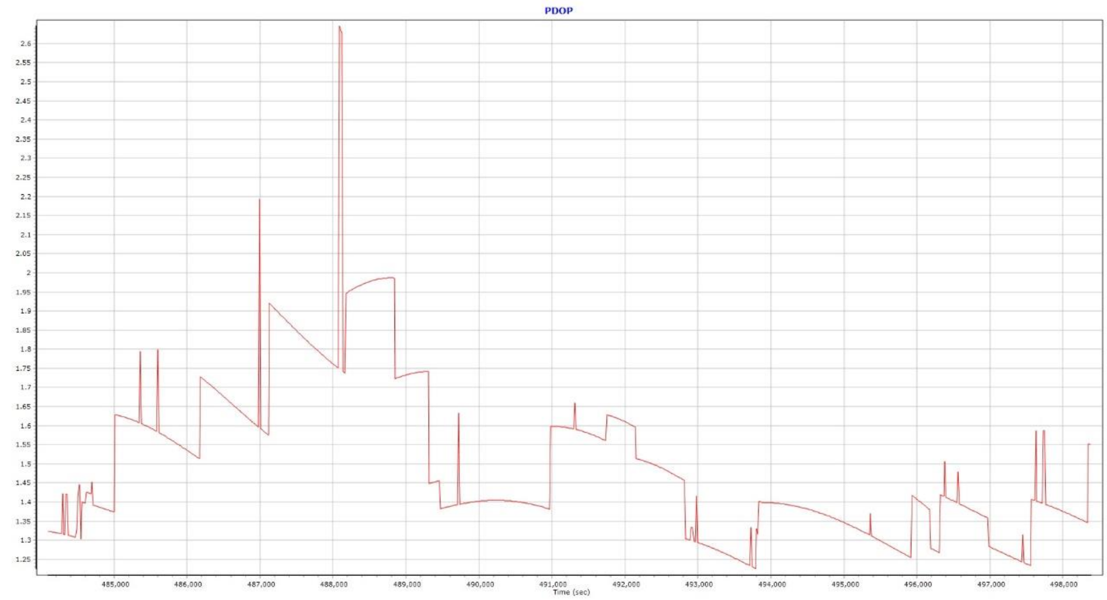
Line #	Hdg	Start (UTC)	End (UTC)	Gd Spd	PDOP/#Sats	GPS Altitude	Crab	Turb (0,-,+)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
Tie	E	14:56	15:07	146	.97/19	13,957			158 Corridor #14
Tie	W	15:18	15:35	132	1.04/19	13422			157 Corridor #13
148	N	15:40	15:47	159	1.08/19	14,314			
147	S	15:52	16:00	142	1.03/20	14,298			
146	N	16:05	16:13	154	1.00/21	14,249			
145	S	16:18	16:26	152	.98/21	14190			
144	N	16:31	16:40	154	.96/21	14,137			
143	S	16:45	16:53	154	.93/21	14,091			
142	N	16:57	17:07	160	.90/22	14,045			
141	S	17:12	17:21	156	.87/22	14,006			
140	N	17:26	17:35	154	.99/19	13,990			
139	S	17:40	17:50	152	.93/19	13,960			Cloud at South end of line may

Total Proj Lines: Lines Flown: Lines Remain: Online Time: Mob Time: Notes:

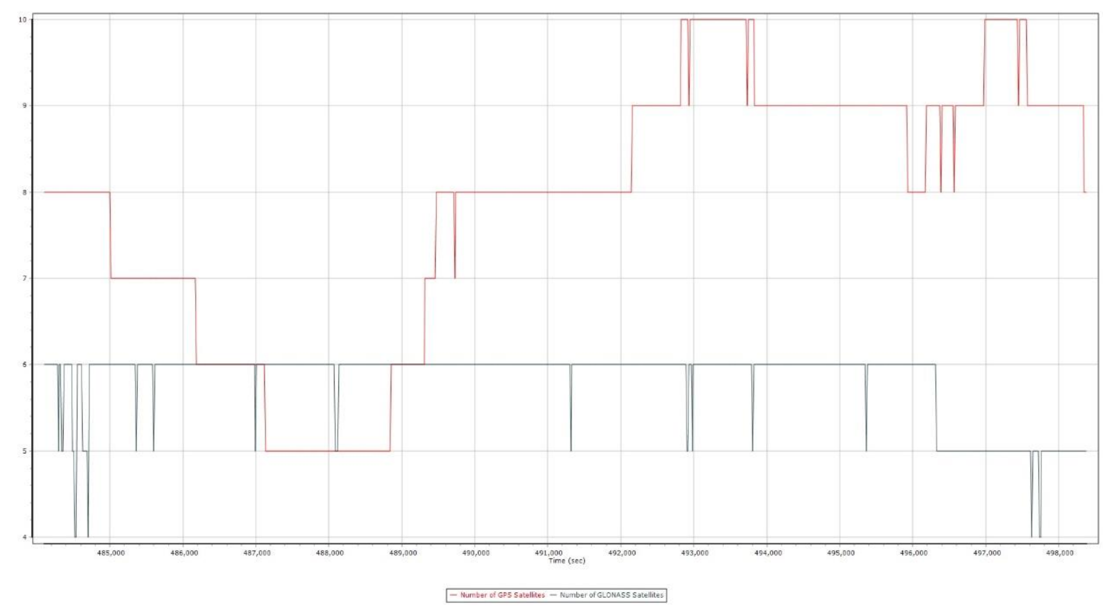
Mission Trajectory



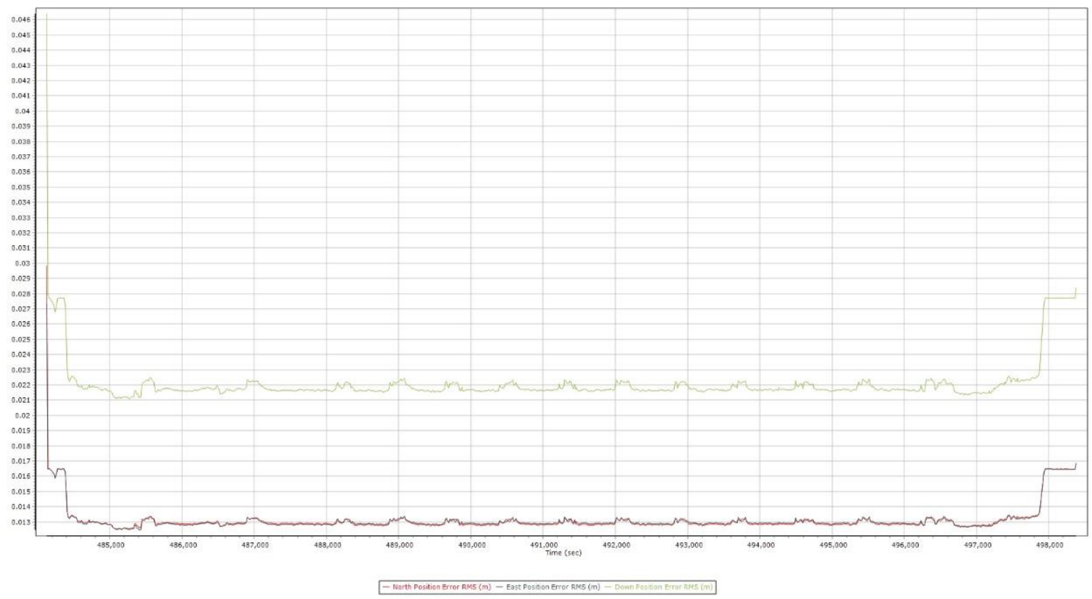
PDOP



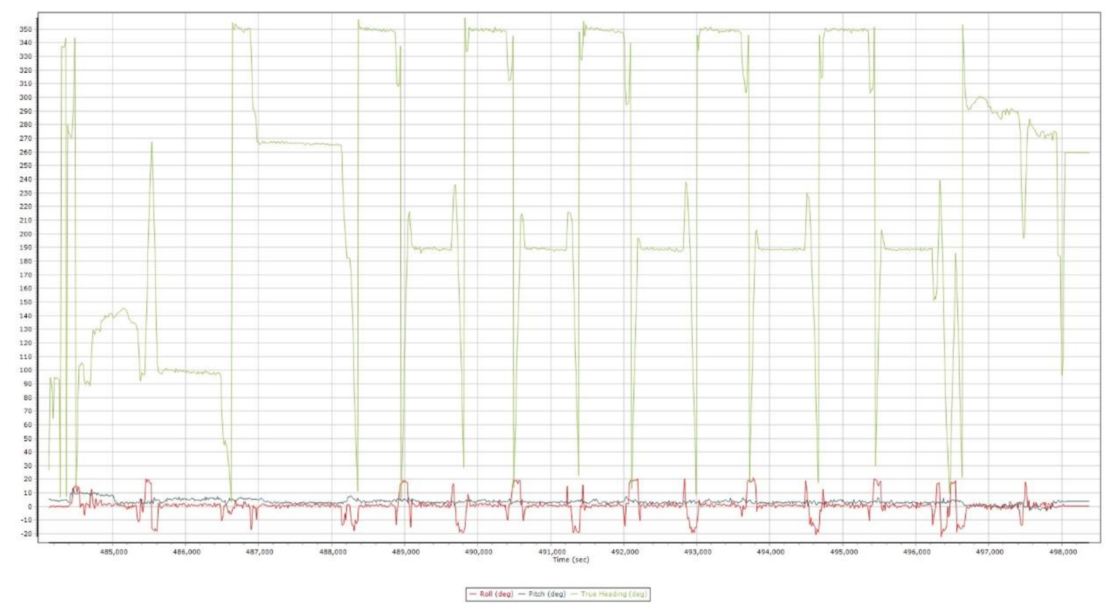
Satellites



RMS (m)

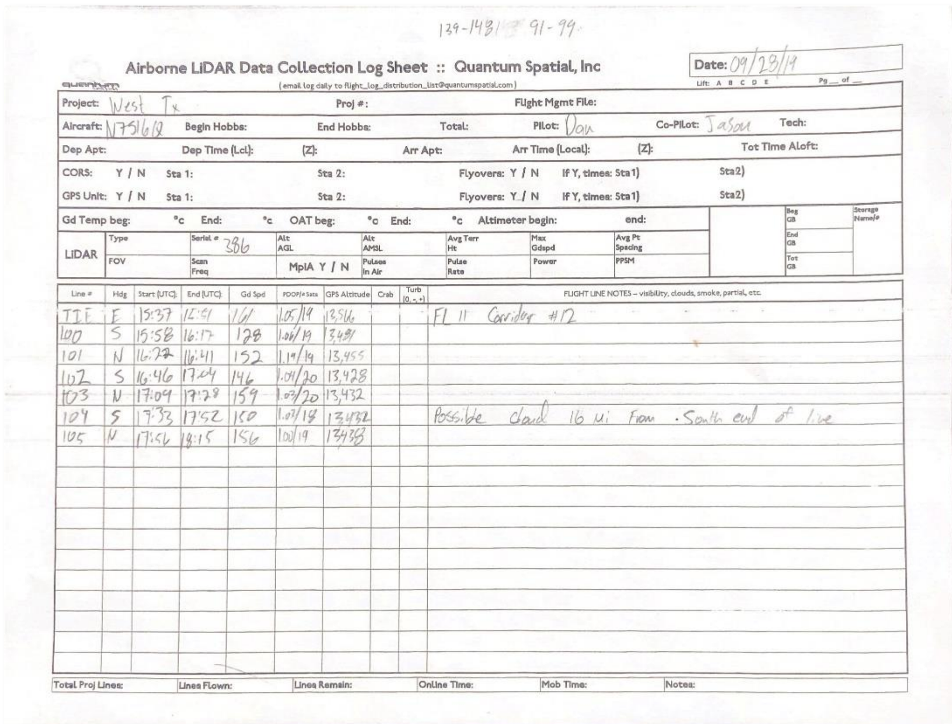

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 12 (20190928B)

Flight Log



139-143 91-99

Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 09/28/19 Lift: A B C D E Pg __ of __

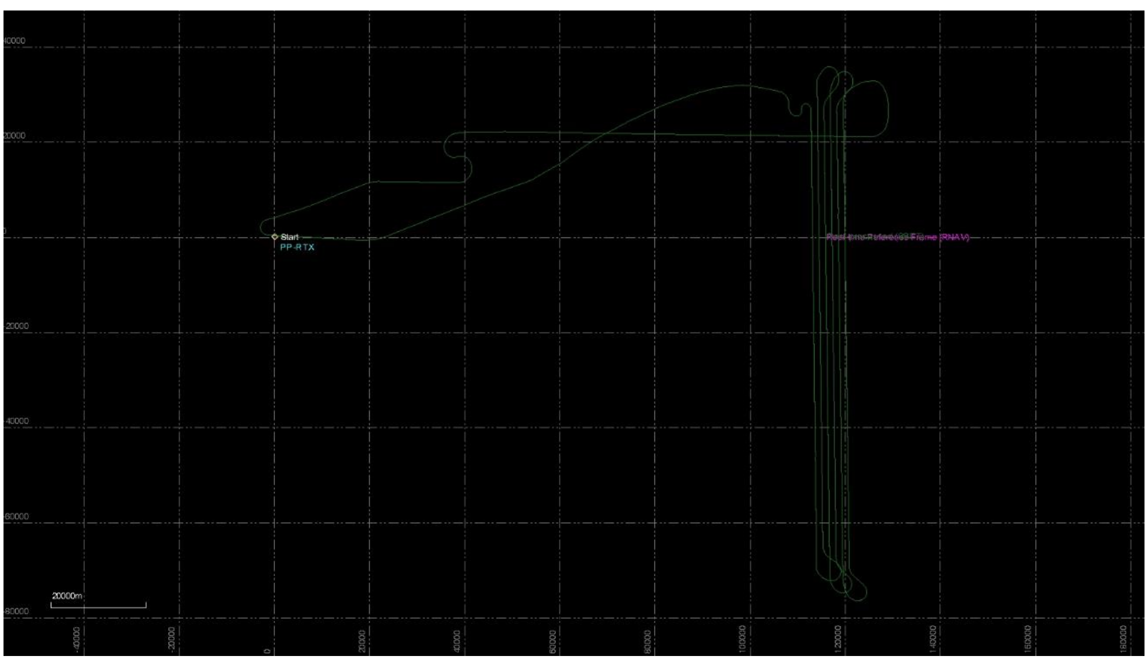
Project: West Tx		Proj #:		Flight Mgmt File:	
Aircraft: N751618	Begin Hobbs:	End Hobbs:	Total:	Pilot: Dan	Co-Pilot: Jason	Tech:
Dep Apt:	Dep Time (Lcl):	(Z):	Arr Apt:	Arr Time (Local):	(Z):	Tot Time Aloft:
CORS: Y / N	Sta 1:	Sta 2:	Flyovers: Y / N	If Y, times: Sta1)	Sta2)	
GPS Unit: Y / N	Sta 1:	Sta 2:	Flyovers: Y / N	If Y, times: Sta1)	Sta2)	
Gd Temp beg: °c	End: °c	OAT beg: °c	End: °c	Altimeter begin:	end:	

LIDAR							
Type	Serial # 386	Alt AGL	Alt AMSL	Avg Terr Ht	Max Gdspd	Avg Pt Spacing	Beg GB / Storage Name/#
FOV	Scan Freq	MpIA Y / N	Pulses in Air	Pulse Rate	Power	PPSM	End GB / Tot GB

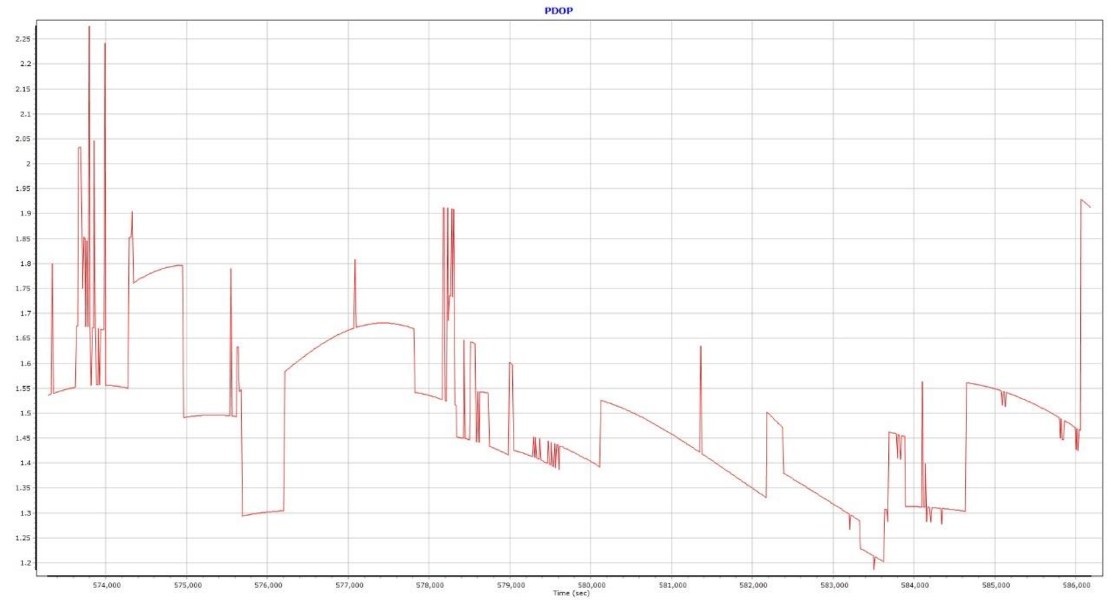
Line #	Hdg	Start (UTC):	End (UTC):	Gd Spd	PDOP/# Sats	GPS Altitude	Crab	Turb (0, -, +)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
TIE	E	15:37	15:51	161	1.05/19	13,516			FL 11 Corridor #12
100	S	15:58	16:17	128	1.06/19	13,491			
101	N	16:22	16:41	152	1.19/19	13,455			
102	S	16:46	17:04	146	1.04/20	13,428			
103	N	17:09	17:28	159	1.03/20	13,432			
104	S	17:33	17:52	150	1.07/18	13432			Possible cloud 16 mi from South end of line
105	N	17:56	18:15	156	1.00/19	13438			

Total Proj Lines:	Lines Flown:	Lines Remain:	Online Time:	Mob Time:	Notes:

