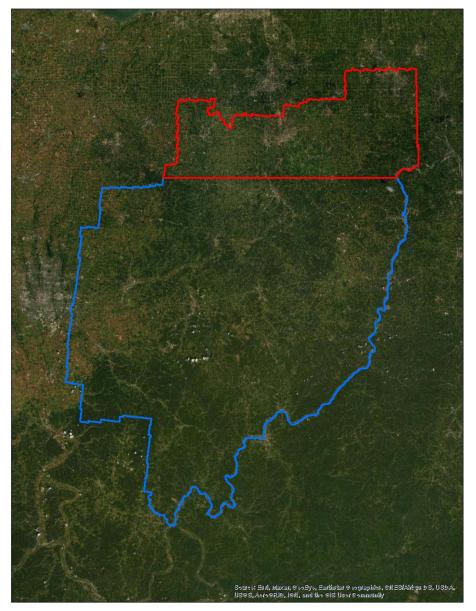
OH Statewide Phase 2 2020 B20

Lidar Mapping Report Project ID 197536 - Work Unit ID 224925

May 2022





Contract # G16PC00022 Task Order # 140G0220F0194



ContractorWoolpertProject #81150

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1. Overview

About

This project contains a comprehensive outline of the 140G0220F0194 - OH Statewide Phase 2 2020 B20 task order issued by the United States Geological Survey's National Geospatial Technical Operations Center (USGS-NGTOC). This task order called for the acquisition and processing of QL0 and QL1 data covering approximately 12,101 square miles in southern Ohio (Figure 1-1).

This report encompasses the Work Unit 224925 area of interest (Figure 1-2). This AOI totals approximately 2,383 square miles and includes the following counties:

- Carroll
- Columbiana
- Holmes
- Mahoning
- Stark
- Tuscarawas
- Wayne

Purpose

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

Specifications

Data for this task order was acquired and produced to meet USGS Lidar Base Specification v2021 revision A standards and the American Society of Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0).

Spatial Reference

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

Horizontal EPSG Code 6549		6549
Datumw		NAD83(2011)
Projection State Plane Ohio North (FIPS 3401)		State Plane Ohio North (FIPS 3401)
	Units	US Survey Feet
Vertical Datum NAVD88		NAVD88
Geoid GEOID1		GEOID18
	Units	US Survey Feet
	Height Type	Orthometric

Table 1-1. Spatial Reference System

Figure 1-1. Project Area

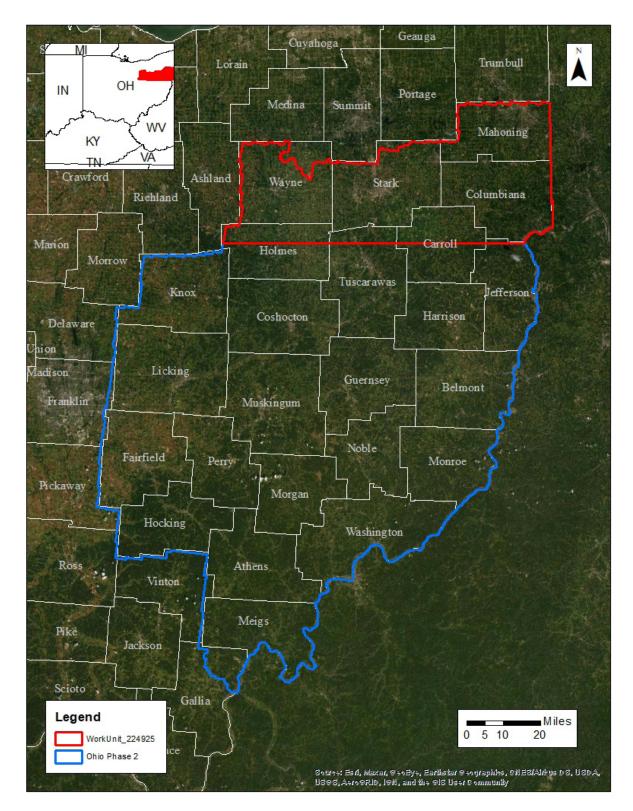
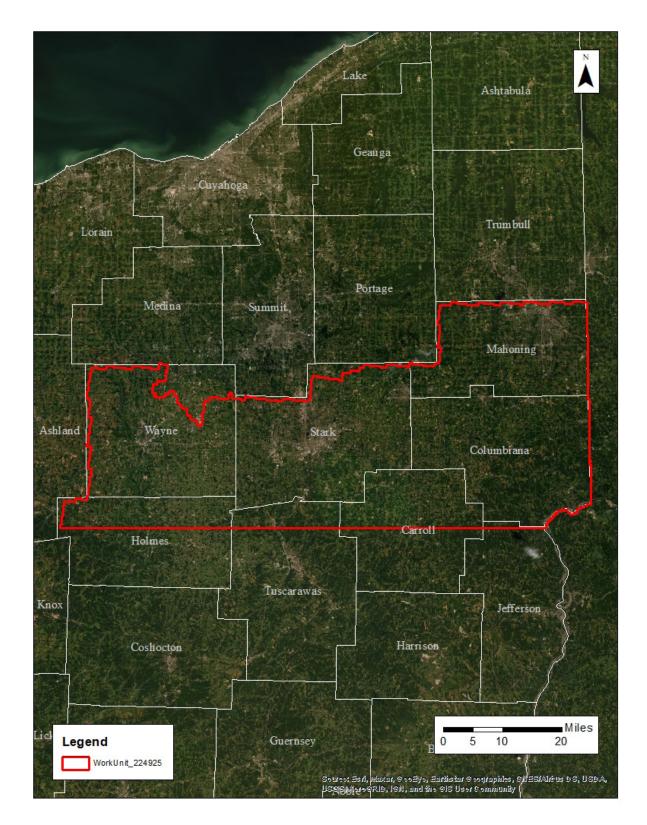


Figure 1-2. Project Area - 197536 - Work Unit 224925



Task Order Deliverables

All data products produced as part of this task order are listed in Table 1-2. All tiled deliverables had a tile of 1,250-feet x 1,250 feet. Tile names are derived from the Ohio (OGRIP) naming schema.

Example: BS20820365

This delivery's tiled dataset contains a total of 42,518 tiles. Some tiles were excluded frome the datasets as they fell over a water body.

BN23820498

BN23830521

BN23850521

BN23860526

Excluded tiles:

- Point Cloud(13) Intensity(14) MSHR (14) •
- BN23820497 ٠ • BN23820498 BN23820498 BN23830521 BN23830521 ٠ • BN23850521 BN23850521 BN23860526 BN23860526 •
- BN23860527 BN23860527 BN23860527 • BN23870527 BN23870527 BN23870527 •
- BN23870528 BN23870528 BN23870528
- BN23870530 BN23870530 BN23870530 •
- BN23870531 BN23870531 BN23870531
- BN24350533 BN24350533 BN24350533 •
- BN24810460
- BN24810460 BN24810460 BN24810461 ٠
- BN24810461 BN24810461
- BN24880482 BN24880482 BN24880482

Table 1-2. Deliverables

Lidar Data		
Classified lidar point cloud data Breaklines used for hydro-	Tiles in LAS v1.4 format Classes • 1 – Processed, but unclassified • 2 – Bare-earth ground • 7 – Low Noise • 9 – Water • 17 – Bridge Decks • 18 – High Noise • 20 – Ignored Ground • Lake and River features as feature classes in an Esri file geodatabase	
flattening	 Water bodies greater than 2 acres as polygon features Rivers 30.5 meters / 100 feet and greater in width as polyline features Bridges used in DEM generation as point features in Esri shapefile format 	
Hydro-flattened bare earth digital elevation model (DEM)	1.25-foot pixel size, 32-bit floating-point; no bridges or overpass structures GeoTIFF format	
Intensity imagery	1.25-foot pixel size, 8-bit gray-scale (linear rescaling from 16-bit intensity) GeoTIFF format	
Vertical Accuracy Data		
Ground control survey report	Survey report in PDF format	
NVA and VVA checkpoints	Gpkg file format	
Interswath and intraswath test results	Esri shapefile format	
Spatial Metadata		
Data extent	Esri shapefile format	
Tile index	Esri shapefile format	
Maximum surface height rasters	GeoTIFF format	
Swath separation images	GeoTIFF format	
Swath polygons	Georeferenced, polygonal representation of the detailed extents of each lidar swath Polygon feature class in an Esri file geodatabase	
Metadata and Reports		
XML metadata	Deliverable-level FGDC CSDGM/USGS MetaParser Compliant metadata in XML format	
Lidar mapping report	Project report with ancillary data in PDF format	

2. Acquisition

Flight Planning

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

Table 2-1. Acquisition Requirements

Specification	Target	
Resolution	 8 points per square meter 0.35-meter nominal point spacing 	
Overlap	At contractor's discretion, but enough to ensure there are no data gaps between usable portions of the swath and to ensure the aggregate nominal point density (ANPD) is achieved	
Acquisition Window	Fall 2020 through Winter 2021	
Data Voids	 Not allowed except Where caused by water bodies Where caused by areas of low near infra-red (NIR) reflectivity (i.e. asphalt or composition roofing) Where caused by lidar shadowing from buildings or other features Where appropriately filled-in by another swath 	
Data Acquisition Conditions	Atmospheric • Cloud and fog-free between the aircraft and ground Ground • Snow free • No unusual flooding or inundation, except in cases where the goal of the collection is to map the inundation Vegetation • Leaf-off is preferred Time of Day • Time of day is not of concern	

Flight plans were created using Leica MissionPro software.

Lidar Sensor Information

Aerial lidar data was acquired for this project using the following lidar sensor systems:

- Terrain Mapper serial number 91511, last calibrated July 3, 2019
- Terrian Mapper serial number 91557, last calibrated July 1, 2020
- Terrian Mapper serial number 91515, last calibrated December 12, 2018 Table 2-2 depicts a summary of sensor information. See Appendix 1 for the sensor calibration reports.

Table 2-2. Leica Terrain Mapper Sensor Info

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

Source: Leica TerrainMapper Data Sheet

https://leica-geosystems.com/en-US/products/airborne-systems/topographic-lidar-sensors/leica-terrainmapper

Lidar Sensor Settings

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

Table 2-3. Lidar Sensor Settings

Settings	Terrain Mapper
Max. Number of Returns	15
Nominal Point Spacing	0.35 m
Nominal Point Density	8 ppsm
Flying Height Above Ground Level	1,372 m
Flight Speed	160 knots
Scan Angle	40°
Scan Rate Used	150 Hz
Pulse Rate Used	1,600.0 kHz
Multi-Pulse in Air	Enabled
Swath Width	1,456 m
Swath Overlap	25%

Timeline

Lidar data was collected from November 29, 2020 through April 19, 2021. A total of 141 individual flight lines were collected. Figure 2-1 shows aerial lidar coverage by lift.

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

GNSS and IMU Equipment

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

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

Base stations were set by acquisition staff and was used to support the aerial data acquisition. Table 2-3 lists the Station ID and coordinates for all base stations operated during acquisition.

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

Figure 2-1. Flight Coverage

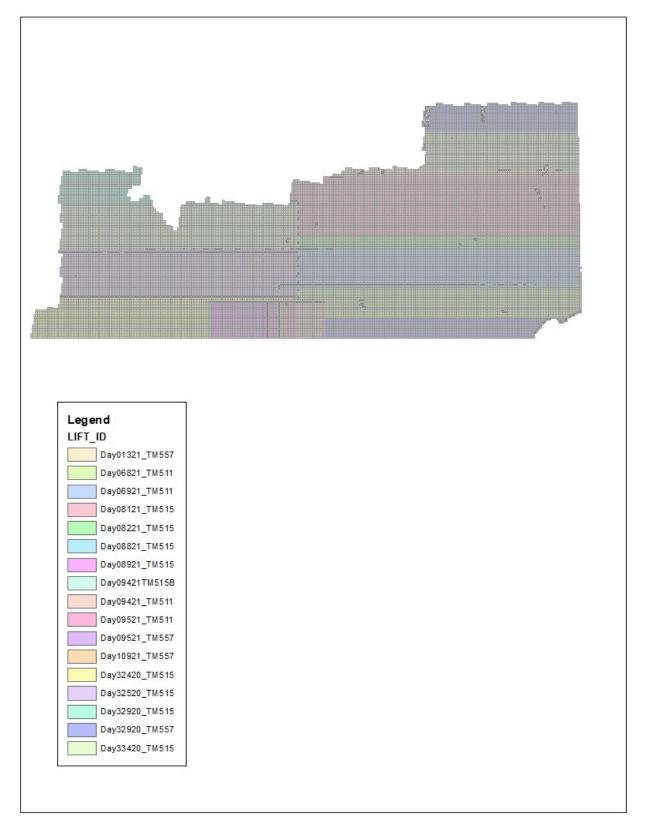


Table 2-4. GNSS Base Stations

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

Acquisition Quality Assurance

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

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

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

3. Processing

Processing Summary

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

GPS-IMU Trajectory Processing

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

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

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

Software: Novatel Inertial Explorer v8.70.6129

Trajectory Quality

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

Combination Separation

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

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

Estimated Positional Accuracy

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

PDOP

The PDOP measures the precision of the GPS solution in regard to the geometry of the satellites acquired

and used for the solution.

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

Geometric Calibration

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

For more information, see the Sensor Calibration Report(s) in Appendix 1.

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

Relative Accuracy: Interswath (Overlap) Consistency

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

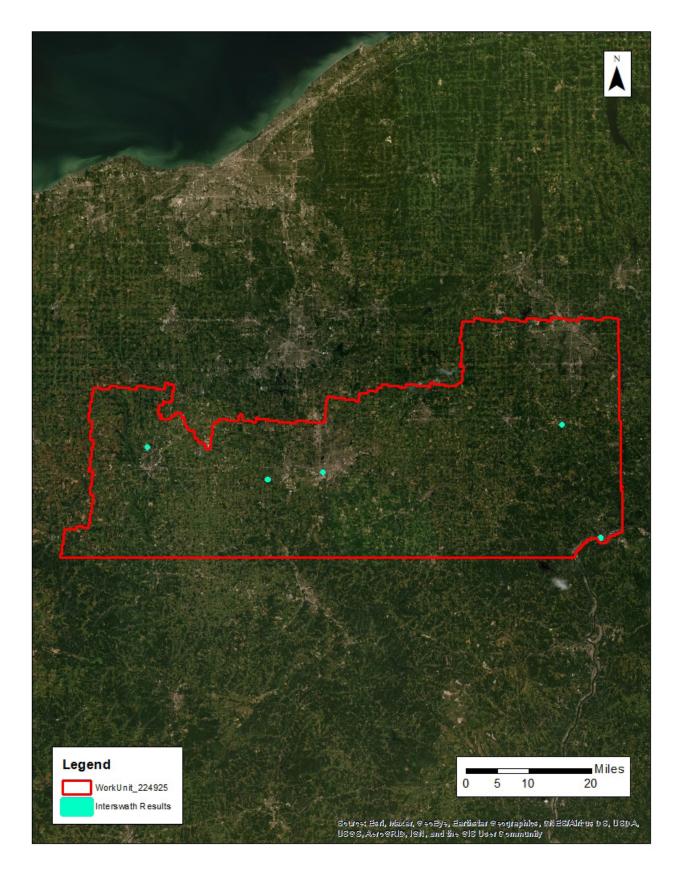
This project required the interswath accuracy to meet ≤ 8 cm RMSDz. Accuracy was assessed in accordance with the USGS Base Specification v2021 revision A.

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

Table 3-1. Interswath Results

Minimum (m)	Maximum (m)	RMSDz (m)
-0.11700000000	0.01700000000	0.0570000000
-0.1200000000	0.0400000000	0.0520000000
-0.0850000000	0.05500000000	0.04400000000
-0.0450000000	0.0700000000	0.0350000000
-0.0370000000	0.03300000000	0.0220000000

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.

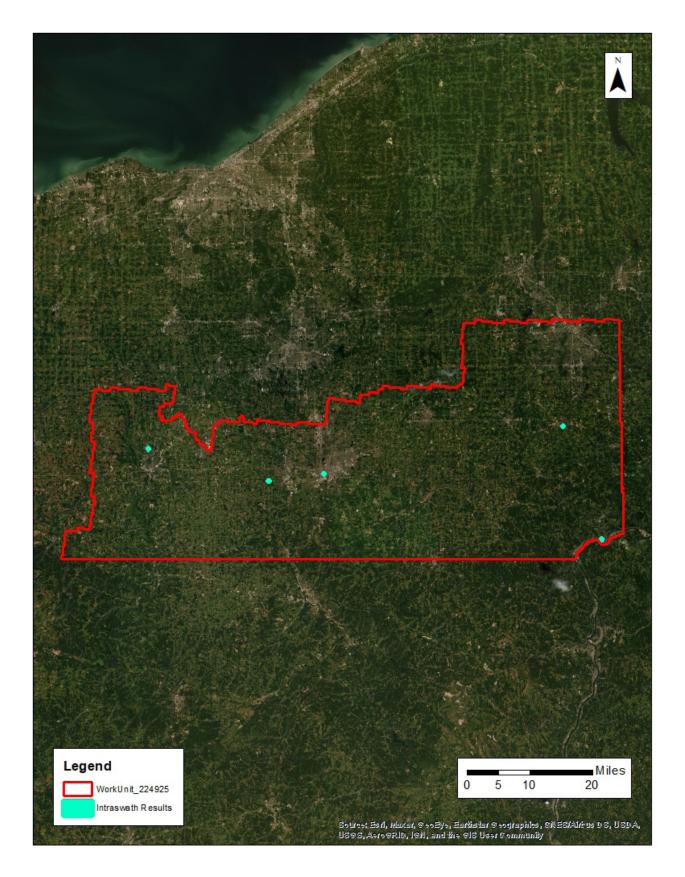
This project required the intraswath accuracy to meet ≤ 6 cm RMSDz. Accuracy was assessed in accordance with the USGS Base Specification v2020 revision A.

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.

Minimum (m)	Maximum (m)	RMSDz (m)
-0.1000000000	0.2700000000	0.0600000000
-0.5130000000	0.9900000000	0.15400000000
-0.2450000000	2.0890000000	0.0890000000
-0.5760000000	0.52300000000	0.0790000000
-0.1320000000	0.19700000000	0.04100000000

Table 3-2. Intraswath Results

Figure 3-2. Intraswath Testing Locations



Lidar Data Classification

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

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

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

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

Table 3-3 lists the point classifications used.

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

Table 3-3. Classified Point Breakdown

Hydrologic Flattening

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

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

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

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

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

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

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

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

Digital Elevation Model

TerraScan was used to add the hydrologic breakline vertices and export the lattice models. Class 2 (ground) lidar points in conjunction with the hydro breaklines and bridge breaklines were used to create 1.25-foot hydro-flattened bare-earth raster DEM files. Using automated scripting routines within ArcMap, a 32-bit floating point raster GeoTIFF file was created for each tile. Files were produced to the full extents of the tile boundaries. Each surface is reviewed using Global Mapper to check for any surface anomalies or incorrect elevations found within the surface.

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

Intensity Imagery

Lidar intensity data derived from the acquired lidar data was linearly rescaled from 16-bit intensity and provided as 1.25-foot pixel, 8-bit, 256 gray scale GeoTIFF files. Files were produced to the full extents of the tile boundaries.

Software: TerraScan v20, Esri ArcMap v10.7

Swath Separation Image

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

QL1 + QL2

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

QL0

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

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

Software: LP360 v2018.2.59.5

Figure 3-3. Svath Separation Image



Metadata

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

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

4. Accuracy Assessment

Horizontal Accuracy

The data set was produced to meet ASPRS "Positional Accuracy Standards for Digital Geospatial Data" (2014) for a 0.148 m RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 0.363 m at a 95% confidence level.

