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West Coast El Nino 2016 B16 LiDAR

Report Produced for U.S. Geological Survey

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Executive Summary

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (LiDAR) technology for the USGS West Coast El Nino LiDAR Project Area.

The LiDAR data were processed and classified according to project specifications. Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area. The project encompasses approximately 75 square miles of coast in Oregon, 486 square miles of coast in Washington and California, and an additional 44 square miles for USACE defined harbors. The data was collected in a corridor approximately 500 meters wide. The project consists of two UTM Zones: UTM 10N and UTM 11N. A total of 2,377 UTM10N tiles and 487 UTM11N tiles were produced for the project. Each tile's extent is 1,500 meters by 1,500 meters.

THE PROJECT TEAM

Dewberry served as the prime contractor for the project. In addition to project management, Dewberry was responsible for LAS classification, all LiDAR products, breakline production, Digital Elevation Model (DEM) production, and quality assurance.

Towill completed ground surveying for the project and delivered surveyed checkpoints. Their task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the LiDAR-derived surface model. Towill also verified the GPS base station coordinates used during LiDAR data acquisition to ensure that the base station coordinates were accurate. Please see Appendix A to view the separate Survey Report that was created for this portion of the project.

Towill completed LiDAR data acquisition and data calibration for the project area.

SURVEY AREA

The project area addressed by this report includes California, Washington, and Oregon coastlines.

DATE OF SURVEY

The LiDAR aerial acquisition was conducted from April 28, 2016 thru May 28, 2016.

COORDINATE REFERENCE SYSTEM

Data produced for the project were delivered in the following reference system.

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 10 and UTM Zone 11
Units: Horizontal units are in meters, Vertical units are in meters.
Geiod Model: Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

For the USGS West Coast El Nino LiDAR Project, the tested $RMSE_z$ of the classified LiDAR data for checkpoints in non-vegetated terrain equaled **5.8 cm** compared with the 10 cm specification; and the NVA of the classified LiDAR data computed using $RMSE_z$ x 1.9600 was equal to **11.4 cm**, compared with the 19.6 cm specification.

For the USGS West Coast El Nino LiDAR Project, the tested VVA of the classified LiDAR data computed using the 95th percentile was equal to **21.1 cm,** compared with the 29.4 cm specification.

Additional accuracy information and statistics for the classified LiDAR data, raw swath data, and bare earth DEM data are found in the following sections of this report.

PROJECT DELIVERABLES

The deliverables for the project are listed below.

1. Raw Point Cloud Data (Swaths)
2. Classified Point Cloud Data (Tiled)
3. Bare Earth Surface (Raster DEM – IMG Format)
4. Intensity Images (16-bit gray scale, tiled, GeoTIFF format)
5. Breakline Data (File GDB)
6. Independent Survey Checkpoint Data (Report with Photos & Points)
7. Calibration Points
8. Metadata
9. Project Report (Acquisition, Processing, QC)
10. Project Extents, Including a shapefile derived from the LiDAR Deliverable

PROJECT TILING FOOTPRINT

A total of two thousand three hundred seventy-seven (2,377) UTM10N tiles and four hundred eighty seven (487) UTM11N tiles were delivered for the project. Each tile's extent is 1,500 meters by 1,500 meters (see Appendix B for a complete listing of delivered tiles).

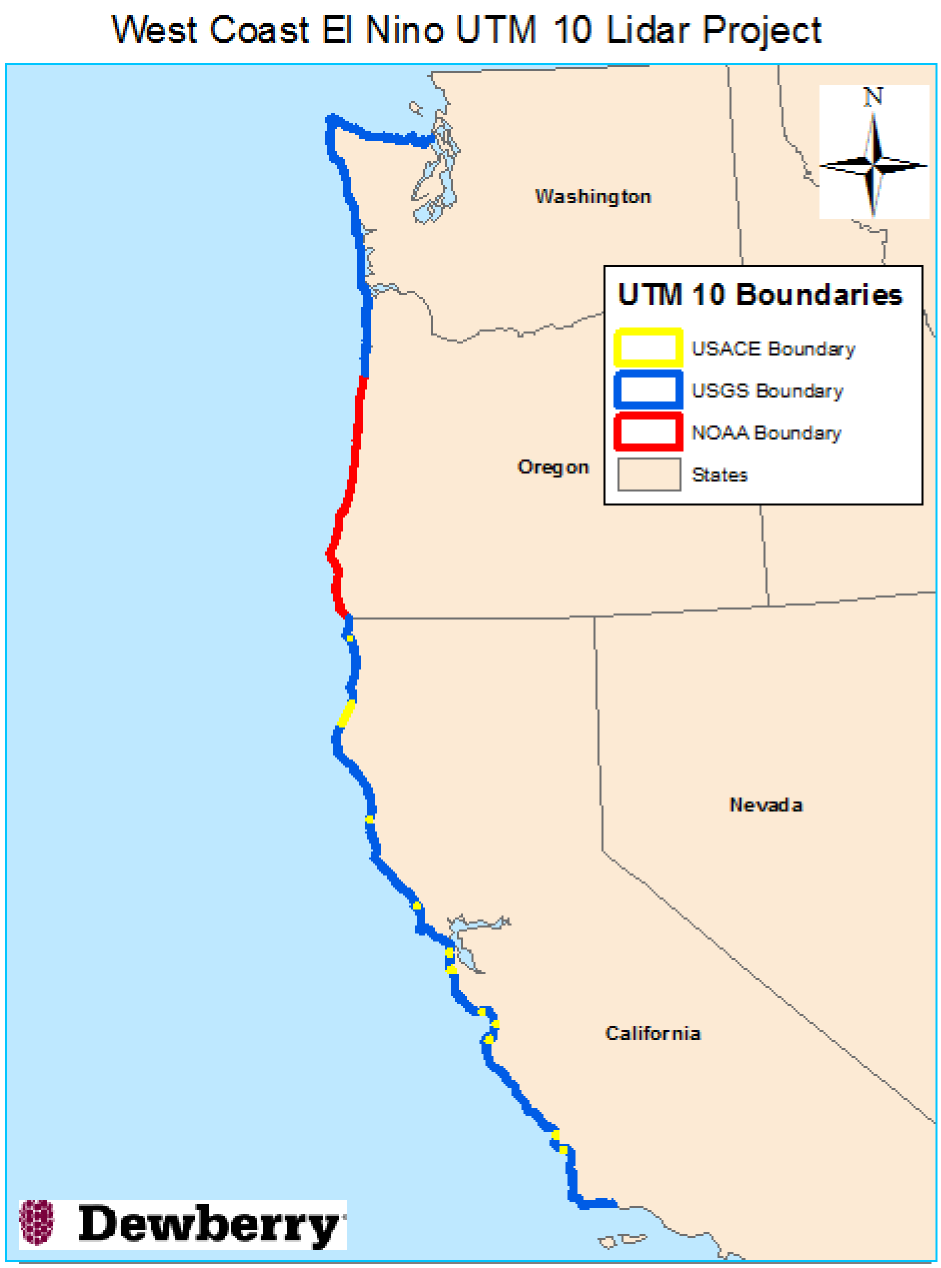


Figure 1 – UTM 10 Project Map

West Coast El Nino UTM 11 Lidar Project

Figure 2 – UTM 11 Project Map

LiDAR Acquisition Report

Dewberry elected to subcontract the LiDAR Acquisition and Calibration activities to Towill. Towill was responsible for providing LiDAR acquisition, calibration and delivery of LiDAR data files to Dewberry.

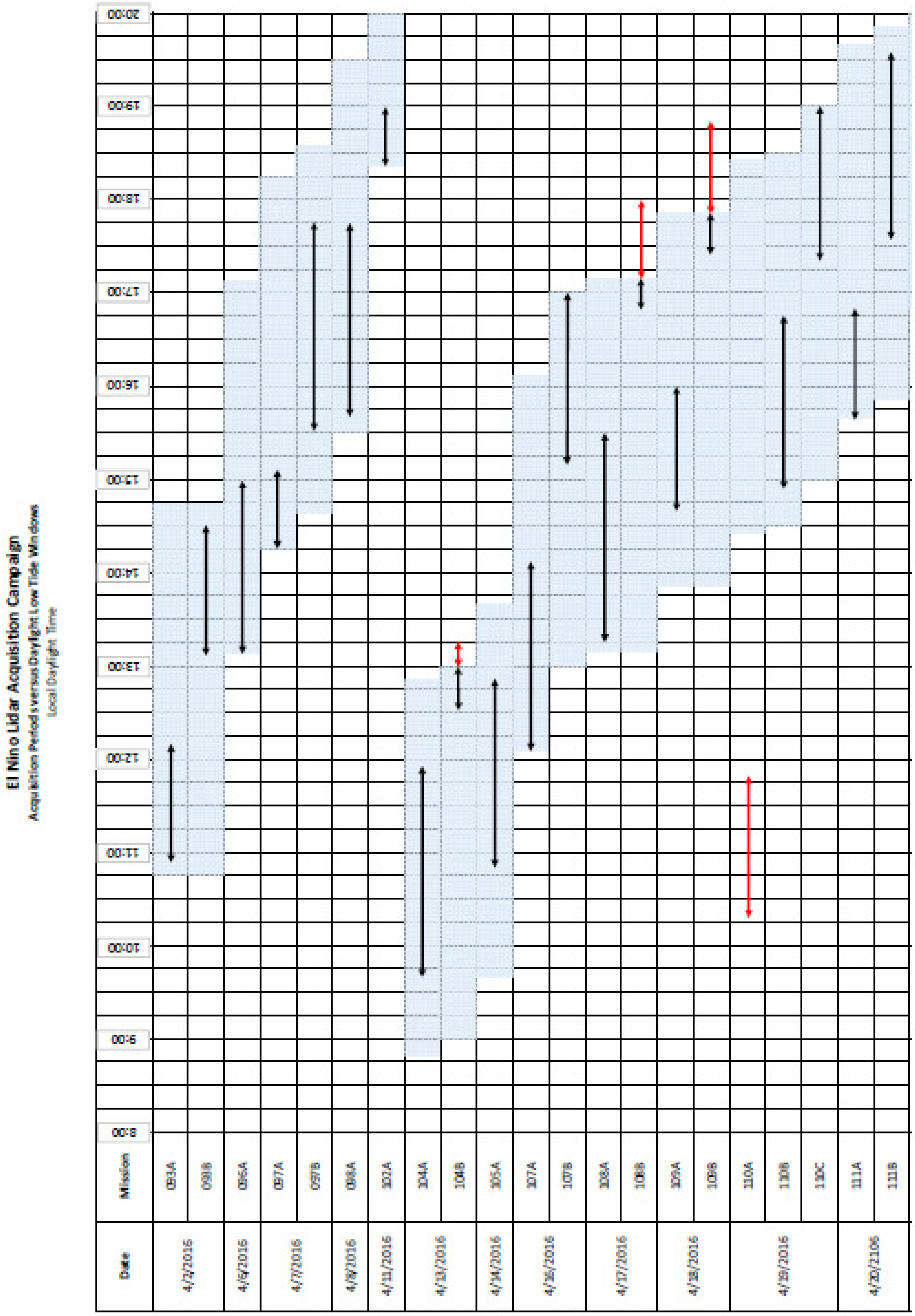
Dewberry received calibrated swath data from Towill in increments beginning in May 2016 and ending in June 2016. Reflights due to data voids were flown in August 2016.

LIDAR ACQUISITION DETAILS

The primary acquisition concept consisted of a combination of both single and multiple passes to ensure adequate coverage of the acquisition boundary on the inland side of the corridor and the land-to-water interface on the coastal side of the corridor. The target flying height for the majority of the acquisition was 800 to 900 meters above mean terrain (AMT). In some cases, due to airspace restrictions or inclement weather, data was collected at a lower altitude but always above 300 meters.

Data covering the coastal side of the corridor was acquired within a 2-hour period centered on the daytime low-tide. Where additional inland passes were necessary for coverage, these data were, at times, acquired outside of the low-tide window. The predicted tides provided by NOAA were used to identify the low-tide times for applicable tidal stations along the coast. The images below show the data acquisition missions versus low-tide periods for each flight day.

A daily review of the real-time, sampled LiDAR data was undertaken to identify missing coverage or data anomalies. Emphasis was placed on ensuring data returns from the water on the coastal side of the corridor and complete coverage of the boundary on the inland side of the corridor.


El Nino Lidar Acquisition Campaign
Acquisition Periods versus Daylight Low Tide Windows
Local Daylight Time
Date
Mission
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
4/2/2016
093A
093B
4/6/2016
096A
4/7/2016
097A
097B
4/8/2016
098A
4/11/2016
102A
4/13/2016
104A
104B
4/14/2016
105A
4/16/2016
107A
107B
4/17/2016
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4/20/2106
111A
111B

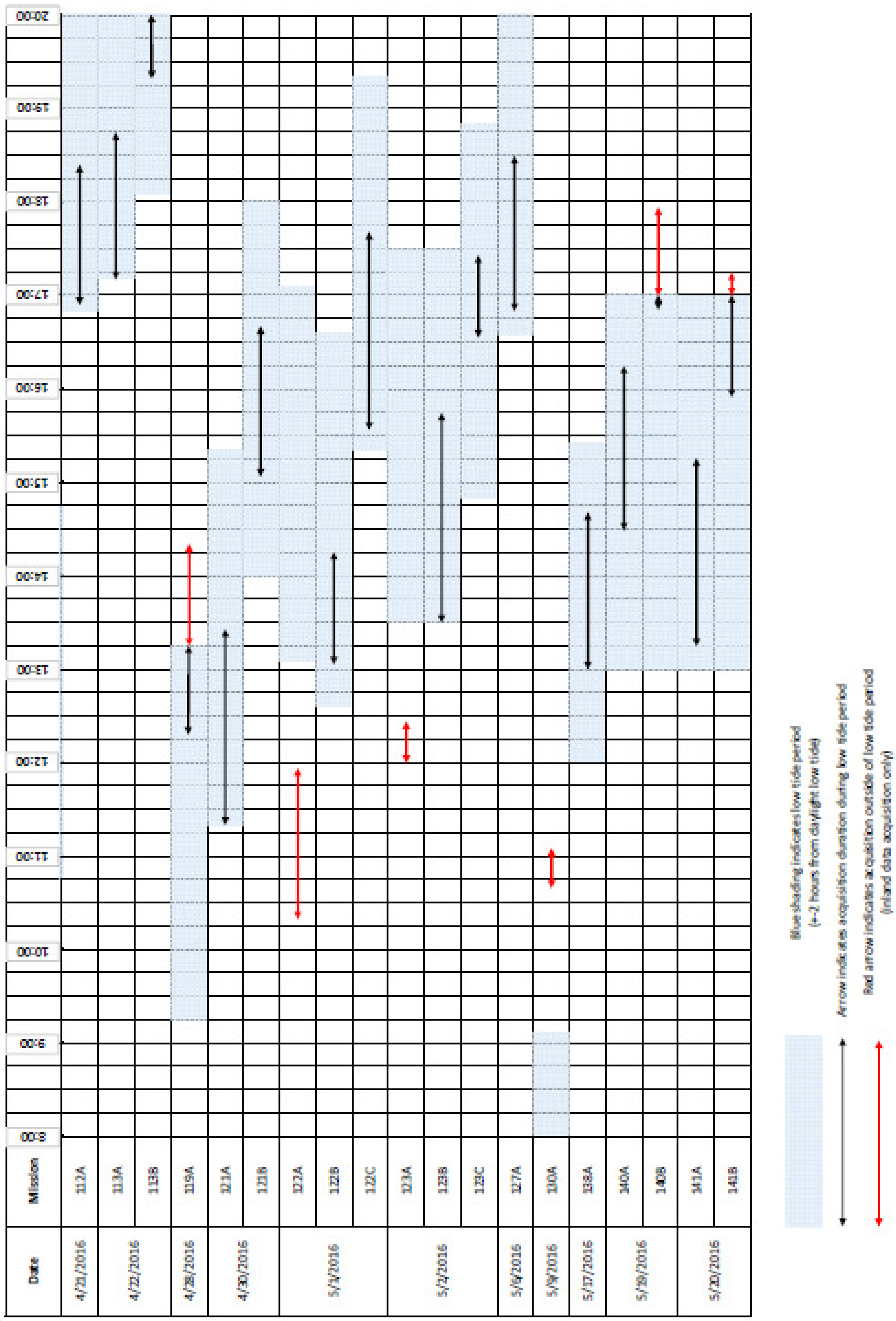


Figure 3 – Data acquisition missions versus low-tide periods for each flight day.

LIDAR SYSTEM PARAMETERS

Towill operated a Bell 206-L3 helicopter (Tail # N545SA) outfitted with an Optech Orion M300 LiDAR system during the collection of the study area. Table 1 illustrates Towill's system parameters for LiDAR acquisition on this project.

Item	Parameter
System	Optech Orion M300
Altitude (AGL meters)	400-900
Approx. Flight Speed (knots)	50
Scanner Pulse Rate (kHz)	275
Scan Frequency (hz)	44
Pulse Duration of the Scanner (nanoseconds)	4
Pulse Width of the Scanner (m)	1.1
Swath width (m)	500
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Beam Divergence (milliradians)	0.25
Nominal Swath Width on the Ground (m)	500
Swath Overlap (%)	n/a
Total Sensor Scan Angle (degree)	45
Computed Down Track spacing (m) per beam	0.32
Computed Cross Track Spacing (m) per beam	0.26
Nominal Pulse Spacing (single swath), (m)	0.3
Nominal Pulse Density (single swath) (ppsm), (m)	12
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.3
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	12
Maximum Number of Returns per Pulse	7

Table 1: Towill LiDAR System Parameters

ACQUISITION STATUS REPORT AND FLIGHTLINES

Upon notification to proceed, the flight crew began acquisition at the southern terminus of the project area. A portion of the coastline was skipped between Long Beach and Ventura and that area located within the Vandenberg restricted airspace. These two areas were collected during the return flight after the appropriate permissions had been obtained.

Due to the enormous linear geographic extent of the project area, and the desire to maximize production during low-tide periods, the exclusive source of control/base station support for this LiDAR campaign consisted of Continuously Operating Reference Stations operated by the Plate Boundary Observatory (PBO) branch of UNAVCO (http://www.unavco.org/projects/major-projects/pbo/pbo.html). The western coastal and coast mountain ranges of the United States include hundreds of the PBO CORS that are publically funded and, with coordination in advance, can be operated at a high collection rate (1-hertz) and the data obtained via simple File Transfer Protocol.

LIDAR CONTROL

Regional PBO stations were identified and arranged to operate and record at a 1-hertz rate during the campaign period. Some missions included a GPS base station operated by the flight crew at the airport of operations. The base station point was tied back to the PBO CORS via common static data. The 1-hertz PBO data and, when applicable, the Towill base station data, were combined appropriately to serve as the Airborne GPS base station data for all missions of the campaign.

The coordinates of all used base stations are provided in the table below. All control and calibration points are also provided in shapefile format as part of the final deliverables.

Name	NAD83 (2011) UTM 10 and UTM11		Ellipsoid Ht (NAD83, m)	Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)		
CABL	372236.2	4743799	38.286	3.3138
CHZZ	423565.5	5037463.2	51.161	13.7379
LFLO	411167.1	4870647.9	-6.042	-41.8686
NEAH	379491.8	5350682	460.245	423.7638
P059	437054.9	4309075.4	-10.822	-44.8962
P067	681014.7	3936067.4	107.594	-999999
P157	388747.2	4456053.3	696.236	662.5538
P172	610788.4	4009949.8	313.19	281.5747
P173	654202.2	3979278	339.828	309.3613
P181	554784.2	4196516.4	72.732	41.3917
P185	435354	4346041.5	146.834	112.3609
P188	480030.4	4279943.9	209.358	176.2669
P210	613110.7	4075226	3.6	-28.7312
P231	597875.7	4053462.4	-25.764	-58.384
P316	409430.6	4601398.3	235.389	200.6068
P415	444157.8	5167195	-15.081	-51.3069
P472	509791.1	3639009.2	138.603	107.0939
P474	523137	3690692	183.653	152.2421
P475	522871.5	3614330.4	-24.285	-56.0208
P523	694544.1	3908905.8	41.984	8.845
P534	567781.8	4101936.4	204.804	172.881
PABH	408787	5229515.5	13.277	-22.5567
PTSG	395694.9	4626415.6	-9.764	-44.8977

SBCC	438595.8	3712790.9	89.406	58.7143
TJRN	763333	3819497	157.816	121.9146
TRND	403289.6	4545376.5	78.68	45.0388
VNDP	718694.2	3826422.3	-9.147	-43.9109
CIRX	321313.4	3775997.2	488.885	459.4922
P161	397420.7	4499209.1	32.868	-0.4304
P177	544617.1	4153585.7	72.321	40.8522
P182	484196	4260755.4	397.293	364.6506
P193	508052.8	4219458.8	67.104	35.7911
P312	439980.5	4375735.2	255.394	221.0791
P315	438685.3	4412861.9	258.381	224.408
P364	385300	4771809	6.807	-28.0971
P365	398489.3	4805500.5	27.467	-7.6408
P366	420956.1	4829502.3	529.468	494.0651
P367	415731.8	4937425.8	23.277	-12.8936
P395	432441.3	4985782.5	53.385	16.4871
P396	435494.7	5017663.2	54.908	17.5736
P397	438592.3	5141203.8	566.625	530.2933
P398	430254.7	5197323.8	23.811	-12.132
P401	383715.2	5310491.7	36.486	0.0991
P402	402148.8	5291142.5	24.01	-12.1035
P403	415000.3	5323856.2	284.951	248.1235
P407	427852.6	5089429.6	-12.778	-49.7953
P435	462502.3	5323040.9	287.623	250.569
P436	489988.3	5321343.7	191.191	154.2866
P437	540344.2	5316642.4	12.789	-24.4073
P525	698986.5	3922467.2	271.978	238.9553
P548	270013.4	3816761.2	1135.502	1105.5551
P733	383767.8	4699821.7	184.951	150.0165
P734	393024.5	4659093.7	113.718	78.6323
PVRS	377721.4	3737865.9	60.538	31.3037
VIMT	360349.9	3777211.6	554.389	525.1132
VNCO	294008.2	3794998.6	26.345	-3.5789

Table 2 – Base Stations used to control LiDAR acquisition

AIRBORN GPS KINEMATIC

The kinematic AGPS data was post-processed using Grafnav version 8.40 software, the de facto kinematic GPS post-processing package in the airborne remote sensing industry. Data is post-processed forward and backward in time exploiting the software's robust Kinematic Ambiguity

Resolution and Multi-Baseline features to mitigate ambiguity drift and minimize poor data as a result of satellite loss of lock. Appendix C summarizes the comparison of the forward and reverse solutions of the post-processed GPS data as well as PDOP and trajectory map for each of the missions.

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

The Optech Orion M300 LiDAR system is subject to a regular maintenance and calibration schedule. The intent of periodic calibration is to monitor and validate components of the overall error budget including IMU boresight and performance, mirror angle readings and pulse gate timing. Several of these parameters can vary during and between missions due to changes in ambient meteorological conditions, different flying heights above ground, and different acquisition variables. The processing software, LMS, carries out a self-calibration of user-defined variables using areas of overlap between flight lines to improve the relative accuracy of the data.

Final LiDAR data processing is accomplished using Optech's Lidar Mapping Suite (LMS) software, version 3.1. During processing of the LiDAR data within LMS, flight lines are processed together in a block and the calibration parameters are adjusted mission-wise, block-wise and strip-wise to improve the overall relative fit of the data. The decoded raw laser observations (ranges, intensities, and mirror angles) and the final processed SBET are combined within LMS to compute the final 3-dimensional coordinates of the return(s) of each laser pulse and output data to LAS version 1.4 file format.

BORESIGHT AND RELATIVE ACCURACY

Data overlap located at the respective beginnings and ends of flight lines, as well as that overlapping data within adjacent flight lines, was analyzed to verify the quality of the data calibration by LMS. This analysis was completed both by manual inspection of terrain and features within the overlapping data and generating "delta-Z" colorized images of the areas of overlap. Vertical differences between ground surfaces of each line are displayed. Color scale is adjusted so that errors greater than the specifications are flagged. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement.

For this project the specifications used are as follow:
Relative accuracy <= 6 cm maximum differences within individual swaths and <=8 cm RMSDz between adjacent and overlapping swaths.

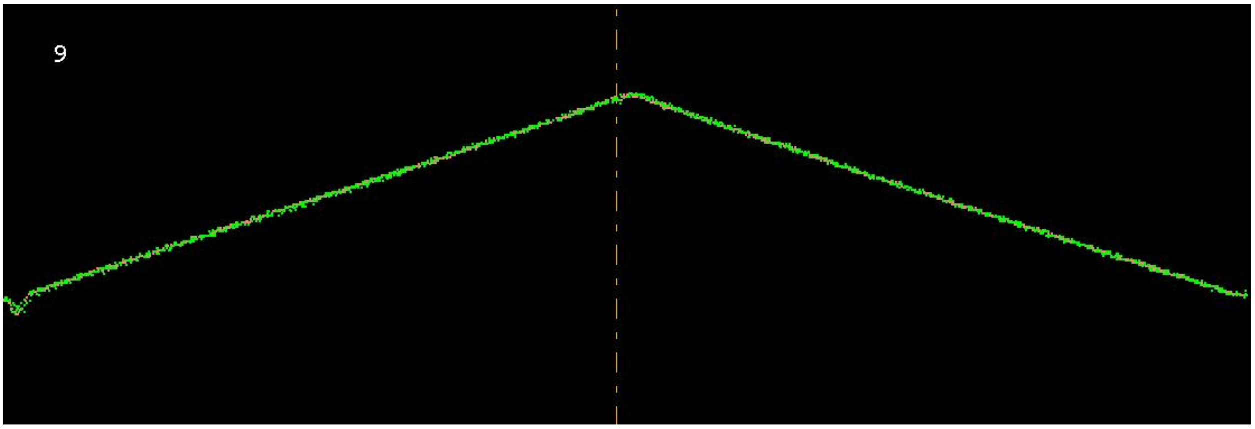


Figure 4 – Profile views showing correct roll and pitch adjustments.

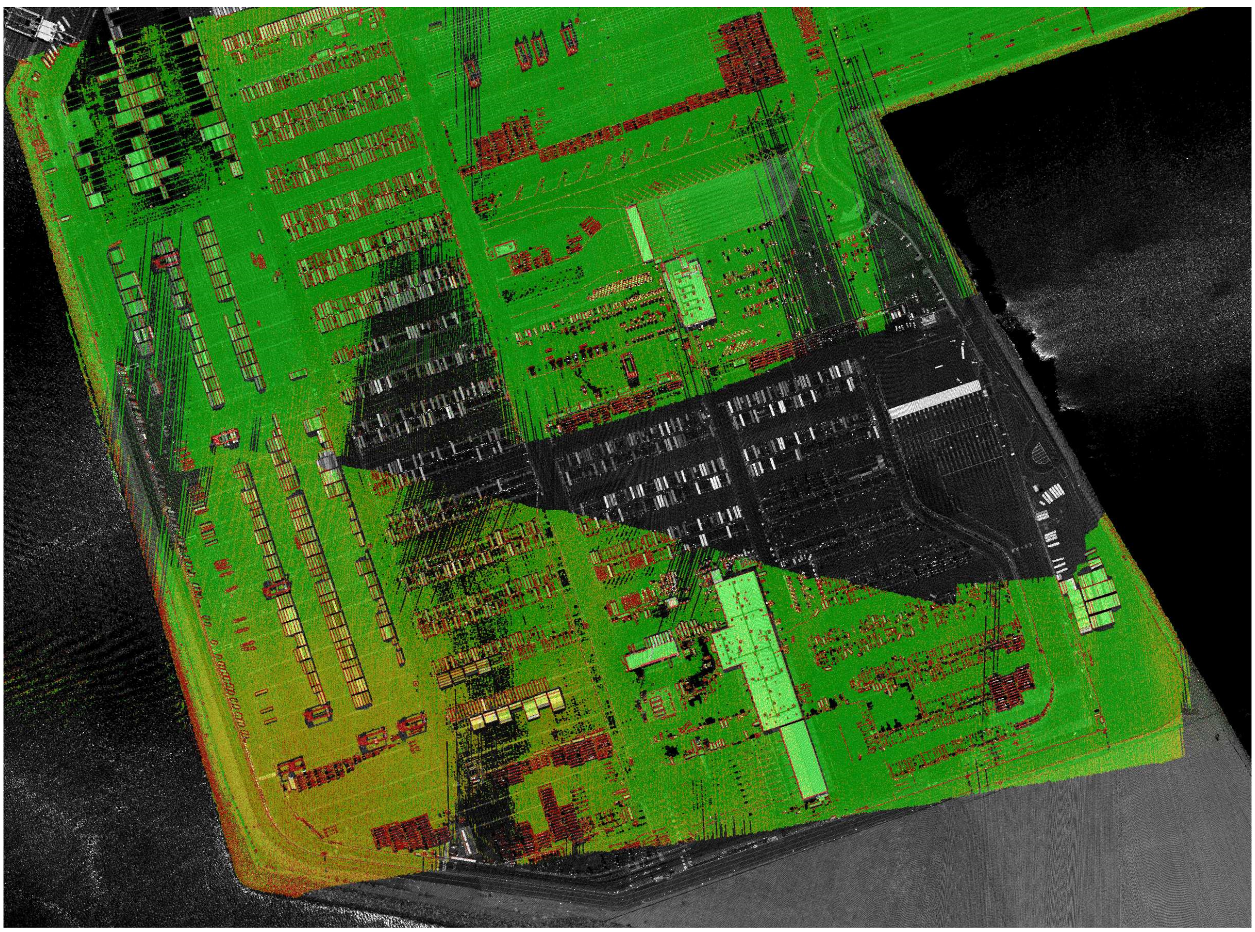


Figure 5 – QC area colored by elevation difference

A different set of QC blocks are generated for final review after all transformations have been applied.

PRELIMINARY VERTICAL ACCURACY ASSESSMENT

A preliminary $RMSE_z$ error check was performed by Towill using internal check points obtained using GPS static observation techniques and compared to $RMSE_z$ project specifications. The LiDAR data is examined in non-vegetated, flat areas away from breaks. LiDAR ground points for each flight line generated by an automatic classification routine are used.

Prior to delivery to Dewberry, the elevation data was verified internally to ensure it met Non-vegetated Vertical Accuracy (NVA) requirements ($RMSE_z \leq 10$ cm and $Accuracy_z$ at the 95% confidence level ≤ 19.6 cm) when compared to the checkpoints. Table 3 summarizes the results of the test.

The calibrated West Coast El Nino LiDAR dataset was tested to 0.127 m vertical accuracy at 95% confidence level based on $RMSE_z$ (0.065 m x 1.9600) when compared to 81 GPS static check points.

The following are the final statistics for the GPS static checkpoints used by Towill to internally verify vertical accuracy.

NAD 83 (2011) UTM Zone 10 and Zone 11	NAVD88 (Geoid 12B)		
Point ID	Known Z (m)	Laser Z (m)	Delta Z
MA45	9.323	9.199	-0.124
MA46	9.335	9.187	-0.148
MA47	7.135	6.992	-0.143
MA48	51.679	51.792	0.113
MA49	6.836	6.982	0.146
MA50	5.563	5.732	0.169
MA51	16.523	16.546	0.023
MA52	5.692	5.659	-0.033
MA53	7.35	7.36	0.01
MA54	14.267	14.29	0.023
MA55	19.994	20.077	0.083
MA56	8.305	8.195	-0.11
MA57	6.625	6.609	-0.016
MA60	4.532	4.566	0.034
MA61	14.192	14.209	0.017
MA62	12.582	12.564	-0.018
MA64	34.356	34.328	-0.028
MA65	5.937	5.981	0.044
MA66	10.004	10.011	0.007
MA67	8.934	8.903	-0.031
MA68	58.84	58.828	-0.012
MA69	10.246	10.25	0.004

MA70	5.922	5.902	-0.02
MA71	6.375	6.347	-0.028
MA72	5.988	5.902	-0.086
MA73	5.842	5.893	0.051
MA74	6.771	6.819	0.048
MA75	23.941	23.89	-0.051
MA76	26.519	26.583	0.064
MA77	4.503	4.505	0.002
MA78	19.311	19.192	-0.119
MA79	45.419	45.485	0.066
MA80	6.022	6.131	0.109
MA81	7.576	7.63	0.054
MA82	4.543	4.627	0.084
MA83	43.709	43.653	-0.056
MA84	3.42	3.386	-0.034
MA85	3.771	3.564	-0.207
MA01	4.749	4.71	-0.039
MA02	6.146	6.158	0.012
MA04	46.484	46.481	-0.003
MA05	69.679	69.675	-0.004
MA06	3.498	3.497	-0.001
MA07	4.57	4.575	0.005
MA08	46.806	46.798	-0.008
MA09	4.858	4.851	-0.007
MA10	34.595	34.633	0.038
MA11	5.638	5.655	0.017
MA12	6.556	6.506	-0.05
MA13	2.933	2.943	0.01
MA14	3.737	3.698	-0.039
MA15	35.956	35.997	0.041
MA16	4.602	4.554	-0.048
MA17	16.05	16.02	-0.03
MA18	7.69	7.734	0.044
MA19	3.969	4.01	0.041
MA20	5.97	6	0.03
MA21	13.111	13.114	0.003
MA22	17.75	17.816	0.066
MA23	47.265	47.241	-0.024
MA24	88.745	88.679	-0.066
MA25	47.612	47.521	-0.091

MA26	26.904	26.837	-0.067
MA27	26.807	26.709	-0.098
MA28	15.025	15.06	0.035
MA29	29.955	29.96	0.005
MA30	12.526	12.636	0.11
MA31	22.59	22.562	-0.028
MA32	61.21	61.225	0.015
MA33	148.681	148.72	0.039
MA34	10.149	10.118	-0.031
MA35	13.675	13.571	-0.104
MA36	2.691	2.707	0.016
MA37	152.314	152.31	-0.004
MA38	36.892	36.88	-0.012
MA39	24.592	24.526	-0.066
MA40	53.236	53.261	0.025
MA41	25.378	25.346	-0.032
MA42	26.438	26.443	0.005
MA43	84.583	84.555	-0.028
MA44	7.975	7.98	0.005

Table 3 – Final statistics for the GPS static checkpoints

Overall the calibrated LiDAR data products collected by Towill meet or exceed the requirements set out in the Statement of Work. The quality control requirements of Towill's quality management program were adhered to throughout the acquisition stage for this project to ensure product quality.

LiDAR Processing & Qualitative Assessment

INITIAL PROCESSING

Once Dewberry receives the calibrated swath data from the acquisition provider, Dewberry performs several validations on the dataset prior to starting full-scale production on the project. These validations include vertical accuracy of the swath data, inter-swath (between swath) relative accuracy validation, intra-swath (within a single swath) relative accuracy validation, verification of horizontal alignment between swaths, and confirmation of point density and spatial distribution. This initial assessment allows Dewberry to determine if the data are suitable for full-scale production. Addressing issues at this stage allows the data to be corrected while imposing the least disruption possible on the overall production workflow and overall schedule.

Final Swath Vertical Accuracy Assessment

Once Dewberry received the calibrated swath data from Towill, Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the fifty non-vegetated (open terrain and urban) independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the LiDAR point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete LiDAR point. Dewberry typically uses LP360 software to test the swath LIDAR vertical accuracy, Terrascan software to test the classified LiDAR vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project. Project specifications require a NVA of 19.6 cm based on the $RMSE_z$ (10 cm) x 1.96. The dataset for the West Coast El Nino LiDAR Project satisfies this criteria. This raw LiDAR swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 5.7 cm, equating to +/- 11.2 cm at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

100 % of Totals	# of Points	$RMSE_z$ NVA Spec=0.10 m	NVA –Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.196 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
Non-Vegetated Terrain	50	0.057	0.112	-0.009	-0.001	-0.115	0.057	-0.173	0.123	0.723

Table 4: NVA at 95% Confidence Level for Raw Swaths

Inter-Swath (Between Swath) Relative Accuracy

Dewberry verified inter-swath or between swath relative accuracy of the dataset by creating Delta-Z (DZ) orthos. According to the SOW, USGS LiDAR Base Specifications v1.2, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL1 data must meet inter-swath relative accuracy of 8 cm RMSDz or less with maximum differences less than 16 cm. These measurements are to be taken in non-vegetated and flat open terrain using single or only returns from all classes. Measurements are calculated in the DZ orthos on 1-meter pixels or cell sizes. Areas in the dataset where overlapping flight lines are within 8 cm of each other within each pixel are colored green, areas in the dataset where overlapping flight lines have elevation differences in each pixel between 8 cm -16 cm are colored yellow, and areas in the dataset where overlapping flight lines have elevation differences in each pixel greater than 16 cm are colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. Areas of vegetation and steep slopes (slopes with 16 cm or more of valid elevation change across 1 linear meter) are expected to appear yellow or red in the DZ orthos. If the project area is heavily vegetated, Dewberry may also create DZ Orthos from the initial ground classification only, while keeping all other parameters consistent. This allows Dewberry to review the ground classification relative accuracy beneath vegetation and to ensure flight line ridges or other issues do not exist in the final classified data.

Flat, open areas are expected to be green in the DZ orthos. Large or continuous sections of yellow or red pixels can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the usability of the data, especially when these yellow/red sections follow the flight lines and not the terrain or areas of vegetation. The DZ orthos for El

Nino West Coast are shown in the figure below; this project meets inter-swath relative accuracy specifications.

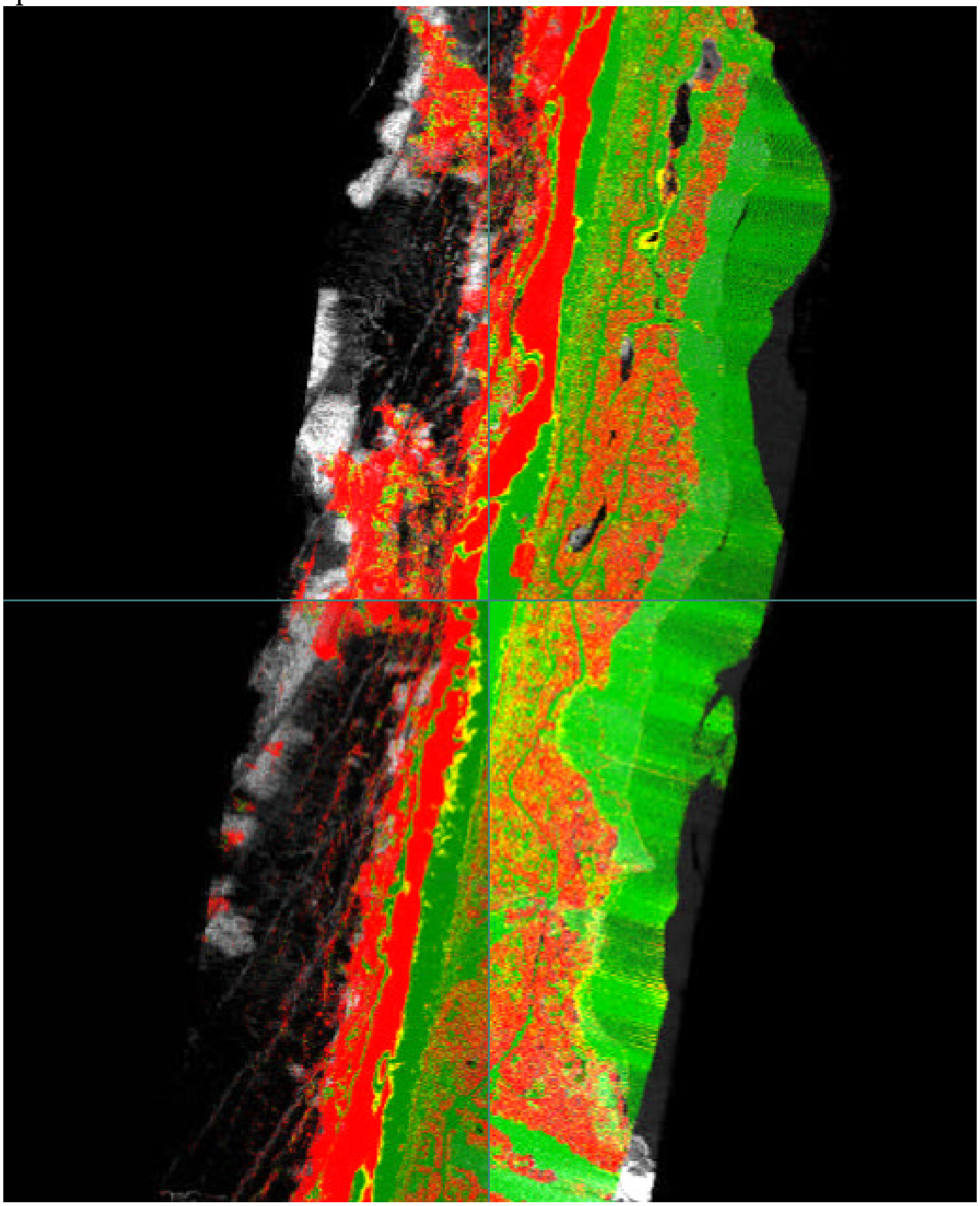


Figure 6– Single return DZ Orthos for the E Nino West Coast Inter-swath relative accuracy passes specifications.

Intra-Swath (Within a Single Swath) Relative Accuracy

Dewberry verifies the intra-swath or within swath relative accuracy by using Quick Terrain Modeler (QTM) scripting and visual reviews. QTM scripting is used to calculate the maximum difference of all points within each 1-meter pixel/cell size of each swath. Dewberry analysts then identify planar surfaces acceptable for repeatability testing and analysts review the QTM results in those areas. According to the SOW, USGS LiDAR Base Specifications v1.2, and ASPRS

Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL1 data must meet intra-swath relative accuracy of 6 cm maximum difference or less. The image below shows two examples of the intra-swath relative accuracy of West Coast El Nino; this project meets intra-swath relative accuracy specifications.

