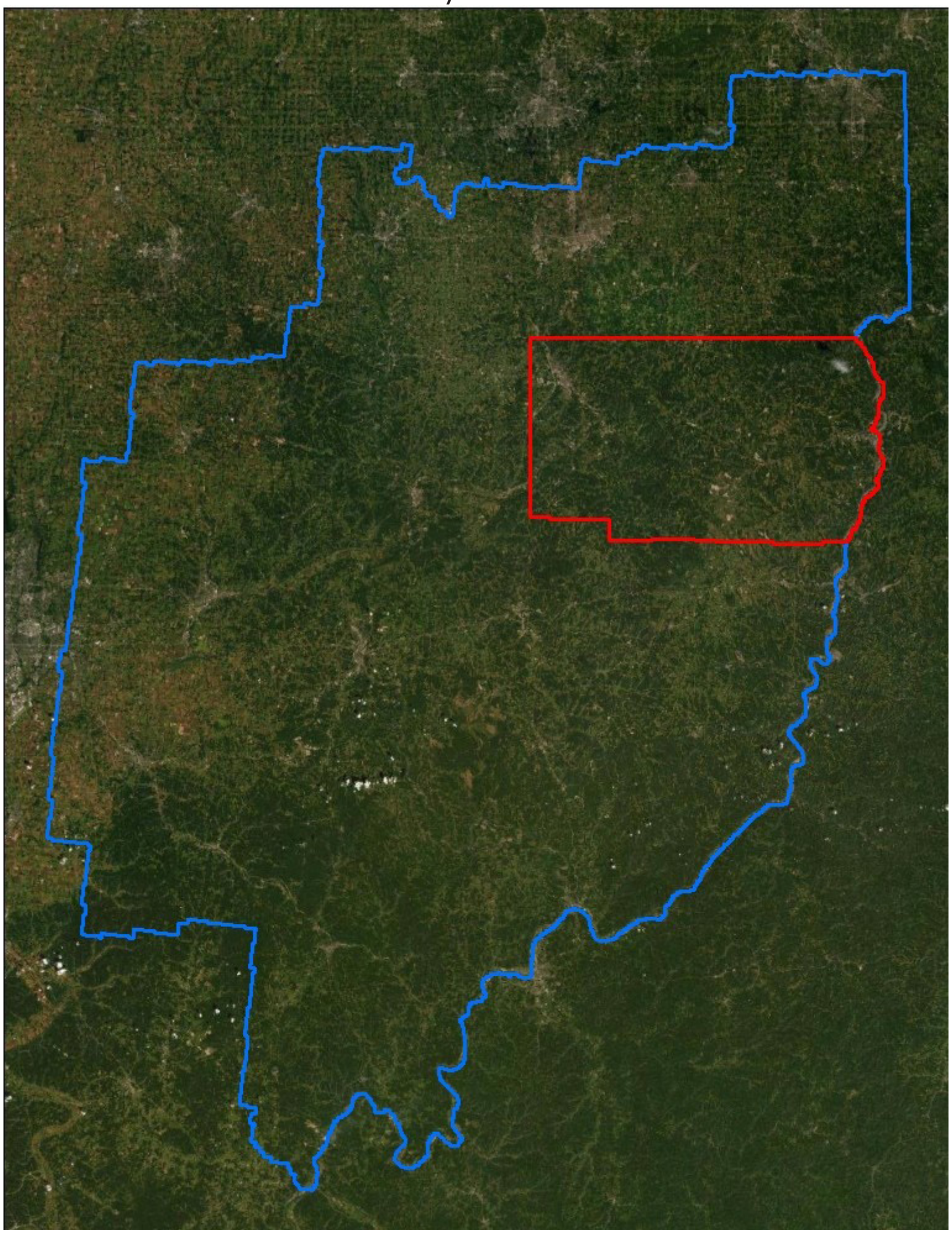
OH Statewide Phase 2 2020 B20

Lidar Mapping Report
Project ID 197536 - Work Unit ID 224919

May 2022



Contract # G16PC00022
Task Order # 140G0220F0194

Contractor Woolpert
Project # 81150

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1. Overview

About

This project contains a comprehensive outline of the 140G0220F0194 - OH Statewide Phase 2 2020 B20 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 QL0 and QL1 data covering approximately 12,101 square miles in southern Ohio (Figure 1-1).

This report encompasses the Work Unit 224919 area of interest (Figure 1-2). This AOI totals approximately 1,382 square miles and includes the following counties:

- Carroll
- Harrison
- Jefferson
- Tuscarawas

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 v2021 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**	6549
	Datumw	NAD83(2011)
	Projection	State Plane Ohio North (FIPS 3401)
	Units	US Survey Feet
Vertical	**Datum**	NAVD88
	Geoid	GEOID18
	Units	US Survey Feet
	Height Type	Orthometric

Figure 1-1. Project Area

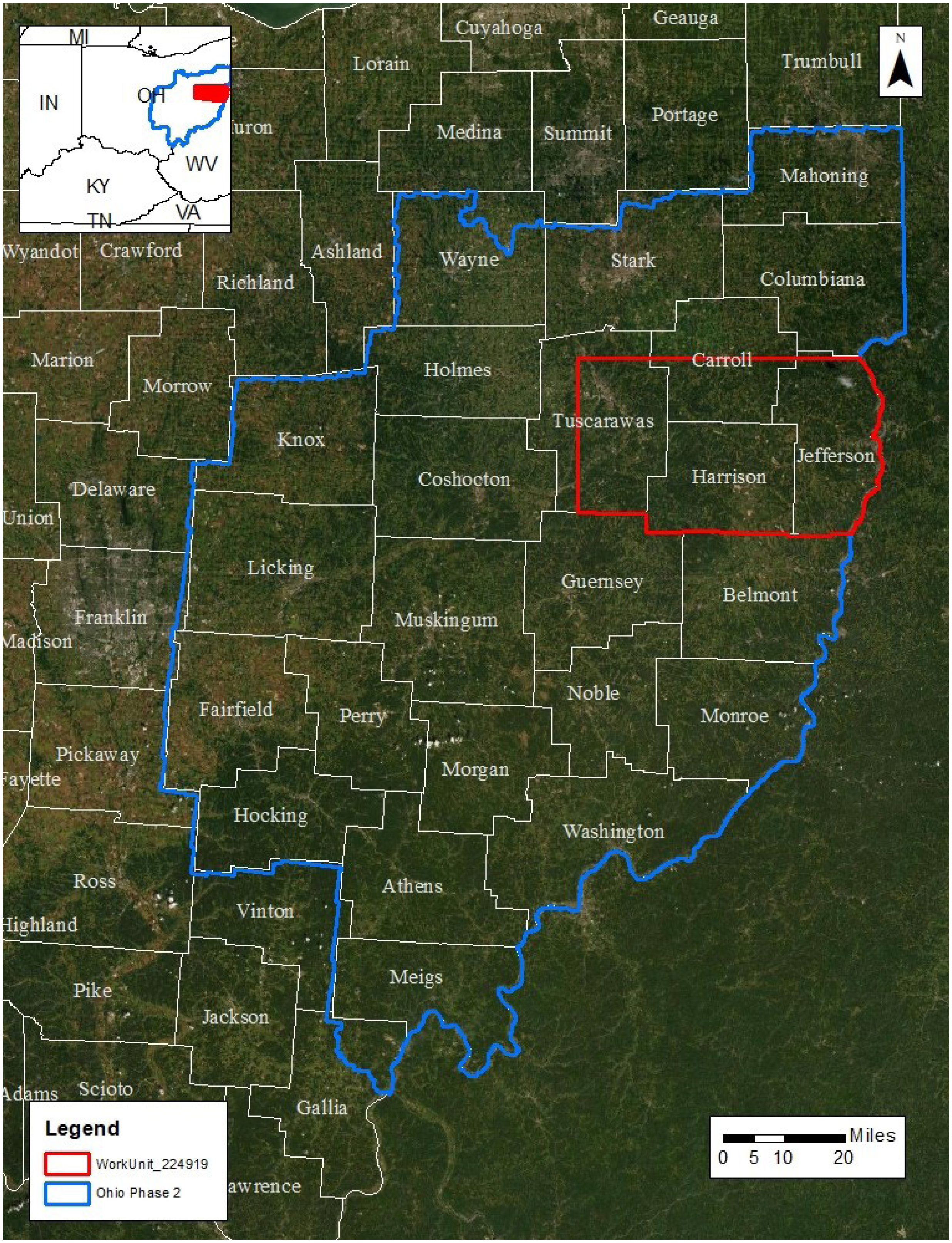
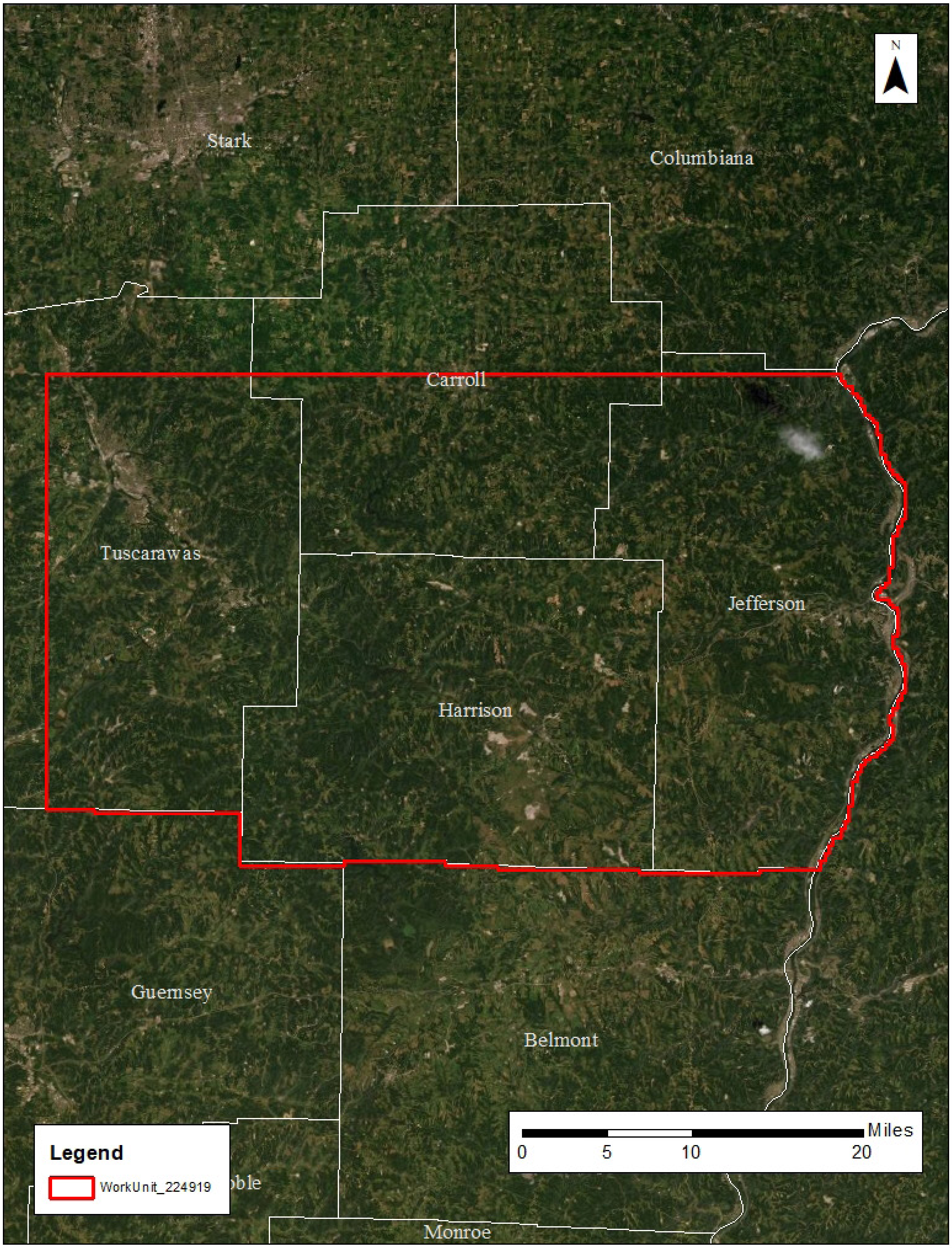


Figure 1-2. Project Area - 197536 - Work Unit 224919



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 of 1,250-feet x 1,250 feet. Tile names are derived from the Ohio (OGRIP) naming schema.

Example: BS20820365

This delivery's tiled dataset contains a total of 24,659 tiles. Some tiles were excluded frome the datasets as they fell over a water body.

Excluded tiles:

- BN23070315
- BN23120318
- BN23380245

Table 1-2. Deliverables

Lidar Data	
Classified lidar point cloud data	Tiles in LAS v1.4 format Classes • 1 – Processed, but unclassified • 2 – Bare-earth ground • 7 – Low Noise • 9 – Water • 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)	1.25-foot pixel size, 32-bit floating-point; no bridges or overpass structures GeoTIFF format
Intensity imagery	1.25-foot pixel size, 8-bit gray-scale (linear rescaling from 16-bit intensity) GeoTIFF format
Vertical Accuracy Data	
NVA and VVA checkpoints	Gpkg file format
Interswath and intraswath test results	Esri shapefile format
Spatial Metadata	
Data extent	Esri shapefile format
Tile index	Esri shapefile format
Maximum surface height rasters	GeoTIFF format
Swath separation images	GeoTIFF format
Swath polygons	Georeferenced, polygonal representation of the detailed extents of each lidar swath Polygon feature class in an Esri file geodatabase
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

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	• 8 points per square meter • 0.35-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	Fall 2020 through Winter 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 for this project using the following lidar sensor systems:

- Terrain Mapper - serial number 91511, last calibrated July 3, 2019
- Terrian Mapper - serial number 91557, last calibrated July 1, 2020
- Terrian Mapper - serial number 91515, last calibrated December 12, 2018
  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	Terrain Mapper
Max. Number of Returns	15
Nominal Point Spacing	0.35 m
Nominal Point Density	8 ppsm
Flying Height Above Ground Level	1,372 m
Flight Speed	160 knots
Scan Angle	40°
Scan Rate Used	150 Hz
Pulse Rate Used	1,600.0 kHz
Multi-Pulse in Air	Enabled
Swath Width	1,456 m
Swath Overlap	25%

Timeline

Lidar data was collected from November 24, 2020 through April 19, 2021. A total of 88 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 Leica Flight Pro 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 2-3 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

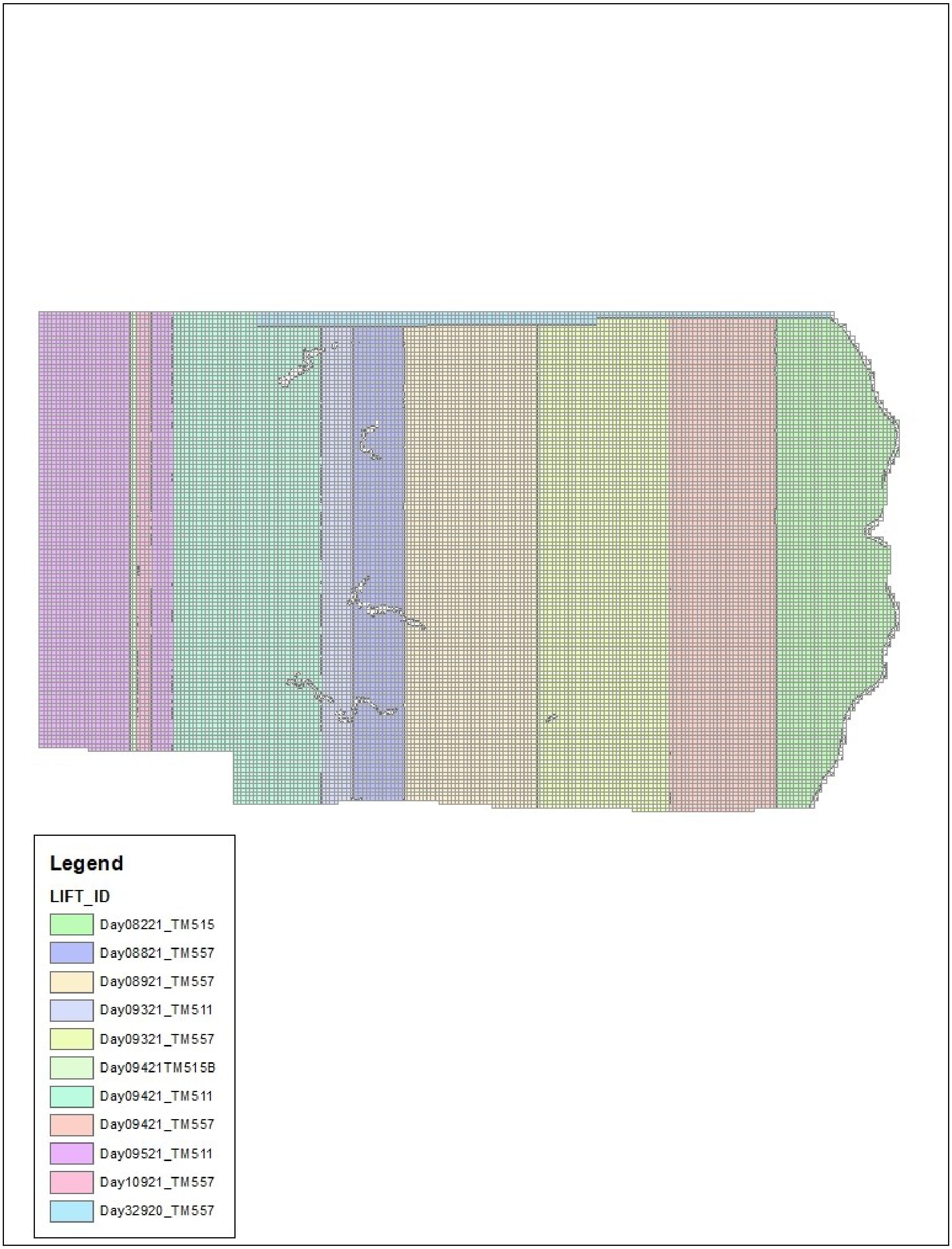


Table 2-4. GNSS Base Stations

Station Name	Longitude (DMS)	Latitude (DMS)	Ellipsoid Height L1 Phase Center (Meters)
OHAL_CORS	40°46'09.73944"	84°06'25.04574"	235.117
OHMA_CORS	40°36'49.73829"	83°04'55.32889"	257.026
OHHA_CORS	41°02'27.93405"	83°40'33.46888"	210.082
MTVR_CORS	40°22'56.57516"	82°30'38.38039"	286.605
OHRI_CORS	40°46'05.33418"	82°33'38.35490"	365.49
OHHU_CORS	41°10'36.35195"	82°33'40.91087°	254.565
OHLA_CORS	41°43'35.53476"	81°17'11.05630"	163.494
OHMN_CORS	41°01'24.70500"	80°46'21.63976"	328.747
TIFF_CORS	41°04'29.89642"	84°09'01.41466"	211.729
GARF_CORS	41°24'56.78161"	81°36'53.60423"	354.314
GUST_CORS	41°27'45.87329"	80°42'58.24972"	283.272
OHMR_CORS	40°32'45.58334"	84°37'50.63693"	236.812
OHLC_CORS	41°43'16.40562"	83°31'34.58723"	151.929
OHSB_CORS	41°38'11.21597"	82°49'47.18063"	148.449
OHAS_CORS	41°55'30.22146"	80°33'03.84441"	181 .661
OHDT_CORS	39°45'53.06211	84°10'50.33473"	196.642
GALP_CORS	38°50'39.14892"	82°16'40.09174"	169.569
STKR_CORS	39°19'33.82494"	82°06'25.62969"	178.128
MCON_CORS	39°39'39.03109"	81°49'45.12175"	272.759
PKTN_CORS	39°02'43.66599"	83°01'27.83159"	144.443
COLB_CORS	39°57'35.11256"	83°02'44.74693"	186.508
OHHO_CORS	39°32'07.27637"	82°26'37.87619"	205.271
OHLI_CORS	39°57'09.13852"	82°24'51.03107"	294.748
FREO_CORS	40°12'05.96943"	81°15'28.22082"	274.771

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: Novatel Inertial Explorer v8.70.6129

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), 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 Report(s) in Appendix 1.

Software: Proprietary Software, TerraMatch v21.002, HxMap 3.4

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.

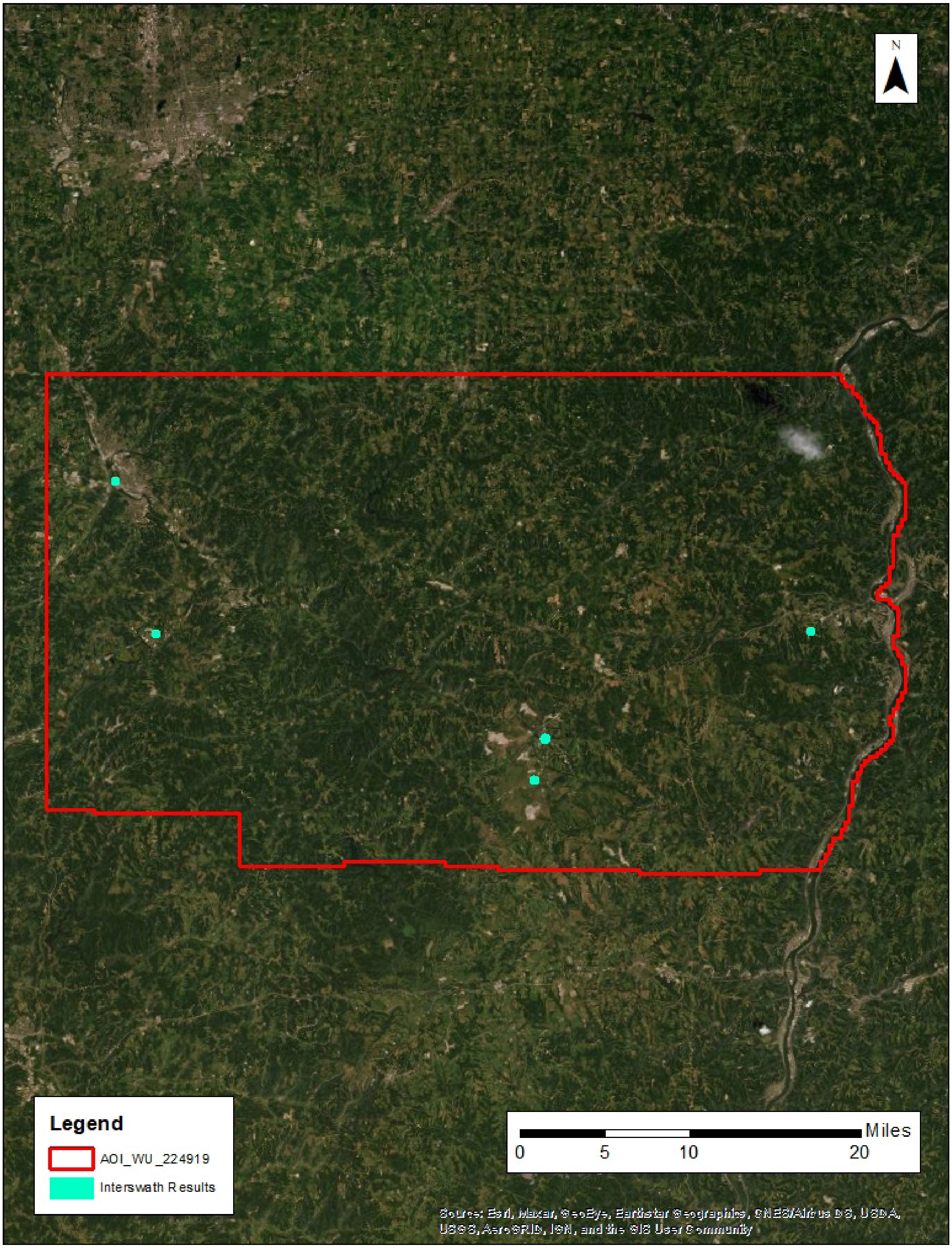
This project required the interswath accuracy to meet ≤ 8 cm RMSDz. Accuracy was assessed in accordance with the USGS Base Specification v2021 revision A.

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)
-0.09300000000	0.01800000000	0.05000000000
-0.06200000000	0.07000000000	0.05200000000
-0.07300000000	0.10000000000	0.06300000000
-0.93000000000	0.01800000000	0.05000000000
-0.07000000000	0.11000000000	0.06600000000

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.

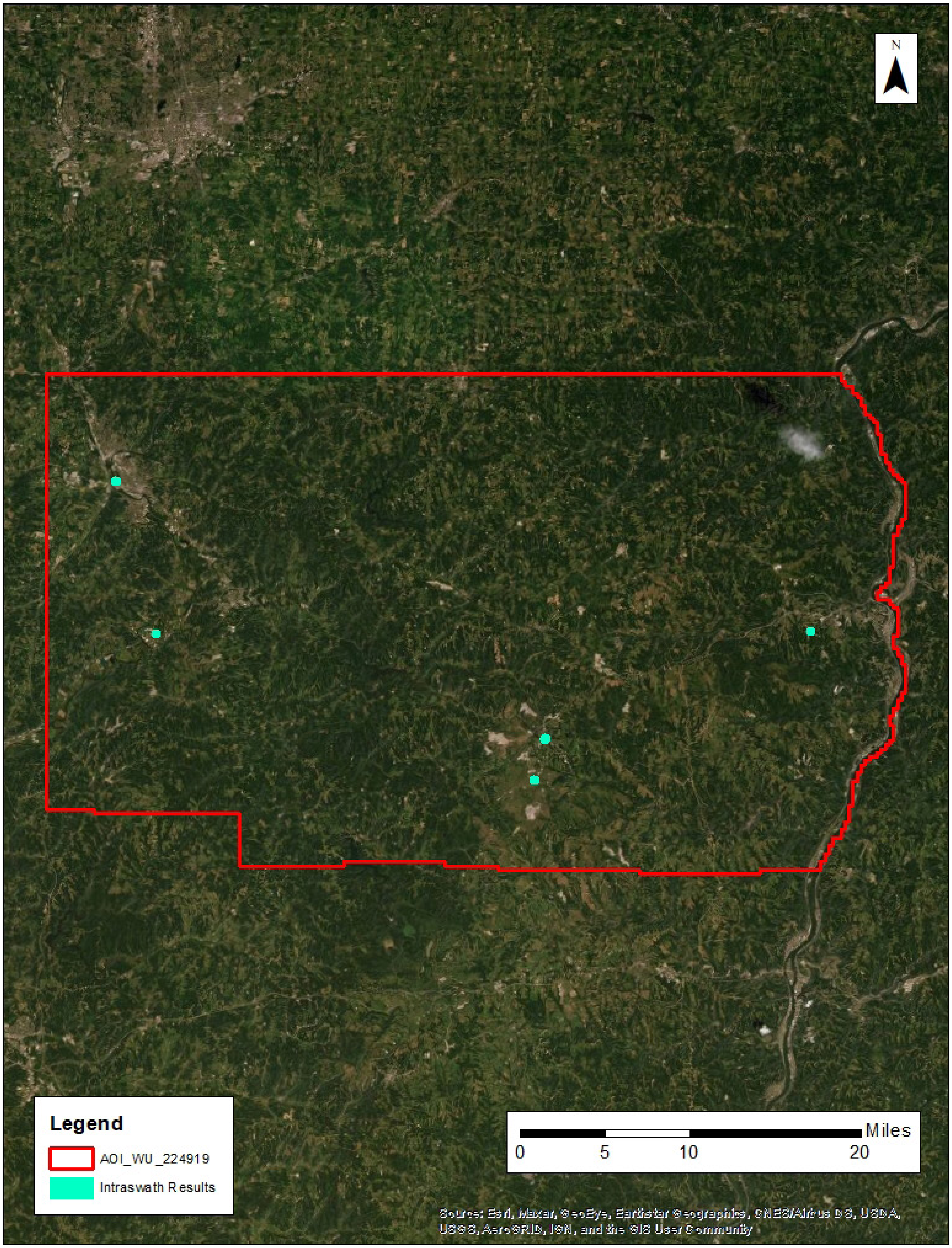
This project required the intraswath accuracy to meet ≤ 6 cm RMSDz. Accuracy was assessed in accordance with the USGS Base Specification v2020 revision A.

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)
-0.12200000000	0.64600000000	0.04900000000
-0.13400000000	0.42800000000	0.14100000000
-0.12400000000	0.36900000000	0.03700000000
-0.32700000000	0.91400000000	0.12700000000
-0.75500000000	1.88000000000	0.08400000000

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 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 point classifications used.