Classified Lidar Point Cloud Testing

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

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

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

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

	Result	Points Used
NVA	0.041 m RMSEz 0.08 m at 95% CL	52
VVA	0.244 m at 95th Percentile	25

Table 4-1. Classified Point Cloud Vertical Accuracy

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	0.092 m RMSEz 0.047 m at 95% CL	52
VVA	0.247 m at 95th Percentile	25

Appendix 1: Sensor Calibration Report

- when it has to be **right**



Leica Geosystems Leica TerrainMapper-LN Calibration Certificate

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



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

1. System Components

Component	Туре	Serial Number
Pod	TerrainMapper Pod	91511
GNSS/IMU	Litef LCI-100C 500 Hz	1139
LiDAR Unit	Hyperion2 LiDAR Unit	5511
Camera Head Lens	CH82 NAT-D 2.8/80	82659 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 Position	Bernhard Riedl Production Manager	15.11.2018	Rich Renhard
Name Position	Robert Bosch Support Engineer	23.05.2019	Xu Wang
Name Position	Michael Vetter Support Engineer	03.07.2019	h.300

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 Φ κ	-0.138877 0.130994 -0.006412	degree degree degree
Boresight		Value	Unit
	Θ Φ	0.001052 -0.001885	degree degree
Receiver 1		Value	Unit
Range	∆ Offset	0.000000	meters
Wedge 0		Value	Unit
Wedge Wedge Position Position Correction	Δ Alpha Δ Offset Χ Υ	0.001241 -0.426898 -0.019523 0.007883	degree degree degree degree
Mount	Roll	-0.020901	degree
Rotation Axis	Pitch Roll Pitch	0.107683 0.103712 0.124140	degree degree degree
Wedge 1		Value	Unit
Wedge Wedge Position Position Correction Mount	Δ Alpha Δ Offset Χ Υ Roll	-0.009545 0.412993 0.004000 0.011085 0.102859	degree degree degree degree degree
Mount	Pitch Speed Pitch	0.025756 1.50E-06	degree degree/rps ²
Rotation Axis	Roll Pitch	0.114811 -0.080531	degree degree
LiDAR Geometric Calibration File			
HYPERION_GEOMETRY_LIDARUNIT-5511	-C-855570-DATETIME-201810)23-153458.XM	ЛL
	Date	23.10.2018	
LiDAR Misalingment Flight LiDAR Misalingment Update Completed	Date 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

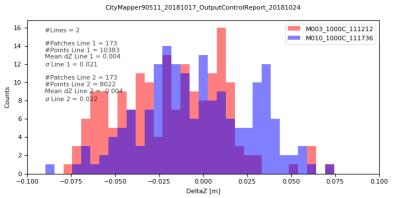
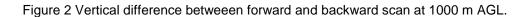


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

Color	Limits [m]	Number of patches	Proportion of total number o 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
	>0.1		0.01



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



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 Lens			CH82 NAT-D 2.8/80
Camera Model			
Focal Length			Distance [mm]
	С		83.00
Radial Symmetric Distorsion			Distance [mm]
	ko k1 k2		0.0000 0.0000 0.0000
Decentering Distortion	р1 р2		Distance [mm] 0.0000 0.0000
Non-Orthogonality Distortion			Distance [mm]
Pixel Size (Height and Width)	b ₁ b ₂		0.0000 0.0000 Distance [mm]
	RGB NIR		0.0052 0.0120
Rows and Columns		Rows	Columns
	Active RGB Raw RGB Active NIR Raw NIR	7752 7788 3654 3366	10320 10336 4478 4500

6.2 Results of Geometric Calibration

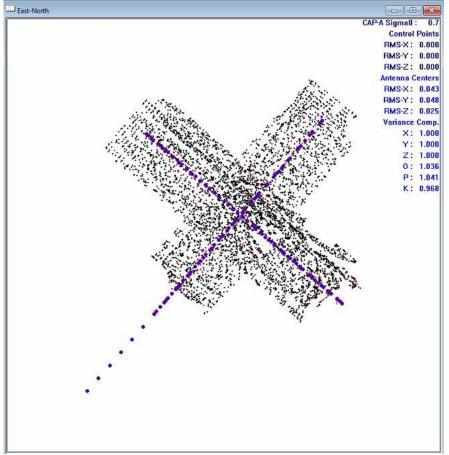
6.2.1 Calibration method for Green Reference Band

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:

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]
```

0.002

0.0007

Co-registration to green better than:

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

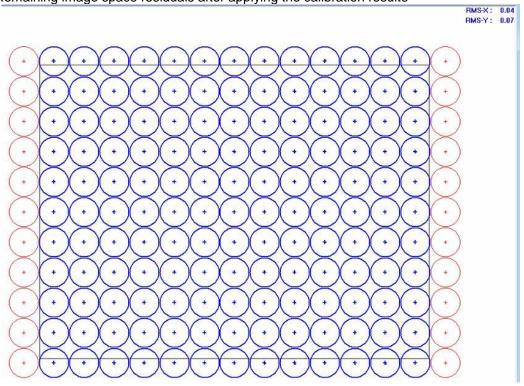
6.3 Estimation Results for Nadir Camera Head and Lens

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

1. System Components

Component	Туре	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			
5 1	•			

3. Inspectors

Name Position	Bernhard Riedl Production Manager	12.12.2018	Rud Runhard
Name Position	Robert Bosch Support Engineer	12.12.2018	4.Cod

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
	К	0.000504	degree
Boresight		Value	Unit
	Θ	0.015419	degree
	Φ	-0.001923	degree
Receiver 1		Value	Unit
Range	∆ Offset	0.000000	meters
Wedge 0		Value	Unit
Wedge	Δ Alpha	-0.043014	degree
Wedge Position	∆ Offset	0.442789	degree
Position Correction	Х	-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	∆ Alpha	-0.005517	degree
Wedge Position	∆ Offset	0.559649	degree
Position Correction	Х	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-551	6-C-855570-DATETIM	E-20181204-161828.XN	ΛL
	Date	04.12.2018	
LIDAD Missiliana and Elimber	Data		

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

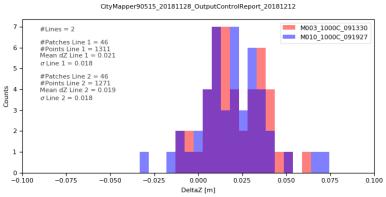
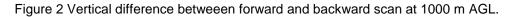


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

	the second s	patches [%]
<=0.04	302593	99.75
0.04-0.07	716	0.24
0.07-0.1	17	0.01
>0.1	29	0.01
	0.04-0.07 0.07-0.1	0.04-0.07 716 0.07-0.1 17



5.2.3 Multi-line accuracy between two perpendicular lines

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

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.



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

1. System Components

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

2. Estimation Process

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

3. Inspectors

Name Position	Bernhard Riedl Production Manager	01.07.2020	Rid Renhard
Name Position	Ivan Belchev Workflow Specialist	01.07.2020	Utres
Name Position	Michael Vetter Support Engineer	01.07.2020	Vete blilad

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

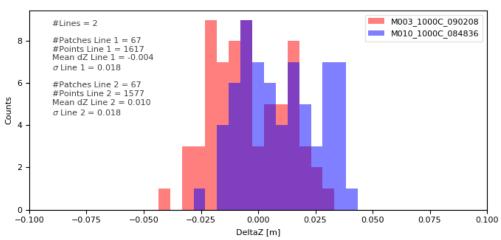
IMU Misalignment		Value	Unit
	ω	-0.063987	degree
	Φ	-0.049738	degree
	К	-0.005305	degree
Boresight		Value	Unit
	Θ	-0.001796	degree
	Φ	-0.003034	degree
Receiver 1		Value	Unit
Range	∆ Offset	0.000000	meters
Wedge 0		Value	Unit
Wedge	Δ Alpha	-0.045434	degree
Wedge Position	∆ Offset	0.352942	degree
Position Correction	Х	-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	∆ Offset	0.393122	degree
Position Correction	Х	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-2	0200625-085747.XM	ЛL
	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



TM-LN-91557_200623_OutputControlReport_200625

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 Lens			CH82 NAT-D 2.8/80
Camera Model			
Focal Length			Distance [mm]
	С		83.00
Radial Symmetric Distorsion			Distance [mm]
	ko k1 k2		0.0000 0.0000 0.0000
Decentering Distortion	р1 р2		Distance [mm] 0.0000 0.0000
Non-Orthogonality Distortion			Distance [mm]
Pixel Size (Height and Width)	b ₁ b ₂		0.0000 0.0000 Distance [mm]
	RGB NIR		0.0052 0.0120
Rows and Columns		Rows	Columns
	Active RGB Raw RGB Active NIR Raw NIR	7752 7788 3654 3366	10320 10336 4478 4500

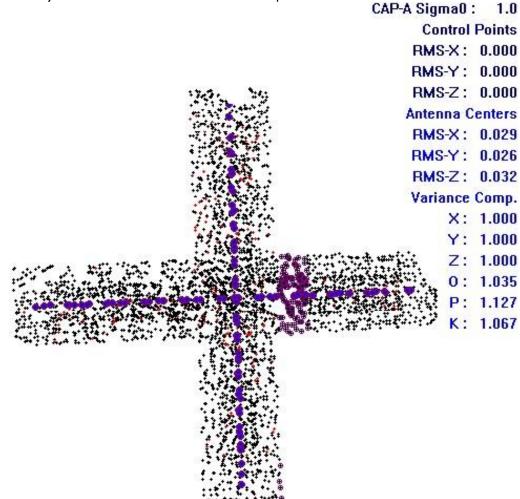
6.2 Results of Geometric Calibration

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]

0.002

Co-registration to green better than:

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

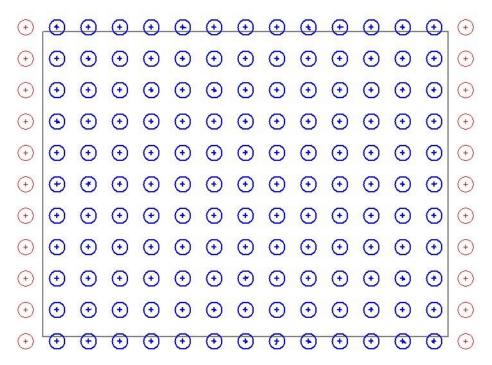
		Component	Serial Number
Camera Head Lens View Direction in Pod Position		CH82 NAT-D 2.8/80 Nadir	82673 80264
IMU Misalignment		Angle [degree]	
	ω Φ κ	0.03017 -0.01221 -0.25213	
Principal Point		Distance [mm]	
	x y	0.0000 0.0000	
Focal Length		Distance [mm]	
	С	83.00	
Geometric Calibration File			
RCD30_Geometry_CameraHead-8	32673798528_	_ensSystem-80264-	B-785423_DateTime-

20200629-142416.xml

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

Remaining image space residuals after applying the calibration results

RMS-X: 0.13 RMS-Y: 0.11



Radius of circles is 0.0010 mm

Appendix 2: Flight Logs

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Point Spacir	ng (m)	Poir	nt Density (pp	osm)	Sca	an Ang	le/FOV	/ (°)	Sca	n Frequency	/ (Hz)	Pulse	Rate	(kHz)	Las	er Po	ower (%)
			8			4	0			150			1600			1(00
				Verify S-Turr									Furns E	Before	Missio	on Yes	
Line #	Direc	tion	Start Time (UTC)					Sate	llite	PDOP			Line N	otes/0	Comme	ents	
41	N	1	14:32:00	14:4	8:00	00:16:00		2	1	1.1							
40	5		14:51:00	15:0		00:14:00		20		1.3							
39	N		15:07:00	15:2			6:00	20		1.3							
38	5		15:26:00	15:4			4:00	19		1.6							
37 36	N S		15:43:00 16:04:00	15:5 16:2			5:00 7:00	19 21		1.5 1.2							
35	N N		16:23:00	16:4			8:00	2		1.2							
34	5		16:43:00	16:5			6:00	23		1.4							
33	N		17:02:00	17:2			8:00	23		1.2							
32	5	5	17:22:00	17:3	9:00	00:1	7:00	22	2	1.2							
31	N		17:42:00	18:0			8:00	2		1.1							
30	S		18:02:00	18:2			8:00	24		1.1							
29	N		18:22:00	18:4			8:00	2:		1.3							
28	5)	18:42:00	19:0	0:00	00:1	8:00	20)	1.4							
											-						
								D- :	4		<u> </u>	lanif. C	T.	A. 6+ -	N A 2 *		
								Page	T		V	erify S-	urns	Arter	IVIISSIO	n	Yes
Additional C	omme	nts															

Project # 1 81150 Crew Gebhart Gebrator Operator Smith Wind Dir (°) 200 Air Spect (# 160 Point Spacing (m 49 48 47	wind kts)	ohio Aiı Ser Le Speed (kts) 17 Altitude	Equip rcraft Make Cessna 404 T nsor Make / eica Terrain N Visibility 10 AGL (ft)	pment / Model / Tai Titan - N7079f Model / Seria Mapper - 905: (il # = al #	Jnique ID Hobbs S 2986. Hobbs E 2992.	tart Loc 7 09 nd Loc	1/19/20	Date (UTC) Day 200 UTC Start 14:40:00 UTC End	of Yea 324 A t D	r Flight # 1 Airports eparting day	
81150 Crew Pilot Gebhart Operator Smith Wind Dir (°) 200 Air Speed (k 160 Point Spacing (m Line # Dir 49 48	wind kts)	ohio Aiı Ser Le Speed (kts) 17 Altitude 6,5	blk 1 Equip rcraft Make Cessna 404 T nsor Make / Eica Terrain N Visibility 10 AGL (ft)	/ Model / Tai Fitan - N7079f Model / Seria Mapper - 9053	il # = al # 15	Hobbs S 2986. Hobbs E	tart Loc 7 09 nd Loc	1/19/20 e al Start :40:00	020 UTC Start 14:40:00	324 A t D	1 Airports eparting	
Crew Pilot Gebhart Operator Smith Wind Dir (°) 200 Air Speed (k 160 Point Spacing (m Line # Dir 49	wind kts)	Aii (Ser Le Speed (kts) 17 Altitude 6,5	Equip rcraft Make Cessna 404 T nsor Make / eica Terrain N Visibility 10 AGL (ft)	/ Model / Tai Fitan - N7079f Model / Seria Mapper - 9053	= al # 15	2986. Hobbs E	Tim tart Loc 7 09 nd Loc	e al Start :40:00	UTC Start 14:40:00	A t D	Airports eparting	
Pilot Gebhart Operator Smith Wind Dir (°) 200 Air Speed (k 160 Point Spacing (m Line # Dir 49	wind kts)	(Ser Le Speed (kts) 17 Altitude 6,5	rcraft Make Cessna 404 T nsor Make / Eica Terrain N Visibility 10 AGL (ft)	/ Model / Tai Fitan - N7079f Model / Seria Mapper - 9053	= al # 15	2986. Hobbs E	tart Loc 7 09 and Loc	al Start :40:00	14:40:00	t D	eparting	