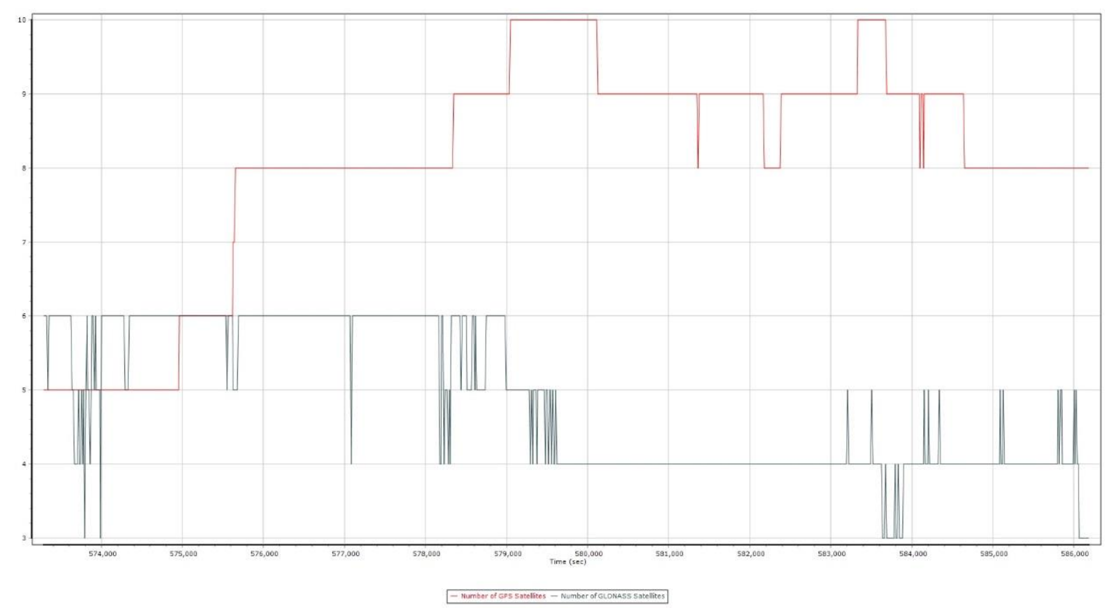
Mission Trajectory



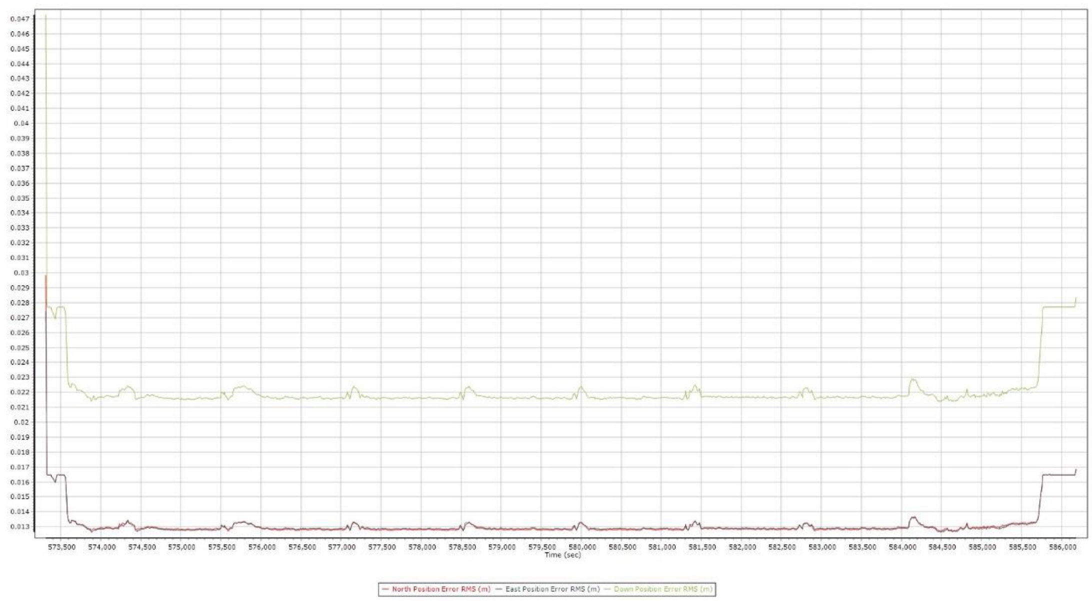
PDOP



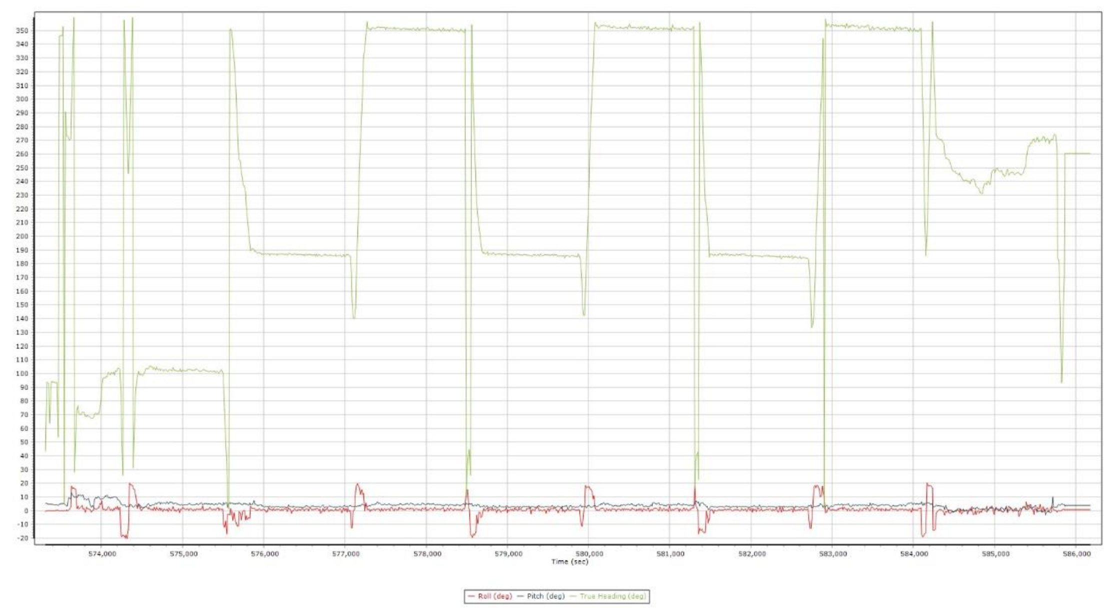
Satellites



RMS (m)

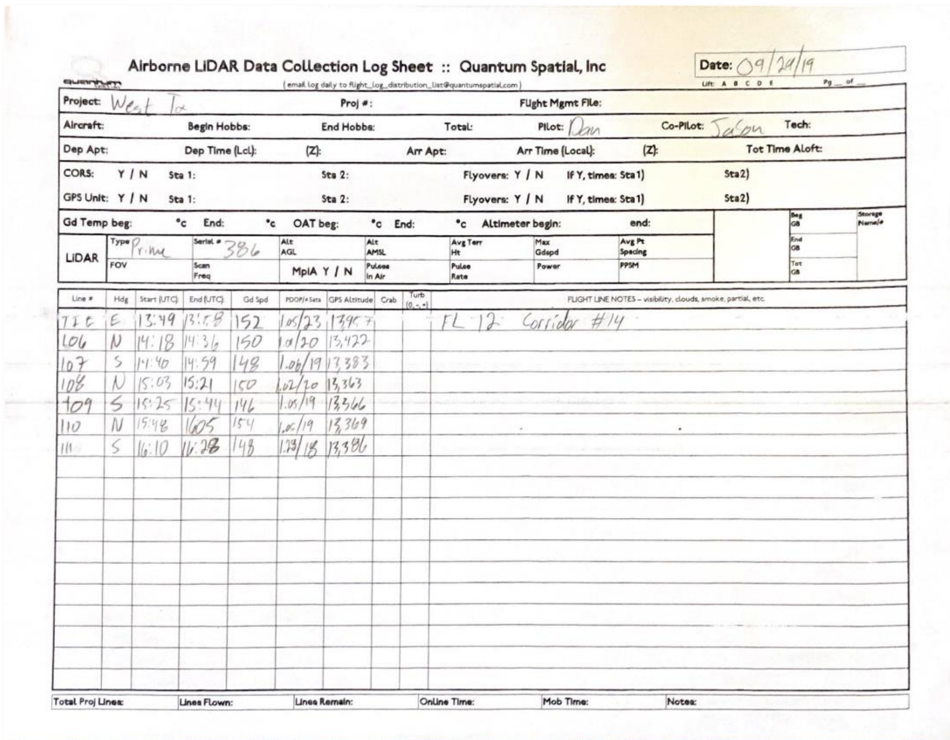

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 13 (20190929A)

Flight Log



Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 09/29/19

Lift: A B C D E Pg __ of __

Project: West Tx Proj #: Flight Mgmt File:

Aircraft: Begin Hobbs: End Hobbs: Total: Pilot: Dan Co-Pilot: Jason Tech:

Dep Apt: Dep Time (Lcl): (Z): Arr Apt: Arr Time (Local): (Z): Tot Time Aloft:

CORS: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

GPS Unit: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

Gd Temp beg: °c End: °c OAT beg: °c End: °c Altimeter begin: end:

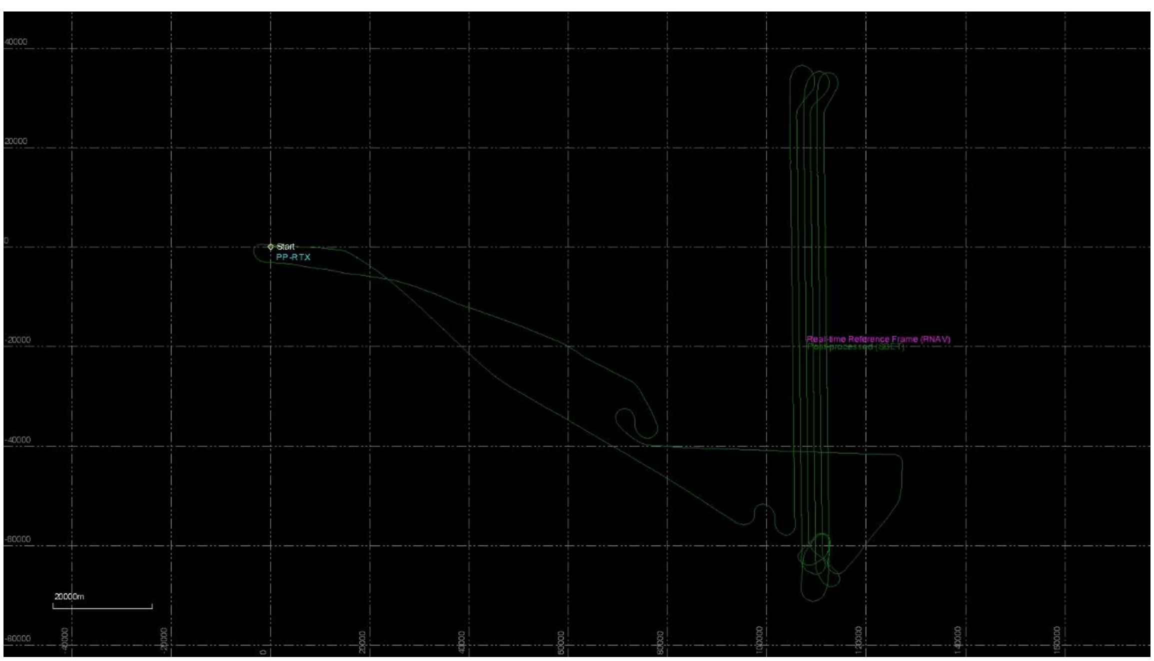
LiDAR: Type Prime | Serial # 386 | Alt AGL | Alt AMSL | Avg Terr Ht | Max Gdspd | Avg Pt Spacing | FOV | Scan Freq | MpIA Y / N | Pulses in Air | Pulse Rate | Power | PPSM

Beg GB | End GB | Tot GB | Storage Name/#

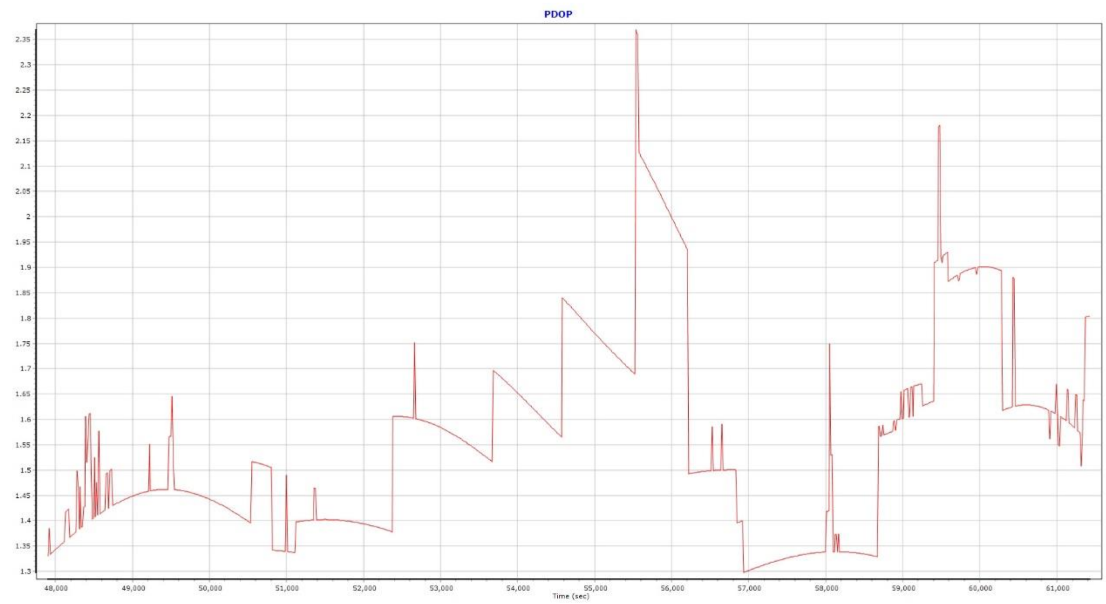
Line #	Hdg	Start (UTC)	End (UTC)	Gd Spd	PDOP/#Sats	GPS Altitude	Crab	Turb (0,-,+)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc
TIE	E	13:49	13:58	152	1.05/23	13,957			FL 12 Corridor #14
106	N	14:18	14:36	150	1.01/20	13,422			
107	S	14:40	14:59	148	1.06/19	13,383			
108	N	15:03	15:21	150	1.02/20	13,363			
109	S	15:25	15:44	146	1.05/19	13,366			
110	N	15:48	1605	154	1.06/19	13,369			
111	S	16:10	16:28	148	1.23/18	13,386			

Total Proj Lines: Lines Flown: Lines Remain: Online Time: Mob Time: Notes:

