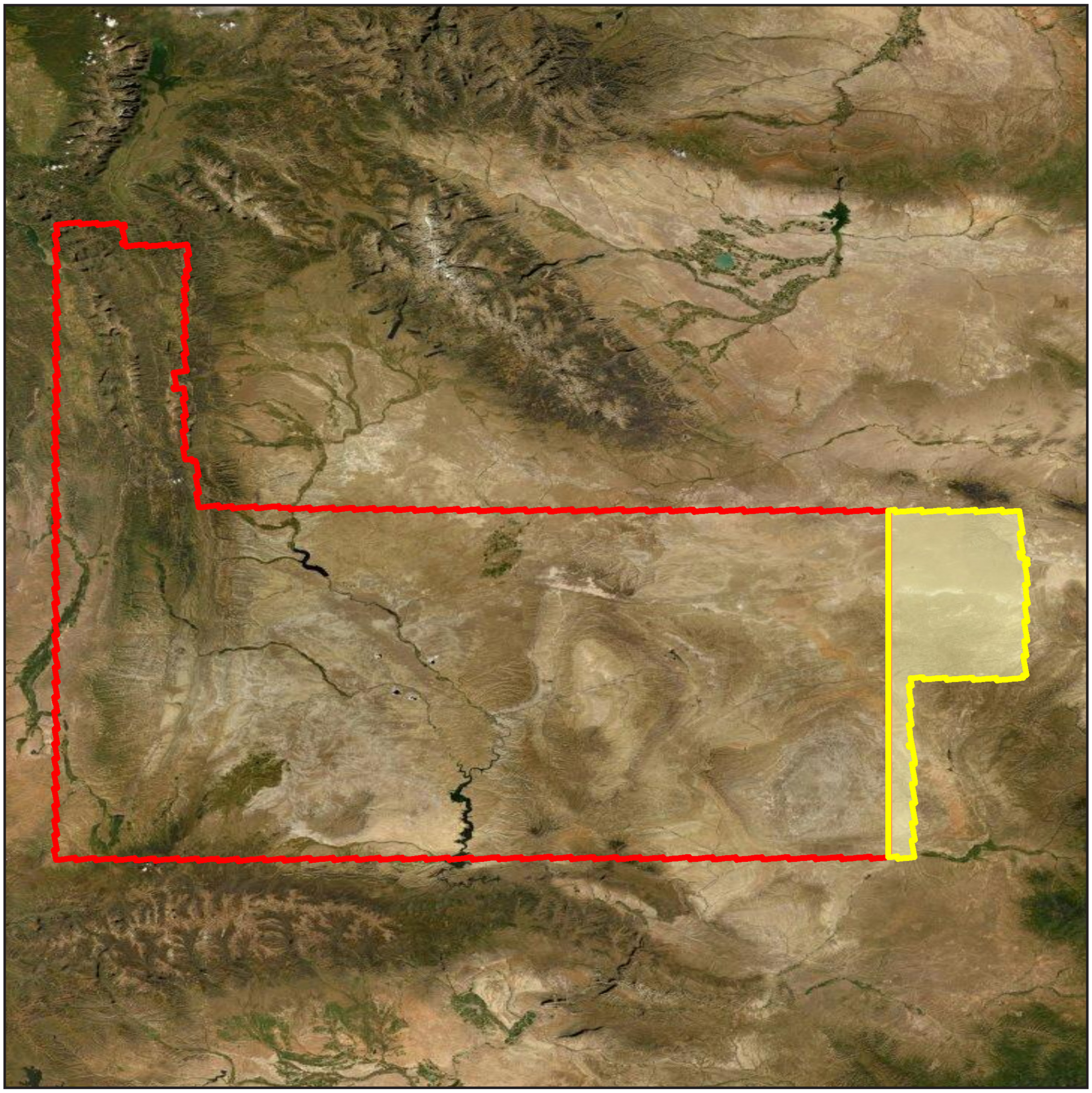
WY Southwest 2020 D20

Lidar Mapping Report
WY Southwest 3 2020 - Work Unit 216474
March 2021



Contract # G16PC00022
Task Order # 140G0220F0107

Contractor Woolpert
Project # 80904

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1. Overview

About

This project contains a comprehensive outline of the 140G0220F0107 WY Southwest 2020 D20 task order issued by the United States Geological Survey's National Geospatial Technical Operations Center (USGS-NGTOC). This task order called for the acquisition and processing of QL2 data over four blocks of interest covering approximately 16,952 square miles in southwestern Wyoming (Figure 1-1).

This report encompasses the Work Unit 216474 area of interest (Figure 1-2). This AOI totals approximately 1,297 square miles and includes the following counties:

Data includes the following counties:

- Carbon

Purpose

This project will support the 3DEP mission, the Natural Resources Conservation Service (NRCS) high resolution elevation enterprise program and the Federal Emergency Management Agency (FEMA) Risk Mapping,

Specifications

Data for this task order was acquired and produced to meet USGS Lidar Base Specification 2020 revision A standards and the American Society of Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0).

Spatial Reference

Geospatial data products were produced using the following horizontal and vertical spatial data reference system information listed in Table 1-1.

Table 1-1. Spatial Reference System

Horizontal	**EPSG Code**	6342
	Datum	NAD83 (2011)
	Projection	UTM Zone 13
	Units	Meters
Vertical	**Datum**	NAVD88
	Geoid	GEOID18
	Units	Meters
	Height Type	Orthometric

Figure 1-1. Project Area

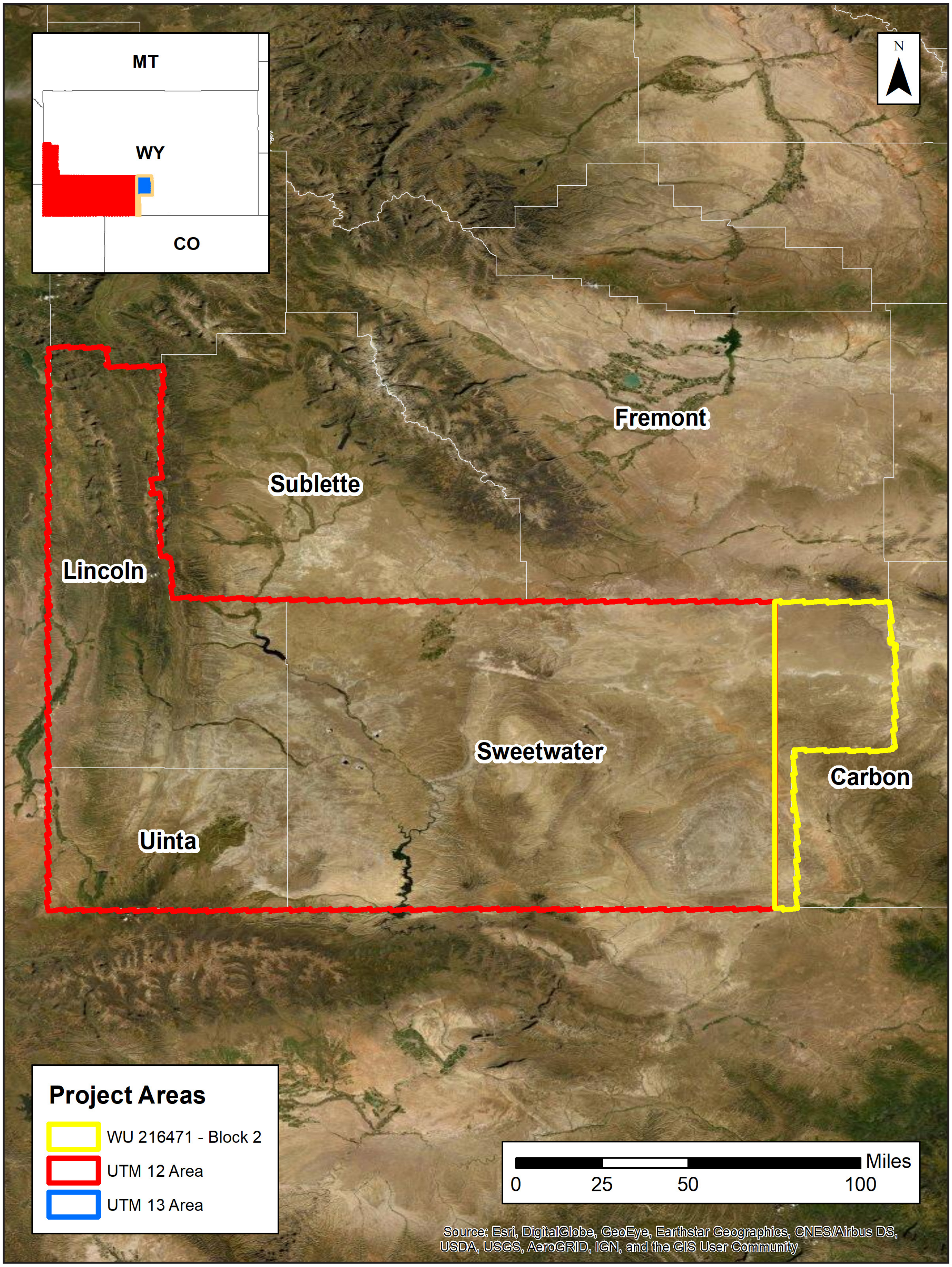
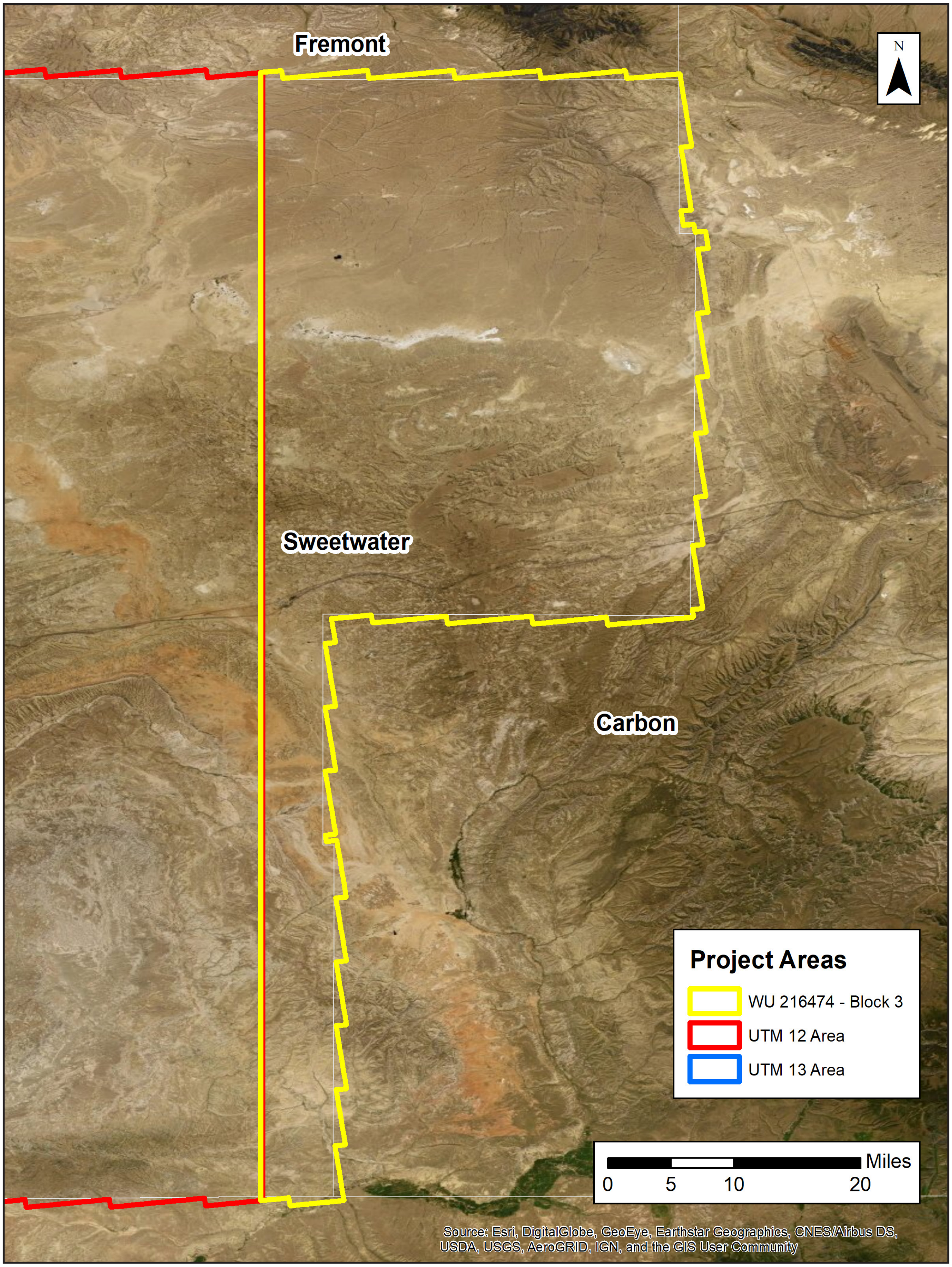


Figure 1-2. Project Area - Work Unit 216474



Task Order Deliverables

All data products produced as part of this task order are listed in Table 1-2. All tiled deliverables had a tile size of 1,000-meters x 1,000 meters. Tile names are derived from the US National Grid.

Example: 12TVM940850

This delivery's tiled dataset contains a total of 3,568 tiles.

Table 1-2. Deliverables

Lidar Data	
Classified lidar point cloud data	Tiles in .las v1.4 format Classes • 1 – Processed, not Classified • 2 – Ground • 7 – Noise • 9 – Water • 10 – Ignored Ground • 17 – Bridge Decks • 18 – High Noise • 20 – Ignored Ground

Breaklines used for hydro-flattening	• Lake and River features as feature classes in an Esri file geodatabase
	  • Water bodies greater than 2 acres as polygon features
	  • Rivers 30.5 meters / 100 feet and greater in width as polyline features
	• Bridges used in DEM generation as point features in Esri shapefile format

Hydro-flattened bare earth digital elevation model (DEM)	1-meter pixel size, 32-bit floating-point; no bridges or overpass structures GeoTIFF format
Intensity imagery	1-meter pixel size, 8-bit gray-scale (linear rescaling from 16-bit intensity) GeoTIFF format
Control Data	
Lidar calibration points	Esri shapefile format
Lidar NVA checkpoints	Esri shapefile format
Lidar VVA checkpoints	Esri shapefile format
Spatial Metadata	
Data extent	Esri shapefile format
Tile index	Esri shapefile format
Interswath and intraswath results	Esri shapefile format
Swath polygons	Georeferenced, polygonal representation of the detailed extents of each lidar swath Polygon feature class in an Esri file geodatabase
Swath separation images	2-meter pixel size, 8-bit, GeoTIFF format
Maximum height separation raster	1-meter pixel size, 8-bit, GeoTIFF format
Other Metadata and Reports	
XML metadata	Deliverable-level FGDC CSDGM/USGS MetaParser-compliant metadata in .xml format
Lidar mapping report	Project report with ancillary data in .pdf format
Ground control survey report	Survey report in .pdf format

2. Acquisition

Flight Planning

Acquisition was planned based on the task order specifications listed in Table 2-1.

Table 2-1. Acquisition Requirements

Specification	Target
Resolution	• 2 points per square meter • 0.71-meter nominal point spacing
Overlap	At contractor's discretion, but enough to ensure there are no data gaps between usable portions of the swath and to ensure the aggregate nominal point density (ANPD) is achieved
Acquisition Window	A period of annual minimal water level in the fall 2020 leaf off window running through April, 2021
Data Voids	Not allowed except • Where caused by water bodies • Where caused by areas of low near infra-red (NIR) reflectivity (i.e. asphalt or composition roofing) • Where caused by lidar shadowing from buildings or other features • Where appropriately filled-in by another swath
Data Acquisition Conditions	Atmospheric • Cloud and fog-free between the aircraft and ground Ground • Snow free • No unusual flooding or inundation, except in cases where the goal of the collection is to map the inundation Vegetation • Leaf-off is preferred Time of Day • Time of day is not of concern

Flight plans were created using Leica MissionPro software.

Lidar Sensor Information

Aerial lidar data was acquired using the following lidar sensor systems:

- Leica TerrainMapper - serial number 91511, last calibrated July 3, 2019
- Leica TerrainMapper - serial number 91513, last calibrated February 25, 2019
- Leica TerrainMapper - serial number 91515, last calibrated June 27, 2019

Table 2-2 depicts a summary of sensor information. See Appendix 1 for the sensor calibration reports.

Table 2-2. Leica Terrain Mapper Sensor Info

Sensor Specifications	
Operating Altitude (m AGL)	300 - 5,500 at 10% reflective target
Maximum Measurement Rate (kHz)	2,000
Scan Angle	20 - 40
Scan Width	Up to 70% of flight altitude
Scan Frequency	Programmable up to 125 Hz (7,500 RPM), 250 scan lines per second
Number of Returns	15
Number of intensity measurements	15
Pulse Mode(s)	Up to 35 pulses in air
Laser Specifications	
Laser Beam Divergence	0.25 mrad (1/e)
Laser Classification	Class 4 laser product
Accuracy	
Range Resolution	< 1 cm RMS
Elevation Accuracy	< 5 cm 1 σ
Horizontal Accuracy	< 13 cm 1 σ
Physical Specifications	
Size (cm), Weight (kg) • Scanner • Control Electronics	 • 37 W x 68 L x 26 H cm, 47 kg • 45 W x 47 D x 25 H cm, 33 kg
Operating Temperature • Scanner • Control Electronics	 • 0 - 40°C cabin-side temperature • 0 - 40°C
Flight Management	Leica FlightPro
Power Consumption	922 W @ 22.0 – 30.3 VDC

Source: Leica TerrainMapper Data Sheet
https://leica-geosystems.com/en-US/products/airborne-systems/topographic-lidar-sensors/leica-terrainmapper

Lidar Sensor Settings

Aerial lidar was acquired using the sensors and settings listed in the Table 2-3.