Gebhart Operator Smith Wind Dir (°) 200 Air Speed (k 160 Point Spacing (n Line # Dir 49	wind kts)	(Ser Le Speed (kts) 17 Altitude 6,5	rcraft Make Cessna 404 T nsor Make / Eica Terrain N Visibility 10 AGL (ft)	/ Model / Tai Fitan - N7079f Model / Seria Mapper - 9053	= al # 15	2986. Hobbs E	7 09 ind Loc	:40:00	14:40:00	t D	eparting	
Operator Smith Wind Dir (°) 200 Air Speed (k 160 Point Spacing (m Line # Dir 49	wind kts)	(Ser Le Speed (kts) 17 Altitude 6,5	Cessna 404 T nsor Make / eica Terrain M Visibility 10 AGL (ft)	fitan - N7079f Model / Seria Mapper - 9053	= al # 15	Hobbs E	7 09 ind Loc	:40:00	14:40:00			
Operator Smith Wind Dir (°) 200 Air Speed (k 160 Point Spacing (m Line # Dir 49	wind kts)	Speed (kts) 17 Altitude 6,5	visibility AGL (ft)	Model / Seria Mapper - 905: (al # 15	Hobbs E	ind Loc			_		
Smith Wind Dir (°) 200 Air Speed (H 160 Point Spacing (n Line # Din 49	Wind kts)	Le Speed (kts) 17 Altitude 6,5	Visibility 10 AGL (ft)	Vapper - 905: (15						Arriving	
Wind Dir (°) 200 Air Speed (l 160 Point Spacing (m Line # Din 49 48	kts)	Speed (kts) 17 Altitude 6,5	Visibility 10 AGL (ft)	(2992.		26.00			Arriving	
200 Air Speed (l 160 Point Spacing (m Line # Din 49 48	kts)	17 Altitude 6,5	10 AGL (ft)		Conditions		6 03	:36:00	20:36:00		day	
200 Air Speed (l 160 Point Spacing (m Line # Din 49 48	kts)	17 Altitude 6,5	10 AGL (ft)	(mi) Ceilir			1					
Air Speed (k 160 Point Spacing (m Line # Din 49 48		Altitude 6,5	AGL (ft)		0 ()	oud Cover	Temp. (°C) Dew	/ Point (°C)	Pres	ssure ("H	
Line # Din 49 48		6,5				Scattered	9		-5		3031	
Point Spacing (m Line # Din 49 48	n) Poin	-	592	Altitude	MSL (ft)	Airfield El	evation (ft)					
Line # Dir 49 48	n) Poin	t Densitv (pr	6,592 7,356 1,009									
Line # Dir 49 48	n) Poin	t Density (pr		•	Settings							
Line # Dir 49 48	,		osm) Sca	an Angle/FOV		an Frequency	(Hz) Pul	se Rate	(kHz) L	aser Pr	ower (%)	
49 48			,	40		150	,	1600			00	
49 48				-+0		130	Vorifie		Before Mic		Yes	
49 48		o				T	vernys	-iums E	Before Miss	51011	res	
48	rection	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP		Line N	otes/Comr	nents		
	е	15:17:00	15:27:00		21	1.1						
47	w	15:31:00	15:46:00		22	1						
	е	15:49:00	15:59:00	00:10:00	18	1.2						
46	w	16:03:00	16:19:00	00:16:00	19	1.1						
45	е	16:23:00	16:33:00	00:10:00	20	1.3	L					
44	w	16:37:00	16:52:00	00:15:00	20	1.3						
43	е	16:54:00	17:04:00	00:10:00	20	1.2						
42	W	17:09:00	17:22:00	00:13:00	22	1						
41	e	17:25:00	17:35:00 17:54:00	00:10:00	23 22	1						
40 39	e w	17:39:00 18:03:00	17:34:00	00:15:00	22	1.3 1.2						
38	e w	18:03:00	18:31:00	00:14:00	24	1.2						
37	e	18:34:00	18:44:00	00:14:00	23	1.3						
36	w	18:48:00	19:01:00	00:13:00	23	1.2						
35	e	19:04:00	19:16:00	00:12:00	24	1.2						
34	w	19:20:00	19:39:00	00:19:00	23	1.3						
		15.20.00	10.00100	00110100		1.0						
						1						
					Page 1		Verify	S-Turns	After Miss	ion	Yes	
Additional Comr	ments											

					ct Info				uisitio				Г	Date		
Project #			Project					U	nique ID		Flight	Date			Year	Flight
81150			ohio						inque is		11/20/2020 325					1
	ew		01110		uipmen	+					Time					rports
	lot		Δiι		•	el / Tail # Hobbs Start			tart	Local Start UTC Start					Departing	
	hart			Cessna 40		-			2992.					4:00		day
	rator					Hobbs E				C End Arrivi						
· ·	hith				Hake / Model / Serial # H Prrain Mapper - 90515 F					-	02:2	-	19:2		-	
311			Le					0.000	2997.	5	02.2	0.00	19.2	0.00		day
14/in al Dia	. / º \		Speed (late)	Vicibil	Conditions bility (mi) Ceiling (ft) Cloud Cov					Tama	• (°C)	Davis	Daint	(°C)	Droco	
Wind Dir	\mathbf{O}	wina	Speed (kts)	kts) Visibility (10		Ceniir	ig (it)				o. (°C) 2	Dew	Point	()		ure ("H
210			18		-			-	cattered				-1			3031
Air Spe			Altitude				MSL (f	[)	Airfield El		n (π)					
10	60		6,5	92		7,5	356		1,	009			_	_	_	_
		D ·			C T	1. /=	Settin	-	- F	(11.)		D :	(1.1.)			1017
oint Spaci	ng (m)	Poin	t Density (pp	osm)	Scan Ang	_	/ ([*])	Sca	n Frequency	(Hz)	Pulse	Rate	(KHZ)	Las		ver (%)
		_				40		_	150			1600			100	
	_	-			_		_			Ve	erify S-1	furns E	Before	Missic	n	Yes
Line #	Direct	ion	Start Time	End Tim	-	ime	Sate	lite	PDOP			Line N	otes/C	Comme	ents	
			(UTC)	(UTC)		-Line							-			
33	e		15:12:00 15:28:00	15:25:0 15:44:0			22 20		1.2 1.2							
32 31	w e		15:28:00	16:00:0		13:00	20		1.2							
30	w		16:03:00 16:19			00:13:00		,)	1.2							
29	e		16:21:00 16:34			00:13:00)	1.3							
28	w		16:38:00	16:53:0	0 00:	00:15:00)	1.2							
27	e		16:56:00	17:09:0	0 00:	00:13:00		2	1.1							
26	w		17:12:00	17:28:0		16:00	23		1.1							
25	e		17:30:00	17:43:0		13:00	23		1.1	<u> </u>						
24 23	w		17:46:00 18:04:00	18:02:0 18:18:0		16:00 14:00	22 23		1.2 1.2							
23	e w		18:04:00	18:37:0		16:00	22		1.2				louds	3/1_1		
22			10.21.00	10.57.0	0 00.	10.00		•	1.5				louus	54 1		
					_											
					_											
							<u> </u>			<u> </u>						
							Page 3	L		V	erify S-	Turns	After I	Missio	n	Yes
dditional C	Commer	nts														

Project #				FIU	ect lı									L L	Date		
			Project						U	nique ID		Flight	Date			f Year	Flight
81150			Ohio Phas	e 2 Blocl	< 2							11/24/2020			32		1
Cr	ew			E	auip	ment						Time				Ai	rports
	ilot		Ai	rcraft N			l / Tai	#		Hobbs S			Start	UTC	Start		
Dar	Perl						N406SD 5			552.1		09:1	9:00				CAK
Ope	rator		Se		r Make / Model / Serial #					Hobbs E		Loca		UTC End			riving
•	nedy				Terrain Mapper - 90557					557.1			5:00	18:5		CAK	
iteri	neay				Conditions						-	10.0	5.00	10.5	5.00		0/ 111
Wind Di	· (°)	Wind	Speed (kts)	Visih						oud Cover	Temr	o. (°C)	Dew	Point	്റ	Press	ure ("H
120	()	wind	5	VISIN	10 25,00					Broken)	Dew	-2	()		30.36
Air Spe	od (kto	•	-											-2			50.30
•	60	·)		e AGL (ft) Altitude MSL (ft) Airfield Elevation 562 7,133 1,226								(11)					
1	00		6,5	002			,			1,	220			-	-	-	-
aliat C:		- ·	+ Decreta /	ang)				Settin	-	- F actor	(11-)	Deal	D-1	(1.1)	•	P	10/2
oint Spaci	ng (m)	Poir	nt Density (pp	ism)	Sca	in Angl		(')	Sca	n Frequency	(HZ)	Pulse	Rate	(KHZ)	Las		ver (%)
			8		_	4()		_	150			1600			100	
					_			_			Ve	rify S-	Furns E	Before	Wissic	n	Yes
Line #	Dire	ction	Start Time (UTC)	End Ti (UTC		Tin On-I	Sate	llite	PDOP			Line N	otes/C	Comme	ents		
1			14:37:00	14:46	-	On-Line 00:09:00		19		1.1							
2		- V	14:49:00	14:58		00:09:00		19		1.1	-						
3			15:02:00	15:11		00:09		2		1							
4	W		15:14:00	15:23	:00	00:09	9:00	20		1.1							
5			15:27:00	15:36	:00	00:09	9:00	19		1.2							
6	W		15:39:00	15:48		00:09		21		1.1							
7		E	15:54:00	16:03		00:09:00		18 19		1.2		Small clouds					
8		V -	16:06:00	16:15		00:09:00				1.1			Small clouds in the relocation for clo				
66 65	-	E V	16:29:00 16:44:00	16:35 16:56		00:06:00		19 21		1.1			reloca	ation	or clou	as	
64		E	17:00:00	17:12		00:12:00		18		1.1							
63		v	17:15:00	17:27		00:12		19		1.1							
62		E	17:31:00	17:43		00:12:00		19		1.2							
61	V	V	17:47:00	17:59		00:12		19		1.2							
60		E	18:03:00	18:16		00:13		20		1.2							
59	V	V	18:19:00	18:33	:00	00:14	4:00	19	9	1.3	<u> </u>				II clou		
	<u> </u>												mx	hobbs	5491.9)	
											<u> </u>						
								Dana	1			anife - C	Turner	^ £1 ~ ~ * *			V
