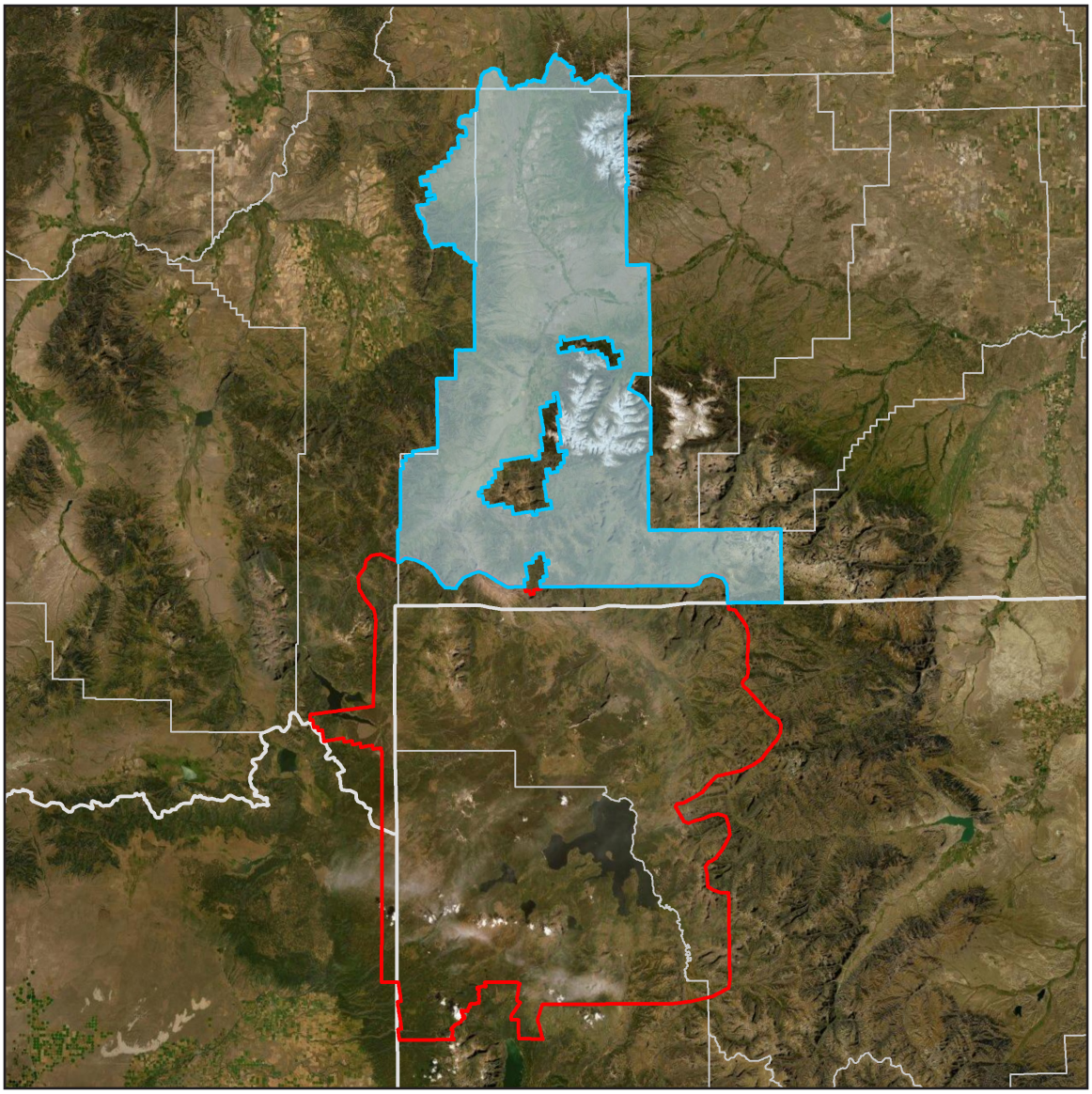
WY Yellowstone NP 2020 D20

Lidar Mapping Report
Work Unit WY Yellowstone NP 1 2020 - 196955

April 2021



Contract # G16PC00022
Task Order # 140G0220F0199

Contractor Woolpert
Project # 81200

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1. Overview

About

This project contains a comprehensive outline of the 140G0220F0199 WY Yellowstone NP2020 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 and QL1 data over two areas of interest covering approximately 6,549 square miles in Yellowstone National Park and Park County, Montana (Figure 1-1).

This report encompasses the Work Unit 196955 area of interest (Figure 1-2). This AOI totals approximately 2,632 square miles and includes the following counties in Montana:

- Gallatin
- Meagher
- Park

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 Assessment and Planning (MAP) program.

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**	6341
	Datum	NAD83 (2011)
	Projection	UTM Zone 12
	Units	Meters
Vertical	**Datum**	NAVD88
	Geoid	GEOID18
	Units	Meters
	Height Type	Orthometric

Figure 1-1. Project Area

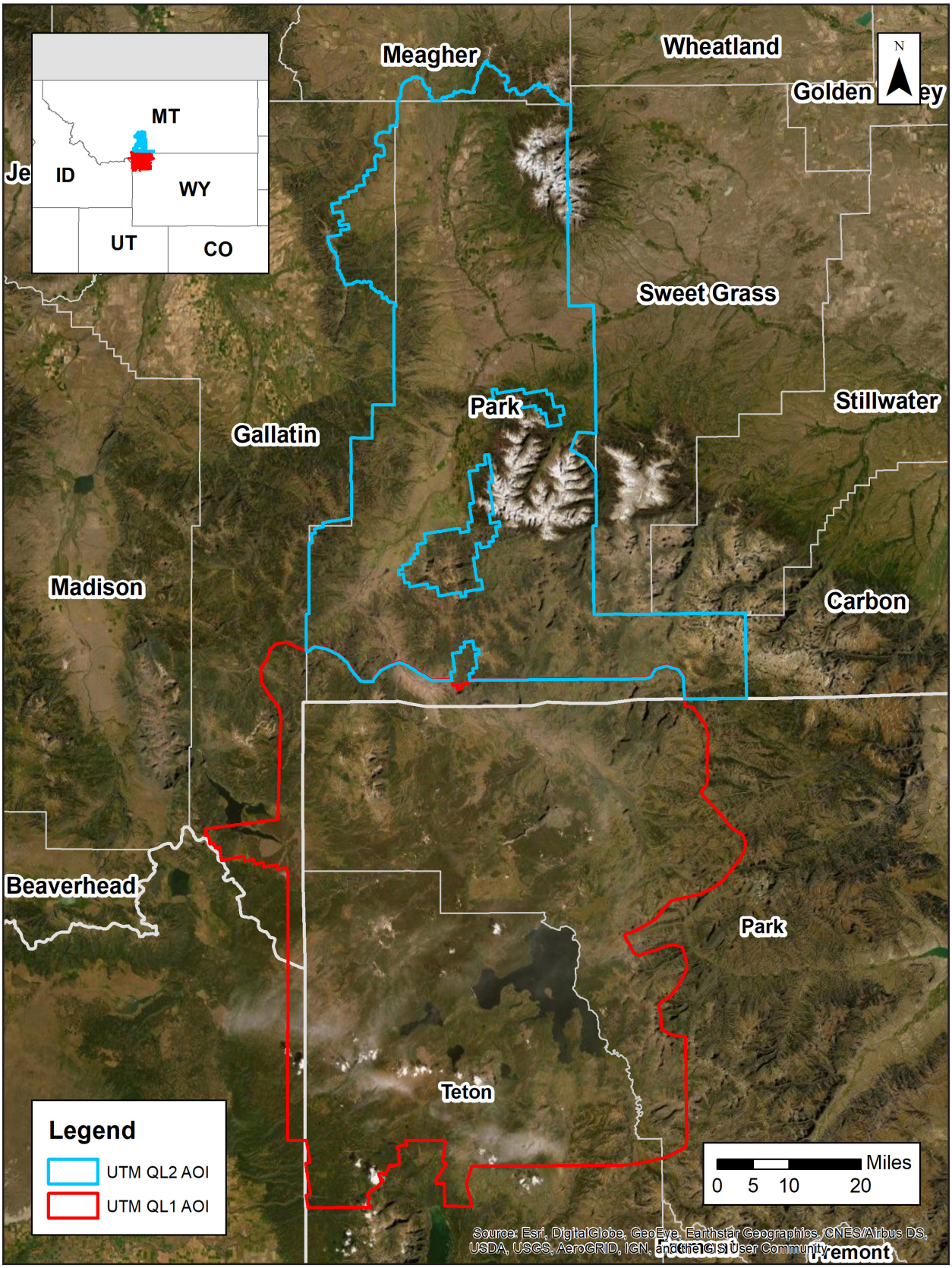
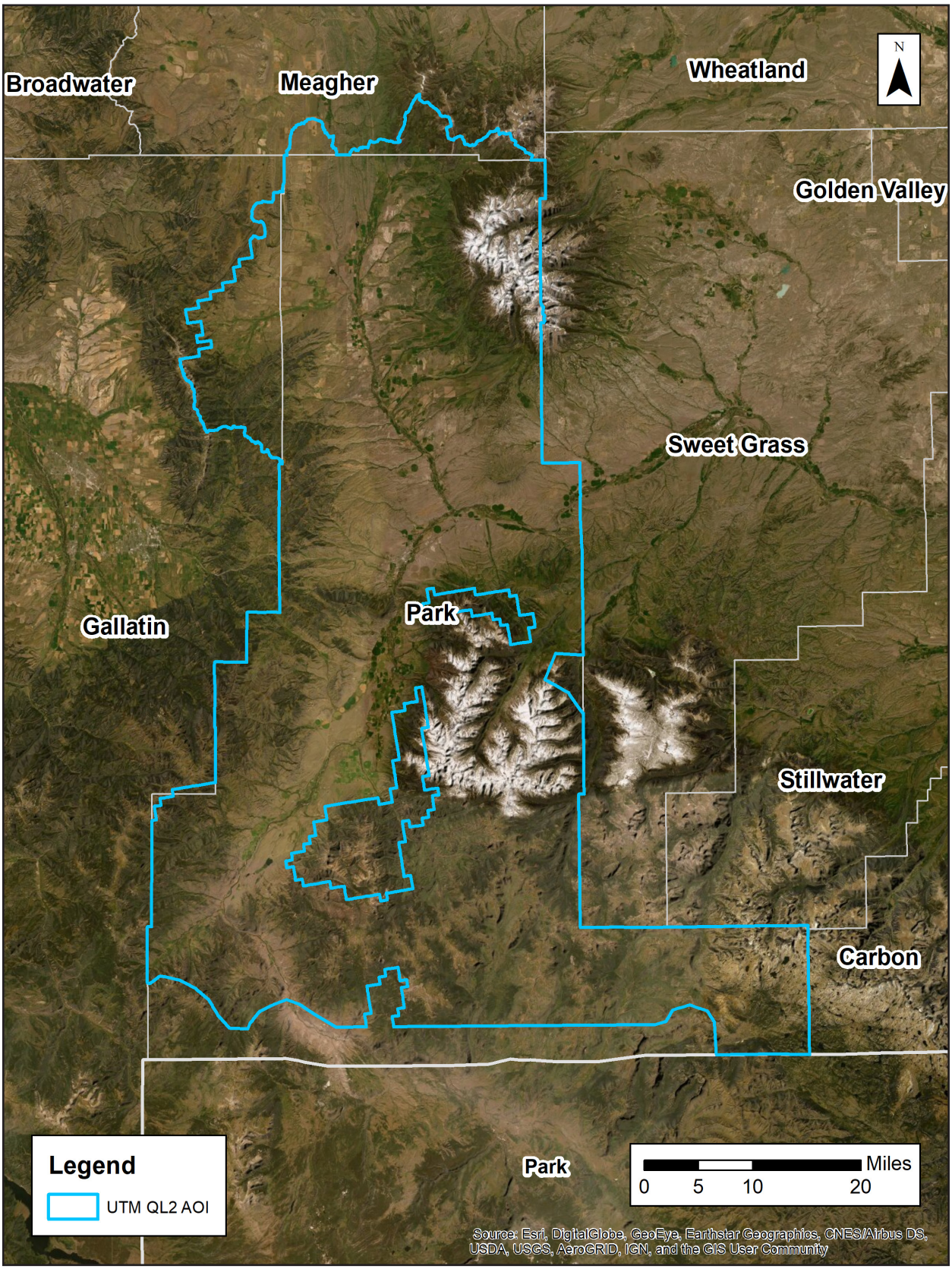


Figure 1-2. Project Area - Work Unit 196955



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-meter x 1,000-meters. Tile names are derived from the US National Grid.

Example: 12TVQ960940

This delivery's tiled dataset contains a total of 7,208 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 • 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
Vertical Accuracy Data	
Ground control survey report	Survey report in PDF format
Calibration control points	Esri shapefile format
NVA and VVA checkpoints	Esri shapefile format
Interswath and intraswath test results	Esri shapefile format

Table 1-2: Deliverables (continued)

Spatial Metadata	
Data extent	Esri shapefile format
Tile index	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 surface height rasters	1-meter pixel size, 32-bit floating point, GeoTIFF format
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	• 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	During period of annual minimal water level and minimal snow in the fall 2020 leaf-off window running through November 15, 2020
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:

- Leica TerrainMapper - serial numbers 511, 515, 557

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	Blocks 1- 3	Block 4
Max. Number of Returns	15	15
Nominal Point Spacing	0.71 m	0.71 m
Nominal Point Density	2 ppsm	2 ppsm
Flying Height Above Ground Level	3,450 m	3,250 m
Flight Speed	150 knots	150 knots
Scan Angle	40°	40°
Scan Rate Used	81 Hz	82 Hz
Pulse Rate Used	670 kHz	650 kHz
Multi-Pulse in Air	Enabled	Enabled
Swath Width	2,511 m	2,366 m
Swath Overlap	25%	25%

Timeline

Lidar data was collected rom September 13, 2020 through October 9, 2020. A total of 158 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

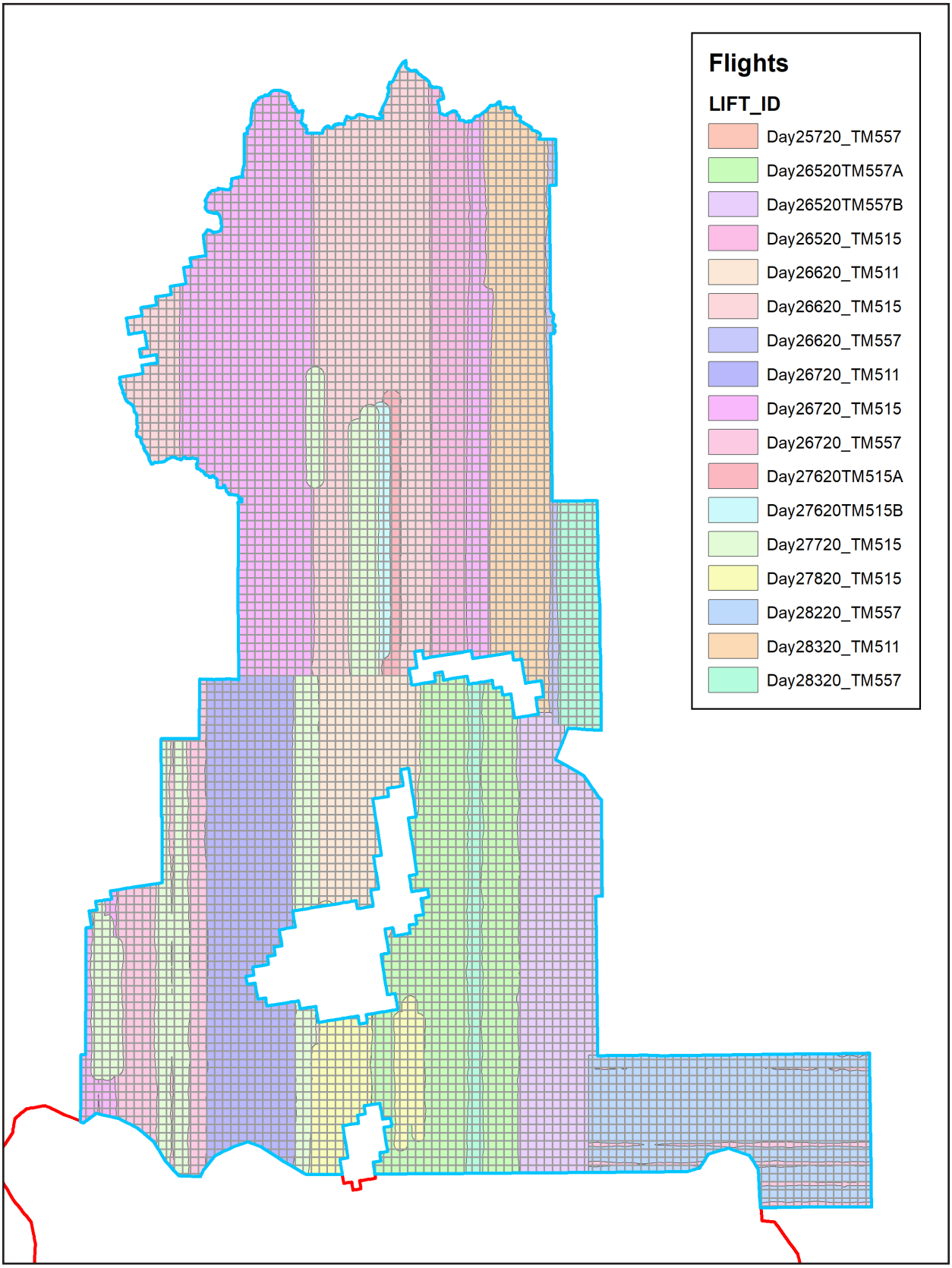


Table 2-4. GNSS Base Stations

Station Name	Longitude (DMS)	Latitude (DMS)	Ellipsoid Height L1 Phase Center (Meters)
MTSU_CORS	45° 39' 40.37685"	111° 2' 42.00897"	1495.554

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 Report(s) 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.

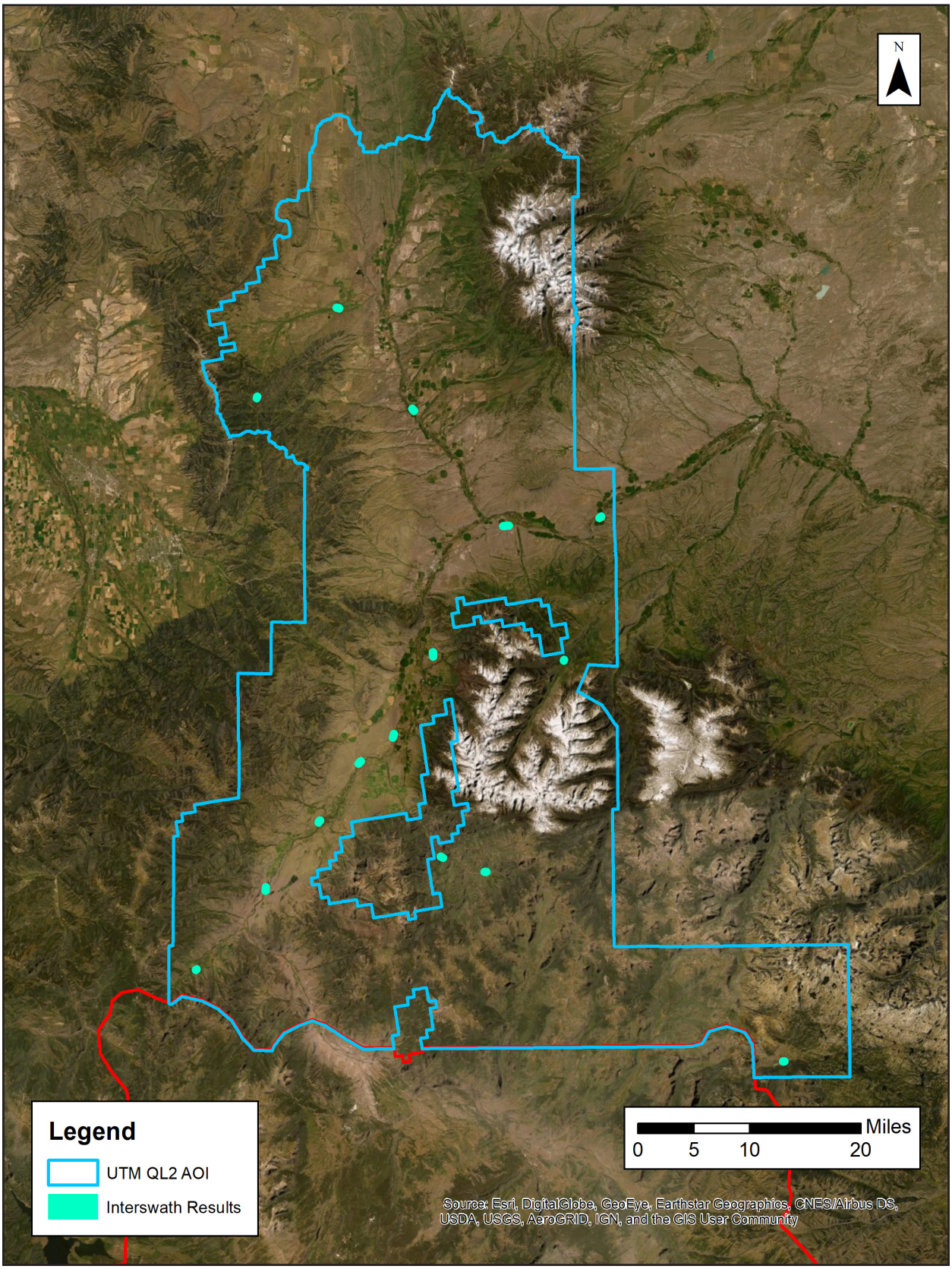
This project required the interswath accuracy to meet ≤ 8 cm RMSDz. Accuracy was assessed in accordance with the USGS Base Specification v2020 revision A.

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)
-0.031	0.056	0.024
-0.035	0.097	0.038
-0.064	0.008	0.031
-0.051	0.050	0.019
-0.092	0.053	0.025
-0.083	0.058	0.025
-0.023	0.058	0.023
-0.061	0.060	0.021
-0.035	0.038	0.017
-0.072	0.047	0.029
-0.035	0.048	0.018
-0.067	0.020	0.026
-0.039	0.036	0.017
-0.089	0.115	0.028
-0.064	0.087	0.025

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.

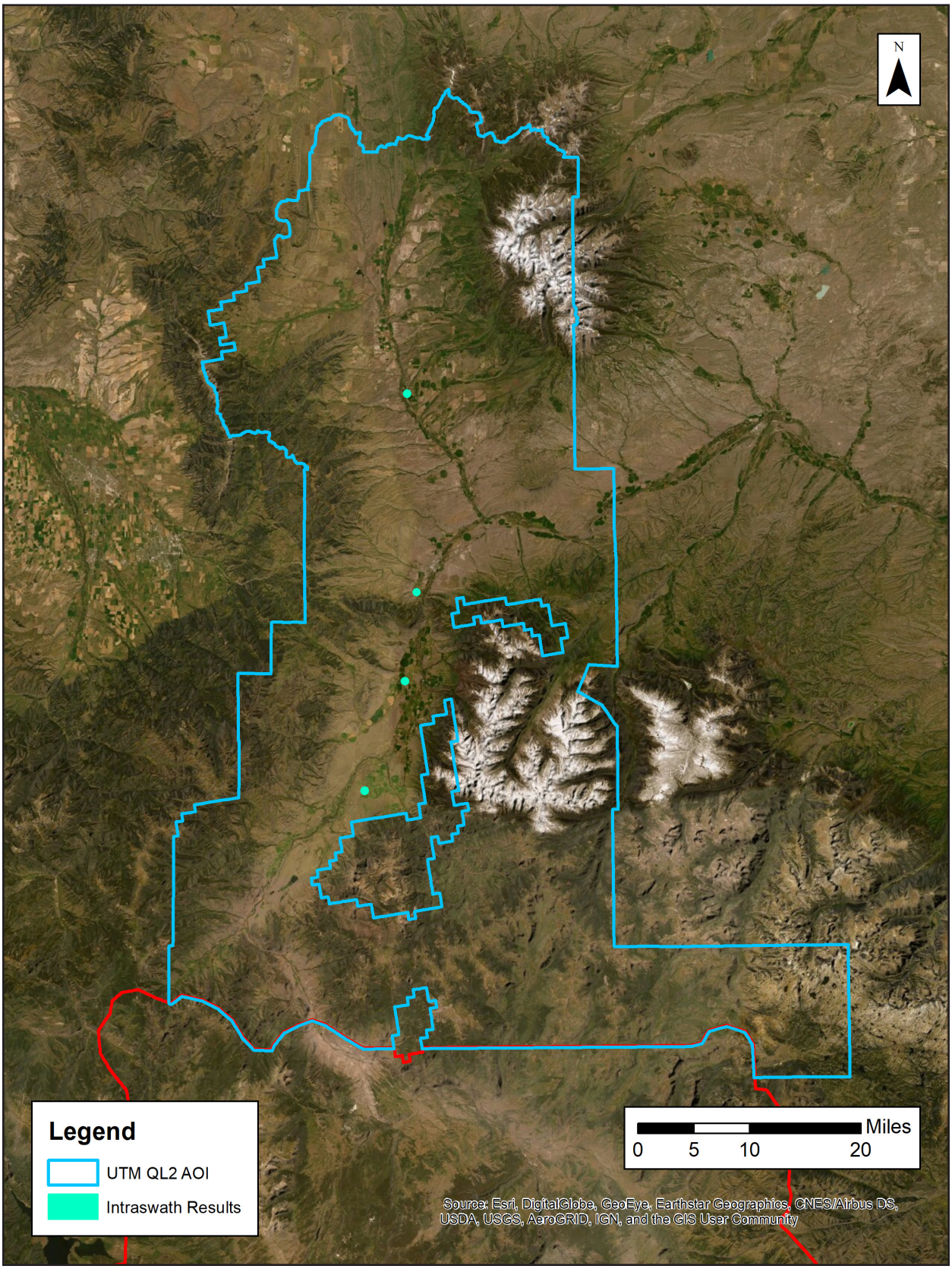
This project required the intraswath accuracy to meet ≤ 6 cm RMSDz. Accuracy was assessed in accordance with the USGS Base Specification v2020 revision A.

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)
1531.660	1531.880	0.036
1476.790	1477.470	0.026
1435.860	1436.020	0.027
1384.340	1384.830	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 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. 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, a 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 files. Files were clipped to the data extent.

Software: TerraScan v20, 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 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 0.249 cm RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 0.609 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	0.042 m RMSEz 0.082 m at 95% CL	125
VVA	0.217 at 95th Percentile	95

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	0.042 m RMSEz 0.082 m at 95% CL	113
VVA	0.205 at 95th Percentile	78

Appendix 1: Sensor Calibration Report

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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

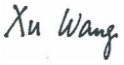
1. System Components

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	
Position	Production Manager		
Name	Robert Bosch	23.05.2019	
Position	Support Engineer		
Name	Michael Vetter	03.07.2019	
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	-0.138877	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

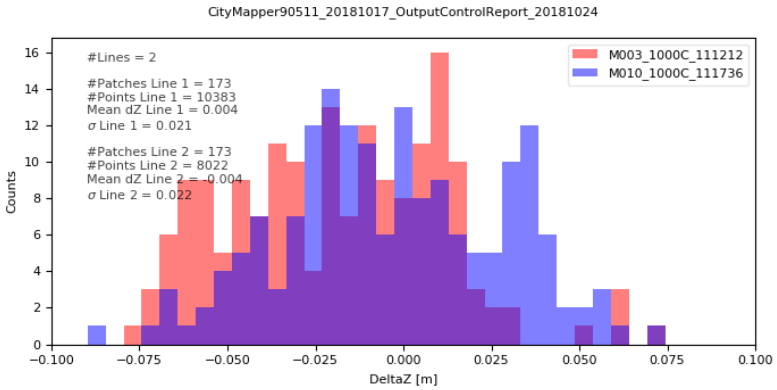
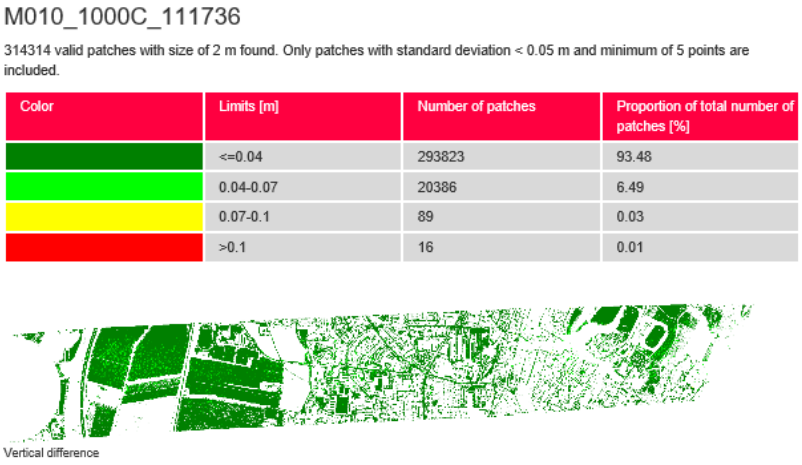


Figure 1 Vertical distance to ground control points at 1000 m AGL.

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

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

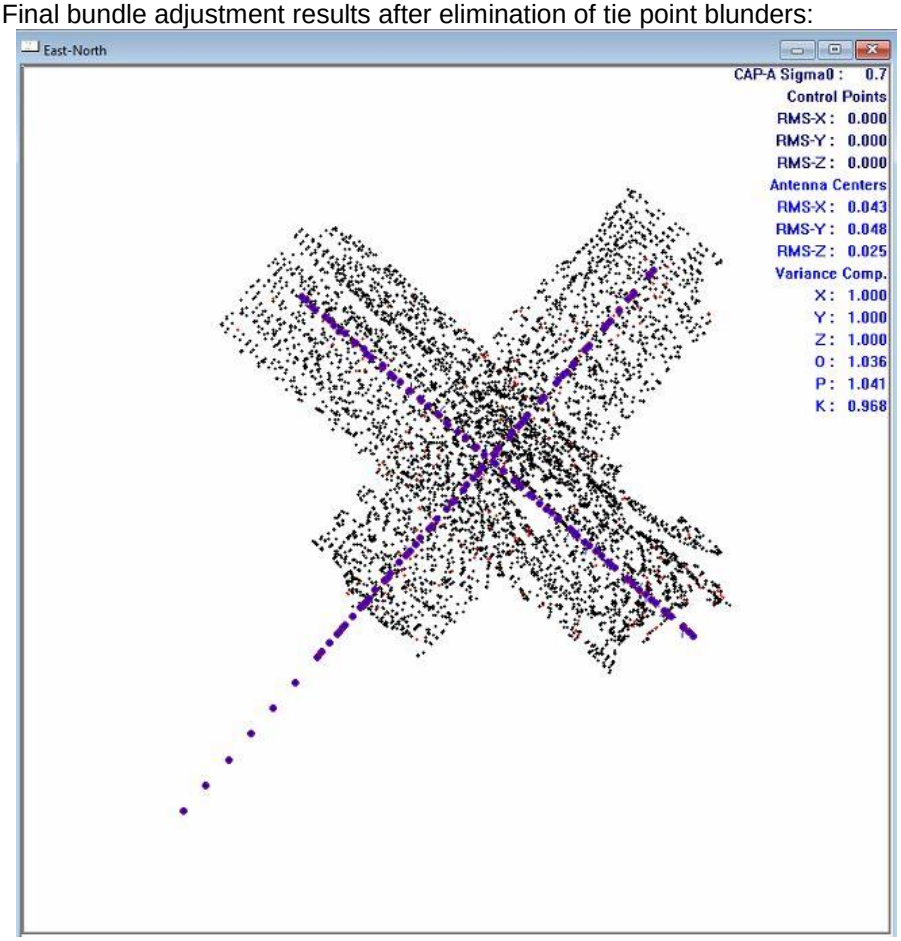
6.2 Results of Geometric Calibration

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

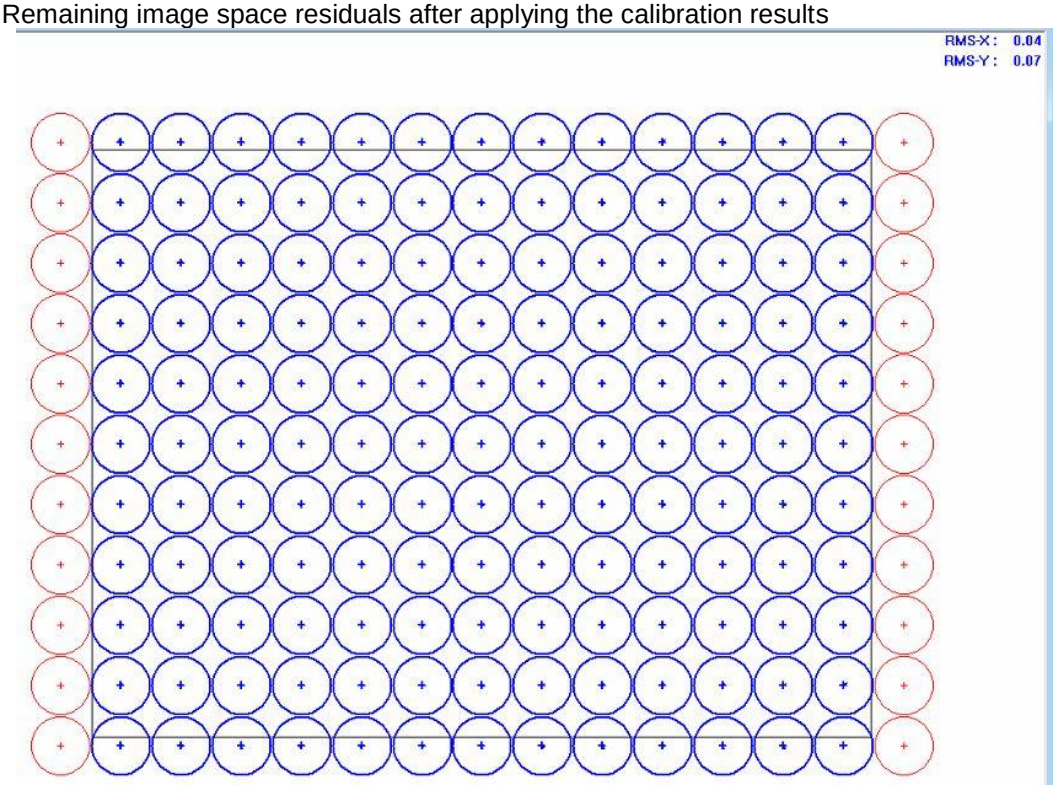
		Component	Serial Number
Camera Head		CH82	82659
Lens		NAT-D 2.8/80	80254
View Direction in Pod Position		Nadir	
IMU Misalignment		**Angle** [degree]	
	ω	-0.00815	
	Φ	0.00028	
	κ	-0.26654	
Principal Point		**Distance** [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		**Distance** [mm]	
	c	83.00	

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

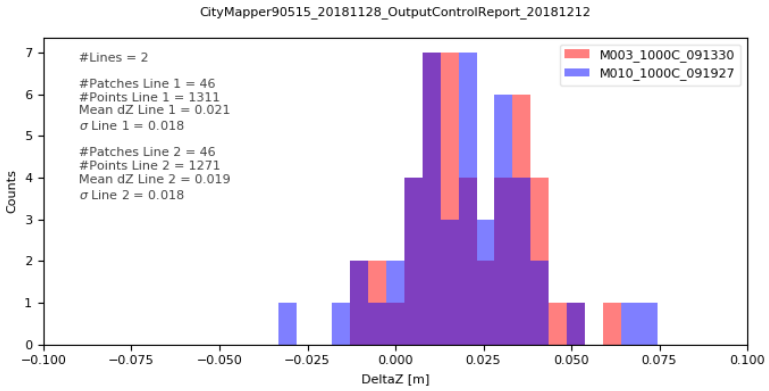


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

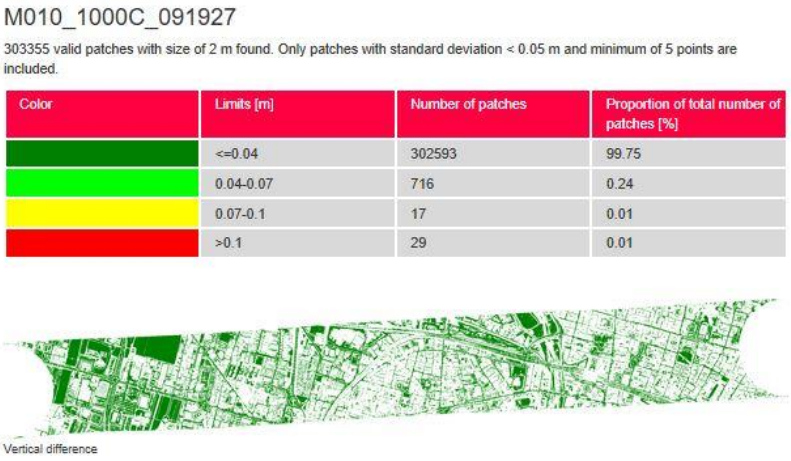


Figure 2 Vertical difference betweeen forward and backward scan at 1000 m AGL.

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.

- 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
CH-9435 Heerbrugg
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

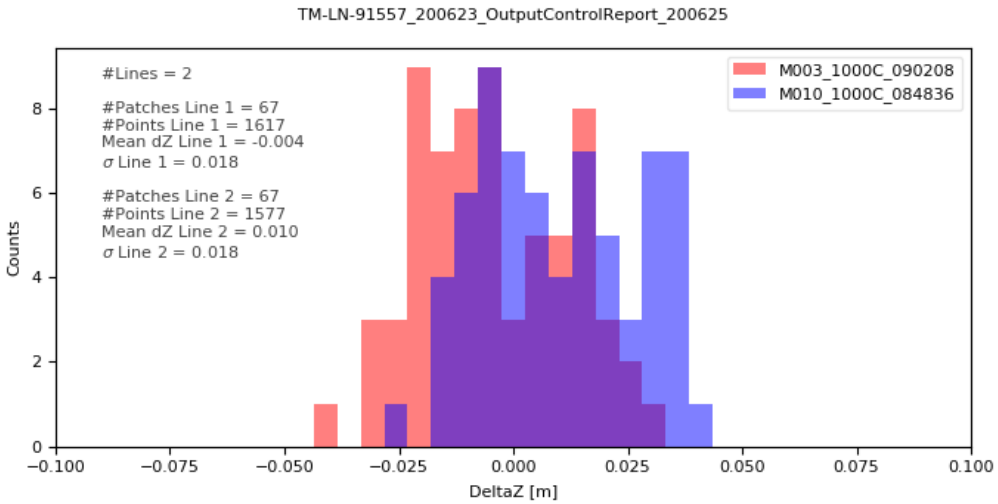


Figure 1 Vertical distance to ground control points at 1000 m AGL.

