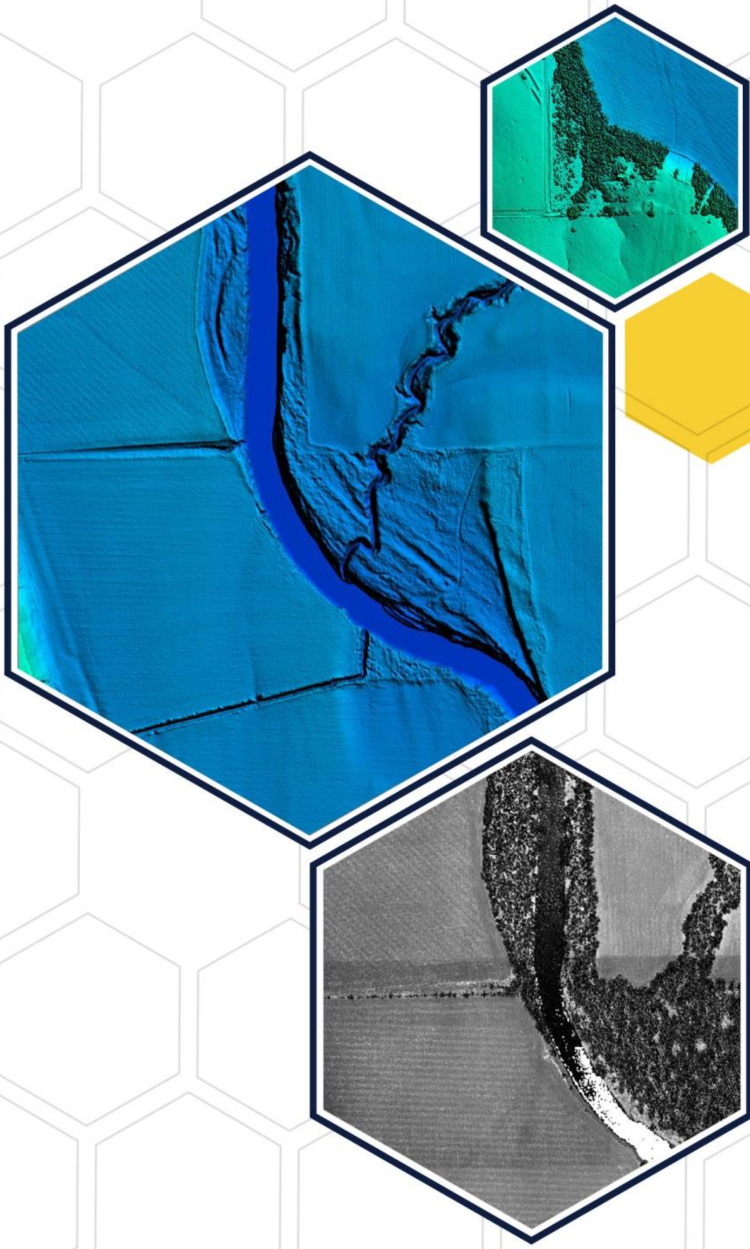


# Aerial Lidar Report

16113
United States Geological Survey, 2017 Alabama 25 Counties Lidar (Block 5)
April 2018

# Table of Contents

# Section 1: Lidar Acquisition

## 1.1 Acquisition

The Atlantic Group, LLC (Atlantic) has successfully completed lidar acquisition for the 2017 Alabama 25 County Lidar (Block 5) Area of Interest (AOI). Lidar for this AOI was acquired in fourteen (14) flight mission completed on April 2nd, 2017. The project area encompasses 1,392,747 acres, 5636 square kilometers or 2176 square miles.

## 1.2 Acquisition Status Report

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

## 1.3 Acquisition Details

Atlantic acquired one-hundred and thirty-one (131) passes of the AOI as a series of perpendicular and/or adjacent flight-lines. Differential GNSS unit in aircraft recorded sample positions at 2 Hz or more frequency. Lidar data was only acquired when a minimum of 6 satellites were in view.

Atlantic lidar sensors are calibrated at a designated site located at the Fayetteville Municipal Airport (FYM) in Fayetteville, TN and are periodically checked and adjusted to minimize corrections at project sites.

## 1.4 Project Purpose

The primary purpose of the lidar survey was to establish measurements of the bare earth surface, as well as top surface feature data for providing geometric inputs for modeling, other numerical modeling and economic related assessments.

## 1.5 Lidar Flight-line Orientation

The following graphic represents the alignment of the project area of interest (AOI) and the flight-lines executed to provide AOI coverage.

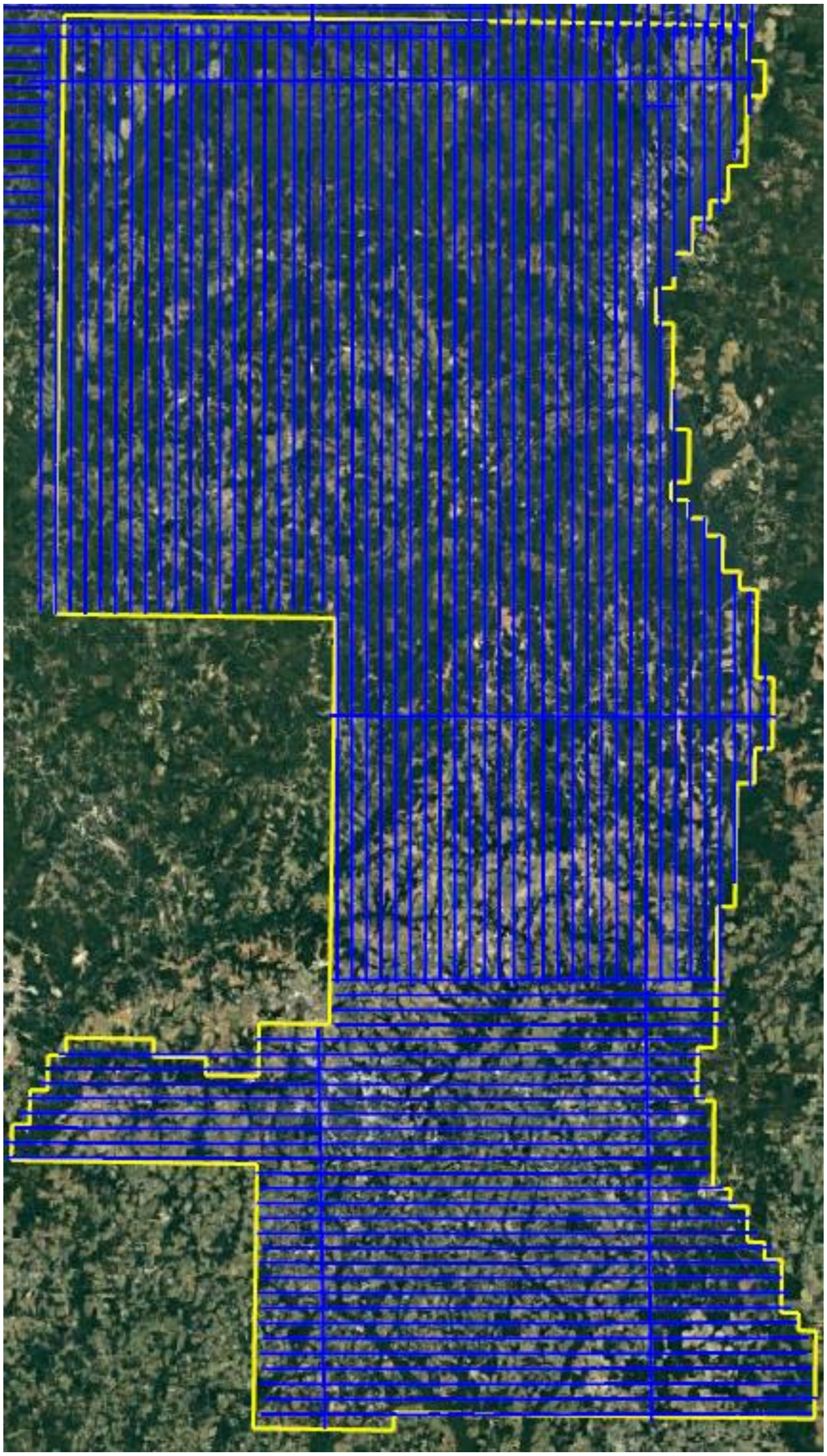


Figure 1: Trajectories as flown by Atlantic

## 1.6 Acquisition Equipment

Atlantic operated a Partenavia S.P.A P 68 C/TC (N775MW) outfitted with a Leica ALS70-HP lidar system during the collection of the project area. Table 1 represents a list of the features and characteristics for the Leica ALS70-HP lidar system:

| Atlantic's Sensor Characteristics | | |
|---|---|---|
| Leica ALS70-HP | | |
| Manufacturer | Leica | |
| Model | ALS70 - HP | |
| Platform | Fixed-Wing | |
| Scan Pattern | Sine, Triangle, Raster | |
| Maximum Scan Rate (Hz) | Sine | 200 |
| | Triangle | 158 |
| | Raster | 120 |
| Field of View (°) | 0 - 75 (Full Angle, User Adjustable) | |
| Maximum Pulse rate (kHz) | 500 | |
| Maximum Flying height (m AGL) | 3500 | |
| Number of returns | Unlimited | |
| Number of Intensity Measurements | 3 (First, Second, Third) | |
| Roll Stabilization (Automatic Adaptive, °) | 75 - Active FOV | |
| Storage Media | Removable 500 GB SSD | |
| Storage Capacity (Hours @ Max Pulse Rate) | 6 | |
| Size (cm) | Scanner | 37 W x 68 L x 26 H |
| | Control Electronics | 45 W x 47 D x 36 H |
| Weight (kg) | Scanner | 43 |
| | Control Electronics | 45 |
| Operating Temperature | 0 - 40 °C | |
| Flight Management | FCMS | |
| Power Consumption | 927 @ 22.0 - 30.3 VDC | |

Table 1: Atlantic Sensor Characteristics

## 1.7 Lidar System Acquisition Parameters

Table 2 illustrates Atlantic's system parameters for lidar acquisition on this project.

| Lidar System Acquisition Parameters | |
|---|---|
| **Item** | **Parameter** |
| System | Leica ALS-70 HP |
| Nominal Pulse Spacing (m) | 0.5267 |
| Nominal Pulse Density (pls/m²) | 3.6 |
| Nominal Flight Height (AGL meters) | 2162 |
| Nominal Flight Speed (kts) | 130 |
| Pass Heading (degree) | Varies |
| Sensor Scan Angle (degree) | 45 |
| Scan Frequency (Hz) | 35.1 |
| Pulse Rate of Scanner (kHz) | 264.8 |
| Line Spacing (m) | 1,141 |
| Pulse Duration of Scanner (ns) | 4 |
| Pulse Width of Scanner (m) | 0.48 |
| Central Wavelength of Sensor Laser (nm) | 1064 |
| Sensor Operated with Multiple Pulses | Yes |
| Beam Divergence (mrad) | 0.22 |
| Nominal Swath Width (m) | 1,663 |
| Nominal Swath Overlap (%) | 20 |
| Scan Pattern | Triangle |

Table 2: Atlantic Lidar System Acquisition Parameters

## 1.8 GNSS Reference Station(s)

SIx (6) Continuously Operating Reference Stations (CORS) were used to control the lidar acquisition for the project area. The coordinates provided in Table 3 below are in NAD83 (2011), Geographic Coordinate System, Ellipsoid, Meters.

| GPS Reference Station Coordinates | | | | | |
|---|---|---|---|---|---|
| **Designation** | **Type** | **PID** | **Latitude (N)** | **Longitude (W)** | **Elevation** |
| **ALTU** | CORS | DP4178 | 31 48 00.71565 | 085 57 15.51042 | 142.530 |
| **AL76** | CORS | DM7125 | 31 52 29.93782 | 085 13 32.45603 | 101.523 |
| **GABY** | CORS | DL2033 | 31 22 39.29715 | 084 56 06.66390 | 64.976 |
| **AL62** | CORS | DM2676 | 32 08 53.34292 | 085 41 12.35093 | 142.213 |
| **ALDO** | CORS | DM2682 | 31 14 22.15190 | 085 26 24.68596 | 81.108 |
| **ALNB** | CORS | DM2684 | 31 22 38.96239 | 085 54 57.74680 | 108.306 |

Table 3: GNSS Reference Station Coordinates

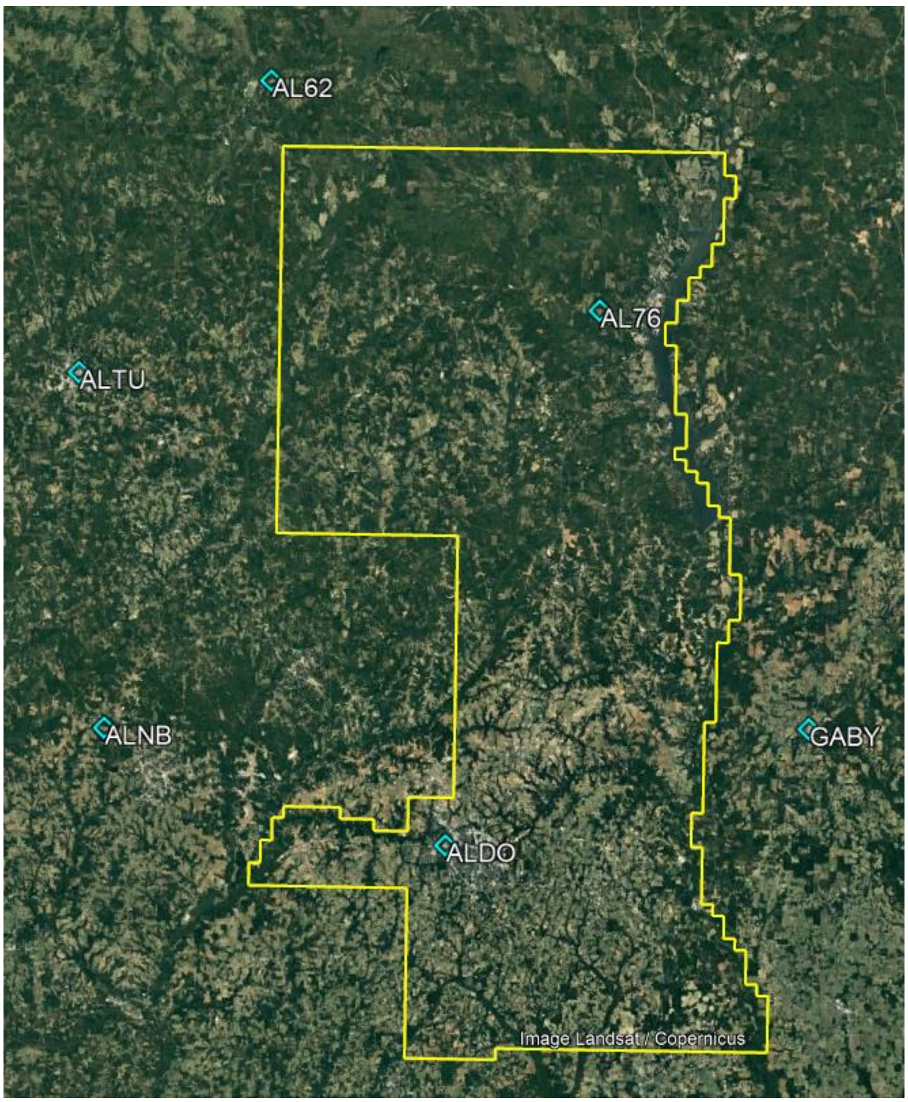



Figure 2: GNSS Reference Station(s)

## 1.9 Airborne GNSS Kinematic

Differential GNSS unit in aircraft collected positions at 2 Hz. Airborne GNSS data was processed using the Inertial Explorer (version 8.60.6717) software. Flights were flown with a minimum of 6 satellites in view (10° above the horizon).

For all flights, the GNSS data can be classified as good, with residuals of 3cm average or better but none larger than 10cm being recorded.

Data collected by the lidar unit is reviewed for completeness, acceptable density and to make sure all data is captured without errors or corrupted values. In addition, all GNSS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database.

GNSS processing results for each lift are included in **Section 5: GNSS Processing**.

# Section 2: Lidar Processing

## 2.1 Lidar Point Cloud Generation

Atlantic used Leica software products to download the IPAS ABGNSS/IMU data and raw laser scan files from the airborne system. Waypoint Inertial Explorer is used to extract the raw IPAS ABGNSS/IMU data, which is further processed in combination with controlled base stations to provide the final Smoothed Best Estimate Trajectory (SBET) for each mission. The SBET's are combined with the raw laser scan files to export the Lidar ASCII Standard (*.las) formatted swath point clouds.

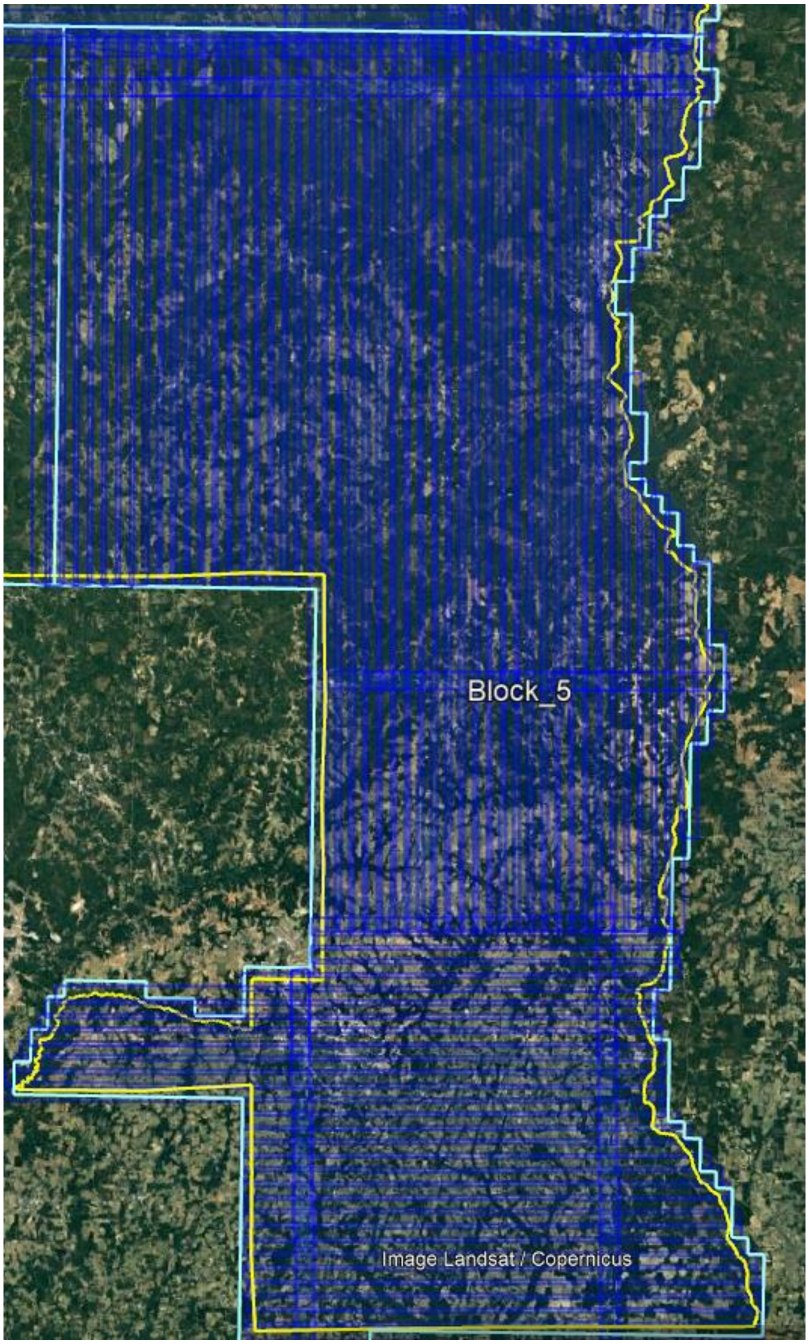



Figure 3: Lidar swath data showing complete coverage

## 2.2 Coordinate Reference System

| | |
|---|---|
| **Horizontal Datum:** | North American Datum of 1983 (2011) |
| **Coordinate System:** | Universal Transverse Mercator Zone 16 North |
| **Vertical Datum:** | North American Vertical Datum of 1988 |
| **Geoid Model:** | Geoid12B |
| **Units of Reference:** | Meters |

## 2.3 Lidar Point Cloud Statistics

Table 4 illustrates the overall lidar point cloud statistics for this project.

| Point Cloud Statistics | |
|---|---|
| **Category** | **Value** |
| Total Points | 36,635,020,968 |
| Nominal Pulse Spacing (m) | 0.5267 |
| Nominal Pulse Density (pls/m²) | 3.60 |
| Nominal Pulse Spacing (ft) | 1.7281 |
| Nominal Pulse Density (pls/ft²) | 0.33 |
| Total Aggregate Points | 27,010,928,522 |
| Aggregate Nominal Pulse Spacing (m) | 0.4617 |
| Aggregate Nominal Pulse Density (pls/m²) | 4.69 |
| Aggregate Nominal Pulse Spacing (ft) | 1.5149 |
| Aggregate Nominal Pulse Density (pls/ft²) | 0.44 |

Table 4: Lidar Point Cloud Statistics

## 2.4 Expected Horizontal Positional Error

As described in Section 7.5 of the ASPRS Positional Accuracy Standards for Digital Geospatial Data the horizontal errors in lidar data are largely a function of GNSS positional error, INS angular error, and flying altitude. Therefore, lidar data collected with GNSS error of 8cm and the IMU error of 0.00427 degrees at an altitude of 2162m; the expected radial horizontal positional error will be RMSEz = 31.0cm.

## 2.5 Smooth Surface Repeatability (Intraswath)

Departures from planarity of first returns within single swaths in non-vegetated areas were assessed at multiple locations with hard surface areas (parking lots or large rooftops) inside the project area. Each area was evaluated using signed difference rasters (maximum elevation – minimum elevation) at a cell size equal to 2 x ANPS, rounded to the next integer. The following graphic depicts a sample of the assessment.

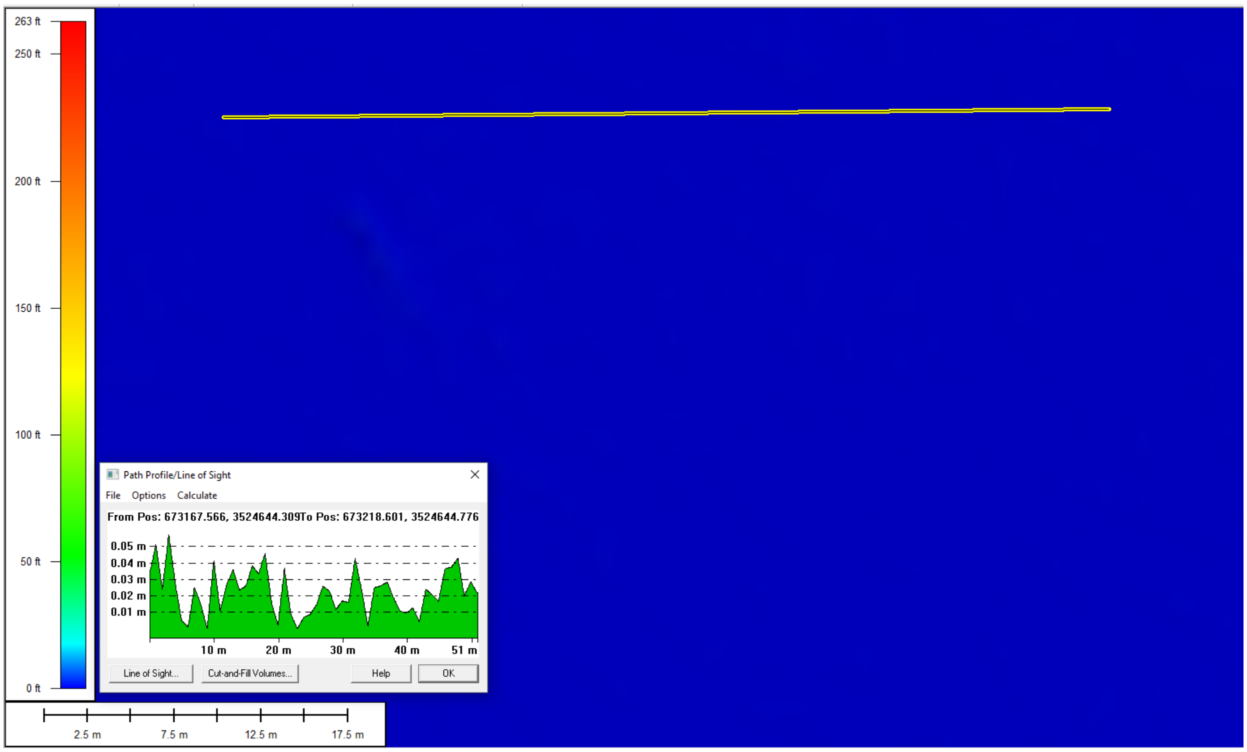



Figure 4: Smooth Surface Repeatability of ≤6cm

## 2.6 Lidar Calibration

Lidar ranging data were initially calibrated using previous best parameters for this instrument and aircraft. Using a combination of GeoCue, TerraScan and TerraMatch; the overlapping swath point clouds are corrected for any orientation or linear deviations to obtain the best fit swath-to-swath calibration. Relative calibration was evaluated using advanced plane-matching analysis and parameter corrections derived. This process was repeated interactively until residual errors between overlapping swaths, across all project missions, was reduced to ≤2cm. A final analysis of the calibrated lidar is preformed using a TerraMatch Tie Line report for an overall statistical model of the project area.

Upon completion of the data calibration, Atlantic runs a complete set of elevation difference intensity rasters (dZ Orthos). A user-defined color ramp is applied depicting the offsets between overlapping swaths based on project specifications. The dZ orthos provide an opportunity to review the data calibration in a qualitative manner. Atlantic assigns green to all offset values that fall below the required RMSDz requirement of the project. A yellow color is assigned for offsets that fall between the RMSDz value and 1.5x of that value. Finally, red values are assigned to all values that fall beyond 1.5x of the RMSDz requirements of the project.

| | | | | |
|---|---|---|---|---|
| No Data | 0m to 0.04m | 0.04m to 0.08m | 0.08m to 0.12m | > 0.12m |

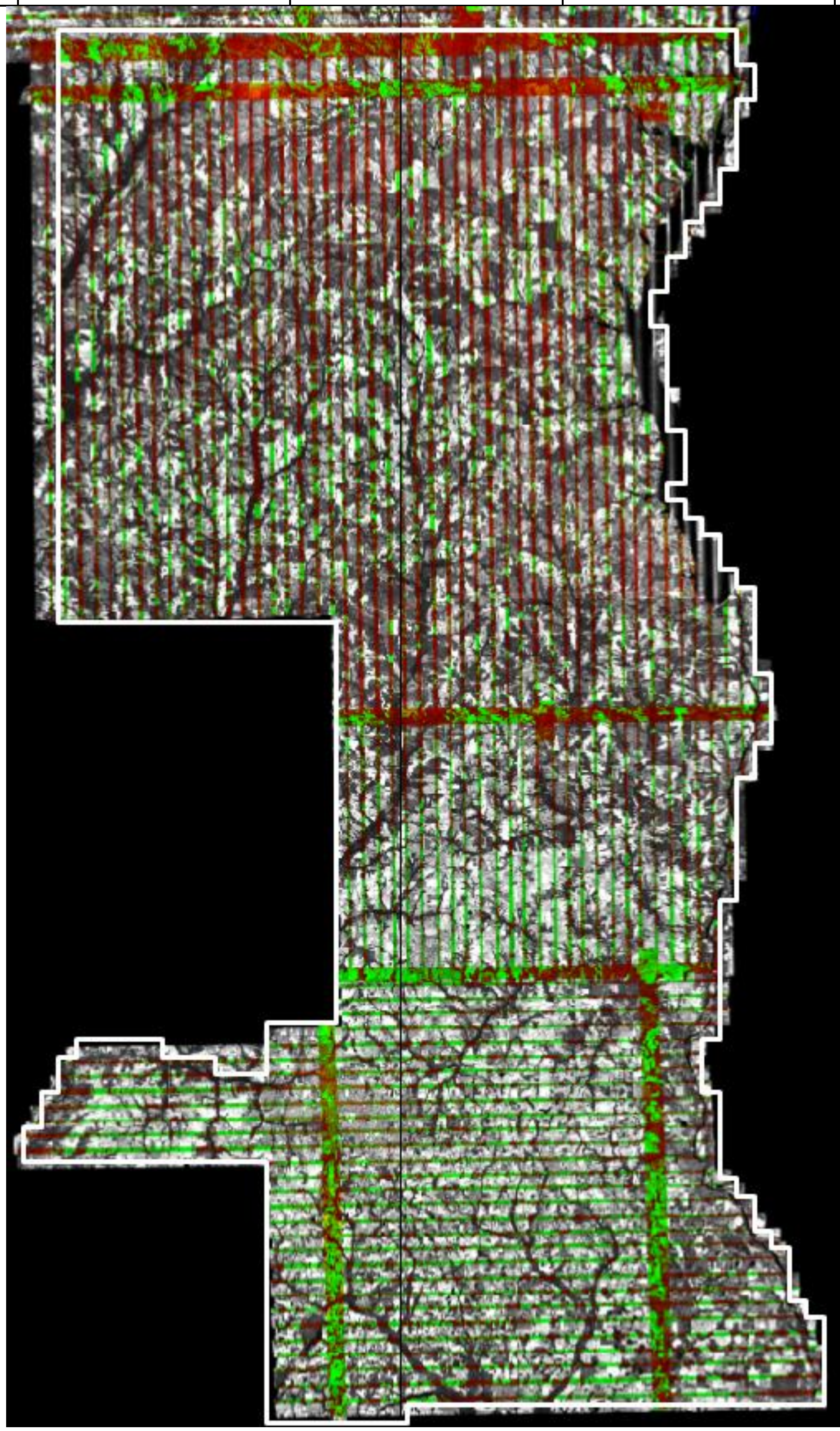


Figure 5: Swath Overlap Difference of ≤8cm, Maximum of ±16cm

## 2.7 Overlap Consistency (Interswath)

An overall statistical assessment of the relative accuracy using TerraMatch Tie Line Report between lidar swaths can be found in Tables 5, 6, 7, and 8 below. The values provided are in meters.

| Average Magnitudes Per Line | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Line | X | Y | Z | Line | X | Y | Z | Line | X | Y | Z |
| 2075 | 0.023 | 0.018 | 0.024 | 2127 | 0.029 | 0.034 | 0.015 | 2179 | 0.023 | 0.019 | 0.016 |
| 2076 | 0.057 | 0.018 | 0.022 | 2128 | 0.04 | 0.035 | 0.018 | 2180 | 0.033 | 0.028 | 0.017 |
| 2077 | 0.025 | 0.024 | 0.019 | 2129 | 0.03 | 0.03 | 0.016 | 2181 | 0.026 | 0.023 | 0.015 |
| 2078 | 0.029 | 0.026 | 0.016 | 2130 | 0.027 | 0.019 | 0.016 | 2182 | 0.018 | 0.022 | 0.017 |
| 2079 | 0.021 | 0.022 | 0.013 | 2131 | 0.015 | 0.017 | 0.016 | 2183 | 0.02 | 0.023 | 0.016 |
| 2080 | 0.016 | 0.019 | 0.014 | 2132 | 0.018 | 0.018 | 0.017 | 2184 | 0.025 | 0.022 | 0.016 |
| 2081 | 0.019 | 0.022 | 0.014 | 2133 | 0.036 | 0.024 | 0.017 | 2185 | 0.025 | 0.022 | 0.015 |
| 2082 | 0.028 | 0.021 | 0.015 | 2134 | 0.015 | 0.016 | 0.02 | 2186 | 0.02 | 0.021 | 0.016 |
| 2083 | 0.015 | 0.015 | 0.02 | 2135 | 0.021 | 0.022 | 0.015 | 2187 | 0.022 | 0.021 | 0.015 |
| 2084 | 0.033 | 0.024 | 0.015 | 2136 | 0.02 | 0.019 | 0.015 | 2188 | 0.016 | 0.017 | 0.016 |
| 2085 | 0.013 | 0.014 | 0.023 | 2137 | 0.024 | 0.022 | 0.016 | 2189 | 0.035 | 0.046 | 0.023 |
| 2086 | 0.03 | 0.021 | 0.016 | 2138 | 0.022 | 0.018 | 0.015 | 2190 | 0.016 | 0.015 | 0.016 |
| 2087 | 0.021 | 0.019 | 0.016 | 2139 | 0.02 | 0.022 | 0.015 | 2131 | 0.016 | 0.019 | 0.021 |
| 2088 | 0.019 | 0.021 | 0.017 | 2140 | 0.021 | 0.022 | 0.016 | 2192 | 0.016 | 0.015 | 0.017 |
| 2089 | 0.021 | 0.025 | 0.016 | 2141 | 0.017 | 0.026 | 0.016 | 2193 | 0.019 | 0.016 | 0.016 |
| 2090 | 0.023 | 0.022 | 0.015 | 2142 | 0.017 | 0.019 | 0.017 | 2194 | 0.018 | 0.021 | 0.015 |
| 2091 | 0.019 | 0.02 | 0.014 | 2143 | 0.022 | 0.019 | 0.018 | 2195 | 0.017 | 0.02 | 0.015 |
| 2092 | 0.017 | 0.025 | 0.015 | 2144 | 0.027 | 0.033 | 0.022 | 2196 | 0.023 | 0.024 | 0.016 |
| 2093 | 0.017 | 0.024 | 0.014 | 2145 | 0.018 | 0.012 | 0.017 | 2197 | 0.024 | 0.02 | 0.016 |
| 2094 | 0.015 | 0.021 | 0.013 | 2146 | 0.016 | 0.016 | 0.017 | 2198 | 0.022 | 0.02 | 0.015 |
| 2095 | 0.011 | 0.017 | 0.013 | 2147 | 0.012 | 0.016 | 0.016 | 2199 | 0.019 | 0.018 | 0.014 |
| 2096 | 0.012 | 0.016 | 0.014 | 2148 | 0.02 | 0.033 | 0.021 | 2200 | 0.019 | 0.04 | 0.025 |
| 2097 | 0.012 | 0.014 | 0.014 | 2149 | 0.018 | 0.014 | 0.015 | 2201 | 0.02 | 0.018 | 0.016 |
| 2098 | 0.01 | 0.012 | 0.016 | 2150 | 0.019 | 0.019 | 0.015 | 2202 | 0.019 | 0.016 | 0.02 |
| 2099 | 0.025 | 0.018 | 0.023 | 2151 | 0.017 | 0.025 | 0.015 | 2203 | 0.031 | 0.018 | 0.02 |
| 2100 | 0.01 | 0.011 | 0.015 | 2152 | 0.018 | 0.024 | 0.016 | 2204 | 0.033 | 0.037 | 0.02 |
| 2101 | 0.014 | 0.022 | 0.02 | 2153 | 0.018 | 0.024 | 0.015 | 2205 | 0.023 | 0.023 | 0.021 |
| 2102 | 0.018 | 0.026 | 0.015 | 2154 | 0.016 | 0.067 | 0.016 | 2206 | 0.025 | 0.028 | 0.016 |
| 2103 | 0.02 | 0.027 | 0.015 | 2155 | 0.024 | 0.028 | 0.016 | 2207 | 0.024 | 0.023 | 0.017 |
| 2104 | 0.017 | 0.026 | 0.013 | 2156 | 0.024 | 0.02 | 0.018 | 2208 | 0.02 | 0.024 | 0.016 |
| 2105 | 0.015 | 0.022 | 0.017 | 2157 | 0.04 | 0.043 | 0.022 | 2254 | 0.021 | 0.022 | 0.021 |
| 2106 | 0.015 | 0.018 | 0.014 | 2158 | 0.019 | 0.023 | 0.016 | 2255 | 0.028 | 0.019 | 0.021 |
| 2107 | 0.013 | 0.017 | 0.015 | 2160 | 0.008 | 0.003 | 0.023 | 2256 | 0.019 | 0.015 | 0.014 |
| 2108 | 0.013 | 0.015 | 0.016 | 2161 | 0.016 | 0.02 | 0.017 | 2257 | 0.018 | 0.014 | 0.015 |
| 2109 | 0.012 | 0.013 | 0.017 | 2162 | 0.026 | 0.032 | 0.017 | 2258 | 0.018 | 0.014 | 0.014 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2110** | 0.019 | 0.021 | 0.022 | **2163** | 0.033 | 0.029 | 0.016 | **2259** | 0.018 | 0.019 | 0.016 |
| **2111** | 0.027 | 0.022 | 0.014 | **2164** | 0.031 | 0.032 | 0.017 | **2260** | 0.019 | 0.024 | 0.015 |
| **2112** | 0.022 | 0.019 | 0.016 | **2165** | 0.039 | 0.026 | 0.017 | **2261** | 0.028 | 0.018 | 0.015 |
| **2113** | 0.02 | 0.017 | 0.018 | **2166** | 0.028 | 0.03 | 0.016 | **2262** | 0.027 | 0.022 | 0.015 |
| **2114** | 0.028 | 0.023 | 0.015 | **2167** | 0.026 | 0.028 | 0.016 | **2276** | 0.013 | 0.01 | 0.014 |
| **2115** | 0.026 | 0.022 | 0.015 | **2168** | 0.03 | 0.023 | 0.021 | **2277** | 0.015 | 0.013 | 0.016 |
| **2116** | 0.018 | 0.029 | 0.021 | **2169** | 0.019 | 0.021 | 0.017 | **2278** | 0.016 | 0.015 | 0.016 |
| **2117** | - | - | 0.016 | **2170** | 0.06 | 0.044 | 0.02 | **2279** | 0.016 | 0.016 | 0.015 |
| **2118** | 0.004 | 0.019 | 0.014 | **2171** | 0.023 | 0.024 | 0.019 | **2280** | 0.016 | 0.023 | 0.016 |
| **2119** | 0.035 | 0.031 | 0.015 | **2172** | 0.017 | 0.019 | 0.016 | **2281** | 0.018 | 0.026 | 0.015 |
| **2120** | 0.034 | 0.029 | 0.015 | **2173** | 0.015 | 0.014 | 0.02 | **2282** | 0.019 | 0.018 | 0.016 |
| **2121** | 0.018 | 0.018 | 0.015 | **2174** | 0.021 | 0.022 | 0.014 | **2283** | 0.016 | 0.019 | 0.016 |
| **2122** | 0.016 | 0.018 | 0.016 | **2175** | 0.026 | 0.028 | 0.015 | **2284** | 0.022 | 0.022 | 0.015 |
| **2123** | 0.02 | 0.021 | 0.021 | **2176** | 0.024 | 0.026 | 0.015 | **2285** | 0.026 | 0.024 | 0.015 |
| **2124** | - | - | 0.014 | **2177** | 0.022 | 0.019 | 0.015 | **2286** | 0.025 | 0.026 | 0.016 |
| **2125** | 0.025 | 0.02 | 0.02 | **2178** | 0.019 | 0.019 | 0.015 | | | | |
| **2126** | 0.019 | 0.029 | 0.014 | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