Table 2-3. Lidar Sensor Settings

Settings	Leica TerrainMapper
Max. Number of Returns	15
Nominal Point Spacing	0.71 m
Nominal Point Density	2 ppsm
Flying Height Above Ground Level	2,500 m
Flight Speed	150 knots
Scan Angle	40°
Scan Rate Used	90 Hz
Pulse Rate Used	600 kHz
Multi-Pulse in Air	Enabled
Swath Width	1,820 m
Swath Overlap	20%

Timeline

Lidar data was collected from June 18, 2020 through July 5, 2020. A total of 47 individual flight lines were collected. Figure 2-1 shows aerial lidar coverage by lift.

For more information, see the Flight Logs in Appendix 2.

GNSS and IMU Equipment

Prior to mobilizing to the project site, flight crews coordinated with the necessary air traffic control personnel to ensure airspace access. Crews were on-site, operating a Global Navigation Satellite System (GNSS) Base Station for the airborne GPS support.

Flight navigation during acquisition was performed using IGI CCNS (Computer Controlled Navigation System). The pilots are skilled at maintaining their planned trajectory, while holding the aircraft steady and level. If atmospheric conditions are such that the trajectory, ground speed, roll, pitch and/or heading cannot be properly maintained, the mission is aborted until suitable conditions occur.

Base stations were set by acquisition staff and was used to support the aerial data acquisition. Table 2-4 lists the Station ID and coordinates for all base stations operated during acquisition.

For more information, see the GPS/IMU graphics in Appendix 3.

Figure 2-1. Flight Coverage with Tile Index

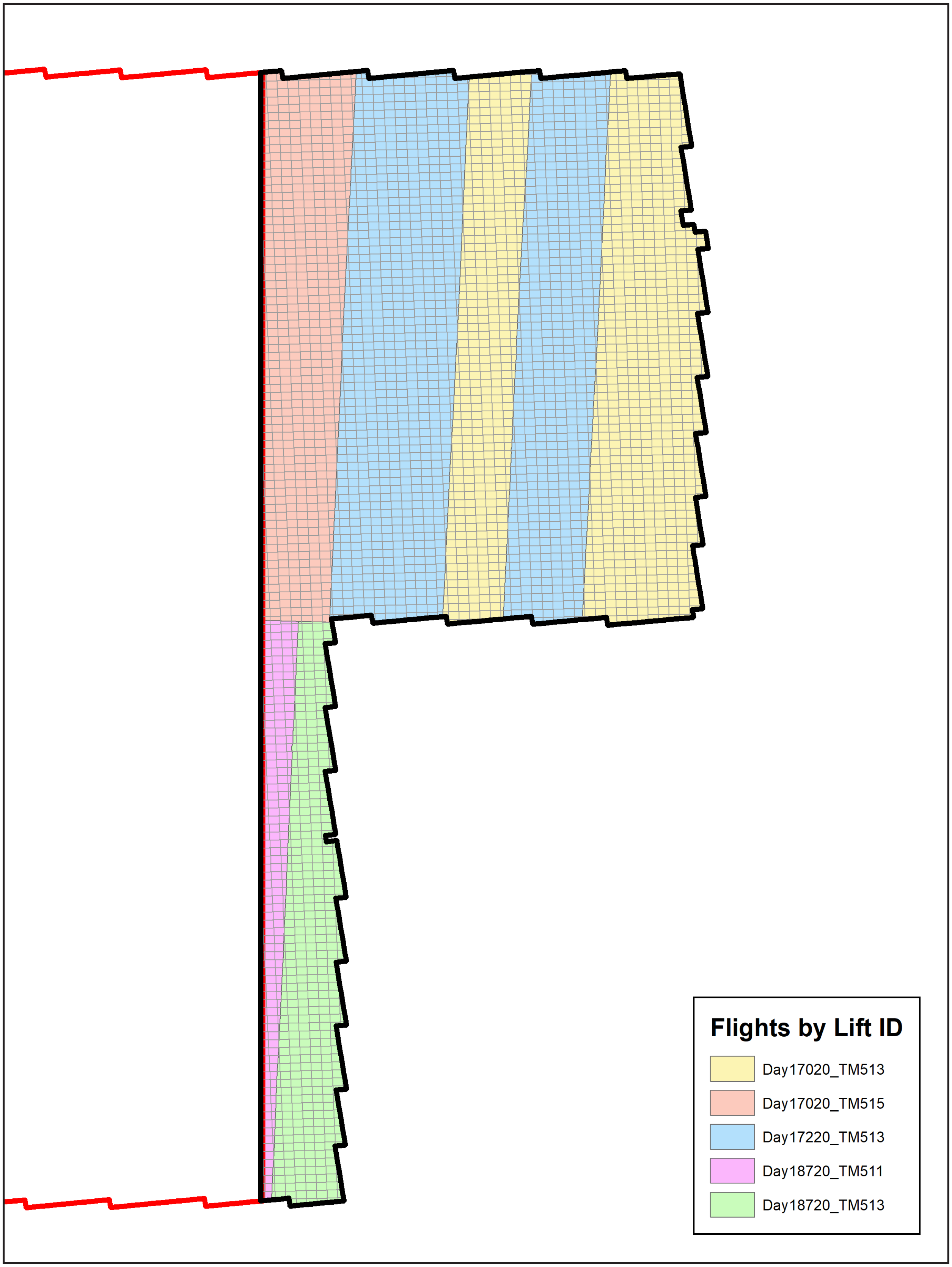


Table 2-4. GNSS Base Stations

Station Name	Longitude (DMS)	Latitude (DMS)	Ellipsoid Height L1 Phase Center (Meters)
P030_CORS	-110° 30’ 46.06698”	41° 44’ 59.31530”	2150.596
TSWY_CORS	-110° 36’ 50.86433”	43° 40’ 26.70325”	2191.496
BLW2_CORS	-109° 33’ 28.03604”	42° 46’ 01.63709”	2216.398
IDDR_CORS	-111° 06’ 36.92145”	43° 44’ 46.00161”	1864.684

Acquisition Quality Assurance

An initial quality control process was immediately performed on to review the data coverage, airborne GPS data, and trajectory solution.

Woolpert developed a quality assurance and validation plan to ensure the acquired lidar data meets the USGS Base Specification requirements. For quality assurance purposes, the lidar data was processed immediately following acquisition to verify the coverage has appropriate density, distribution, and no unacceptable data voids. Accompanying GPS data was post processed using differential and Kalman filter algorithms to derive a best estimate of trajectory. The quality of the solution was verified to be consistent with the accuracy requirements of the task order. Any required re-flights were scheduled at the earliest opportunity.

The spatial distribution of the geometrically usable first return lidar points was reviewed for density requirements as well as regular and uniform point distribution - verifying the lidar data is spaced so that 90% of the cells in a 2*NPS grid placed over the data contain at least one lidar point. The NPS assessment is made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath. Additionally, the data was reviewed for unacceptable data voids – verifying no area greater than or equal to $(4 \times ANPS)^2$ exhibited data coverage gaps.

3. Processing

Processing Summary

Once the lidar data passed initial QC, the dataset was corrected for aircraft orientation and movement. This process used airborne inertial, orientation, and GPS data collected during acquisition along with ground-based GPS data. The data went through a geometric calibration that further corrected each laser point. This calibrated data set was used to create the LAS point cloud. The LAS point data was initially classified into “ground” and “non-ground”, then further refined using the classes specified in this task order. Breaklines were drawn to denote hydrological features. After the hydro-flattening process, the final deliverables products were created.

GPS-IMU Trajectory Processing

Kinematic corrections for the aircraft position were resolved using aircraft GPS and static ground GPS (1-Hz) for each geodetic control (base station) for three subsystems: inertial measurement unit (IMU), sensor orientation information, and airborne GPS data.

Post-processing of the IMU system data and aircraft position with attitude data was completed to compute an optimally accurate, blended navigation solution based on Kalman filtering technology, or the smoothed best estimate of trajectory (SBET).

For more information, see the GPS/IMU graphics in Appendix 3.

Software: POSPac Software v. 5.3, IPAS Pro v.1.35., Novatel Inertial Explorer v8.60.6129

Trajectory Quality

The GNSS trajectory and high-quality IMU data are key factors in determining the overall positional accuracy of the final sensor data. Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the combined separation, the estimated positional accuracy, and the positional dilution of precision (PDOP).

Combination Separation

Combined separation is a measure of the difference between the forward-run and the backward-run solution of the trajectory. The Kalman filter was processed in both directions to remove the combined directional anomalies. In general, when these two solutions match closely, an optimally accurate and reliable solution is achieved.

The data for this task order was processed with a goal to maintain a combined separation difference of less than ten (10) centimeters.

Estimated Positional Accuracy

Estimated positional accuracy plots the standard deviations of the east, north, and vertical directions along a time scale of the trajectory. It illustrates loss of satellite lock issues, as well as issues arising from long baselines, noise, and/or other atmospheric interference.

PDOP

The PDOP measures the precision of the GPS solution in regard to the geometry of the satellites acquired and used for the solution.

The data for this task order was processed with a goal to maintain an average PDOP value below 3.0. Brief periods of PDOP over 3.0 are acceptable due to the calibration and control process if other metrics are within specification.

Geometric Calibration

After the initial phase was complete, a formal reduction process was performed on the data. Laser point position was calculated by associating the SBET position to each laser point return time, scan angle, intensity, etc. Raw laser point cloud data was created for the whole project area in LAS format. Automated line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Statistical reports were generated for comparison and used to make the necessary adjustments to remove any residual systematic error.

For more information, see the Sensor Calibration Reports in Appendix 1.

Software: Proprietary Software, TerraMatch v20, Leica CloudPro 1.2.4

Relative Accuracy: Interswath (Overlap) Consistency

Interswath or overlap consistency was assessed at multiple locations within overlap in non-vegetated areas containing only single returns and located in areas with slopes of less than 10 degrees. To the extent allowed by the data, test areas were chosen where the full width of the overlap was represented. These overlap areas include adjacent, overlapping parallel swaths within a project, cross-tie swaths and a sample of intersecting project swaths in both flight directions, and adjacent, overlapping lifts.

This project required the interswath accuracy to meet ≤ 8 cm RMSDz. Accuracy was assessed in accordance with the USGS Base Specification v2020 revision A.

The interswath consistency results were produced as polygon features in Esri shapefile format. Table 3-1 lists the interswath test results. Figure 3-1 depicts the location of the interswath test locations.

Table 3-1. Interswath Results

Minimum (m)	Maximum (m)	RMSDz (m)
-0.040	0.035	0.014

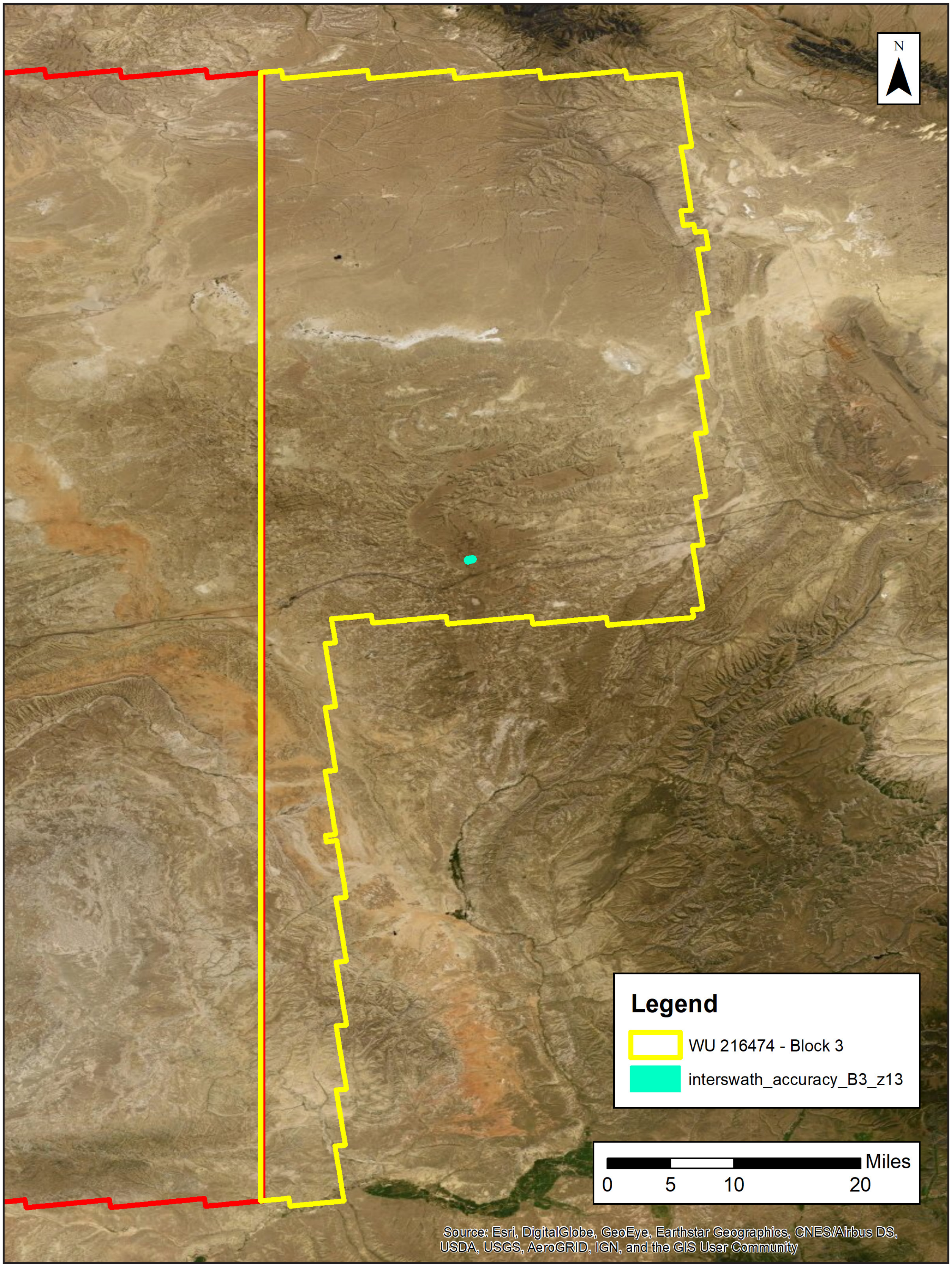
Swath Separation Images

All point returns (except those flagged as withheld or classified as noise) were used to create a swath separation image covering the deliverable area. The imagery was derived from TIN datasets to reduce the number of false difference values on sloped areas. This imagery metadata denotes areas where two or more swaths overlap within a pixel, based on the point source ID. Pixels are assigned color values based on the vertical difference of the swaths based on the following:

0 - 8 cm	Green
8 - 16 cm	Yellow
> 16 cm	Red

Swath separation images were produced with a 2-meter cell size in GeoTIFF format.

Figure 3-1. Interswath Testing Locations



Relative Accuracy: Intraswath Precision

Intraswath precision (or smooth surface precision) was performed on hard surfaces with areas consisting of approximately 100 pixels (ex.: parking lots, large rooftops) and containing only single return lidar points. Sample areas were selected where full width of the swath(s) (left, center, and right) were represented to the extent the data allowed.

