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U.S. Department of Agriculture

Mississippi Sunflower

Lidar Report

September, 2018

EXECUTIVE SUMMARY

The U.S. Department of Agriculture (USDA) contracted with The Sanborn Map Company, Inc. (Sanborn) to provide remote sensing services for partial Bolivar, Coahoma, Sunflower, and Washington counties Mississippi in the form of Lidar. Utilizing a multi-return system, Light Detection and Ranging (Lidar) detects 3-dimensional positions and attributes to form a point cloud. The high accuracy airborne system is integrated with both Global Navigation Satellite System (GNSS) and an Inertial Measure Unit (IMU) for accurate position and orientation. Acquisition of the project area's ~1,224mi² was completed on April 5th, 2018.

The Leica CityMapper was used to collect data for the aerial survey campaign. The sensor is attached to the aircraft's underside and emits rapid laser pulses that are used to calculate ranges between the aircraft and subsequent terrain below. The Airborne Lidar System (ALS) is boresighted by completing multiple passes over a known ground surface before the project acquisition. During data processing, the calibration parameters are updated and used during post-processing of the lidar point cloud.

Differential GNSS unit in aircraft sampled positions at 2Hz or higher frequency. Lidar data was only acquired when GNSS PDOP is ≤4 and at least 6 satellites are in view. Collection conditions were for leaf-off vegetation. The atmosphere was free of clouds and fog between the aircraft and ground. The ground was free of snow and extensive flooding or any other type of inundation

The contents of this report summarize the methods used to establish the base station coordinates, perform the lidar data acquisition and processing as well as the results of these methods.

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1.0 INTRODUCTION

This document contains the technical write-up of the lidar campaign, including system calibration techniques, and the collection and processing of the lidar data.

1.1 Contact Information

Questions regarding the technical aspects of this report should be addressed to:

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1.2 Purpose of Lidar Acquisition

The objective of this project is to collect accurate measurements of the bare-earth surface as well as above ground features to be provided as geometric inputs for surface and/or change modeling as is relates survey assessments.

1.3 Project Location

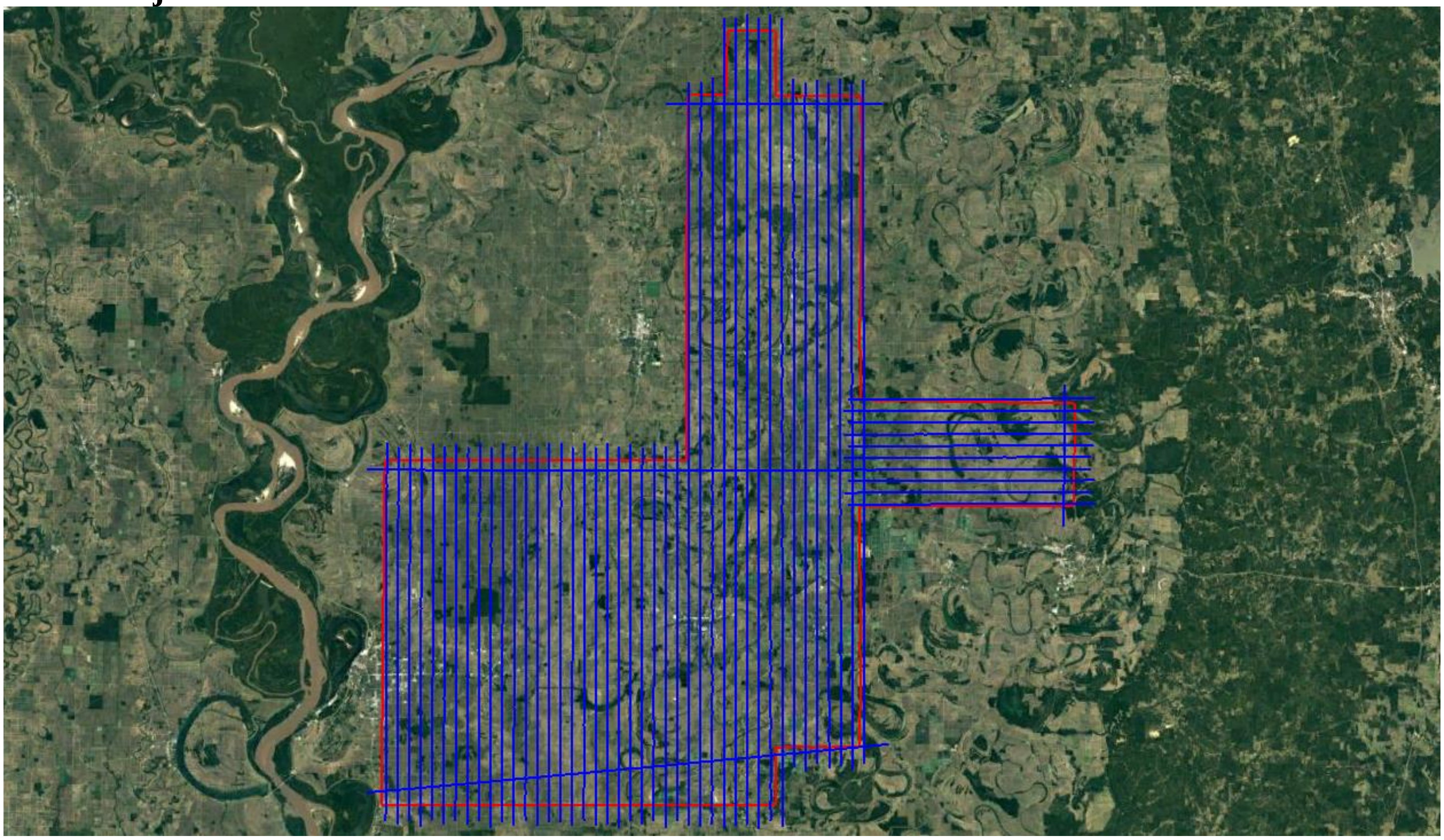


Figure 1: AOI and Trajectories As-Flown

2.0 ACQUISITION

2.1 Introduction

This section outlines the lidar system, flight reporting and data acquisition methodology used during the collection of the Mississippi Sunflower campaign. Although Sanborn conducts all lidar missions with the same rigorous and strict procedures and processes, all lidar collections are unique.

2.2 Acquisition Parameters

Sanborn specifically defined the collection parameters to accomplish the desired project specifications. **Table 1** shows the planned acquisition parameters utilized for this aerial survey with the sensor(s) installed.

Planned Acquisition Parameters	
Sensor	Leica City Mapper
Aircraft	N7139C – Piper Navajo
Flying Height (AGL)	2300m
Air Speed (kts)	150
Field of View (degrees)	40
Overlap (%)	30
Pulse Rate (kHz)	353500
Scan Rate (Hz)	100
Laser Footprint (m)	0.55
Mode (PIA)	6
Point Spacing (m)	0.6
Point Density (pls/m²)	2.7
Swath Width (m)	1674

Table 1: Lidar Acquisition Parameters

2.3 Field Work Procedures

Sanborn's standard procedure before every mission is to perform pre-flight checks to ensure correct operation of all systems. All cables were checked and the sensor head glass was cleaned. A five minute static session was conducted on the ground with the engines running prior to take-off in order to establish fine-alignment of the IMU and to resolve GNSS ambiguities.

The project acquisition consisted of four (4) missions. During the data collection, the operator recorded information on log sheets which includes weather conditions, lidar operation parameters, flight line statistics and PDOP. Near the end of each mission, GNSS ambiguities are again resolved by flying within ten kilometers of the base stations to aid in post-processing.

Preliminary data processing was performed in the field immediately following the missions for quality control of GNSS data and to ensure sufficient coverage of the project AOI. Any problematic data could then be re-flown immediately as required. Final data processing was completed in the Colorado Springs, CO office. **Table 2** below shows the flight acquisition metrics for the entire collection. **Table 3** contains the base station names and locations in operation during acquisition. Base station coordinates are provided in NAD83 (2011), Geographic Coordinate System, Ellipsoid, Meters.

Date	Sensor	Serial #	Tail #	MissionID	PDOP	Start (UTC)	End (UTC)
3/21/2018	Leica City Mapper	CM1014	N7139C	20180321_1	1.1	19:13:29	23:38:31
3/22/2018	Leica City Mapper	CM1014	N7139C	20180322_1	1.1	13:36:23	18:27:13
3/23/2018	Leica City Mapper	CM1014	N7139C	20180323_1	1.2	13:21:02	18:24:18
4/5/2018	Leica City Mapper	CM1014	N7139C	20180405_1	1.2	15:39:17	19:16:20

Table 2: Collection Date Time by Mission

Designation	Type	PID	Latitude (N)	Longitude (W)	Elevation
MSB5	CORS	DJ3657	34 06 52.25184	090 41 24.99226	25.466
MSB6	CORS	DJ3659	34 06 51.35585	090 41 24.94880	25.363
MSGN	CORS	DO9482	33 20 19.30467	091 02 27.43769	17.590

Table 3: GNSS Reference Station Coordinates

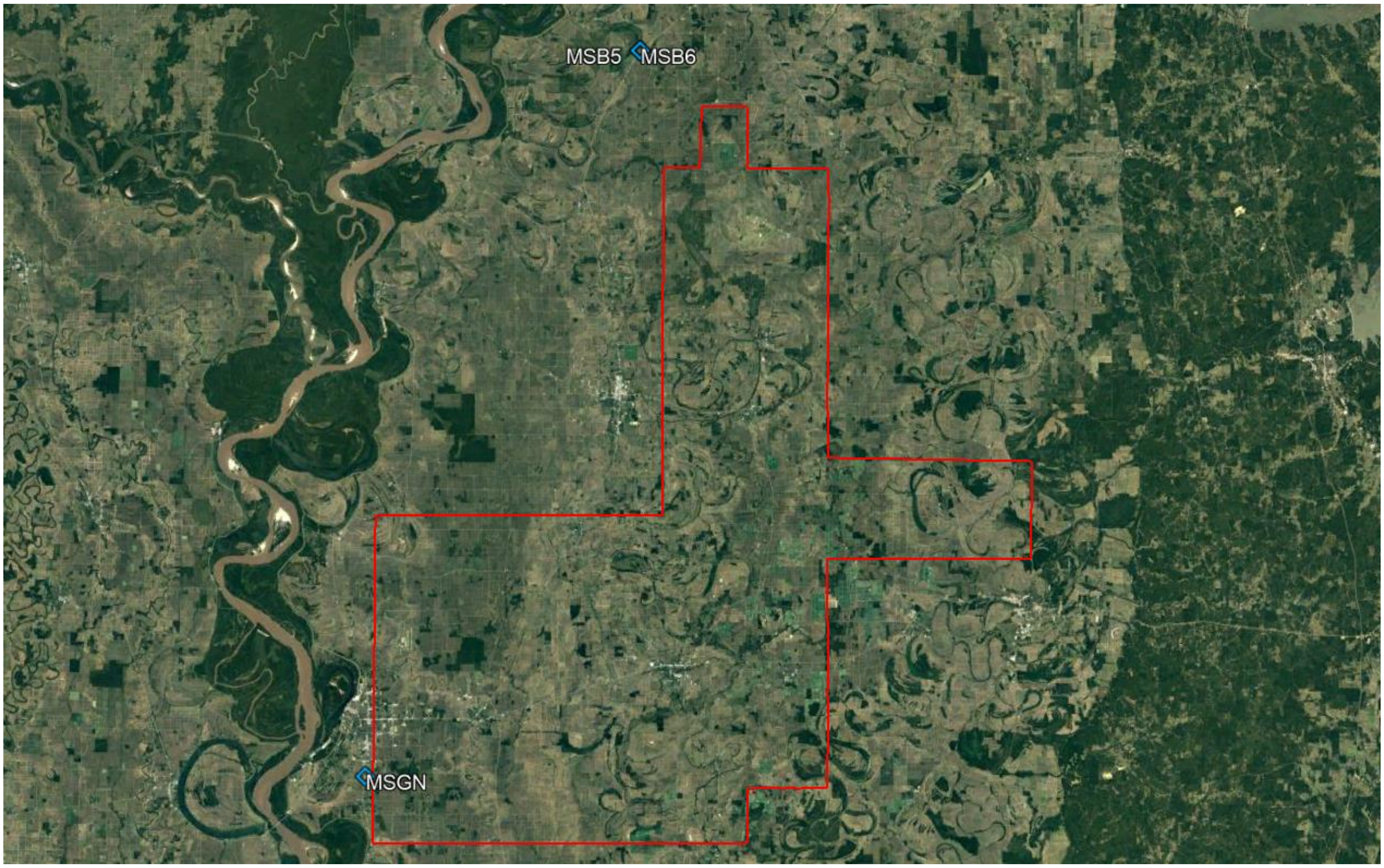


Figure 2: GNSS Reference Stations

3.0 PROCESSING

3.1 Introduction

The ABGNSS/IMU data was post-processed using Waypoint Inertial Explorer software to create Smoothed Best Estimate Trajectory (SBET) file(s). Please see **Appendix A** for an in depth assessment of the processed airborne trajectories. The SBET was then combined with the laser range measurements in Leica HxMap software to produce the 3-dimensional coordinates resulting in an accurate set of Raw Point Cloud (RPC) mass points. These raw swath (*.las) files are output in WGS84, UTM, Ellipsoid, Meters and transformed to the project Coordinate Reference System (CRS) upon ingest into GeoCue before project wide calibration.