Table 5: Average Tie Line Magnitudes per Line

| Internal Observation Statistics | | | |
|---|---|---|---|
| **Category** | **X** | **Y** | **Z** |
| **Average Magnitude** | 0.016 | 0.017 | 0.016 |
| **RMS Values** | 0.026 | 0.027 | 0.022 |
| **Maximum Values** | 0.156 | 0.158 | 0.159 |
| **Observation Weight** | 130470.0 | 130470.0 | 927406.0 |

Table 6: Tie Line Observation Statistics

| Overall Relative Accuracy | |
|---|---|
| **Category** | **Mismatch** |
| **Average 3D Mismatch** | 0.01933 |
| **Average XY Mismatch** | 0.02846 |
| **Average Z Mismatch** | 0.01640 |

Table 7: Relative Accuracy Results

| TerraMatch Tie Lines | |
|---|---|
| **Category** | **Observations** |
| **Section Lines** | 336,503 |
| **Roof Lines** | 61,450 |

Table 8: Total Tie Lines

## 2.8 Lidar Classification

Atlantic uses multiple automated filtering routines on the calibrated lidar point cloud identifying and extracting bare-earth and above ground features. GeoCue, TerraScan, and TerraModeler software was used for the initial batch processing and manual editing of the lidar point clouds. Atlantic utilized collected breakline data to preform classification for classes' 9-Water and 10-Ignored Ground in LP360. Outlined in Table 9 are the classification codes utilized for this project.

| ASPRS Standard Lidar Point Classes | |
|---|---|
| **Code** | **Description** |
| 1 | Unclassified |
| 2 | Ground |
| 7 | Low Noise |
| 9 | Water |
| 10 | Ignored Ground |
| 17 | Bridges |
| 18 | High Noise |
| Flags | Overlap & Withheld |

Table 9: Point Cloud Classification Scheme

# Section 3: Lidar Accuracy

## 3.1 Ground Surveyed Check Points

Atlantic established a total of sixty-two (62) check points for this Block 5 project (35 NVA + 27 VVA). Point cloud data accuracy was tested against a Triangulated Irregular Network (TIN) constructed from lidar points in clear and open areas. A clear and open area can be characterized with respect to topographic and ground cover variation such that a minimum of 5 times the NPS exists with less than 1/3 of the $RMSE_Z$ deviation from a low-slope plane. Slopes that exceed 10 percent were avoided. Each land cover type representing 10 percent or more of the total project area were tested and reported with a VVA. In land cover categories other than dense urban areas, the tested points did not have obstructions 45 degrees above the horizon to ensure a sufficient TIN surface. The VVA value is provided as a target. It is understood that in areas of dense vegetation, swamps, or extremely difficult terrain, this value may be exceeded. The NVA value is a requirement that must be met, regardless of any allowed “busts” in the VVA(s) for individual land cover types within the project. Checkpoints for each assessment (NVA & VVA) are required to be well-distributed throughout the land cover type, for the entire project area.

## 3.2 Vertical Accuracy Requirements

Below are the vertical accuracy reporting requirements for this project:

**Vertical Accuracy Reporting Requirements in Meters:**

$RMSE_Z$ ≤ 10.0cm (Non-Vegetated Swath, DEM)
NVA ≤ 19.6cm 95% Confidence Level (Swath, DEM)
VVA ≤ 29.4cm $95^{th}$ Percentile (DEM)

**Vertical Accuracy Reporting Requirements in Feet:**

$RMSE_Z$ ≤ 0.328ft (Non-Vegetated Swath, DEM)
NVA ≤ 0.643ft 95% Confidence Level (Swath, DEM)
VVA ≤ 0.965ft $95^{th}$ Percentile (DEM)

*The terms FVA (Fundamental Vertical Accuracy), SVA (Supplemental Vertical Accuracy) and CVA (Consolidated Vertical Accuracy) are from the National Digital Elevation Program (NDEP) Guidelines for Digital Elevation Data (2004). The term FVA refers to open terrain, urban and levee classes; the term SVA refers to classes tested that are in addition or supplemental to the open terrain; the term CVA refers to the consolidated accuracy of the data from all classes (FVA + SVA).

*The terms NVA (Non-vegetated Vertical Accuracy) and VVA (Vegetated Vertical Accuracy) are from the ASPRS Positional Accuracy Standards for Digital Geospatial Data v1.0 (2014). The term NVA refers to assessments in clear, open areas (which typically produce only single lidar returns); the term VVA refers to assessments in vegetated areas (typically characterized by multiple return lidar).

## 3.3 Check Point Distribution

The following graphics depict the location and distribution of NVA and VVA check points established for this project.

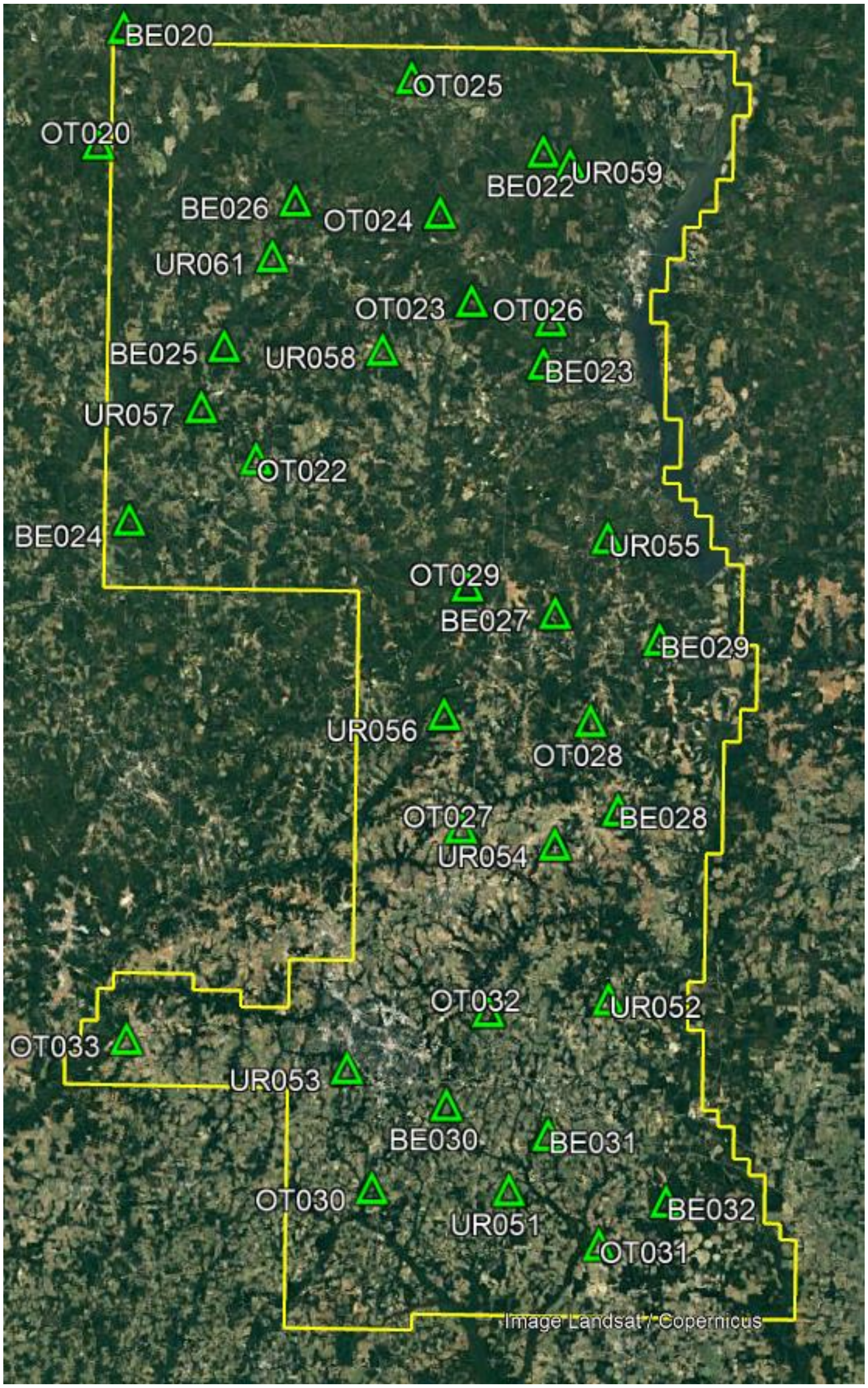



Figure 6: Non-vegetated Vertical Accuracy (NVA) Check Point Distribution

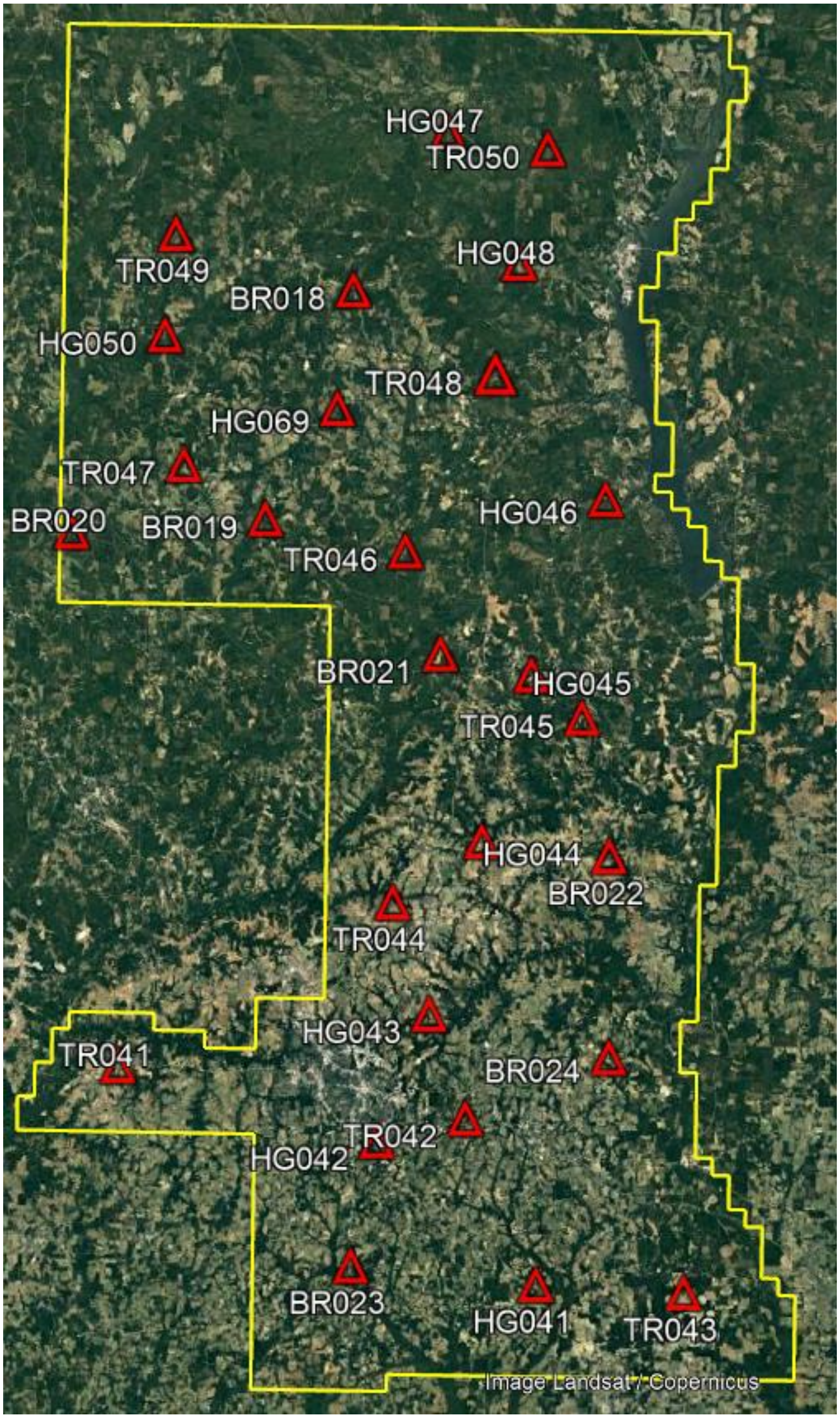



Figure 7: Vegetated Vertical Accuracy (VVA) Check Point Distribution

## 3.4 Vertical Accuracy Results

An overall statistical assessment of the check points can be found in Tables 10 and 11 below. The values provided are in meters.

| Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA) | | | | |
|---|---|---|---|---|
| Broad Land Cover Type | # of Points | RMSEz | 95% Confidence Level | 95th Percentile |
| NVA of Point Cloud | 35 | 0.064 | 0.126 | |
| NVA of Bare Earth | 35 | 0.066 | 0.130 | |
| NVA of DEM | 33 | 0.064 | 0.125 | |
| VVA of Bare Earth | 27 | 0.088 | | 0.153 |

Table 10: Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA)

| Vegetated Vertical Accuracy (VVA) 5% Outliers > 95th Percentile (0.154m) | | | | | | |
|---|---|---|---|---|---|---|
| PointID | Easting | Northing | KnownZ | LaserZ | Description | DeltaZ |
| TR045 | 671925.349 | 3488543.897 | 122.877 | 123.071 | Trees | 0.194 |

Table 11: 5% Outlier Check Points

## 3.5 Check Point Assessment

A vertical accuracy assessment of the NVA & VVA check points against the lidar point cloud and bare-earth lidar can be found in Tables 12, 13, 14, and 15 below. The coordinates provided are in NAD83 (2011), UTM Zone 16 North, NAVD88 (Geoid12B), Meters.

| Non-vegetated Vertical Accuracy (NVA) Check Point Assessment (Point Cloud) | | | | | | |
|---|---|---|---|---|---|---|
| PointID | Easting | Northing | KnownZ | LaserZ | Description | DeltaZ |
| BE020 | 626503.165 | 3550471.020 | 160.114 | 160.115 | Bare Earth/Open Terrain | 0.001 |
| BE022 | 666203.488 | 3539409.817 | 88.190 | 88.272 | Bare Earth/Open Terrain | 0.082 |
| BE023 | 666540.708 | 3519552.442 | 119.464 | 119.463 | Bare Earth/Open Terrain | -0.001 |
| BE024 | 627848.325 | 3504380.202 | 163.519 | 163.425 | Bare Earth/Open Terrain | -0.094 |
| BE025 | 636504.852 | 3520756.644 | 151.249 | 151.236 | Bare Earth/Open Terrain | -0.013 |
| BE026 | 642966.957 | 3534474.216 | 168.628 | 168.646 | Bare Earth/Open Terrain | 0.018 |
| BE027 | 668019.953 | 3496291.830 | 129.510 | 129.375 | Bare Earth/Open Terrain | -0.135 |
| BE028 | 674200.736 | 3477975.543 | 108.100 | 108.184 | Bare Earth/Open Terrain | 0.084 |
| BE029 | 677847.029 | 3493952.211 | 105.336 | 105.258 | Bare Earth/Open Terrain | -0.078 |
| BE030 | 658507.807 | 3450171.349 | 88.354 | 88.260 | Bare Earth/Open Terrain | -0.094 |
| BE031 | 668107.389 | 3447529.588 | 74.812 | 74.753 | Bare Earth/Open Terrain | -0.059 |
| BE032 | 679284.631 | 3441451.315 | 56.105 | 56.122 | Bare Earth/Open Terrain | 0.017 |
| OT020 | 624296.578 | 3539561.222 | 148.351 | 148.472 | Bare Earth/Open Terrain | 0.121 |
| OT022 | 639680.121 | 3510262.257 | 150.800 | 150.801 | Bare Earth/Open Terrain | 0.001 |
| OT023 | 659699.883 | 3525315.170 | 143.755 | 143.735 | Bare Earth/Open Terrain | -0.020 |
| OT024 | 656577.523 | 3533528.567 | 105.503 | 105.483 | Bare Earth/Open Terrain | -0.020 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **OT025** | 653709.699 | 3546127.123 | 96.300 | 96.314 | Bare Earth/Open Terrain | 0.014 |
| **OT026** | 667156.608 | 3523616.755 | 97.238 | 97.179 | Bare Earth/Open Terrain | -0.059 |
| **OT027** | 659482.458 | 3476139.634 | 118.035 | 118.081 | Bare Earth/Open Terrain | 0.046 |
| **OT028** | 671496.047 | 3486257.456 | 112.045 | 112.085 | Bare Earth/Open Terrain | 0.040 |
| **OT029** | 659728.630 | 3498728.501 | 139.936 | 139.886 | Bare Earth/Open Terrain | -0.050 |
| **OT030** | 651622.087 | 3442271.520 | 70.319 | 70.372 | Bare Earth/Open Terrain | 0.053 |
| **OT031** | 673036.254 | 3437322.329 | 47.331 | 47.293 | Bare Earth/Open Terrain | -0.038 |
| **OT032** | 662305.107 | 3459014.227 | 83.564 | 83.471 | Bare Earth/Open Terrain | -0.093 |
| **OT033** | 628324.936 | 3455866.853 | 108.009 | 108.085 | Bare Earth/Open Terrain | 0.076 |
| **UR051** | 664496.726 | 3442299.037 | 60.418 | 60.338 | Urban | -0.080 |
| **UR052** | 673579.727 | 3460293.958 | 72.074 | 72.057 | Urban | -0.017 |
| **UR053** | 649119.772 | 3453465.249 | 100.191 | 100.118 | Urban | -0.073 |
| **UR054** | 668319.795 | 3474674.399 | 112.989 | 112.914 | Urban | -0.075 |
| **UR055** | 672823.347 | 3503368.376 | 143.838 | 143.761 | Urban | -0.077 |
| **UR056** | 657735.108 | 3486683.763 | 123.473 | 123.504 | Urban | 0.031 |
| **UR057** | 634442.145 | 3515000.279 | 151.785 | 151.680 | Urban | -0.105 |
| **UR058** | 651397.826 | 3520617.928 | 157.020 | 157.045 | Urban | 0.025 |
| **UR059** | 668721.749 | 3538206.419 | 81.630 | 81.680 | Urban | 0.050 |
| **UR061** | 640886.993 | 3529212.251 | 163.071 | 163.036 | Urban | -0.035 |

Table 12: Lidar Point Cloud NVA Assessment

| **Non-vegetated Vertical Accuracy (NVA) Check Point Assessment (Bare-Earth)** | | | | | | |
|---|---|---|---|---|---|---|
| **PointID** | **Easting** | **Northing** | **KnownZ** | **LaserZ** | **Description** | **DeltaZ** |
| **BE020** | 626503.165 | 3550471.020 | 160.114 | 160.115 | Bare Earth/Open Terrain | 0.001 |
| **BE022** | 666203.488 | 3539409.817 | 88.190 | 88.272 | Bare Earth/Open Terrain | 0.082 |
| **BE023** | 666540.708 | 3519552.442 | 119.464 | 119.463 | Bare Earth/Open Terrain | -0.001 |
| **BE024** | 627848.325 | 3504380.202 | 163.519 | 163.425 | Bare Earth/Open Terrain | -0.094 |
| **BE025** | 636504.852 | 3520756.644 | 151.249 | 151.236 | Bare Earth/Open Terrain | -0.013 |
| **BE026** | 642966.957 | 3534474.216 | 168.628 | 168.646 | Bare Earth/Open Terrain | 0.018 |
| **BE027** | 668019.953 | 3496291.830 | 129.510 | 129.375 | Bare Earth/Open Terrain | -0.135 |
| **BE028** | 674200.736 | 3477975.543 | 108.100 | 108.184 | Bare Earth/Open Terrain | 0.084 |
| **BE029** | 677847.029 | 3493952.211 | 105.336 | 105.258 | Bare Earth/Open Terrain | -0.078 |
| **BE030** | 658507.807 | 3450171.349 | 88.354 | 88.260 | Bare Earth/Open Terrain | -0.094 |
| **BE031** | 668107.389 | 3447529.588 | 74.812 | 74.753 | Bare Earth/Open Terrain | -0.059 |
| **BE032** | 679284.631 | 3441451.315 | 56.105 | 56.122 | Bare Earth/Open Terrain | 0.017 |
| **OT020** | 624296.578 | 3539561.222 | 148.351 | 148.472 | Bare Earth/Open Terrain | 0.121 |
| **OT022** | 639680.121 | 3510262.257 | 150.800 | 150.801 | Bare Earth/Open Terrain | 0.001 |
| **OT023** | 659699.883 | 3525315.170 | 143.755 | 143.735 | Bare Earth/Open Terrain | -0.020 |
| **OT024** | 656577.523 | 3533528.567 | 105.503 | 105.483 | Bare Earth/Open Terrain | -0.020 |
| **OT025** | 653709.699 | 3546127.123 | 96.300 | 96.314 | Bare Earth/Open Terrain | 0.014 |
| **OT026** | 667156.608 | 3523616.755 | 97.238 | 97.179 | Bare Earth/Open Terrain | -0.059 |
| **OT027** | 659482.458 | 3476139.634 | 118.035 | 118.081 | Bare Earth/Open Terrain | 0.046 |
| **OT028** | 671496.047 | 3486257.456 | 112.045 | 112.085 | Bare Earth/Open Terrain | 0.040 |

| | | | | | | |
|---|---|---|---|---|---|---|
| OT029 | 659728.630 | 3498728.501 | 139.936 | 139.886 | Bare Earth/Open Terrain | -0.050 |
| OT030 | 651622.087 | 3442271.520 | 70.319 | 70.372 | Bare Earth/Open Terrain | 0.053 |
| OT031 | 673036.254 | 3437322.329 | 47.331 | 47.293 | Bare Earth/Open Terrain | -0.038 |
| OT032 | 662305.107 | 3459014.227 | 83.564 | 83.471 | Bare Earth/Open Terrain | -0.093 |
| OT033 | 628324.936 | 3455866.853 | 108.009 | 108.085 | Bare Earth/Open Terrain | 0.076 |
| UR051 | 664496.726 | 3442299.037 | 60.418 | 60.338 | Urban | -0.080 |
| UR052 | 673579.727 | 3460293.958 | 72.074 | 72.057 | Urban | -0.017 |
| UR053 | 649119.772 | 3453465.249 | 100.191 | 100.118 | Urban | -0.073 |
| UR054 | 668319.795 | 3474674.399 | 112.989 | 112.914 | Urban | -0.075 |
| UR055 | 672823.347 | 3503368.376 | 143.838 | 143.713 | Urban | -0.125 |
| UR056 | 657735.108 | 3486683.763 | 123.473 | 123.504 | Urban | 0.031 |
| UR057 | 634442.145 | 3515000.279 | 151.785 | 151.677 | Urban | -0.108 |
| UR058 | 651397.826 | 3520617.928 | 157.020 | 157.031 | Urban | 0.011 |
| UR059 | 668721.749 | 3538206.419 | 81.630 | 81.680 | Urban | 0.050 |
| UR061 | 640886.993 | 3529212.251 | 163.071 | 163.027 | Urban | -0.044 |

Table 13: Bare-Earth Lidar NVA Assessment

| Non-vegetated Vertical Accuracy (NVA) Check Point Assessment (DEM) | | | | | | |
|---|---|---|---|---|---|---|
| PointID | Easting | Northing | KnownZ | DEMZ | Description | DeltaZ |
| BE022 | 666203.488 | 3539409.817 | 88.190 | 88.267 | Bare Earth/Open Terrain | -0.077 |
| BE023 | 666540.708 | 3519552.442 | 119.464 | 119.457 | Bare Earth/Open Terrain | 0.007 |
| BE024 | 627848.325 | 3504380.202 | 163.519 | 163.439 | Bare Earth/Open Terrain | 0.080 |
| BE025 | 636504.852 | 3520756.644 | 151.249 | 151.227 | Bare Earth/Open Terrain | 0.022 |
| BE026 | 642966.957 | 3534474.216 | 168.628 | 168.649 | Bare Earth/Open Terrain | -0.021 |
| BE027 | 668019.953 | 3496291.830 | 129.510 | 129.358 | Bare Earth/Open Terrain | 0.152 |
| BE028 | 674200.736 | 3477975.543 | 108.100 | 108.171 | Bare Earth/Open Terrain | -0.071 |
| BE029 | 677847.029 | 3493952.211 | 105.336 | 105.263 | Bare Earth/Open Terrain | 0.073 |
| BE030 | 658507.807 | 3450171.349 | 88.354 | 88.275 | Bare Earth/Open Terrain | 0.079 |
| BE031 | 668107.389 | 3447529.588 | 74.812 | 74.753 | Bare Earth/Open Terrain | 0.059 |
| BE032 | 679284.631 | 3441451.315 | 56.105 | 56.121 | Bare Earth/Open Terrain | -0.016 |
| OT022 | 639680.121 | 3510262.257 | 150.800 | 150.804 | Bare Earth/Open Terrain | -0.004 |
| OT023 | 659699.883 | 3525315.170 | 143.755 | 143.765 | Bare Earth/Open Terrain | -0.010 |
| OT024 | 656577.523 | 3533528.567 | 105.503 | 105.464 | Bare Earth/Open Terrain | 0.039 |
| OT025 | 653709.699 | 3546127.123 | 96.300 | 96.324 | Bare Earth/Open Terrain | -0.024 |
| OT026 | 667156.608 | 3523616.755 | 97.238 | 97.180 | Bare Earth/Open Terrain | 0.058 |
| OT027 | 659482.458 | 3476139.634 | 118.035 | 118.074 | Bare Earth/Open Terrain | -0.039 |
| OT028 | 671496.047 | 3486257.456 | 112.045 | 112.096 | Bare Earth/Open Terrain | -0.051 |
| OT029 | 659728.630 | 3498728.501 | 139.936 | 139.882 | Bare Earth/Open Terrain | 0.054 |
| OT030 | 651622.087 | 3442271.520 | 70.319 | 70.342 | Bare Earth/Open Terrain | -0.023 |
| OT031 | 673036.254 | 3437322.329 | 47.331 | 47.299 | Bare Earth/Open Terrain | 0.032 |
| OT032 | 662305.107 | 3459014.227 | 83.564 | 83.459 | Bare Earth/Open Terrain | 0.105 |
| OT033 | 628324.936 | 3455866.853 | 108.009 | 108.026 | Bare Earth/Open Terrain | -0.017 |
| UR051 | 664496.726 | 3442299.037 | 60.418 | 60.329 | Urban | 0.089 |

| | | | | | | |
|---|---|---|---|---|---|---|
| UR052 | 673579.727 | 3460293.958 | 72.074 | 72.047 | Urban | 0.027 |
| UR053 | 649119.772 | 3453465.249 | 100.191 | 100.131 | Urban | 0.060 |
| UR054 | 668319.795 | 3474674.399 | 112.989 | 112.913 | Urban | 0.076 |
| UR055 | 672823.347 | 3503368.376 | 143.838 | 143.692 | Urban | 0.146 |
| UR056 | 657735.108 | 3486683.763 | 123.473 | 123.457 | Urban | 0.016 |
| UR057 | 634442.145 | 3515000.279 | 151.785 | 151.701 | Urban | 0.084 |
| UR058 | 651397.826 | 3520617.928 | 157.020 | 157.054 | Urban | -0.034 |
| UR059 | 668721.749 | 3538206.419 | 81.630 | 81.677 | Urban | -0.047 |
| UR061 | 640886.993 | 3529212.251 | 163.071 | 163.023 | Urban | 0.048 |

Table 14: Bare=Earth DEM NVA Assessment

| Vegetated Vertical Accuracy (VVA) Check Point Assessment (Bare Earth) | | | | | | |
|---|---|---|---|---|---|---|
| PointID | Easting | Northing | KnownZ | LaserZ | Description | DeltaZ |
| BR018 | 651136.542 | 3525874.351 | 186.180 | 186.317 | Brush | 0.137 |
| BR019 | 643687.504 | 3505613.047 | 138.062 | 138.150 | Brush | 0.088 |
| BR020 | 626590.815 | 3504254.562 | 148.310 | 148.300 | Brush | -0.010 |
| BR021 | 659322.342 | 3493987.318 | 141.405 | 141.511 | Brush | 0.106 |
| BR022 | 674528.298 | 3476434.225 | 94.159 | 94.147 | Brush | -0.012 |
| BR023 | 652234.413 | 3440058.720 | 64.474 | 64.563 | Brush | 0.089 |
| BR024 | 674757.145 | 3458727.199 | 89.082 | 89.095 | Brush | 0.013 |
| HG041 | 668615.913 | 3438656.579 | 49.548 | 49.638 | High Grass | 0.090 |
| HG042 | 654368.716 | 3451095.838 | 93.308 | 93.361 | High Grass | 0.053 |
| HG043 | 658828.923 | 3462302.315 | 91.589 | 91.708 | High Grass | 0.119 |
| HG044 | 663244.670 | 3477576.048 | 104.751 | 104.904 | High Grass | 0.153 |
| HG045 | 667413.881 | 3492246.521 | 126.521 | 126.585 | High Grass | 0.064 |
| HG046 | 673713.707 | 3507781.518 | 77.686 | 77.665 | High Grass | -0.021 |
| HG047 | 659278.770 | 3539930.900 | 120.141 | 120.138 | High Grass | -0.003 |
| HG048 | 665745.827 | 3528428.590 | 120.592 | 120.571 | High Grass | -0.021 |
| HG050 | 634541.645 | 3521671.536 | 121.560 | 121.541 | High Grass | -0.019 |
| HG069 | 649900.046 | 3515408.400 | 146.690 | 146.738 | High Grass | 0.048 |
| TR041 | 631420.359 | 3457318.265 | 108.000 | 108.052 | Trees | 0.052 |
| TR042 | 662166.260 | 3453185.363 | 82.422 | 82.470 | Trees | 0.048 |
| TR043 | 681680.354 | 3438145.393 | 45.406 | 45.568 | Trees | 0.162 |
| TR044 | 655462.918 | 3472100.683 | 102.984 | 103.011 | Trees | 0.027 |
| TR046 | 656110.889 | 3502967.515 | 117.384 | 117.232 | Trees | -0.152 |
| TR047 | 636408.636 | 3510287.752 | 141.751 | 141.653 | Trees | -0.098 |
| TR048 | 663819.078 | 3518638.179 | 122.366 | 122.502 | Trees | 0.136 |
| TR049 | 635356.079 | 3530592.147 | 168.551 | 168.421 | Trees | -0.130 |
| TR050 | 668107.139 | 3538559.055 | 82.610 | 82.593 | Trees | -0.017 |
| TR052 | 620874.089 | 3548481.543 | 158.887 | 158.967 | Trees | 0.080 |

Table 15: Bare-Earth Lidar VVA Assessment

# Section 4: Certification

## 4.1 Limitations of Use

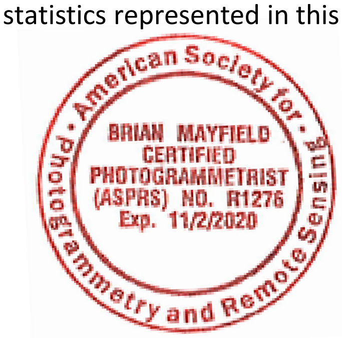
The accuracy assessment confirms that the data may be used for the intended applications stated in the **Project Purpose** section of this document. The dataset may also be used as a topographic input for other applications, but the user should be aware that this lidar dataset was designed with a specific purpose and was not intended to meet specifications and/or requirements of users outside of the U.S. Geological Survey.

It should also be noted that lidar points do not represent a continuous surface model. Lidar points are discrete measurements of the surface and any values derived within a triangle of three lidar points are interpolated. As such, the user should not use the resultant lidar dataset for vertical placement of a planimetric feature such as a headwall, building footprint or any other planimetric feature unless there is an associated lidar point that can be reasonably located on this structure.

Consideration should be given by the end user of this dataset to the fact that this lidar dataset was developed differently and that previous lidar datasets that may be available for this geographic location. It is likely that the data in this project was created using different geodetic control, a different Geoid, newer lidar technology and more up-to-date processing techniques. As such, any direct comparative analysis performed between this dataset and previous datasets could result in misleading or inaccurate results. Users are encouraged to proceed with caution while performing this type of comparative analysis and to completely understand the variables that make each of these datasets unique and not corollary.