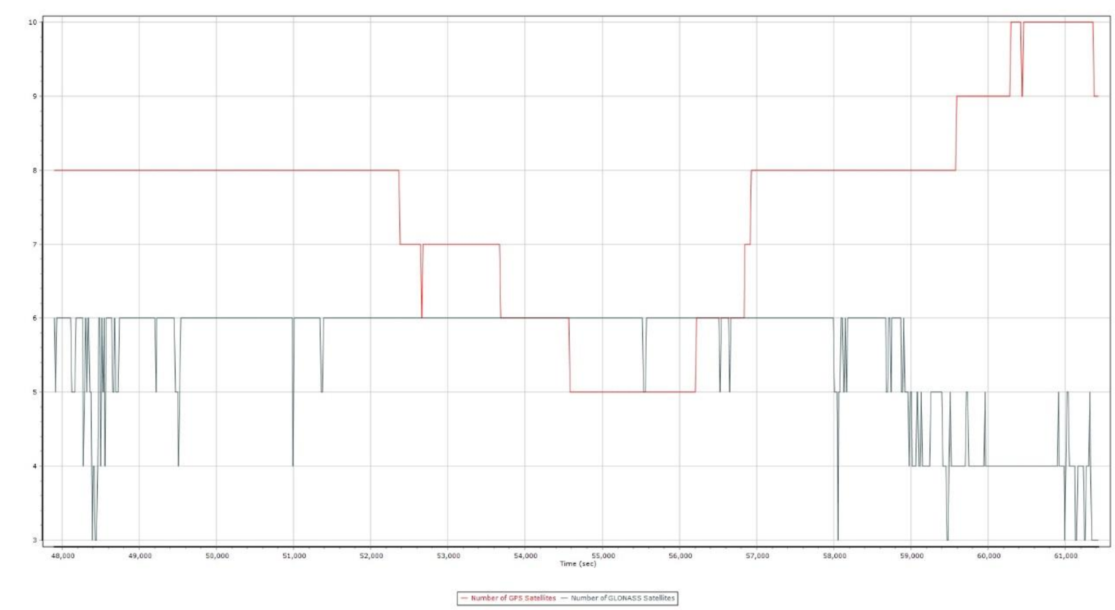
Mission Trajectory



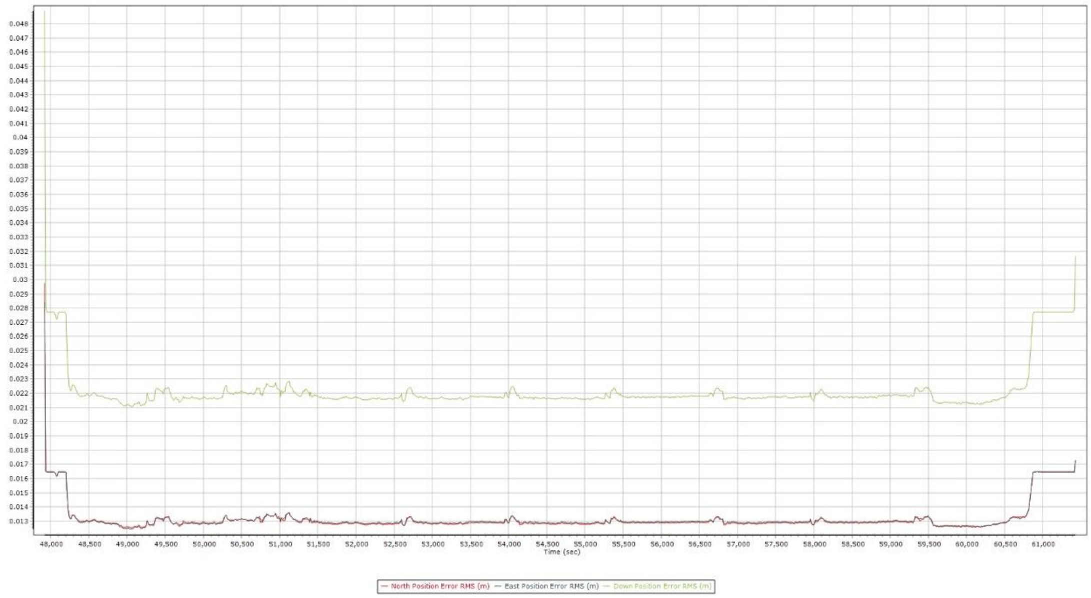
PDOP



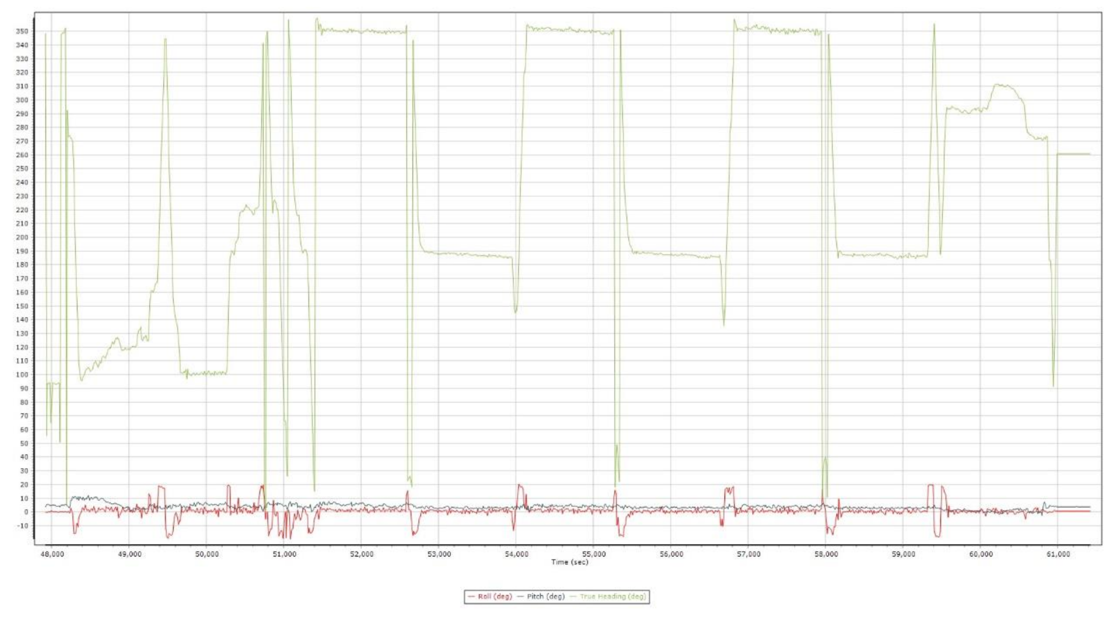
Satellites



RMS (m)

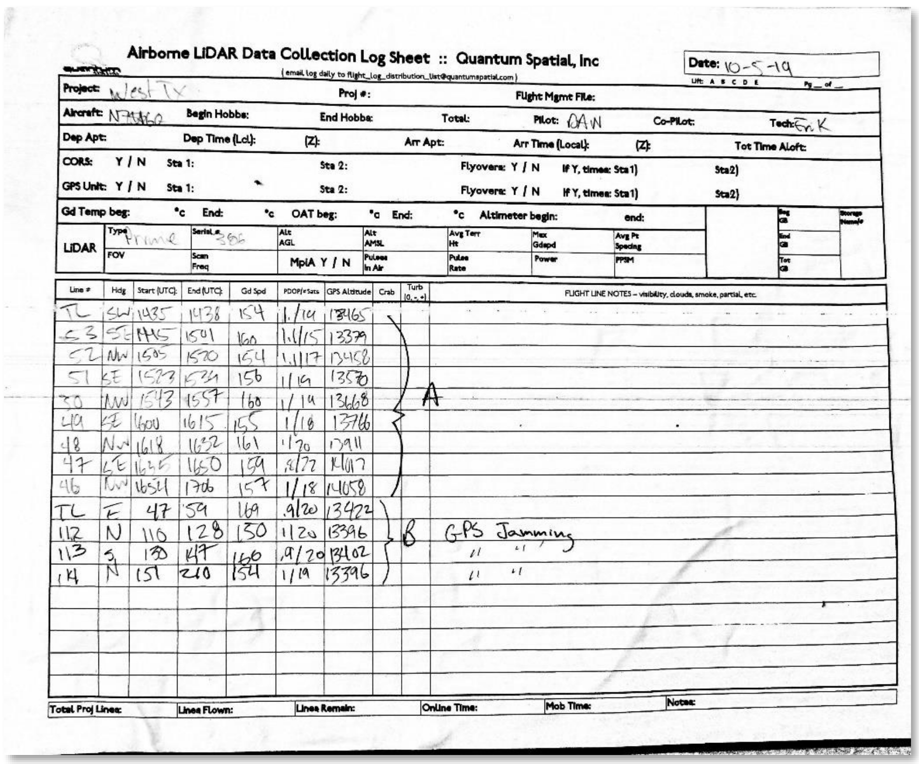

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 14 (20191005A)

Flight Log



Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 10-5-19 Lift: A B C D E Pg __ of __

Project: West Tx Proj #: Flight Mgmt File:

Aircraft: N7[illegible] Begin Hobbs: End Hobbs: Total: Pilot: DAW Co-Pilot: Tech: Eri K

Dep Apt: Dep Time (Lcl): (Z): Arr Apt: Arr Time (Local): (Z): Tot Time Aloft:

CORS: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

GPS Unit: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

Gd Temp beg: °c End: °c OAT beg: °c End: °c Altimeter begin: end:

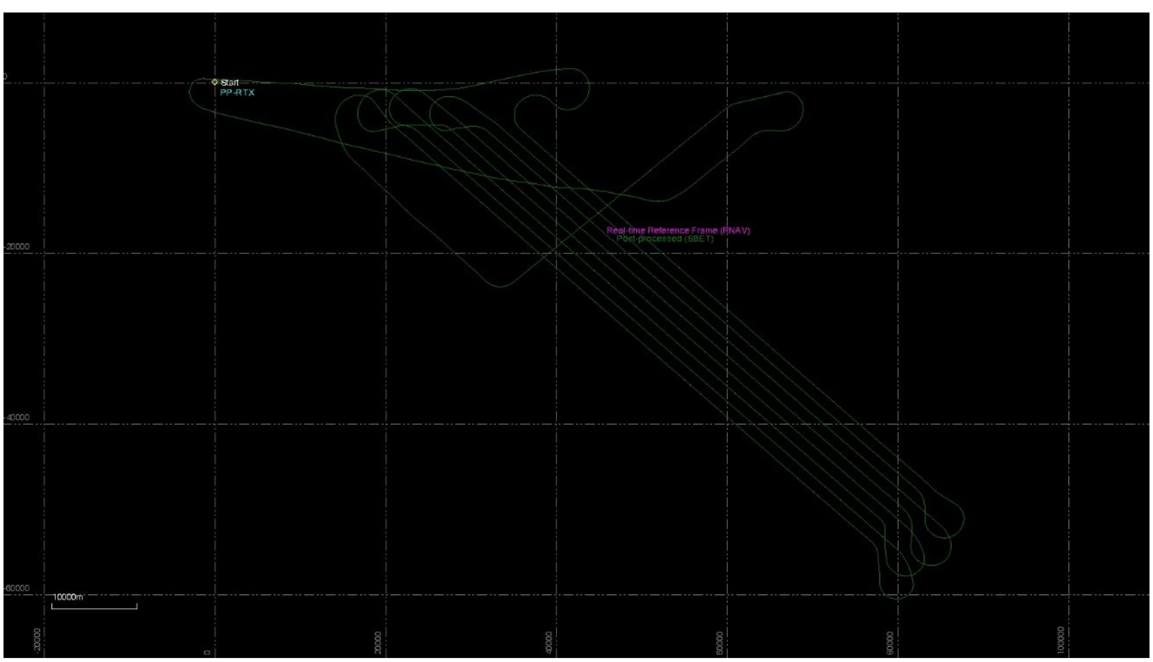
LiDAR Type: Prime Serial #: 386 Alt AGL Alt AMSL Avg Terr Ht Max Gdspd Avg Pt Spacing Beg GB End GB Tot GB Storage Name/#

FOV Scan Freq MpiA Y / N Pulses In Air Pulse Rate Power PPSM

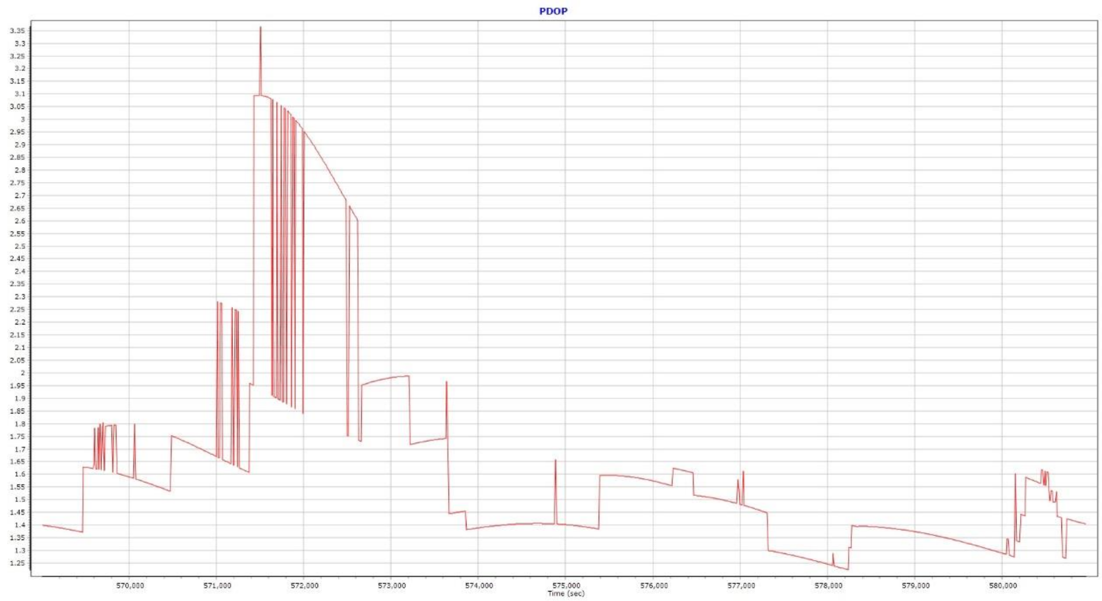
Line #	Hdg	Start (UTC):	End (UTC):	Gd Spd	PDOP/#Sats	GPS Altitude	Crab	Turb (0, -, +)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
TL	SW	1435	1438	154	1./14	13465			A
53	SE	1445	1501	160	1.1/15	13379			
52	NW	1505	1520	154	1.1/17	13458			
51	SE	1523	1534	156	1/19	13570			
50	NW	1543	1557	160	1/14	13668			
49	SE	1600	1615	155	1/18	13766			
48	NW	1618	1632	161	1/20	13911			
47	SE	1635	1650	159	.8/22	14017			
46	NW	1654	1706	157	1/18	14058			
TL	E	47	59	169	.9/20	13422			B
112	N	110	128	150	1/20	13396			GPS Jamming
113	S	130	147	160	.9/20	13402			" "
114	N	151	210	154	1/19	13396			" "

Total Proj Lines: Lines Flown: Lines Remain: Online Time: Mob Time: Notes:

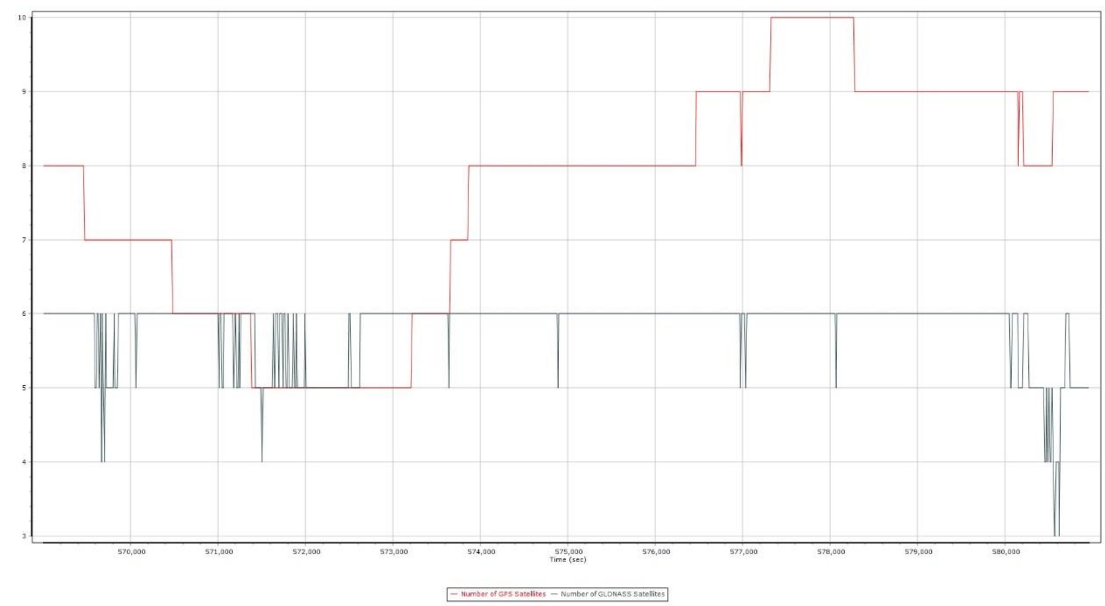
Mission Trajectory



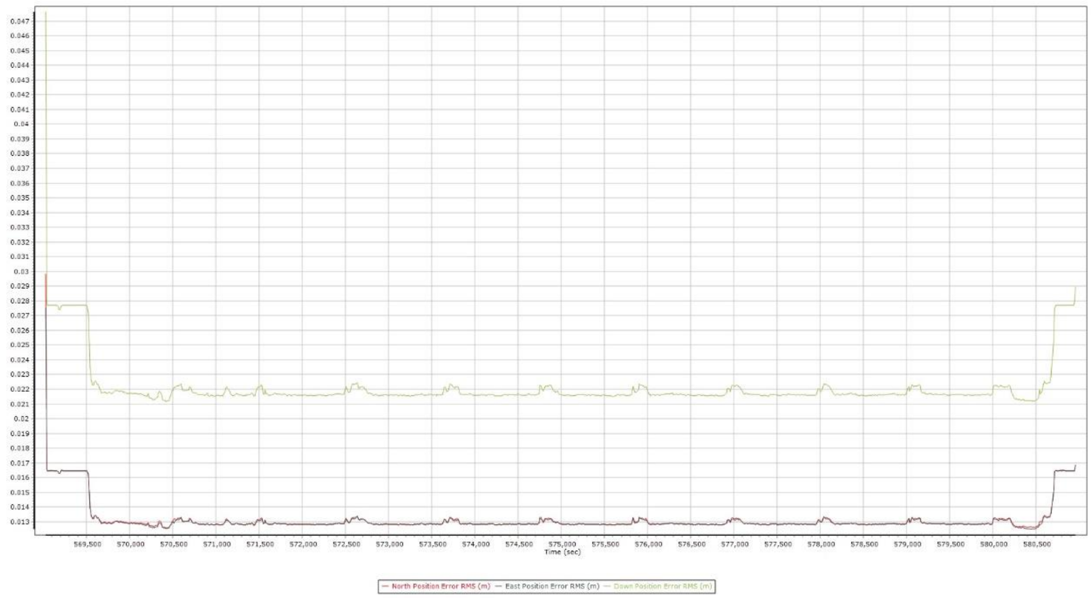
PDOP



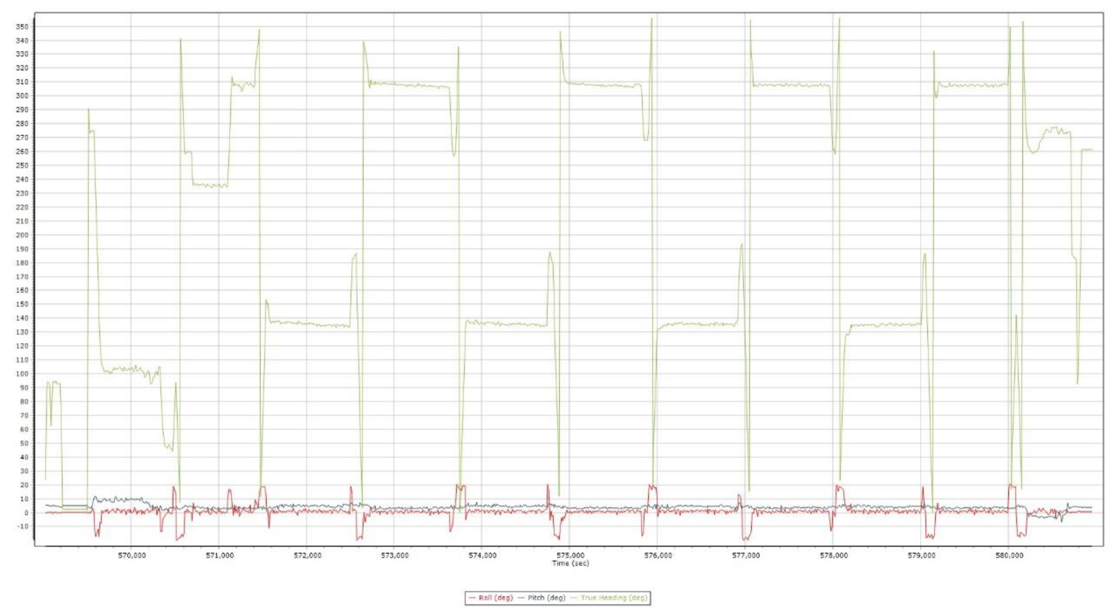
Satellites



RMS (m)