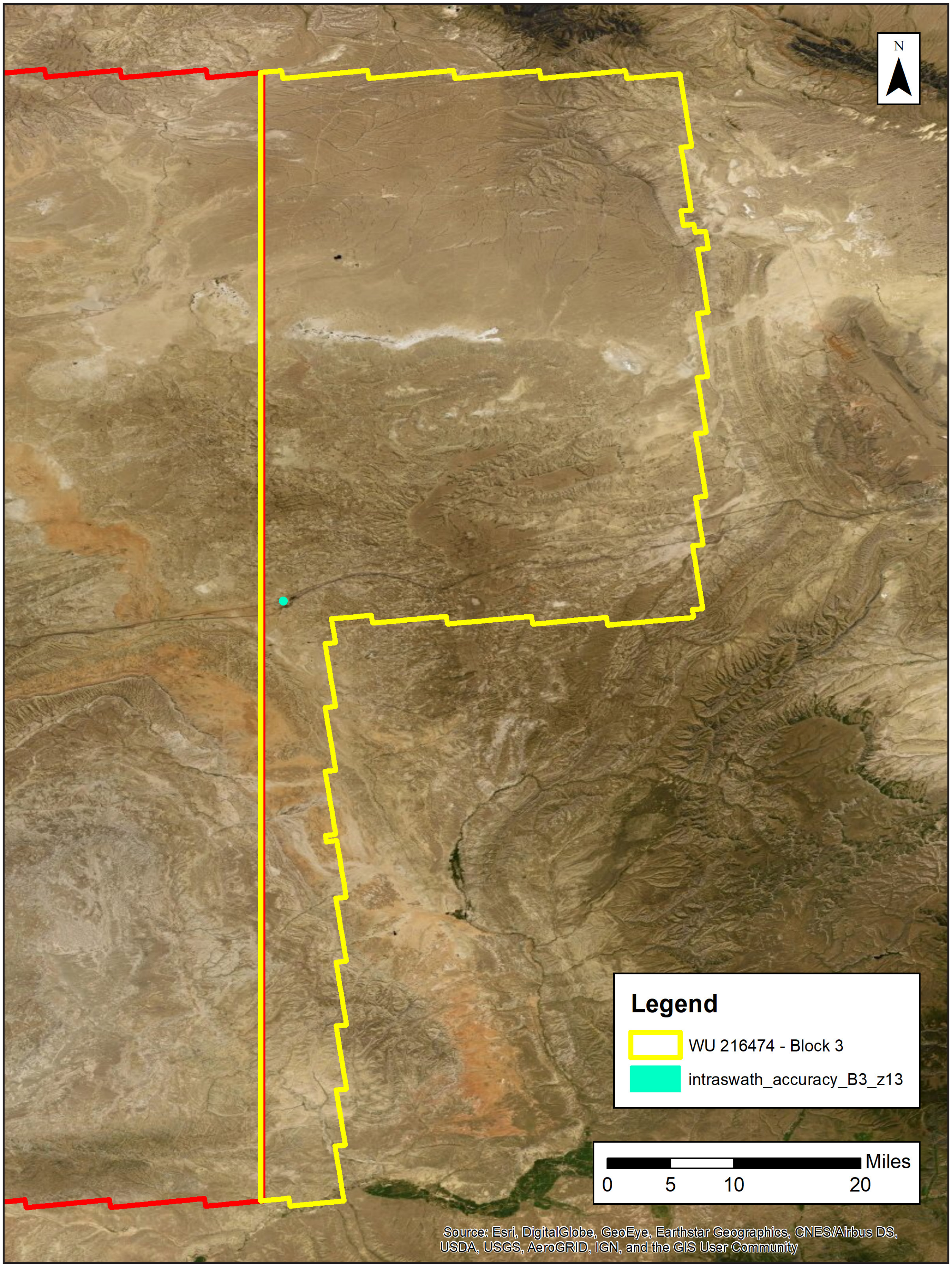
This project required the intraswath accuracy to meet ≤ 6 cm RMSDz. Accuracy was assessed in accordance with the USGS Base Specification v2020 revision A.

The intraswath precision results were produced as polygon features in Esri shapefile format. Table 3-2 lists the intraswath test results. Figure 3-2 depicts the location of the intraswath test locations.

Table 3-2. Intraswath Results

Minimum (m)	Maximum (m)	RMSDz (m)
-0.106	0.070	0.035

Figure 3-2. Intraswath Testing Locations



Lidar Data Classification

LAS data was initially classified as ground and non-ground points "first and only" as well as "last of many" lidar returns. Additional filters were created to meet the task order classification specifications. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data. Based on the statistical analysis, the lidar data was then adjusted to reduce the vertical bias when compared to the survey ground control of higher accuracy.

The bare-earth (Class 2 - Ground) lidar points underwent a manual QA/QC step to verify the quality of the DEM as well as a peer-based QC review. This included a review of the DEM surface to remove artifacts and ensure topographic quality. After the bare-earth surface is finalized, it is then used to generate all hydro-breaklines through a semi-automated process.

All ground (Class 2) lidar data inside of the Lake Pond and Double Line Drain hydro flattening breaklines were then classified to water (Class 9) using TerraScan/LP360 macro functionality. A buffer of 0.7 meters was also used around each hydro-flattened feature to classify these ground (Class 2) points to Ignored Ground (Class 20). All Lake Pond Island and Double Line Drain Island features were checked to ensure that the ground (Class 2) points were reclassified to the correct classification after the automated classification was completed.

All overlap data was processed through automated functionality provided by TerraScan to classify the overlapping flight line data to approved classes by USGS. The overlap data was classified using standard LAS overlap bit. These classes were created through automated processes only and were not verified for classification accuracy. Due to software limitations within TerraScan, these classes were used to trip the withheld bit within various software packages. These processes were reviewed and accepted by USGS through numerous conference calls and pilot study areas.

All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper was used as a final check of the bare earth dataset. GeoCue was then used to create the deliverable industry-standard LAS files. Woolpert proprietary software and LP360 was used to perform final statistical analysis of the classes in the LAS files, on a per tile level to verify final classification metrics and full LAS header information.

Table 3-3 lists the total number of points within each class.

Table 3-3. Lidar Point Classes

Class Number	Class Name
Class 1	Processed, but unclassified
Class 2	Bare earth
Class 7	Low noise
Class 9	Water
Class 17	Bridge deck
Class 18	High noise
Class 20	Ignored ground

Hydrologic Flattening

The lidar task order required compilation of breaklines defining the following types of water body features:

Lakes, reservoirs, ponds	Minimum of 2-acres or greater Compiled as closed polygons, collected at a constant elevation
Rivers, streams	Nominal width of 30.5 meters / 100 feet Compiled in direction of flow, with both sides maintaining an equal elevation gradient
Bridge breaklines	Breaklines used to enforce a logical terrain surface below a bridge

Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing lidar data:

1. The newly acquired lidar data was utilized to manually compile the hydrologic features in a 2D environment using the lidar intensity and bare earth surface. Open Source imagery was used as reference when necessary.
2. An integrated software approach was applied to combine the lidar data and 2D breaklines. This process “drapes” the 2D breaklines onto the 3D lidar surface model to assign an elevation. A monotonic process is performed to ensure the streams are consistently flowing in a gradient manner. A secondary step within the program verifies an equally matching elevation of both stream edges. The breaklines that characterize the closed water bodies are draped onto the 3D lidar surface and assigned a constant elevation at or just below ground elevation.
3. All classified ground points from inside the hydrologic feature polygons were reclassified to water, class nine (9).
4. All classified ground points were reclassified from within a buffer along the hydrologic feature breaklines to buffered ground, class twenty (20). The buffer distance was approximately the task order designed nominal pulse spacing distance.
5. Breaklines used for bridge removal during the hydrologic flattening were included with the hydrologic breakline geodatabase deliverable. The purpose of these breaklines is for a more aesthetically pleasing DEM appearance.
6. The lidar ground points and breaklines were used to generate a digital elevation model (DEM).
7. QA/QC for this task was performed by reviewing the hydrologically flattened DEM and hydrologic breakline features. Additionally, a combined approach utilizing commercial off the shelf software and proprietary methods were used to review the overall connectivity of the hydrologic breaklines.

TerraScan was used to add the hydrologic breakline vertices and export the lattice models.

Breaklines defining the water bodies greater than 2-acres were provided as polygon features. Rivers and streams with a nominal minimum width of 30.5 meters (100 feet) were provided as polyline features. All lake and river breaklines compiled as part of the flattening process were provided in an Esri file geodatabase.

Breaklines used for DEM generation were provided as point features in Esri shapefile format.

Software: TerraScan v20, TerraModeler v20, Esri ArcMap v10.7, LP360 v2019.1.30.4

Digital Elevation Model

TerraScan was used to add the hydrologic breakline vertices and export the lattice models. Class 2 (ground) lidar points in conjunction with the hydro breaklines and bridge breaklines were used to create 1-meter hydro-flattened bare-earth raster DEM files. Using automated scripting routines within ArcMap, an 32-bit floating point raster GeoTIFF file was created for each tile. Files were clipped to the data extent. Each surface is reviewed using Global Mapper to check for any surface anomalies or incorrect elevations found within the surface.

Software: TerraScan v20, GDAL 2.4.0, Esri ArcMap v10.7, Global Mapper v20.0

Intensity Imagery

Lidar intensity data derived from the acquired lidar data was linearly rescaled from 16-bit intensity and provided as 1-meter pixel, 8-bit, 256 gray scale GeoTIFF format intensity imagery files. Files were clipped to the data extent.

Software: TerraScan v20, GDAL 2.4.0, Esri ArcMap v10.7

Metadata

FGDC CSDGM/USGS MetaParser-compliant metadata was produced in XML format. The metadata includes a complete description of the task order client information, contractor information, project purpose, lidar acquisition and ground survey collection parameters, lidar acquisition and ground survey collection dates, spatial reference system information, data processing including acquisition quality assurance procedures, GPS and base station processing, geometric calibration, lidar classification, hydrologic flattening, intensity imagery development, and final product development.

Other metadata deliverables included Esri shapefiles of the ground control and QA/QC points, interswath and intraswath test results, data extent, and tile index. A georeferenced, polygonal representation of the detailed extents of each acquired lidar swath was produced as a polygon feature class in an Esri file geodatabase. Swath separation images were produced in GeoTIFF format. Maximum height separation rasters were produced in JPEG 2000 format.

4. Accuracy Assessment

Horizontal Accuracy

The data set was produced to meet ASPRS “Positional Accuracy Standards for Digital Geospatial Data” (2014) for a 0.186 cm RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 0.455 cm at a 95% confidence level.

Classified Lidar Point Cloud Testing

This project required Non-Vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA) to be tested on the classified lidar point cloud data. The dataset was required to meet a target NVA value of 19.6 cm at a 95% confidence level using an RMSEz target value of 10 cm x 1.9600 and a target VVA value of 30 cm at the 95th percentile. Testing was assessed and reported using guidelines developed by the National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing (ASPRS).

The NVA and VVA values were calculated using independent checkpoints that were not used in the calibration or post processing of the lidar point cloud data. Checkpoints were distributed throughout the project area. NVA checkpoints were located in bare earth and urban (non-vegetated) land cover classes. VVA checkpoints were located in brush/tall grass/weeds (vegetated) land cover classes. These checkpoints were surveyed using GPS techniques. See the survey report for acquisition methodologies.

Testing was performed using TINs created from the final calibrated and controlled swath data. For each NVA checkpoint, an elevation value was derived from the TIN at the point’s x,y location. This value was compared to the checkpoint’s surveyed elevation value.

The classified lidar point cloud accuracy test results are listed below in Table 4-1.

Table 4-1. Classified Point Cloud Vertical Accuracy

	Result	Points Used
NVA	0.022 m RMSEz 0.043 m at 95% CL	24
VVA	0.135 at 95th Percentile	19

Digital Elevation Model Testing

This project required Non-Vegetated Accuracy (NVA) and Vegetated Vertical Accuracy (VVA) testing of the digital elevation model (DEM) dataset. The calculated NVA value was required to meet 19.6 cm at a 95% confidence level using an RMSEz target value of 10 cm x 1.9600. VVA was required to meet 30 cm at the 95th percentile error. Testing was assessed and reported using guidelines developed by the National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing (ASPRS).

Testing was performed using the bare earth DEM created as part of this task order. For each checkpoint, an elevation value was derived from the DEM at the point’s x,y location. This value was compared to the checkpoint’s surveyed elevation value.

The NVA and VVA values were calculated using independent checkpoints that were not used in the calibration or post processing of the lidar point cloud data. Checkpoints were distributed throughout the project area. NVA checkpoints were located in bare earth and urban (non-vegetated) land cover classes. VVA checkpoints were located in brush/tall grass/weeds (vegetated) land cover classes. These checkpoints were surveyed using GPS techniques. See the survey report for acquisition methodologies.

The classified lidar point cloud accuracy test results are listed below in Table 4-2.

Table 4-2. DEM Vertical Accuracy

	Result	Points Used
NVA	0.028 m RMSEz 0.055 m at 95% CL	24
VVA	0.127 at 95th Percentile	19

Appendix 1: Sensor Calibration Report

- when it has to be **right**

Leica Geosystems
Leica TerrainMapper-LN
Calibration Certificate

Product	Leica TerrainMapper-LN
Serial Number	91511
Date	03 July 2019
Inspector	Mark O’Neal

Leica Geosystems AG
Heinrich-Wild-Strasse
CH-9435 Heerbrugg
Schweiz
www.leica-geosystems.com

Document Code: 871495

1. System Components

Component	Type	Serial Number
Pod	TerrainMapper Pod	91511
GNSS/IMU	Litef LCI-100C 500 Hz	1139
LiDAR Unit	Hyperion2 LiDAR Unit	5511
Camera Head	CH82	82659
Lens	NAT-D 2.8/80	80254

2. Estimation Process

		Passed	Date	Inspector
Image Flight	completed	ok	10.05.2019	Philip Benz
Image Quality Check	checked	ok	16.05.2019	Philip Benz
Image Calibration	completed	ok	18.05.2019	Xu Wang
Image Misalignment Update	completed	ok	02.07.2019	Mark O’Neal
LiDAR Flight	completed	ok	10.17.2018	Deniz Arslan
LiDAR Quality Check	checked	ok	23.10.2018	Rene Heirli
LiDAR Calibration and Accuracy	completed	ok	24.10.2018	Robert Bosch
LiDAR Misalingment Update	completed			

3. Inspectors

Name	Bernhard Riedl	15.11.2018	Riedl Bernhard
Position	Production Manager		
Name	Robert Bosch	23.05.2019	Xu Wang
Position	Support Engineer		
Name	Michael Vetter	03.07.2019	R. Bosch
Position	Support Engineer		

4. Remarks

5. LiDAR Calibration Results

The calibration results for the LiDAR Unit are only valid for:

- IMU and Pod as listed in the System Components section

5.1 LiDAR Geometric Calibration Results

IMU Misalignment		**Value**	**Unit**
	ω	-0.138877	degree
	Φ	0.130994	degree
	κ	-0.006412	degree
Boresight		**Value**	**Unit**
	Θ	0.001052	degree
	Φ	-0.001885	degree
Receiver 1		**Value**	**Unit**
Range	Δ Offset	0.000000	meters
Wedge 0		**Value**	**Unit**
Wedge	Δ Alpha	0.001241	degree
Wedge Position	Δ Offset	-0.426898	degree
Position Correction	X	-0.019523	degree
	Y	0.007883	degree
Mount	Roll	-0.020901	degree
	Pitch	0.107683	degree
Rotation Axis	Roll	0.103712	degree
	Pitch	0.124140	degree
Wedge 1		**Value**	**Unit**
Wedge	Δ Alpha	-0.009545	degree
Wedge Position	Δ Offset	0.412993	degree
Position Correction	X	0.004000	degree
	Y	0.011085	degree
Mount	Roll	0.102859	degree
	Pitch	0.025756	degree
	Speed Pitch	1.50E-06	degree/rps^2
Rotation Axis	Roll	0.114811	degree
	Pitch	-0.080531	degree

LiDAR Geometric Calibration File

HYPERION_GEOMETRY_LIDARUNIT-5511-C-855570-DATETIME-20181023-153458.XML

	Date	23.10.2018	
LiDAR Misalingment Flight	Date	-	
LiDAR Misalingment Update Completed	Date	-	

5.2 LiDAR Unit Accuracy Check

Accuracy checks:

- Deviation of two perpendicular lines to GCP's
- Difference of two perpendicular lines
- Difference of forward and backward scan of one line

5.2.1 Multi-line accuracy of two perpendicular lines to ground control points

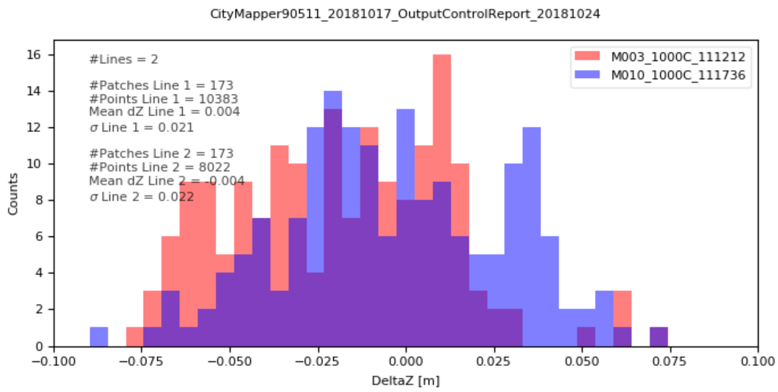


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

M010_1000C_111736

314314 valid patches with size of 2 m found. Only patches with standard deviation < 0.05 m and minimum of 5 points are included.

Color	Limits [m]	Number of patches	Proportion of total number of patches [%]
(dark green)	<=0.04	293823	93.48
(light green)	0.04-0.07	20386	6.49
(yellow)	0.07-0.1	89	0.03
(red)	>0.1	16	0.01

Vertical difference

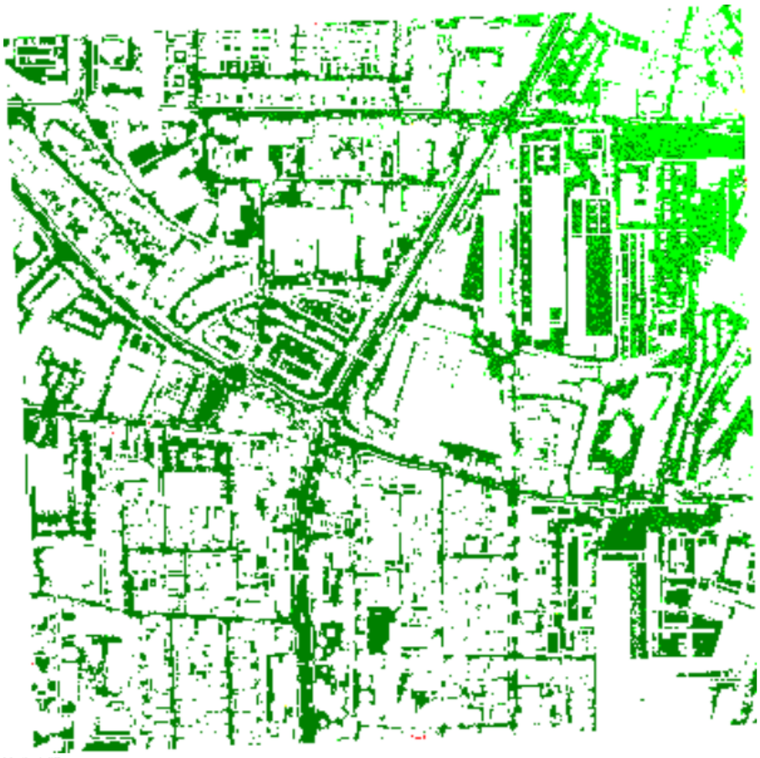
Figure 2 Vertical difference betweeen forward and backward scan at 1000 m AGL.