The Optech-LMS pre-processing software created raw swath files with all return values. This multi-return information was processed and classified to obtain the required feature for delivery. All lidar data is processed using the ASPRS binary LAS format version 1.4. **Table 4** illustrates the achieved point cloud statistics.

Category	Value
Total Points	15,913,770,164
Nominal Pulse Spacing (m)	0.60
Nominal Pulse Density (pls/m²)	2.7
Nominal Pulse Spacing (ft)	1.98
Nominal Pulse Density (pls/ft²)	0.3
Aggregate Total Points	13,589,252,433
Aggregate Nominal Pulse Spacing (m)	0.53
Aggregate Nominal Pulse Density (pls/m²)	3.6
Aggregate Nominal Pulse Spacing (ft)	1.73
Aggregate Nominal Pulse Density (pls/ft²)	0.3

Table 4: Point Cloud Statistics

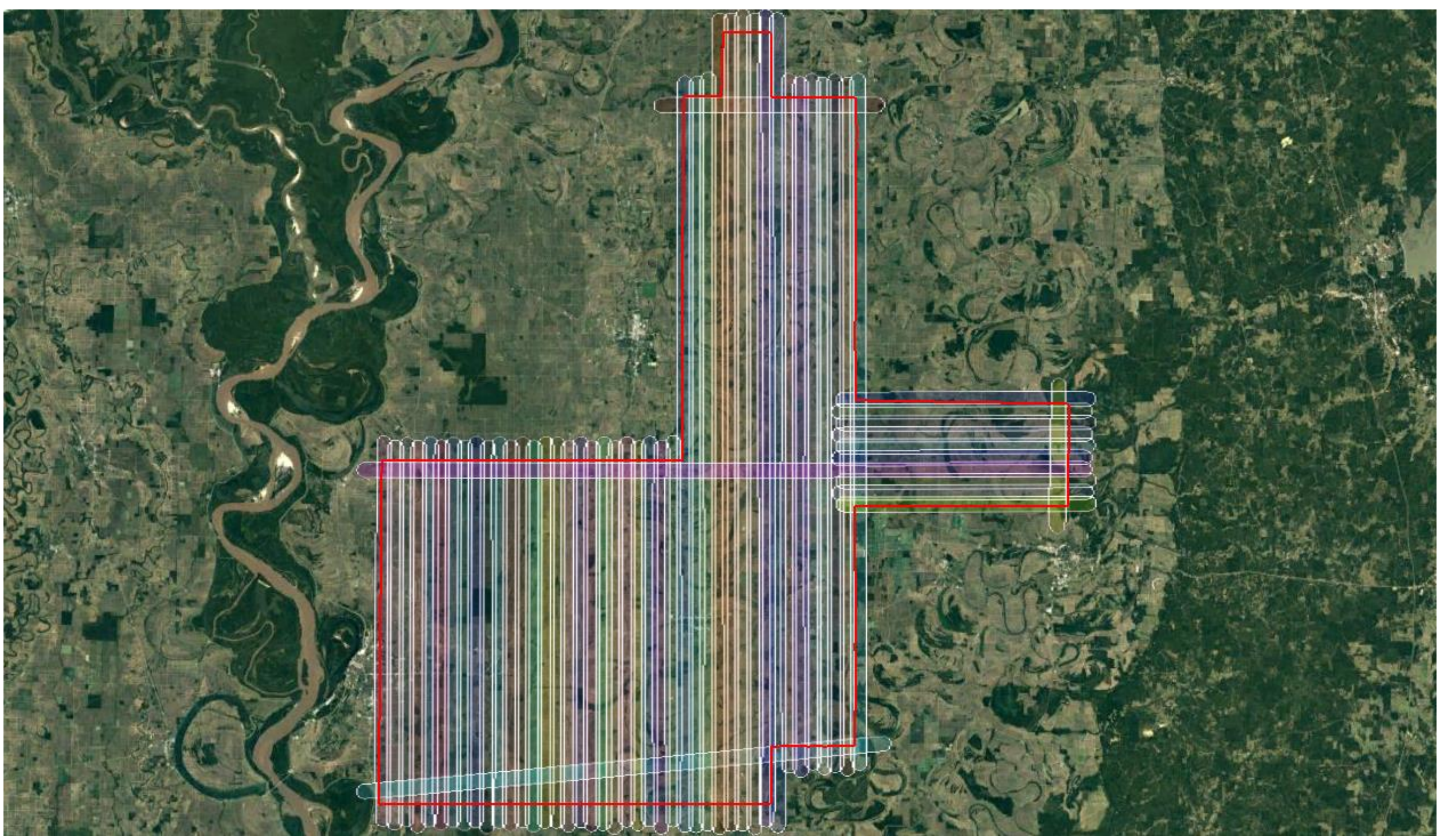


Figure 3: Raw Point Cloud Coverage

3.2 Coordinate Reference System

Horizontal Datum:	North American Datum of 1983 (2011)
Projection:	Universal Transverse Mercator Zone 15 North
Vertical Datum:	North American Vertical Datum of 1988
Geoid Model:	Geoid12B
Units:	Meters

3.3 Calibration

Sanborn uses Leica HxMap and the latest boresight values to combine the processed SBET with the laser scan files to produce the lidar point cloud. The data is processed by mission and is output in ASPRS LASv1.4 Point Data Record Format (PDRF) 6 with 16bit linearly scaled intensities to the nearest 0.001 3D position. Each mission is produced in WGS84, UTM, Ellipsoid, Meters and transformed to the project CRS upon import into GeoCue.

Each mission in imported into GeoCue where each individual flight line is assigned a unique flight line number. The SBET is cut per mission into TerraScan Trajectory files based on flight line number and timestamp to be utilized during the calibration process. The project area(s) are broken into logical blocks based on AOIs or predetermined delivery blocks and the individual flight lines are populated into calibration tile grids. These calibration tile grids are prepared for scanner, line, mission, block and eventual project wide calibration routines by first running point cloud filters to identify ground and building features to be used during TerraMatch processes.

After successful point cloud filters have been run on the calibration dataset TerraMatch is used to extract Tie Line Observations. TerraMatch Tie Lines are 3D vectors extracted from the lidar points cloud intended to reduce the overwhelming data size to a more manageable amount. Each Tie Line is extracted using a series of parameters designed to identify features such a flat or sloping ground or roofline apexes that geospatially correlates to the same observation of an overlapping flight line. These collected 3D vectors are then utilized across multiple iterations to reduce the average offset from line to line, mission to mission, and block to block. TerraMatch Solutions are calculated to adjust Roll, Heading, Pitch, X, Y and Z in combination to reduce the Root Mean Square Deviation (RMSDr and RMSDz). These solutions are calculated, applied, and checked throughout the calibration process.

Sanborn takes advantage of both visual and statistical validation methodologies to review and ensure overlap consistency of the lidar data meets and/or exceeds project specifications. Differential Elevation (dZ) rasters are color ramp (Dark Green, Green, Yellow, Orange, Red) based visual representations produced to identify vertical offsets between flight lines. The dZ rasters are reviewed in their entirety for flight lines and areas that exceed the required RMSDz. Furthermore, an additional set of TerraMatch Tie Lines are produced after corrections are applied and a Tie Line Report is produced to assess the X. Y. and Z offset averages for each line and the project. This visual and statistical review guarantees the relative accuracy of the lidar dataset. **Table 5** outlines the relative accuracy requirements of the project. **Tables 6 – 9** are the relative accuracies achieved.

Category	Value
Smooth Surface Repeatability (m)	≤0.06
Swath overlap difference, RMSDz (m)	≤0.08
Swath overlap difference, Maximum (m)	±0.16