Table 3-3. Classified Point Breakdown

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.
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 1.25-foot hydro-flattened bare-earth raster DEM files. Using automated scripting routines within ArcMap, a 32-bit floating point raster GeoTIFF file was created for each tile. Files were produced to the full extents of the tile boundaries. 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 1.25-foot pixel, 8-bit, 256 gray scale GeoTIFF files. Files were produced to the full extents of the tile boundaries.

Software: TerraScan v20, Esri ArcMap v10.7

Swath Separation Image

A swath separation image is generated to visualize the DZ between the overlapping areas of the flight lines. To generate this surface a point insertion method is used as the primary algorithm. All returns for all point classes except classes 7 and 18 are used in the calculation for each cell. GSD and color ramp values are dependent on the Quality Level and point spacing for the project. The GSD for the surface is no more then 4 times the NPS of the lidar data rounded to an appropriate whole number. The color ramp for the following QL levels are as follows:

QL1 + QL2

- Less than 8 cm – Green
- 8 cm to 16 cm – Yellow
- Greater than 16 cm – Red

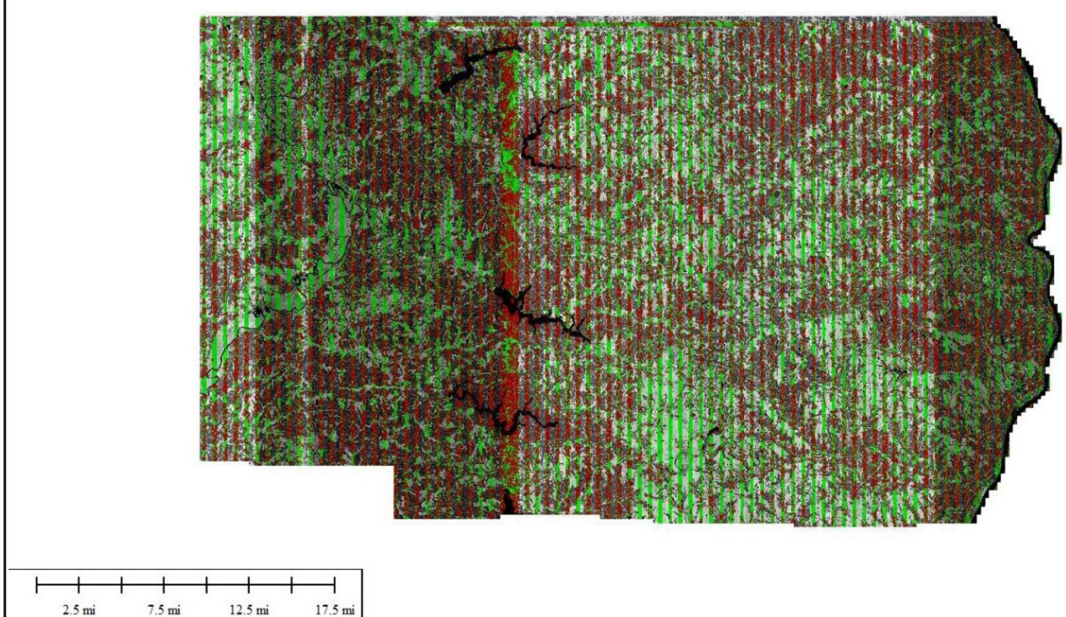
QL0

- Less than 4 cm – Green
- 4 cm to 8 cm – Yellow
- Greater than 8 cm – Red

Intensity values are modulated to 50% to ensure that there is no oversaturation of intensities values throughout the surface.

Software: LP360 v2018.2.59.5

Figure 3-3. Svath Separation Image



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 GeoTIFF format.

4. Accuracy Assessment

Horizontal Accuracy

The data set was produced to meet ASPRS "Positional Accuracy Standards for Digital Geospatial Data" (2014) for a 0.148 m RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 0.363 m 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	0.038 m RMSEz 0.075 m at 95% CL	25
VVA	0.206 m at 95th Percentile	23

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 0.30 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 Accuracy

	Result	Points Used
NVA	0.080 m RMSEz 0.041 m at 95% CL	25
VVA	0.213 m at 95th Percentile	23

Appendix 1: Sensor Calibration Report

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

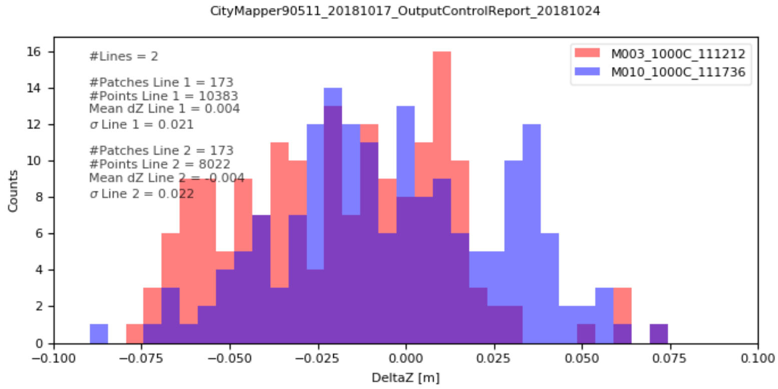


Figure 1 Vertical distance to ground control points at 1000 m AGL.

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 [%]
	<=0.04	293823	93.48
	0.04-0.07	20386	6.49
	0.07-0.1	89	0.03
	>0.1	16	0.01

Vertical difference

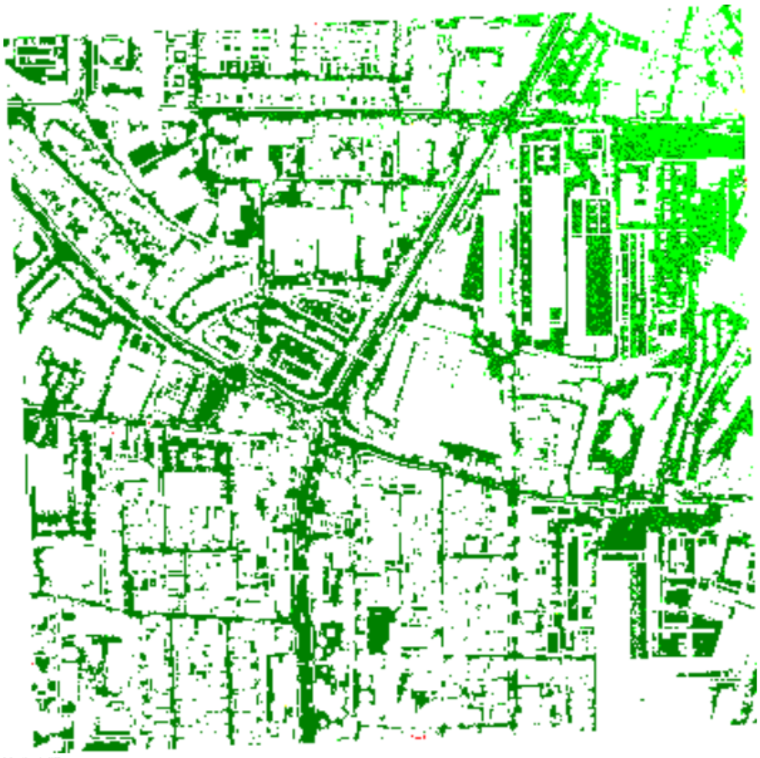
Figure 2 Vertical difference betweeen forward and backward scan at 1000 m AGL.

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

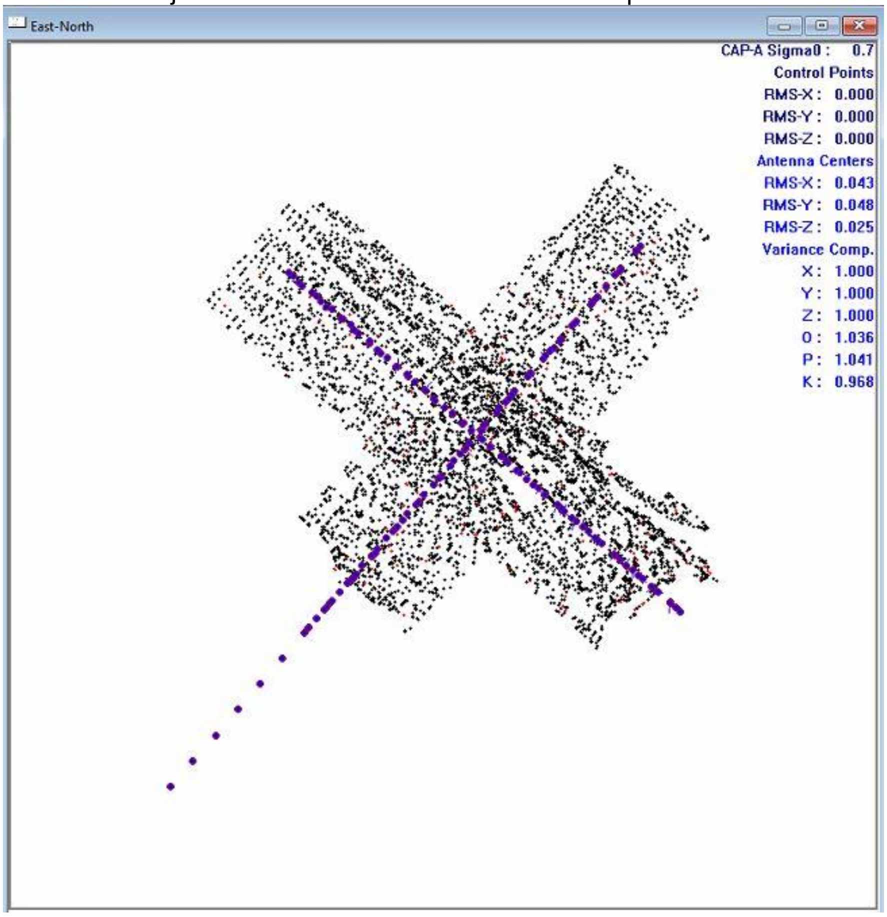
6.2 Results of Geometric Calibration

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*

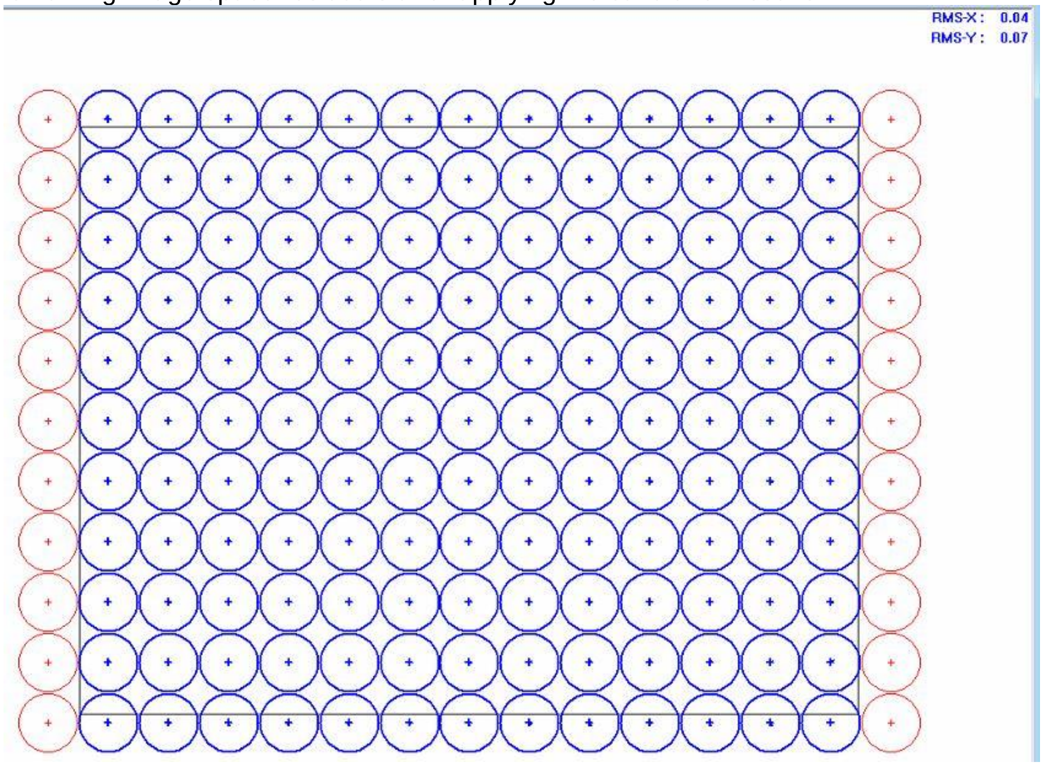
		Component	Serial Number
Camera Head		CH82	82659
Lens		NAT-D 2.8/80	80254
View Direction in Pod Position		Nadir	
IMU Misalignment		**Angle** [degree]	
	ω	-0.00815	
	Φ	0.00028	
	κ	-0.26654	
Principal Point		**Distance** [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		**Distance** [mm]	
	c	83.00	

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

- when it has to be **right**

Leica Geosystems
Leica TerrainMapper-L
Calibration Certificate

Product	Leica TerrainMapper-L
Serial Number	90515
Date	12 December 2018
Inspector	Robert Bosch

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	90515
GNSS/IMU	Litef LCI-100C 500 Hz	1226
LiDAR Unit	Hyperion2 LiDAR Unit	5516

2. Estimation Process

		Passed	Date	Inspector
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			

3. Inspectors

Name	Bernhard Riedl	12.12.2018
Position	Production Manager	
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	-0.022555	degree
	Φ	0.056357	degree
	κ	0.000504	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	04.12.2018
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

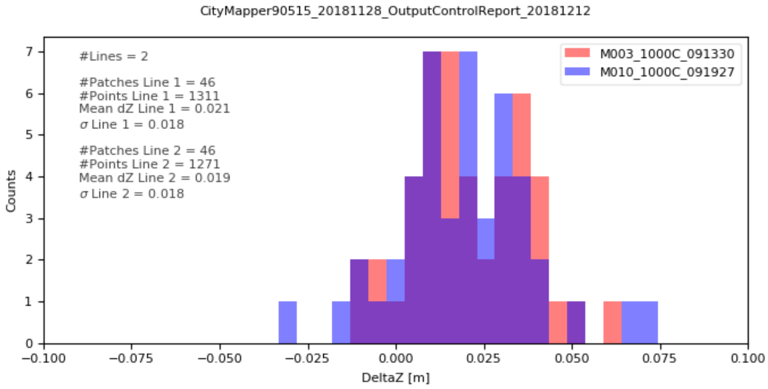


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

M010_1000C_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 [%]
	<=0.04	302593	99.75
	0.04-0.07	716	0.24
	0.07-0.1	17	0.01
	>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 [%]
(dark green)	<=0.04	29546	99.86
(green)	0.04-0.07	38	0.13
(yellow)	0.07-0.1	1	0.00
(red)	>0.1	3	0.01

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

- when it has to be **right**

Leica Geosystems
Leica TerrainMapper-LN
Calibration Certificate

Product	Leica TerrainMapper-LN
Serial Number	91557
Date	01 July 2020
Inspector	Ivan Belchev

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

Document Code: 871495

1. System Components

Component	Type	Serial Number
Pod	TerrainMapper Pod	91557
GNSS/IMU	Litef LCI-100C 500 Hz	1346
LiDAR Unit	Hyperion2 LiDAR Unit	5561
Camera Head	CH82	82673
Lens	NAT-D 2.8/80	80264

2. Estimation Process

		Passed	Date	Inspector
Image Flight	completed	ok	23.06.2020	Deniz Arslan
Image Quality Check	checked	ok	29.06.2020	Bernhard Riedl
Image Calibration	completed	ok	29.06.2020	Zoltan Poth
Image Misalingment Update	completed			
LiDAR Flight	completed	ok	23.06.2020	Deniz Arslan
LiDAR Quality Check	checked	ok	26.06.2020	Rene Heierli
LiDAR Calibration and Accuracy	completed	ok	25.06.2020	Michael Vetter
LiDAR Misalingment Update	completed			

3. Inspectors

Name	Bernhard Riedl	01.07.2020	
Position	Production Manager		
Name	Ivan Belchev	01.07.2020	
Position	Workflow Specialist		
Name	Michael Vetter	01.07.2020	
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	-0.063987	degree
	Φ	-0.049738	degree
	κ	-0.005305	degree
Boresight		**Value**	**Unit**
	Θ	-0.001796	degree
	Φ	-0.003034	degree
Receiver 1		**Value**	**Unit**
Range	Δ Offset	0.000000	meters
Wedge 0		**Value**	**Unit**
Wedge	Δ Alpha	-0.045434	degree
Wedge Position	Δ Offset	0.352942	degree
Position Correction	X	-0.014623	degree
	Y	0.020330	degree
Mount	Roll	0.210896	degree
	Pitch	0.426854	degree
Rotation Axis	Roll	0.232742	degree
	Pitch	0.169968	degree
Wedge 1		**Value**	**Unit**
Wedge	Δ Alpha	0.003457	degree
Wedge Position	Δ Offset	0.393122	degree
Position Correction	X	0.019198	degree
	Y	-0.002307	degree
Mount	Roll	0.020583	degree
	Pitch	0.038667	degree
	Speed Pitch	1.50E-06	degree/rps^2
Rotation Axis	Roll	0.061823	degree
	Pitch	0.034555	degree

LiDAR Geometric Calibration File

HYPERION_GEOMETRY_LIDARUNIT-5561-D-855570-DATETIME-20200625-085747.XML

	Date	25.06.2020	
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

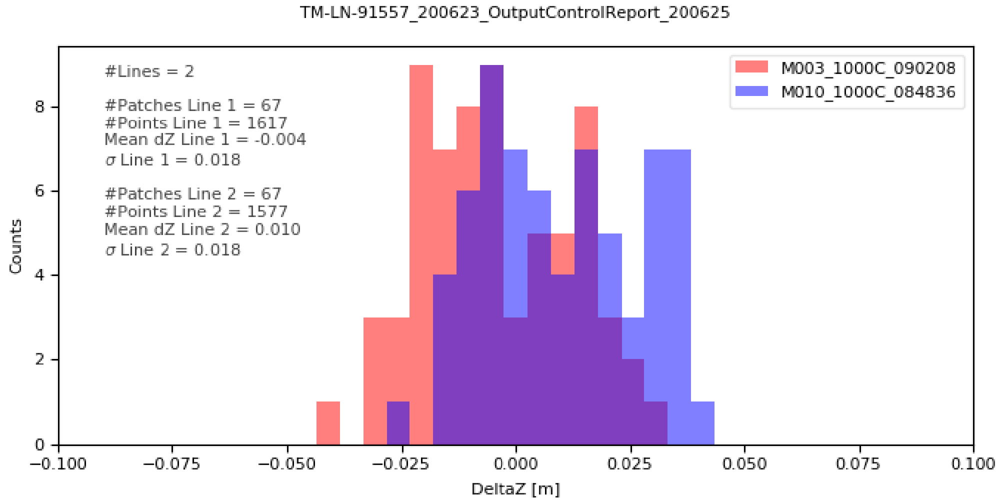


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

M003_1000C_090208

377750 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	372019	98.48
	0.04-0.07	5529	1.46
	0.07-0.1	169	0.04
	>0.1	33	0.01

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_090208_vs_M010_1000C_084836

50693 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	50354	99.33
	0.04-0.07	327	0.65
	0.07-0.1	6	0.01
	>0.1	6	0.01

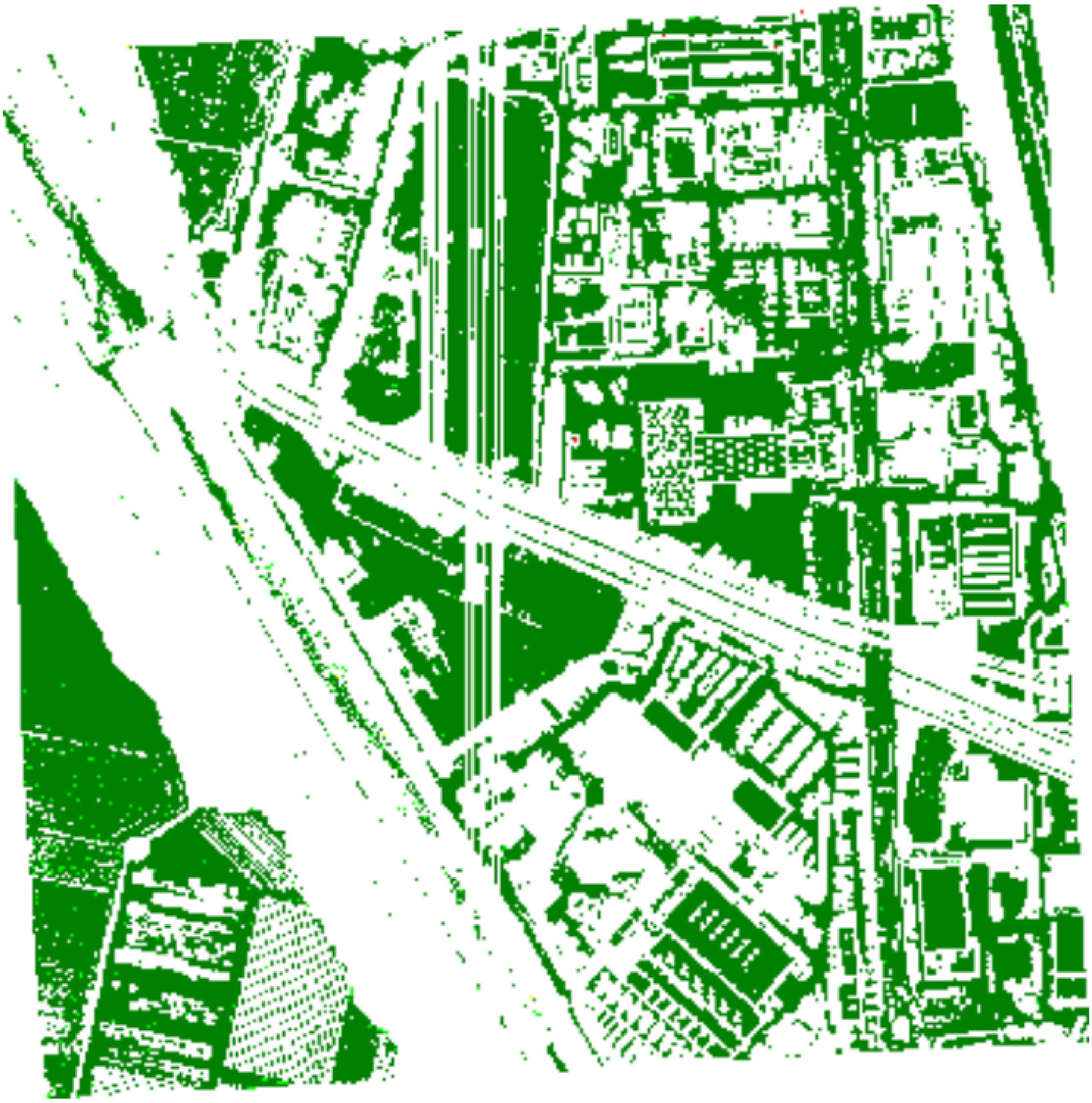


Figure 3 Vertical difference betweeen two perpendicular lines at 1000 m AGL.

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

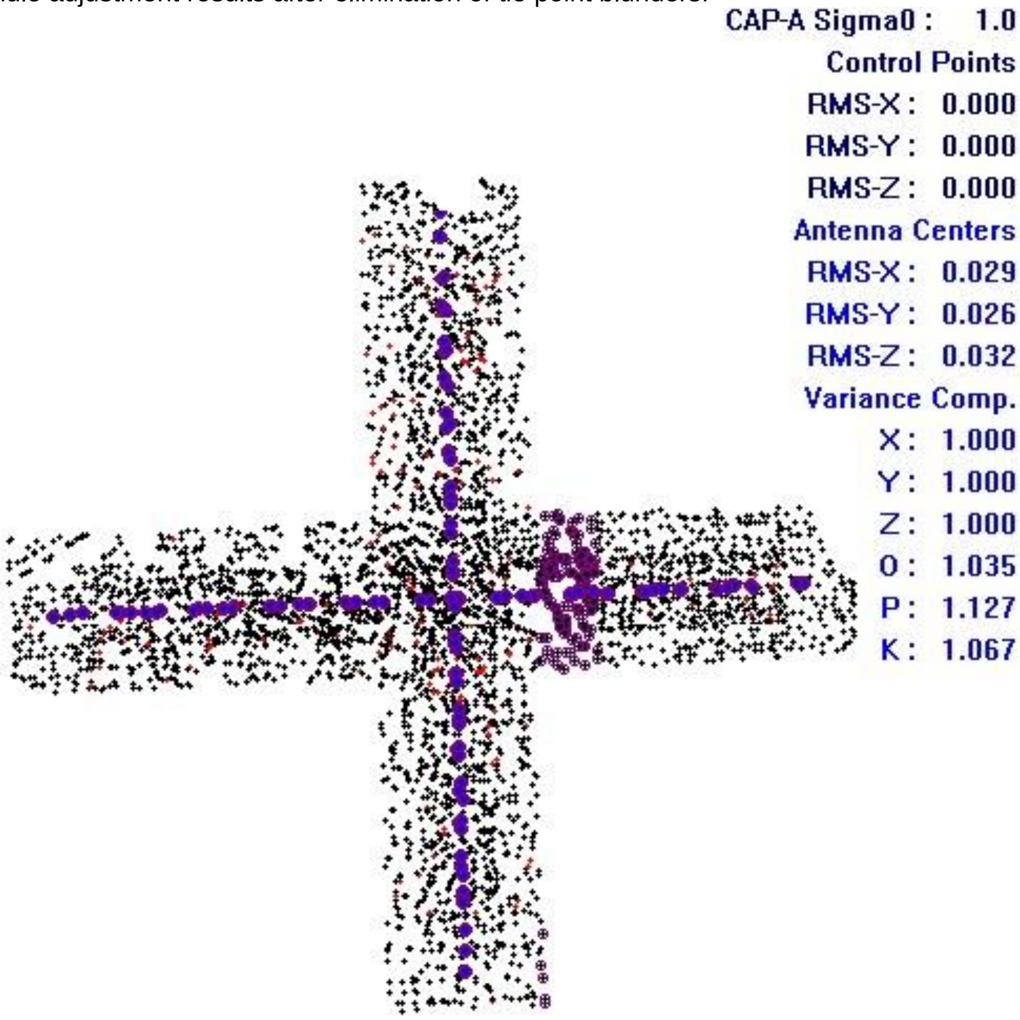
6.2 Results of Geometric Calibration

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

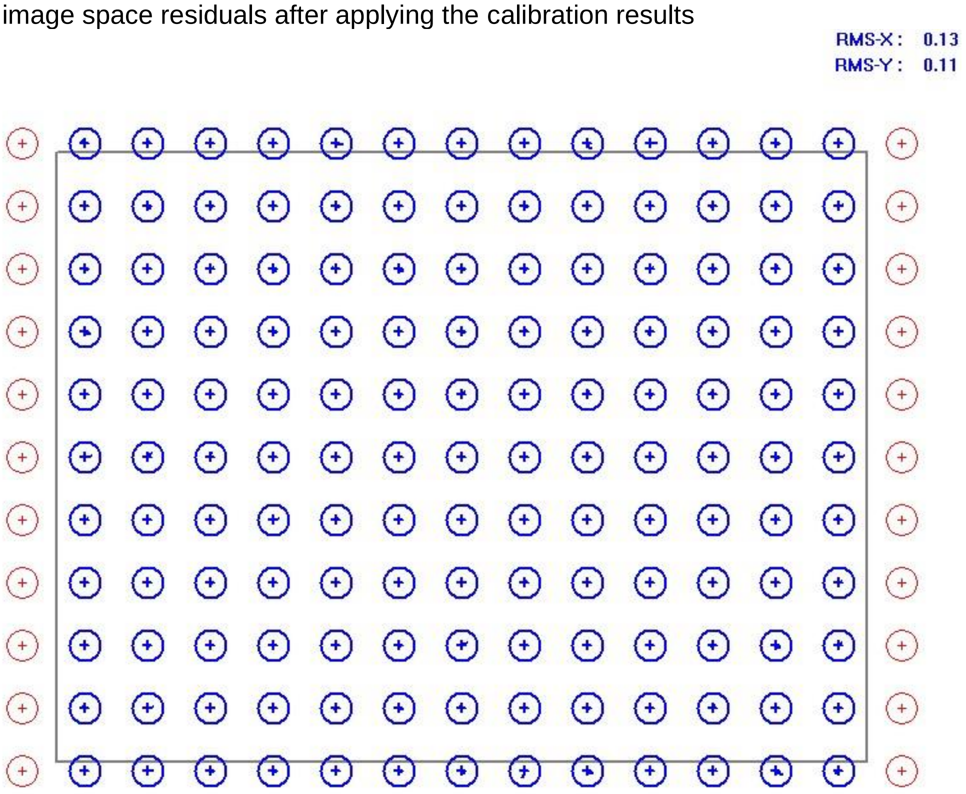
		Component	Serial Number
Camera Head		CH82	82673
Lens		NAT-D 2.8/80	80264
View Direction in Pod Position		Nadir	
IMU Misalignment		**Angle** [degree]	
	ω	0.03017	
	Φ	-0.01221	
	κ	-0.25213	
Principal Point		**Distance** [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		**Distance** [mm]	
	c	83.00	