5.2.3 Multi-line accuracy between two perpendicular lines

M003_1000C_111212_vs_M010_1000C_111736

39940 valid patches with size of 2 m found. Only patches with standard deviation < 0.05 m and minimum of 5 points are included.

Color	Limits [m]	Number of patches	Proportion of total number of patches [%]
	<=0.04	32066	80.29
	0.04-0.07	7841	19.63
	0.07-0.1	21	0.05
	>0.1	12	0.03



Vertical difference

Figure 3 Vertical difference betweeen two perpendicular lines at 1000 m AGL.

6. Imaging Sensors Estimation Results

The estimation results for the camera head and lens combination are only valid for:

- IMU and Pod as listed in the System Components section.
- Camera Head, lens and specified position as listed in the Estimation Results sections.

6.1 Camera Model of distortion free images

All factory calibration results contain fixed nominal focal lengths and zero principal point offsets.
Leica HxMap applies the grid to create distortion-free images of nominal focal length and pixel size.

6.1.1 CH8x Model

			Component
Camera Head			CH82
Lens			NAT-D 2.8/80
Camera Model			
Focal Length			**Distance** [mm]
	c		83.00
Radial Symmetric Distorsion			**Distance** [mm]
	k_0		0.0000
	k_1		0.0000
	k_2		0.0000
Decentering Distortion			**Distance** [mm]
	p_1		0.0000
	p_2		0.0000
Non-Orthogonality Distortion			**Distance** [mm]
	b_1		0.0000
	b_2		0.0000
Pixel Size (Height and Width)			**Distance** [mm]
	RGB		0.0052
	NIR		0.0120
Rows and Columns		**Rows**	**Columns**
	Active RGB	7752	10320
	Raw RGB	7788	10336
	Active NIR	3654	4478
	Raw NIR	3366	4500

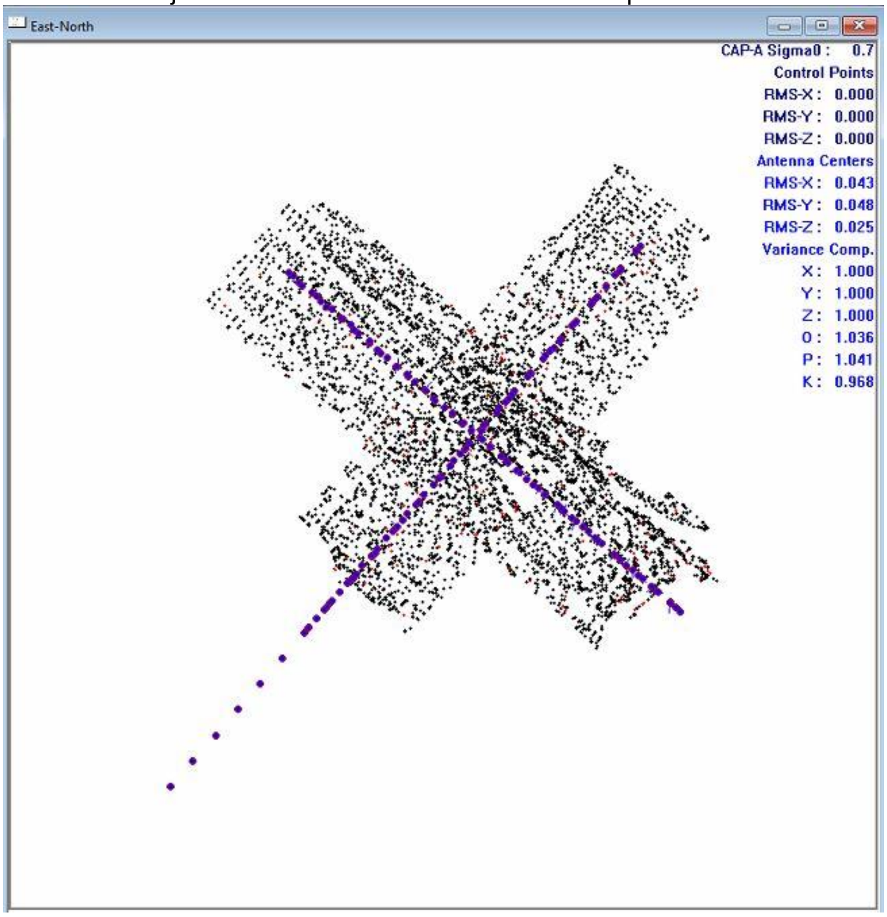
6.2 Results of Geometric Calibration

6.2.1 Calibration method for Green Reference Band

Estimation of additional parameters (focal length, principal point, radial symmetric distortion, correction grid) and IMU misalignment in simultaneous bundle adjustment

Reference band (green)	Distance [mm]
Resulting sigma naught of bundle adjustment:	0.0007

Final bundle adjustment results after elimination of tie point blunders:



6.2.2 Calibration method for Other Spectral Bands

Estimation of additional parameters (correction grid), based on the result for green in simultaneous bundle adjustment

Other Spectral Bands	Distance [mm]
Co-registration to green better than:	0.002

Leica HxMap applies the grid to create distortion-free images of nominal focal length and fixed pixel size of 0.0052 mm.

6.3 *Estimation Results for Nadir Camera Head and Lens*

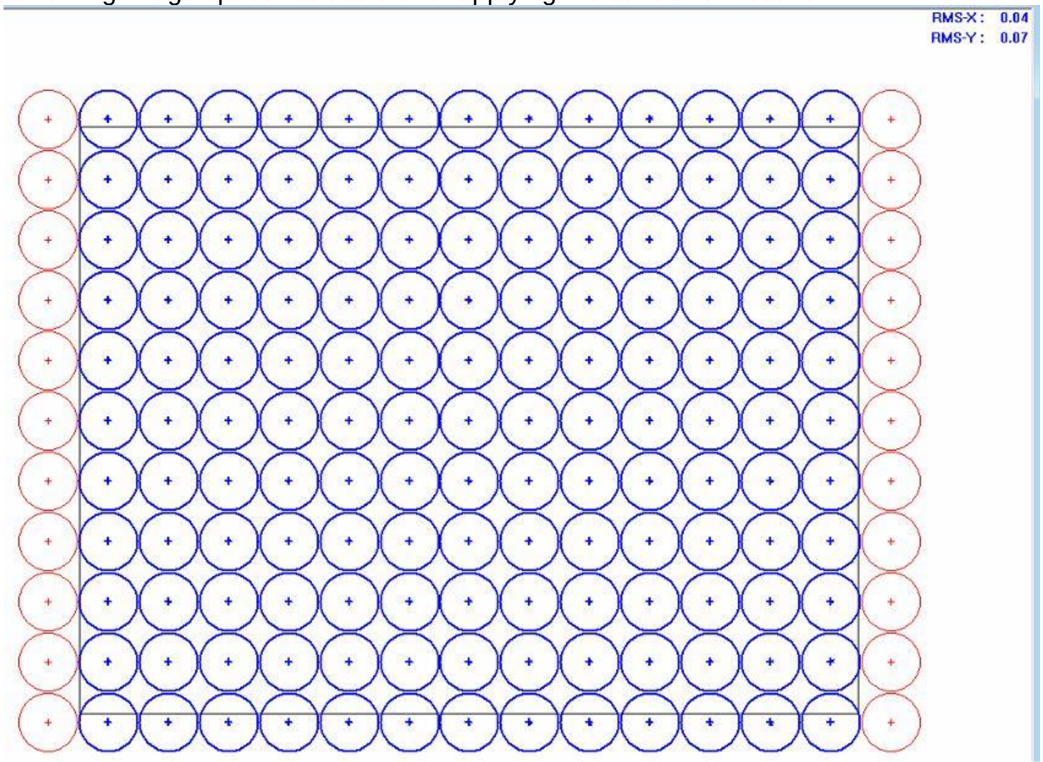
		Component	Serial Number
Camera Head		CH82	82659
Lens		NAT-D 2.8/80	80254
View Direction in Pod Position		Nadir	
IMU Misalignment		**Angle** [degree]	
	ω	-0.00815	
	Φ	0.00028	
	κ	-0.26654	
Principal Point		**Distance** [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		**Distance** [mm]	
	c	83.00	

Geometric Calibration File

RCD30_Geometry_CameraHead-82659-E-798528_LensSystem-80254-B-785423_DateTime-20190518-214751.xml

Geometric Calibration Date	Date	18.05.2019
Radiometric Calibration Date	Date	05.02.2019
Misalingment Flight	Date	23.06.2019
Misalingment Update Completed	Date	02.07.2019

Remaining image space residuals after applying the calibration results



Radius of circles is 0.0007 mm

Leica Geosystems
Leica TerrainMapper-LN
Calibration Certificate

Product	Leica TerrainMapper-LN
Serial Number	91513
Date	25 February 2019
Inspector	Xu Wang

Leica Geosystems AG
Heinrich-Wild-Strasse
CH-9435 Heerbrugg
Schweiz
www.leica-geosystems.com

Document Code: 871495

1. System Components

Component	**Type**	**Serial Number**
TerrainMapper Pod	TerrainMapper Pod	91513
GNSS/IMU	Litef LCI-100C 500 Hz	1205
LiDAR Unit	Hyperion2 LiDAR Unit	5513
Camera Head	CH82	82644
Lens	NAT-D 2.8/80	80245

2. Estimation Process

		Passed	**Date**	**Inspector**
Image Flight	completed	ok	14.02.2019	Deniz Arslan
Image Quality Check	checked	ok	24.02.2019	Bernhard Riedl
Image Calibration	completed	ok	25.02.2019	Xu Wang
Image Misalignment Update	completed			
LiDAR Flight	completed	ok	04.02.2019	Deniz Arslan
LiDAR Quality Check	checked	ok	04.02.2019	René Heierli
LiDAR Calibration and Accuracy	completed	ok	07.02.2019	Xu Wang
LiDAR Misalignment Update	completed			

3. Inspectors

Name	Bernhard Riedl	25.02.2019	
Position	Production Manager		
Name	Robert Bosch	25.02.2019	
Position	Support Engineer		
Name	Michael Vetter	25.02.2019	
Position	Support Engineer		

4. Remarks

5. LiDAR Calibration Results

The calibration results for the LiDAR Unit are only valid for:

- IMU and Pod as listed in the System Components section

5.1 LiDAR Geometric Calibration Results

IMU Misalignment		**Value**	**Unit**
	ω	-0.006841	degree
	Φ	0.032871	degree
	κ	-0.061655	degree
Boresight		**Value**	**Unit**
	Θ	0.004111	degree
	Φ	0.002086	degree
Receiver 1		**Value**	**Unit**
Range	Δ Offset	0.000000	meters
Wedge 0		**Value**	**Unit**
Wedge	Δ Alpha	-0.039072	degree
Wedge Position	Δ Offset	0.993387	degree
Position Correction	X	-0.023366	degree
	Y	0.002286	degree
Mount	Roll	0.192519	degree
	Pitch	0.679010	degree
Rotation Axis	Roll	0.027303	degree
	Pitch	0.110180	degree
Wedge 1		**Value**	**Unit**
Wedge	Δ Alpha	-0.006531	degree
Wedge Position	Δ Offset	0.521209	degree
Position Correction	X	0.002034	degree
	Y	-0.002471	degree
Mount	Roll	-0.015741	degree
	Pitch	-0.056400	degree
	Speed Pitch	1.50E-06	degree/rps^2
Rotation Axis	Roll	-0.029805	degree
	Pitch	-0.043904	degree

LiDAR Geometric Calibration File

HYPERION_GEOMETRY_LIDARUNIT-5513-C-855570-DATETIME-20190207-172145.XML

	Date	07.02.2019	
LiDAR Misalignment Flight	Date	**-**	
LiDAR Misalignment Update Completed	Date	**-**	

5.2 LiDAR Unit Accuracy Check

Accuracy checks:

- Deviation of two perpendicular lines to GCP’s
- Difference of two perpendicular lines
- Difference of forward and backward scan of one line

5.2.1 Multi-line accuracy of two perpendicular lines to ground control points

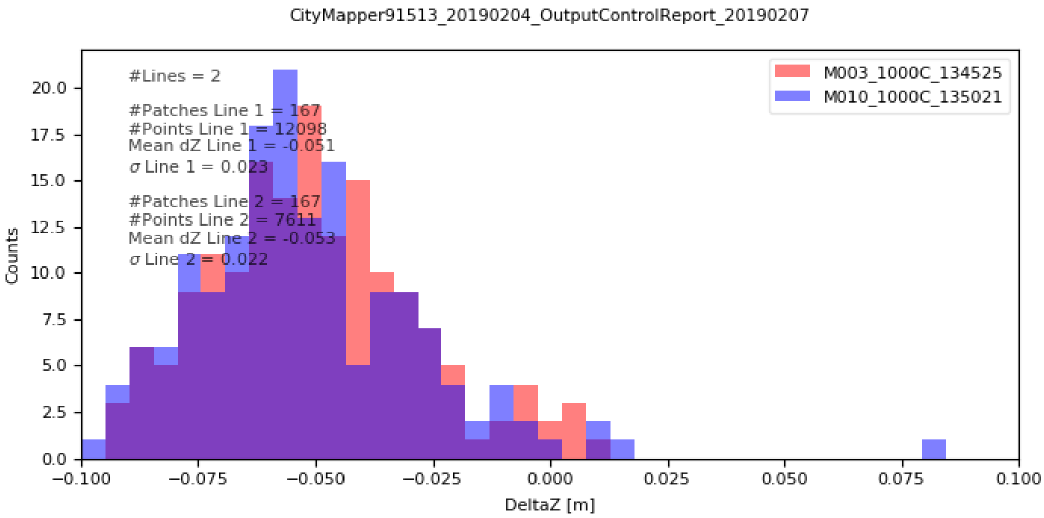


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

M010_1000C_135021

373128 valid patches with size of 2 m found. Only patches with standard deviation < 0.05 m and minimum of 5 points are included.

Color	Limits [m]	Number of patches	Proportion of total number of patches [%]
(dark green)	<=0.04	372822	99.92
(light green)	0.04-0.07	233	0.06
(yellow)	0.07-0.1	23	0.01
(red)	>0.1	50	0.01

Vertical difference

Figure 2 Vertical difference betweeen forward and backward scan at 1000 m AGL.

5.2.3 *Multi-line accuracy between two perpendicular lines*

M003_1000C_134525_vs_M010_1000C_135021

41041 valid patches with size of 2 m found. Only patches with standard deviation < 0.05 m and minimum of 5 points are included.

Color	Limits [m]	Number of patches	Proportion of total number of patches [%]
	<=0.04	41014	99.93
	0.04-0.07	20	0.05
	0.07-0.1	4	0.01
	>0.1	3	0.01

Vertical difference

Figure 3 Vertical difference betweeen two perpendicular lines at 1000 m AGL.

6. Imaging Sensors Estimation Results

The estimation results for the camera head and lens combination are only valid for:

- IMU and Pod as listed in the System Components section.
- Camera Head, lens and specified position as listed in the Estimation Results sections.

6.1 Camera Model of distortion free images

All factory calibration results contain fixed nominal focal lengths and zero principal point offsets.
Leica HxMap applies the grid to create distortion-free images of nominal focal length and pixel size.