It is encouraged that the user refers to the full FGDC Metadata and project reports for a complete understanding on the content of this dataset.

I, hereby, certify to the extent of my knowledge that the statements and statistics represented in this document are true and factual.




Brian J. Mayfield, ASPRS Certified Photogrammetrist #R1276

# Section 5: GNSS Processing

Inertial Explorer version 8.60.6717

Plots by Mission: Coverage Map, Estimated Position Accuracy, Number of Satellites, Combined Separation, and PDOP.

| | |
|---|---|
| **Coverage Map** | The Coverage Map plot shows the Aircraft GNSS-IMU Trajectory in reference to localized GNSS Reference Stations. |
| **Estimated Position Accuracy** | The Estimated Position Accuracy plot shows the standard deviations of the east, north, and up directions versus time for the solution. The total standard deviation with a distance dependent component is also plotted. |
| **Number of Satellites** | Plots the number of satellites used in the solution as a function of time. The number of GPS satellites, GLONASS satellites, and the total number of satellites are distinguished with separate lines. |
| **Combined Separation** | Plots the north, east, and height position difference between any two solutions loaded into the project. This is most often the forward and reverse processing results, unless other solutions have been loaded from the Combine Solutions dialog. Plotting the difference between forward and reverse solutions can be very helpful in quality checking. When processing both directions, no information is shared between forward and reverse processing. Thus both directions are processed independently of each other. When forward and reverse solutions agree closely, it helps provide confidence in the solution. To a lesser extent, this plot can also help gauge solution accuracy. |
| **PDOP** | PDOP is a unit less number which indicates how favorable the satellite geometry is to 3D positioning accuracy. A strong satellite geometry, where the PDOP is low, occurs when satellites are well distributed in each direction (north, south, east and west) as well as directly overhead. Values in the range of 1-2 indicate very good satellite geometry, 2-3 are adequate in the sense that they do not generally, by themselves, limit positioning accuracy. Values between 3 and 4 are considered marginal, and values approaching or exceeding 5 can be considered poor. PDOP spikes can occur on aircraft turns were the antenna angle is unfavorable, these spikes while aesthetically unfavorable do not generally reduce the accuracy of the acquired data. |

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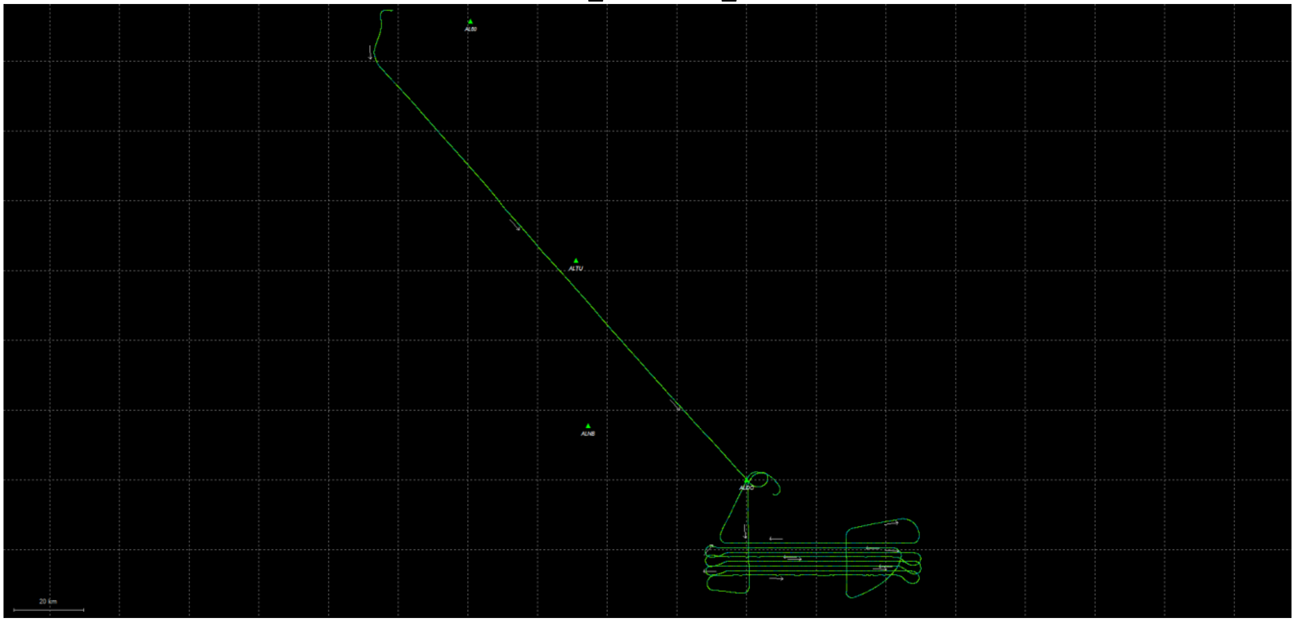

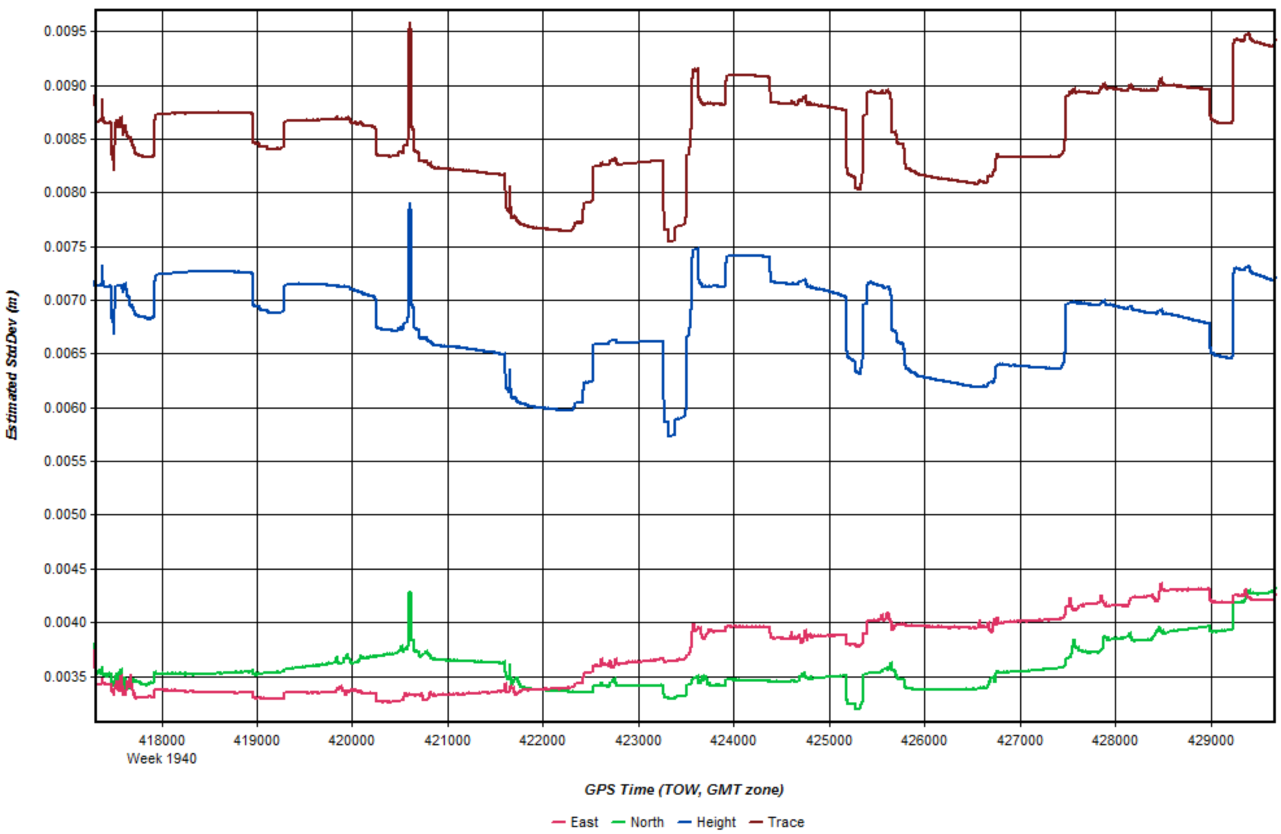

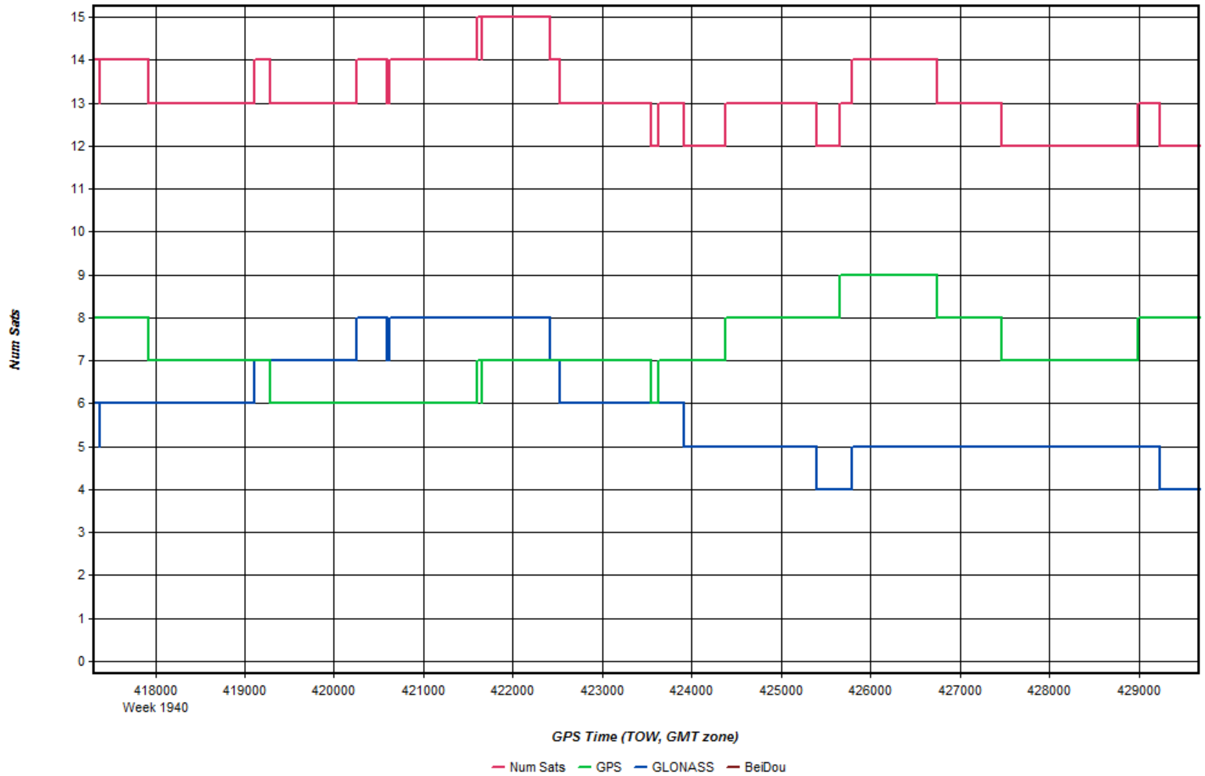
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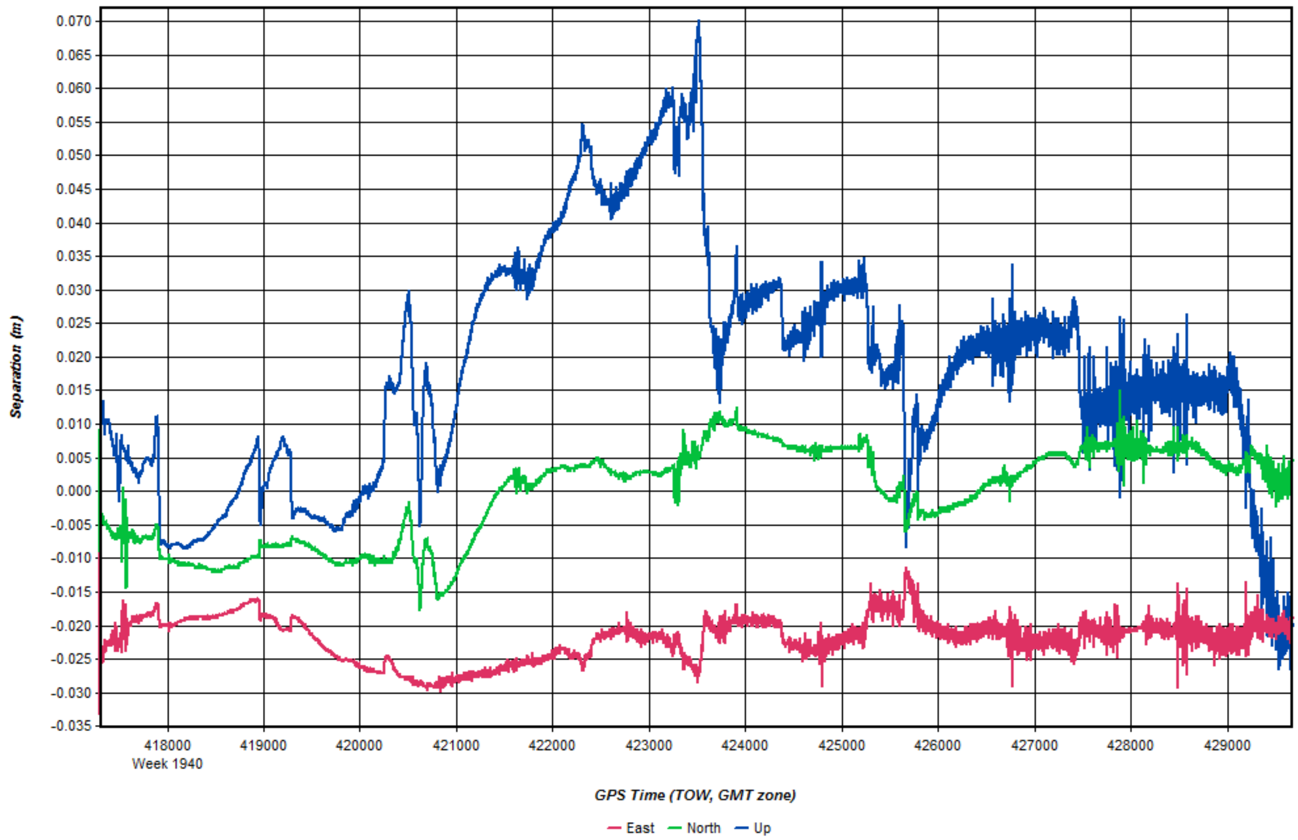
Num Sats
GPS
GLONASS
BeiDou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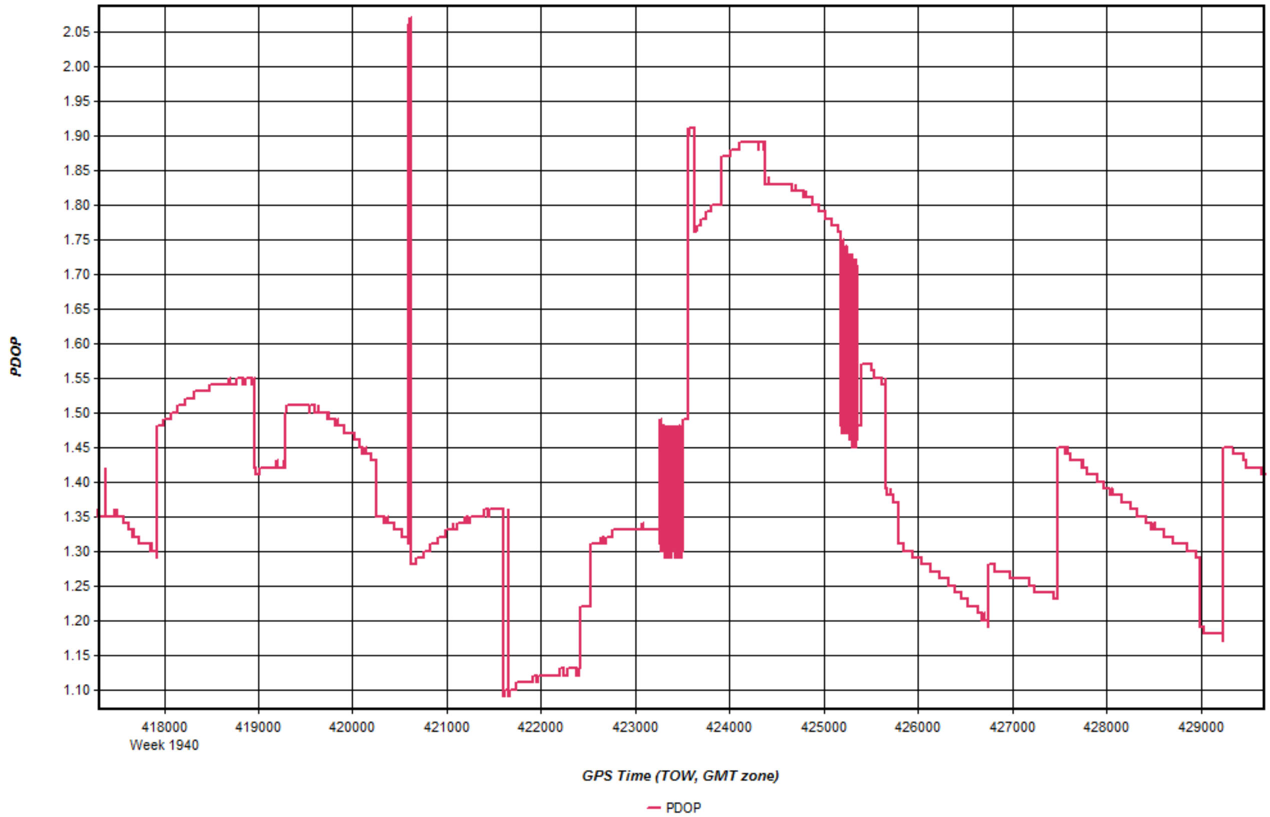
East
North
Up

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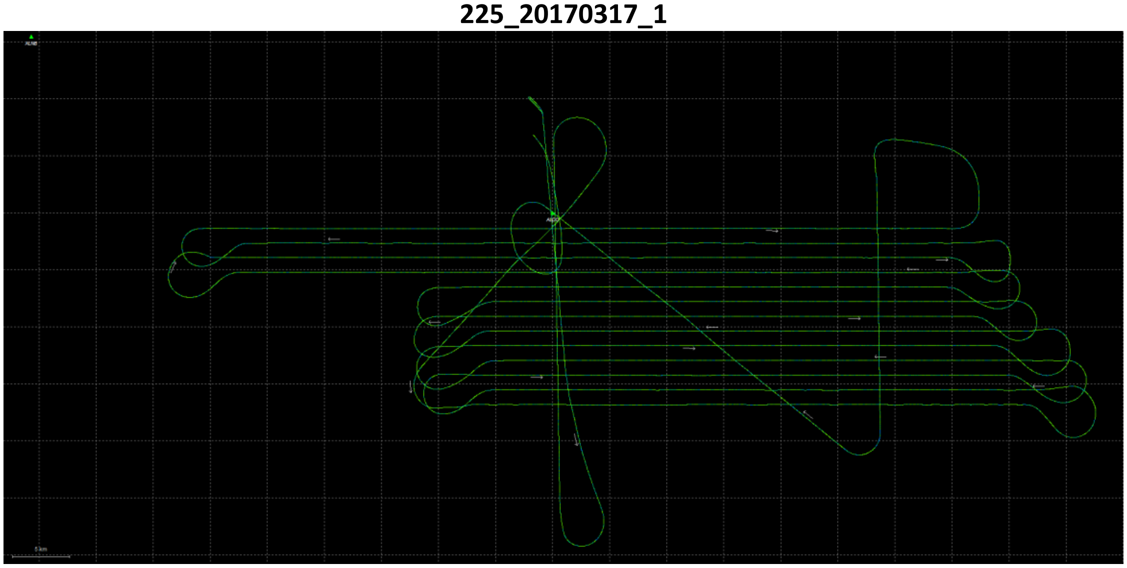

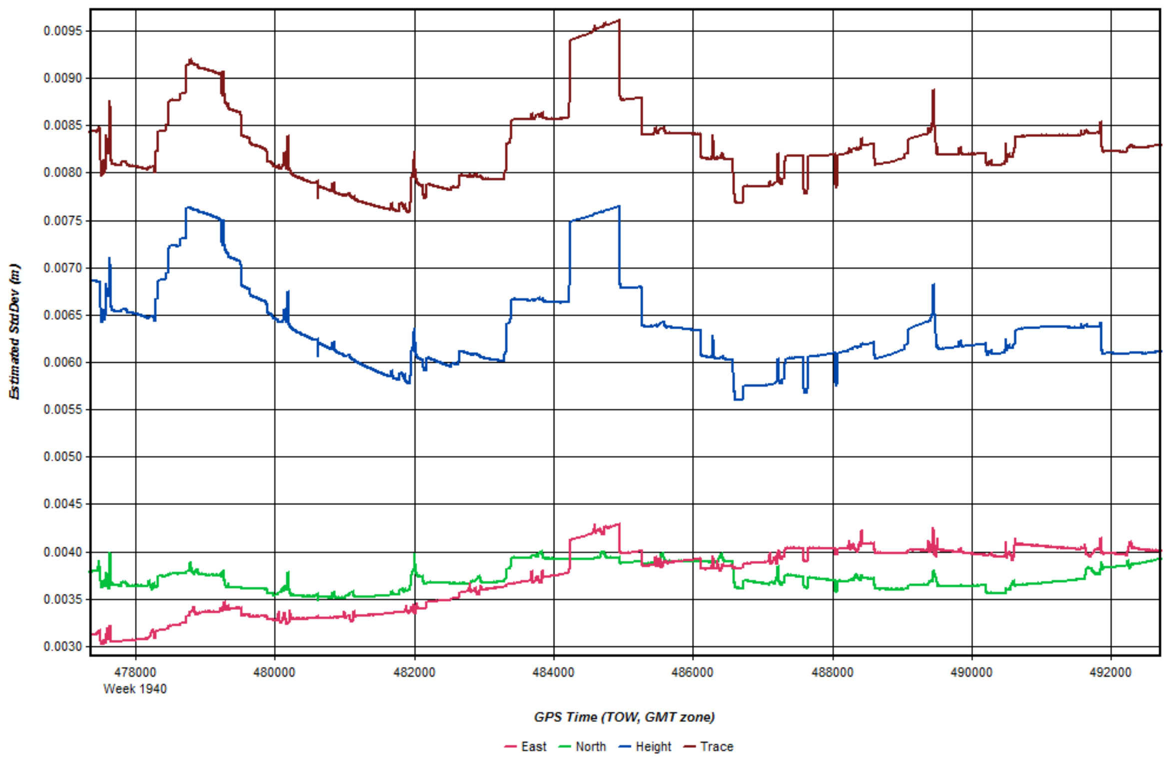
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0.0040
0.0035
0.0030
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Week 1940
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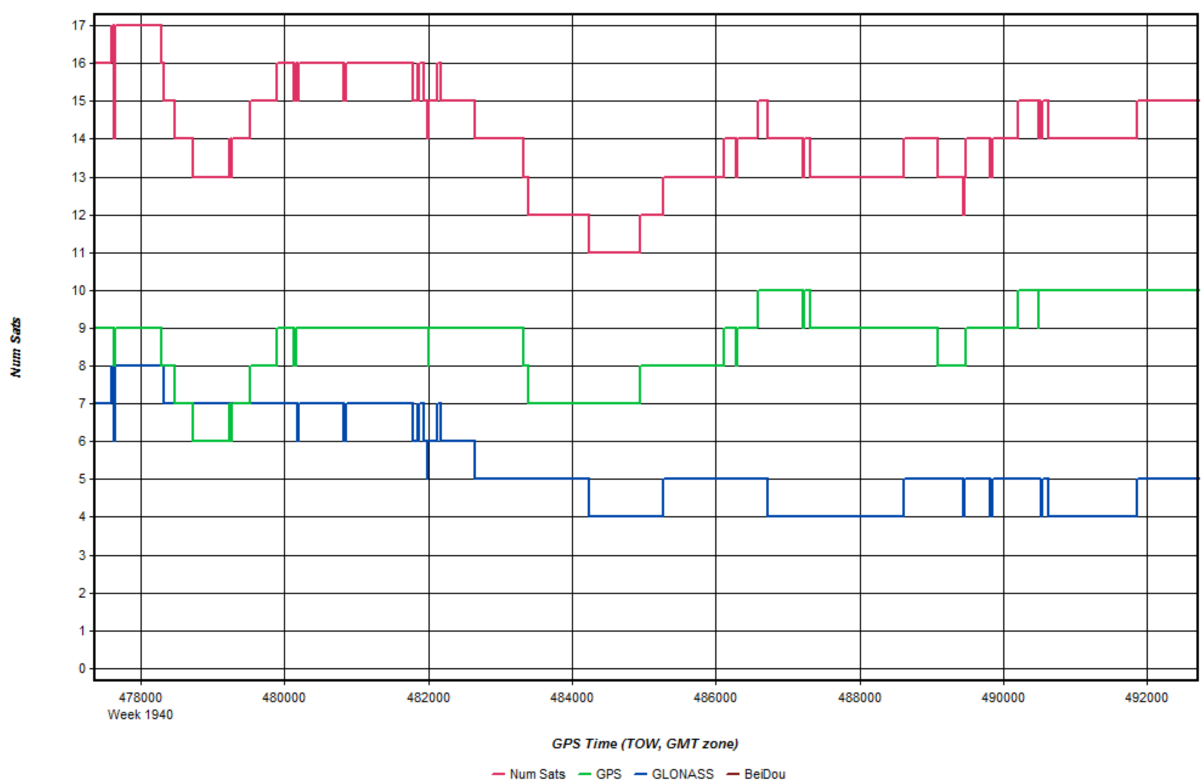
482000
484000
486000
488000
490000
492000
GPS Time (TOW, GMT zone)
East
North
Height
Trace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Week 1940
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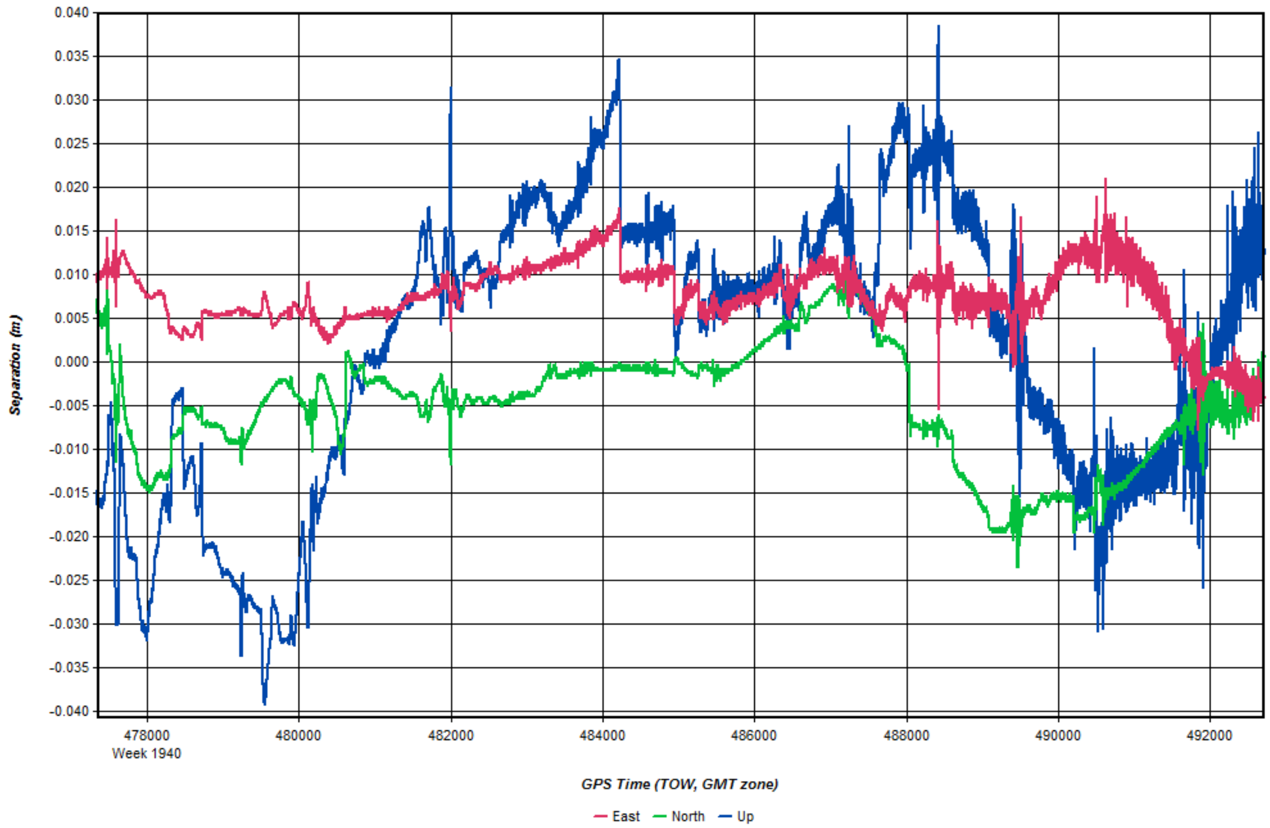
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou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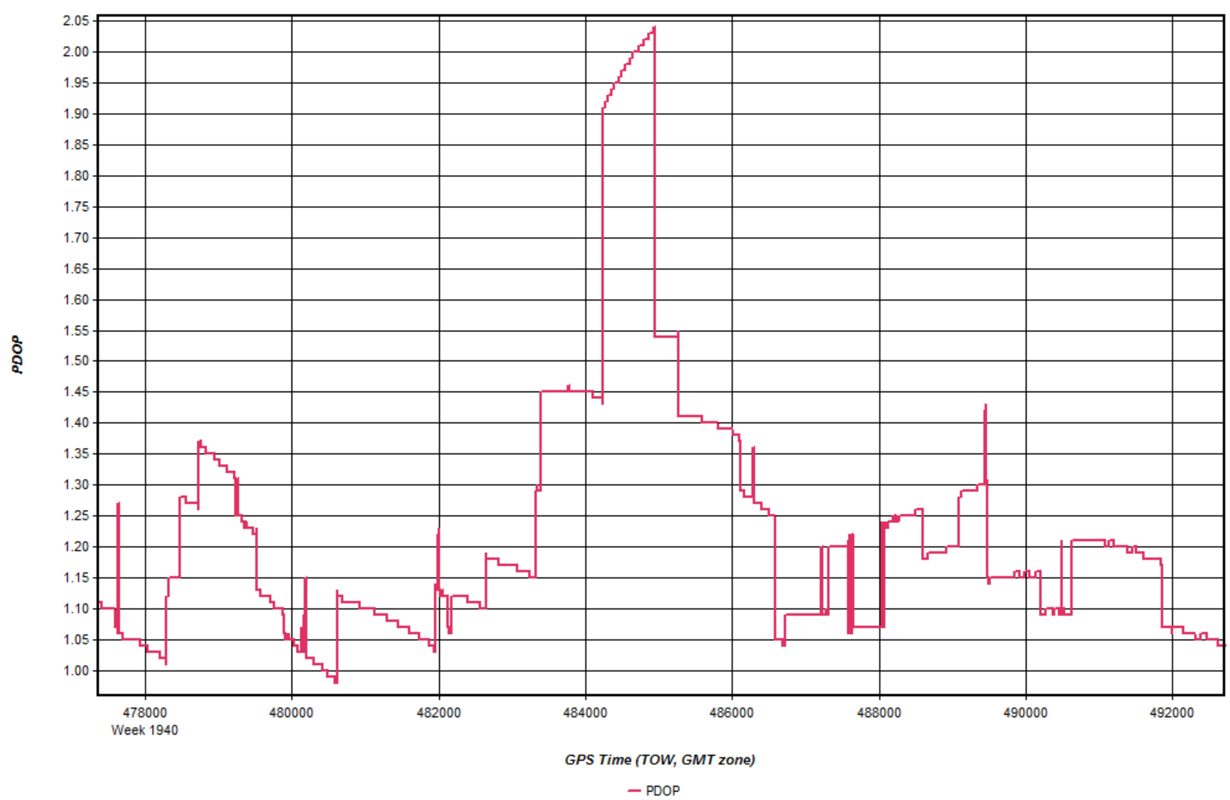
Week 1940
East
North
Up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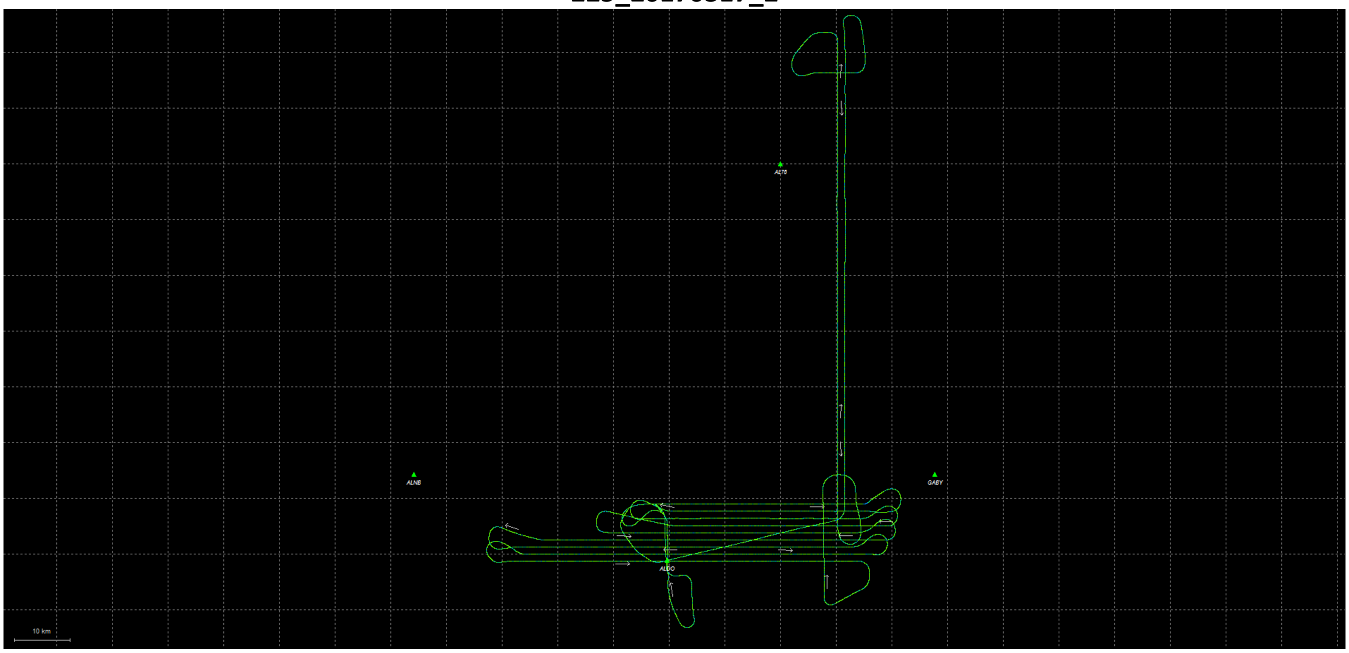