Geometric Calibration File

RCD30_Geometry_CameraHead-82673---798528_LensSystem-80264-B-785423_DateTime-20200629-142416.xml

Geometric Calibration Date	Date	29.06.2020	
Radiometric Calibration Date	Date	30.01.2020	
Misalingment Flight	Date	-	
Misalingment Update Completed	Date	-	

Remaining image space residuals after applying the calibration results



Radius of circles is 0.0010 mm

Appendix 2: Flight Logs

Woolpert Lidar Acquisition Log

Project Info			Date		
Project #	Project Name	Unique ID	Flight Date (UTC)	Day of Year	Flight #
81150	Ohio Phase 2 Block 2	Day329_90557_1	11/24/2020	329	1

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Dar Perl	Reims 406 - N406SD	552.1	09:19:00	14:19:00	CAK
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Kennedy	Leica Terrain Mapper - 90557	557.1	13:55:00	18:55:00	CAK

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
120	5	10	25,000	Broken	2	-2	30.36

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
160	6,562	7,133	1,226

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
	8	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
1	E	14:37:00	14:46:00	00:09:00	19	1.1	
2	W	14:49:00	14:58:00	00:09:00	19	1.1	
3	E	15:02:00	15:11:00	00:09:00	21	1	
4	W	15:14:00	15:23:00	00:09:00	20	1.1	
5	E	15:27:00	15:36:00	00:09:00	19	1.2	
6	W	15:39:00	15:48:00	00:09:00	21	1.1	
7	E	15:54:00	16:03:00	00:09:00	18	1.2	Small clouds in the area
8	W	16:06:00	16:15:00	00:09:00	19	1.1	Small clouds in the area
66	E	16:29:00	16:35:00	00:06:00	19	1.1	relocation for clouds
65	W	16:44:00	16:56:00	00:12:00	21	1	
64	E	17:00:00	17:12:00	00:12:00	18	1.1	
63	W	17:15:00	17:27:00	00:12:00	19	1.1	
62	E	17:31:00	17:43:00	00:12:00	19	1.2	
61	W	17:47:00	17:59:00	00:12:00	19	1.2	
60	E	18:03:00	18:16:00	00:13:00	20	1.2	
59	W	18:19:00	18:33:00	00:14:00	19	1.3	West end all clouds
							mx hobbs 5491.9

Page 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 #
81150	oh blk 2,6		03/23/2021	082	1

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Gebhart	Cessna 404 Titan - N475RC	2425.4	10:39:00	14:39:00	day
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Smith	Leica Terrain Mapper - 90515	2431.5	04:45:00	20:45:00	day

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
150	11	10		Broken	13	1	3006

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
160	6,562	7,133	1,009

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
		40	150	1603	100

Verify S-Turns Before Mission: Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
37	e	15:40:00	15:57:00		21	1.2	blk 2
38	w	16:00:00	16:16:00		19	1.4	
39	e	16:19:00	16:36:00	00:17:00	17	1.7	
55	s	16:48:00	16:54:00	00:06:00	16	1.5	blk 6
54	n	16:57:00	17:03:00	00:06:00	17	1.2	
53	s	17:07:00	17:15:00	00:08:00	18	1.2	
52	n	17:18:00	17:25:00	00:07:00	16	1.4	
51	s	17:28:00	17:37:00	00:09:00	17	1.3	
50	n	17:41:00	17:50:00	00:09:00	21	1.1	
49	s	17:53:00	18:04:00	00:11:00	21	1.1	
48	n	18:07:00	18:16:00	00:09:00	20	1.1	
47	s	18:19:00	18:32:00	00:13:00	20	1.1	
46	n	18:36:00	18:48:00	00:12:00	22	1.1	
45	s	18:51:00	19:04:00	00:13:00	20	1.2	
44	n	19:08:00	19:22:00	00:14:00	19	1.3	
43	s	19:25:00	19:42:00	00:17:00	16	1.9	

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 #
81150	oh blk 6		03/29/2021	088	1

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Gebhart	Reims 406 - N406SD	757.9	10:21:00	14:21:00	day
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Smith	Leica Terrain Mapper - 90557	764.5	05:09:00	21:09:00	day

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
180	3	10		Clear	5	-5	3028

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
160	6,562	7,133	1,009

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
		40	150	1603	100

Verify S-Turns Before Mission: Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
1	s	18:10:00	18:27:00		22	1.1	
2	n	18:30:00	18:47:00		22	1.1	
3	s	18:50:00	19:06:00	00:16:00	21	1.3	
4	n	19:09:00	19:26:00	00:17:00	18	1.4	
5	s	19:29:00	19:44:00	00:15:00	19	1.2	
6	n	19:47:00	20:04:00	00:17:00	18	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 #
81150	oh blk 6		03/30/2021	089	1

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Gebhart	Reims 406 - N406SD	764.5	10:08:00	14:08:00	day
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Smith	Leica Terrain Mapper - 90557	765.8	04:35:00	20:35:00	day

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
210	21	10		Few	14	-2	3005

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
160	6,562	7,129	1,009

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
		40	150	1603	100

Verify S-Turns Before Mission: Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
7	s	15:06:00	15:24:00		21	1.3	
8	n	15:27:00	15:43:00		20	1.4	
9	s	15:46:00	16:05:00	00:19:00	20	1.8	
10	n	16:08:00	16:24:00	00:16:00	20	1.5	
11	s	16:27:00	16:46:00	00:19:00	19	1.6	
12	n	16:49:00	17:04:00	00:15:00	16	1.5	
13	s	17:07:00	17:26:00	00:19:00	19	1.2	
14	n	17:29:00	17:45:00	00:16:00	21	1.1	
15	s	17:48:00	18:09:00	00:21:00	20	1.1	
16	n	18:12:00	18:26:00	00:14:00	19	1.1	
17	s	18:29:00	18:47:00	00:18:00	17	1.2	
18	n	18:50:00	19:06:00	00:16:00	14	1.8	
19	s	19:09:00	19:27:00	00:18:00	15	1.4	

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 #
81150	Ohio lidar block 4/5	Day093_90511_1	04/03/2021	093	1

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Swain	Cessna 404 Titan - N404CP	8279.6	10:03:00	14:03:00	DAY
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Kennedy	Leica Terrain Mapper - 90511	8286.2	16:36:00	20:36:00	DAY

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
210	10	10	25,000	Broken	3	-8	30.42

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
160	6,562	7,139	1,009

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
	8	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
40	N	14:49:00	15:08:00	00:19:00	19	1.3	
39	S	15:10:00	15:29:00	00:19:00	19	1.4	
38	N	15:31:00	15:50:00	00:19:00	20	1.9	
37	S	15:52:00	16:11:00	00:19:00	22	1.2	
36	N	16:13:00	16:31:00	00:18:00	25	1.1	
35	S	16:33:00	16:51:00	00:18:00	23	1.4	
34	N	16:53:00	17:12:00	00:19:00	26	1.1	
33	S	17:14:00	17:32:00	00:18:00	26	1.1	
32	N	17:35:00	17:53:00	00:18:00	23	1.2	
31	S	17:55:00	18:13:00	00:18:00	25	1.1	
30	N	18:16:00	18:34:00	00:18:00	22	1.2	
44	S	18:45:00	19:00:00	00:15:00	17	1.7	Start Block 5 @ 7169 MSL
43	N	19:02:00	19:17:00	00:15:00	18	1.3	
42	S	19:19:00	19:34:00	00:15:00	19	1.2	

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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 #**
81150	oh blk 6		04/03/2021	093	1

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Gebhart	Reims 406 - N406SD	770.8	10:16:00	14:16:00	day
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Smith	Leica Terrain Mapper - 90557	777.1	04:41:00	20:41:00	day

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
220	13	10		Few	6	-7	3041

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
160	6,562	7,129	1,009

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
		40	150	1603	100

Verify S-Turns Before Mission Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
20	s	15:20:00	15:36:00		19	1.8	
21	n	15:39:00	15:56:00		20	1.6	
22	s	15:59:00	16:16:00	00:17:00	20	1.3	
23	n	16:19:00	16:36:00	00:17:00	22	1.1	
24	s	16:39:00	16:55:00	00:16:00	20	1.3	
25	n	16:58:00	17:13:00	00:15:00	24	1.2	
26	s	17:18:00	17:34:00	00:16:00	24	1.1	
27	n	17:37:00	17:53:00	00:16:00	21	1.1	
28	s	17:56:00	18:12:00	00:16:00	24	1.1	
29	n	18:15:00	18:31:00	00:16:00	22	1.2	
30	s	18:34:00	18:50:00	00:16:00	20	1.3	
31	n	18:53:00	19:10:00	00:17:00	18	1.5	
32	s	19:13:00	19:29:00	00:16:00	18	1.3	

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 #**
81150	Ohio lidar block 5	Day094_90511_1	04/04/2021	094	1

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Swain	Cessna 404 Titan - N404CP	8286.2	09:40:00	13:39:00	DAY
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Kennedy	Leica Terrain Mapper - 90511	8292.5	15:53:00	19:53:00	DAY

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
210	4	10			11	-2	30.24

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
160	6,562	7,169	1,009

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
	8	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
41	N	14:32:00	14:48:00	00:16:00	21	1.1	
40	S	14:51:00	15:05:00	00:14:00	20	1.3	
39	N	15:07:00	15:23:00	00:16:00	20	1.3	
38	S	15:26:00	15:40:00	00:14:00	19	1.6	
37	N	15:43:00	15:58:00	00:15:00	19	1.5	
36	S	16:04:00	16:21:00	00:17:00	21	1.2	
35	N	16:23:00	16:41:00	00:18:00	21	1.4	
34	S	16:43:00	16:59:00	00:16:00	23	1.2	
33	N	17:02:00	17:20:00	00:18:00	24	1.2	
32	S	17:22:00	17:39:00	00:17:00	22	1.2	
31	N	17:42:00	18:00:00	00:18:00	25	1.1	
30	S	18:02:00	18:20:00	00:18:00	24	1.1	
29	N	18:22:00	18:40:00	00:18:00	21	1.3	
28	S	18:42:00	19:00:00	00:18:00	20	1.4	

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 #
81150	Ohio LiDAR Phase II	Day094_90515	04/04/2021	094	

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Hagan	Cessna 404 Titan - N475RC	2459.1	09:45:00	13:45:00	KDAY
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Nardone	Leica Terrain Mapper - 90515	2460.4	11:30:00	15:30:00	KOSU

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
280	3	10		Clear	-2	-8	30.42

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
160	6,562	7,169	998

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.35	8	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
25	N	14:38:00	15:02:00		22	1.3	Block 5, pav error puled off line
25	N	15:09:00	15:23:00		21	1.2	
24	S	15:25:00	15:44:00	00:19:00	21	1.1	Pav Error last 10 miles

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Verify S-Turns After Mission

Additional Comments

Woolpert Lidar Acquisition Log

Project Info			Date		
Project #	**Project Name**	**Unique ID**	**Flight Date (UTC)**	**Day of Year**	**Flight #**
81150	oh blk 6		04/04/2021	094	1

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Gebhart	Reims 406 - N406SD	777.1	10:13:00	14:13:00	day
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Smith	Leica Terrain Mapper - 90557	782.4	03:40:00	19:40:00	day

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
250	5	10		Few	13	-1	3024

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
160	6,562	7,129	1,009

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
		40	150	1603	100

Verify S-Turns Before Mission Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
33	n	15:19:00	15:37:00		19	1.6	
34	s	15:40:00	15:55:00		20	1.4	
35	n	15:58:00	16:15:00	00:17:00	21	1.3	
36	s	16:18:00	16:34:00	00:16:00	21	1.1	
37	n	16:37:00	16:54:00	00:17:00	21	1.3	
38	s	16:57:00	17:12:00	00:15:00	23	1.2	
39	n	17:15:00	17:34:00	00:19:00	23	1.2	
40	s	17:37:00	17:52:00	00:15:00	23	1.1	
41	n	17:55:00	18:13:00	00:18:00	24	1.2	
42	s	18:16:00	18:31:00	00:15:00	21	1.3	

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 #**
81150	Ohio LiDAR Phase II	Day095_90511	04/05/2021	095	

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Gibilaro	Cessna 404 Titan - N404CP	8292.5	10:45:00	14:45:00	KDAY
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Nardone	Leica Terrain Mapper - 90511	8296.1	02:30:00	18:45:00	KDAY

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
190	5	10		Clear	14	4	30.13

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
160	6,562	7,169	998

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.35	8	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
21	N	15:39:00	15:59:00		16	1.5	Block 5
22	S	16:01:00	16:21:00		20	1.1	
23	N	16:24:00	16:43:00	00:19:00	20	1.3	
26	S	16:45:00	17:04:00	00:19:00	21	1.1	
27	N	17:07:00	17:25:00	00:18:00	22	1	

Verify S-Turns After Mission

Additional Comments

Woolpert Lidar Acquisition Log

Project Info			Date		
Project #	Project Name	Unique ID	Flight Date (UTC)	Day of Year	Flight #
81150	Ohio LiDAR Phs2 QL1 Blk 5	#VALUE!	04/19/2021	109	

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Gable	Reims 406 - N406SD	5.2	09:24:00	13:24:00	CAK
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Denham	Leica TM557	6	01:33:00	17:33:00	KRST

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
220	3	10		Clear	8	6	29.86

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
160		7,169	

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
		40	150	1603	100

Verify S-Turns Before Mission Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
25	S	13:44:00	14:02:00		19	1.3	

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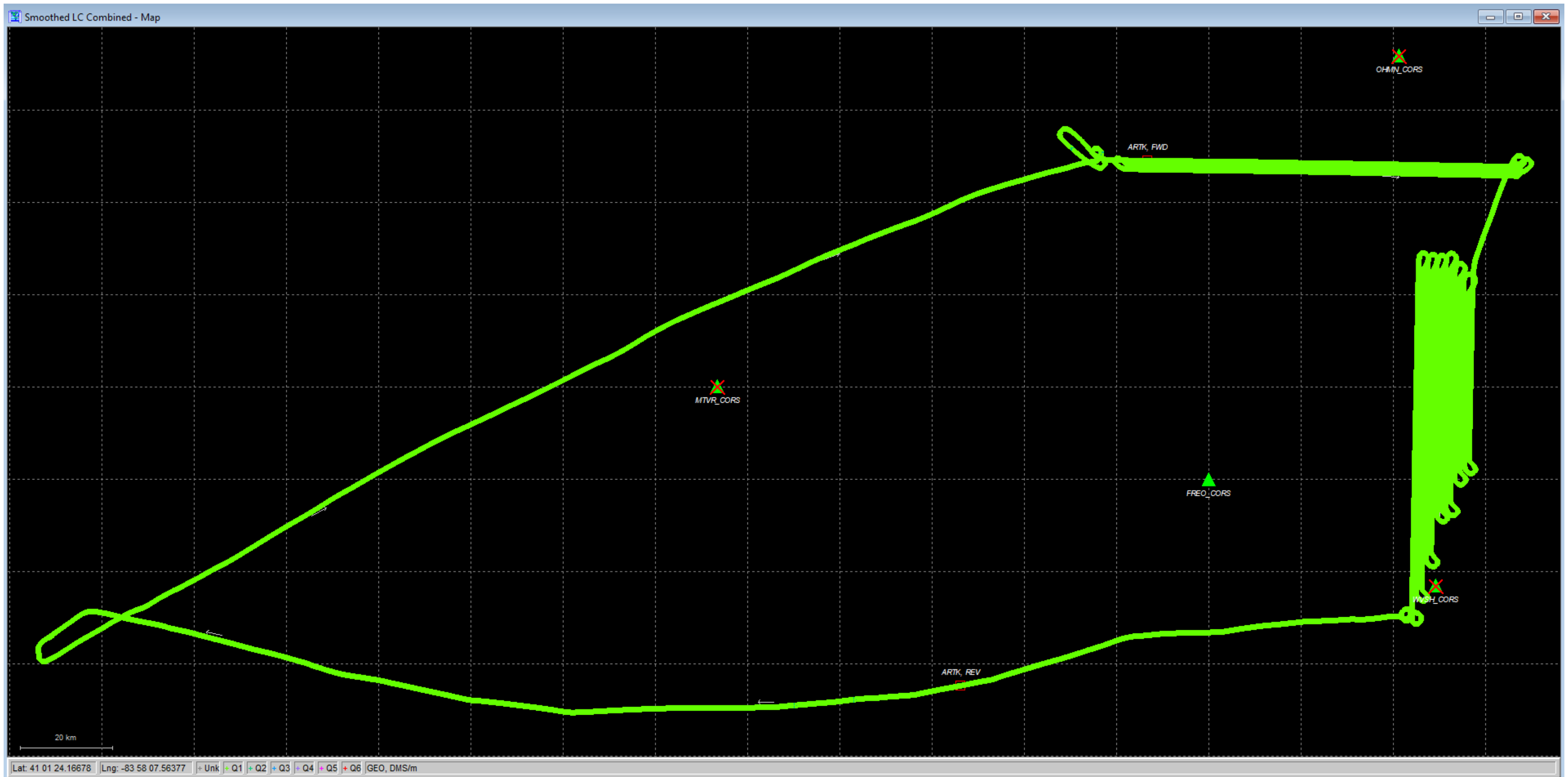
Verify S-Turns After Mission Yes