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

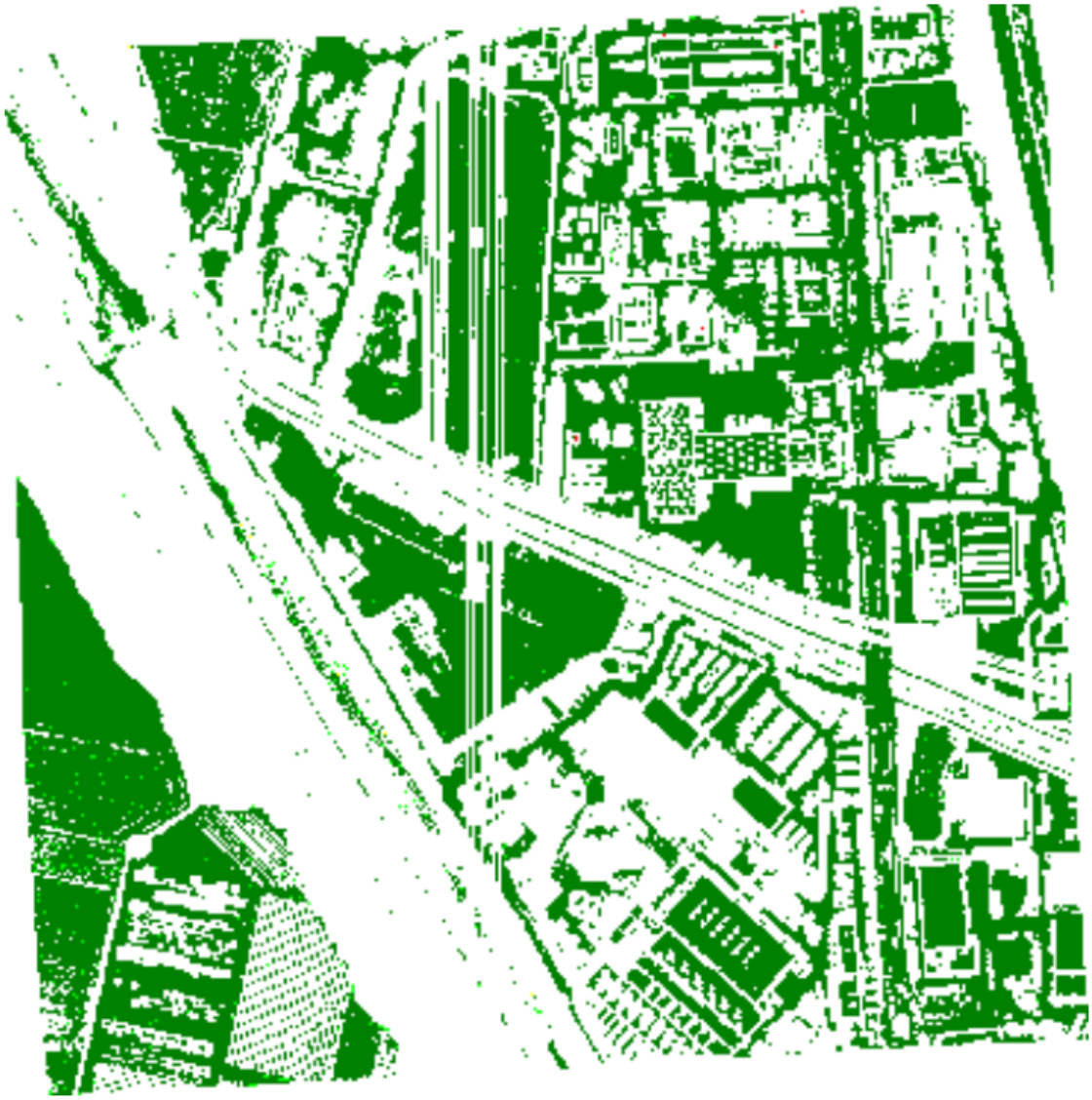


Figure 3 Vertical difference betweeen two perpendicular lines at 1000 m AGL.

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

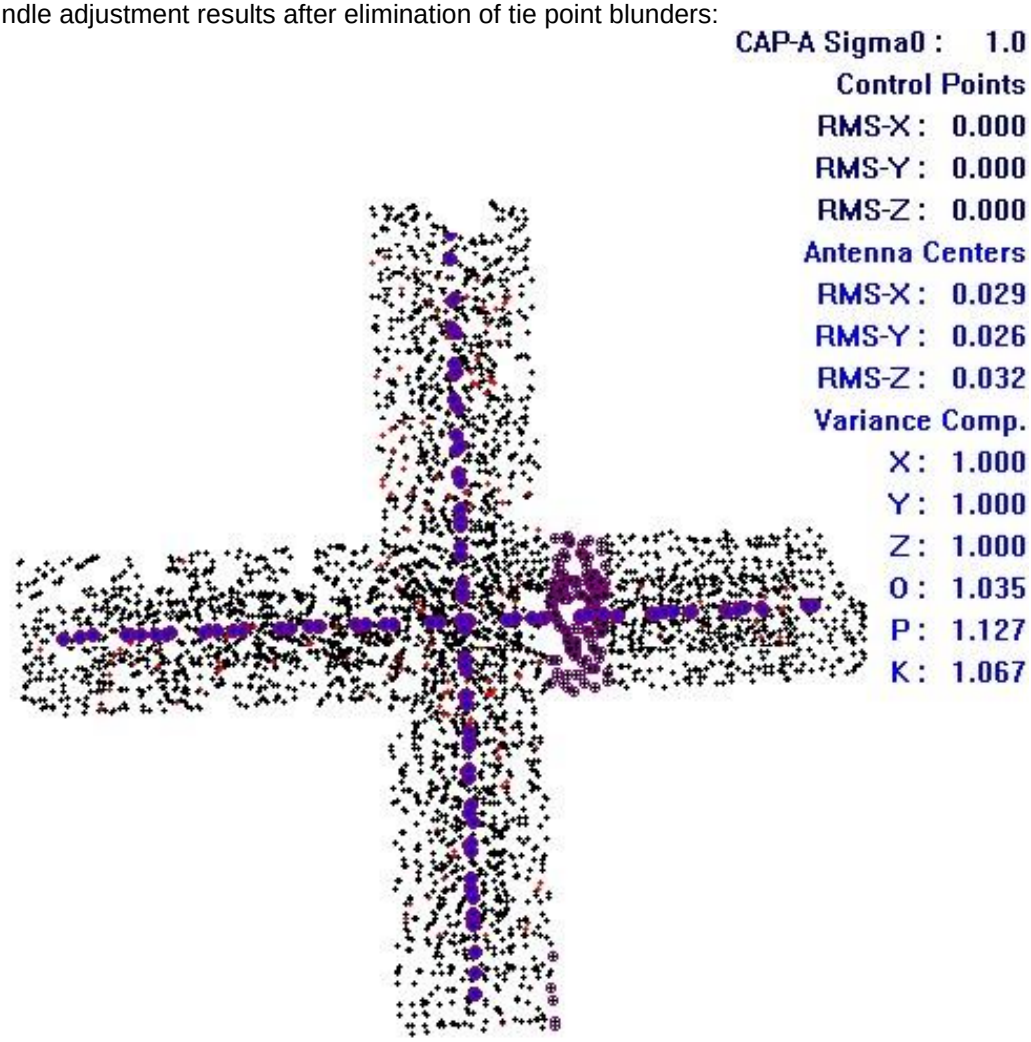
6.2 Results of Geometric Calibration

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

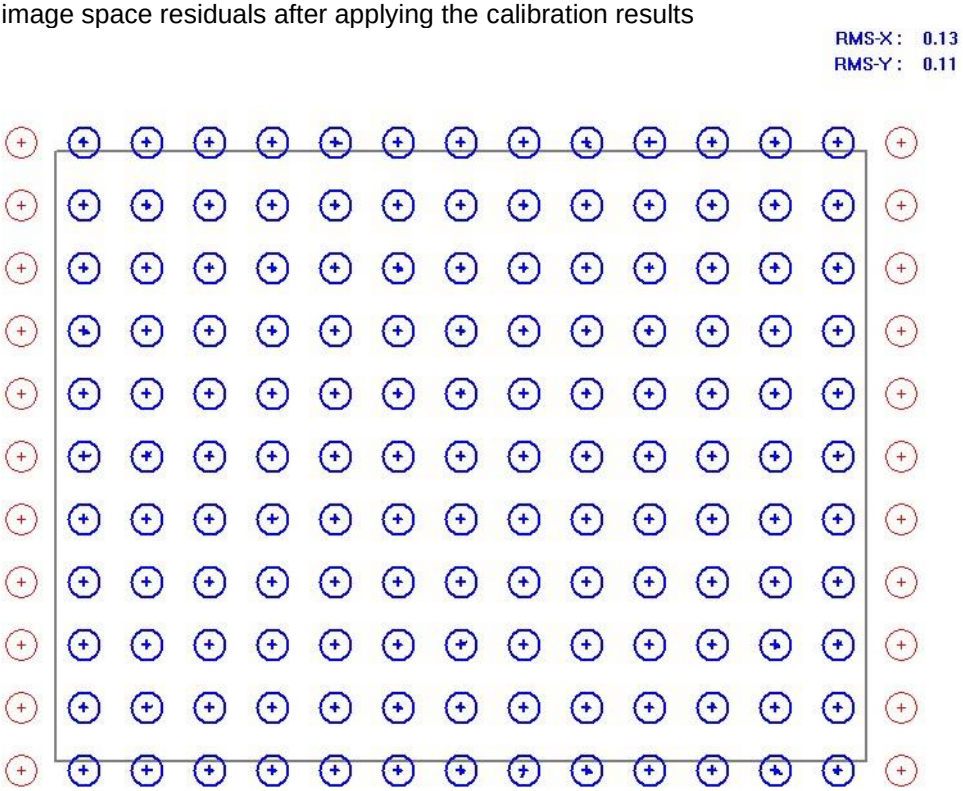
		Component	Serial Number
Camera Head		CH82	82673
Lens		NAT-D 2.8/80	80264
View Direction in Pod Position		Nadir	
IMU Misalignment		**Angle** [degree]	
	ω	0.03017	
	Φ	-0.01221	
	κ	-0.25213	
Principal Point		**Distance** [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		**Distance** [mm]	
	c	83.00	

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 #**
81200	Park Co. Montana Blks 2,3 and 4	Day257_91557_A	09/13/2020	257	A

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Comer	Cessna 404 Titan - N532NM	461.4	11:37:00	17:37:00	KBZN
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Ryan	Leica Terrain Mapper - 91557	464.4	12:56:00	18:56:00	KBZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
0	0	10		Clear	17	4	3019

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	10,663	17,415	4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7	2	40	81	670	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	17:37:00	17:46:00	00:09:00	17	1.4	BLOCK 4/ 17,415 MSL
2	W	17:49:00	17:58:00	00:09:00	17	1.4	some smoke and snow
							BLOCK 3/ 16,509 MSL
29	N	18:07:00	18:13:00	00:06:00	17	1.3	N.G. aborted line due to strong wind
							BLOCK 2/ 15,879 MSL
1	S	18:29:00	18:35:00	00:06:00	19	1.1	
2	N	18:38:00	18:45:00	00:07:00	19	1.1	
3	S	18:49:00	18:56:00	00:07:00	16	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 #**
81200	Park Co MT Block 1	Day265_90515_1	09/21/2020	265	1

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Gibilaro	Cessna 404 Titan - N7079F	2921.1	11:54:00	17:54:00	LAR
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Kennedy	Leica Terrain Mapper - 90515	2925.9	16:39:00	22:41:00	BZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
10	3	10		Clear	21	1	30.11

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	11,319	15,512	4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7		40	81	670	100

							Verify S-Turns Before Mission	Yes
Line #	**Direction**	**Start Time (UTC)**	**End Time (UTC)**	**Time On-Line**	**Satellite**	**PDOP**	**Line Notes/Comments**	
35	S	20:45:00	21:01:00	00:16:00	21	1.2		
34	N	21:04:00	21:19:00	00:15:00	21	1.2		
33	S	21:23:00	21:39:00	00:16:00	22	1.1		
32	N	21:42:00	21:58:00	00:16:00	24	1.1		
31	S	22:02:00	22:18:00	00:16:00	25	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 #
81200	Park Co. Montana Block 3	Day265_91557_A	09/21/2020	265	A

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Comer	Reims 406 - N406SD	464.4	08:26:00	14:26:00	KBZN
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Ryan	Leica Terrain Mapper - 91557	470.7	13:26:00	19:26:00	KBZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
0	0	10	20,000	Scattered	3	1	3015

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	11,319	16,509	4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7	2	40	81	670	100

		Verify S-Turns Before Mission	Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
1	N	14:26:00	14:30:00	00:04:00	21	1.2	
2	S	14:35:00	14:42:00	00:07:00	20	1.2	
3	N	14:46:00	14:53:00	00:07:00	21	1.1	
4	S	14:56:00	15:03:00	00:07:00	19	1.3	
5	N	15:06:00	15:14:00	00:08:00	18	1.4	
6	S	15:23:00	15:37:00	00:14:00	20	1.3	sm cloud 8 mi from south end
7	N	15:40:00	15:54:00	00:14:00	20	1.2	sm cloud 8 mi from south end
8	S	15:58:00	16:12:00	00:14:00	22	1.1	sm cloud 8 mi from south end
9	N	16:16:00	16:31:00	00:15:00	19	1.4	
10	S	16:33:00	16:48:00	00:15:00	20	1.2	
11	N	16:53:00	17:08:00	00:15:00	20	1.2	
12	S	17:11:00	17:25:00	00:14:00	18	1.4	
13	N	17:29:00	17:43:00	00:14:00	18	1.3	
14	S	17:46:00	18:00:00	00:14:00	19	1.2	
15	N	18:03:00	18:17:00	00:14:00	19	1	
16	S	18:20:00	18:34:00	00:14:00	17	1.2	
17	N	18:38:00	18:53:00	00:15:00	19	1.1	
18	S	18:56:00	19:10:00	00:14:00	18	1.2	
19	N	19:12:00	19:26:00	00:14:00	20	1	

	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 #
81200	Park Co. Montana Blocks 3 & 1	Day265_91557_B	09/21/2020	265	B

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Comer	Reims 406 - N406SD	470.7	15:03:00	21:03:00	KBZN
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Ryan	Leica Terrain Mapper - 91557	475.1	18:22:00	00:22:00	KBZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
0	0	10	20,000	Scattered	22	0	3009

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	11,319	16,509	4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7	2	40	81	670	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	21:03:00	21:17:00	00:14:00	20	1.3	BLOCK 3 16,509
21	N	21:20:00	21:33:00	00:13:00	23	1	
22	S	21:36:00	21:49:00	00:13:00	22	1.1	
23	N	21:52:00	22:05:00	00:13:00	24	1.1	
24	S	22:08:00	22:21:00	00:13:00	25	1.1	
25	N	22:24:00	22:38:00	00:14:00	24	1.1	
26	S	22:42:00	22:53:00	00:11:00	26	1	
27	N	22:57:00	23:09:00	00:12:00	22	1.6	
28	S	23:13:00	23:24:00	00:11:00	22	1.6	
29	N	23:27:00	23:38:00	00:11:00	23	1.4	
							BLOCK 1 15,512 MSL
52	N	23:43:00	23:50:00	00:07:00	25	1.1	
51	S	23:54:00	00:01:00	00:07:00	26	1.1	
50	N	00:04:00	00:11:00	00:07:00	26	1	
49	S	00:15:00	00:22:00	00:07:00	23	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 #**
81200	Park Co/Yellowstone	Day266_90511_A	09/22/2020	266	A

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Diepenbroek	Cessna 404 Titan - N404CP	8040.6	09:20:00	15:20:00	BZN
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Stanton	Leica Terrain Mapper - 90511	8044.8	13:51:00	19:51:00	BZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
0	0	7	40,000	Clear	9	4	30.07

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	11,319	15,879	4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7	2	40	81	670	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	16:04:00	16:08:00	00:04:00	22	1.2	Park Co Block 2 hazey from smoke
39	S	16:12:00	16:16:00	00:04:00	22	1.2	90% R1, lower values at river
38	N	16:19:00	16:24:00	00:05:00	20	1.3	
37	S	16:27:00	16:34:00	00:07:00	22	1.1	
36	N	16:37:00	16:45:00	00:08:00	21	1.2	
35	S	16:48:00	17:01:00	00:13:00	21	1.1	
34	N	17:04:00	17:16:00	00:12:00	20	1.2	
33	S	17:20:00	17:34:00	00:14:00	20	1.3	
32	N	17:37:00	17:57:00	00:20:00	21	1.2	Some speed issues
31	S	17:56:00	18:10:00	00:14:00	21	1	
30	N	18:12:00	18:27:00	00:15:00	18	1.4	Some speed issues
29	S	18:31:00	18:45:00	00:14:00	19	1.2	
28	N	18:48:00	19:02:00	00:14:00	19	1.2	
27	S	19:05:00	19:19:00	00:14:00	23	1	Some speed issues

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 #
81200	Park Co MT Block 1	Day266_90515_1	09/22/2020	266	1

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Gibilaro	Cessna 404 Titan - N7079F	2925.9	08:04:00	14:04:00	BZN
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Kennedy	Leica Terrain Mapper - 90515	2931.4	13:38:00	19:38:00	BZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
0	0	10		Clear	3	0	30.07

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	11,319	15,512	4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7		40	81	670	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	14:30:00	14:48:00	00:18:00	22	1.2	
29	S	14:51:00	15:09:00	00:18:00	21	1.3	
28	N	15:12:00	15:29:00	00:17:00	21	1.3	
27	S	15:33:00	15:51:00	00:18:00	20	1.3	
26	N	15:54:00	16:11:00	00:17:00	23	1.2	
25	S	16:14:00	16:30:00	00:16:00	19	1.4	
24	N	16:34:00	16:50:00	00:16:00	21	1.2	
23	S	16:53:00	17:09:00	00:16:00	21	1.1	
22	N	17:12:00	17:28:00	00:16:00	20	1.3	
21	S	17:32:00	17:48:00	00:16:00	20	1.2	
20	N	17:50:00	18:06:00	00:16:00	20	1.1	
1	S	18:20:00	18:24:00	00:04:00	19	1.3	
2	N	18:27:00	18:32:00	00:05:00	19	1.3	
3	S	18:36:00	18:41:00	00:05:00	19	1.2	
4	N	18:44:00	18:50:00	00:06:00	20	1.1	
5	S	18:54:00	18:59:00	00:05:00	21	1.1	
6	N	19:02:00	19:08:00	00:06:00	22	1	
7	S	19:12:00	19:19:00	00:07:00	22	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 #**
81200	Park Co. Block 1 and 4	Day266_91557_A	09/22/2020	266	A

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Comer	Reims 406 - N406SD	475.1	08:28:00	14:28:00	KBZN
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Ryan	Leica Terrain Mapper - 91557	479.9	12:07:00	18:07:00	KBZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
180	3	10		Clear	6	1	3006

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	11,319	15,512	4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7	2	40	81	670	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	14:28:00	14:29:00	00:01:00	22	1.2	Block 4 / N.G. Aborted line due to high wind	
							BLOCK 1 15,512 MSL	
48	N	14:37:00	14:54:00	00:17:00	21	1.3		
47	S	14:57:00	15:15:00	00:18:00	23	1.1		
46	N	15:19:00	15:35:00	00:16:00	21	1.3		
45	S	15:39:00	15:56:00	00:17:00	20	1.3		
44	N	16:01:00	16:17:00	00:16:00	22	1.2		
43	S	16:22:00	16:39:00	00:17:00	22	1.2		
42	N	16:43:00	16:59:00	00:16:00	21	1.1		
41	S	17:03:00	17:19:00	00:16:00	20	1.2		
40	N	17:23:00	17:39:00	00:16:00	20	1.3		
39	S	17:42:00	17:58:00	00:16:00	21	1.1		
38	N	18:02:00	18:07:00	00:05:00	21	1.2	N.G. aborted line	
							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 #**
81200	Park Co/Yellowstone	Day267_90511_A	09/23/2020	267	A

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Diepenbroek	Cessna 404 Titan - N404CP	8044.8	08:02:00	14:02:00	BZN
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Stanton	Leica Terrain Mapper - 90511	8048.8	12:18:00	18:18:00	BZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
160	4	10	40,000	Clear	10	3	30.15

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	11,319	15,879	4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7	2	40	81	670	100

Verify S-Turns Before Mission: Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
26	S	14:44:00	14:58:00	00:14:00	21	1.1	Park Co Block 2 hazey from smoke
25	N	15:01:00	15:15:00	00:14:00	21	1.3	90% R1, lower values at river
24	S	15:17:00	15:31:00	00:14:00	21	1.3	
23	N	15:34:00	15:50:00	00:16:00	22	1.2	
22	S	15:52:00	16:05:00	00:13:00	23	1.3	
21	N	16:08:00	16:23:00	00:15:00	24	1.2	
20	S	16:25:00	16:39:00	00:14:00	22	1.2	
19	N	16:41:00	16:56:00	00:15:00	23	1.2	
18	S	16:59:00	17:12:00	00:13:00	20	1.2	
17	N	17:15:00	17:30:00	00:15:00	20	1.2	
16	S	17:32:00	17:46:00	00:14:00	20	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 #**
81200	Park Co MT Block 1 & 2	Day267_90515_1	09/23/2020	267	1

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Gibilaro	Cessna 404 Titan - N7079F	2931.4	08:25:00	14:25:00	BZN
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Kennedy	Leica Terrain Mapper - 90515	2938.1	15:05:00	21:05:00	BZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
160	4	10		Clear	10	3	30.15

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	11,319	15,512	4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7		40	81	670	100

							Verify S-Turns Before Mission	Yes
Line #	**Direction**	**Start Time (UTC)**	**End Time (UTC)**	**Time On-Line**	**Satellite**	**PDOP**	**Line Notes/Comments**	
36	N	14:55:00	15:11:00	00:16:00	1.1	1.3		
37	S	15:14:00	15:30:00	00:16:00	21	1.3		
38	N	15:39:00	15:55:00	00:16:00	22	1.2	clouds on north end	
8	S	16:05:00	16:12:00	00:07:00	24	1.2		
9	N	16:15:00	16:23:00	00:08:00	22	1.2		
10	S	16:26:00	16:36:00	00:10:00	23	1.1		
11	N	16:39:00	16:48:00	00:09:00	23	1.2		
12	S	16:53:00	17:09:00	00:16:00	22	1.1		
13	N	17:12:00	17:28:00	00:16:00	20	1.2		
14	S	17:32:00	17:49:00	00:17:00	20	1.2		
15	N	17:52:00	18:09:00	00:17:00	20	1.3		
16	S	18:13:00	18:30:00	00:17:00	16	1.3		
17	N	18:33:00	18:50:00	00:17:00	17	1.1		
18	S	18:53:00	19:09:00	00:16:00	19	1.1		
19	N	19:15:00	19:31:00	00:16:00	20	1		
1	S	19:53:00	20:00:00	00:07:00	17	1.3	Block 2 @ 15879 MSL	
2	N	20:04:00	20:11:00	00:07:00	20	1.3		
3	S	20:15:00	20:22:00	00:07:00	21	1.2		
4	N	20:25:00	20:33:00	00:08:00	21	1.2		
5	S	20:36:00	20:43:00	00:07:00	21	1.2		
					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 #
81200	Yellowstone Park Co Blocks 4 and 2	Day267_91557_A	09/23/2020	267	A

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Comer	Reims 406 - N406SD	479.9	09:01:00	15:01:00	KBZN
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Ryan	Leica Terrain Mapper - 91557	485.9	14:01:00	20:01:00	KBZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
160	4	10	18,000	Scattered	10	3	3015

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	10,663	17,415	4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7	2	40	82	650	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	15:01:00	15:09:00	00:08:00	21	1.5	BLOCK 4 17,415 MSL
3	W	15:13:00	15:22:00	00:09:00	21	1.3	
4	E	15:25:00	15:33:00	00:08:00	21	1.2	
5	W	15:37:00	15:43:00	00:06:00	22	1.2	N. G. stopped line due to clouds
3	E	15:48:00	15:52:00	00:04:00	24	1.2	N. G. stopped line due to clouds
18	W	16:02:00	16:06:00	00:04:00	24	1.2	sm cloud beginning of east end
17	E	16:10:00	16:14:00	00:04:00	24	1.2	
16	W	16:18:00	16:22:00	00:04:00	21	1.2	
15	E	16:30:00	16:39:00	00:09:00	23	1.3	
14	W	16:44:00	16:52:00	00:08:00	22	1.2	
13	E	16:56:00	17:05:00	00:09:00	19	1.2	sm cloud 1 mile from east end
12	W	17:09:00	17:17:00	00:08:00	20	1.2	sm cloud 1 mile from east end
15	S	17:36:00	17:50:00	00:14:00	20	1.1	BLOCK 2 15,879 MSL
14	N	17:54:00	18:06:00	00:12:00	20	1.3	
13	S	18:10:00	18:22:00	00:12:00	15	1.5	
12	N	18:27:00	18:40:00	00:13:00	15	1.4	
11	S	18:43:00	18:56:00	00:13:00	17	1.2	
10	N	19:02:00	19:14:00	00:12:00	19	1.1	small cloud north end last mile
6	S	19:20:00	19:27:00	00:07:00	20	1	
7	N	19:31:00	19:39:00	00:08:00	18	1.3	
8	S	19:42:00	19:49:00	00:07:00	18	1.2	
9	N	19:53:00	20:01:00	00:08:00	17	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 #**
81200	Park Co Reflights	Day276_90515_1	10/02/2020	276	1

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Gibilaro	Cessna 404 Titan - N7079F	2955.1	09:10:00	15:10:00	BZN
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Kennedy	Leica Terrain Mapper - 90515		10:29:00	16:29:00	BZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
0	0	10		Clear	8	0	30.27

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	11,349	15,512	4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.35		40	81	670	100

Verify S-Turns Before Mission	Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
27	S	15:32:00	15:40:00	00:08:00	21	1.3	Manual activation on some partial reflights
26	S	16:03:00	16:11:00	00:08:00	24	1.2	Extreme PAV vibrations. Mission ended

Page 1		**Verify S-Turns After Mission**	Yes

Additional Comments

Woolpert Lidar Acquisition Log

Project #	Project Name	Unique ID	Flight Date (UTC)	Day of Year	Flight #
81200	Park Co Reflights	Day277_90515_1	10/03/2020	277	1

Crew	Equipment	Hobbs	Local	UTC	Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Gebhart	Cessna 404 Titan - N7079F	2956.4	10:12:00	16:12:00	BZN
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Kennedy	Leica Terrain Mapper - 90515	2959.4	13:11:00	19:11:00	BZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
120	3	10		Clear	7	2	30.29

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	11,349	15,512	4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.35		40	81	670	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	16:28:00	16:37:00	00:09:00	18	1.3	
24	N	16:41:00	16:49:00	00:08:00	19	1.2	
20	S	16:53:00	16:56:00	00:03:00	20	1.2	
							Manual test fires between blocks
3	S	17:08:00	17:14:00	00:06:00	22	1	Block 2 @ 15879 MSL
4	N	17:17:00	17:21:00	00:04:00	20	1.1	Frequent smoke, possible snow, all block 2
5	S	17:24:00	17:27:00	00:03:00	19	1.3	
11	N	17:33:00	17:47:00	00:14:00	18	1.2	
12	S	17:50:00	18:03:00	00:13:00	18	1.2	
13	N	18:06:00	18:19:00	00:13:00	19	1.2	
27	S	18:24:00	18:39:00	00:15:00	22	1	
28	N	18:42:00	18:56:00	00:14:00	21	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 #
81200	Park Co Reflights	Day278_90515_1	10/04/2020	278	1

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Gebhart	Cessna 404 Titan - N7079F	2959.4	10:43:00	16:43:00	BZN
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Kennedy	Leica Terrain Mapper - 90515	2961.7	13:02:00	19:02:00	BZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
10	3	10		Clear	12	5	30.12

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	11,349	15,879	4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.35		40	81	670	100

Verify S-Turns Before Mission: Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
29	S	17:06:00	17:10:00	00:04:00	21	1	
30	N	17:13:00	17:22:00	00:09:00	22	0.9	
31	S	17:24:00	17:30:00	00:06:00	19	1.1	
32	N	17:32:00	17:38:00	00:06:00	18	1.3	
33	S	17:41:00	17:45:00	00:04:00	17	1.3	
34	N	17:48:00	17:52:00	00:04:00	18	1.1	
35	S	17:55:00	18:01:00	00:06:00	17	1.2	
5	N	18:09:00	18:12:00	00:03:00	17	1.2	Line restarted once, altitude too low
6	S	18:16:00	18:19:00	00:03:00	20	1	
7	N	18:21:00	18:24:00	00:03:00	20	1	
14	N	18:29:00	18:37:00	00:08:00	20	1	

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 #**
81200	Park CO MT B4 / Yellowstone NP B2	Day282_91557_1	10/08/2020	282	1

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Dar Perl	Reims F406 - N406SD	519	09:21:00	15:21:00	KBZN
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Fanning	Leica Terrain Mapper - 91557	524.2	13:06:00	19:06:00	KBZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
180	4	6	18,000	Few	4	-2	29.94

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	10,663	17,415	4,471

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7	2	40	82	650	100

Verify S-Turns Before Mission Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
2	E	15:21:00	15:29:00	00:08:00	25	1.1	PITCH 5°-6° ON WEST SIDE OF LINE.
4	W	15:32:00	15:40:00	00:08:00	24	1.2	LIGHT SNOW AND MOD PERMAFROST
5	E	15:44:00	15:52:00	00:08:00	25	1.1	(PF) ON EAST SIDE OF LINE.
6	W	15:56:00	16:04:00	00:08:00	24	1.1	L5: 165Kts+ @ WEST SIDE OF LINE
7	E	16:08:00	16:16:00	00:08:00	22	1.3	L5-L8: MOD/HEAVY PF
8	W	16:20:00	16:28:00	00:08:00	22	1.2	L5-L8: LIGHT SEASONAL SNOW
9	E	16:31:00	16:39:00	00:08:00	21	1.2	L9-L11: MANY SMALL LAKES.
10	W	16:43:00	16:51:00	00:08:00	22	1.1	
11	E	16:56:00	17:04:00	00:08:00	22	1.2	5°-6° PITCH WEST SIDE OF LNE
13	W	17:08:00	17:16:00	00:08:00	21	1.3	
15	E	17:20:00	17:28:00	00:08:00	21	1.2	
17	W	17:31:00	17:35:00	00:04:00	21	1.1	B4 PARK CO MT COMPLETE
81	S	17:44:00	17:56:00	00:12:00	19	1.2	BEGIN YELLOWSTONE NP B2
82	N	18:00:00	18:11:00	00:11:00	22	1	MSL ALT VARIES, POINT DENSITY=8PPSM
83	S	18:14:00	18:24:00	00:10:00	21	1	SCAN FREQ = 150Hz, PULSE RATE = 1580kHz
84	N	18:28:00	18:35:00	00:07:00	19	1.2	
85	S	18:43:00	18:52:00	00:09:00	19	1.2	MODERATE CHOP
86	N	18:56:00	19:06:00	00:10:00	18	1.2	LIGHT SEASONAL SNOW EVIDENT ON
							NORTHERN SLOPES.

Verify S-Turns After Mission Yes

Additional Comments

4346 GB WU: 08:55MST WD: 13:43MST **NOTE:** EXISTENCE OF GLACIATED TERRAIN AND PERMAFROST IN PARK CO BLOCK 4. PARTICULARLY IN LINES 4-8 & 13 & 15. A LIGHT SEASONAL SNOW ALSO EXISTS IN SMALL AMOUNTS ON MOST OF THE NORTHERLY SLOPES. THE UPPERS WERE BLOWING 38Kts+ FROM THE WEST, GS ON WEST SIDE OF LINES WAS 165Kts+ AT TIMES (L2,5,7,9,11,15), PITCH 4°-6°. MAINT HOBBS: 5465.1.

Woolpert Lidar Acquisition Log

Project Info			Date		
Project #	**Project Name**	**Unique ID**	**Flight Date (UTC)**	**Day of Year**	**Flight #**
81200	Park Co reflights Blk 1 / PAGE 1	Day283_90511_A	10/09/2020	283	A

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Comer	Cessna 404 Titan - N404CP	8101.4	08:38:00	14:38:00	KBZN
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Ryan	Leica Terrain Mapper - 90511	8106.9	12:57:00	18:57:00	KBZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
140	7	10	18,000	Few	1	-5	3000

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	11,319	15,512	4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7	2	40	81	670	100

		Verify S-Turns Before Mission	Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
38	S	14:38:00	14:44:00	00:06:00	21	1.2	north 20 mi
39	S	14:54:00	15:10:00	00:16:00	22	1.2	
40	N	15:13:00	15:31:00	00:18:00	23	1.1	
41	S	15:36:00	15:52:00	00:16:00	24	1.2	
42	N	15:55:00	16:13:00	00:18:00	21	1.4	
43	S	16:16:00	16:32:00	00:16:00	22	1.2	
44	N	16:36:00	16:55:00	00:19:00	25	1.1	
45	S	16:57:00	17:14:00	00:17:00	25	1.1	

		Page 1	Verify S-Turns After Mission	Yes

Additional Comments

PAGE 1

Woolpert Lidar Acquisition Log

Project Info			Date		
Project #	**Project Name**	**Unique ID**	**Flight Date (UTC)**	**Day of Year**	**Flight #**
81200	Yellowstone Block 2 / PAGE 2	Day283_90511_A	10/09/2020	283	A

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Comer	Cessna 404 Titan - N404CP	8101.4	08:38:00	14:38:00	KBZN
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Ryan	Leica Terrain Mapper - 90511	8106.9	12:57:00	18:57:00	KBZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
140	7	0,010	18,000	Few	1	-5	3000

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	6,998		4,473

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.35	8	40	150	1580	100

Verify S-Turns Before Mission	Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
69	S	17:24:00	17:37:00	00:13:00	22	1.1	Altitude varies between all lines
70	N	17:40:00	17:53:00	00:13:00	20	1.2	
71	S	17:56:00	18:09:00	00:13:00	24	1	
72	N	18:13:00	18:25:00	00:12:00	23	1	
73	S	18:28:00	18:41:00	00:13:00	22	1.1	
74	N	18:44:00	18:57:00	00:13:00	20	1.2	

Page 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 #**
81200	Park Co, MT B1&B3; Yellowstone NP B1&B4	Day283_91557_1	10/09/2020	283	1

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Dar Perl	Reims F406 - N406SD	524.2	08:42:00	14:42:00	KBZN
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Fanning	Leica Terrain Mapper - 91557	529.1	11:40:00	17:40:00	KBZN

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
140	7	10	21,000	Few	1	-5	30

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	11,319	15,512	4,471

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.7	2	40	81	670	100

Verify S-Turns Before Mission Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
49	N	14:42:00	14:49:00	00:07:00	22	1.1	PARK CO B1 (2PPSM)
50	S	14:53:00	15:00:00	00:07:00	23	1.2	
51	N	15:04:00	15:11:00	00:07:00	22	1.2	
52	S	15:15:00	15:22:00	00:07:00	23	1.1	
14	S	15:31:00	15:45:00	00:14:00	24	1.2	BEGIN PARK CO B3 (2PPSM)
							16,509' MSL
58	S	15:58:00	16:11:00	00:13:00	22	1.2	BEGIN YELLOWSTONE NP B1 (8PPSM)
							MSL VARIES;150Hz SCAN FREQ;
							1580kHz PULSE RATE; 6998' AGL;
							0.35m POINT SPACING;
							EYE SAFE OFF¤
61	S	16:25:00	16:36:00	00:11:00	21	1.2	BEGIN YELLOWSTONE NP B4
62	N	16:40:00	16:50:00	00:10:00	25	1.4	(8PPSM); MSL VARIES
63	S	16:54:00	17:04:00	00:10:00	24	1.2	
68	N	17:08:00	17:14:00	00:06:00	22	1.4	MODERATE/HEAVY PERMAFROST
69	S	17:17:00	17:23:00	00:06:00	21	1.3	AND GLACIATED TERRAIN PRESENT ON
70	N	17:26:00	17:32:00	00:06:00	22	1.1	ALL B4 LINES 61-71; LIGHT SEASONAL.
71	S	17:34:00	17:40:00	00:06:00	20	1.2	YELLOWSTONE NP B4 COMPLETE!