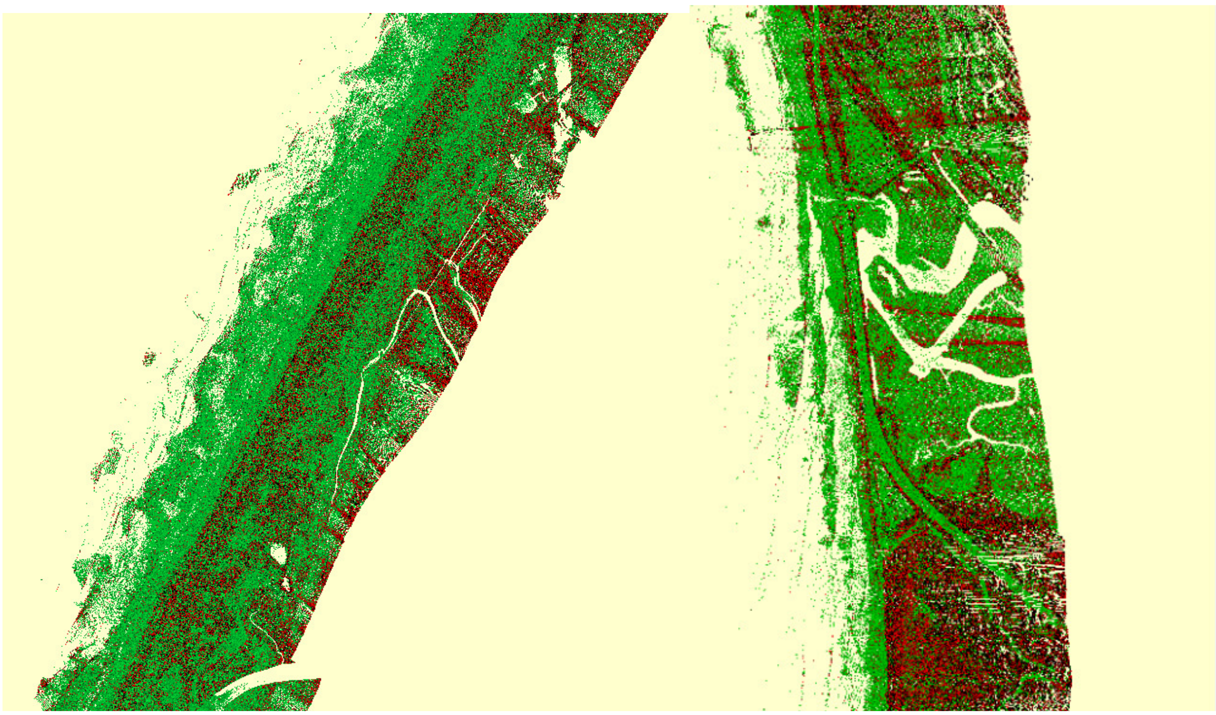


Figure 7–Intra-swath relative accuracy. These images show a portion of the dataset; flat, open areas are colored green as they are within 6 cm whereas sloped or vegetated terrain is colored red because it exceeds 6 cm maximum difference, as expected, due to actual slope/terrain change or the height of vegetation. Intra-swath relative accuracy passes specifications.

Horizontal Alignment

To ensure horizontal alignment between adjacent or overlapping flight lines, Dewberry uses QTM scripting and visual reviews. QTM scripting is used to create files similar to DZ orthos for each swath but this process highlights planar surfaces, such as roof tops. In particular, horizontal shifts or misalignments between swaths on roof tops and other elevated planar surfaces are highlighted. Visual reviews of these features, including additional profile verifications, are used to confirm the results of this process. The image below shows an example of the horizontal alignment between swaths for West Coast El Nino; no horizontal alignment issues were identified.

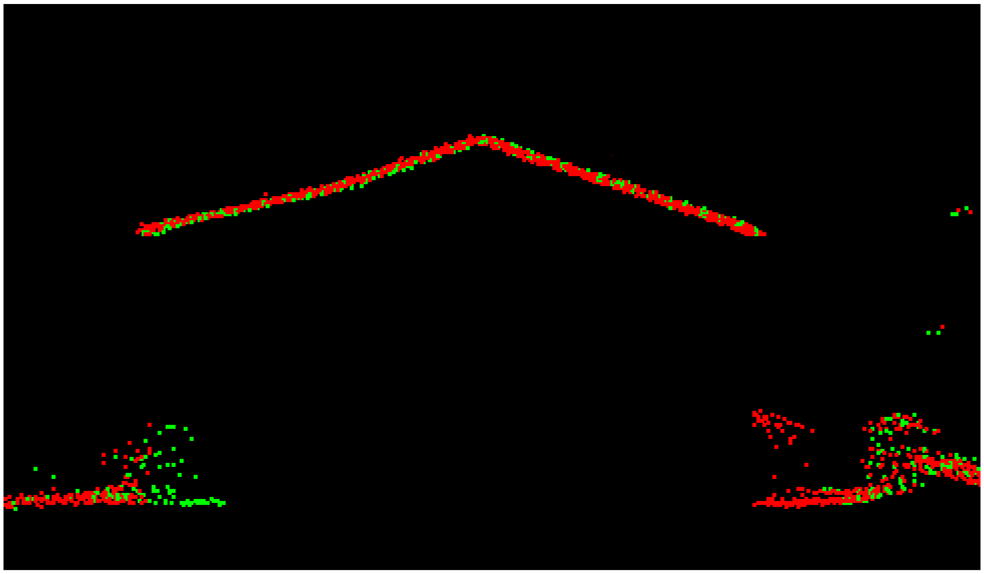


Figure 8 Horizontal Alignment. Two separate flight lines differentiated by color (Red/Green) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.35 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 8 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics, the project area was determined to have an ANPS of 0.12 meters or an ANPD of 66 points per square meter which satisfies the project requirements.

The spatial distribution of points must be uniform and free of clustering. This specification is tested by creating a grid with cell sizes equal to the design NPS*2. QTM scripting is then used to calculate the number of first return points of each swath within each grid cell. At least 90% of the cells must contain 1 LiDAR point, excluding acceptable void areas such as water or low NIR reflectivity features, i.e. some asphalt and roof composition materials. This project passes spatial distribution requirements, as shown in the image below.

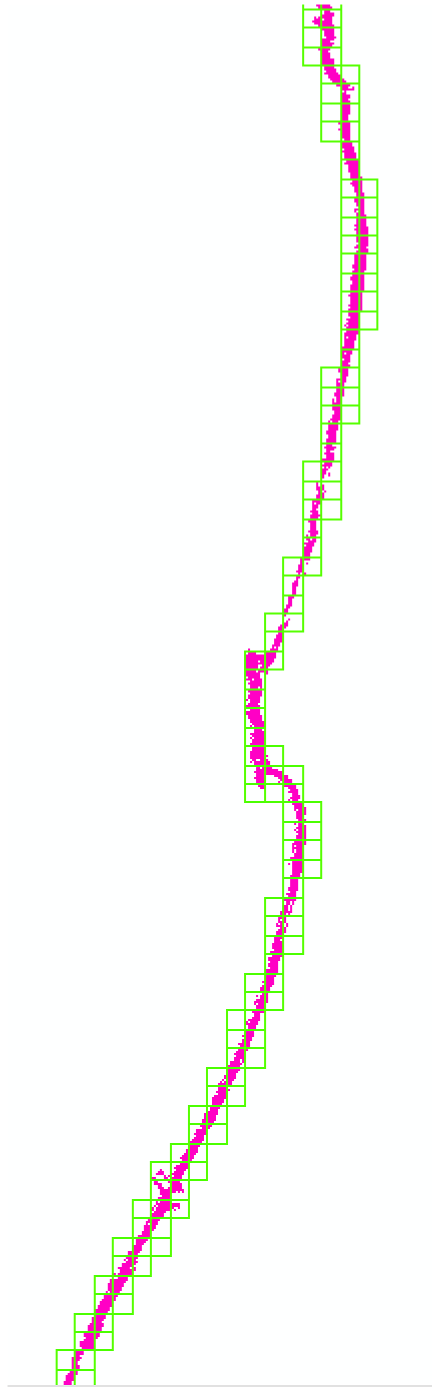


Figure 9– Spatial Distribution. The 2*NPS tile grid is shown in green and all tiles containing at least one LiDAR point are colored pink.

DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. The data was processed using GeoCue and TerraScan software. The initial step is the setup of the GeoCue project, which is done by importing a project defined tile boundary index encompassing the entire project area. The acquired 3D laser point clouds, in LAS binary format, were imported into the GeoCue project and tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classifies any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. Points along flight line edges that are geometrically unusable are identified as withheld and classified to a separate class so that they will not be used in the initial ground algorithm. After points that could negatively affect the ground are removed from class 1, the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model.

This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model.

Each tile was then imported into Terrascan and a surface model was created to examine the ground classification. Dewberry analysts visually reviewed the ground surface model and corrected errors in the ground classification such as vegetation, buildings, and bridges that were present following the initial processing conducted by Dewberry. Dewberry analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points are removed from the ground classification. Bridge decks are classified to class 17 using bridge breaklines compiled by Dewberry. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by Dewberry to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water. During this water classification routine, points that are within 1x NPS or less of the hydrographic features are moved to class 10, an ignored ground due to breakline proximity. Coastal areas in the project that were flown outside of low tide acquisition periods were classified to Class 64 so that these points were not used in the final ground. With one exception (discussed in more detail in the LiDAR Qualitative Assessment section below), the beach or land/water interface bare earth points were classified from those points flown within the low tide acquisition windows. In some areas along the land/water interface, multiple flight lines were acquired within low tide windows, but temporal differences exist between the overlapping flight lines. Bare earth ground points from these overlapping flight lines are not always consistent. In these instances, Dewberry chose one flight line to classify as bare earth class 2. The alternate bare earth points from the overlapping flight lines were classified to Class 65, temporal ground, so that data users have easy access to the alternate ground surface. Overage points are then identified in Terrascan and GeoCue is used to set the overlap bit for the overage points and the withheld bit is set on the withheld points previously identified in Terrascan before the ground classification routine was performed.

The LiDAR tiles were classified to the following classification schema:

- Class 1 = Unclassified, used for all other features that do not fit into the Classes 2, 7, 9, 10, 17, or 18, including vegetation, buildings, etc.

- Class 2 = Bare-Earth Ground
- Class 7 = Low Noise
- Class 9 = Water, points located within collected breaklines
- Class 10 = Ignored Ground due to breakline proximity
- Class 17 = Bridge Decks
- Class 18 = High Noise
- Class 64 = Flown Outside of Low Tide Window
- Class 65 = Temporal Ground

After manual classification, the LAS tiles were peer reviewed and then underwent a final QA/QC. After the final QA/QC and corrections, the LAS files were then converted from LAS v1.2 to LAS v1.4 using GeoCue software. At this time, all headers, appropriate point data records, and variable length records, including spatial reference information, are updated in GeoCue software and then verified using proprietary Dewberry tools.

LiDAR Qualitative Assessment

Dewberry's qualitative assessment utilizes a combination of statistical analysis and interpretative methodology or visualization to assess the quality of the data for a bare-earth digital terrain model (DTM). This includes creating pseudo image products such as LiDAR orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models as well as reviewing the actual point cloud data. This process looks for anomalies in the data, areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model, and other classification errors. This report will present representative examples where the LiDAR and post processing had issues as well as examples of where the LiDAR performed well.

VISUAL REVIEW

The following sections describe common types of issues identified in LiDAR data and the results of the visual review for West Coast El Nino.

Data Voids

The LAS files are used to produce density grids using the commercial software package QT Modeler (QTM) which creates a 3-dimensional data model derived from Class 2 (ground) points in the LAS files. Grid spacing is based on the project density deliverable requirement for un-obscured areas. Acceptable voids (areas with no LiDAR returns in the LAS files) that are present in the majority of LiDAR projects include voids caused by bodies of water. One small void impacting one tile is present in the West Coast El Nino LiDAR project. This small void is inland and does not impact the beach or land/water interface. The presence of this void was brought to the attention of USGS and deemed OK since it impacted very little data.

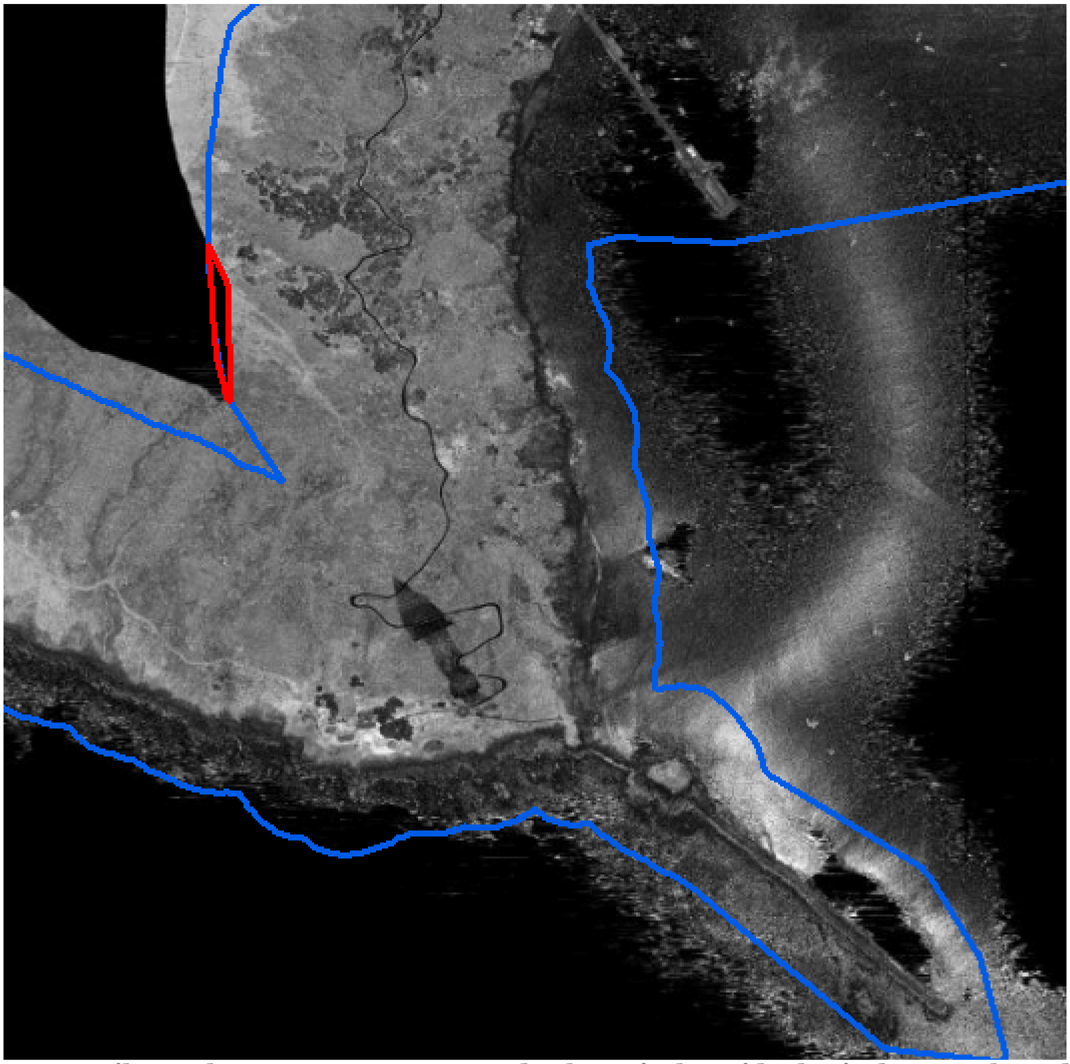


Figure 10 – Tile number 10SGD70353892. Red polygon is the void. Blue is the USGS boundary.

Artifacts

Artifacts are caused by the misclassification of ground points and usually represent vegetation and/or man-made structures. The artifacts identified are usually low lying structures, such as porches or low vegetation used as landscaping in neighborhoods and other developed areas. These low lying features are extremely difficult for the automated algorithms to detect as non-ground and must be removed manually. The vast majority of these features have been removed but a small number of these features are still in the ground classification. The limited numbers of features remaining in the ground are usually 0.3 meters or less above the actual ground surface, and should not negatively impact the usability of the dataset.

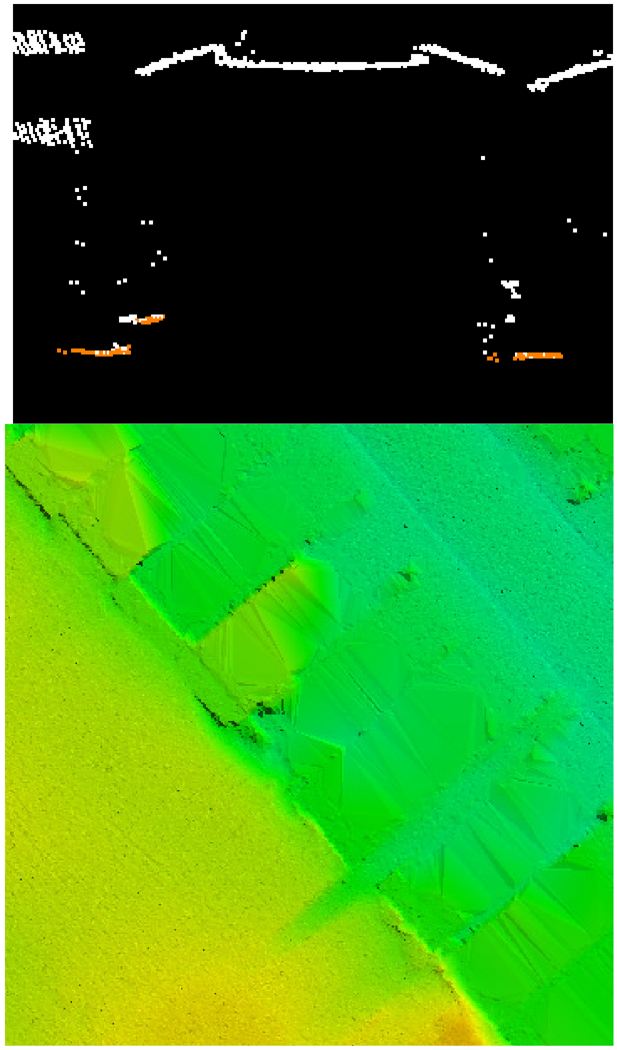


Figure 11 – Tile number 11SKT29403781. Profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and a TIN of the surface is shown in the bottom view. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.

Bridge Removal Artifacts

The DEM surface models are created from TINs or Terrains. TIN and Terrain models create continuous surfaces from the inputs. Because a continuous surface is being created, the TIN or Terrain will use interpolation to continue the surface beneath the bridge where no LiDAR data was acquired. Locations where bridges were removed will generally contain less detail in the bare-earth surface because these areas are interpolated.

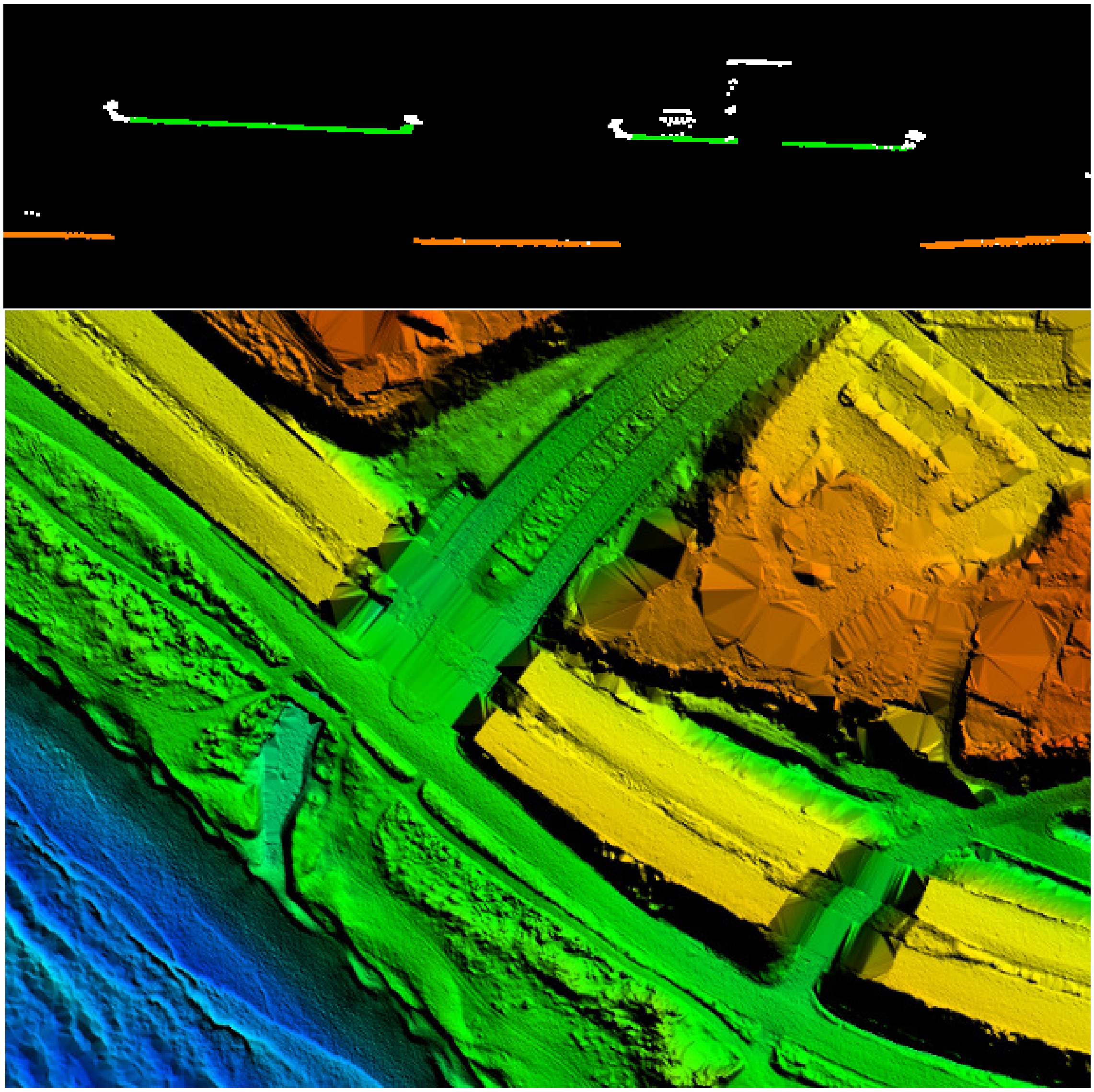


Figure 12 – Tile number 11SKT28953793. The DEM in the bottom view shows an area where bridges have been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view shows the LiDAR points of this particular feature colored by class. All bridge points have been removed from ground (orange) and are bridge deck (green).

Culverts and Bridges

Bridges have been removed from the bare earth surface while culverts remain in the bare earth surface. In instances where it is difficult to determine if the feature is a culvert or bridge, such as with some small bridges, Dewberry erred on assuming they would be culverts especially if they are on secondary or tertiary roads. Below is an example of a culvert that has been left in the ground surface.

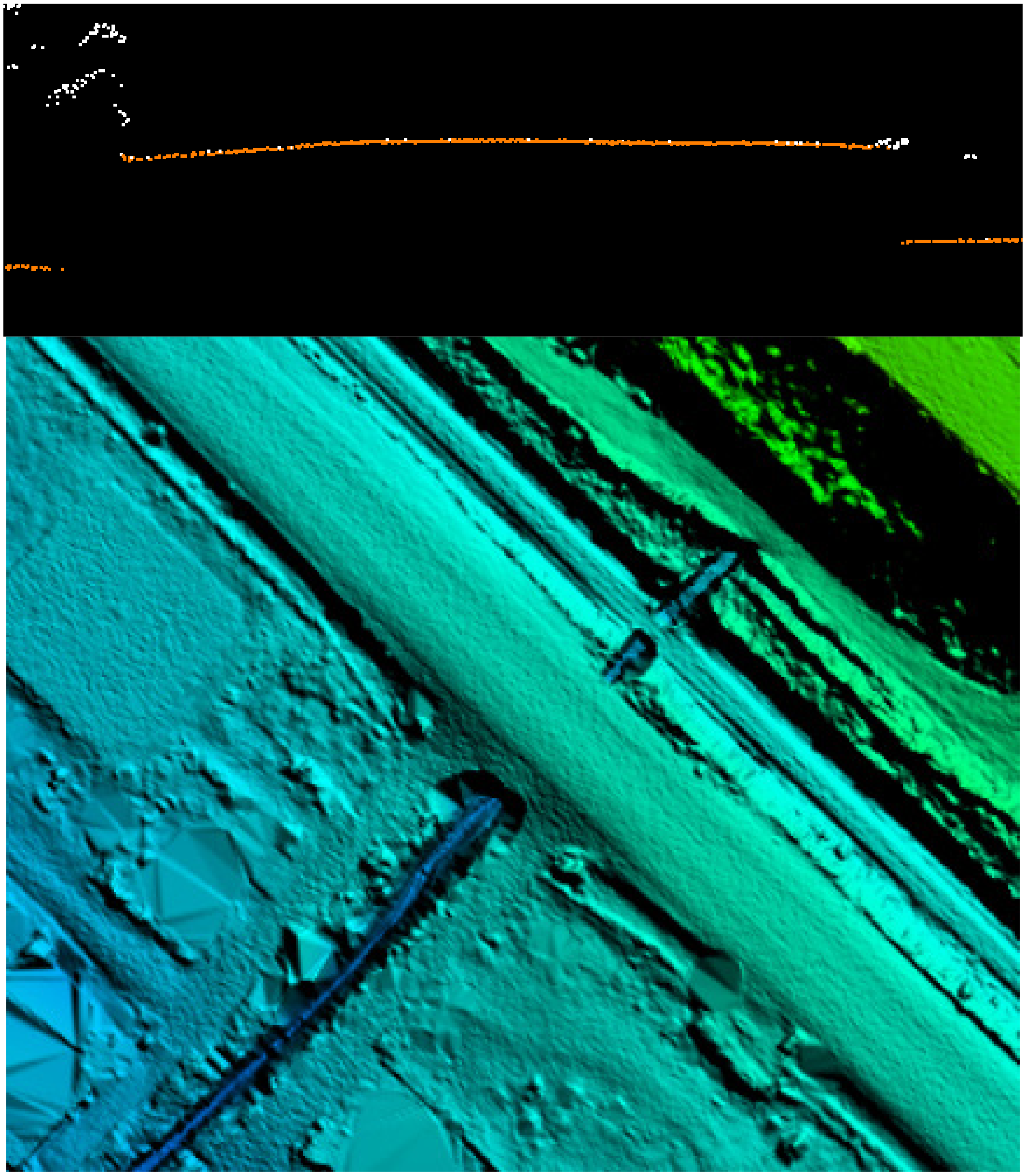


Figure 13– Tile number 15SKT28203798. Profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

Tidal Window Requirements

Dewberry identified an approximate 8 mile stretch where the flight line covering the land/water interface was flown within one hour past the 2 hour low tide window. This time delay results in the flight line being acquired when the tide is approximately 1 foot higher than the low tide. The flight line was still acquired approximately 2.5 feet lower than the high tide for the day. The affected area is in California along a particularly rocky shoreline where there is little beach before the cliffs. An image is shown below.

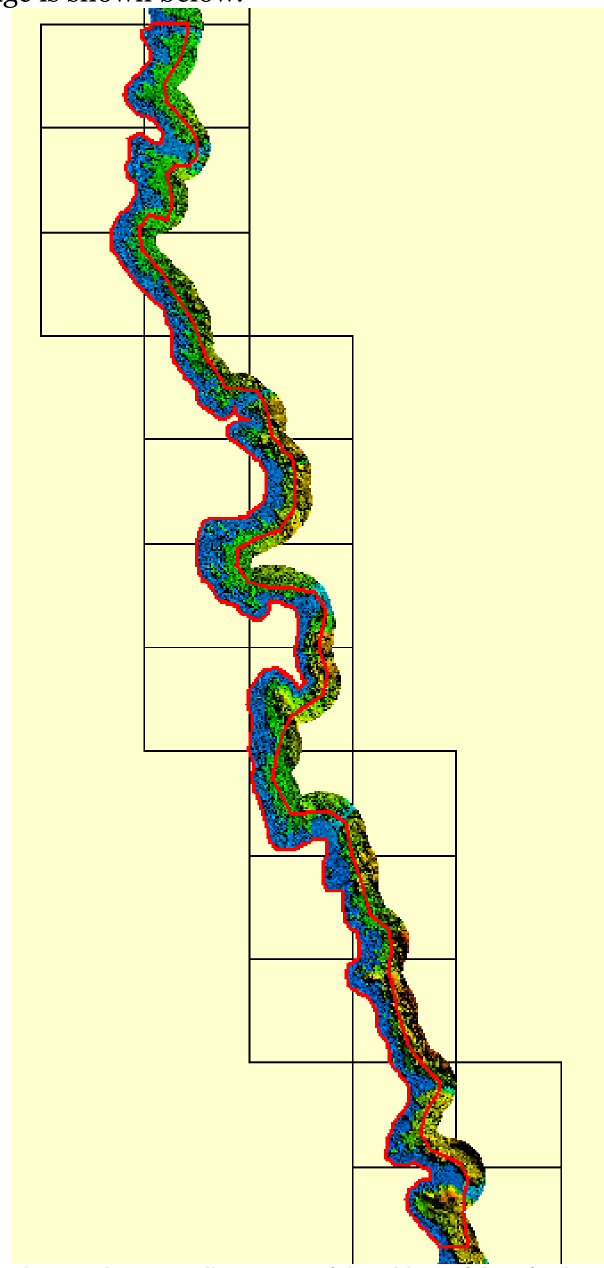


Figure 14- Image above shows the area flown outside of low tide window. Red= Boundary of area affected.

Temporal Ground

Dewberry noticed artifacts along beaches affecting 248 tiles throughout the El Nino Lidar project during one of our internal DEM reviews. The artifacts are a result of temporal differences between two overlapping swaths flown on two separate dates but within the low tide window of each date flown. Dewberry used one swath to classify the most consistent ground and classified ground from the overlapping swath to class 65, Temporal Ground.

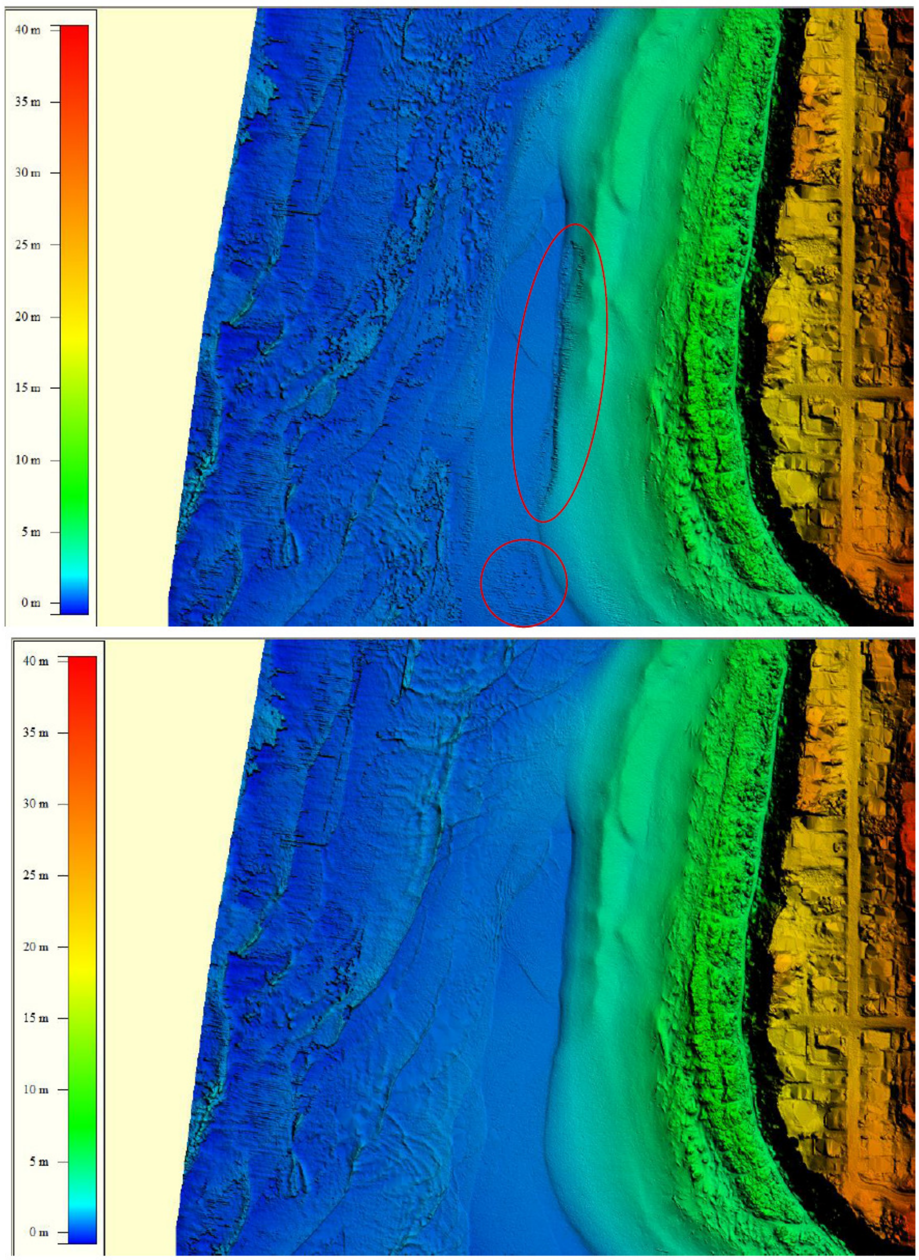


Figure 15- Tile 10TDQ41854975- The top image shows artifacts in the beach area due to temporal differences of overlapping flight lines. The bottom image shows the artifacts removed from the final ground once class 65, Temporal Ground, was implemented in the classification routine.

FORMATTING

After the final QA/QC is performed and all corrections have been applied to the dataset, all LiDAR files are updated to the final format requirements and the final formatting, header information, point data records, and variable length records are verified using Dewberry proprietary tools. The table below lists some of the main LiDAR header fields that are updated and verified.

Classified LiDAR Formatting		
Parameter	**Requirement**	**Pass/Fail**
LAS Version	1.4	Pass
Point Data Format	Format 6	Pass
Coordinate Reference System	NAD83 (2011) UTM Zone 10 and UTM Zone 11, meters and NAVD88 (Geoid 12B), meters in WKT Format	Pass
Global Encoder Bit	Should be set to 17 for Adjusted GPS Time	Pass
Time Stamp	Adjusted GPS Time (unique timestamps)	Pass
System ID	Should be set to the processing system/software and is set to NIIRS10 for GeoCue software	Pass
Multiple Returns	The sensor shall be able to collect multiple returns per pulse and the return numbers are recorded	Pass
Intensity	16 bit intensity values are recorded for each pulse	Pass
Classification	Required Classes include: Class 1: Unclassified Class 2: Ground Class 7: Low Noise Class 9: Water Class 10: Ignored Ground Class 17: Bridge Decks Class 18: High Noise Class 64: Flown Outside Low Tide Window Class 65: Temporal Ground	Pass
Overlap and Withheld Points	Overlap (Overage) and Withheld points are set to the Overlap and Withheld bits	Pass
Scan Angle	Recorded for each pulse	Pass

XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Table 5: Main LiDAR header fields

LiDAR Positional Accuracy

BACKGROUND

Dewberry quantitatively tested the dataset by testing the vertical accuracy of the LiDAR. The vertical accuracy is tested by comparing the discreet measurement of the survey checkpoints to that of the interpolated value within the three closest LiDAR points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the LiDAR data is actually tested. However there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to the next contiguous LiDAR measurement, and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy. Dewberry typically uses LP360 software to test the swath LIDAR vertical accuracy, Terrascan software to test the classified LiDAR vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Dewberry also tests the horizontal accuracy of LiDAR datasets when checkpoints are photo-identifiable in the intensity imagery. Photo-identifiable checkpoints in intensity imagery typically include checkpoints located at the ends of paint stripes on concrete or asphalt surfaces or checkpoints located at 90 degree corners of different reflectivity, e.g. a sidewalk corner adjoining a grass surface. The XY coordinates of checkpoints, as defined in the intensity imagery, are compared to surveyed XY coordinates for each photo-identifiable checkpoint. These differences are used to compute the tested horizontal accuracy of the LiDAR. As not all projects contain photo-identifiable checkpoints, the horizontal accuracy of the LiDAR cannot always be tested.

SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment, ninety two (92) check points were surveyed for the project and are located within bare earth/open terrain, grass/weeds/crops, and forested/fully grown land cover categories. Please see appendix A to view the survey report which details and validates how the survey was completed for this project.

Checkpoints were evenly distributed throughout the project area so as to cover as many flight lines as possible using the “dispersed method” of placement.

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table.

Point ID	NAD83 (2011) UTM Zone 10 and Zone 11		NAVD88 (Geoid 12B)
	Easting X (m)	Northing Y (m)	Elevation (m)
CP01	487356.7	3609421.133	3.825
CP03	471758.807	3658464.484	16.183
CP05	433872.508	3702708.923	69.622
CP07	390351.568	3736550.9	3.588
CP09	362828.378	3763139.519	4.864
CP11	312071.298	3773517.429	11.753
CP13	268033.741	3808653.053	2.805
CP15	762983.115	3818429.812	39.3874
CP17	719418.3	3840433.867	16.3765
CP18	714535.253	3871687.284	7.5056
CP20	694036.4315	3916332.96	5.8322
CP23	653409.087	3952420.495	15.7076
CP24	638337.011	3976303.729	47.0066
CP26	599243.1435	4020824.97	47.52
CP28	605387.78	4057845.356	27.8267
CP30	574274.6015	4094257.208	30.5789
CP32	552705.1215	4128352.701	6.15715
CP34	544575.938	4168860.774	61.6958
CP36	510773.226	4208749.869	10.3
CP38	497187.908	4240705.328	2.71385
CP40	463297.377	4280958.534	34.97435
CP41	443369.632	4301363.329	32.5174
CP43	430229.559	4353595.893	25.3917
CP45	428478.1975	4403366.107	84.49625
CP46	408770.633	4430846.417	15.928
CP48	385736.8845	4492179.976	9.0742
CP50	403496.42	4545768.153	6.63825
CP52	408471.547	4605246.942	5.9577
CP53	395918.095	4626484.284	16.543
CP55	384141.112	4681306.538	6.6905
CP56	385036.855	4710238.546	14.1749
CP58	372662.896	4743708.906	59.3349
CP59	383287.053	4773464.005	22.83135
CP61	396721.634	4812014.777	5.41055
CP63	407340.877	4859446.28	4.2792
CP65	413740.802	4918436.985	12.38685
CP67	419275.9445	4976310.139	39.47065

CP69	424154.255	5034574.766	8.30305
CP71	424551.497	5085566.442	62.0716
CP73	418543.3055	5138520.068	6.0258
CP75	416133.956	5184591.198	6.2273
CP76	410795.543	5197870.813	6.2858
CP77	411039.8565	5213669.419	5.6367
CP79	397929.9365	5267764.194	23.261
CP81	377652.0645	5308779.769	4.44215
CP83	385505.203	5356684.107	21.72125
CP85	429261.236	5335065.501	7.59595
CP87	481486.688	5328820.27	43.6411
CP89	508589.0765	5327794.062	3.80555
KK23	653412.379	3952411.703	15.5171
CP02	475530.07	3629985.235	27.9
CP04	455068.821	3686247.479	45.717
CP06	412168.712	3720974.7	3.521
CP08	368269.371	3737869.464	45.734
CP10	338016.754	3766897.193	33.59
CP12	291334.175	3791124.412	6.42
CP14	240089.549	3812051.689	4.434
CP16	729406.082	3821560.589	5.1935
CP90	518140.234	5332263.165	3.36705
CP91	404763.367	5345724.904	10.2712
CP88	493944.41	5330196.512	3.2883
CP86	457612.162	5332216.305	4.2269
CP84	406885.053	5345828.918	5.9472
CP82	376627.234	5351115.071	22.6317
CP80	393891.755	5284758.814	35.312
CP78	405778.708	5239138.461	7.3061
CP74	418733.586	5155512.475	6.5263
CP72	424494.105	5114205.189	11.0967
CP70	426677.169	5064028.358	9.5295
CP68	424001.72	5004781.23	7.1447
CP66	414619.804	4947527.748	27.5028
CP64	410685.631	4890294.787	14.4585
CP62	402620.774	4834790.803	7.25
CP60	387060.361	4787945.602	5.5383
CP57	375915.297	4735419.35	20.54855
CP54	395011.734	4655570.846	5.656
CP51	408563.356	4570850.714	7.00205
CP49	399629.622	4519519.624	7.2396
CP47	384417.874	4467920.598	9.7166
CP44	433978.9935	4379890.558	27.7015

CP42	438114.933	4330526.523	55.98315
CP39	481785.369	4261184.436	146.836
CP37	502193.835	4214337.607	14.6302
CP35	536432.4965	4190736.529	147.6003
CP33	549283.726	4143770.156	22.231
CP31	553906.465	4115390.783	16.7149
CP29	601407.291	4087985.261	14.3482
CP27	595926.814	4046163.777	28.1387
CP25	621407.995	4000196.84	88.5666
CP21	684959.475	3925852.275	13.1725
CP22	672943.2175	3934846.461	12.82895
CP19	706269.857	3895404.942	2.0663

Table 6: West Coast El Nino LiDAR project surveyed accuracy checkpoints

The figures below shows the location of the QA/QC checkpoints used to test the positional accuracy of the dataset.