Additional Comments

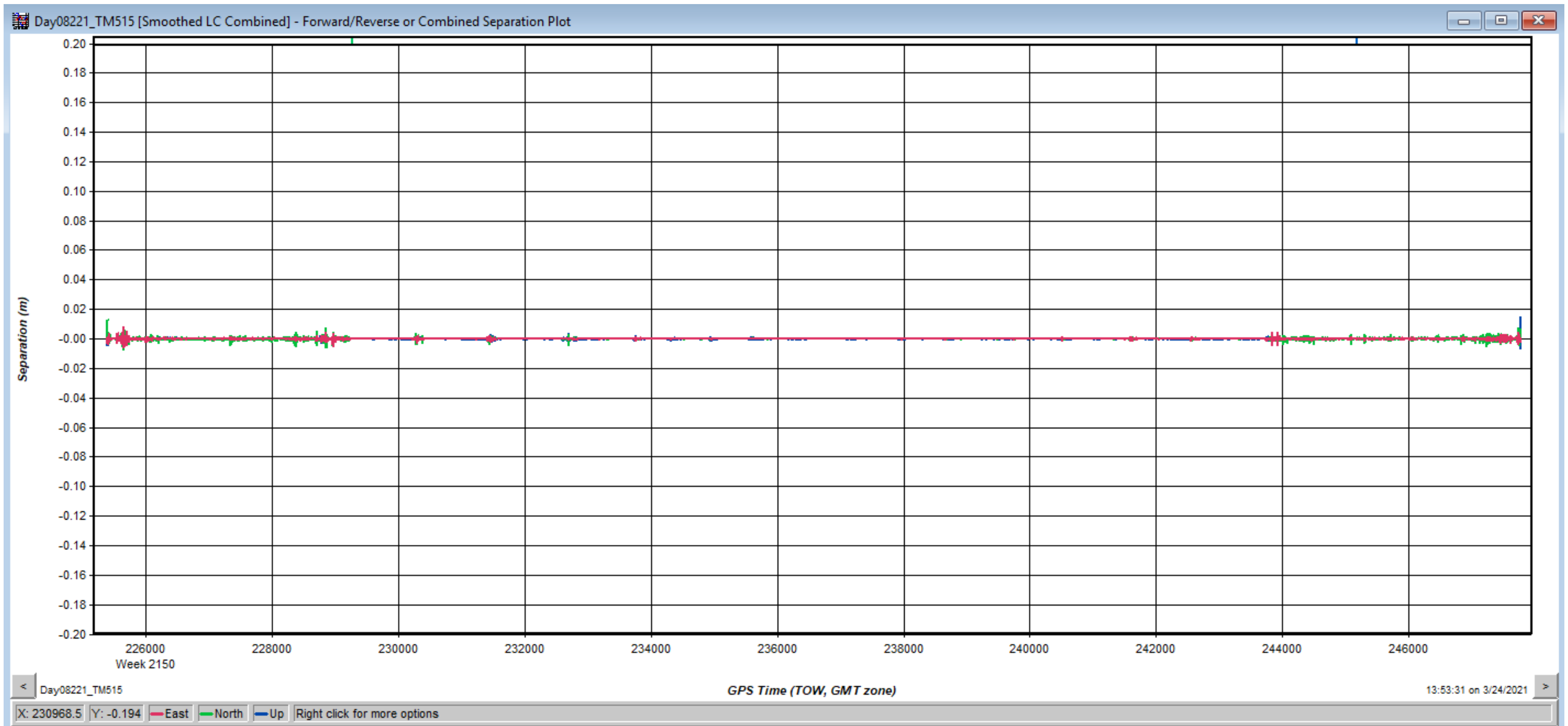
Maintenance 5701.6 - 5702.2

Appendix 3: GPS / IMU Graphics

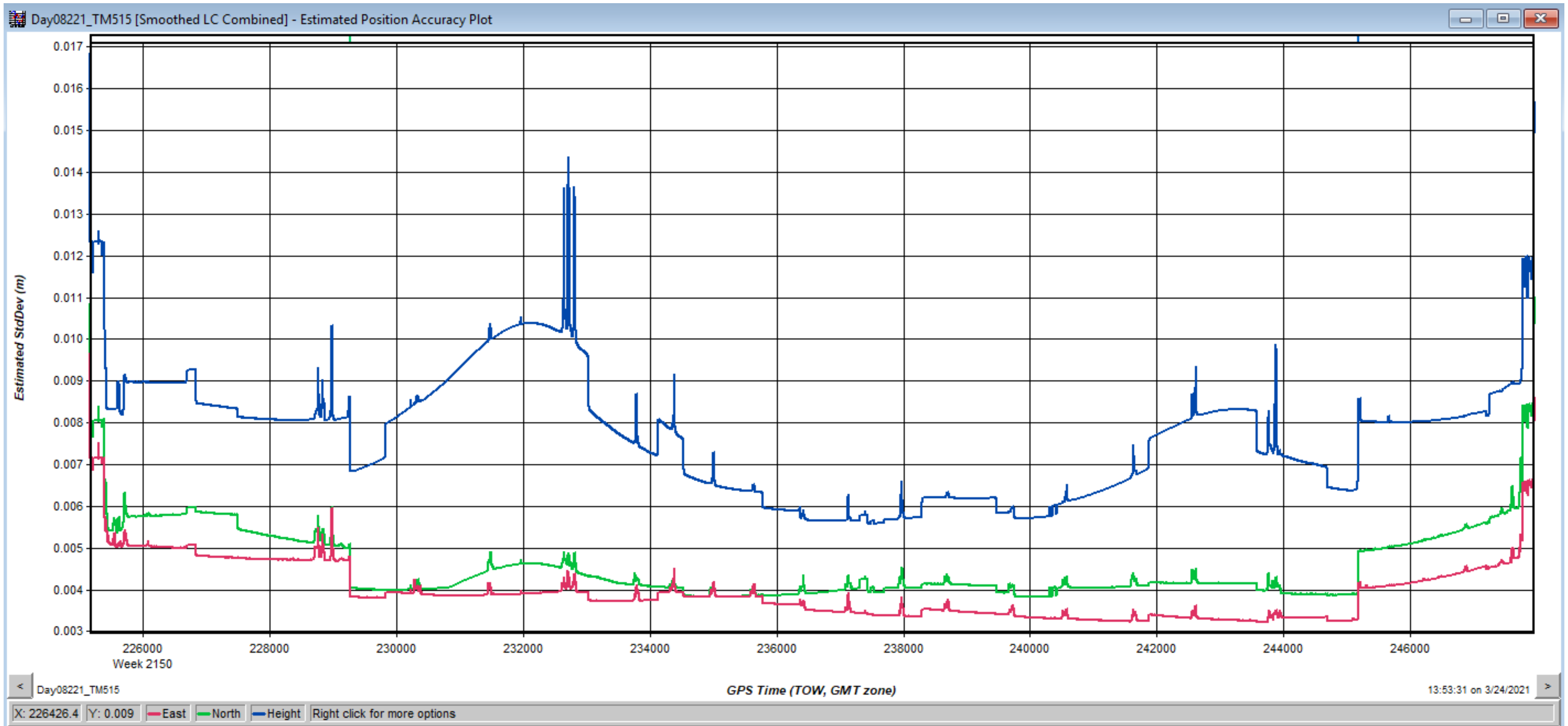
Day08221_TM515
Trajectory



Day08221_TM515
Forward/Reverse or Combined Separation Plot

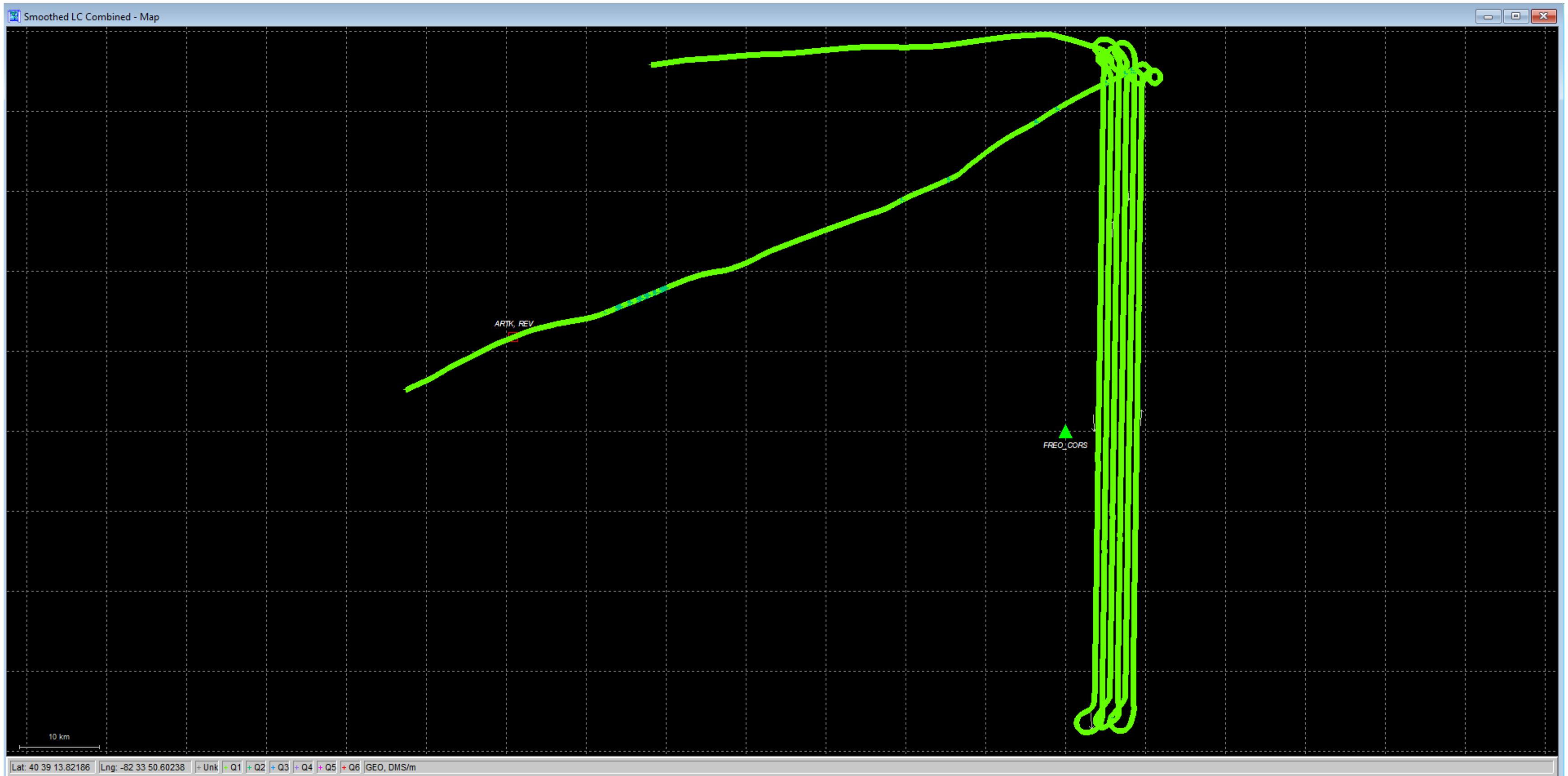


Day08221_TM515
Estimated Position Accuracy



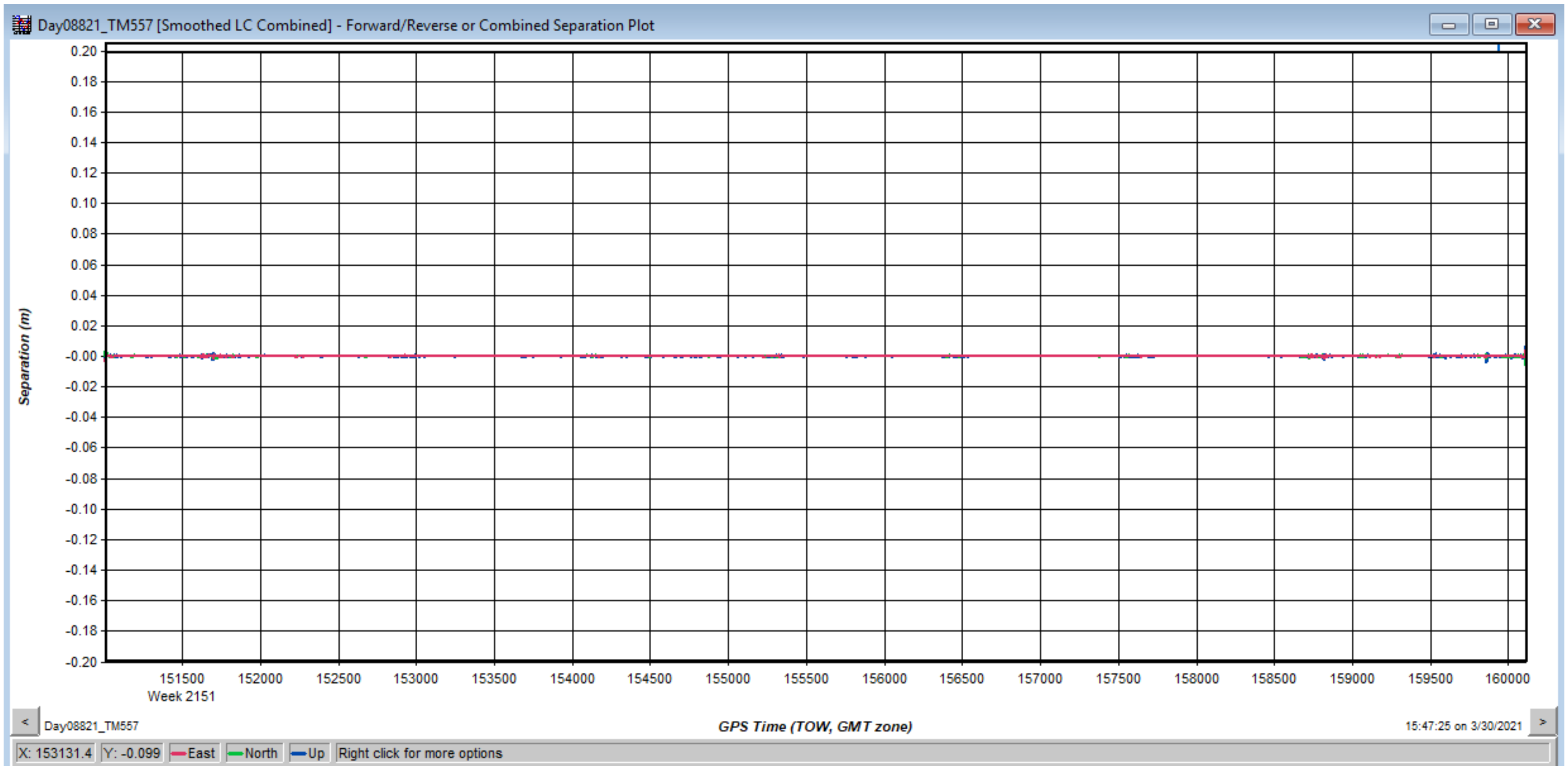
Day08221_TM515
PDOP Plot

Day08821_TM557
Trajectory

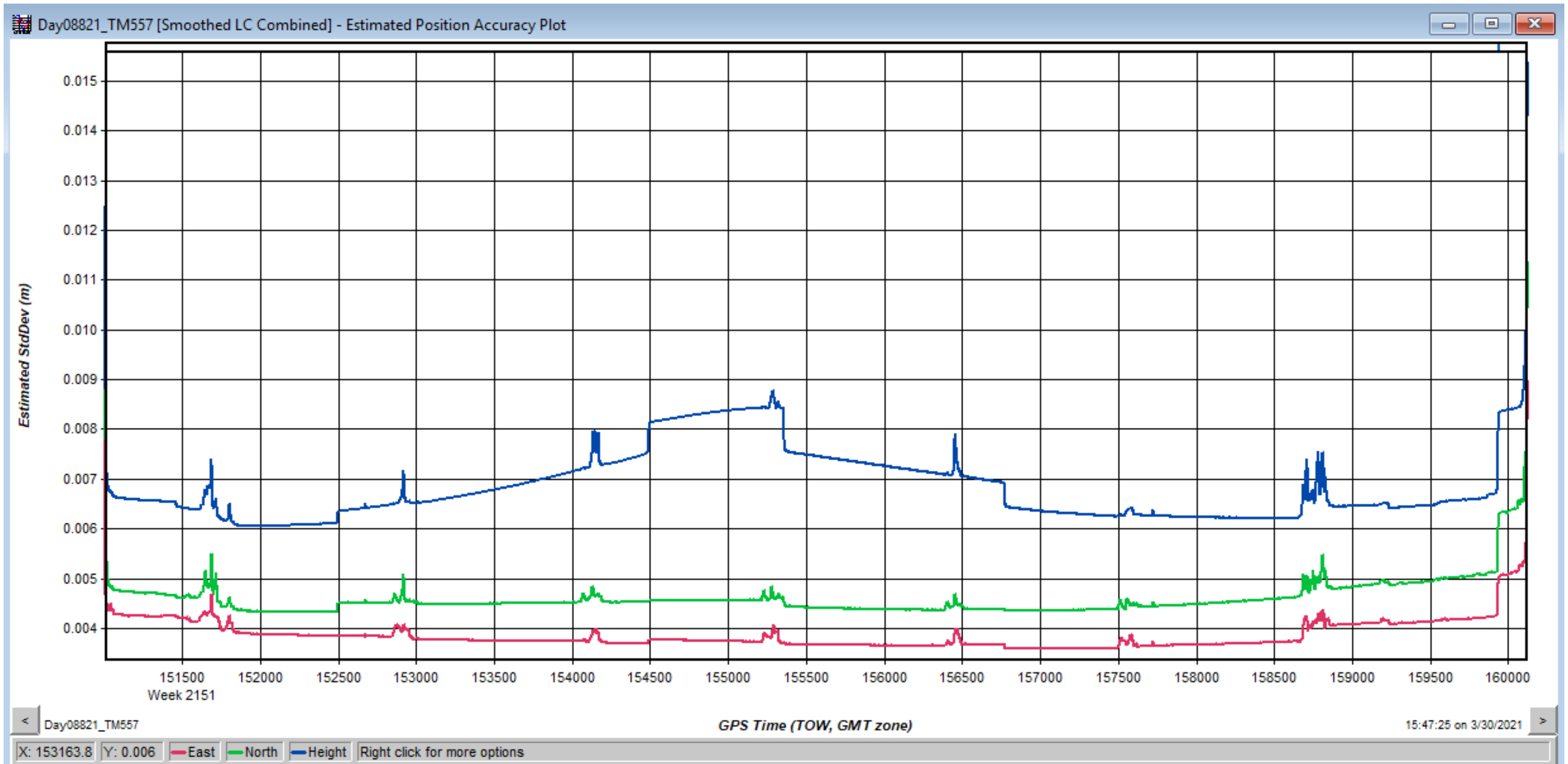


Day08821_TM557

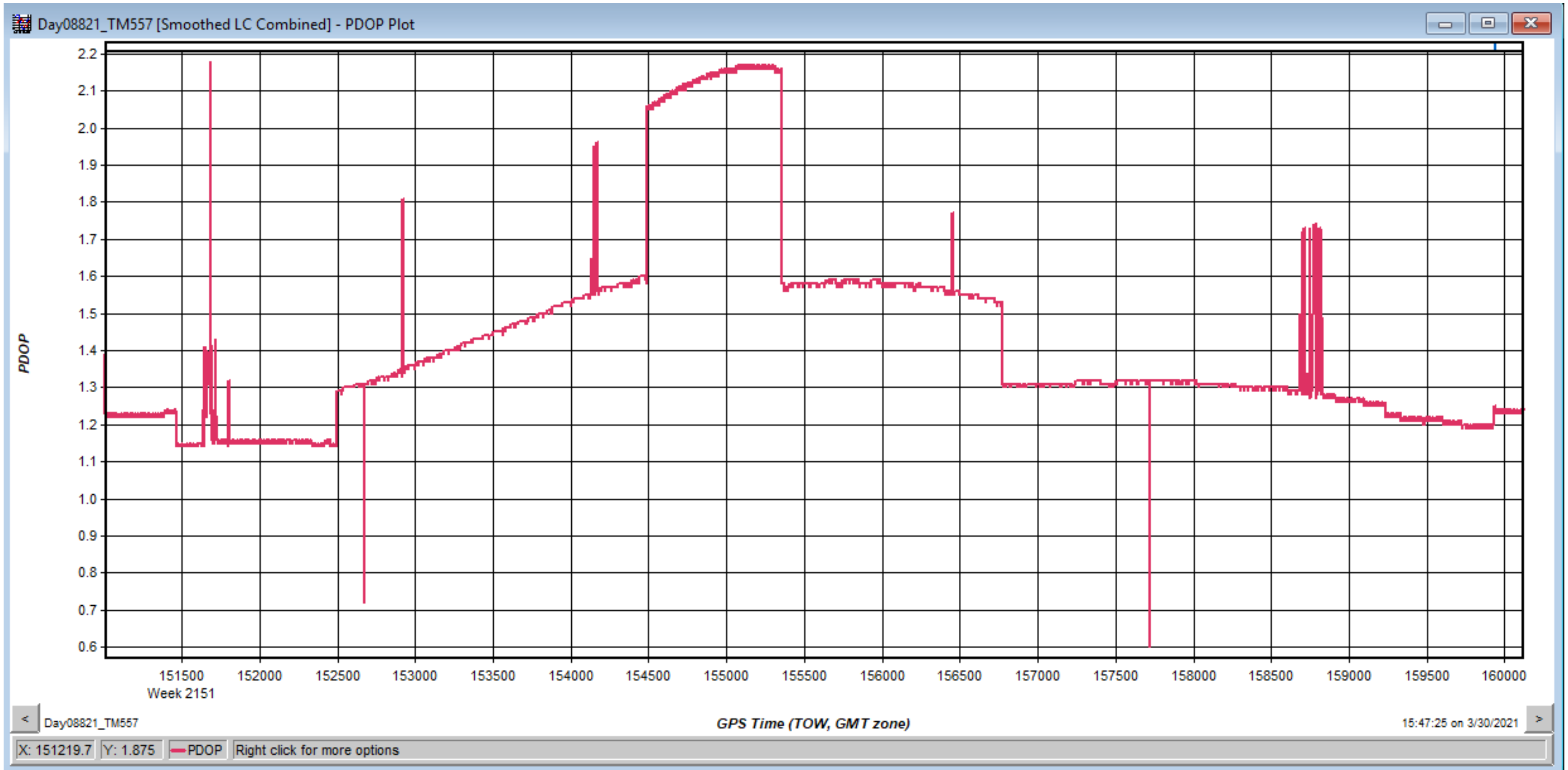
Forward/Reverse or Combined Separation Plot



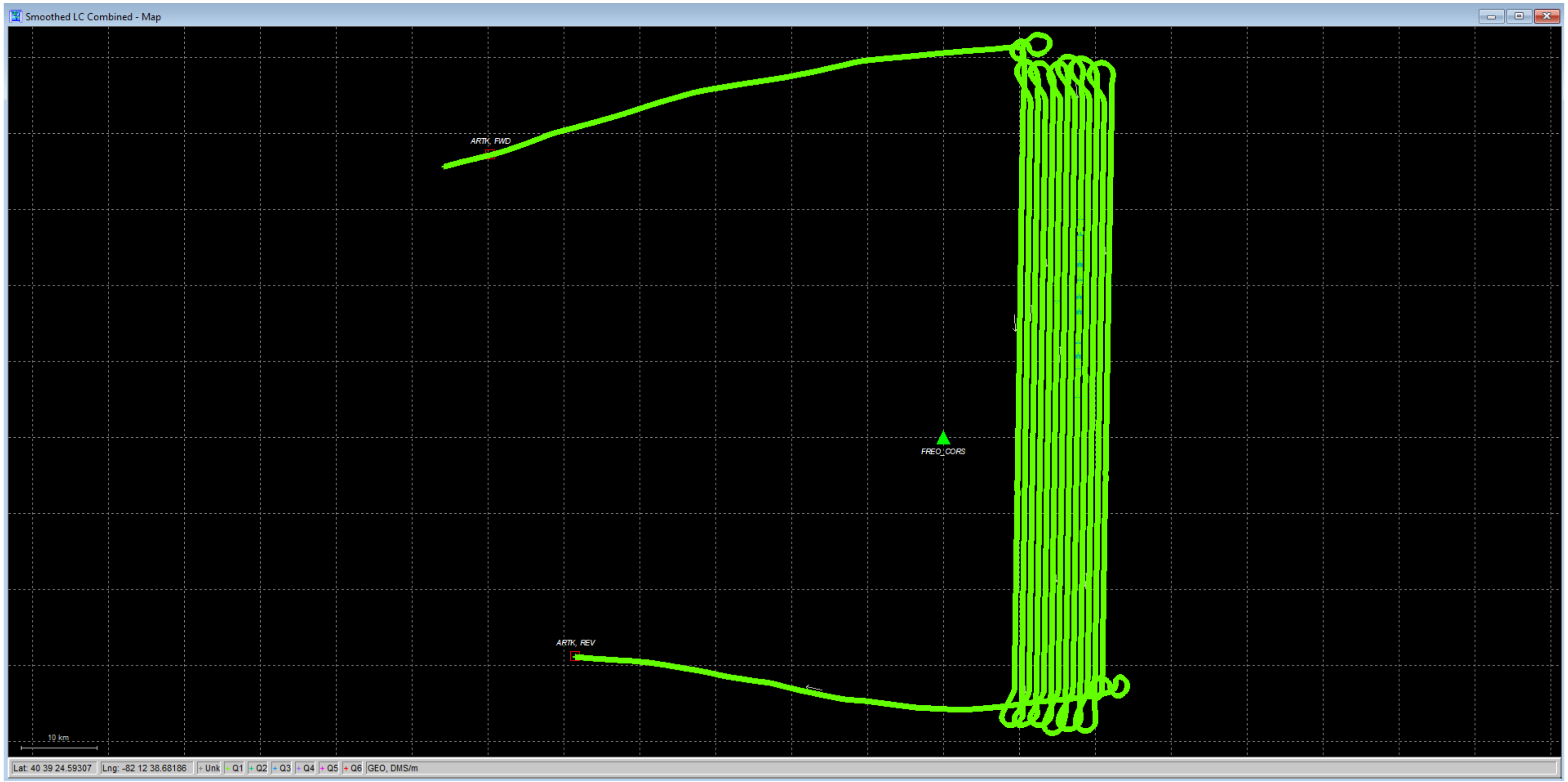
Day08821_TM557
Estimated Position Accuracy



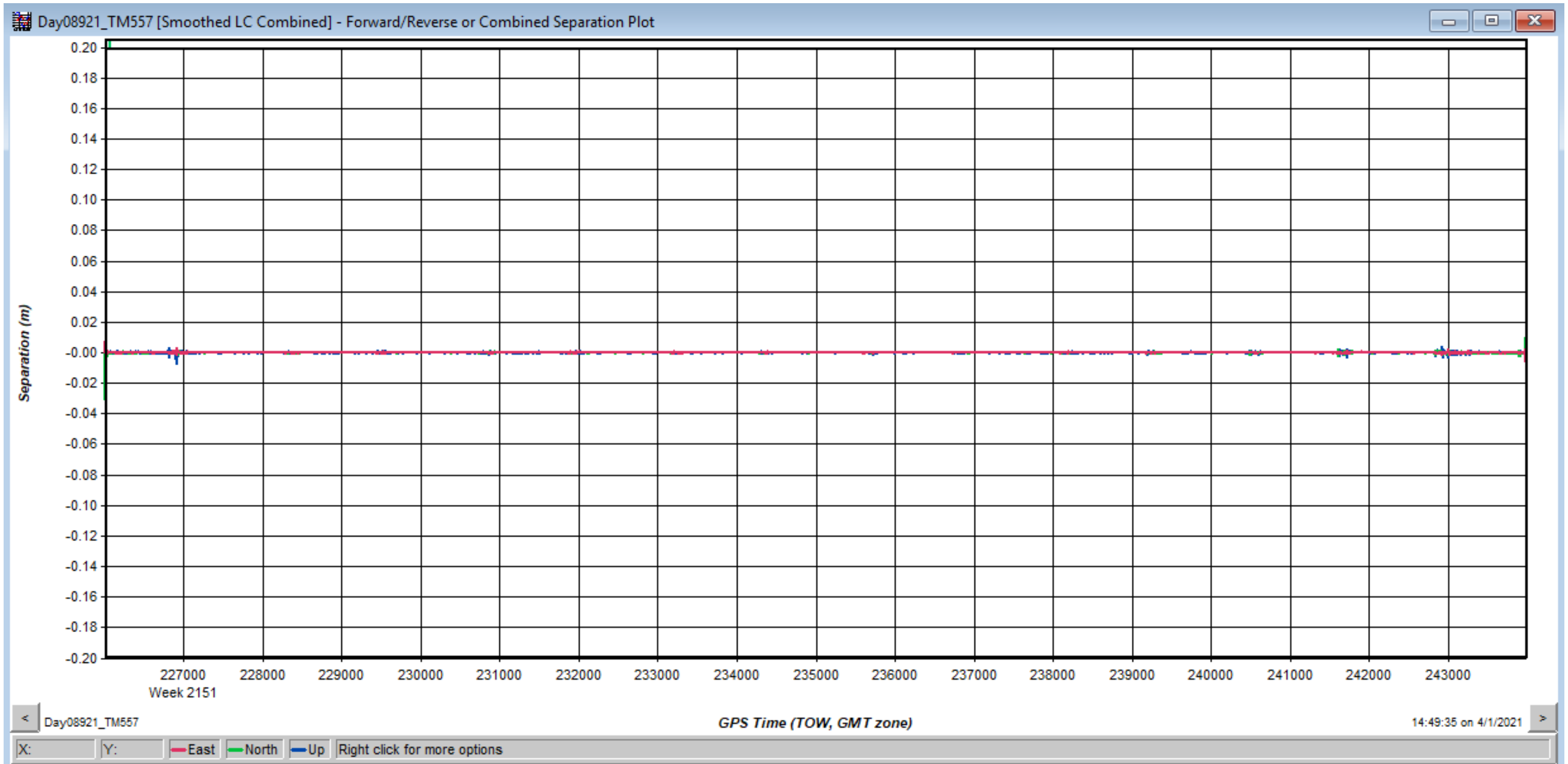
Day08821_TM557
PDOP Plot



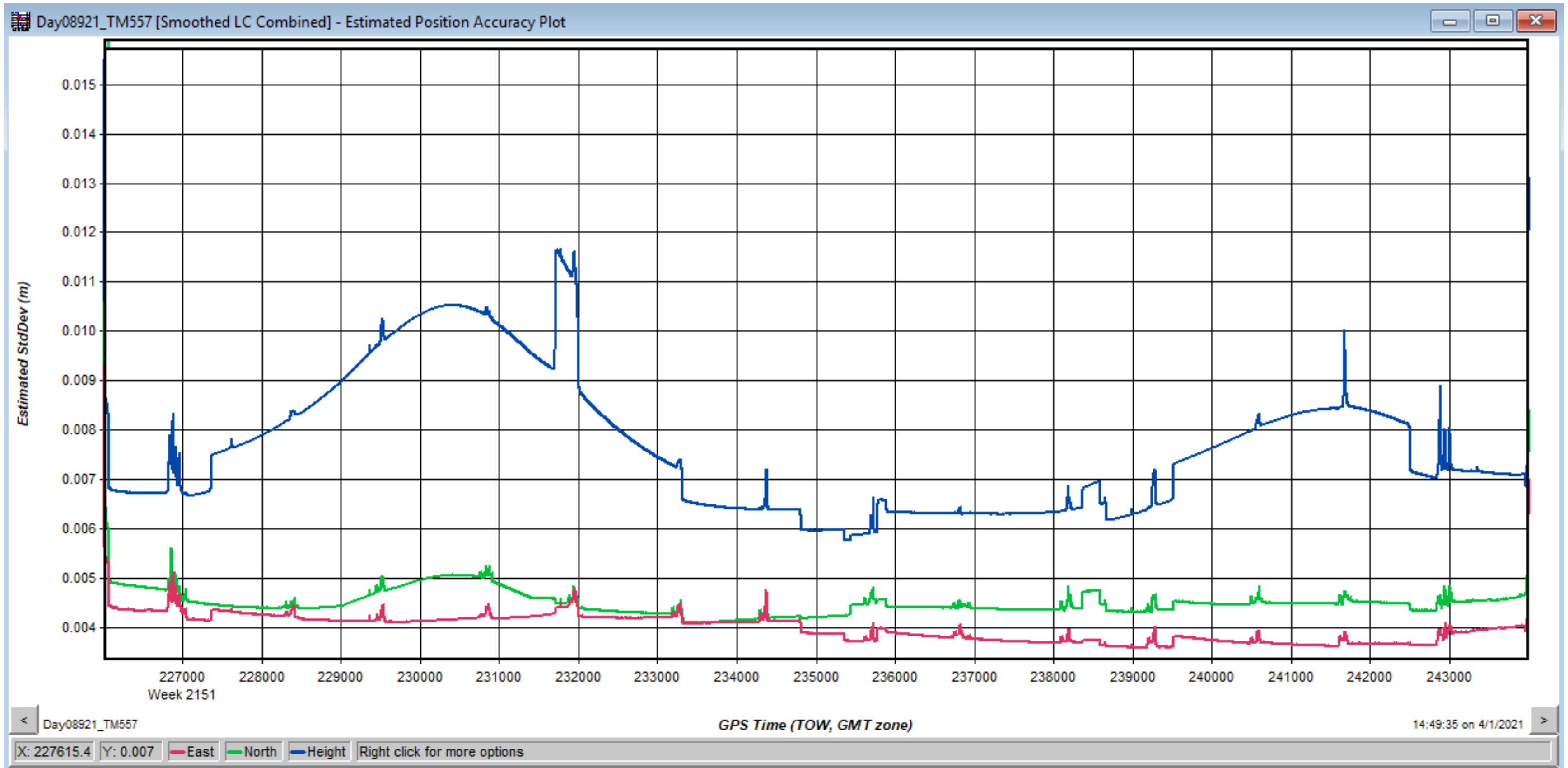
Day08921_TM557
Trajectory



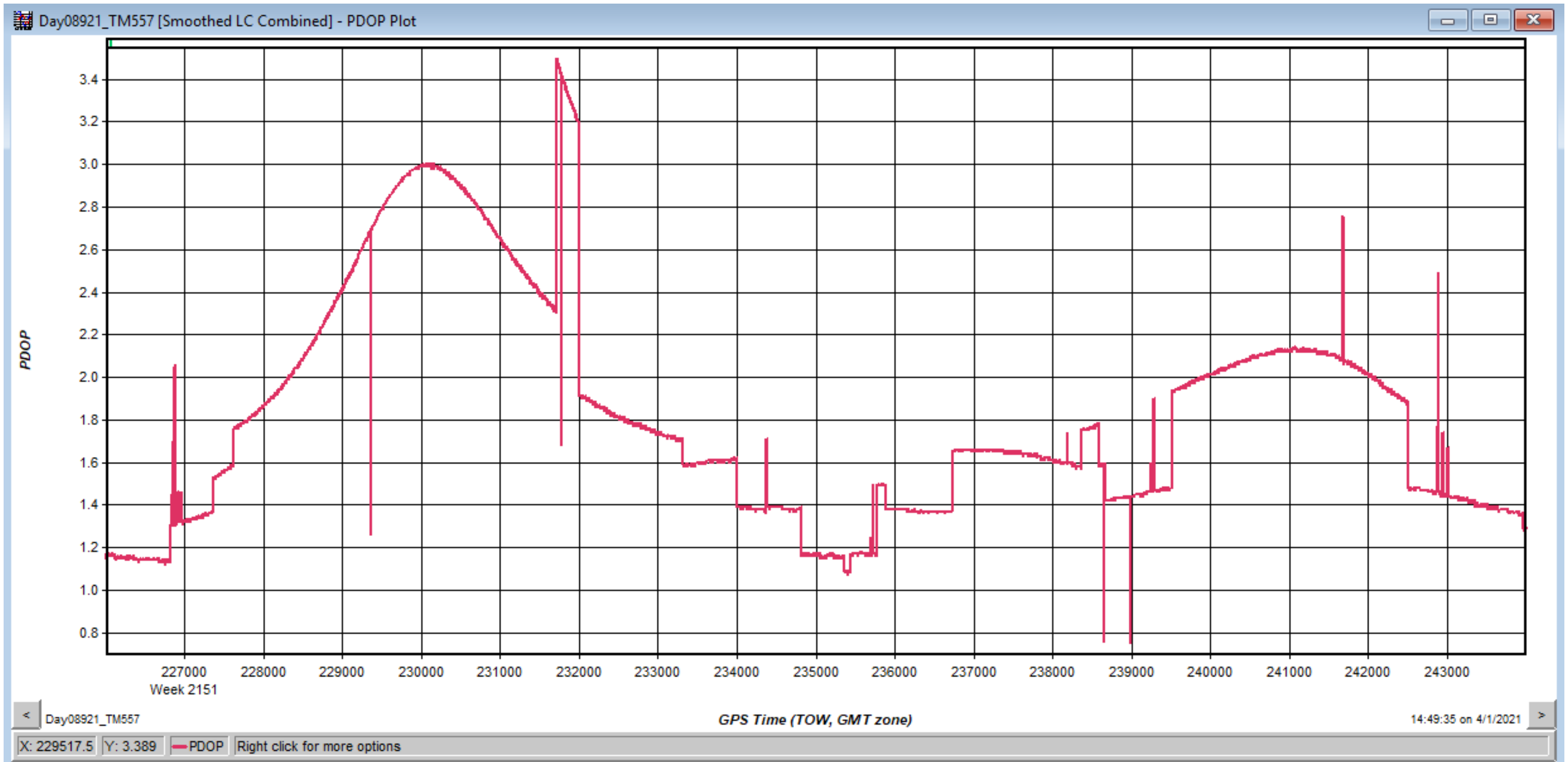
Day08921_TM557
Forward/Reverse or Combined Separation Plot