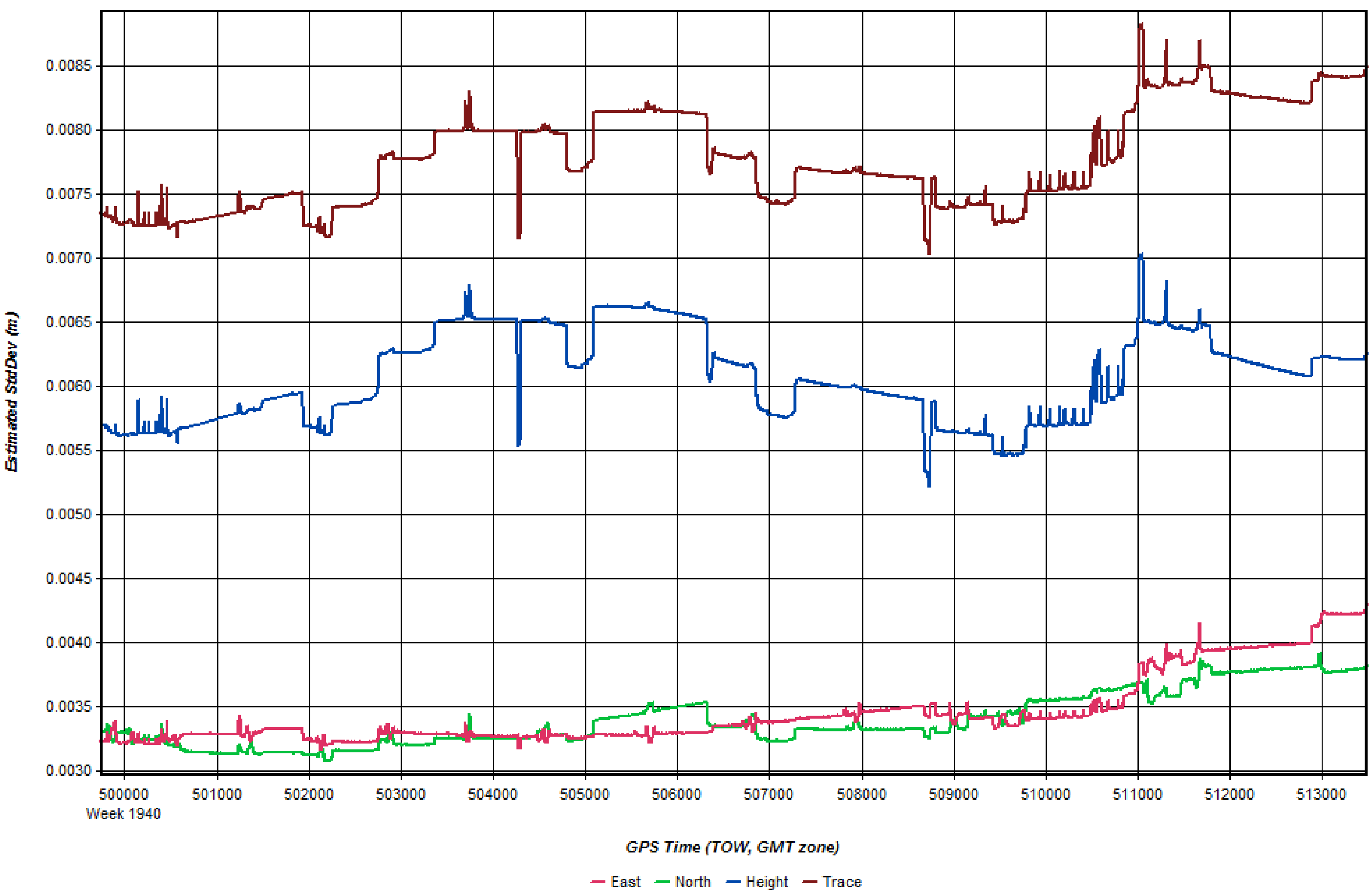

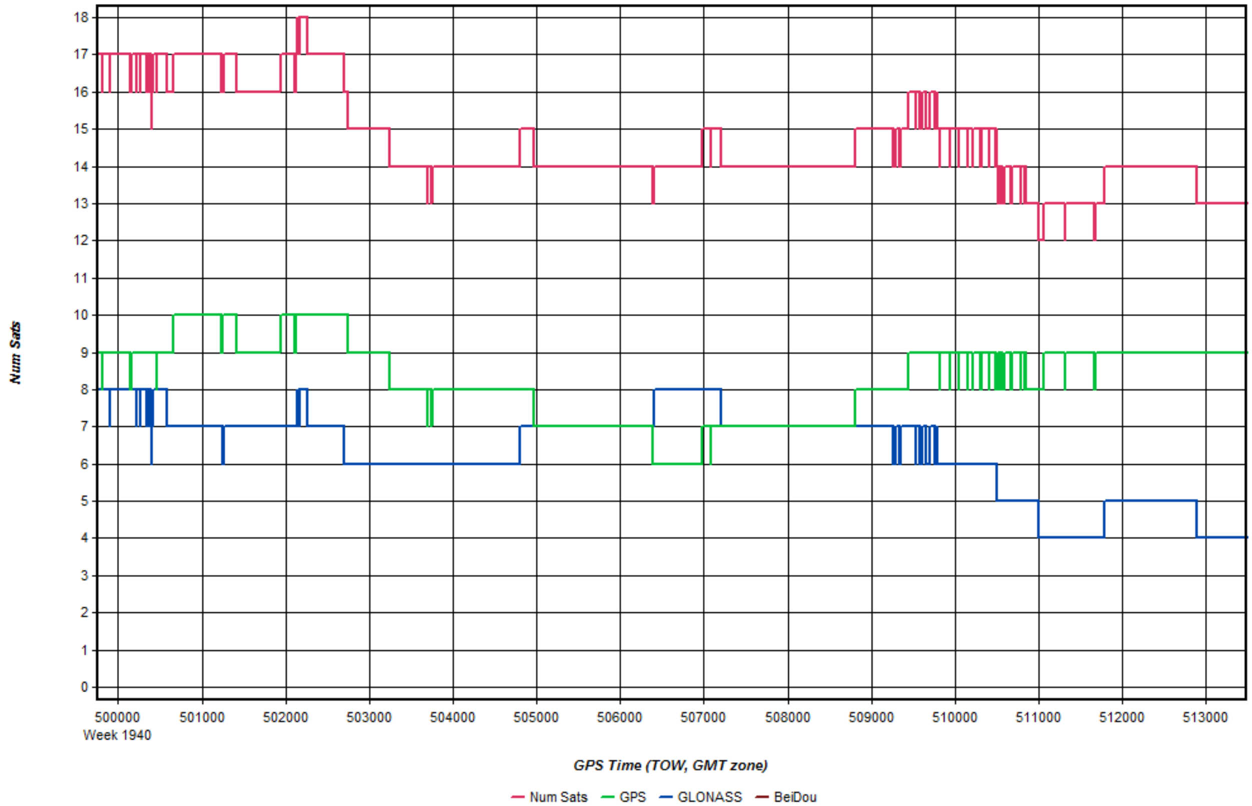
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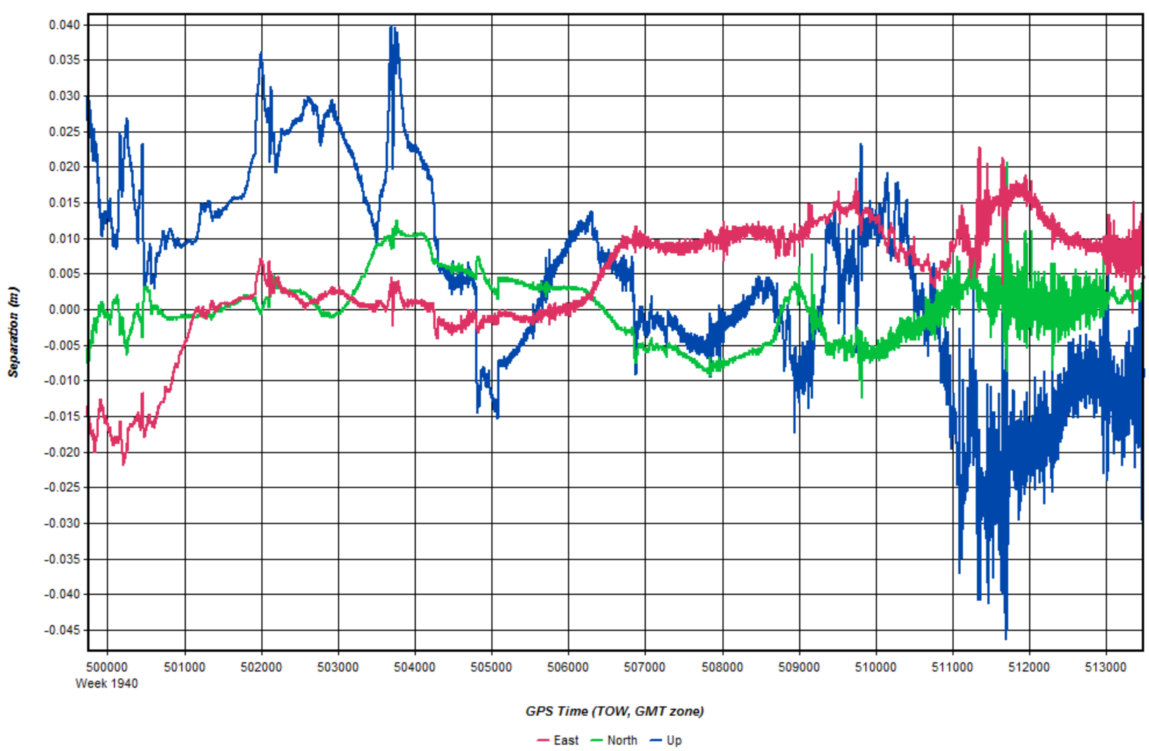
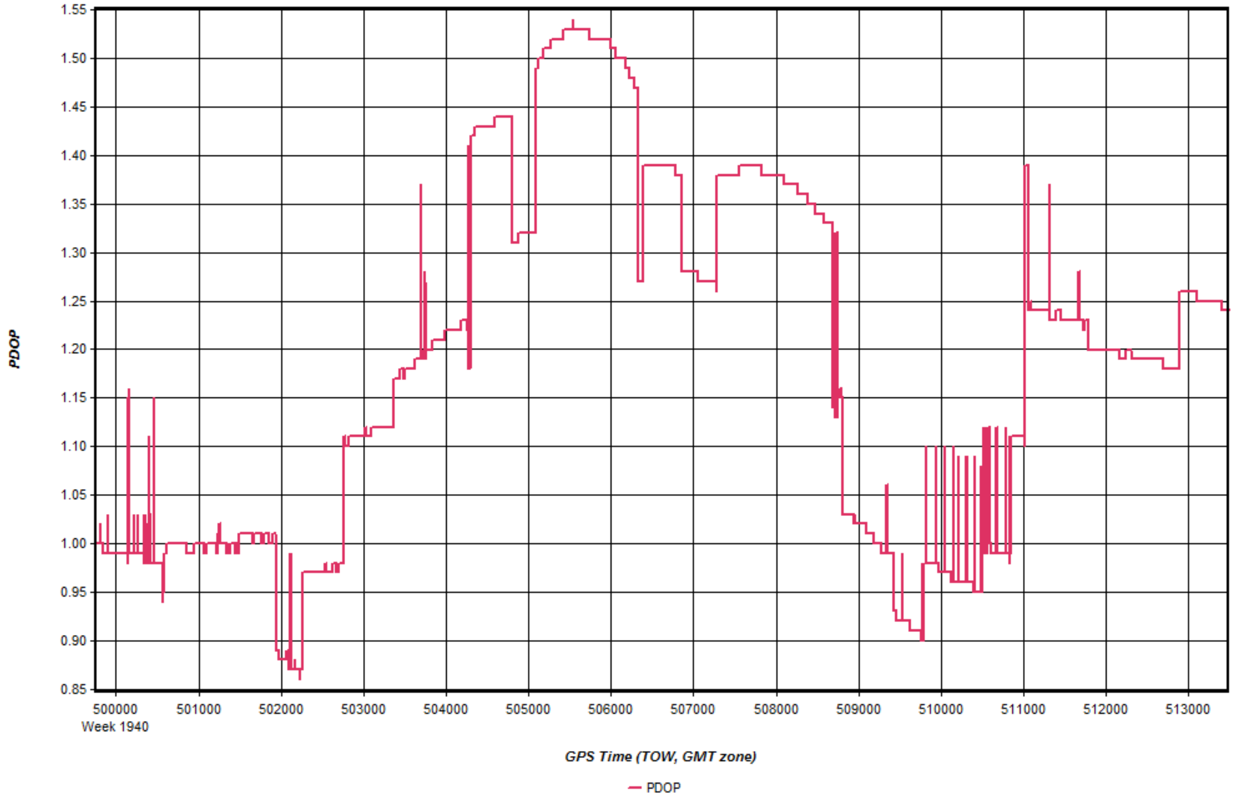
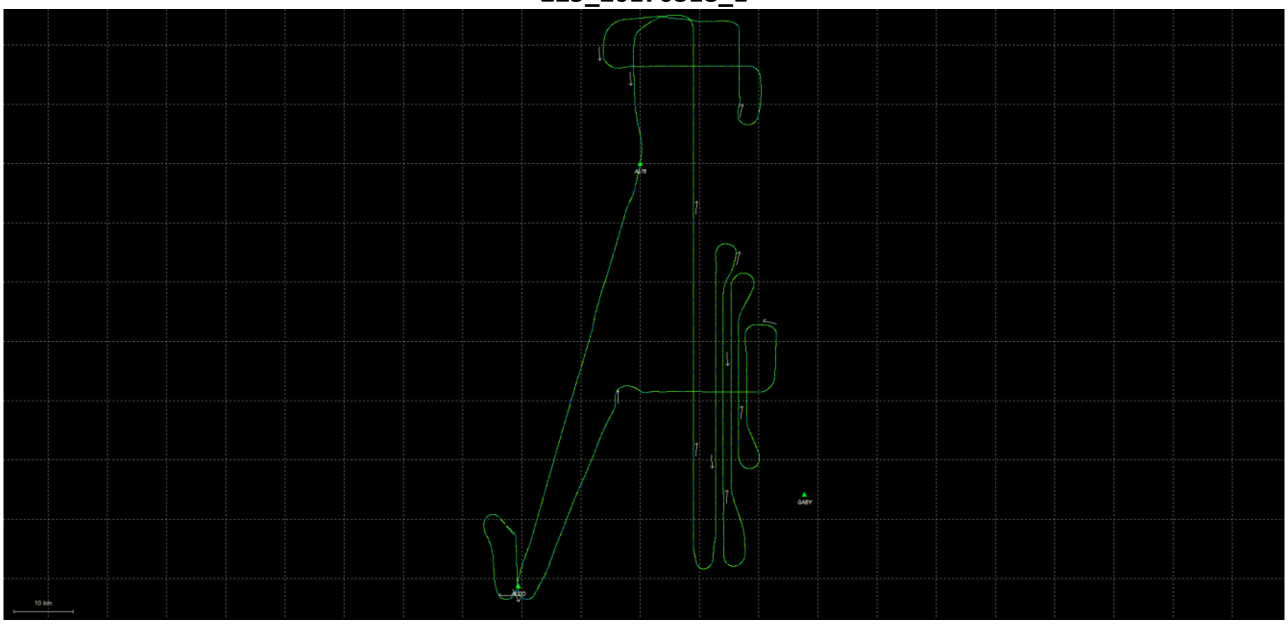
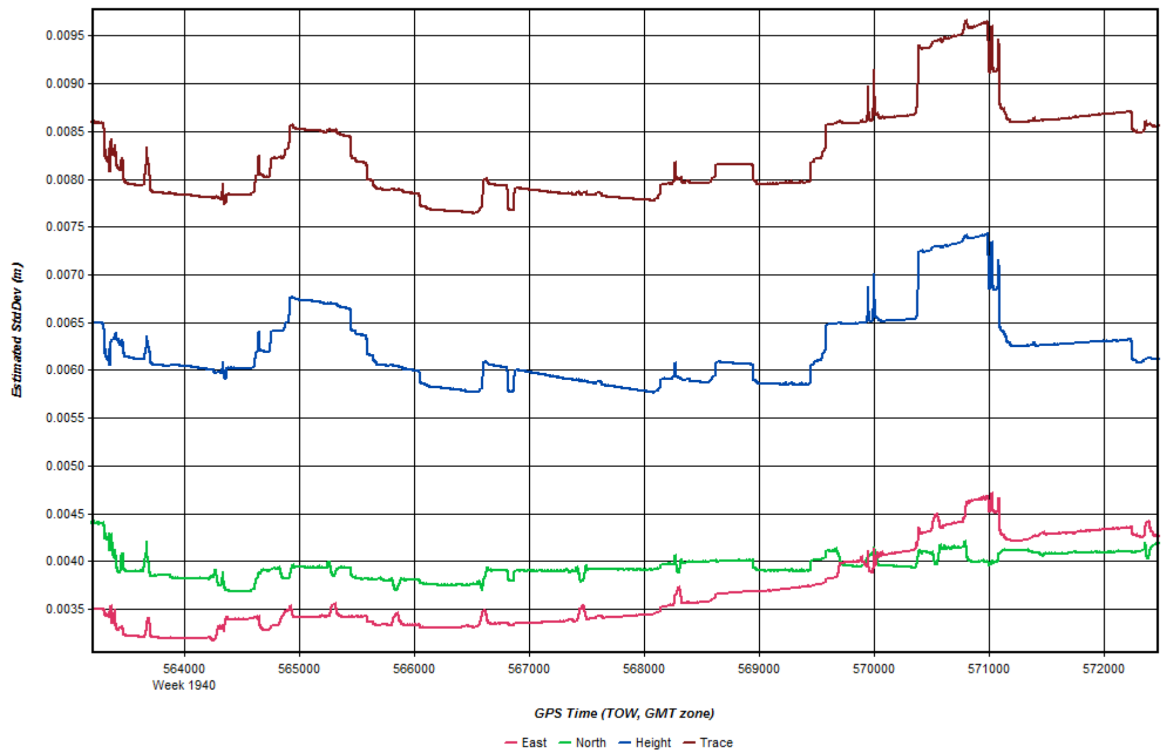
Week 1940
Num Sats
GPS
GLONASS
BeiDou

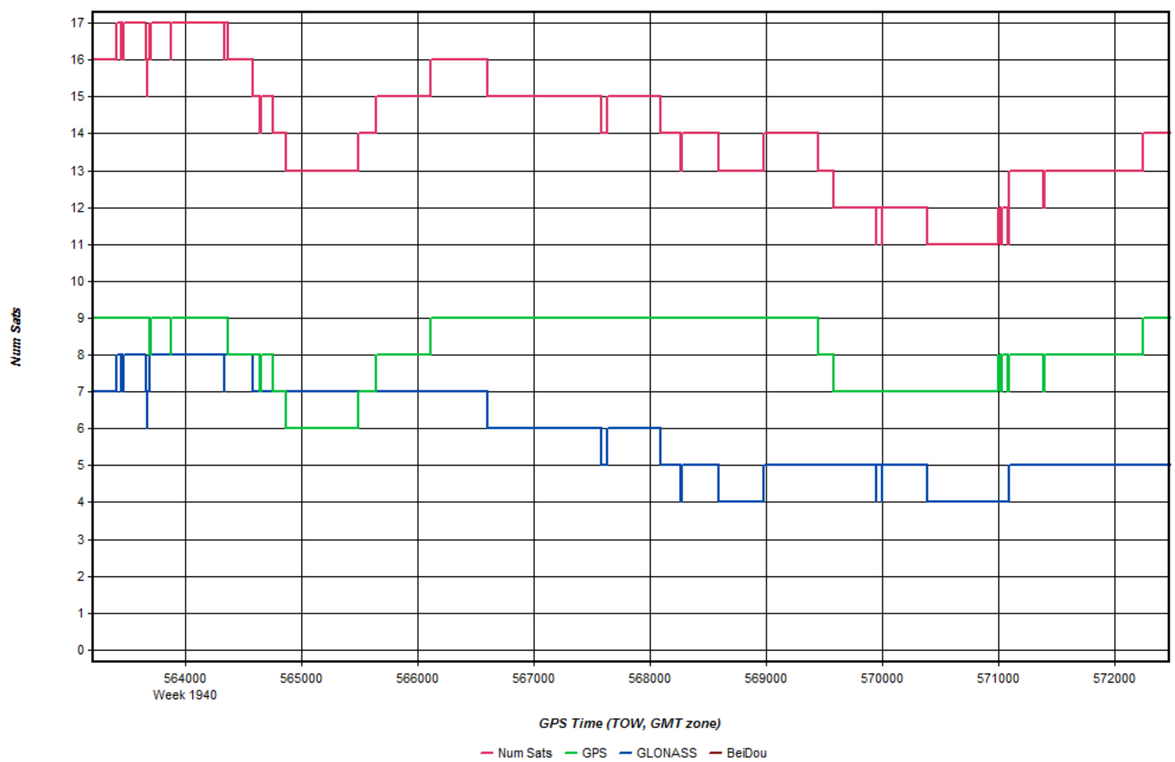

Separation (m)
GPS Time (TOW, GMT zone)
Week 1940
East
North
Up

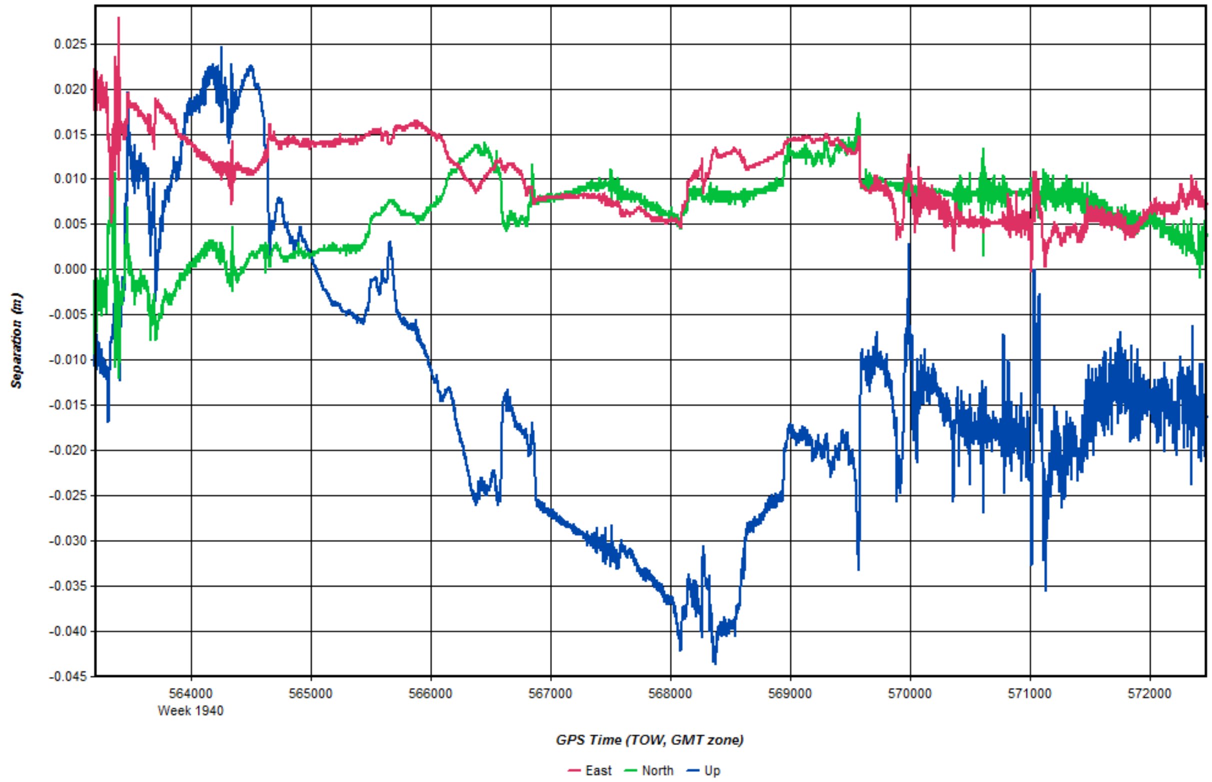


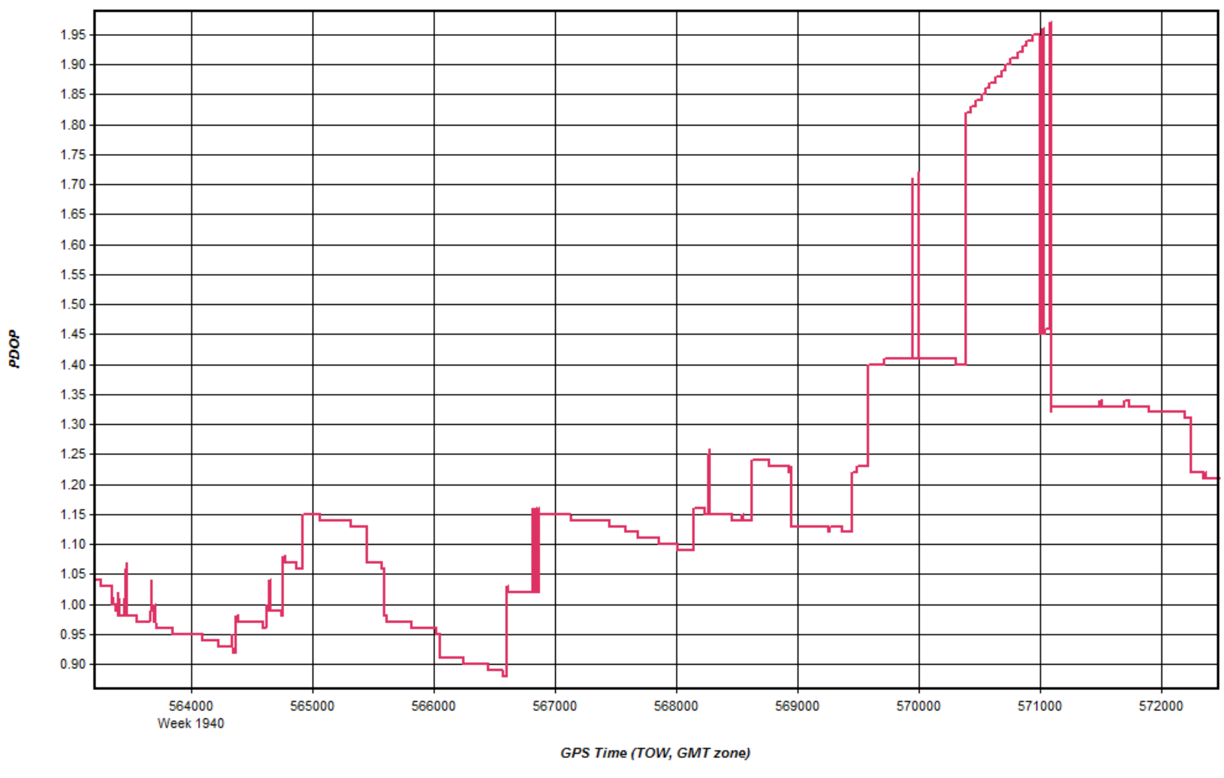

**225_20170318_1**



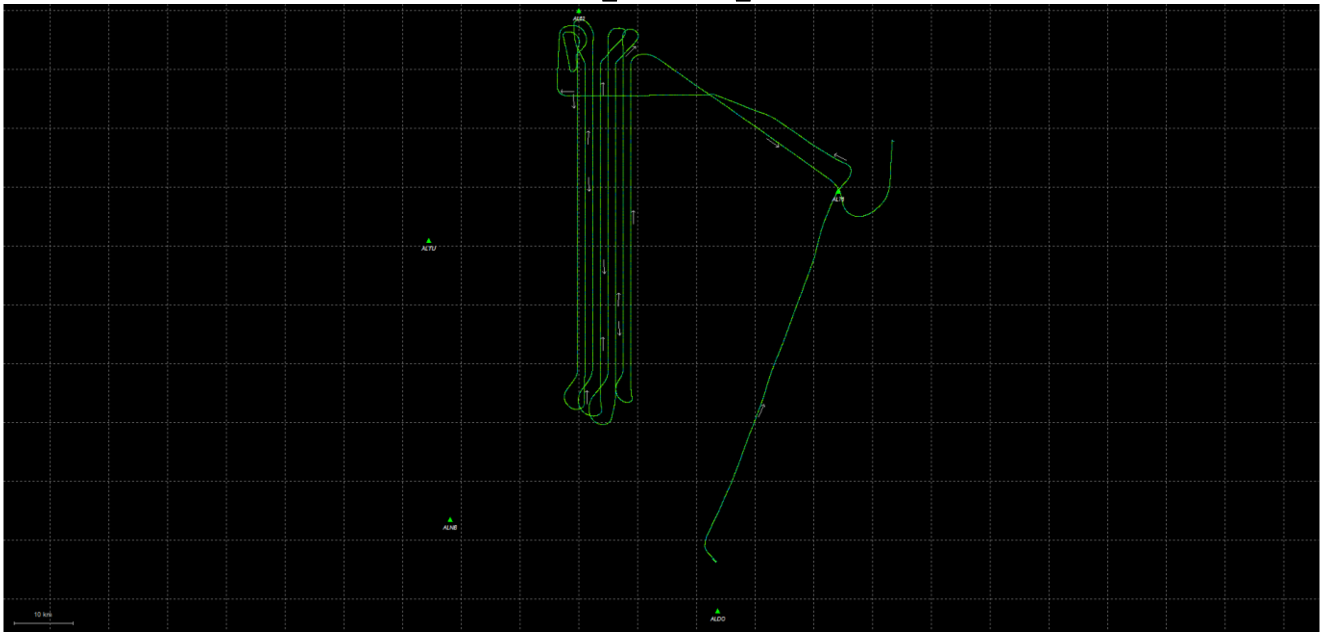

0.0095
0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
0.0035
Estimated StdDev (m)
564000
Week 1940
565000
566000
567000
568000
569000
570000
571000
572000
GPS Time (TOW, GMT zone)
East
North
Height
Trace

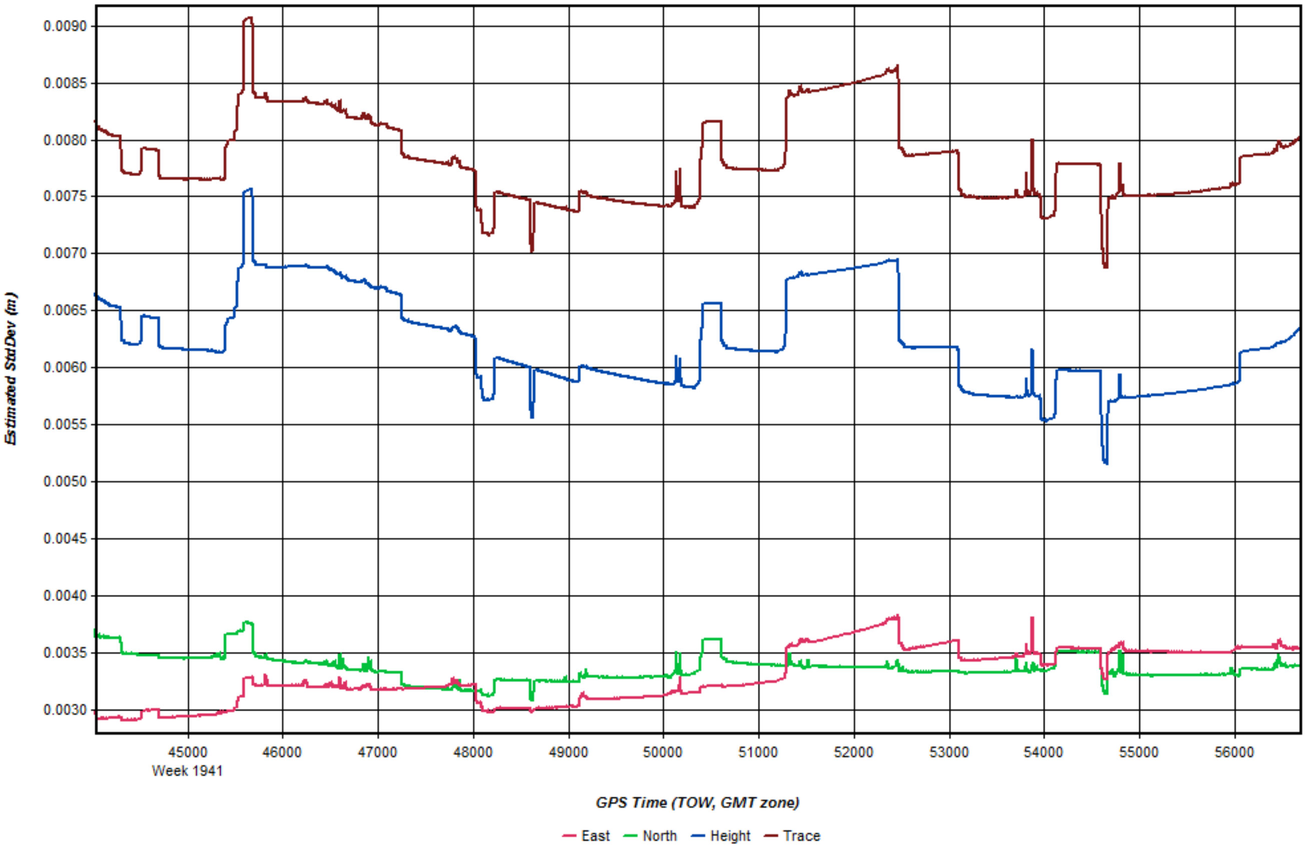

17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Num Sats
564000
Week 1940
565000
566000
567000
568000
569000
570000
571000
572000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