6.1.1 CH8x Model

			Component
Camera Head			CH82
Lens			NAT-D 2.8/80
Camera Model			
Focal Length			**Distance** [mm]
	c		83.00
Radial Symmetric Distorsion			**Distance** [mm]
	k_0		0.0000
	k_1		0.0000
	k_2		0.0000
Decentering Distortion			**Distance** [mm]
	p_1		0.0000
	p_2		0.0000
Non-Orthogonality Distortion			**Distance** [mm]
	b_1		0.0000
	b_2		0.0000
Pixel Size (Height and Width)			**Distance** [mm]
	RGB		0.0052
	NIR		0.0120
Rows and Columns		**Rows**	**Columns**
	Active RGB	7752	10320
	Raw RGB	7788	10336
	Active NIR	3654	4478
	Raw NIR	3366	4500

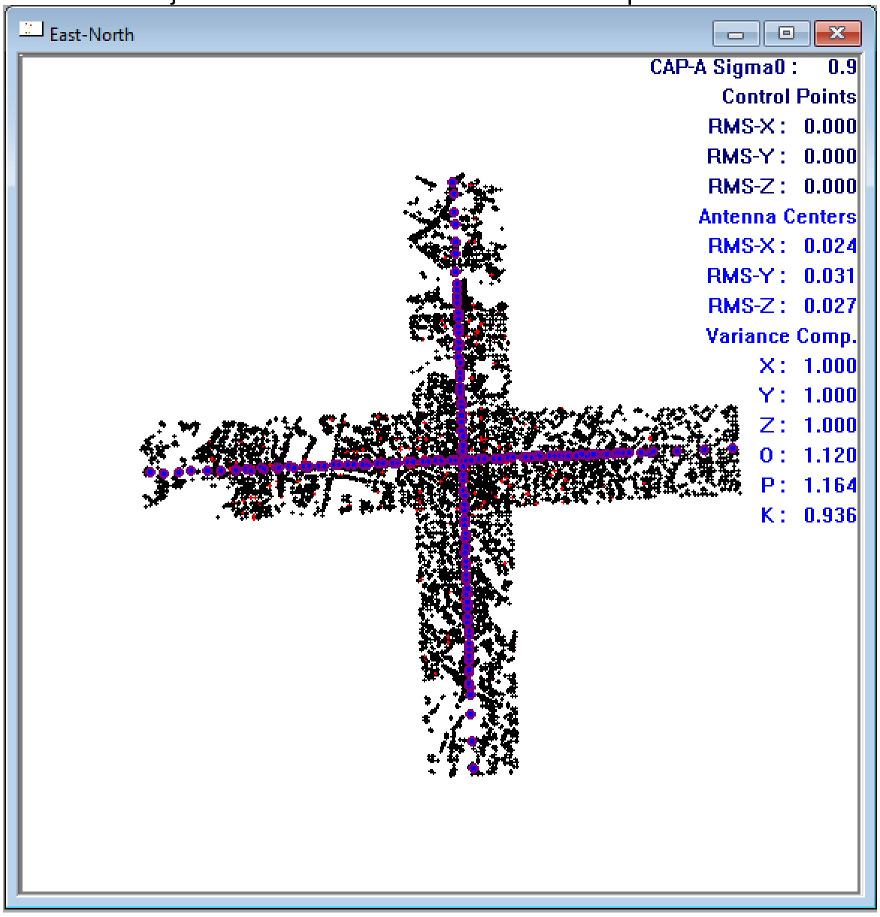
6.2 Results of Geometric Calibration

6.2.1 Calibration method for Green Reference Band

Estimation of additional parameters (focal length, principal point, radial symmetric distortion, correction grid) and IMU misalignment in simultaneous bundle adjustment

Reference band (green)	**Distance** [mm]
Resulting sigma naught of bundle adjustment:	0.0010

Final bundle adjustment results after elimination of tie point blunders:



6.2.2 Calibration method for Other Spectral Bands

Estimation of additional parameters (correction grid), based on the result for green in simultaneous bundle adjustment

Other Spectral Bands	**Distance** [mm]
Co-registration to green better than:	0.002

Leica HxMap applies the grid to create distortion-free images of nominal focal length and fixed pixel size of 0.0052 mm.

6.3 Estimation Results for Nadir Camera Head and Lens

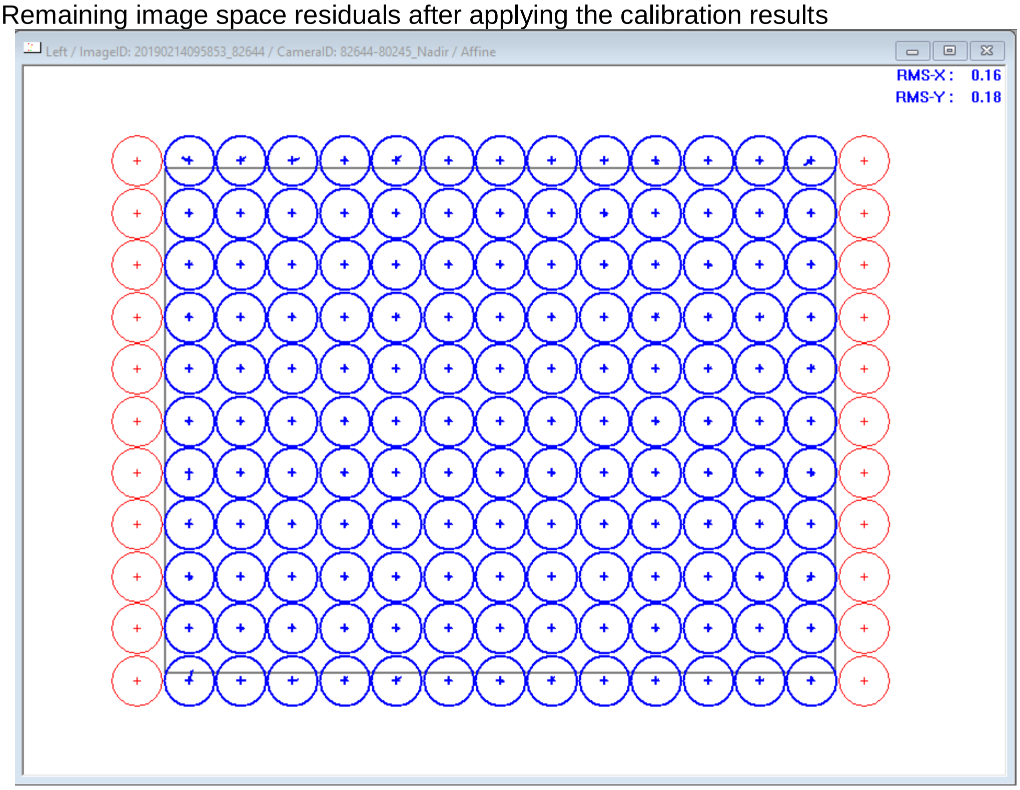
		Component	**Serial Number**
Camera Head		CH82	82644
Lens		NAT-D 2.8/80	80245
View Direction in Pod Position		Nadir	
IMU Misalignment		**Angle** [degree]	
Valid for this calibration flight only	ω	-0.009454	
	Φ	-0.048891	
	κ	-0.023235	
Principal Point		**Distance** [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		**Distance** [mm]	
	c	83.00	

Geometric Calibration File

RCD30_Geometry_CameraHead-82644-E-798528_LensSystem-80245-B-785423_DateTime-20190225-115639.xml

Geometric Calibration Date	Date	25.02.2019
Radiometric Calibration Date	Date	11.01.2019
Misalignment Flight	Date	-
Misalignment Update Completed	Date	-

Remaining image space residuals after applying the calibration results



Radius of circles is 0.0010 mm

- when it has to be **right**

Leica Geosystems
Leica TerrainMapper-LN
Calibration Certificate

Product	Leica TerrainMapper-LN
Serial Number	91515
Date	27 June 2019
Inspector	Mark O’Neal

Leica Geosystems AG
Heinrich-Wild-Strasse
CH-9435 Heerbrugg
Schweiz
www.leica-geosystems.com

Document Code: 871495

1. System Components

Component	Type	Serial Number
Pod	TerrainMapper Pod	91515
GNSS/IMU	Litef LCI-100C 500 Hz	1226
LiDAR Unit	Hyperion2 LiDAR Unit	5516
Camera Head	CH82	82658
Lens	NAT-D 2.8/80	80253

2. Estimation Process

		Passed	Date	Inspector
Image Flight	completed	ok	10.05.2019	Philip Benz
Image Quality Check	checked	ok	16.05.2019	Bernhard Riedl
Image Calibration	completed	ok	23.05.2019	Xu Wang
Image Misalignment Update	completed	ok	25.06.2019	Mark O'Neal
LiDAR Flight	completed	ok	29.11.2018	Philip Benz
LiDAR Quality Check	checked	ok	06.12.2018	Rene Heierli
LiDAR Calibration and Accuracy	completed	ok	12.12.2018	Robert Bosch
LiDAR Misalignment Update	completed	ok	27.06.2019	Mark O'Neal

3. Inspectors

Name	Bernhard Riedl	27.06.2019
Position	Production Manager	
Name	Xu Wang	27.06.2019
Position	Support Engineer	
Name	Robert Bosch	12.12.2018
Position	Support Engineer	

4. Remarks

5. LiDAR Calibration Results

The calibration results for the LiDAR Unit are only valid for:

- IMU and Pod as listed in the System Components section

5.1 LiDAR Geometric Calibration Results

IMU Misalignment		**Value**	**Unit**
	ω	-0.017122	degree
	Φ	0.048251	degree
	κ	0.000135	degree
Boresight		**Value**	**Unit**
	Θ	0.015419	degree
	Φ	-0.001923	degree
Receiver 1		**Value**	**Unit**
Range	Δ Offset	0.000000	meters
Wedge 0		**Value**	**Unit**
Wedge	Δ Alpha	-0.043014	degree
Wedge Position	Δ Offset	0.442789	degree
Position Correction	X	-0.012826	degree
	Y	0.000012	degree
Mount	Roll	0.045379	degree
	Pitch	0.210132	degree
Rotation Axis	Roll	0.031087	degree
	Pitch	0.076675	degree
Wedge 1		**Value**	**Unit**
Wedge	Δ Alpha	-0.005517	degree
Wedge Position	Δ Offset	0.559649	degree
Position Correction	X	0.030760	degree
	Y	-0.001169	degree
Mount	Roll	0.012366	degree
	Pitch	0.054254	degree
	Speed Pitch	1.50E-06	degree/rps^2
Rotation Axis	Roll	0.032485	degree
	Pitch	-0.029191	degree

LiDAR Geometric Calibration File

HYPERION_GEOMETRY_LIDARUNIT-5516-C-855570-DATETIME-20181204-161828.XML

	Date	12.04.2018
LiDAR Misalignment Flight	Date	06.14.2019
LiDAR Misalignment Update Completed	Date	06.27.2019

5.2 LiDAR Unit Accuracy Check

Accuracy checks:

- Deviation of two perpendicular lines to GCP's
- Difference of two perpendicular lines
- Difference of forward and backward scan of one line

5.2.1 Multi-line accuracy of two perpendicular lines to ground control points

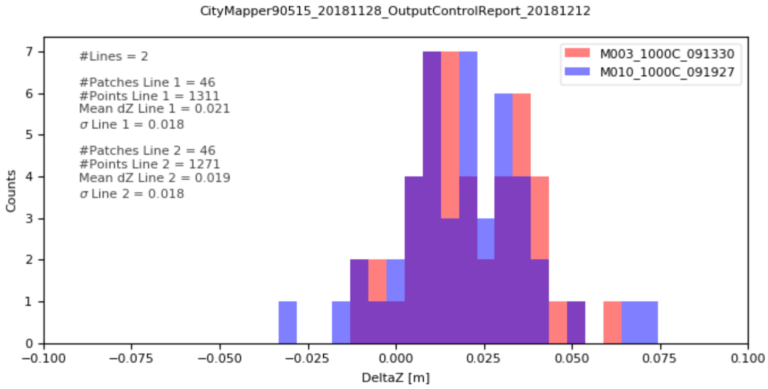


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

M010_1000C_091927

303355 valid patches with size of 2 m found. Only patches with standard deviation < 0.05 m and minimum of 5 points are included.

Color	Limits [m]	Number of patches	Proportion of total number of patches [%]
(dark green)	<=0.04	302593	99.75
(light green)	0.04-0.07	716	0.24
(yellow)	0.07-0.1	17	0.01
(red)	>0.1	29	0.01

Vertical difference

Figure 2 Vertical difference betweeen forward and backward scan at 1000 m AGL.

5.2.3 Multi-line accuracy between two perpendicular lines

M003_1000C_091330_vs_M010_1000C_091927

29588 valid patches with size of 2 m found. Only patches with standard deviation < 0.05 m and minimum of 5 points are included.

Color	Limits [m]	Number of patches	Proportion of total number of patches [%]
	<=0.04	29546	99.86
	0.04-0.07	38	0.13
	0.07-0.1	1	0.00
	>0.1	3	0.01

Vertical difference

Figure 3 Vertical difference betweeen two perpendicular lines at 1000 m AGL.

6. Imaging Sensors Estimation Results

The estimation results for the camera head and lens combination are only valid for:

- IMU and Pod as listed in the System Components section.
- Camera Head, lens and specified position as listed in the Estimation Results sections.

6.1 Camera Model of distortion free images

All factory calibration results contain fixed nominal focal lengths and zero principal point offsets.
Leica HxMap applies the grid to create distortion-free images of nominal focal length and pixel size.

6.1.1 CH8x Model

			Component
Camera Head			CH82
Lens			NAT-D 2.8/80
Camera Model			
Focal Length			**Distance** [mm]
	c		83.00
Radial Symmetric Distorsion			**Distance** [mm]
	k_0		0.0000
	k_1		0.0000
	k_2		0.0000
Decentering Distortion			**Distance** [mm]
	p_1		0.0000
	p_2		0.0000
Non-Orthogonality Distortion			**Distance** [mm]
	b_1		0.0000
	b_2		0.0000
Pixel Size (Height and Width)			**Distance** [mm]
	RGB		0.0052
	NIR		0.0120
Rows and Columns		**Rows**	**Columns**
	Active RGB	7752	10320
	Raw RGB	7788	10336
	Active NIR	3654	4478
	Raw NIR	3366	4500

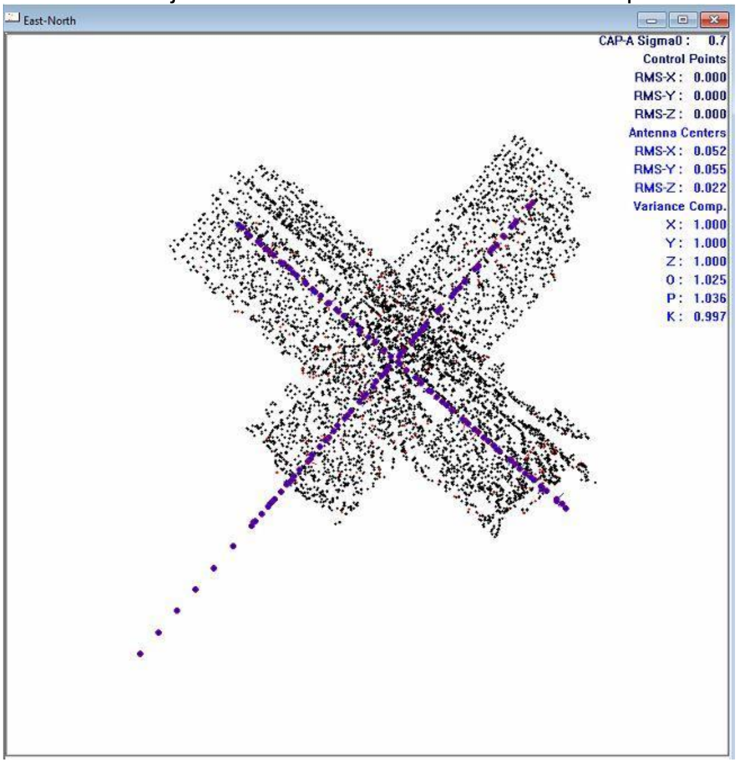
6.2 Results of Geometric Calibration

6.2.1 Calibration method for Green Reference Band

Estimation of additional parameters (focal length, principal point, radial symmetric distortion, correction grid) and IMU misalignment in simultaneous bundle adjustment

Reference band (green)	**Distance** [mm]
Resulting sigma naught of bundle adjustment:	0.0007

Final bundle adjustment results after elimination of tie point blunders:



6.2.2 Calibration method for Other Spectral Bands

Estimation of additional parameters (correction grid), based on the result for green in simultaneous bundle adjustment

Other Spectral Bands	**Distance** [mm]
Co-registration to green better than:	0.002

Leica HxMap applies the grid to create distortion-free images of nominal focal length and fixed pixel size of 0.0052 mm.