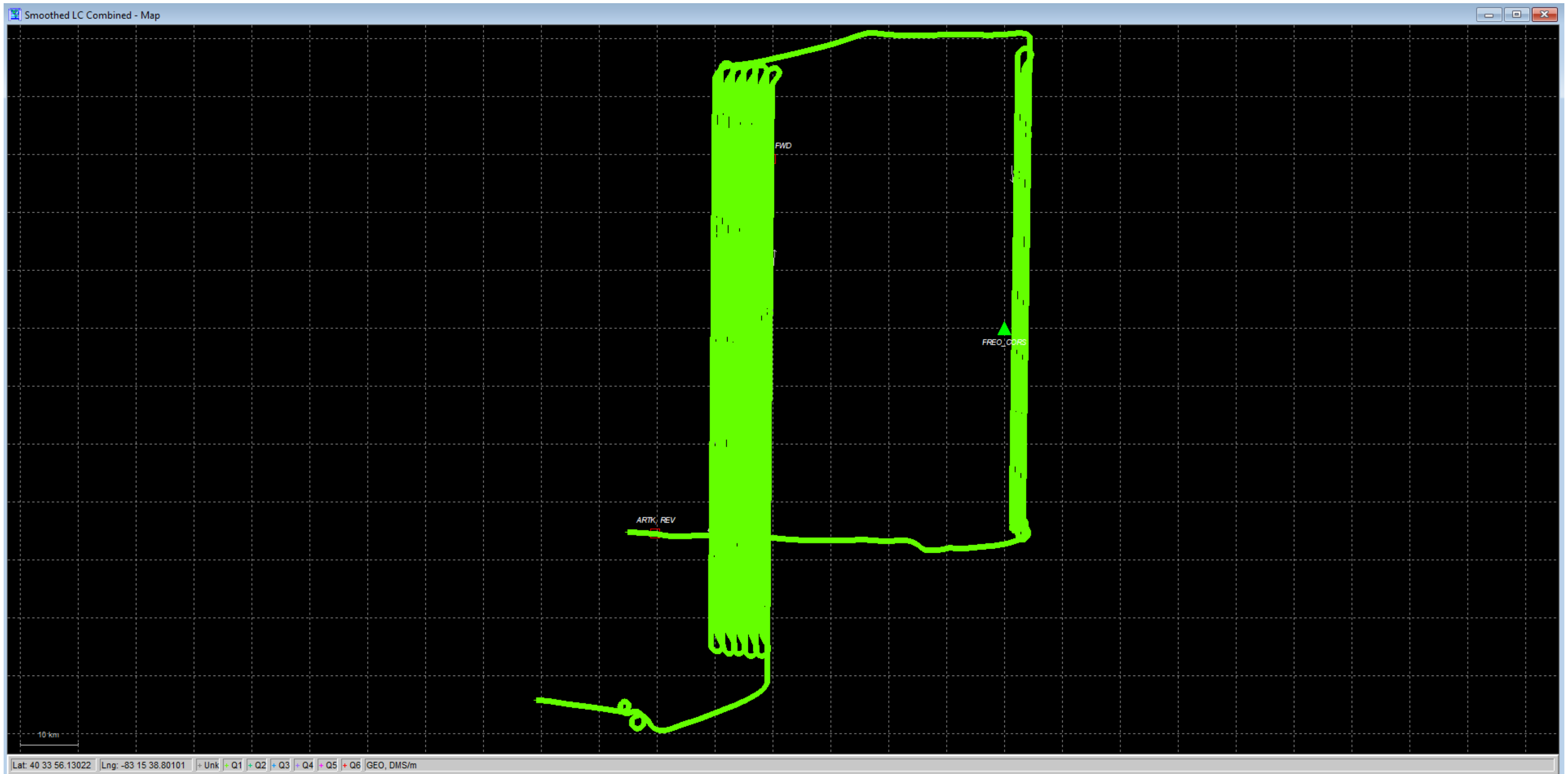
Day08921_TM557
Estimated Position Accuracy



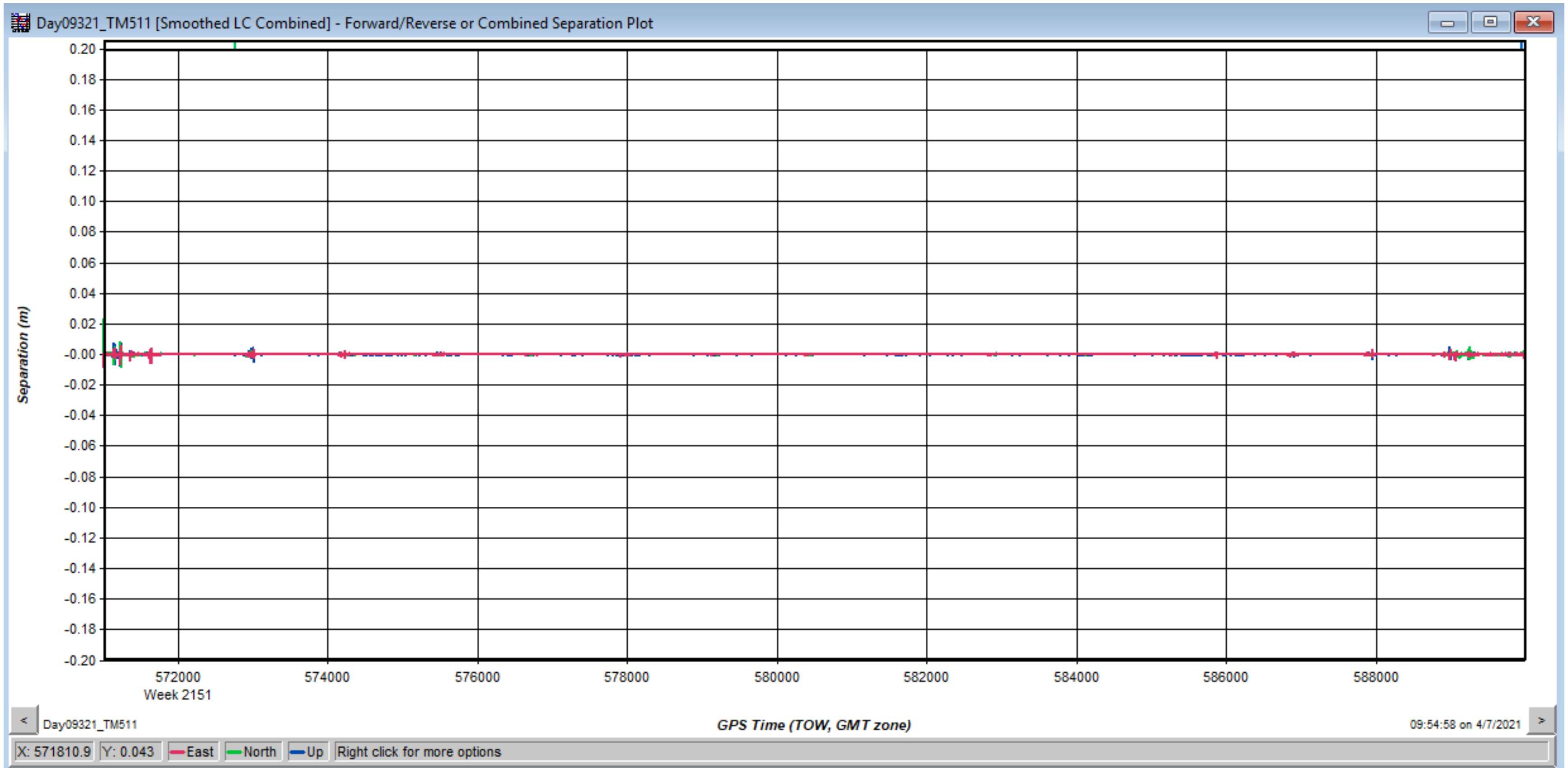
Day08921_TM557
PDOP Plot



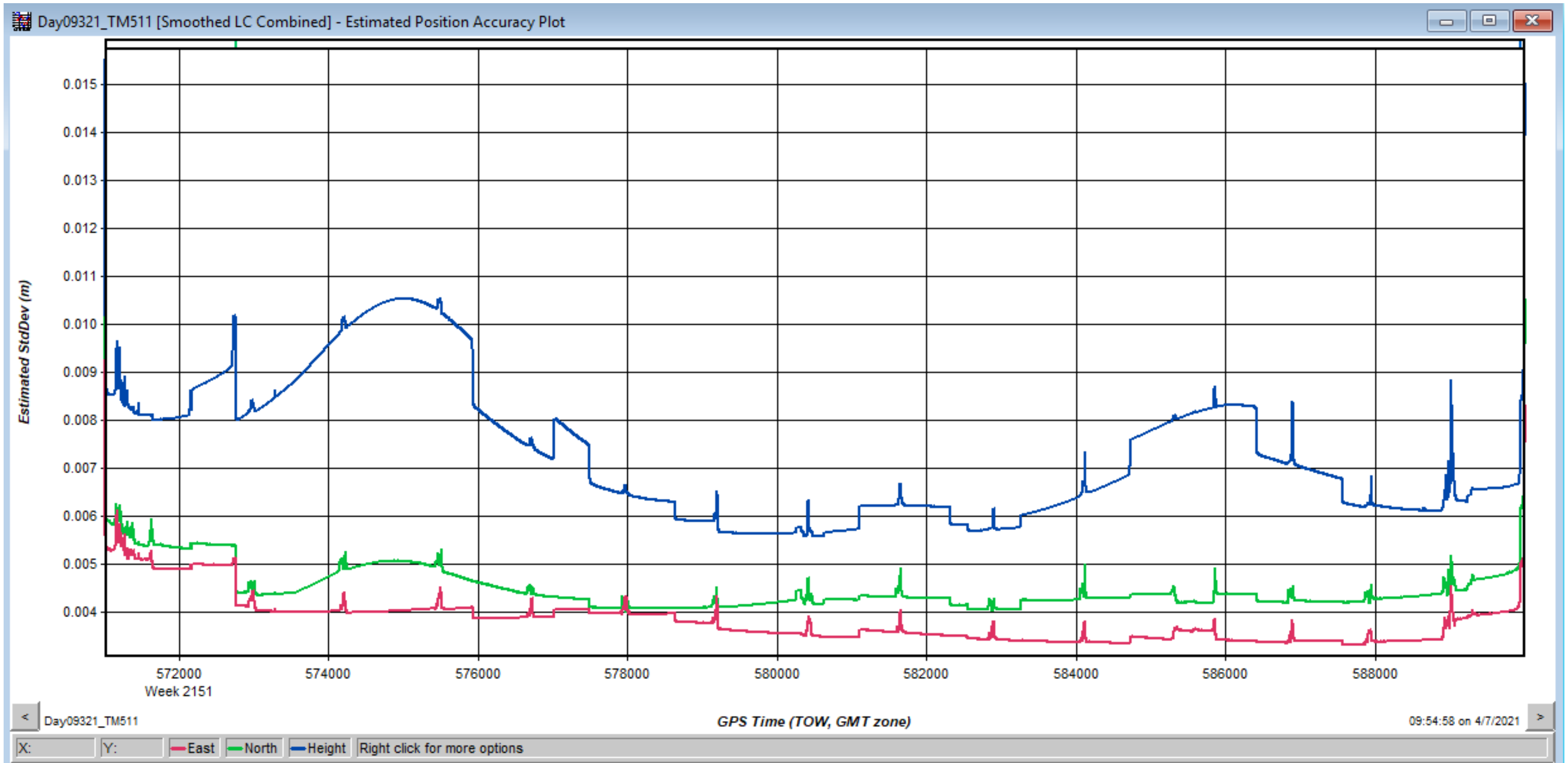
Day09321_TM511
Trajectory



Day09321_TM511
Forward/Reverse or Combined Separation Plot

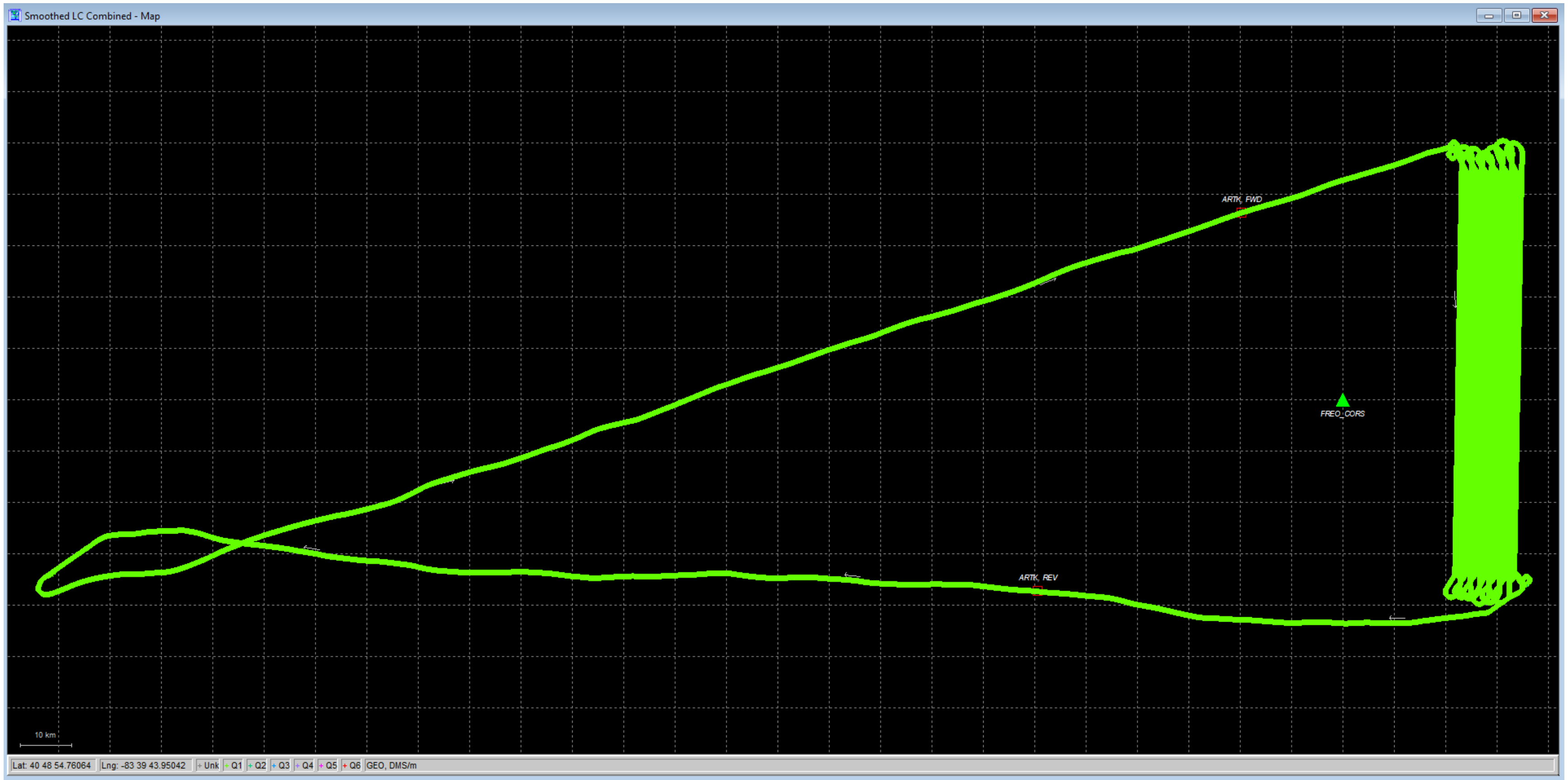


Day09321_TM511
Estimated Position Accuracy

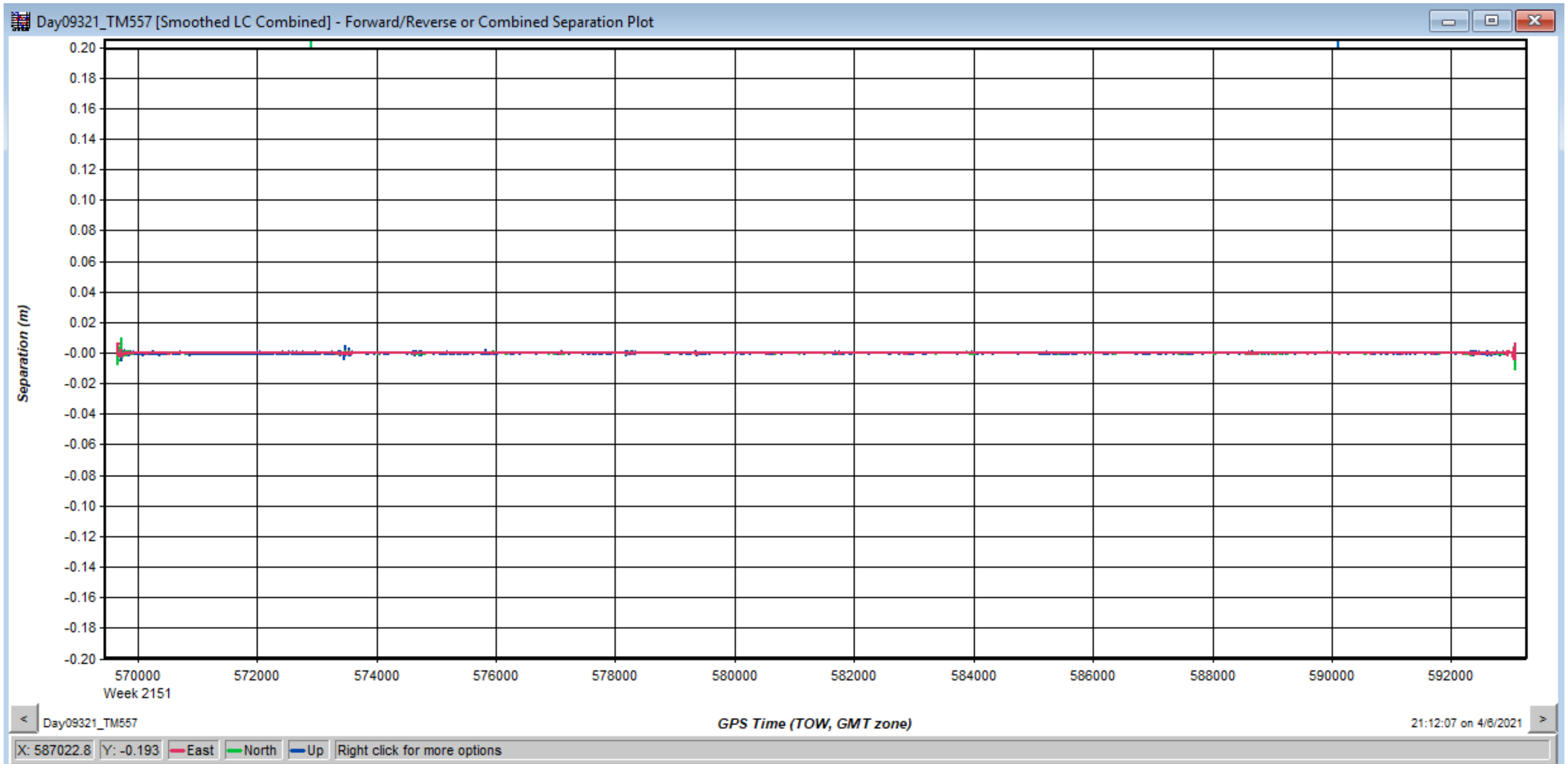


Day09321_TM511
PDOP Plot

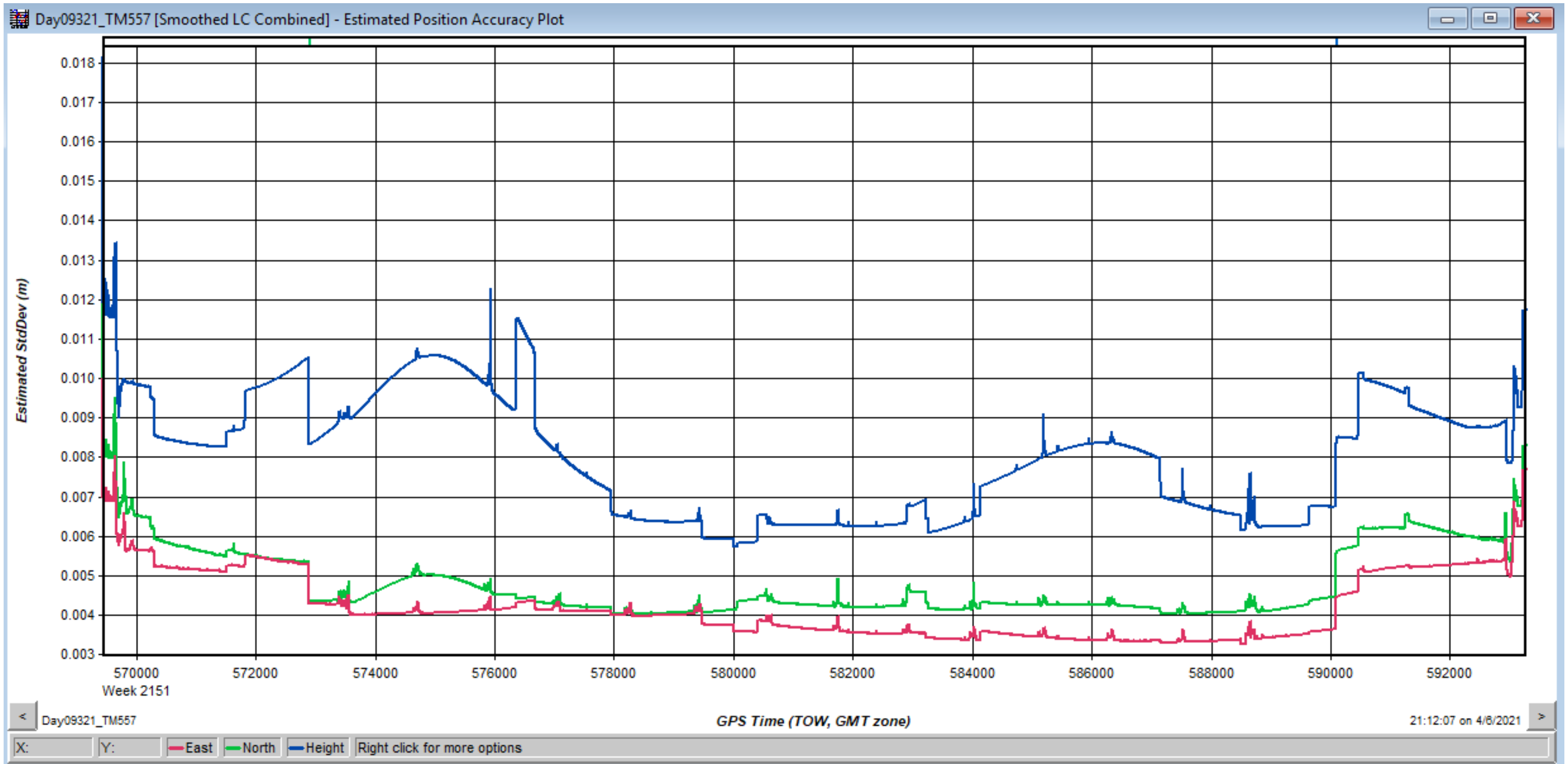
Day09321_TM557
Trajectory



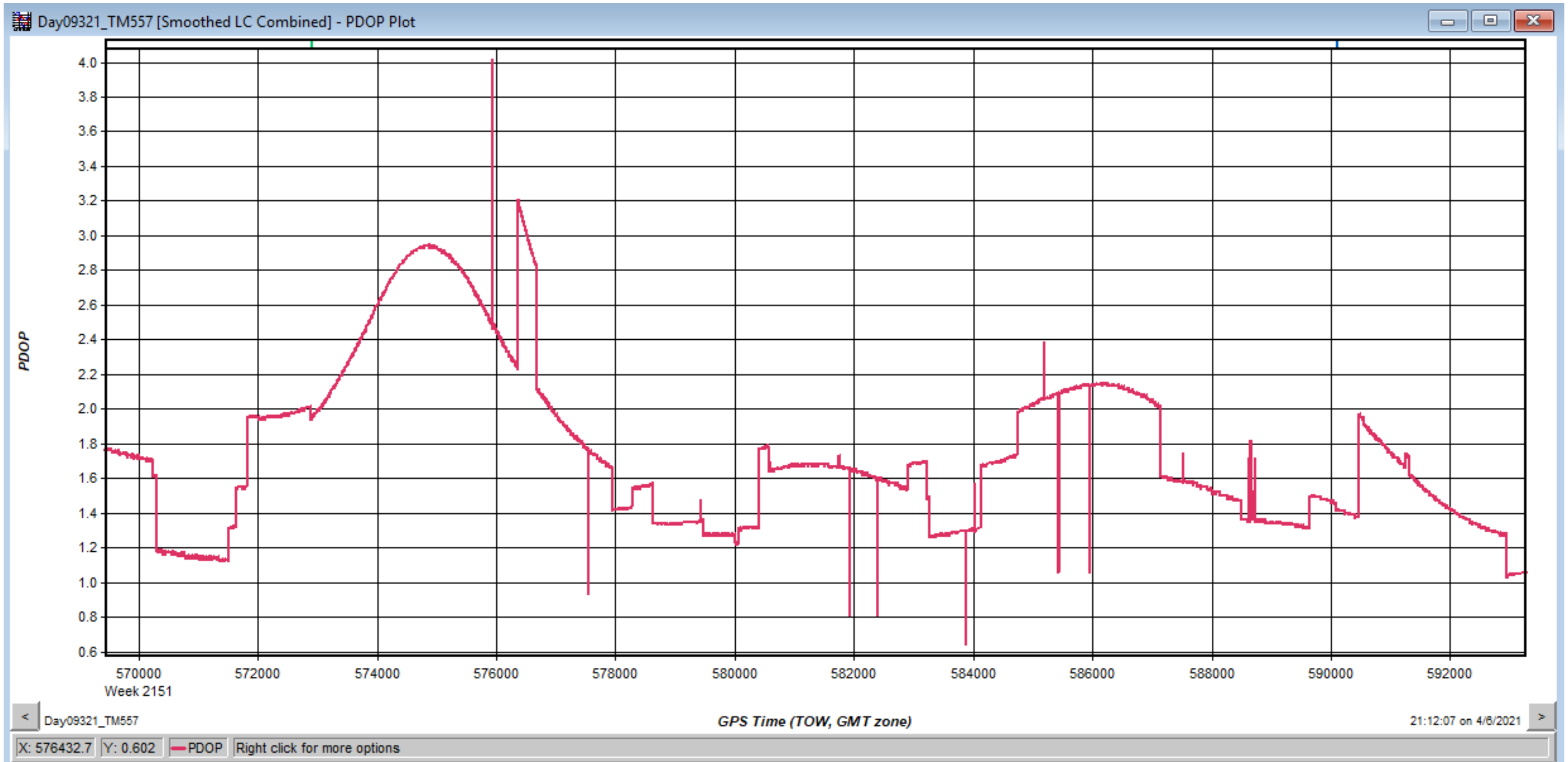
Day09321_TM557
Forward/Reverse or Combined Separation Plot



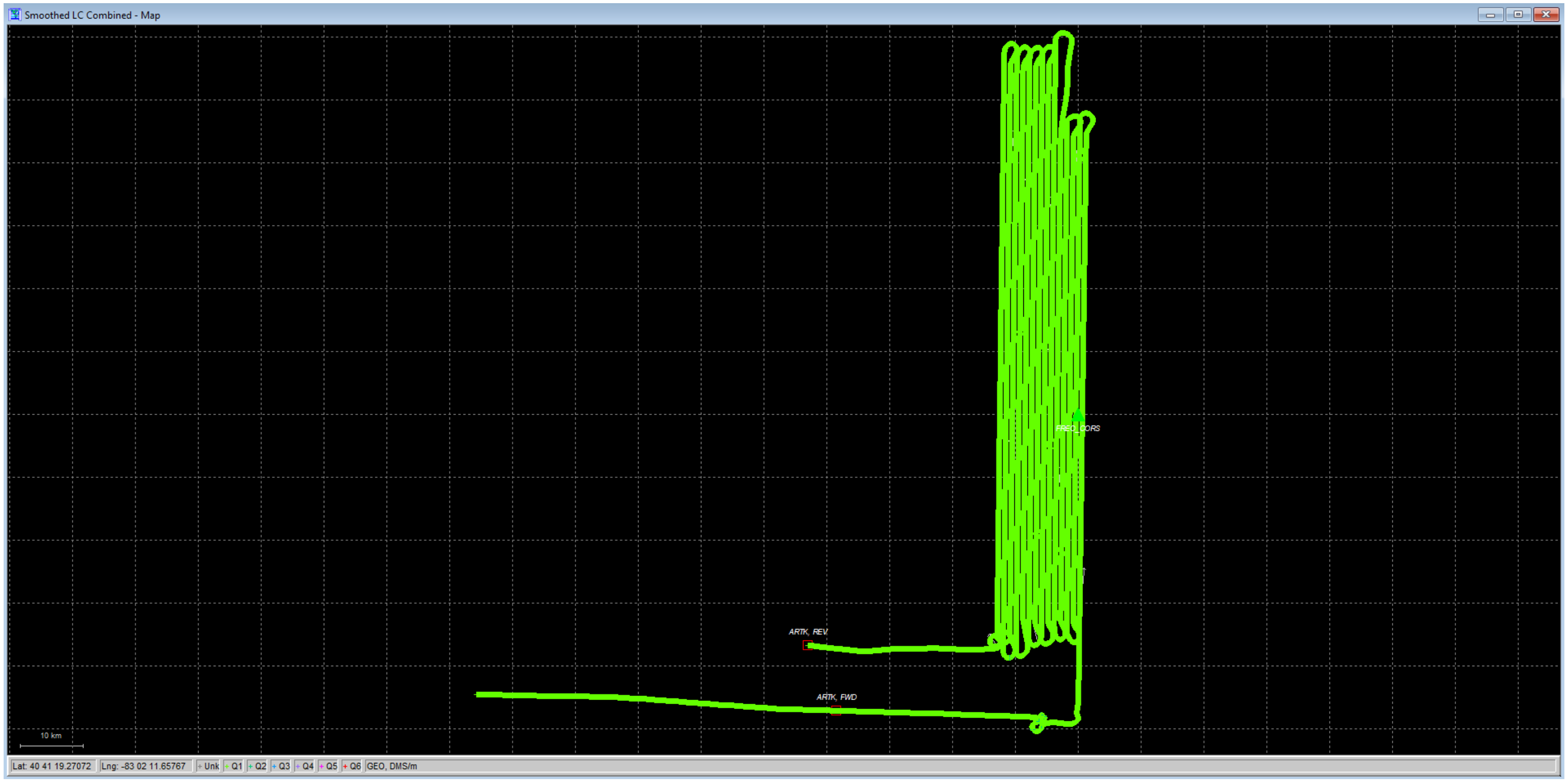
Day09321_TM557
Estimated Position Accuracy