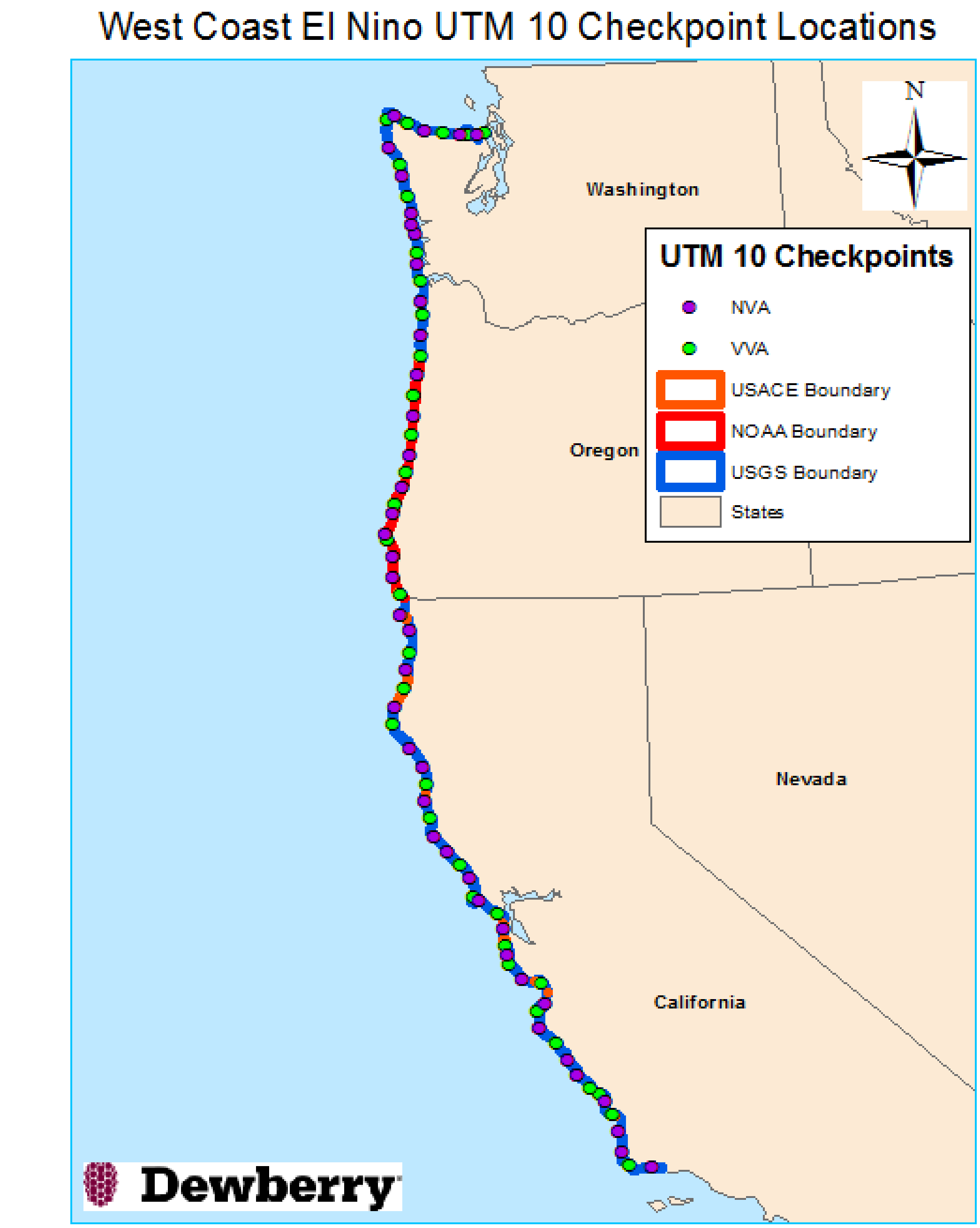


Figure 16 – Location of QA/QC Checkpoints in UTM Zone 10

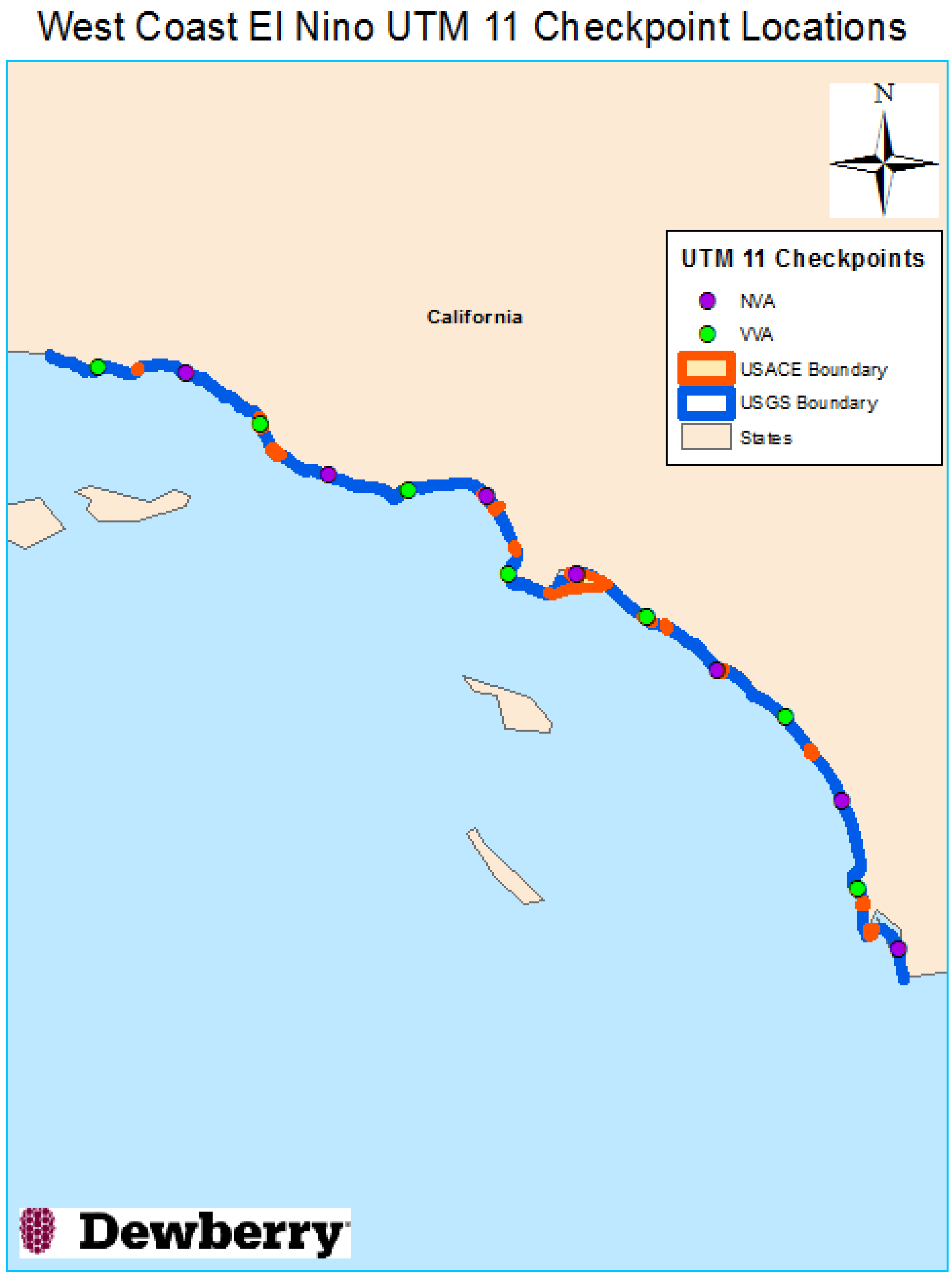


Figure 17 – Location of QA/QC Checkpoints in UTM Zone 11

VERTICAL ACCURACY TEST PROCEDURES

NVA (Non-vegetated Vertical Accuracy) is determined with check points located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) and urban areas, where there is a very high probability that the LiDAR sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The NVA determines how well the calibrated LiDAR sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. For the West Coast El Nino LiDAR project, vertical accuracy must be 19.6 cm or less based on an $RMSE_z$ of 10 cm x 1.9600.

VVA (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all vegetated land cover categories combined. The West Coast El Nino LiDAR Project VVA standard is 29.4 cm based on the 95th percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the VVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from VVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas VVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

The relevant testing criteria are summarized in Table 7.

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using $RMSE_z$ *1.9600	19.6 cm (based on $RMSE_z$ (10 cm) * 1.9600)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined at the 95% confidence level	29.4 cm (based on combined 95th percentile)

Table 7 — Acceptance Criteria

The primary QA/QC vertical accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications.
2. Next, Dewberry interpolated the bare-earth LiDAR DTM to provide the z-value for every checkpoint.
3. Dewberry then computed the associated z-value differences between the interpolated z-value from the LiDAR data and the ground truth survey checkpoints and computed NVA, VVA, and other statistics.
4. The data were analyzed by Dewberry to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by the scope of work. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. This report provides tables, graphs and figures to summarize and illustrate data quality.

VERTICAL ACCURACY RESULTS

The table below summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the fully classified LiDAR LAS files.

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	50	11.4	
VVA	42		21.1

Table 8 — Tested NVA and VVA

This LiDAR dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =5.8 cm, equating to +/- 11.4 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 21.1 cm at the 95th percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and LiDAR data. This shows that the majority of LiDAR elevations were within +/- 10 cm of the checkpoints elevations, but there were some outliers where LiDAR and checkpoint elevations differed by up to -50 cm.

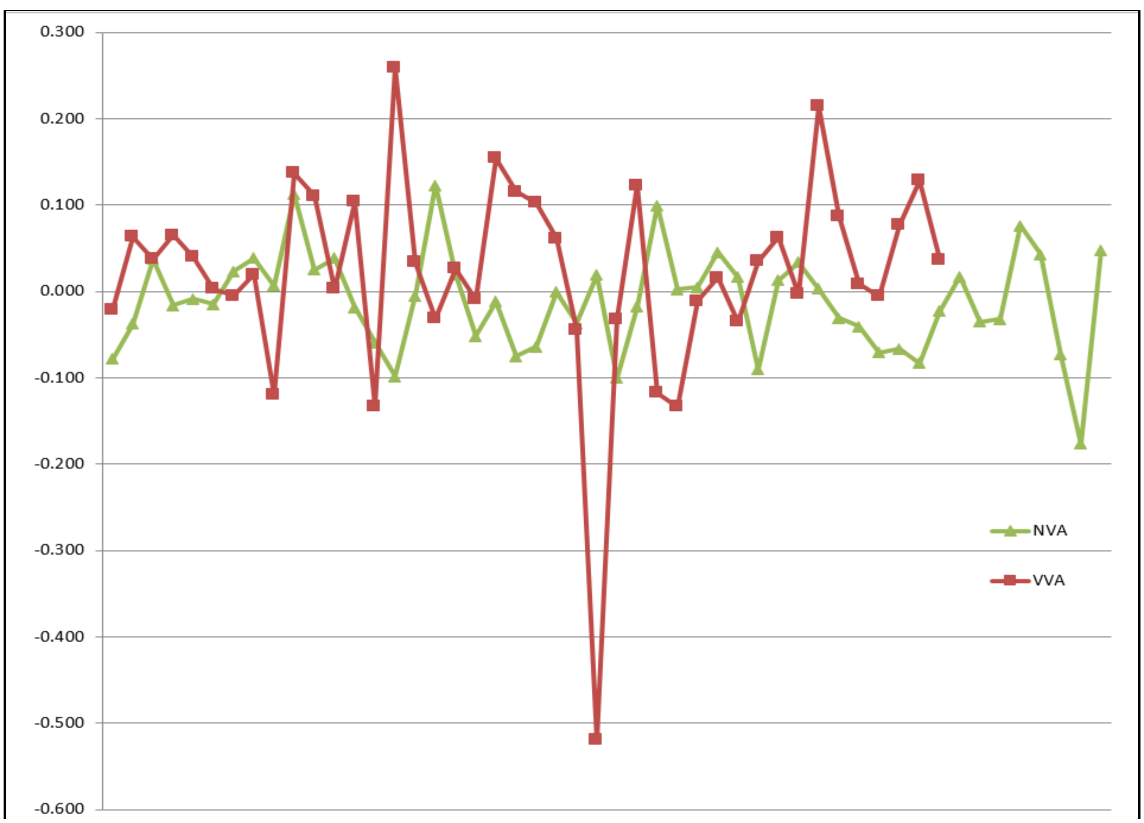


Figure 18 – Magnitude of elevation discrepancies per land cover category

Table 9 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83 (2011) UTM Zone 10 and Zone 11		NAVD88 (Geoid 12B)	LiDAR Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
CP31	553906.465	4115390.783	16.715	16.929	0.214	0.214
CP57	375915.297	4735419.350	20.549	20.029	-0.520	0.520
CP80	393891.755	5284758.814	35.312	35.571	0.259	0.259

Table 9 — 5% Outliers

Table 10 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	50	0.058	-0.012	-0.010	-0.076	0.058	0.633	-0.177	0.123
VVA	42	N/A	0.021	0.030	-2.100	0.120	9.411	-0.520	0.259

Table 10 — Overall Descriptive Statistics

The figure below illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the LiDAR triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.520 meters and a high of +0.259 meters, the histogram shows that the majority of the discrepancies are skewed on the positive side. The vast majority of points are within the ranges of -0.05 meters to +0.05 meters.

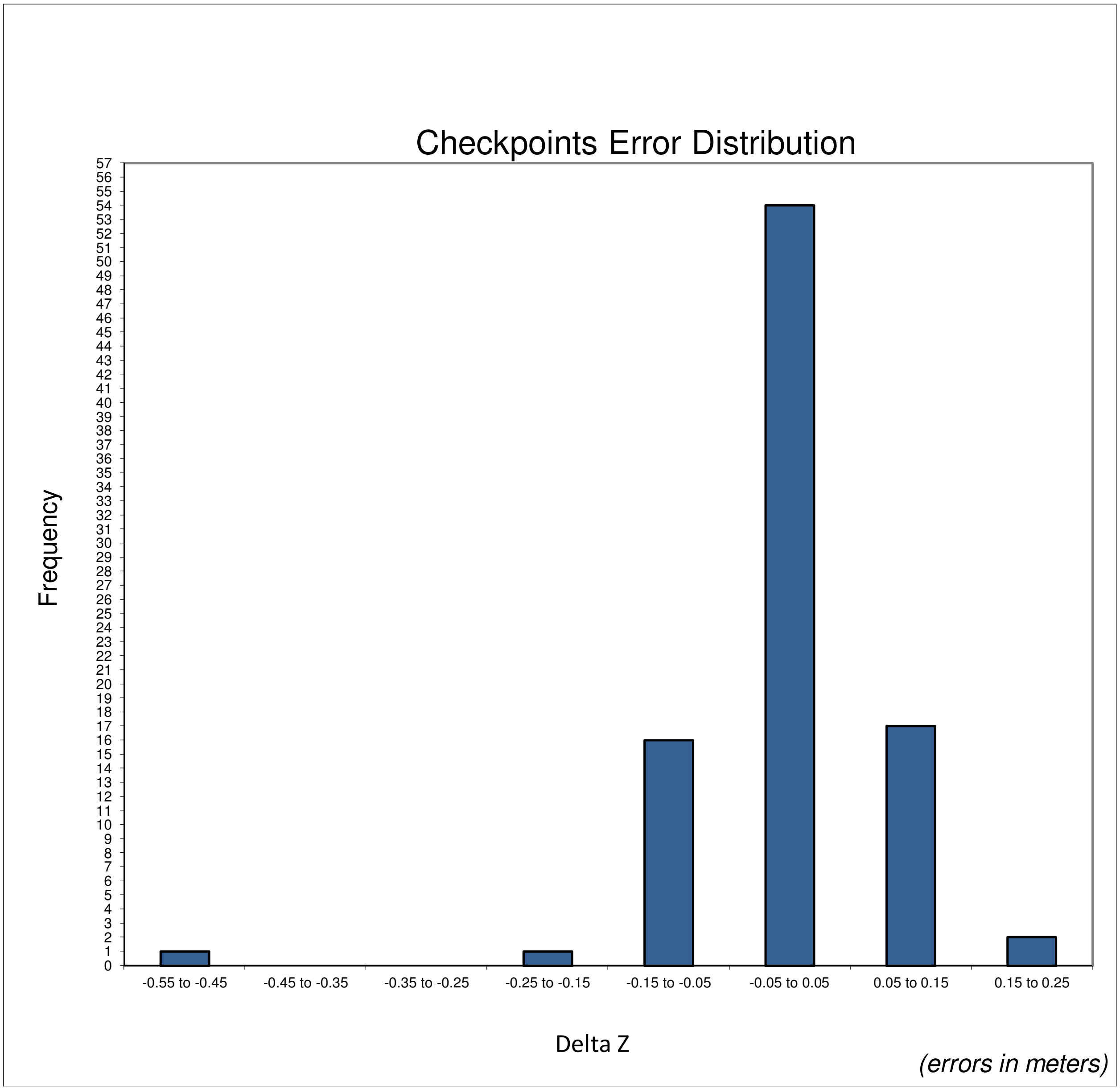


Figure 19 — Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the LiDAR dataset for the West Coast El Nino LiDAR Project satisfies the project's pre-defined vertical accuracy criteria.

HORIZONTAL ACCURACY TEST PROCEDURES

Horizontal accuracy testing requires well-defined checkpoints that can be identified in the dataset. Elevation datasets, including LiDAR datasets, do not always contain well-defined checkpoints suitable for horizontal accuracy assessment. However, the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) recommends at least half of the NVA vertical check points should be located at the ends of paint stripes or other point features visible on the LiDAR intensity image, allowing them to double as horizontal check points.

Dewberry reviews all NVA checkpoints to determine which, if any, of these checkpoints are located on photo-identifiable features in the intensity imagery. This subset of checkpoints are then used for horizontal accuracy testing.

The primary QA/QC horizontal accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications and tried to locate half of the NVA checkpoints on features photo-identifiable in the intensity imagery.
2. Next, Dewberry identified the well-defined features in the intensity imagery.
3. Dewberry then computed the associated xy-value differences between the coordinates of the well-defined feature in the LiDAR intensity imagery and the ground truth survey checkpoints.
4. The data were analyzed by Dewberry to assess the accuracy of the data. Horizontal accuracy was assessed using NSSDA methodology where horizontal accuracy is calculated at the 95% confidence level. This report provides the results of the horizontal accuracy testing.

HORIZONTAL ACCURACY RESULTS

Three checkpoints were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the LiDAR dataset. As only three (3) checkpoints were photo-identifiable, the results are not statistically significant enough to report as a final tested value, but the results of the testing are still shown in the table below.

Using NSSDA methodology (endorsed by the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014)), horizontal accuracy at the 95% confidence level (called ACCURACYr) is computed by the formula RMSEr * 1.7308 or RMSExy * 2.448.

No horizontal accuracy requirements or thresholds were provided for this project. However, LiDAR datasets are generally calibrated by methods designed to ensure a horizontal accuracy of 1 meter or less at the 95% confidence level.

# of Points	$RMSE_x$ (Target=0.409 m)	$RMSE_y$ (Target=0.409 m)	$RMSE_r$ (Target=0.578 m)	$ACCURACY_r$ ($RMSE_r$ x 1.7308) Target=1 m
3	0.041	0.115	0.122	0.211

Table 11-Tested horizontal accuracy at the 95% confidence level

Actual positional accuracy of this dataset was found to be RMSEx = 4.1 cm and RMSEy = 11.5 cm which equates to +/- 21.1 cm at 95% confidence level.

Breakline Production & Qualitative Assessment Report

BREAKLINE PRODUCTION METHODOLOGY

Dewberry used GeoCue software to develop LiDAR stereo models of the West Coast El Nino LiDAR Project area so the LiDAR derived data could be viewed in 3-D stereo using Socet Set softcopy photogrammetric software. Using LiDARgrammetry procedures with LiDAR intensity imagery, Dewberry used the stereo models developed by Dewberry to stereo-compile the tidal breaklines in accordance with the project's Data Dictionary.

BREAKLINE QUALITATIVE ASSESSMENT

Dewberry completed breakline qualitative assessments according to a defined workflow. The following workflow diagram represents the steps taken by Dewberry to provide a thorough qualitative assessment of the breakline data.

Completeness and horizontal placement is verified through visual reviews against LiDAR intensity imagery. Automated checks are applied on all breakline features to validate topology, including the 3D connectivity of features.

The next step is to compare the elevation of the breakline vertices against the ground elevation extracted from the ESRI Terrain built from the LiDAR ground points, keeping in mind that a discrepancy is expected because of the hydro-enforcement applied to the breaklines and because of the interpolated imagery used to acquire the breaklines. A given tolerance is used to validate if the elevations differ too much from the LiDAR.

After all corrections and edits to the breakline features, the breaklines are imported into the final GDB and verified for correct formatting.

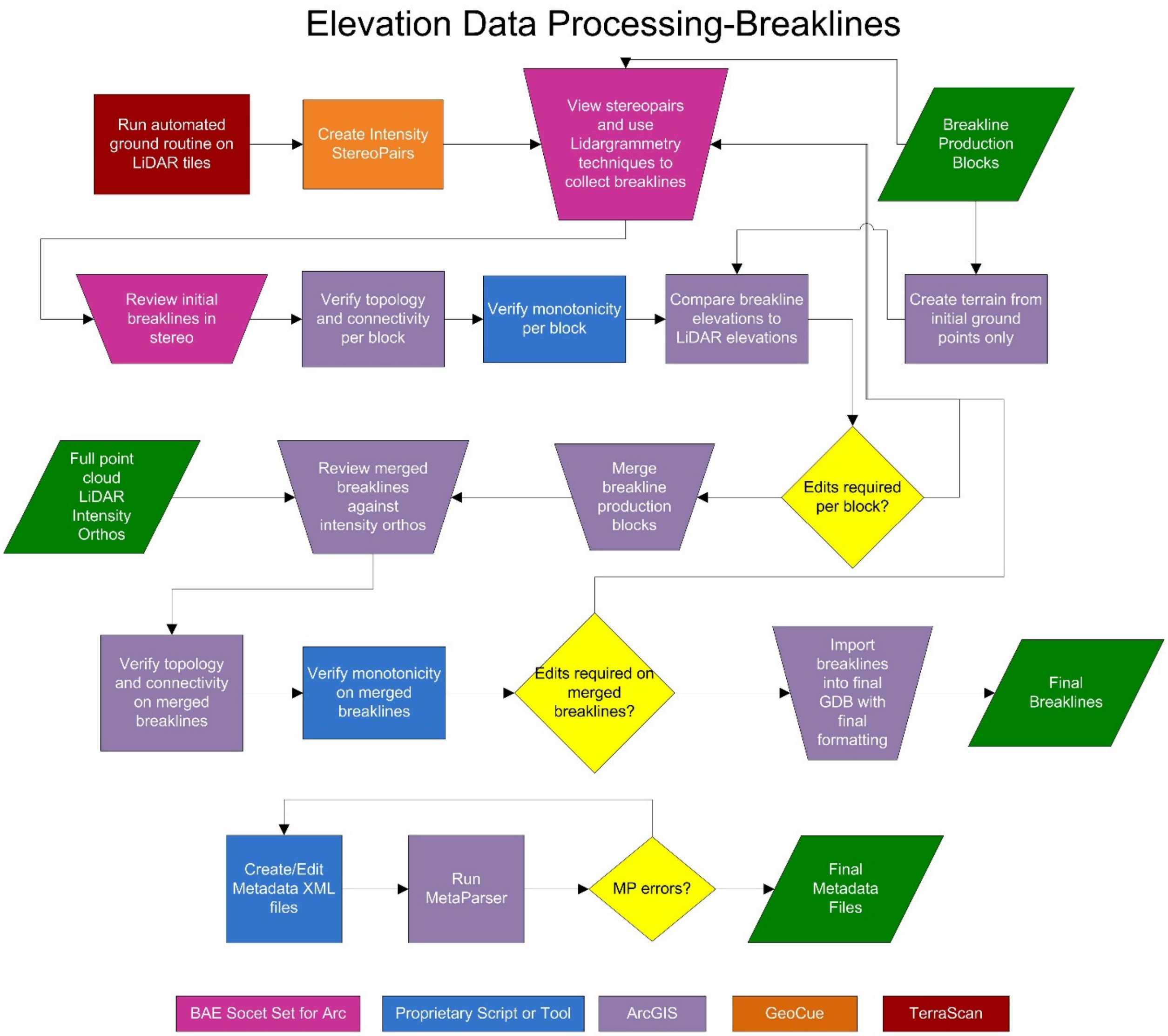


Figure 20-Breakline QA/QC workflow

BREAKLINE CHECKLIST

The following table represents a portion of the high-level steps in Dewberry's Production and QA/QC checklist that were performed for this project.

Pass/Fail	Validation Step
Pass	Use intensity imagery, stereo pairs, and terrains to collect breaklines according to project specifications.
Pass	In areas of heavy vegetation or where the exact shoreline is hard to delineate, it is better to err on placing the breakline *slightly* inside or seaward of the shoreline (breakline can be inside shoreline by 1x-2x NPS).

Pass	After each producer finishes breakline collection for a block, each producer must perform a completeness check, breakline variance check, and all automated checks on their block before calling that block complete and ready for the final merge and QC
Pass	After breaklines are completed for production blocks, all production blocks should be merged together and all checks-completeness, breakline variance, and automated checks-should be performed on the final, merged GDB. Ensure correct snapping-horizontal (x,y) and vertical (z)-between all production blocks.
Pass	Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency. Features should be collected consistently across tile bounds. Check that the horizontal placement of breaklines is correct. Breaklines should be compared to full point cloud intensity imagery and terrains
Pass	Breaklines are correctly edge-matched to adjoining datasets in completion, coding, and horizontal placement.
Pass	Using a terrain created from LiDAR ground (all ground including 2 and 10) and water points (class 9), compare breakline Z values to interpolated LiDAR elevations.
Pass	Perform all Topology and Data Integrity Checks
N/A	Perform hydro-flattening and hydro-enforcement checks including monotonicity and flatness from bank to bank on linear hydrographic features and flatness of water bodies. Tidal waters should preserve as much ground as possible and can include variations or be non-monotonic.

Table 12-A subset of the high-level steps from Dewberry's Production and QA/QC checklist performed for this project.

DATA DICTIONARY

The following data dictionary was used for this project.

Horizontal and Vertical Datum

The horizontal datum shall be North American Datum of 1983 (2011), Units in Meters. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in Meters. Geoid12B shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to UTM Zone 10 and UTM Zone 11, Horizontal Units in Meters and Vertical Units in Meters.

Tidal Waters

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: TIDAL_WATERS
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will outline the land / water interface at the time of LiDAR acquisition.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
TIDAL_WATERS	The coastal breakline will delineate the land water interface using LiDAR data as reference. In flight line boundary areas with tidal variation the coastal shoreline may show stair stepping as no feathering is allowed. Stair stepping is allowed to show as much ground as the collected data permits.	The feature shall be extracted at the apparent land/water interface, as determined by the LiDAR intensity data, to the extent of the tile boundaries. Differences caused by tidal variation are acceptable and breaklines delineated should reflect that change with no feathering. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding LiDAR points. Acceptable variance in the negative direction will be defined for each project individually. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Breaklines shall snap and merge seamlessly with linear hydrographic features.

Beneath Bridge Breaklines

Feature Dataset: BREAKLINES
Feature Type: Polyline
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: Bridge_Breaklines
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polyline feature class is used to enforce terrain beneath bridge decks where ground data may not have been acquired. Enforcing the terrain beneath bridge decks prevents bridge saddles.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Bridge Breaklines	Bridge Breaklines should be used where necessary to enforce terrain beneath bridge decks and to prevent bridge saddles in the bare earth DEMs.	Bridge breaklines should be collected beneath bridges where bridge saddles exist or are likely to exist in the bare earth DEMs. Bridge breaklines should be collected perpendicular to the bridge deck so that the endpoints are on either side of the bridge deck. Typically two bridge breaklines are collected per bridge deck, one at either end of the bridge deck to enforce the terrain under the full bridge deck. The endpoints of the bridge breaklines will match the elevation of the ground at their xy position to enforce the ground/bare earth elevations beneath the bridge deck and prevent bridge saddles from forming.

DEM Production & Qualitative Assessment

DEM PRODUCTION METHODOLOGY

Dewberry utilized ESRI software and Global Mapper for the DEM production and QC process. ArcGIS software is used to generate the products and the QC is performed in both ArcGIS and Global Mapper. The figure below shows the entire process necessary for bare earth DEM production, starting from the LiDAR swath processing.

The final bare-earth LiDAR points are used to create a terrain. The final 3D breaklines collected for the project are also enforced in the terrain. As this is a research project focusing on the land/water interface and beach areas, tidal waters were not hydro-flattened in the terrains. Not enforcing tidal water breaklines in terrain preserves as much information as possible in the coastal areas. Bridge breaklines were enforced in the terrain. The terrain is then converted to raster format using linear interpolation. For most projects, a single terrain/DEM can be created for the whole project. For very large projects, multiple terrains/DEMs may be created. The DEM(s) is reviewed for any issues requiring corrections, including remaining LiDAR misclassifications, erroneous breakline elevations, and processing artifacts. After corrections are applied, the DEM(s) is then split into individual tiles following the project tiling scheme. The tiles are verified for final formatting and then loaded into Global Mapper to ensure no missing or corrupt tiles and to ensure seamlessness across tile boundaries.

Figure 21-DEM Production Workflow

DEM QUALITATIVE ASSESSMENT

Dewberry performed a comprehensive qualitative assessment of the bare earth DEM deliverables to ensure that all tiled DEM products were delivered with the proper extents, were free of processing artifacts, and contained the proper referencing information. This process was performed in ArcGIS software with the use of a tool set Dewberry has developed to verify that the raster extents match those of the tile grid and contain the correct projection information. The DEM data was reviewed at a scale of 1:5000 to review for artifacts caused by the DEM generation process. To perform this review Dewberry creates HillShade models and overlays a partially transparent colorized elevation model to review for these issues. All corrections are completed using Dewberry's proprietary correction workflow. Upon completion of the corrections, the DEM data is loaded into Global Mapper for its second review and to verify corrections. Once the DEMs are tiled out, the final tiles are again loaded into Global Mapper to ensure coverage, extents, and that the final tiles are seamless.

The images below show an example of a bare earth DEM.

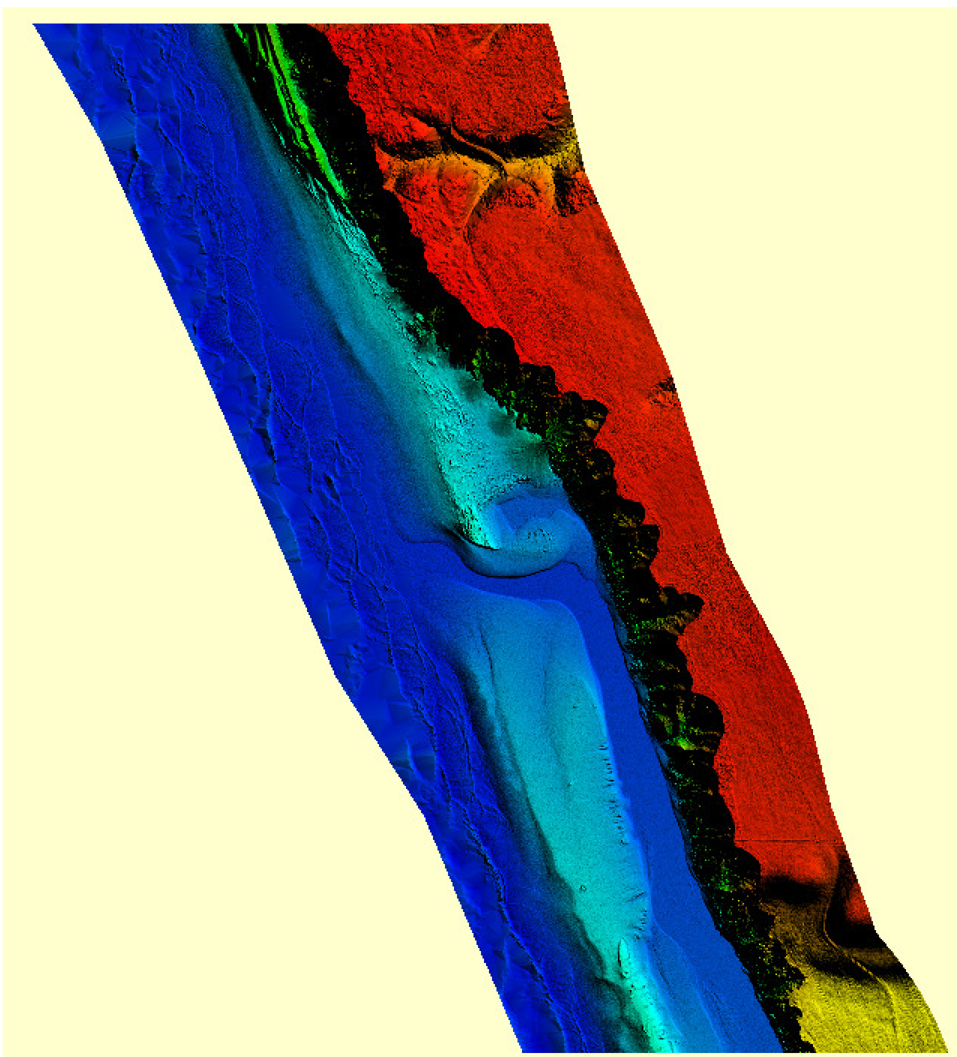


Figure 22-Tiles 10TCN37354740, 10TCN37504740. The image above is of the bare earth DEM

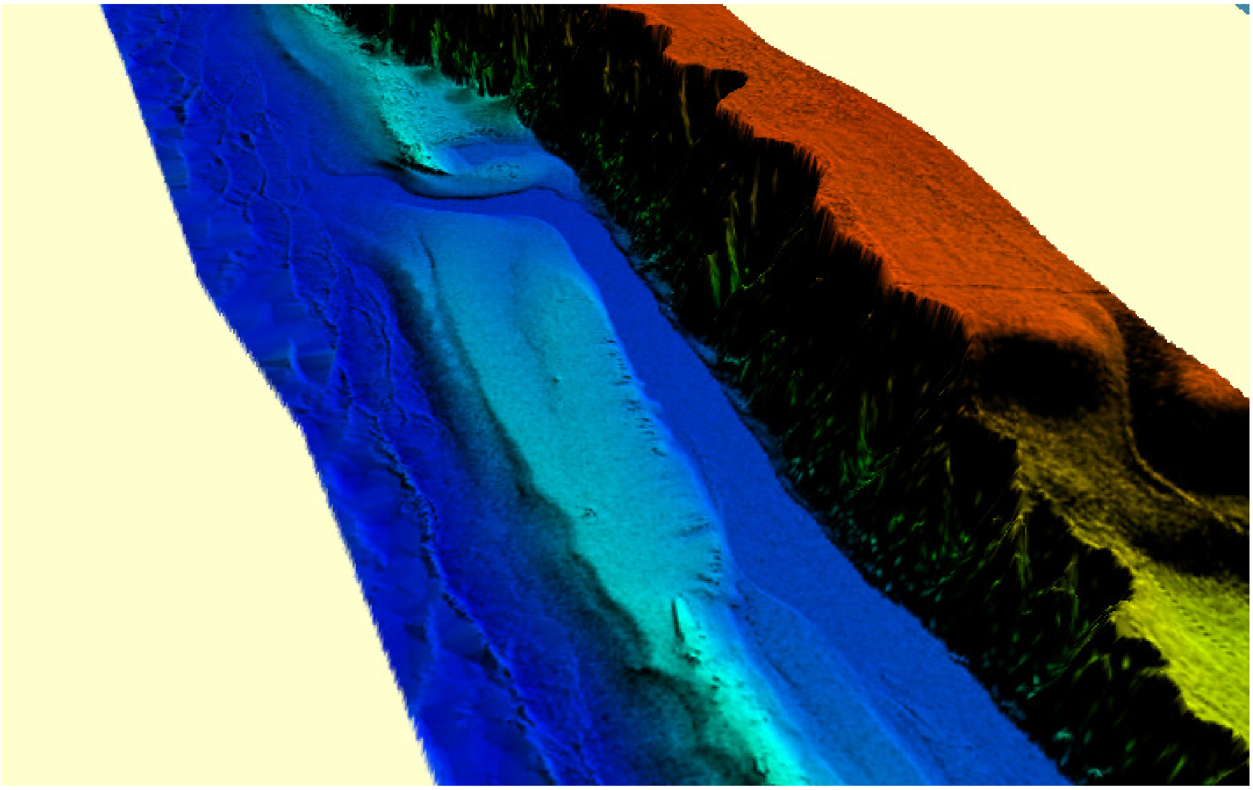


Figure 23- Tiles 10TCN37354740, 10TCN37504740. 3D Profile view of the bare earth DEM

DEM VERTICAL ACCURACY RESULTS

The same 92 checkpoints that were used to test the vertical accuracy of the LiDAR were used to validate the vertical accuracy of the final DEM products as well. Accuracy results may vary between the source LiDAR and final DEM deliverable. DEMs are created by averaging several LiDAR points within each pixel which may result in slightly different elevation values at each survey checkpoint when compared to the source LAS, which does not average several LiDAR points together but may interpolate (linearly) between two or three points to derive an elevation value. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations. Dewberry typically uses LP360 software to test the swath LIDAR vertical accuracy, Terrascan software to test the classified LiDAR vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Table 13 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	50	11.6	
VVA	42		20.4

Table 13 – DEM tested NVA and VVA

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =5.9 cm, equating to +/- 11.6 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 20.4 cm at the 95th percentile.

Table 14 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83 UTM Zone 10 and Zone 11		NAVD88 (Geoid 12B)	DEM Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
CP57	375915.297	4735419.350	20.549	20.005	-0.544	0.544
CP80	393891.755	5284758.814	35.312	35.559	0.247	0.247

Table 14 – 5% Outliers

Table 15 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	50	0.059	-0.012	-0.003	-0.095	0.059	0.445	-0.173	0.127
VVA	42	N/A	0.027	0.032	-2.279	0.124	10.097	-0.544	0.247

Table 15 – Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the West Coast El Nino LiDAR Project satisfies the project's pre-defined vertical accuracy criteria.

DEM CHECKLIST

The following table represents a portion of the high-level steps in Dewberry's bare earth DEM Production and QA/QC checklist that were performed for this project.

Pass/Fail	Validation Step
Pass	Masspoints (LAS to multipoint) are created from ground and tidal water points only (class 2 ground, Class 9 Water, class 10 ignored ground points)
Pass	Create a terrain for each production block using the final bare earth LiDAR points and final breaklines.
Pass	Convert terrains to rasters using project specifications for grid type, formatting, and cell size
Pass	Create hillshades for all DEMs

Pass	Manually review bare-earth DEMs in ArcMap with hillshades to check for issues
Pass	DEMs should not be hydro-flattened or hydro-enforced as required by project specifications
Pass	DEMs should be seamless across tile boundaries
N/A	Water should be flowing downhill without excessive water artifacts present
N/A	Water features should NOT be floating above surrounding
Pass	Bridges should NOT be present in bare-earth DEMs.
Pass	Any remaining bridge saddles where below bridge breaklines were not used need to be fixed by adding below bridge breaklines and re-processing.
Pass	All qualitative issues present in the DEMs as a result of LiDAR processing and editing issues must be marked for corrections in the LiDAR These DEMs will need to be recreated after the LiDAR has been corrected.
Pass	Calculate DEM Vertical Accuracy including NVA, VVA, and other statistics
Pass	Split the DEMs into tiles according to the project tiling scheme
Pass	Verify all properties of the tiled DEMs, including coordinate reference system information, cell size, cell extents, and that compression has not been applied to the tiled DEMs
Pass	Load all tiled DEMs into Global Mapper to verify complete coverage to the (buffered) project boundary and that no tiles are corrupt.

Table 16-A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project.

Appendix A: Survey Report

1.1 *Project Summary*

Dewberry is under contract to the United States Geological Survey to provide surveyed control points for the above referenced USGS Task Order. Towill, Inc. was subcontracted by Dewberry to complete this task. The control points will be used to validate the newly acquired lidar and generate both Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA) reports.

The ground survey was conducted during periods in April and May, 2016. The exclusive source of control for this Lidar campaign and Control survey consisted of Continuously Operating Reference Stations operated by the Plate Boundary Observatory (PBO) branch of UNAVCO (http://www.unavco.org/projects/major-projects/pbo/pbo.html). The western coastal and coast mountain ranges of the United States include hundreds of the PBO CORS that are publically funded and, with coordination in advance, can be operated at a high collection rate (1-hertz) and the data obtained via simple File Transfer Protocol.

The horizontal datum for this project is the latest realization of NAD83, namely NAD83(2011), epoch of 2010.0. The datum is realized by the published horizontal coordinates of the PBO CORS. These values were obtained via the National Geodetic Survey (NGS - www.ngs.noaa.gov/CORS) and the Scripps Orbit and permanent Array Center (SOPAC - sopac.ucsd.edu/processing). See Table 1 for a list of the published coordinate values.

The vertical datum for this project is NAVD88. The datum is realized by the published ellipsoid heights of the PBO CORS and the absolute application of the geoid model GEOID12B. These heights were obtained via the National Geodetic Survey (NGS - www.ngs.noaa.gov/CORS) and the Scripps Orbit and permanent Array Center (SOPAC - sopac.ucsd.edu/processing). See Table 1 for a list of the published ellipsoid heights.