6.3 Estimation Results for Nadir Camera Head and Lens

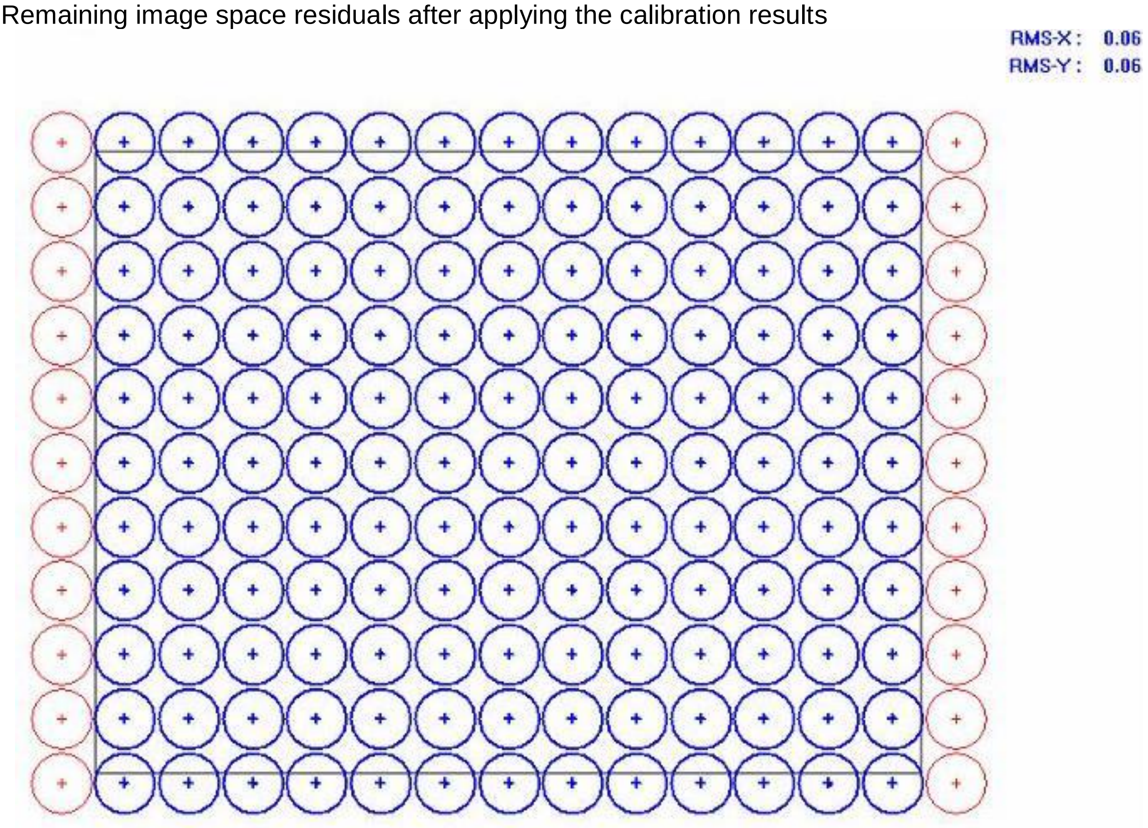
		Component	Serial Number
Camera Head		CH82	82658
Lens		NAT-D 2.8/80	80253
View Direction in Pod Position		Nadir	
IMU Misalignment		**Angle** [degree]	
	ω	0.07949	
	Φ	-0.00801	
	κ	-0.22593	
Principal Point		**Distance** [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		**Distance** [mm]	
	c	83.00	

Geometric Calibration File

RCD30_Geometry_CameraHead-82658-E-798528_LensSystem-80253-B-785423_DateTime-20190521-110247.xml

Geometric Calibration Date	Date	21.05.2019
Radiometric Calibration Date	Date	05.06.2019
Misalignment Flight	Date	14.06.2019
Misalignment Update Completed	Date	25.06.2019

Remaining image space residuals after applying the calibration results



Radius of circles is 0.0007 mm

Appendix 2: Flight Logs

Woolpert Lidar Acquisition Log

Project Info			Date		
Project #	Project Name	Unique ID	Flight Date (UTC)	Day of Year	Flight #
80997/80904	80904/ BLK9 SWest and 80997/BLK6 SCentral	Day170_90513_A	06/18/2020	170	A

Crew	Equipment	Time					Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Hoover	Cessna 404 Titan - N532NM	566.9	08:24:00	14:24:00	CPR
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Ryan	Leica Terrain Mapper - 90513	574.4	14:59:00	20:59:00	CPR

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
240	8	10	7,000	Few	10	2	3021

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	8,202	13,310	5,344

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7	2	40	90	600	100

Verify S-Turns Before Mission: Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
							80997 South Central BLOCK 6
3	S	14:24:00	14:28:00	00:04:00	19	1.1	partial line 1-12
2	S	14:37:00	14:55:00	00:18:00	18	1.2	
1	N	14:59:00	15:17:00	00:18:00	18	1.2	
18	S	15:22:00	15:23:00	00:01:00	17	1.3	partial line 1-20
66	S	15:32:00	15:33:00	00:01:00	17	1.2	partial line 1-8? / eye safety shut off
66	S	15:39:00	15:40:00	00:01:00	17	1.2	partial line 1-14
60	S	15:47:00	15:55:00	00:08:00	21	1	partial line 1-75
							80904 South West BLOCK 9
69	S	16:33:00	16:39:00	00:06:00	17	1.1	
68	N	16:43:00	16:54:00	00:11:00	20	0.9	
67	S	16:58:00	17:10:00	00:12:00	19	1	
66	N	17:13:00	17:28:00	00:15:00	18	1.1	
65	S	17:31:00	17:47:00	00:16:00	16	1.4	
64	N	17:50:00	18:05:00	00:15:00	16	1.4	
63	S	18:09:00	18:24:00	00:15:00	18	1.1	
62	N	18:28:00	18:43:00	00:15:00	23	1	
61	S	18:46:00	19:02:00	00:16:00	21	1.1	
60	N	19:05:00	19:21:00	00:16:00	22	1.1	
53	S	19:28:00	19:43:00	00:15:00	22	1.1	
52	N	19:46:00	20:02:00	00:16:00	22	1.2	
51	S	20:06:00	20:21:00	00:15:00	21	1.3	
50	N	20:24:00	20:40:00	00:16:00	21	1.1	
49	S	20:43:00	20:59:00	00:16:00	21	1.2	

Verify S-Turns After Mission: Yes

Additional Comments

Woolpert Lidar Acquisition Log

Project Info			Date		
Project #	Project Name	Unique ID	Flight Date (UTC)	Day of Year	Flight #
80997	South Central Wyoming	Day170_90515_A	06/18/2020	170	A

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Gilibaro	Cessna 404 Titan - N7079F	2731.4	08:25:00	14:25:00	CPR
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
DeHart	Leica Terrain Mapper - 90515	2734.4	11:06:00	17:06:00	CPR

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
240	10	10	12,000	Clear	10	1.7	30.21

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
160	7,553	12,897	5,344

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.35	10	40	89	600	100

Verify S-Turns Before Mission: Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
78	S	14:25:00	14:45:00	00:20:00	20	1.2	Block 4
79	N	14:49:00	15:09:00	00:20:00	22	1.1	Light Clouds on north end of block
80	S	15:12:00	15:32:00	00:20:00	19	1.3	Light Clouds on north end of block
54	N	15:49:00	16:04:00	00:15:00	23	1	Block 3
53	S	16:08:00	16:24:00	00:16:00	17	1.2	
40	N	16:30:00	16:45:00	00:15:00	18	1.1	
41	N	16:53:00	17:06:00	00:13:00	21	1	Block 1, Clouded out

Verify S-Turns After Mission: Yes

Additional Comments

Woolpert Lidar Acquisition Log

Project Info			Date		
Project #	Project Name	Unique ID	Flight Date (UTC)	Day of Year	Flight #
80904	Wyoming Southwest BLOCK 9	Day172_90513_A	06/20/2020	172	A

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Hoover	Cessna 404 Titan - N532NM	574.4	11:24:00	17:24:00	CPR
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Ryan	Leica Terrain Mapper - 90513	579.9	15:44:00	21:44:00	KRKS

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
200	11	10	6,000	Scattered	19	6	3007

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	8,202	14,672	5,344

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7	2	40	90	600	100

Verify S-Turns Before Mission: Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
59	S	17:24:00	17:39:00	00:15:00	15	1.3	
48	N	17:44:00	18:00:00	00:16:00	15	1.4	
47	S	18:02:00	18:18:00	00:16:00	17	1.1	
46	N	18:21:00	18:36:00	00:15:00	17	1.1	
45	S	18:39:00	18:54:00	00:15:00	16	1.2	
44	N	18:57:00	19:13:00	00:16:00	16	1.3	
43	S	19:16:00	19:31:00	00:15:00	18	1.1	
42	N	19:34:00	19:49:00	00:15:00	18	1.3	
41	S	19:52:00	20:08:00	00:16:00	18	1.2	
58	N	20:14:00	20:29:00	00:15:00	17	1.2	
57	S	20:32:00	20:48:00	00:16:00	18	1.2	
56	N	20:51:00	21:07:00	00:16:00	17	1.4	
55	S	21:10:00	21:25:00	00:15:00	17	1.2	
54	N	21:28:00	21:44:00	00:16:00	17	1.2	

Verify S-Turns After Mission: Yes

Additional Comments

No Base Station set up. Use CORS

Woolpert Lidar Acquisition Log

Project Info			Date		
Project #	Project Name	Unique ID	Flight Date (UTC)	Day of Year	Flight #
80904	SW Wyoming Block 10	Day187_90511_1	07/05/2020	187	1

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Gebhart	Cessna 404 Titan - N404CP	7798.6	07:59:00	13:59:00	RKS
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Kennedy	Leica Terrain Mapper - 90511	7803.2	12:37:00	18:37:00	RKS

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
70	4	10		Clear	16	-1	30.23

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	8,202	14,373	6,765

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7	2	40	150	1600	100

Verify S-Turns Before Mission: Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
30	N	14:26:00	14:43:00	00:17:00	17	1.3	
31	S	14:45:00	15:02:00	00:17:00	22	1	
32	N	15:04:00	15:21:00	00:17:00	19	1.2	
33	S	15:23:00	15:39:00	00:16:00	19	1.1	
34	N	15:42:00	15:58:00	00:16:00	23	0.9	
35	S	16:00:00	16:16:00	00:16:00	24	1	
36	N	16:19:00	16:35:00	00:16:00	19	1.3	
37	S	16:37:00	16:54:00	00:17:00	19	1.4	
38	N	16:56:00	17:13:00	00:17:00	19	1.2	
39	S	17:15:00	17:32:00	00:17:00	23	1.1	
40	N	17:34:00	17:50:00	00:16:00	21	1.2	
41	S	17:52:00	18:09:00	00:17:00	23	1.1	

Verify S-Turns After Mission: Yes

Additional Comments

Woolpert Lidar Acquisition Log

Project Info			Date		
Project #	Project Name	Unique ID	Flight Date (UTC)	Day of Year	Flight #
80904	Wyoming Southwest Block 10	Day187_90513_A	07/05/2020	187	A

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Comer	Cessna 404 Titan - N532NM	613.6	08:26:00	14:26:00	KRKS
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Ryan	Leica Terrain Mapper - 90513	618.5	12:30:00	18:30:00	KRKS

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
120	4	10		Clear	18	0	3023

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	8,202	14,249	6,765

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7	2	40	90	600	100

Verify S-Turns Before Mission: Yes

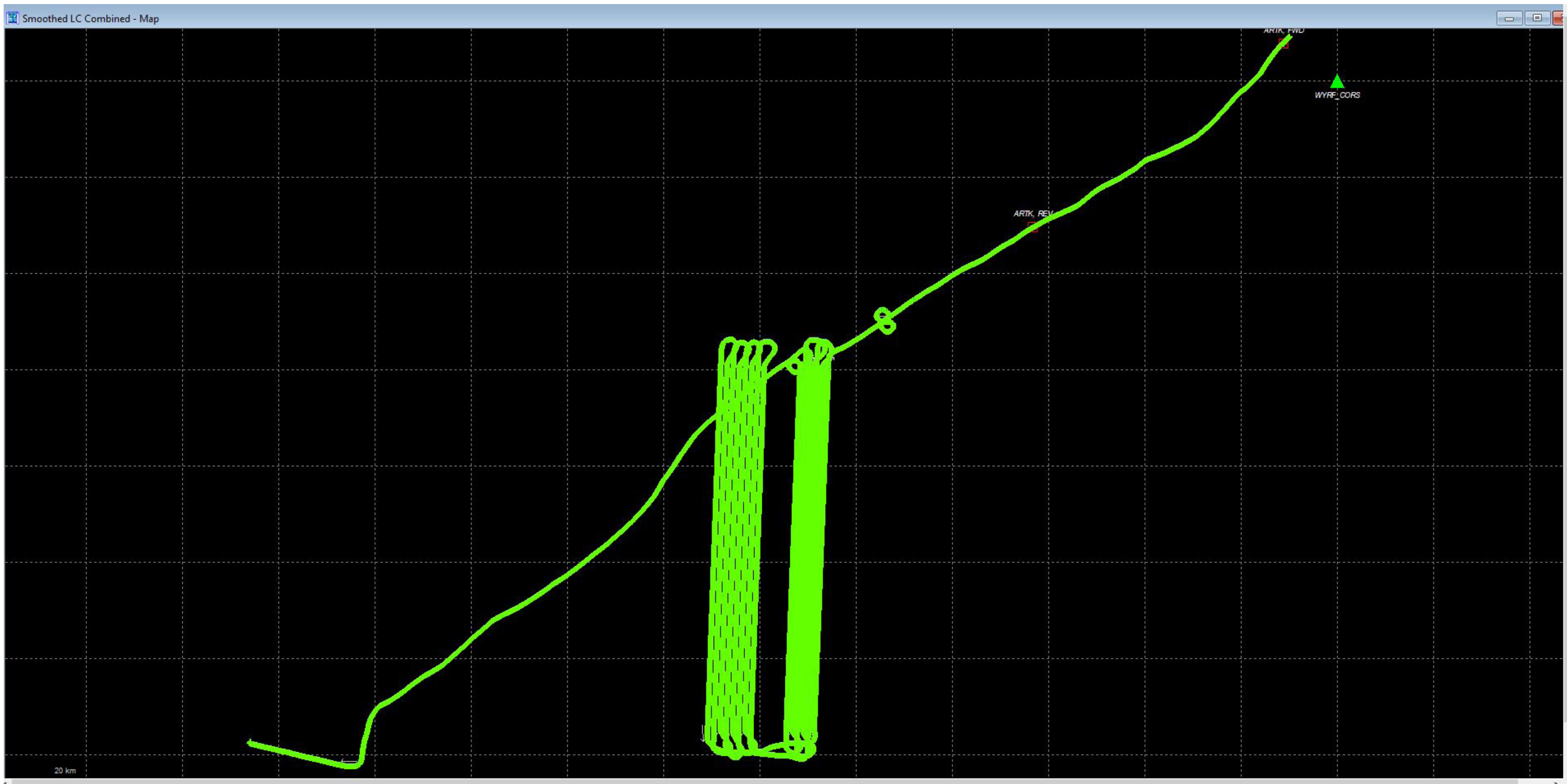
Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
47	N	14:26:00	14:33:00	00:07:00	17	1.3	
46	S	14:39:00	14:49:00	00:10:00	20	1	
45	N	14:53:00	15:08:00	00:15:00	18	1.2	
44	S	15:11:00	15:28:00	00:17:00	18	1.2	
43	N	15:31:00	15:47:00	00:16:00	21	1	
42	S	15:51:00	16:07:00	00:16:00	20	1	
16	N	16:15:00	16:31:00	00:16:00	16	1.3	
15	S	16:34:00	16:50:00	00:16:00	16	1.4	
14	N	16:54:00	17:10:00	00:16:00	16	1.4	
13	S	17:13:00	17:30:00	00:17:00	18	1.2	
12	N	17:34:00	17:50:00	00:16:00	18	1.2	very strong winds
11	S	17:53:00	18:10:00	00:17:00	19	1.3	very strong winds
9	N	18:13:00	18:30:00	00:17:00	20	1.1	very strong winds