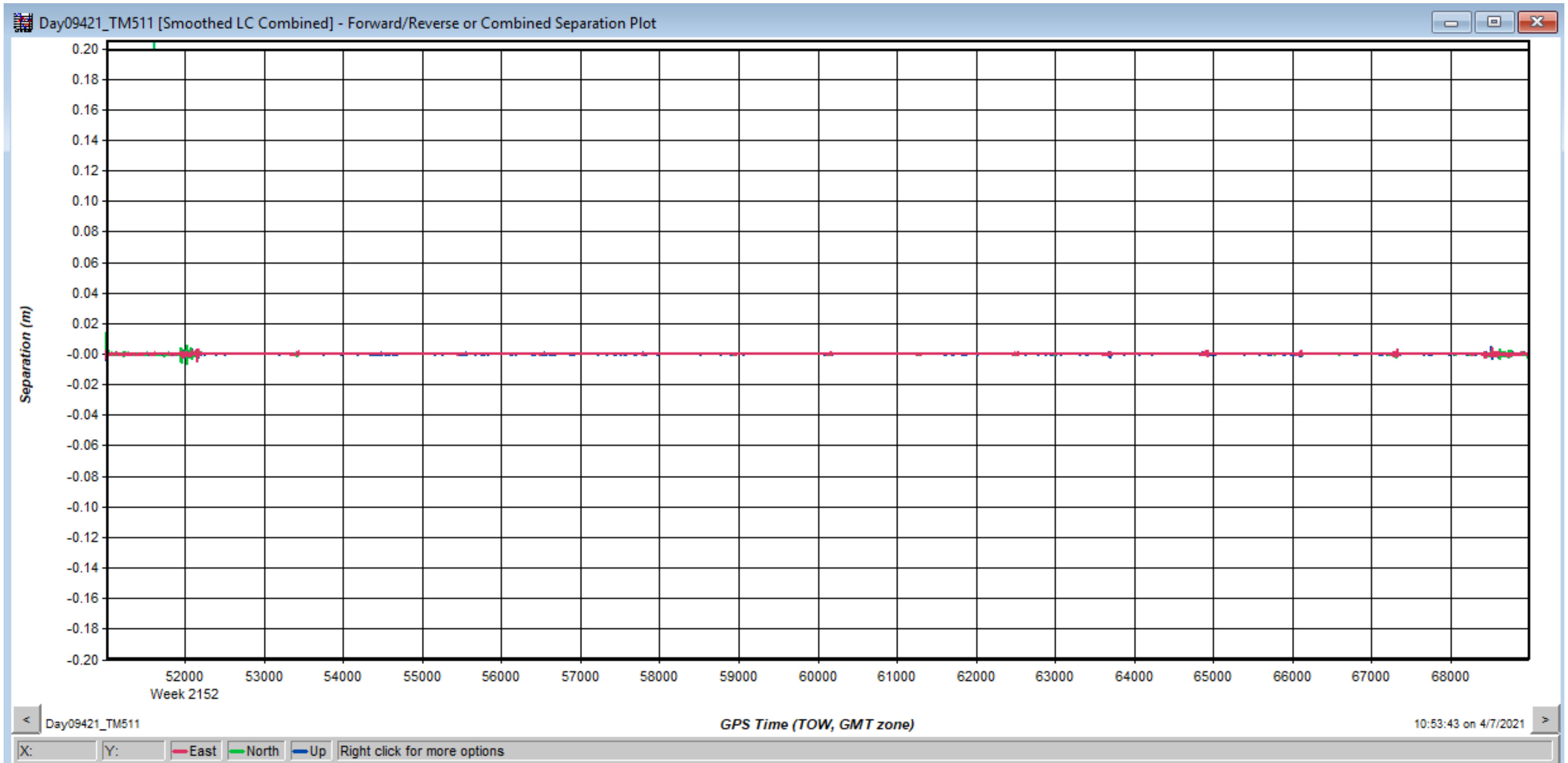
Day09321_TM557
PDOP Plot



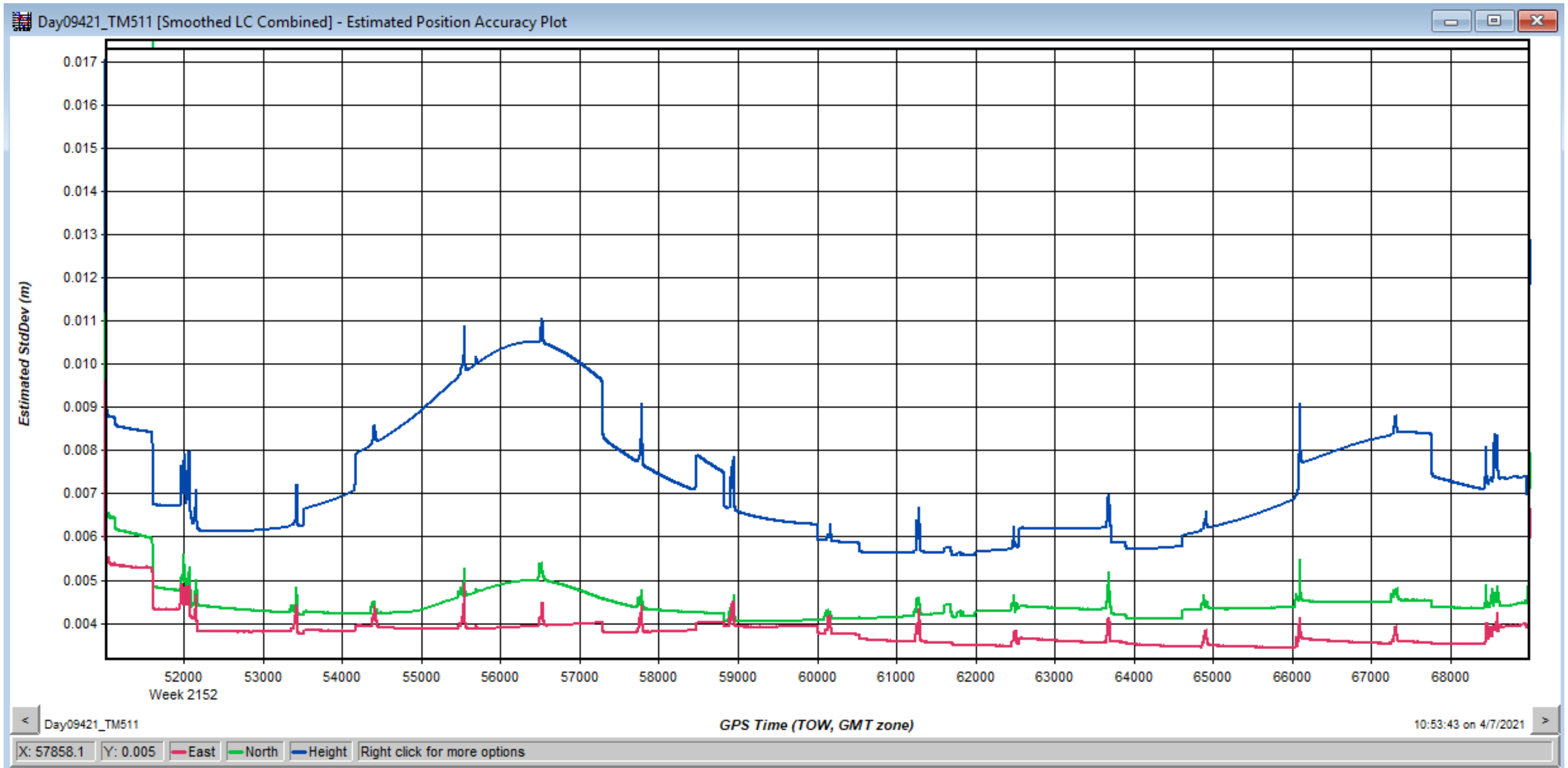
Day09421_TM511
Trajectory



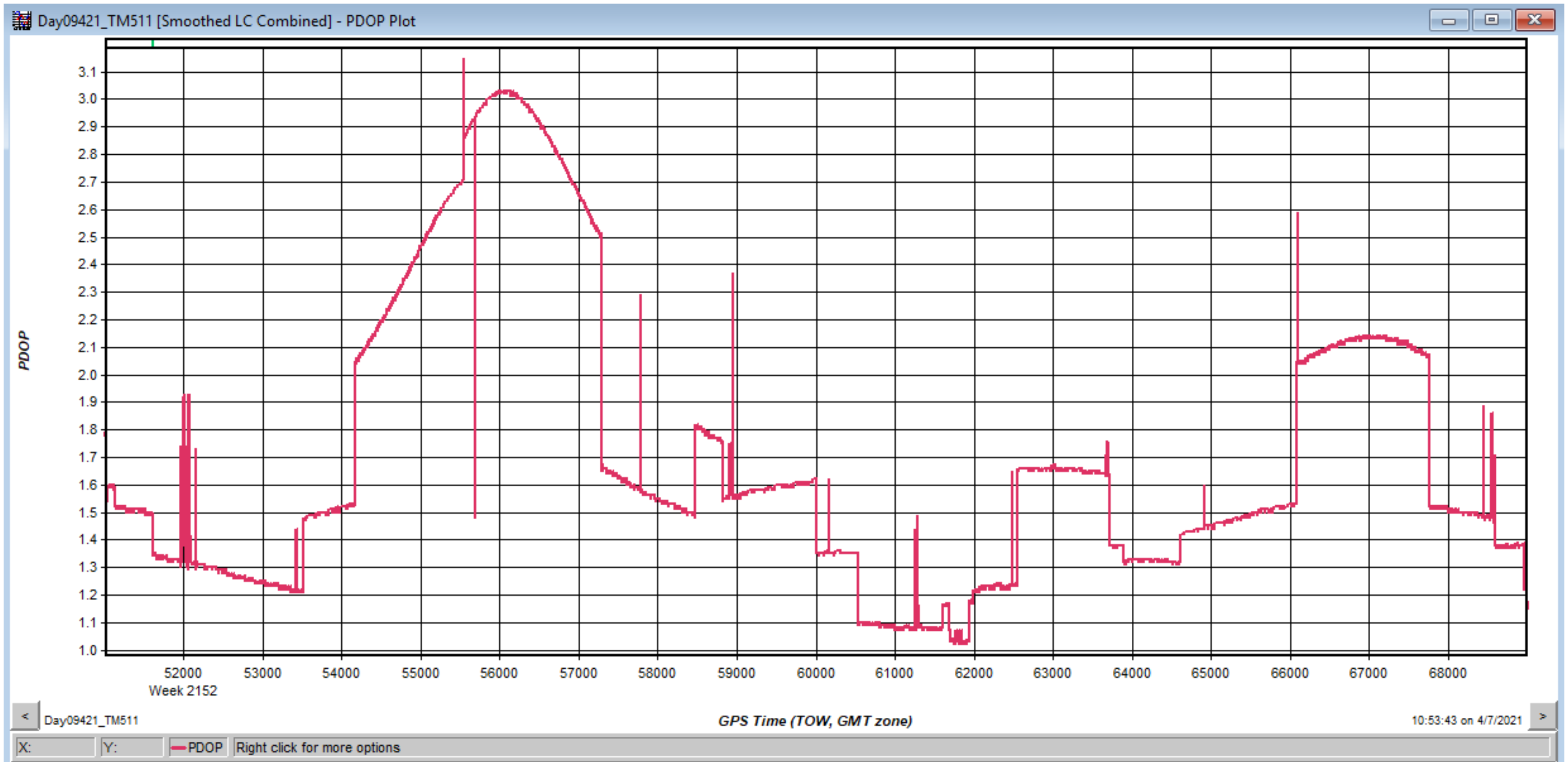
Day09421_TM511
Forward/Reverse or Combined Separation Plot



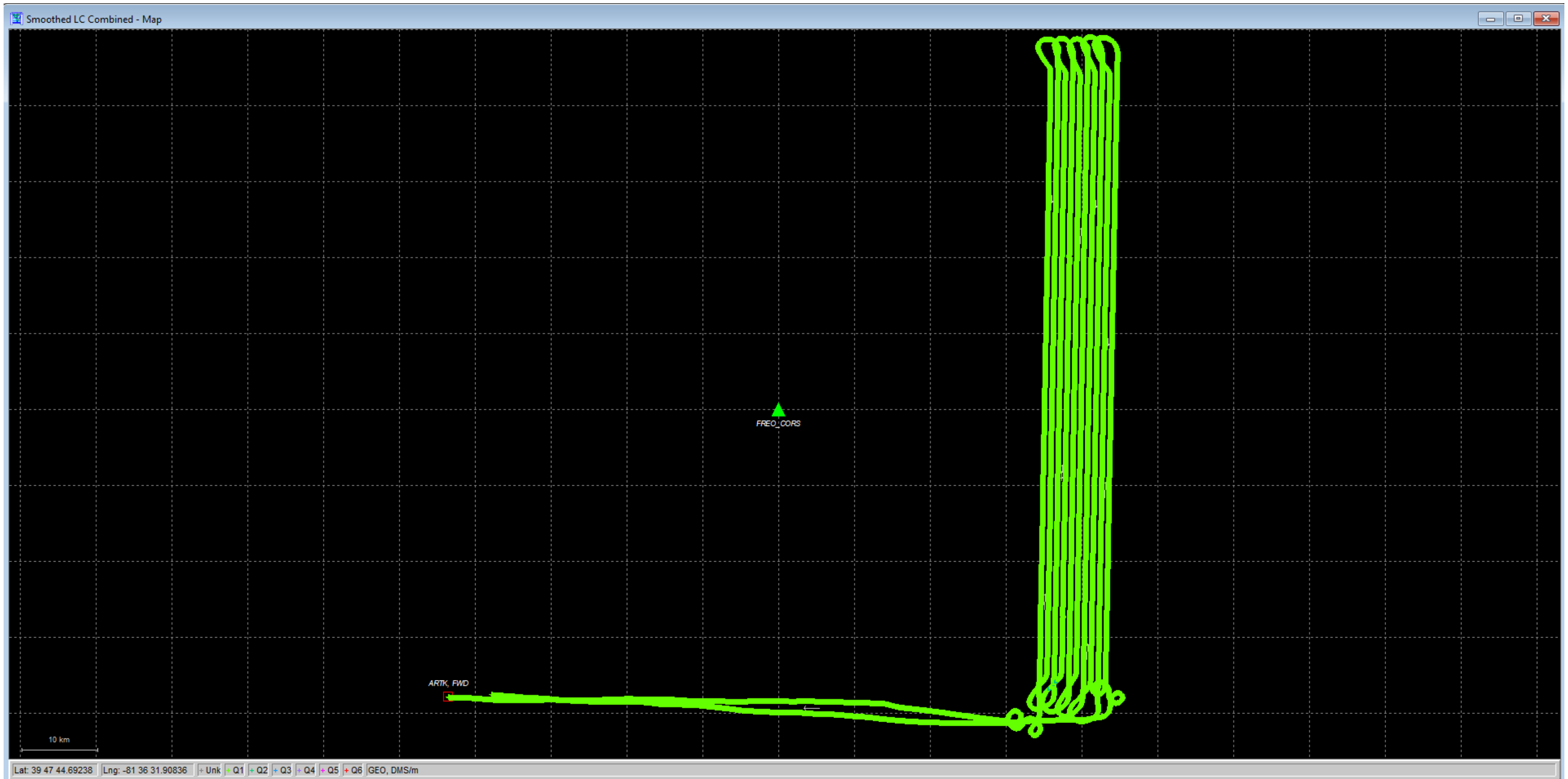
Day09421_TM511
Estimated Position Accuracy



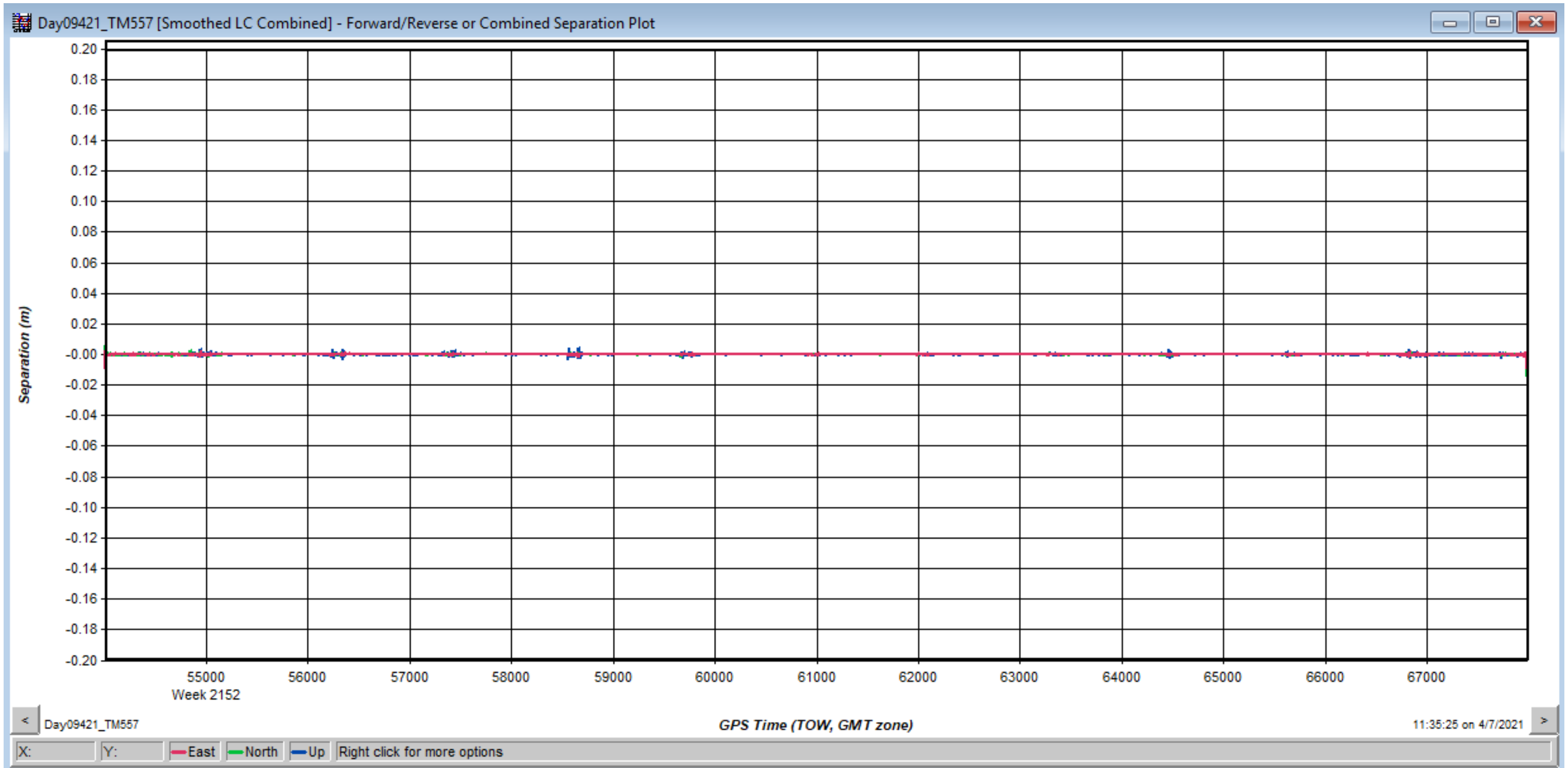
Day09421_TM511
PDOP Plot



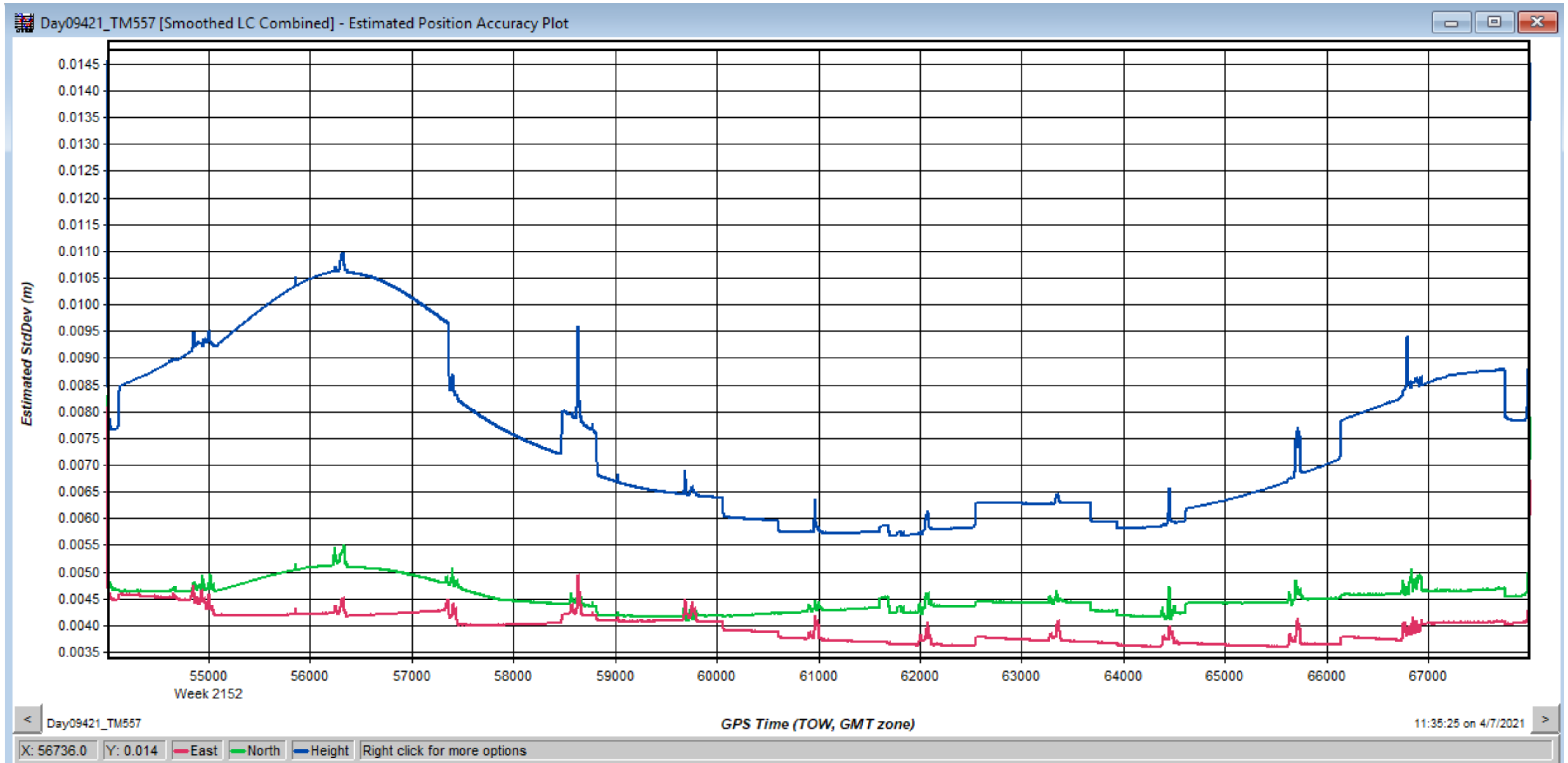
Day09421_TM557
Trajectory



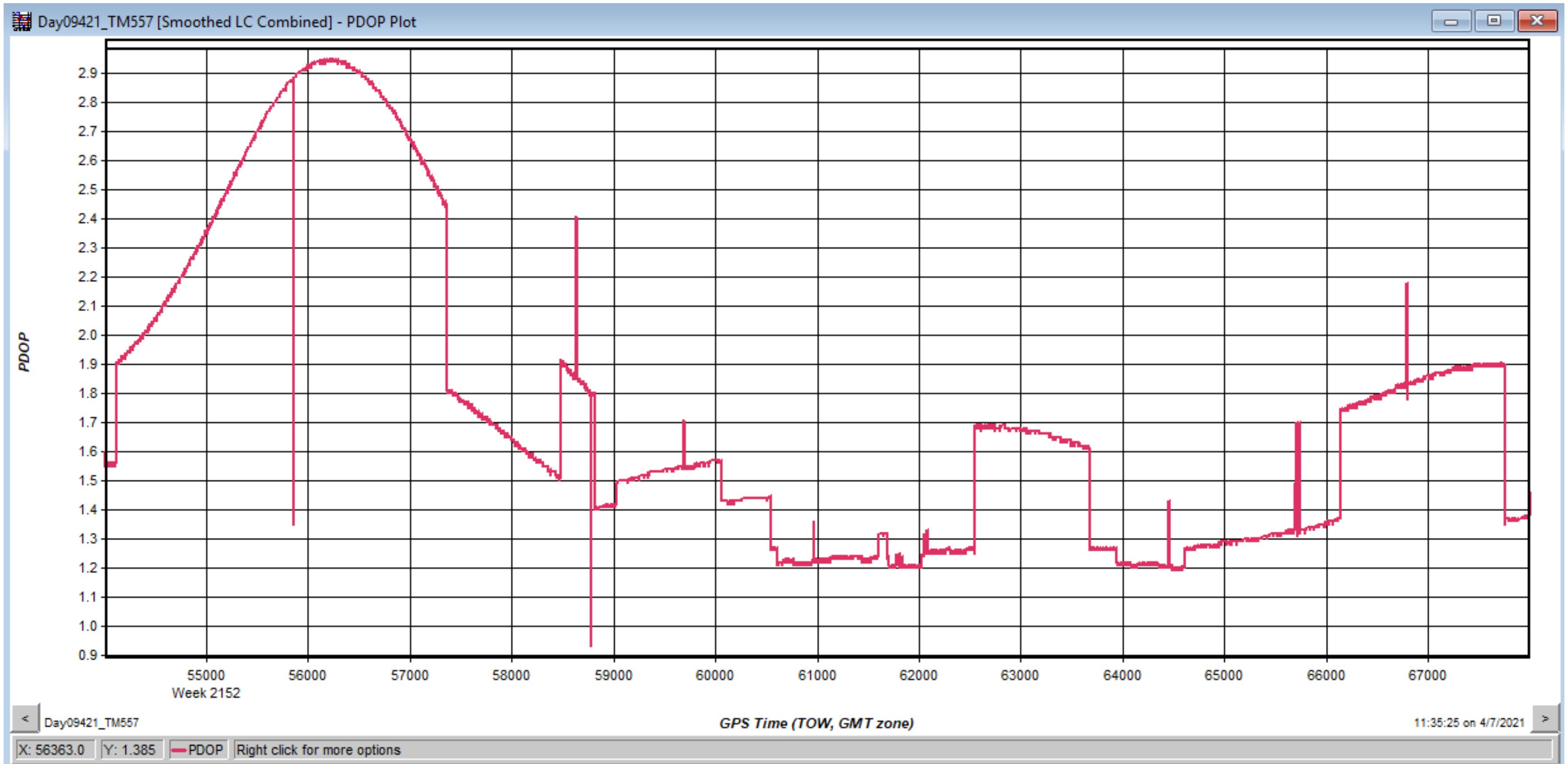
Day09421_TM557
Forward/Reverse or Combined Separation Plot