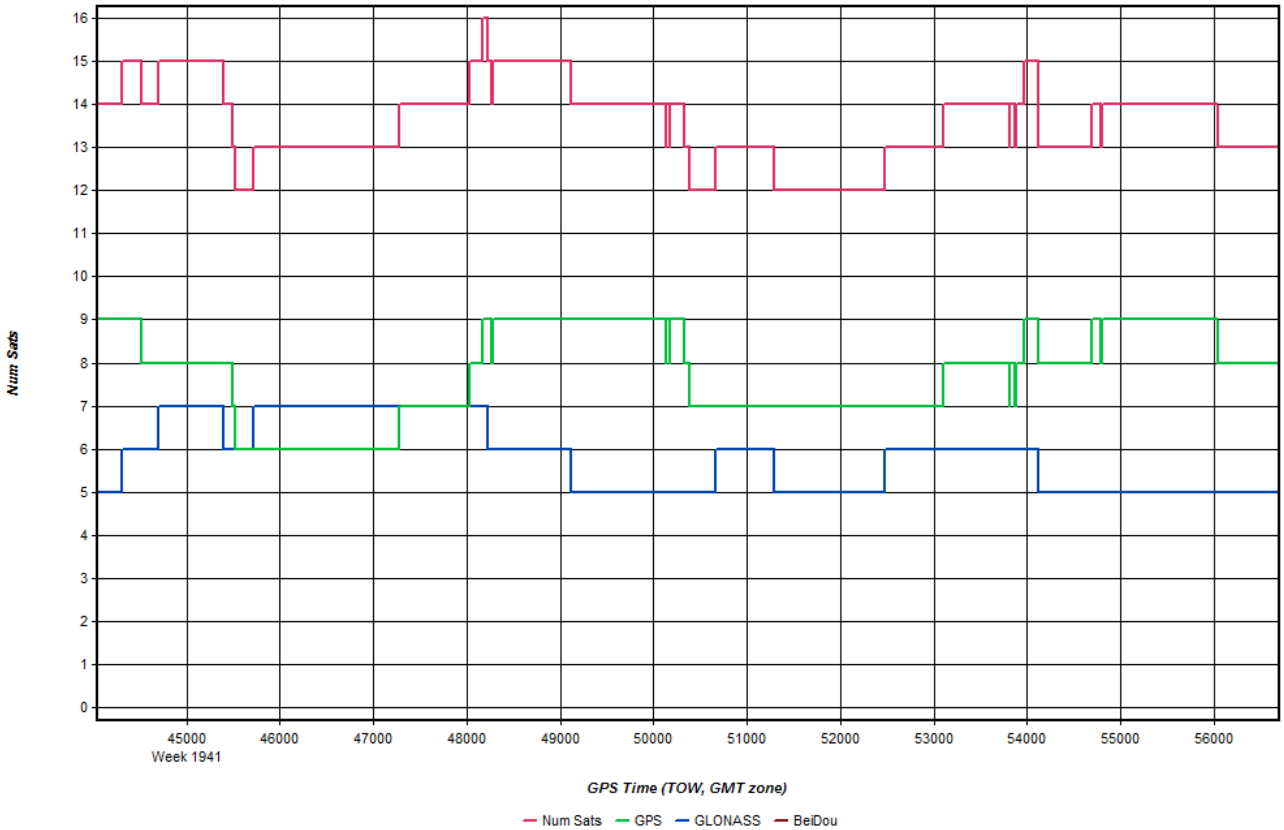

Separation (m)
GPS Time (TOW, GMT zone)
Week 1940
East
North
Up

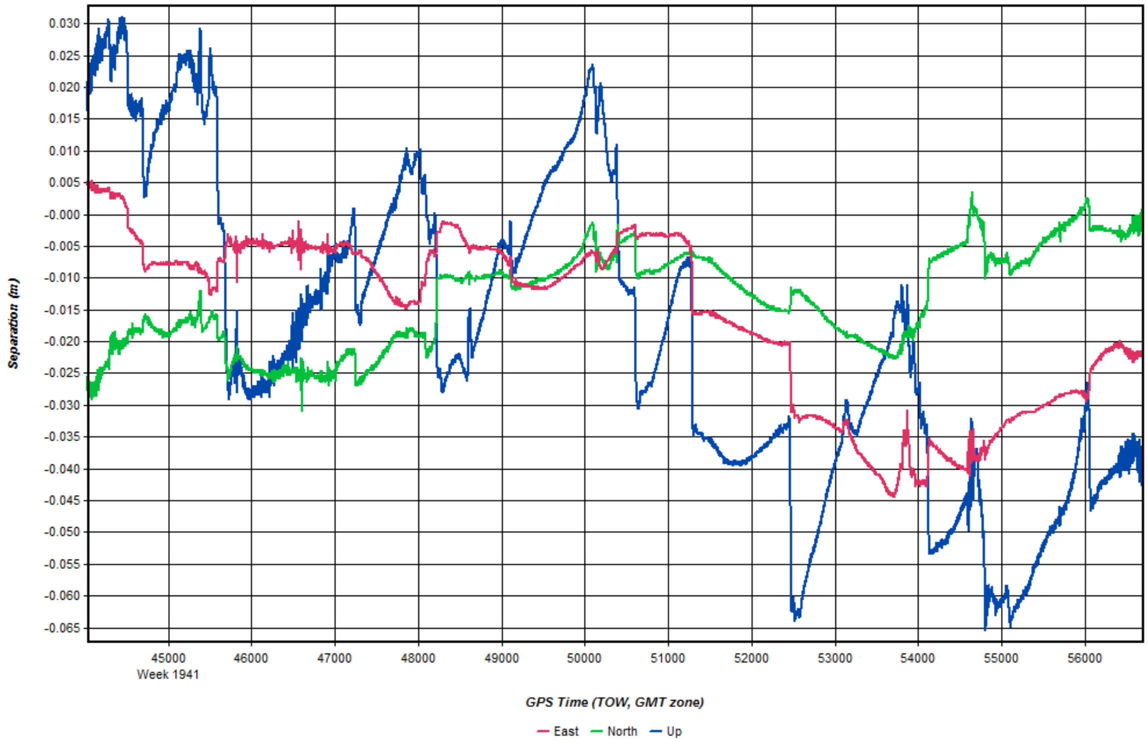

PDOP
GPS Time (TOW, GMT zone)
Week 1940
PDOP

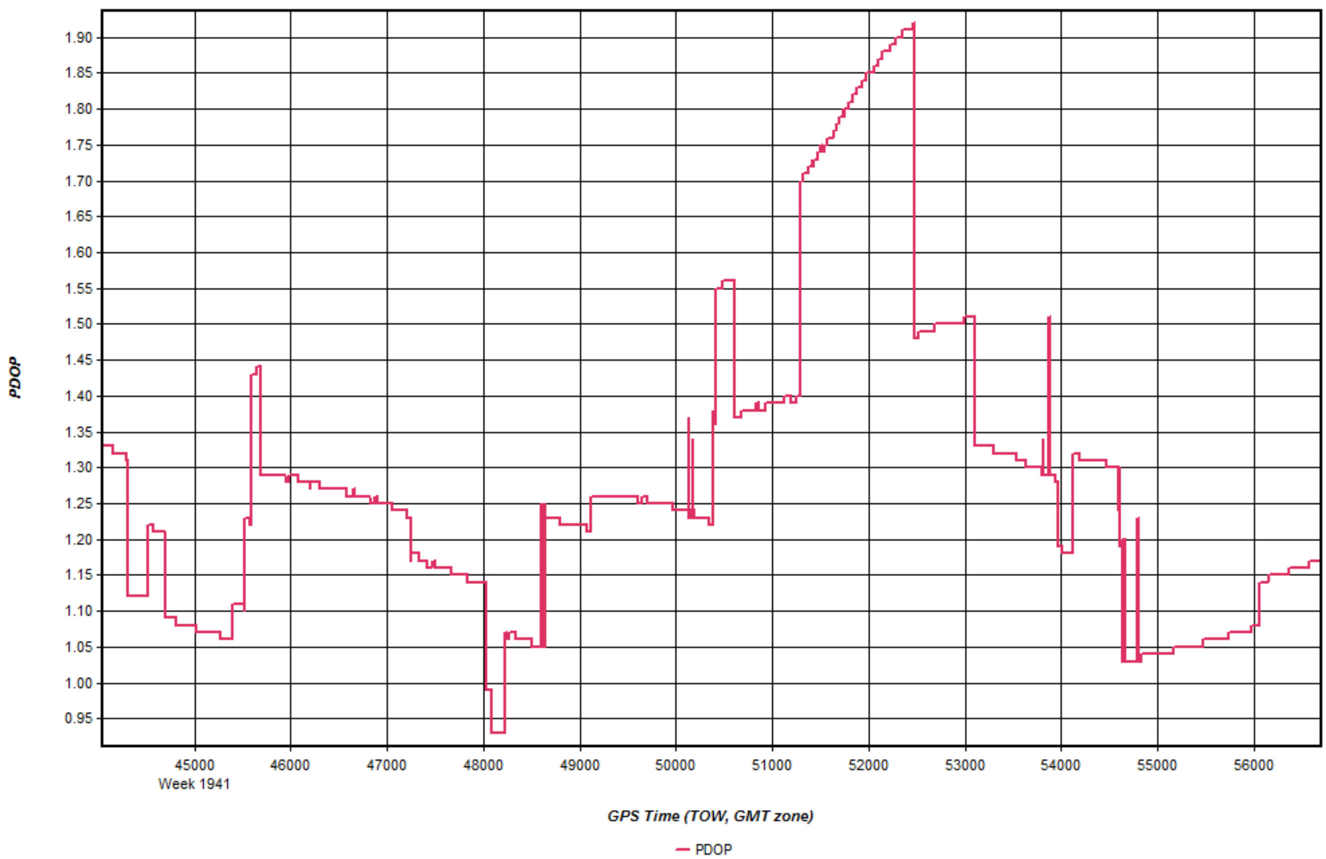
**225_20170319_1**



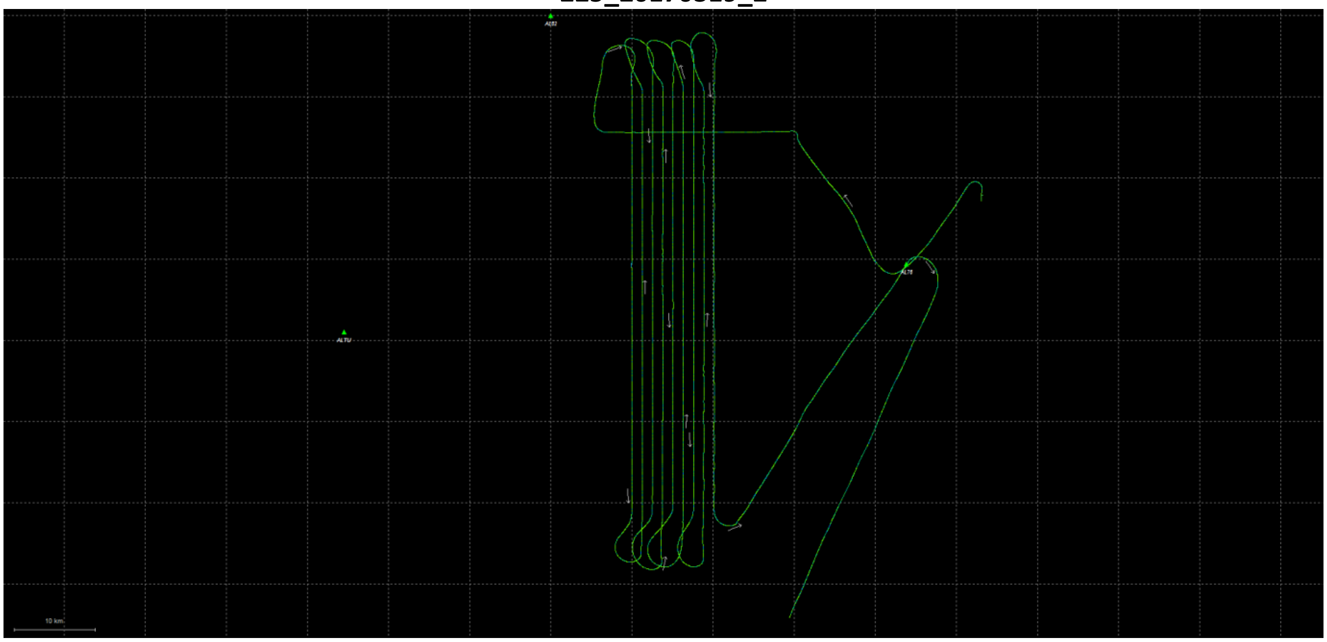


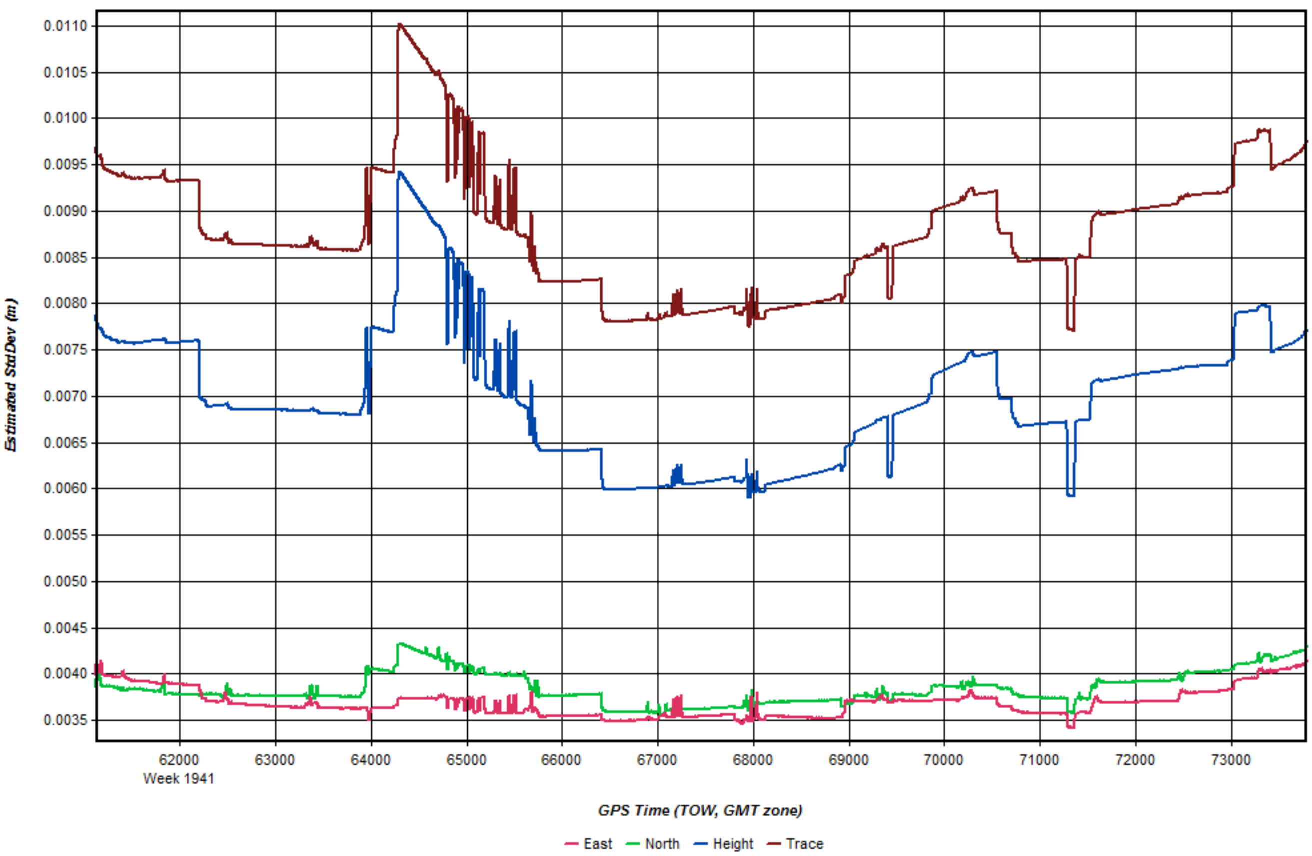

16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Num Sats
45000
Week 1941
46000
47000
48000
49000
50000
51000
52000
53000
54000
55000
56000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

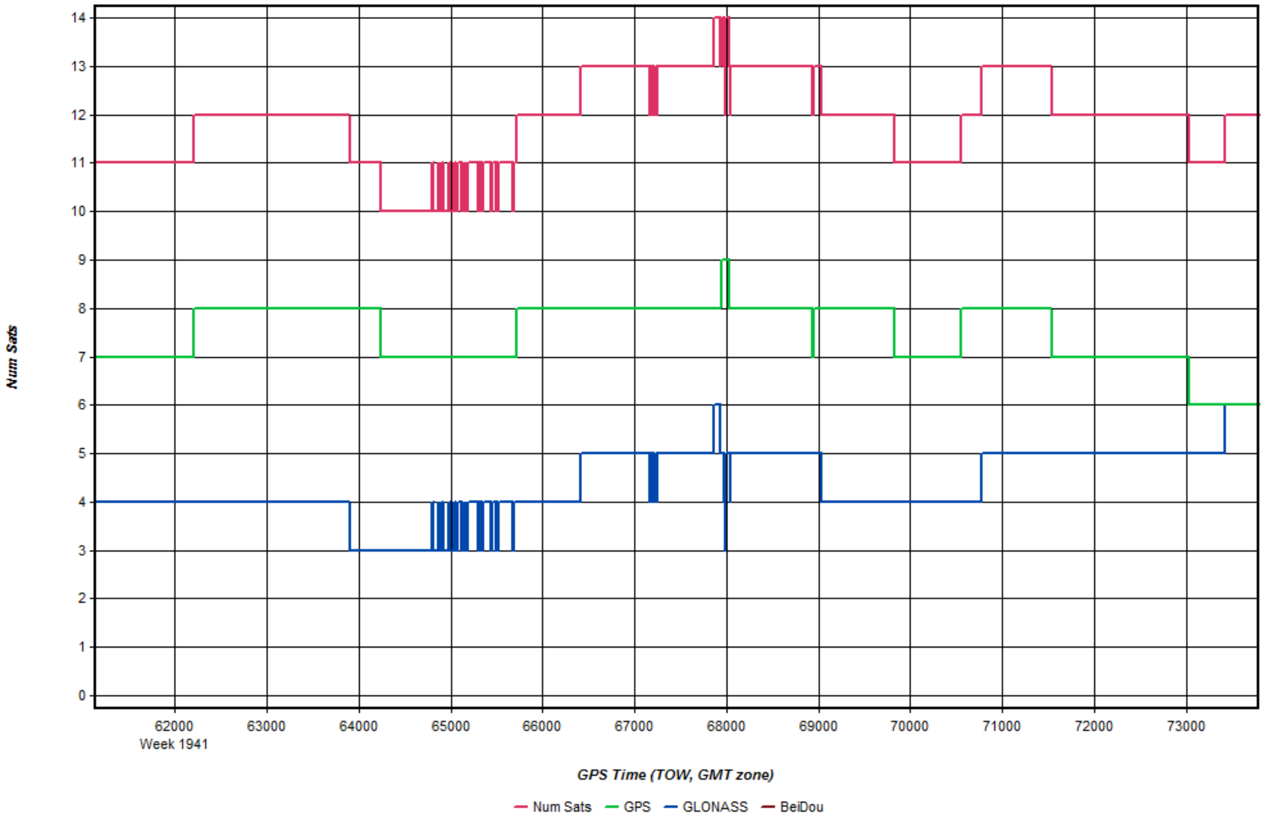

Separation (m)
0.030
0.025
0.020
0.015
0.010
0.005
-0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-0.035
-0.040
-0.045
-0.050
-0.055
-0.060
-0.065
45000
Week 1941
46000
47000
48000
49000
50000
51000
52000
53000
54000
55000
56000
GPS Time (TOW, GMT zone)
East
North
Up

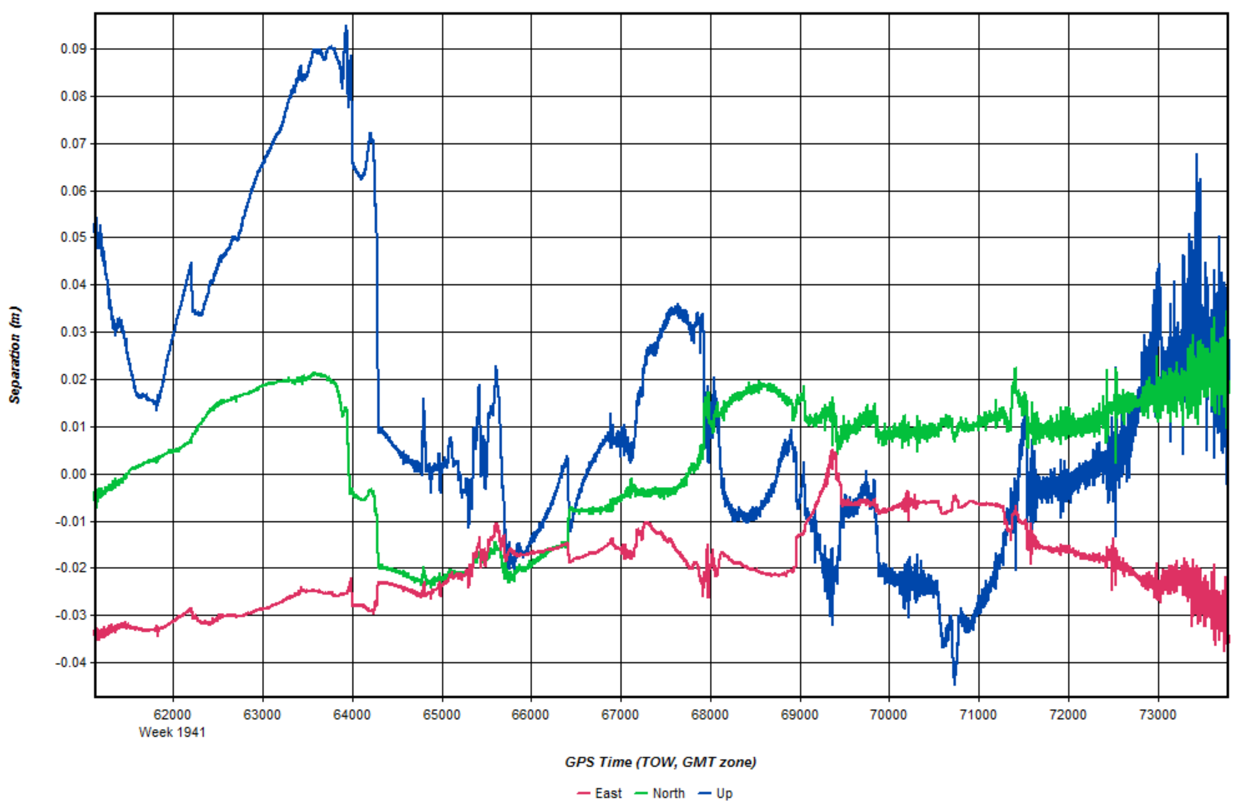

PDOP
1.90
1.85
1.80
1.75
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
45000
Week 1941
46000
47000
48000
49000
50000
51000
52000
53000
54000
55000
56000
GPS Time (TOW, GMT zone)
PDOP

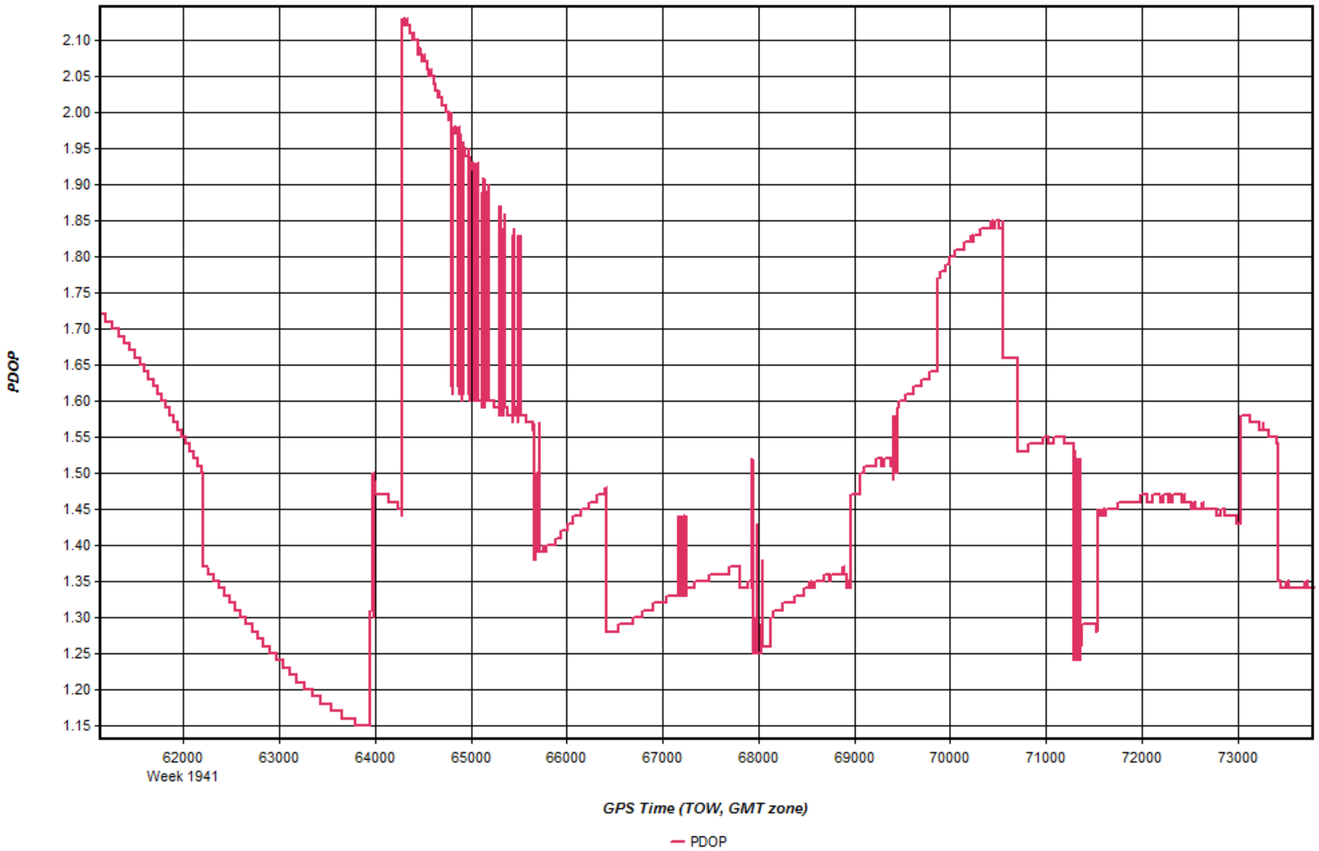
**225_20170319_2**



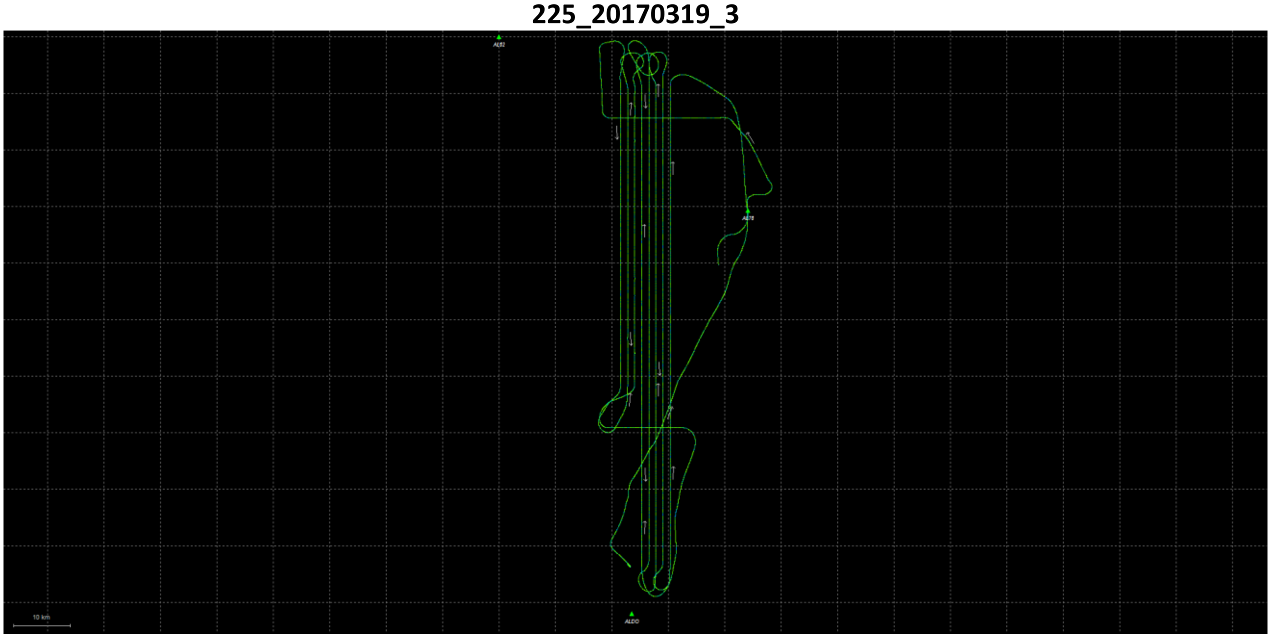


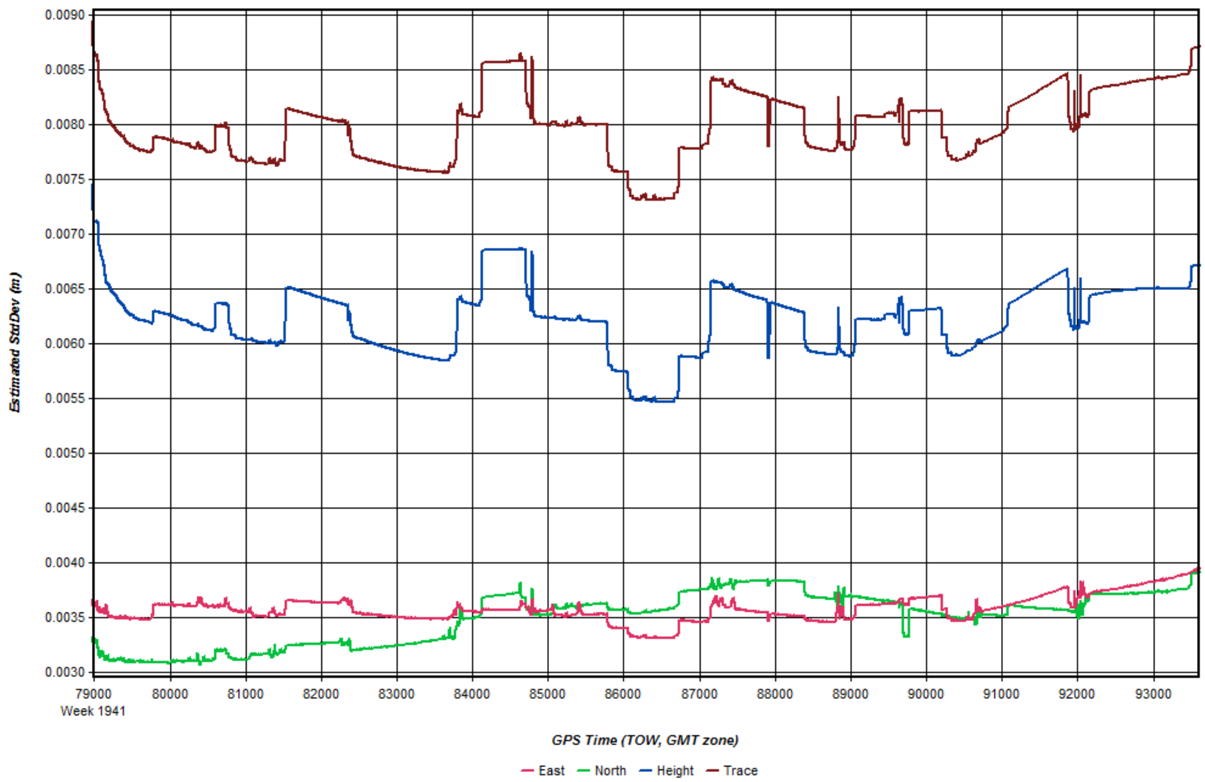

Num Sats
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
62000
Week 1941
63000
64000
65000
66000
67000
68000
69000
70000
71000
72000
73000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

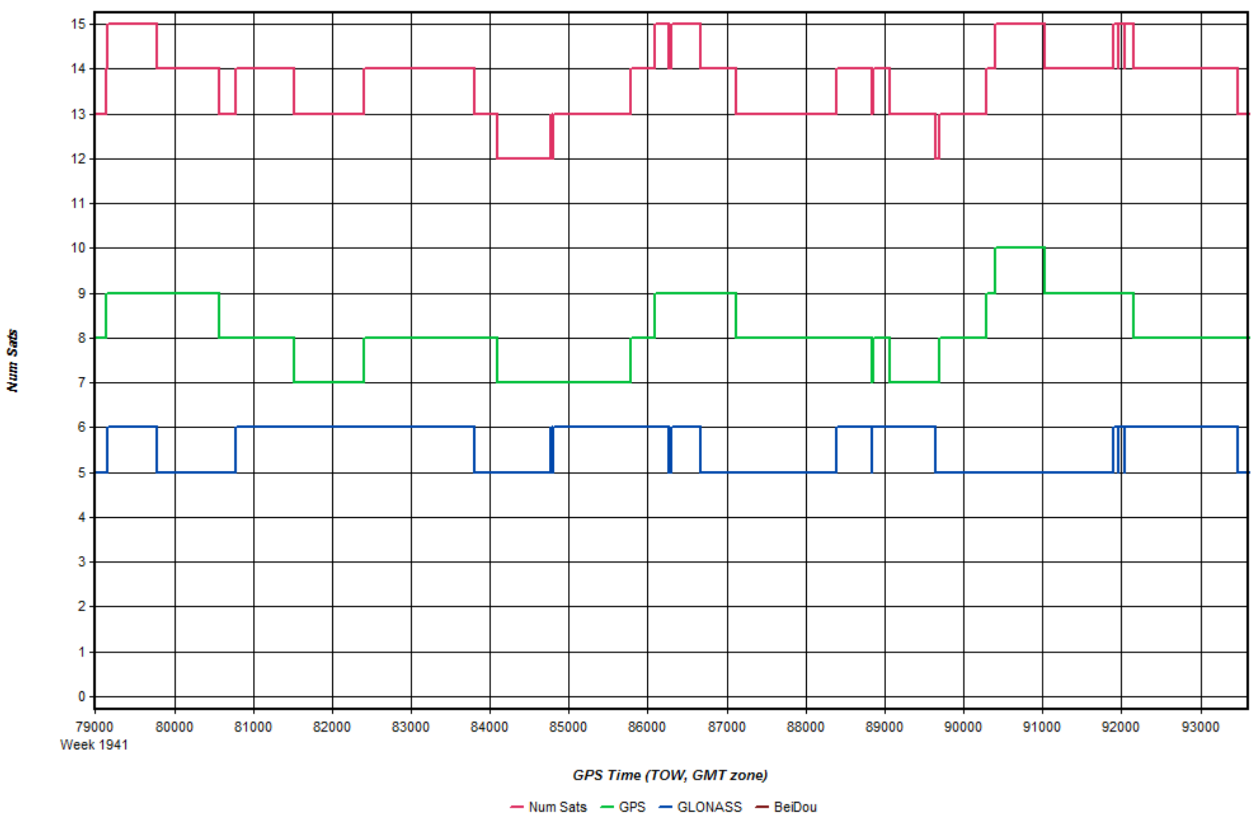

Separation (m)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
62000
Week 1941
63000
64000
65000
66000
67000
68000
69000
70000
71000
72000
73000
GPS Time (TOW, GMT zone)
East
North
Up