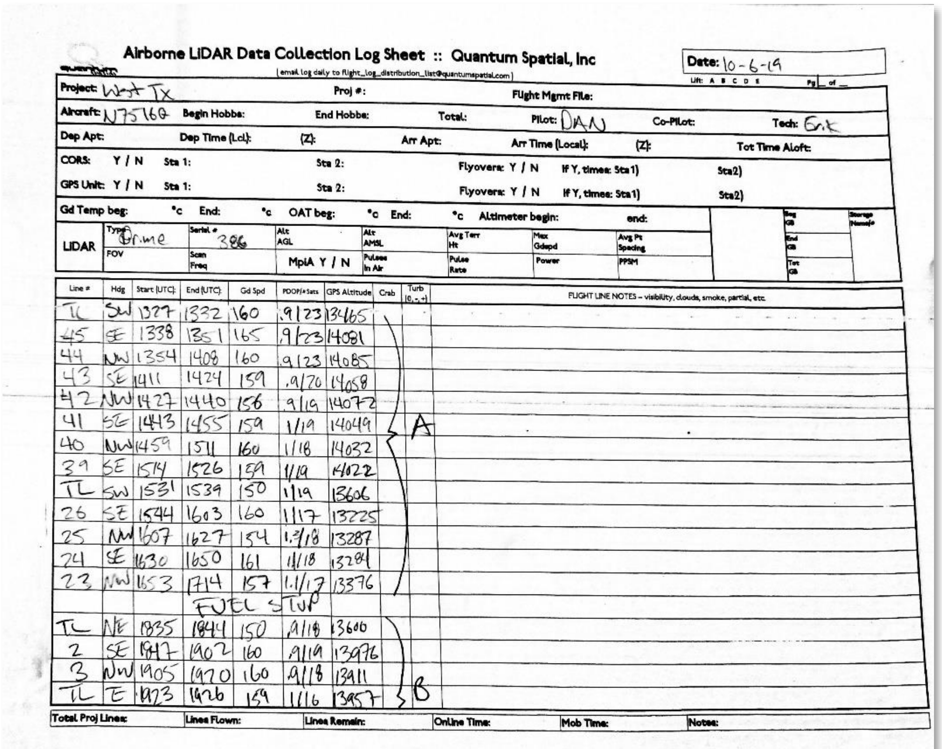

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 15 (20191006A)

Flight Log


Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 10-6-19

Lift: A B C D E Pg __ of __

Project: West Tx Proj #: Flight Mgmt File:

Aircraft: N7516Q Begin Hobbs: End Hobbs: Total: Pilot: DAN Co-Pilot: Tech: Erik

Dep Apt: Dep Time (Lcl): (Z): Arr Apt: Arr Time (Local): (Z): Tot Time Aloft:

CORS: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

GPS Unit: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

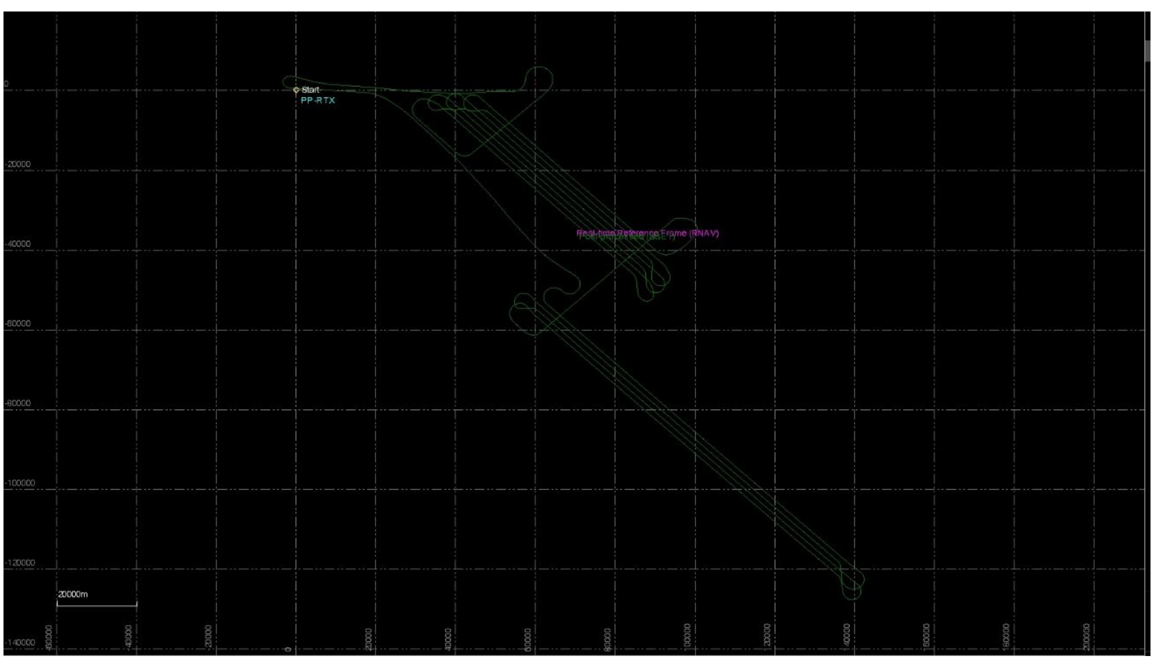
Gd Temp beg: °c End: °c OAT beg: °c End: °c Altimeter begin: end:

LIDAR — Type: Prime Serial #: 386 Alt AGL: Alt AMSL: Avg Terr Ht: Max Gdspd: Avg Pt Spacing: FOV: Scan Freq: MpiA Y / N Pulses In Air: Pulse Rate: Power: PPSM: Beg GB: End GB: Tot GB: Storage Name/#:

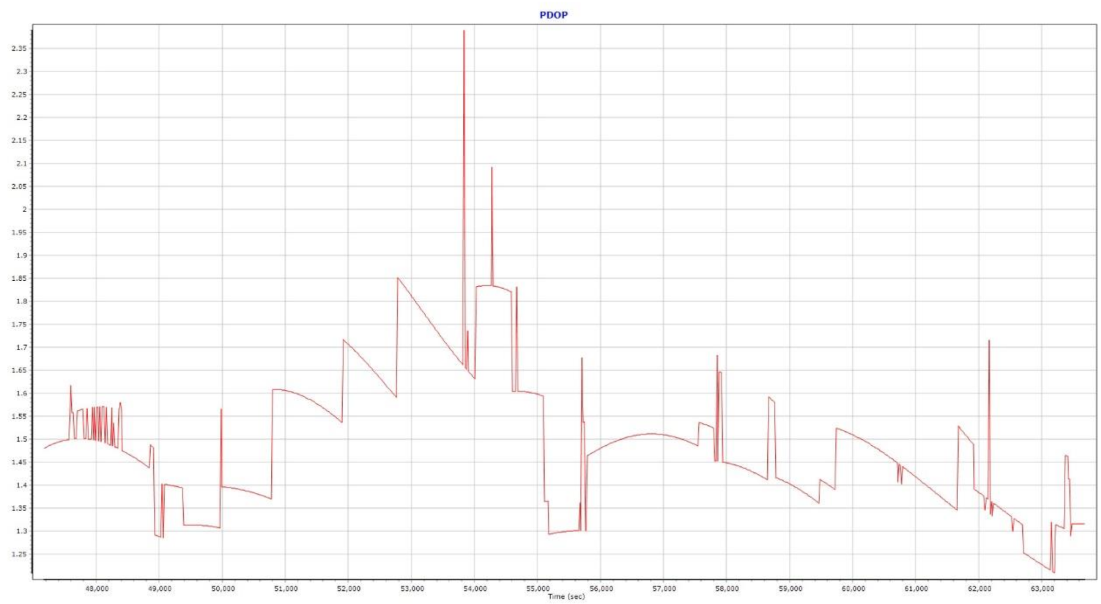
Line #	Hdg	Start (UTC)	End (UTC)	Gd Spd	PDOP/#Sats	GPS Altitude	Crab	Turb (0,-,+)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
TL	SW	1327	1332	160	.9/23	13465			
45	SE	1338	1351	165	.9/23	14081			
44	NW	1354	1408	160	.9/23	14085			
43	SE	1411	1424	159	.9/20	14058			
42	NW	1427	1440	156	.9/19	14072			
41	SE	1443	1455	159	1/19	14049		A	
40	NW	1459	1511	160	1/18	14032			
39	SE	1514	1526	159	1/19	14022			
TL	SW	1531	1539	150	1/19	13606			
26	SE	1544	1603	160	1/17	13225			
25	NW	1607	1627	154	1.3/18	13287			
24	SE	1630	1650	161	1.1/18	13284			
23	NW	1653	1714	157	1.1/17	13376			
			FUEL STOP						
TL	NE	1835	1844	150	.9/18	13600			
2	SE	1847	1902	160	.9/19	13976			
3	NW	1905	1920	160	.9/18	13911			
TL	E	1923	1926	159	1/16	13957		B	

Total Proj Lines: Lines Flown: Lines Remain: Online Time: Mob Time: Notes:

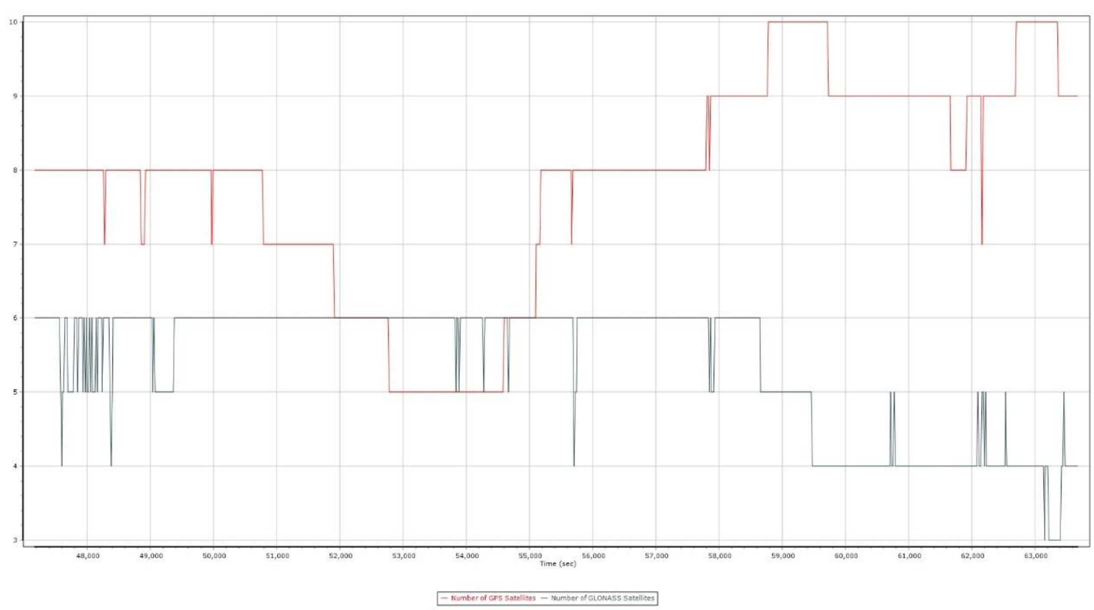
Mission Trajectory



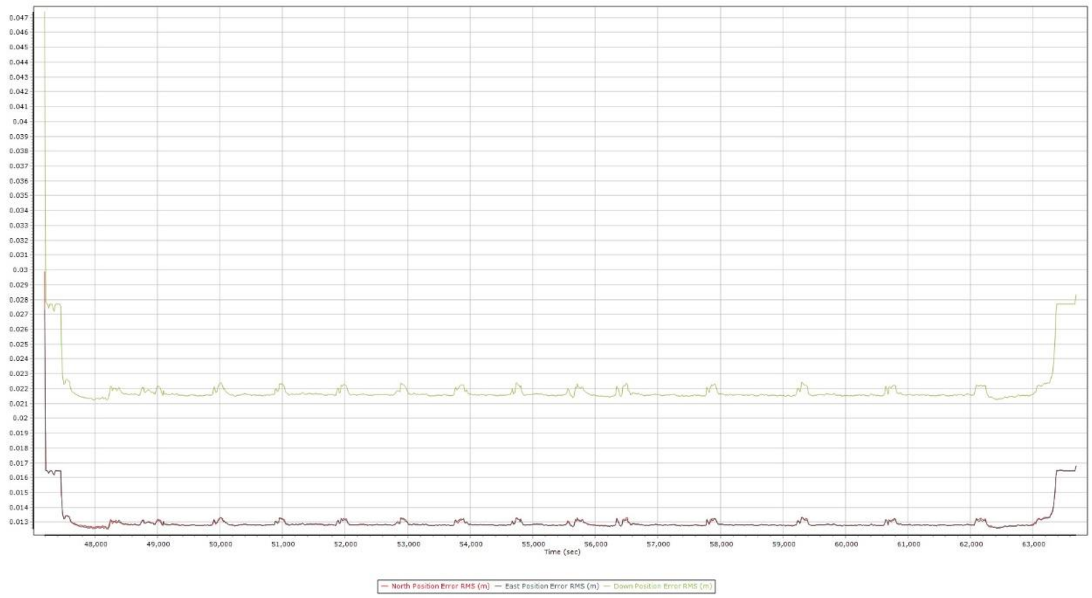
PDOP



Satellites

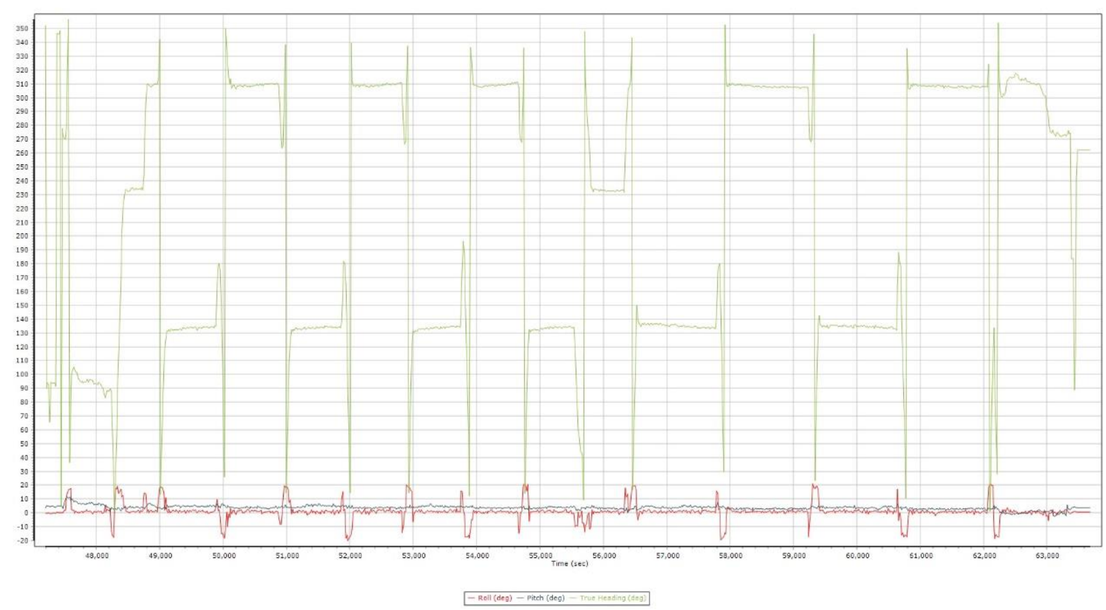


RMS (m)



Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

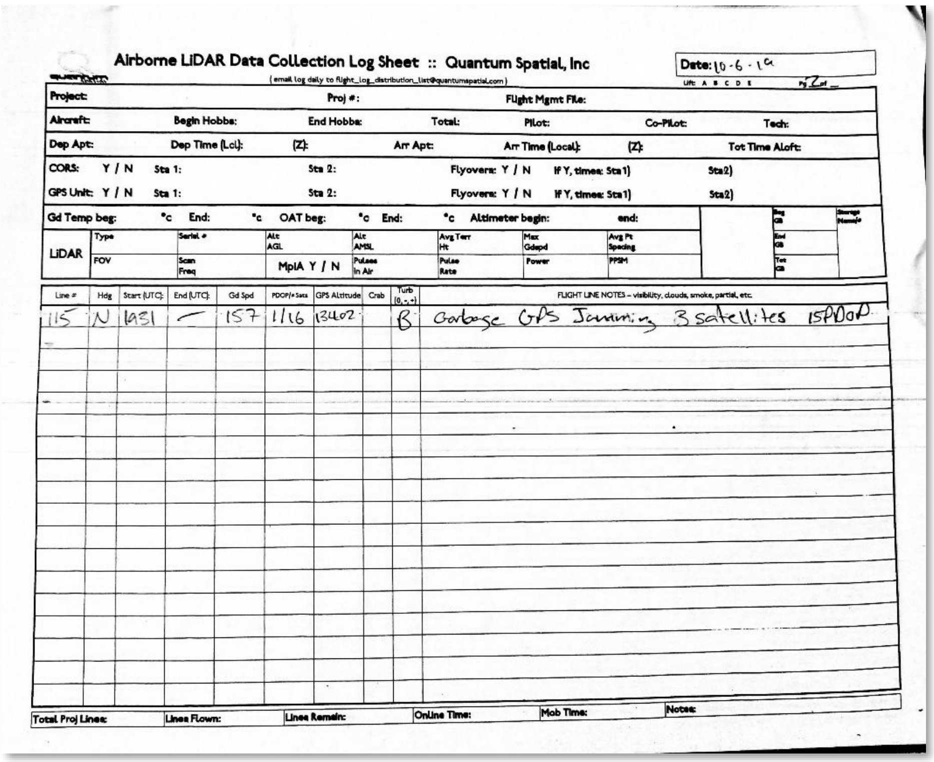
RPH (deg)



Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 16 (20191006B)

Flight Log



Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 10-6-19

Lift: A B C D E   Pg 2 of __

Project: Proj #:   Flight Mgmt File:

Aircraft: Begin Hobbs: End Hobbs: Total: Pilot: Co-Pilot: Tech:

Dep Apt: Dep Time (Lcl):   (Z):   Arr Apt: Arr Time (Local):   (Z):   Tot Time Aloft:

CORS: Y / N   Sta 1:   Sta 2:   Flyovers: Y / N   If Y, times: Sta1)   Sta2)

GPS Unit: Y / N   Sta 1:   Sta 2:   Flyovers: Y / N   If Y, times: Sta1)   Sta2)

Gd Temp beg: °c   End: °c   OAT beg: °c   End: °c   Altimeter begin: end:

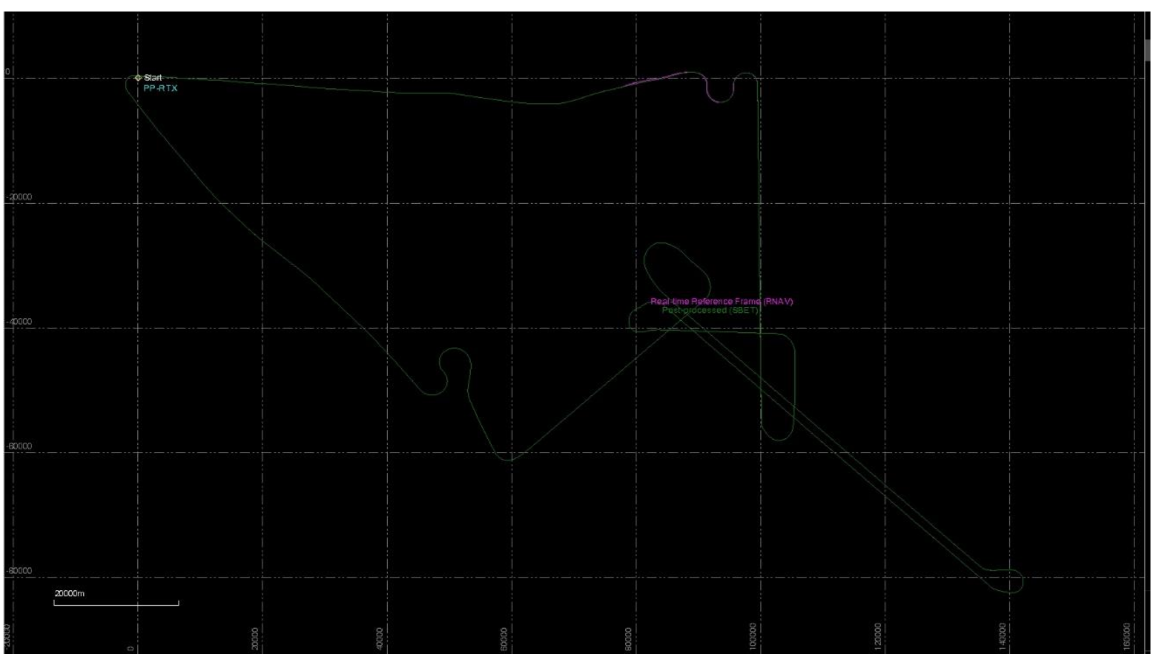
LiDAR: Type   Serial #   Alt AGL   Alt AMSL   Avg Terr Ht   Max Gdspd   Avg Pt Spacing
FOV   Scan Freq   MpIA Y / N   Pulses in Air   Pulse Rate   Power   PPSM

Beg GB   End GB   Tot GB   Storage Name/#

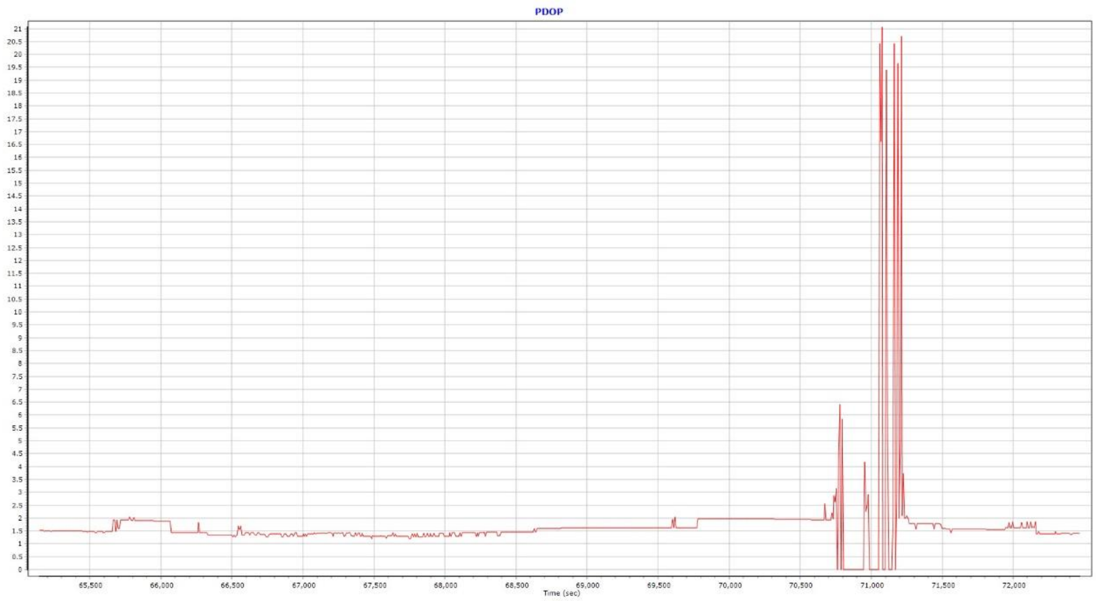
Line #	Hdg	Start (UTC):	End (UTC):	Gd Spd	PDOP/# Sats	GPS Altitude	Crab	Turb (0, -, +)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
115	N	1931	—	157	1/16	13402		B	Garbage GPS Jamming 3 satellites 15PDOP

Total Proj Lines: Lines Flown: Lines Remain: Online Time: Mob Time: Notes:

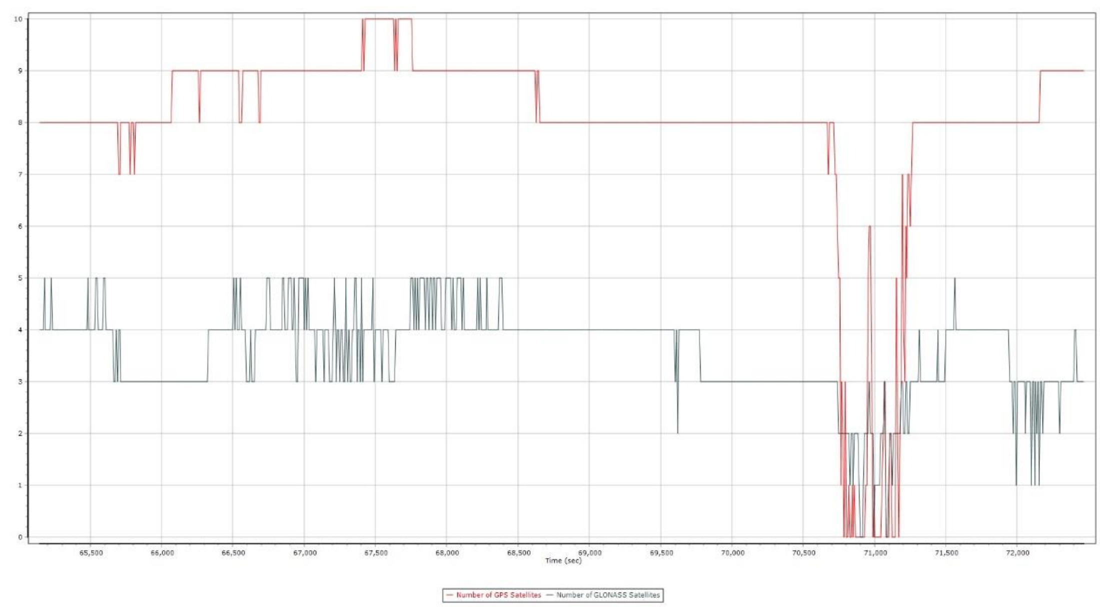
Mission Trajectory



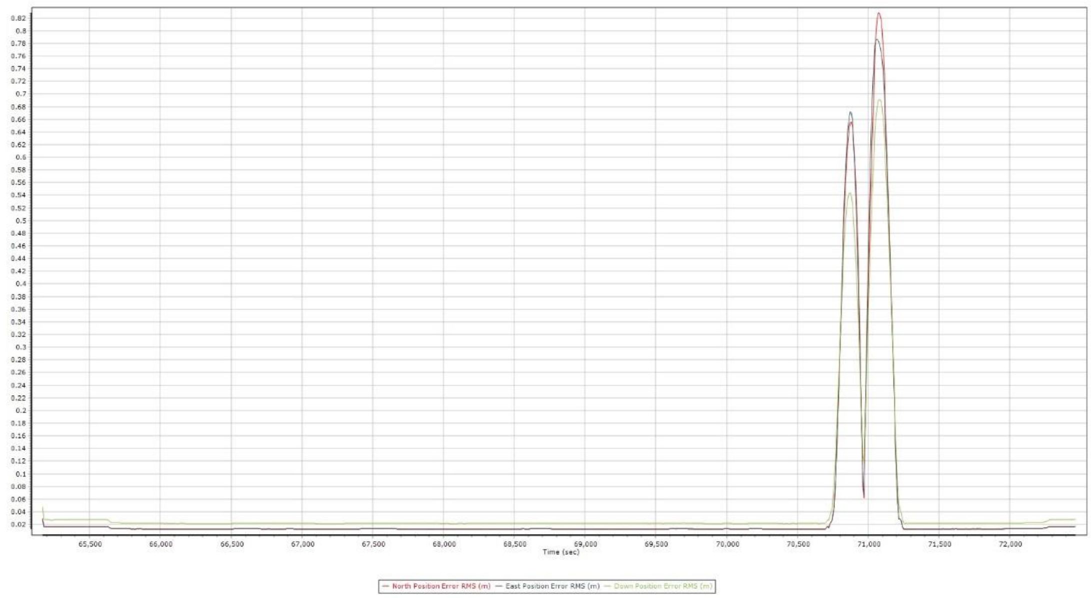
PDOP



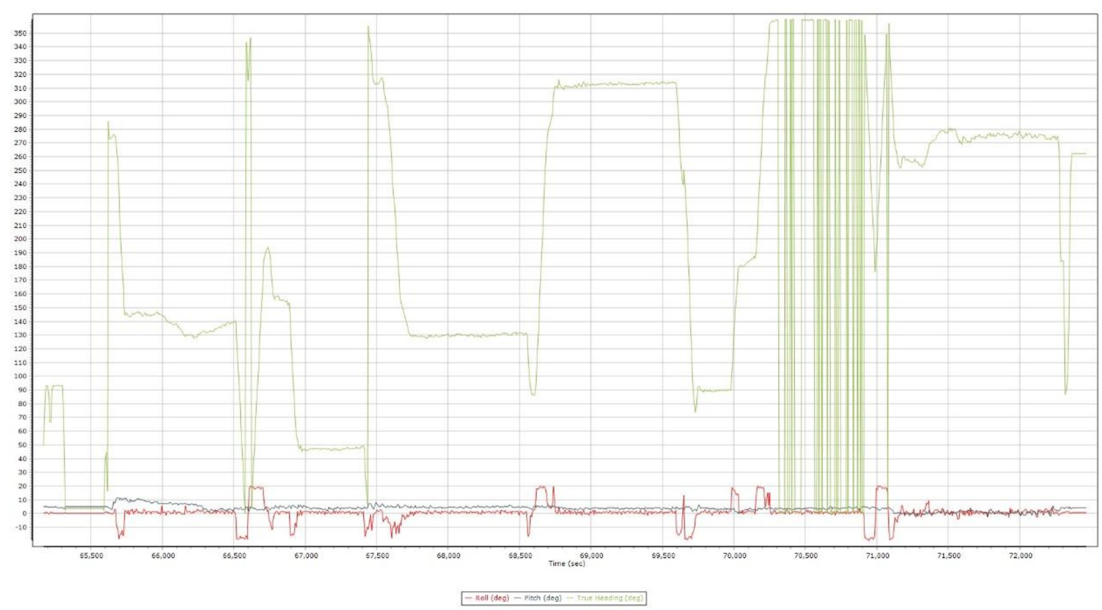
Satellites



RMS (m)

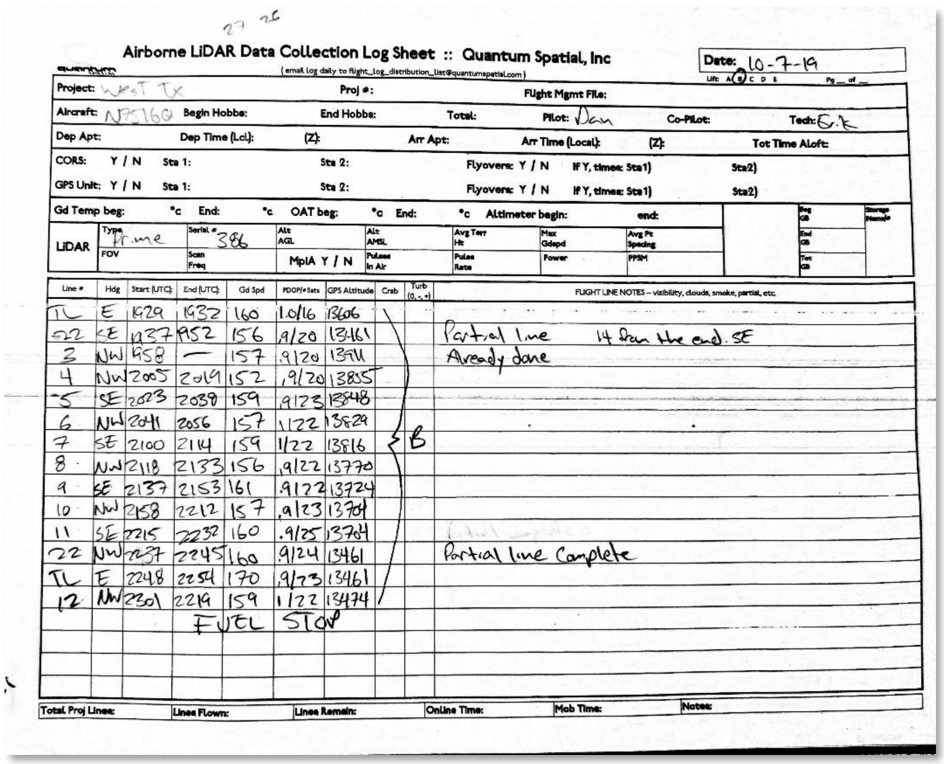

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 17 (20191007B)

Flight Log



27 26

Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 10-7-19

Lift: A (B) C D E Pg __ of __

Project: West Tx Proj #: Flight Mgmt File:

Aircraft: N7516Q Begin Hobbs: End Hobbs: Total: Pilot: Dan Co-Pilot: Tech: E.K

Dep Apt: Dep Time (Lcl): (Z): Arr Apt: Arr Time (Local): (Z): Tot Time Aloft:

CORS: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

GPS Unit: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

Gd Temp beg: °c End: °c OAT beg: °c End: °c Altimeter begin: end:

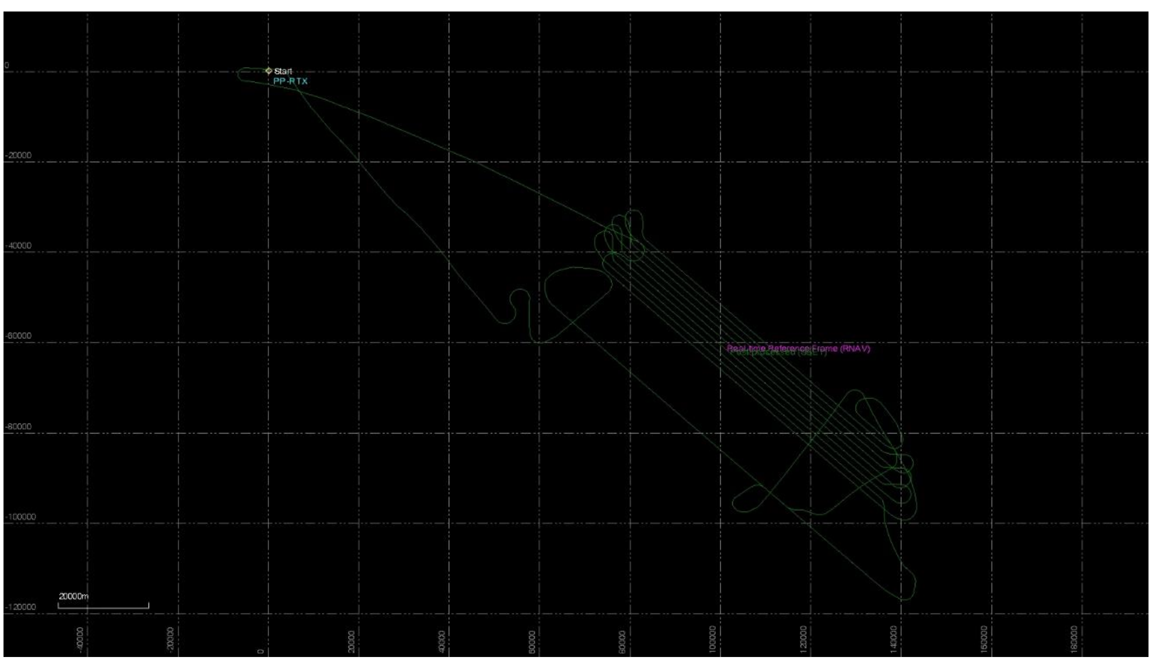
LiDAR Type: Prime Serial #: 386 Alt AGL Alt AMSL Avg Terr Ht Max Gdspd Avg Pt Spacing Beg GB Storage Name/#

FOV Scan Freq MpIA Y / N Pulses in Air Pulse Rate Power PPSM End GB Tot GB

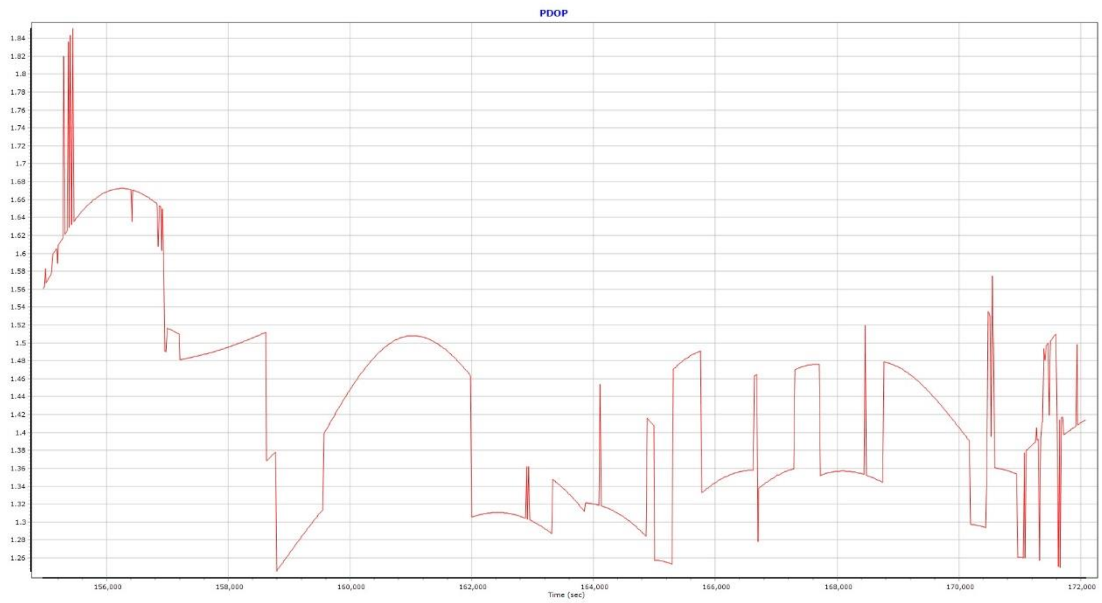
Line #	Hdg	Start (UTC)	End (UTC)	Gd Spd	PDOP/#Sats	GPS Altitude	Crab	Turb (0, -, +)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
TL	E	1929	1932	160	1.0/16	13606			
22	SE	1937	1952	156	.9/20	13461			Partial line 14 from the end. SE
3	NW	1958	—	157	.9/20	13911			Already done
4	NW	2005	2019	152	.9/20	13855			
5	SE	2023	2038	159	.9/23	13848			
6	NW	2041	2056	157	1/22	13829			
7	SE	2100	2114	159	1/22	13816		B	
8	NW	2118	2133	156	.9/22	13770			
9	SE	2137	2153	161	.9/22	13724			
10	NW	2158	2212	157	.9/23	13704			
11	SE	2215	2232	160	.9/25	13704			
22	NW	2237	2245	160	.9/24	13461			Partial line Complete
TL	E	2248	2254	170	.9/23	13461			
12	NW	2301	2219	159	1/22	13474			
			FUEL	STOP					