Table 5: Relative Accuracy Requirements

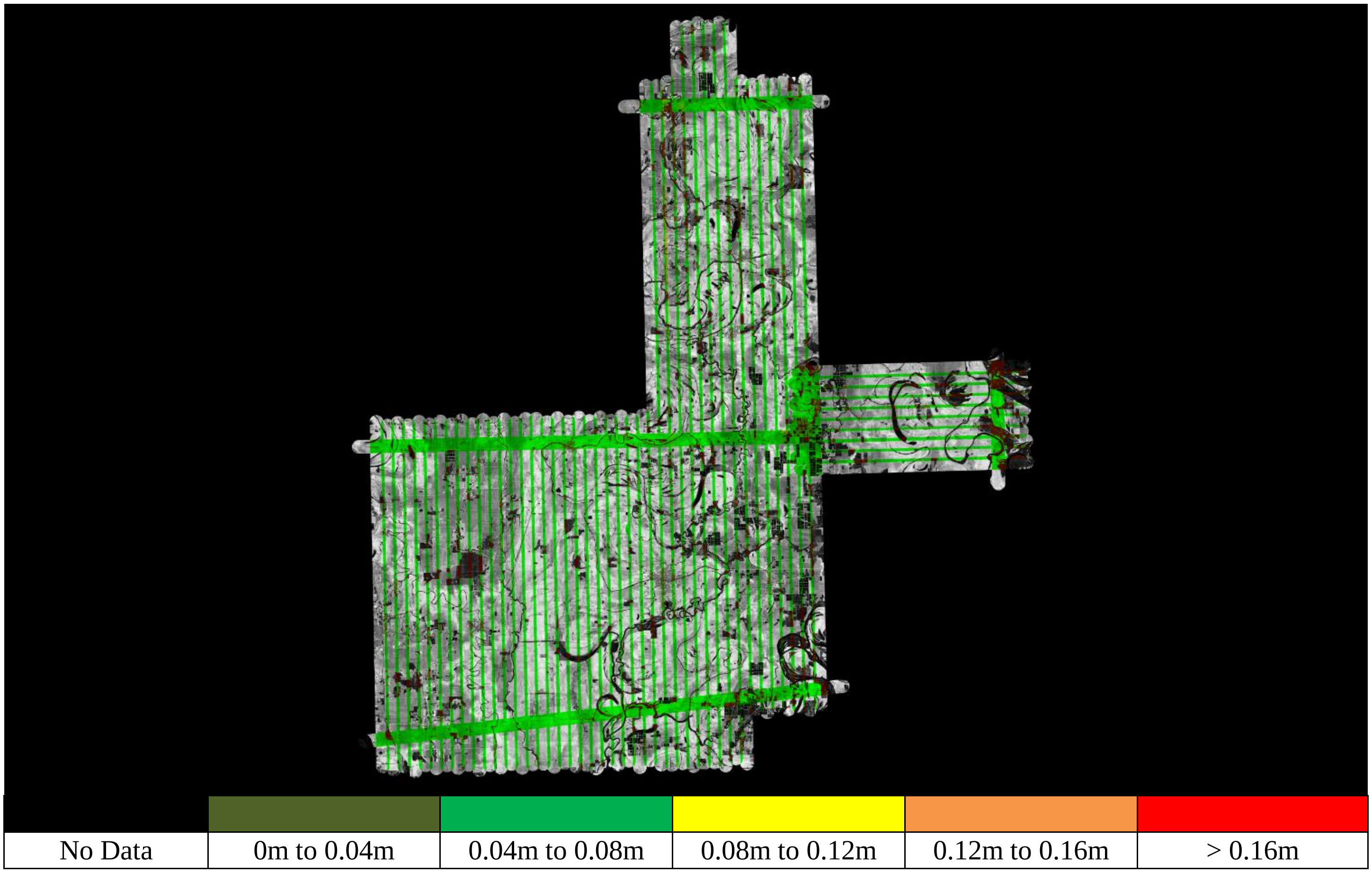


Figure 4: dZ Rasters

Line	X	Y	Z	Line	X	Y	Z	Line	X	Y	Z
1	0.015	0.023	0.012	**20**	0.018	0.034	0.011	**39**	0.027	0.045	0.014
2	0.014	0.018	0.022	**21**	0.023	0.030	0.014	**40**	0.038	0.033	0.015
3	0.023	0.025	0.035	**22**	0.028	0.036	0.012	**41**	0.027	0.028	0.033
4	0.032	0.037	0.014	**23**	0.023	0.028	0.029	**42**	0.013	0.023	0.022
5	0.024	0.030	0.025	**24**	0.030	0.033	0.012	**43**	0.018	0.010	0.042
6	0.011	0.012	0.018	**25**	0.022	0.030	0.014	**44**	0.025	0.025	0.014
7	0.014	0.013	0.011	**26**	0.021	0.018	0.015	**45**	0.014	0.020	0.017
8	0.022	0.021	0.019	**27**	0.012	0.024	0.011	**46**	0.024	0.016	0.021
9	0.029	0.032	0.010	**28**	0.032	0.010	0.016	**47**	0.012	0.013	0.012
10	0.024	0.028	0.021	**29**	0.021	0.025	0.015	**48**	0.018	0.008	0.016
11	0.014	0.015	0.033	**30**	0.020	0.028	0.023	**49**	0.019	0.011	0.009
12	0.015	0.015	0.021	**31**	0.034	0.052	0.012	**50**	0.011	0.016	0.010
13	0.014	0.028	0.017	**32**	0.022	0.030	0.016	**51**	0.012	0.018	0.017
14	0.020	0.046	0.016	**33**	0.017	0.024	0.020	**52**	0.034	0.046	0.019
15	0.027	0.039	0.016	**34**	0.019	0.025	0.014	**53**	0.040	0.019	0.016
16	0.023	0.019	0.031	**35**	0.028	0.036	0.011	**54**	0.013	0.008	0.013
17	0.020	0.039	0.014	**36**	0.031	0.059	0.022	**55**	0.016	0.009	0.018
18	0.014	0.026	0.015	**37**	0.028	0.069	0.031				
19	0.016	0.023	0.038	**38**	0.027	0.046	0.016				

Table 6: Average Magnitudes by Line (Meters)

Category	X	Y	Z
Average Magnitude	0.019	0.025	0.019
RMS Values	0.028	0.040	0.024
Maximum Values	0.149	0.159	0.157
Observation Weight	6823.0	6823.0	635732.0

Table 7: Internal Observation Statistics (Meters)

Category	Mismatch
Average 3D Mismatch	0.01890
Average XY Mismatch	0.03859
Average Z Mismatch	0.01857

Table 8: Overall Relative Accuracy (Meters)

Category	Observations
Section Lines	255,253
Roof Lines	3,353

Table 9: Vector Observations

3.4 Lidar Classification

Lidar filtering was accomplished using GeoCue with TerraSolid processing and modeling software. The filtering process reclassifies all the data into classes with in the point cloud file based scheme. Once the data is classified, the entire dataset is reviewed and manually edited for anomalies that are outside the required guidelines of the product specification or contract requirements. This can include, but is not limited to, removing bridges, structures, filling culverts, and manually analyzing the bare-earth surface by classifying features that belong in non-extraneous classification codes. **Table 10** outlines the point classes leveraged in the lidar dataset.

Code	Description	Definition
1	Unclassified	Processed, but unclassified
2	Ground	Bare-earth surface
7	Low Noise	Erroneous returns below bare-earth surface
9	Water	Hydrologically identified water surface points
10	Ignored Ground	Bare-earth points near breaklines excluded from
17	Bridge Decks	Structure carrying a means of transit of higher
18	High Noise	Erroneous atmospheric returns above bare-earth
Flag	Overlap	Overage points lying within overlapping areas of two or more swaths
Flag	Withheld	Outliers, blunders, noise points, geometrically unreliable points near the extreme edge of the swath

Table 10: Lidar Classification Scheme

3.5 Accuracy Assessment

The lidar dataset was evaluated using a total of one hundred and sixteen (116) check points (63 NVA + 53 VVA). The end result provided an RMSEz that fell within project specifications. Please see the **Attachment A** for the full Vertical Accuracy Report and the project **Metadata** for an in-depth accuracy assessment. **Table 11** outlines the absolute accuracy requirements of the project. **Table 12** shows high level statistics and mean errors for the area processed by Sanborn.

Category	Value
RMSEz (m)	≤0.10
@ 95-percent confidence level (m)	≤0.294

Table 11: Absolute Accuracy Requirements

Broad Land Cover Type	# of Points	RMSEz	95% Confidence Level	95th Percentile
NVA of Point Cloud	63	0.055	0.107	
NVA of Bare Earth	63	0.055	0.108	
NVA of DEM	63	0.054	0.107	
VVA of Bare Earth	53	0.123		0.192
VVA of DEM	53	0.178		0.179

Table 12: Vertical Accuracy Assessment of Check Points (Meters)

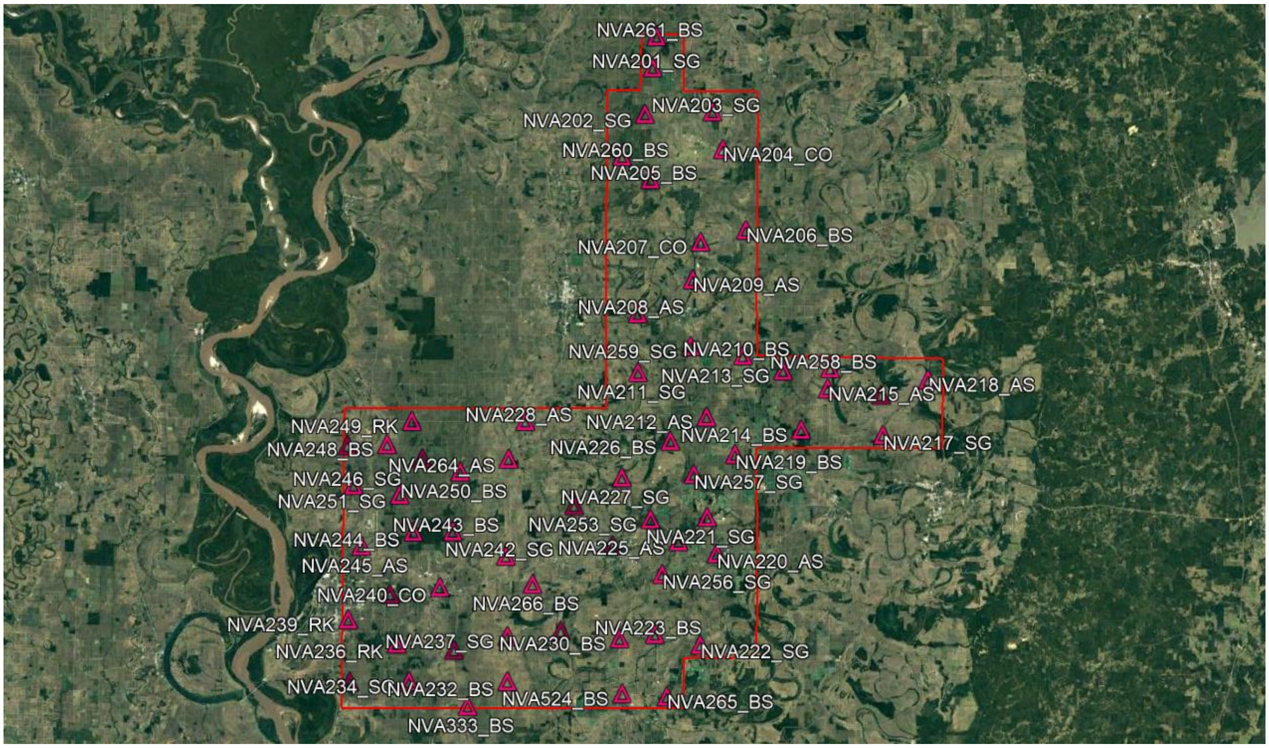


Figure 5: Non-vegetated Check Point Distribution

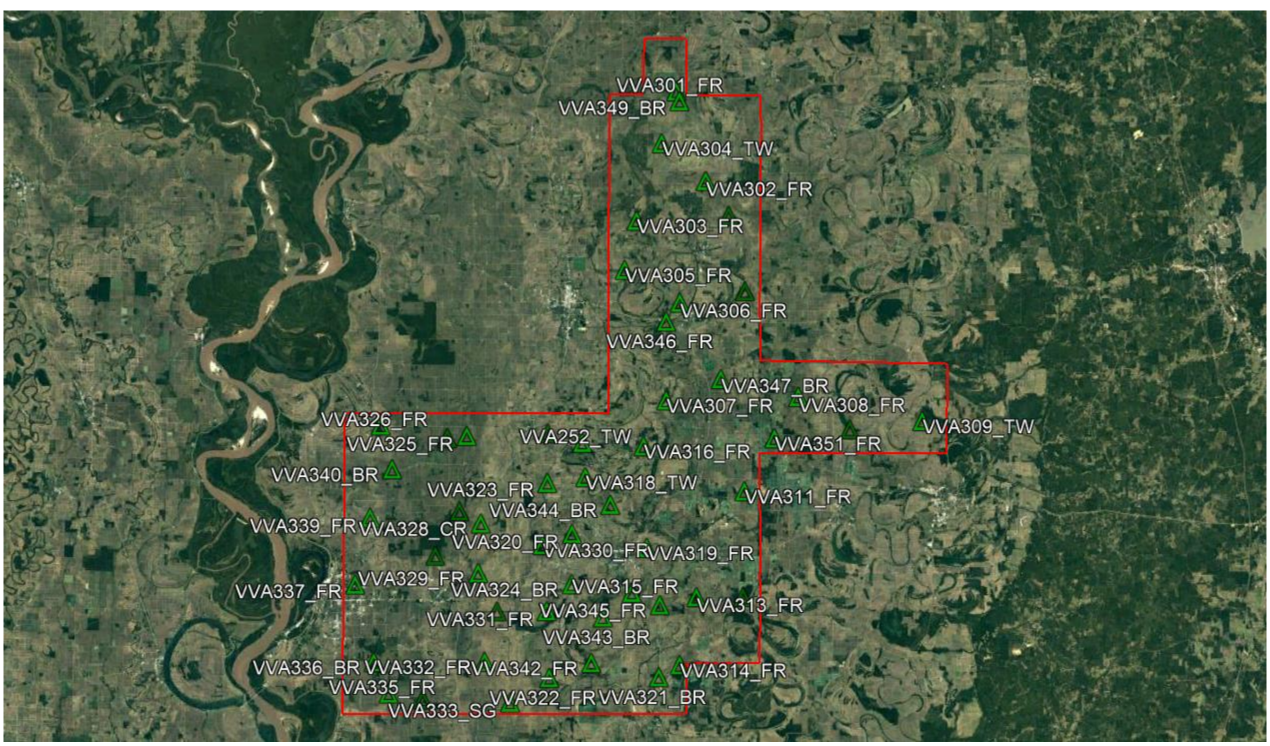


Figure 6: Vegetated Check Point Distribution

4.0 PRODUCT GENERATION

Once the lidar surface was finalized and manually QC'd for anomalies, the required deliverables were then generated and/or organized. The following products were generated using the final coordinate system as defined in the contract, and provided in section 4.0 of this report.