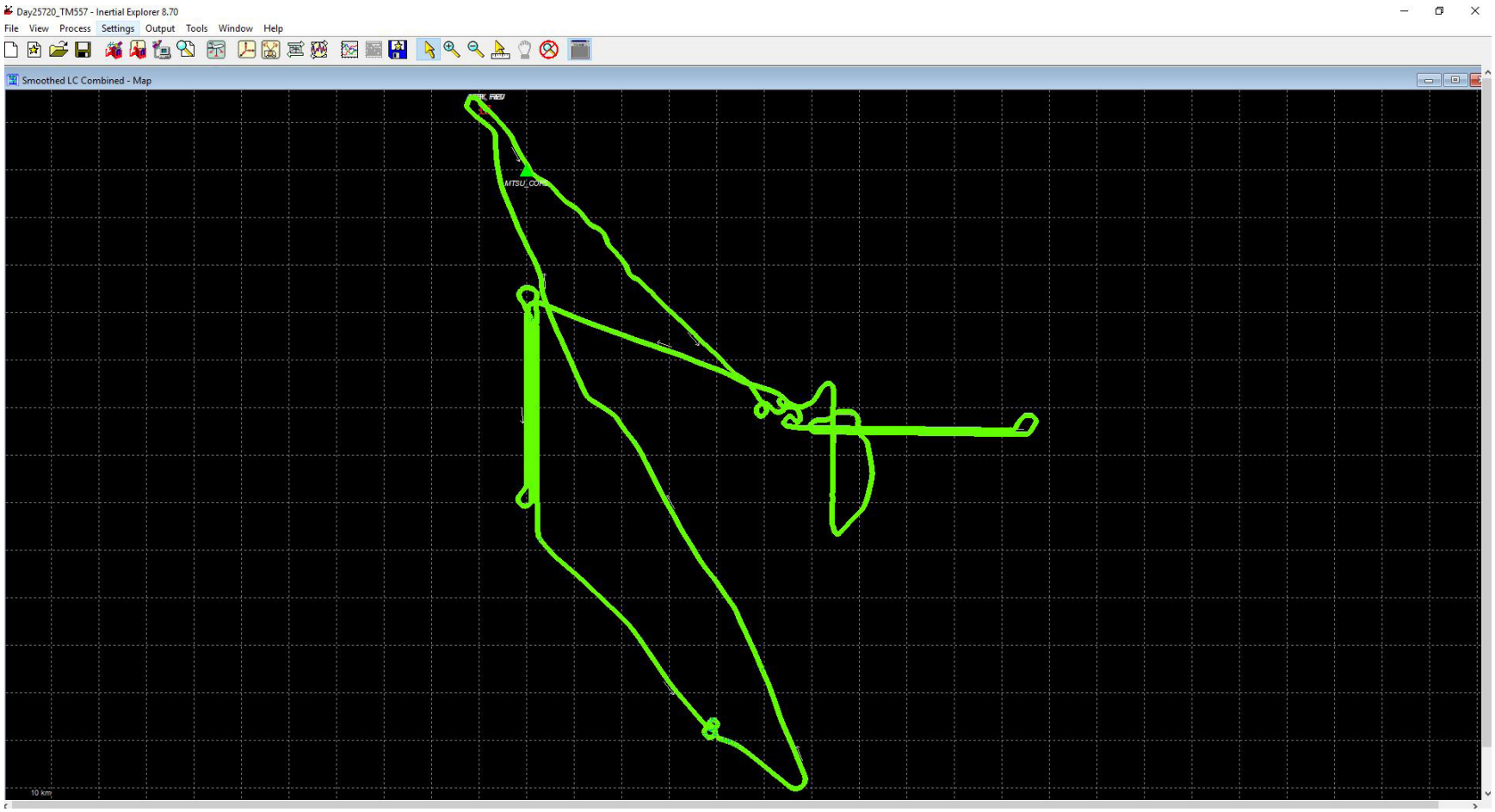
Verify S-Turns After Mission Yes

Additional Comments

3976GB WU: 08:21MST WD: 12:35MST MAINT HOBBS: 5469.3

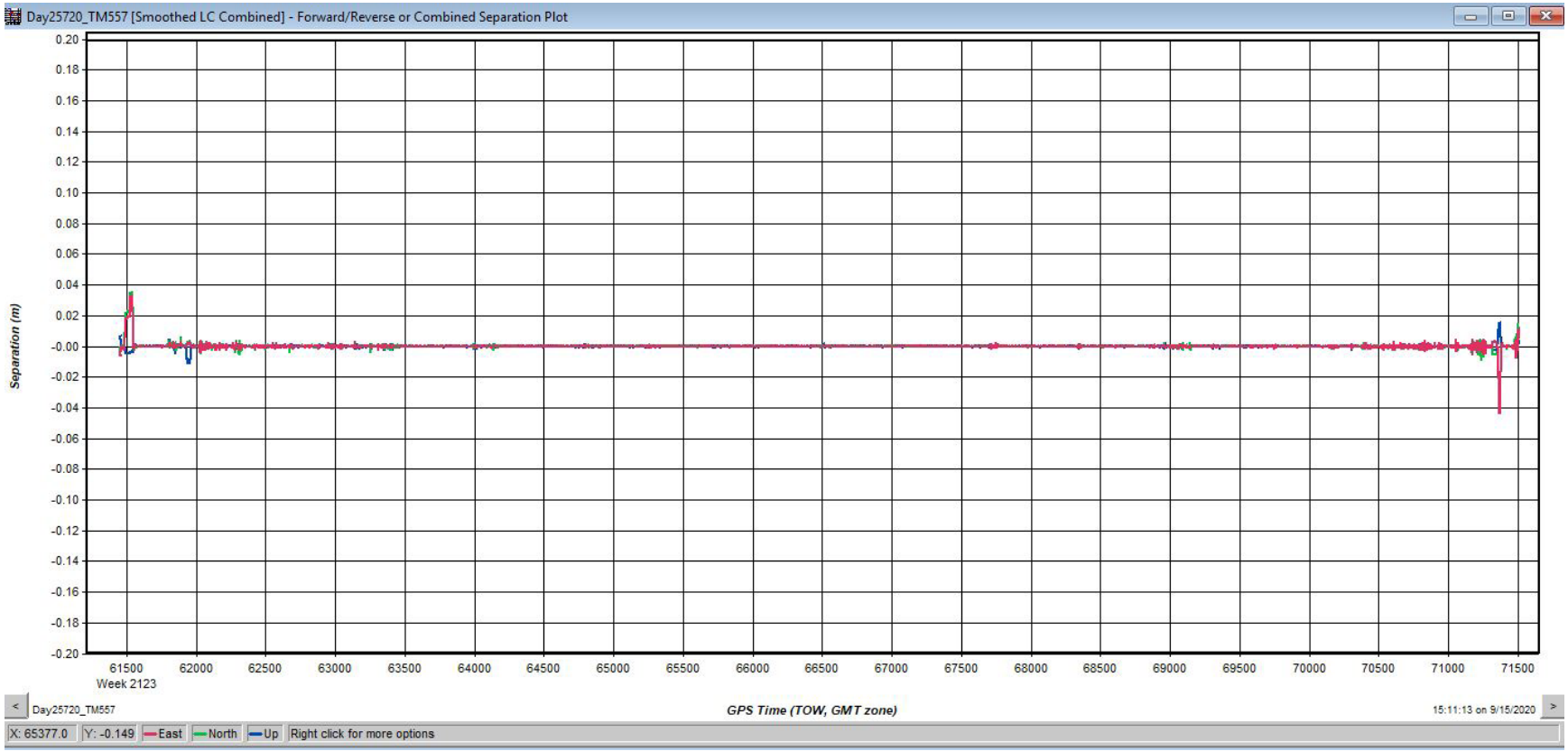
Appendix 3: GPS / IMU Graphics

Day25720_TM557
Trajectory

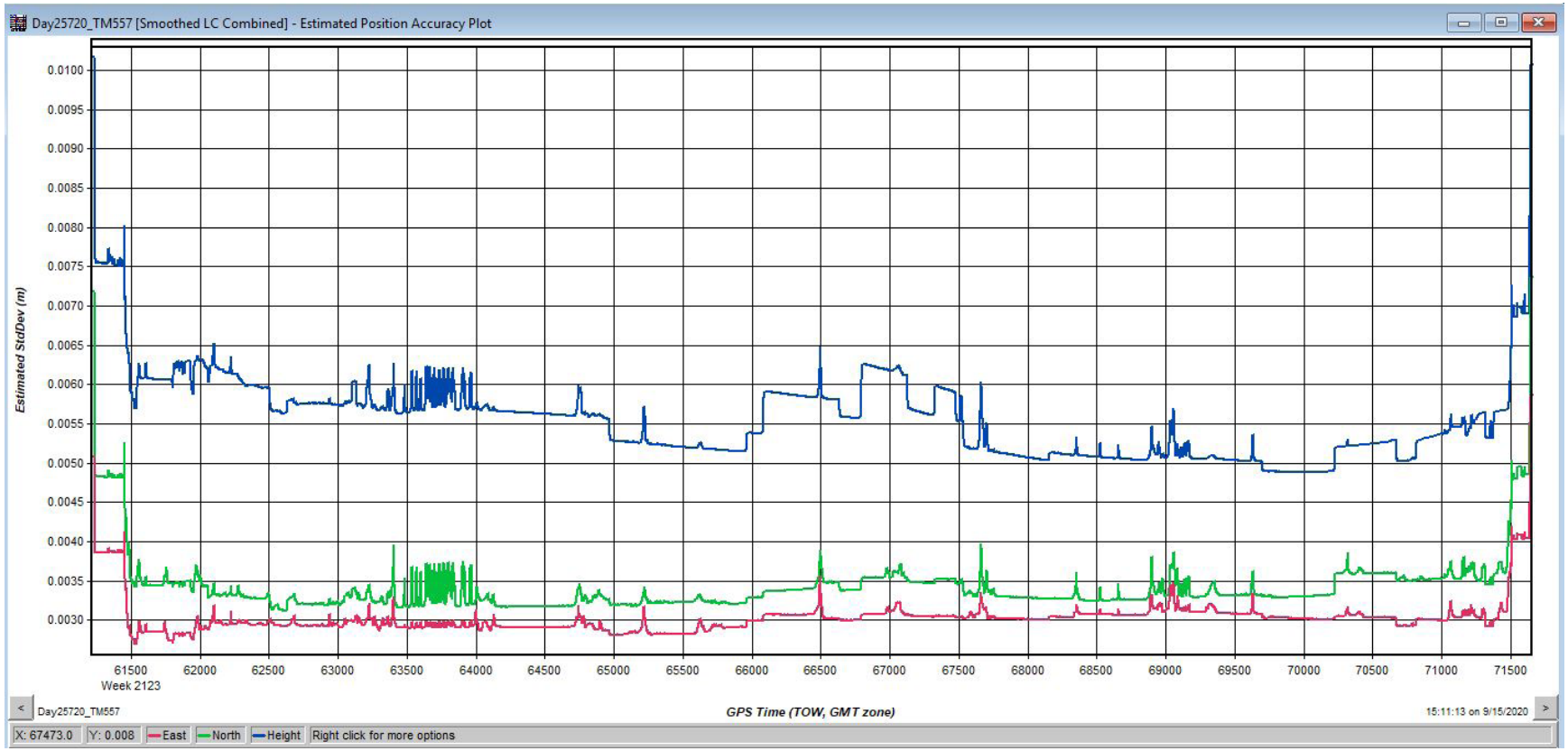


Day25720_TM557

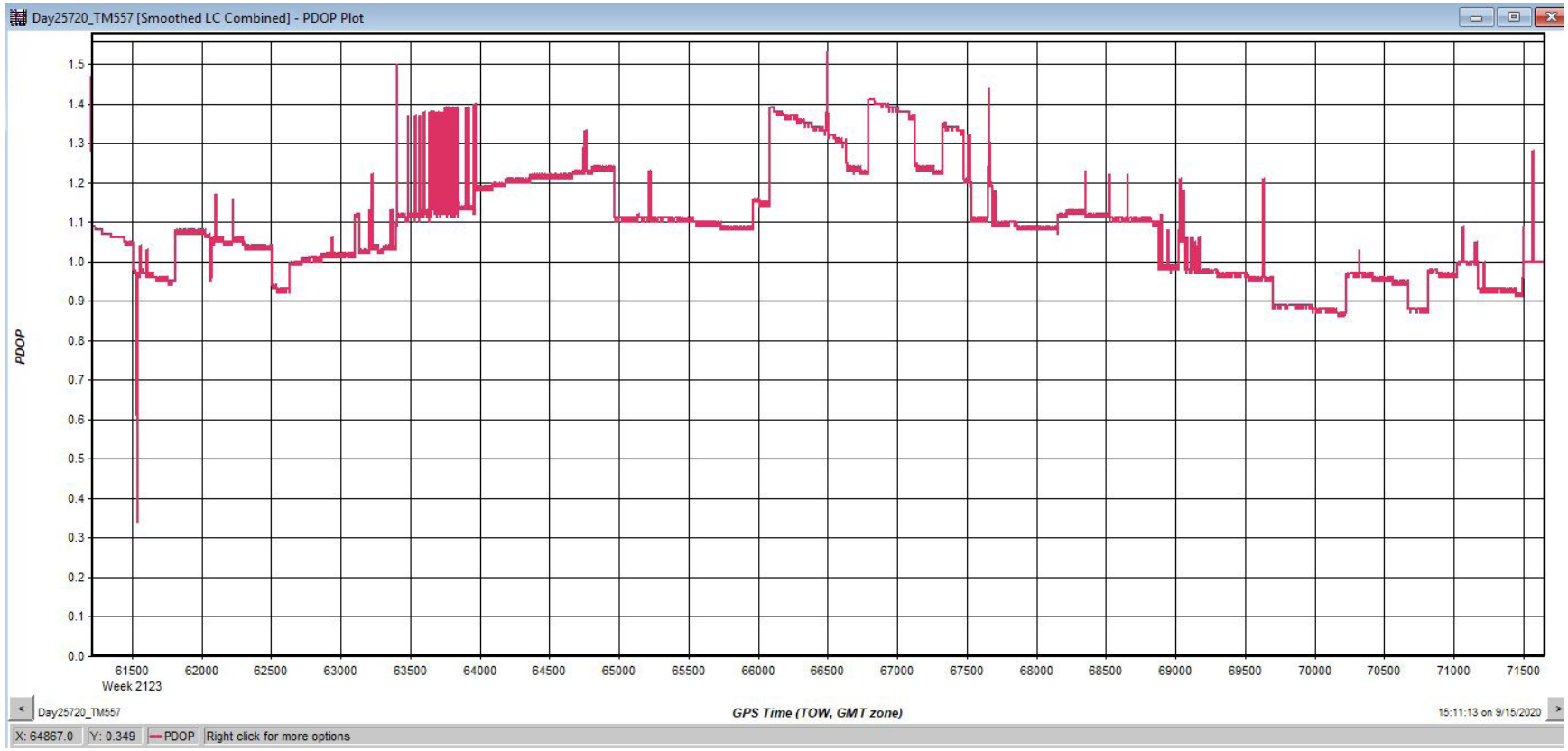
Forward/Reverse or Combined Separation Plot



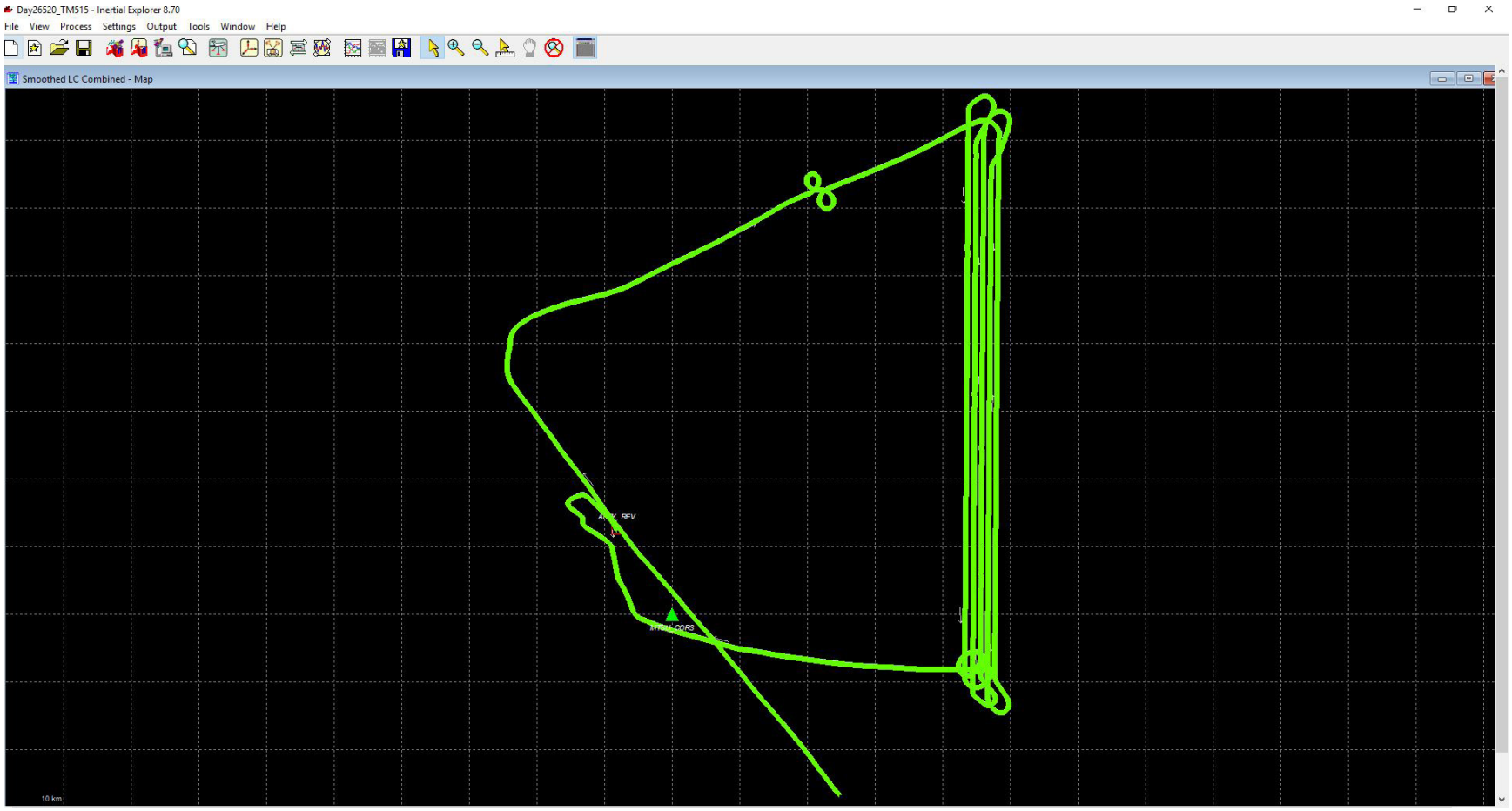
Day25720_TM557
Estimated Position Accuracy



Day25720_TM557
PDOP Plot

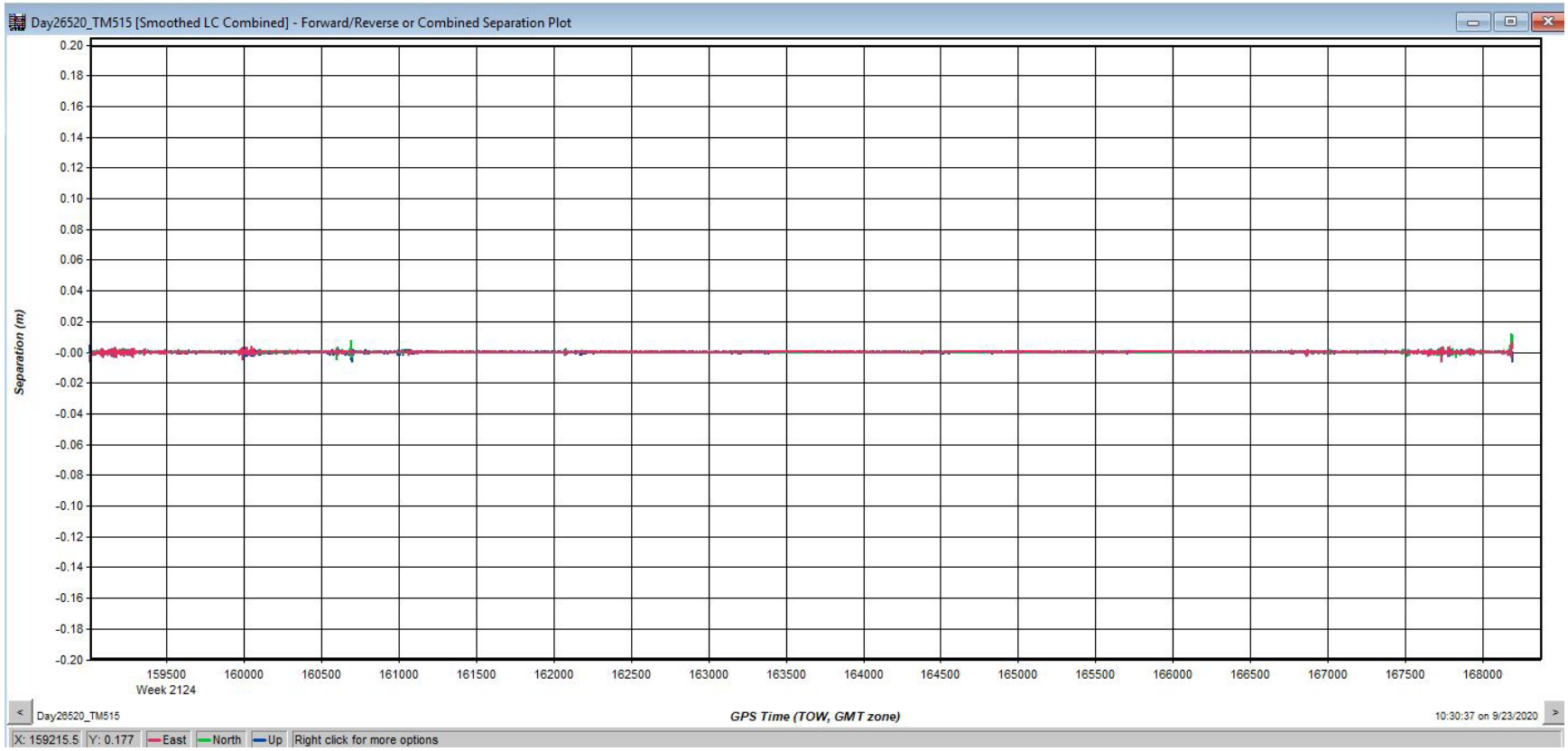


Day26520_TM515
Trajectory

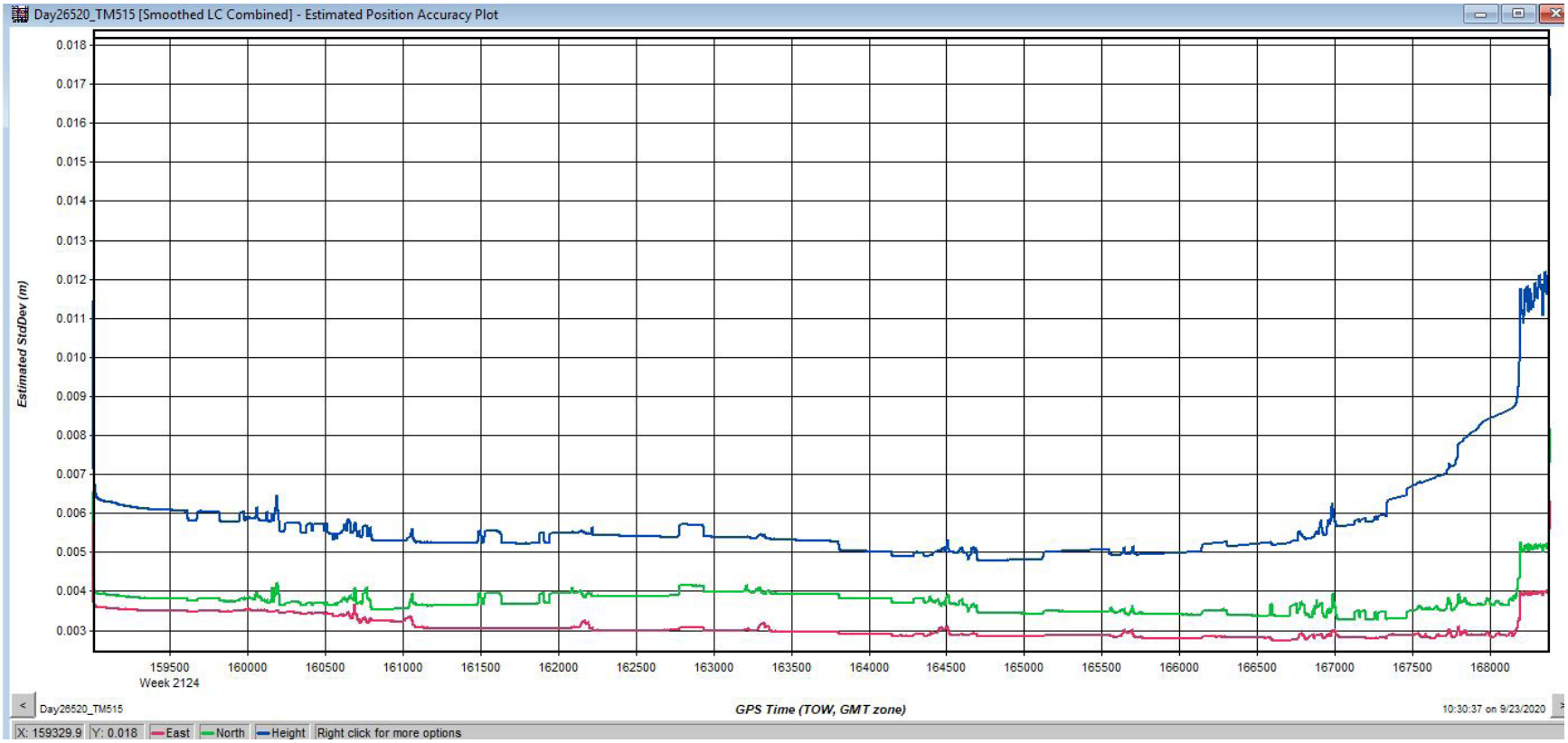


Day26520_TM515

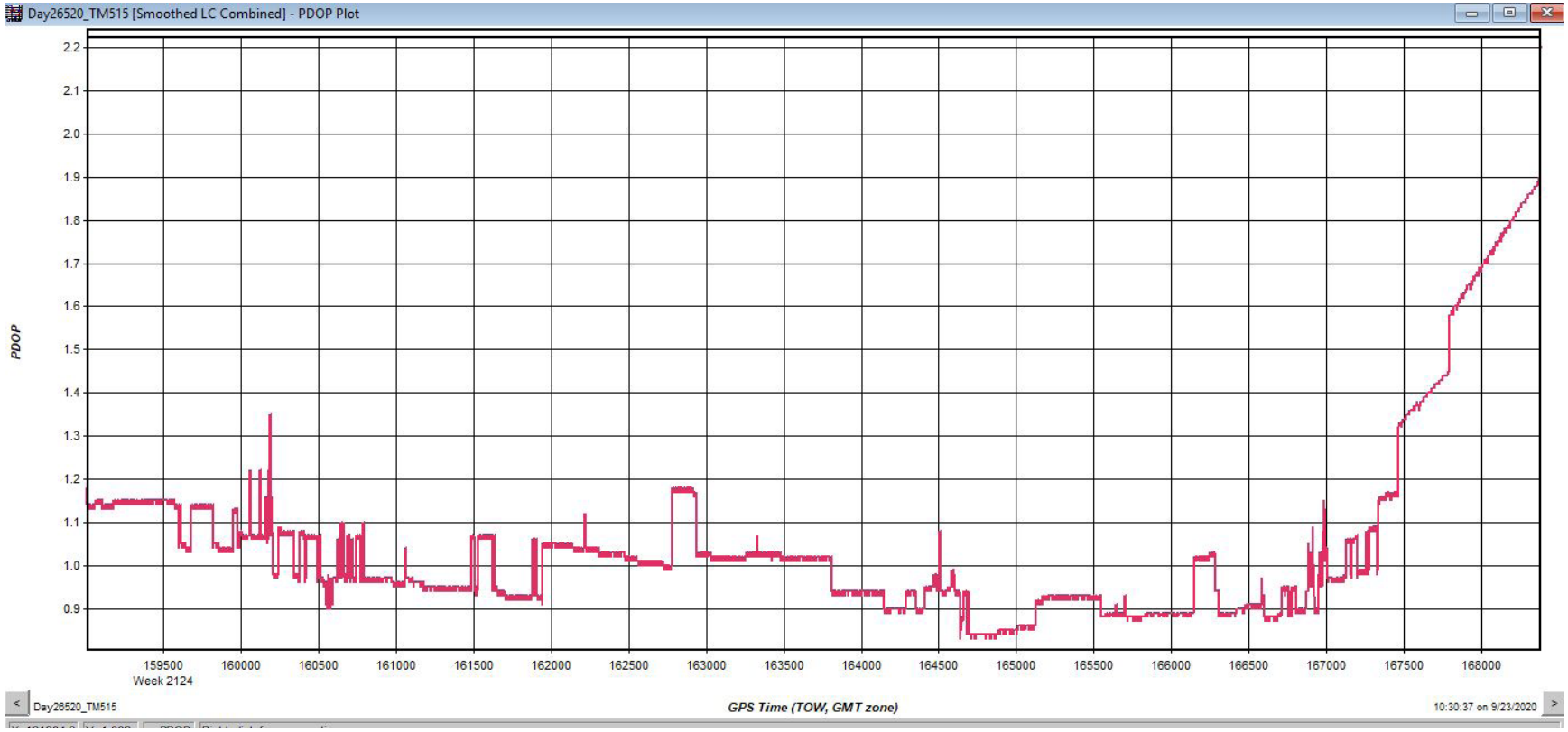
Forward/Reverse or Combined Separation Plot



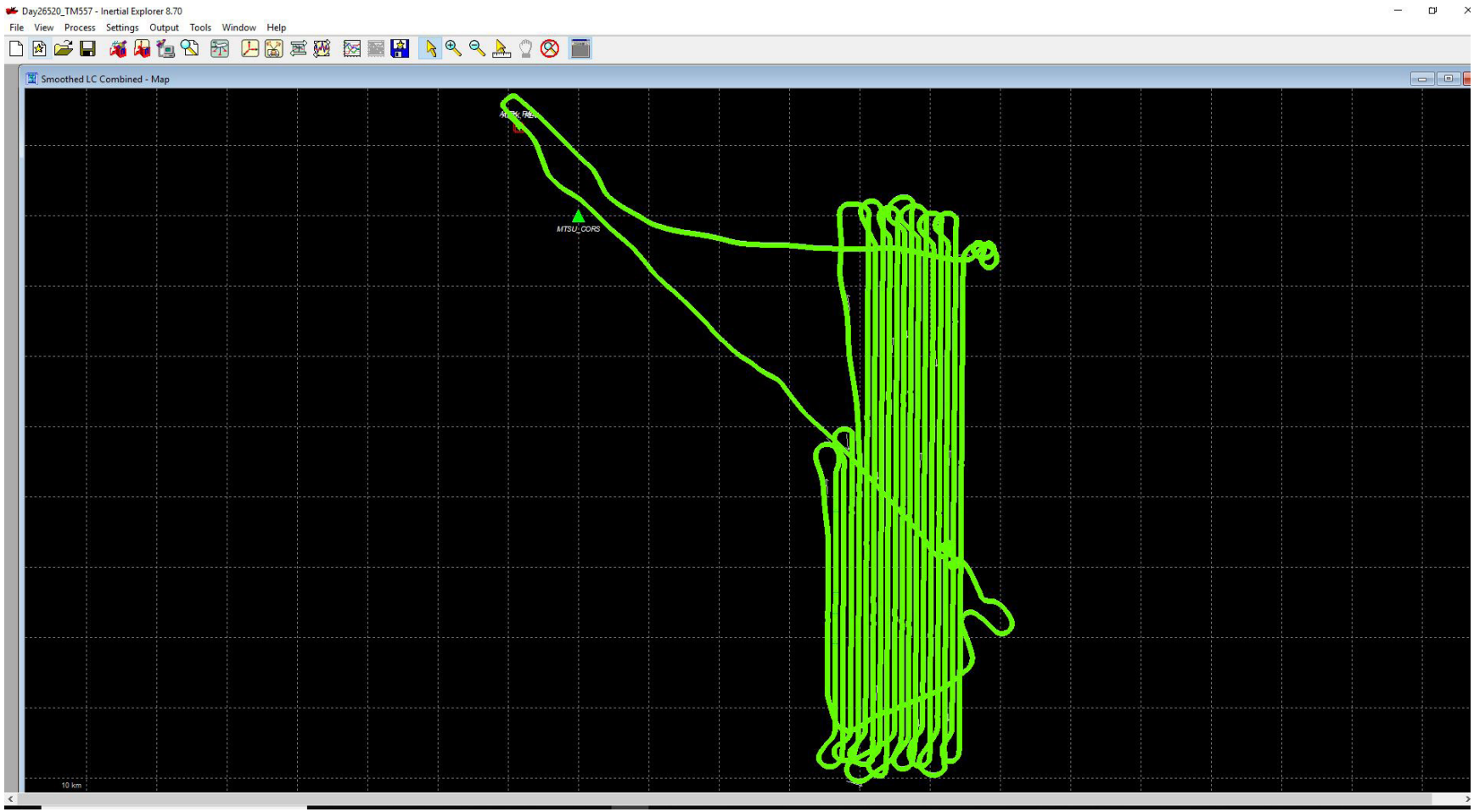
Day26520_TM515
Estimated Position Accuracy



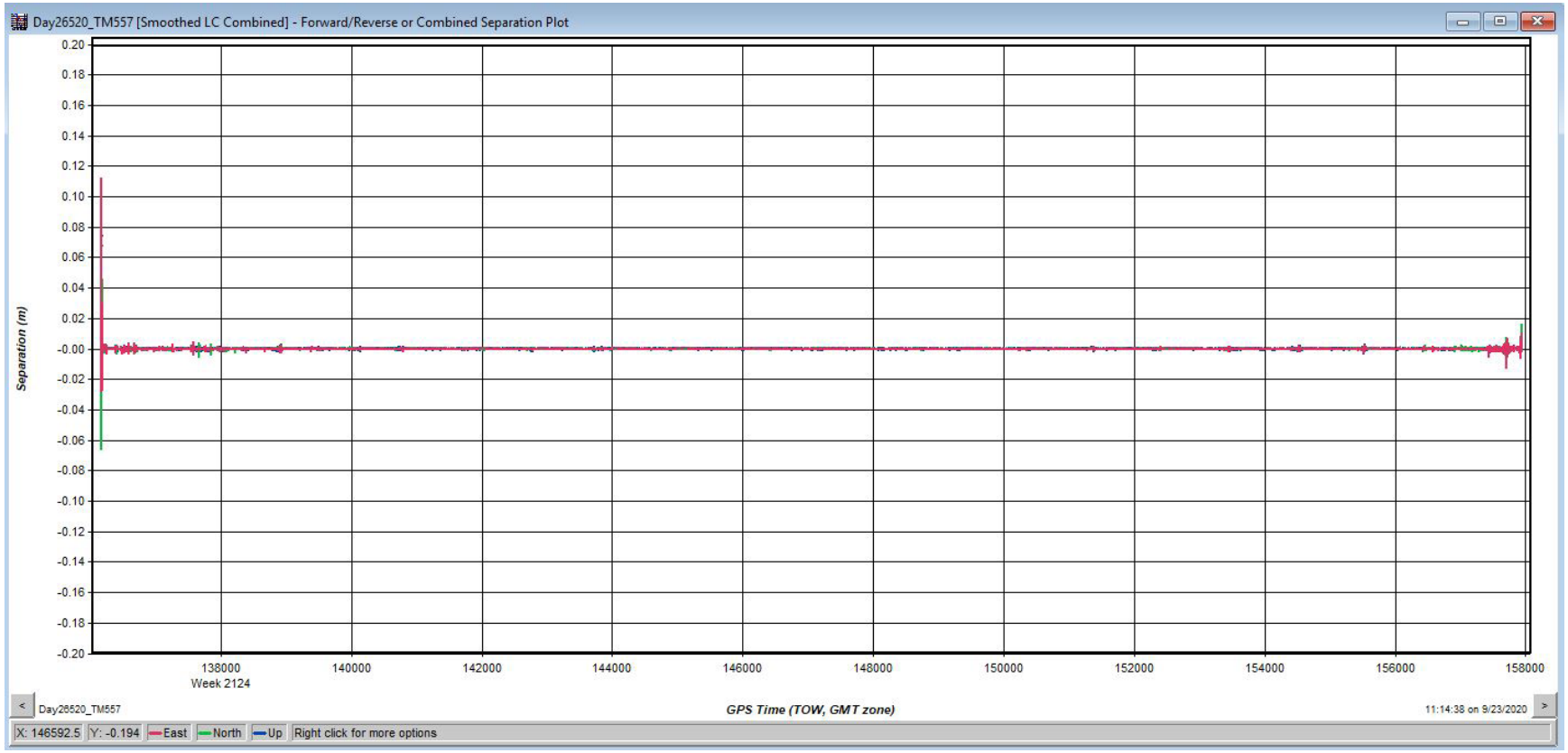
Day26520_TM515
PDOP Plot



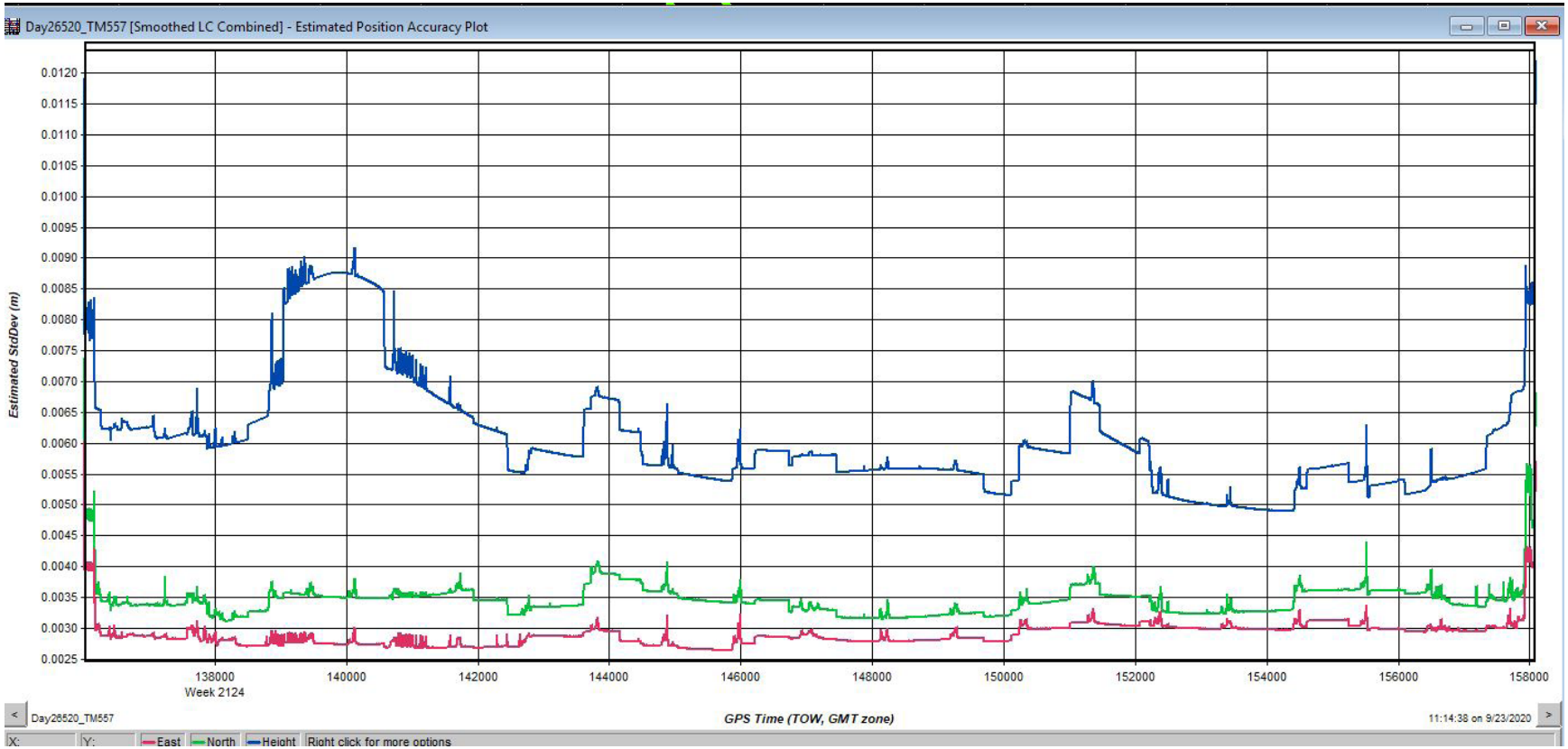
Day26520_TM557_A
Trajectory



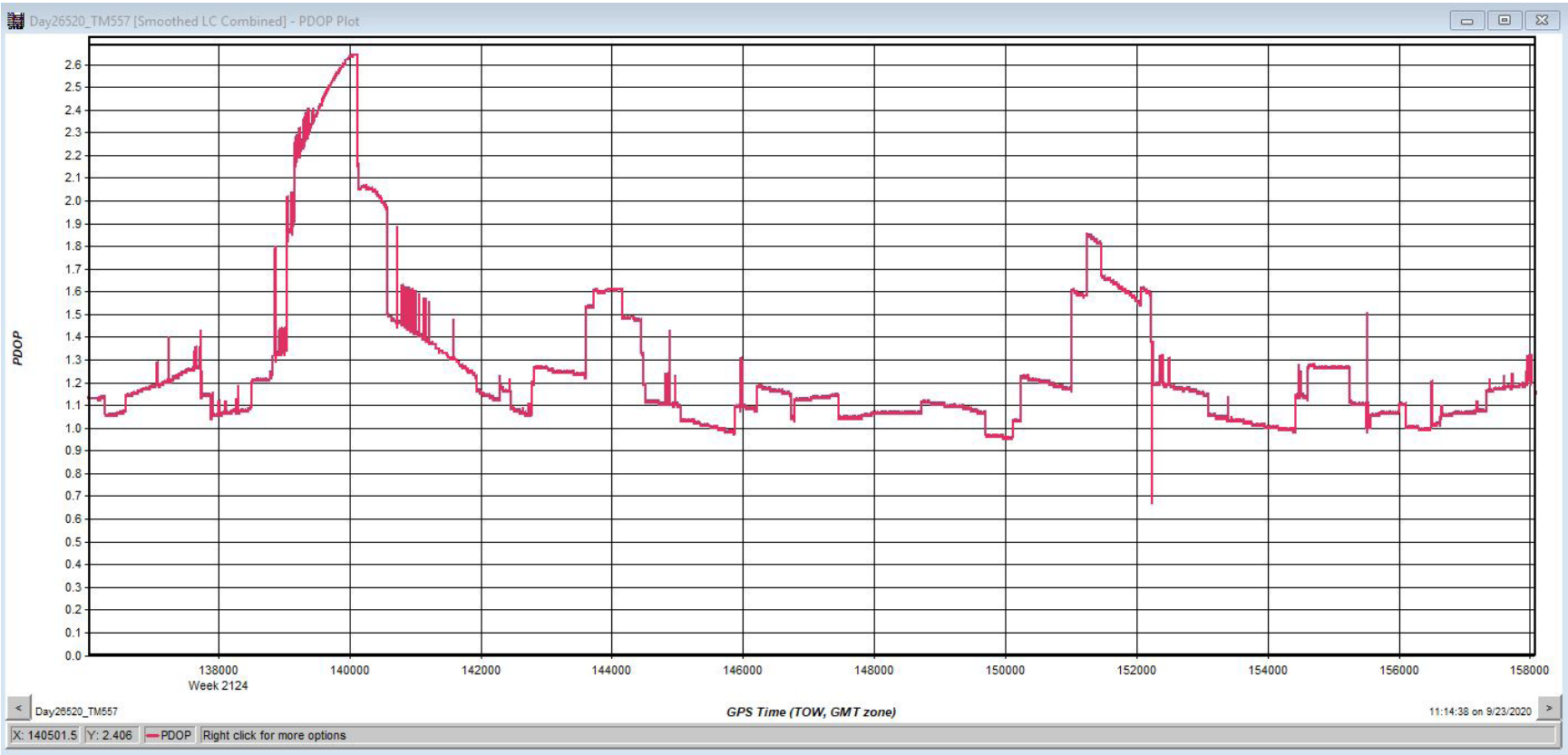
Day26520_TM557_A
Forward/Reverse or Combined Separation Plot