Total Proj Lines: Lines Flown: Lines Remain: Online Time: Mob Time: Notes:

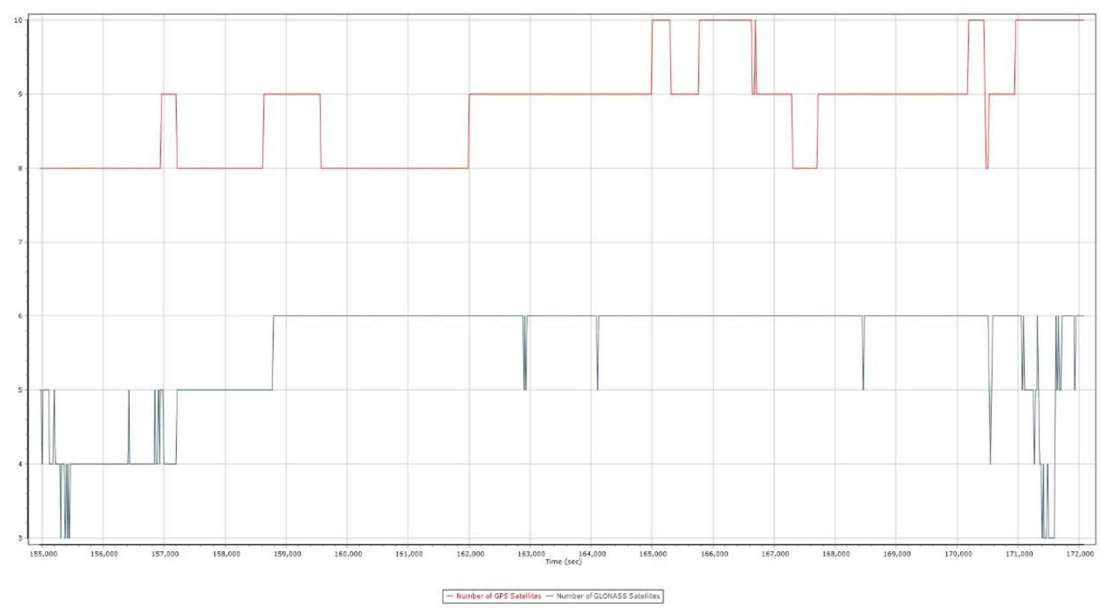
Mission Trajectory



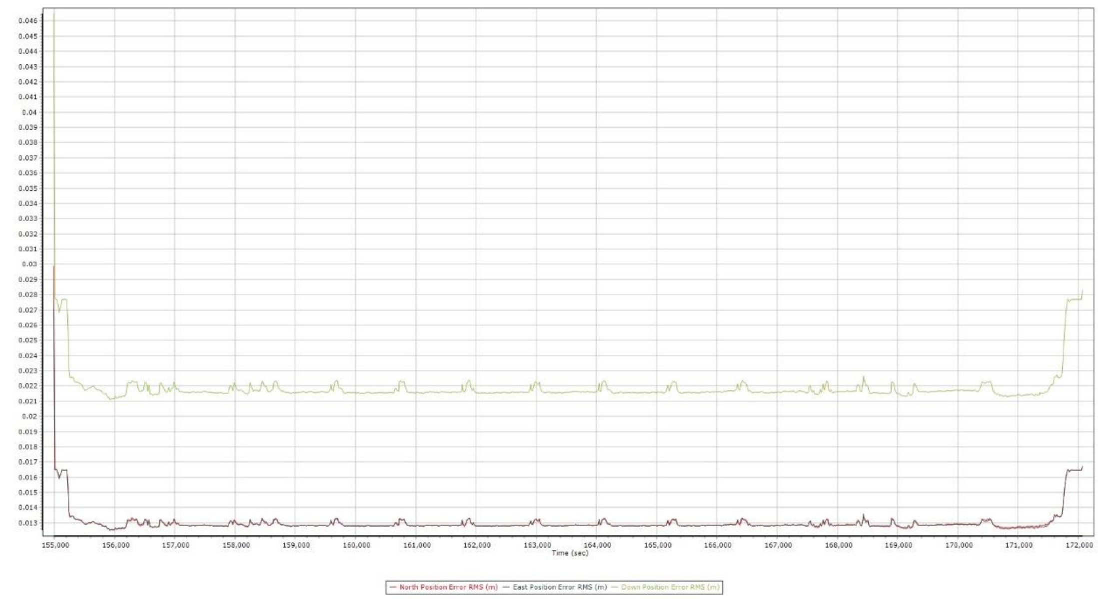
PDOP



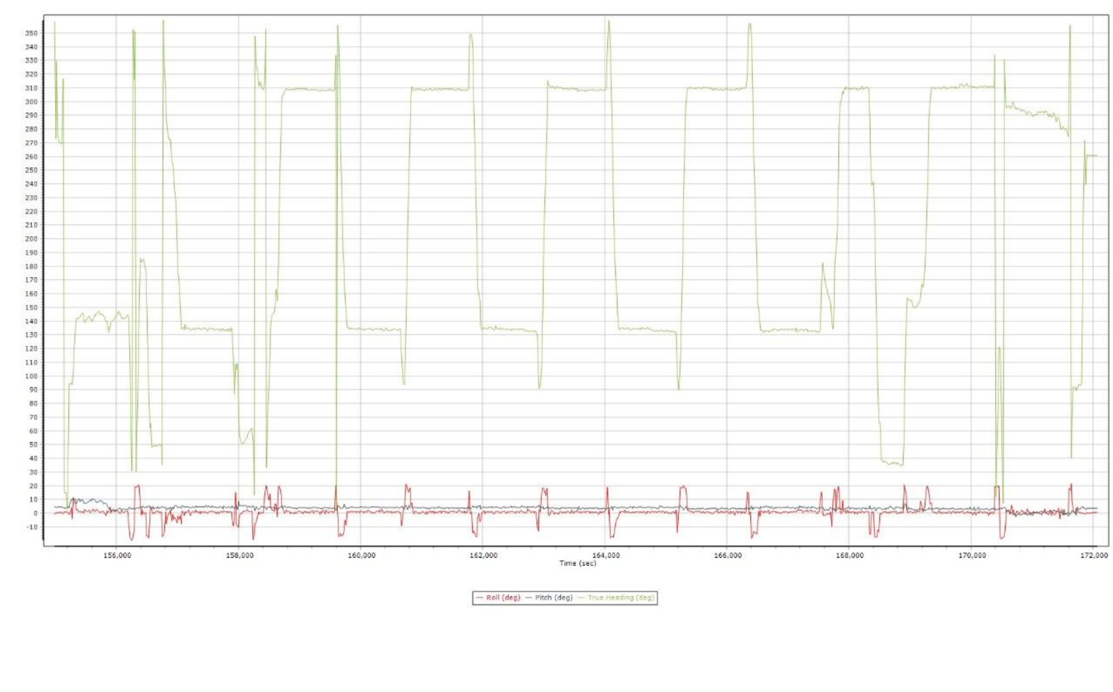
Satellites



RMS (m)

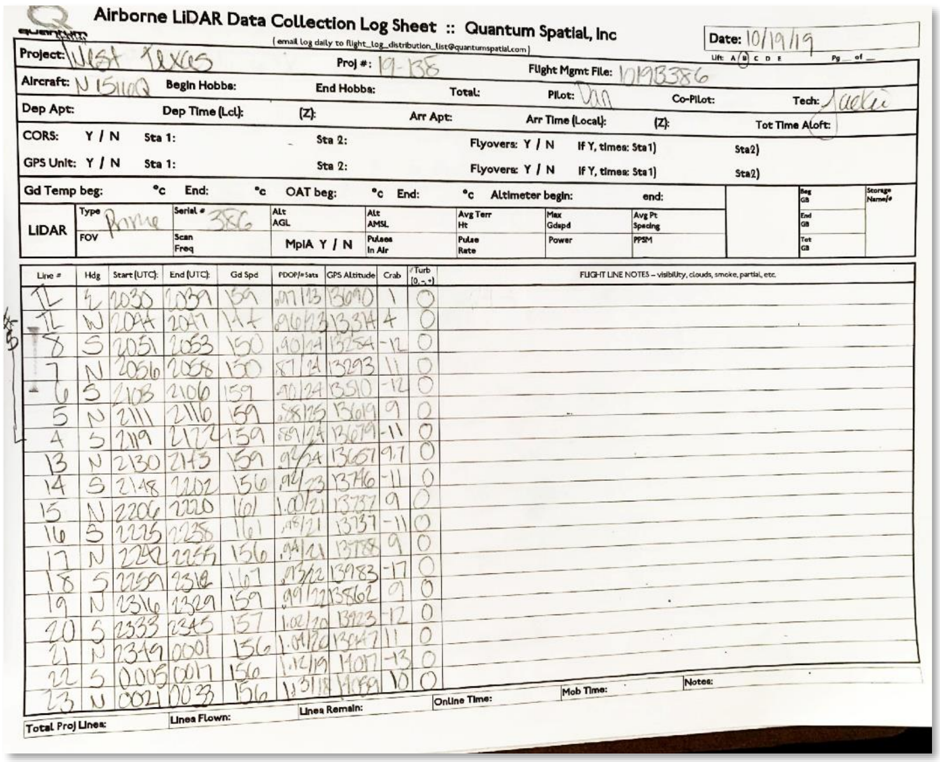

0.046
0.045
0.044
0.043
0.042
0.041
0.04
0.039
0.038
0.037
0.036
0.035
0.034
0.033
0.032
0.031
0.03
0.029
0.028
0.027
0.026
0.025
0.024
0.023
0.022
0.021
0.02
0.019
0.018
0.017
0.016
0.015
0.014
0.013
155,000
156,000
157,000
158,000
159,000
160,000
161,000
162,000
163,000
164,000
165,000
166,000
167,000
168,000
169,000
170,000
171,000
172,000
Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


350
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
156,000
158,000
160,000
162,000
164,000
166,000
168,000
170,000
172,000
Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 19 (20191019A)

Flight Log



Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 10/19/19 Lift: A (B) C D E Pg ___ of ___

Project: West Texas Proj #: 19-138 Flight Mgmt File: 10193386

Aircraft: N 1511Q Begin Hobbs: End Hobbs: Total: Pilot: Dan Co-Pilot: Tech: Jackie

Dep Apt: Dep Time (Lcl): (Z): Arr Apt: Arr Time (Local): (Z): Tot Time Aloft:

CORS: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

GPS Unit: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

Gd Temp beg: °c End: °c OAT beg: °c End: °c Altimeter begin: end:

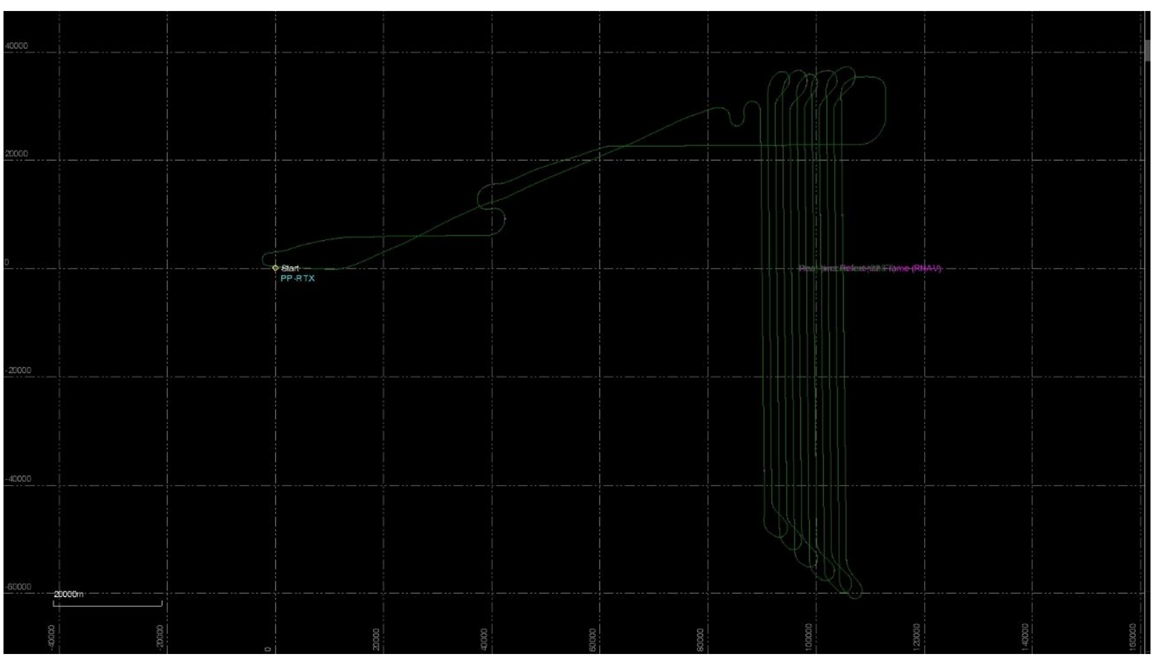
LIDAR Type: Prime Serial #: 386 Alt AGL: Alt AMSL: Avg Terr Ht: Max Gdspd: Avg Pt Spacing: Beg GB: Storage Name/#:

FOV: Scan Freq: MpIA Y / N Pulses In Air: Pulse Rate: Power: PPSM: End GB: Tot GB:

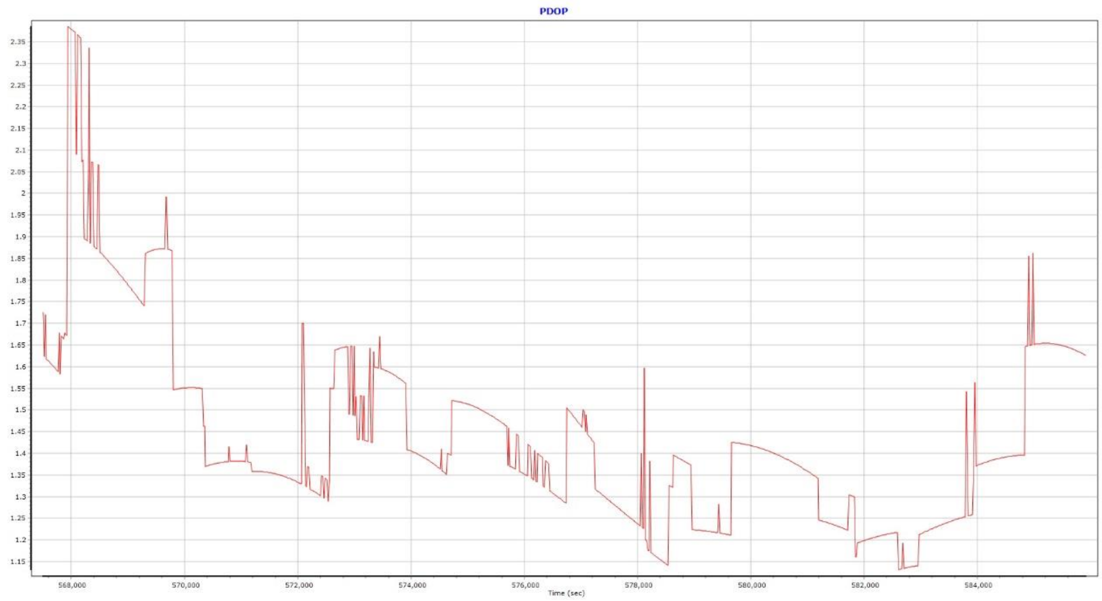
Line #	Hdg	Start (UTC):	End (UTC):	Gd Spd	PDOP/#Sats	GPS Altitude	Crab	Turb (0, -, +)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
TL	S	2030	2039	159	.97/13	13690	1	0	
TL	N	2044	2047	147	.96/23	13,314	4	0	
8	S	2051	2053	150	.90/24	13254	-12	0	
7	N	2056	2058	150	.87/24	13293	11	0	
6	S	2103	2106	159	.90/24	13510	-12	0	
5	N	2111	2116	159	.88/25	13619	9	0	
4	S	2119	2122	159	.89/24	13679	-11	0	
13	N	2130	2143	159	.92/24	13657	9.7	0	
14	S	2148	2202	156	.92/23	13746	-11	0	
15	N	2206	2220	161	1.00/21	13737	9	0	
16	S	2225	2238	161	.98/21	13737	-11	0	
17	N	2242	2255	156	.94/21	13788	9	0	
18	S	2259	2312	167	.93/22	13983	-17	0	
19	N	2316	2329	159	.99/22	13862	9	0	
20	S	2333	2345	157	1.02/20	13923	-12	0	
21	N	2349	0001	156	1.04/20	13947	11	0	
22	S	0005	0017	156	1.12/19	14017	-13	0	
23	N	0021	0033	156	1.13/18	14059	10	0	

Total Proj Lines: Lines Flown: Lines Remain: Online Time: Mob Time: Notes:

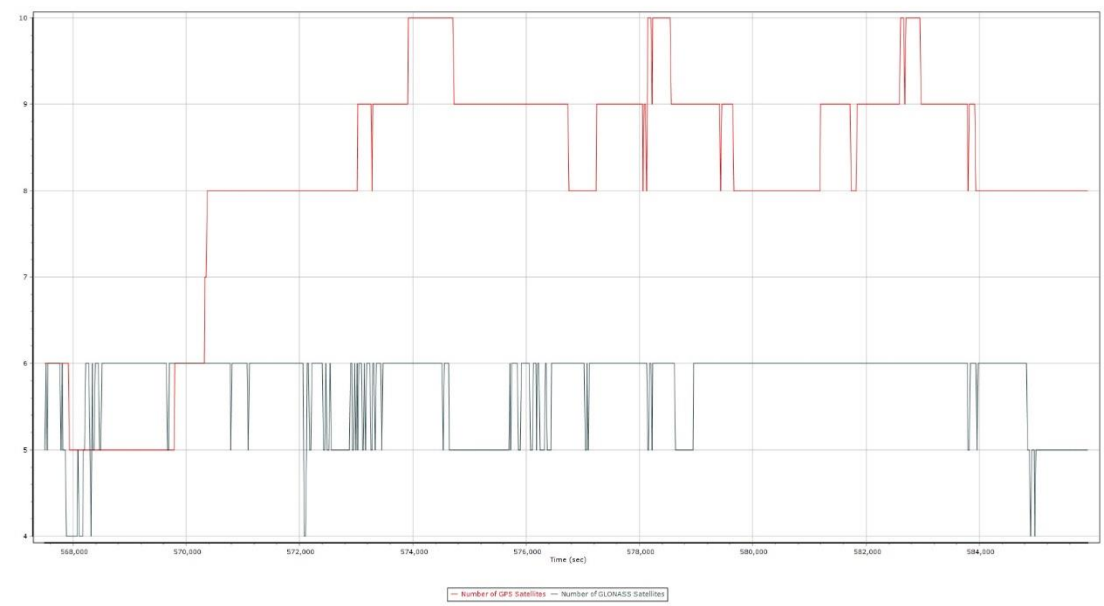
Mission Trajectory



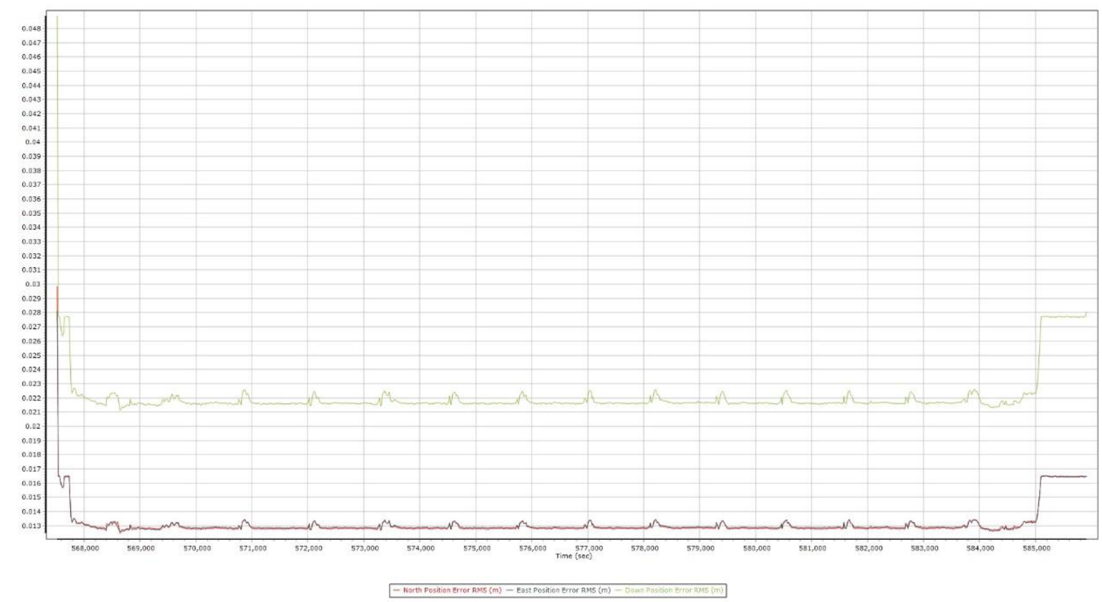
PDOP



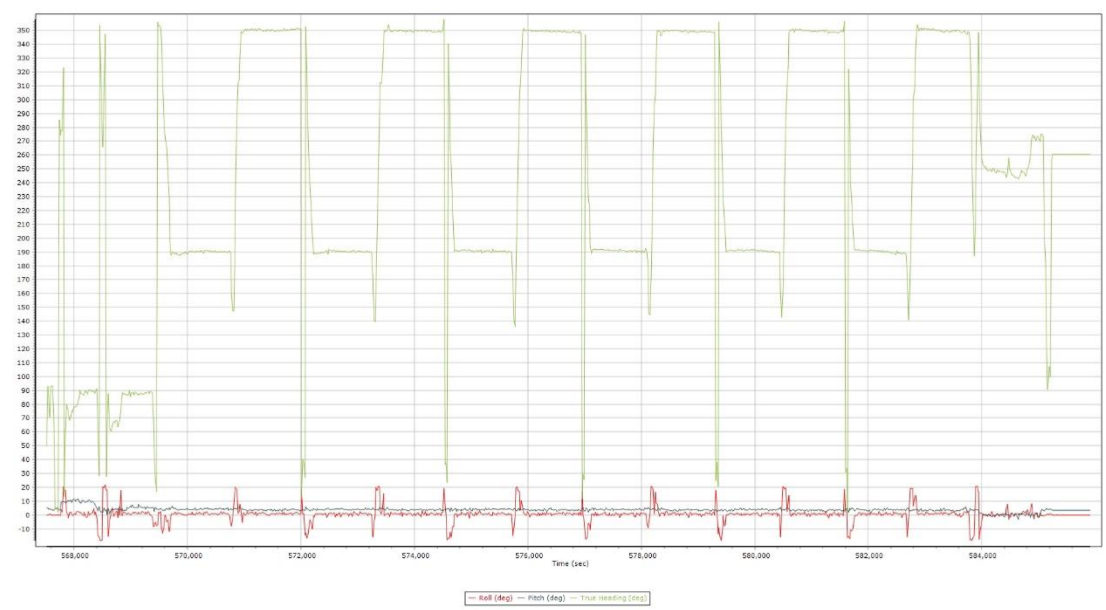
Satellites



RMS (m)

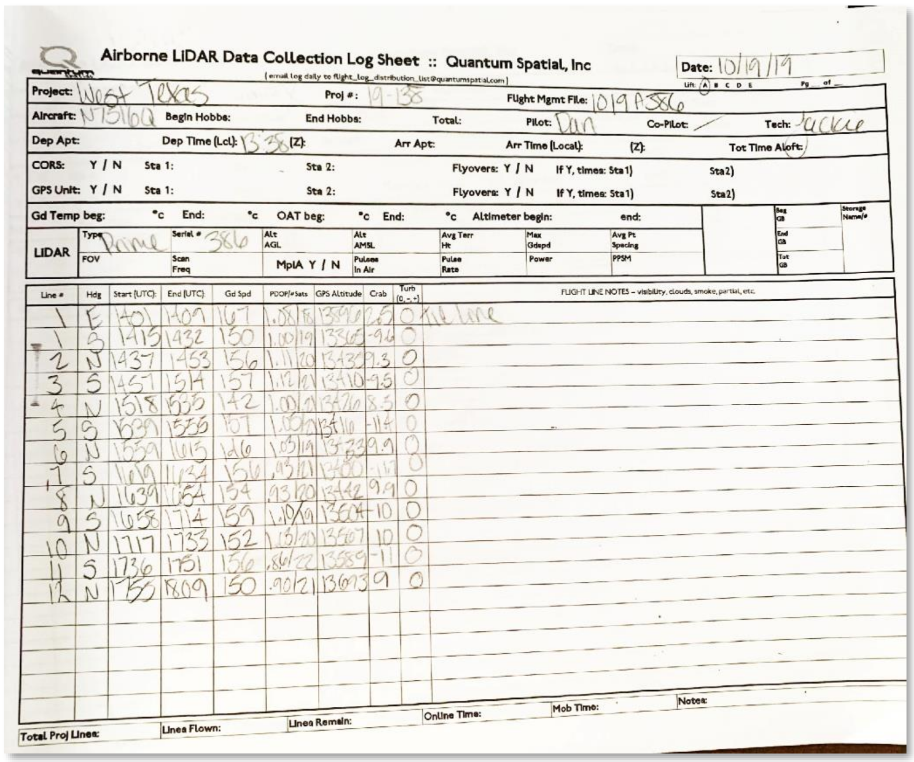

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 20 (20191019B)

Flight Log



Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 10/19/19 Lift: A B C D E Pg __ of __

Project: West Texas Proj #: 19-138 Flight Mgmt File: 1019A386

Aircraft: N7516Q Begin Hobbs: End Hobbs: Total: Pilot: Dan Co-Pilot: / Tech: Jackie

Dep Apt: Dep Time (Lcl): 13:38 (Z): Arr Apt: Arr Time (Local): (Z): Tot Time Aloft:

CORS: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

GPS Unit: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

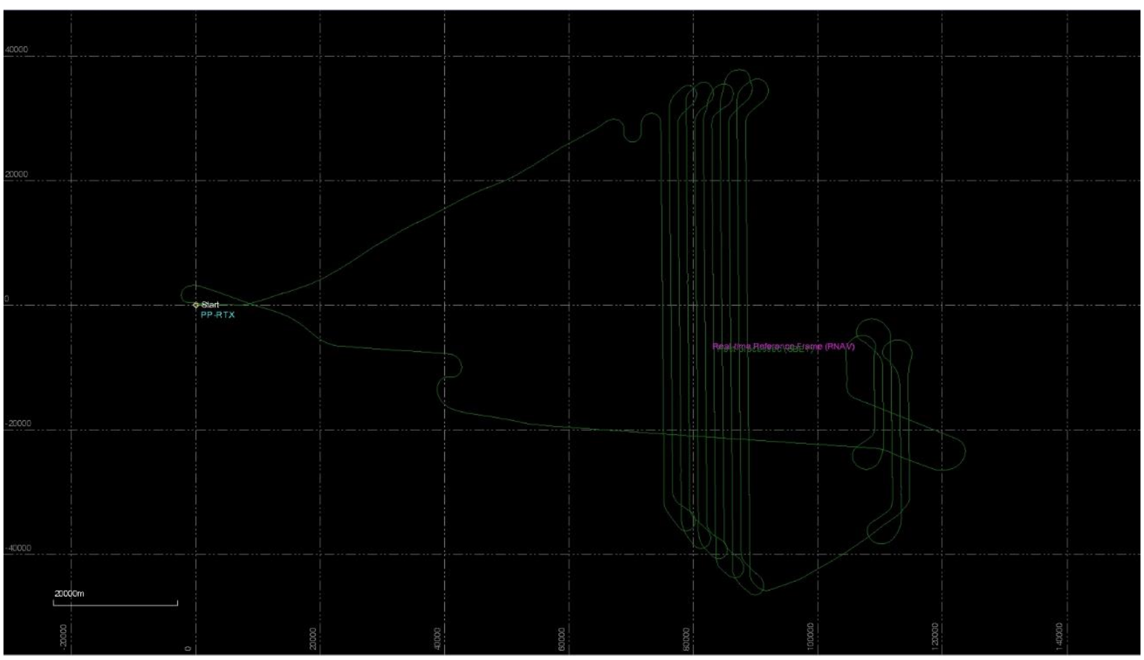
Gd Temp beg: °c End: °c OAT beg: °c End: °c Altimeter begin: end:

LIDAR — Type: Prime; Serial #: 386; Alt AGL; Alt AMSL; Avg Terr Ht; Max Gdspd; Avg Pt Spacing; FOV; Scan Freq; MpIA Y / N; Pulses In Air; Pulse Rate; Power; PPSM; Beg GB; End GB; Tot GB; Storage Name/#

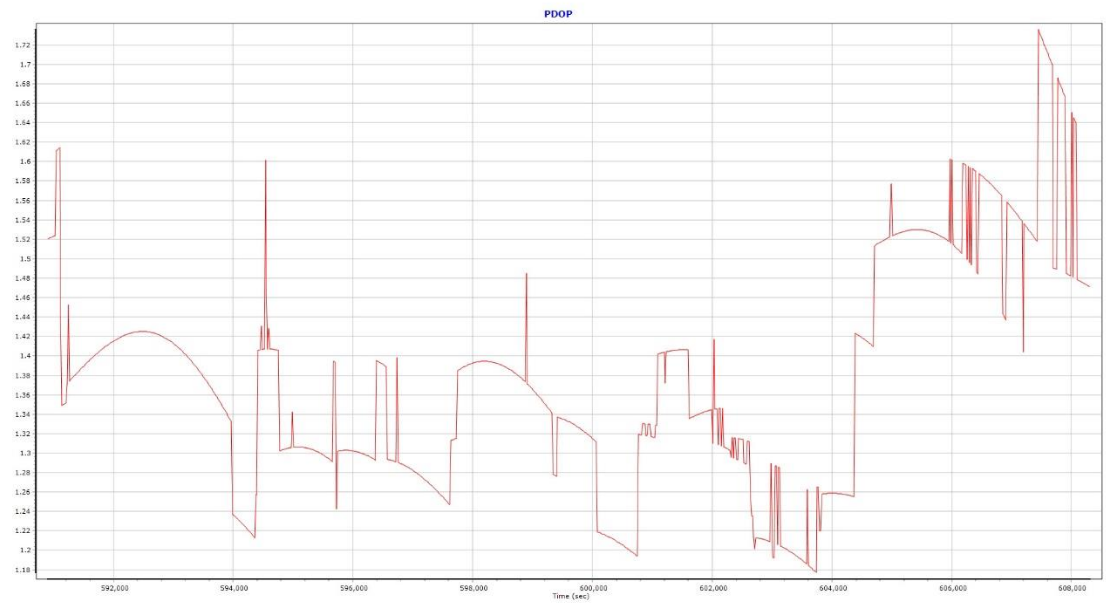
Line #	Hdg	Start (UTC)	End (UTC)	Gd Spd	PDOP/#Sats	GPS Altitude	Crab	Turb (0,-,+)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
1	E	1401	1409	167	1.08/18	13596	2.5	0	tie line
1	S	1415	1432	150	1.00/19	13365	-9.6	0	
2	N	1437	1453	156	1.11/20	13430	9.3	0	
3	S	1457	1514	157	1.12/21	13410	-9.5	0	
4	N	1518	1535	142	1.00/21	13426	8.5	0	
5	S	1539	1556	157	1.00/20	13410	-11.4	0	
6	N	1559	1615	146	1.03/19	13433	9.9	0	
7	S	1619	1634	156	.93/21	13400	-11.7	0	
8	N	1639	1654	154	.93/20	13442	9.9	0	
9	S	1658	1714	159	1.10/19	13604	-10	0	
10	N	1717	1733	152	1.13/20	13507	10	0	
11	S	1736	1751	156	.86/22	13589	-11	0	
12	N	1755	1809	150	.90/21	13673	9	0	

Total Proj Lines: Lines Flown: Lines Remain: Online Time: Mob Time: Notes:

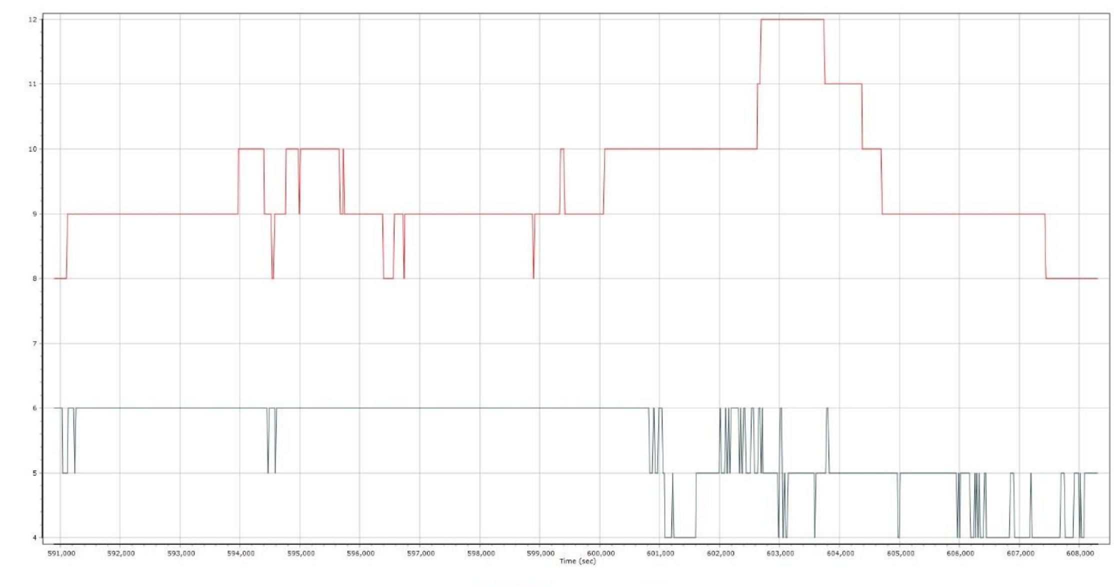
Mission Trajectory



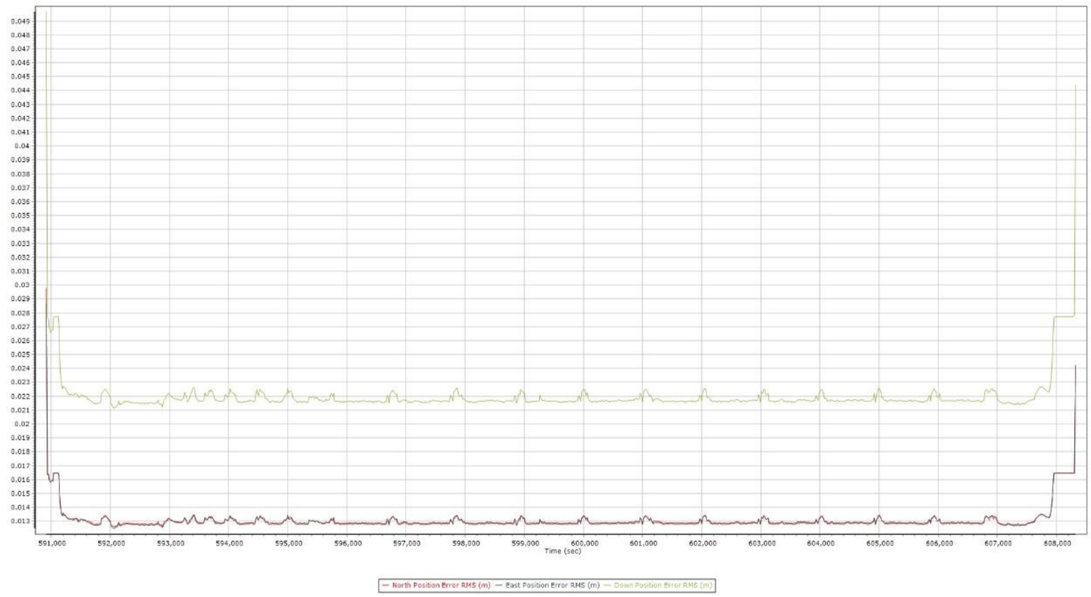
PDOP



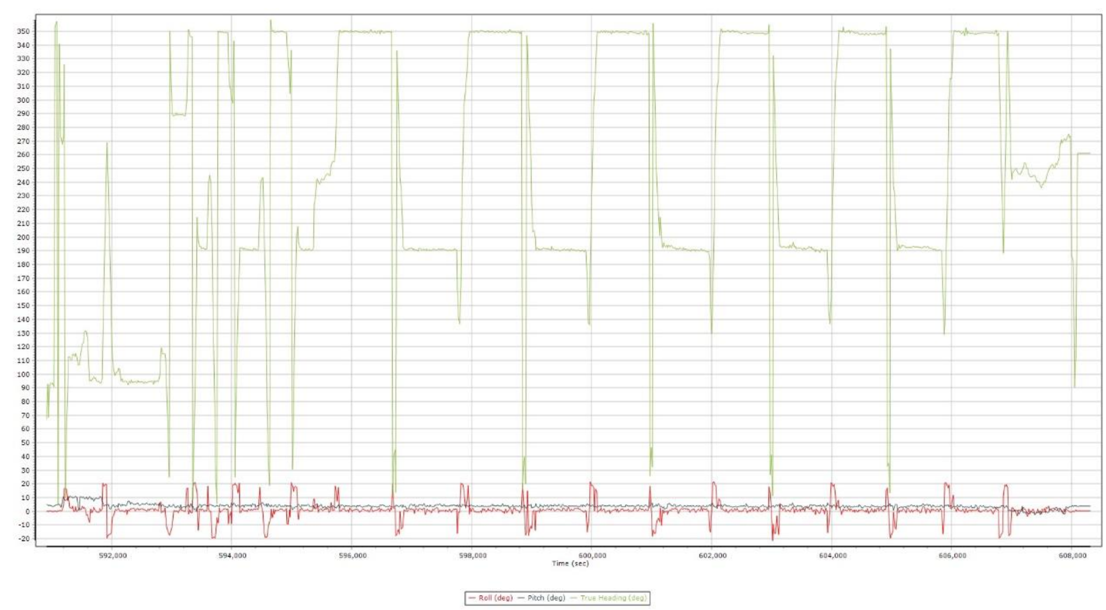
Satellites



RMS (m)

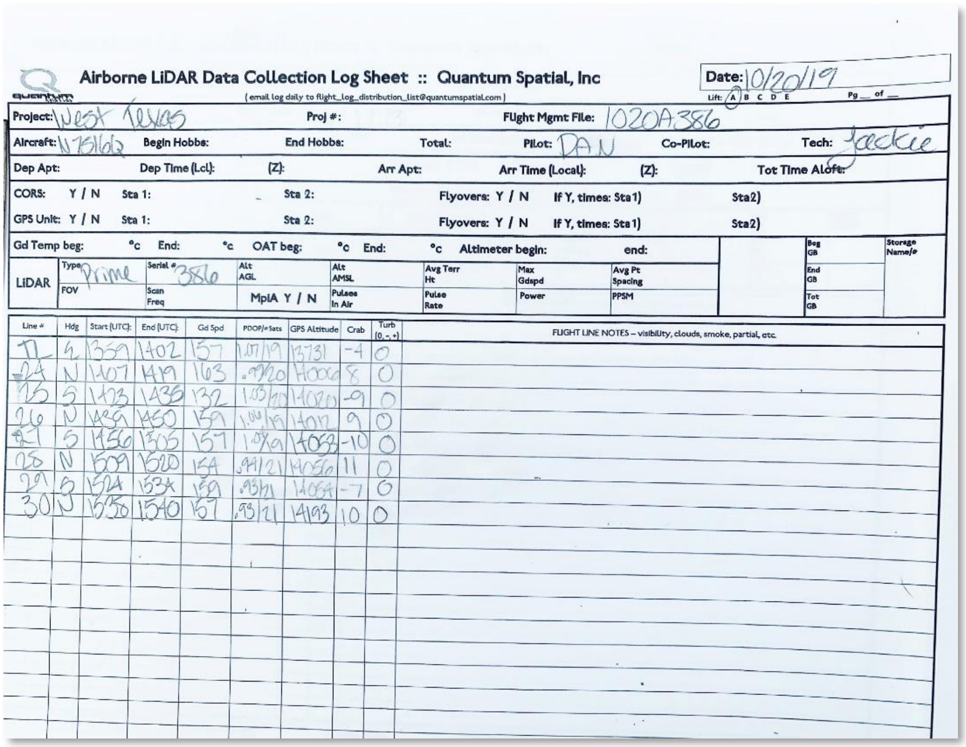

Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)

Mission 21 (20191020A)

Flight Log



Airborne LiDAR Data Collection Log Sheet :: Quantum Spatial, Inc

(email log daily to flight_log_distribution_list@quantumspatial.com)

Date: 10/20/19

Lift: (A) B C D E Pg __ of __

Project: West Texas Proj #: Flight Mgmt File: 1020A386

Aircraft: N751GQ Begin Hobbs: End Hobbs: Total: Pilot: DAN Co-Pilot: Tech: Jackie

Dep Apt: Dep Time (Lcl): (Z): Arr Apt: Arr Time (Local): (Z): Tot Time Aloft:

CORS: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

GPS Unit: Y / N Sta 1: Sta 2: Flyovers: Y / N If Y, times: Sta1) Sta2)

Gd Temp beg: °c End: °c OAT beg: °c End: °c Altimeter begin: end:

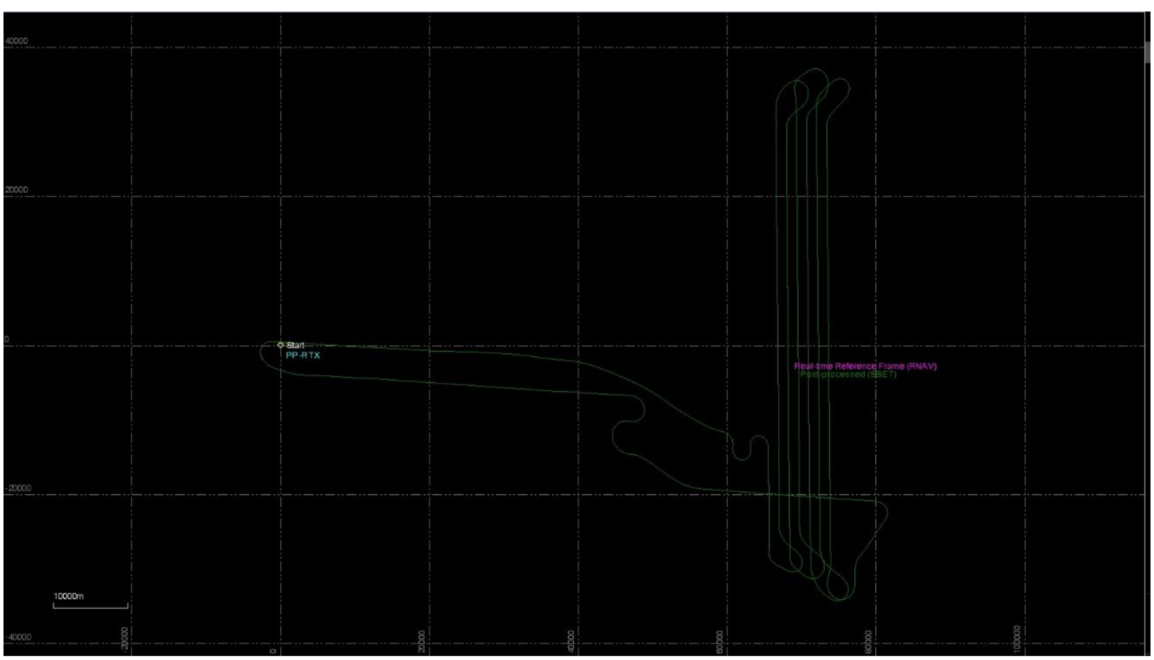
LiDAR Type: Prime Serial #: 3860 Alt AGL Alt AMSL Avg Terr Ht Max Gdspd Avg Pt Spacing

FOV Scan Freq MpiA Y / N Pulses In Air Pulse Rate Power PPSM

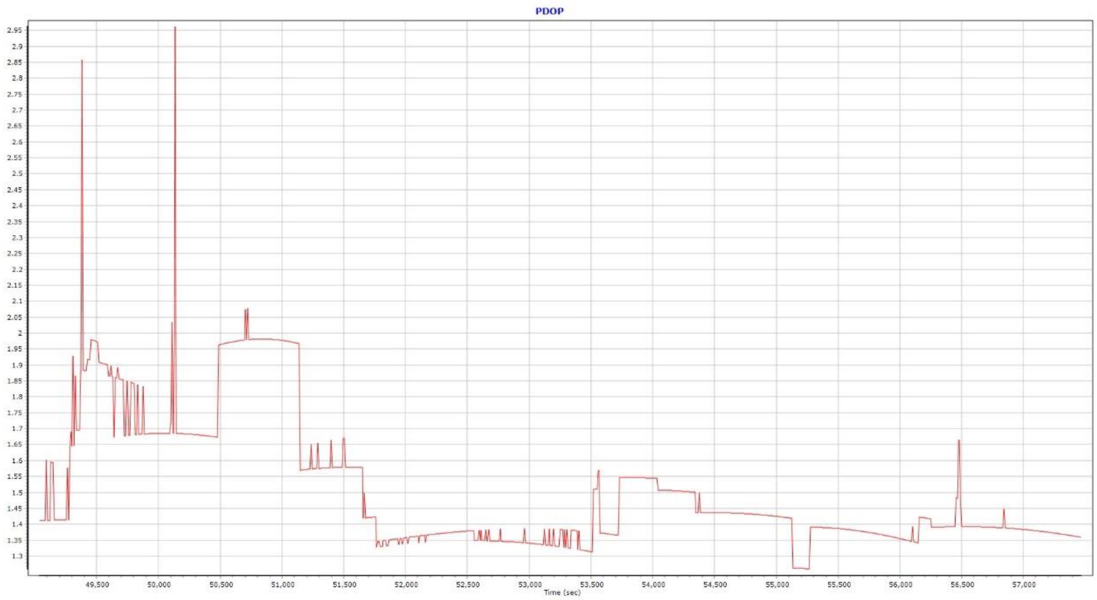
Beg GB End GB Tot GB Storage Name/#

Line #	Hdg	Start (UTC):	End (UTC):	Gd Spd	PDOP/#Sats	GPS Altitude	Crab	Turb (0, -, +)	FLIGHT LINE NOTES – visibility, clouds, smoke, partial, etc.
T1	S	1359	1402	157	1.07/19	13731	-4	0	
24	N	1407	1419	163	.99/20	14006	8	0	
25	S	1423	1435	132	1.03/20	14020	-9	0	
26	N	1439	1450	159	1.04/19	14012	9	0	
27	S	1456	1505	157	1.05/19	14053	-10	0	
28	N	1509	1520	154	.94/21	14056	11	0	
29	S	1524	1534	159	.93/21	14054	-7	0	
30	N	1530	1540	157	.93/21	14193	10	0	

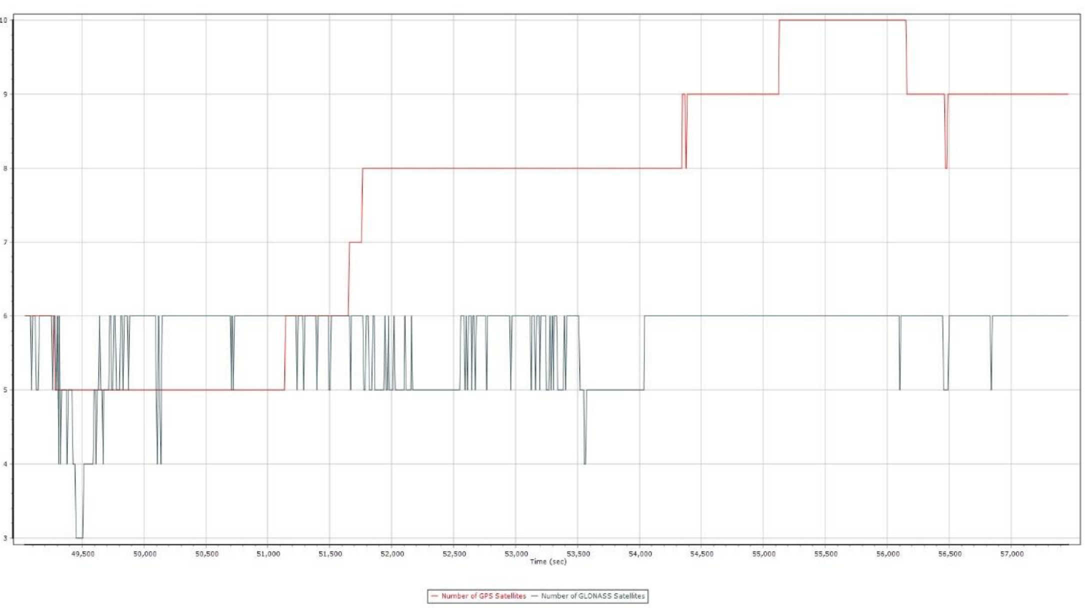
Mission Trajectory



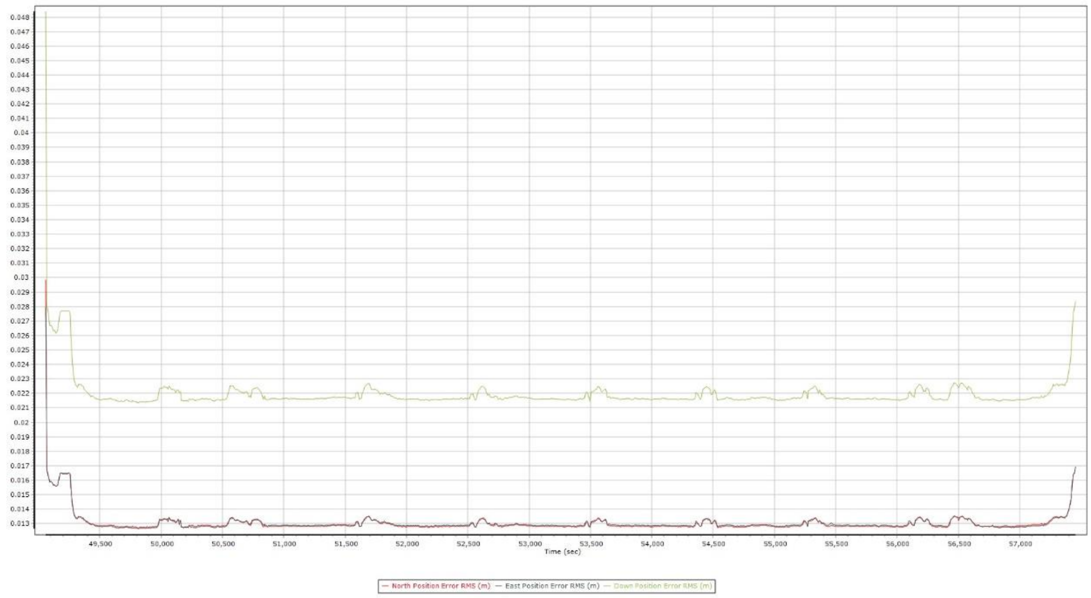
PDOP



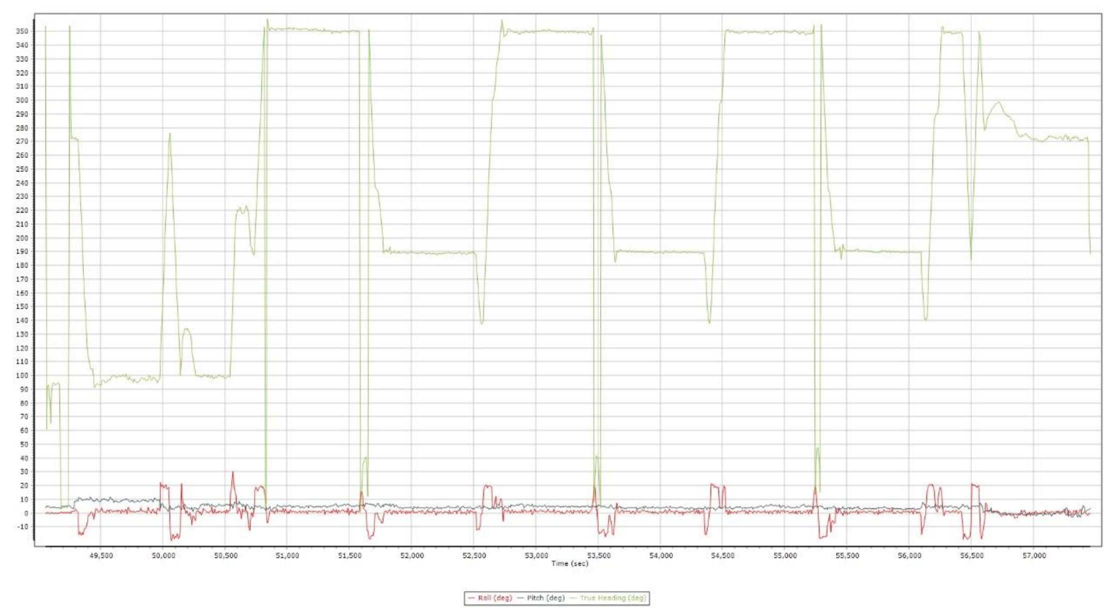
Satellites



RMS (m)


Time (sec)
North Position Error RMS (m)
East Position Error RMS (m)
Down Position Error RMS (m)

RPH (deg)


Time (sec)
Roll (deg)
Pitch (deg)
True Heading (deg)