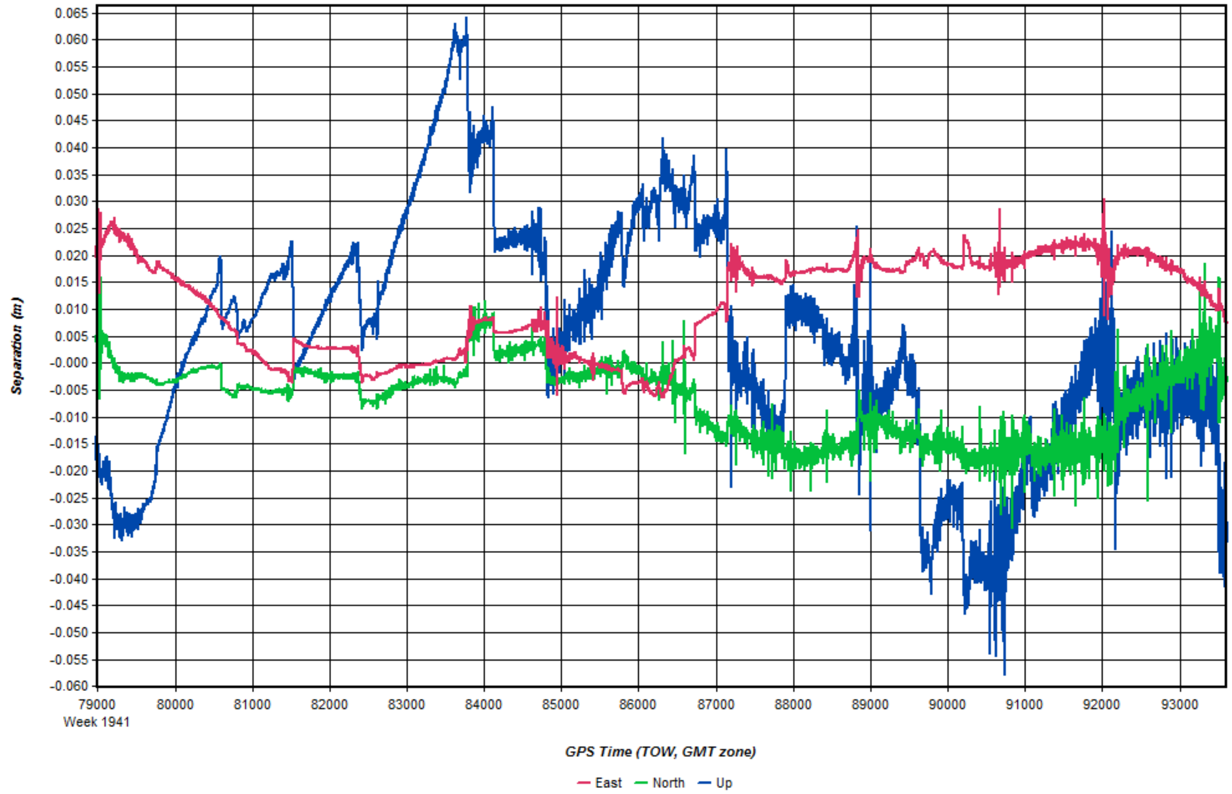


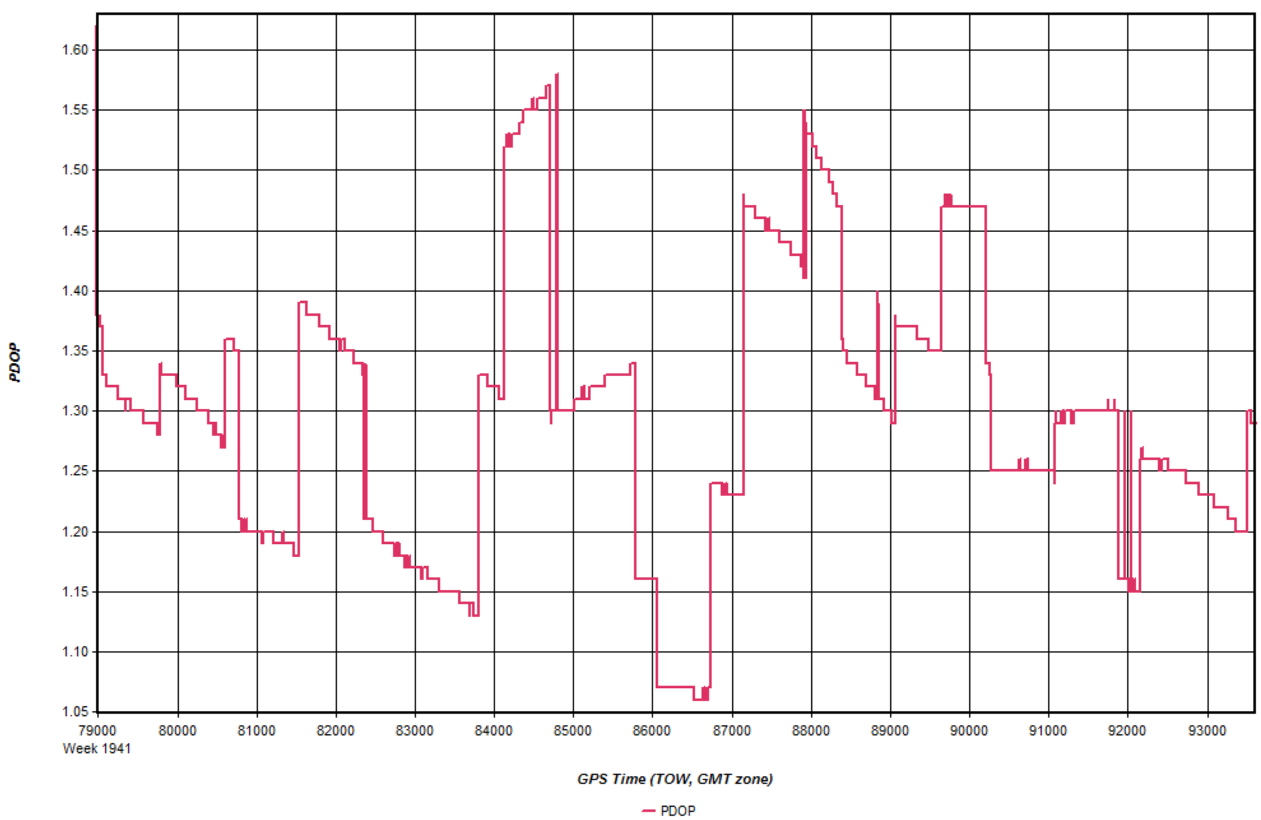

**225_20170319_3**



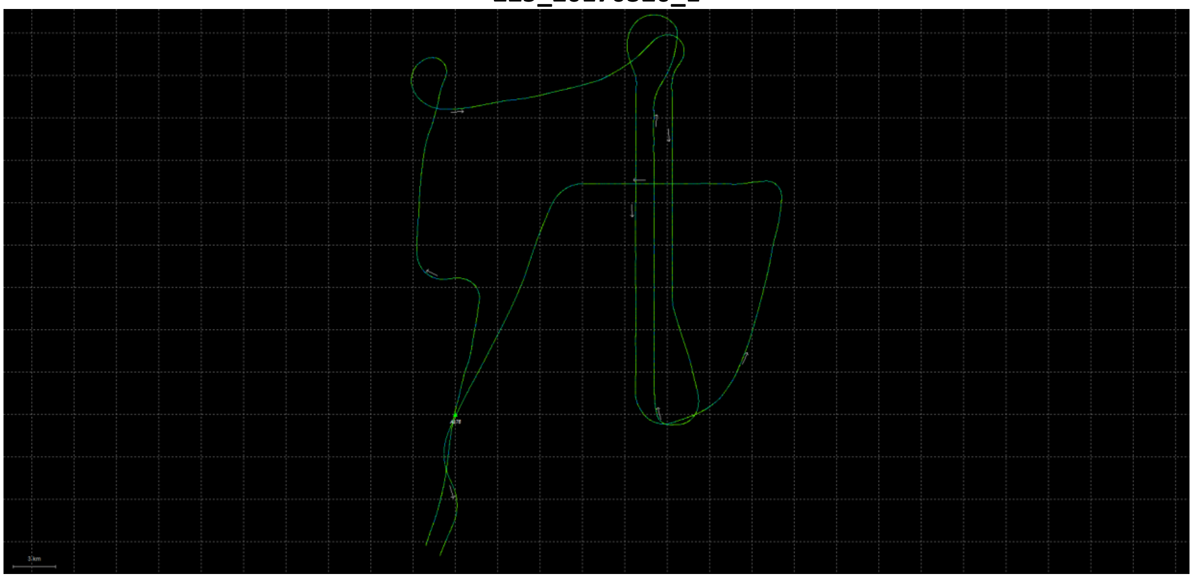

Estimated StdDev (m)
0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
0.0035
0.0030
79000
Week 1941
80000
81000
82000
83000
84000
85000
86000
87000
88000
89000
90000
91000
92000
93000
GPS Time (TOW, GMT zone)
East
North
Height
Trace

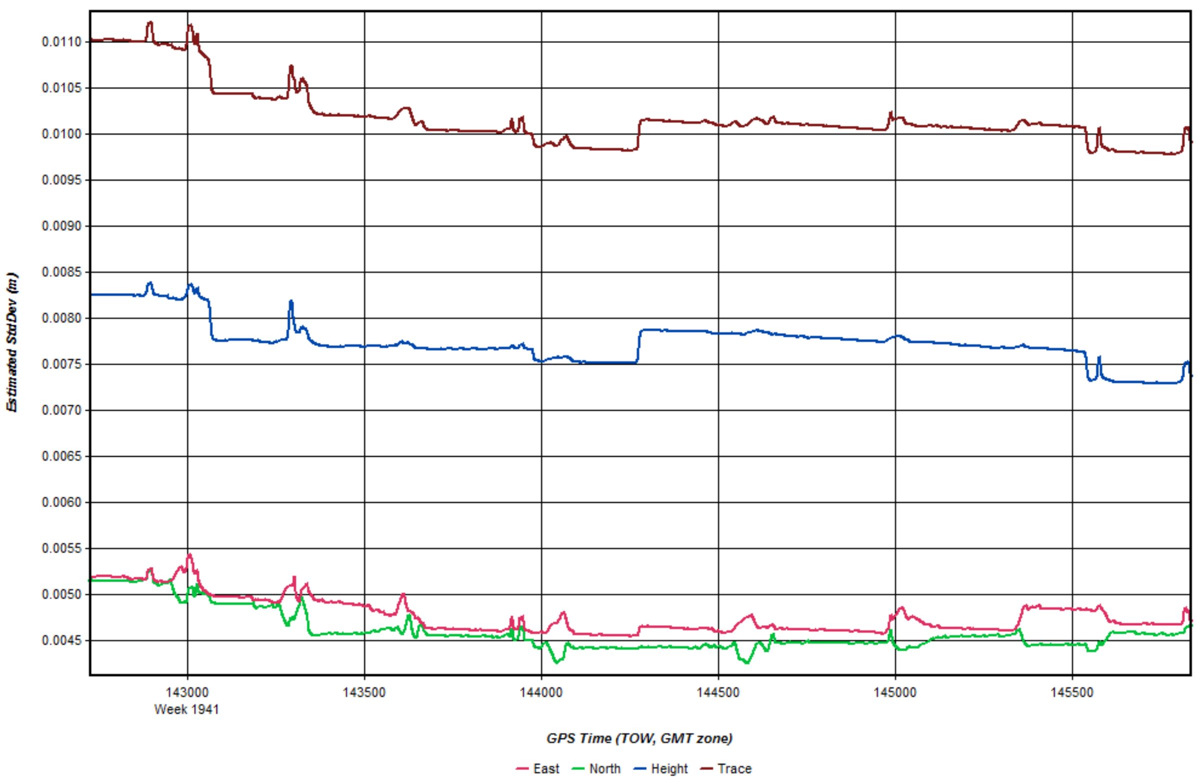

Num Sats
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
79000
Week 1941
80000
81000
82000
83000
84000
85000
86000
87000
88000
89000
90000
91000
92000
93000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

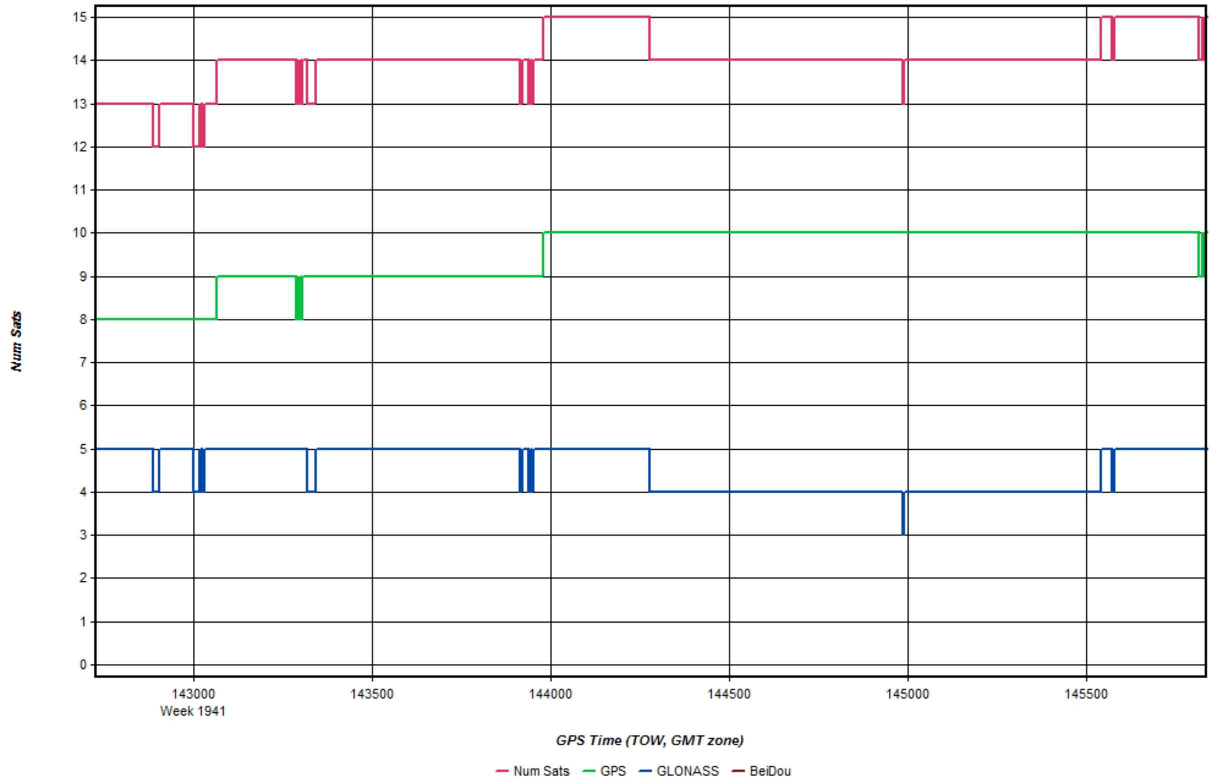

Separation (m)
0.065
0.060
0.055
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
-0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-0.035
-0.040
-0.045
-0.050
-0.055
-0.060
79000
Week 1941
80000
81000
82000
83000
84000
85000
86000
87000
88000
89000
90000
91000
92000
93000
GPS Time (TOW, GMT zone)
East
North
Up

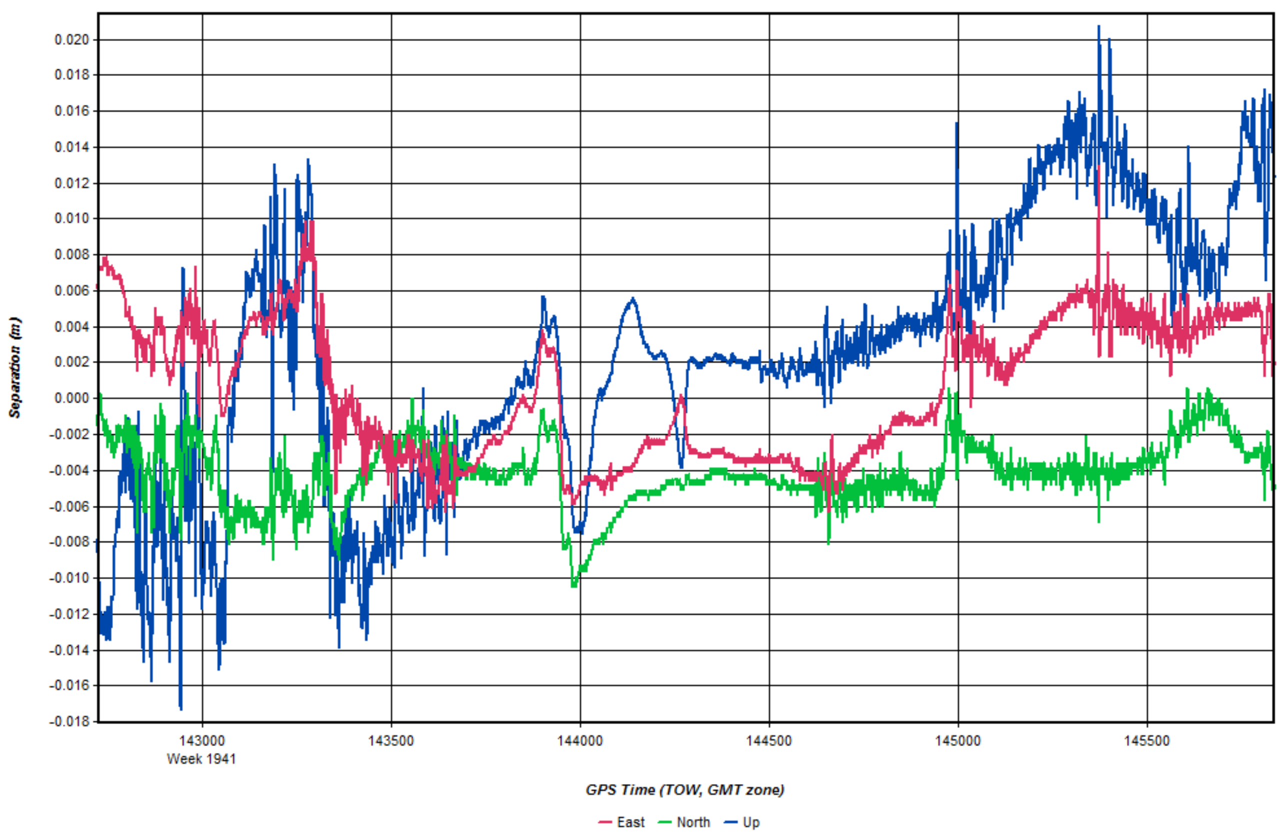

PDOP
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
79000
Week 1941
80000
81000
82000
83000
84000
85000
86000
87000
88000
89000
90000
91000
92000
93000
GPS Time (TOW, GMT zone)
PDOP

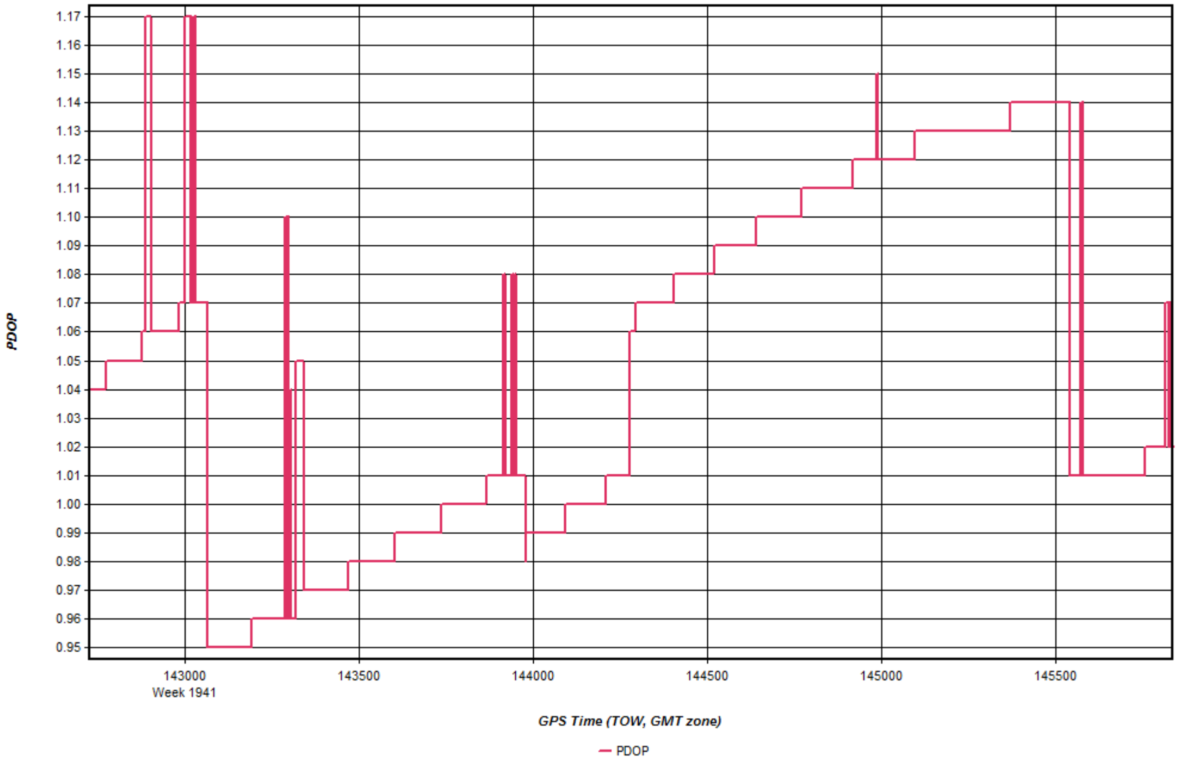
**225_20170320_1**



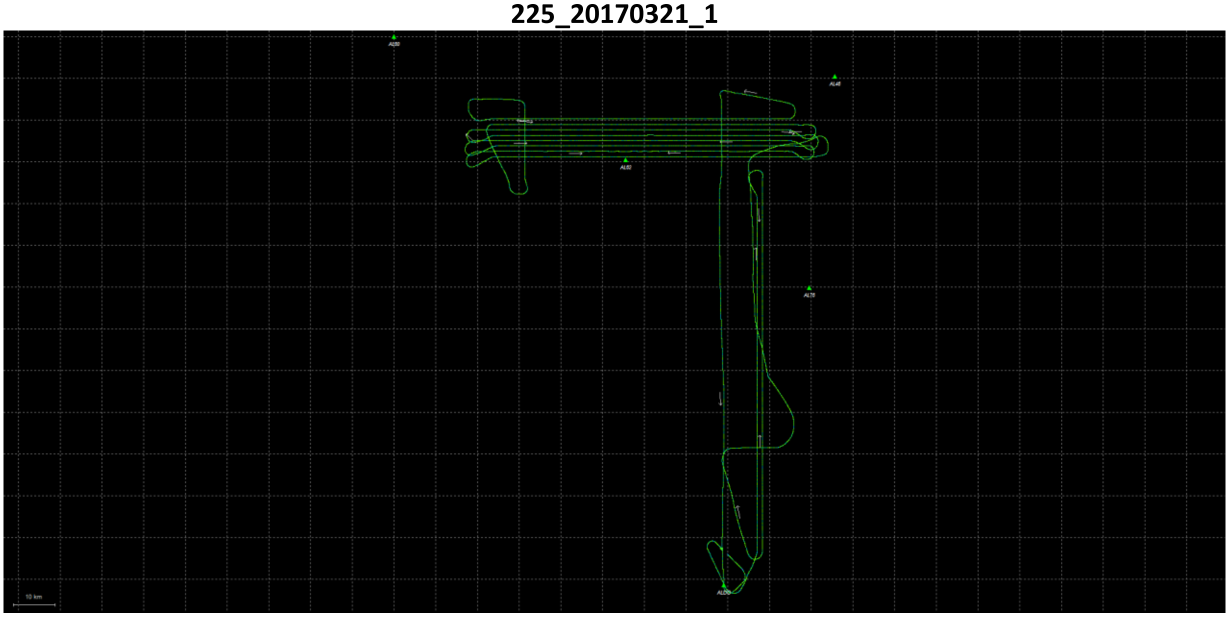


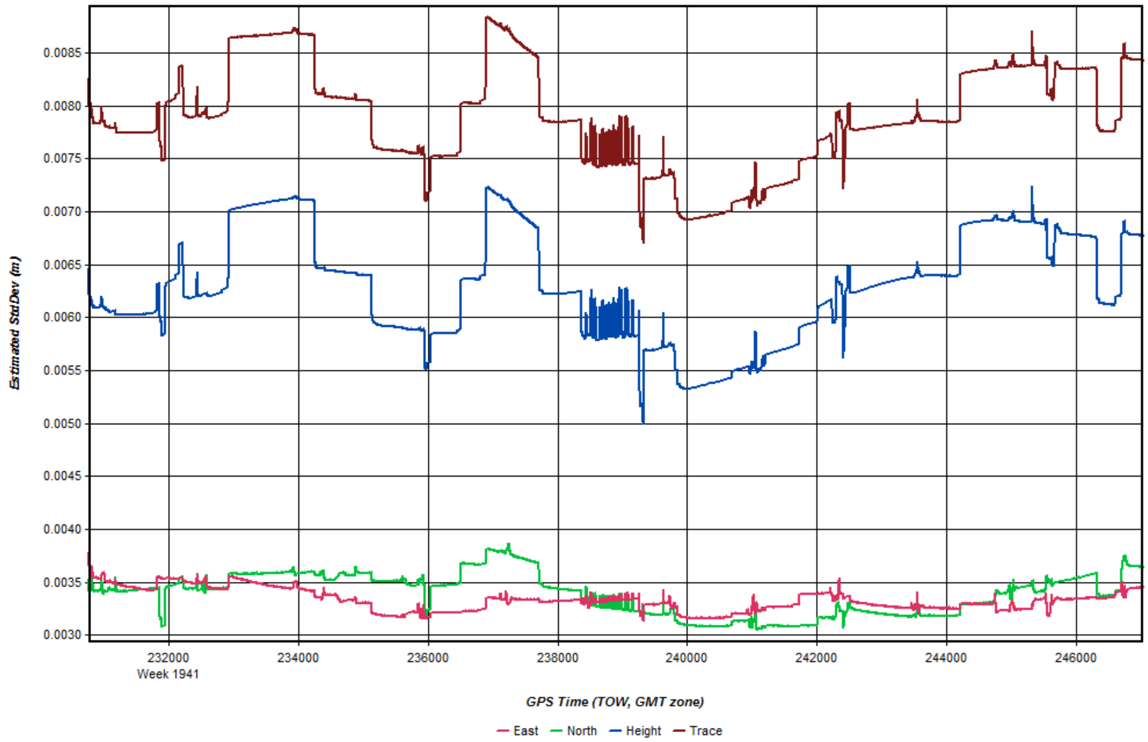

Num Sats
GPS Time (TOW, GMT zone)
Week 1941
Num Sats
GPS
GLONASS
BeiDou

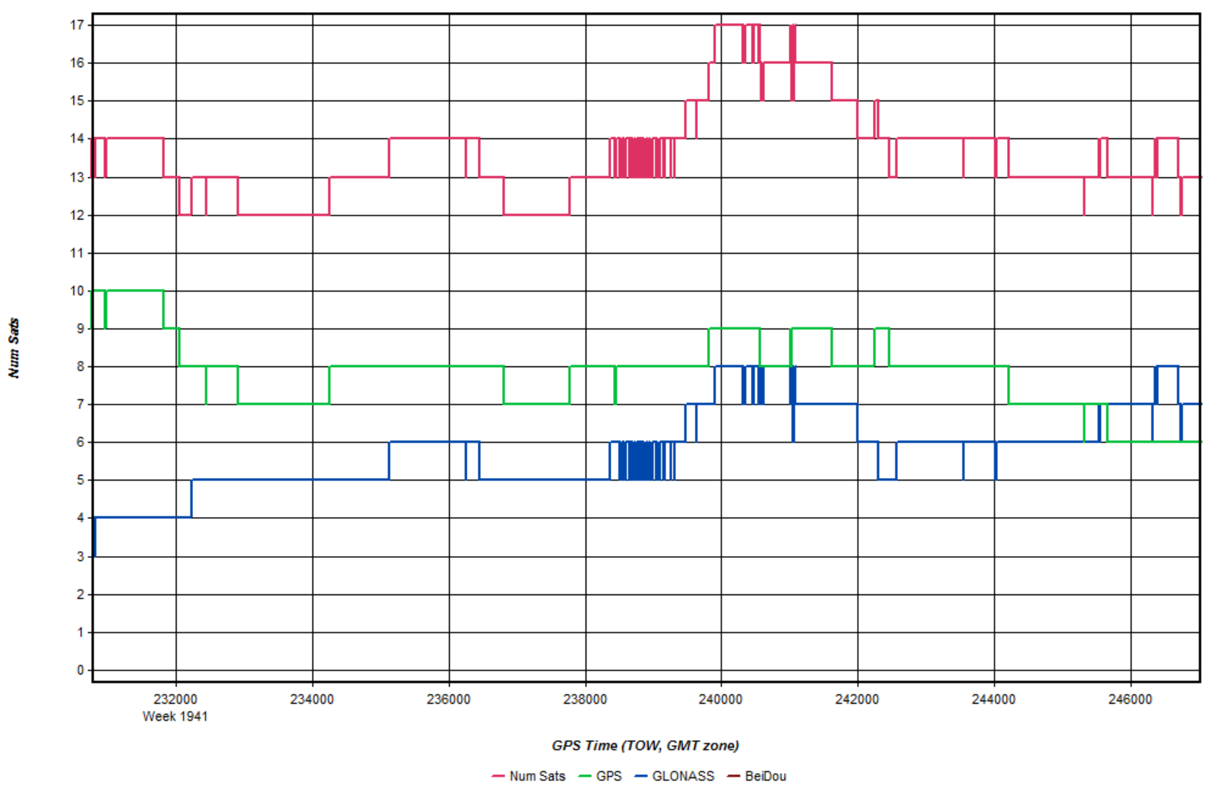

Separation (m)
GPS Time (TOW, GMT zone)
Week 1941
East
North
Up

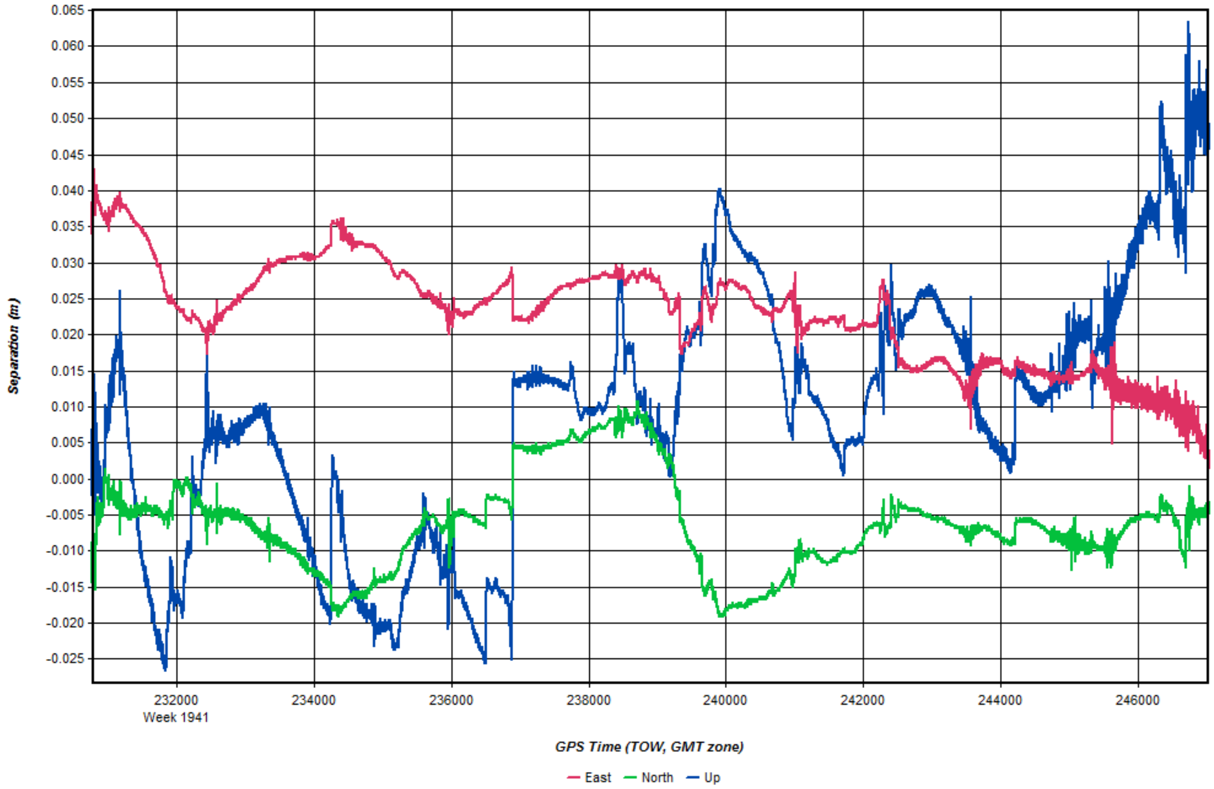


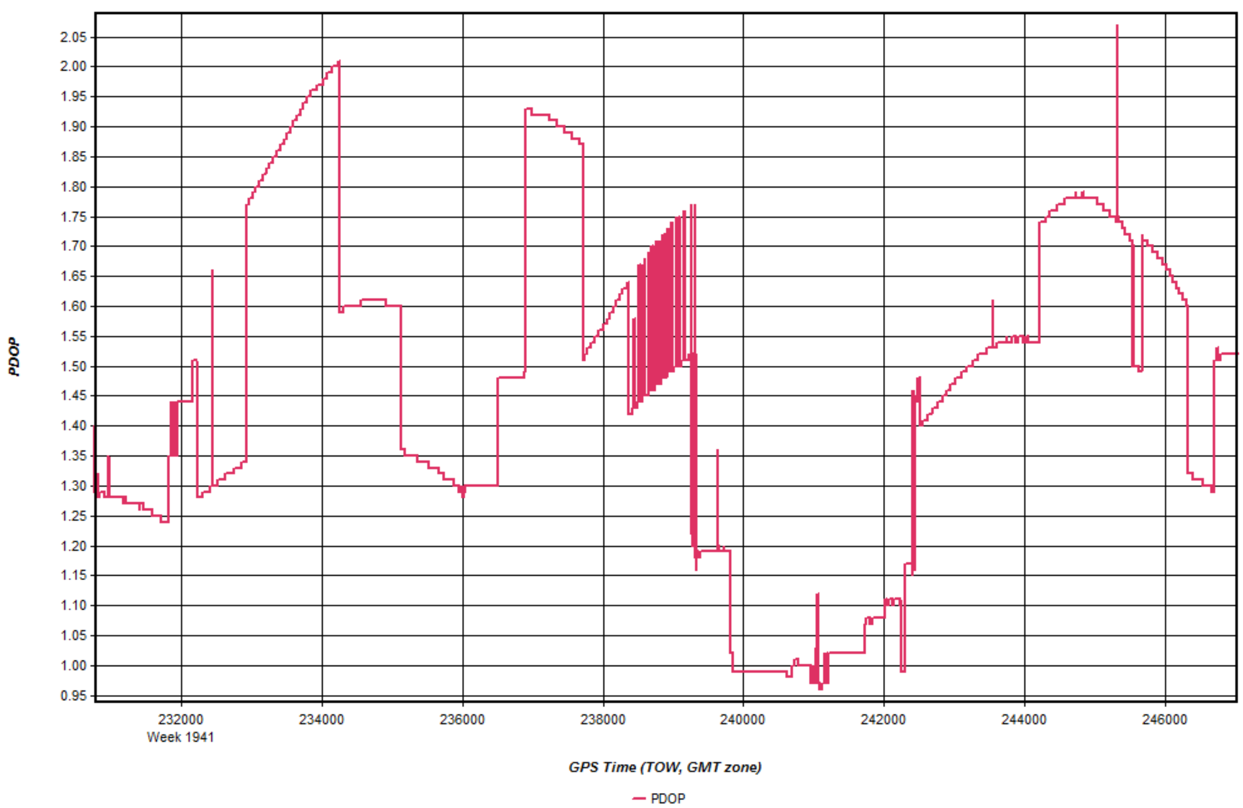

**225_20170321_1**



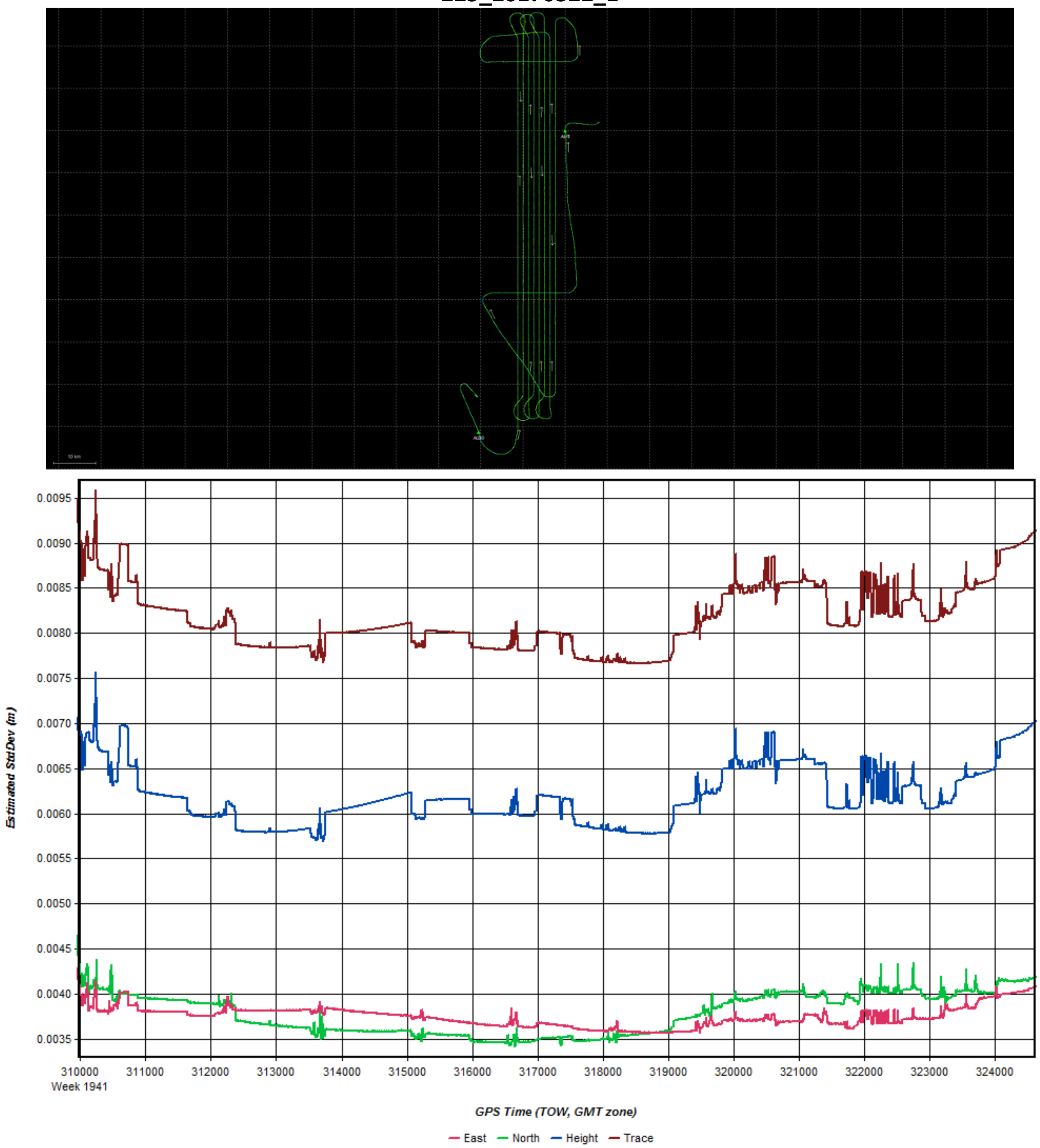

Estimated StdDev (m)
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
0.0035
0.0030
232000
Week 1941
234000
236000
238000
240000
242000
244000
246000
GPS Time (TOW, GMT zone)
East
North
Height
Trace