ما بيد الما	.	a ha						Page	T		V	enty S	Turns	Aiter	VII5510	1	Yes
dditional C	.omme	nts															

						t Lid	ar A	\cq	uisitio	n Lo	og					
				Proje	ect Info								[Date		
Project #			Project	Name				U	nique ID		Flight	Date	(UTC)	Day o	f Year	Flight
81150			Gallia C	o LiDAR				Day	013_91557		01	/13/20	21	0	13	
Cre	ew			E	quipme	nt					Time				Ai	rports
Pil	lot		Ai	rcraft M	ake / Mo	odel / Tai	#		Hobbs St	tart	Local	Start	UTC	Start	De	parting
Cost	anzo			Reims	406 - N	406SD			5516.3	3	10:3	0:00	15:3	0:00		KDAY
Oper	rator		Se			del / Seria	al #		Hobbs E	nd	Loca	l End	UTC		Δ	rriving
-	done					per - 9155			5521	-		0:00	20:3	-		KDAY
Narc	Jone						Conditi	ons	5521		05.5	0.00	20.5	0.00		
Wind Dir	(°)	Wind	Speed (kts)	Vicibi	lity (mi)	-	ng (ft)		oud Cover	Tomr	o. (°C)	Dow	Point	(°C)	Droce	ure ("H
170		wind	7		10				Broken		, (C) 2	Dew	-3	()		30.12
-	مط (البعم				10		000			<u> </u>			-3			30.12
Air Spe			Altitude			Altitude	•	t)	Airfield El		ι (π)					
1:	30		4,5	00			908		1,0	009			-	-	-	-
							Settin	-	_	/					-	1
oint Spacin	ng (m)	Poin	nt Density (pp	osm)	Scan A	ngle/FOV	/(")	Sca	n Frequency	(Hz)	Pulse	Rate	(kHz)	Las		wer (%)
0.7			2			40			90	_		600			10	-
							8			Ve	erify S-1	Turns E	Before	Missi	on	Yes
Line #	Direc	tion	Start Time (UTC)	End Tir (UTC		Time Dn-Line	Sate	llite	PDOP			Line N	otes/C	Comme	ents	
52	S		16:24:00	16:36:	00		1	7	1.3			Gallia	Co @!	5000 N	/ISL	
64	N		16:40:00	16:42:			1	5	1.5							
53	N		16:49:00	17:01:		0:12:00	1		1.2							
54	S		17:04:00	17:10:		0:06:00	1		1.2							
55	N		17:13:00	17:19:		0:06:00	1		1.1							
56	S		17:22:00	17:28:		0:06:00	10		1.1	<u> </u>						
57	N		17:30:00	17:36:		0:06:00	1		1.2							
58 59	S N		17:38:00 17:46:00	17:44: 17:52:		0:06:00 0:06:00	14		1.1 1.5							
60	S		17:55:00	17:52:		0:08:00	14		1.5							
61	N		18:01:00	18:05:		0:04:00	14		1.4							
62	S		18:08:00	18:11:		0:03:00	14		1.8							
63	N		18:14:00	18:16:		0:02:00	14		1.8							
19	E		18:58:00	19:11:	00 00	0:13:00	1	7	1.1		Ohio) LIDAR	Block	2 @7	133 M	SL
20	W	′	19:15:00	19:31:	00 00	0:16:00	1	5	1.2							
										<u> </u>						
	<u> </u>															
							Page	1		V	erify S	Turns	After l	Missio	n	
dditional C	ommen	ts														

				Projec	t Info								[Date		
Project #			Project	Name				U	nique ID		Flight	Date	(UTC)	Day of	f Yea	r Flight
81764			fairfield,	oh blk 1,2							03,	/09/20	21	06	58	1
Cr	ew			Equ	uipmen	t					Time				Α	irports
Pi	lot		Ai	rcraft Mak	•		il #		Hobbs S	tart	Local	Start	UTC	Start		eparting
Geb	hart			Cessna 404	-	-			8230.4	4	10:2	1:00	15:2	1:00		day
	rator			nsor Make					Hobbs E		Loca		UTC			Arriving
	hith			ica Terrai	-	-			8237.4	-	05:1	-	22:1			-
	IILII		Le		тиарре		Conditio		0257.4	+	05.1	0.00	22.1	0.00		day
	(0)	1400	6 1(1)		(.)	1			1.0	-	(80)		.	(80)	_	///-
Wind Di	r (°)	Wind	Speed (kts)	Visibilit			ng (ft)	Clo	oud Cover		o. (°C)	Dew	Point	(°C)	Pres	sure ("H
210			8	10			000		Few		.2		-2			3042
Air Spe	ed (kts	5)	Altitude	AGL (ft)	A	ltitude	MSL (ft))	Airfield El	evatior	n (ft)					
1	30		4,5	601		5,1	L08		1,	009						
							Setting	gs								
oint Spaci	ng (m)	Poir	t Density (pp	osm) s	Scan Ang	gle/FOV	/ (°)	Sca	n Frequency	(Hz)	Pulse	Rate	(kHz)	Las	er Po	wer (%)
						40			150			1323			10	00
										Ve	rify S-1	Furns E	Before	Missic	on	Yes
			Start Time	End Tim	e Ti	me					-					
Line #	Dire	ction	(UTC)	(UTC)		-Line	Satelli	ite	PDOP			Line N	otes/0	Comme	ents	
50		5	16:00:00	16:09:00)		19		1.2							
51	r	า	16:12:00	16:18:00			19		1.2				fairfi	eld		
52		S	16:20:00	16:26:00	00:	06:00	18		1.3							
53	r	า	16:29:00	16:35:00) 00:	06:00	18		1.3							
54		S	16:38:00	16:44:00) 00:	06:00	18		1.3							
55	r	า	16:46:00	16:52:00	00:	06:00	19		1.3							
56		S	16:55:00	17:01:00		06:00	17		1.6							
57	r	า	17:04:00	17:09:00		05:00	17		1.7							
58		5	17:12:00	17:18:00		06:00	17		1.7							
59	r	า	17:21:00	17:27:00	_	06:00	16		1.7							
60		5	17:30:00	17:34:00	_	04:00	19		1.3							
61		<u>ו</u>	17:36:00	17:39:00		03:00	19		1.3	<u> </u>						
62		S	17:42:00	17:46:00	_	04:00	19		1.2							
21		v	18:24:00	18:38:00		14:00	19		1.4				oh bl			
58	<u> </u>	9	18:54:00	19:08:00		14:00	23		1.1				oh bl	κZ		
57 56		V a	19:11:00 19:29:00	19:26:00 19:43:00	_	15:00 14:00	22 25		1.2 1.1							
55		e V	19:29:00	20:01:00	_	15:00	25		1.1	<u> </u>						
54		5	20:05:00	20:21:00		16:00	24		1.2							
53	<u> </u>	V	20:24:00	20:41:00	_	17:00	18		1.8							
52		2 2	20:44:00	21:00:00		16:00	20		1.4							
51		v	21:03:00	21:19:00	_	16:00	18		1.3							
							Page 1			V	erify S-	Turns	After	Missio	n	Yes
dditional (Comme	ents														

				Noo	lpe	rt Lid	ar /	<u>Acq</u>	uisitic	on L	og					
				Proje	ct Inf	0								Date		
Project #			Project	Name				U	nique ID		Flight	Date	(UTC)	Day o	f Year	Flight
81150			oh bl	k 1,2							03,	/10/20	21	06	59	1
Cr	ew			Eq	luipm	ent					Time				Ai	rports
Pi	lot		Aiı	craft Ma	ke / N	1odel / Ta i	l #		Hobbs St	art	Local	Start	UTC	Start	De	parting
Geb	hart		(Cessna 40)4 Tita	n - N404Cl	>		8237.4	1	10:2	0:00	15:2	0:00		day
Ope	rator		Ser	nsor Mak	e / Mo	odel / Seria	al #		Hobbs E	nd	Loca	l End	UTC	End	Α	rriving
Sm	nith		Le	ica Terra	in Maj	pper - 905:	11		8243.2	1	03:5	8:00	20:5	8:00		day
					•		Condit	ions								•
Wind Dir	· (°) V	Vind	Speed (kts)	Visibil	ity (m	i) Ceilir	ng (ft)	Clo	ud Cover	Temp	o. (°C)	Dew	Point	(°C)	Press	ure ("H
190			14		10	· ·	000		Broken		.6		-2			3026
	ed (kts)		Altitude	AGL (ft)		Altitude			Airfield El	evation	n (ft)					
-	60		6,5		-		56	-,		009	. (,					
			0,5			7,5	Settir	וסכ	±,(
Point Spaci	ng (m)	Poin	t Density (pp	sm)	Scan	Angle/FOV		-	n Frequency	(H7)	Dules	Rate	(kH2)	l ar	er Do	wer (%)
Sint Spaci	יة (^{ייי}) א	rom	r Density (bb	,511)	Juli	40	()	Jud	150	(114)	ruise	1603	(112)	Las	100	
						40			130		rify 6 7		Rafara	Missi) Yes
			Short Time	Fired T:	I	Tires				ve	rify S-1		Jeiore	10115510		162
Line #	Direct	ion	Start Time (UTC)	End Tin (UTC)		Time On-Line	Sate	llite	PDOP			Line N	otes/C	Commo	ents	
			(010)	(010)		On-Line										
22	e		16:02:00	16:15:0	0		2	2	1.2				oh bl	k 1		
49	e		16:22:00	16:40:0		00:18:00	2		1.2				oh bl			
48	w		16:43:00	17:02:0		00:19:00	19		1.5				0.1.2.			
47	e		17:05:00	17:22:0		00:17:00	19		1.8							
46	w		17:25:00	17:45:0	00	00:20:00	20	0	1.5							
45	е		17:48:00	18:05:0	_	00:17:00	2	0	1.3							
44	w		18:08:00	18:27:0		00:19:00	1		1.4							
43	e		18:30:00	18:46:0		00:16:00	20	-	1.2							
42	w	_	18:49:00	19:08:0 19:27:0		00:19:00	2		1.1 1.1							
41 40	e w		19:11:00 19:30:00	19:27:0		00:16:00 00:19:00	19 21		1.1							
40			15.50.00	15.45.0		00.15.00	2.	1	1.2							
		_														
					-+											
					-											
							Page	1		V	erify S-	Turns	After	Missio	n	Yes
Additional C	Commen	ts					rage	1			eriiy 5-	- i urns	Aiter	VIISSIO		res

			Wool	pert Li	dar Ac	quisitio	on Log					
			Project	Info					0	Date		
Project #		Project	: Name			Unique ID	Fligh	nt Date	(UTC)	Day o	f Year	Flight
81150		oh bl	k 2,6				0	3/23/20)21	08	32	1
Crew			Eau	ipment			Time	2			Ai	rports
Pilot		Ai	-	e / Model / T	ail #	Hobbs S		l Start	UTC	Start		parting