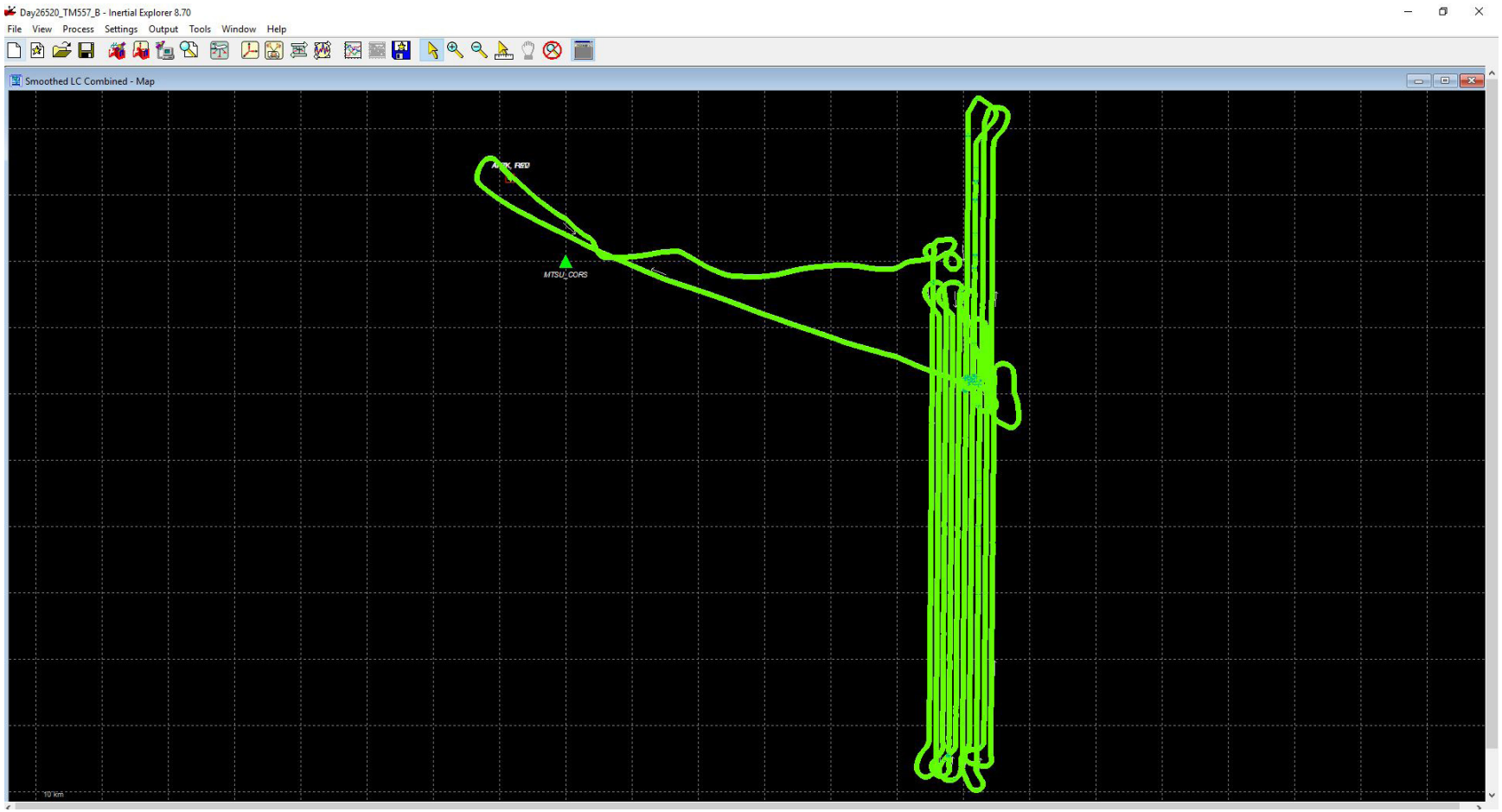
Day26520_TM557_A
Estimated Position Accuracy



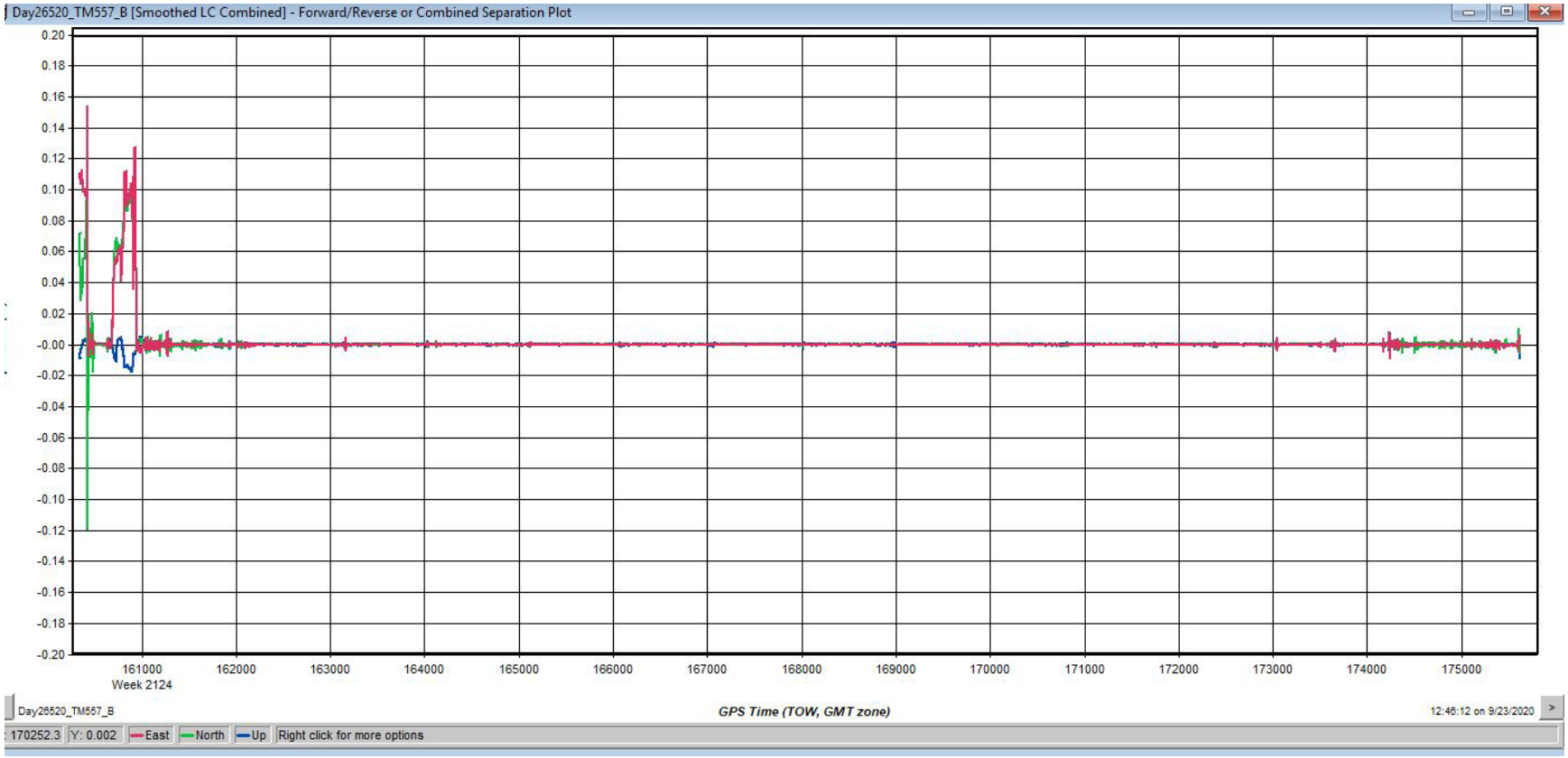
Day26520_TM557_A
PDOP Plot



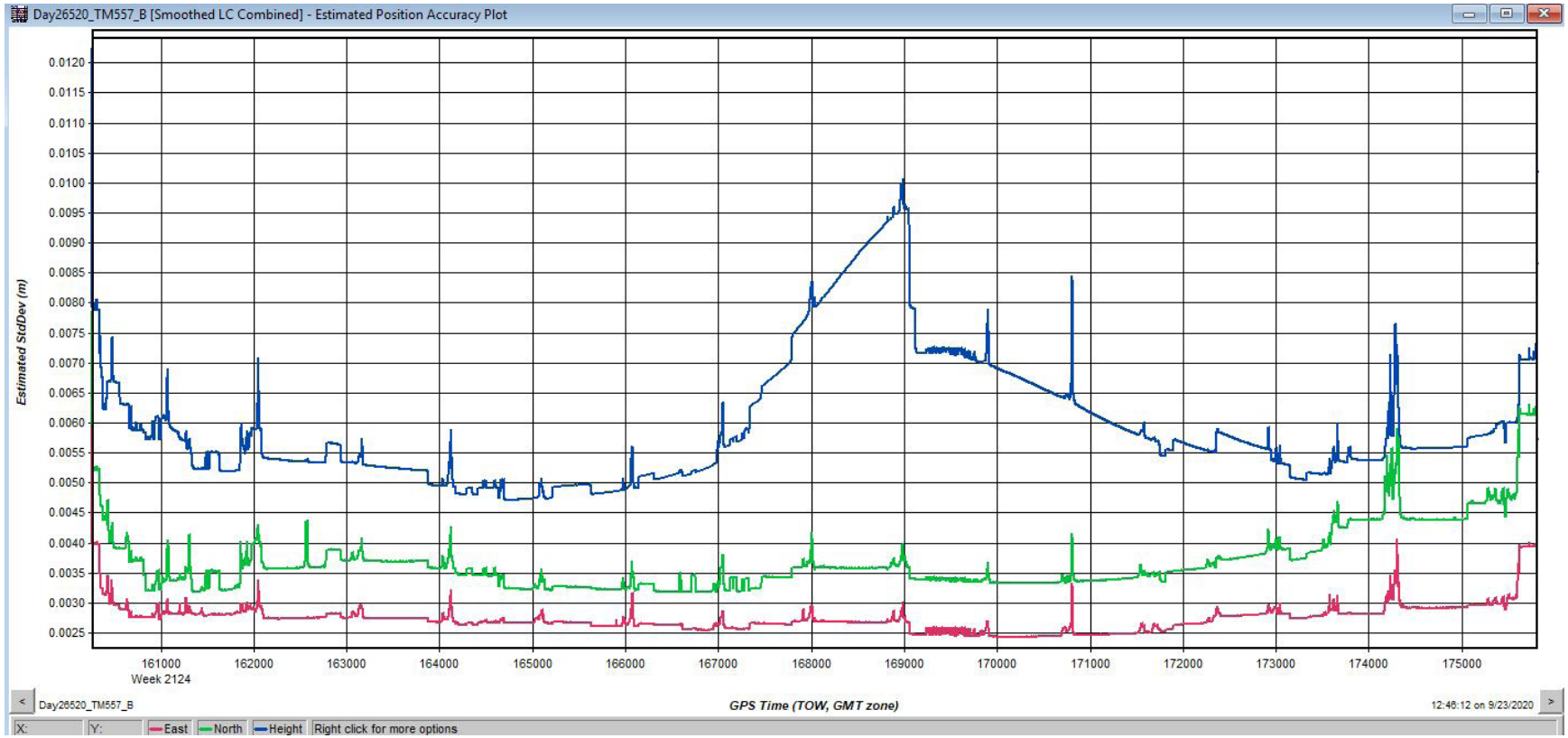
Day26520_TM557_B
Trajectory



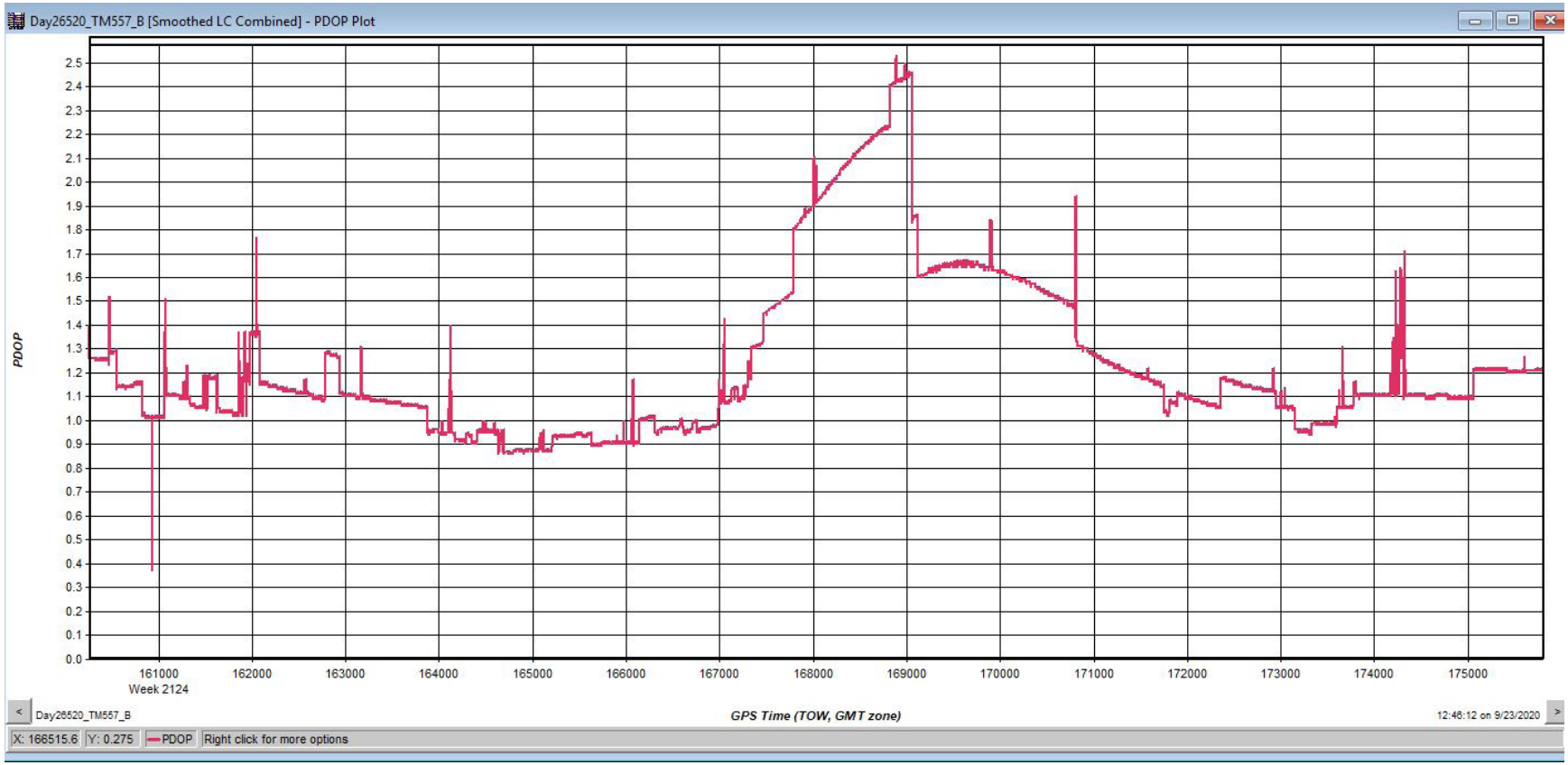
Day26520_TM557_B
Forward/Reverse or Combined Separation Plot



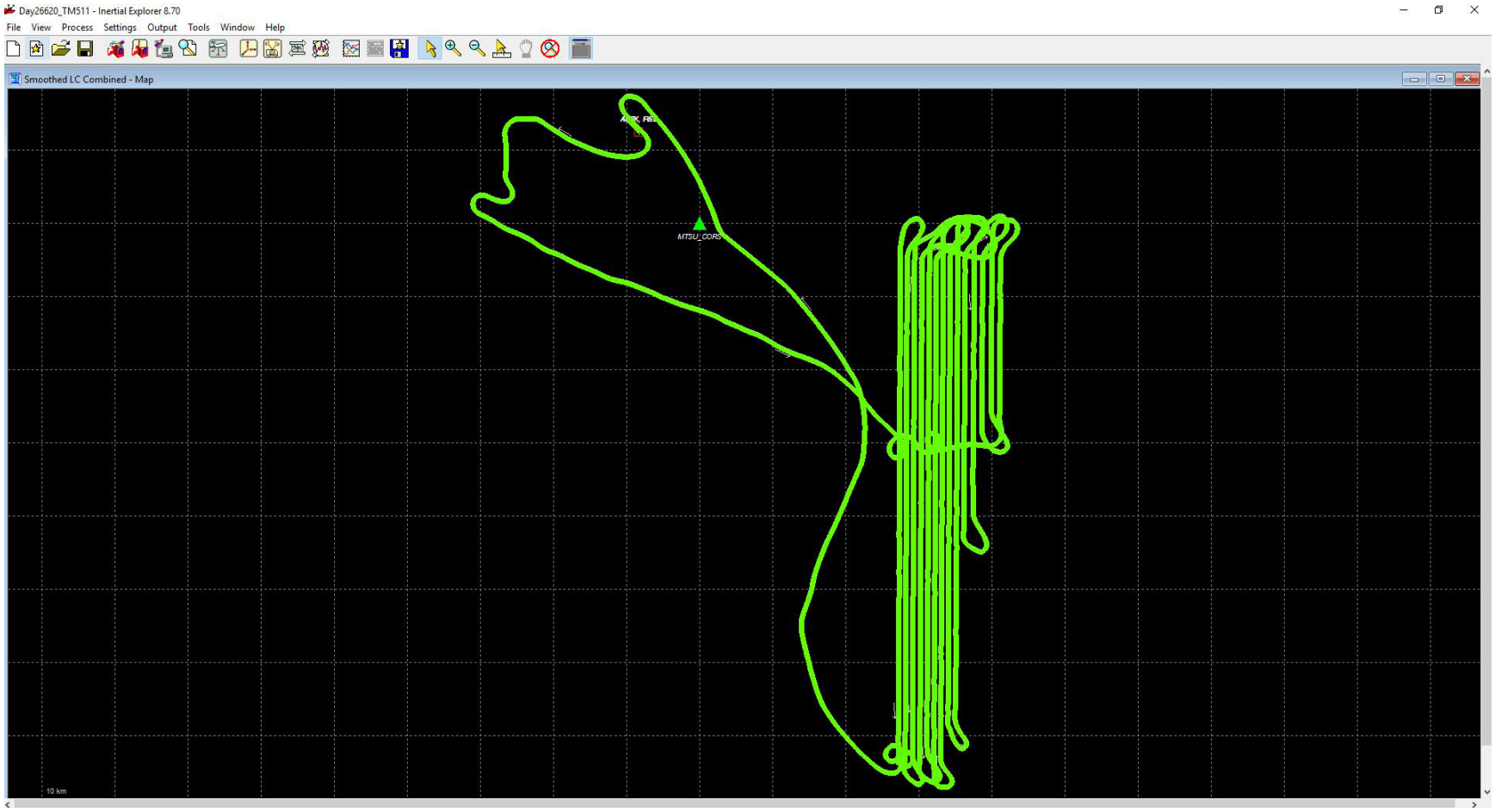
Day26520_TM557_B
Estimated Position Accuracy



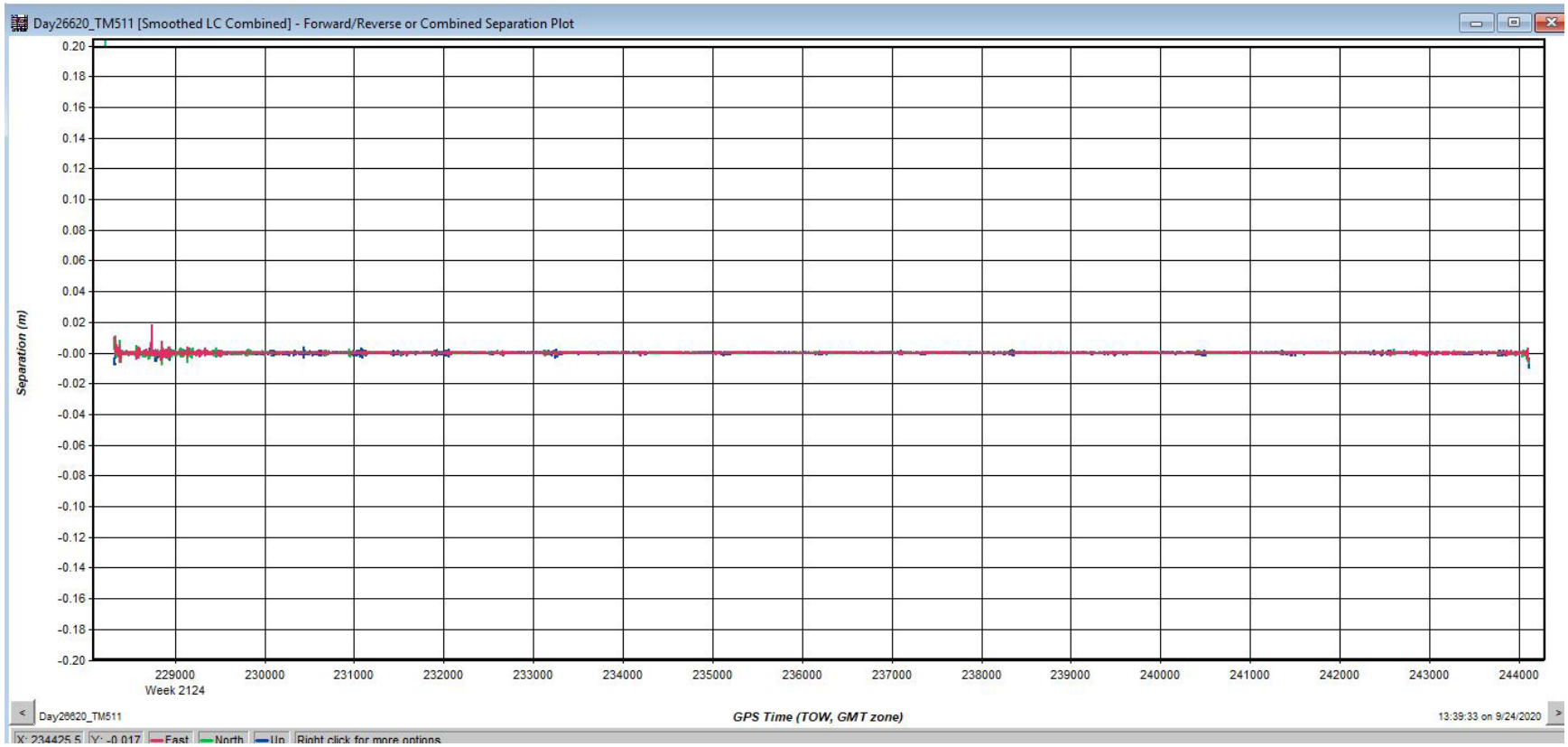
Day26520_TM557_B
PDOP Plot



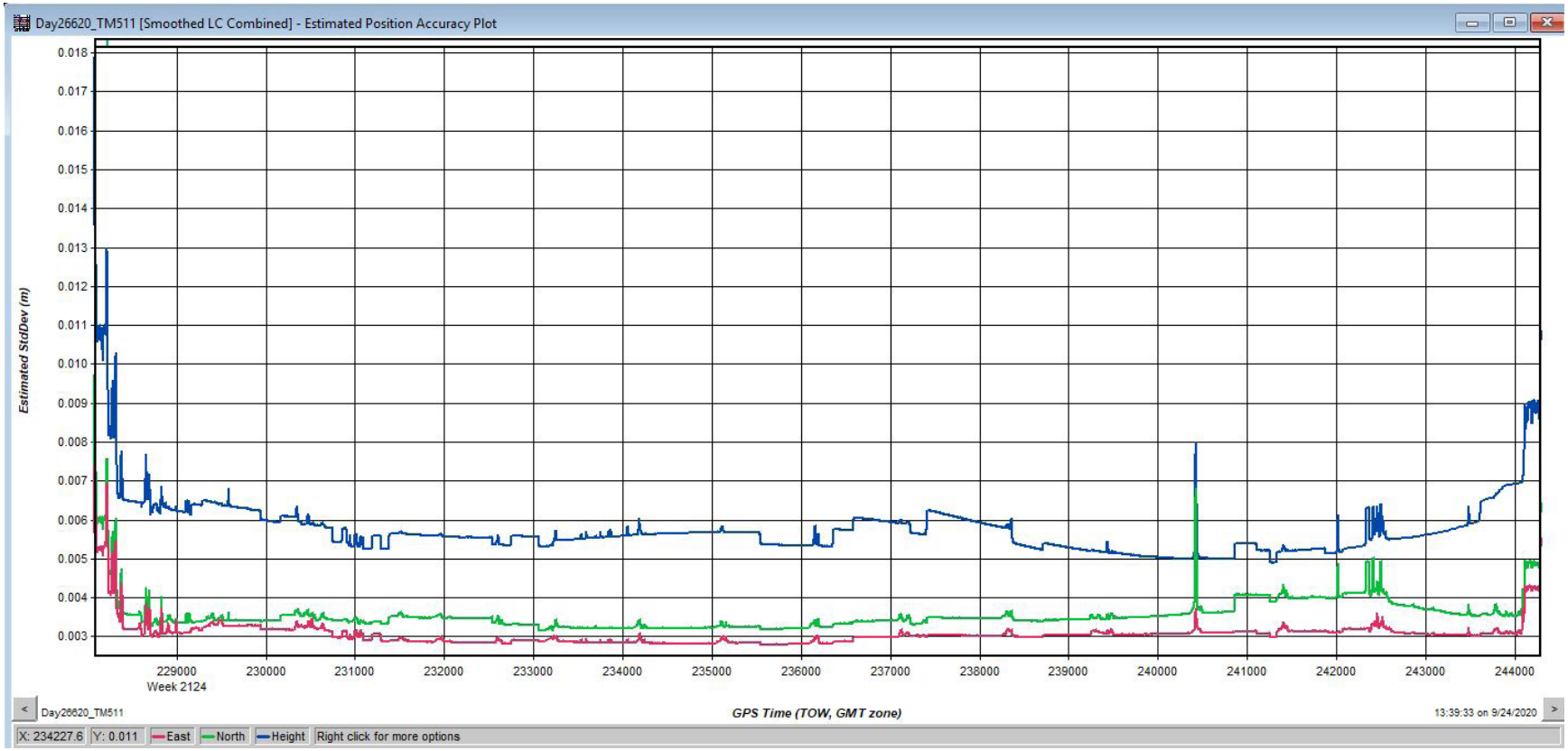
Day26620_TM511
Trajectory



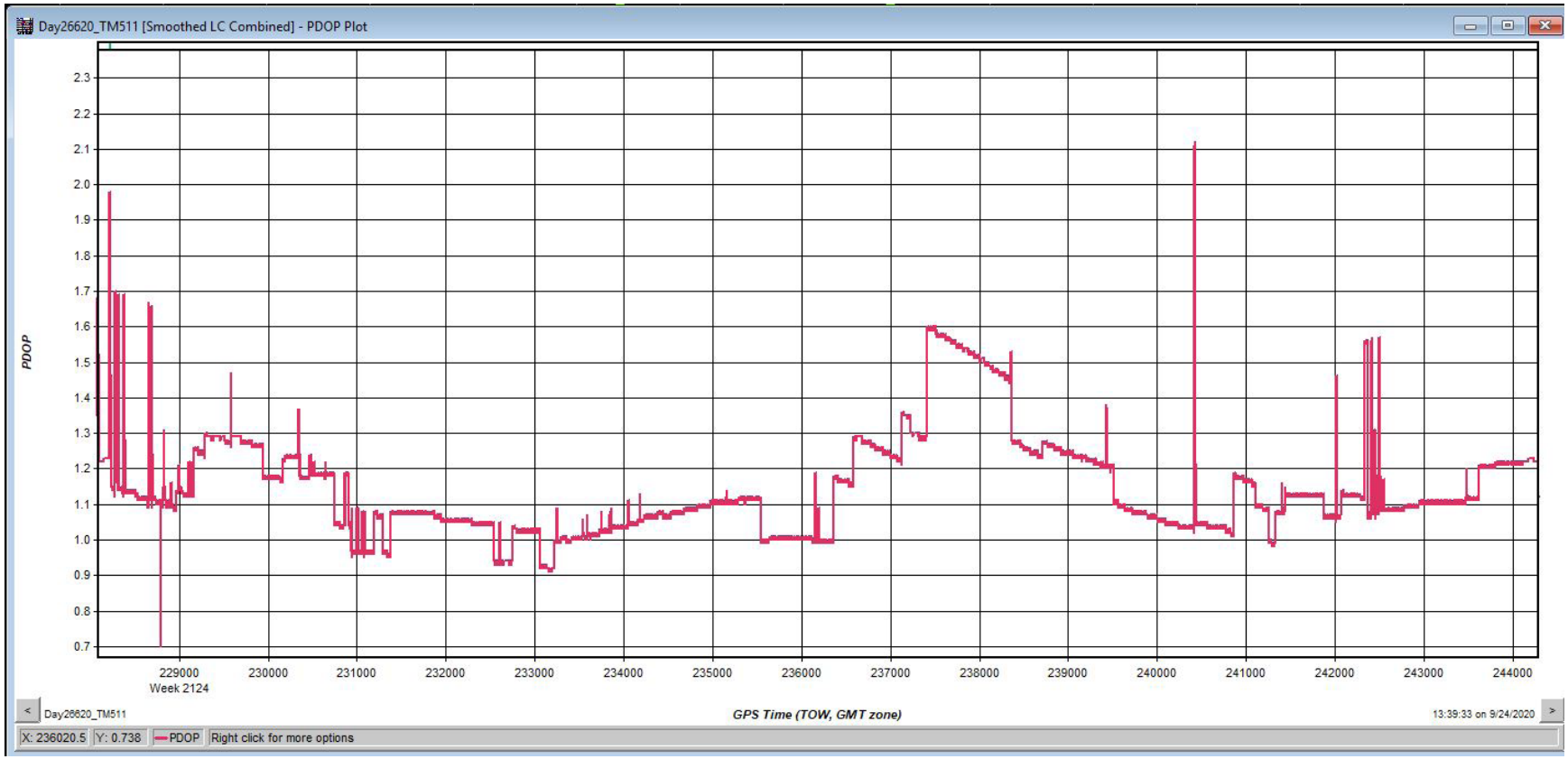
Day26620_TM511
Forward/Reverse or Combined Separation Plot



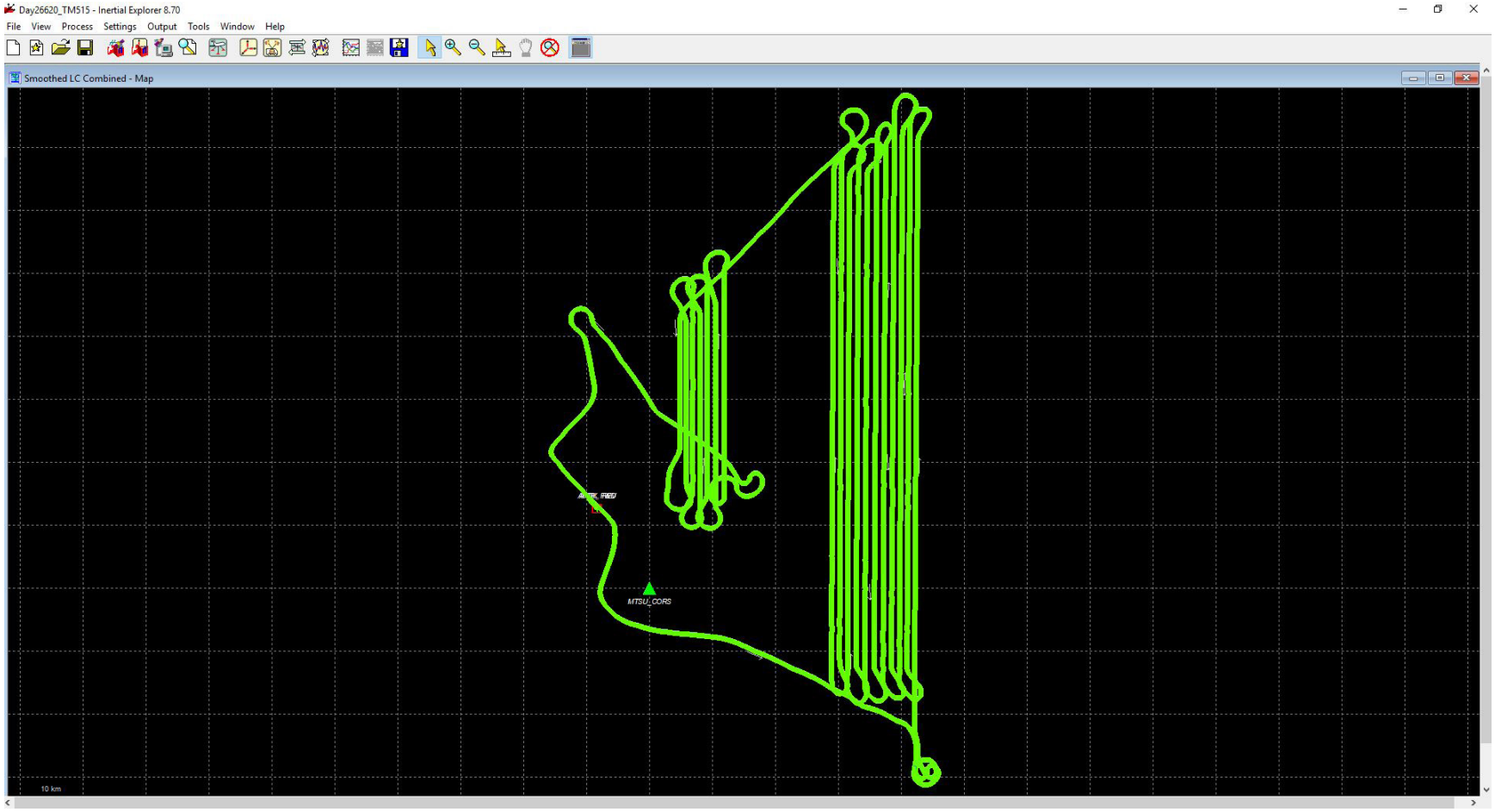
Day26620_TM511
Estimated Position Accuracy