Classified Point Cloud
The Classified Point Cloud, containing all returns, is delivered in LASv1.4 (*.las) format and meets project specifications. The Classified Point Cloud contains file names referencing the tile index.

Bare-Earth Digital Terrain Model
32-bit ERDAS Imagine (*.img) 1m elevation rasters were created from the bare-earth points in the processed lidar dataset. Each pixel contains an elevation value interpolated from the lidar.

First-Return Digital Surface Model
32-bit ERDAS Imagine (*.img) 1m elevation rasters were created from the first-return points in the processed lidar dataset. Each pixel contains an elevation value interpolated from the lidar.

Intensity Rasters
8-bit GeoTIFF (*.tiff) 1m intensity rasters were created from the first-return points in the processed lidar dataset.

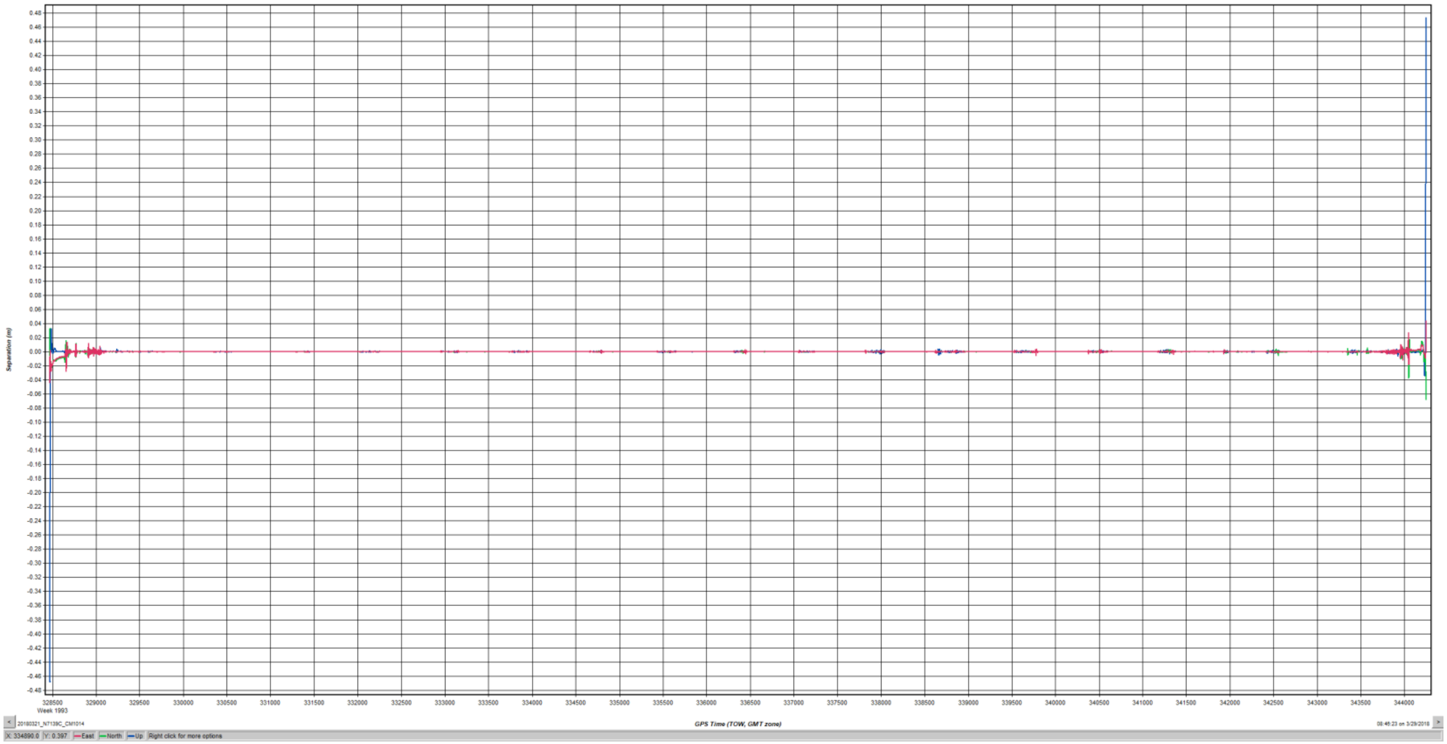
Other Deliverables
Vertical Accuracy Report
Metadata

A final QC process was undertaken to validate all deliverables for the project. Prior to release of data for delivery, Sanborn's Quality control/quality assurance department reviews the data and then releases it for delivery.

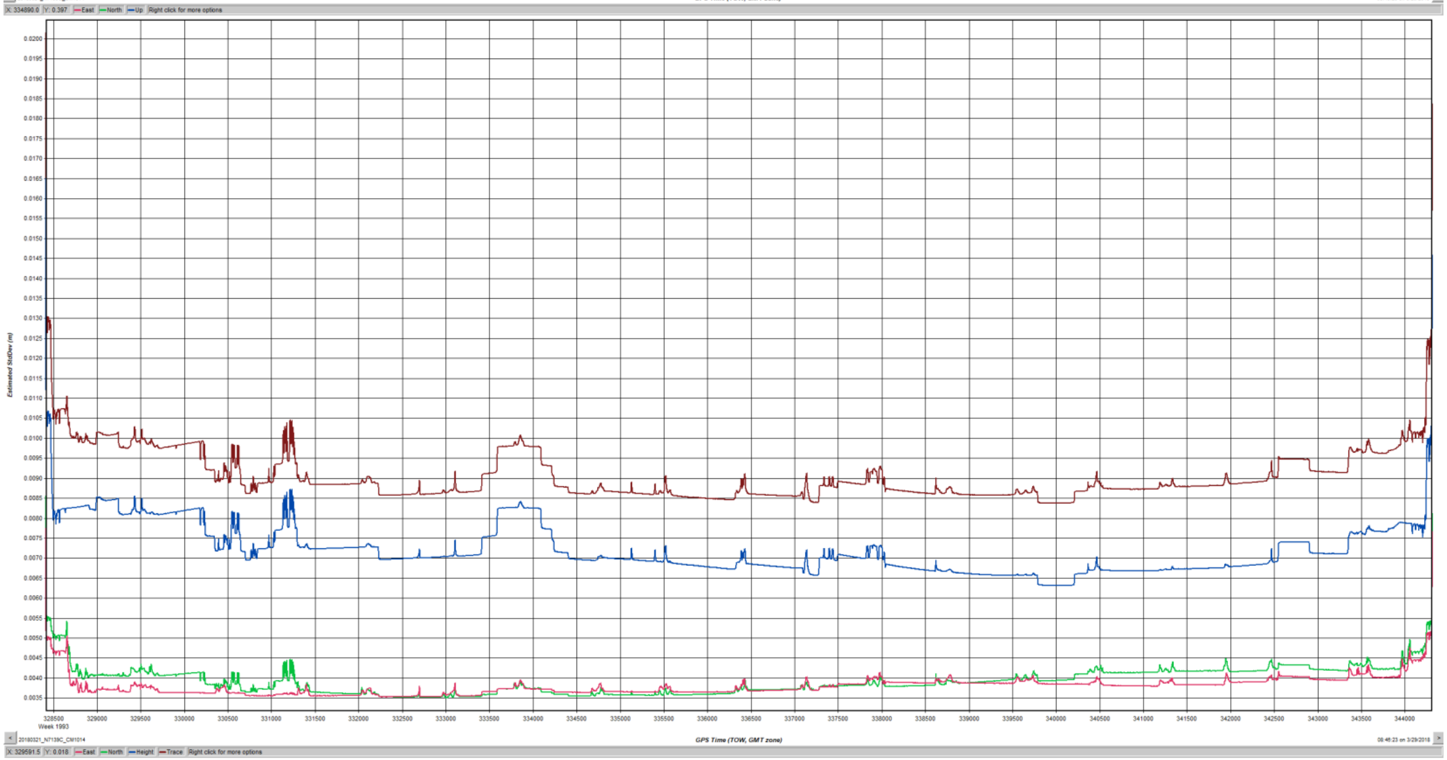
APPENDIX A – ABGNSS/IMU PLOTS

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.
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.
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.

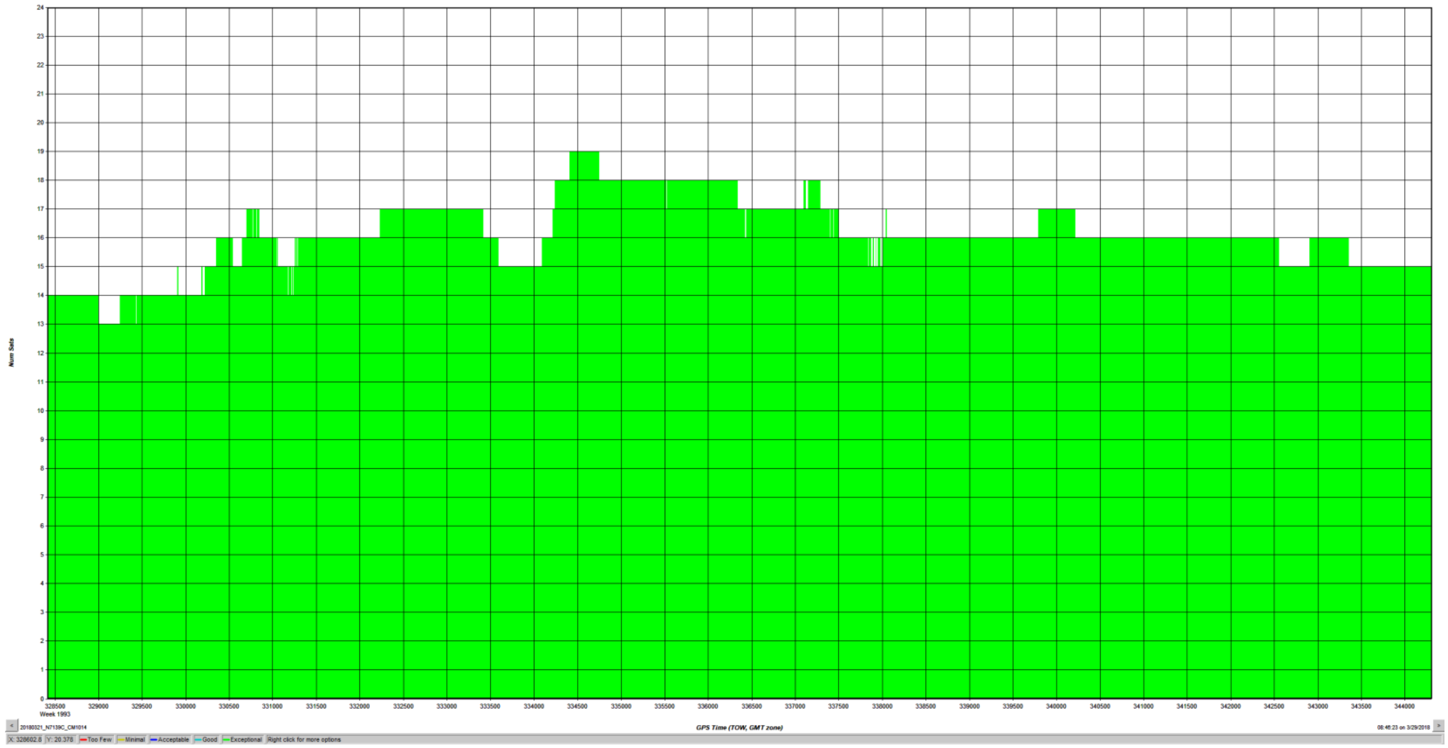
20180321_1



Separation (m)
GPS Time (TOW, GMT zone)
Week 1993
East
North
Up
Right click for more options