Gebhart				Titan - N475		2425.		39:00	14:3			day
					-	Hobbs E		al End			•	-
Operator				/ Model / Se					UTC		A	rriving
Smith		Le	eica Terrain	Mapper - 90		2431.	5 04:	45:00	20:4	5:00		day
					Condition							
Wind Dir (°)	Wind	Speed (kts)	Visibility	/ (mi) Ceil	ling (ft)	Cloud Cover	Temp. (°C)	Dew	/ Point	(°C)	Press	sure ("H
150		11	10			Broken	13		1			3006
Air Speed (kt	s)	Altitude	AGL (ft)	Altitud	le MSL (ft)	Airfield El	evation (ft)					
160		6,5	62	7	,133	1,	009					
		,		#	Settings	,						
oint Spacing (m)	Poin	t Density (pr	osm) Sa	an Angle/FC		an Frequency	(Hz) Pule	e Rate	(kHz)	Las	er Pov	wer (%)
Pacing (iii)			J	40		150	<u></u> , rui:	1603	····-/		10	
				40		130	Varify C		Poferr	N/:!		
							Verify S	-iurns	berore	1115510	חכ	Yes
Line # Dire	ction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP		Line N	lotes/C	Comme	ents	
37	e	15:40:00	15:57:00		21	1.2			blk :	2		
38	N	16:00:00	16:16:00		19	1.4						
	e	16:19:00	16:36:00	00:17:00	17	1.7						
	S	16:48:00	16:54:00	00:06:00	16	1.5			blk	6		
-	n	16:57:00	17:03:00	00:06:00	17	1.2						
	S	17:07:00	17:15:00	00:08:00	18	1.2	ļ					
	n	17:18:00	17:25:00	00:07:00	16	1.4						
	S	17:28:00	17:37:00	00:09:00	17	1.3	ļ					
	n c	17:41:00	17:50:00	00:09:00	21	1.1						
	s n	17:53:00 18:07:00	18:04:00 18:16:00	00:11:00	21	1.1						
	n c	18:07:00	18:32:00	00:13:00	20	1.1						
	s n	18:36:00	18:48:00	00:13:00	20	1.1						
45	s	18:51:00	19:04:00		20	1.1						
	n	19:08:00	19:22:00		19	1.2						
43	s	19:25:00	19:42:00			1.9						
			13.42.00		10							
					Page 1		Verify	S-Turns	After I	Missio	n	Yes

			Wool	pert Li	dar Ac	quisitio	on Log					
			Project	Info					0	Date		
Project #		Project	: Name			Unique ID	Fligh	nt Date	(UTC)	Day o	f Year	Flight
81150		oh bl	k 2,6				0	3/23/20)21	08	32	1
Crew			Eau	ipment			Time	2			Ai	rports
Pilot		Air	-	e / Model / T	ail #	Hobbs S		l Start	UTC	Start		parting
Gebhart				Titan - N475		2425.		39:00	14:3			day
					-	Hobbs E		al End			•	-
Operator				/ Model / Se					UTC		A	rriving
Smith		Le	eica Terrain	Mapper - 90		2431.	5 04:	45:00	20:4	5:00		day
					Condition							
Wind Dir (°)	Wind	Speed (kts)	Visibility	/ (mi) Ceil	ling (ft)	Cloud Cover	Temp. (°C)	Dew	/ Point	(°C)	Press	sure ("H
150		11	10			Broken	13		1			3006
Air Speed (kt	s)	Altitude	AGL (ft)	Altitud	le MSL (ft)	Airfield El	evation (ft)					
160		6,5	62	7	,133	1,	009					
		,		#	Settings	,						
oint Spacing (m)	Poin	t Density (pr	osm) Sa	an Angle/FC		an Frequency	(Hz) Pule	e Rate	(kHz)	Las	er Pov	wer (%)
pacing (iii)			J	40		150	<u></u> , rui:	1603	····-/		10	
				40		130	Varify C		Poferre	N/:!		
							Verify S	-iurns	berore	1115510	חכ	Yes
Line # Dire	ction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP		Line N	lotes/C	Comme	ents	
37	e	15:40:00	15:57:00		21	1.2			blk :	2		
38	N	16:00:00	16:16:00		19	1.4						
	e	16:19:00	16:36:00	00:17:00	17	1.7						
	S	16:48:00	16:54:00	00:06:00	16	1.5			blk	6		
-	n	16:57:00	17:03:00	00:06:00	17	1.2						
	S	17:07:00	17:15:00	00:08:00	18	1.2	ļ					
	n	17:18:00	17:25:00	00:07:00	16	1.4						
	S	17:28:00	17:37:00	00:09:00	17	1.3	ļ					
	n c	17:41:00	17:50:00	00:09:00	21	1.1						
	s n	17:53:00 18:07:00	18:04:00 18:16:00	00:11:00	21	1.1						
	n c	18:07:00	18:32:00	00:13:00	20	1.1						
	s n	18:36:00	18:48:00	00:13:00	20	1.1						
45	s	18:51:00	19:04:00		20	1.1						
	n	19:08:00	19:22:00		19	1.2						
43	s	19:25:00	19:42:00			1.9						
			13.42.00		10							
					Page 1		Verify	S-Turns	After I	Missio	n	Yes

						Lid	ar A	vcd	uisitio	n Lo	og					
				Project	: Info									Date		
Project #			Project						nique ID			Date		Day o	f Year	Flight
81150			Ohio Lidar B	lock 7 and	5			Day0	88_90515_A			/29/20	21	08	38	A
Cr	ew			-	ipment						Time				Ai	rports
Pi	lot		Ai	rcraft Mak	e / Mod	el / Tai	#		Hobbs St	tart	Local	Start	UTC	Start	De	parting
Ha	gen			Cessna 404	Titan - N	1475RC	2		2437.8	8	11:0	2:00	15:0	2:00		KDAY
Ope	rator		Sei	nsor Make	/ Model	/ Seria	al #		Hobbs E	nd	Loca	l End	UTC	End	A	rriving
Ry	an		Le	eica Terrain	Mapper	[.] - 9051	L5		2444.3	3	15:4	8:00	19:4	8:00		KDAY
						C	Conditio	ons								
Wind Dir	(°)	Wind	Speed (kts)	Visibilit	y (mi)	Ceilir	ng (ft)	Clo	oud Cover	Temp	o. (°C)	Dew	Point	(°C)	Press	sure ("H
0			0	10)				Clear	:	3		-3			3027
Air Spe	ed (kts)	Altitude	AGL (ft)	A	ltitude	MSL (f	t)	Airfield El	evatior	ו (ft)					
10	50		6,5	62		6,9	965		1,	009						
			,			-	Settin	gs	· · ·							
oint Spacir	ng (m)	Poir	nt Density (pp	sm) S	can Ang			-	n Frequency	(Hz)	Pulse	Rate	(kHz)	Las	er Po	wer (%)
• *	. ,					0			150			1600	. ,		10	
										Ve	erify S-1	Furns E	Before	Missio	on	Yes
			Start Time	End Time	: Ti	ne										
Line #	Dired	tion	(UTC)	(UTC)	On-	Line	Sate	lite	PDOP			Line N	otes/C	Comme	ents	
39	E		15:02:00	15:14:00	00:1	2:00	20)	1.3			BLOO	СК7 б	6965M	SL	
40	V	V	15:19:00	15:33:00	00:1	4:00	20)	1.2							
41	E		15:39:00	15:52:00		.3:00	18		1.5							
42	V		15:56:00	16:13:00	_	7:00	19		1.6							
43	E		16:16:00	16:30:00		4:00	2:		1.3							
44 45	V		16:32:00 16:52:00	16:49:00 17:05:00		.7:00 .3:00	2: 2(1.1 1.4							
53	V		17:08:00	17:25:00		.7:00	23		1.4				reflig	ht		
								-						,		
												BLOO	CK 5 7	'169M	SL	
1	Ν	1	17:34:00	17:54:00	00:2	0:00	25	5	1.1							
2	5		17:56:00	18:13:00	_	.7:00	23		1.1							
3	Ν		18:16:00	18:35:00		.9:00	25		1.1							
4	9 N		18:41:00	19:01:00		0:00	23 19		1.3 1.7							
6	יי <u>פ</u>		19:03:00 19:27:00	19:25:00 19:48:00		2:00	20		1.7							
U		,	19.27.00	19.40.00	00.2	1.00	2(,	1.2							
							<u> </u>									
					_											
							Page	1	1	v	erify S-	Turns	After	Missio	n	Yes
dditional C	omme	nts					0-				1 -	-	-			

			Woolp	ert	Lida	ar A	٩cd	uisitio	n L	og					
			Project	Info								D	ate		
Project #		Projec	t Name				U	nique ID		Flight	t Date	(UTC) [Day o	f Year	Flight #
81150		Ohio LiDA	R Phase II				Day	089_90515		03	/30/20)21	08	39	
Cr	ew		Equi	pment						Time				Aiı	ports
Pi	lot	Ai	rcraft Make	/ Mode	l / Tail	#		Hobbs S	tart	Local	Start	UTC S	tart	Dep	parting
Ha	gan		Cessna 404 1	Fitan - N	475RC			2444.	3	09:4	5:00	13:45	:00	K	DAY
Ope	rator	Se	nsor Make /	Model	/ Seria	#		Hobbs E	End	Loca	l End	UTC	End	Ar	riving
Naro	done	Le	eica Terrain l	Mapper	- 9051	5		2449.	5	03:1	.5:00	19:15	:00	к	MGY
					C	onditi	ons								
Wind Dir	·(°) Win	d Speed (kts)	Visibility	(mi)	Ceilin	g (ft)	Clo	oud Cover	Tem	p. (°C)	Dew	/ Point ((°C)	Press	ure ("Hg)
190		22	10					Clear		2		-3			0.36
Air Spe	ed (kts)	Altitude	AGL (ft)	Alt	titude	MSL (f	t)	Airfield El	evatior	n (ft)					
-	60		562		7,1				98	. ,					
						Settin	ØS					_	_	_	_
Point Spacir	ng (m) Po	int Density (pr	osm) Sc	an Angl			-	n Frequency	(H7)	Pulse	e Rate	(kHz)	Las	er Pov	ver (%)
0.35	· <u>s</u> (, · · ·	8	551117 50	4(()		150	(112)	- T unse	1600	(((12)		100	
0.55		0		-10	5			150	Ve	rify S_		Before I	Missie		, Yes
	_	Start Time	End Time	Tin					Ve	illy 3-	i ui iis i	Selure I	115510	511	165
Line #	Direction	(UTC)	(UTC)	On-L		Sate	llite	PDOP			Line N	otes/Co		ents	
7	N	14:45:00	15:05:00									Block	5		
8	S	15:07:00	15:34:00												
9 10	N S	15:36:00 15:58:00	15:56:00 16:24:00	00:20					-						