Verify S-Turns After Mission: Yes

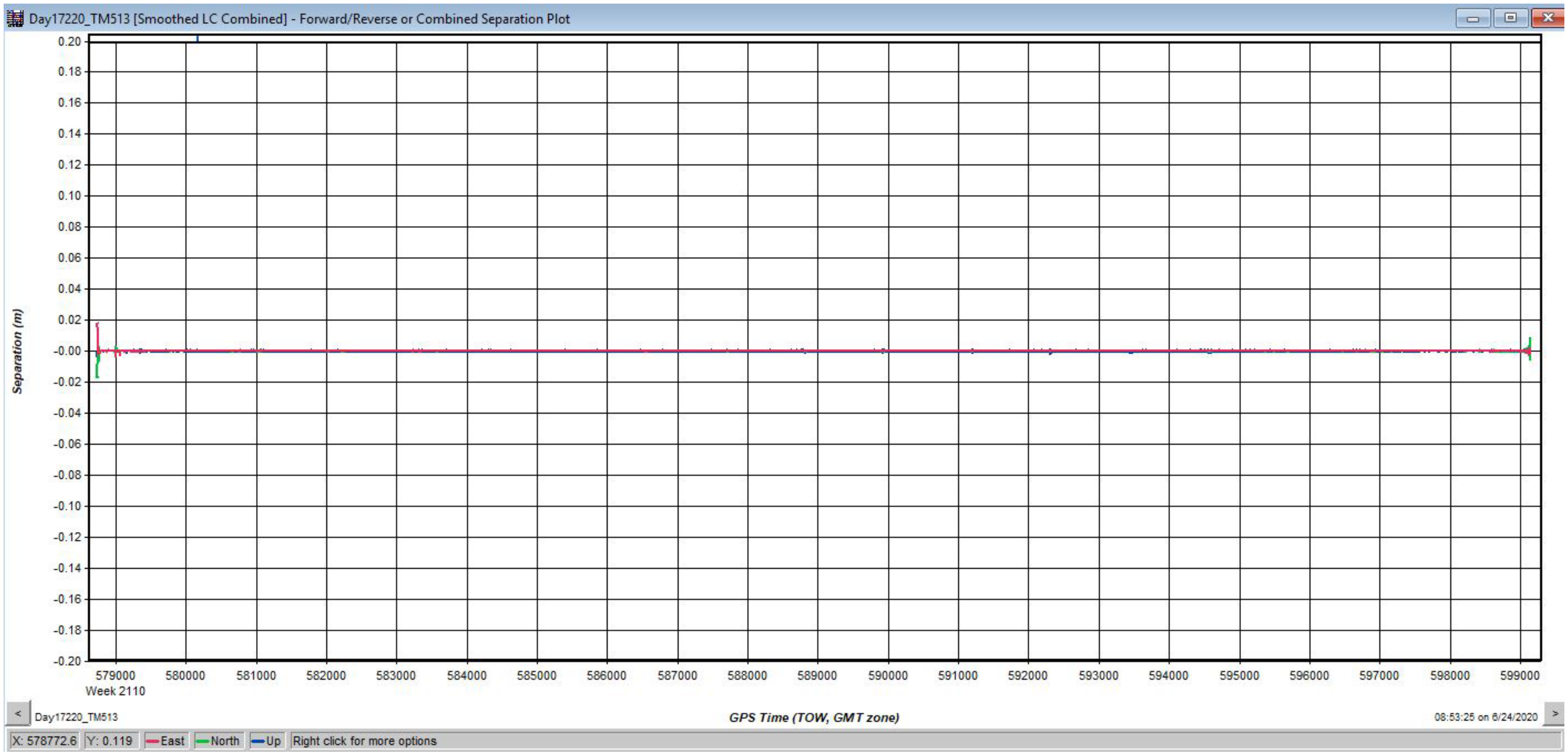
Additional Comments

Appendix 3: GPS / IMU Graphics

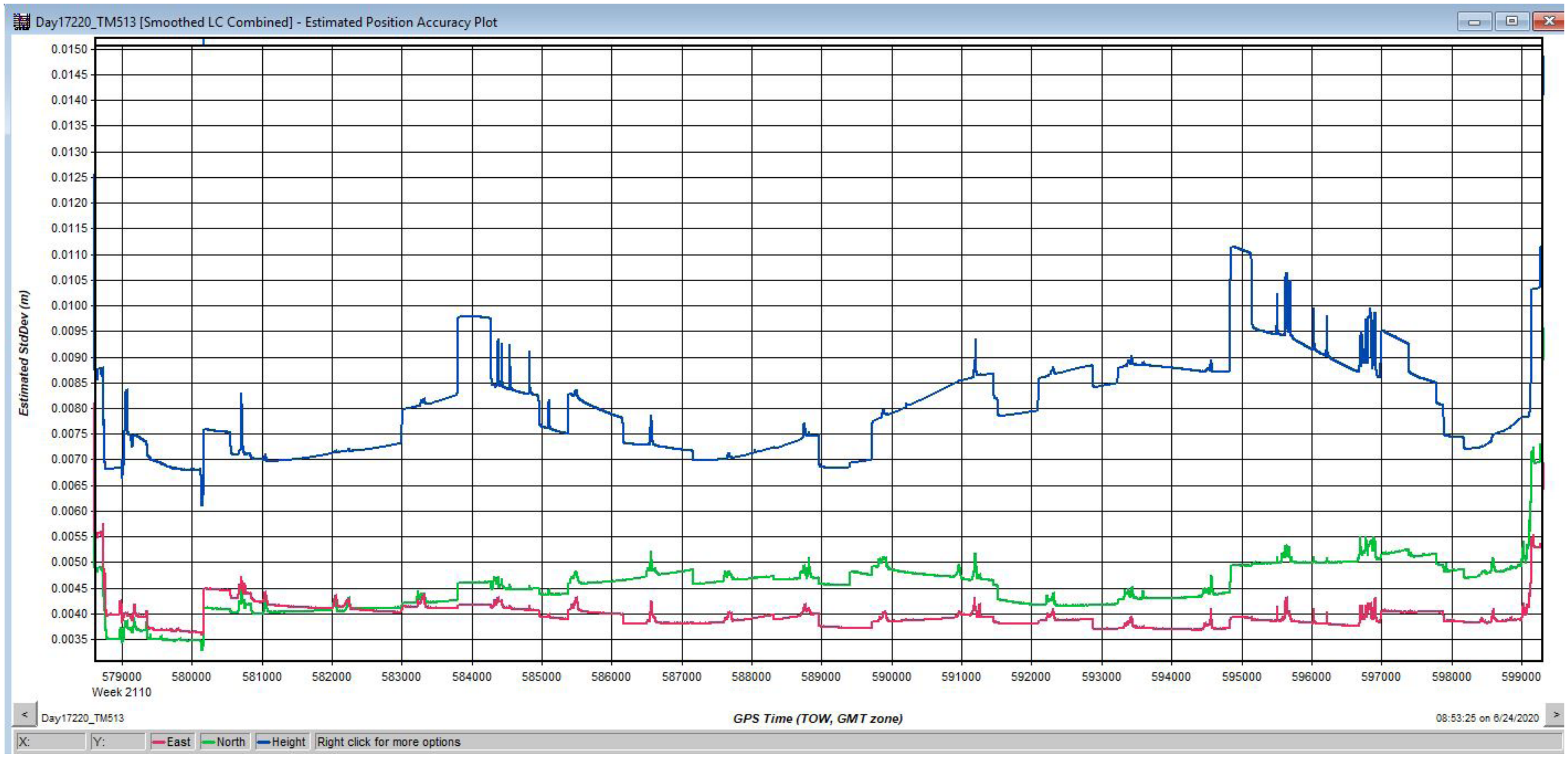
Day17220_TM513
Trajectory



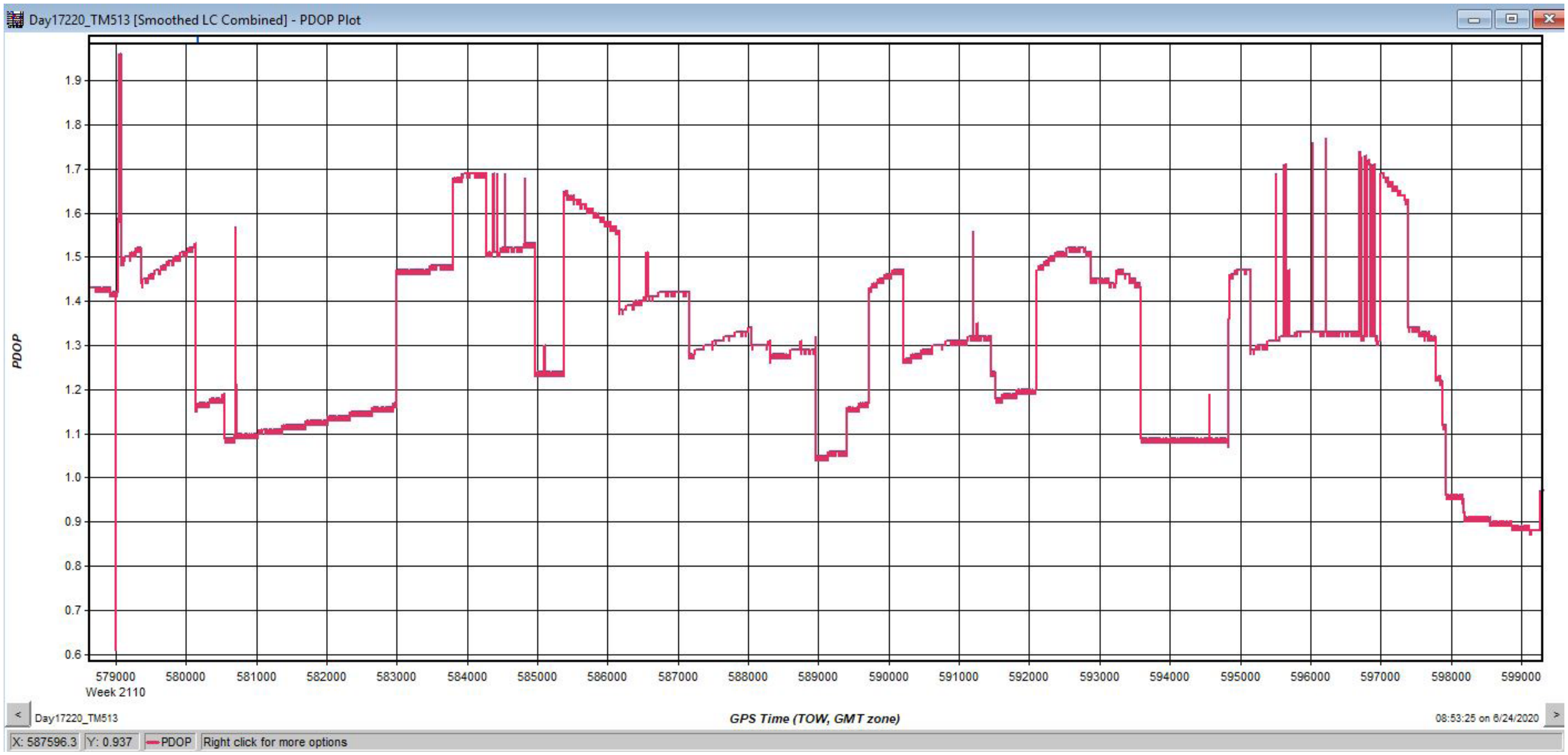
Day17220_TM513
Forward/Reverse or Combined Separation Plot



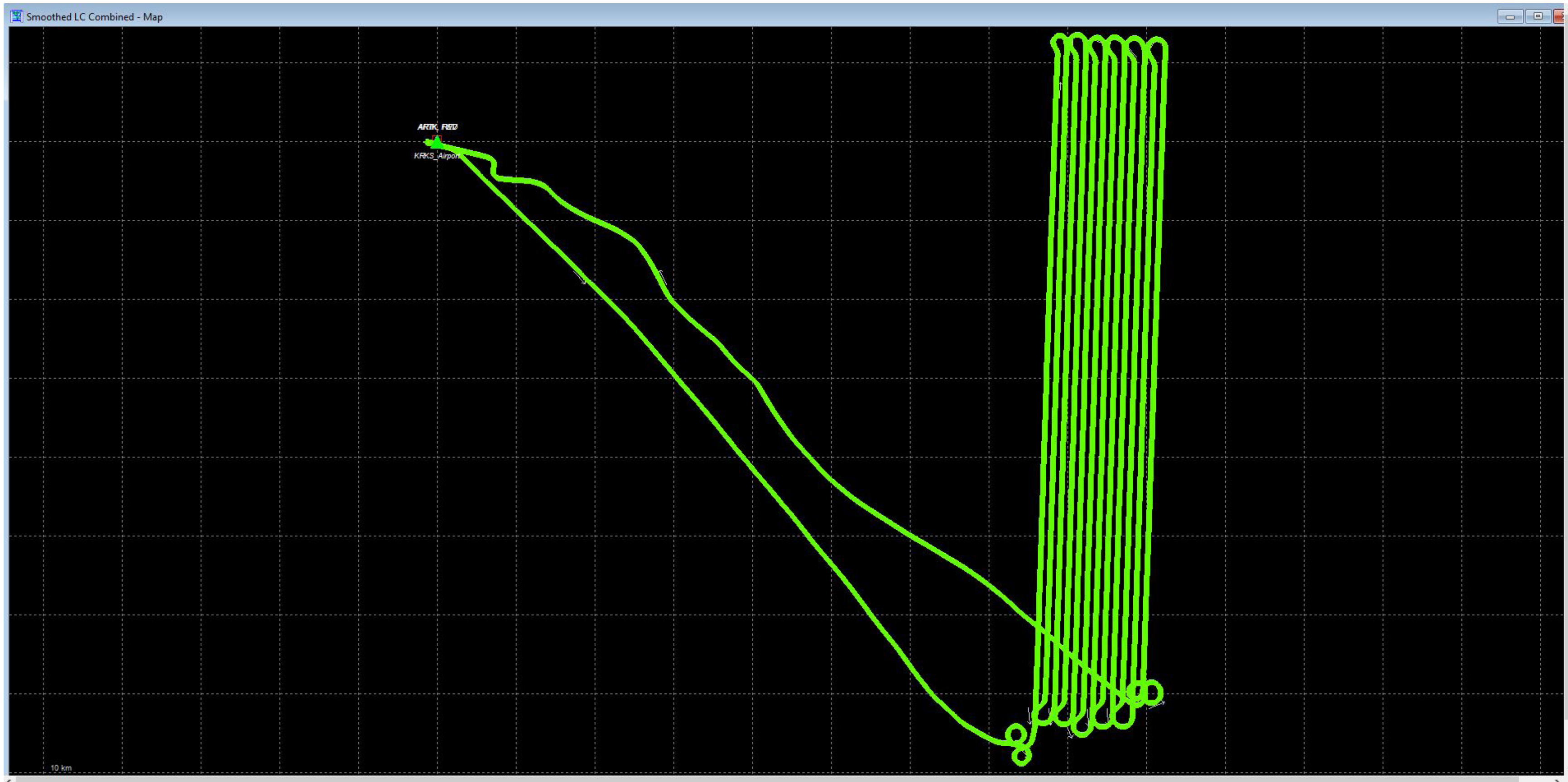
Day17220_TM513
Estimated Position Accuracy