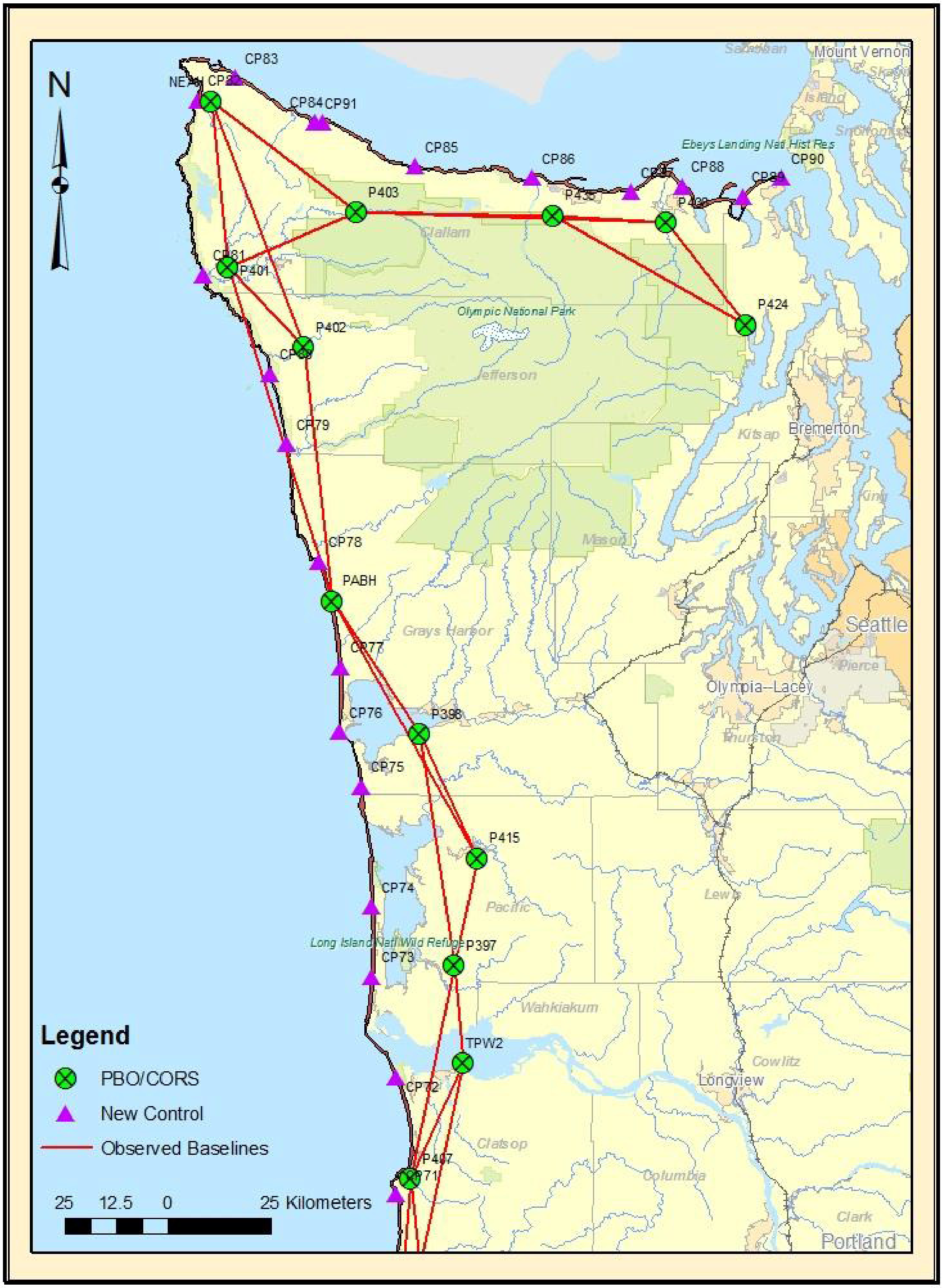
1.2 *Points of Contact*

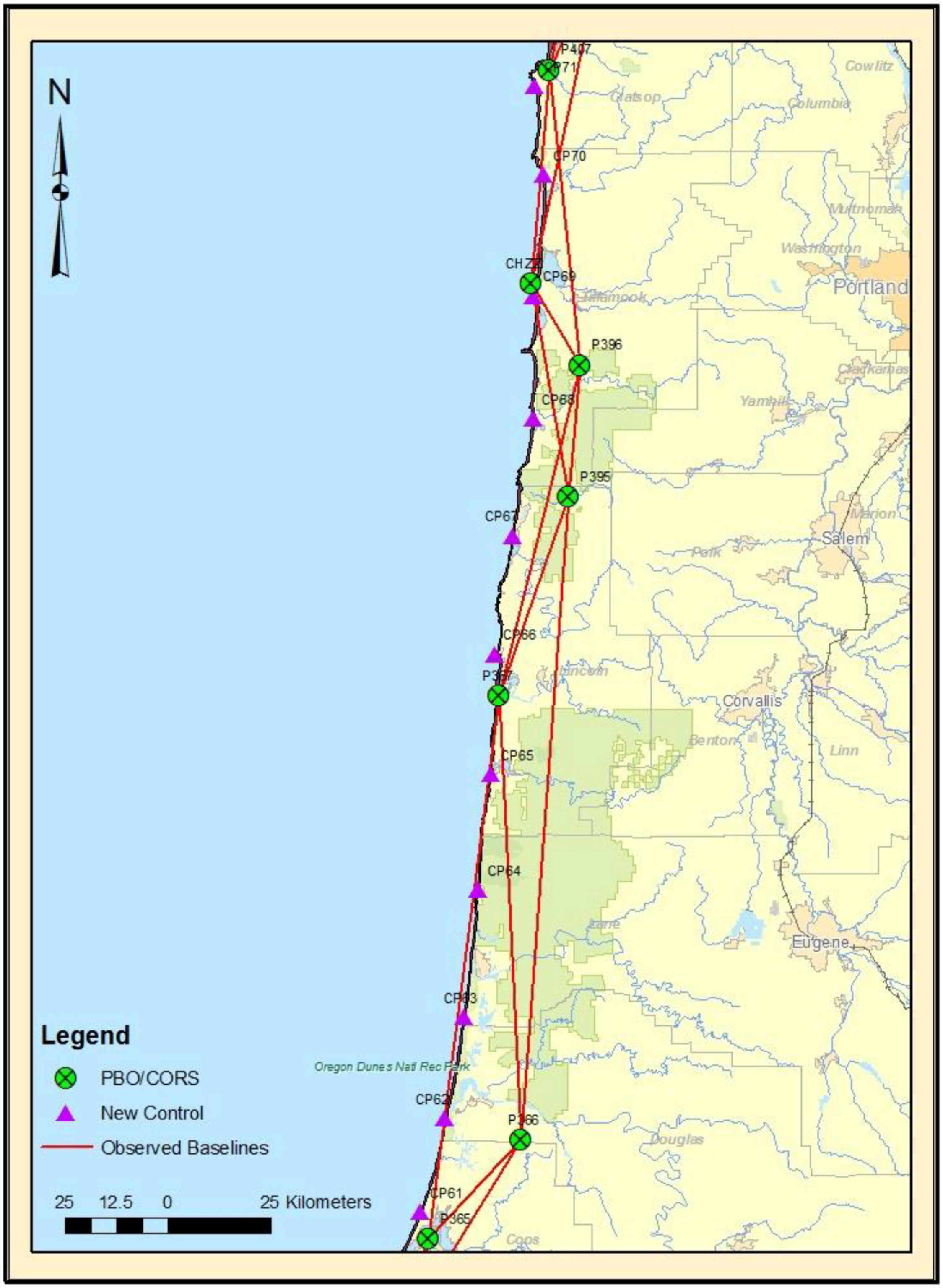
Questions regarding the technical aspects of this report should be addressed to:

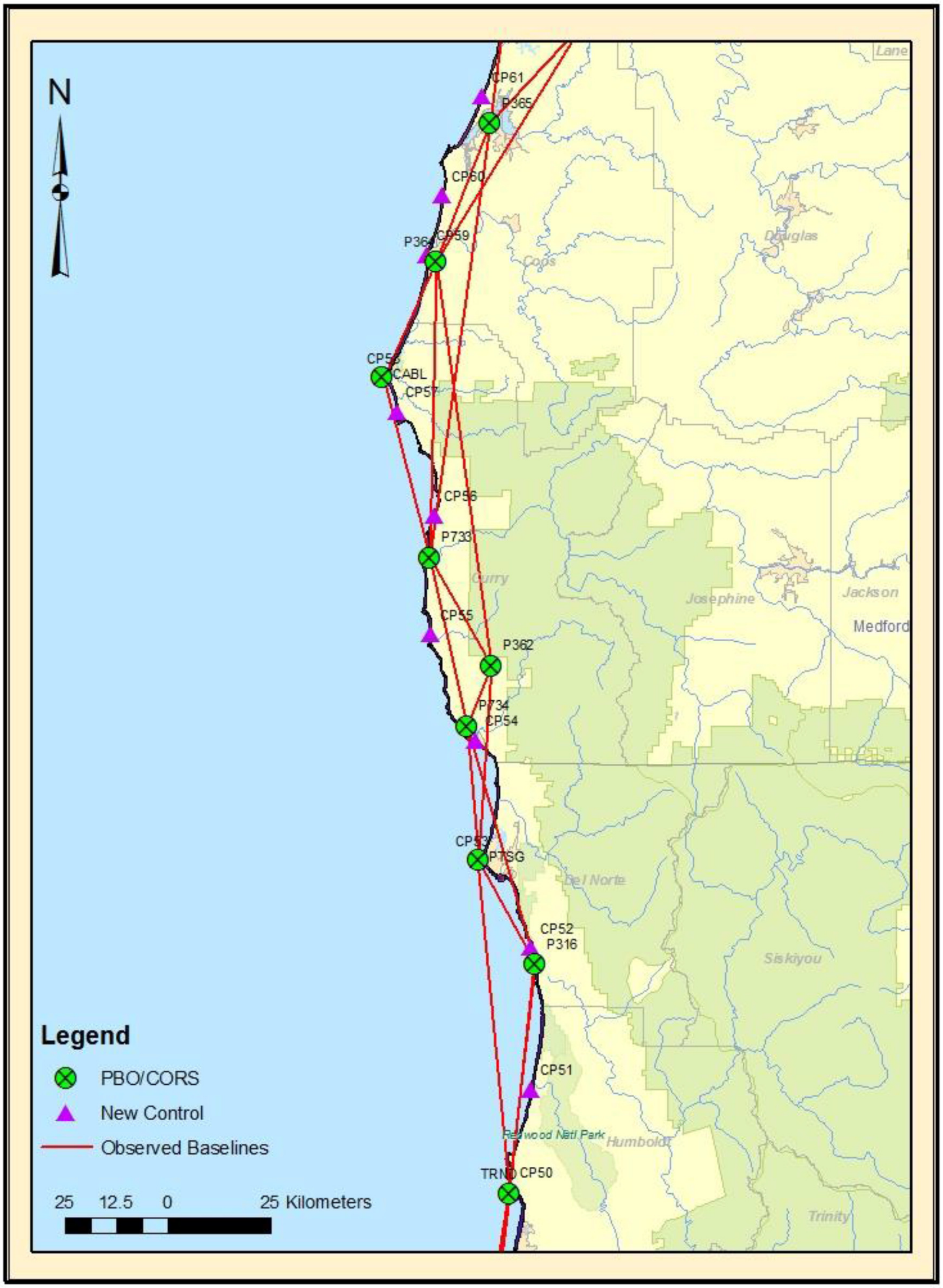
Towill, Inc.
Keith Kirkby, PE
Survey Engineer
7222 Commerce Center Dr.
Suite 230
Colorado Springs, CO 80924
(719) 243-5990

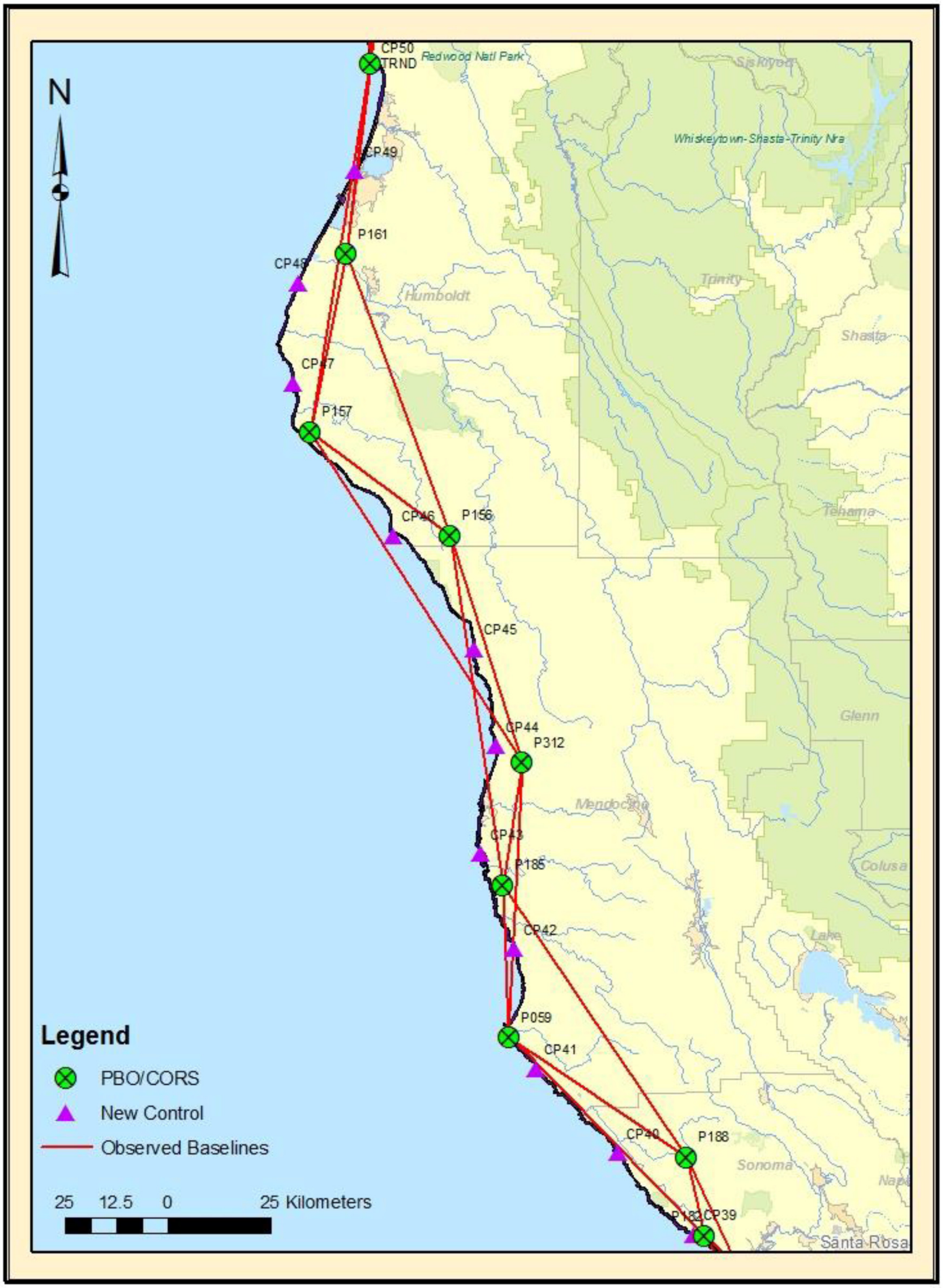
1.3 *Project Area*

The project boundary falls along an approximately 500 meter wide corridor on the coastline between Tijuana, Mexico and Port Townsend, WA as depicted below:


N
CP83
CP84
CP91
CP85
CP86
CP88
CP90
P403
P424
P401
P402
CP79
CP78
PABH
CP77
CP76
CP75
P415
CP74
P397
CP73
TPW2
CP72
Clallam
Olympic National Park
Jefferson
Kitsap
Bremerton
Mason
Grays Harbor
Seattle
Pierce
Olympia--Lacey
Thurston
Lewis
Pacific
Long Island Natl Wild Refuge
Wahkiakum
Cowlitz
Longview
Clatsop
Columbia
Clark
Portland
Mount Vernon
Ebeys Landing Natl Hist Res
Legend
PBO/CORS
New Control
Observed Baselines
25 12.5 0 25 Kilometers


N
Legend
PBO/CORS
New Control
Observed Baselines
25 12.5 0 25 Kilometers
P407
CP71
CP70
CHZZ
CP69
P396
CP68
P395
CP67
CP66
CP65
CP64
CP63
CP62
P366
CP61
P365
Clatsop
Columbia
Cowlitz
Multnomah
Washington
Portland
Tillamook
Clackamas
Yamhill
Marion
Salem
Polk
Lincoln
Corvallis
Benton
Linn
Lane
Eugene
Oregon Dunes Natl Rec Park
Douglas
Coos

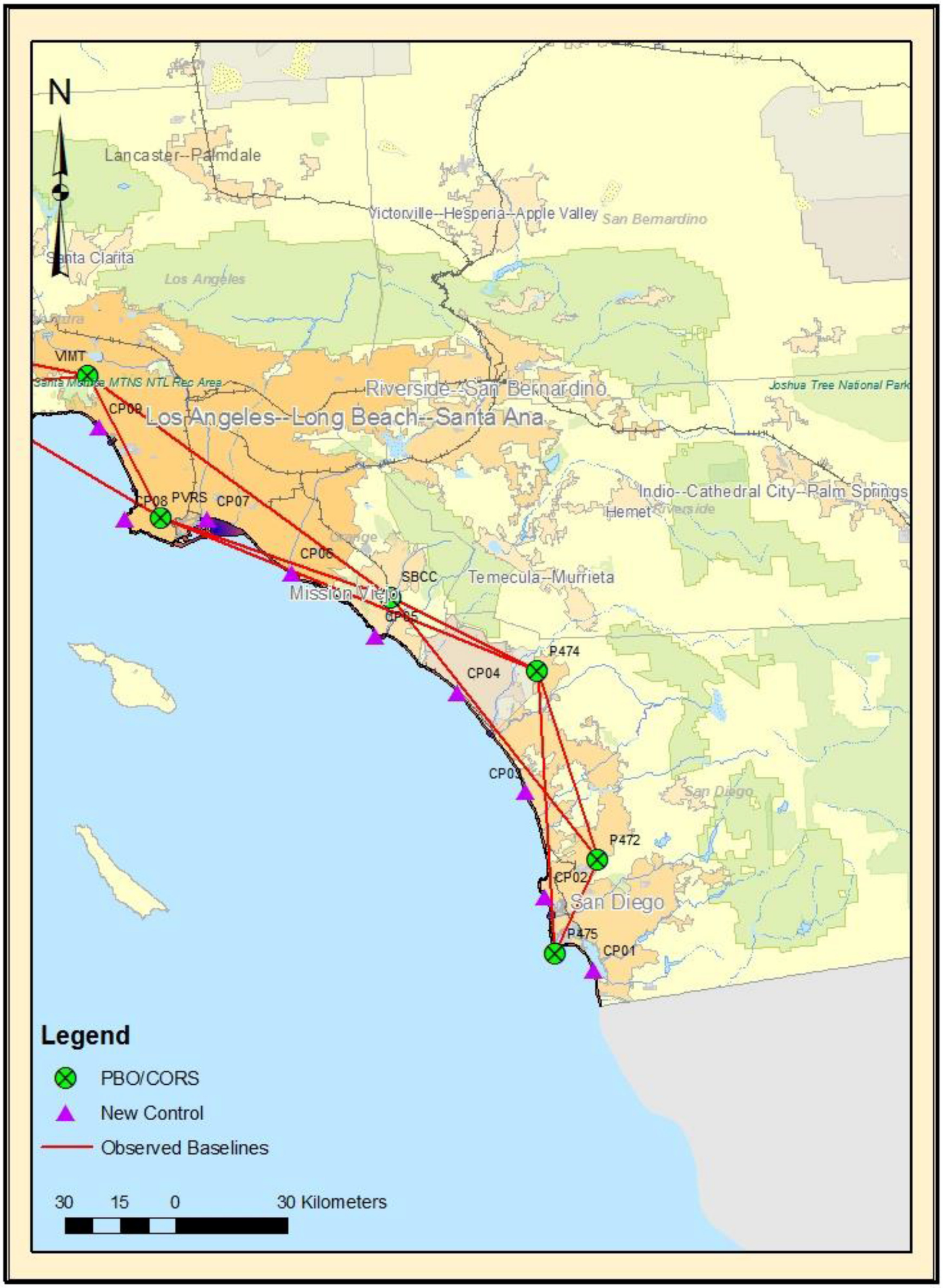

N
CP61
P365
CP60
P364
CP59
CP58
CABL
CP57
CP56
P733
CP55
P362
P734
CP54
CP53
P7SG
CP52
P316
CP51
TRND
CP50
Lane
Douglas
Coos
Curry
Josephine
Jackson
Medford
Del Norte
Siskiyou
Redwood Natl Park
Humboldt
Trinity
Legend
PBO/CORS
New Control
Observed Baselines
25 12.5 0 25 Kilometers


N
CP50
TRND
Redwood Natl Park
Siskiyou
Whiskeytown-Shasta-Trinity Nra
CP49
P161
CP48
Humboldt
Trinity
Shasta
CP47
P157
CP46
P156
Tehama
CP45
CP44
P312
Glenn
Mendocino
CP43
P185
Colusa
CP42
Lake
P059
CP41
CP40
P188
Sonoma
Napa
P182
CP39
Santa Rosa
Legend
PBO/CORS
New Control
Observed Baselines
25 12.5 0 25 Kilometers


N
Legend
PBO/CORS
New Control
Observed Baselines
25 12.5 0 25 Kilometers
CP39
CP38
P193
CP37
CP36
P181
CP35
CP34
P178
CP32
CP31
P534
CP30
P212
CP29
CP28
CP27
CP26
P172
CP25
Santa Rosa
Petaluma
Napa
Vacaville
Fairfield
Vallejo
Davis
Sacramento
Lodi
Stockton
Antioch
Concord
San Rafael--Novato
San Francisco--Oakland
Livermore
Tracy
San Jose
Gilroy--Morgan Hill
Santa Cruz
Watsonville
Salinas
Seaside--Monterey--Marina
Point Reyes Nat'l Seashore
Yolo
Sonoma
Solano
Contra Costa
San Joaquin
Alameda
Stanislaus
Santa Clara
San Benito
Monterey


P172
CP25
N
P173
CP24
CP23KK23
CP22
P067
CP21
P525
CP20
CP19
CP18
P513
CP17
VNDP
CP16
TIRN
CP15
CP14
San Benito
Fresno
Monterey
Kings
Tulare
Kern
Atascadero--Paso Robles
San Luis Obispo
Santa Maria
Santa Barbara
Lompoc
Channel Islands National Park
Legend
PBO/CORS
New Control
Observed Baselines
25 12.5 0 25 Kilometers


N
Bakersfield
Kern
San Luis Obispo
San Bernardino
Santa Barbara
Lancaster--Palmdale
Victorville--Hesperia--Apple Valley
Ventura
Santa Clarita
Los Angeles
CP14
CP13
Santa Barbara
VNCO
CP12
Simi Valley
Camarillo
Thousand Oaks
Oxnard
VIMT
CIRX
CP11
CP10
CP09
Santa Monica MTNS NTL Rec Area
Channel Islands National Park
Los Angeles--Long Beach--Santa Ana
Riverside
CP08
PVRS
CP07
Orange
CP06
SBCC
Mission Viejo
CP05
San Diego
CP04
Legend
PBO/CORS
New Control
Observed Baselines
30 15 0 30 Kilometers


N
Lancaster--Palmdale
Victorville--Hesperia--Apple Valley
San Bernardino
Santa Clarita
Los Angeles
VIMT
Riverside--San Bernardino
Joshua Tree National Park
CP09
Los Angeles--Long Beach--Santa Ana
Indio--Cathedral City--Palm Springs
Hemet
CP08
PVRS
CP07
CP06
SBCC
Temecula--Murrieta
Mission Viejo
CP05
P474
CP04
CP03
San Diego
P472
CP02
P475
CP01
Legend
PBO/CORS
New Control
Observed Baselines
30
15
0
30 Kilometers

2.1 *Survey Equipment*

All GPS observations were accomplished using Trimble Navigation R7 dual frequency GPS receivers and accompanying Trimble Zephyr Geodetic antennae. Instrument heights were measured twice in units of feet and meters and the values reduced and compared in the field prior to leaving each station.

Control point observation data were logged for a minimum of 45 minutes and as much as 60 minutes depending on proximity to operating PBO/CORS.

2.2 *Survey Point Detail*

Ninety-two control points were established along the coastline. The control points were marked with either 12" spikes or PK nails and consisted of a combination of bare-earth, bare-earth/photo-identifiable, and low vegetation ground cover classes. Relative static GPS observation and processing techniques were used for all survey measurements.

The Ground Control Point locations are detailed in section 4 of this document, "Ground Control Point Documentation Reports".

2.3 *Network Design*

A primary geodetic network consisting of 55 PBO/CORS stations was established by downloading several 24-hour data files for each station for multiple days and post-processing the resulting baselines. The resulting network comprises 107 baselines of a minimum 24-hour duration each. Ninety-two new control points were established and subsequently tied into two of the PBO/CORS stations by downloading the appropriate 24-hour RINEX files and post-processing the static observation in Trimble Business Center. The project diagrams above illustrate the primary network connections and the new control point locations.

2.4 *Data Post-processing and Analysis*

Observed relative GPS baselines were processed in Trimble Business Center. All processed observations consist of quasi-independent baselines (i.e. in accordance with the "n-1 baselines" rule where n = number of receivers in a given 'session'). The International GPS Service for Geodynamics (IGS) rapid precise orbits (igr) were used in the processing of all baseline vectors. The 'igr' orbits are published with a latency of approximately 30 hours. These orbits are globally accurate to within ~5cm and are particularly important when processing long baselines.

One temorary base station point (in addition to the PBO/CORS) was established at the Florence Municipal Airport in Florence, OR. This point was tied into two local PBO stations via static GPS data acquired during the campaign.

It is well known that the Earth's crust deforms over time. The geometric variations of the Earth's surface over time must be taken into account for the realization of terrestrial reference systems. It is for this reason that there is inherent inconsistency between the 'published' coordinates of the PBO/CORS and the current survey campaign.
For the purpose of the new control survey, the methodology employed by Towill was to transform the published control coordinates to the mid–epoch of the GPS survey using the National Geodetic Survey software HTDP (Horizontal Time Dependent Positioning) software. The software employs crustal motion models that incorporate both continuous and episodic components of crustal motion. These models assume that points on the Earth's surface move with constant horizontal velocities. This is a generally accepted approach, except for years following the accelerated motion of the plates associated with large earthquakes. The episodic motion (created by earthquakes) is modeled by dislocation theory. The Northridge Earthquake of 1994 is an example. It is modeled by dislocation theory and is incorporated into the HTDP software.
The published geodetic coordinates of the PBO/CORS were transformed using HTDP from the published values (NAD83[2011], epoch 2010.0), to the datum and epoch associated with the new surveys, viz., NAD83[2011], epoch 2016.35. This ensures compatibility between the GPS observations (vectors), and the coordinates used as constraints in the final network adjustment.

2.5 *Adjustments*
A minimally constrained, primary network adjustment was executed to verify the internal integrity of the baseline computations and to derive appropriate a-priori baseline observation weighting factors. In the resulting adjustment, the estimated variance factor (σ_{0}^{2} = 1.0002) passed the χ^2–test. This indicates appropriate *a priori* estimates of the accuracy of the GPS baseline vectors. None of the 321 vector component residuals or associated standardized residuals were flagged for possible rejection under the τ-max test at the 95 percent level of confidence. The relative horizontal accuracy of the network can be assessed by reviewing the relative 95 percent confidence regions (ellipses) of the adjustment. All station pairings meet the Federal Geodetic Control Subcommittee (FGCS) relative positioning standard for Order B surveys (8mm + 8ppm).
The HTDP-translated latitude and longitude of each PBO/CORS and the published ellipsoid height on the GRS80 ellipsoid were held as weighted observations in a fully constrained primary network adjustment. The estimated variance factor (σ_{0}^{2} = 0.9868) passed the χ^2–test at the 95 percent level of confidence. This indicates that network was not being unduly distorted by the imposition of constraints. No residuals were flagged for possible rejection.
Ninety-two control points were established and tied into two of the PBO/CORS stations by downloading the appropriate 24-hour RINEX files and post-processing the static observation in Trimble Business Center. These processed vectors were incorporated into a third least-squares adjustment to derive final coordinates and elevations of each of the newly established control points. The adjusted final coordinates were then run through HTDP to translate the values back to 2010.0 from the mid-epoch of the survey.

2.6 *Published PBO Coordinates / Adjustment Constraints*
The published coordinates of the PBO / CORS stations that were used as control for this survey and, ultimately, constraints (following the HTDP process described above) in the

network adjustments is tabulated below:

PBO / CORS Published Coordinates and Ellipsoid Heights

Horizontal Datum: NAD83(2011)
Epoch: 2010.0
Linear Unit: International Meter

Point	Latitude	º	'	"	Longitude	º	'	"	Ellipsoid Height
NGS Published Coordinates									
CABL	N	42	50	09.94308	W	124	33	47.98620	38.286
CHZZ	N	45	29	11.44093	W	123	58	41.18376	51.161
LFLO	N	43	59	00.96713	W	124	06	27.69084	-6.042
NEAH	N	48	17	52.26367	W	124	37	29.60004	460.245
P059	N	38	55	42.03419	W	123	43	34.25628	-10.822
P067	N	35	33	06.29824	W	121	00	10.60668	107.594
P157	N	40	14	51.15527	W	124	18	29.00880	696.236
P172	N	36	13	41.05535	W	121	46	02.02944	313.190
P173	N	35	56	44.56712	W	121	17	25.15020	339.828
P181	N	37	54	52.34987	W	122	22	36.26760	72.732
P185	N	39	15	40.67993	W	123	44	57.55488	146.834
P188	N	38	40	04.27069	W	123	13	46.37496	209.358
P210	N	36	48	58.08233	W	121	43	54.58008	3.600
P231	N	36	37	18.02341	W	121	54	19.42416	-25.764
P316	N	41	33	32.86577	W	124	05	10.06188	235.389
P415	N	46	39	21.55259	W	123	43	47.45496	-15.081
P472	N	32	53	21.13976	W	117	06	16.85412	138.603
P474	N	33	21	18.68098	W	117	14	55.24188	183.653
P475	N	32	39	59.01142	W	117	14	38.11776	-24.285
P523	N	35	18	16.00618	W	120	51	36.93060	41.984
P534	N	37	03	40.41997	W	122	14	15.34524	204.804
PABH	N	47	12	46.06456	W	124	12	16.43148	13.277
PTSG	N	41	46	57.85558	W	124	15	18.66132	-9.794

Point	Latitude	º	'	"	Longitude	º	'	"	Ellipsoid Height
SBCC	N	33	33	10.78852	W	117	39	41.30280	89.406
TJRN	N	34	29	00.49571	W	120	07	57.17748	157.816
TRND	N	41	03	13.97729	W	124	09	03.06396	78.680
VNDP	N	34	33	22.71092	W	120	36	59.17428	-9.147
SOPAC SECTOR Published Coordinates									
CIRX	N	34	06	34.38086	W	118	56	14.21628	488.885
P161	N	40	38	14.49384	W	124	12	47.05236	32.868
P177	N	37	31	41.39000	W	122	29	42.13464	72.321
P182	N	38	29	42.04021	W	123	10	52.43052	397.293
P193	N	38	07	22.55902	W	122	54	29.25540	67.104
P312	N	39	31	45.03011	W	123	41	54.09492	255.394
P315	N	39	51	48.88562	W	123	43	00.77268	258.381
P364	N	43	05	25.16694	W	124	24	33.38532	6.807
P365	N	43	23	43.85245	W	124	15	12.47796	27.467
P366	N	43	36	51.50484	W	123	58	46.47828	529.468
P367	N	44	35	06.87286	W	124	03	41.59584	23.277
P395	N	45	01	20.19122	W	123	51	27.03708	53.385
P396	N	45	18	34.23391	W	123	49	22.36332	54.908
P397	N	46	25	17.81465	W	123	47	56.91588	566.625
P398	N	46	55	32.81066	W	123	54	58.05864	23.811
P401	N	47	56	13.86182	W	124	33	25.20540	36.486
P402	N	47	45	58.38217	W	124	18	21.16656	24.010
P403	N	48	03	44.34448	W	124	08	27.08628	284.951
P407	N	45	57	16.72355	W	123	55	51.55968	-12.778
P435	N	48	03	34.36160	W	123	30	11.73996	287.623
P436	N	48	02	43.07377	W	123	08	03.59016	191.191
P437	N	48	00	06.49840	W	122	27	32.90436	12.789
P525	N	35	25	32.74939	W	120	48	29.25720	271.978

Point	Latitude	º	'	"	Longitude	º	'	"	Ellipsoid Height
P548	N	34	28	00.48986	W	119	30	14.14980	1135.502
P733	N	42	26	31.24331	W	124	24	47.81268	184.951
P734	N	42	04	35.87203	W	124	17	35.66652	113.718
PVRS	N	33	46	25.89424	W	118	19	14.07036	60.538
VIMT	N	34	07	35.19970	W	118	30	51.84000	554.389
VNCO	N	34	16	32.74244	W	119	14	15.56124	26.345

Notes: Ellipsoid heights are to the Antenna Reference Point (ARP) for the respective PBO/CORS ante

2.7 *Station Reoccupation Comparison*

The allowable tolerance of ± 5cm within the 95% confidence level was specified for the survey accuracy. Forty-six of the control points were occupied a second time at least 4 hours, and in most cases several hours or days, after the initial occupation.

The computed coordinate values and elevations of the re-occupations were compared with those of the initial occupations to evaluate the accuracy of the survey effort. The RMS of the difference in coordinates is 0.007, 0.006 and 0.020 meters for each of northing, easting, and elevation, respectively. The reoccupation results are tabulated below:

Dewberry

El Nino Lidar Campaign Control

RE-OCCUPATION COMPARISON

Point Name	Re-occupation Name	dNorthing (Meter)	dEasting (Meter)	dElev (Meter)
CP01	CP01_R	0.003	0.009	-0.016
CP03	CP03_R	-0.008	0.000	-0.028
CP05	CP05_R	-0.007	0.001	-0.021
CP06	CP06_R	0.000	0.000	-0.019
CP09	CP09_R	-0.002	0.000	-0.015
CP11	CP11_R	-0.010	0.001	0.019
CP13	CP13_R	0.007	-0.009	0.011
CP15	CP15_R	0.003	0.000	0.001
CP18	CP18_R	0.004	0.000	-0.008
CP20	CP20_R	0.010	0.009	-0.005
CP22	CP22_R	-0.002	0.009	-0.003
CP24	CP24_R	0.008	-0.018	0.019
CP26	CP26_R	0.002	-0.001	-0.011
CP28	CP28_R	-0.003	0.000	0.004
CP30	CP30_R	-0.007	0.009	-0.018
CP32	CP32_R	0.001	0.009	-0.002
CP34	CP34_R	0.013	0.000	-0.015
CP35	CP35_R	0.005	-0.009	0.004
CP38	CP38_R	-0.005	0.000	-0.011
CP40	CP40_R	0.010	0.000	0.023
CP42	CP42_R	-0.009	-0.008	0.000
CP44	CP44_R	0.007	0.009	0.024
CP45	CP45_R	0.004	-0.009	0.024

Point Name	Re-occupation Name	dNorthing (Meter)	dEasting (Meter)	dElev (Meter)
CP48	CP48_R	-0.005	0.009	0.024
CP50	CP50_R	0.001	0.000	0.001
CP51	CP51_R	0.001	0.000	-0.001
CP55	CP55_R	0.003	0.000	0.007
CP57	CP57_R	-0.003	0.000	0.006
CP59	CP59_R	0.002	-0.008	0.007
CP61	CP61_R	0.001	0.000	0.003
CP63	CP63_R	-0.004	0.000	0.044
CP65	CP65_R	0.001	0.000	0.013
CP67	CP67_R	0.002	-0.007	0.005
CP69	CP69_R	-0.002	0.000	0.008
CP71	CP71_R	-0.005	0.000	-0.015
CP73	CP73_R	0.003	-0.007	-0.006
CP75	CP75_R	-0.006	0.000	-0.008
CP77	CP77_R	0.001	-0.007	0.011
CP79	CP79_R	0.005	-0.007	-0.041
CP81	CP81_R	0.014	0.001	-0.037
CP83	CP83_R	0.003	0.000	0.018
CP85	CP85_R	0.013	0.000	-0.038
CP87	CP87_R	0.010	0.000	0.017
CP89	CP89_R	-0.020	-0.007	0.035
CP90	CP90_R	0.021	0.000	0.044

Appendix B: Complete List of Delivered Tiles

10SGD73203813	10SEG54754146	10TCL39754518	10TDR42455013	10UDU41405343
10SGD73353813	10SEG54904146	10TCL39904518	10TDR42305014	10UDU37205344
10SGD73053814	10SEG54754147	10TCL39904519	10TDR42455014	10UDU37355344
10SGD73203814	10SEG54904147	10TDL40054519	10TDR42305016	10UDU37505344
10SGD73353814	10SEG54304149	10TCL39904521	10TDR42455016	10UDU40205344
10SGD73503814	10SEG54454149	10TDL40054521	10TDR42305017	10UDU40355344
10SGD73653814	10SEG54604149	10TDL40054522	10TDR42455017	10UDU40505344
10SGD73803814	10SEG54754149	10TDL40204522	10TDR42305019	10UDU40655344
10SGD73953814	10SEG54154150	10TDL40054524	10TDR42455019	10UDU40805344
10SGD74103814	10SEG54304150	10TDL40204524	10TDR42005020	10UDU40955344
10SGD74253814	10SEG54454150	10TDL40054525	10TDR42155020	10UDU41105344
10SGD73053816	10SEG54604150	10TDL40204525	10TDR42305020	10UDU37355346
10SGD73203816	10SEG54754150	10TDL40204527	10TDR42155022	10UDU37505346
10SGD73653816	10SEG54154152	10TDL40354527	10TDR42305022	10UDU39905346
10SGD73803816	10SEG54304152	10TDL40204528	10TDR42305023	10UDU40055346
10SGD73953816	10SEG54154153	10TDL40354528	10TDR42455023	10UDU40205346
10SGD74103816	10SEG54304153	10TDL40354530	10TDR42305025	10UDU40355346
10SGD74253816	10SEG54154155	10TDL40354531	10TDR42455025	10UDU40655346
10SGD74403816	10SEG54304155	10TDL40504531	10TDR42305026	10UDU40805346
10SGD74553816	10SEG54154156	10TDL40354533	10TDR42455026	10UDU37355347
10SGD74703816	10SEG54304156	10TDL40504533	10TDR42305028	10UDU37505347
10SGD74853816	10SEG54154158	10TDL40354534	10TDR42455028	10UDU39605347
10SGD75003816	10SEG54304158	10TDL40504534	10TDR42305029	10UDU39755347
10SGD75153816	10SEG54154159	10TDL40504536	10TDR42455029	10UDU39905347
10SGD75303816	10SEG54304159	10TDL40504537	10TDR42305031	10UDU40055347
10SGD76503816	10SEG54154161	10TDL40654537	10TDR42455031	10UDU40205347
10SGD76653816	10SEG54304161	10TDL40504539	10TDR42305032	10UDU37355349
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10SGD76953816	10SEG54304162	10TDL40504540	10TDR42305034	10UDU37655349
10SGD77103816	10SEG54454162	10TDL40654540	10TDR42455034	10UDU39455349
10SGD77253816	10SEG54304164	10TDL40504542	10TDR42305035	10UDU39605349
10SGD77403816	10SEG54454164	10TDL40654542	10TDR42455035	10UDU39755349
10SGD73053817	10SEG54304165	10TDL40204543	10TDR42305037	10UDU39905349
10SGD73203817	10SEG54454165	10TDL40354543	10TDR42455037	10UDU37355350
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10SGD74703817	10SEG54454167	10TDL40204545	10TDR42455038	10UDU37655350
10SGD74853817	10SEG54304168	10TDL40354545	10TDR42455040	10UDU39155350
10SGD75003817	10SEG54454168	10TDL40504545	10TDR42455041	10UDU39305350
0SGD75153817	10SEG54304170	10TDL40204546	10TDR42455043	10UDU39455350
10SGD75303817	10SEG54454170	10TDL40354546	10TDR42605043	10UDU37505352
10SGD75453817	10SEG54304171	10TDL40204548	10TDR42455044	10UDU37655352

10SGD75603817	10SEG54454171	10TDL40204549	10TDR42605044	10UDU39005352
10SGD75753817	10SEG54304173	10TDL40204551	10TDR42455046	10UDU39155352
10SGD75903817	10SEG54454173	10TDL40204552	10TDR42605046	10UDU39305352
10SGD76053817	10SEG54304174	10TDL40204554	10TDR42455047	10UDU37505353
10SGD76203817	10SEG54304176	10TDL40354554	10TDR42605047	10UDU37655353
10SGD76353817	10SEG54154177	10TDL40354555	10TDR42455049	10UDU38705353
10SGD76503817	10SEG54304177	10TDL40354557	10TDR42605049	10UDU38855353
10SGD76653817	10SEG54154179	10TDL40504557	10TDR42455050	10UDU39005353
10SGD76803817	10SEG54304179	10TDL40504558	10TDR42605050	10UDU37355355
10SGD76953817	10SEG54154180	10TDL40504560	10TDR42455052	10UDU37505355
10SGD77103817	10SEG54304180	10TDL40504561	10TDR42605052	10UDU37655355
10SGD77253817	10SEG54454180	10TDL40654561	10TDR42605053	10UDU38405355
10SGD77403817	10SEG54154182	10TDL40654563	10TDR42605055	10UDU38555355
10SGD72903819	10SEG54304182	10TDL40654564	10TDR42605056	10UDU38705355
10SGD73053819	10SEG54454182	10TDL40654566	10TDR42605058	10UDU38855355
10SGD72753820	10SEG54604182	10TDL40804566	10TDR42605059	10UDU37205356
10SGD72903820	10SEG54454183	10TDL40654567	10TDR42605061	10UDU37355356
10SGD72603822	10SEG54604183	10TDL40804567	10TDR42605062	10UDU37955356
10SGD72753822	10SEG54004185	10TDL40654569	10TDR42455064	10UDU38105356
10SGD72903822	10SEG54154185	10TDL40804569	10TDR42605064	10UDU38255356
10SGD72303823	10SEG54304185	10TDL40804570	10TDR42455065	10UDU38405356
10SGD72453823	10SEG54454185	10TDL40804572	10TDR42605065	10UDU38555356
10SGD72603823	10SEG54604185	10TDL40804573	10TDR42305067	10UDU37055358
10SGD72753823	10SEG53854186	10TDL40954573	10TDR42455067	10UDU37205358
10SGD71703825	10SEG54004186	10TDL40804575	10TDR42305068	10UDU37355358
10SGD71853825	10SEG54154186	10TDL40954575	10TDR42455068	10UDU37805358
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10SGD72303825	10SEG54604186	10TDL40954578	10TDR42305071	10UDU38255358
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10SGD71403828	10SEG53254191	10TDL41104584	10TDR42455080	10UDU37805359
10SGD71553828	10SEG53404191	10TDL40954585	10TDR42455082	10UDU37955359
10SGD71553829	10SEG53554191	10TDL41104585	10TDR42305083	10UDU38105359
10SGD71553831	10SEG52504192	10TDL40954587	10TDR42455083	10UDU37205361
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10SGD71553832	10SEG53254192	10TDL40954588	10TDR42455085	10UDU37505361
10SGD71703832	10SEG53404192	10TDL41104588	10TDR42155086	10UDU37655361