Estimated StdDev (m)
GPS Time (TOW, GMT zone)
Week 1993
East
North
Height
Trace
Right click for more options


Num Sats
Week 1993
20180321_N7139C_CM1014
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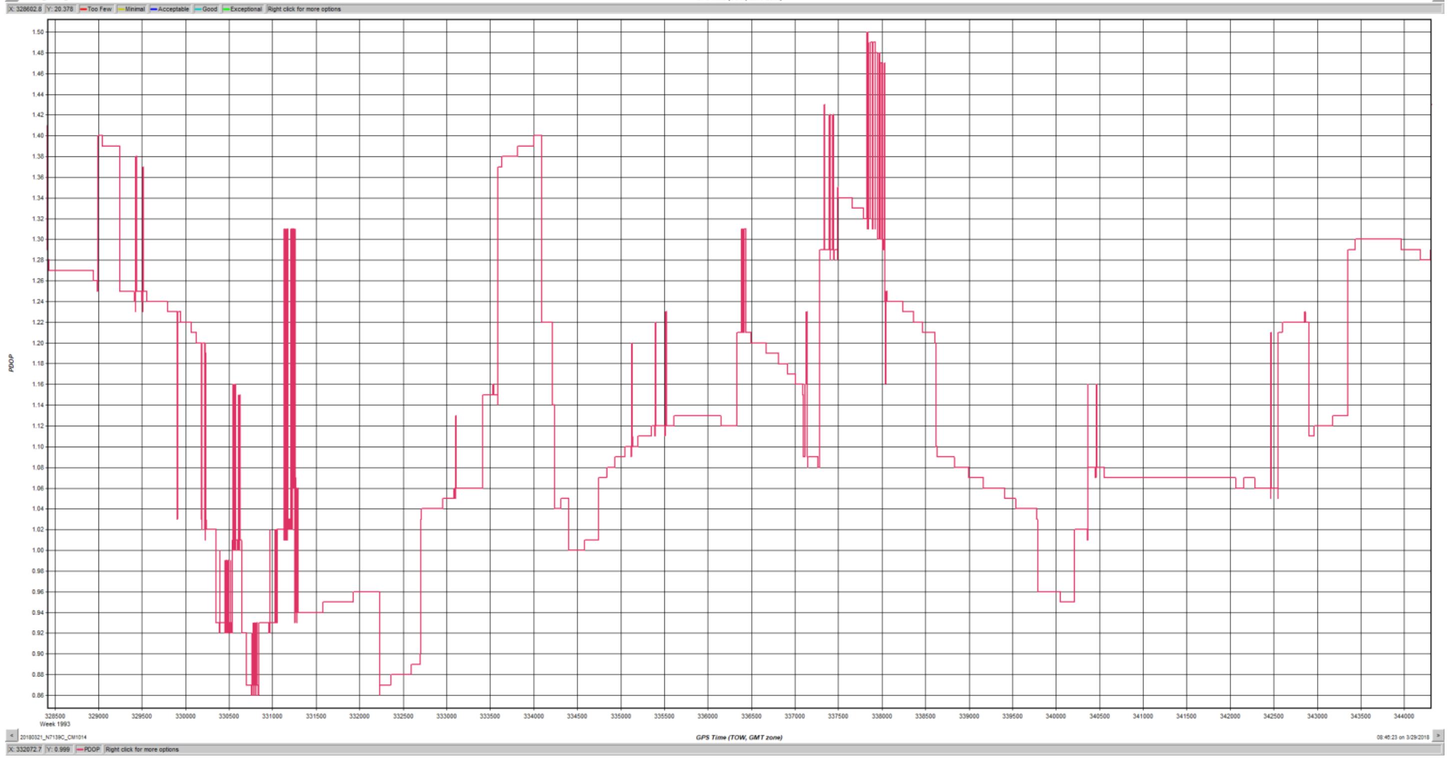
Y: 20.378
Too Few
Minimal
Acceptable
Good
Exceptional
Right click for more options


PDOP
Week 1993
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GPS Time (TOW, GMT zone)
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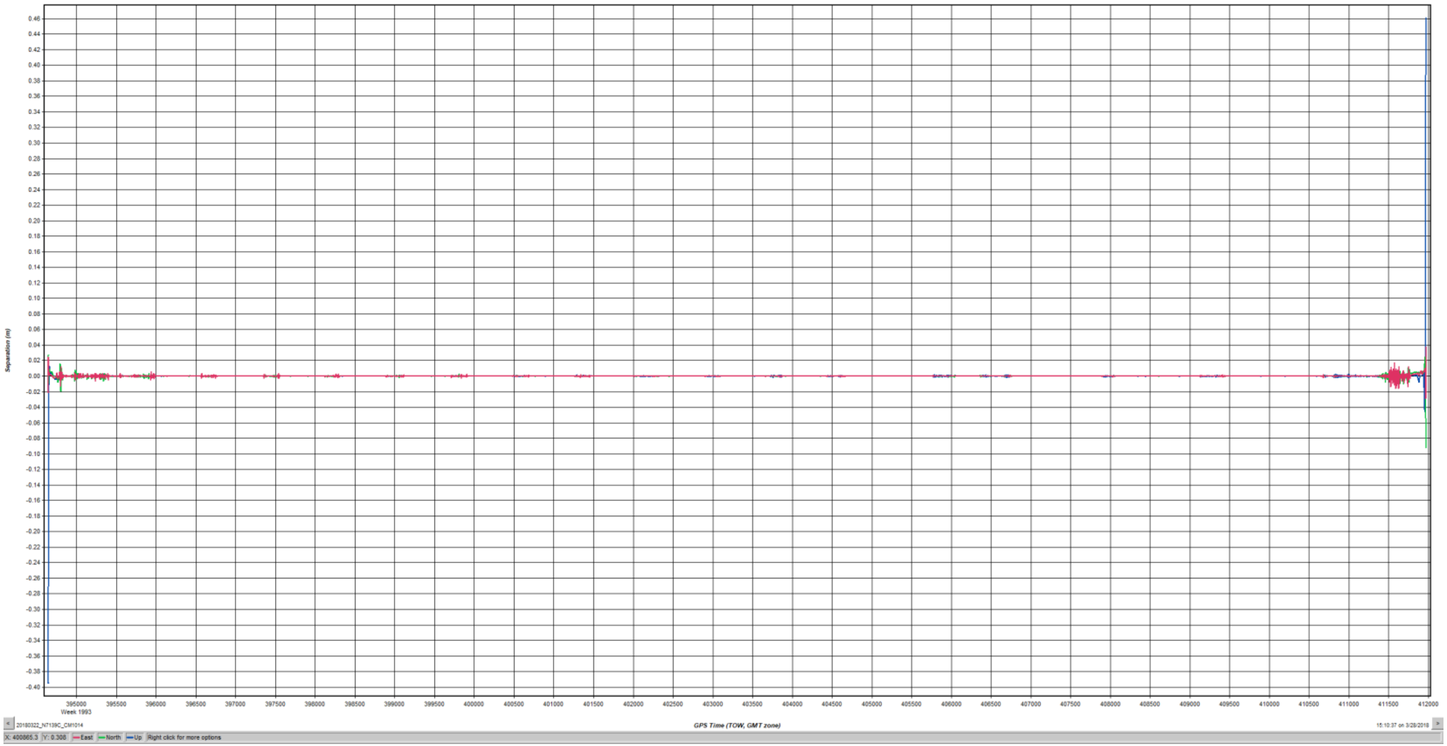
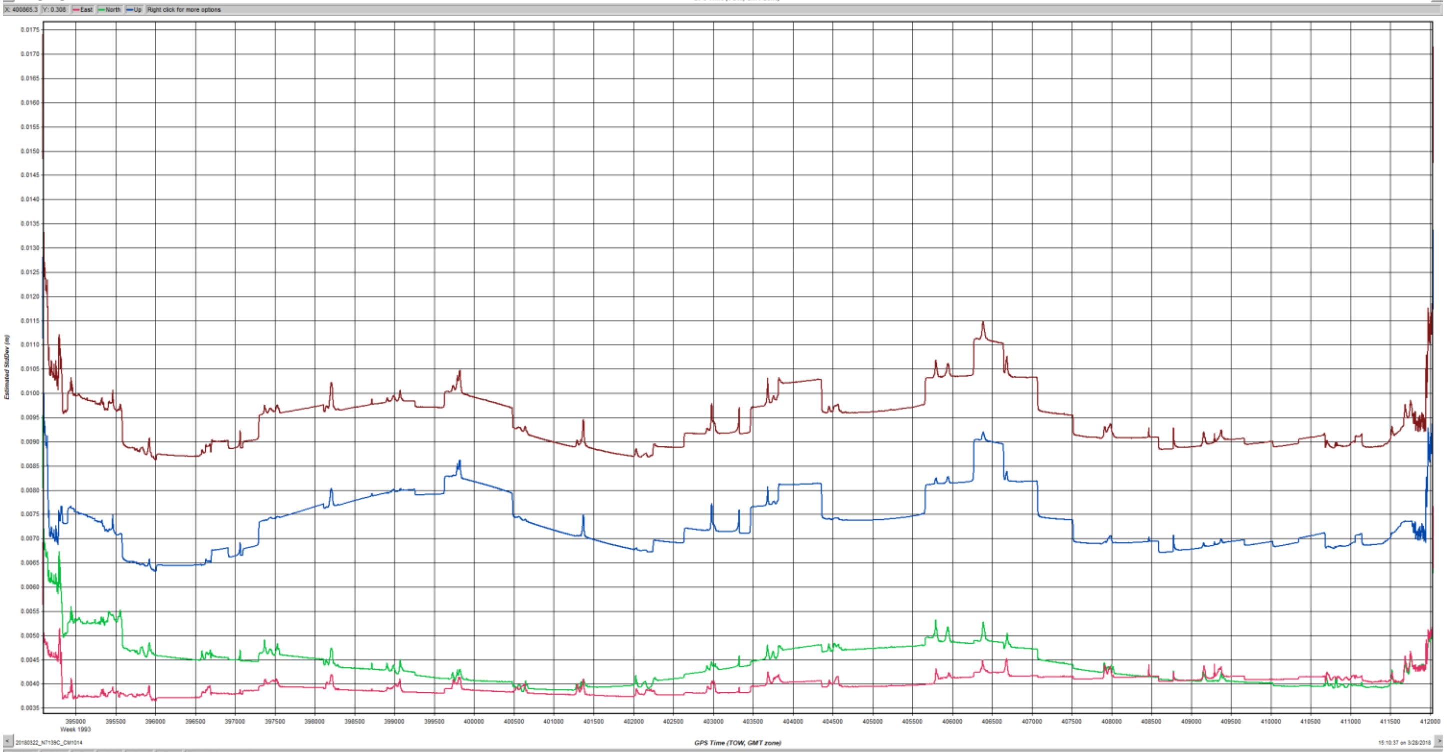
Y: 0.999
PDOP
Right click for more options