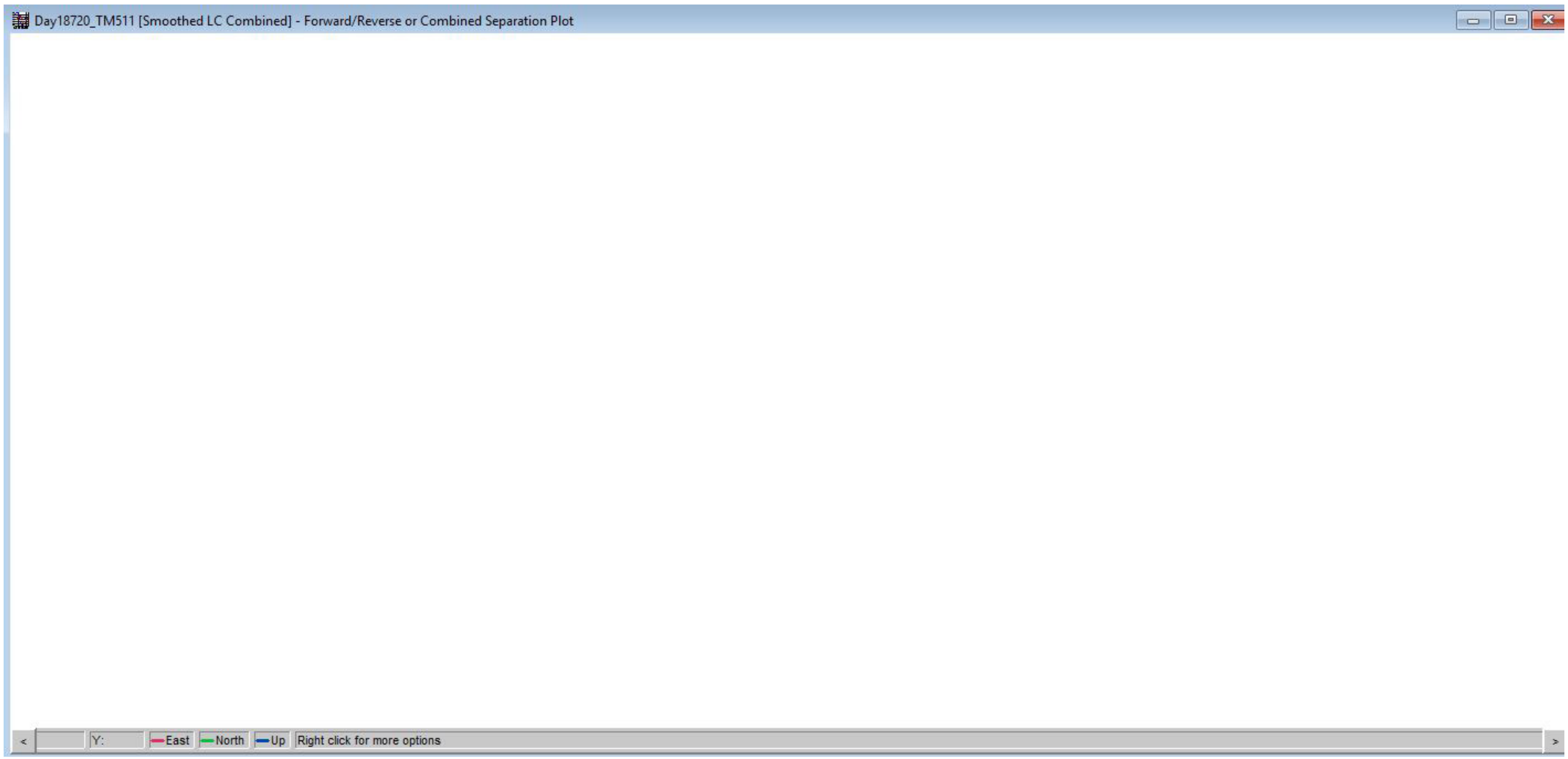
Day17220_TM513
PDOP Plot



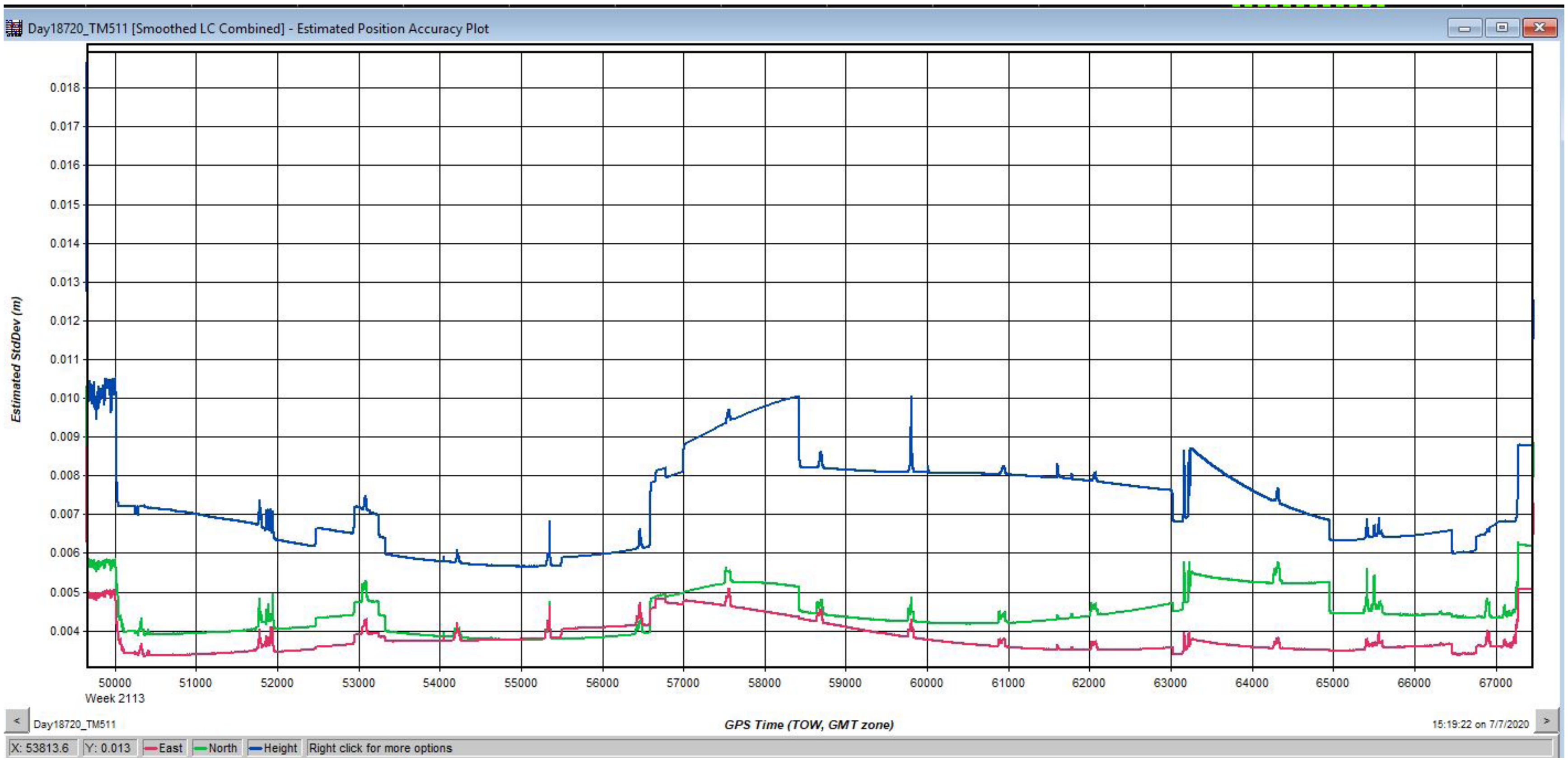
Day18720_TM511
Trajectory



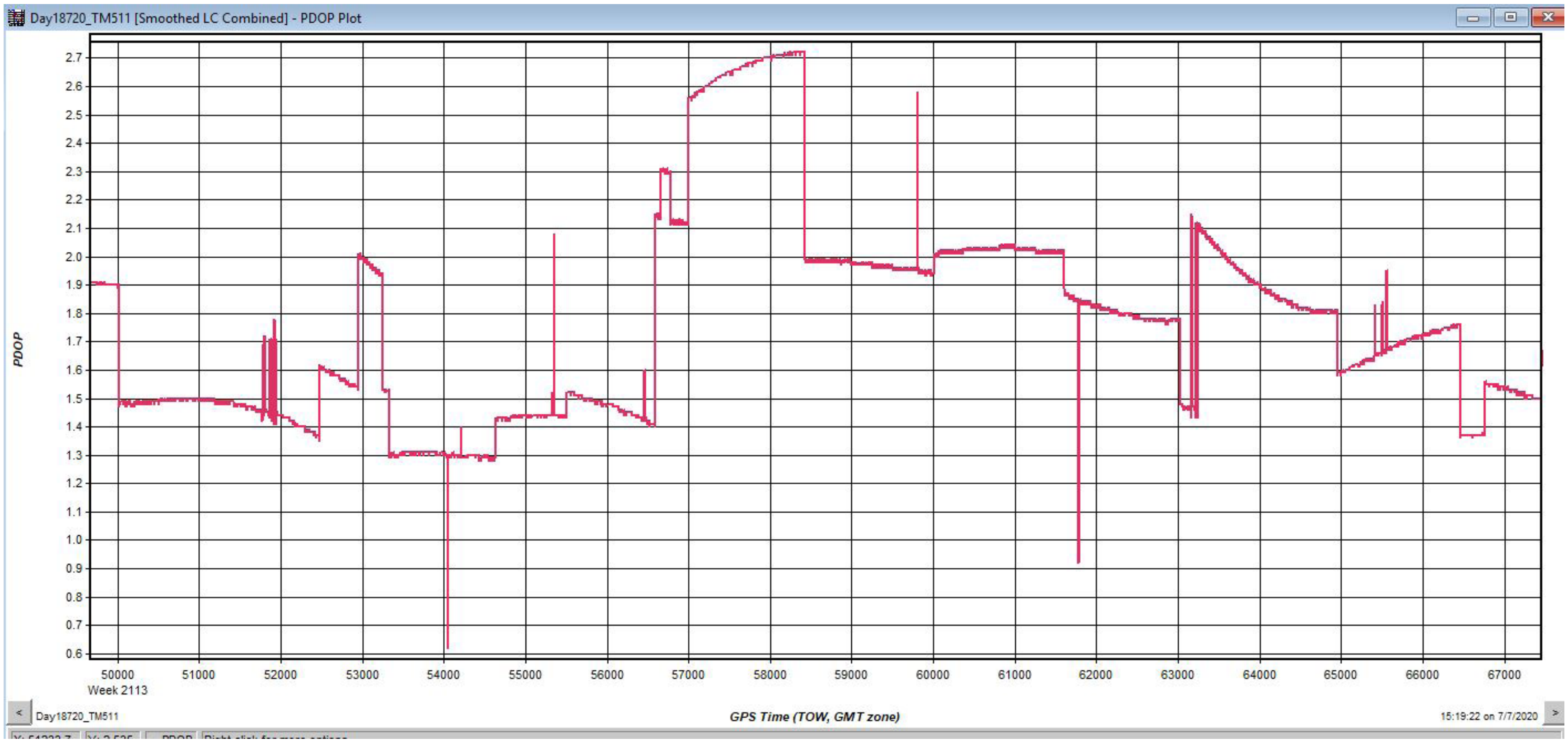
Day18720_TM511
Forward/Reverse or Combined Separation Plot



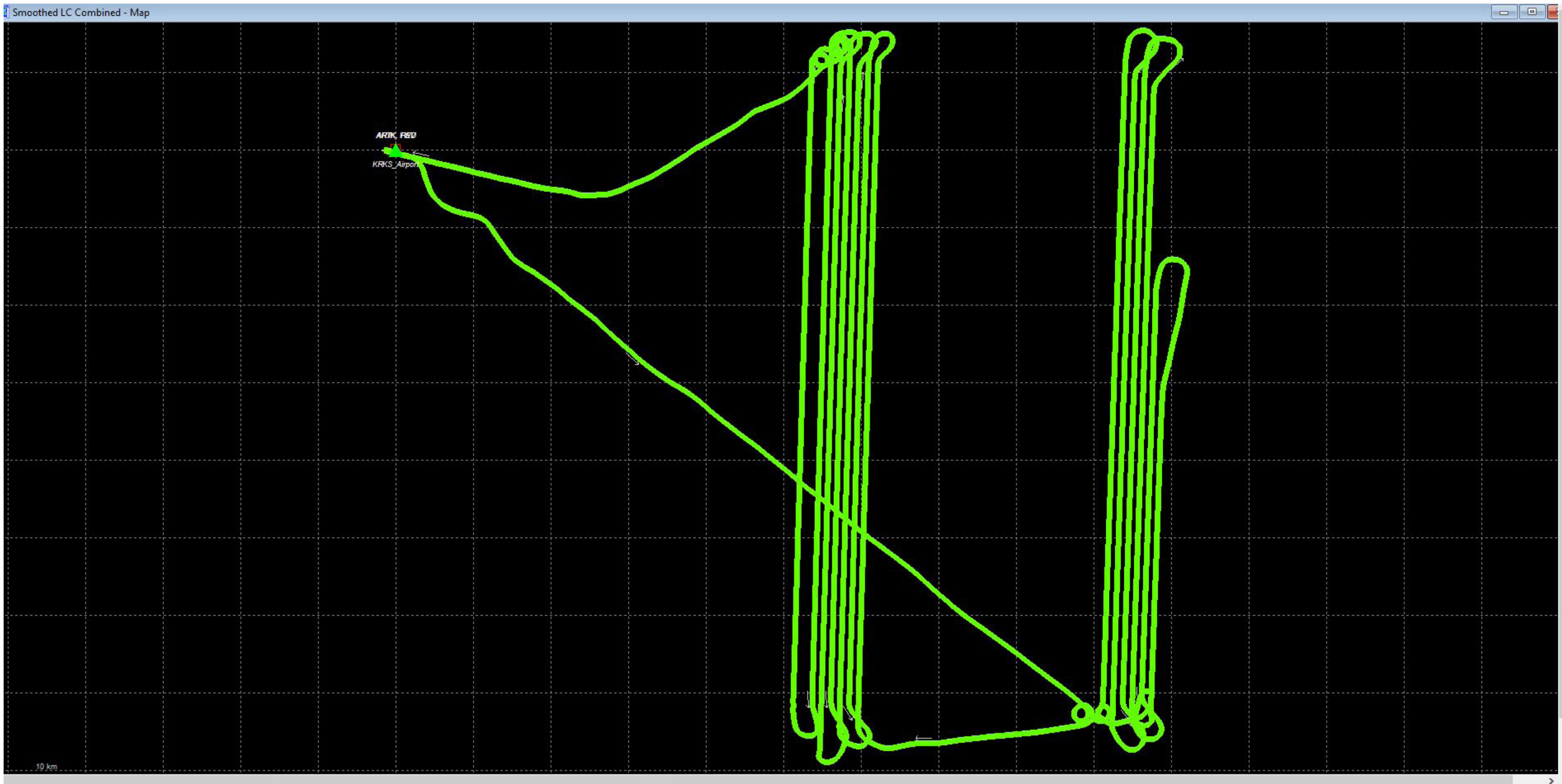
Day18720_TM511
Estimated Position Accuracy



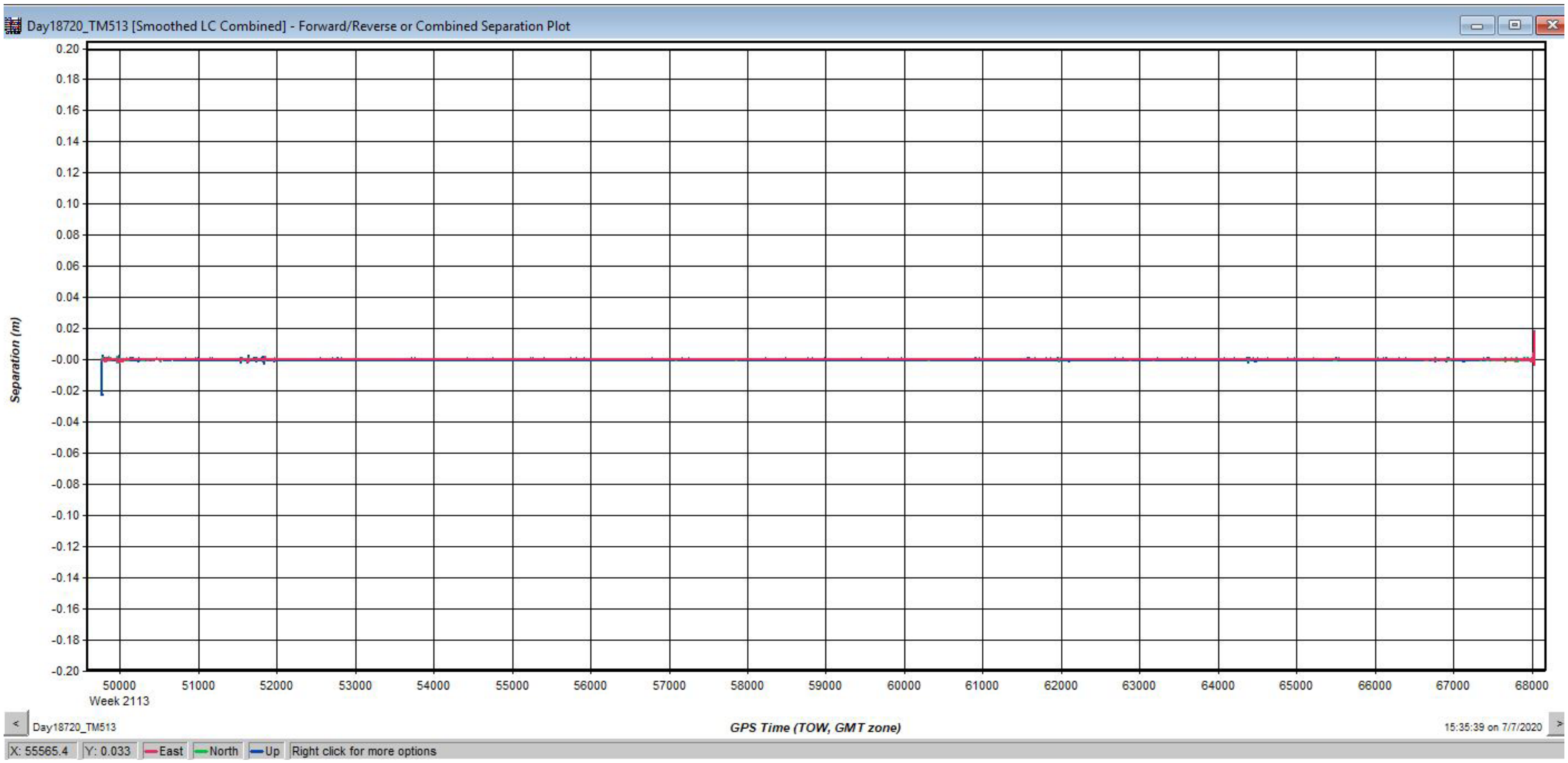
Day18720_TM511
PDOP Plot



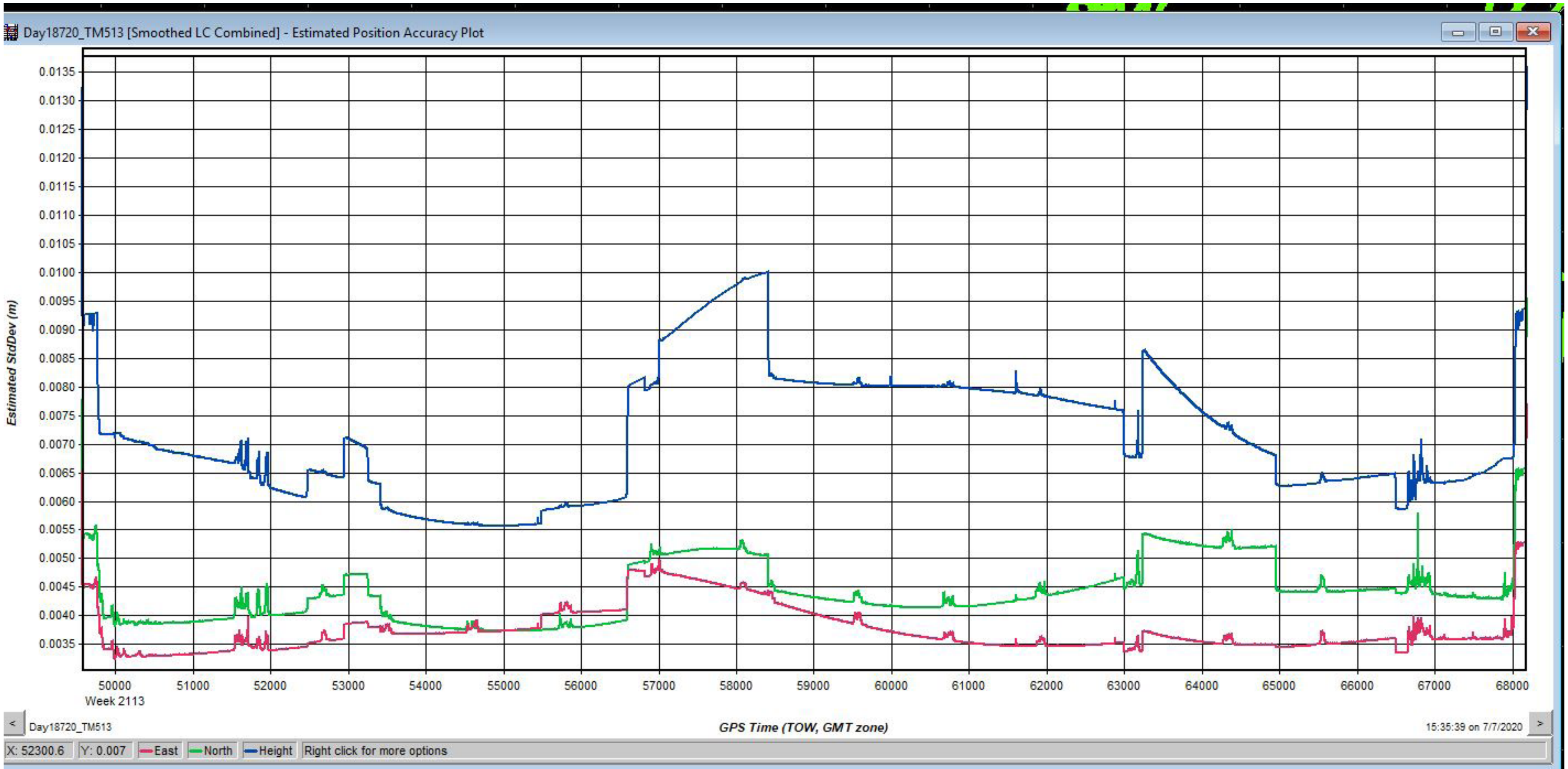
Day18720_TM513
Trajectory



Day18720_TM513
Forward/Reverse or Combined Separation Plot



Day18720_TM513
Estimated Position Accuracy



Day18720_TM513
PDOP Plot