10	S N	16:26:00	16:24:00	00:20					-						
11	S	16:50:00	17:16:00	00:20											
13	N	17:18:00	17:37:00	00:19											
14	S	17:41:00	18:06:00	00:25											
		-													
				+											
						Page	1		V	erify S	-Turns	After N	lissio	n	
Additional C	omments														

				Wo	olp	ert	Lid	ar A	٨cq	uisit	tior	n Lo	Ŋg					
				Pro	ject lı	nfo									C	Date		
Project #			Project	Name					U	nique IC)		Flight	Date	UTC)	Day o	f Year	Flight
81150		Oł	nio LiDA	R Phase	e II				Day	094_905	515		04,	/04/20	21	09	94	
Crev	N				Equip	ment							Time				Ai	rports
Pilo	t		Ai	rcraft N	/lake /	/ Mode	l / Tail	#		Hob	bs Sta	art	Local	Start	UTC	Start	De	parting
Haga	n			Cessna	404 Ti	itan - N	475RC	;		2	459.1		09:4	5:00	13:4	5:00	ł	(DAY
Opera	tor		Sei	nsor Ma	ake / I	Model	/ Seria	nl #		Ho	bbs Er	nd	Loca	End	UTC	End	A	rriving
Nardo	one		Le	eica Ter	rain N	lapper	- 9051	.5		2	460.4		11:3	0:00	15:30	0:00	ŀ	OSU
								onditi	ons									
Wind Dir ('	°) W	ind Spee	d (kts)	Visil	bility (mi)	Ceilin	g (ft)	Clo	oud Cov	er	Temp). (°C)	Dew	Point	(°C)	Press	ure ("H
280	·	3			10					Clear					-8			30.42
Air Speed	d (kts)	Å	Altitude	AGL (ft	:)	Alt	titude	MSL (f	t)		eld Ele	vation	(ft)					
	· ·		6,5				7,1	-			99		. ,					
			- /-					Settin	gs									
Point Spacing	(m) F	Point Den	sitv (pr	sm)	Sca	n Angle			-	n Frequ	encv	Hz)	Pulse	Rate	kHz)	Las	er Pov	ver (%)
0.35			8			4(.,		150		-,		1600	/		100	
												Ve	rify S-1		efore	Missio		Yes
Line #	Directio	n	t Time JTC)	End T (UT		Tim On-L		Sate	llite	PDC)P			Line N				
25	N		38:00	15:02	-			2	2	1.3	3		Bloc	k 5, pa	v error	puler	l off lir	ne
25	N		09:00	15:23				2		1.2			Biec	n 9) pu		pulce		
24	S		25:00	15:44		00:19	9:00	2		1.1				Pav Er	ror las	t 10 m	iles	
		_																
		_																
		_																
		_																
		_																
		_																
		_																
		_																
		_																
		1						Page	1			14	erify S-	Turns	Aftor N	Missio	n	
dditional Cor	monto							i age	*			ve	y J-			113310	. 1	

				Woo	olpe	e <mark>rt Lic</mark>	dar A	Acq	uisitio	n Lo	Ŋg					
				Proj	ect In	fo							[Date		
Project #			Project	Name				U	nique ID		Flight	Date	(UTC)	Day o	f Year	Flight #
81150			Ohio LiDA	R Phase	II			Day	095_90511		04,	/05/20	21	09	95	
Cre	ew			E	quipr	nent					Time				Ai	rports
Pi	lot		Ai	rcraft M	ake /	Model / Ta	ail #		Hobbs St	art	Local	Start	UTC	Start	De	parting
Gibi	ilaro			Cessna 4	404 Tit	an - N4040	CP		8292.5	5	10:4	5:00	14:4	5:00	I	KDAY
Ope	rator		Sei	nsor Ma	ke / N	1odel / Ser	ial #		Hobbs E	nd	Loca	l End	UTC	End	Α	rriving
Naro	done		Le	eica Terr	ain Ma	apper - 90	511		8296.1	1	02:3	0:00	18:4	5:00	I	KDAY
							Conditi	ons							•	
Wind Dir	· (°)	Wind	Speed (kts)	Visib	ility (n	ni) Ceil	ing (ft)	Clo	oud Cover	Temp	o. (°C)	Dew	Point	(°C)	Press	ure ("H
190	.,		5		10	-			Clear		4		4			30.13
Air Spe	ed (kts)	Altitude	AGL (ft)		Altitud	e MSL (f	t)	Airfield El	evation	(ft)					
	60		6,5				,169			98	. ,					
			-)0				Settin	gs								
Point Spacir	1g (m)	Poin	t Density (pp	sm)	Scar	n Angle/FC	1	-	n Frequency	(Hz)	Pulse	Rate	(kHz)	Las	er Pov	wer (%)
0.35	-0 ()		8		5501	40	- ()		150	··/		1600	,,		10	
										Ve	rify S-1		Before	Missie		Yes
Line #	Direo	tion	Start Time	End Ti		Time	Sate	llite	PDOP			Line N				105
21			(UTC)	(UTC	-	On-Line	1	<u> </u>	1 5				Diad			
21 22	N S		15:39:00 16:01:00	15:59 16:21			1	-	1.5 1.1				Block	(5		
22	N N		16:24:00	16:43		00:19:00	2		1.1							
26			16:45:00	17:04		00:19:00	2		1.1							
27	N	1	17:07:00	17:25		00:18:00	2	2	1							
					[
										<u> </u>						
										<u> </u>						
							Page	1		14	erify S-	Turne	After !	Missie	n	
dditional C	00000	atc					Page	1		V	enny 3-	101115		4112210		

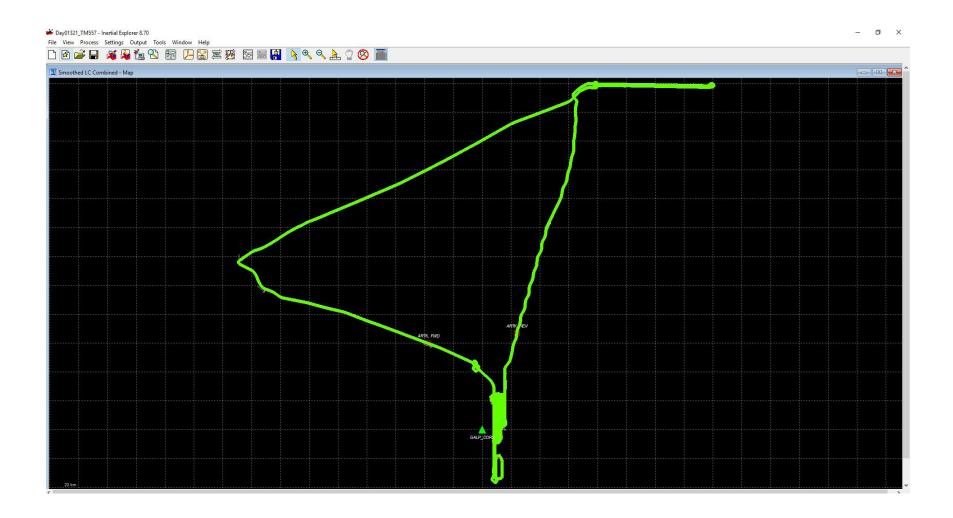
				Noc	olpe	ert Lic	lar /	<u>\cq</u>	uisitic	<u>on L</u>	og					
				Proj	ect Inf	fo							[Date		
Project #			Project	Name				U	nique ID		Flight	Date	(UTC)	Day o	f Year	Flight
81150			oh b								04,	/05/20	21	09	95	1
Cr	ew			E	quipn	nent					Time				Ai	r ports
Pi	lot		Aiı	craft M	ake / I	Model / Ta	il #		Hobbs St	art	Local		UTC	Start	De	parting
Geb	hart			Reim	s 406 -	N406SD			782.4		11:1	8:00	15:1	8:00		day
Оре	rator		Ser	isor Ma	ke / M	odel / Ser	ial #		Hobbs E	nd	Loca	l End	UTC	End	Ar	riving
Sm	nith		Le	ica Terr	ain Ma	ipper - 905	57		786.4		03:1	8:00	19:1	8:00		day
							Condit	ions								
Wind Dir	· (°)	Wind	Speed (kts)	Visib	ility (m	ni) Ceili	ng (ft)	Clo	ud Cover	Temp	o. (°C)	Dew	Point	(°C)	Press	ure ("H
190			5		10				Few	1	4		4			3013
Air Spe	ed (kts)		Altitude	AGL (ft)		Altitude	e MSL (f	t)	Airfield Ele	evatior	n (ft)					
1	60		6,5	62		7,	169		1,(009						
							Settir	ngs								
oint Spaci	ng (m)	Poin	t Density (pp	osm)	Scan	Angle/FO	V (°)	Scar	n Frequency	(Hz)	Pulse	Rate	(kHz)	Las	er Pov	ver (%)
						40			150			1603			100)
										Ve	rify S-1	Furns E	Before	Missio	on	Yes
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81150 Ohio LiDAR Phase II Day329_90515 11/24/2020 329 Crew Equipment Time Arrors Arrors Bild Aircraft Make / Model / Serial # Hobbs Start Local Start UTC Start Departing Gibllaro Cessna 404 Titan - N7079F 2997.5 09.45:00 15''''''''''''''''''''''''''''''''''''					Pro	ject l	nfo								l	Date		
Crew Equipment Time Aircraft Make / Model / Tail # Hobbs Start Local Start UTC Start Departing Gibilaro Cessna 404 Trian - N7079F 2997.5 09:45:00 19:00:00 KDAY Operator Sensor Make / Model / Serial # Hobbs Start Local Start UTC End Arriving Nardone Leica Terrain Mapper - 90515 3001.9 02:00:00 21:00:00 KDAY Wind Dir (*) Wind Speed (kts) Visibility (mi) Ceiling (t) Cloud Cover Temp. (*C) Dew Point (*C) Pressure (*I 190 3 8 25,000 Few 0 -2 30.13 Air Speed (kts) Altitude AGL (ft) Altitude MSL (ft) Airfield Elevation (ft) user Power (%, 0.5 10.00	Project #			Project	: Name					U	nique ID		Flig	ht Date	(UTC)	Day o	f Year	Flight
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Gibilaro Cessna 404 Titan - N7079F 2997.5 09:45:00 19:0:0:00 KDAY Operator Sensor Make / Model / Serial # Hobbs End Local End UTC End Arriving Nardone Leica Terrain Mapper - 90515 3001.9 02.0:0:00 21.0:0:00 KDAY Wind Dir (*) Wind Speed (kts) Visibility (mi) Ceiling (t) Cloud Cover Temp. (*C) Dew Point (*C) Pressure (*F 190 3 8 25,000 Few 0 -2 30.13 Air Speed (kts) Altitude ASL (ft) Altitude MSL (ft) Intuitude MSL (ft) Intuitude MSL (ft) 100 100 2 30.13 Oint Spacing (m) Point Density (ppsm) Scan Angle/FOV (*) Scan Frequency (Hz) Pulse Rate (kHz) Laser Power (% 0.35 8 35:9 150 110 100 100 1 E 15:30:00 15:34:30 21 1.1 1 1 1 E 15:36:00 00:05:00 19 1.1 1 <td>Cro</td> <td>ew</td> <td></td> <td></td> <td></td> <td>Equip</td> <td>ment</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>Tim</td> <td>e</td> <td></td> <td></td> <td>Ai</td> <td>irports</td>	Cro	ew				Equip	ment						Tim	e			Ai	irports