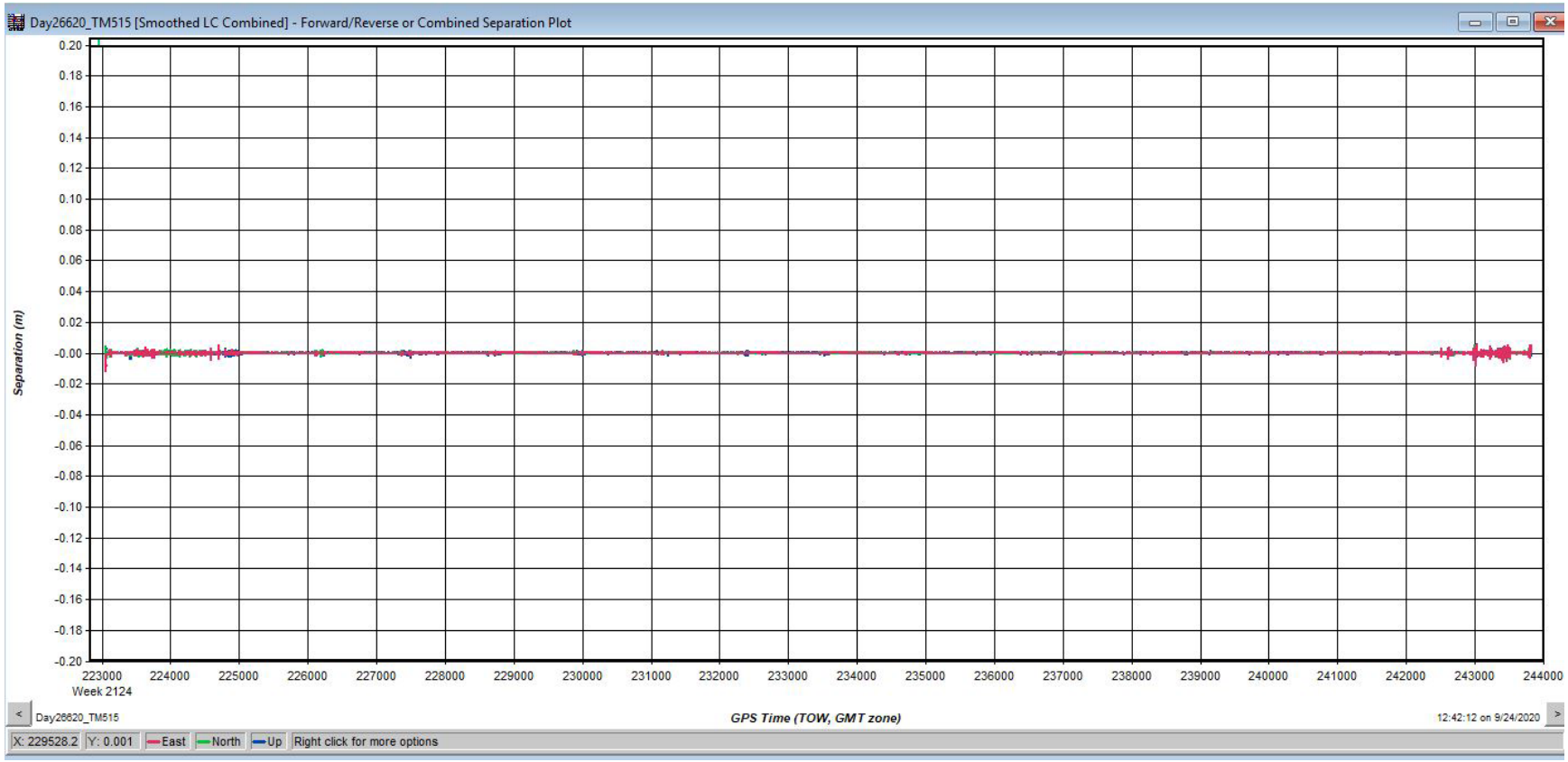
Day26620_TM511
PDOP Plot



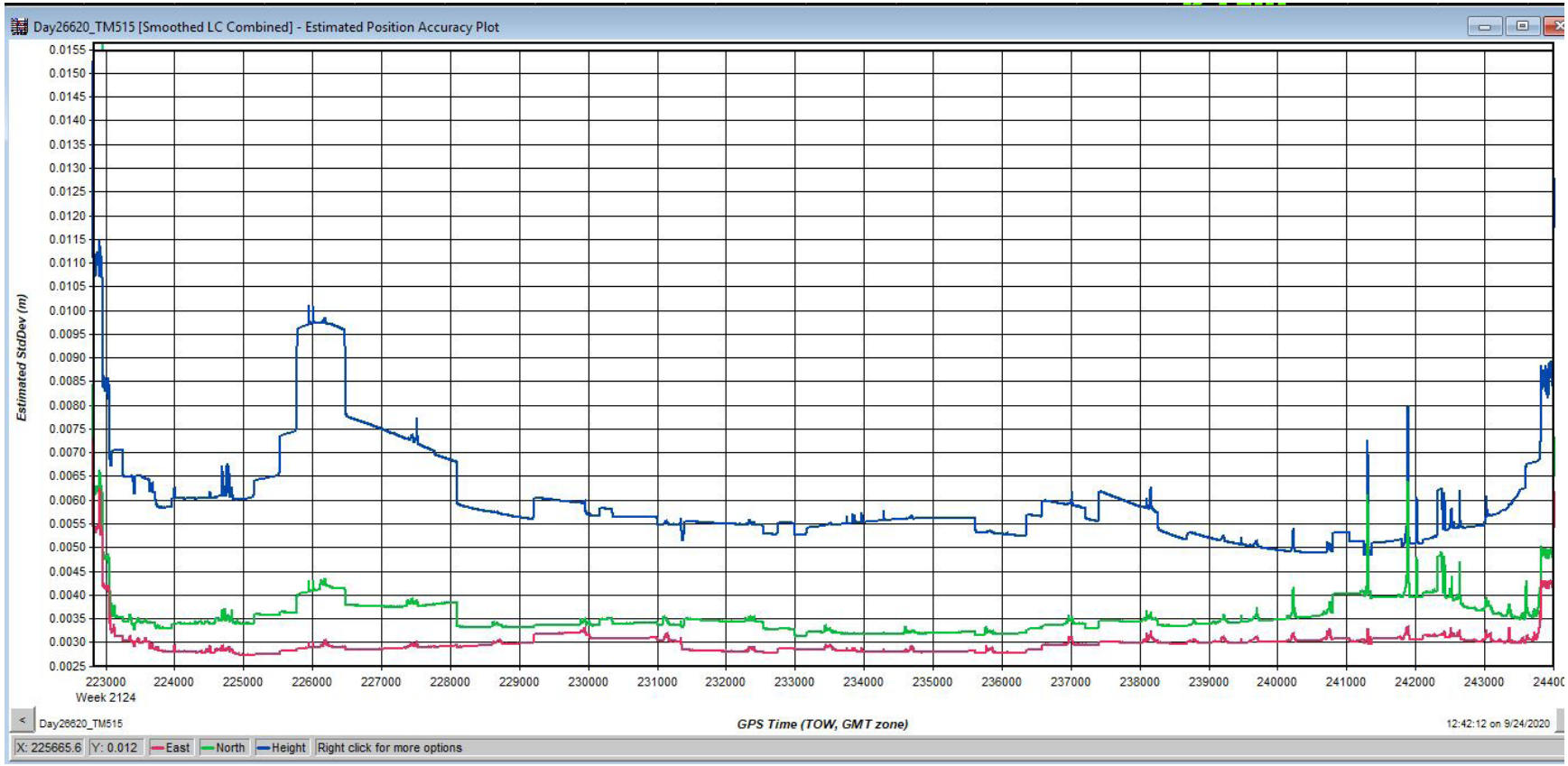
Day26620_TM515
Trajectory



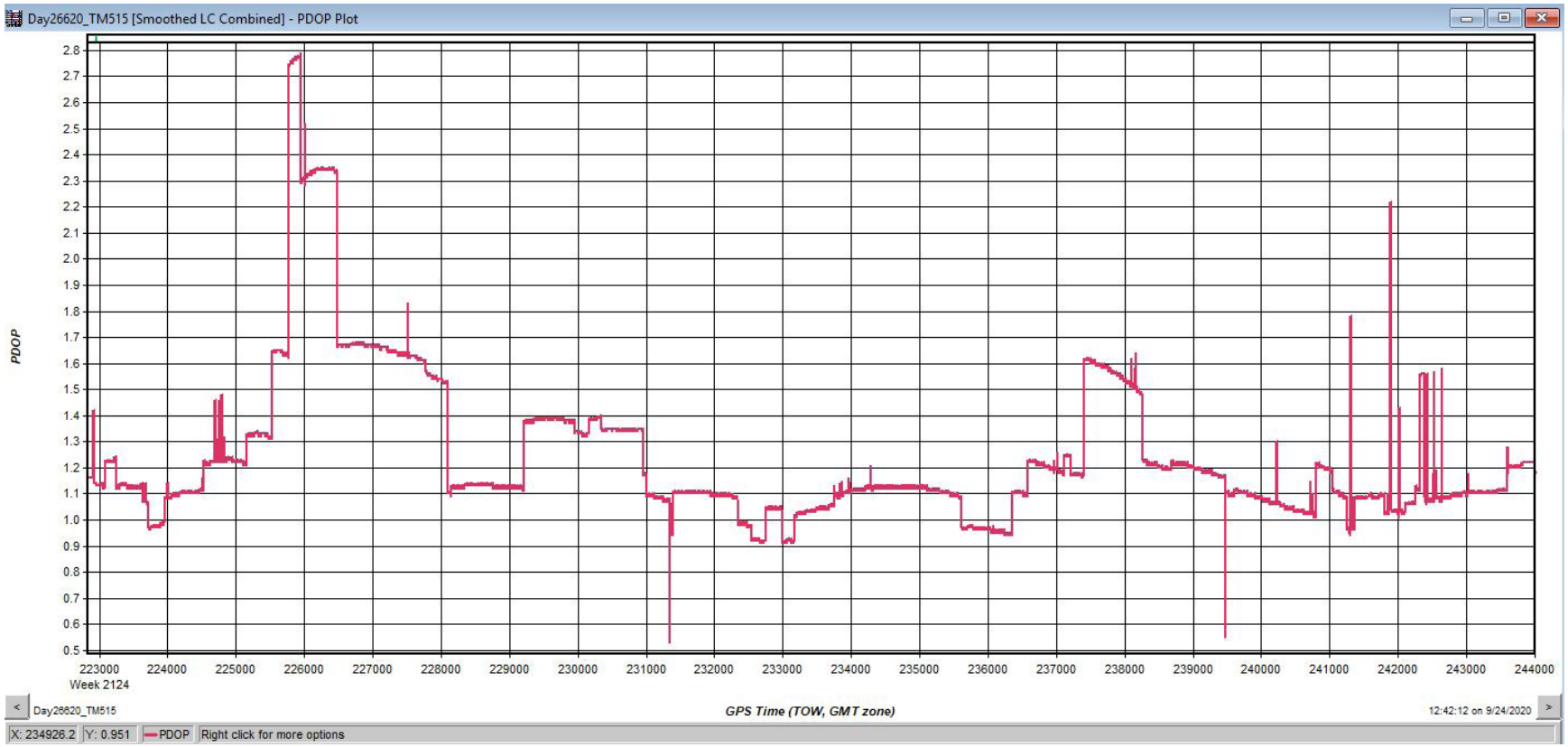
Day26620_TM515
Forward/Reverse or Combined Separation Plot



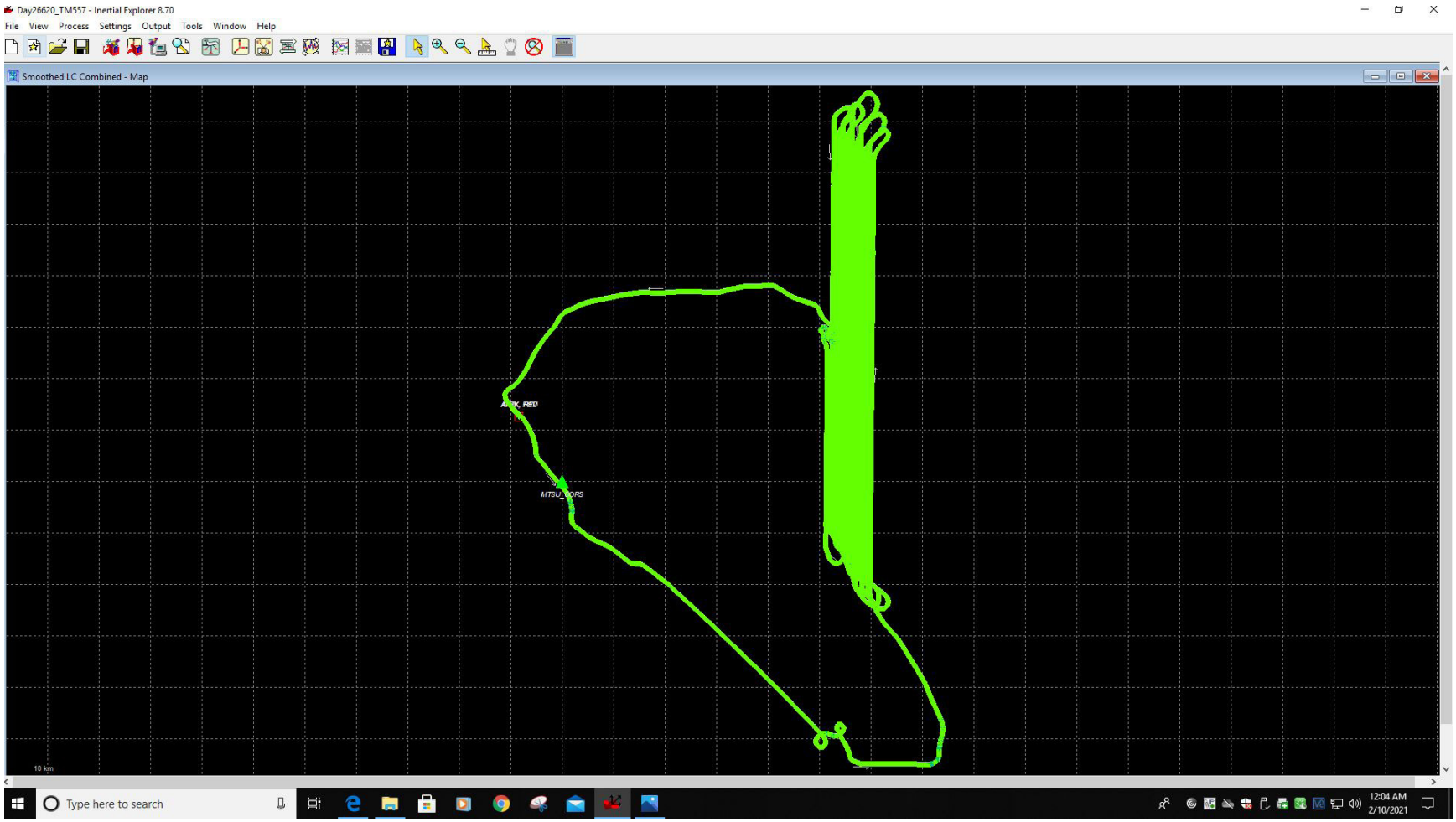
Day26620_TM515
Estimated Position Accuracy



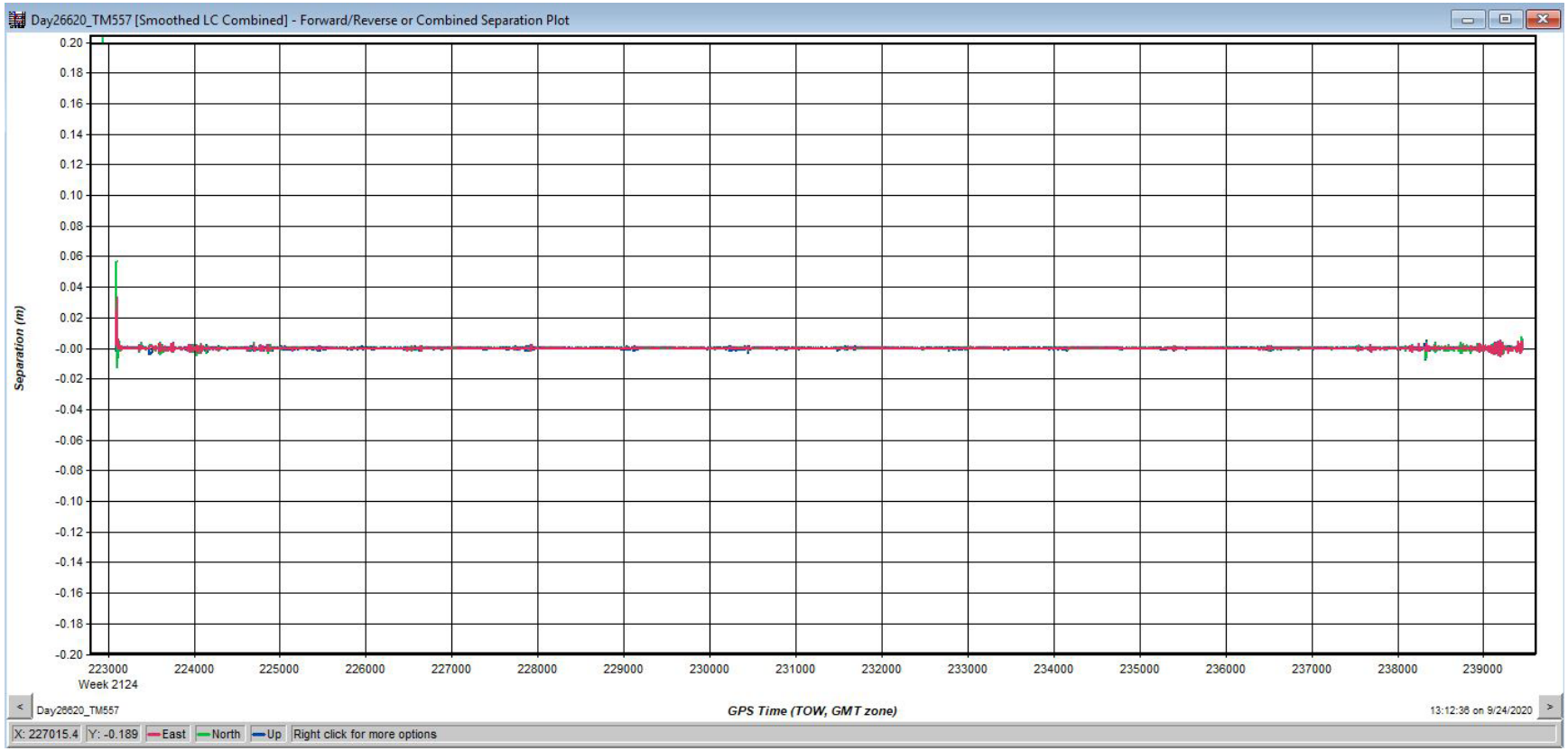
Day26620_TM515
PDOP Plot



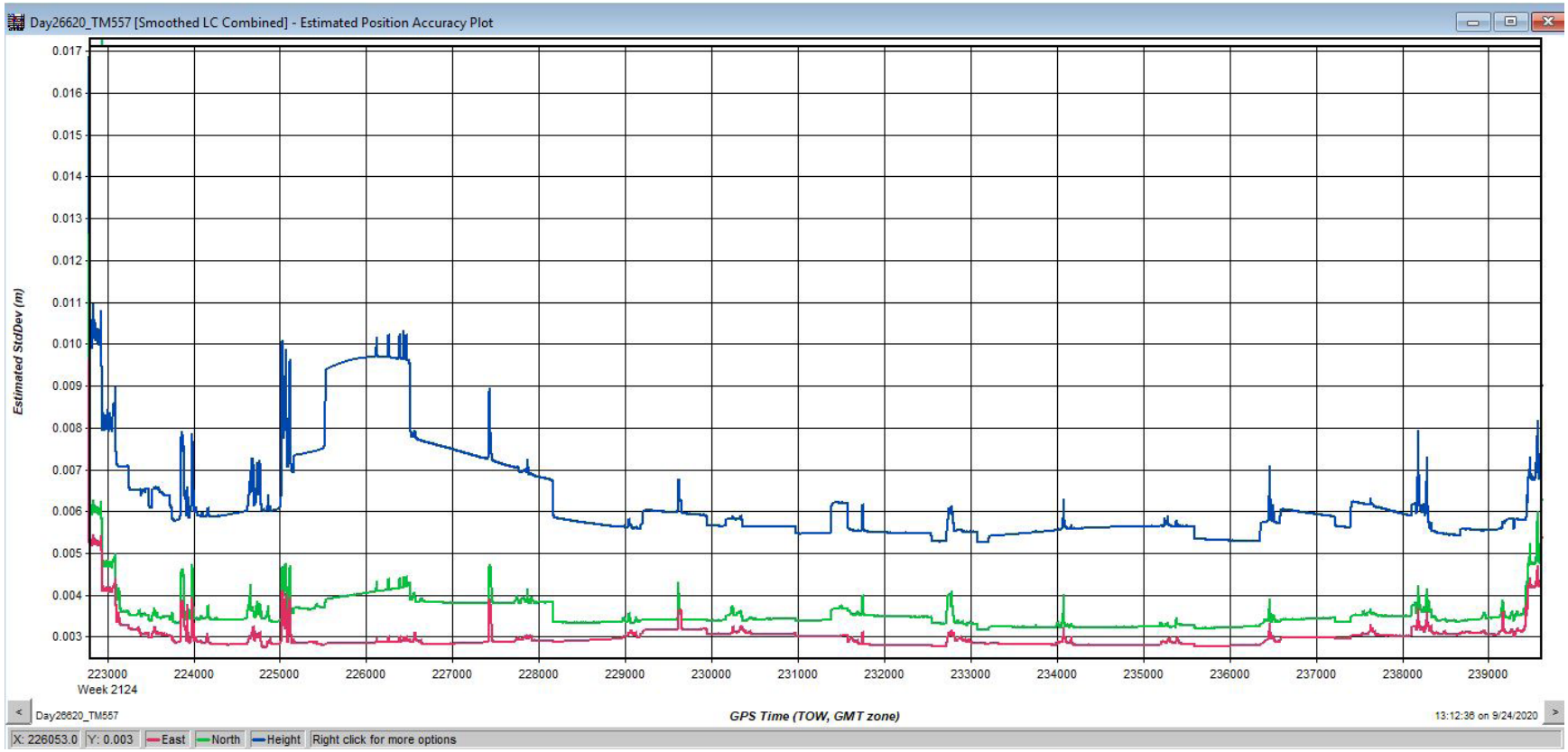
Day26620_TM557
Trajectory



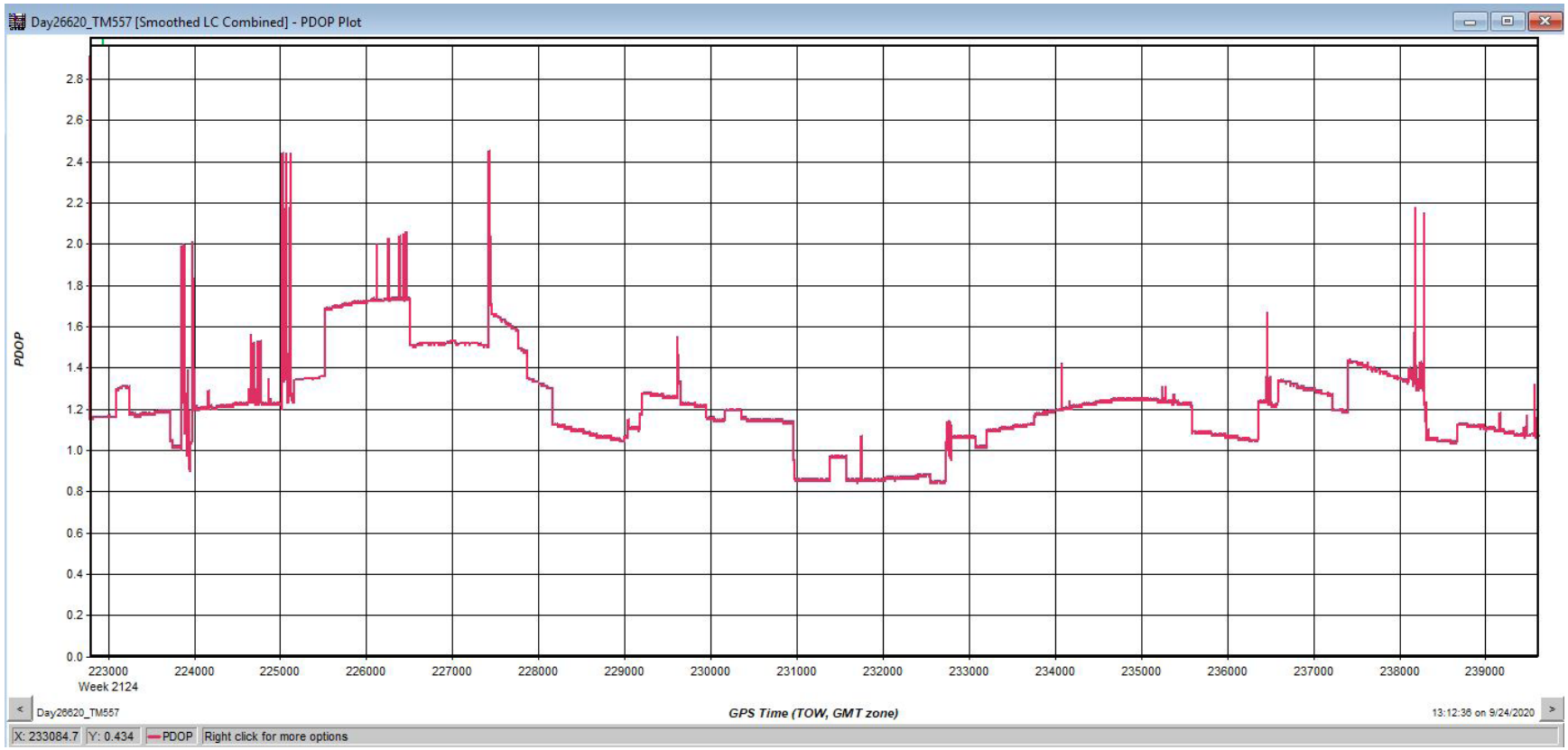
Day26620_TM557
Forward/Reverse or Combined Separation Plot



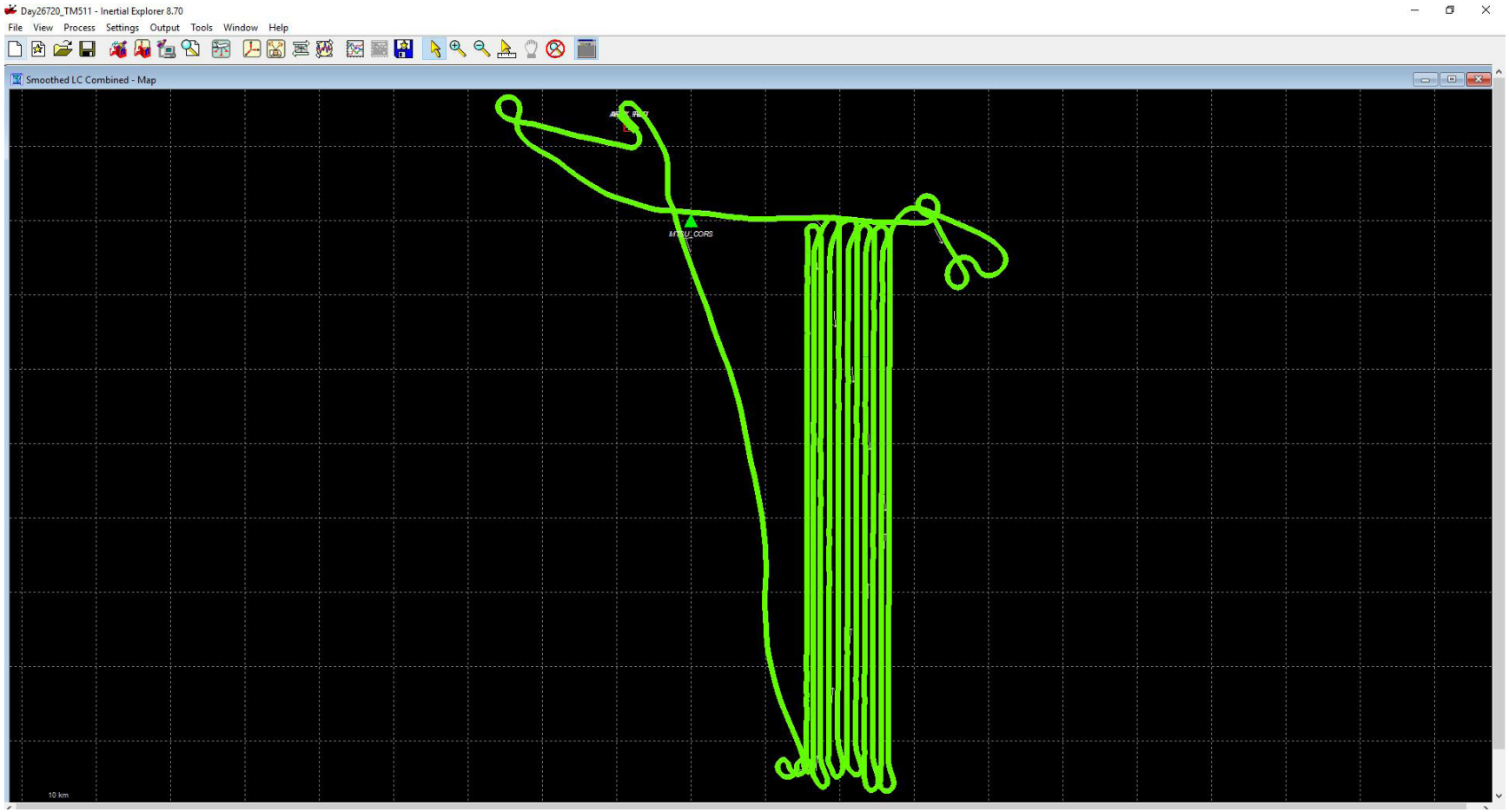
Day26620_TM557
Estimated Position Accuracy



Day26620_TM557
PDOP Plot

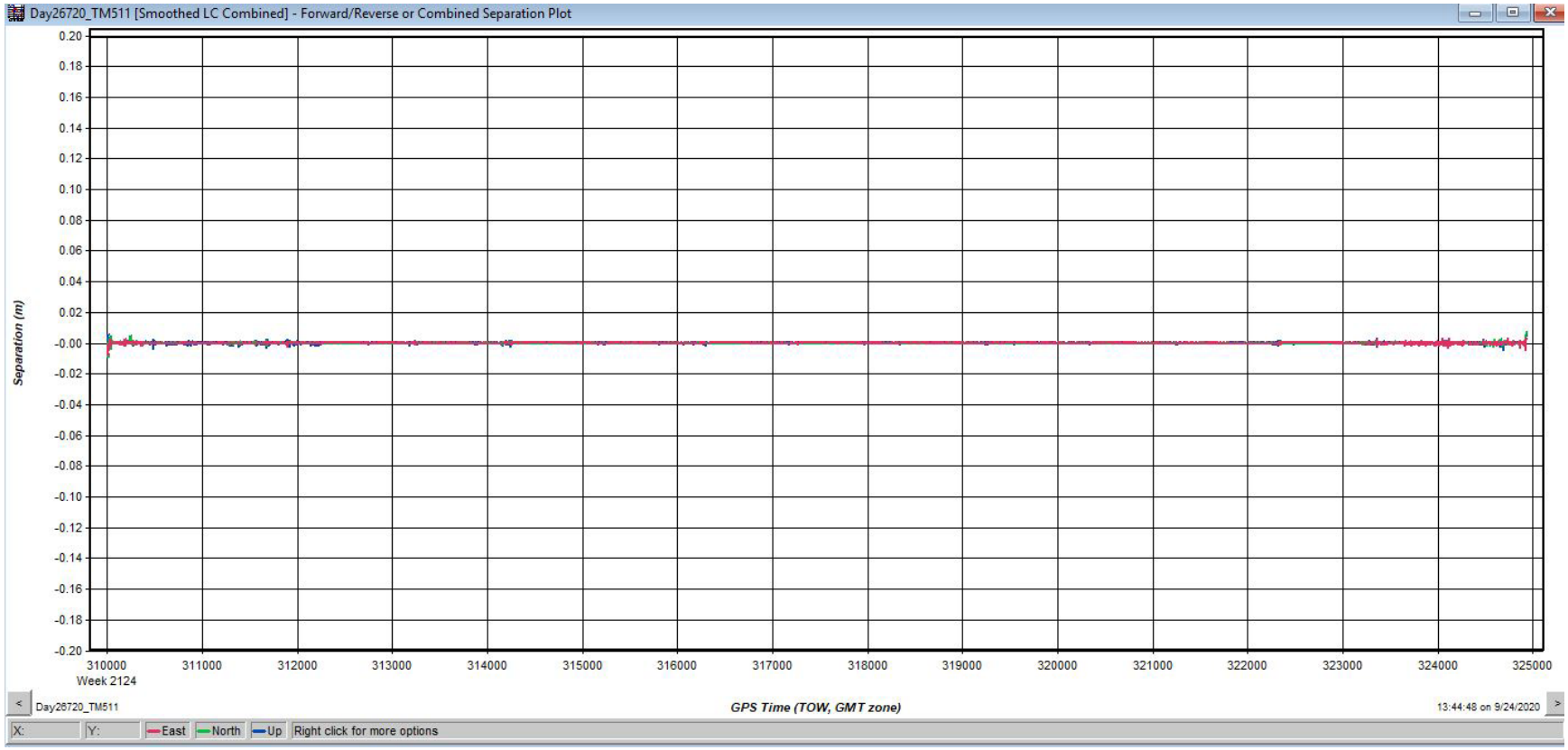


Day26720_TM511
Trajectory

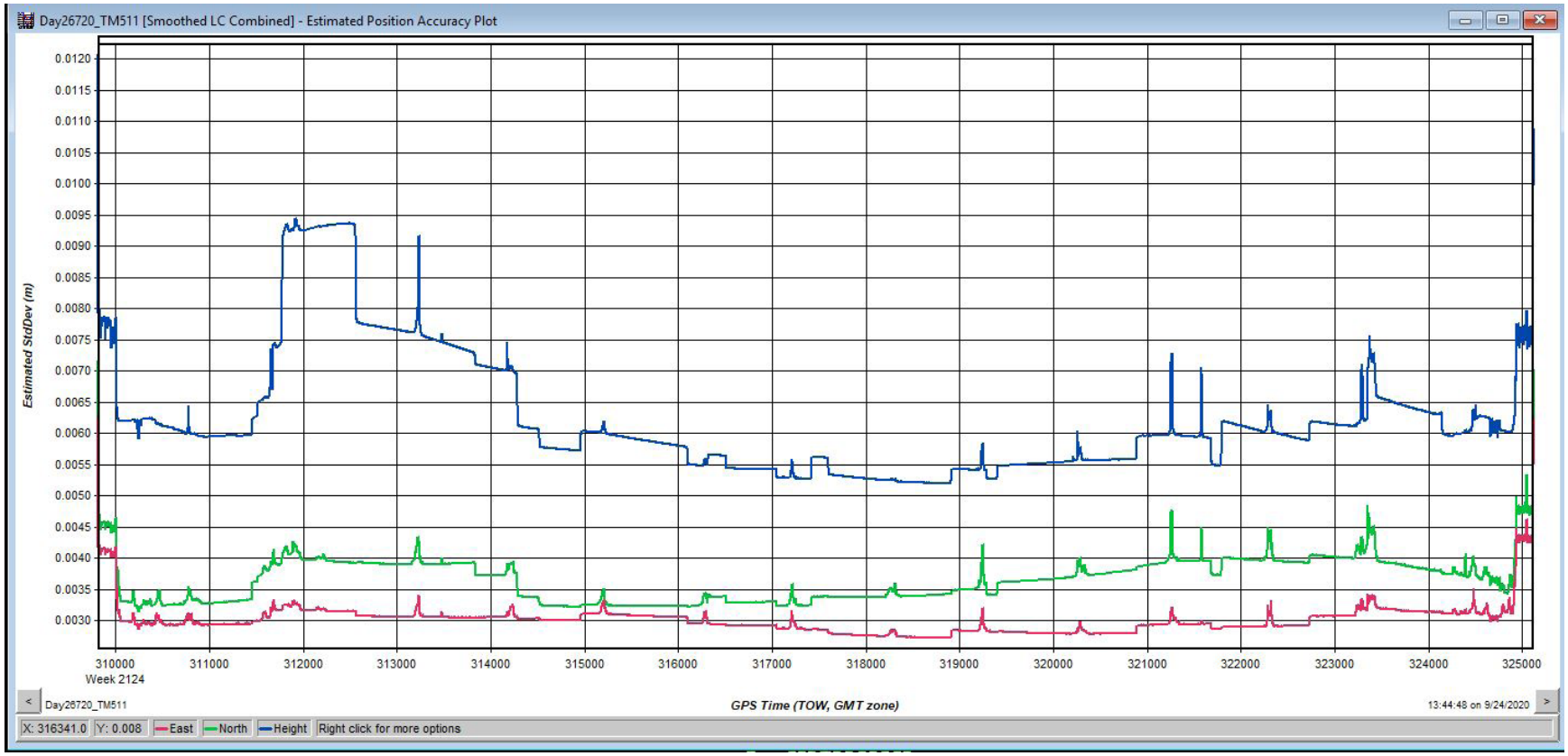


Day26720_TM511

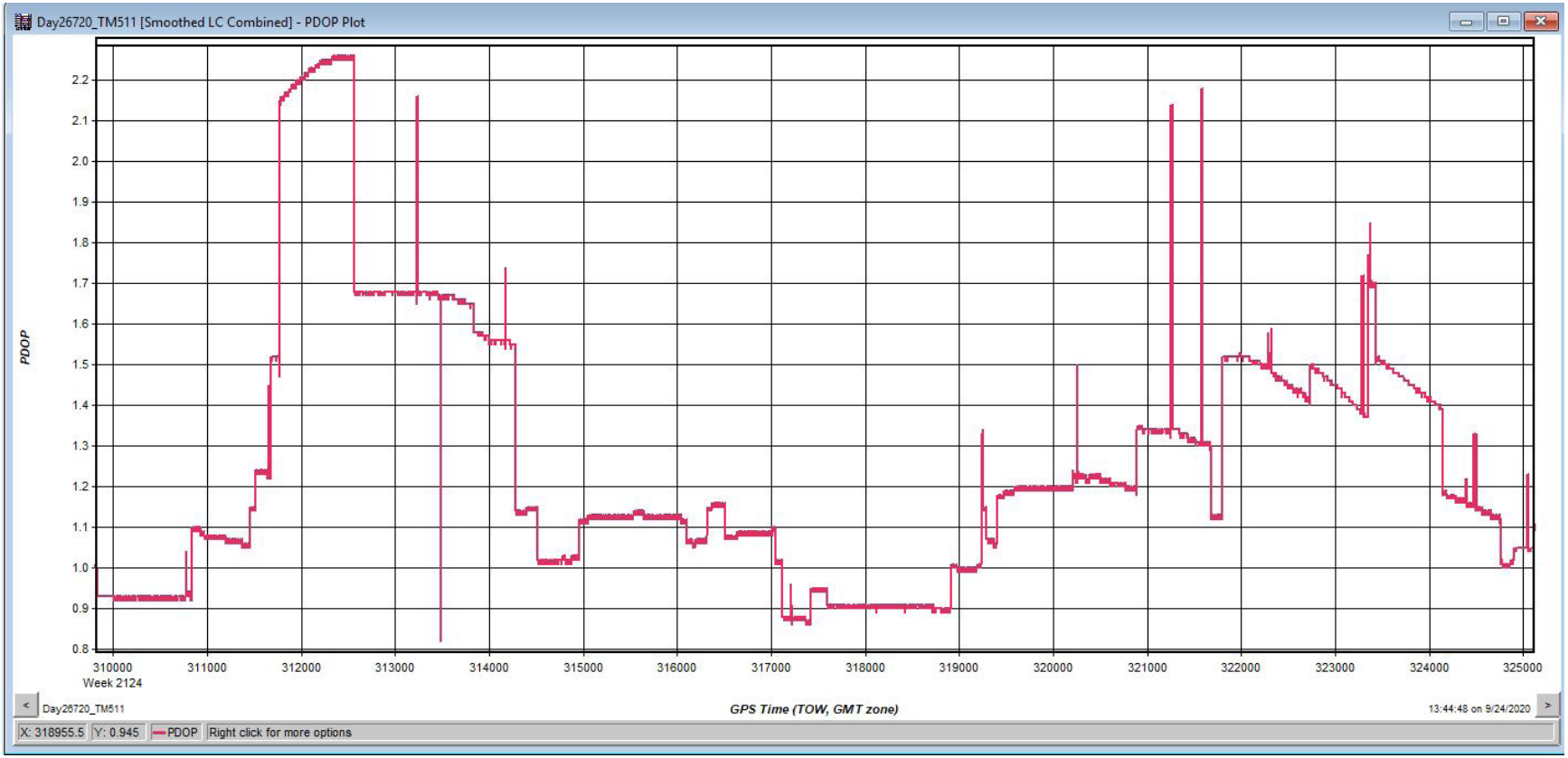
Forward/Reverse or Combined Separation Plot