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10SEF57154093	10TCK38554464	10TDQ41404947	10UDU45755332	11SKU23853810
10SEF57304093	10TCK38404465	10TDQ41554947	10UDU45905332	11SKU24303810
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10SEF57004095	10TCK38404467	10TDQ41554948	10UDU48455332	11SKU24603810
10SEF57154095	10TCK38254468	10TDQ41554950	10UDU48605332	11SKU24753810
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10SEF57154096	10TCK38254471	10TDQ41554954	10UDU49205332	11SKU25503810
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10SEG55204122	10TCL38854501	10TDQ42004989	10UDU37055337	11SMS47703624
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10SEG54754144	10TCL39754515	10TDR42455011	10UDU40955343	11SLT38853736
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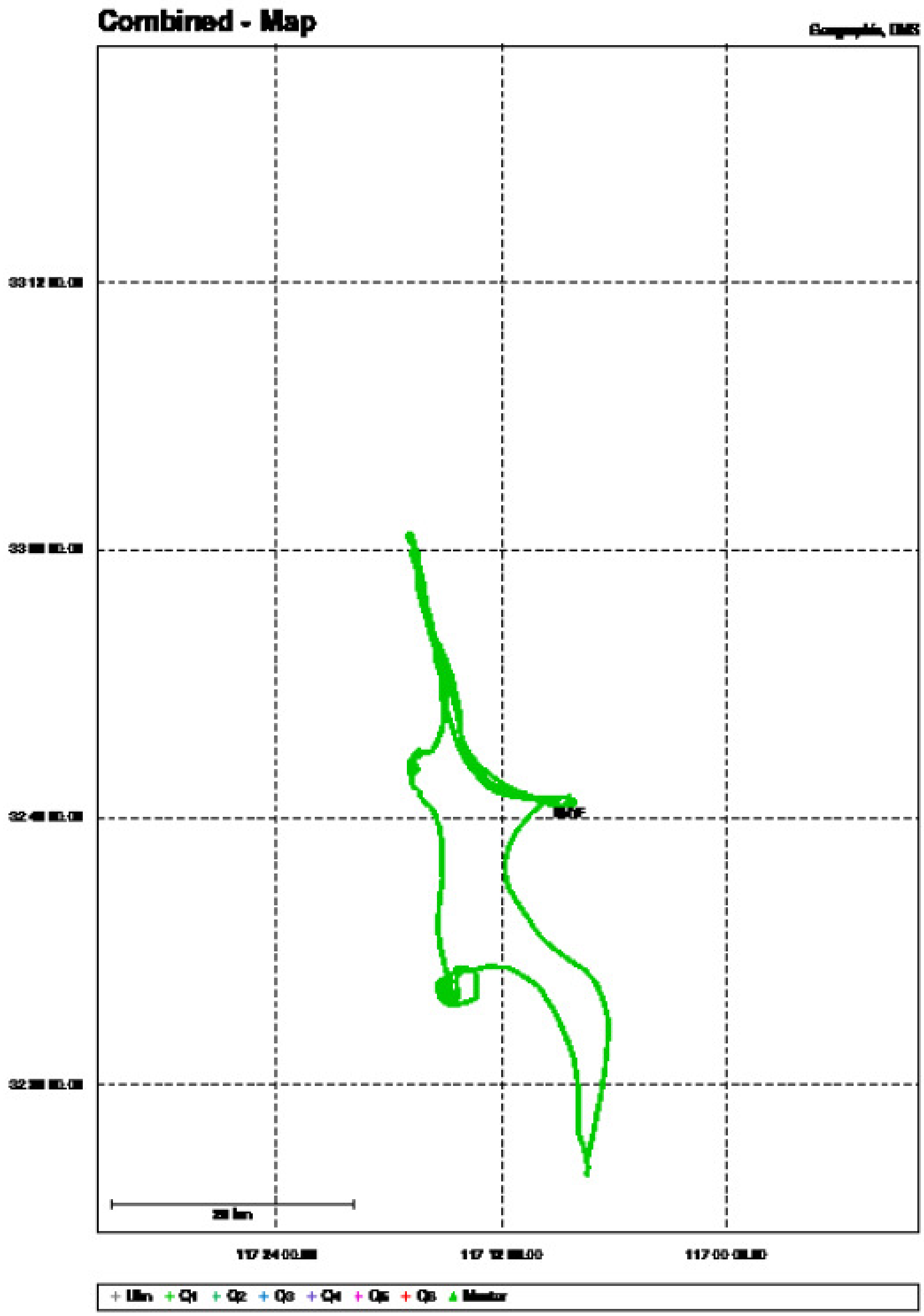
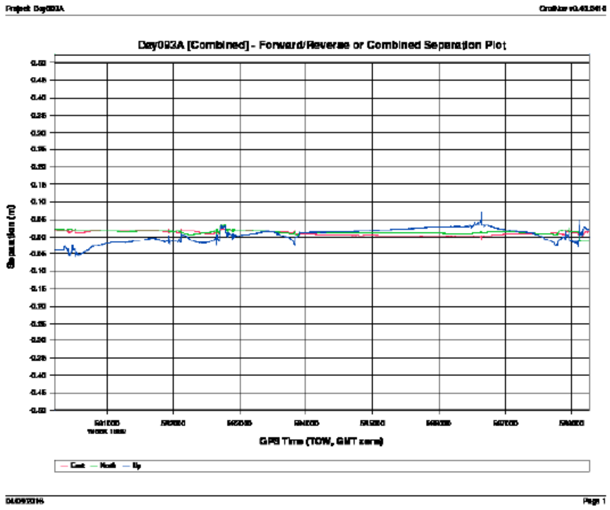
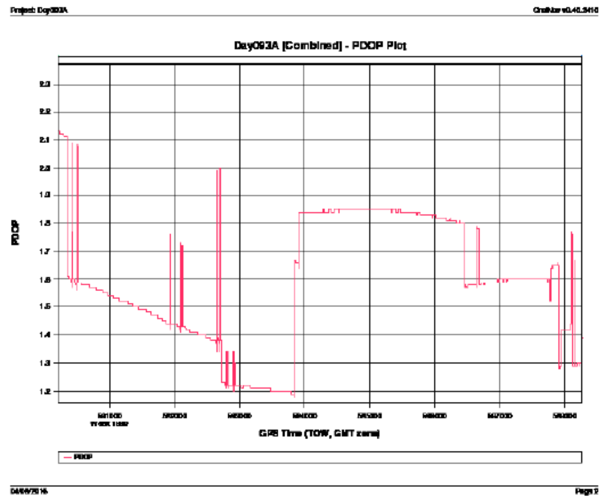
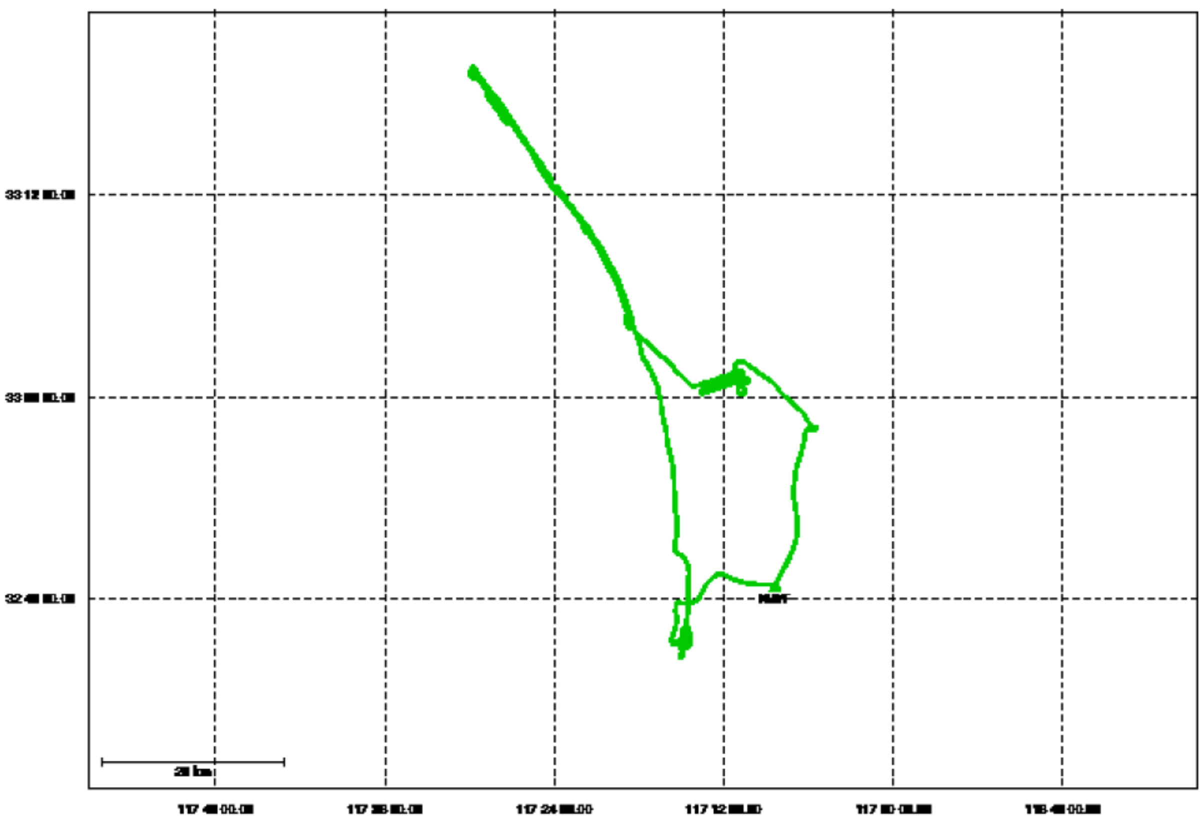
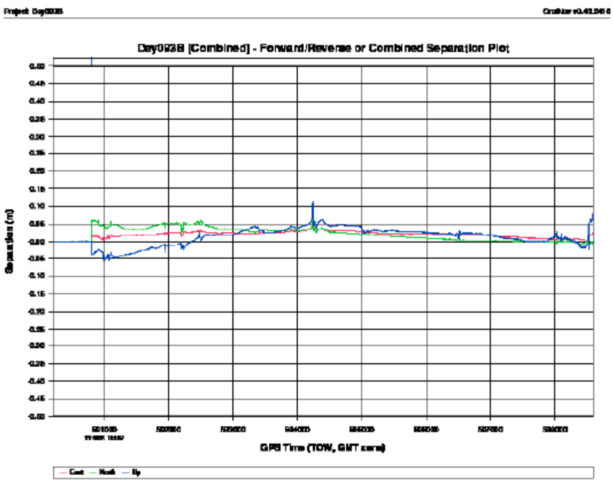
Appendix C: GPS Processing

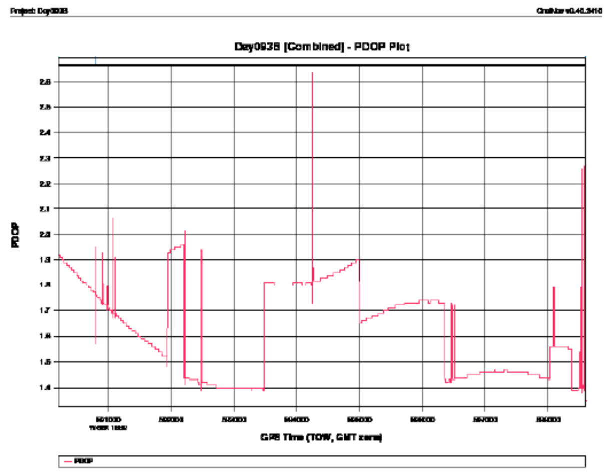


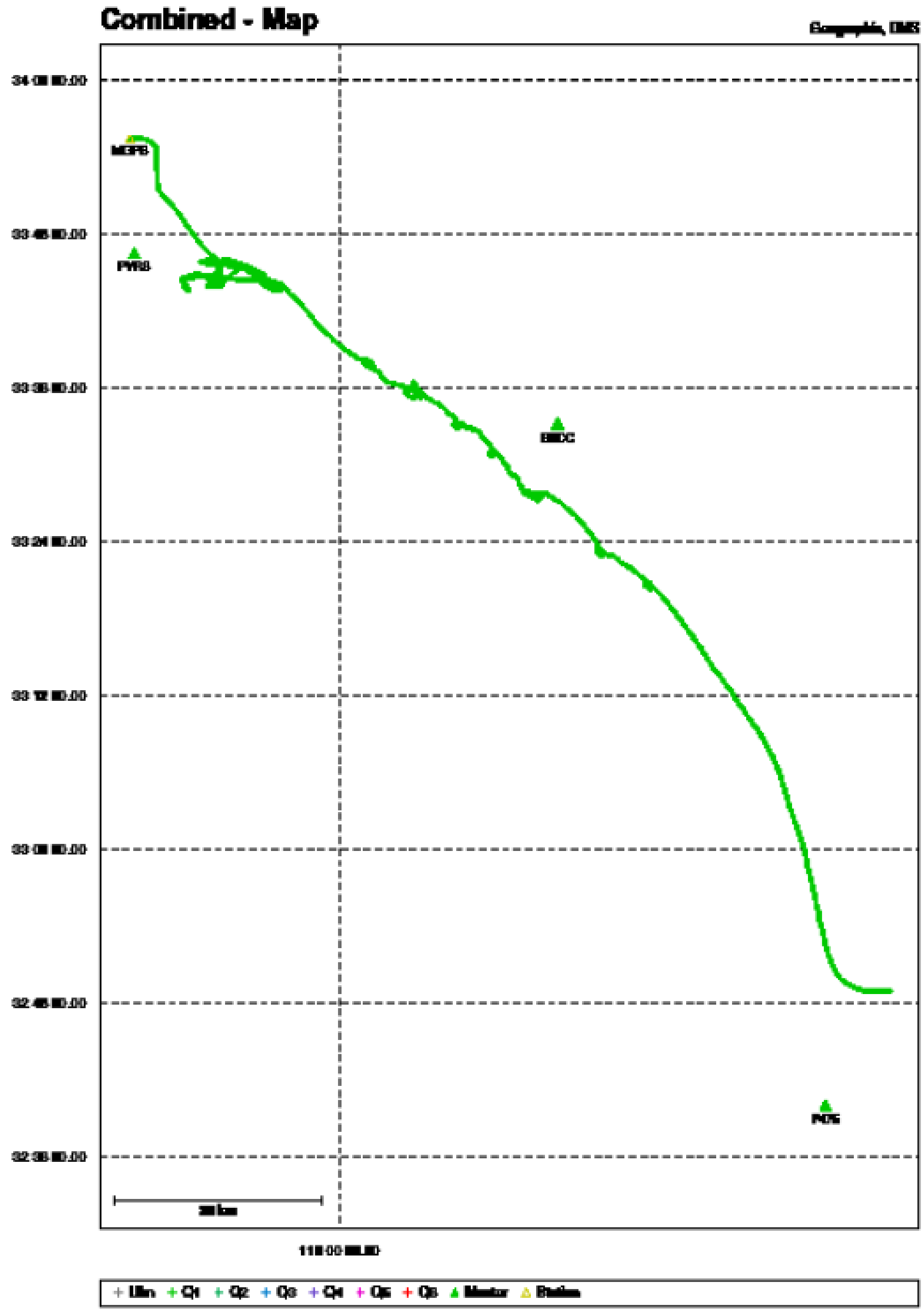

Day093A [Combined] - Forward/Reverse or Combined Separation Plot
GPS Time (TOW, GMT zone)

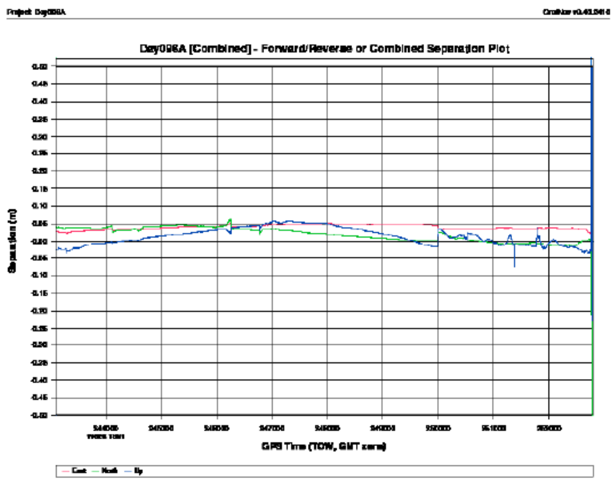

Day093A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zone)

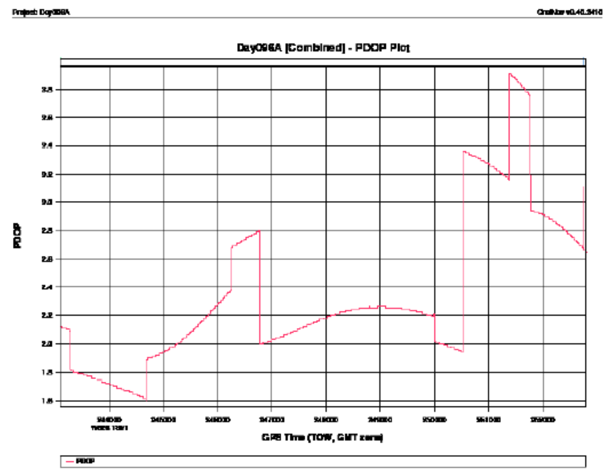


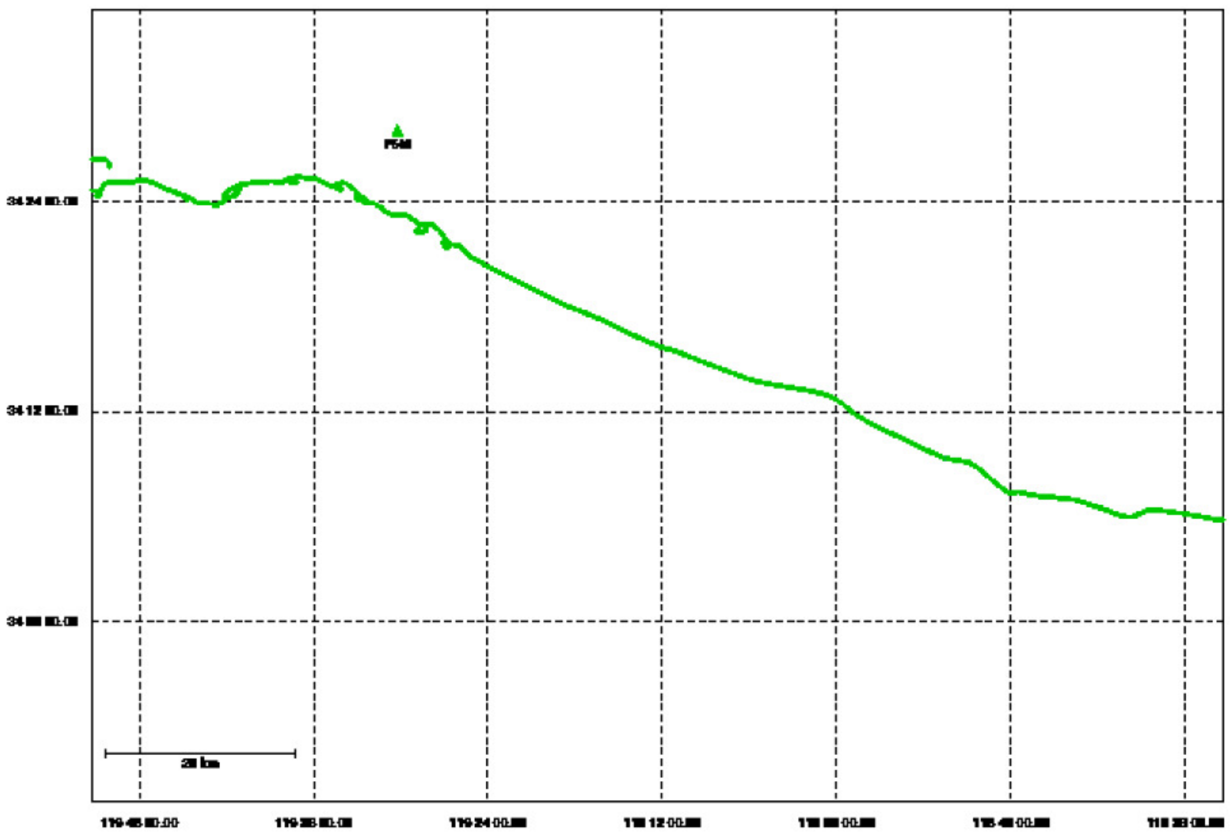

Day0938 [Combined] - Forward/Reverse or Combined Separation Plot
GPS Time (TOW, GMT zero)

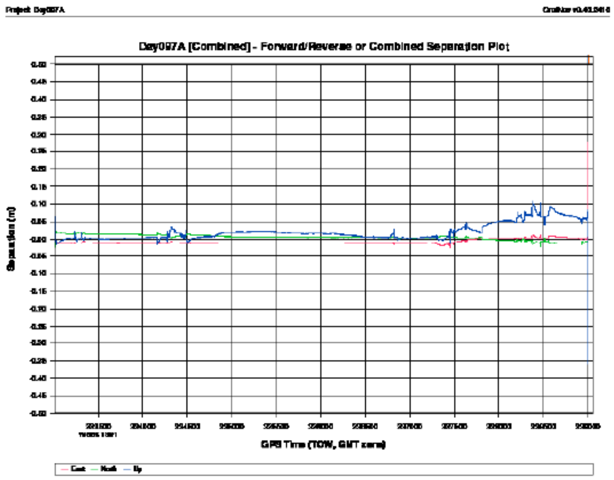

Day0938 [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

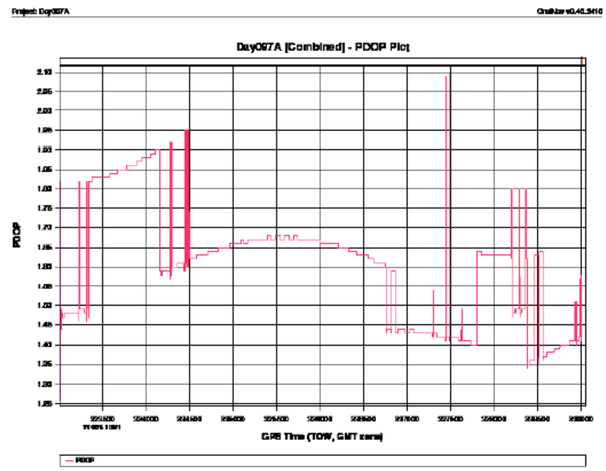

Combined - Map

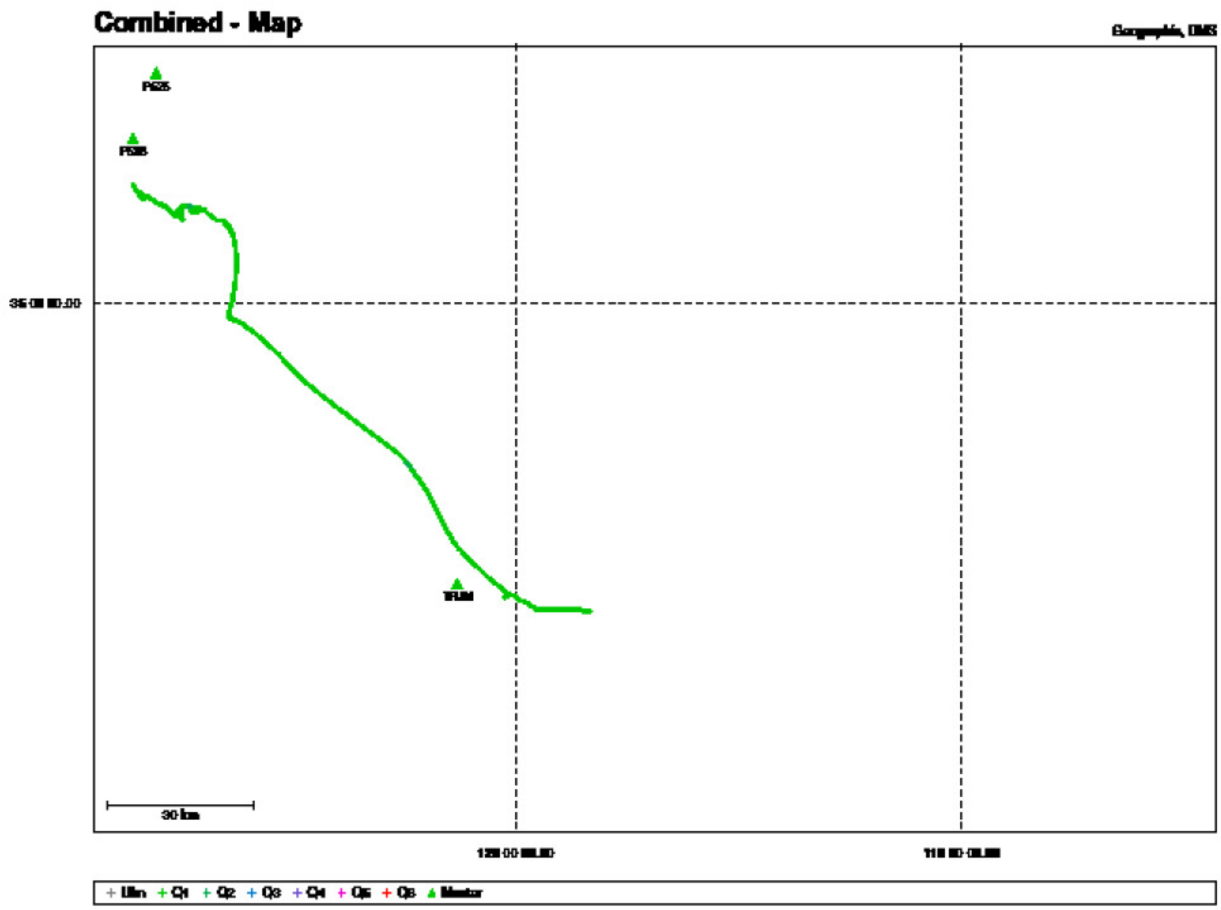

Day096A [Combined] - Forward/Reverse or Combined Separation Plot

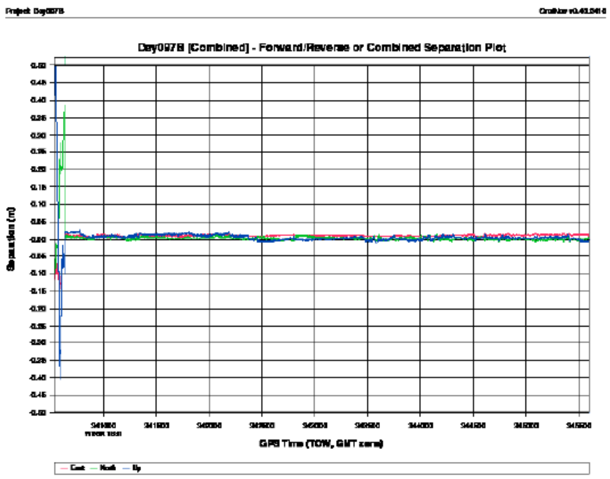

Day096A [Combined] - PDOP Plot

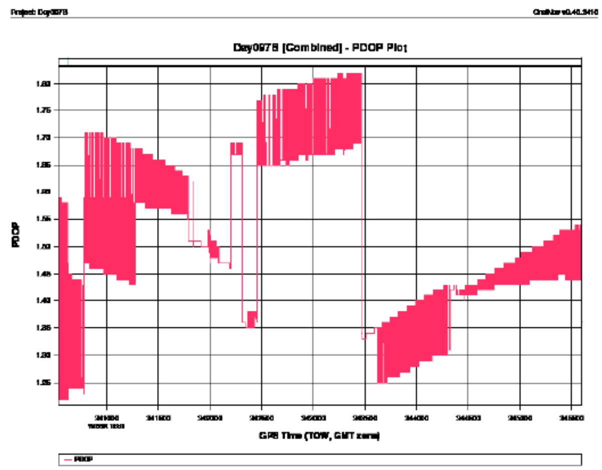


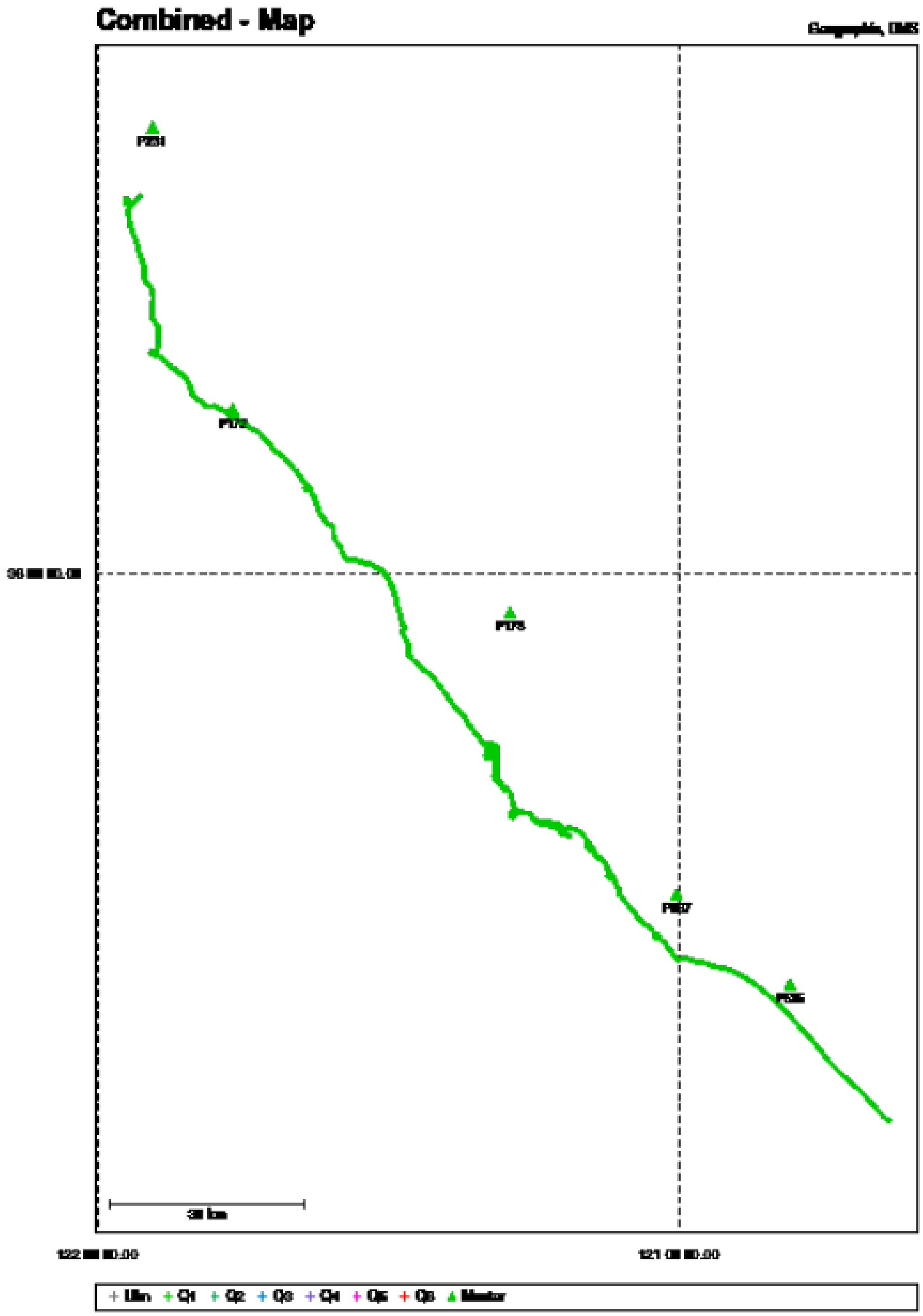

Day097A [Combined] - Forward/Reverse or Combined Separation Plot
GPS Time (TOW, GMT zero)

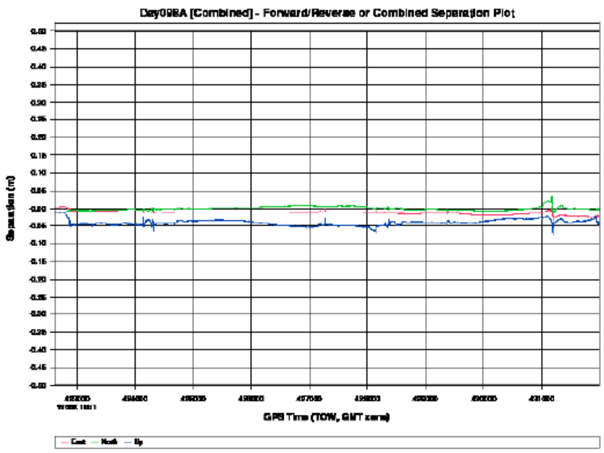

Day097A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

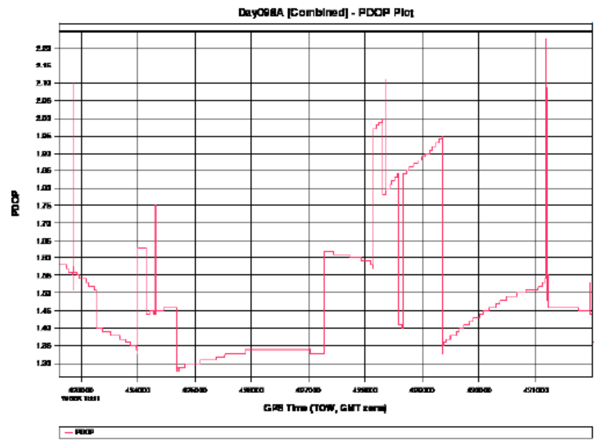

Combined - Map
30 km


Day097B [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zone)

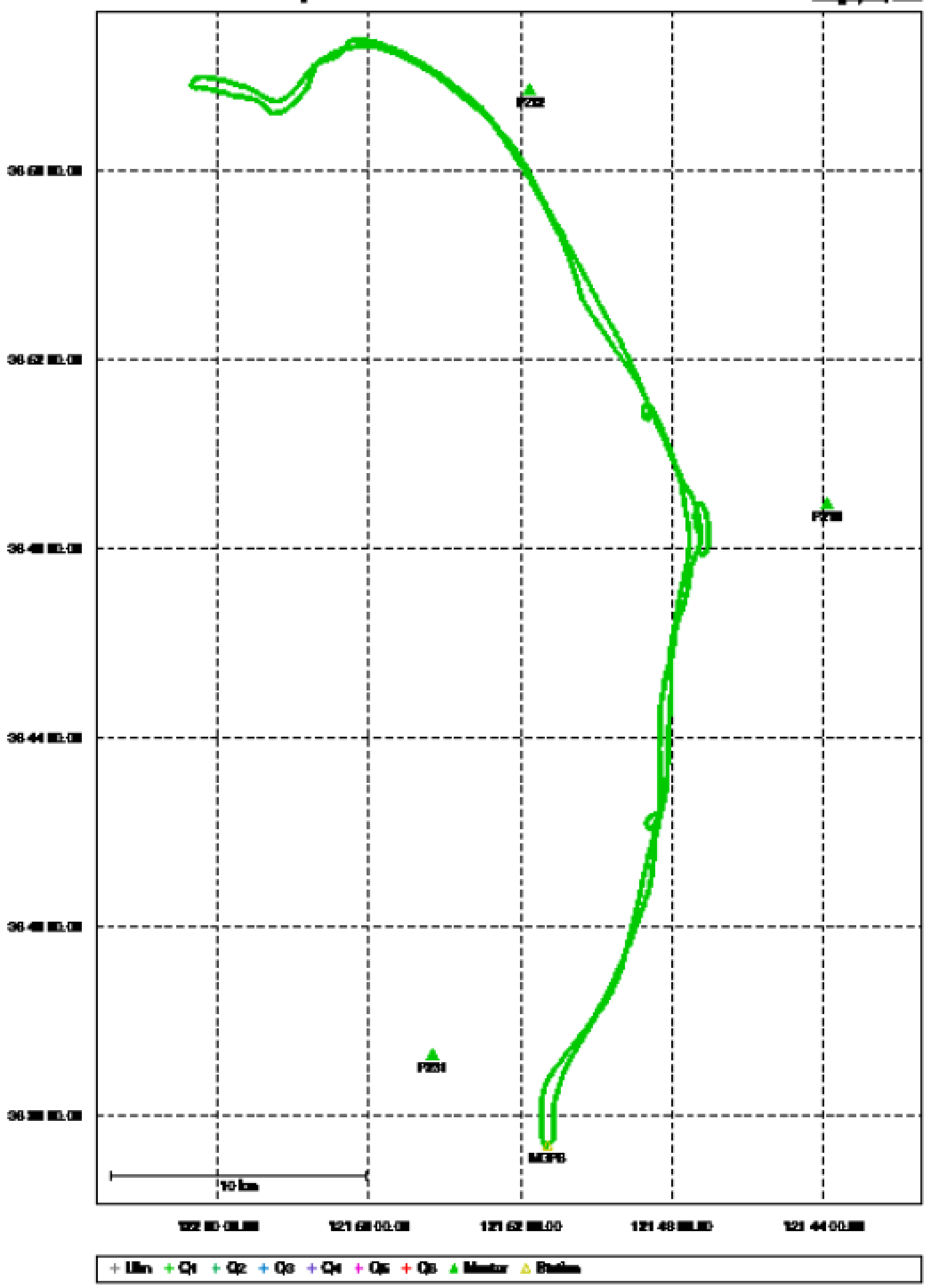

Day097B [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zone)

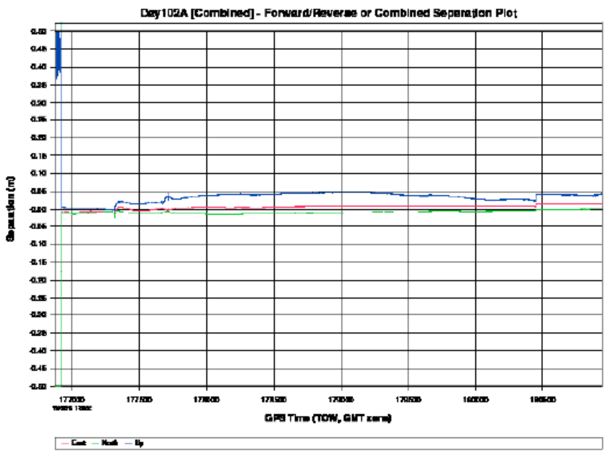

Combined - Map

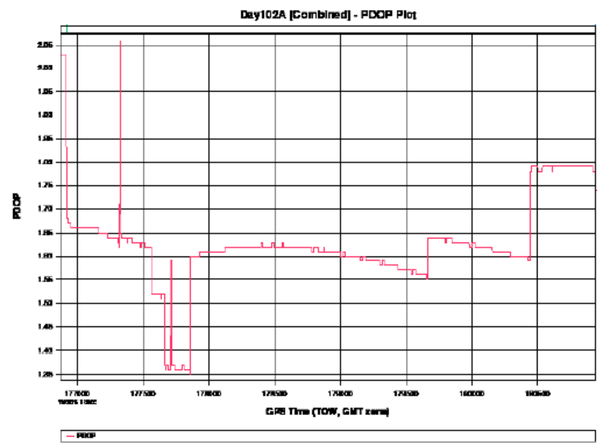

Day098A [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)
East
North
Up


Day098A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

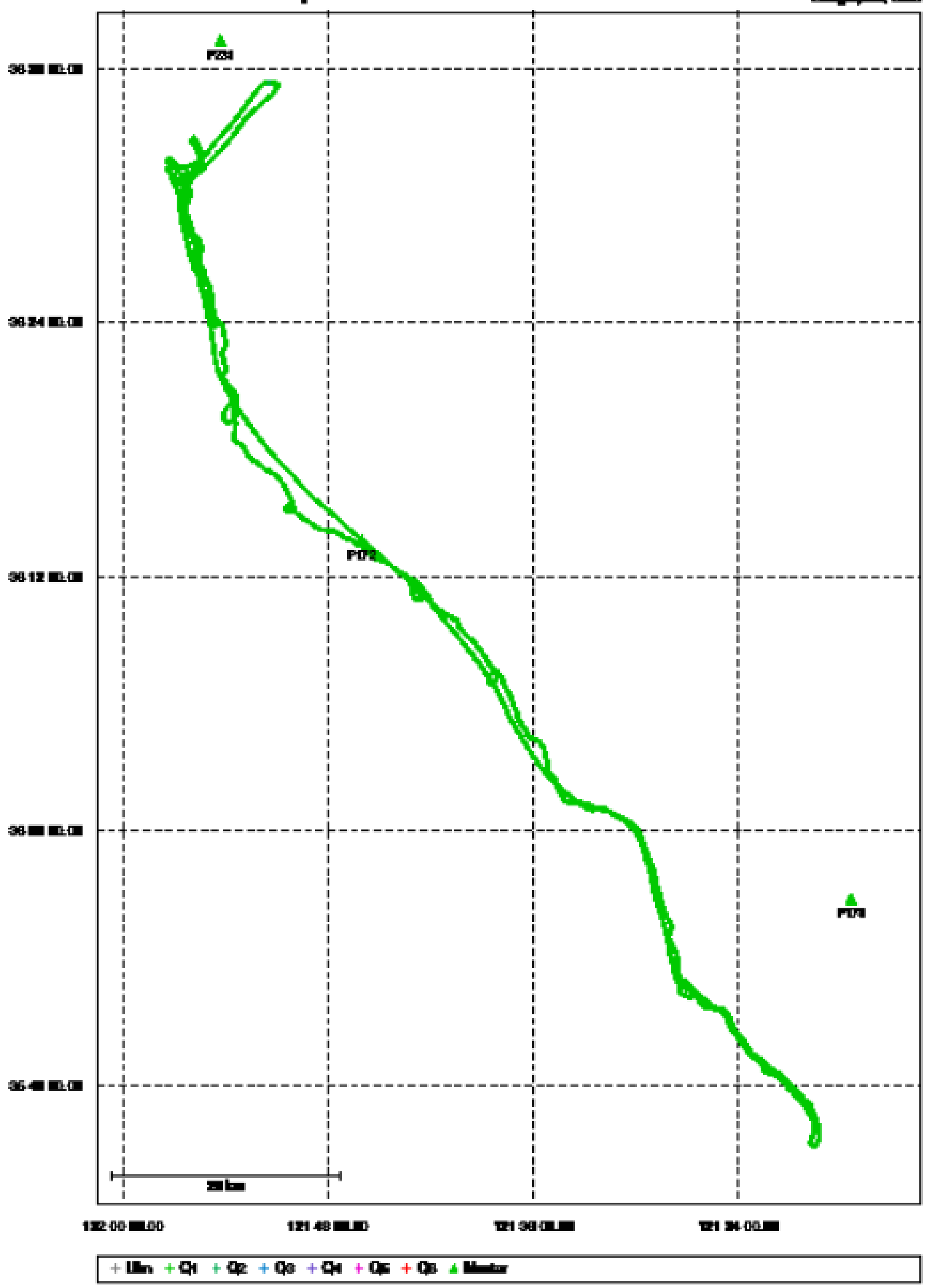
Combined - Map

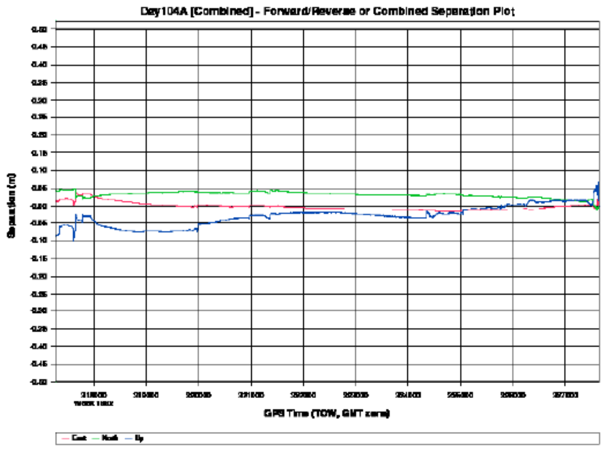


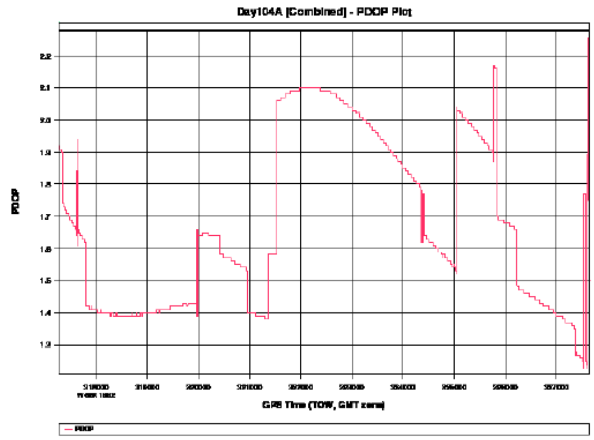

Day102A [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)