20180322_1


Separation (m)
GPS Time (TOW, GMT zone)
East
North
Up
Right click for more options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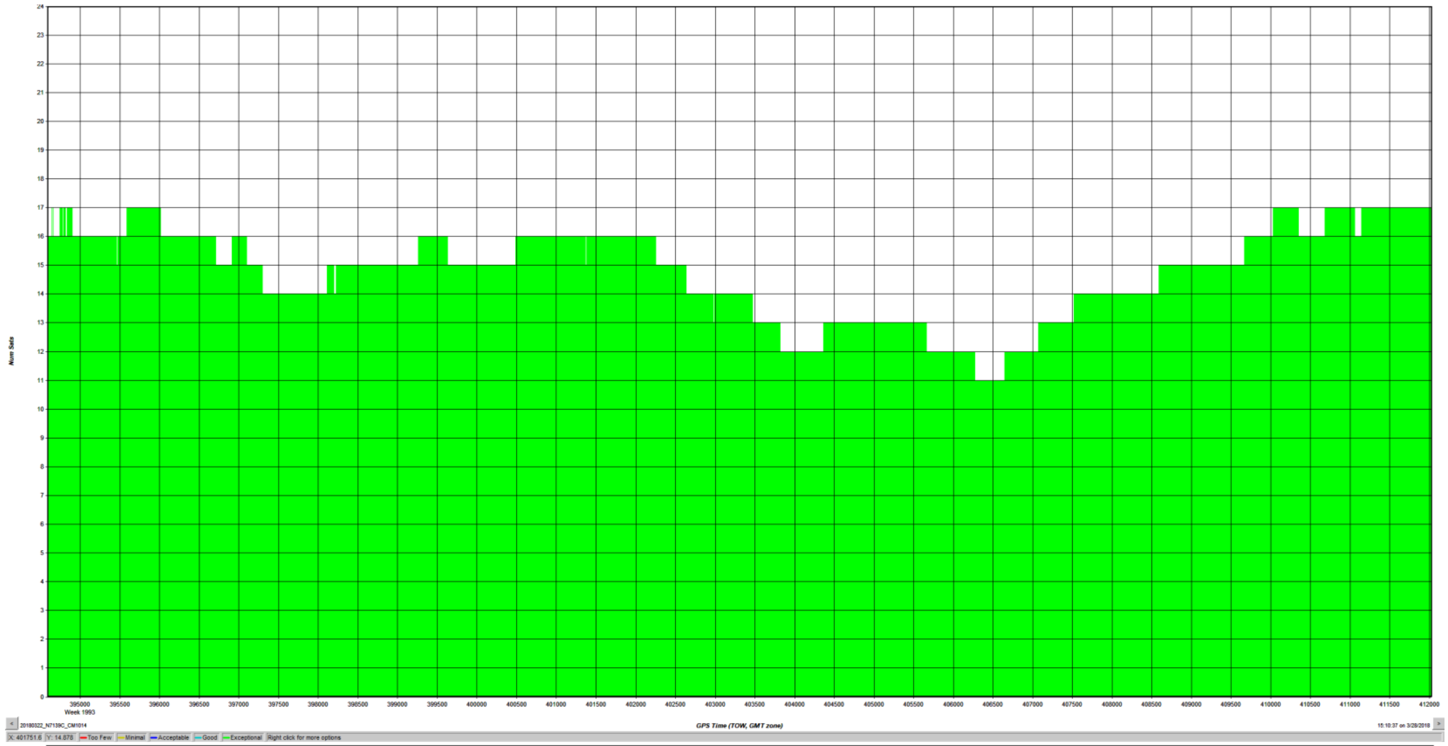
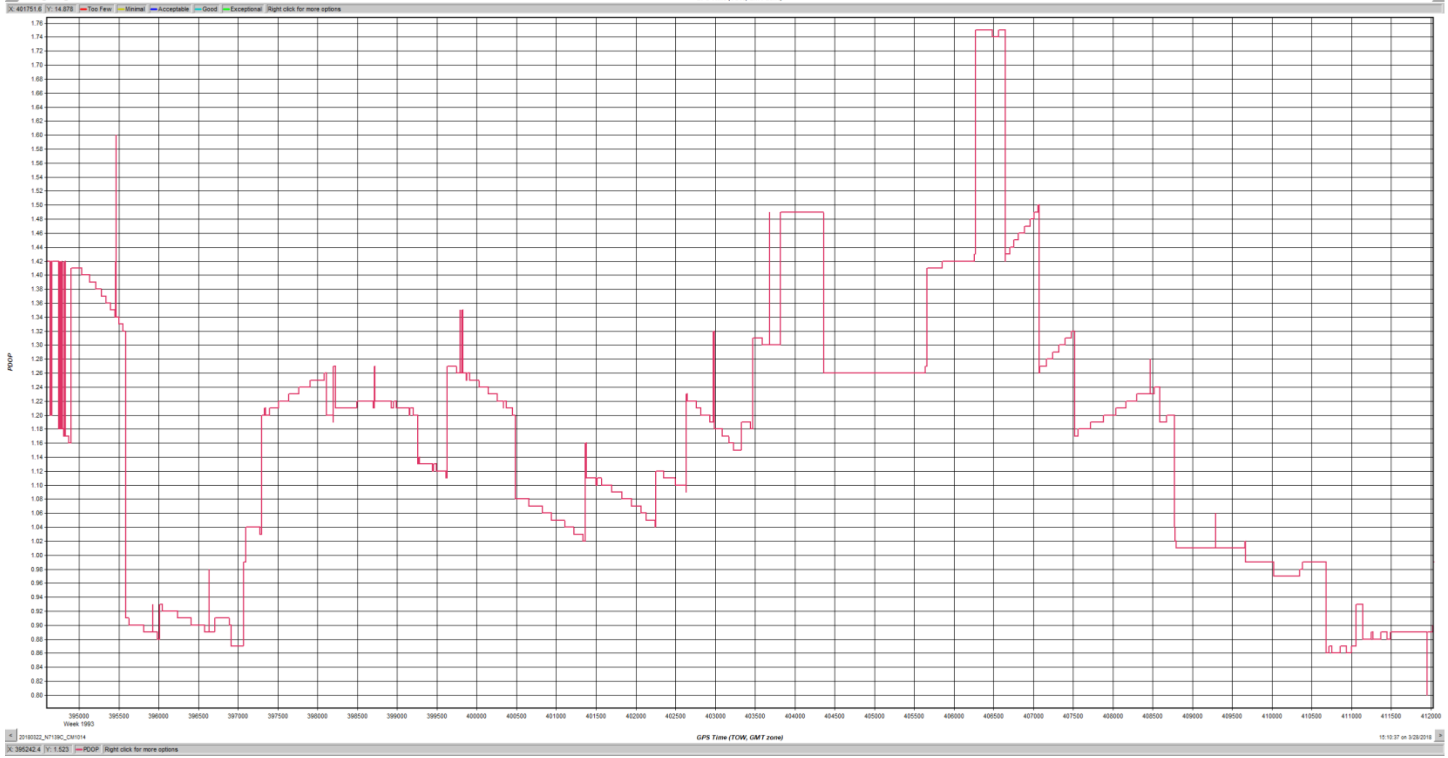
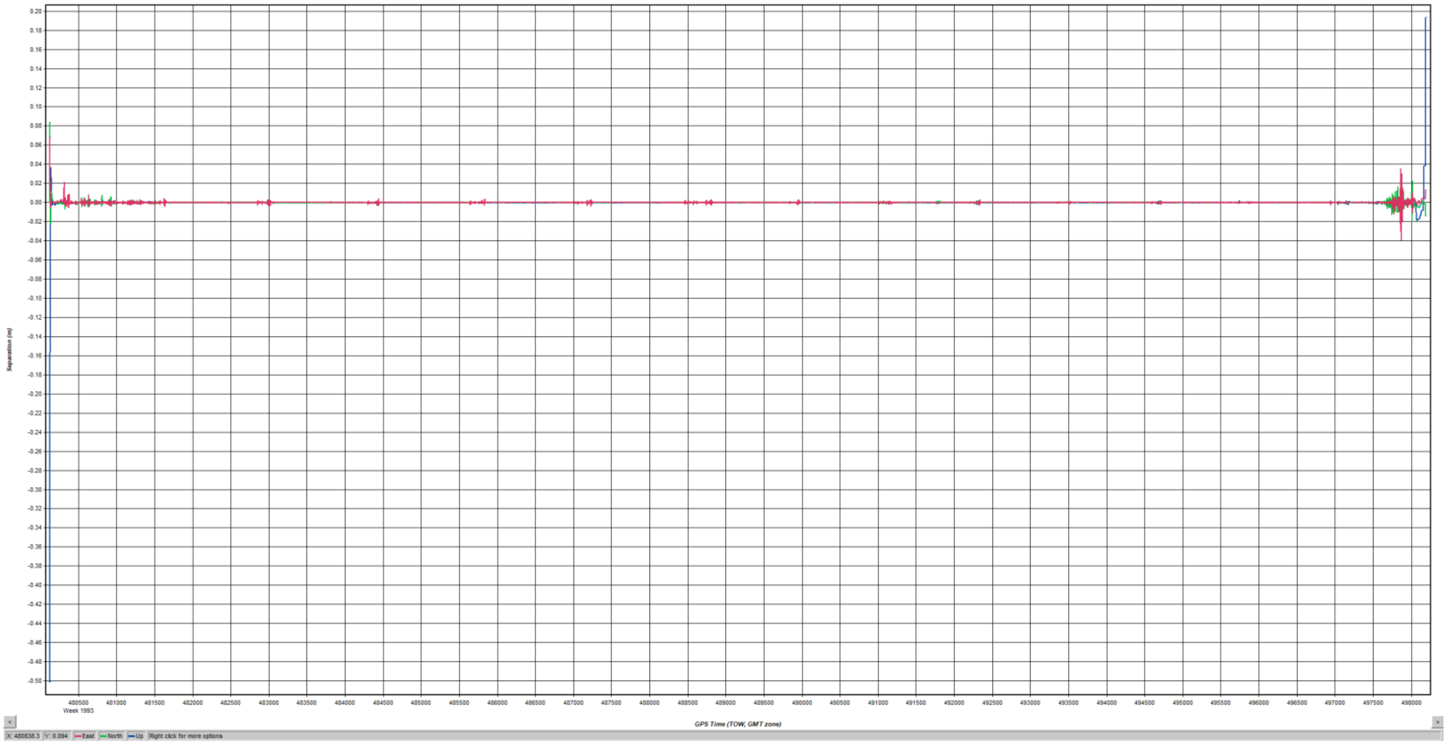
GPS Time (TOW, GMT zone)
East
North
Height
Trace
Right click for more options