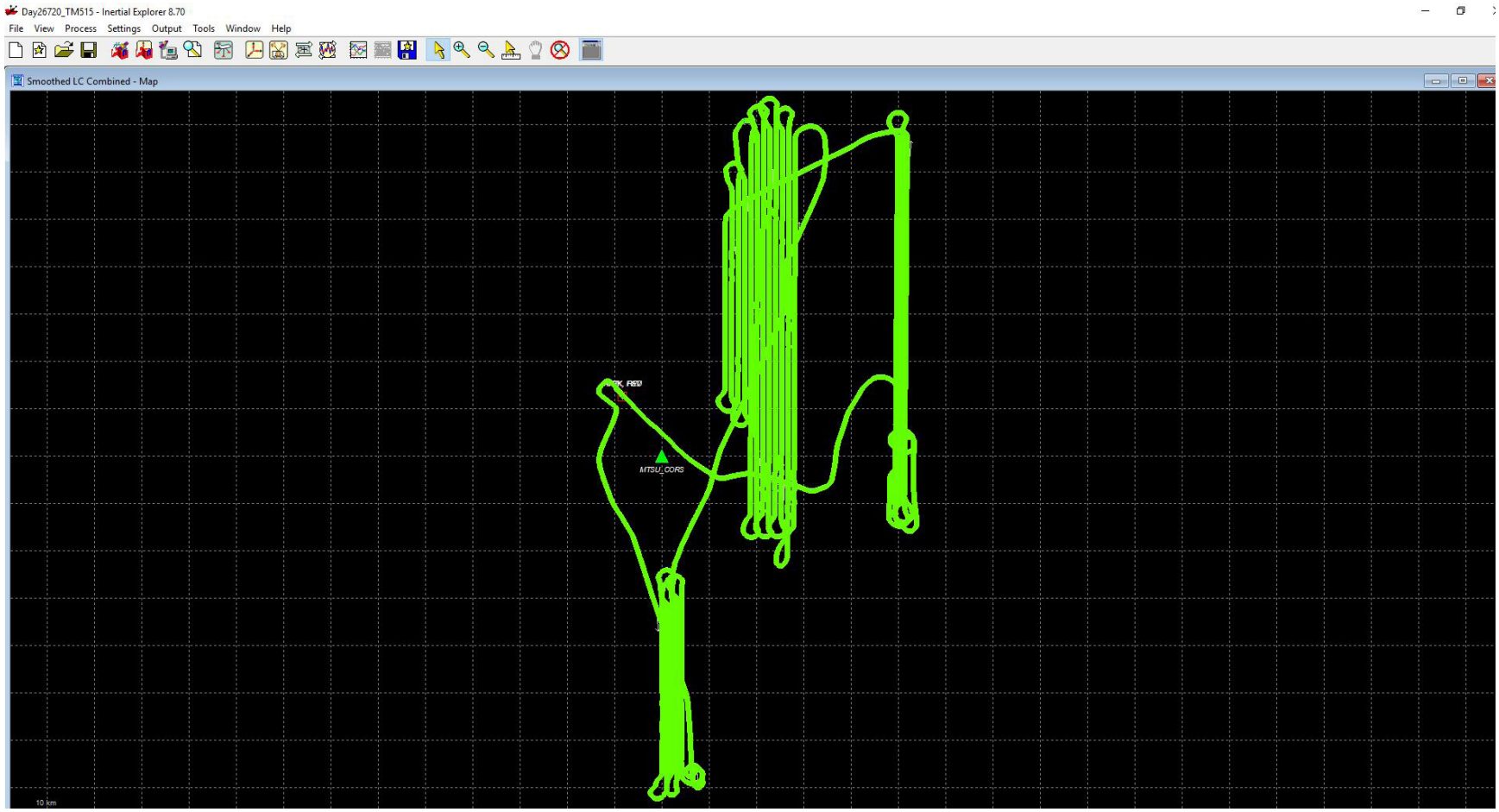
Day26720_TM511
Estimated Position Accuracy



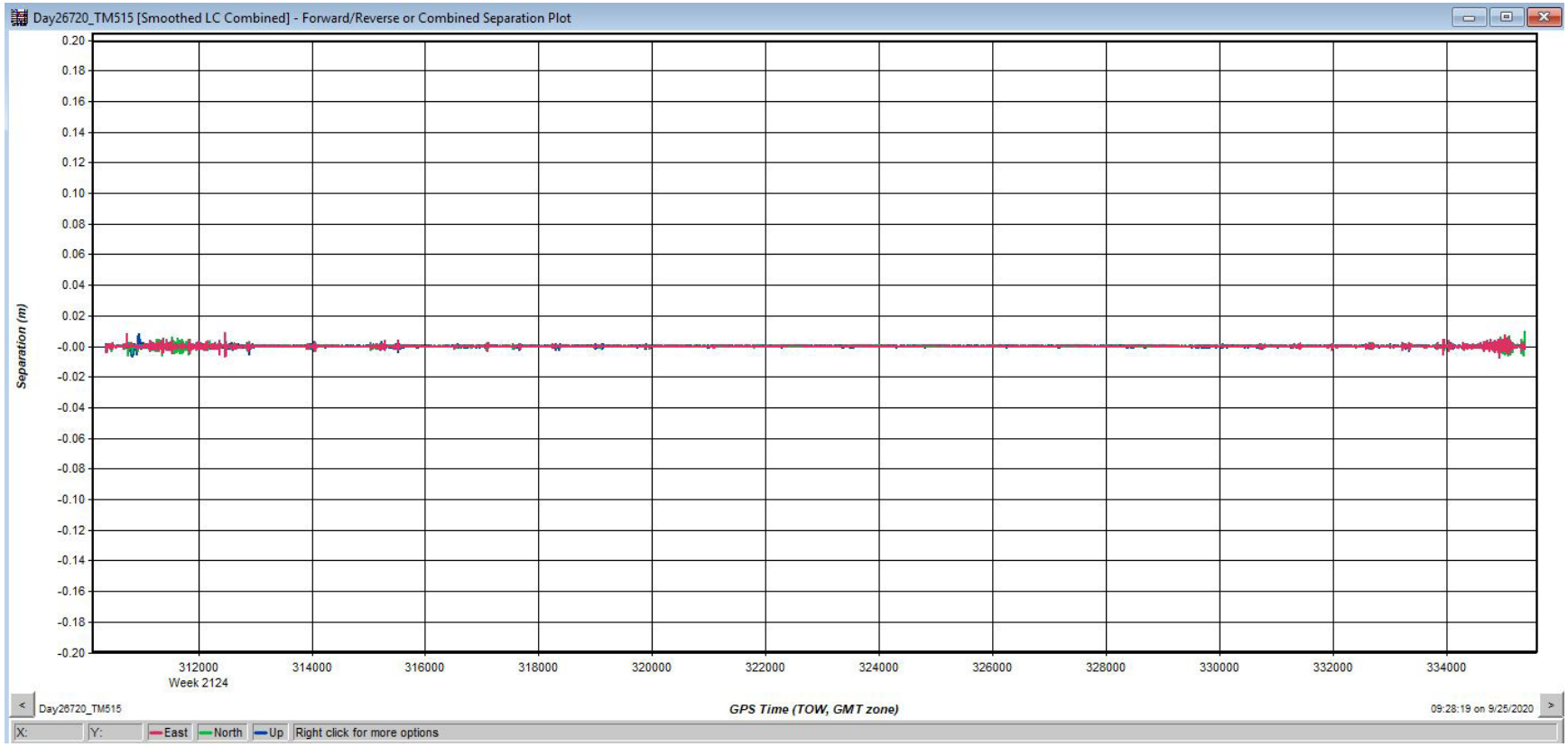
Day26720_TM511
PDOP Plot



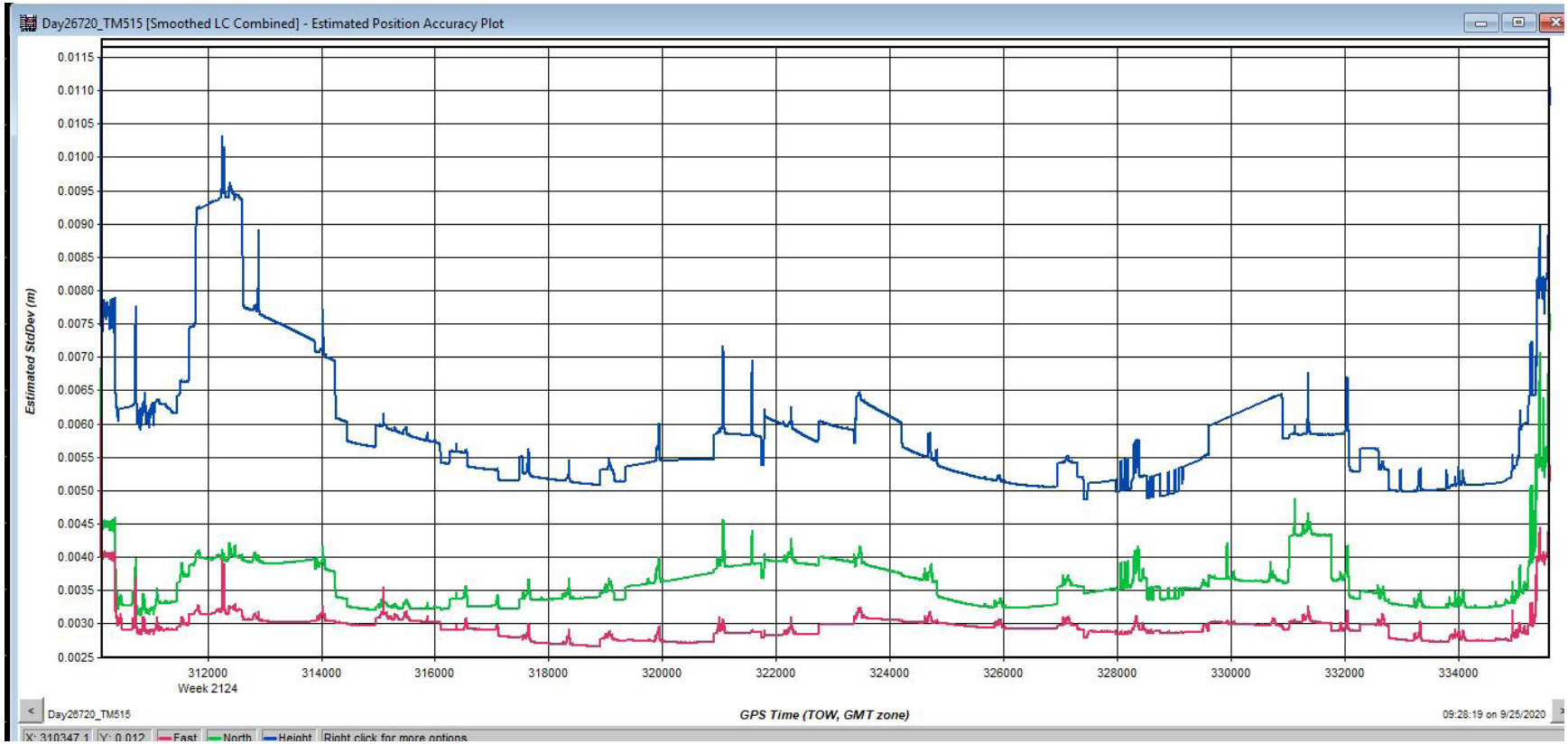
Day26720_TM515
Trajectory



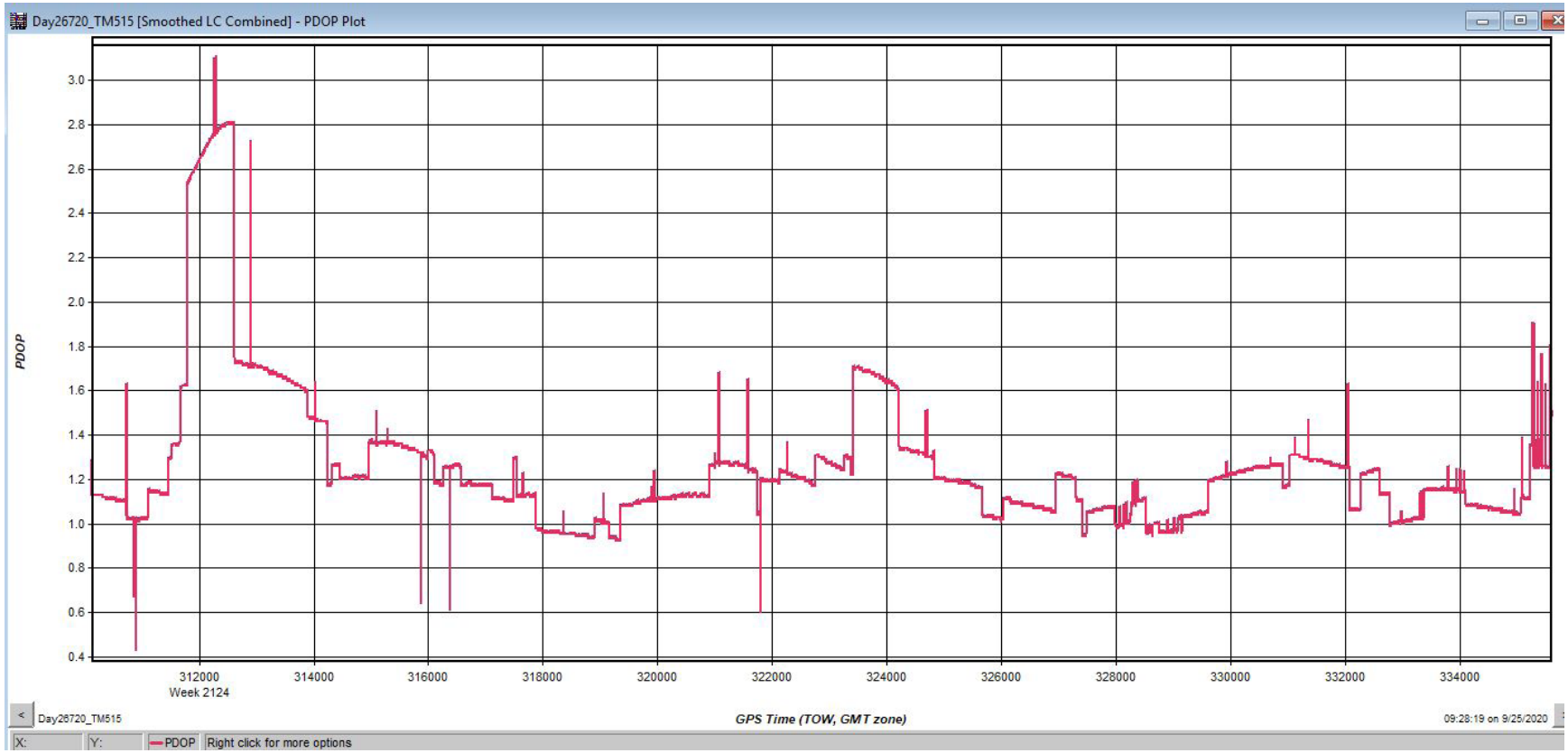
Day26720_TM515
Forward/Reverse or Combined Separation Plot



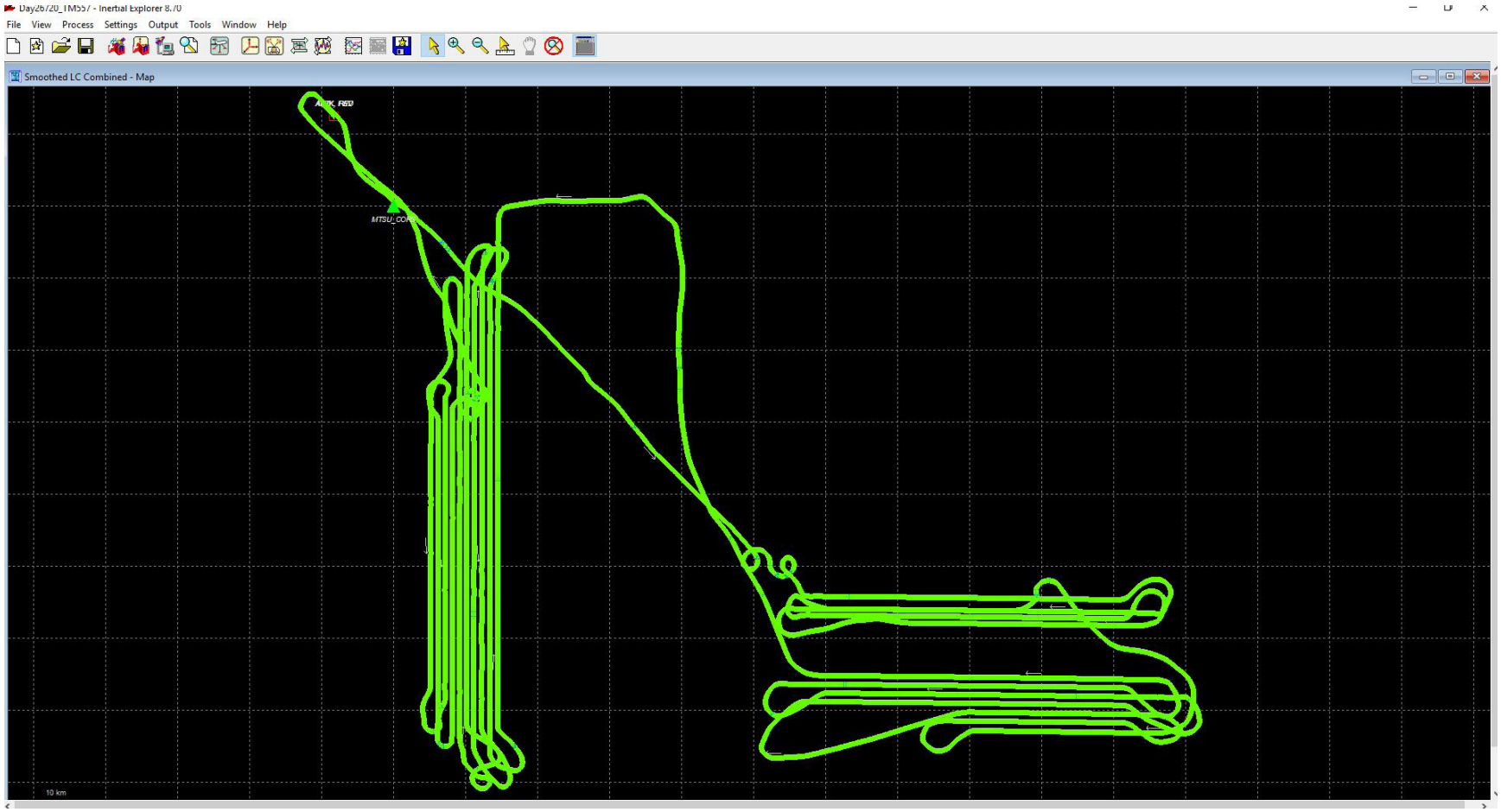
Day26720_TM515
Estimated Position Accuracy



Day26720_TM515
PDOP Plot

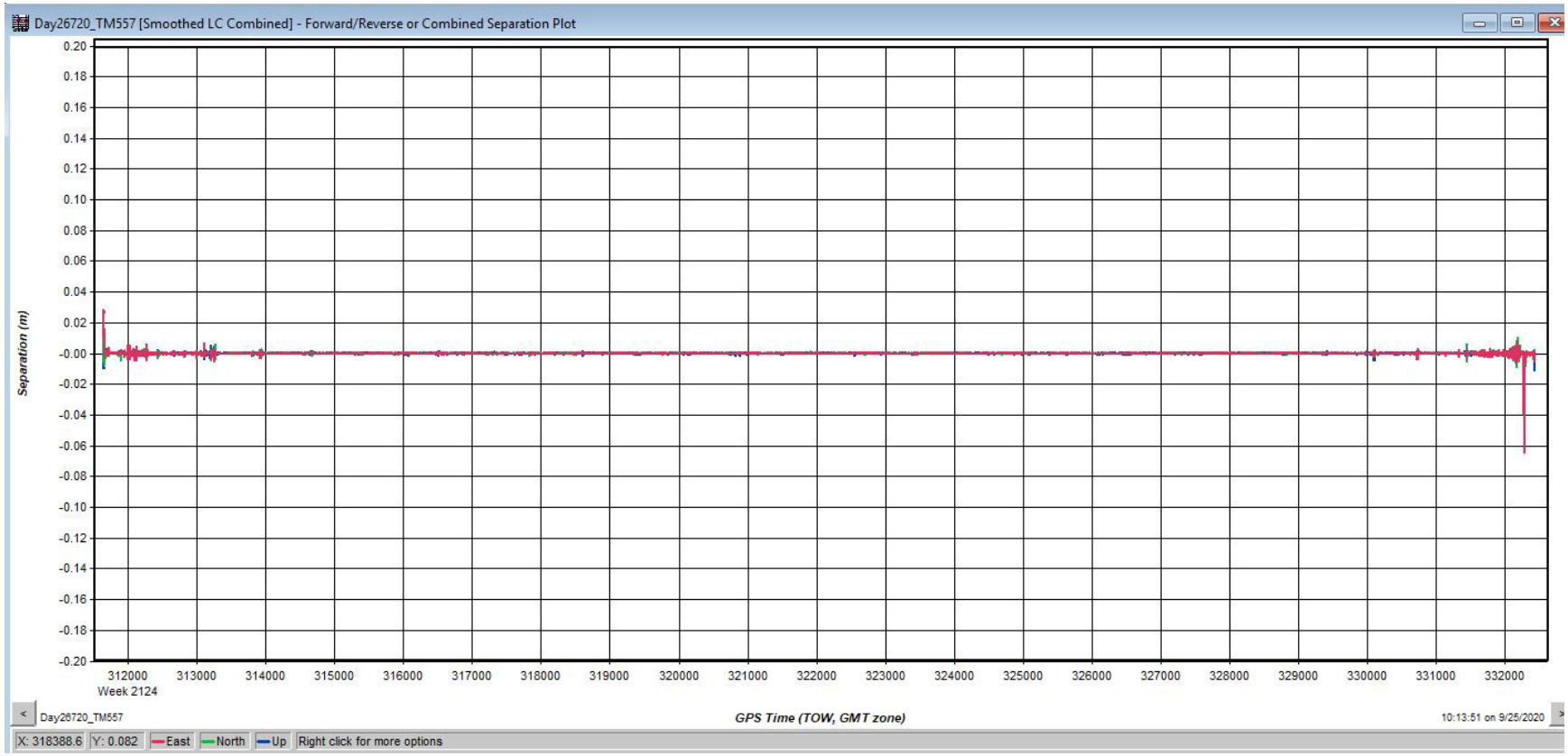


Day26720_TM557
Trajectory

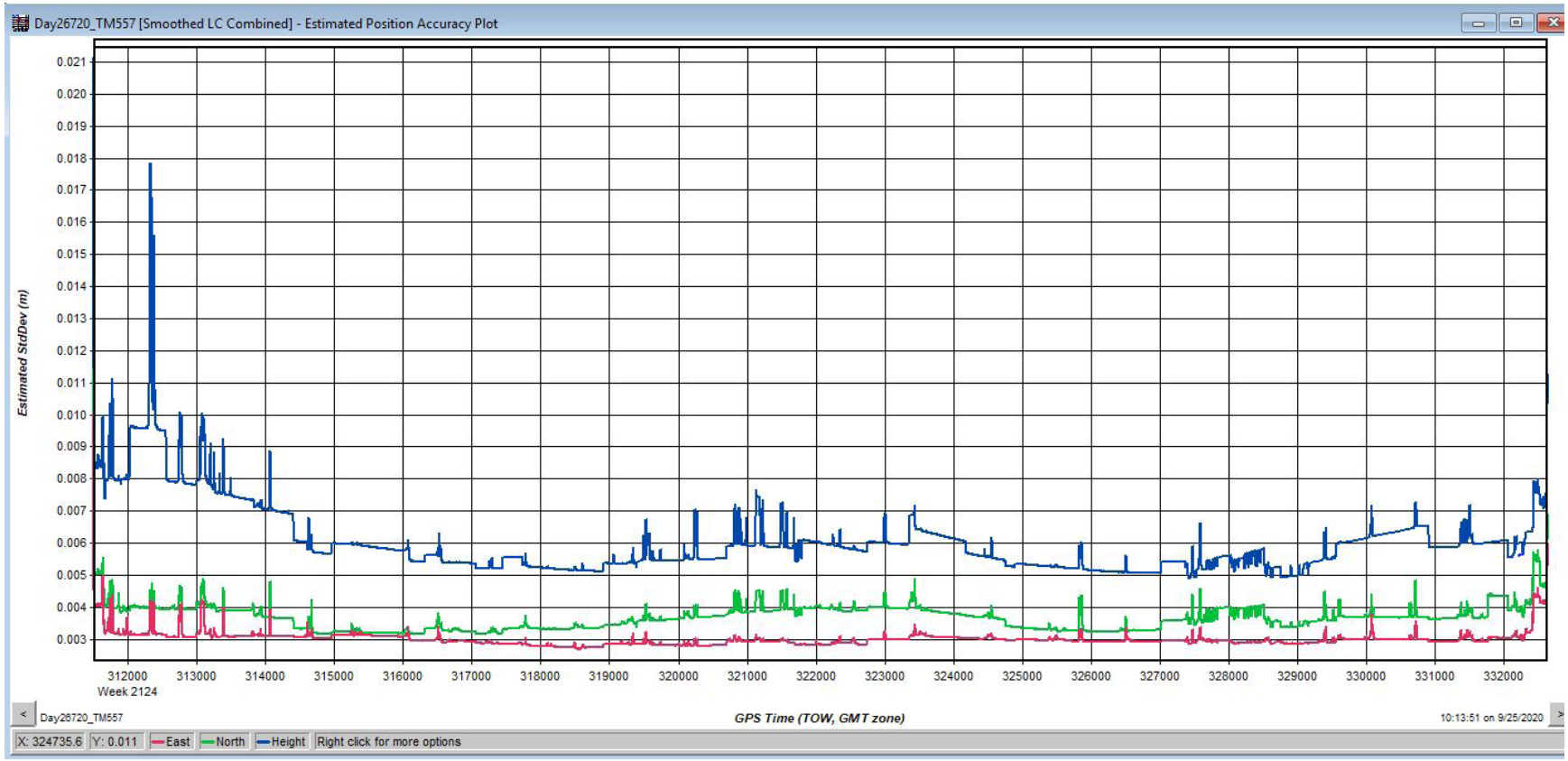


Day26720_TM557

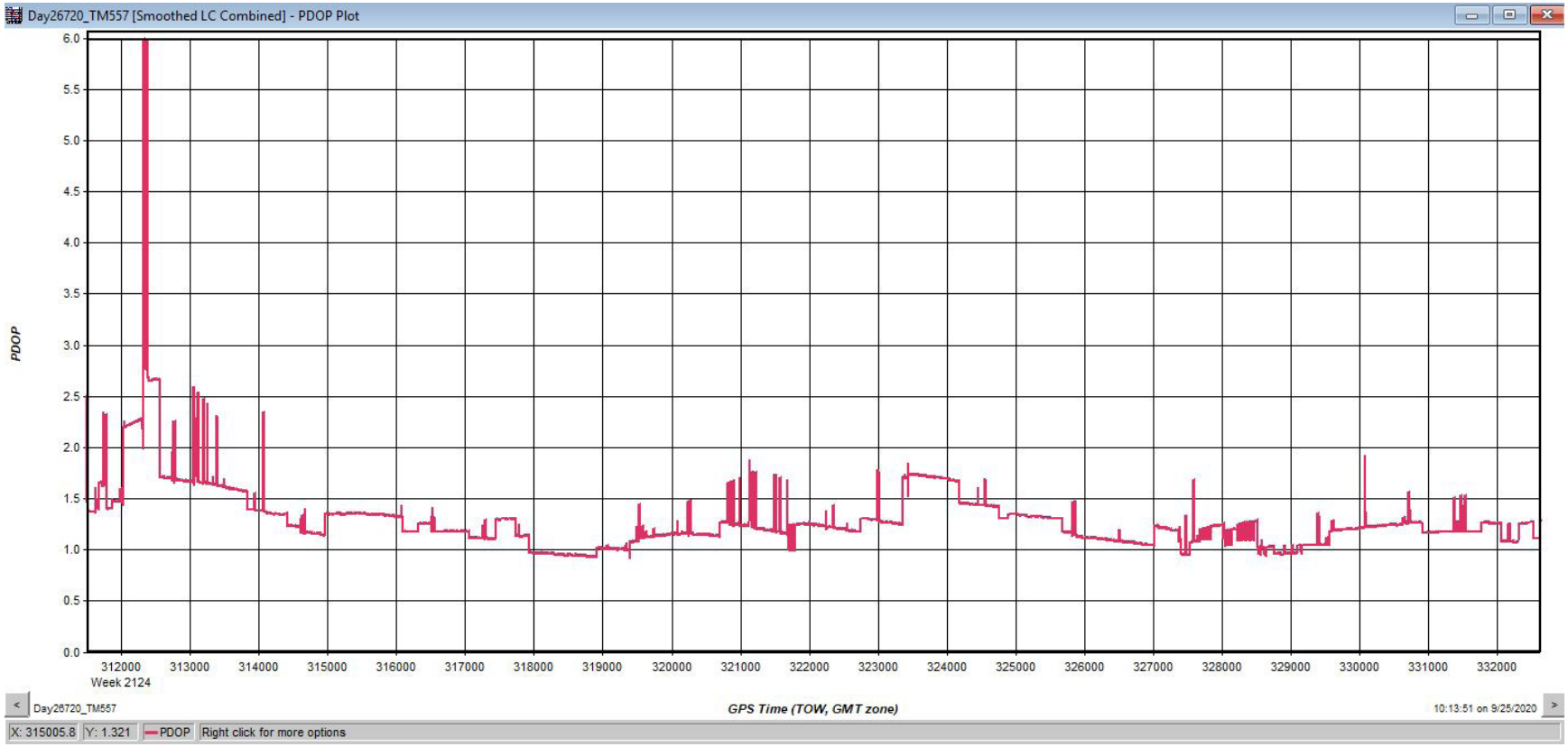
Forward/Reverse or Combined Separation Plot



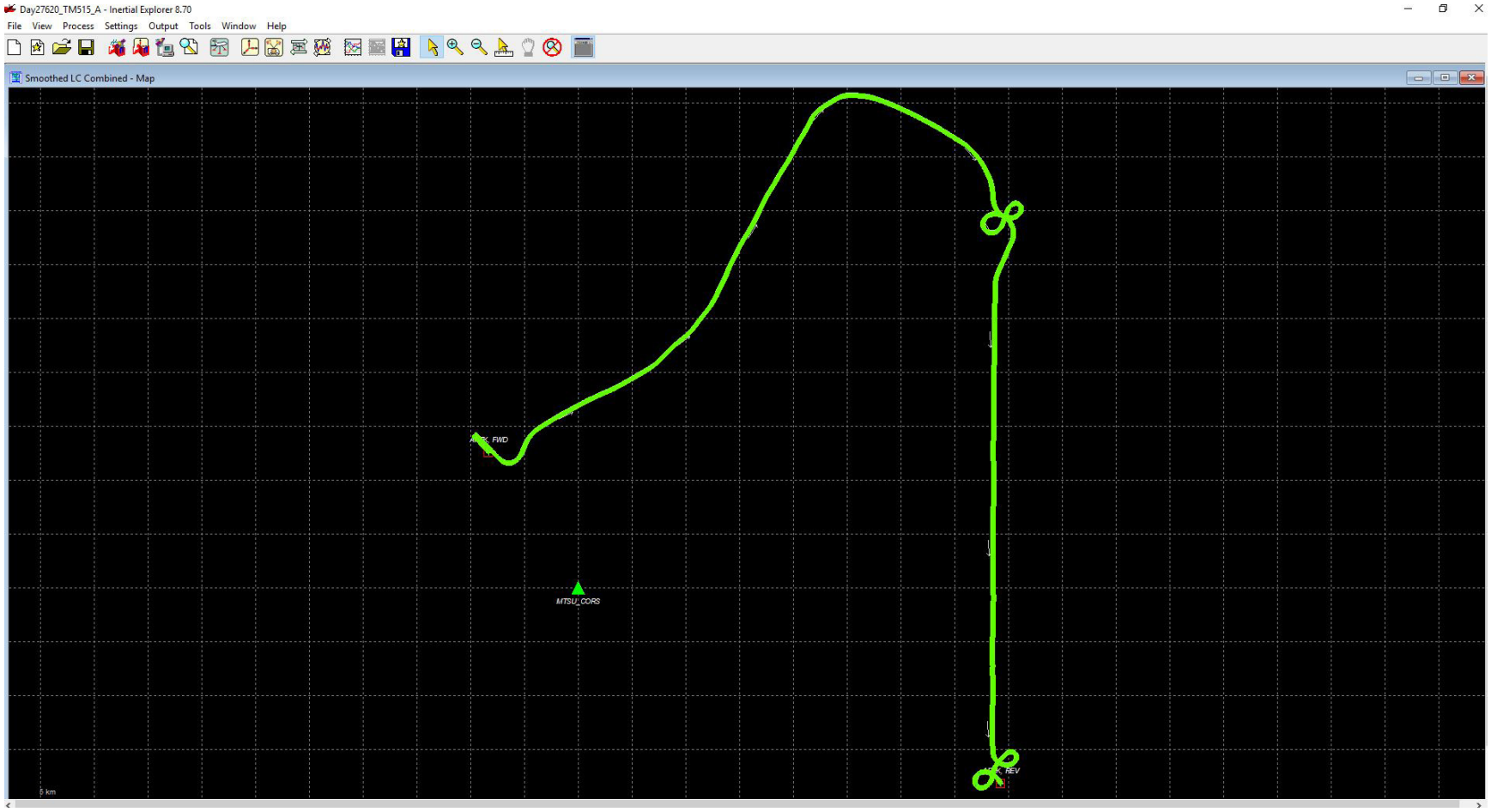
Day26720_TM557
Estimated Position Accuracy



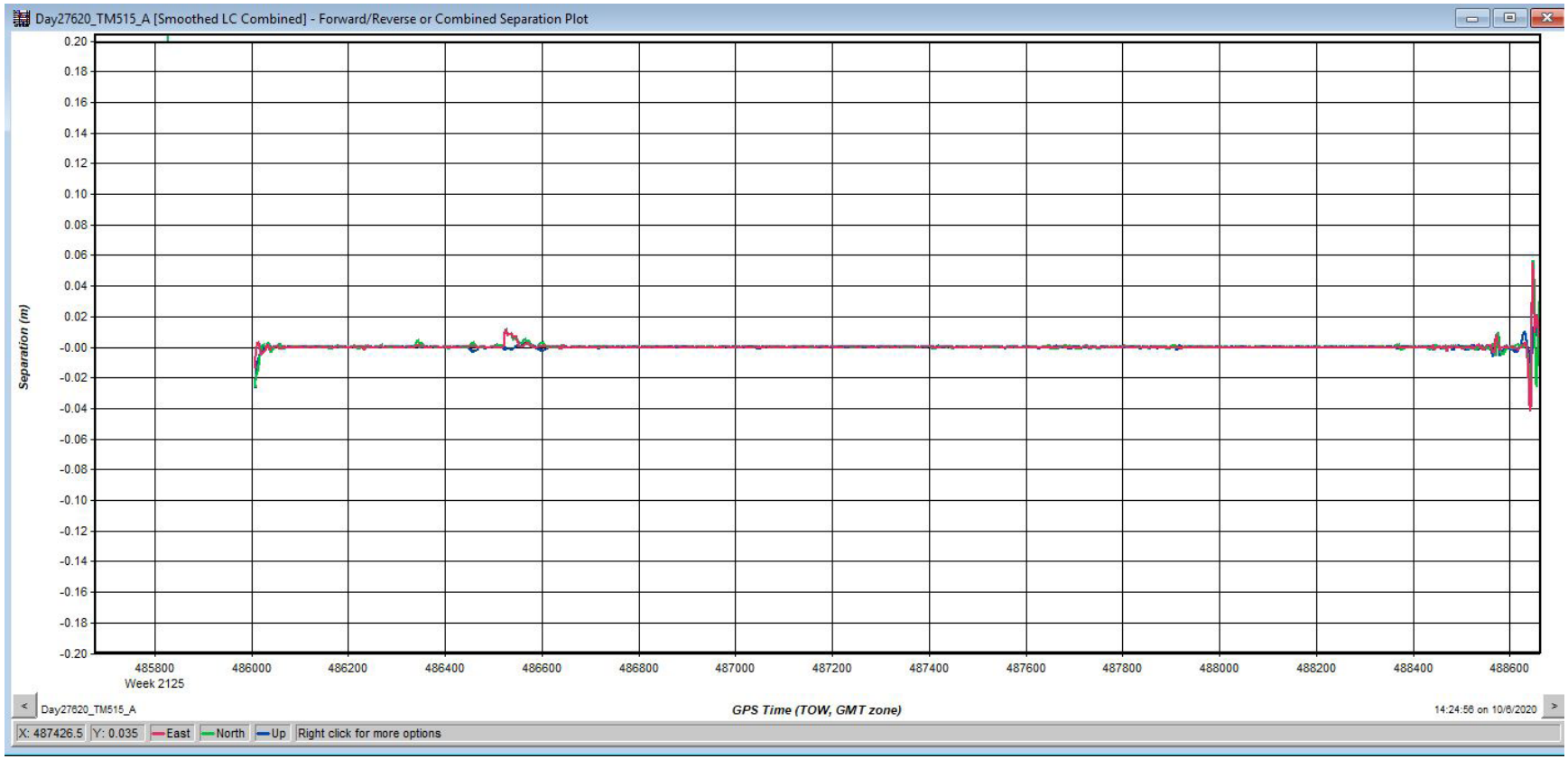
Day26720_TM557
PDOP Plot



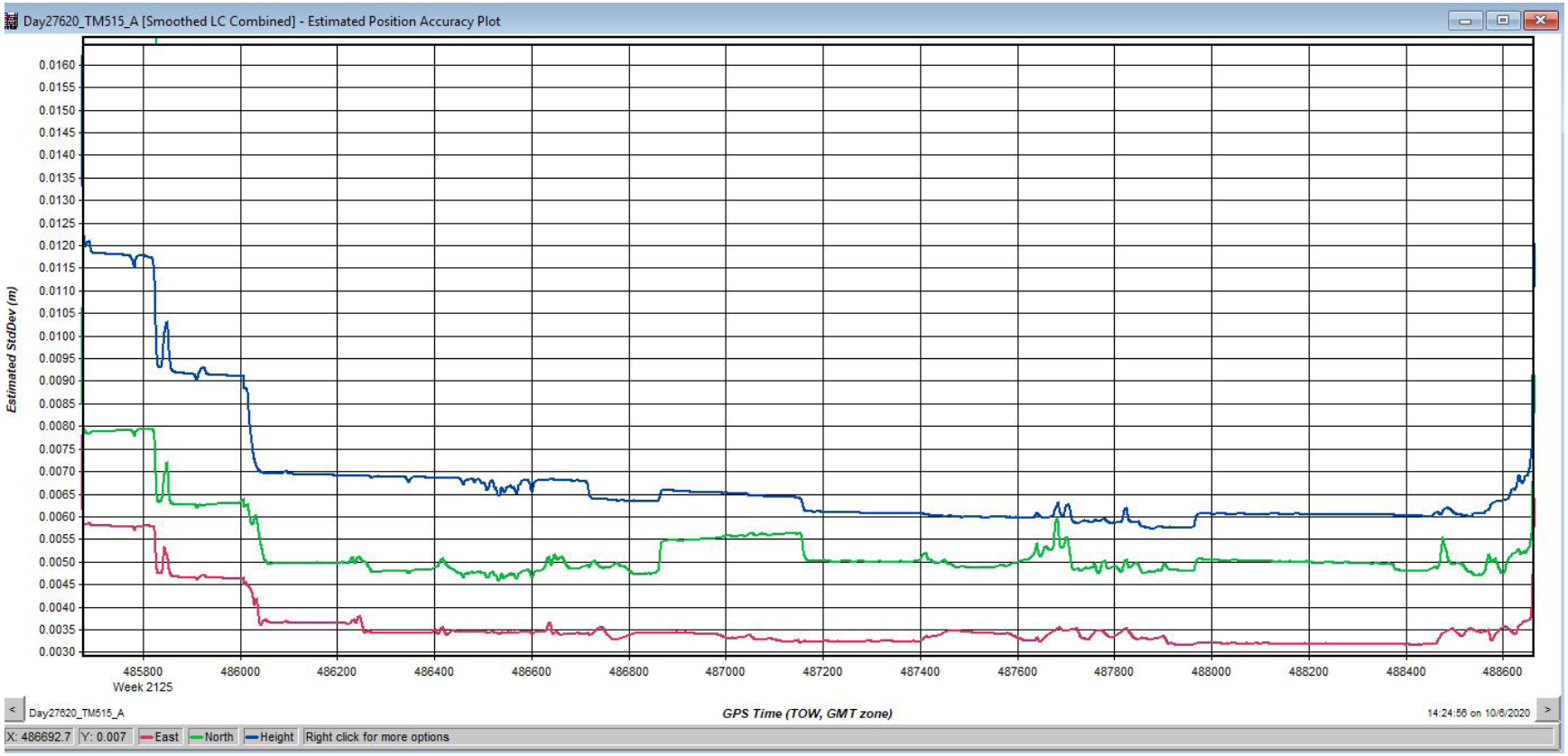
Day27620_TM515_A
Trajectory



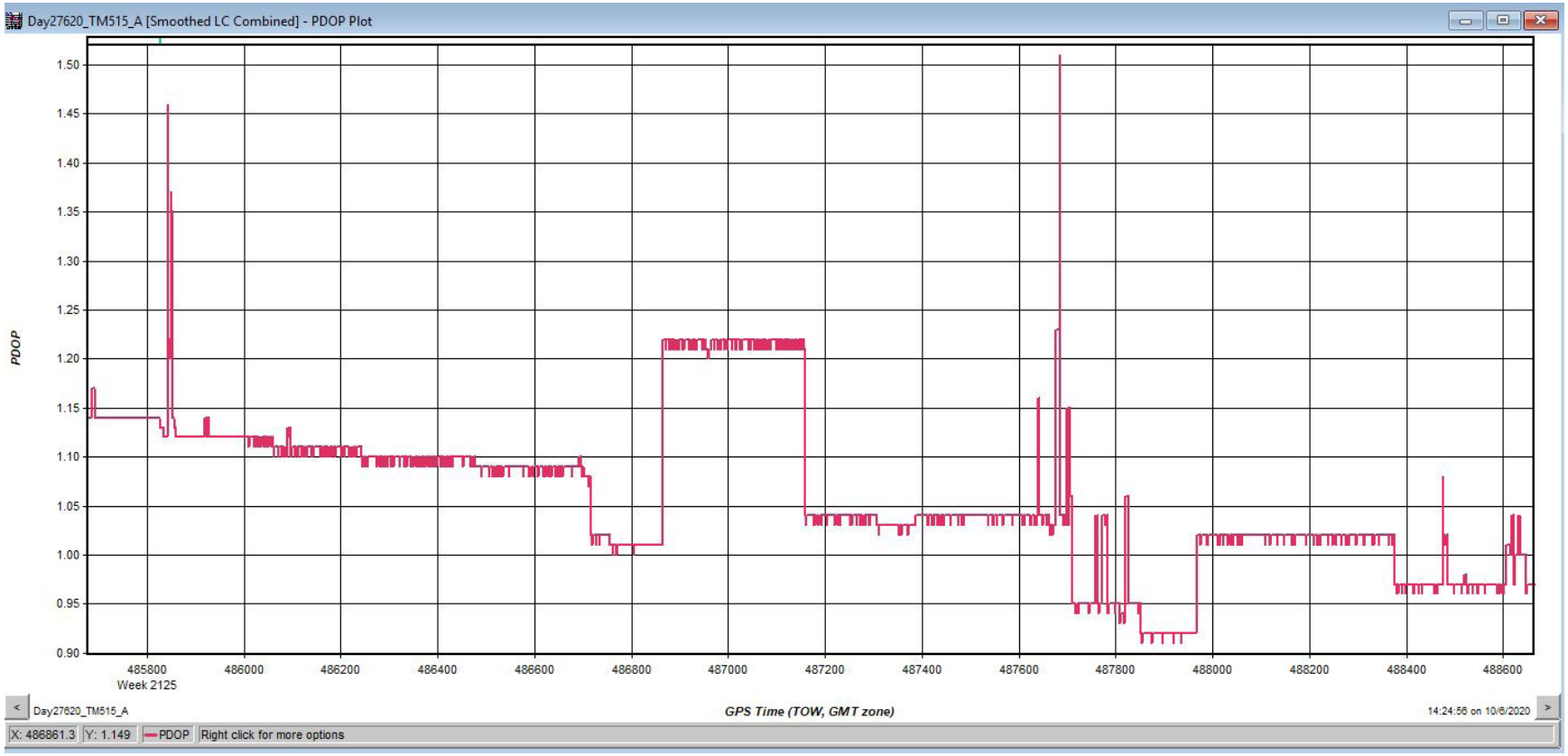
Day27620_TM515_A
Forward/Reverse or Combined Separation Plot