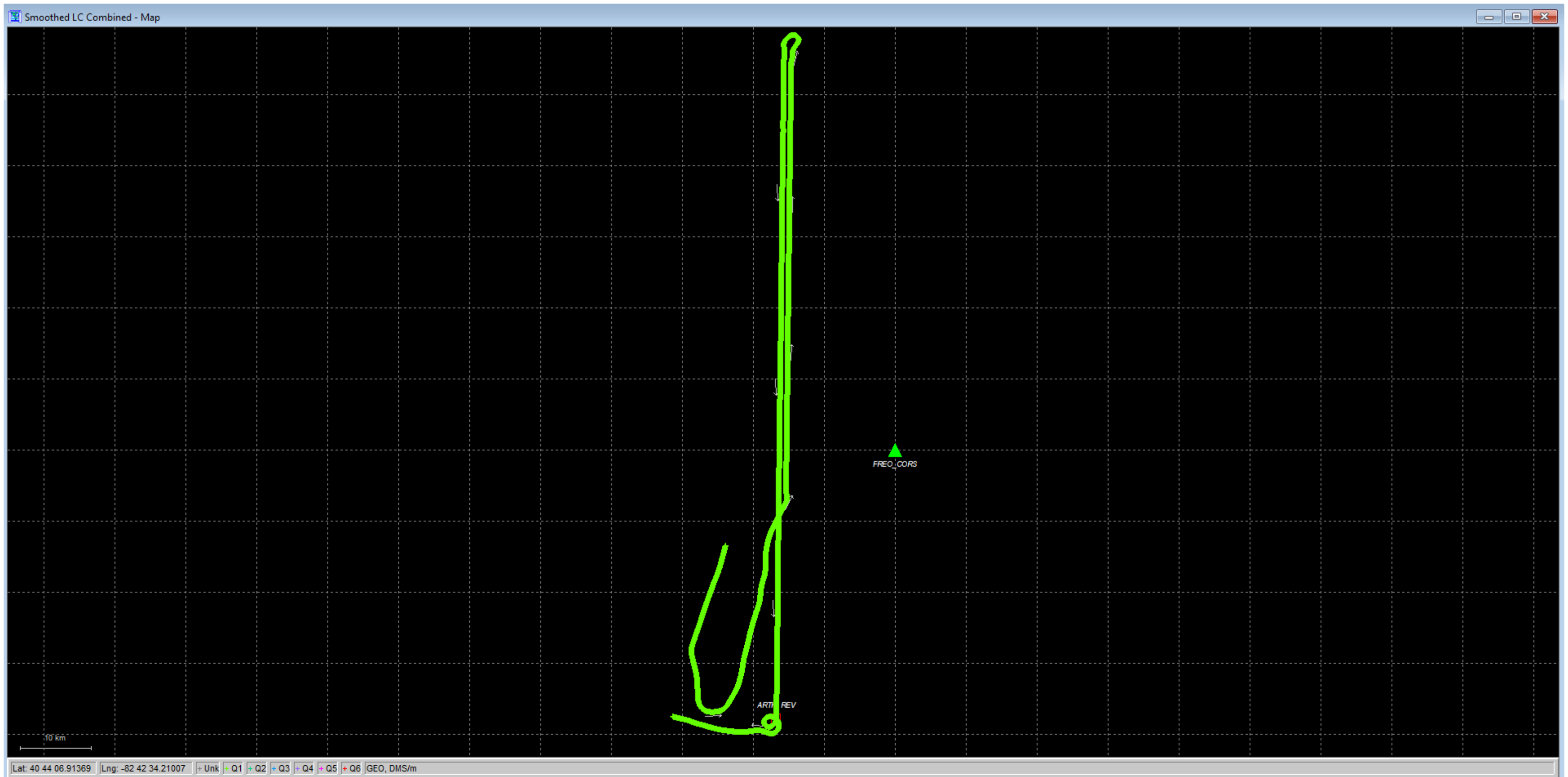
Day09421_TM557
Estimated Position Accuracy



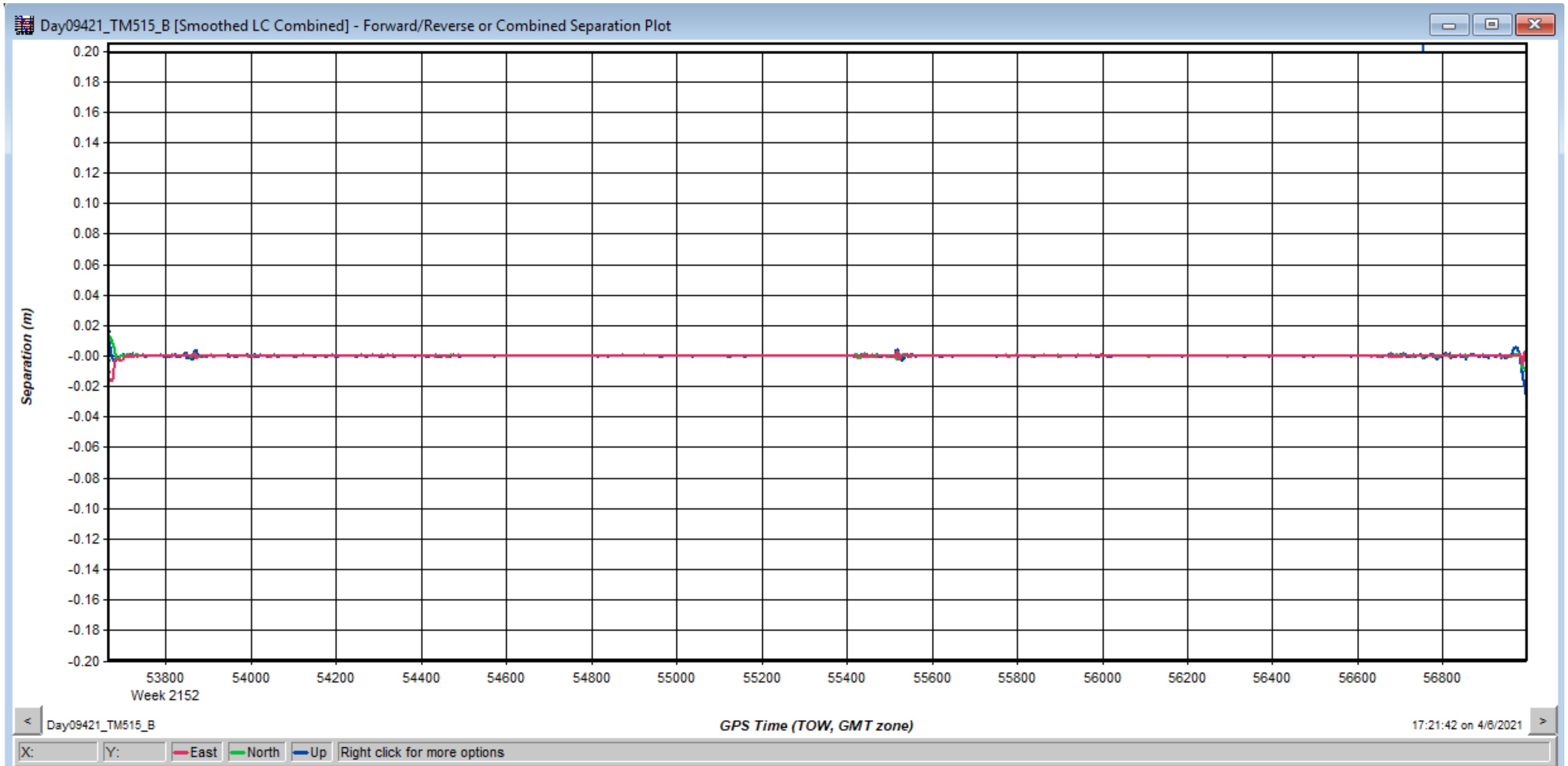
Day09421_TM557
PDOP Plot



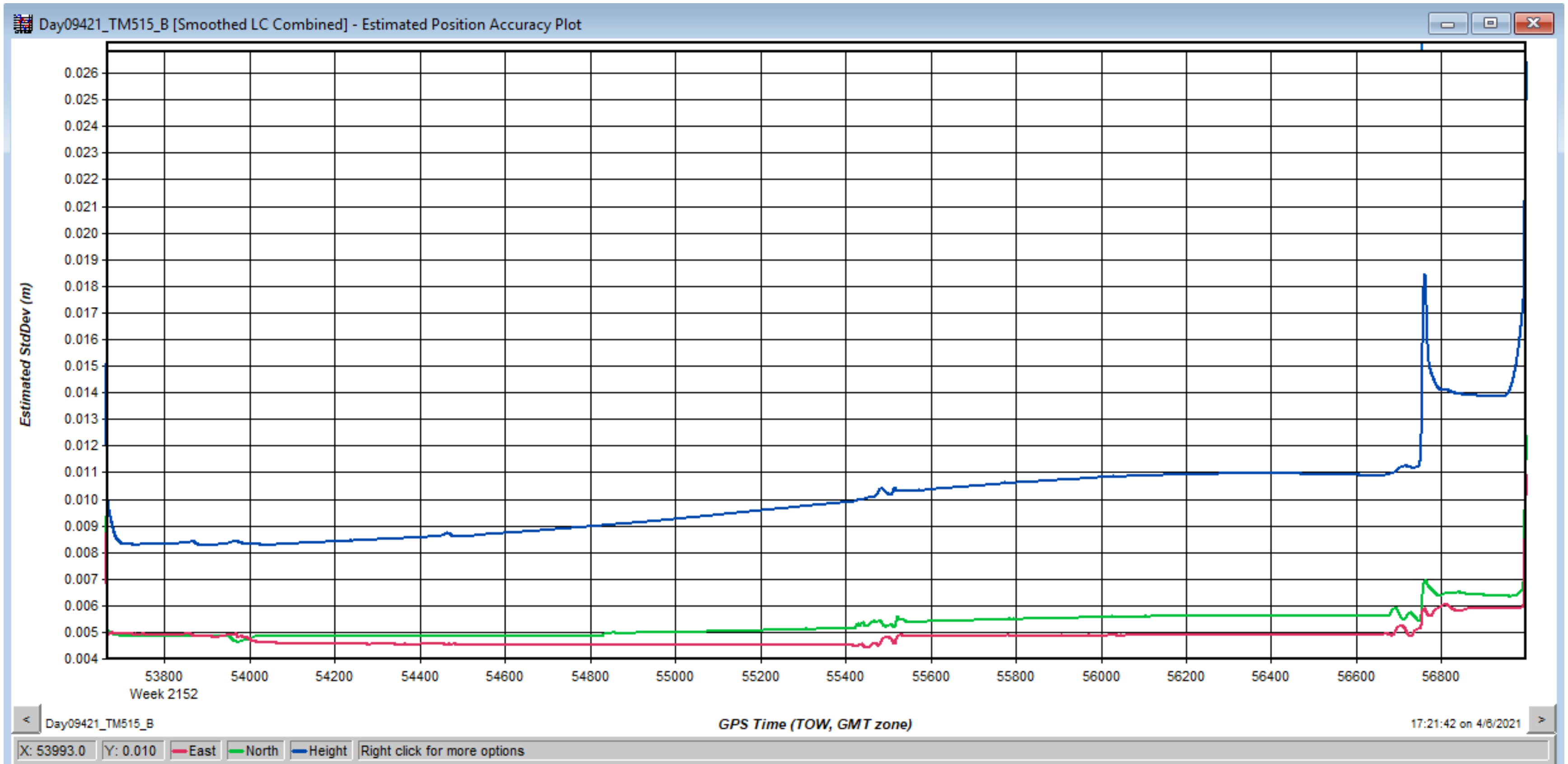
Day09421_TM515_B
Trajectory



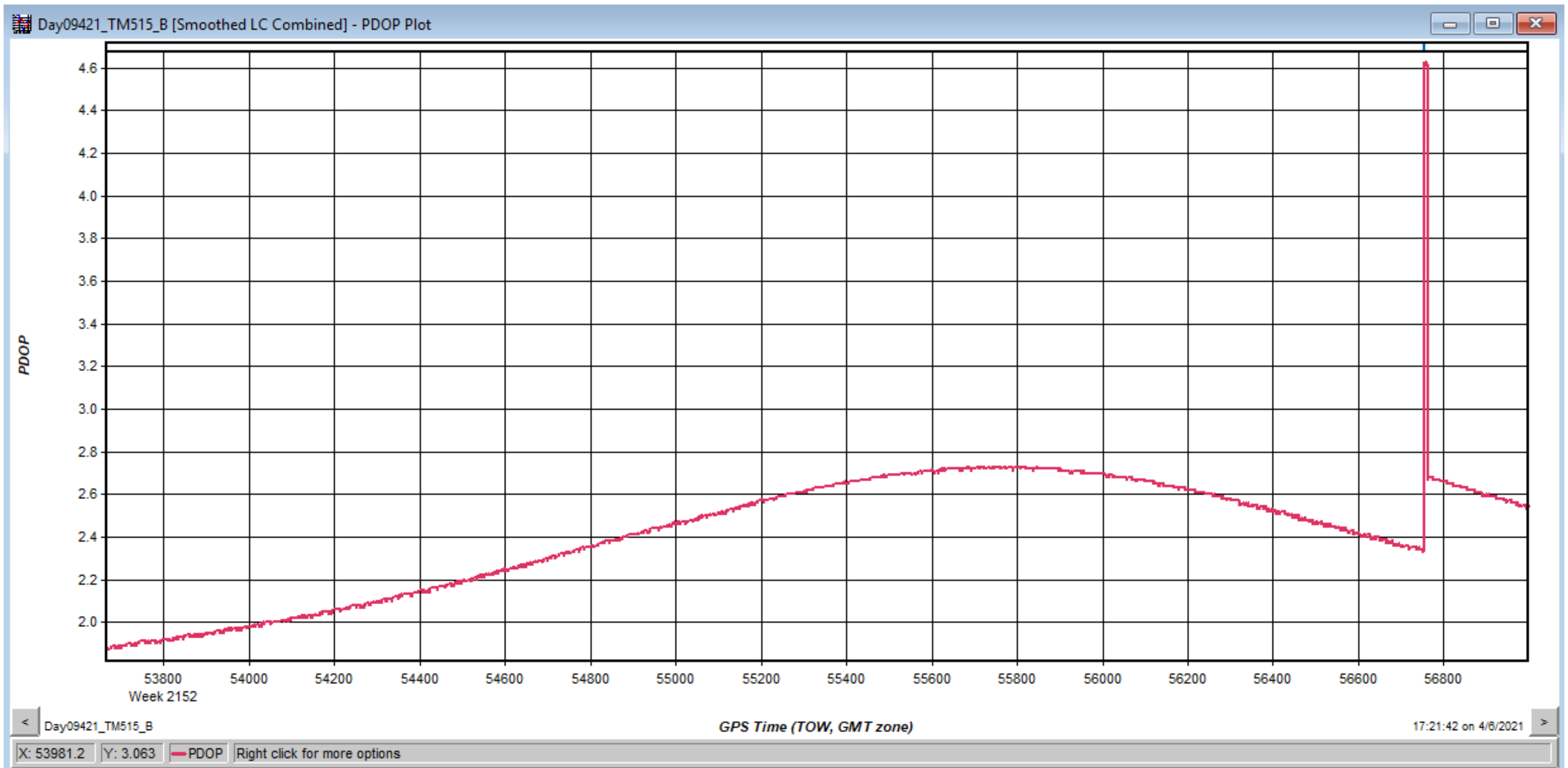
Day09421_TM515_B
Forward/Reverse or Combined Separation Plot



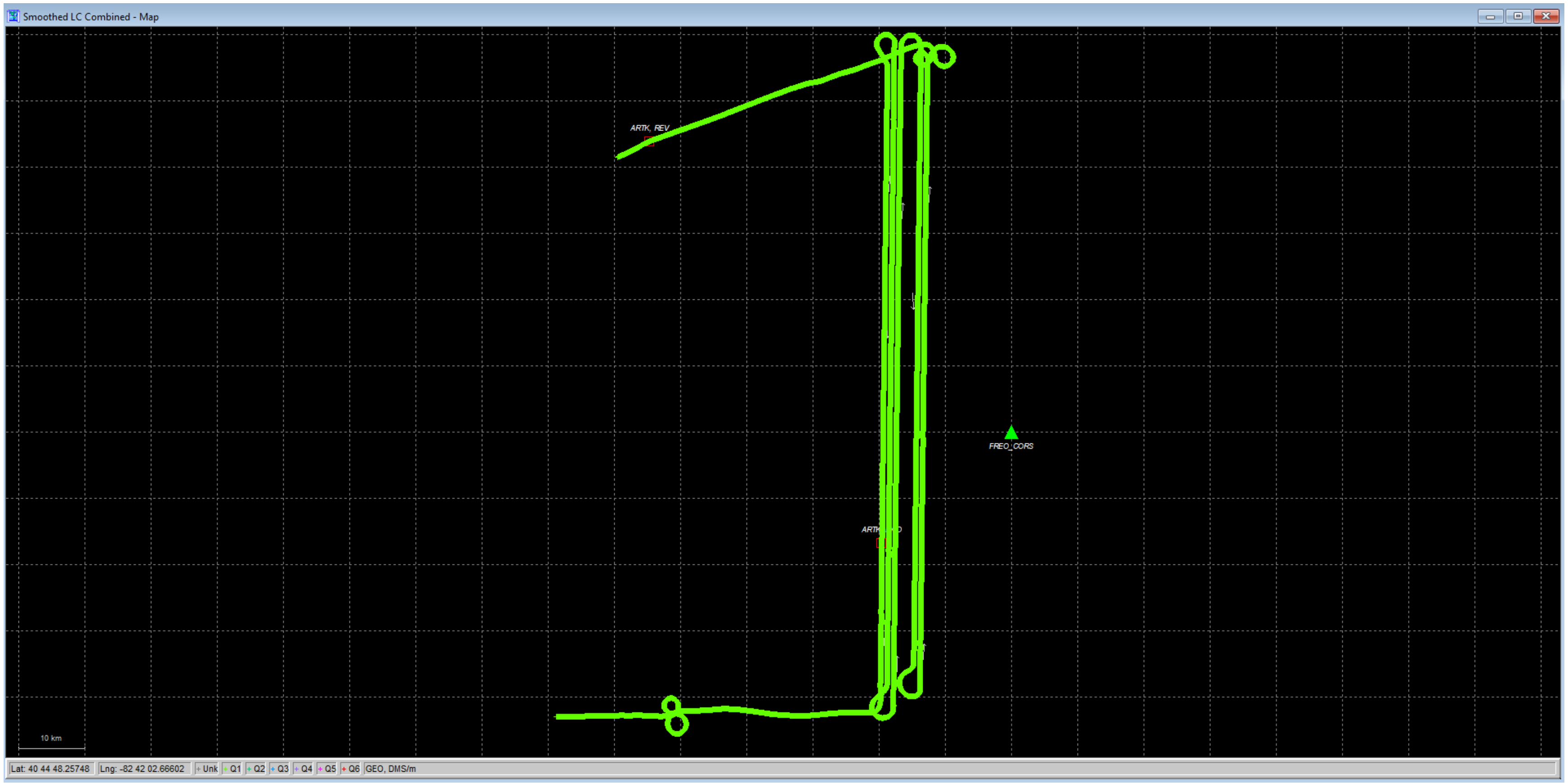
Day09421_TM515_B
Estimated Position Accuracy



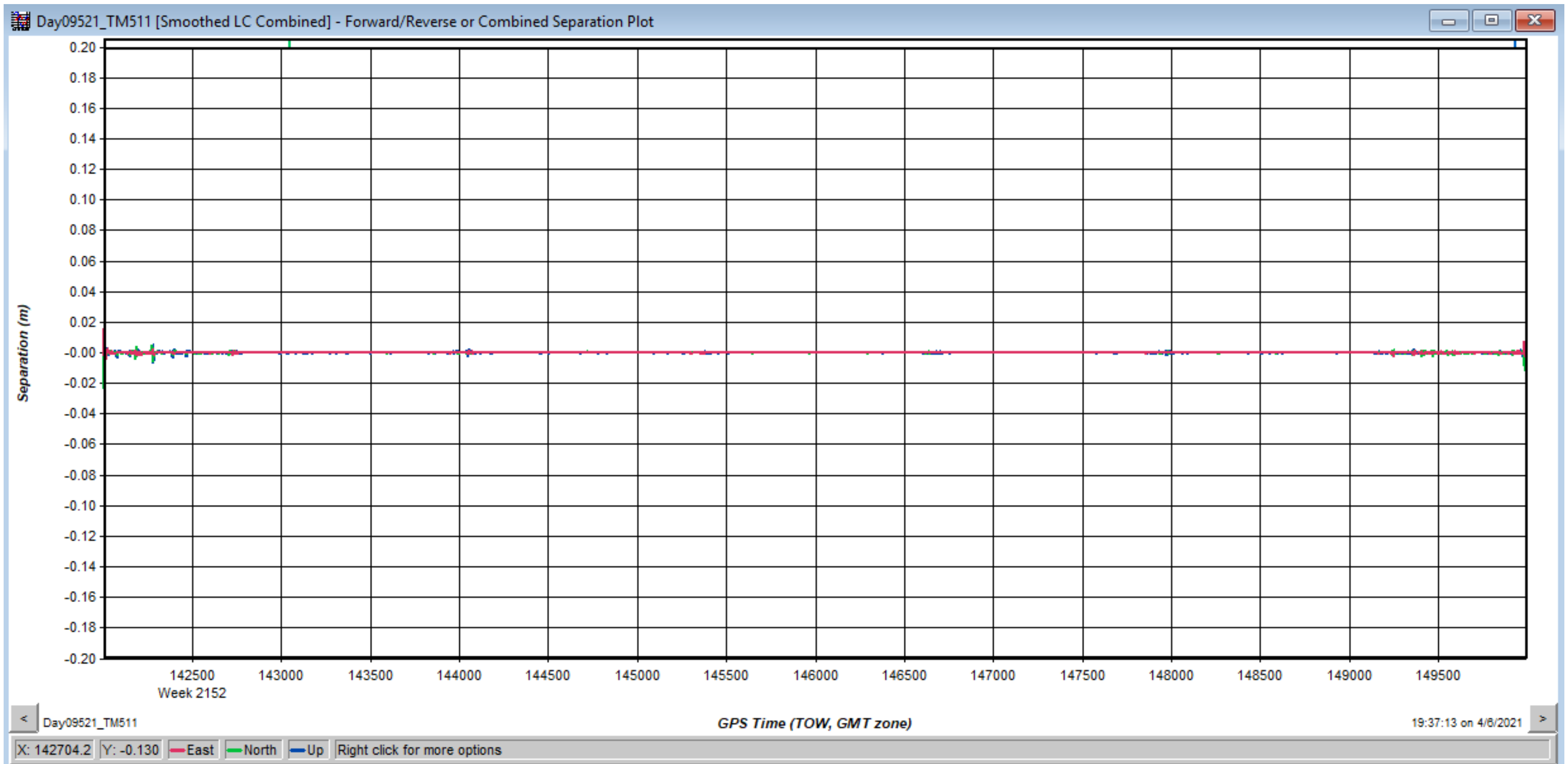
Day09421_TM515_B
PDOP Plot



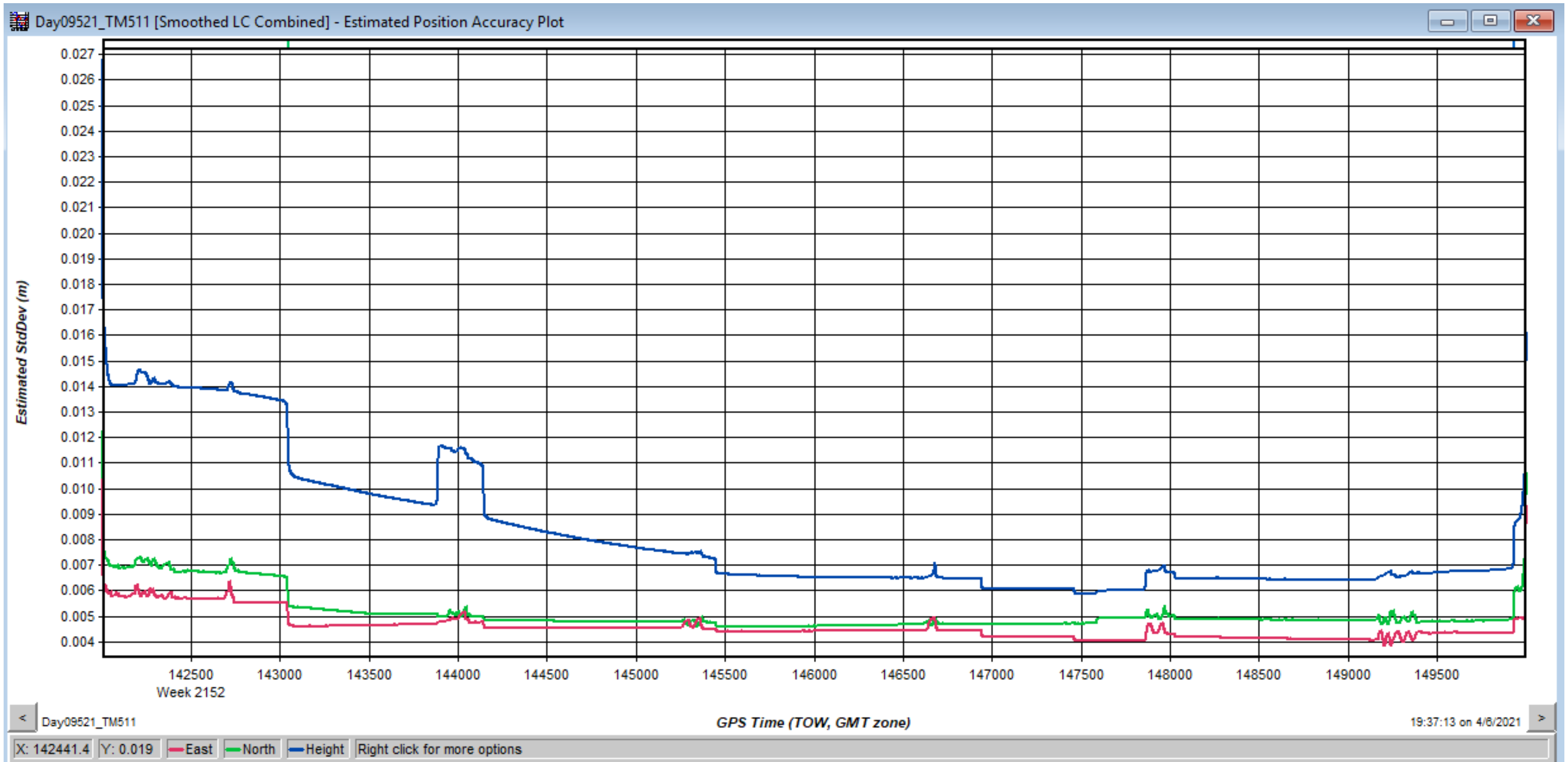
Day09521_TM511
Trajectory



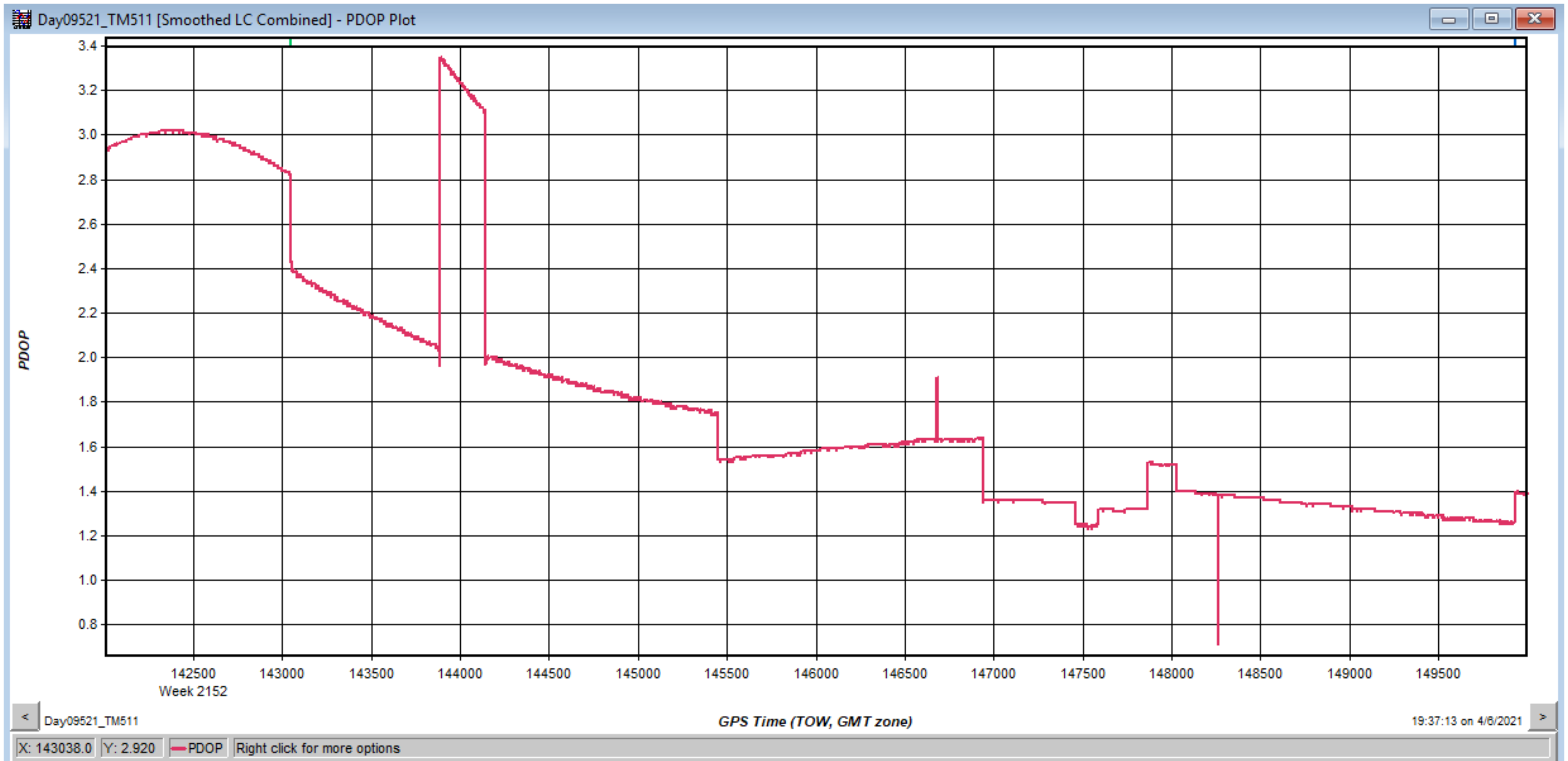
Day09521_TM511
Forward/Reverse or Combined Separation Plot