Operator Sensor Make / Model / Serial # Hobbs End Local End UTC End Arriving Nardone Leica Terrain Mapper - 90515 3001.9 02.00:00 21.00:00 KDAY Wind Dir (*) Wind Speed (kts) Visibility (mi) Celling (ft) Celling (ft) Celling (ft) Arriving Perseure (*) 0.13 * * 30.13 * * 30.13 * * 30.13 * * 30.13 * * 30.13 * * 30.13 * * 30.13 * * 30.13 * * 30.13 * * 30.13 * * 30.13 * * 30.13 * * 30.13 * * 10.0 * 30.13 * * 10.10 * 10.10 * * * * * * * * *	Pi	lot		Ai	rcraft I	Make ,	/ Mode	el / Tai	l #		Hobbs	s Start	Loc	al Start	UTC	Start	De	parting
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18	W	15:38:00	15:52		00:13:00		.8	1.2							
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14	W	16:43:00	16:56		00:13:00	-	20	1.1							
13	E	17:00:00	17:13		00:13:00		20	1.2							
12	W	17:16:00	17:29		00:13:00		20	1.2							
11	E	17:32:00	17:45	5:00	00:13:00	2	21	1.2							
		_													
												BLK	2		
9	E	17:52:00	18:02		00:09:00		1	1.2							
10	W	18:05:00	18:14		00:09:00		1	1.3							
11	E	18:17:00	18:26		00:09:00		1	1.2							
12 13	W E	18:29:00 18:42:00	18:38 18:52		00:09:00 00:09:00		22	1.2 1.2							
13	W	18:42:00	18:5		00:10:00		2	1.2							
15	E	19:07:00	19:17		00:10:00		.5 !1	1.1							
16	Ŵ	19:20:00	19:30		00:10:00		1	1.2							
17	E	19:33:00	19:44		00:11:00		1	1.1	1						
18	W	19:48:00	20:00	00:0	00:12:00	2	20	1.2							
						Page	1		V	erify S	Turns	After	Missio	n	
Additional Co	mments														

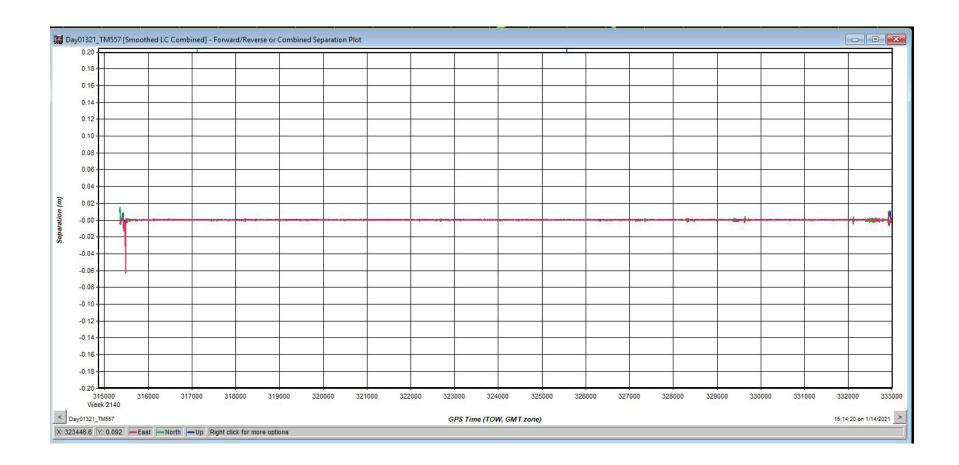
Appendix 3: GPS / IMU Graphics

Day01321_TM557 Trajectory



Day01321_TM557

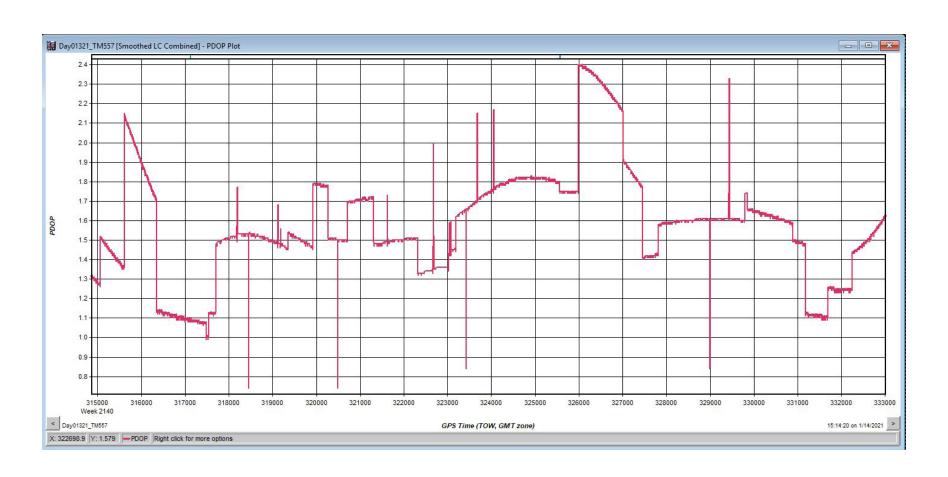
Forward/Reverse or Combined Separation Plot



Day01321_TM557 Estimated Position Accuracy

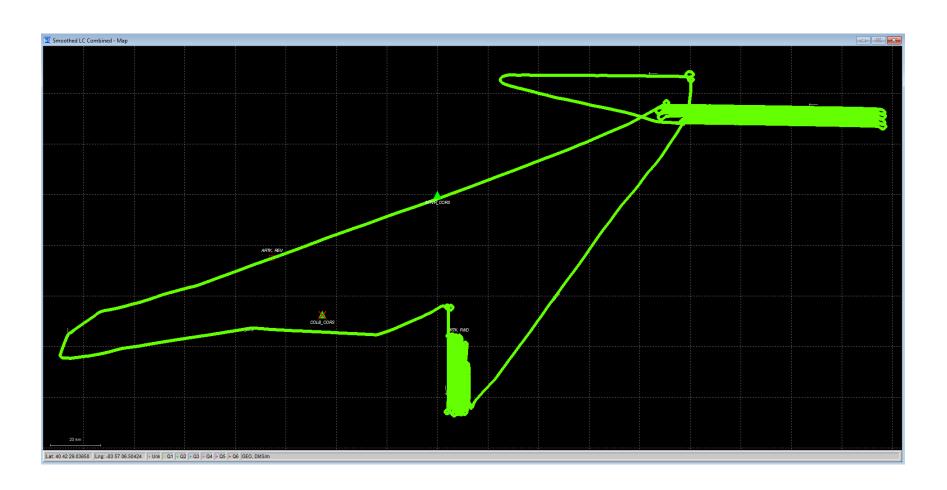
Day01321_TM557 [Smoothed LC Combined] - Estimated Position Accuracy Plot 0.019 0.018 0.017 0.016 0.015 0.014 0.013 Estimated StdDev (m) 0.012 0.011 0.010 0.009 0.008 0.007 0.006 L 0.005 0.004 all 0.003 -315000 Week 2140 316000 317000 318000 319000 320000 321000 322000 323000 324000 325000 326000 327000 328000 329000 330000 331000 332000 333000 < Day01321_TM557 15:14:20 on 1/14/2021 > GPS Time (TOW, GMT zone) 5044 4 54 0 047 5 5-++ 5

Day01321_TM557 PDOP Plot

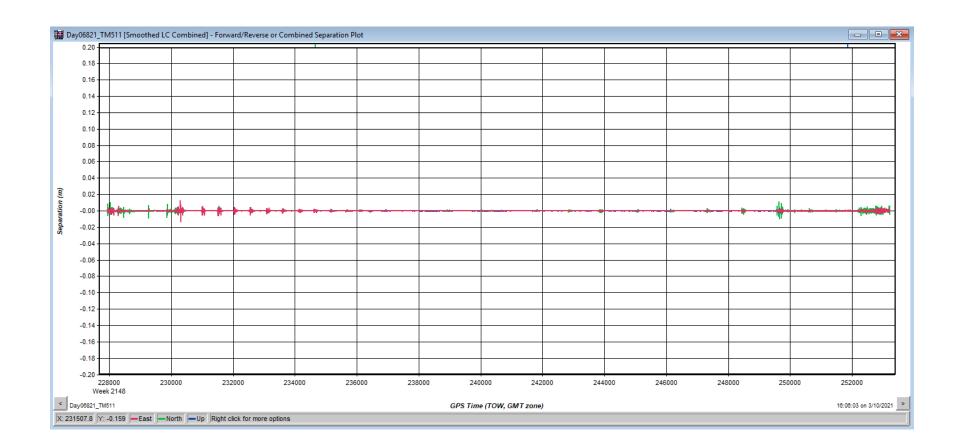


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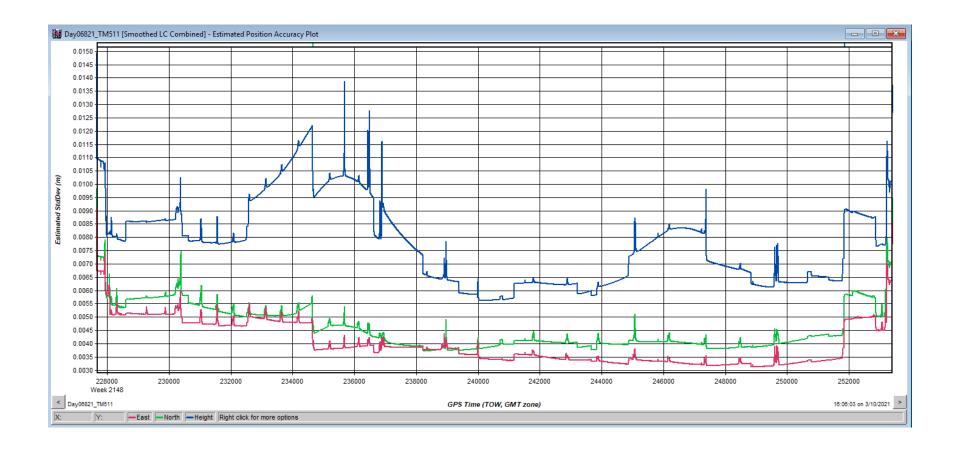
Day06821_TM511 Trajectory



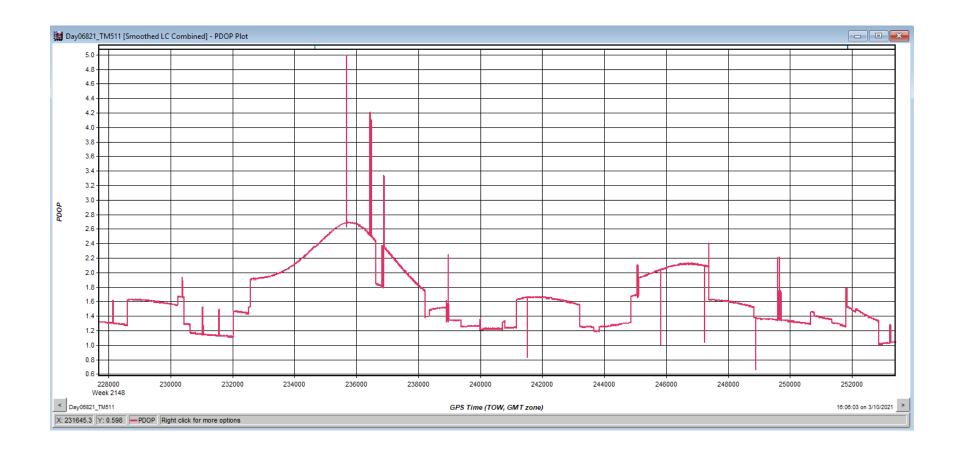
Day06821_TM511



Day06821_TM511 Estimated Position Accuracy



Day06821_TM511 PDOP Plot

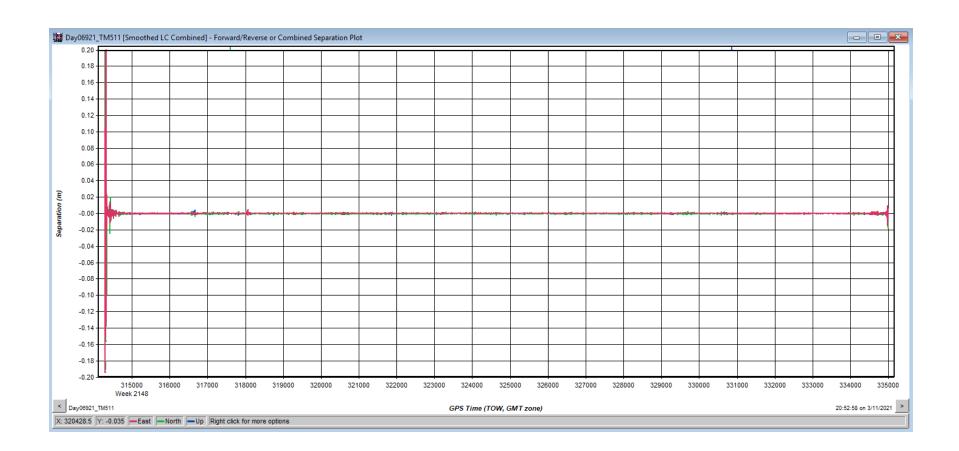


United States Geological Survey

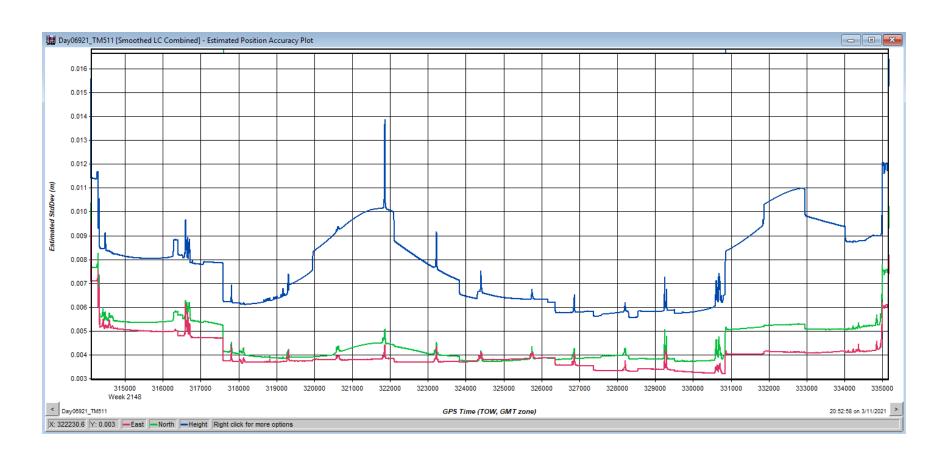
Day06921_TM511 Trajectory



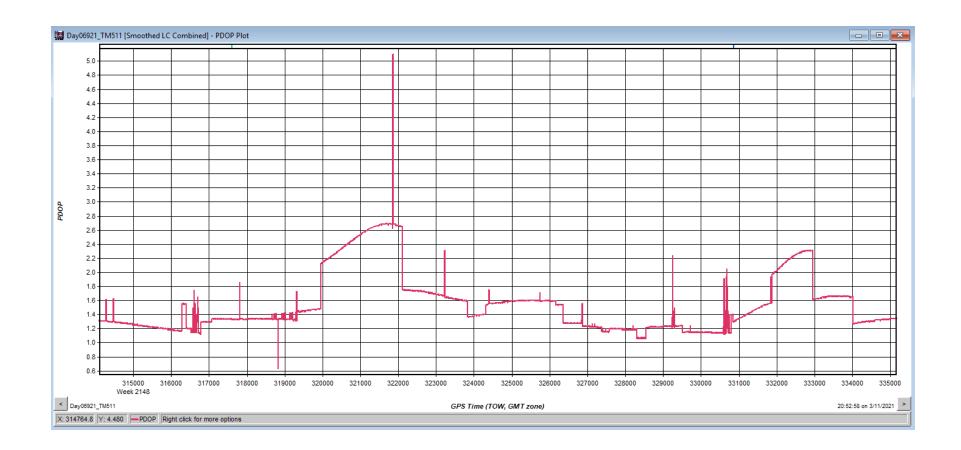
Day06921_TM511



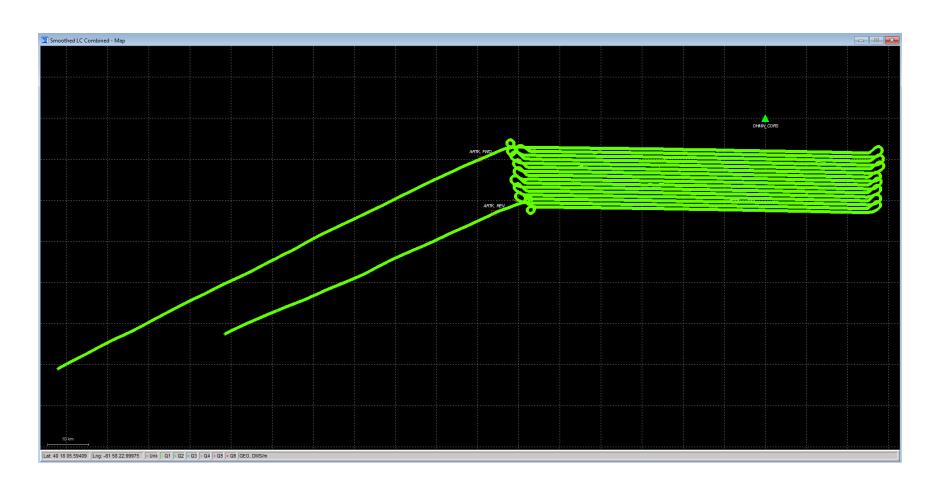
Day06921_TM511 Estimated Position Accuracy



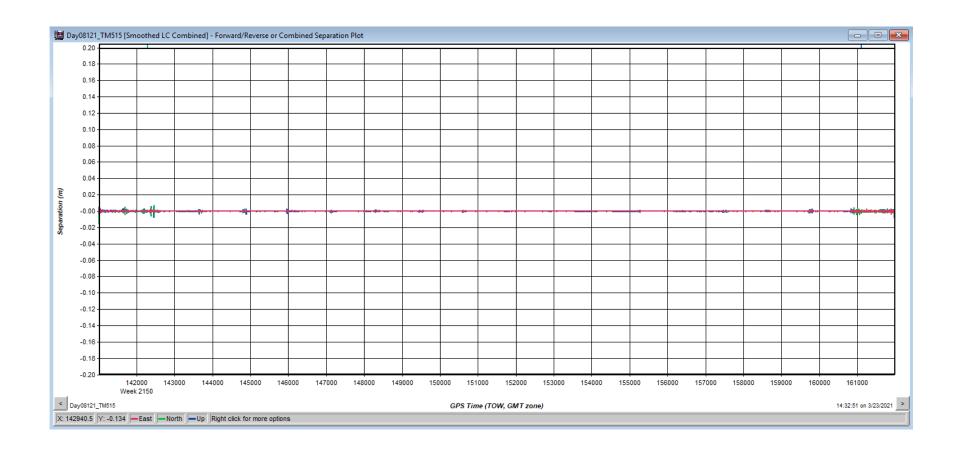
Day06921_TM511 PDOP Plot



Day08121_TM515 Trajectory

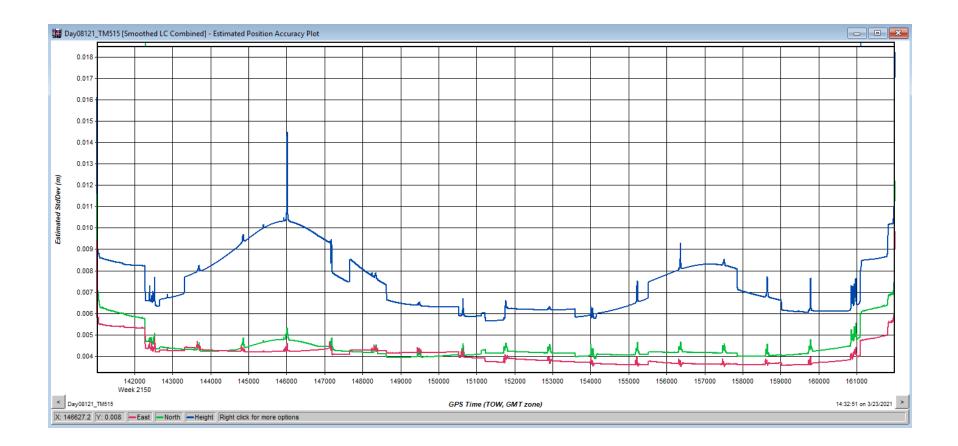


Day08121_TM515

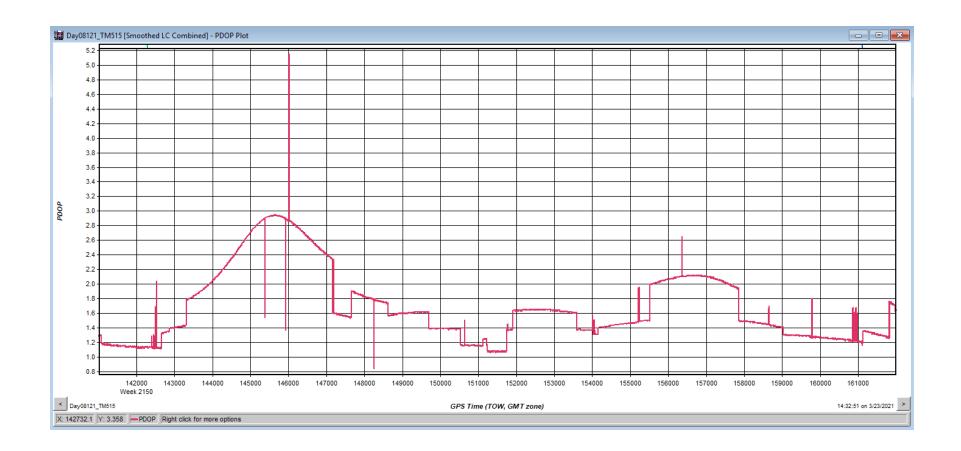


Day08121_TM515

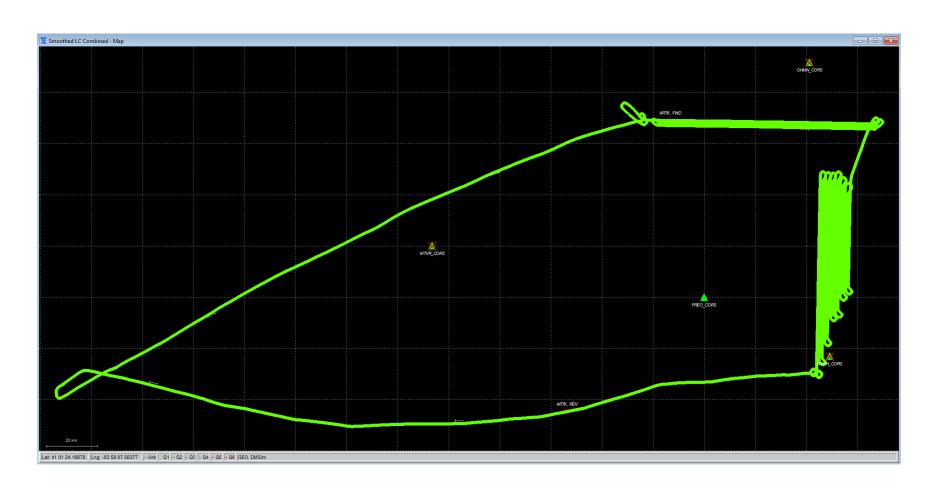
Estimated Position Accuracy



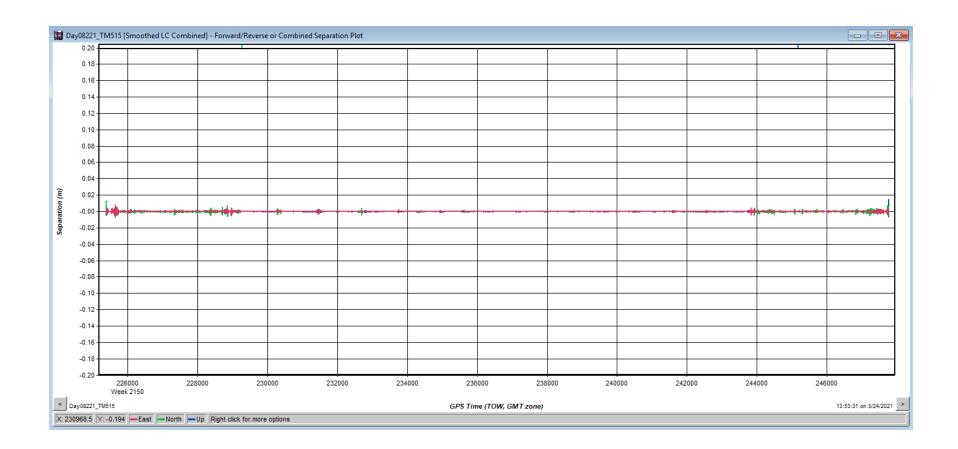
Day08121_TM515 PDOP Plot



Day08221_TM515 Trajectory

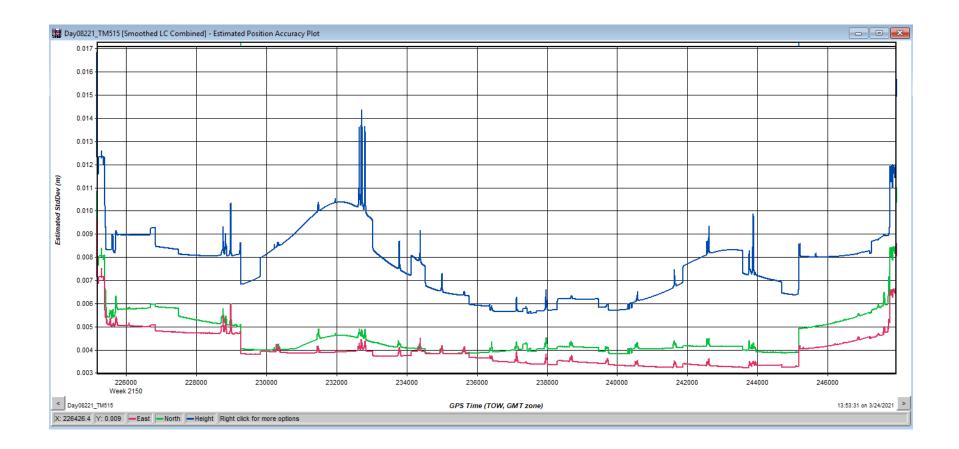


Day08221_TM515



Day08221_TM515

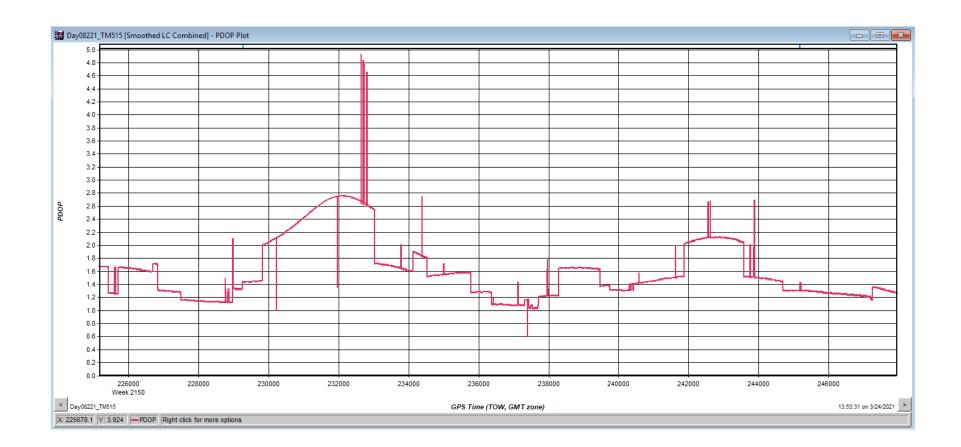
Estimated Position Accuracy



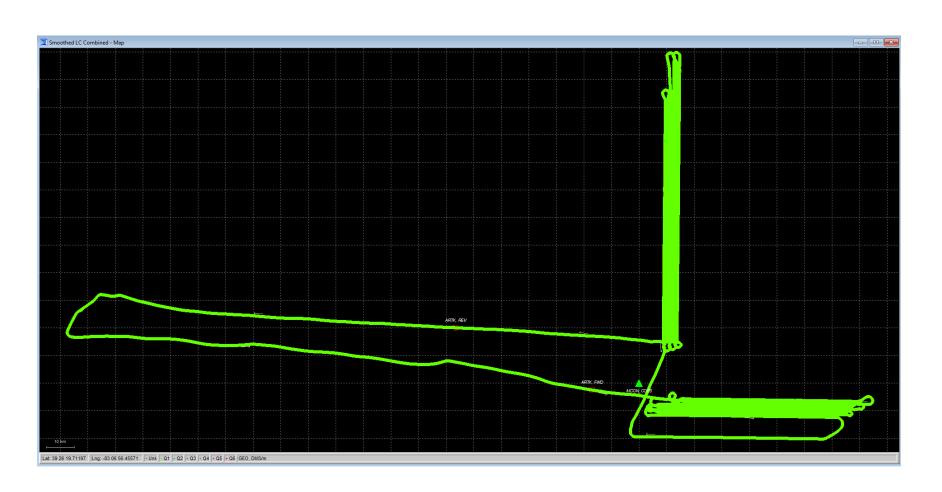
Day08221_TM515

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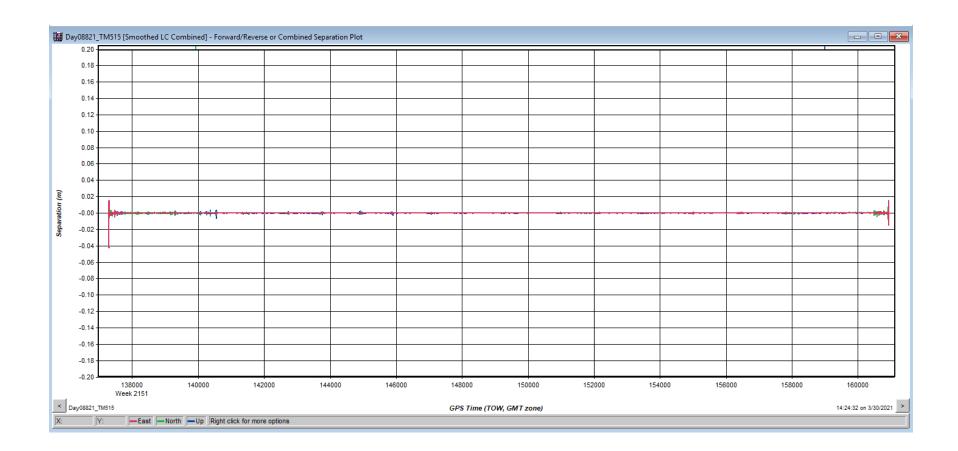
140G0220F0194 - OH Statewide Phase 2 2020 B20



Day08821_TM515 Trajectory

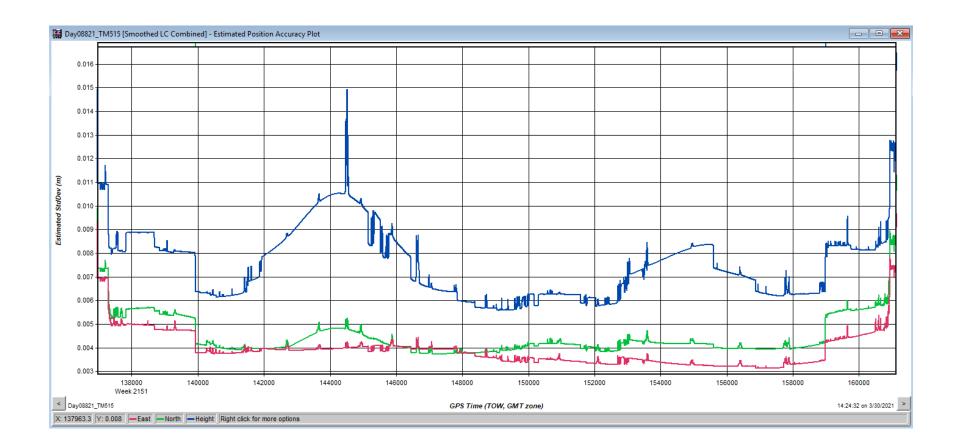


Day08821_TM515

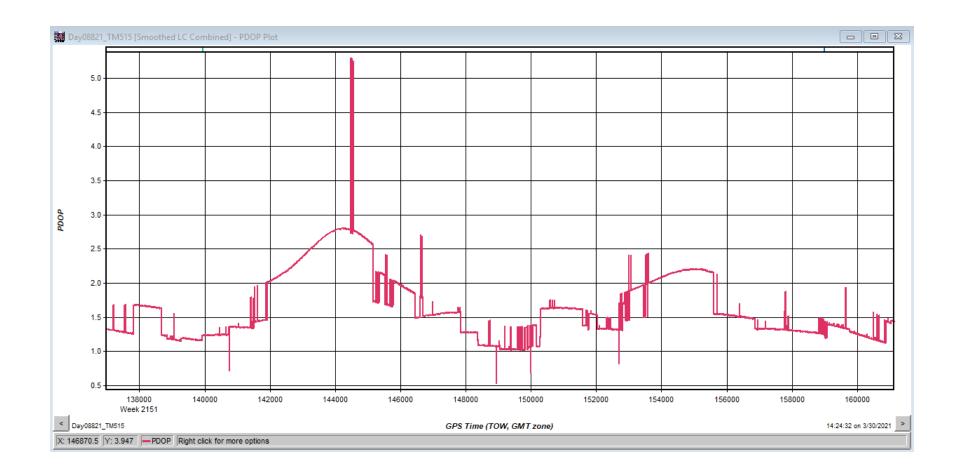


Day08821_TM515

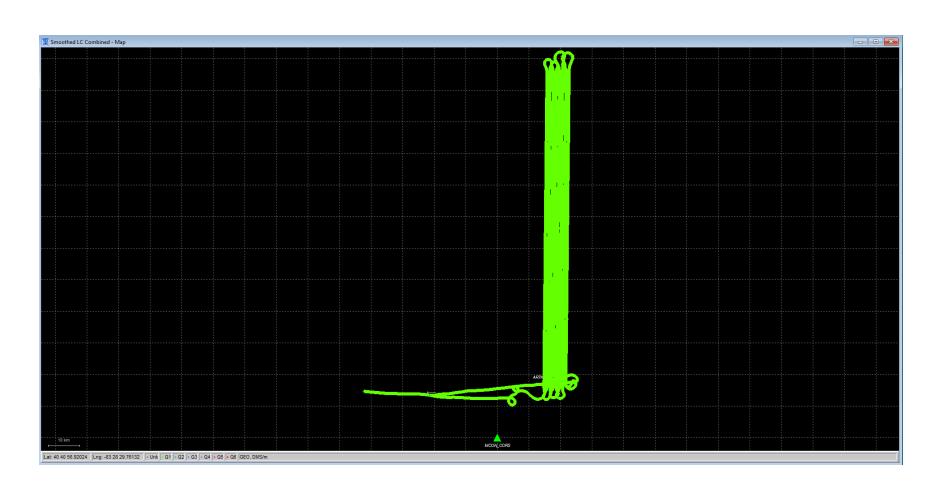
Estimated Position Accuracy



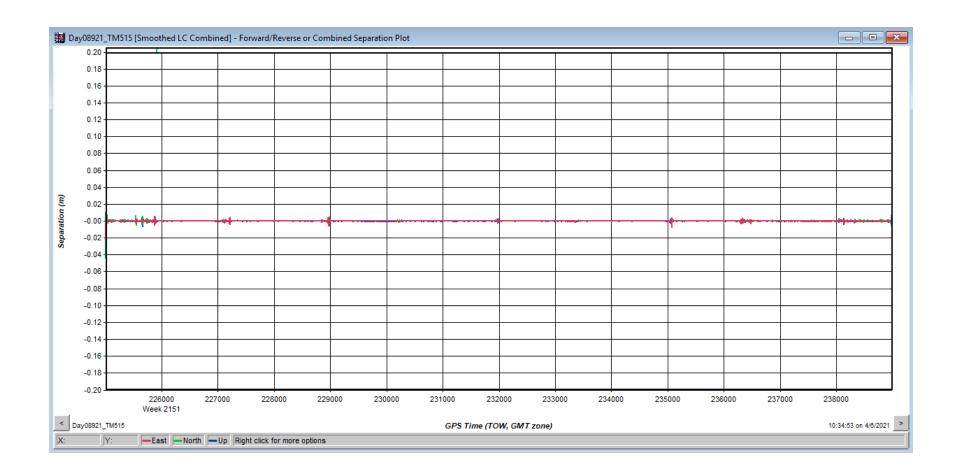
Day08821_TM515 PDOP Plot



Day08921_TM515 Trajectory



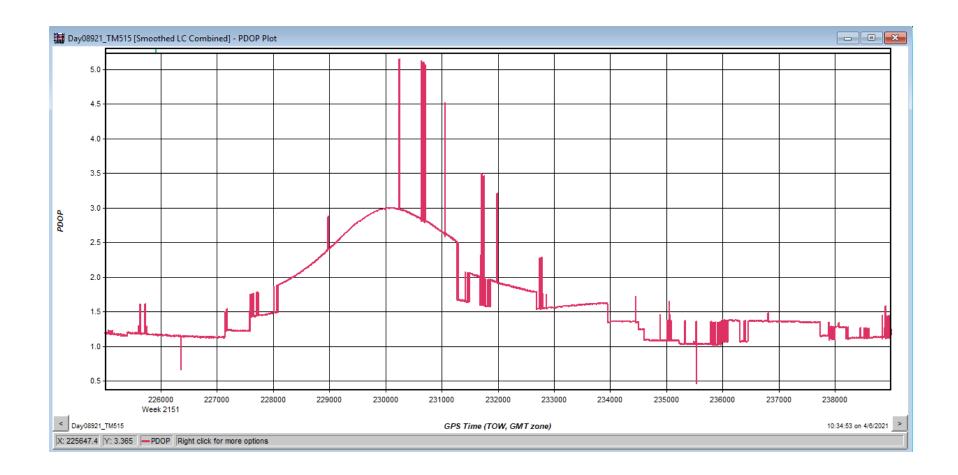
Day08921_TM515



Day08921_TM515 Estimated Position Accuracy

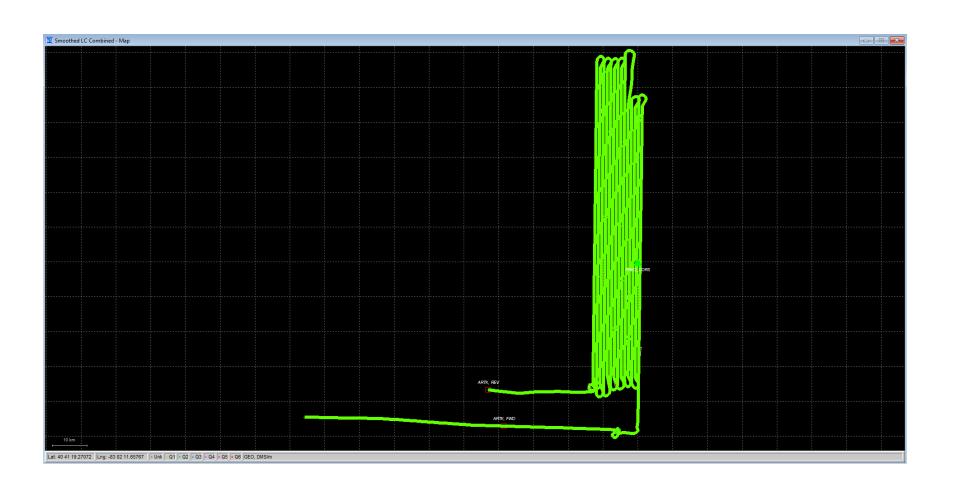


Day08921_TM515 PDOP Plot

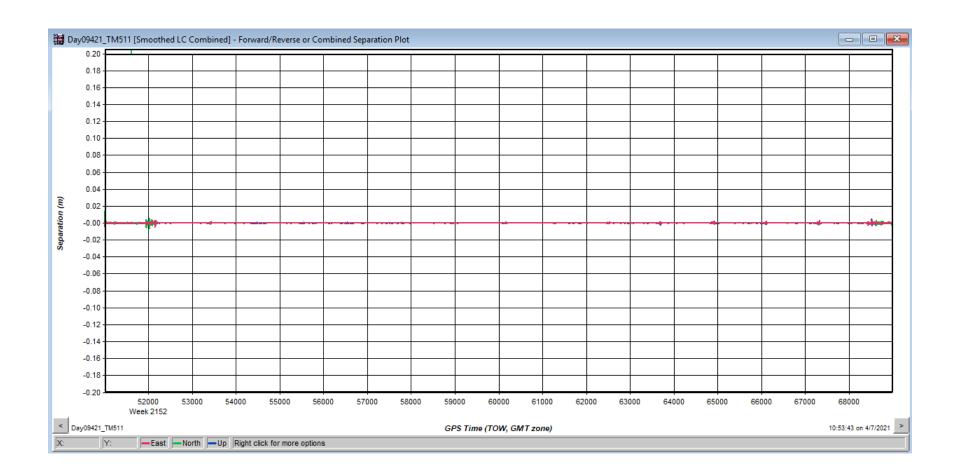


United States Geological Survey

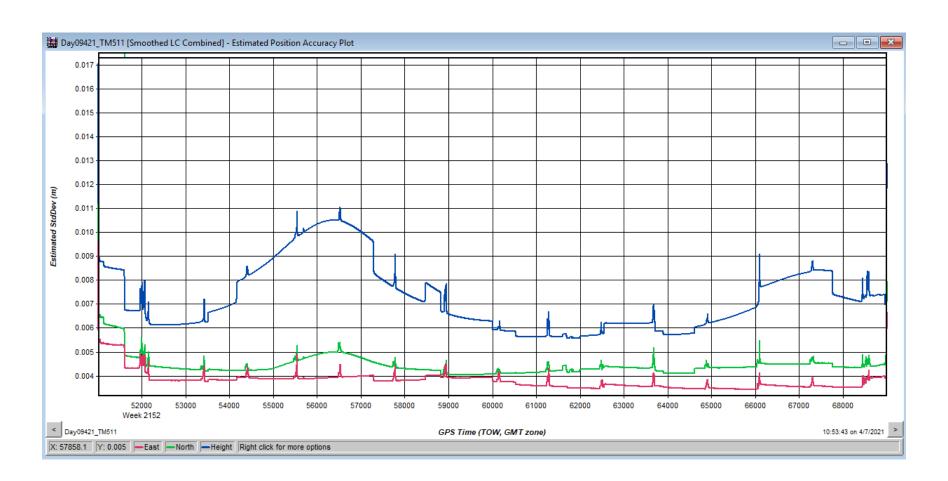
Day09421_TM511 Trajectory



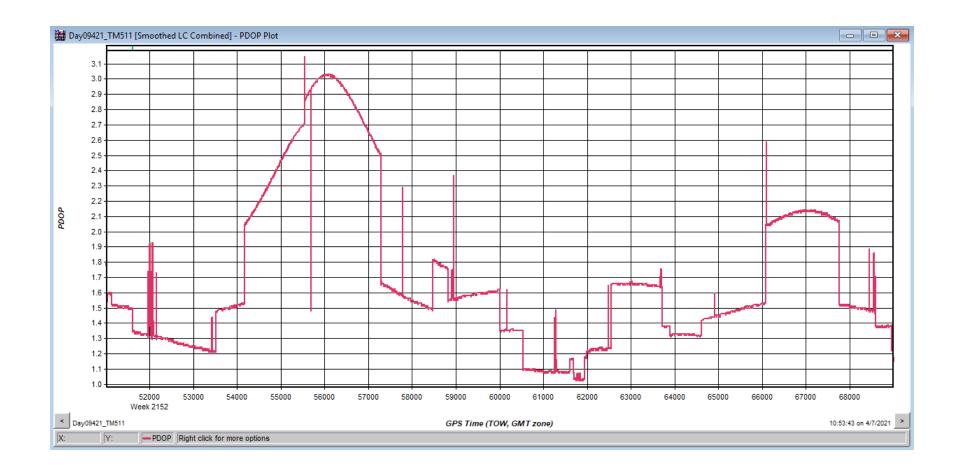
Day09421_TM511



Day09421_TM511 Estimated Position Accuracy

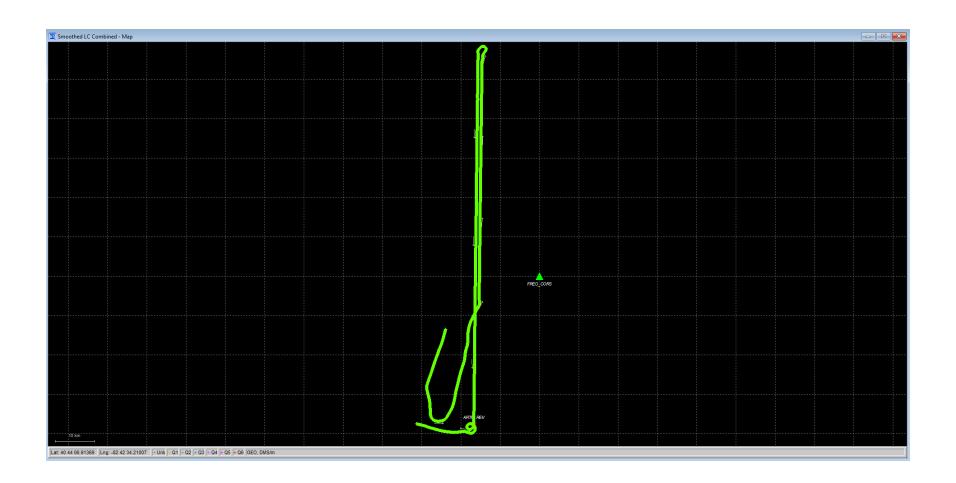


Day09421_TM511 PDOP Plot

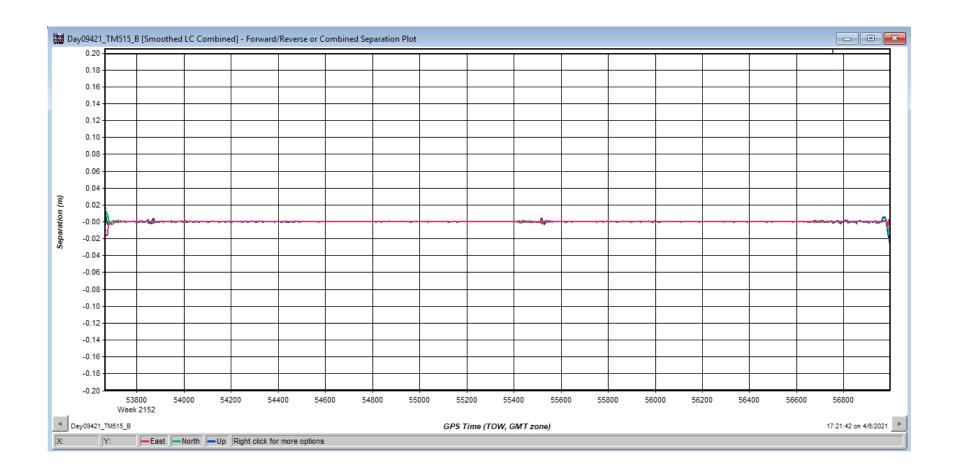


Day09421_TM515_B

Trajectory



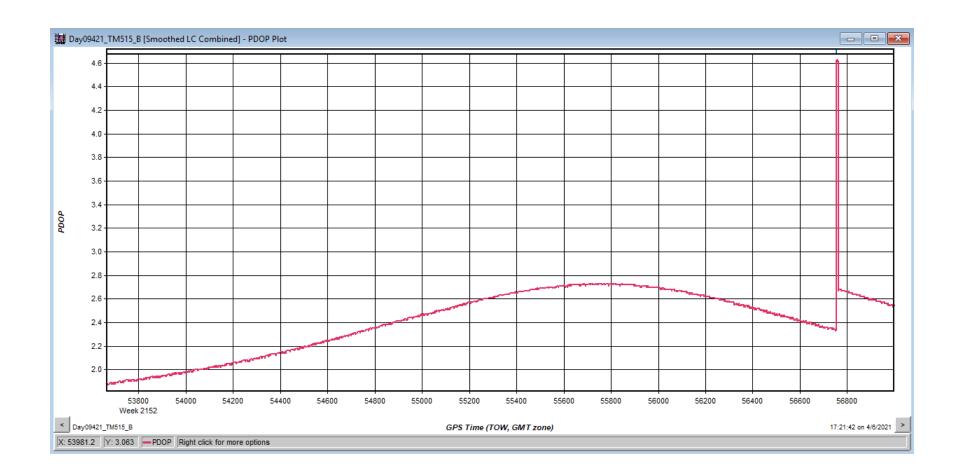
Day09421_TM515_B



Day09421_TM515_B Estimated Position Accuracy

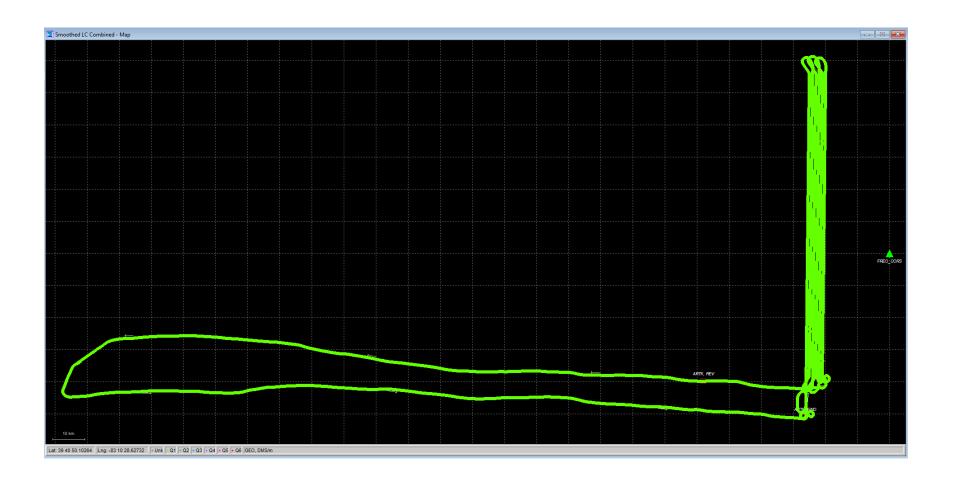
Day09421_TM515_B [Smoothed LC Combined] - Estimated Position Accuracy Plot - C X 0.026 0.025 0.024 0.023 0.022 0.021 0.020 0.019 0.018 Estimated StdDev (m) 0.017 0.016 0.015 0.014 0.013 0.012 0.011 0.010 0.009 0.008 0.007 0.006 \sim ~ 0.005 0.004 53800 54000 54600 55000 55200 55400 55600 55800 56000 56200 56400 56600 56800 54200 54400 54800 Week 2152 < Day09421_TM515_B 17:21:42 on 4/6/2021 > GPS Time (TOW, GMT zone) X: 53993.0 Y: 0.010 -East North -Height Right click for more options

Day09421_TM515_B PDOP Plot

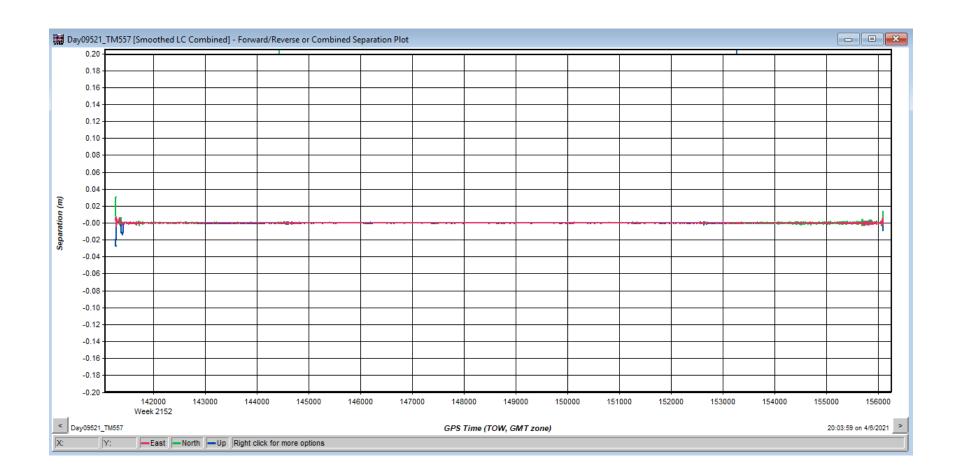


Day09521_TM557

Trajectory

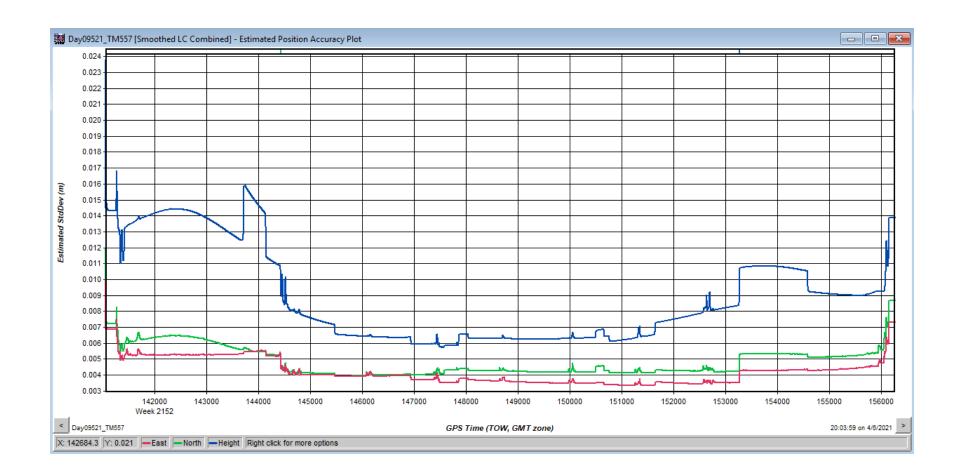


Day09521_TM557



Day09521_TM557

Estimated Position Accuracy



Day09521_TM557 PDOP Plot

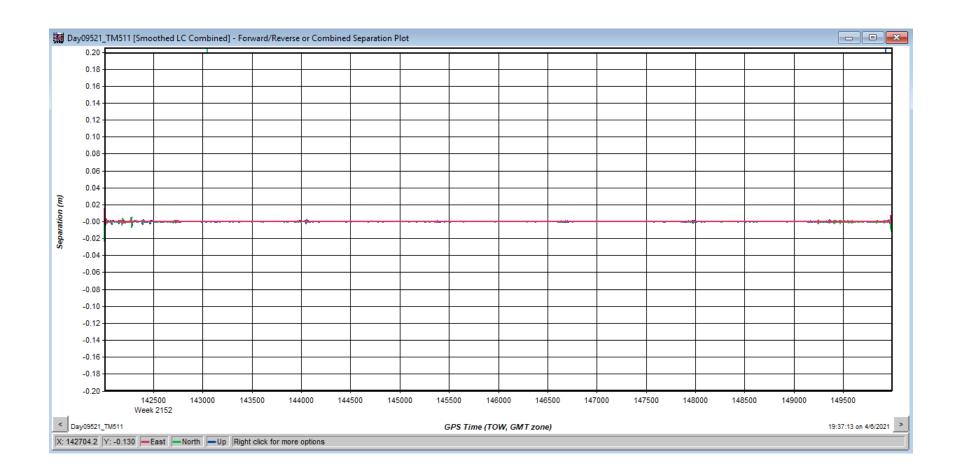


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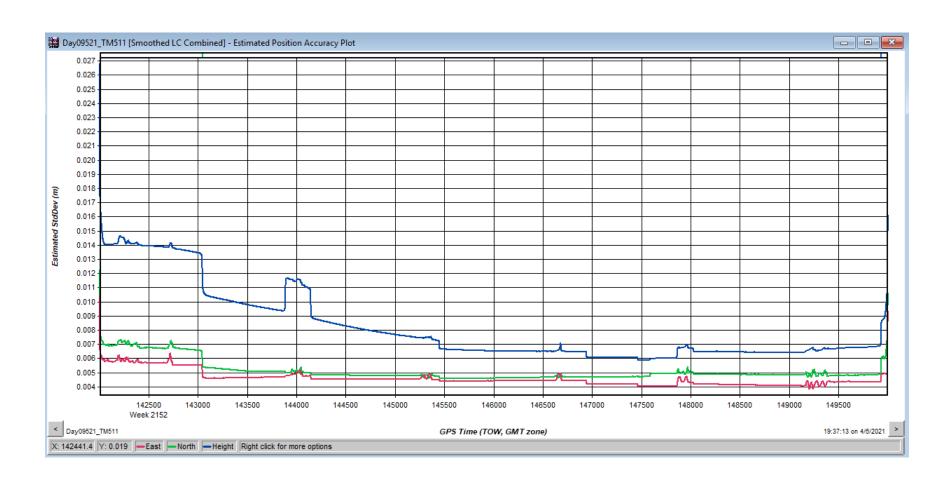
Day09521_TM511 Trajectory



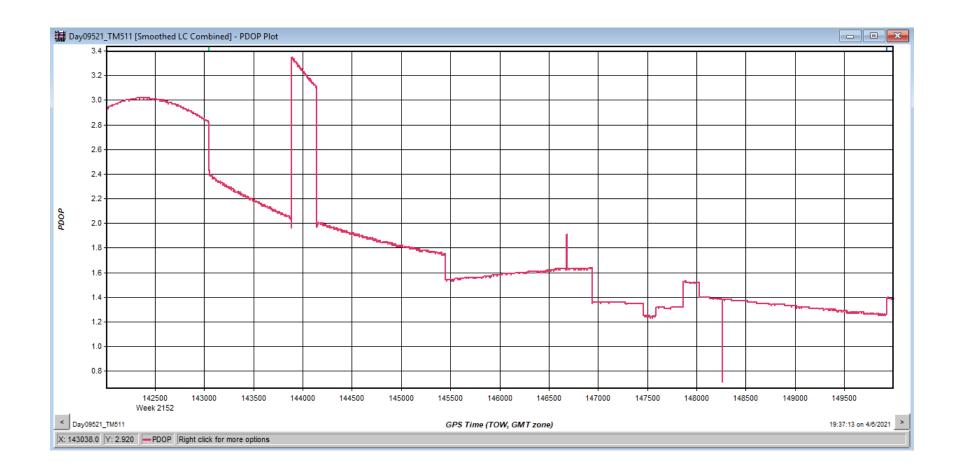
Day09521_TM511



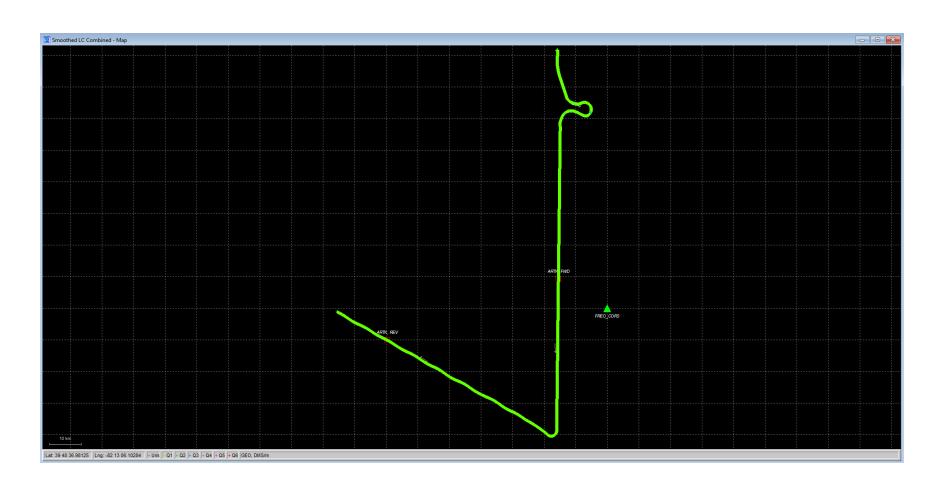
Day09521_TM511 Estimated Position Accuracy



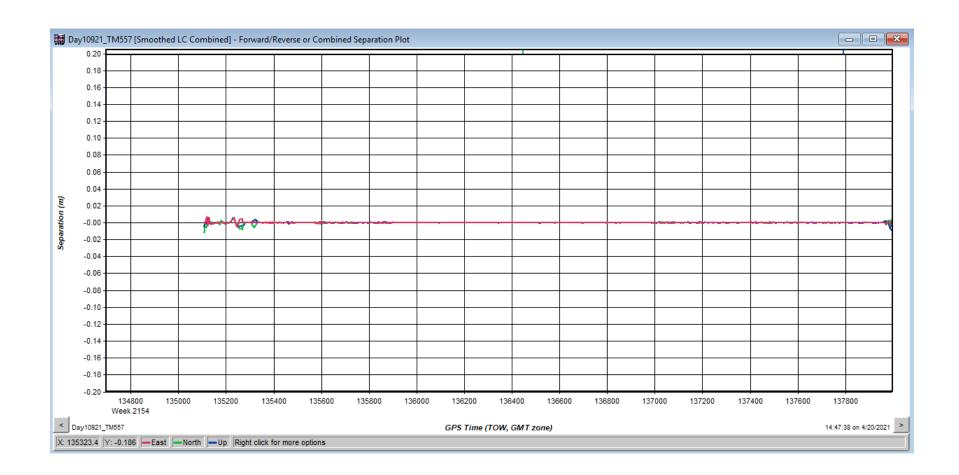
Day09521_TM511 PDOP Plot



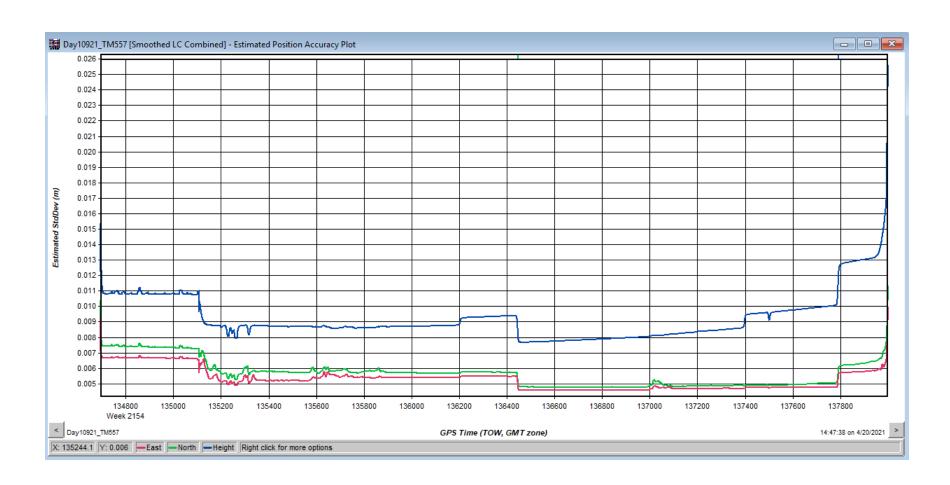
Day10921_TM557 Trajectory



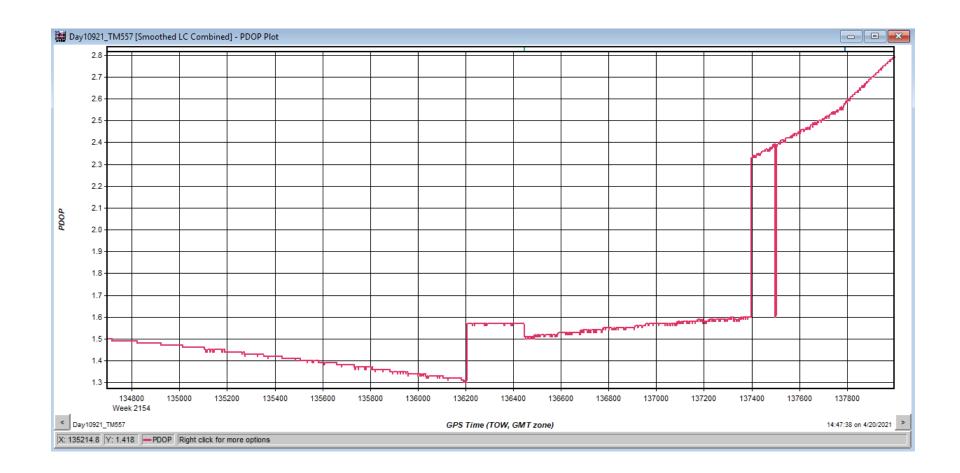
Day10921_TM557



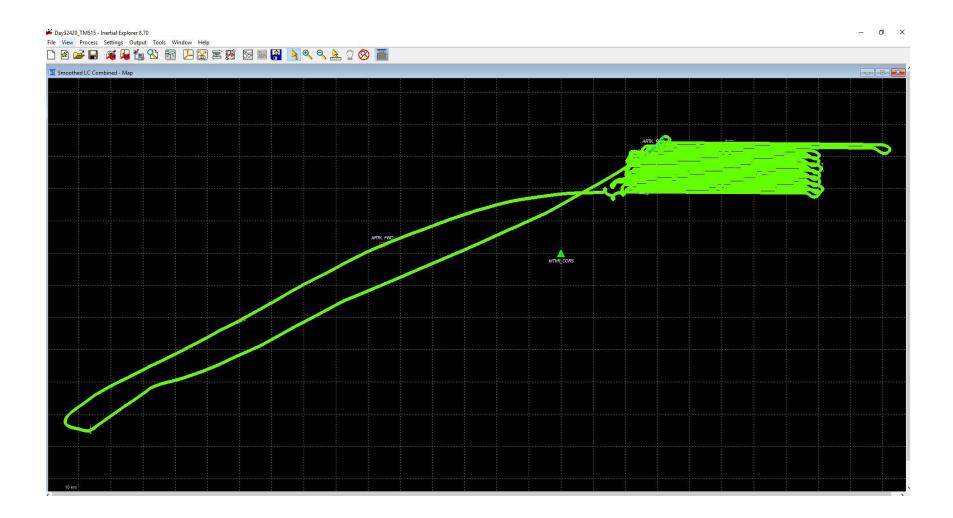
Day10921_TM557 Estimated Position Accuracy



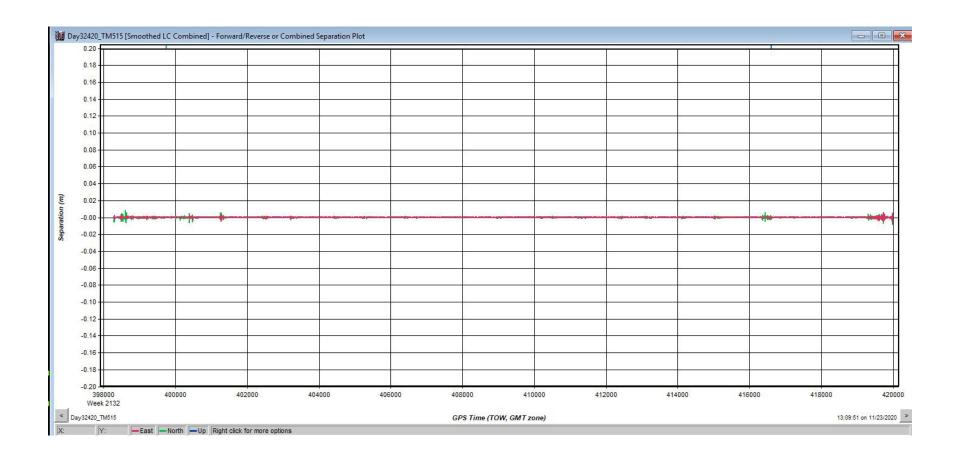
Day10921_TM557 PDOP Plot



Day32420_TM515 Trajectory

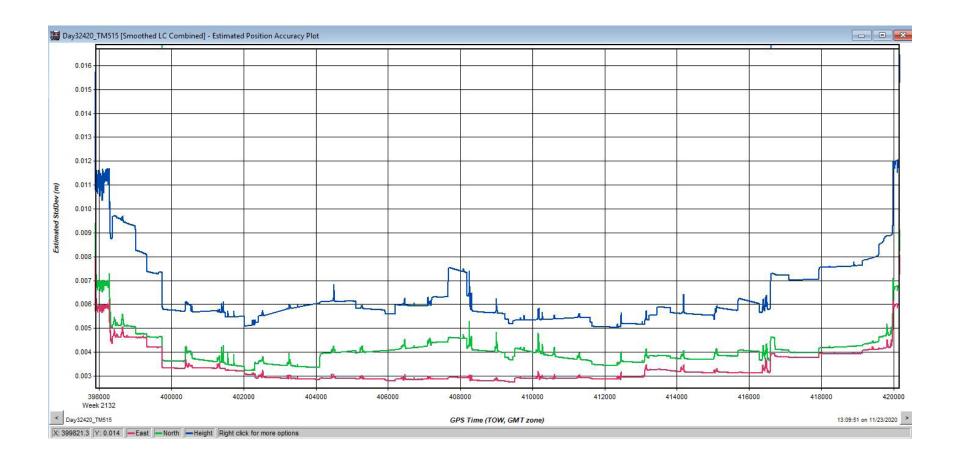


Day32420_TM515

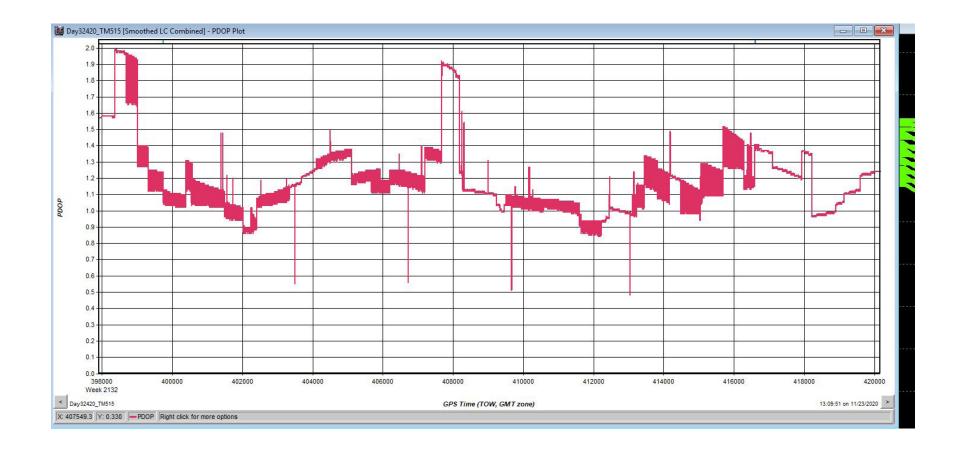


Day32420_TM515

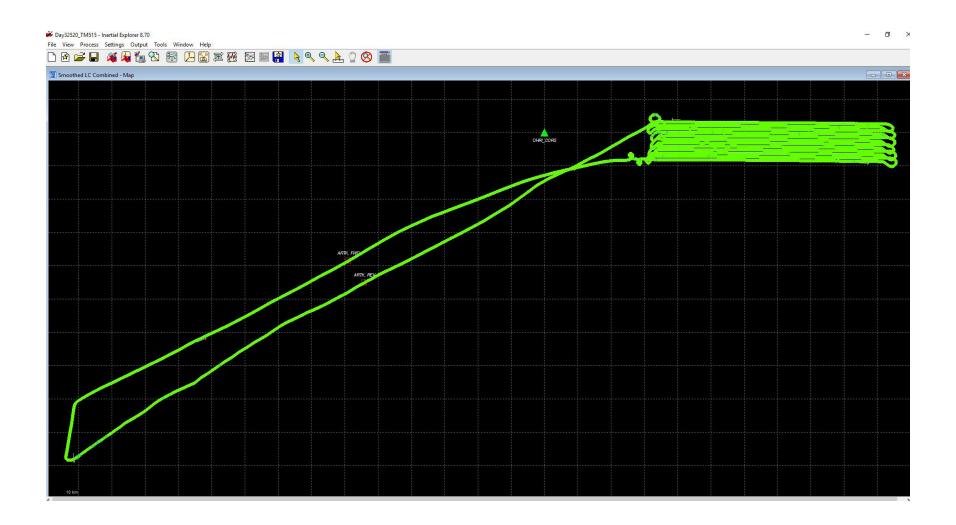
Estimated Position Accuracy



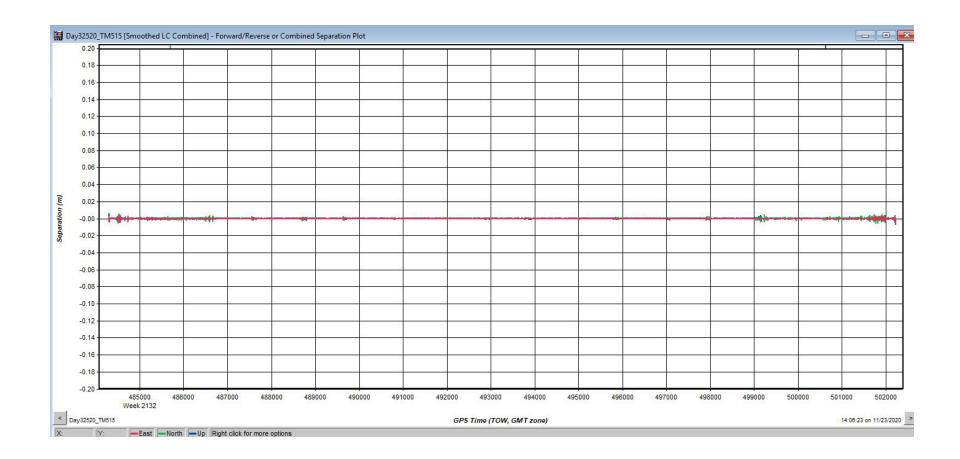
Day32420_TM515 PDOP Plot



Day32520_TM515 Trajectory

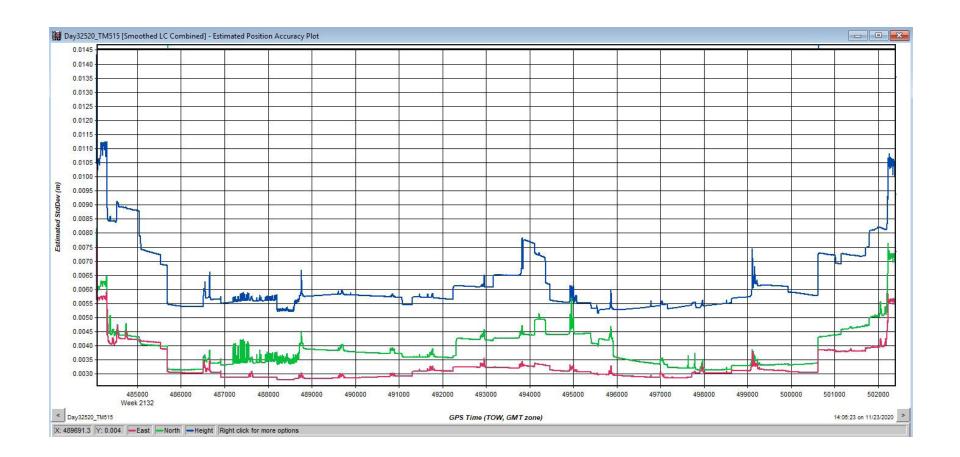


Day32520_TM515

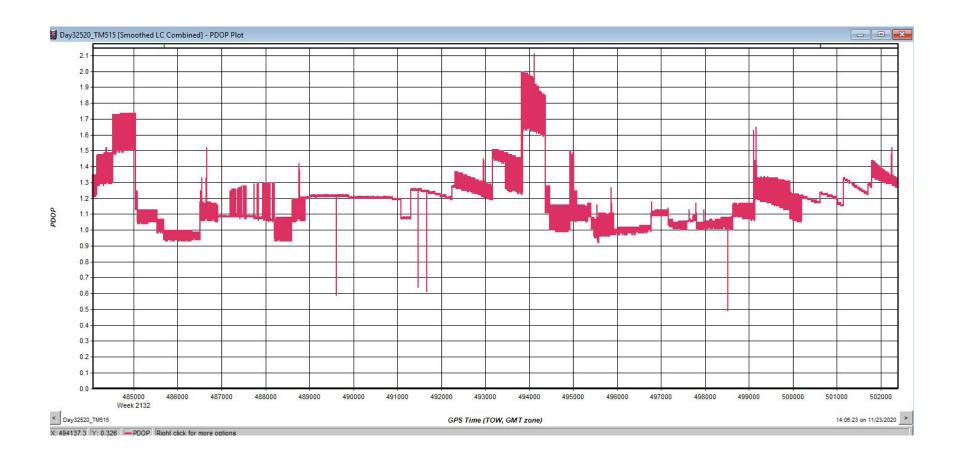


Day32520_TM515

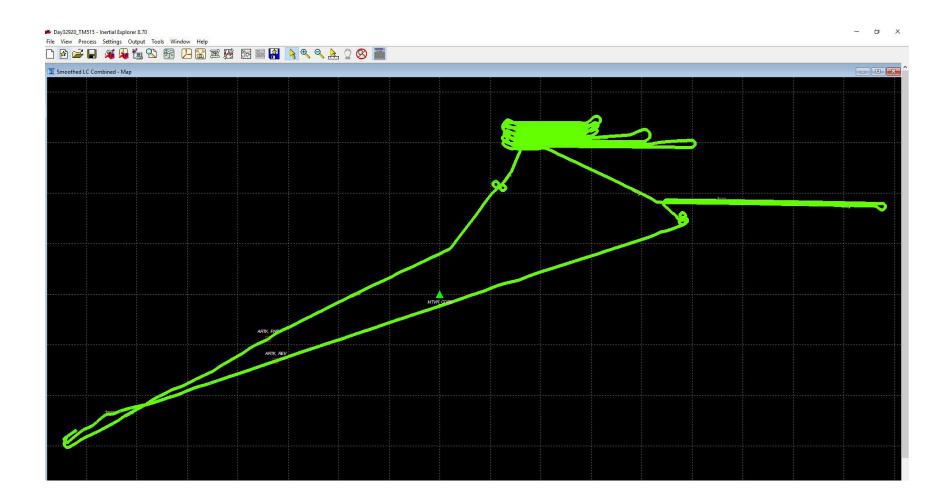
Estimated Position Accuracy



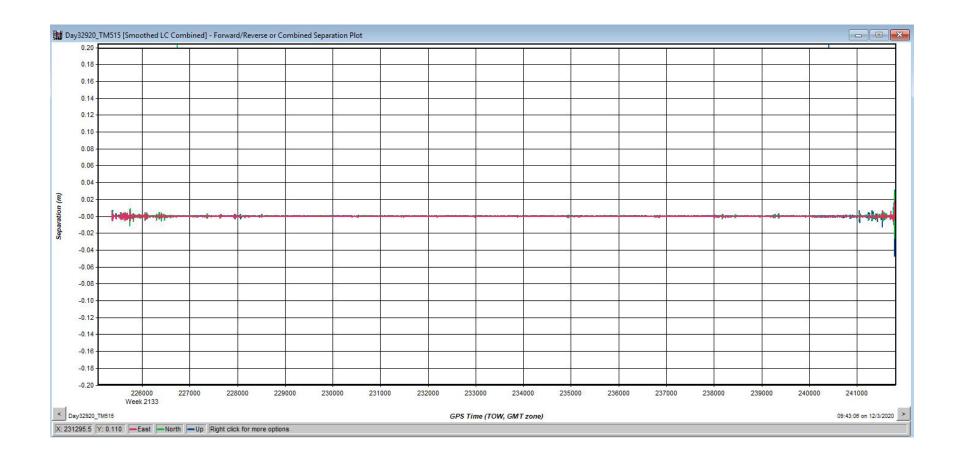
Day32520_TM515 PDOP Plot



Day32920_TM515 Trajectory

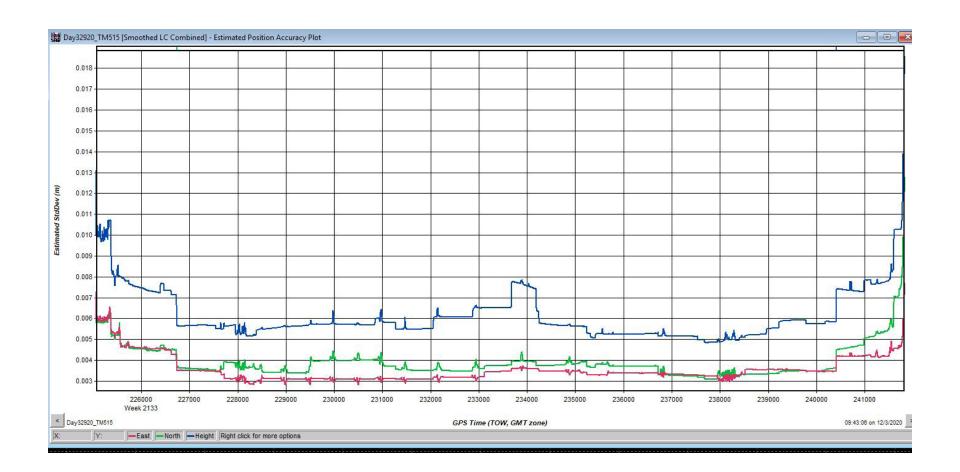


Day32920_TM515

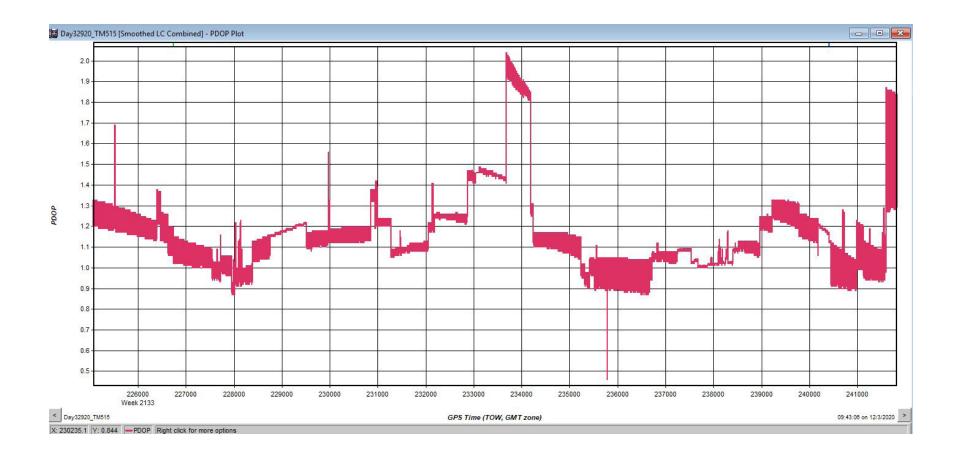


Day32920_TM515

Estimated Position Accuracy



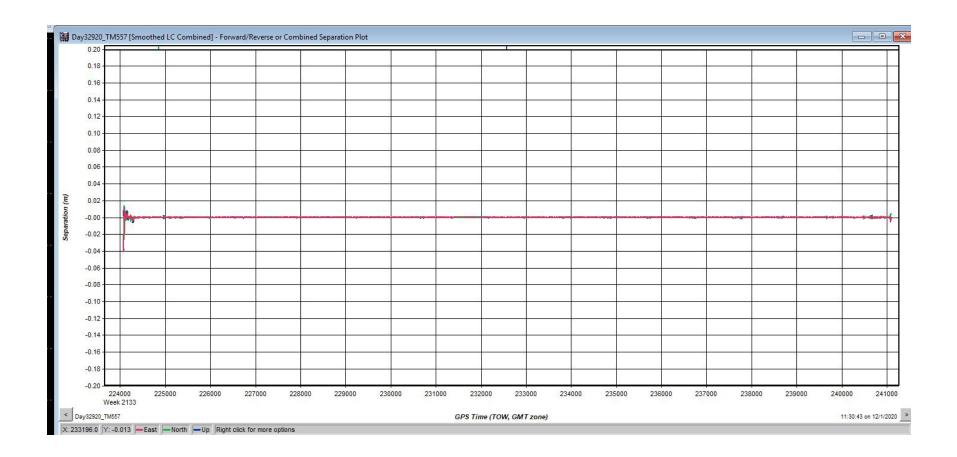
Day32920_TM515 PDOP Plot



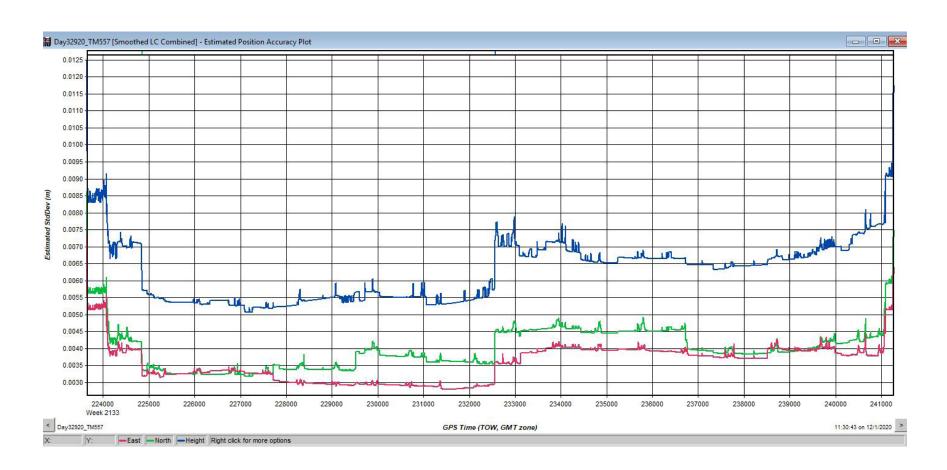
Day32920_TM557 Trajectory

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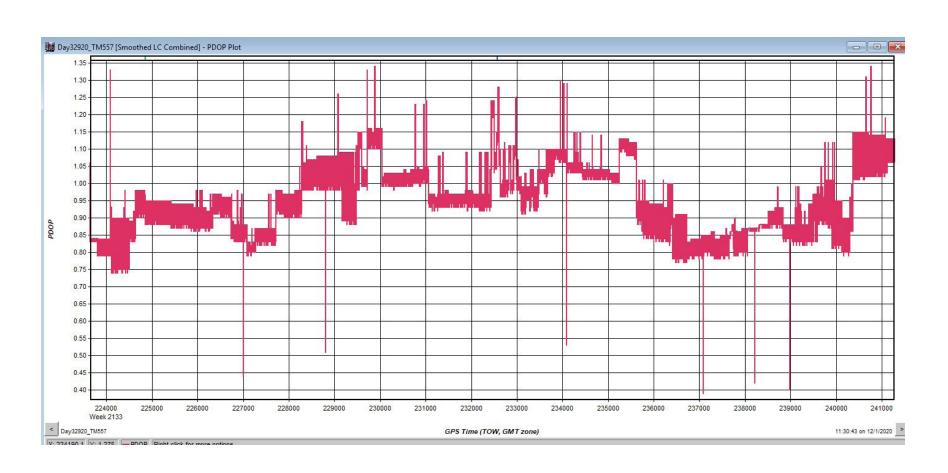
Day32920_TM557



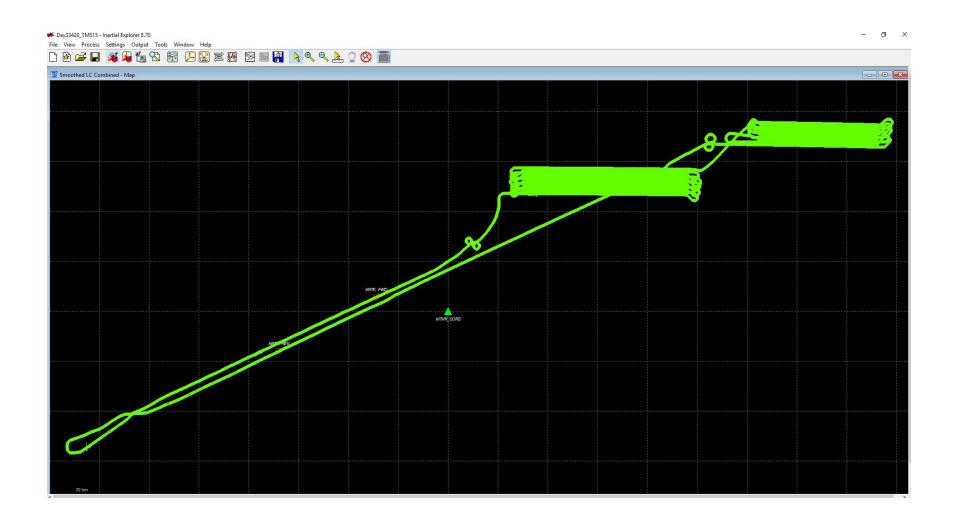
Day32920_TM557 Estimated Position Accuracy



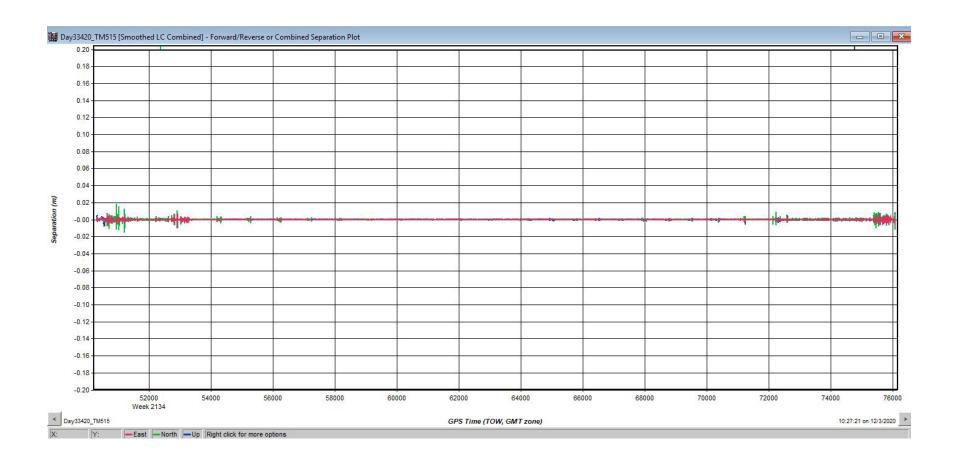
Day32920_TM557 PDOP Plot



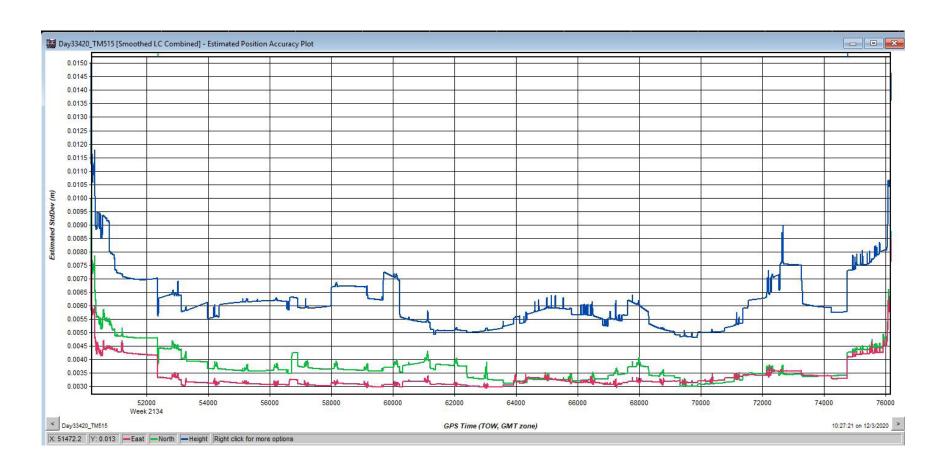
Day33420_TM515 Trajectory



Day33420_TM515



Day33420_TM515 Estimated Position Accuracy



Day33420_TM515 PDOP Plot