Day102A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

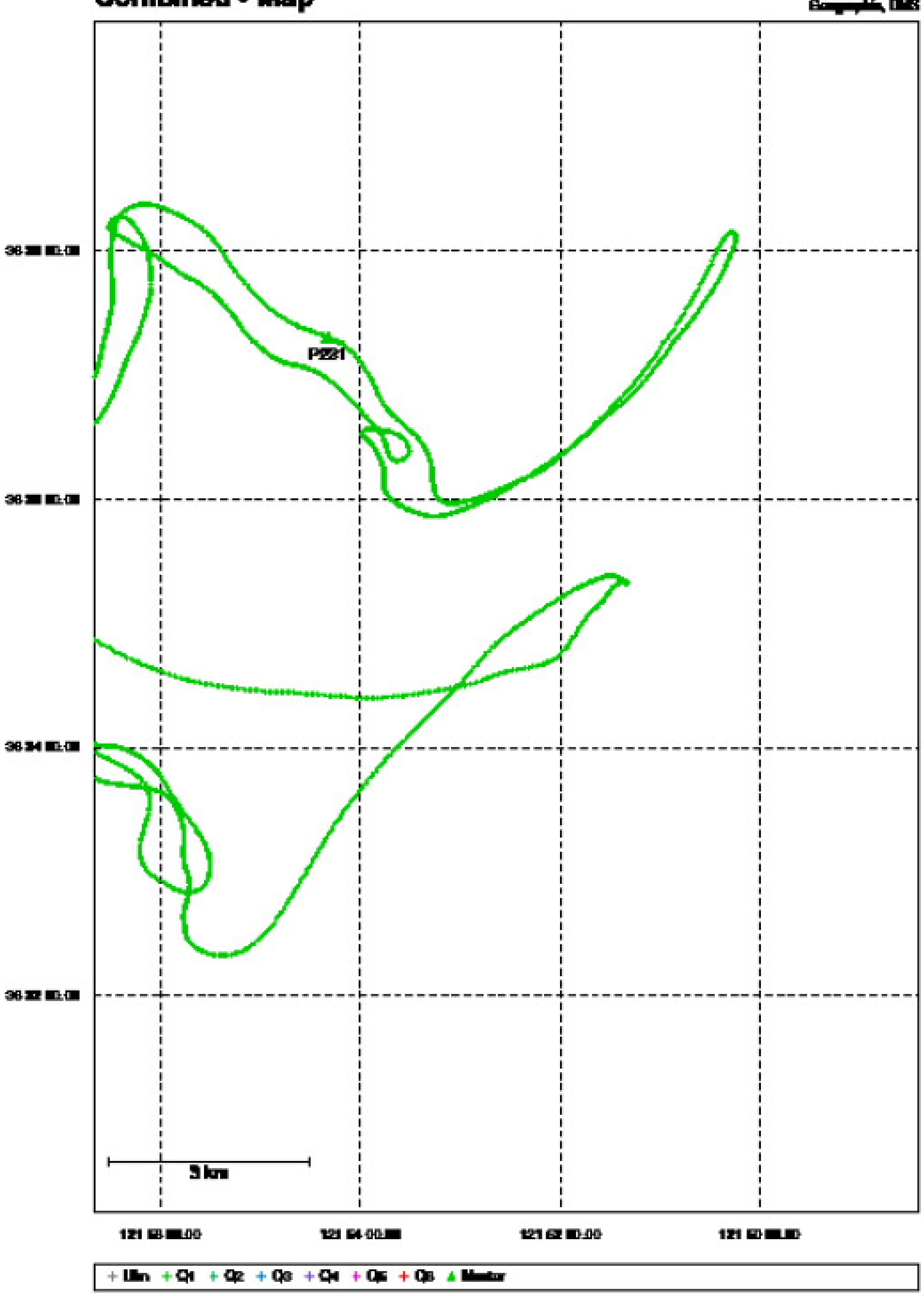
Combined - Map

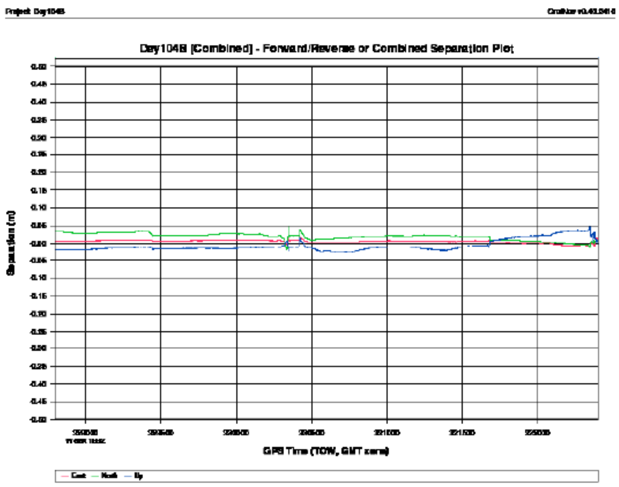


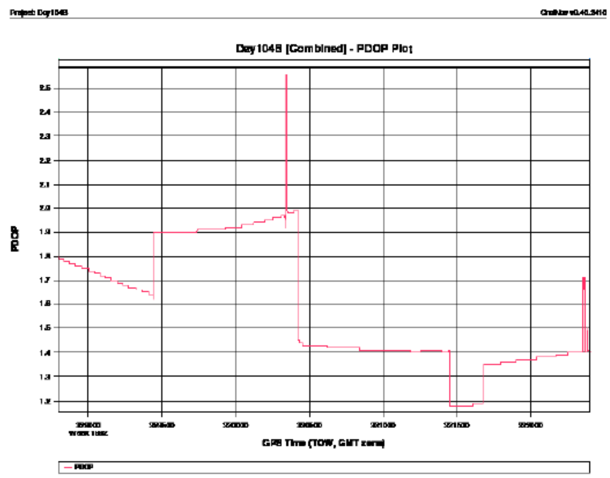

Day104A [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)

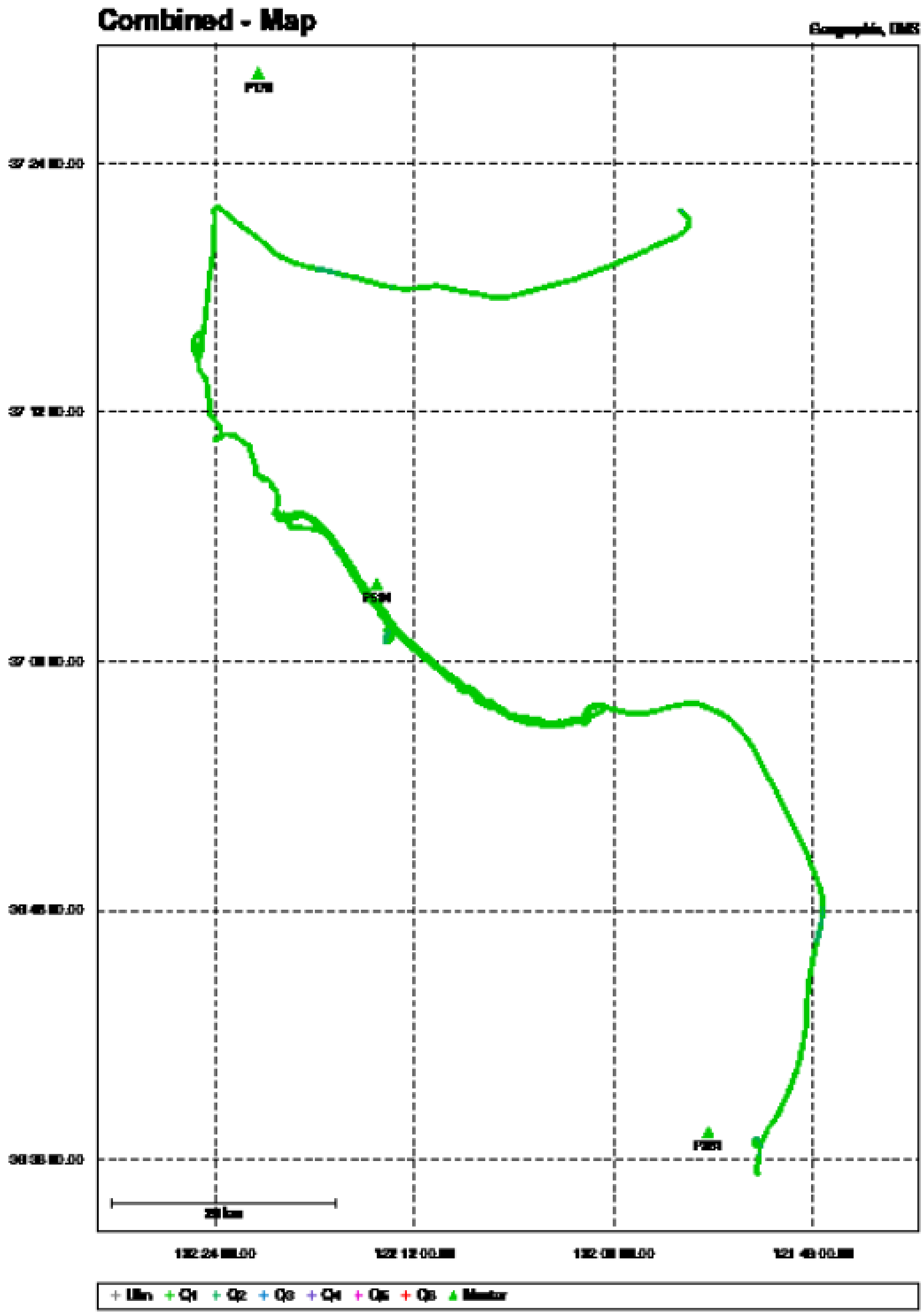

Day104A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

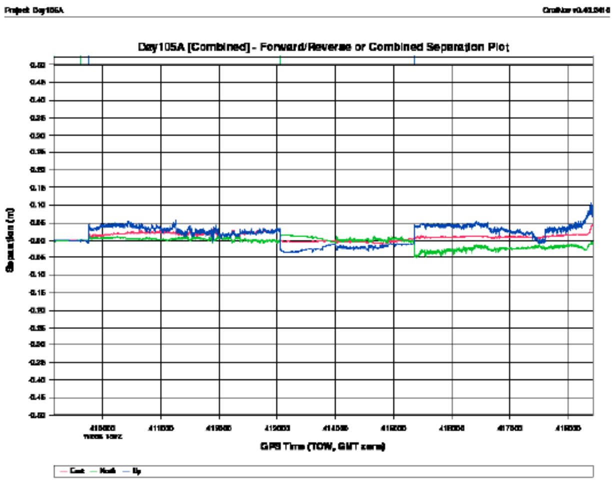
Combined - Map

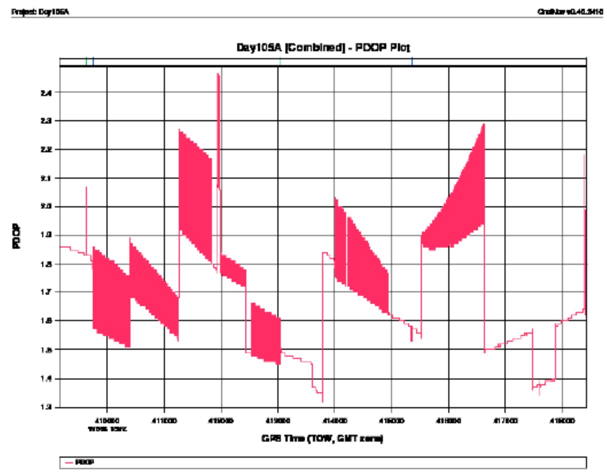



Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zone)

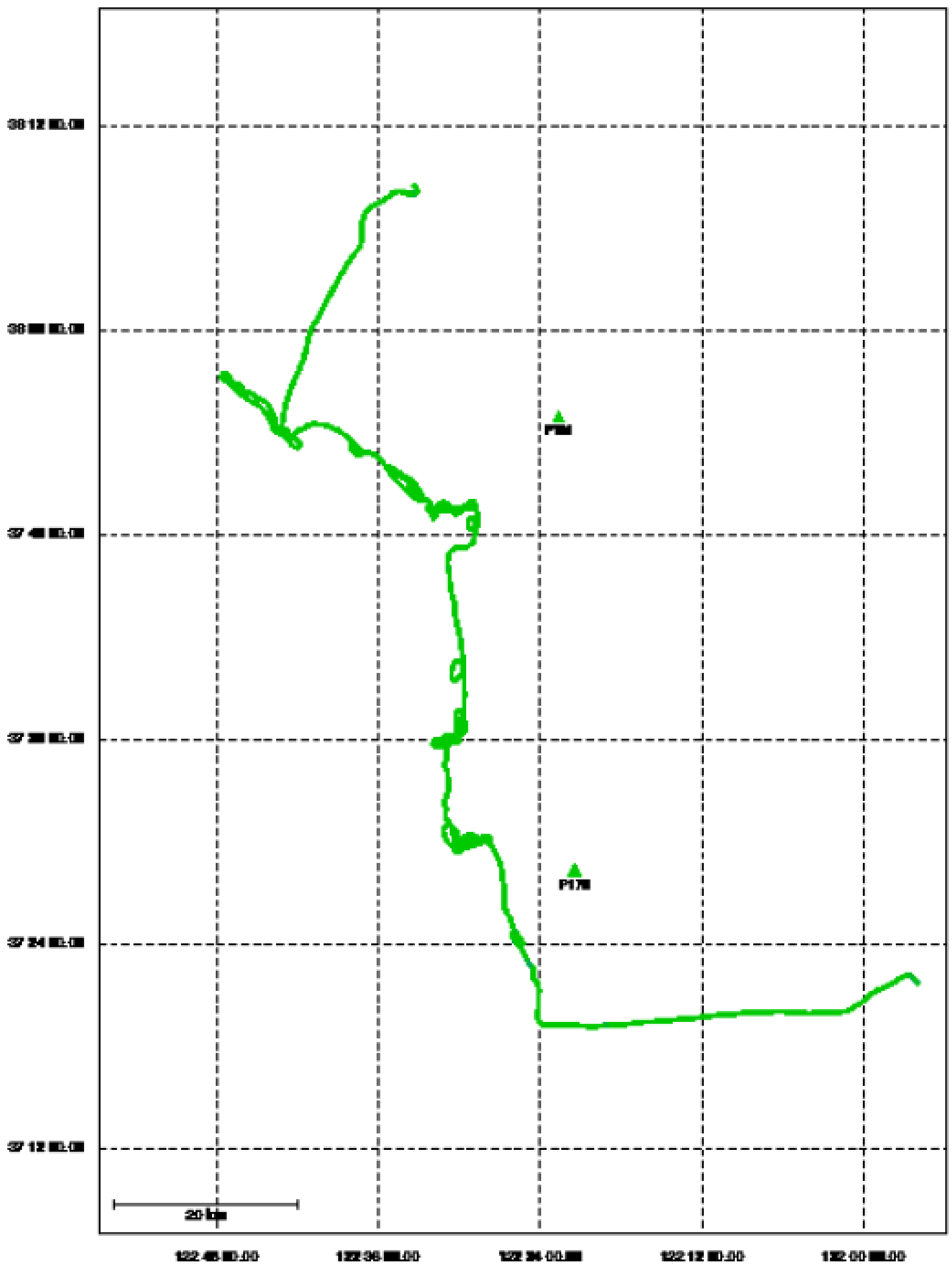

PDOP Plot
PDOP
GPS Time (TOW, GMT zone)

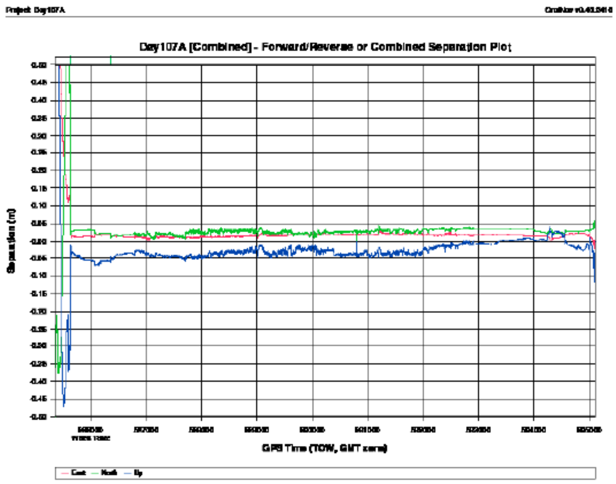

Combined - Map

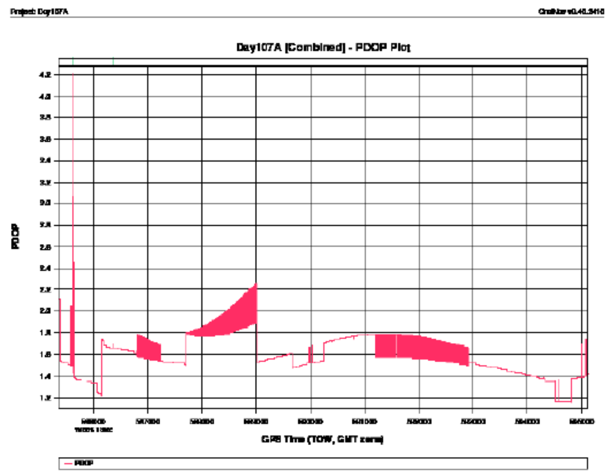

Day105A [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)

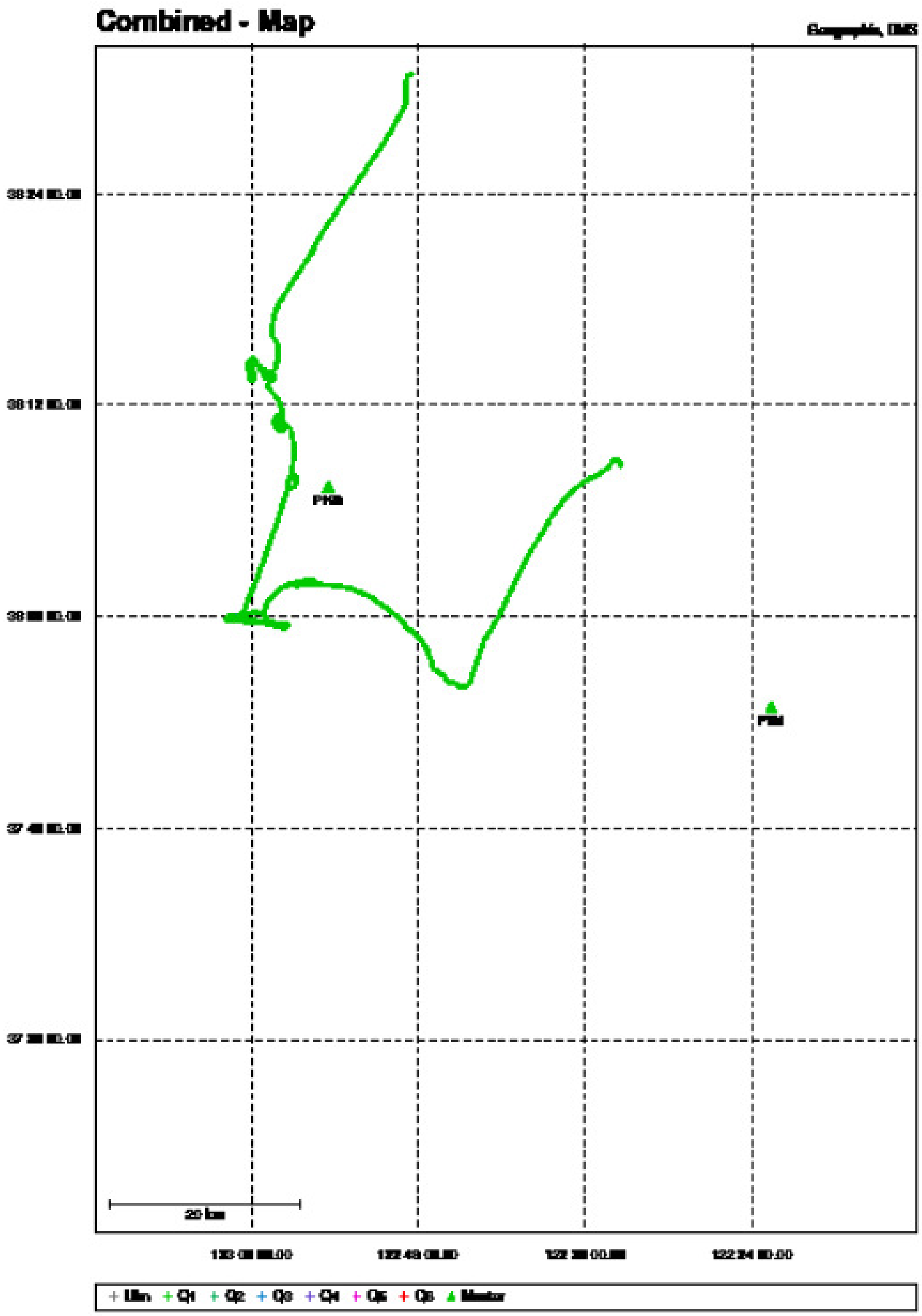

Day105A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

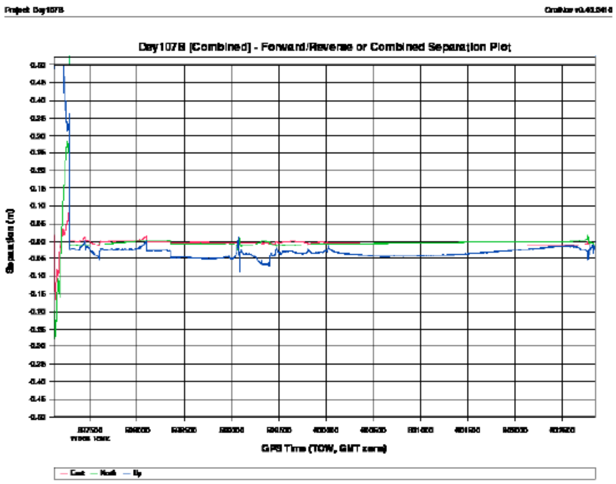
Project: Day 107A

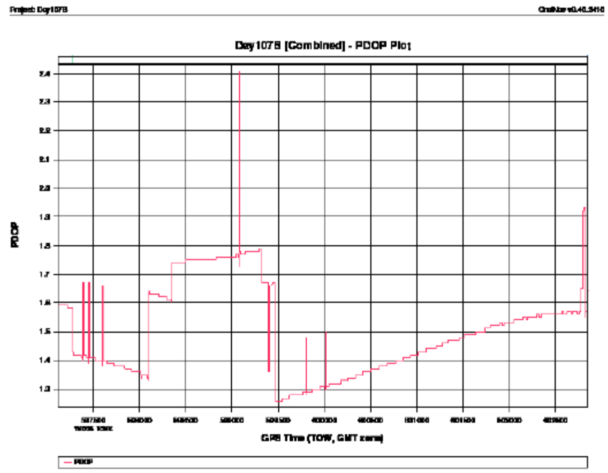


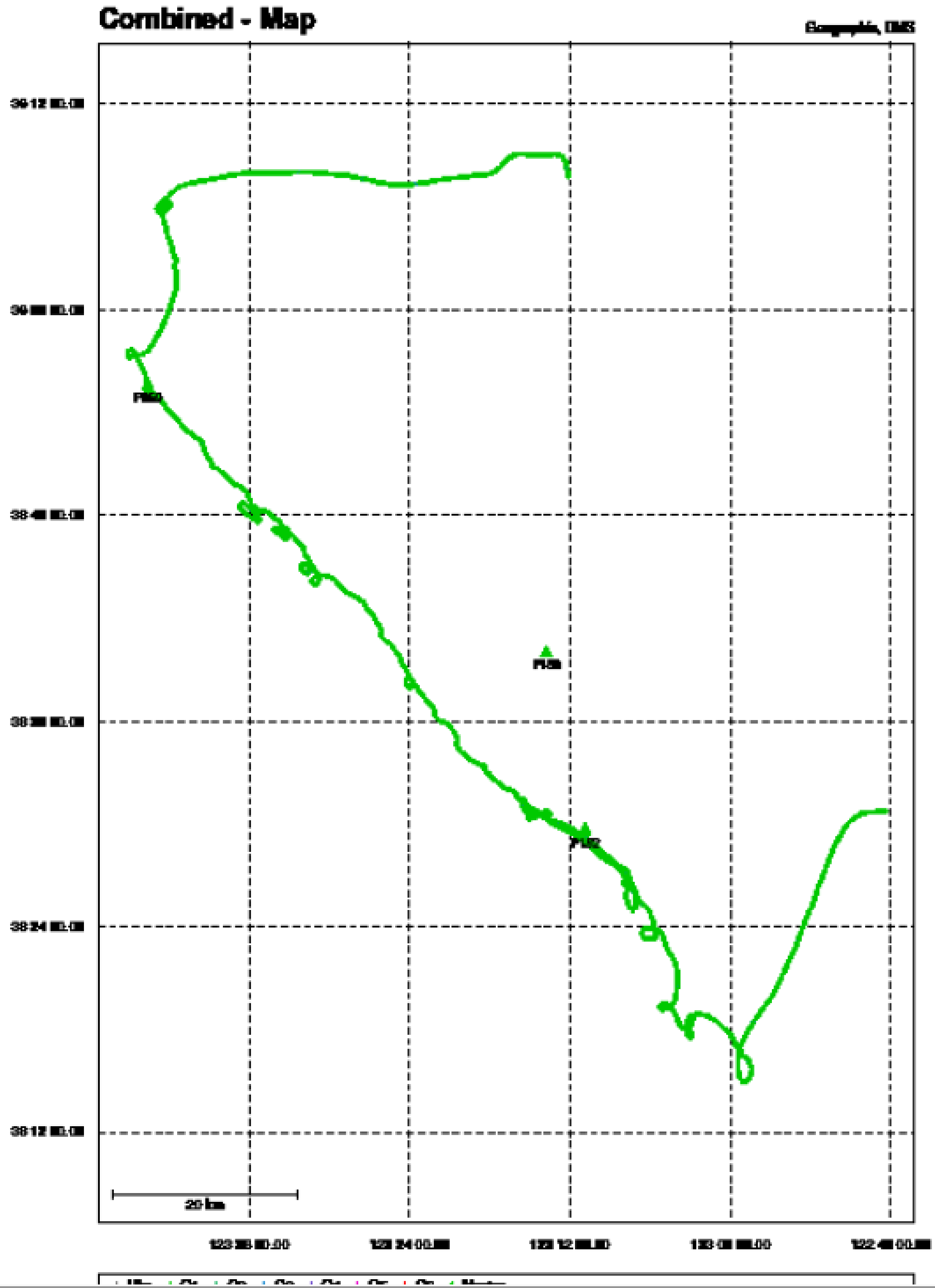

Day107A [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zone)

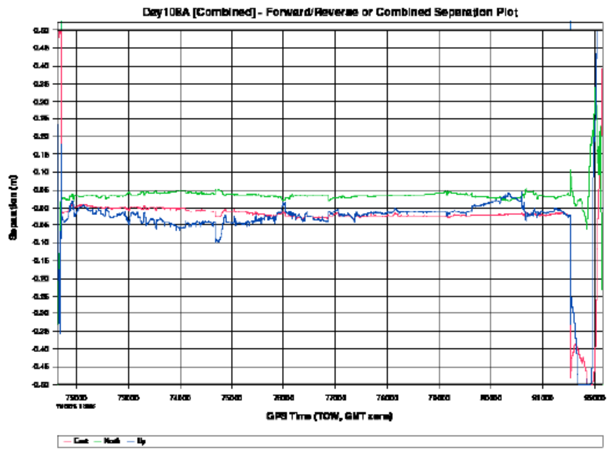

Day107A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zone)