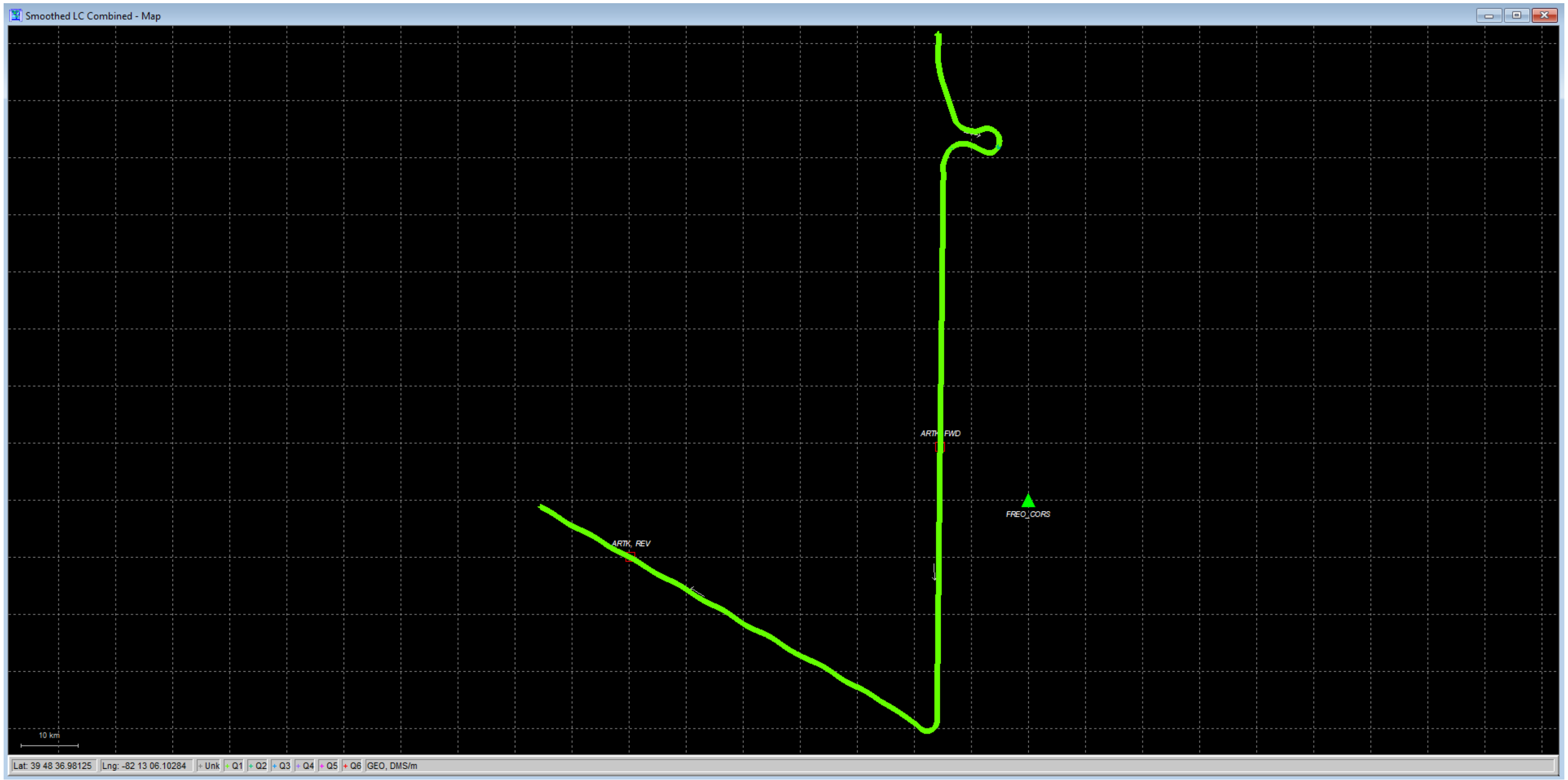
Day09521_TM511
Estimated Position Accuracy



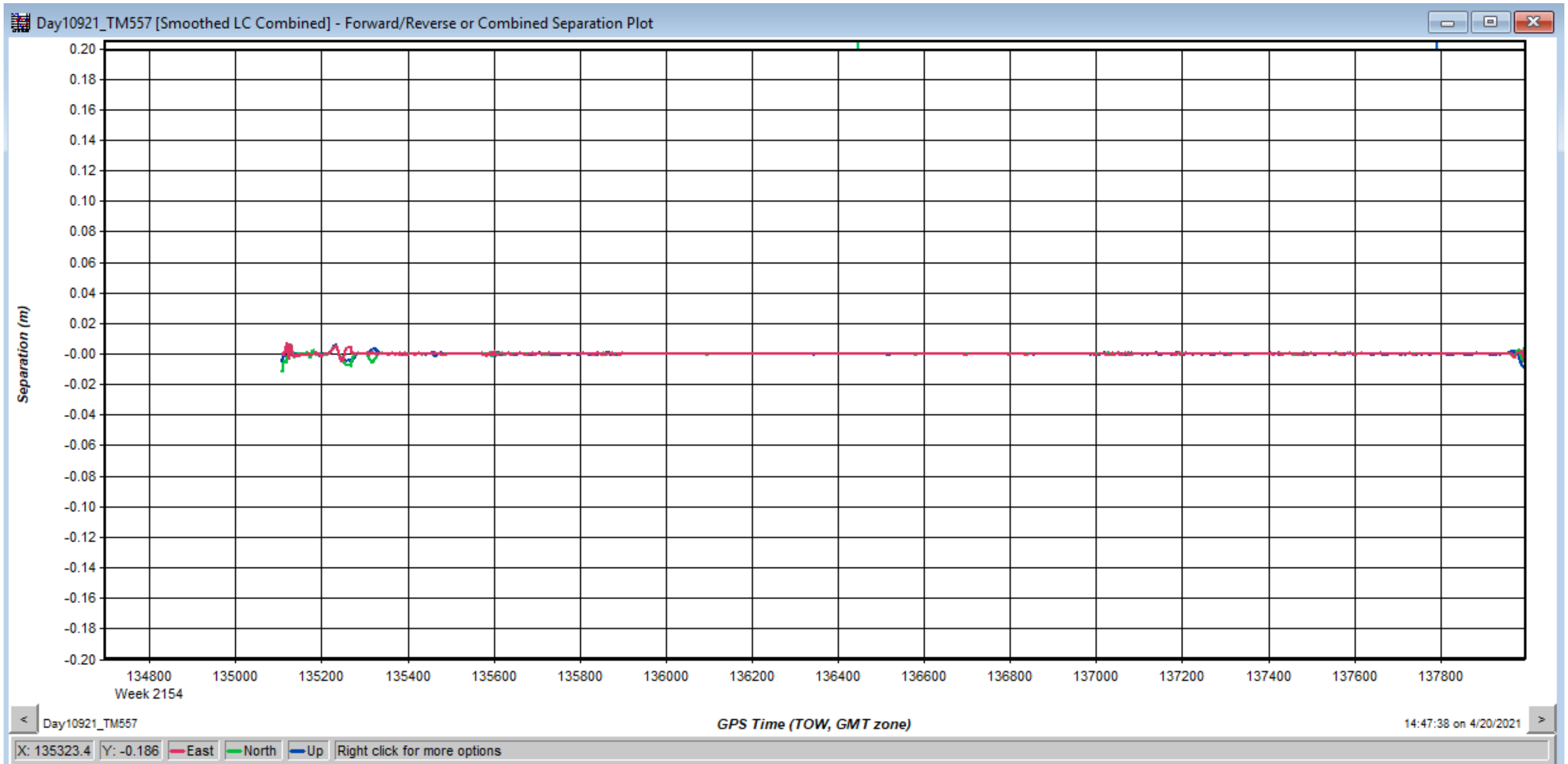
Day09521_TM511
PDOP Plot



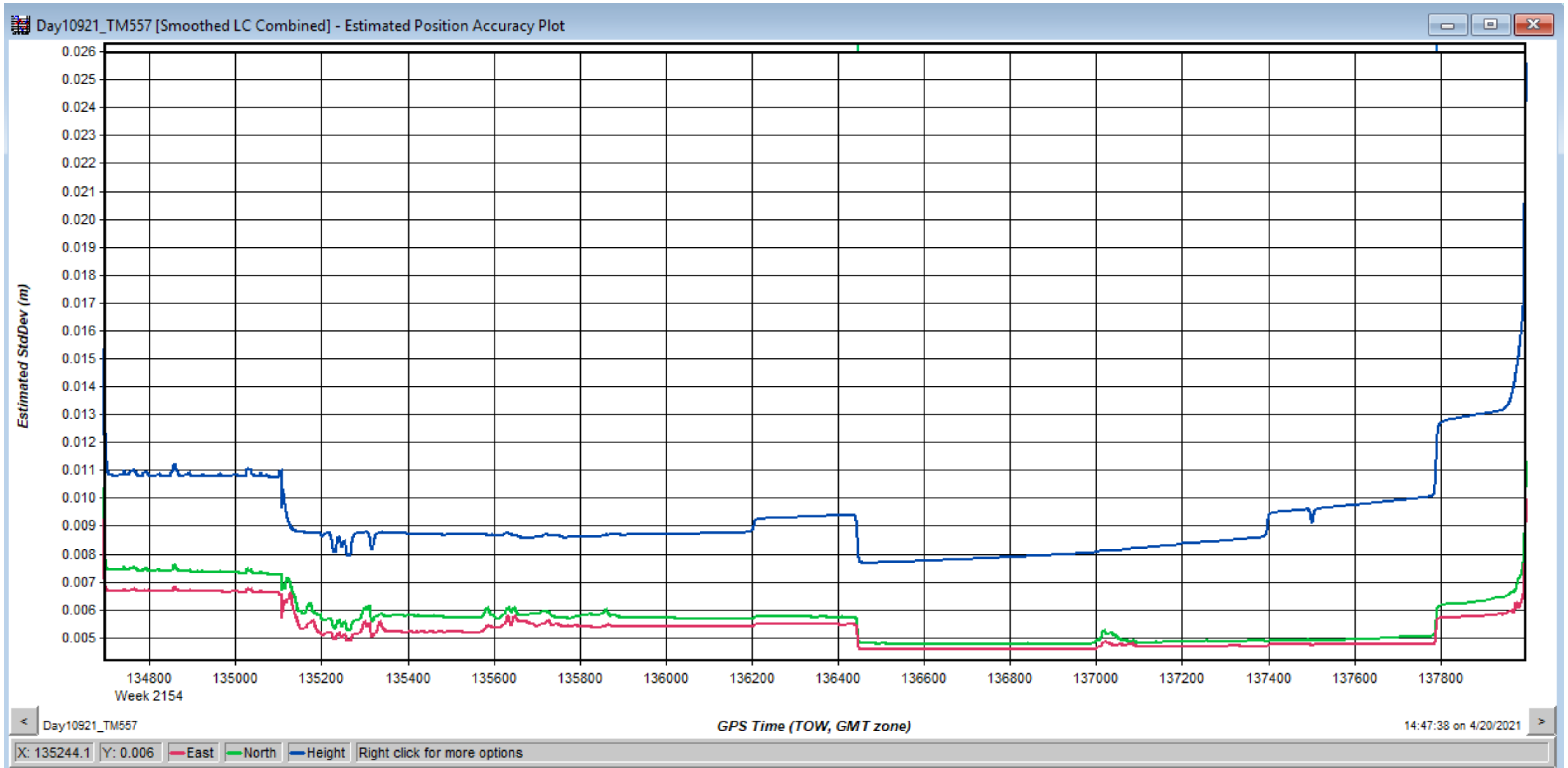
Day10921_TM557
Trajectory



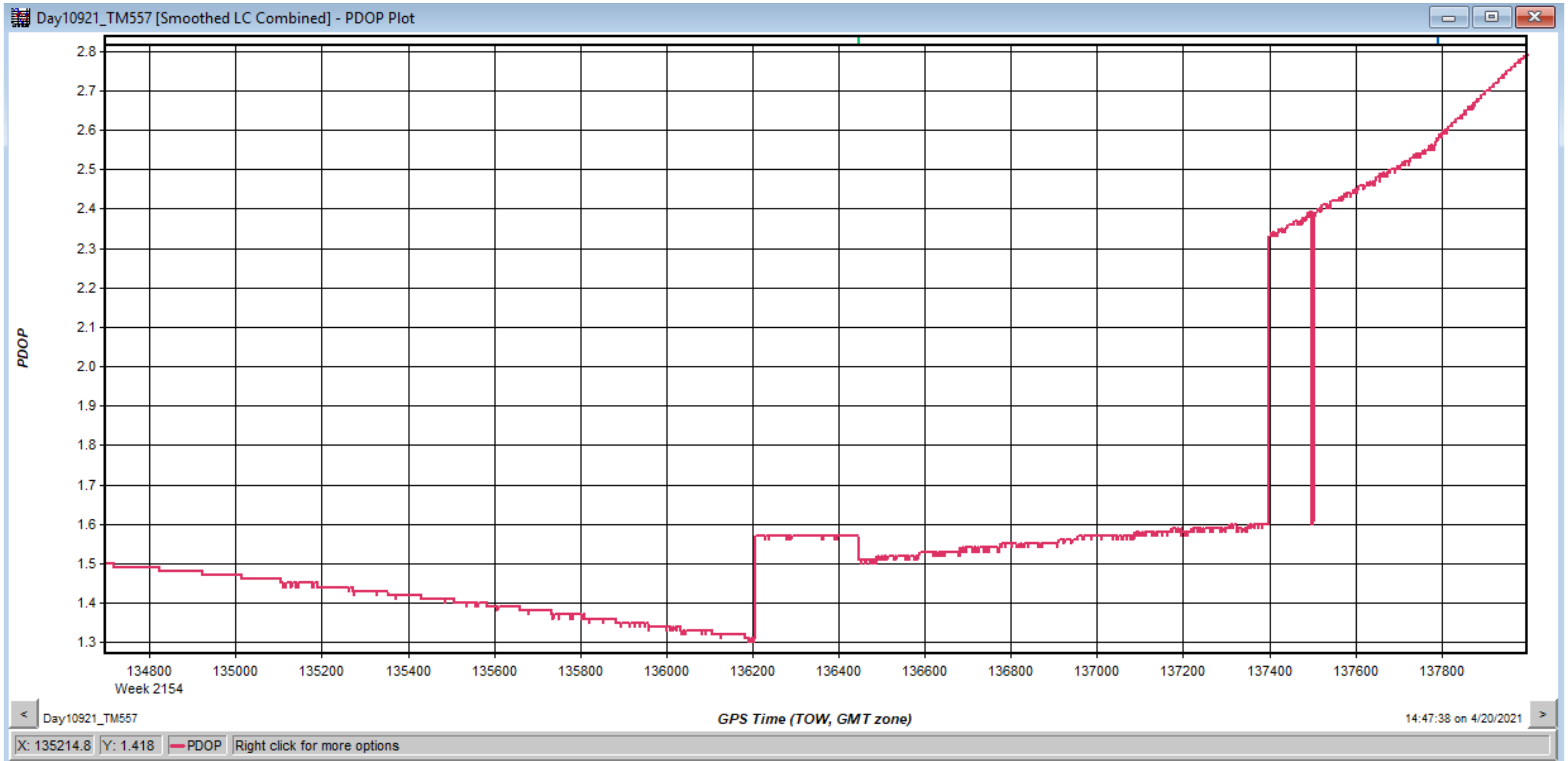
Day10921_TM557
Forward/Reverse or Combined Separation Plot



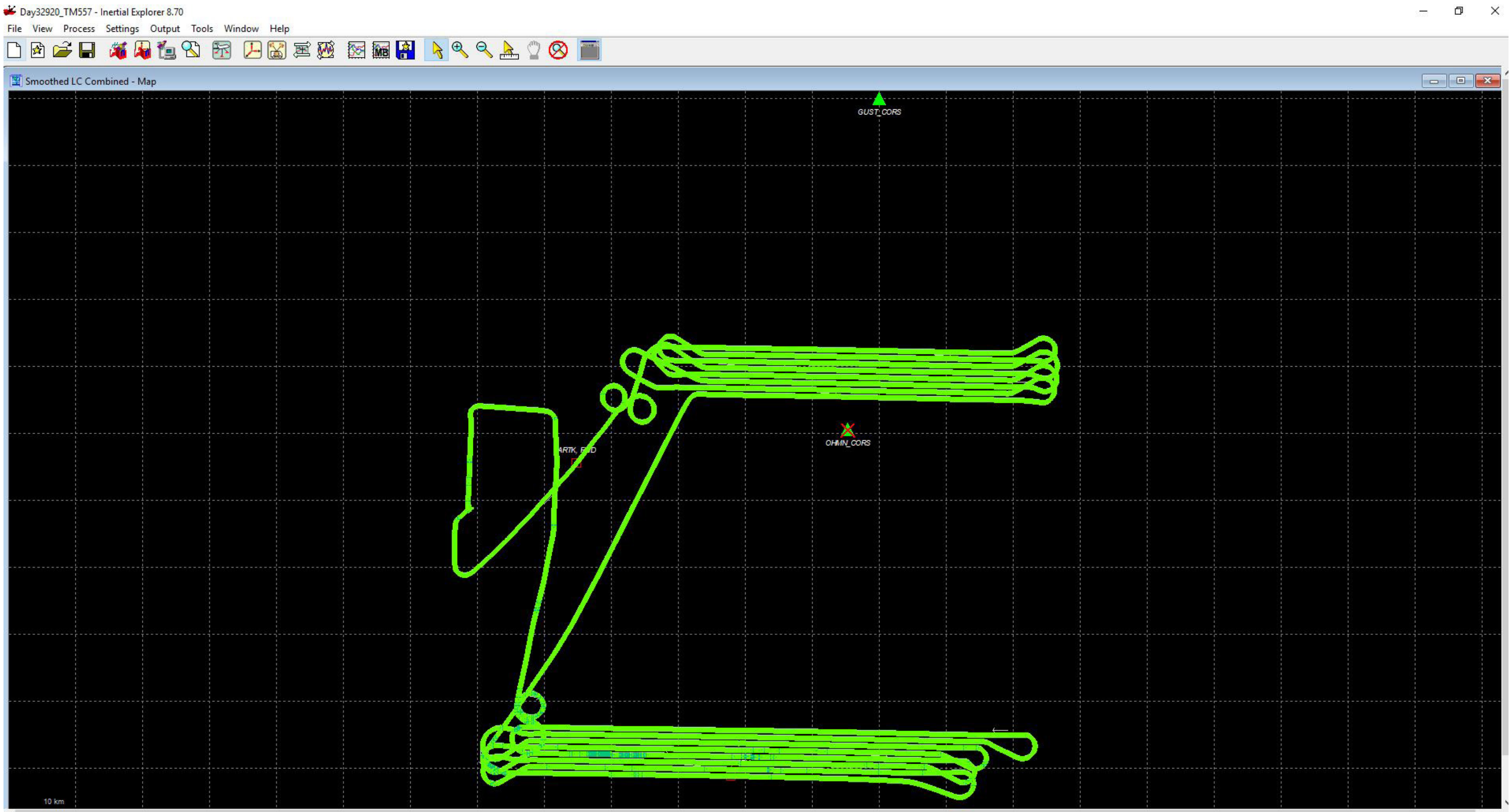
Day10921_TM557
Estimated Position Accuracy



Day10921_TM557
PDOP Plot

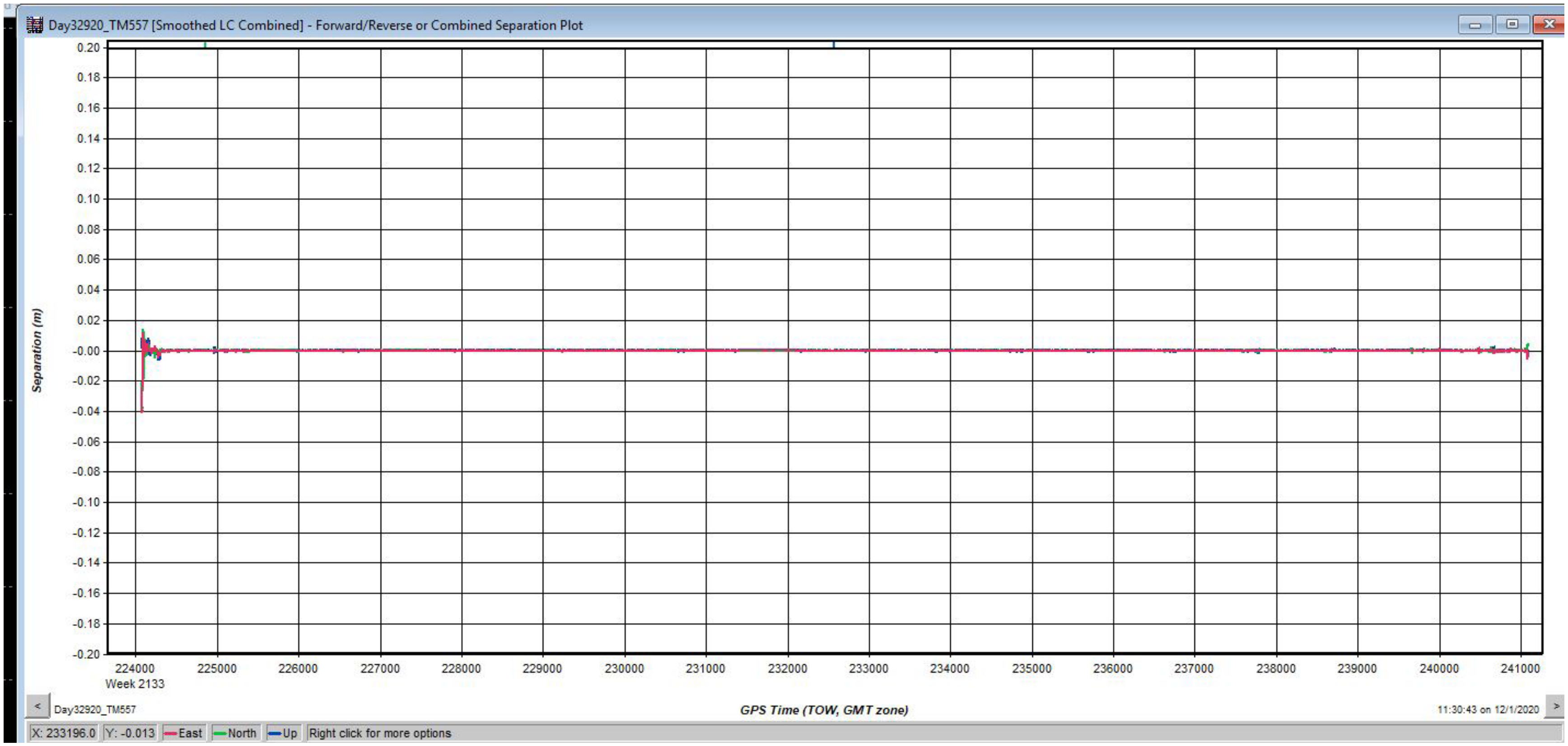


Day32920_TM557
Trajectory

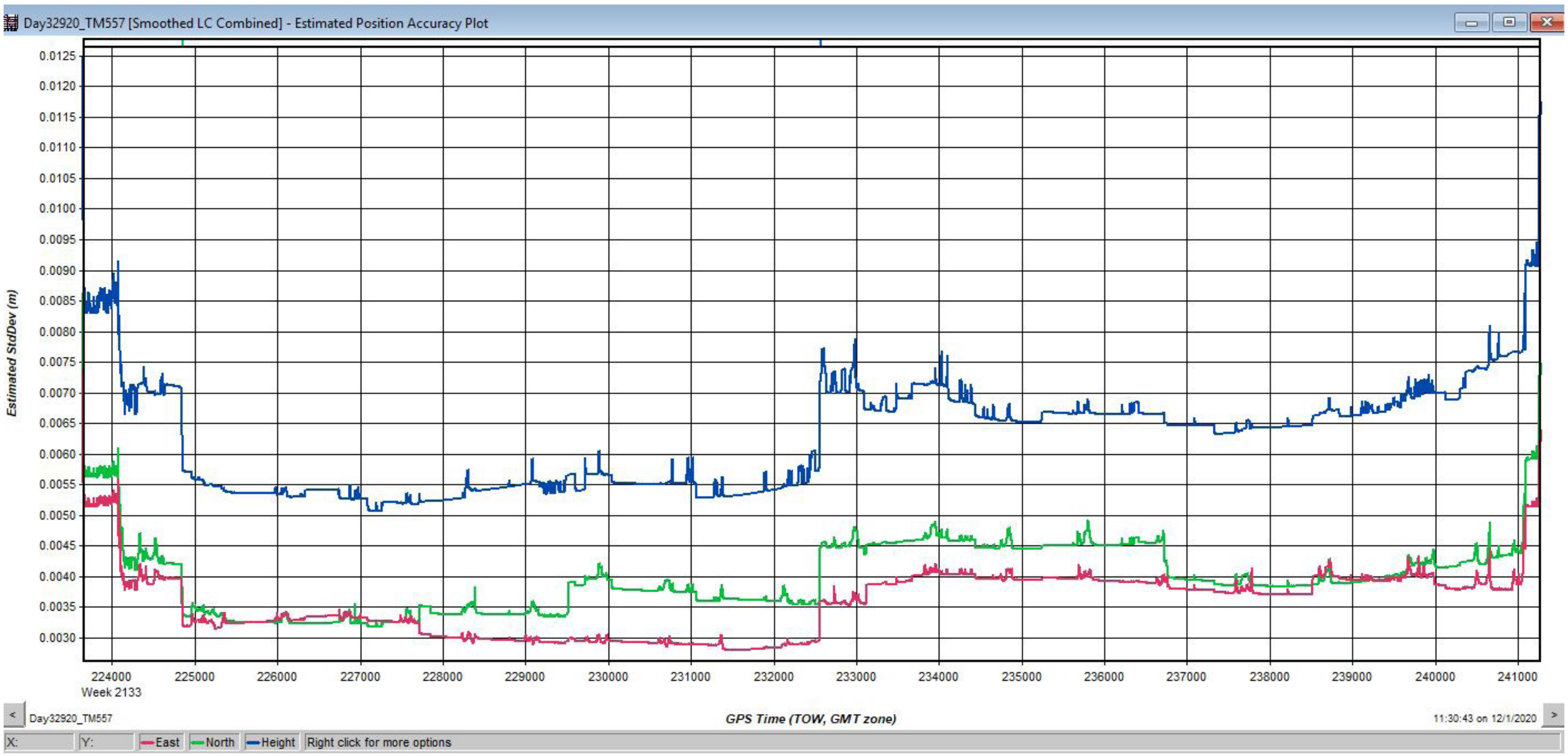


Day32920_TM557

Forward/Reverse or Combined Separation Plot



Day32920_TM557
Estimated Position Accuracy



Day32920_TM557
PDOP Plot