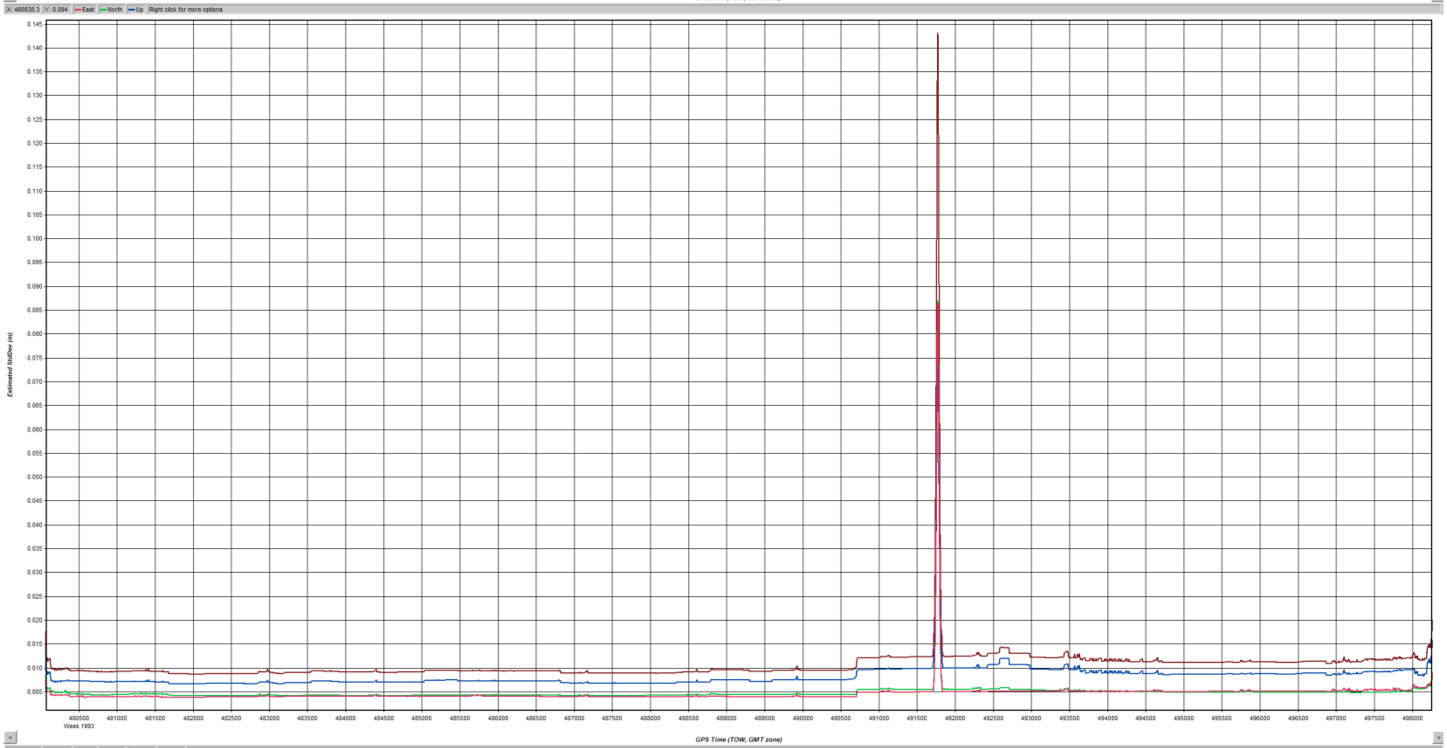

Num Sats
GPS Time (TOW, GMT zone)


PDOP
GPS Time (TOW, GMT zone)

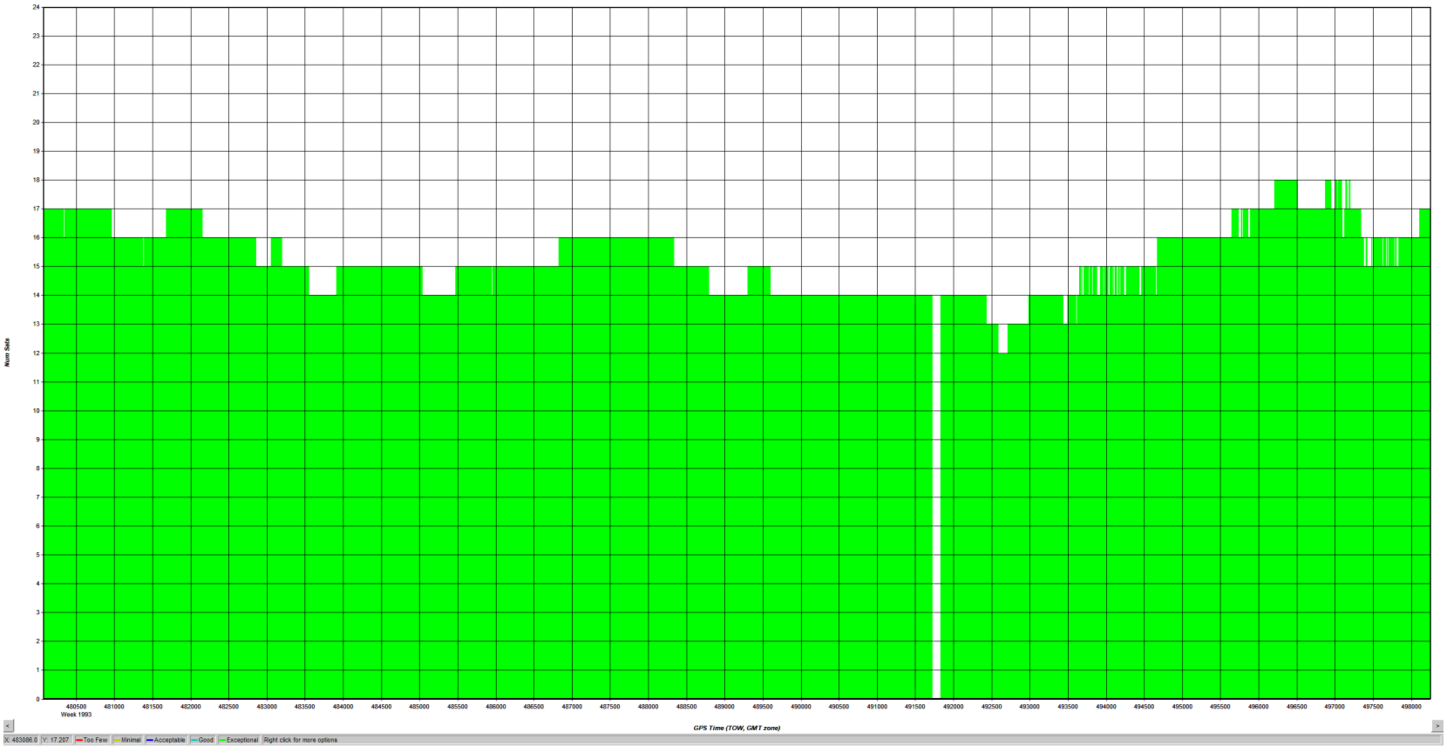
20180323_1

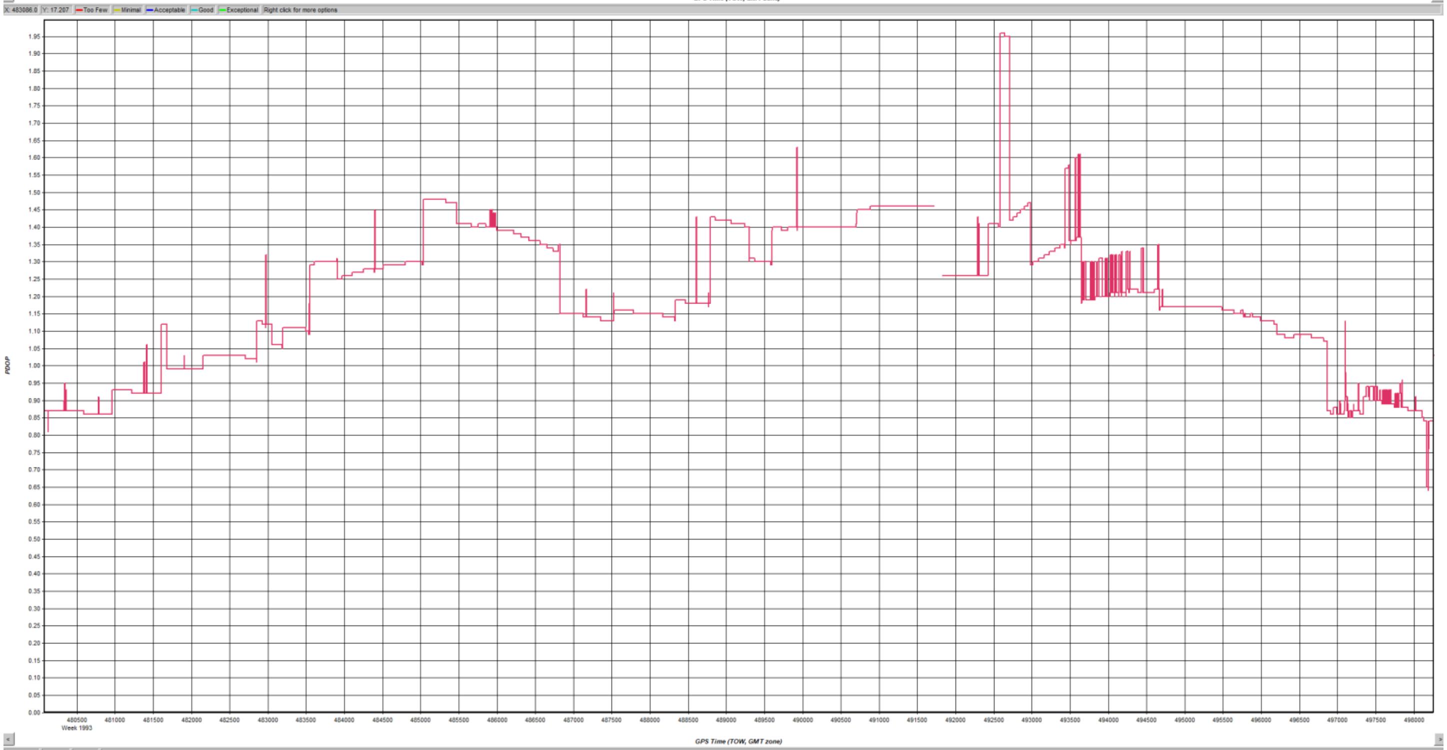


Separation (m)
GPS Time (TOW, GMT zone)
Week 1993
East
North
Up
Right click for more options