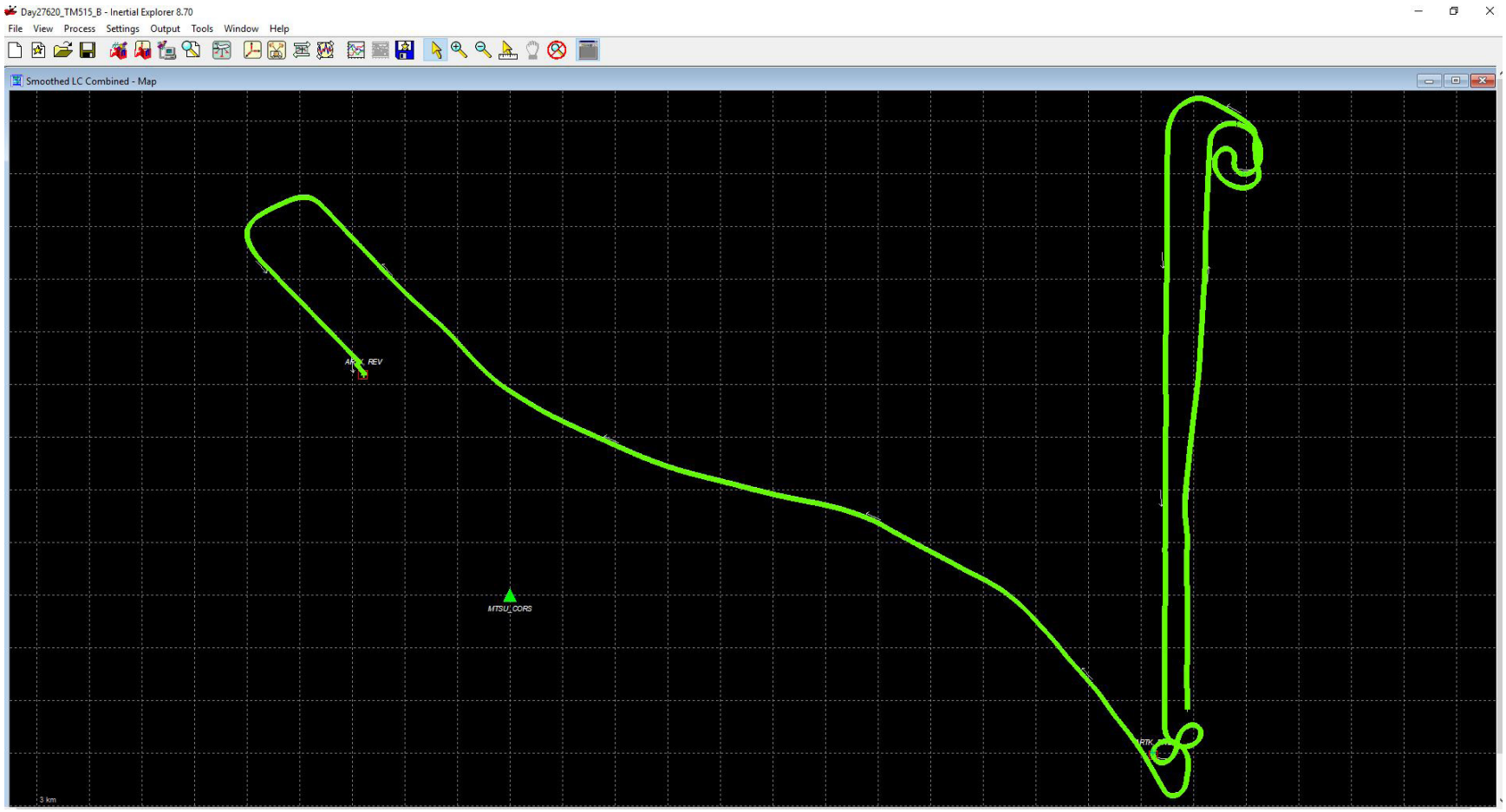
Day27620_TM515_A
Estimated Position Accuracy



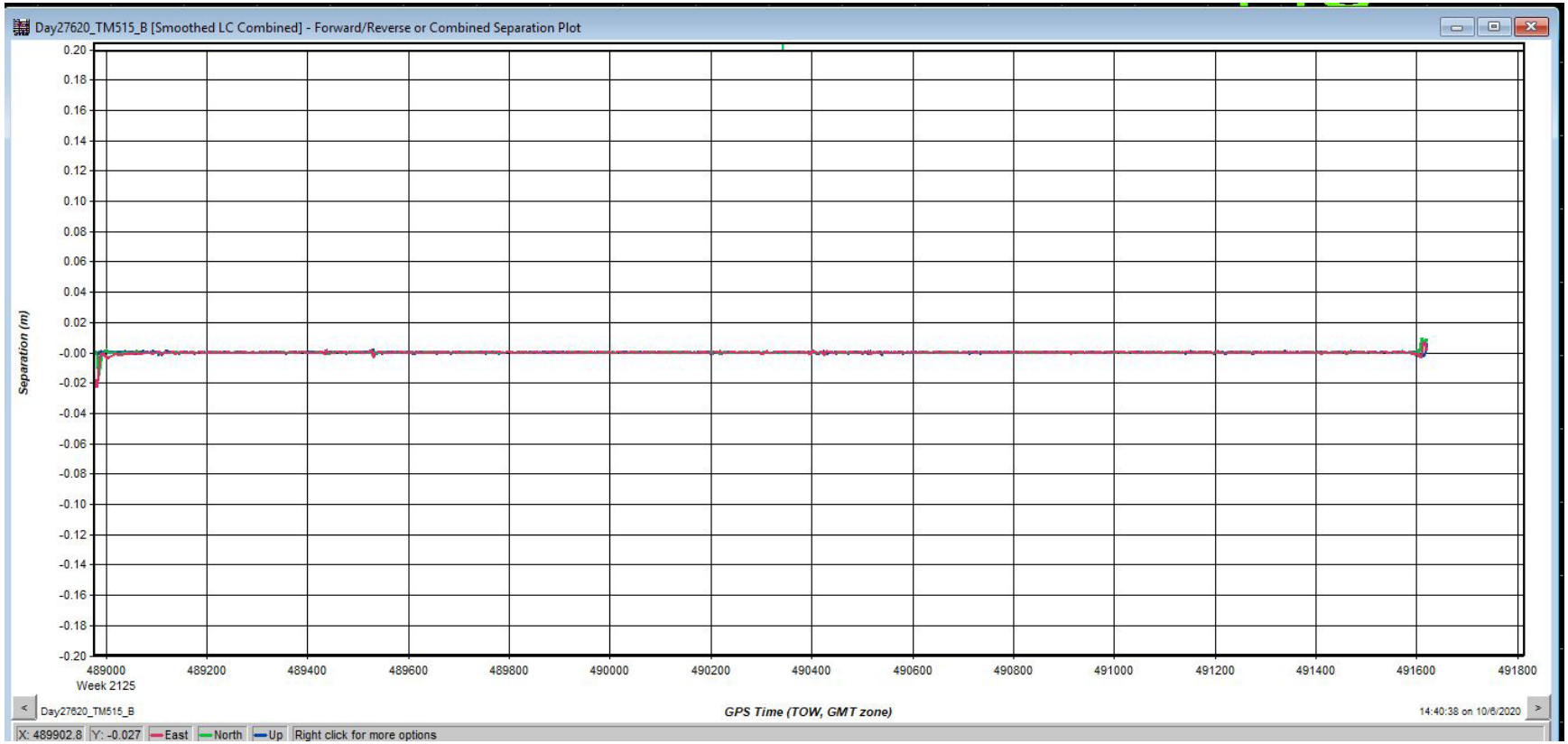
Day27620_TM515_A
PDOP Plot



Day27620_TM515_B
Trajectory

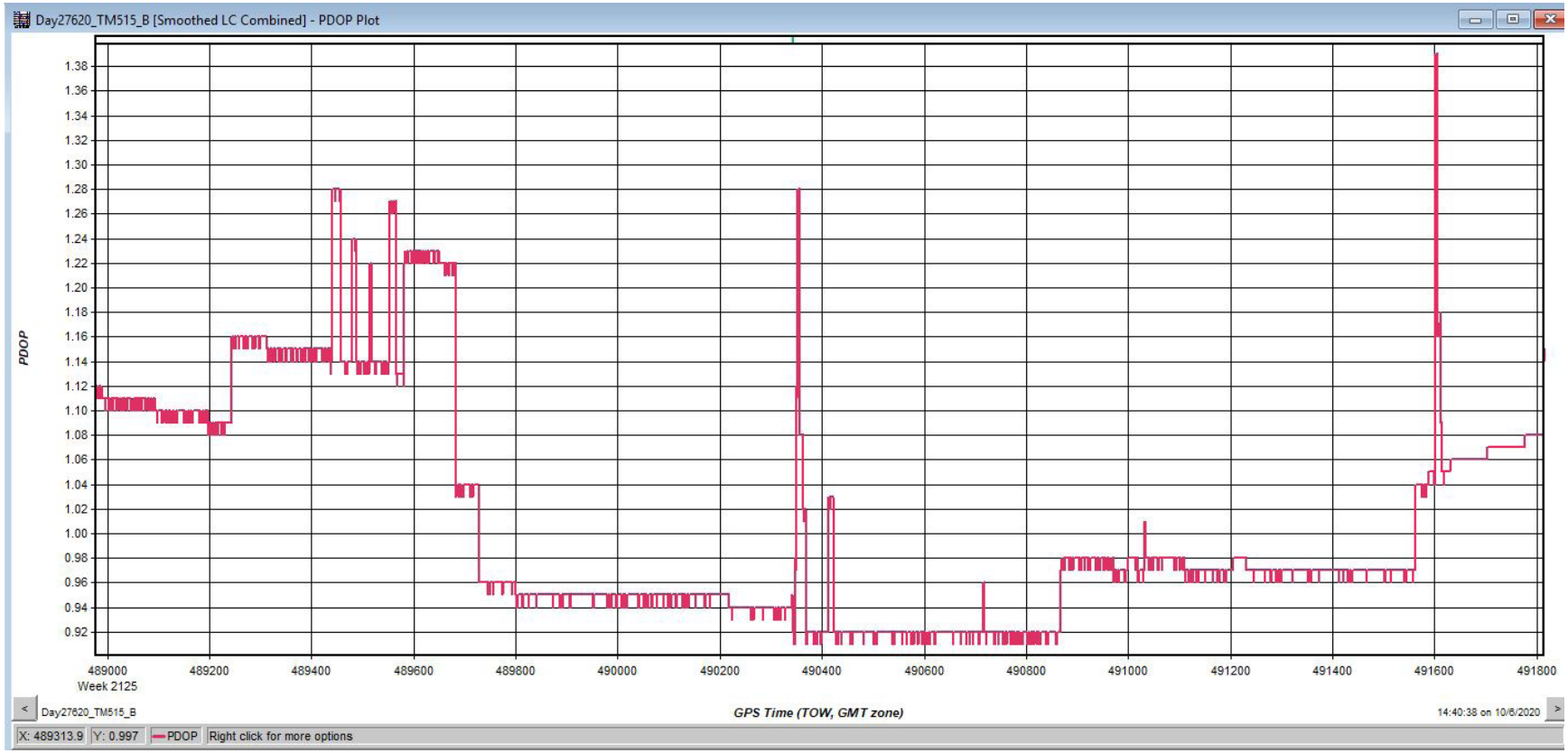


Day27620_TM515_B
Forward/Reverse or Combined Separation Plot

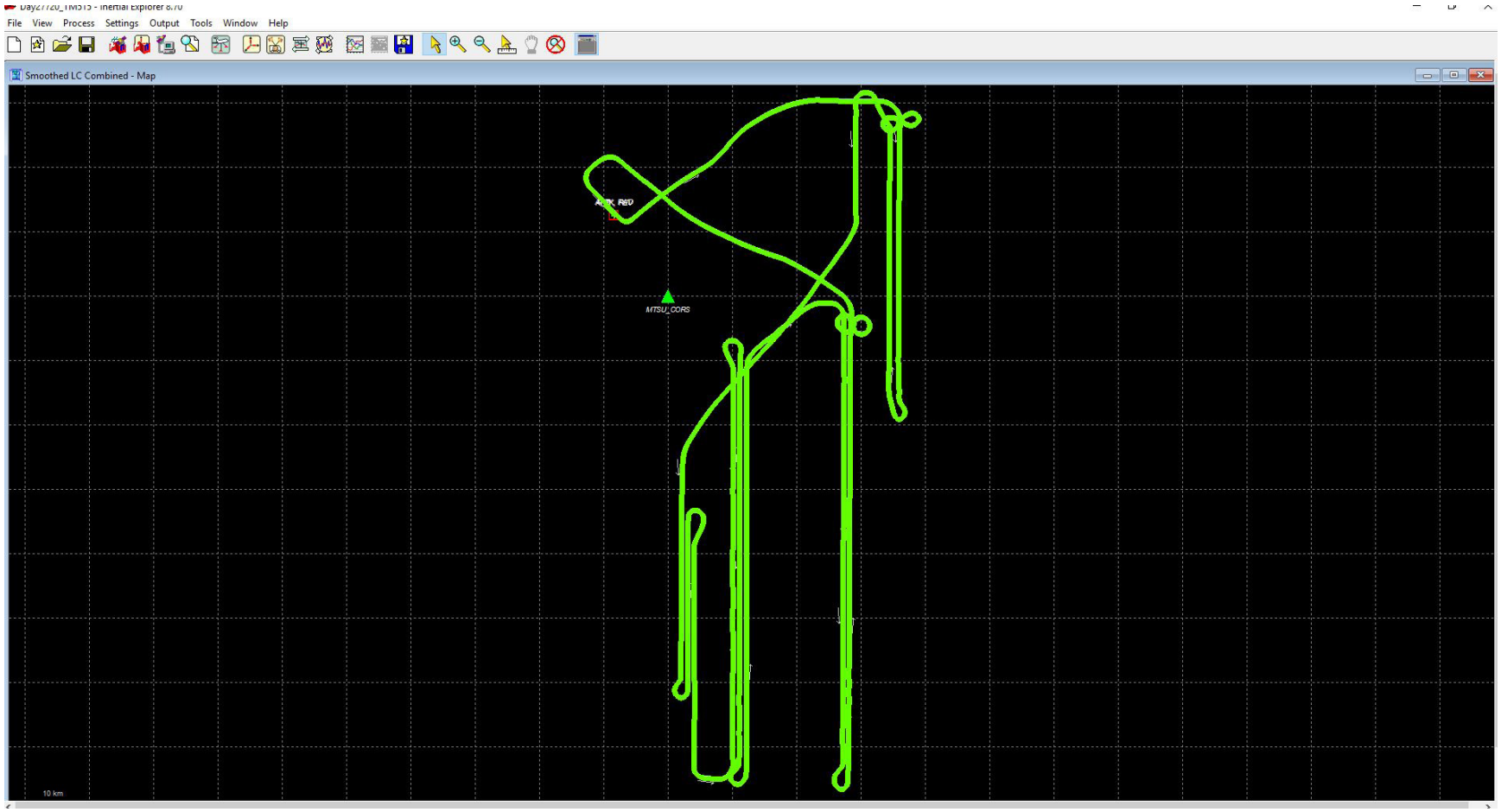


Day27620_TM515_B
Estimated Position Accuracy

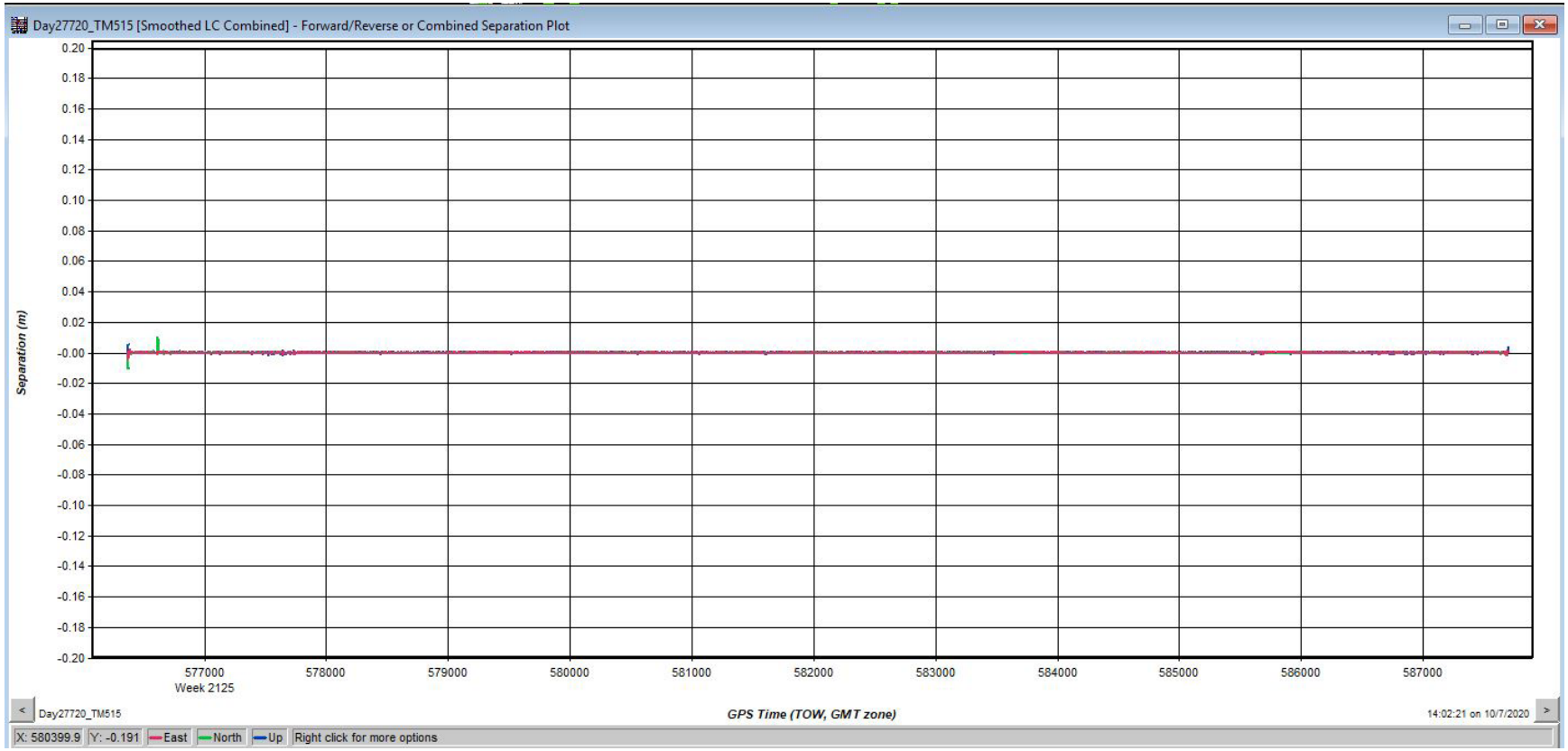
Day27620_TM515_B
PDOP Plot



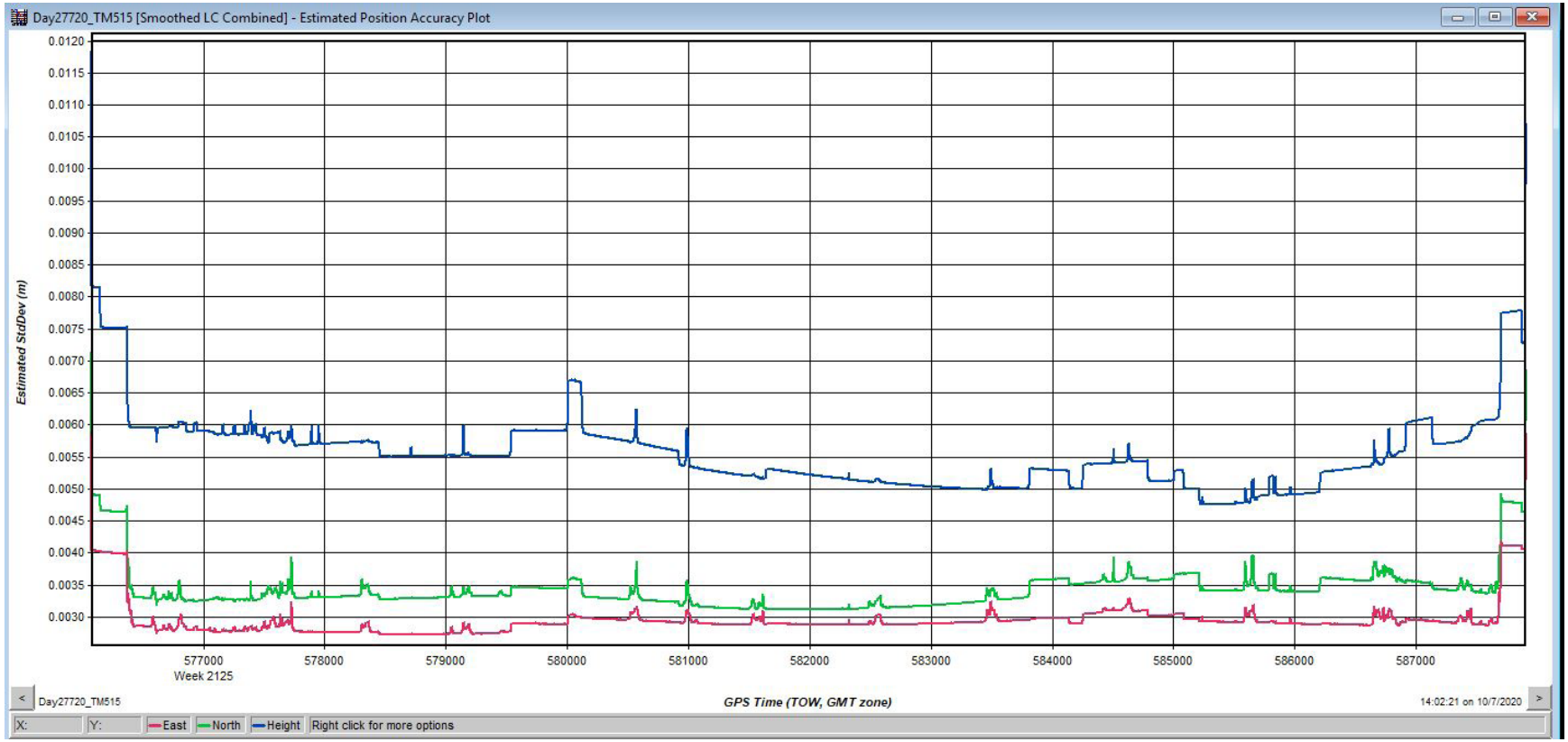
Day27720_TM515
Trajectory



Day27720_TM515
Forward/Reverse or Combined Separation Plot

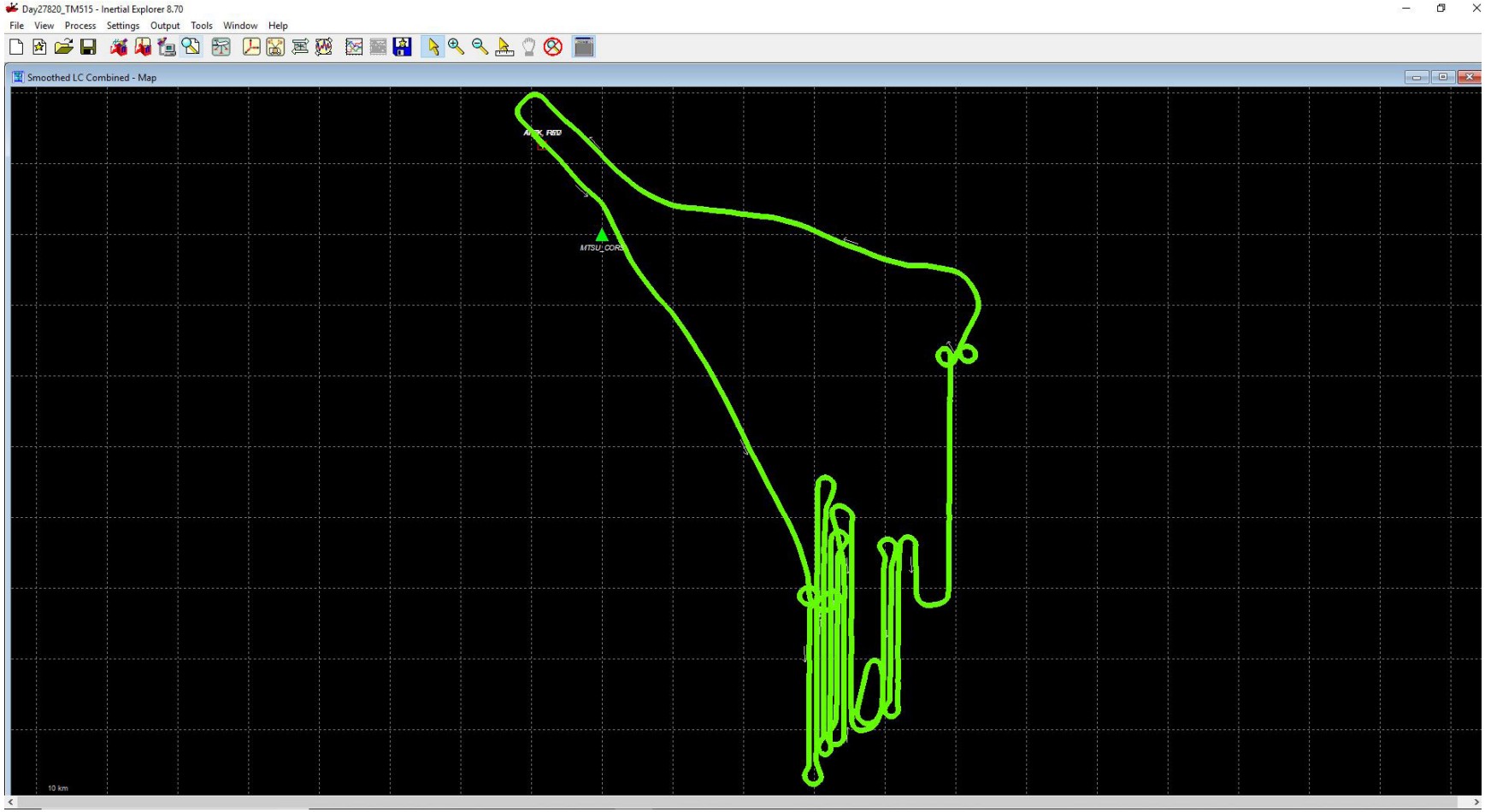


Day27720_TM515
Estimated Position Accuracy



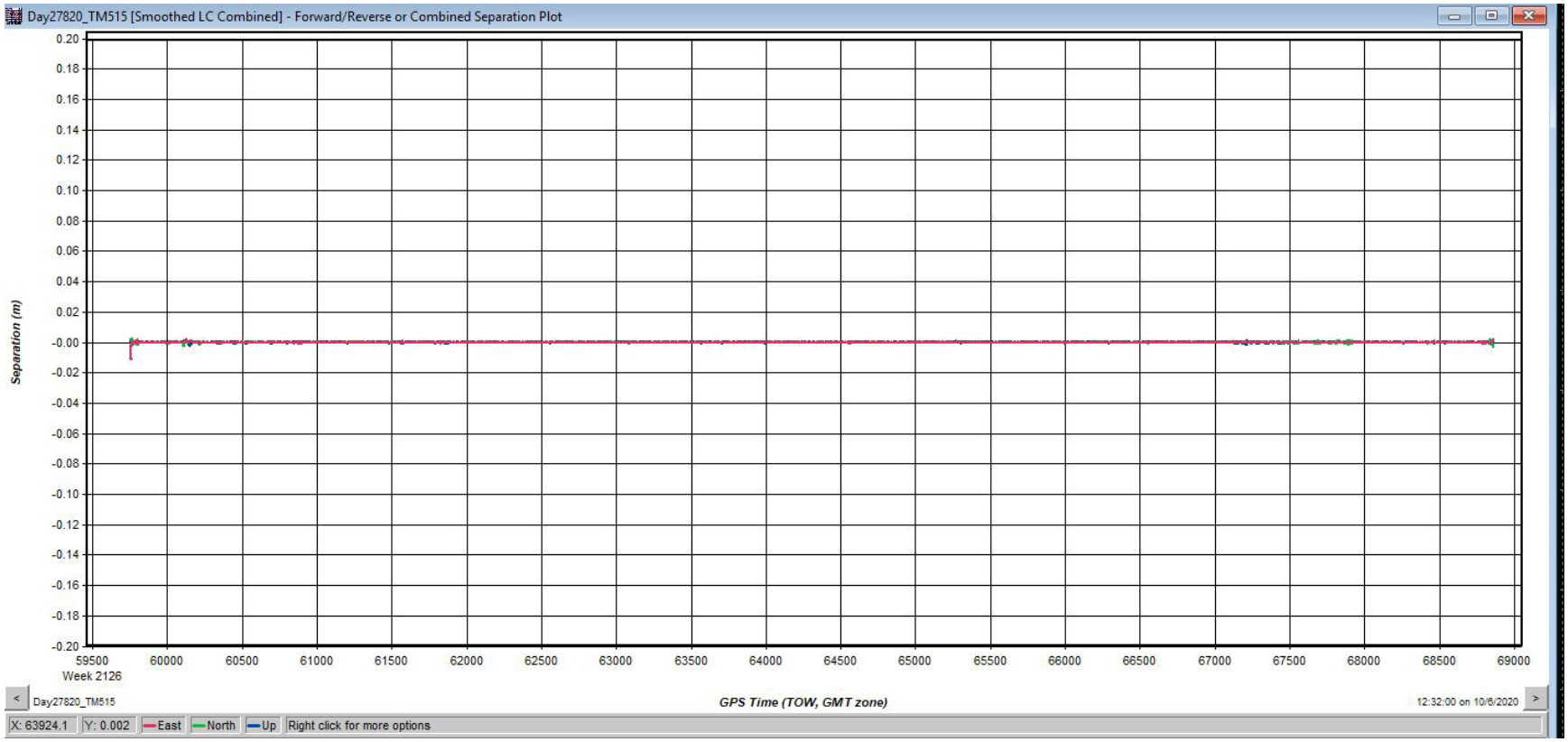
Day27720_TM515
PDOP Plot

Day27820_TM515
Trajectory

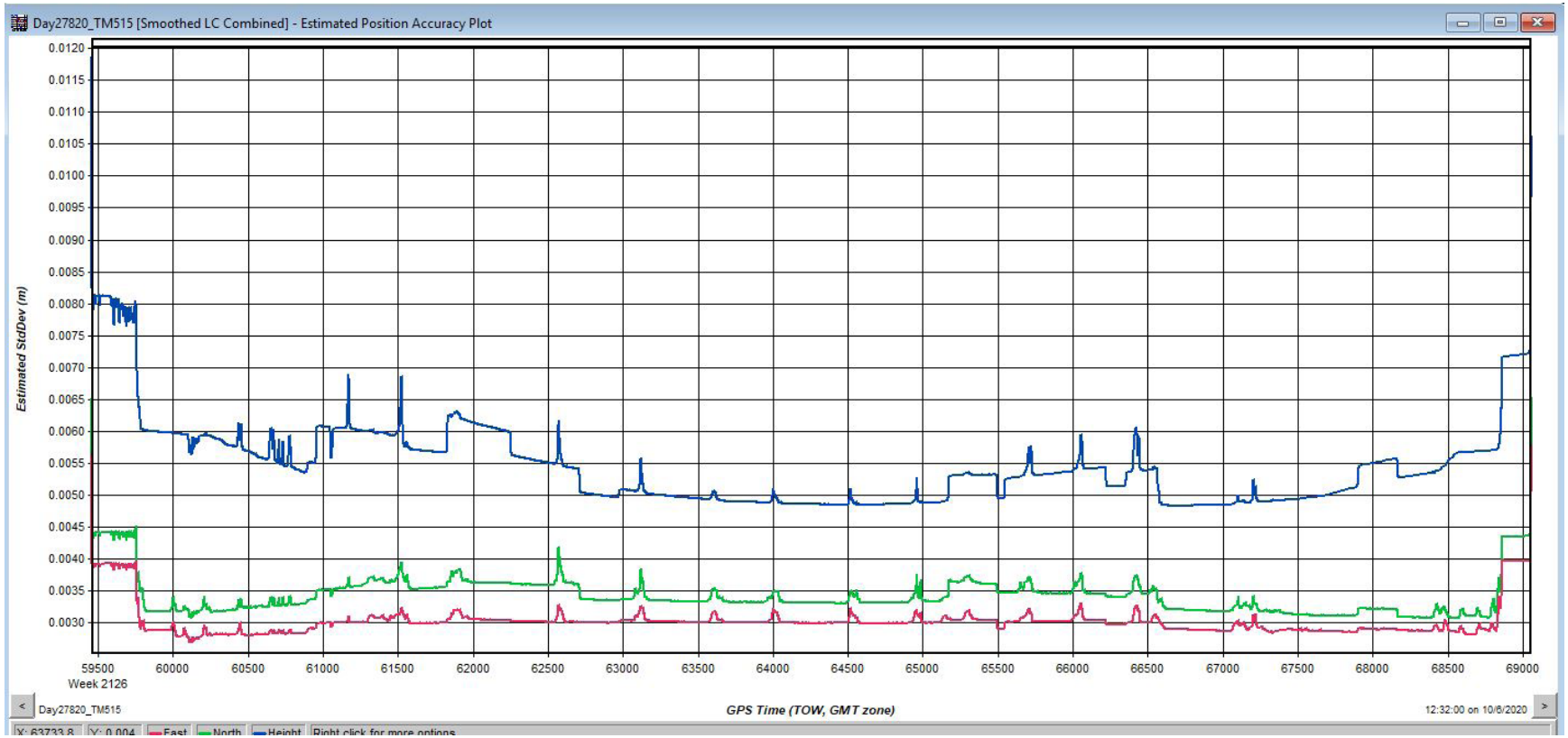


Day27820_TM515

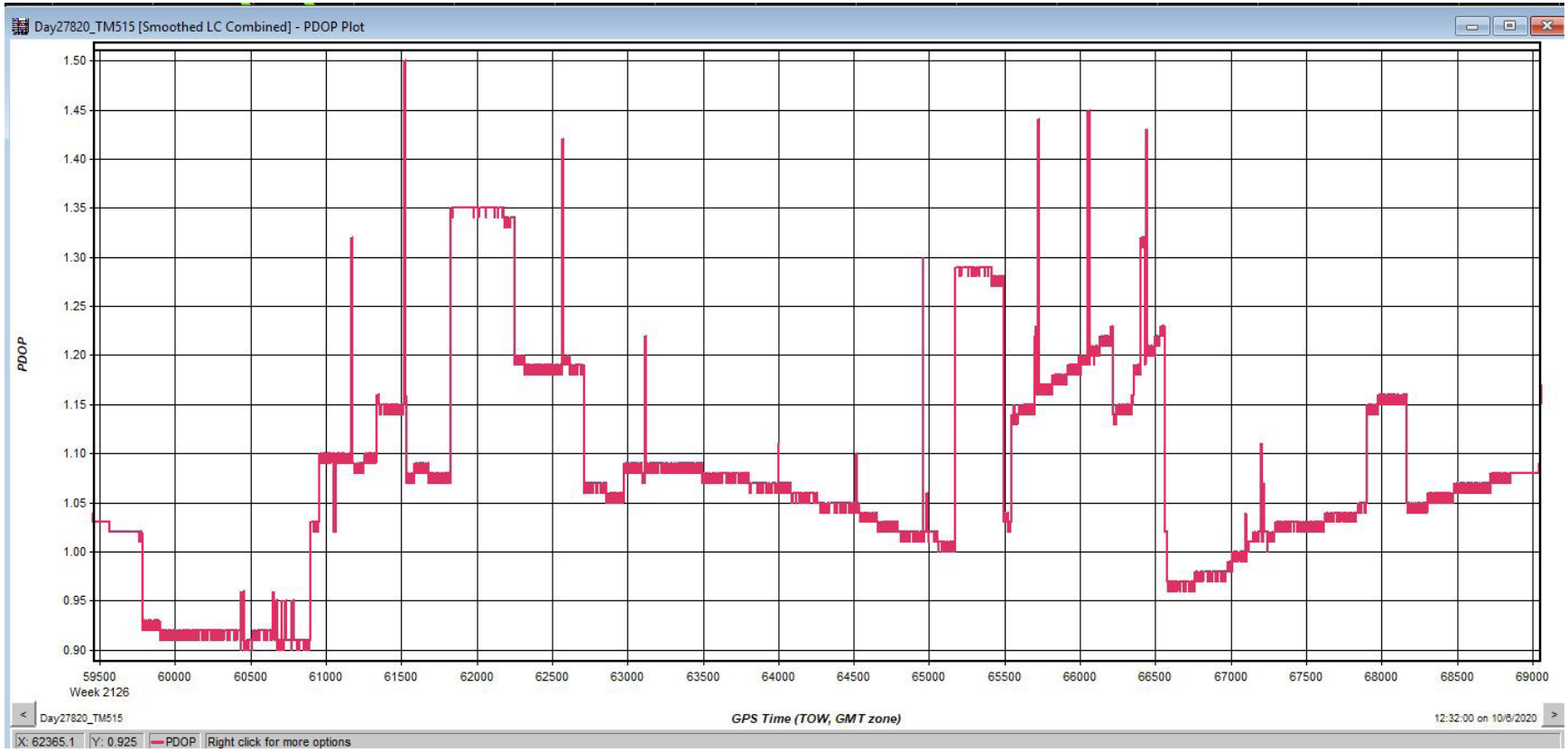
Forward/Reverse or Combined Separation Plot