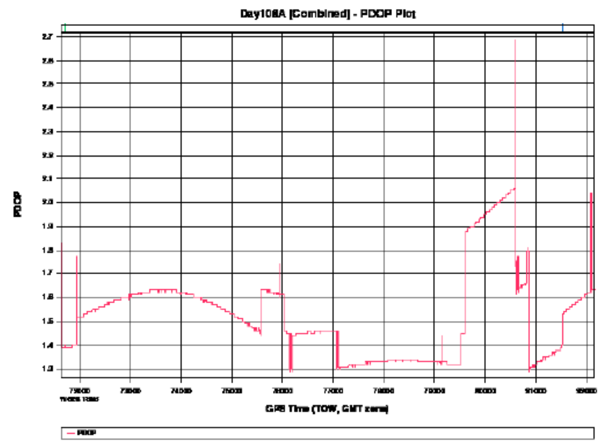

Combined - Map

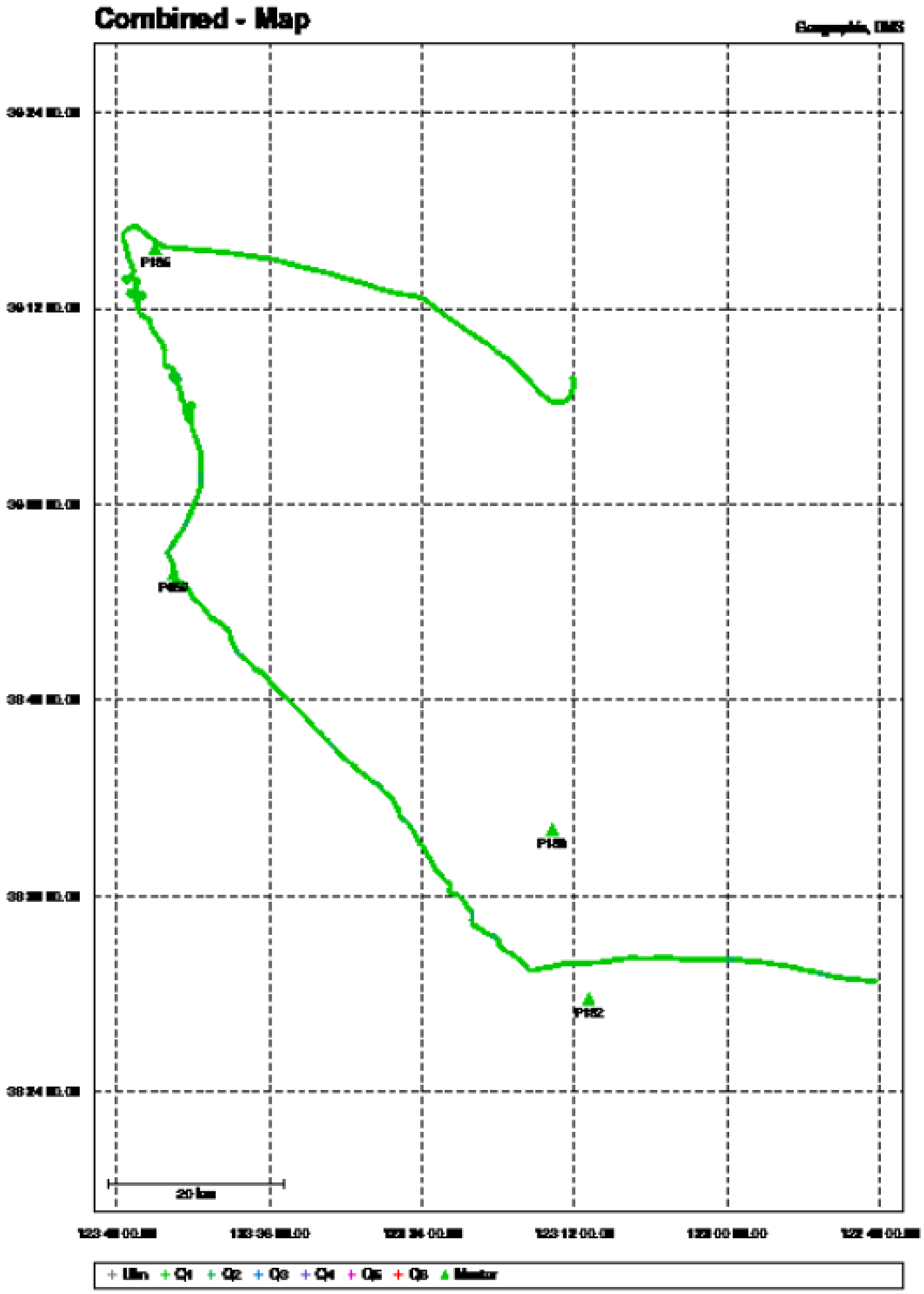

Day107B [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)
East
North
Up

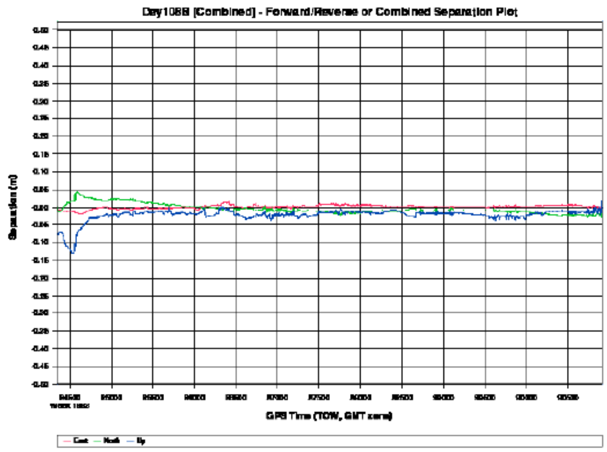

Day107B [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)
PDOP

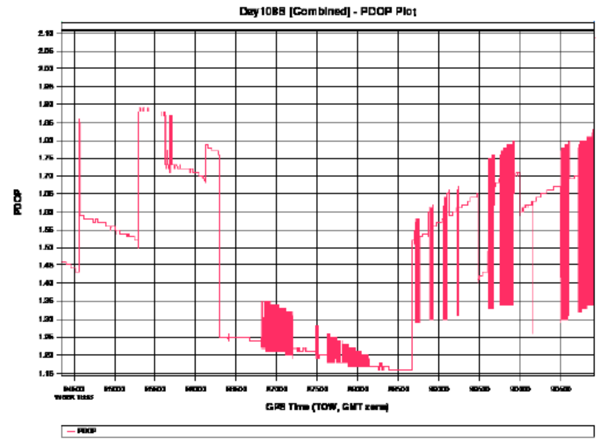

Combined - Map
20 km

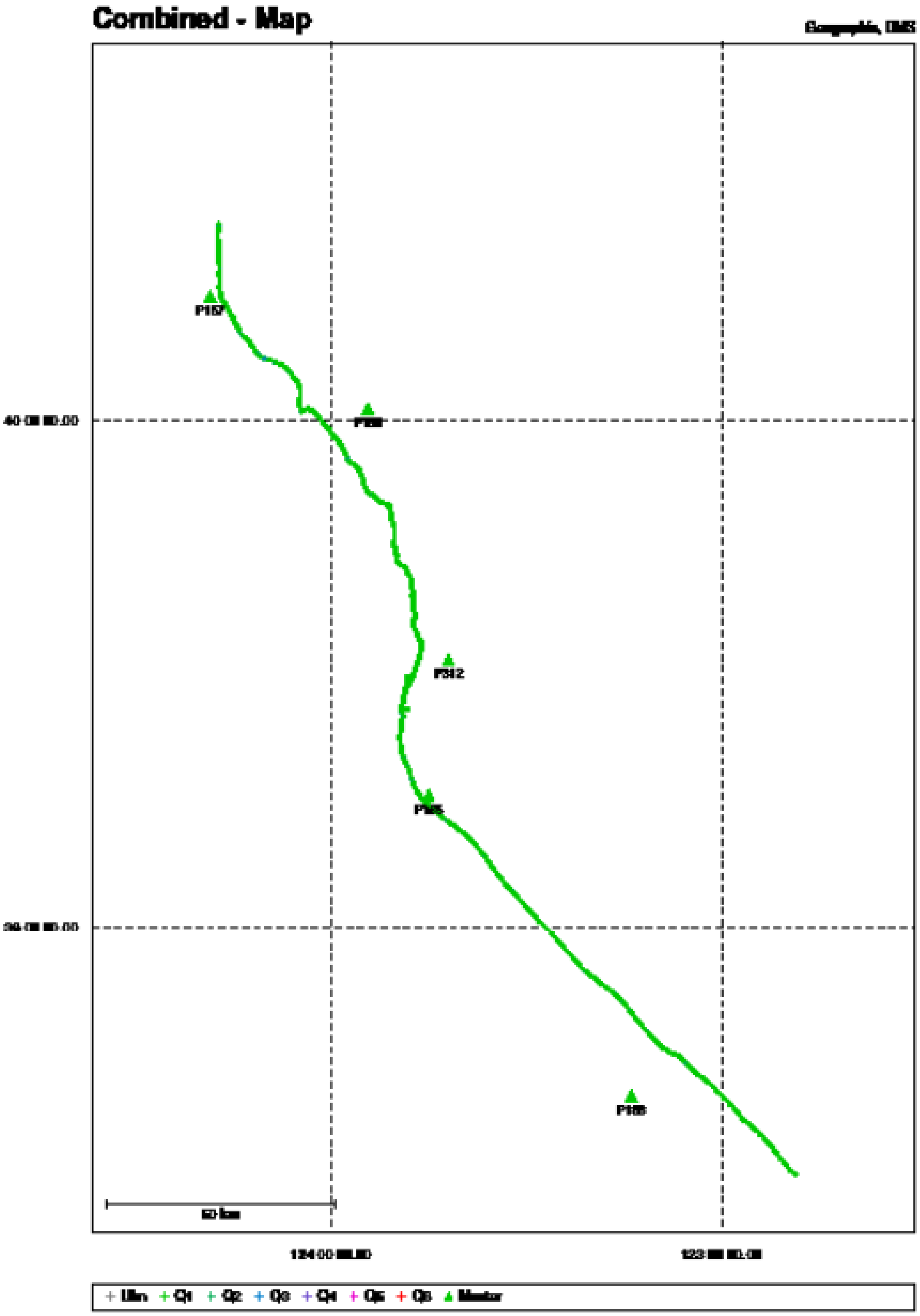

Day108A [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)
East
North
Up

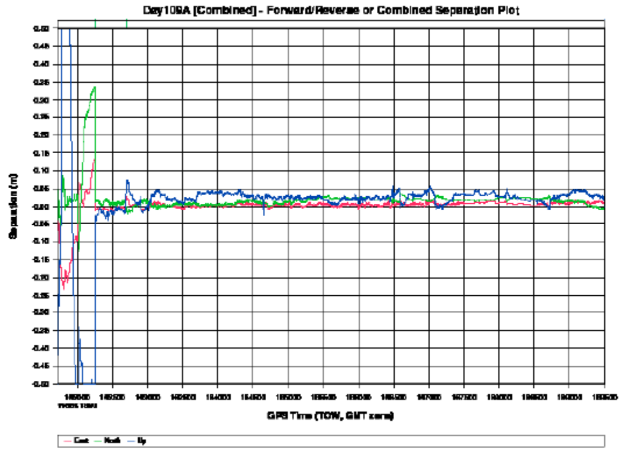

Day108A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)
PDOP

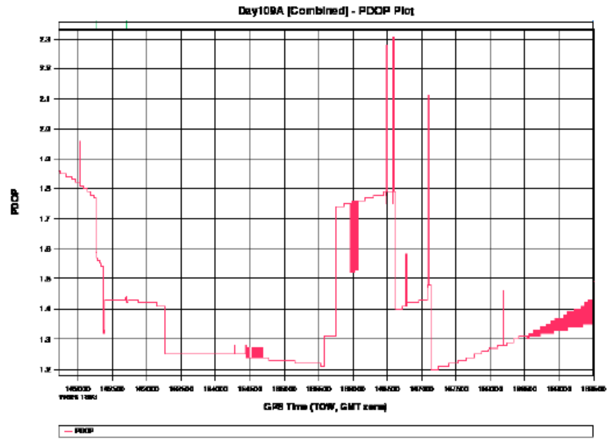

Combined - Map

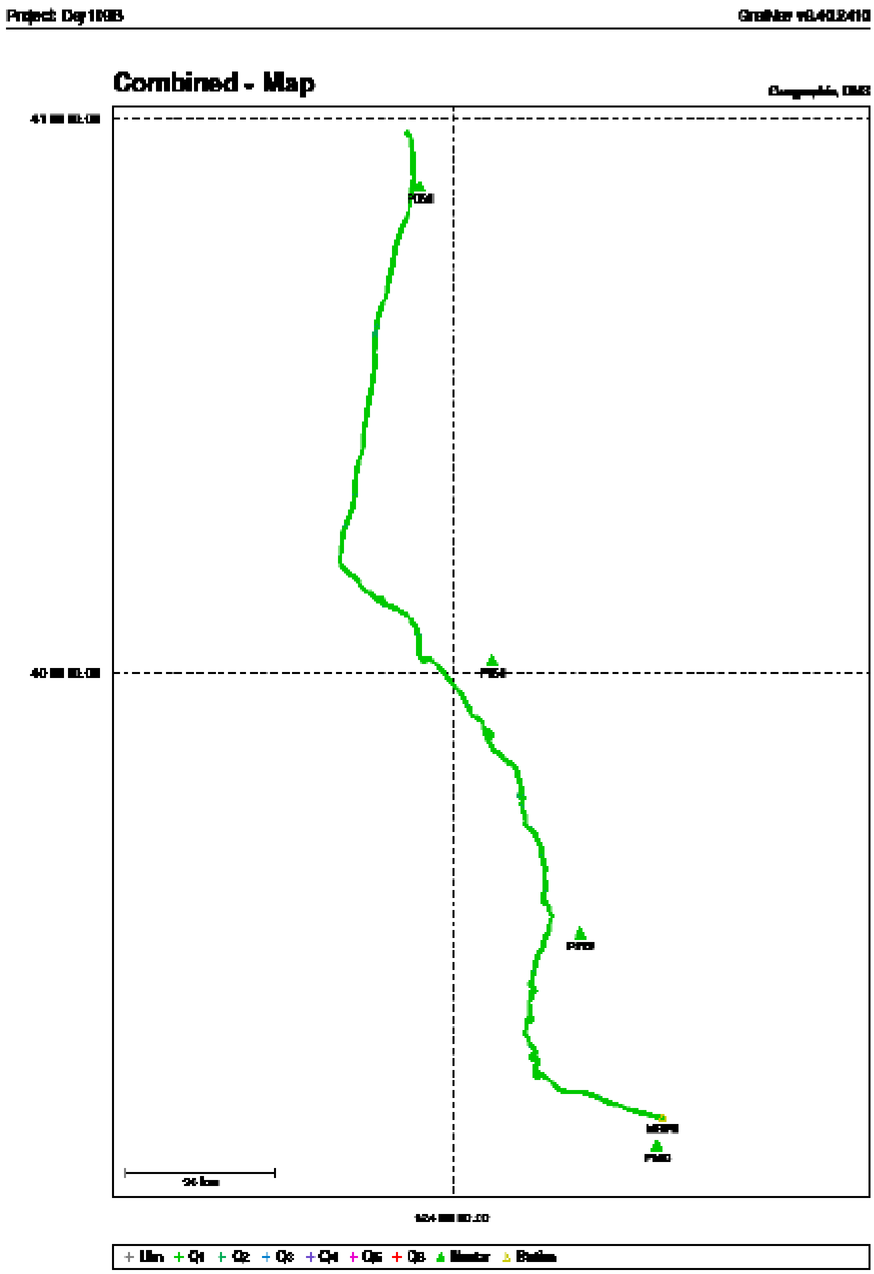


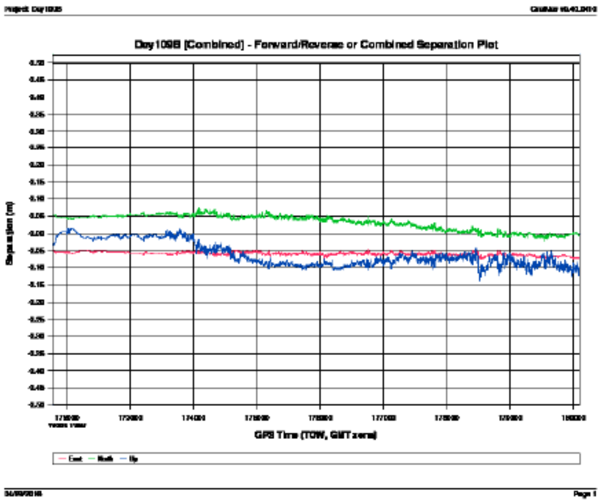


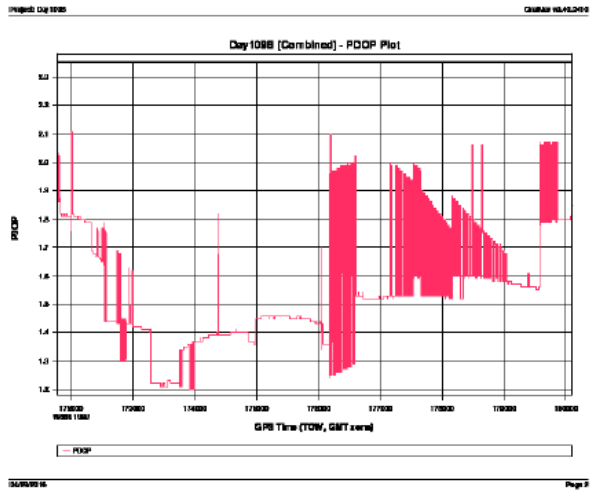

Combined - Map
P157
P312

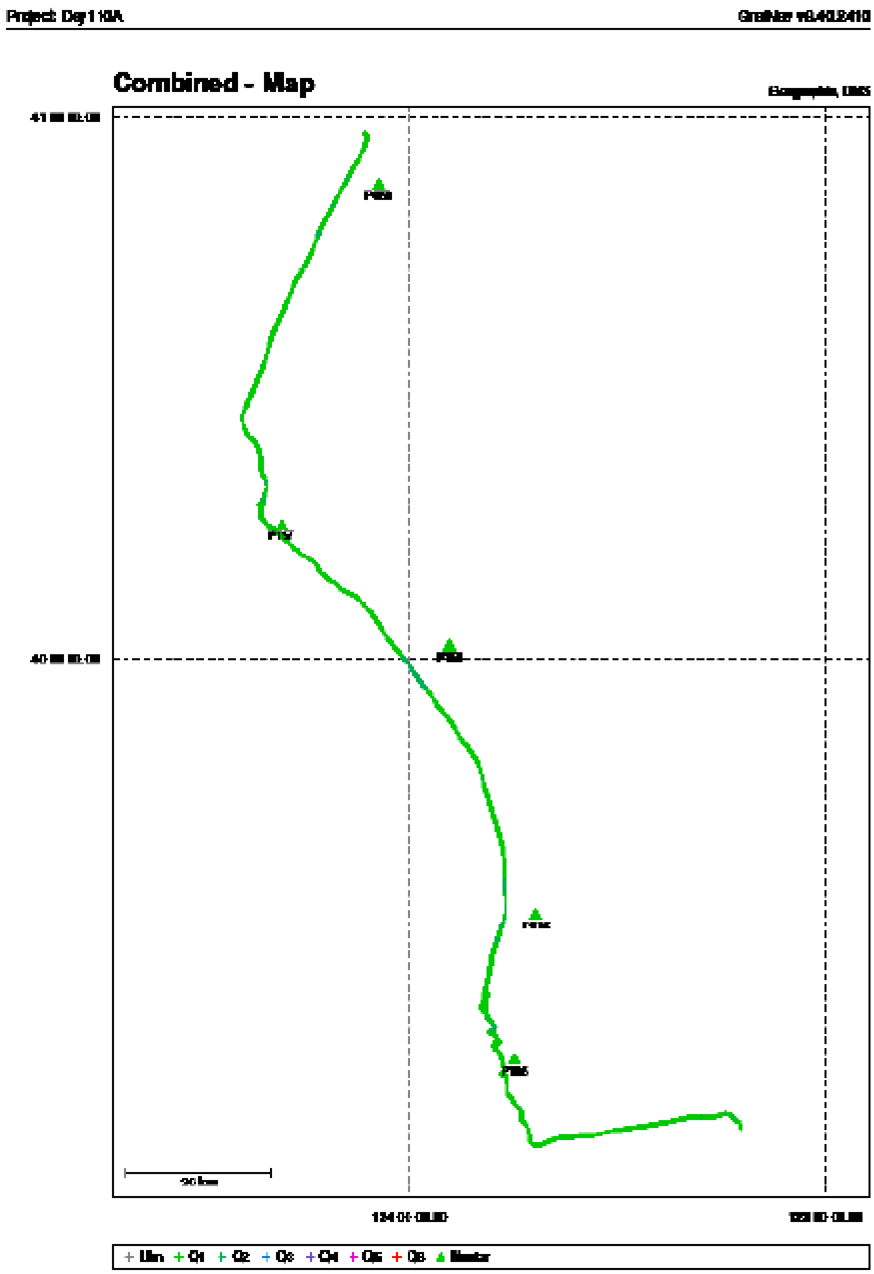

Day109A [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)

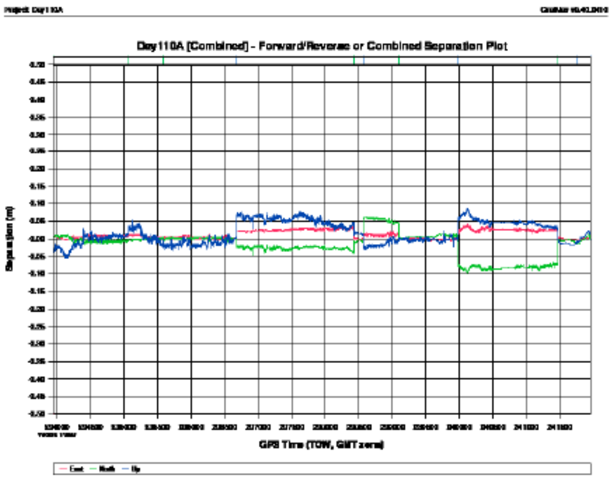

Day109A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

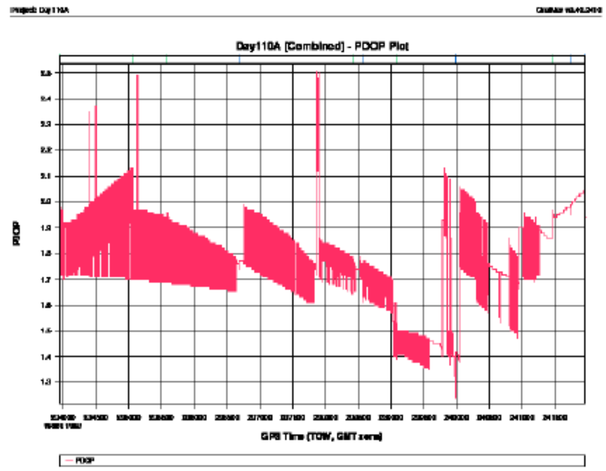

Combined - Map

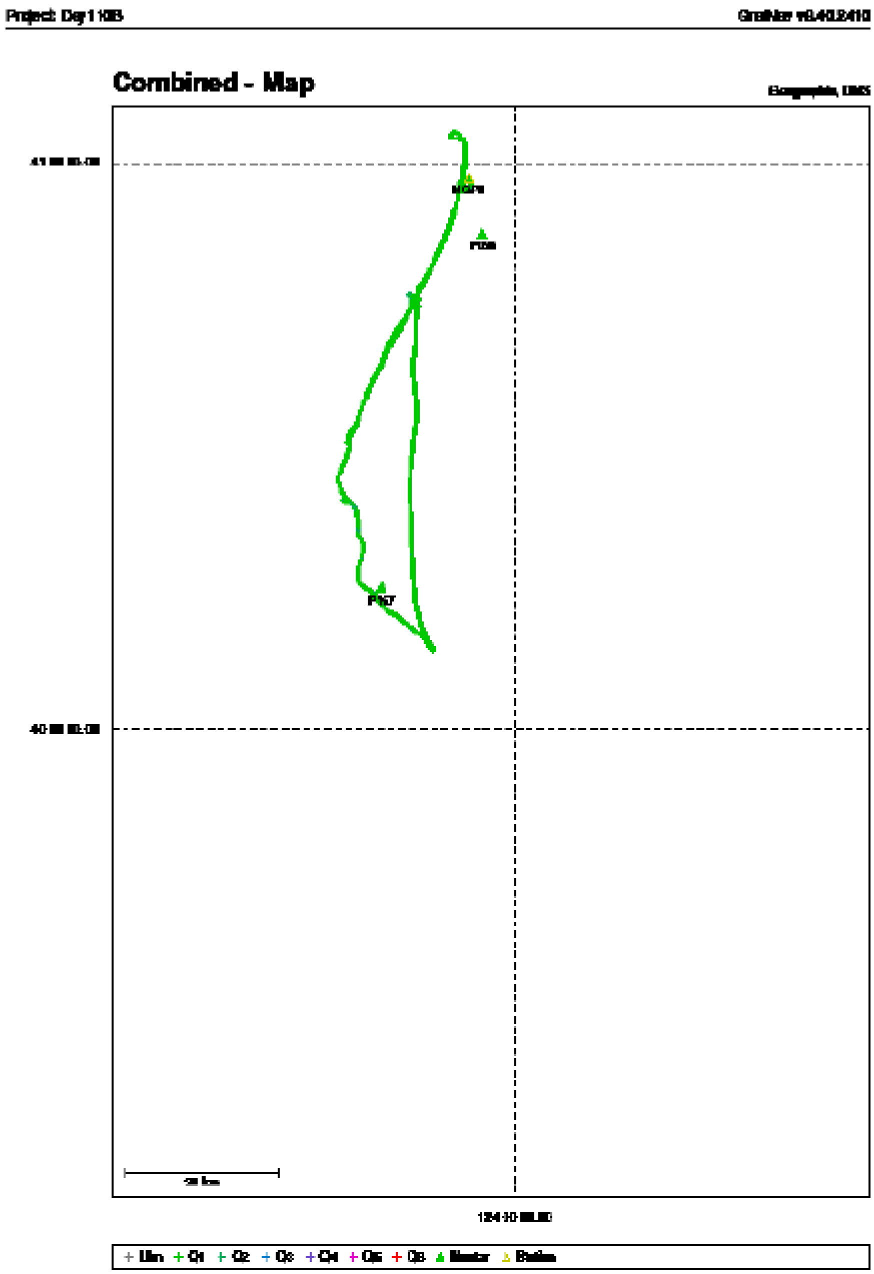


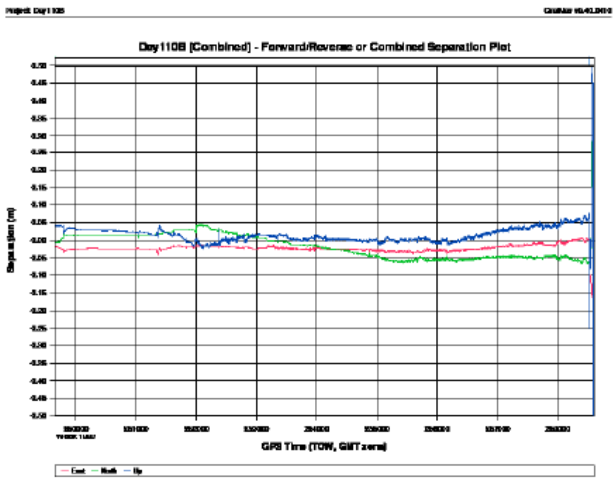


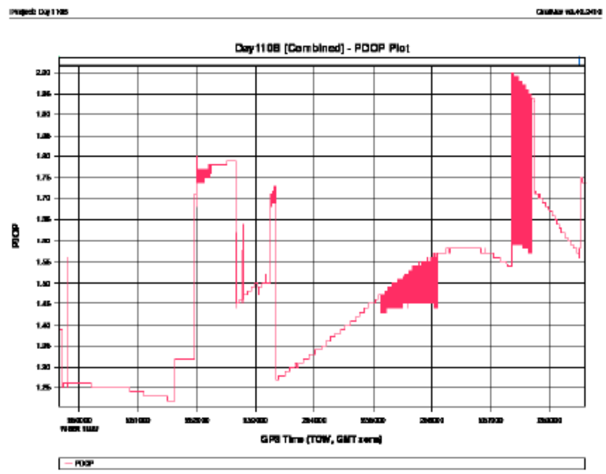

Combined - Map

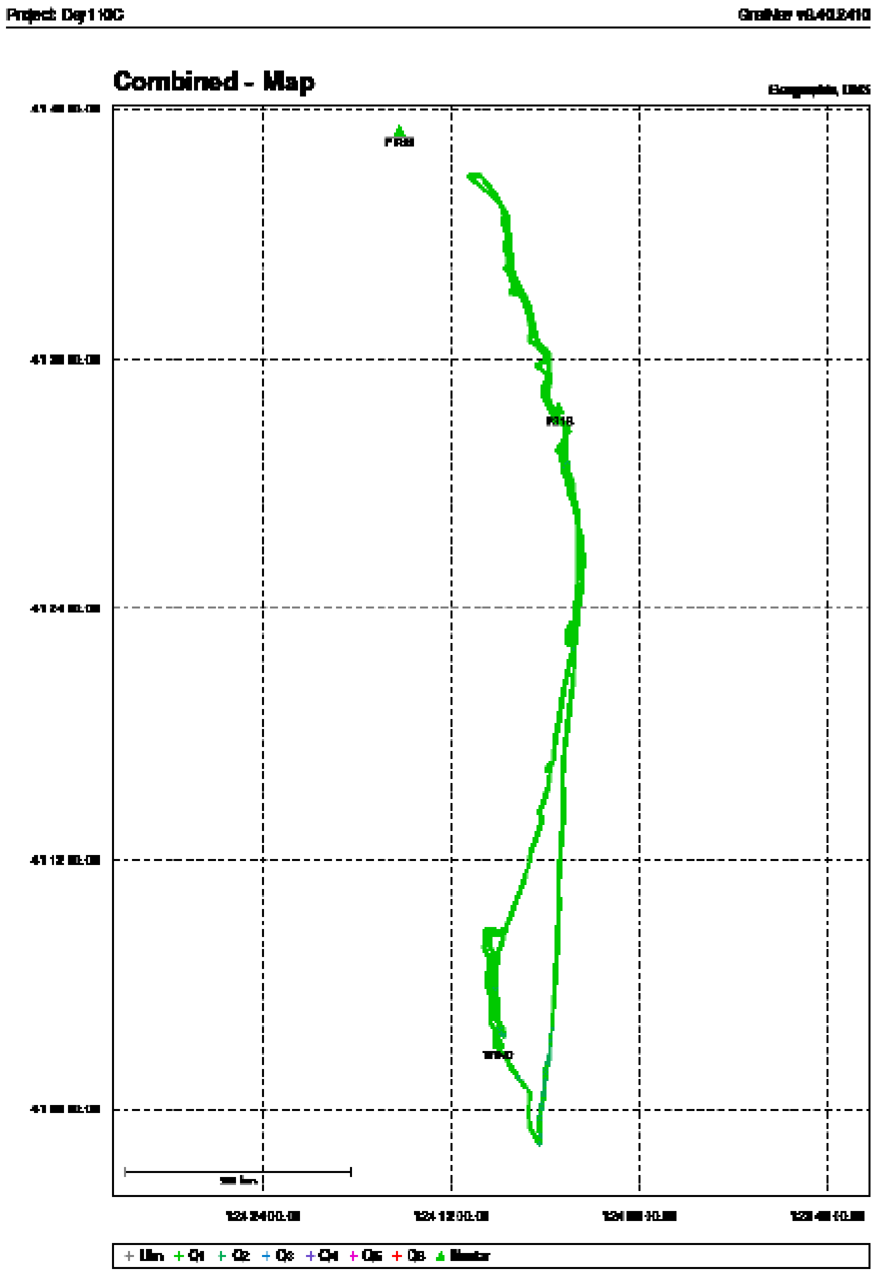

Day110A [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)
East
North
Up

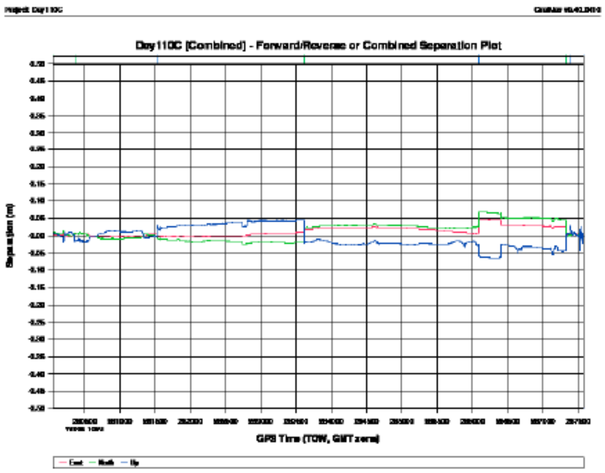

Day110A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)
PDOP

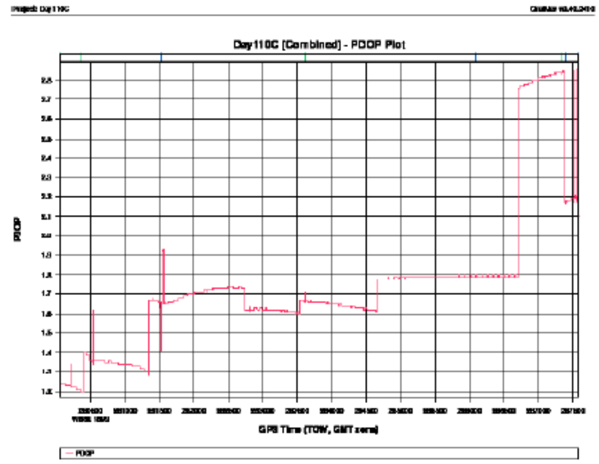

Combined - Map


Day110B (Combined) - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)
East
North
Up


Day110B (Combined) - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)
PDOP

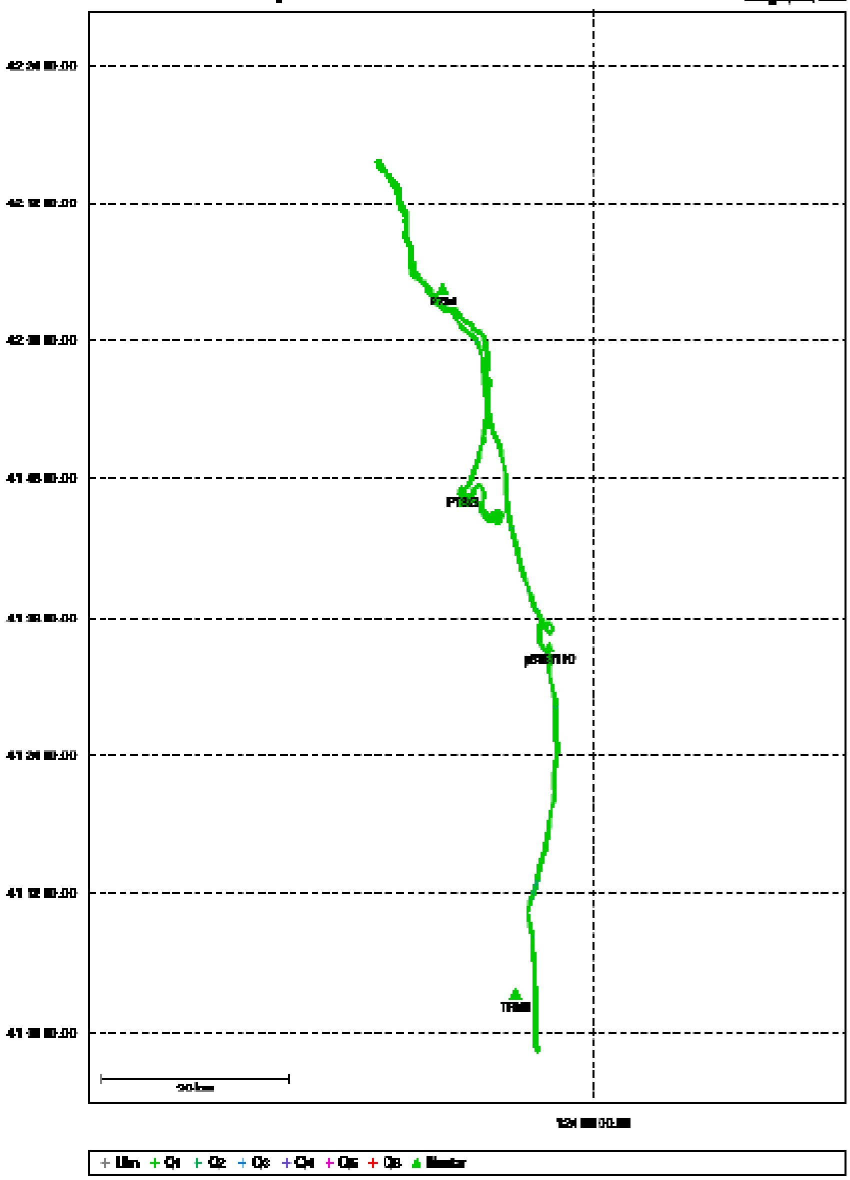

Combined - Map


Day110C [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)

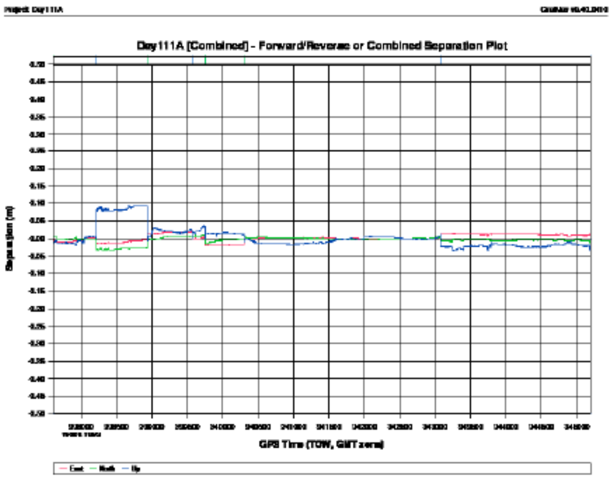

Day110C [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

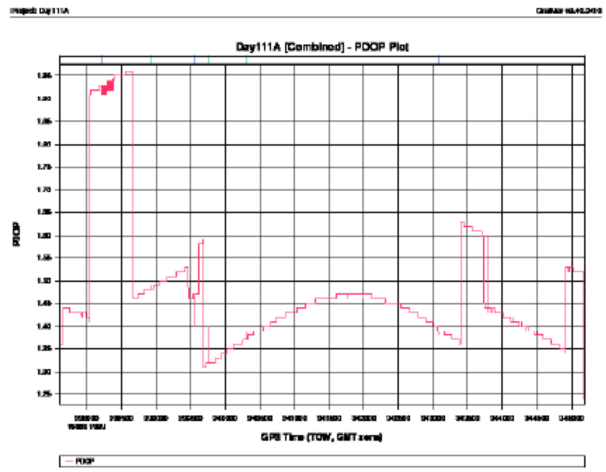
Project: Day111A

Combined - Map



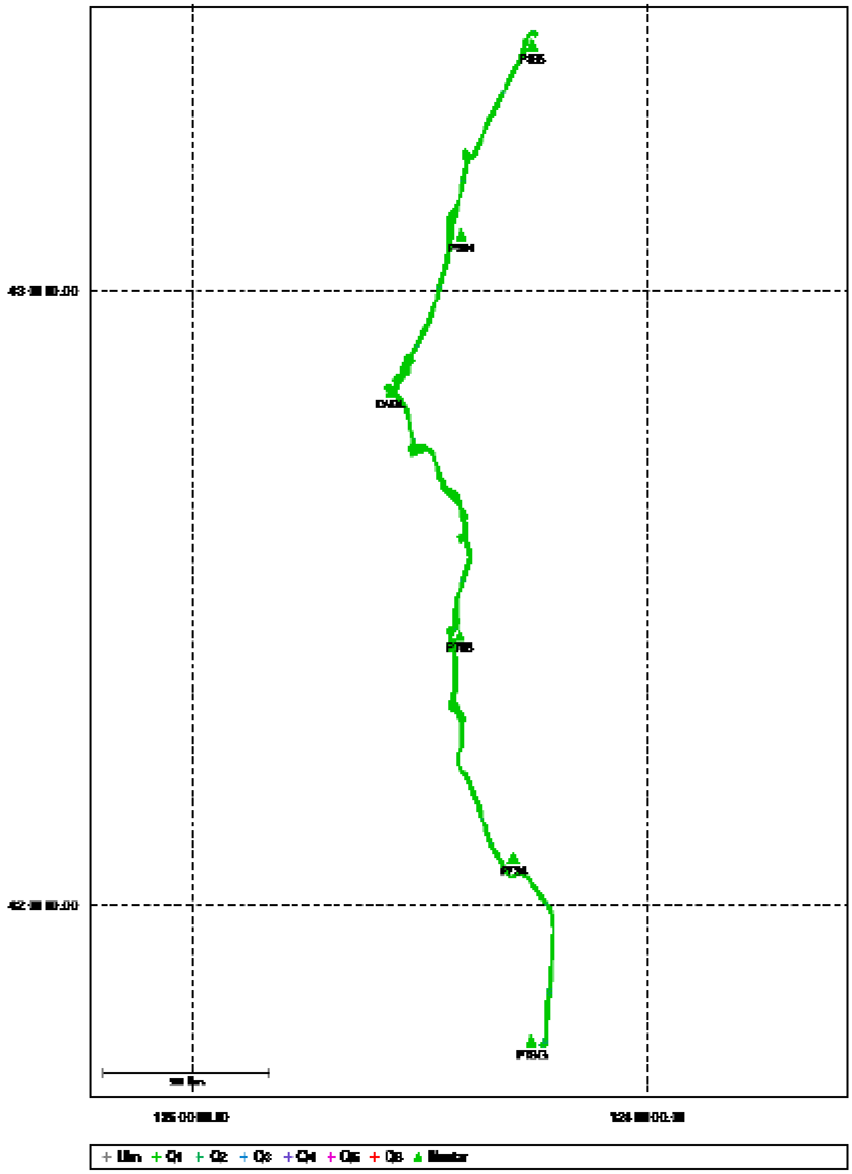
Dewberry


Day111A [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)
East
North
Up

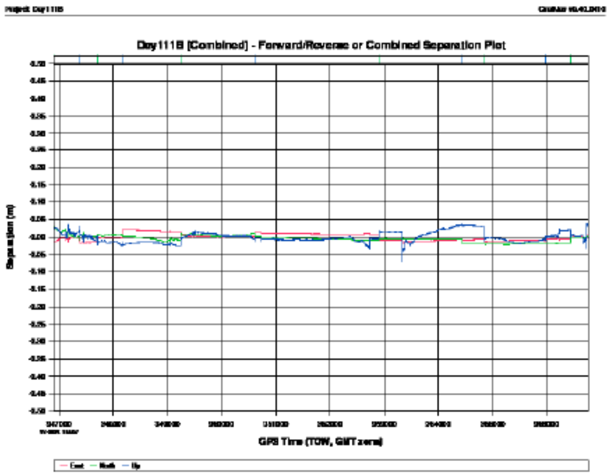

Day111A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

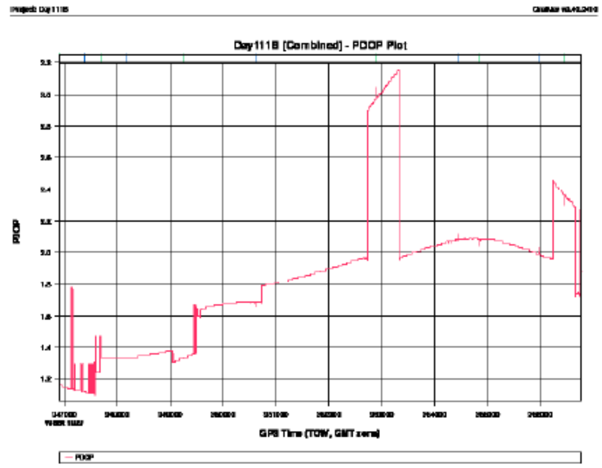
Project: Day111B

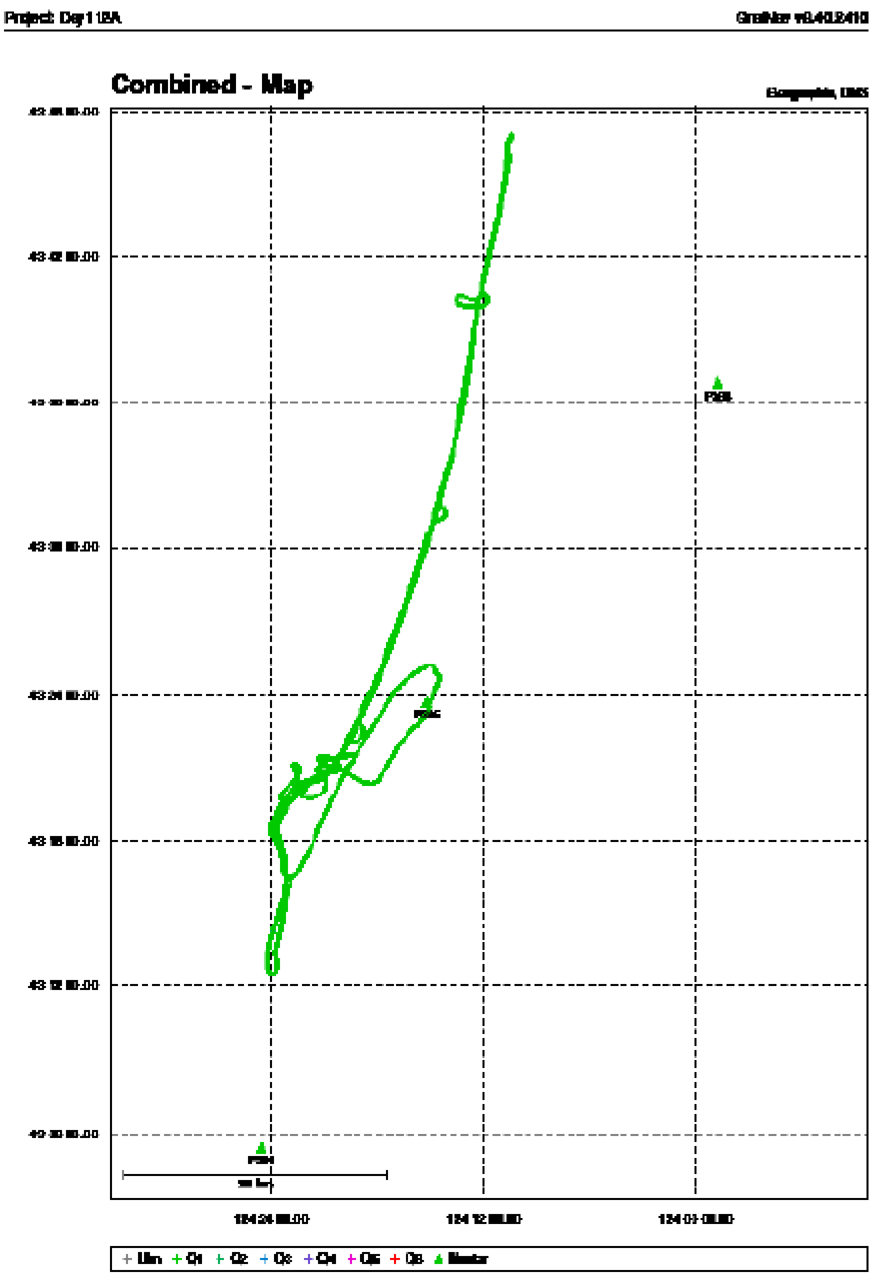
Combined - Map

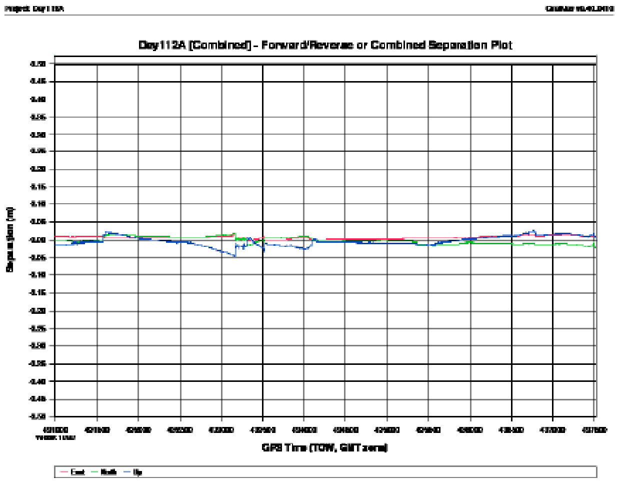


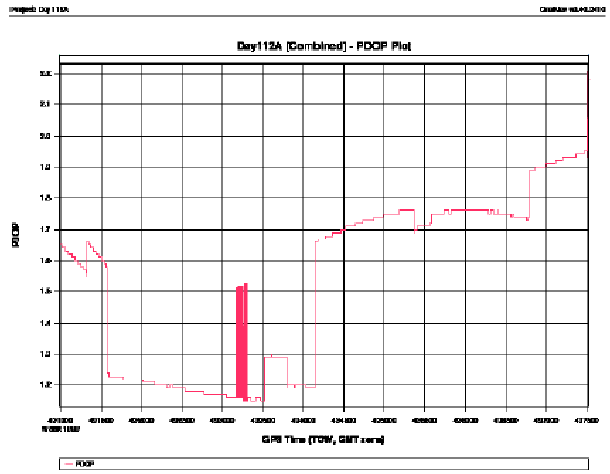
Dewberry

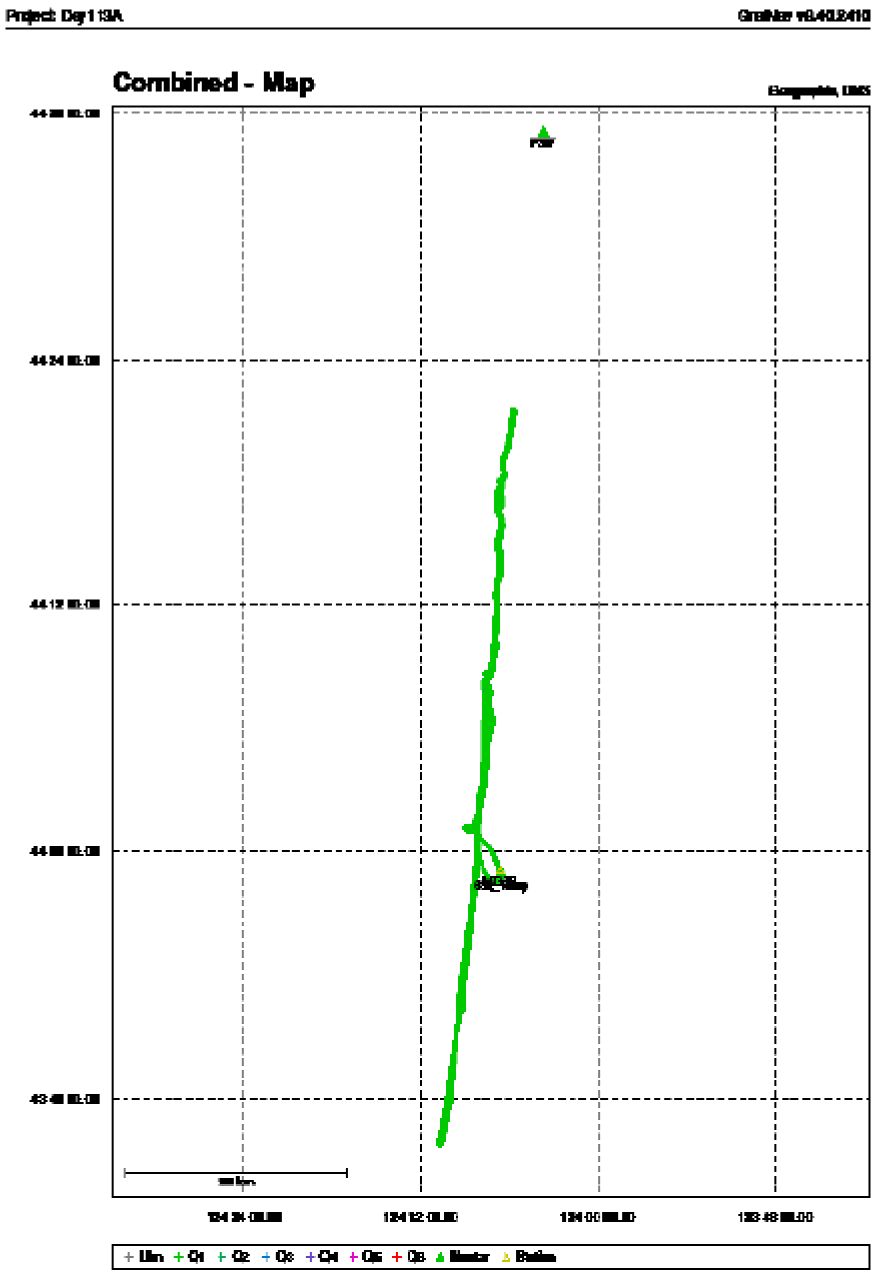

Day111B [Combined] - Forward/Reverse or Combined Separation Plot
GPS Time (TOW, GMT zero)

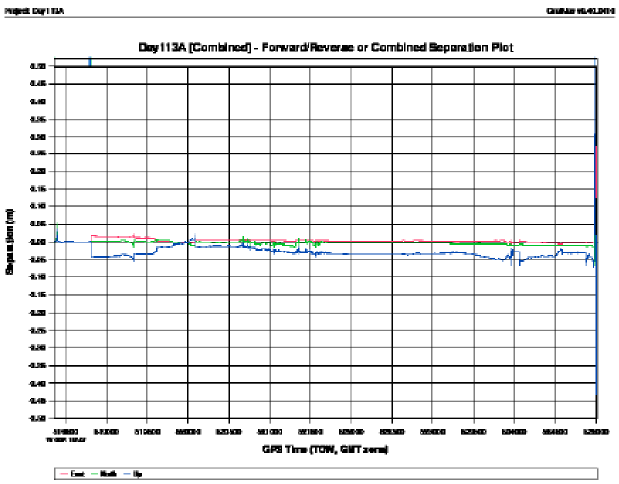

Day111B [Combined] - PDOP Plot
GPS Time (TOW, GMT zero)