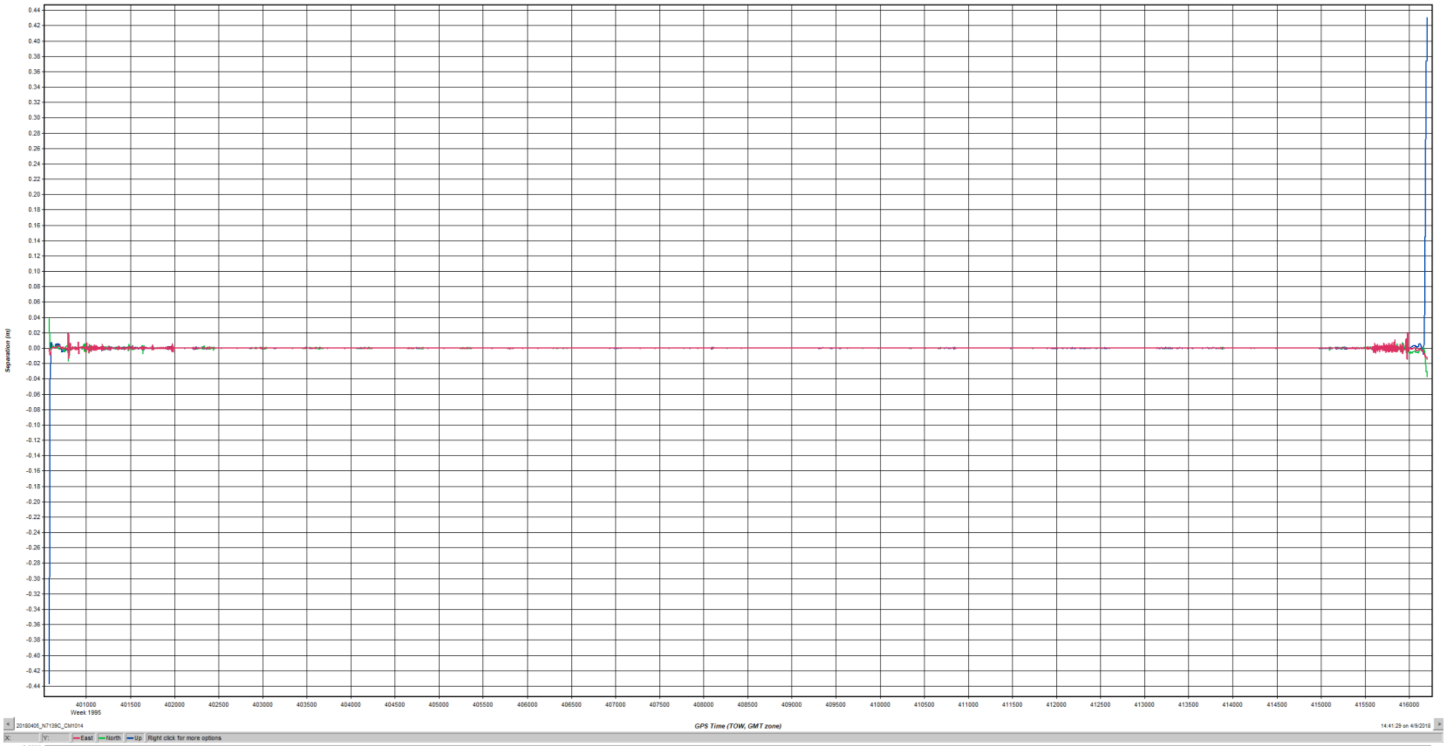


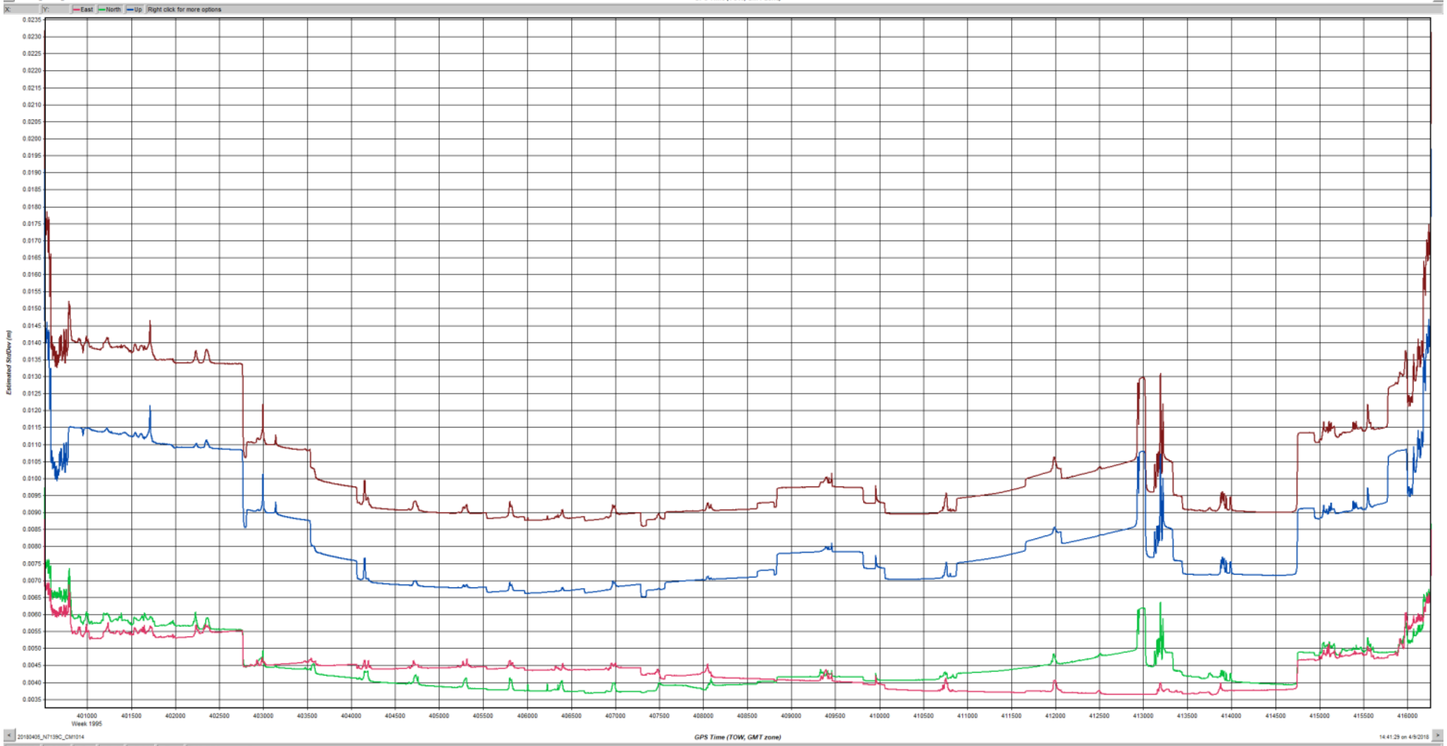
Estimated StdDev (m)
GPS Time (TOW, GMT zone)
Week 1993
East
North
Height
Trace
Right click for more options

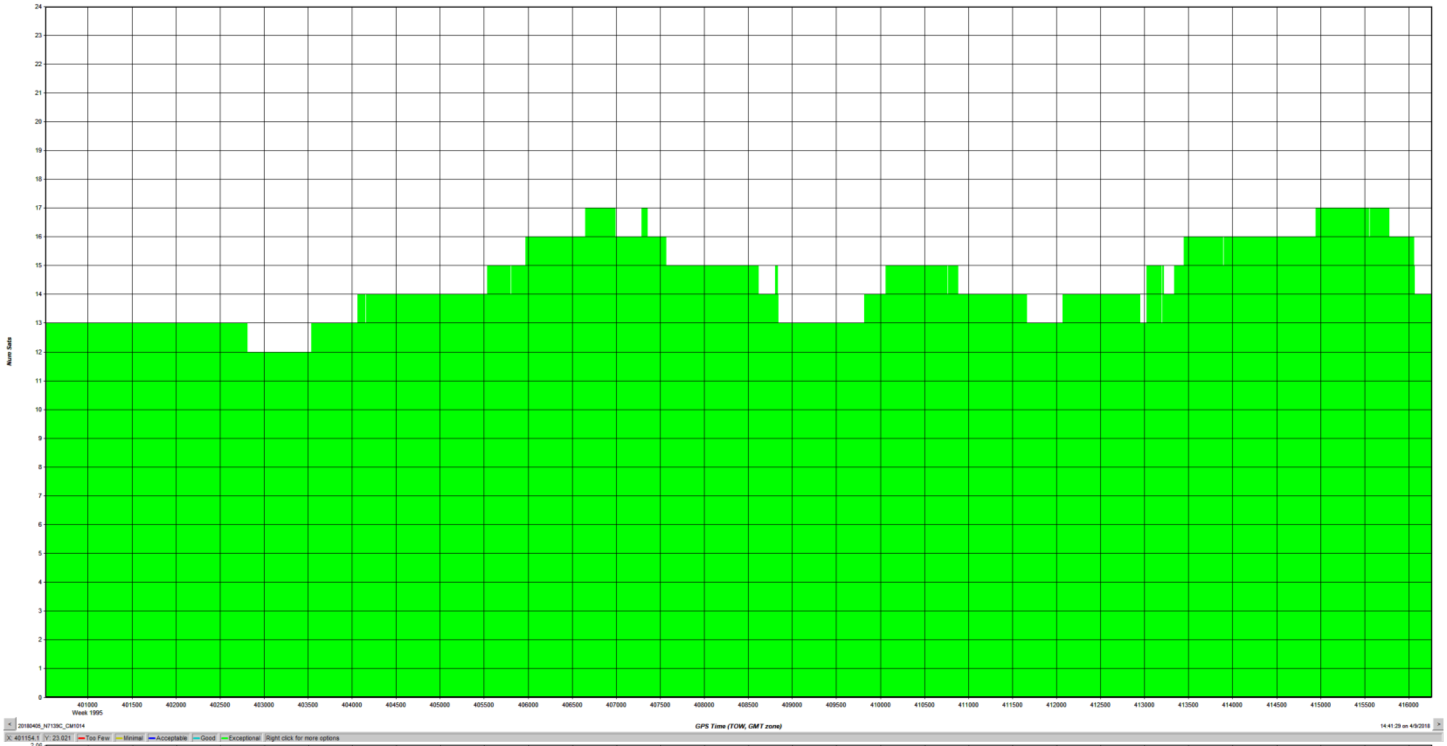

Num Sats
Week 1993
GPS Time (TOW, GMT zone)
Too Few
Minimal
Acceptable
Good
Exceptional
Right click for more options


PDOP
Week 1993
GPS Time (TOW, GMT zone)
PDOP
Right click for more options

20180405_1



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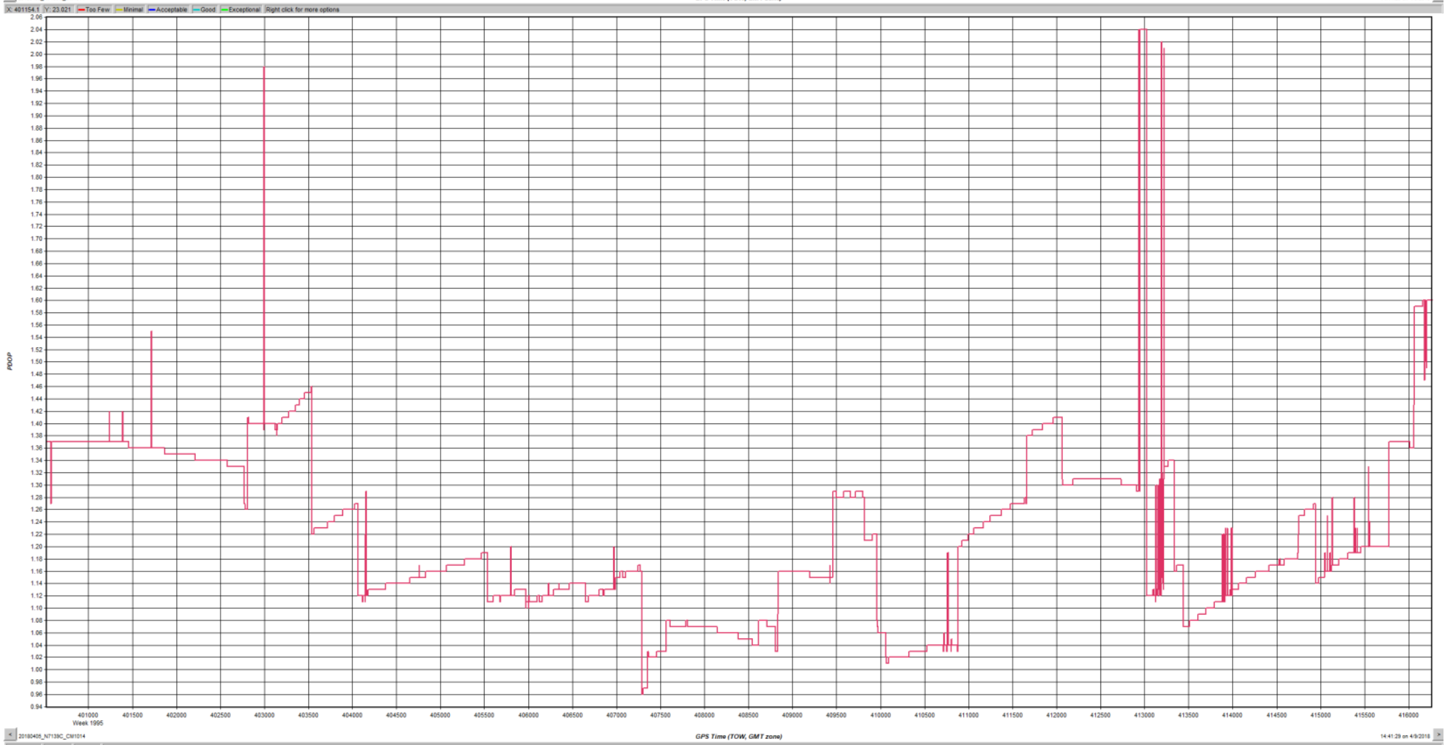
Week 1995
20180405_N7139C_CM1014
GPS Time (TOW, GMT zone)
14:41:29 on 4/9/2018
X: 401154.1 Y: 23.021
Too Few
Minimal
Acceptable
Good
Exceptional
Right click for more options


PDOP
Week 1995
20180405_N7139C_CM1014
GPS Time (TOW, GMT zone)
14:41:29 on 4/9/2018
X: 402511.0 Y: 1.791
PDOP
Right click for more options