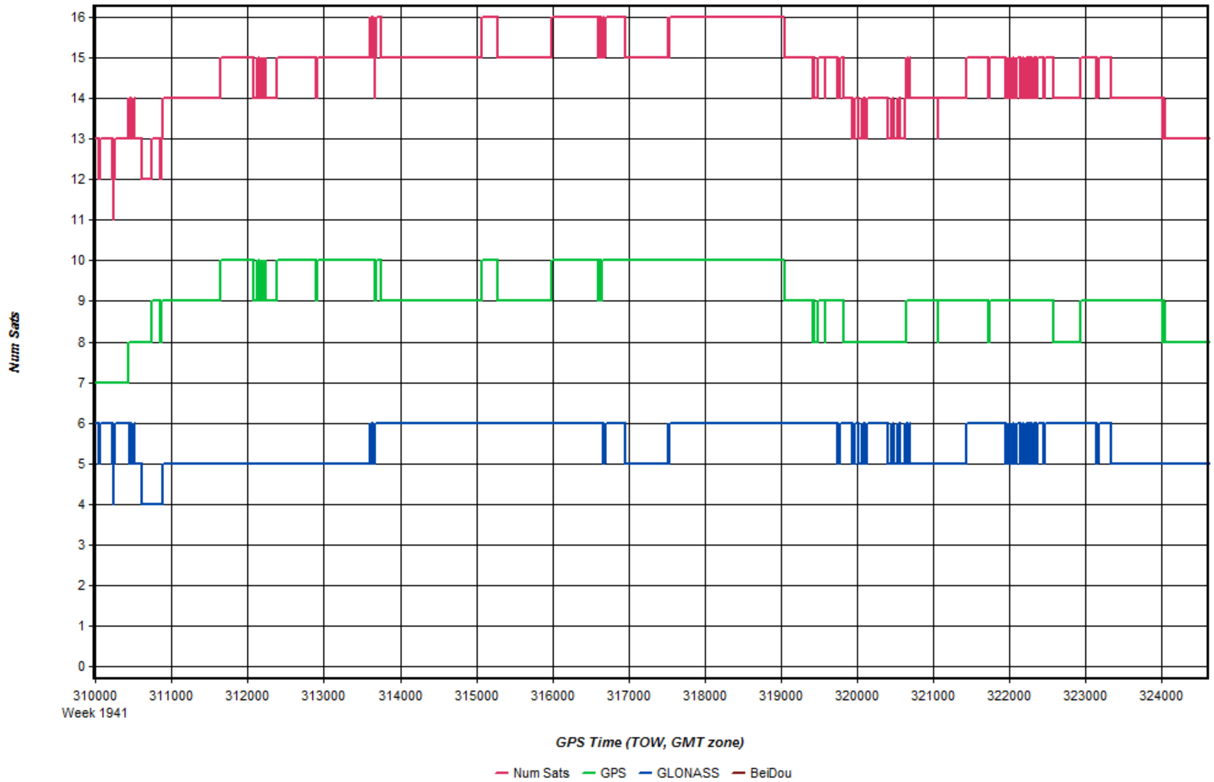

Num Sats
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
232000
Week 1941
234000
236000
238000
240000
242000
244000
246000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

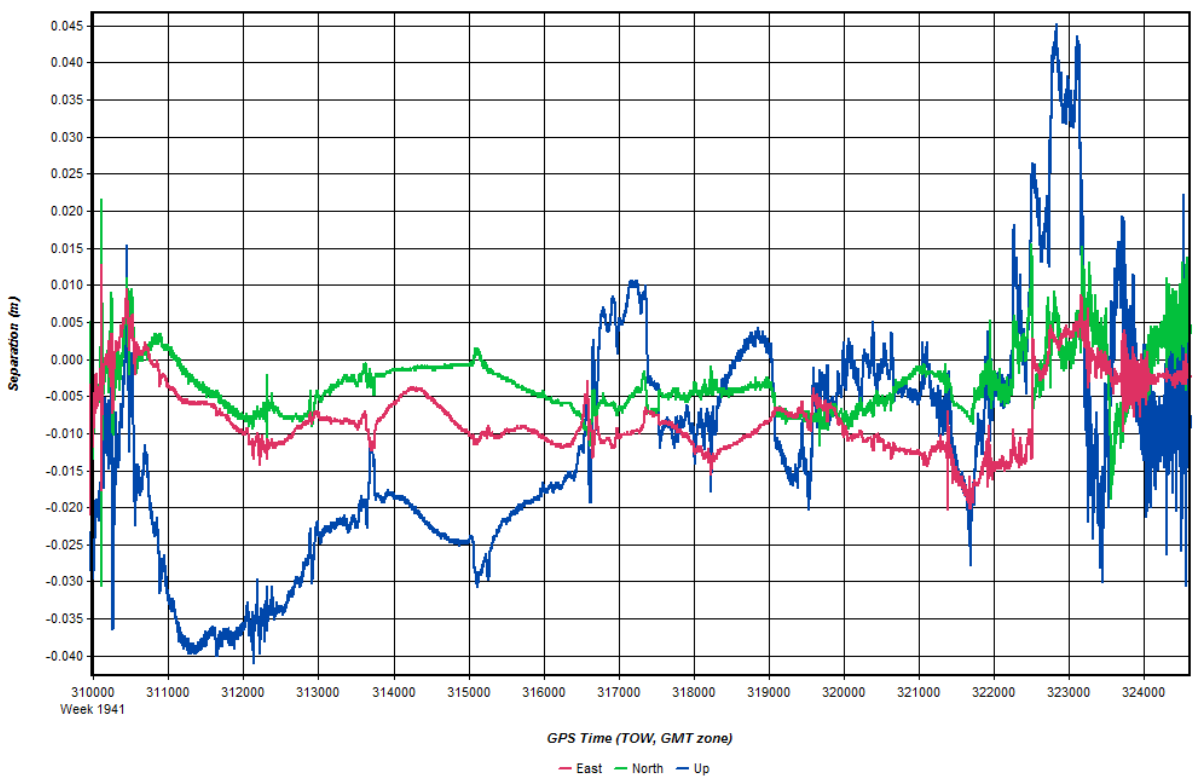

Separation (m)
GPS Time (TOW, GMT zone)
Week 1941
East
North
Up

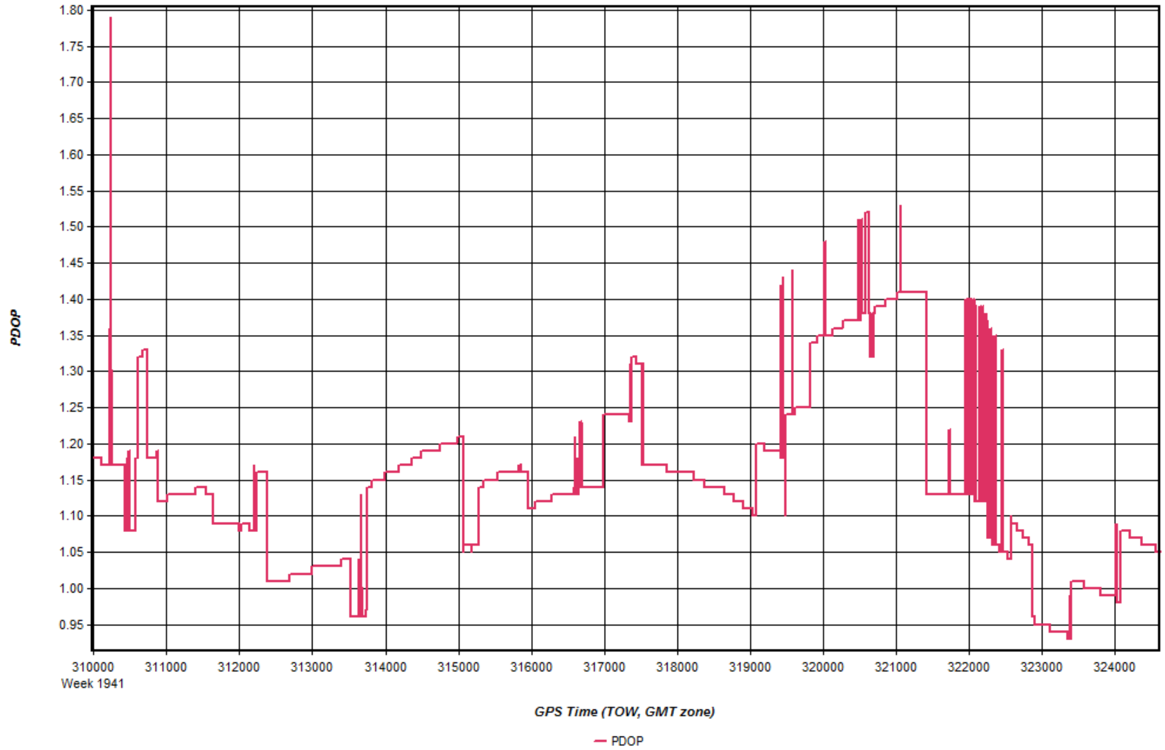

PDOP
GPS Time (TOW, GMT zone)
Week 1941
PDOP

**225_20170322_1**

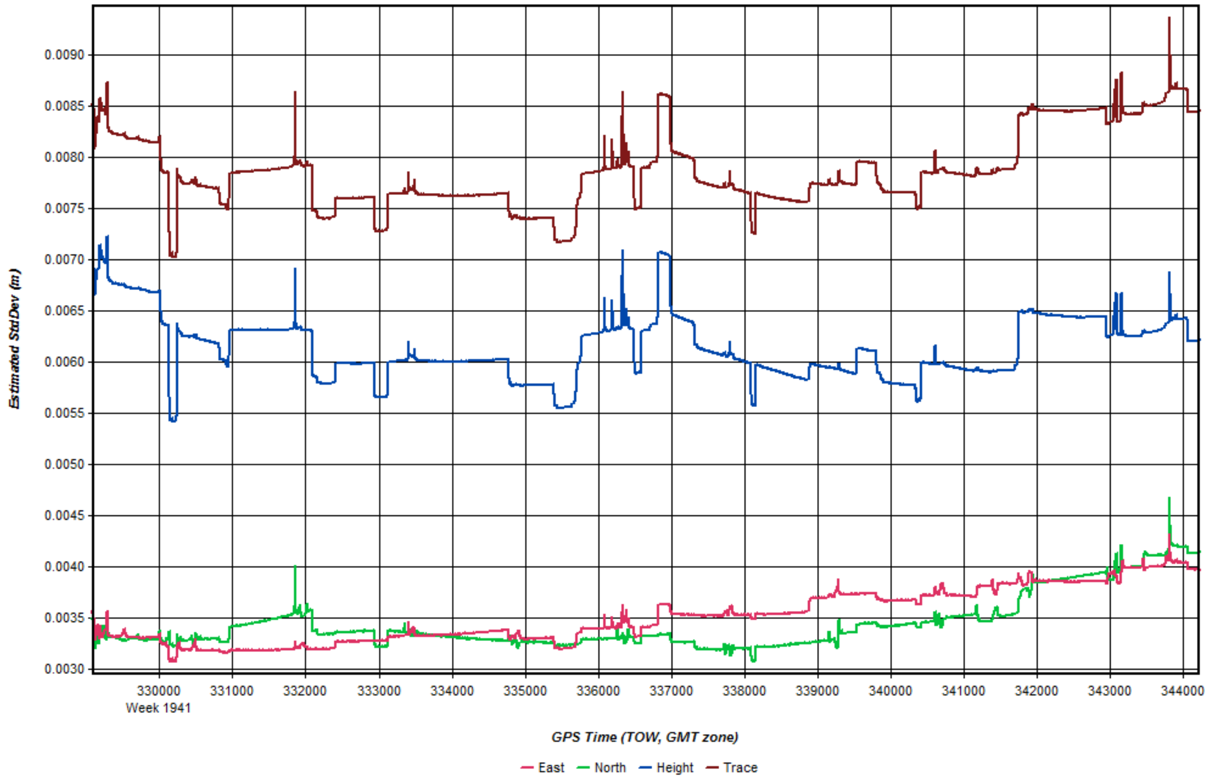


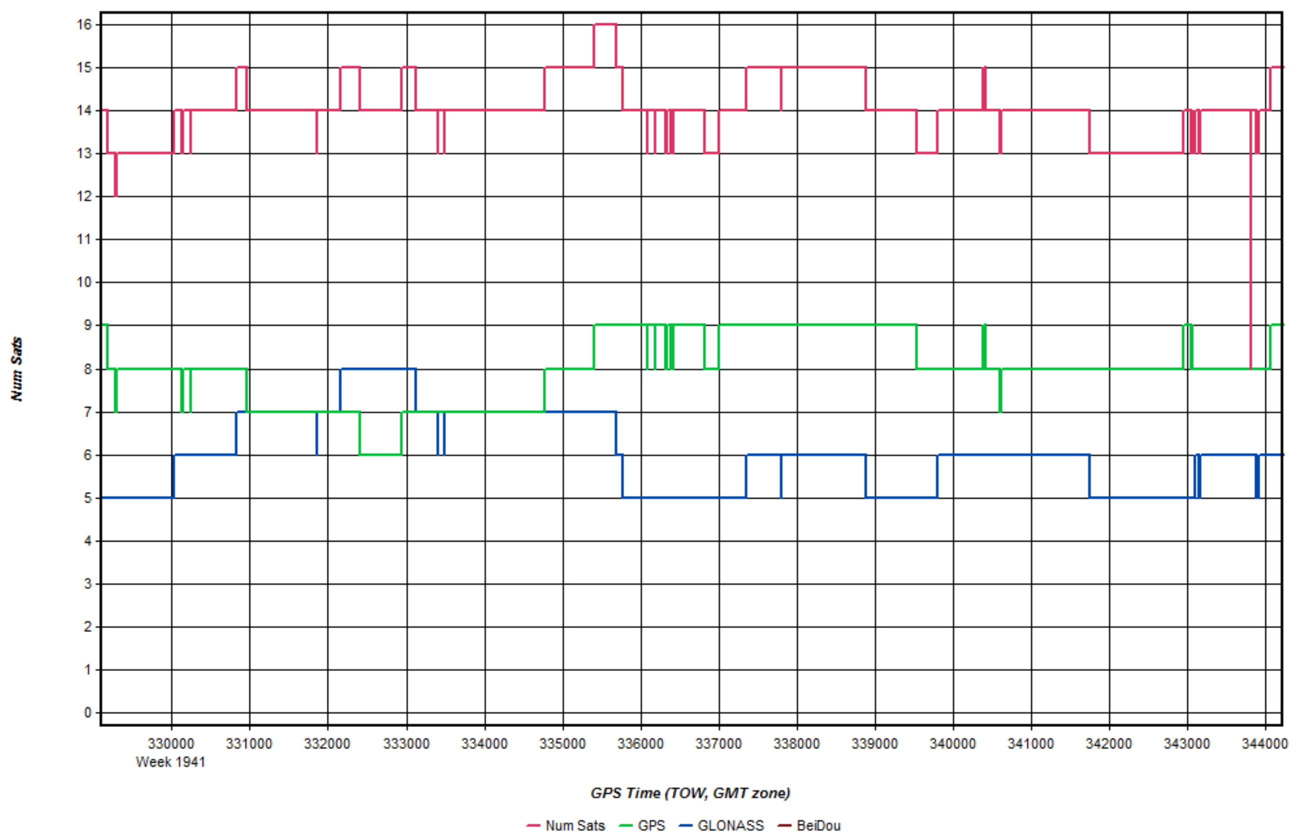

Num Sats
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
310000
Week 1941
311000
312000
313000
314000
315000
316000
317000
318000
319000
320000
321000
322000
323000
324000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

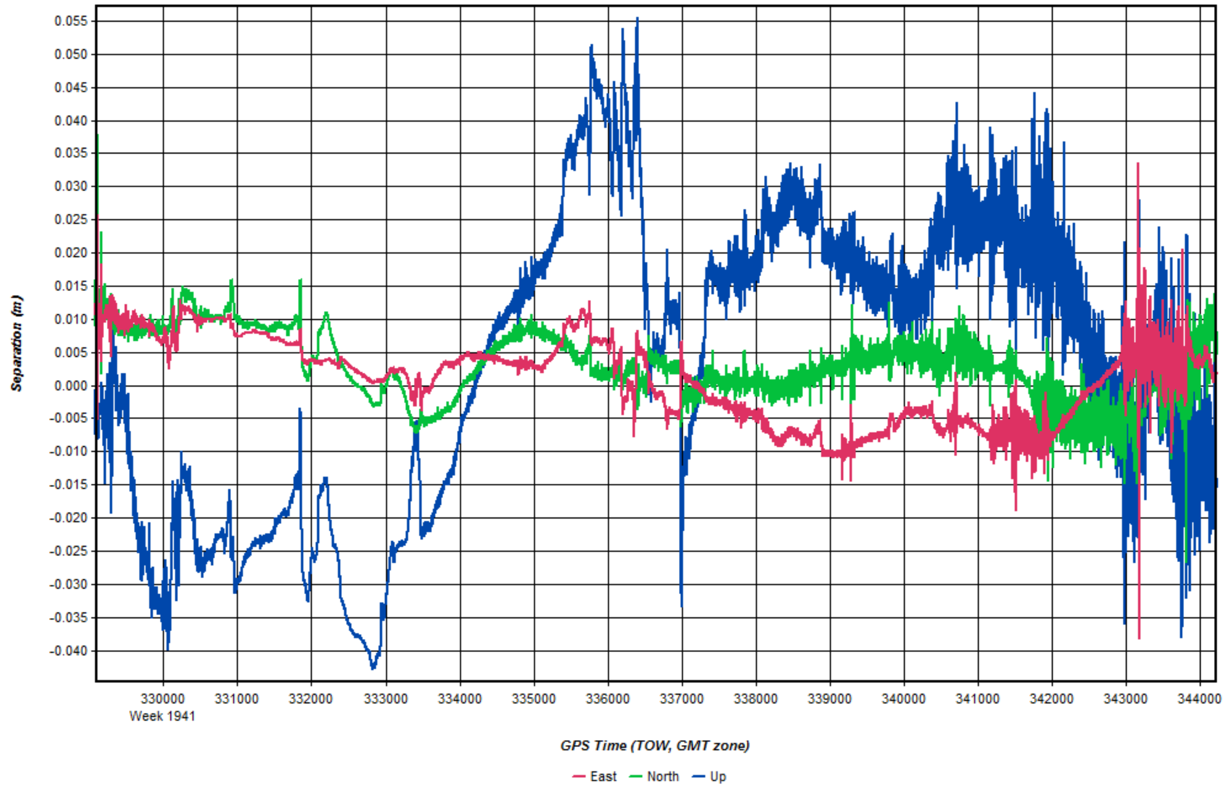

Separation (m)
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-0.035
-0.040
310000
Week 1941
311000
312000
313000
314000
315000
316000
317000
318000
319000
320000
321000
322000
323000
324000
GPS Time (TOW, GMT zone)
East
North
Up

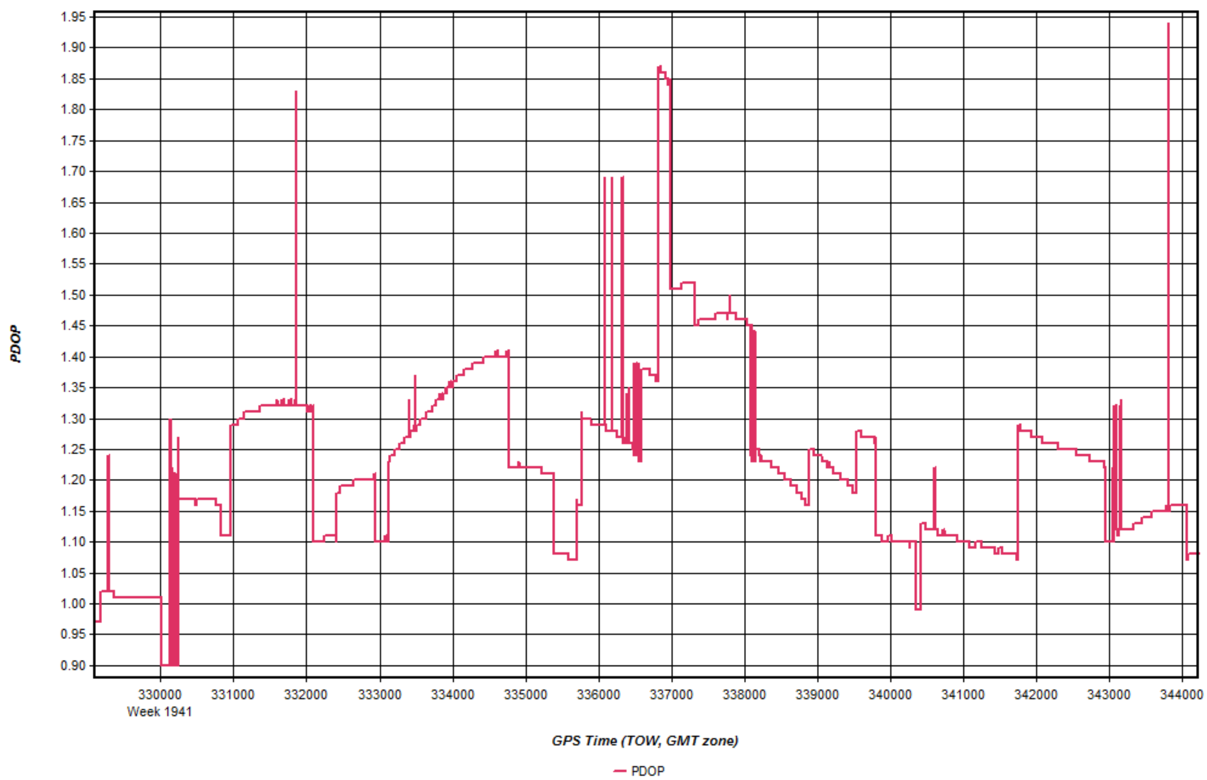



**225_20170322_2**

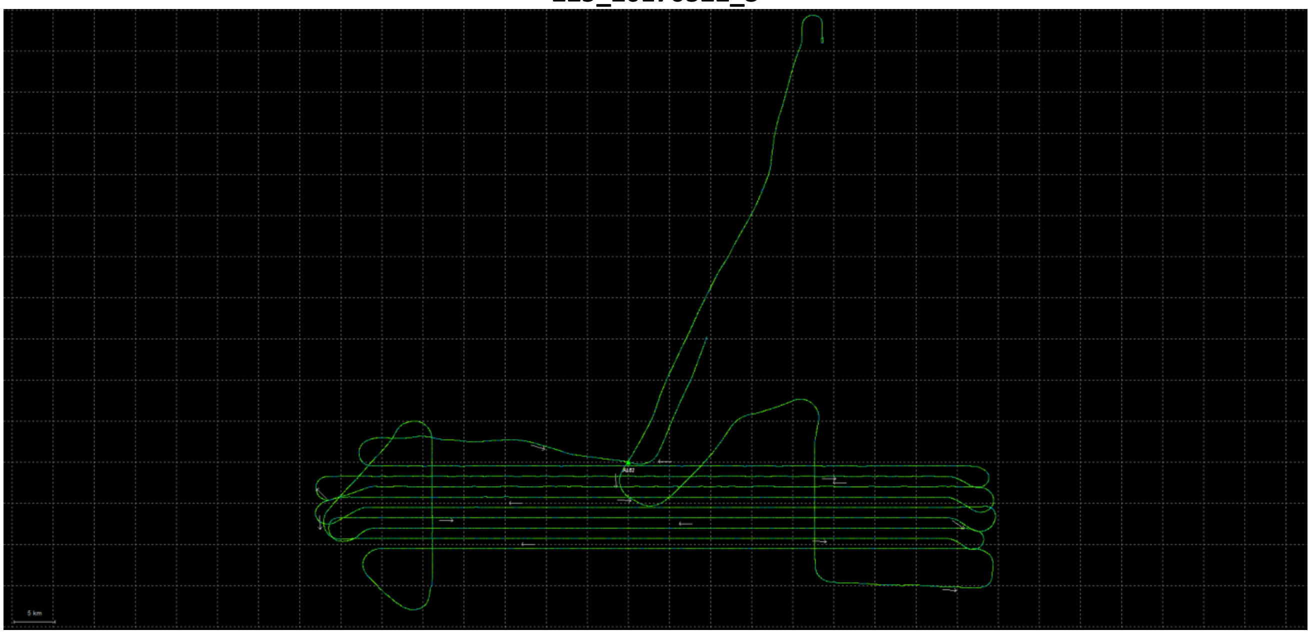

Estimated Std Dev (m)
0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
0.0035
0.0030
330000
Week 1941
331000
332000
333000
334000
335000
336000
337000
338000
339000
340000
341000
342000
343000
344000
GPS Time (TOW, GMT zone)
East
North
Height
Trace

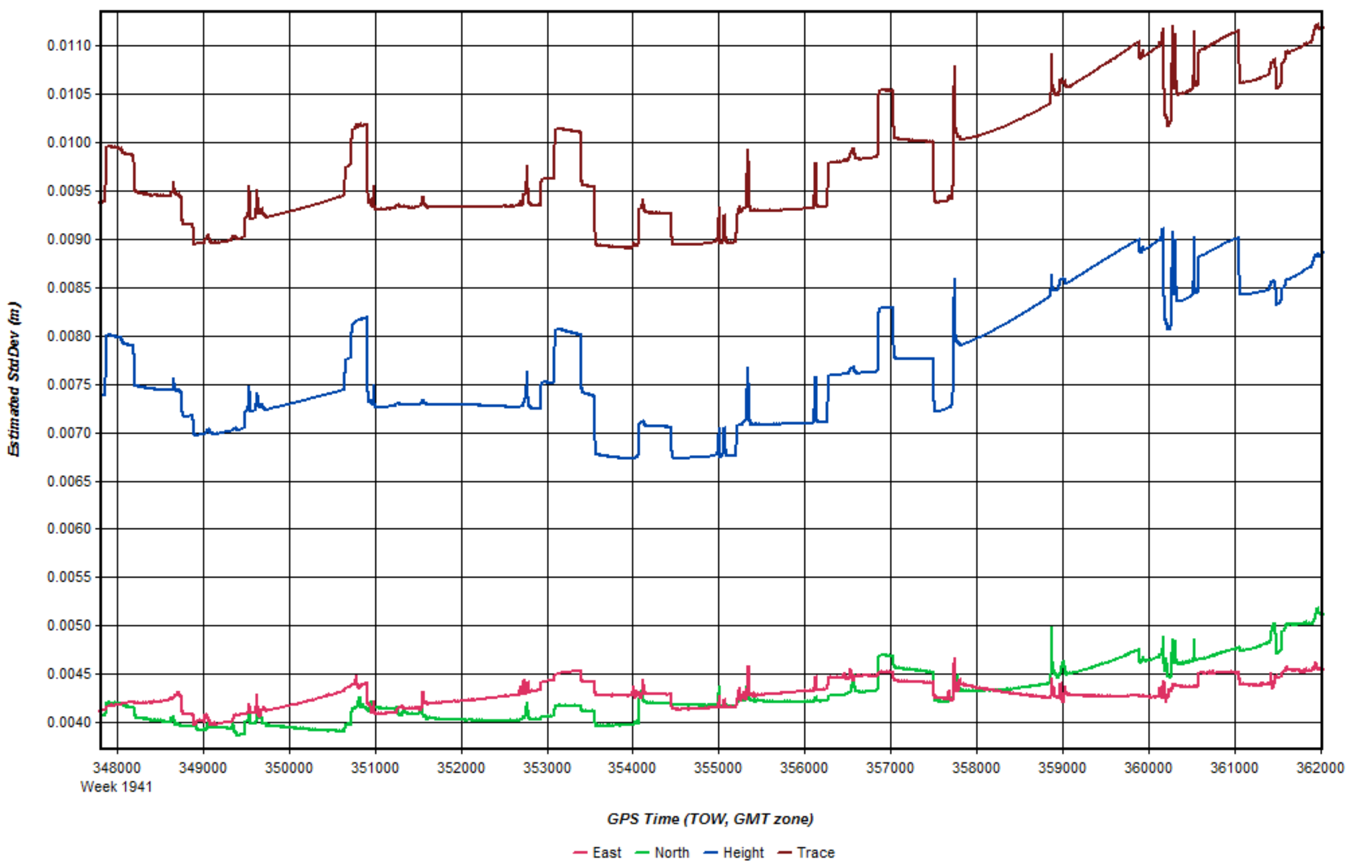

Num Sats
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
330000
Week 1941
331000
332000
333000
334000
335000
336000
337000
338000
339000
340000
341000
342000
343000
344000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

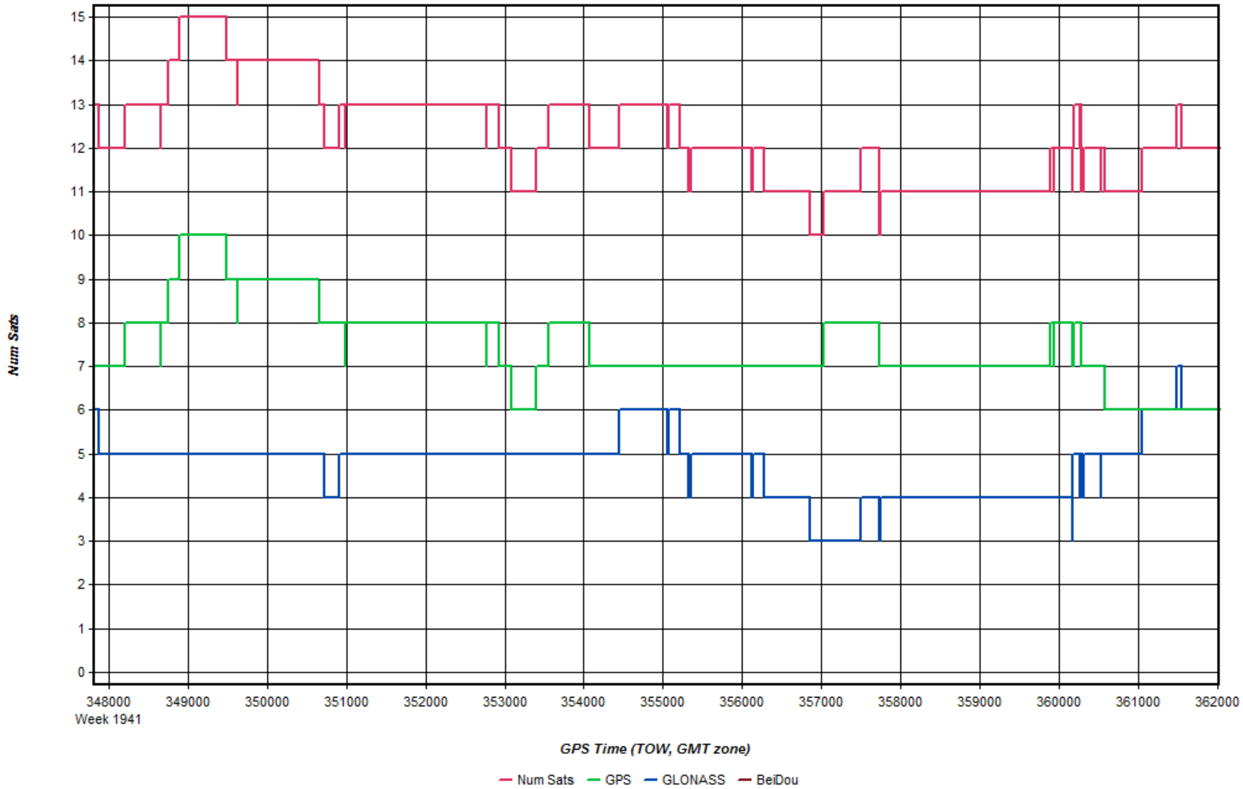

Separation (m)
0.055
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-0.035
-0.040
330000
Week 1941
331000
332000
333000
334000
335000
336000
337000
338000
339000
340000
341000
342000
343000
344000
GPS Time (TOW, GMT zone)
East
North
Up