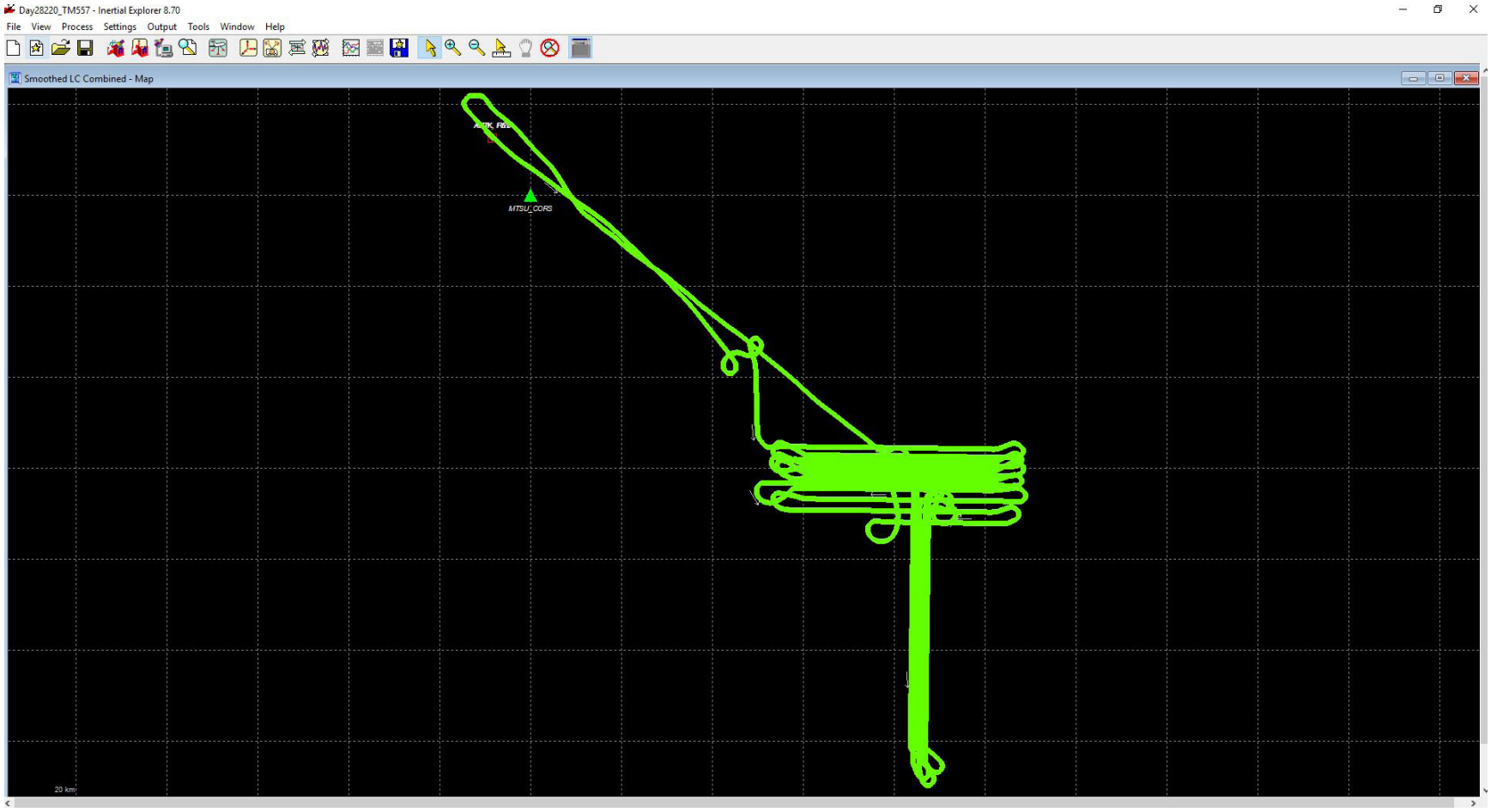
Day27820_TM515
Estimated Position Accuracy



Day27820_TM515
PDOP Plot

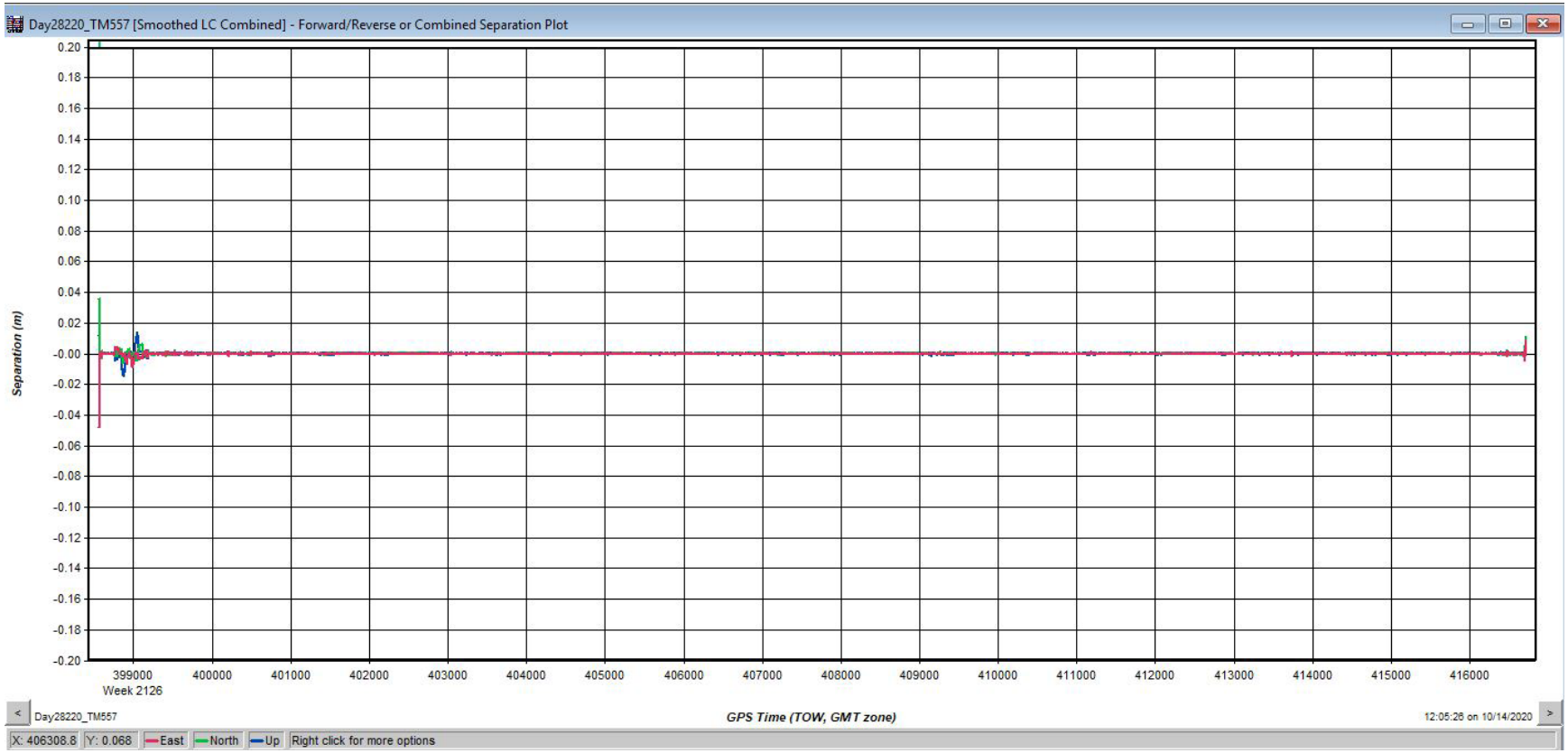


Day28220_TM557
Trajectory

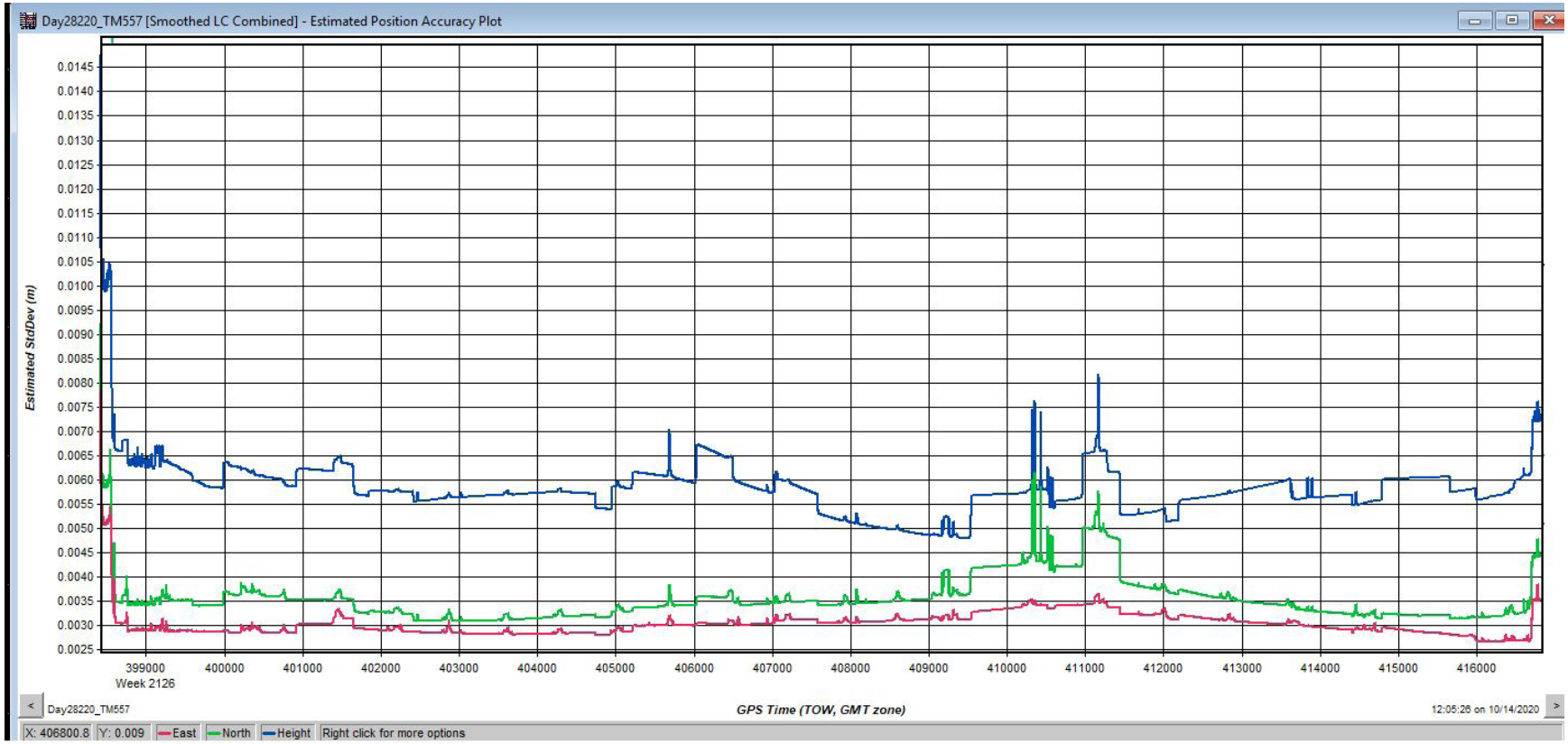


Day28220_TM557

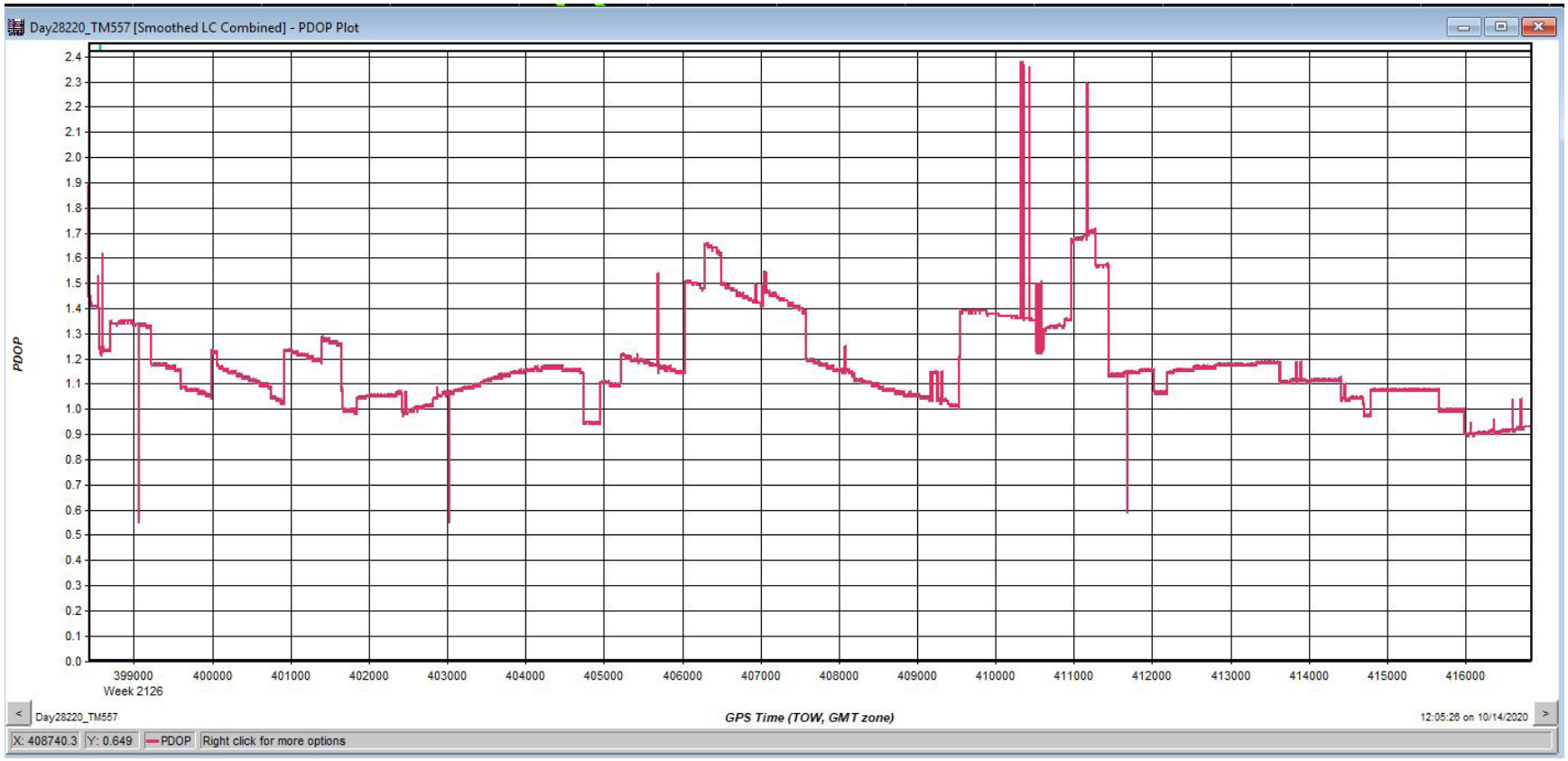
Forward/Reverse or Combined Separation Plot



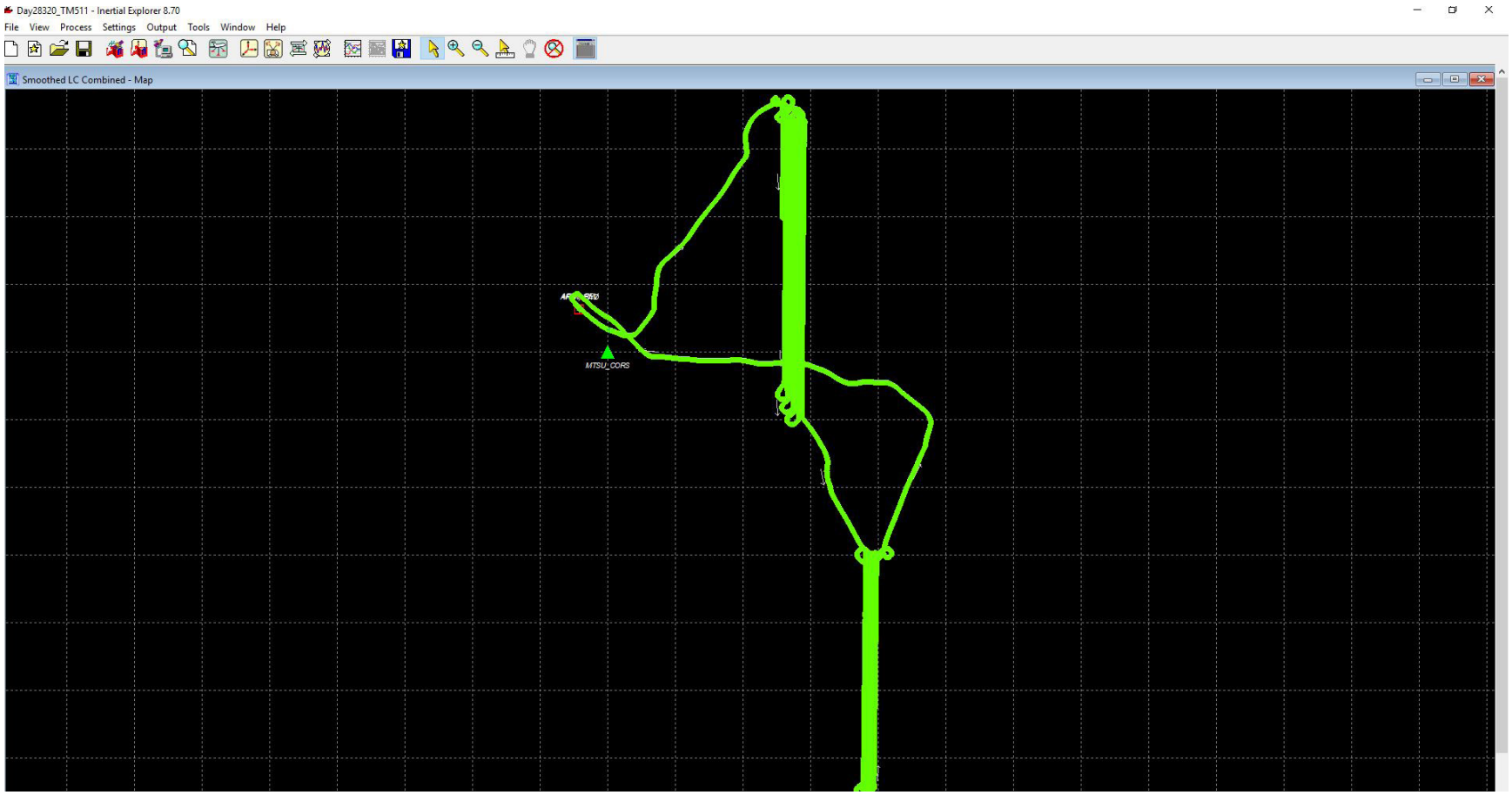
Day28220_TM557
Estimated Position Accuracy



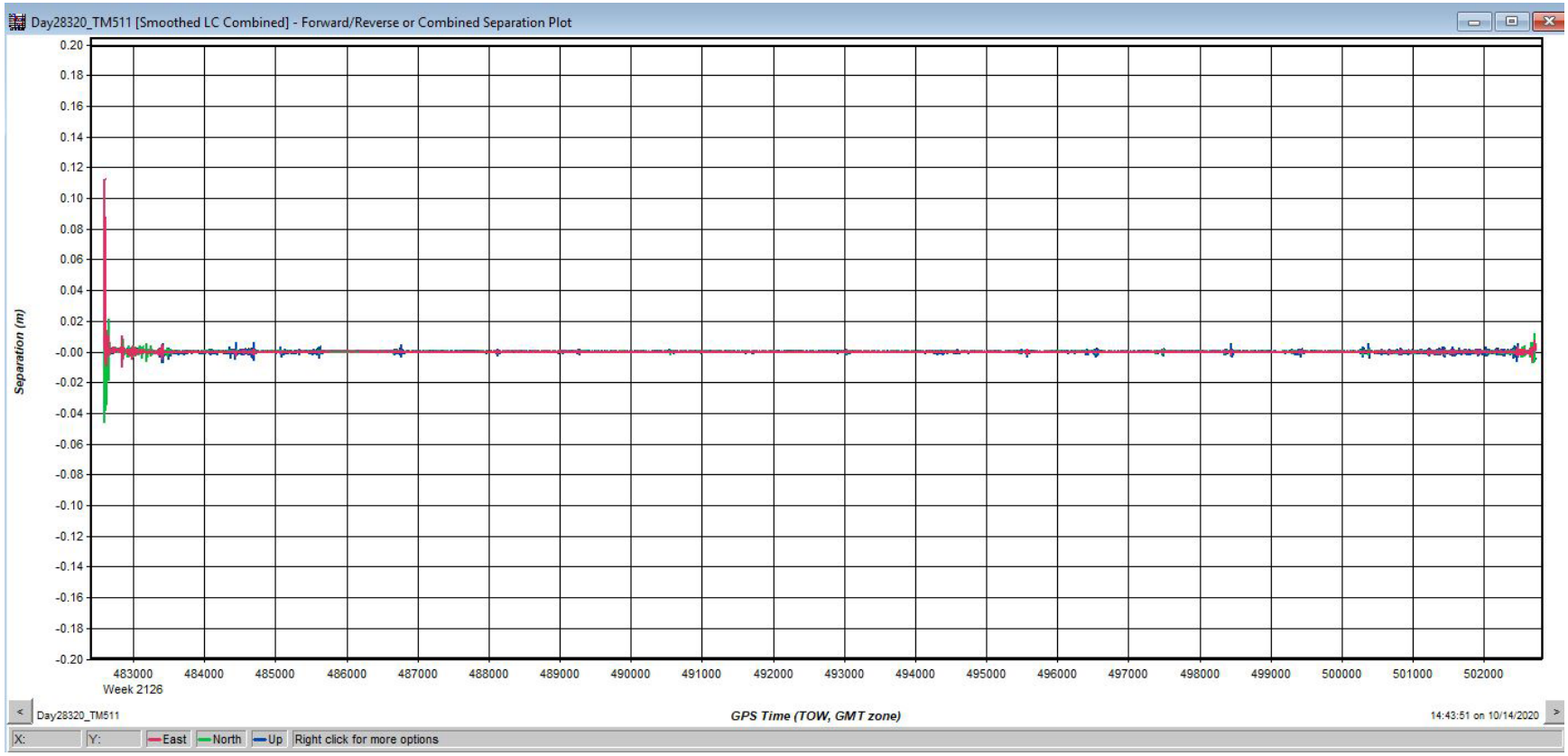
Day28220_TM557
PDOP Plot



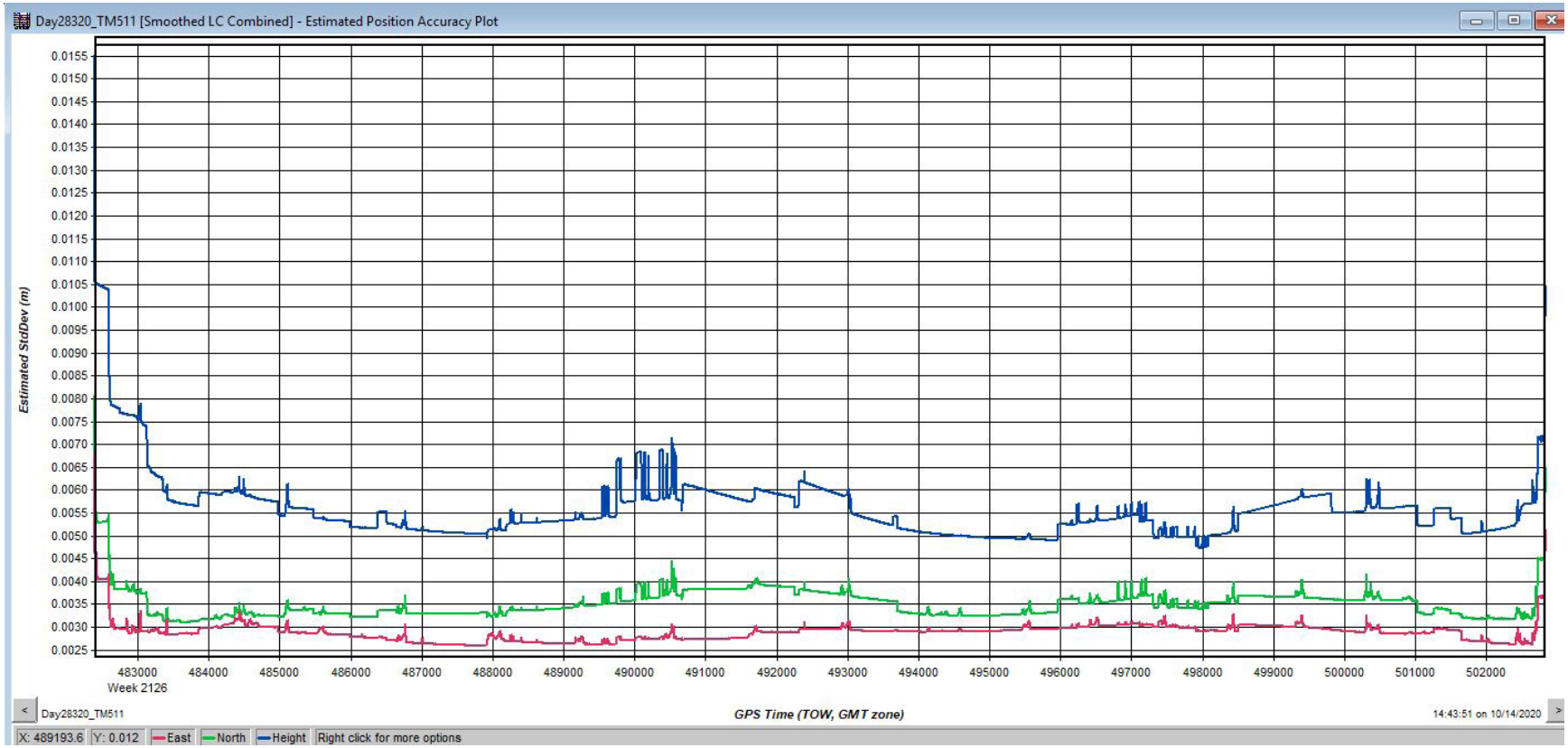
Day28320_TM511
Trajectory



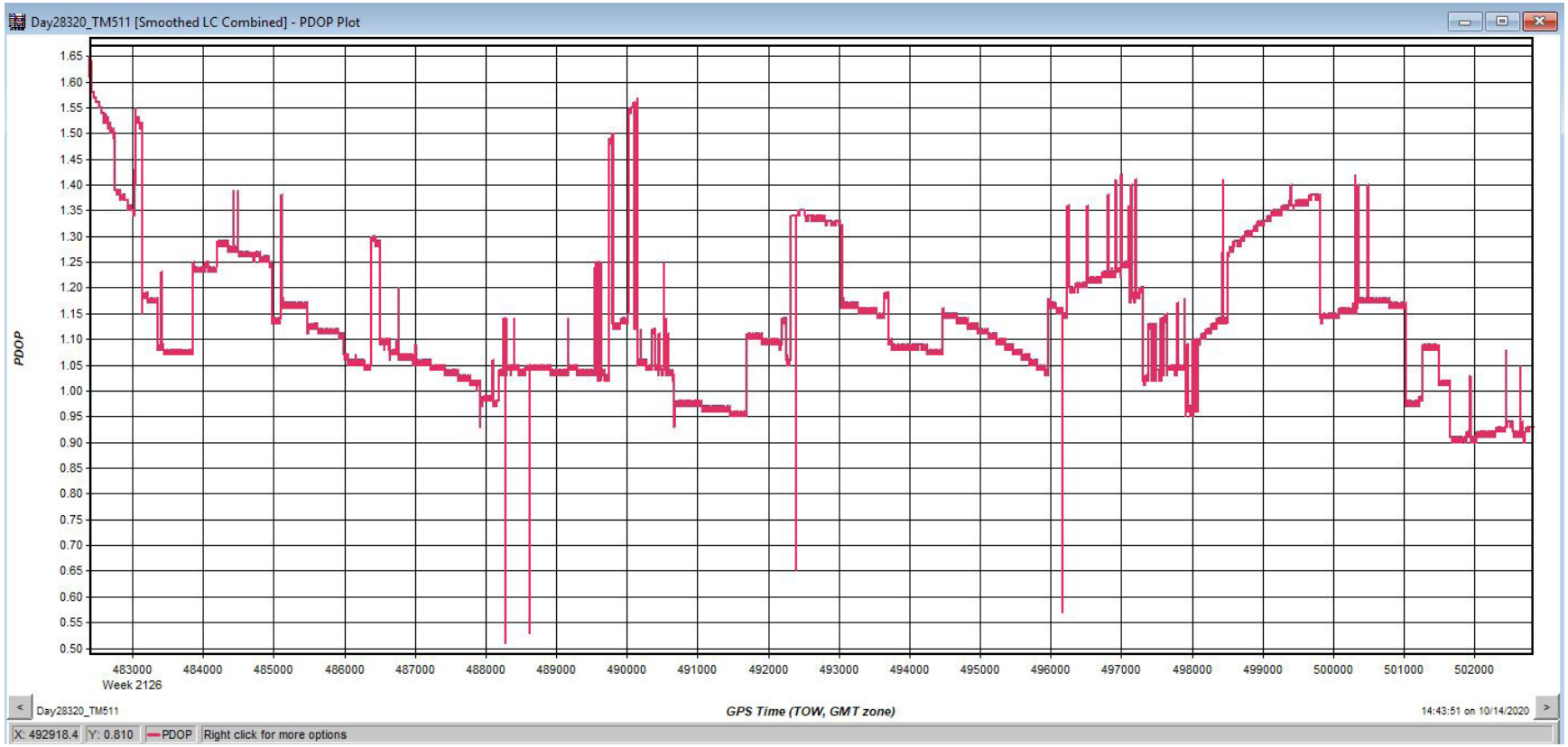
Day28320_TM511
Forward/Reverse or Combined Separation Plot



Day28320_TM511
Estimated Position Accuracy

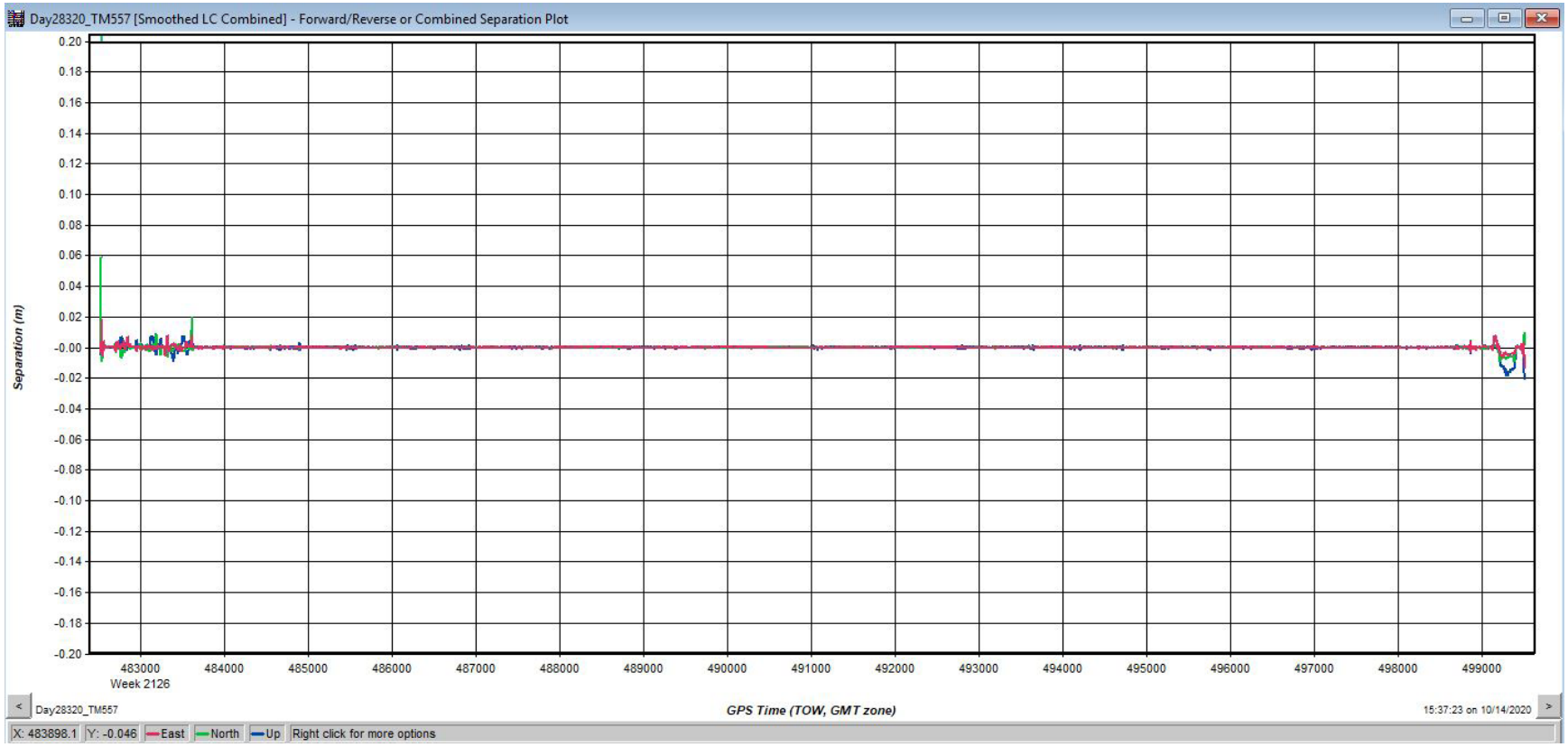


Day28320_TM511
PDOP Plot

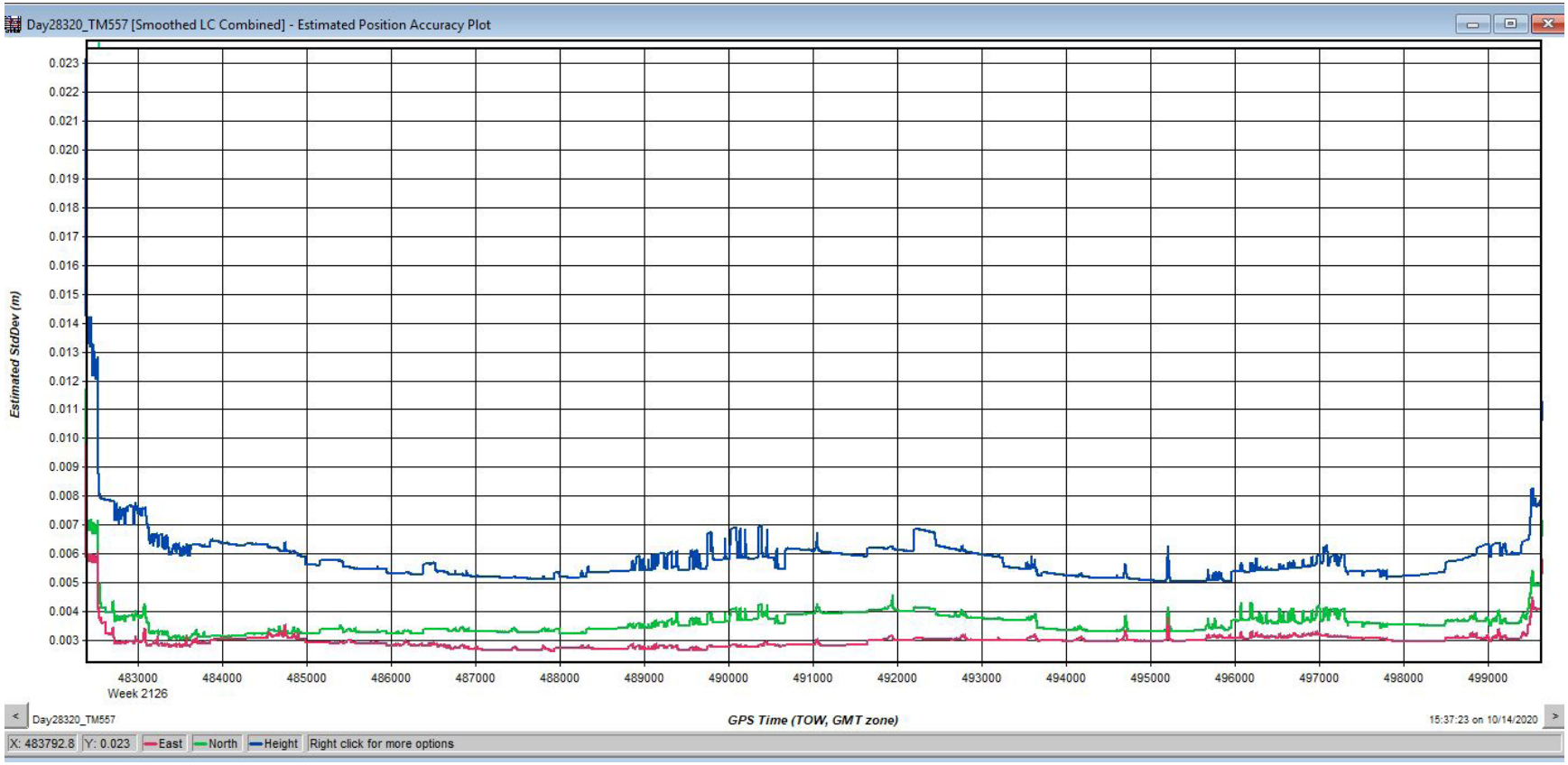


Day28320_TM557
Trajectory

Day28320_TM557
Forward/Reverse or Combined Separation Plot



Day28320_TM557
Estimated Position Accuracy



Day28320_TM557
PDOP Plot