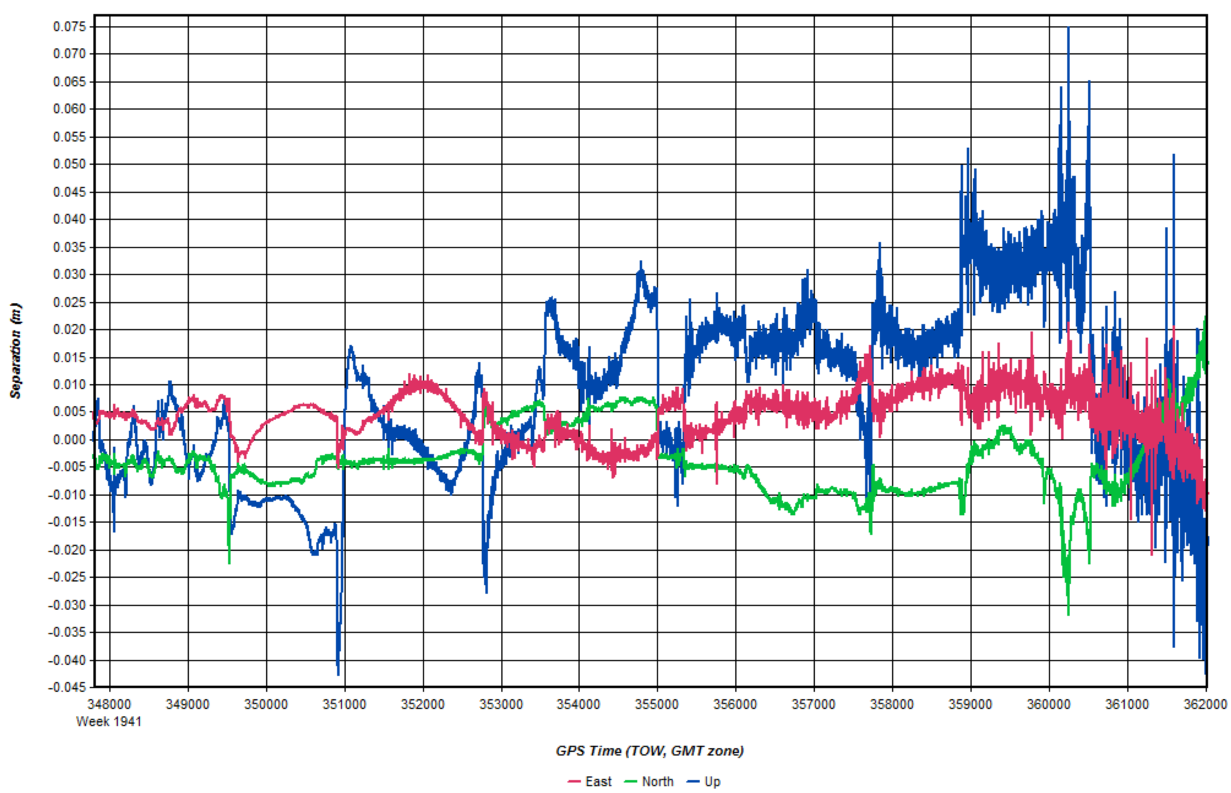

PDOP
1.95
1.90
1.85
1.80
1.75
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
330000
Week 1941
331000
332000
333000
334000
335000
336000
337000
338000
339000
340000
341000
342000
343000
344000
GPS Time (TOW, GMT zone)
PDOP

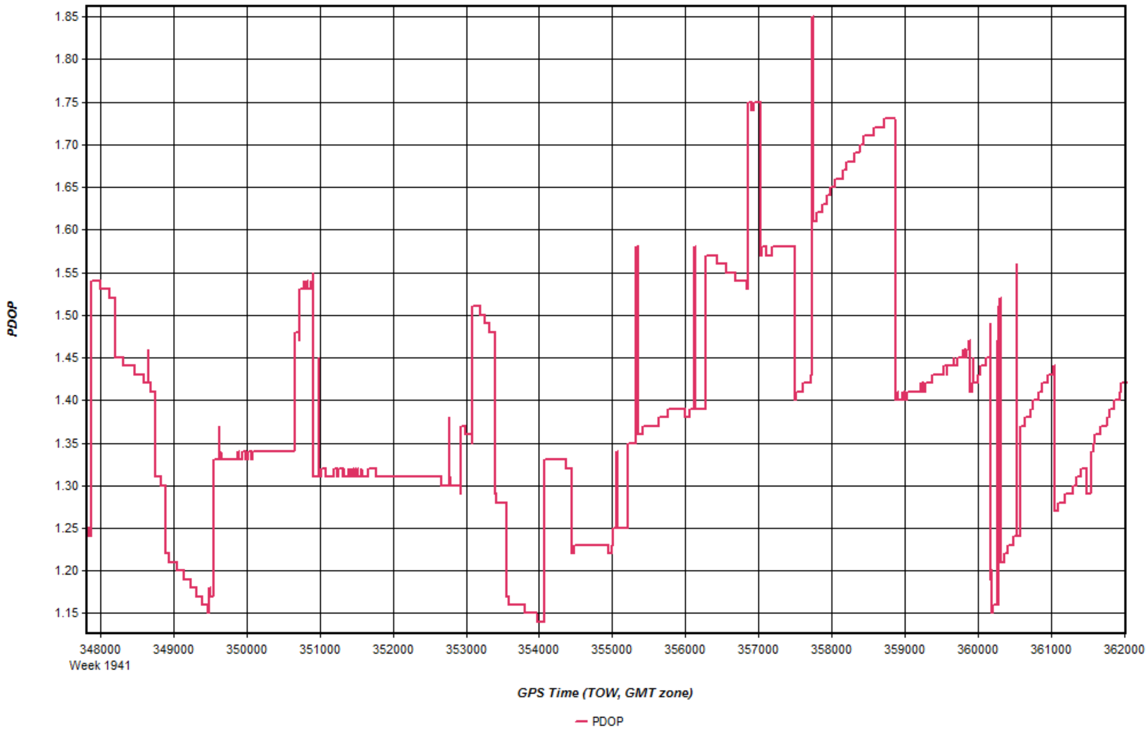
**225_20170322_3**



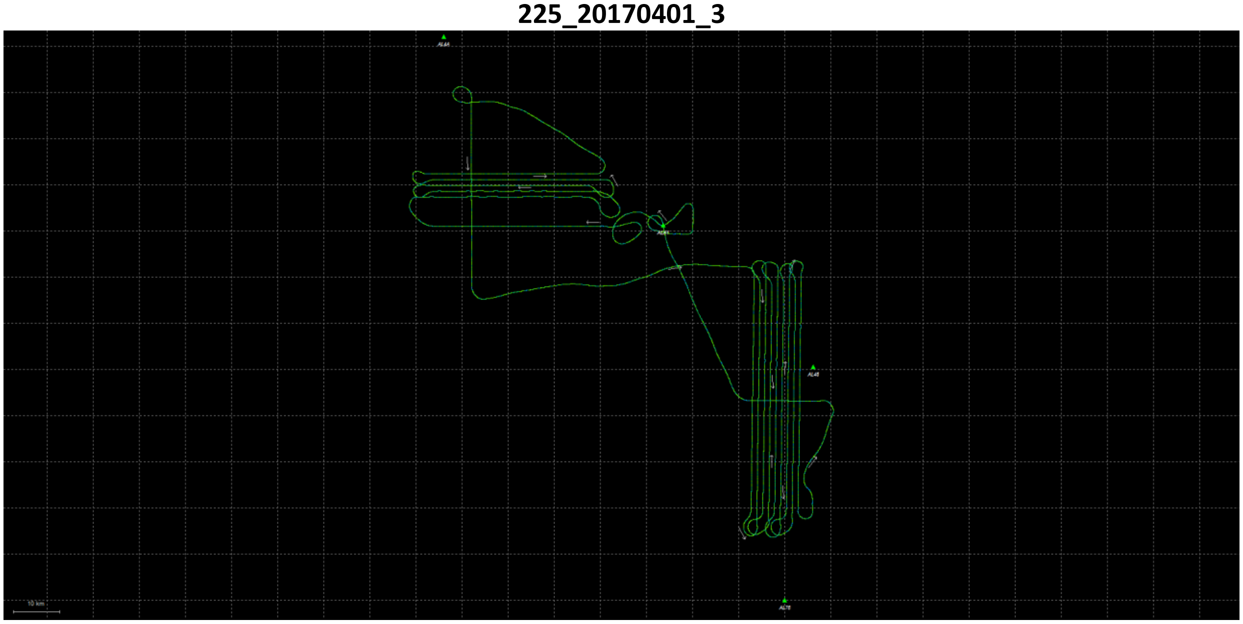


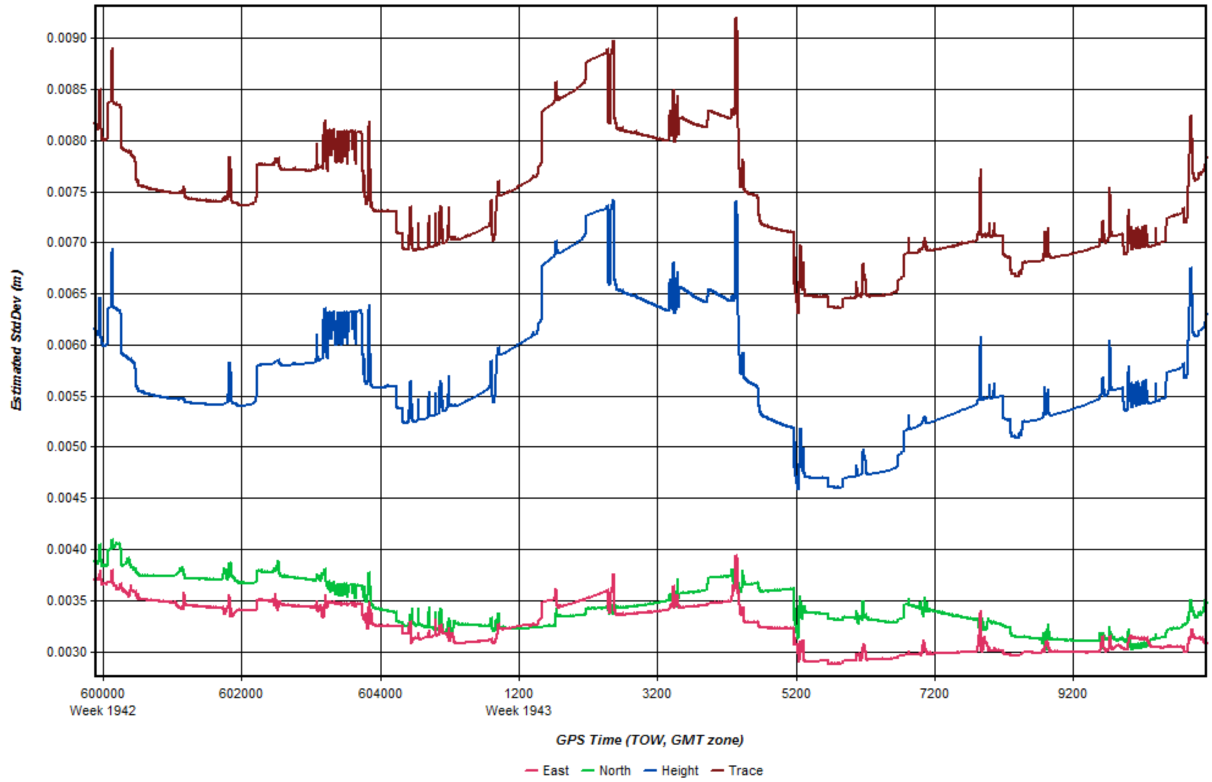

Num Sats
GPS Time (TOW, GMT zone)
Week 1941
Num Sats
GPS
GLONASS
BeiDou

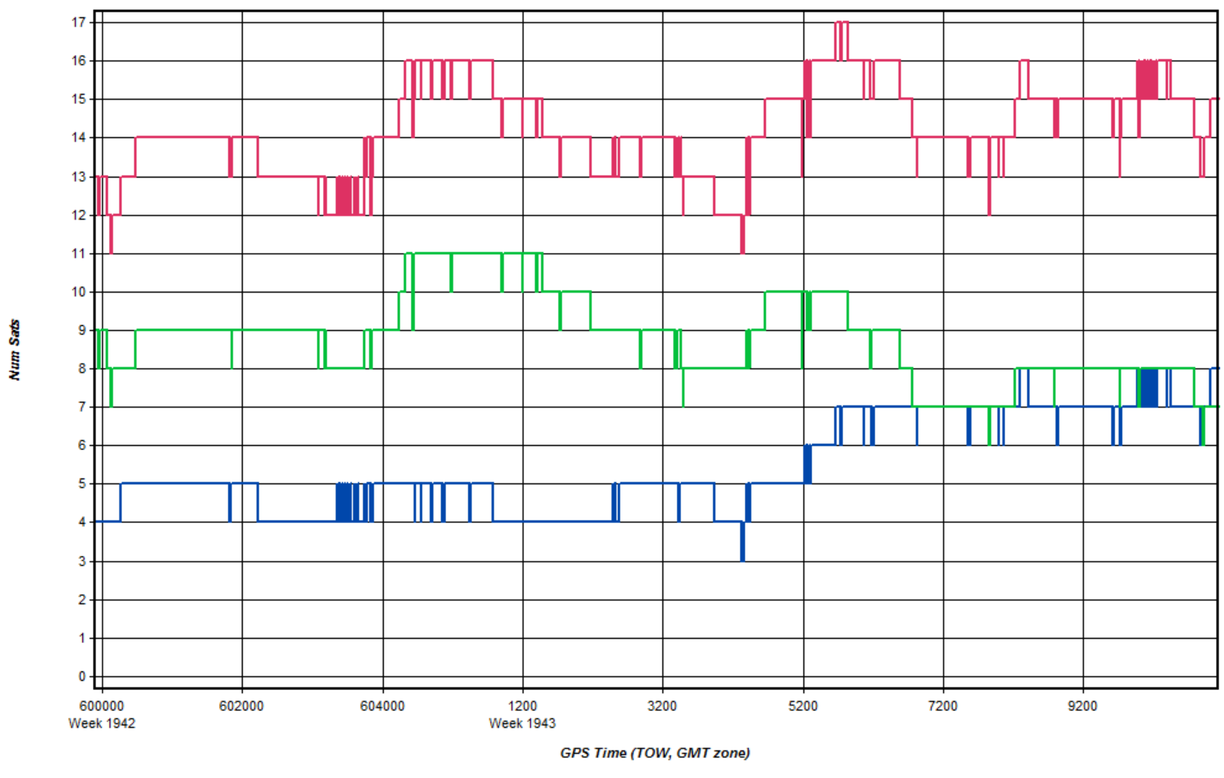

Separation (m)
GPS Time (TOW, GMT zone)
Week 1941
East
North
Up

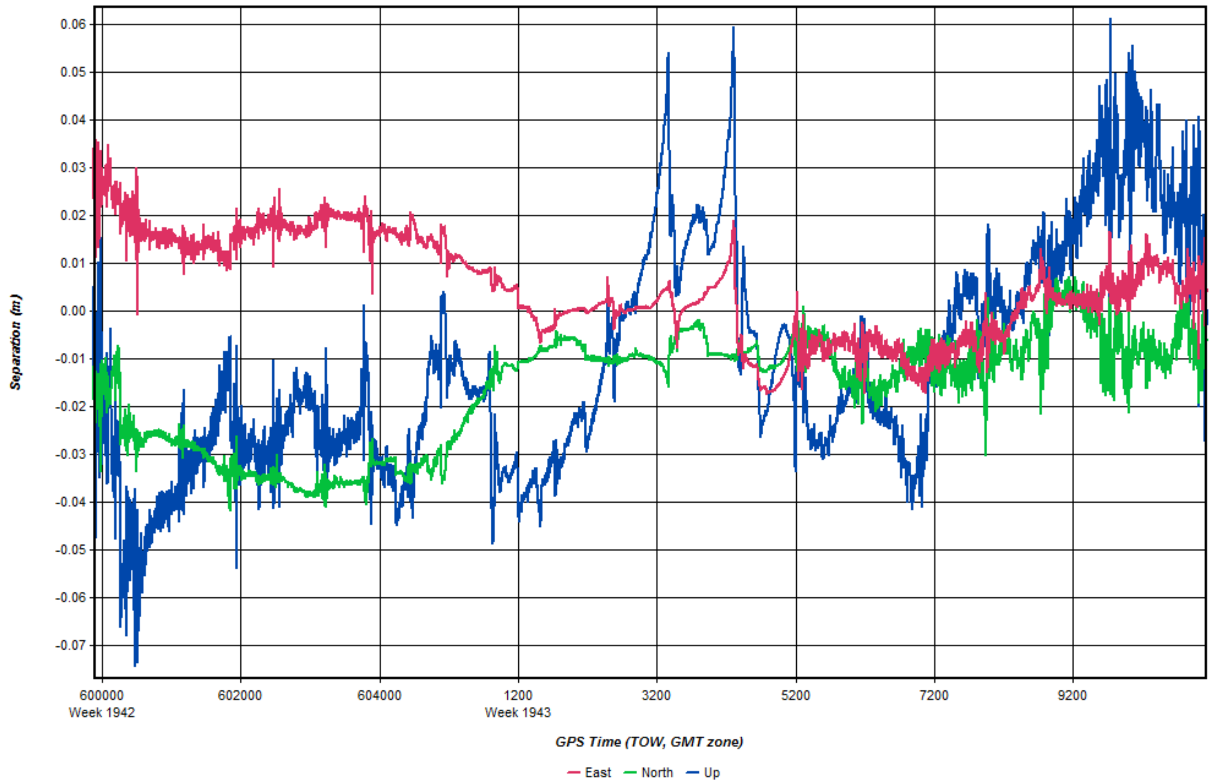


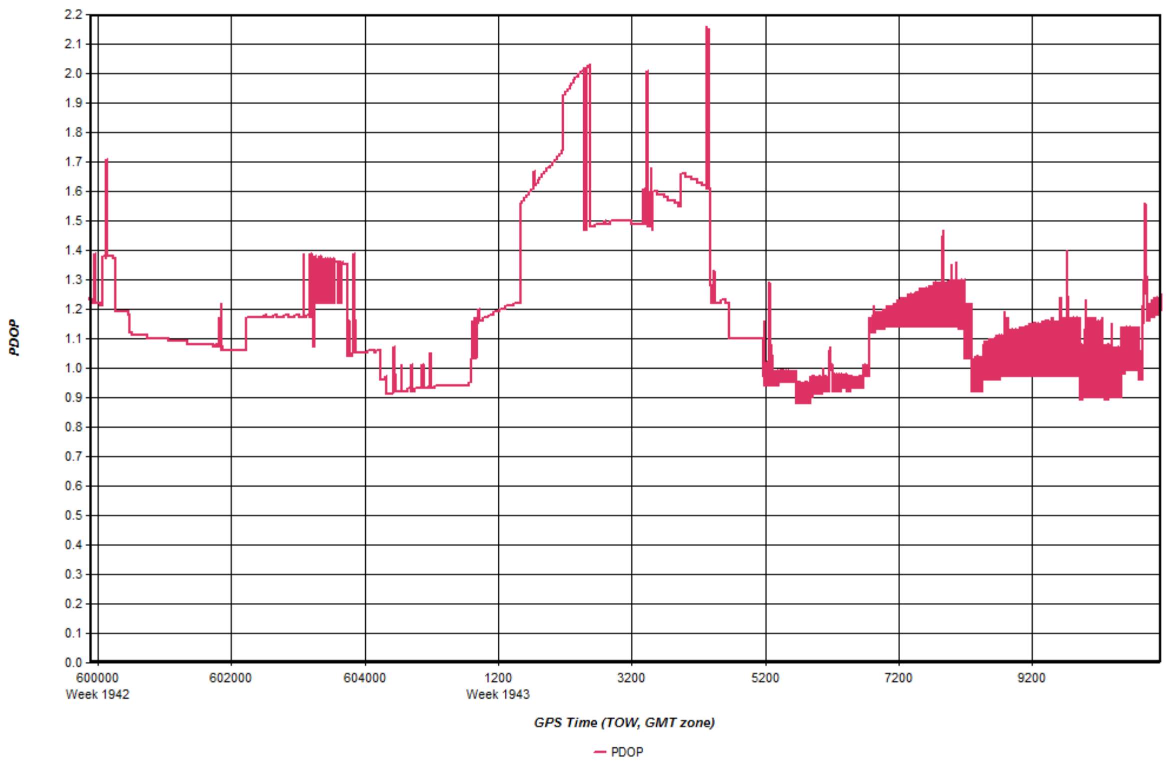

**225_20170401_3**



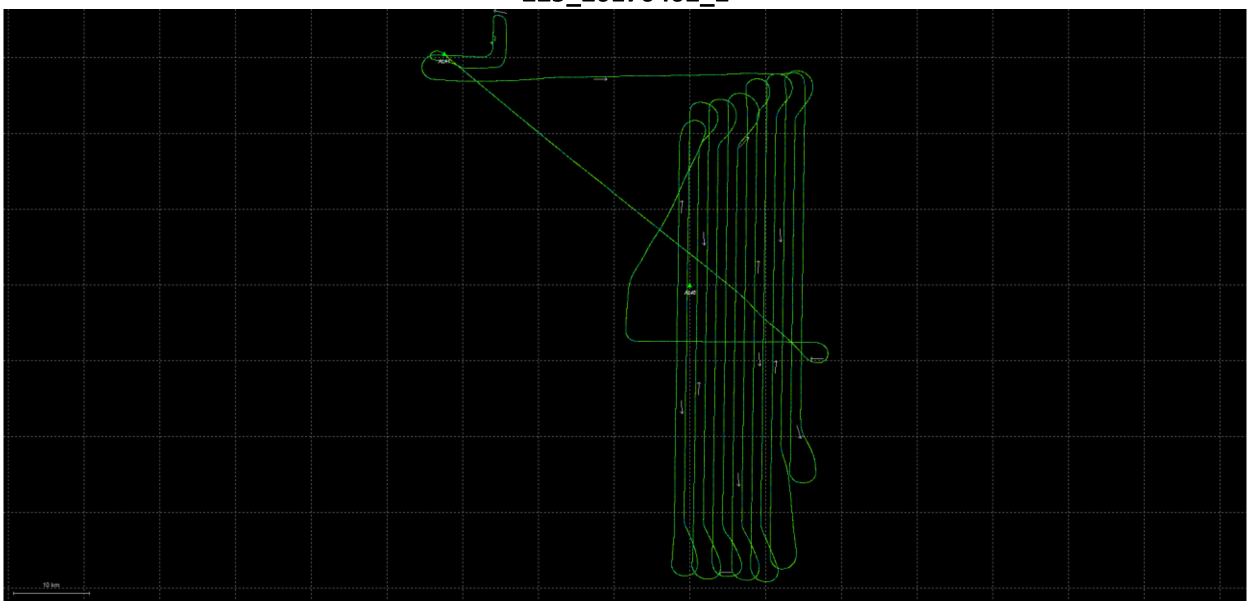

0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
0.0035
0.0030
Estimated StdDev (m)
600000
Week 1942
602000
604000
1200
Week 1943
3200
5200
7200
9200
GPS Time (TOW, GMT zone)
East
North
Height
Trace

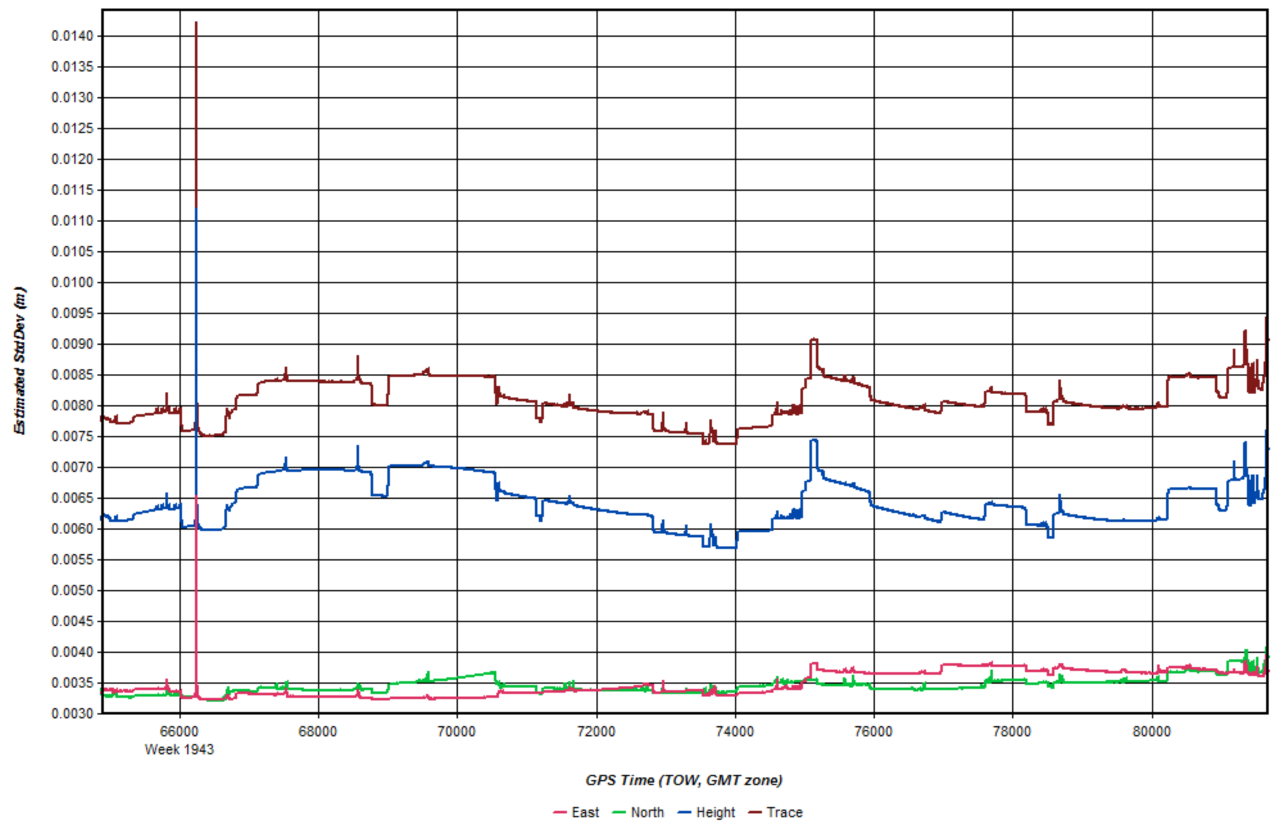

17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Num Sats
600000
Week 1942
602000
604000
1200
Week 1943
3200
5200
7200
9200
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou

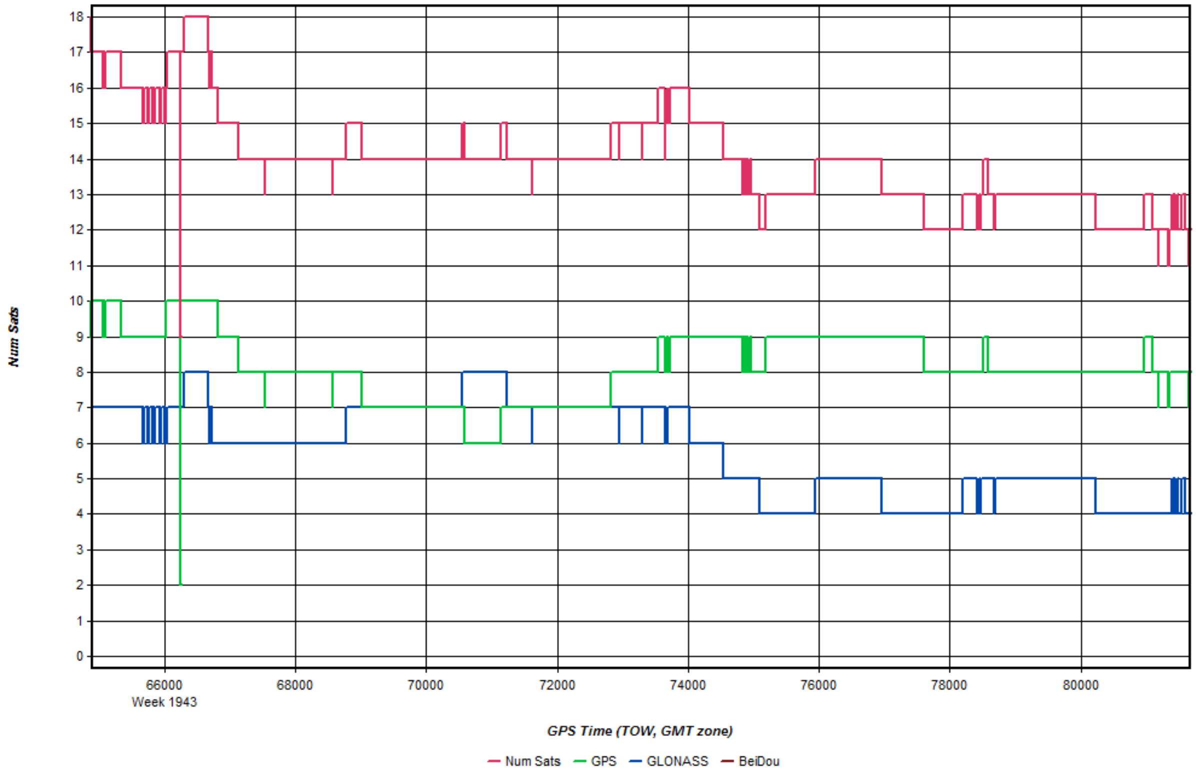

Separation (m)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
600000
Week 1942
602000
604000
1200
Week 1943
3200
5200
7200
9200
GPS Time (TOW, GMT zone)
East
North
Up

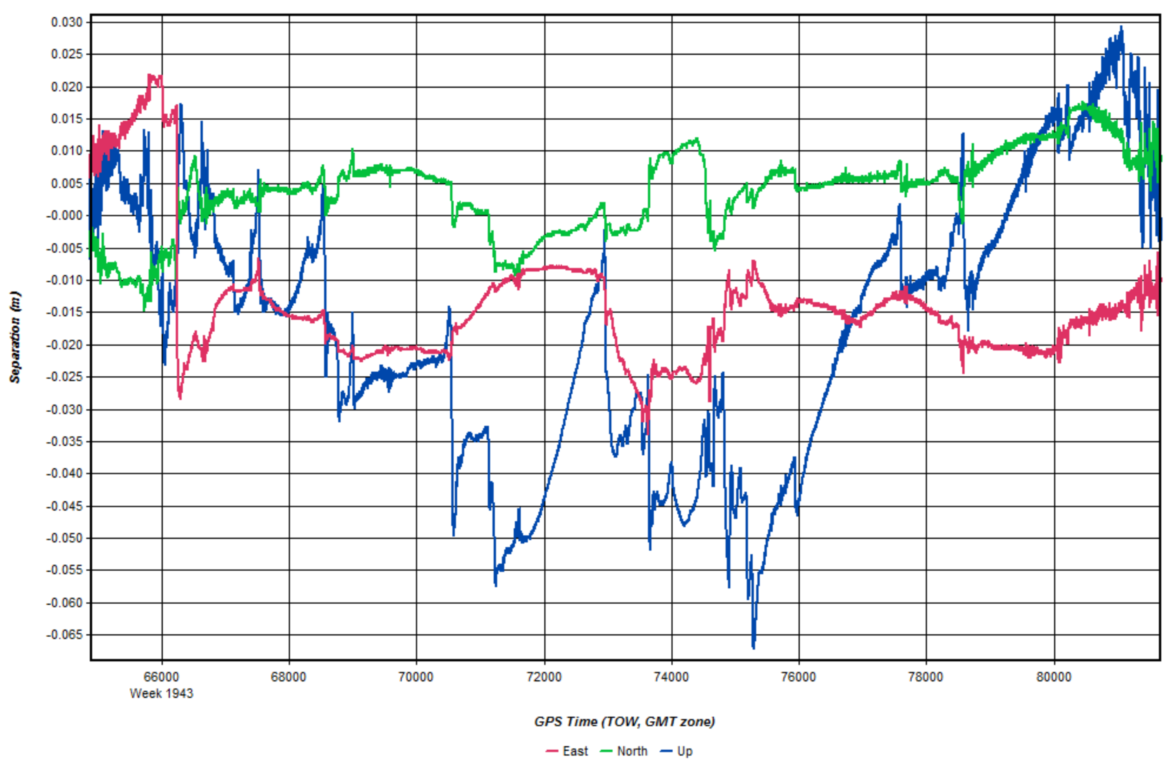

PDOP
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
600000
Week 1942
602000
604000
1200
Week 1943
3200
5200
7200
9200
GPS Time (TOW, GMT zone)
PDOP

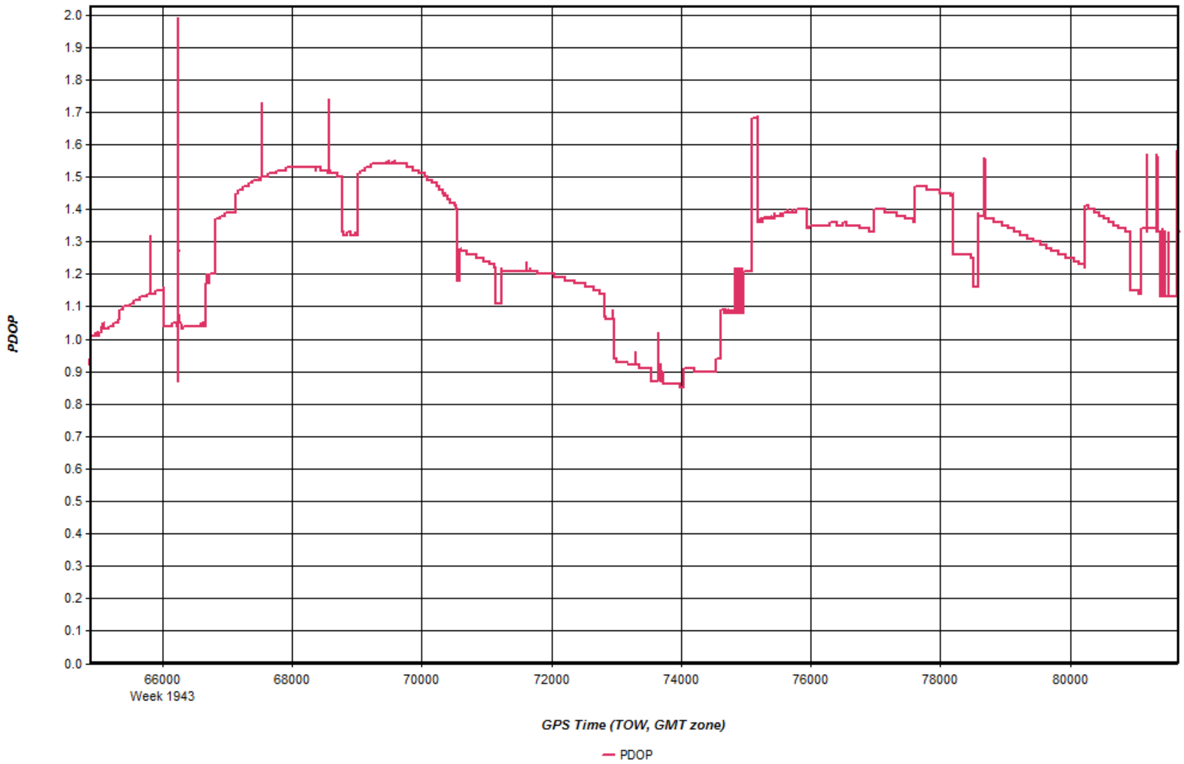
**225_20170402_2**






Num Sats
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
66000
Week 1943
68000
70000
72000
74000
76000
78000
80000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS
BeiDou


Separation (m)
0.030
0.025
0.020
0.015
0.010
0.005
-0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-0.035
-0.040
-0.045
-0.050
-0.055
-0.060
-0.065
66000
Week 1943
68000
70000
72000
74000
76000
78000
80000
GPS Time (TOW, GMT zone)
East
North
Up


2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PDOP
66000
Week 1943
68000
70000
72000
74000
76000
78000
80000
GPS Time (TOW, GMT zone)
PDOP