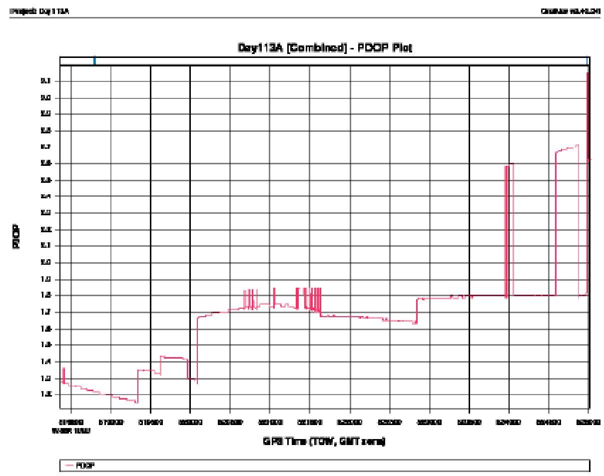

Combined - Map

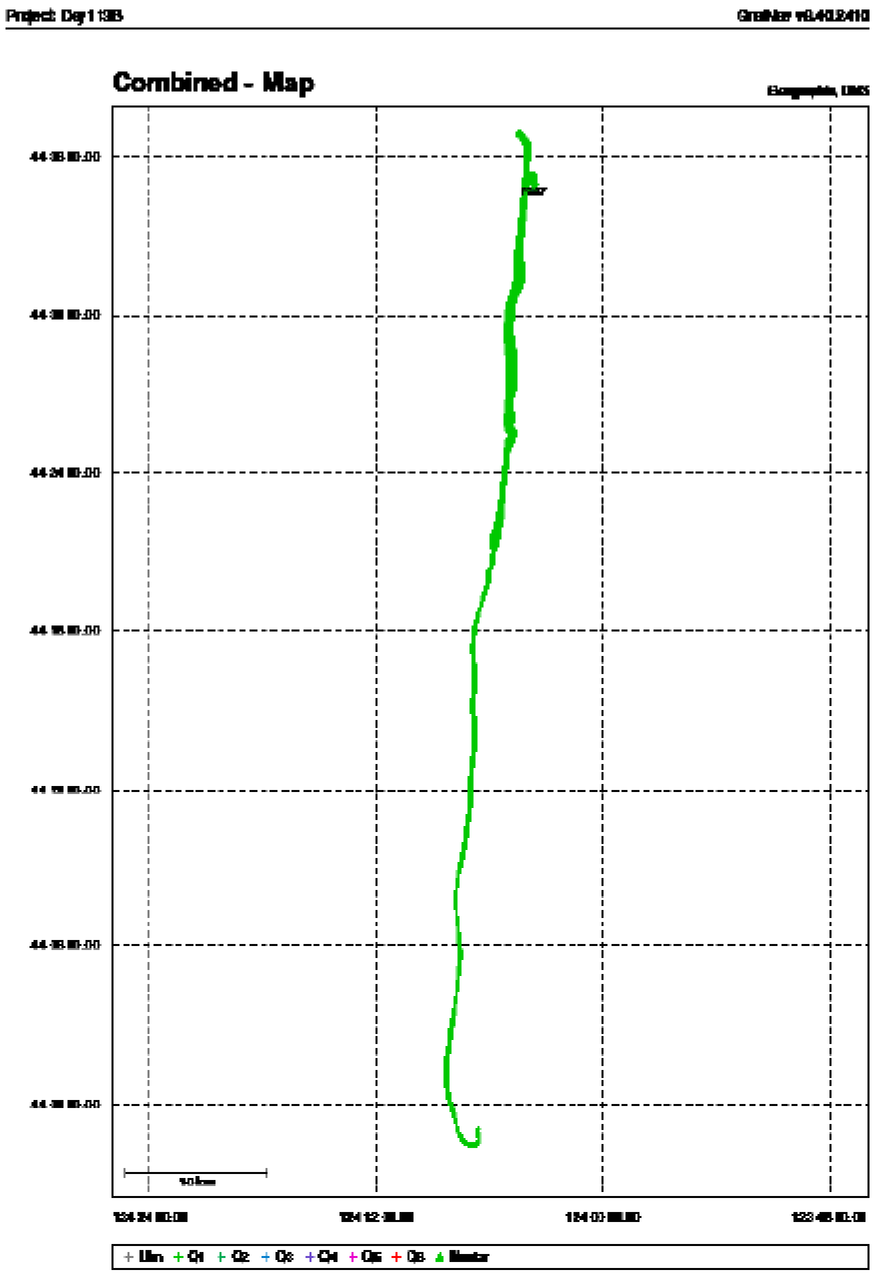


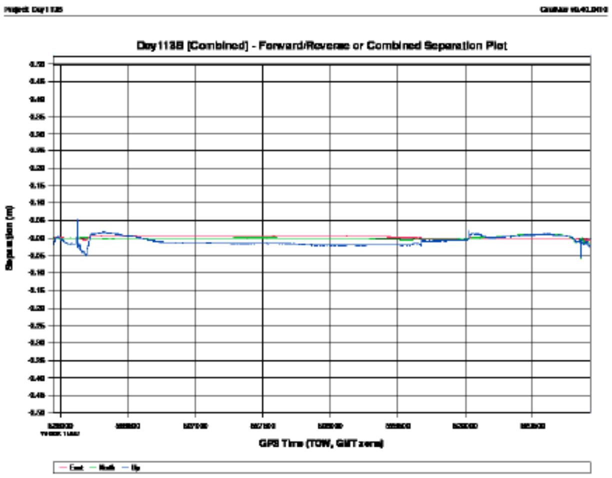


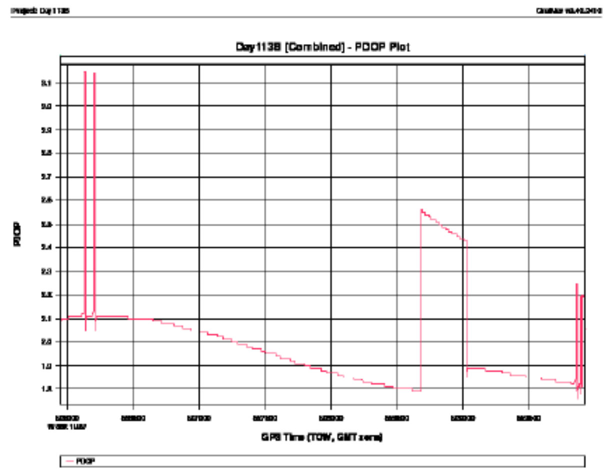

Combined - Map

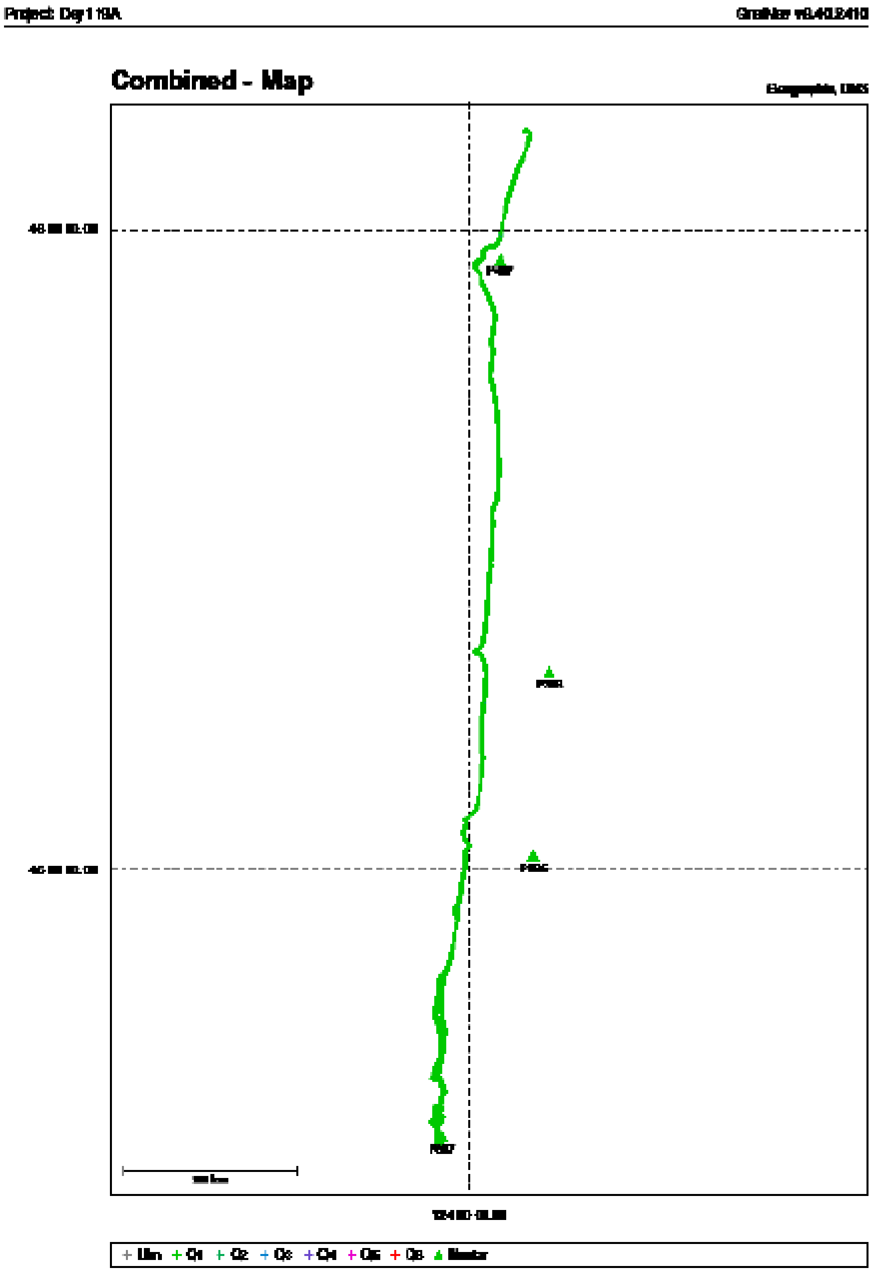

Day113A (Combined) - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zone)
East
North
Up

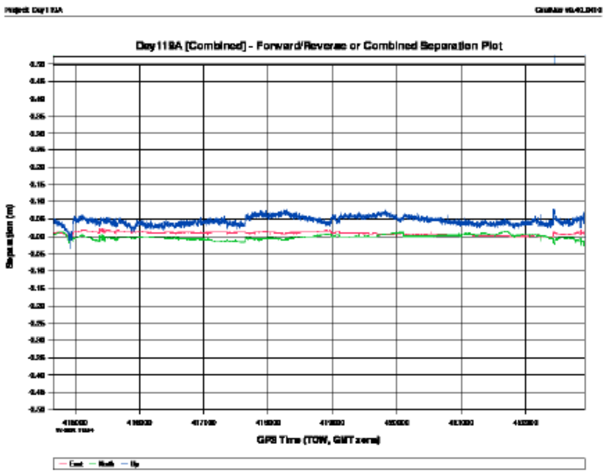

Day113A (Combined) - PDOP Plot
PDOP
GPS Time (TOW, GMT zone)
PDOP

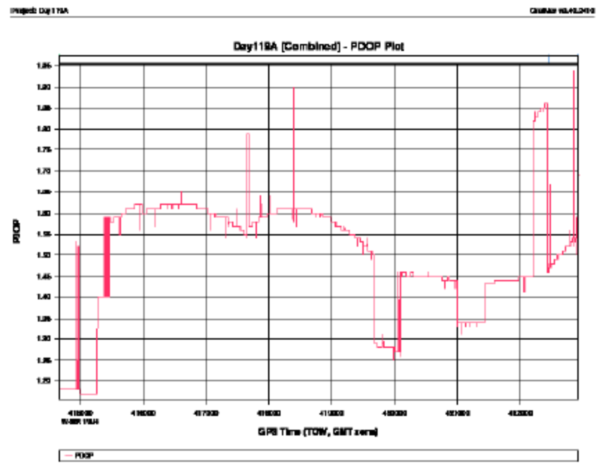

Combined - Map

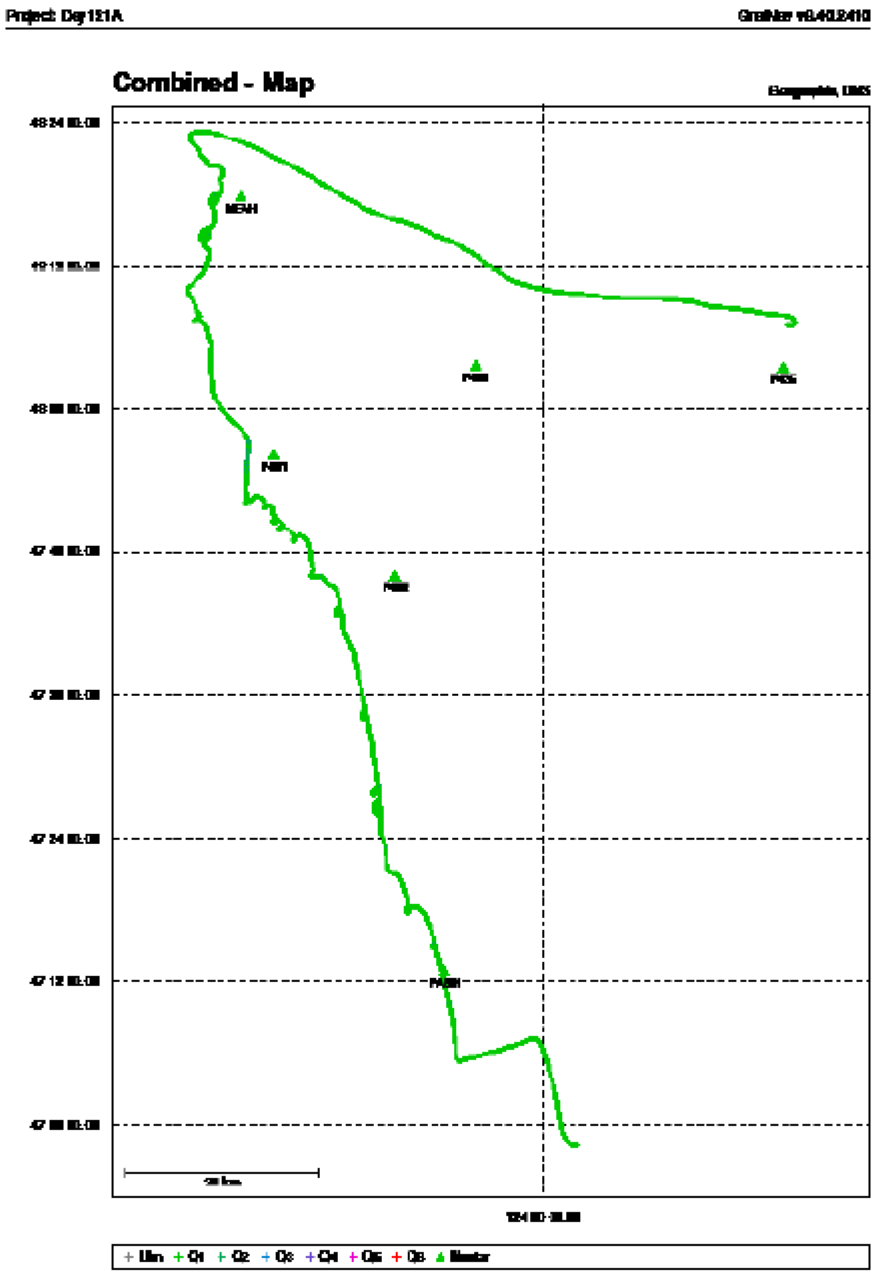

Day113B [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)
East
North
Up

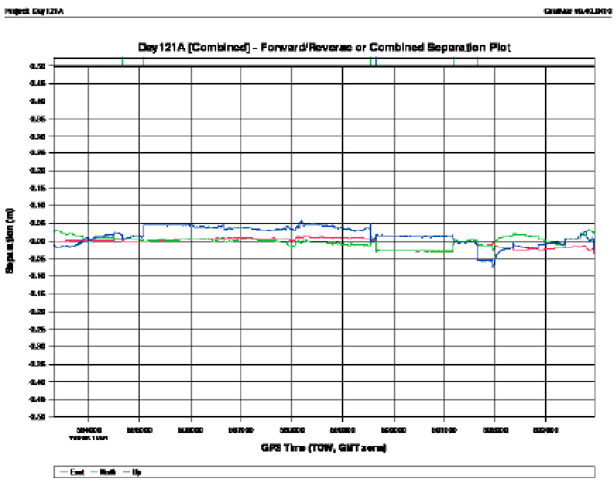

Day113B [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)
PDOP

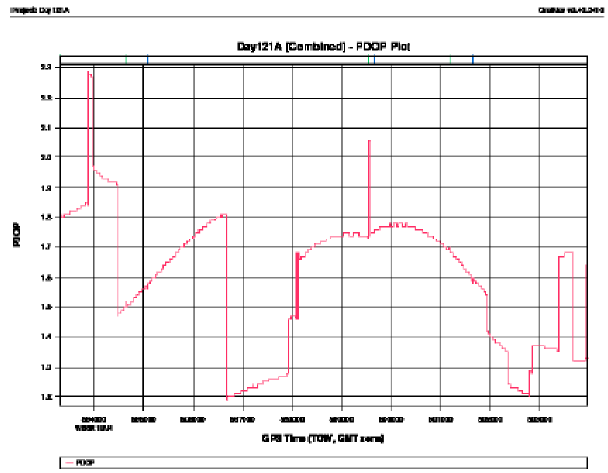

Project: Day119A
Combined - Map


Day119A [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)

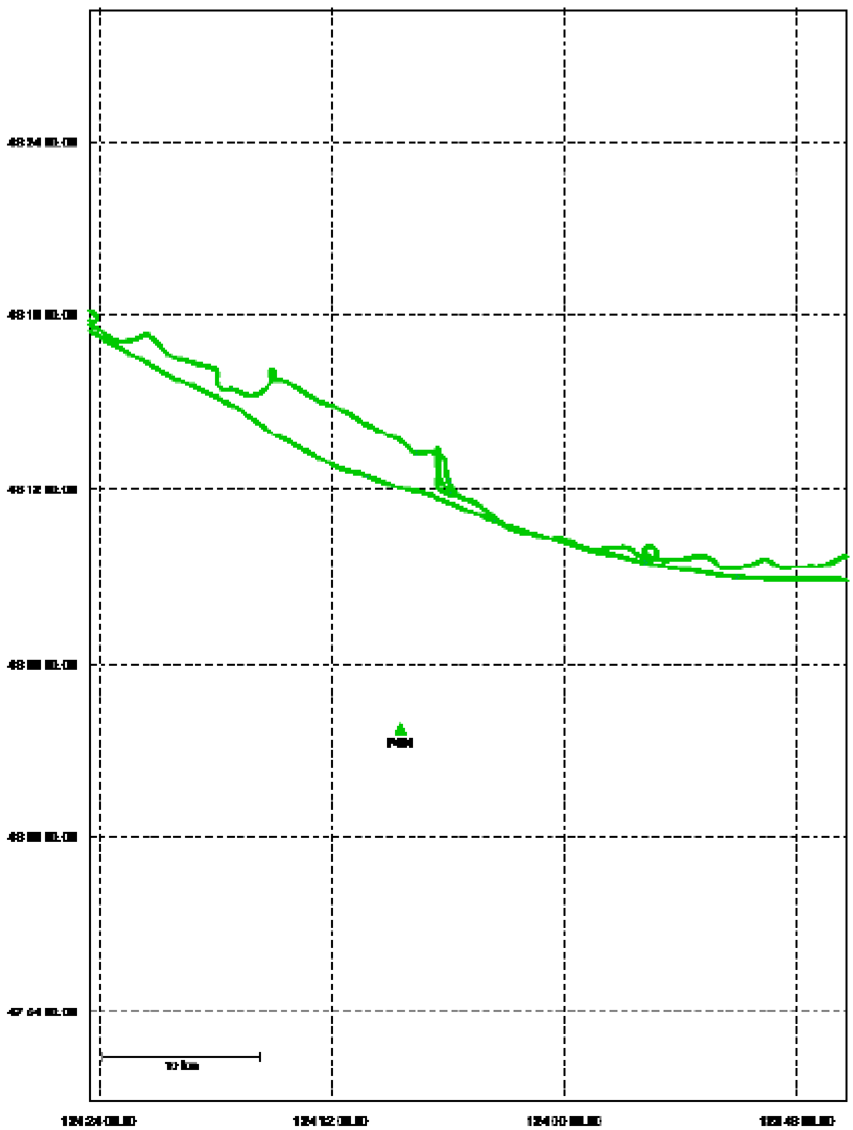

Day119A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

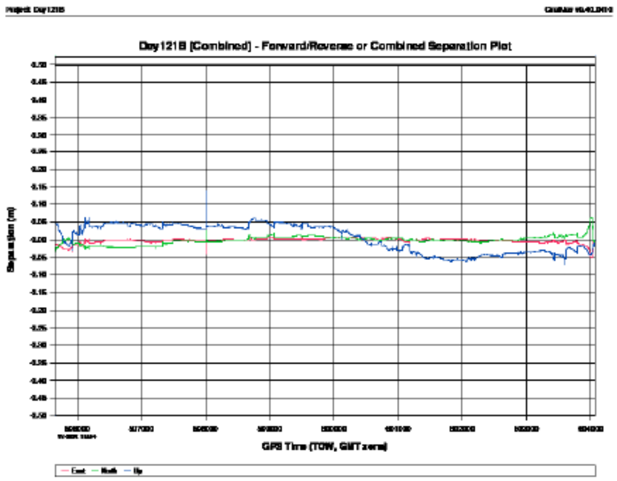

Combined - Map

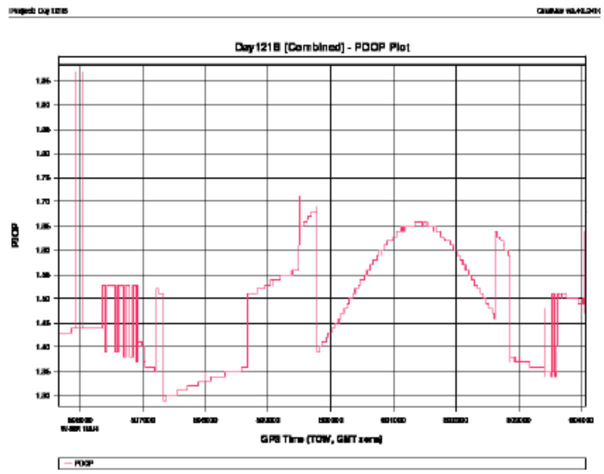

Day121A (Combined) - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)
East
North
Up

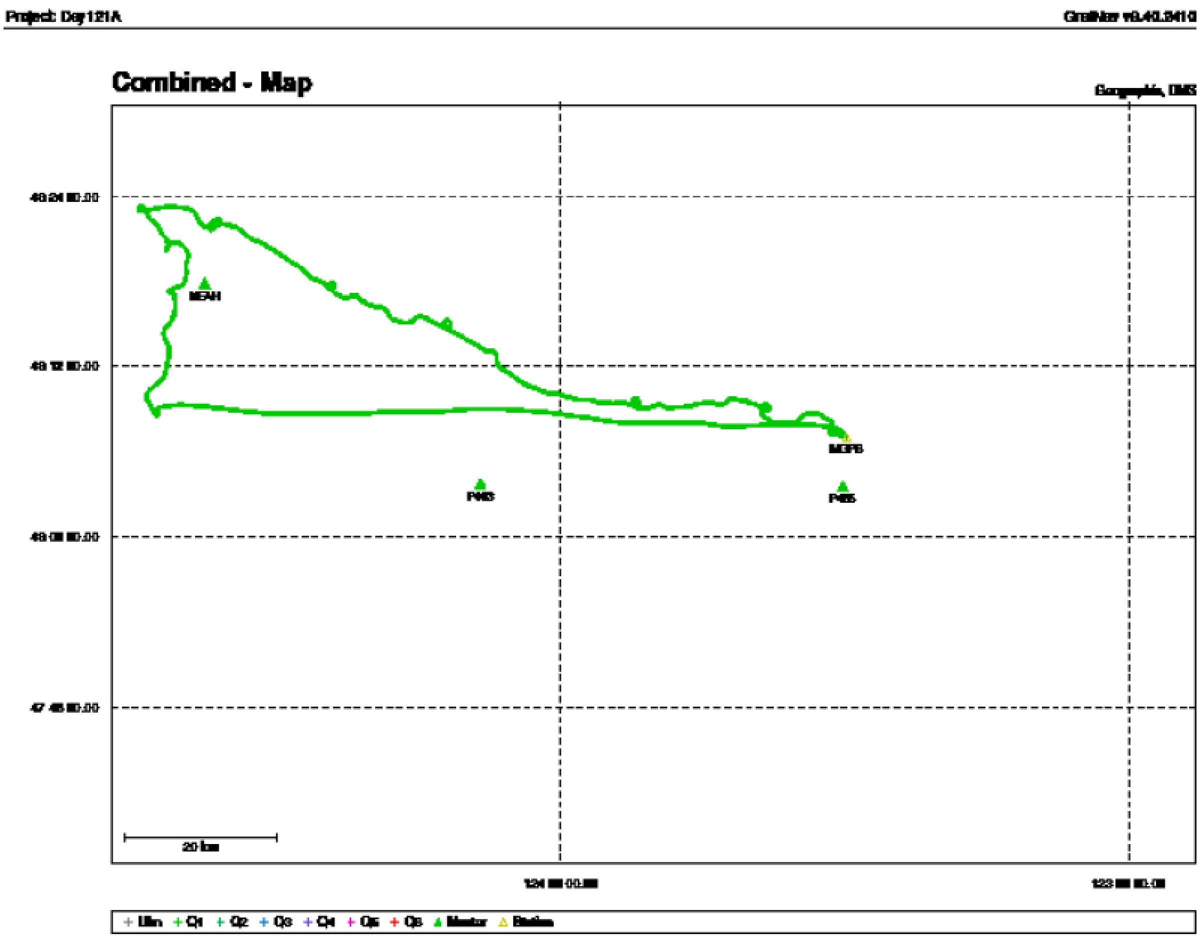

Day121A (Combined) - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)
PDOP

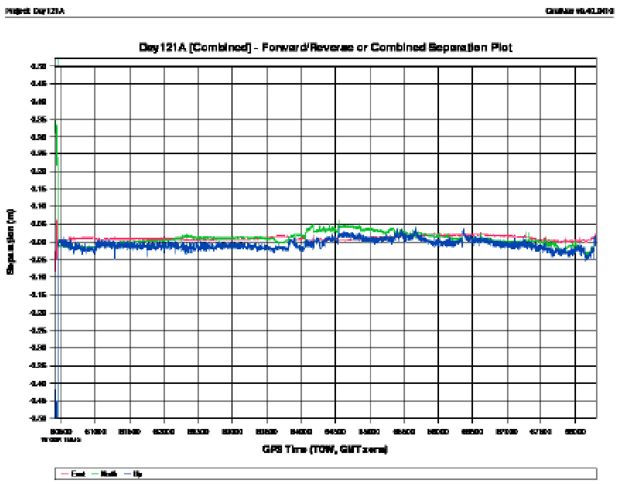
Project: Day121B

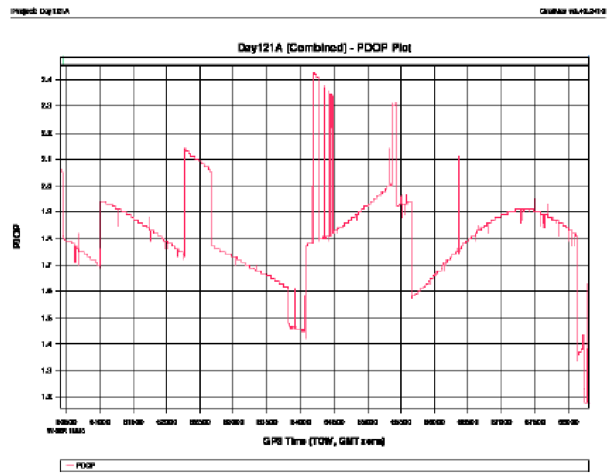


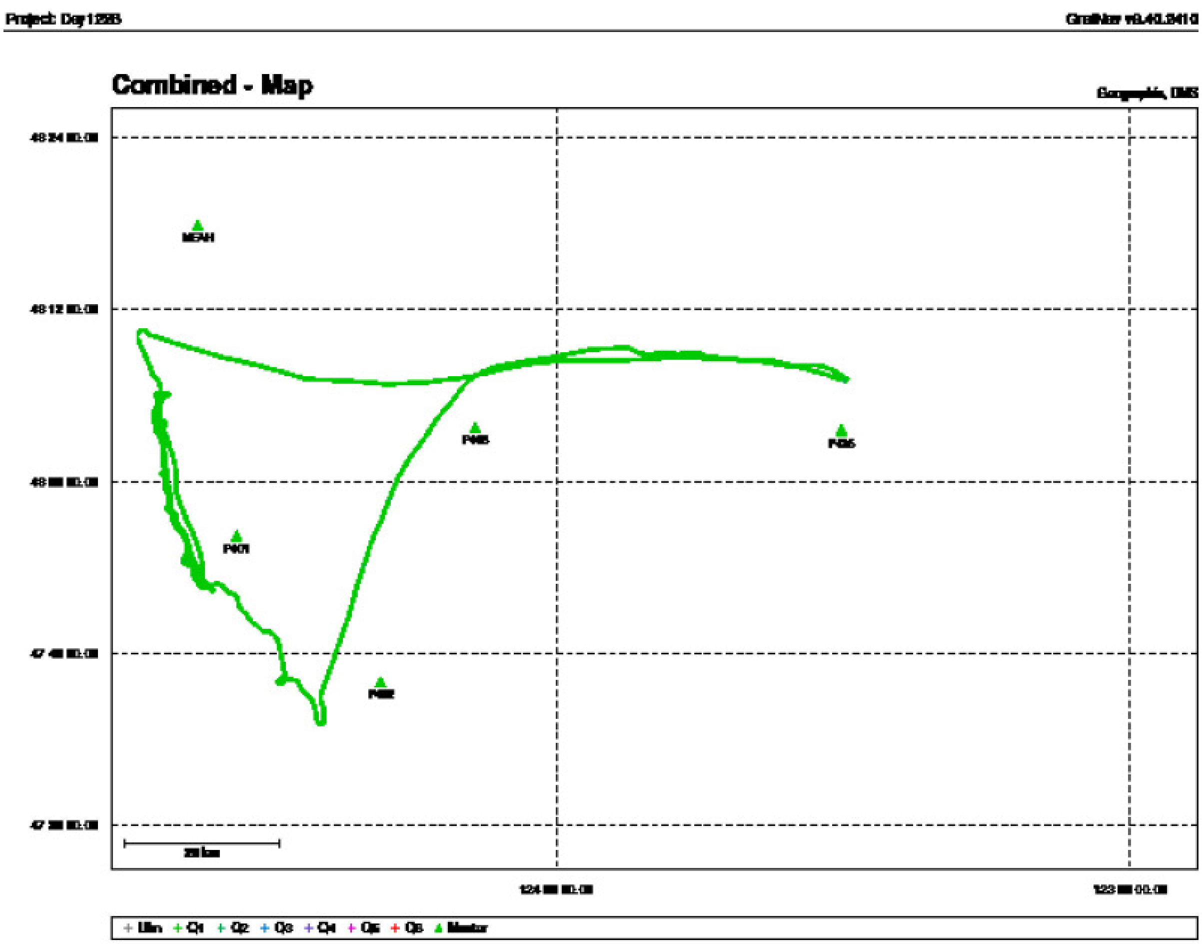

Day121B (Combined) - Forward/Reverse or Combined Separation Plot
GPS Time (TOW, GMT zero)

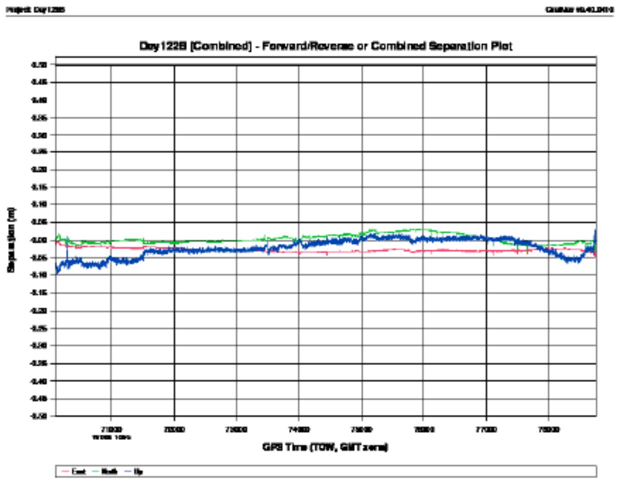

Day121B (Combined) - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

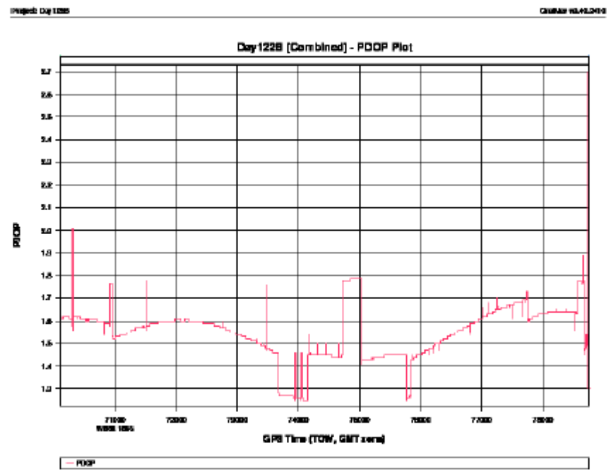

Project: Day121A
Combined - Map

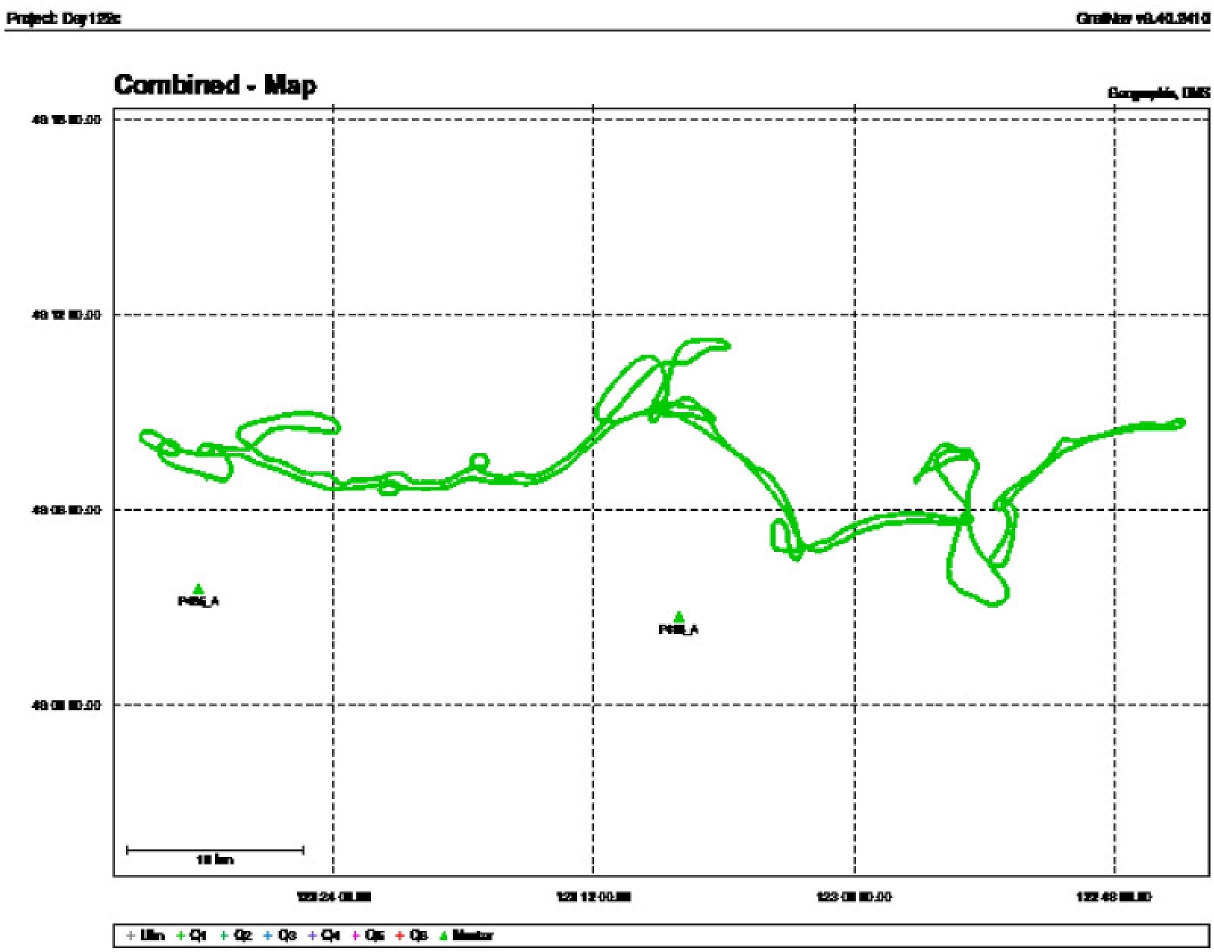

Day121A [Combined] - Forward/Reverse or Combined Separation Plot
GPS Time (TOW, GMT zero)

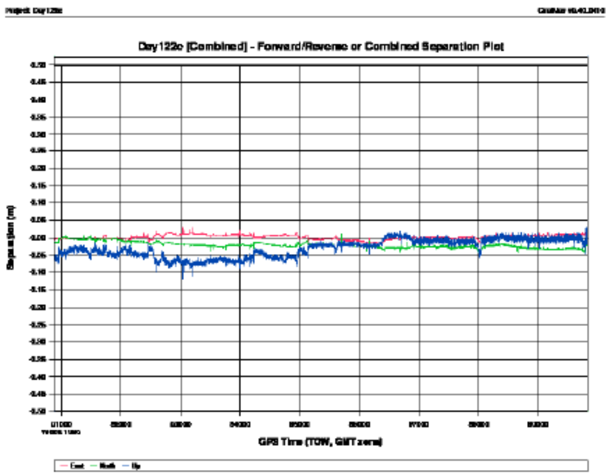

Day121A [Combined] - PDOP Plot
GPS Time (TOW, GMT zero)

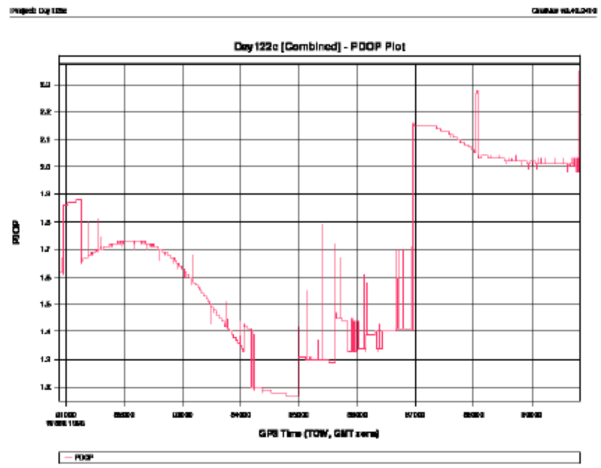

Combined - Map

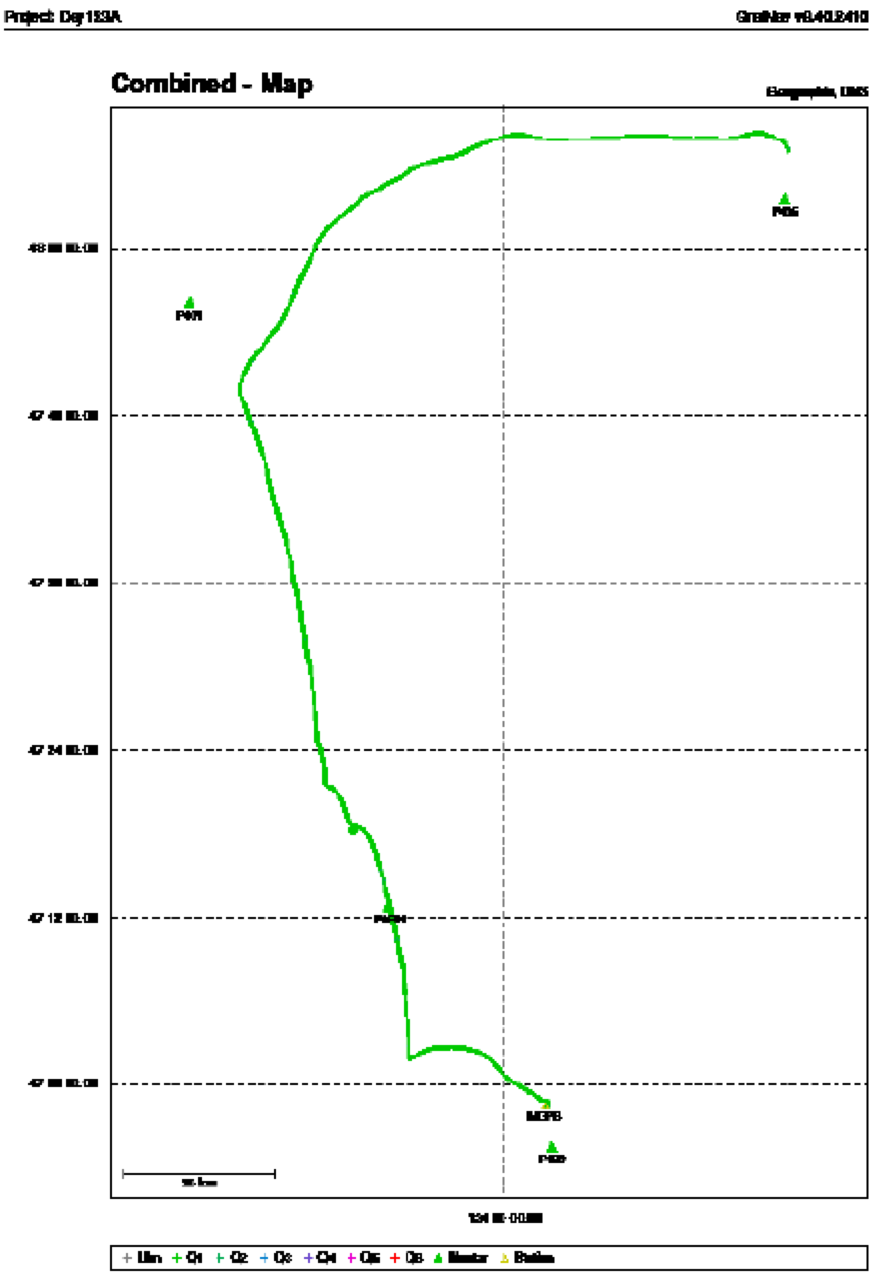

Day122B (Combined) - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)

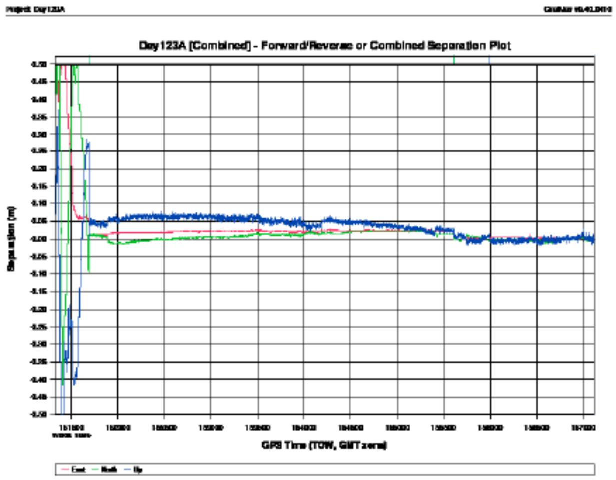

Day122B (Combined) - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

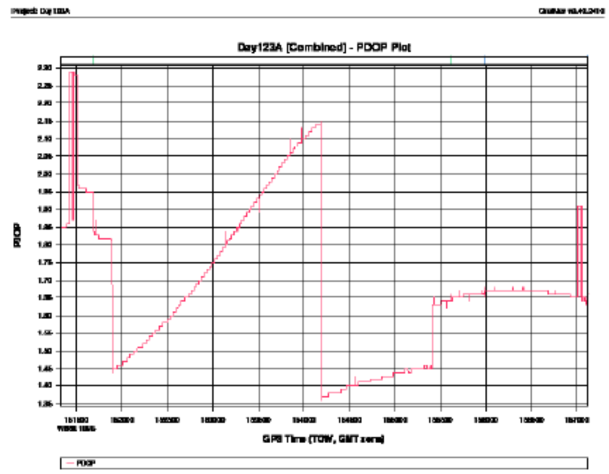

Combined - Map
10 km

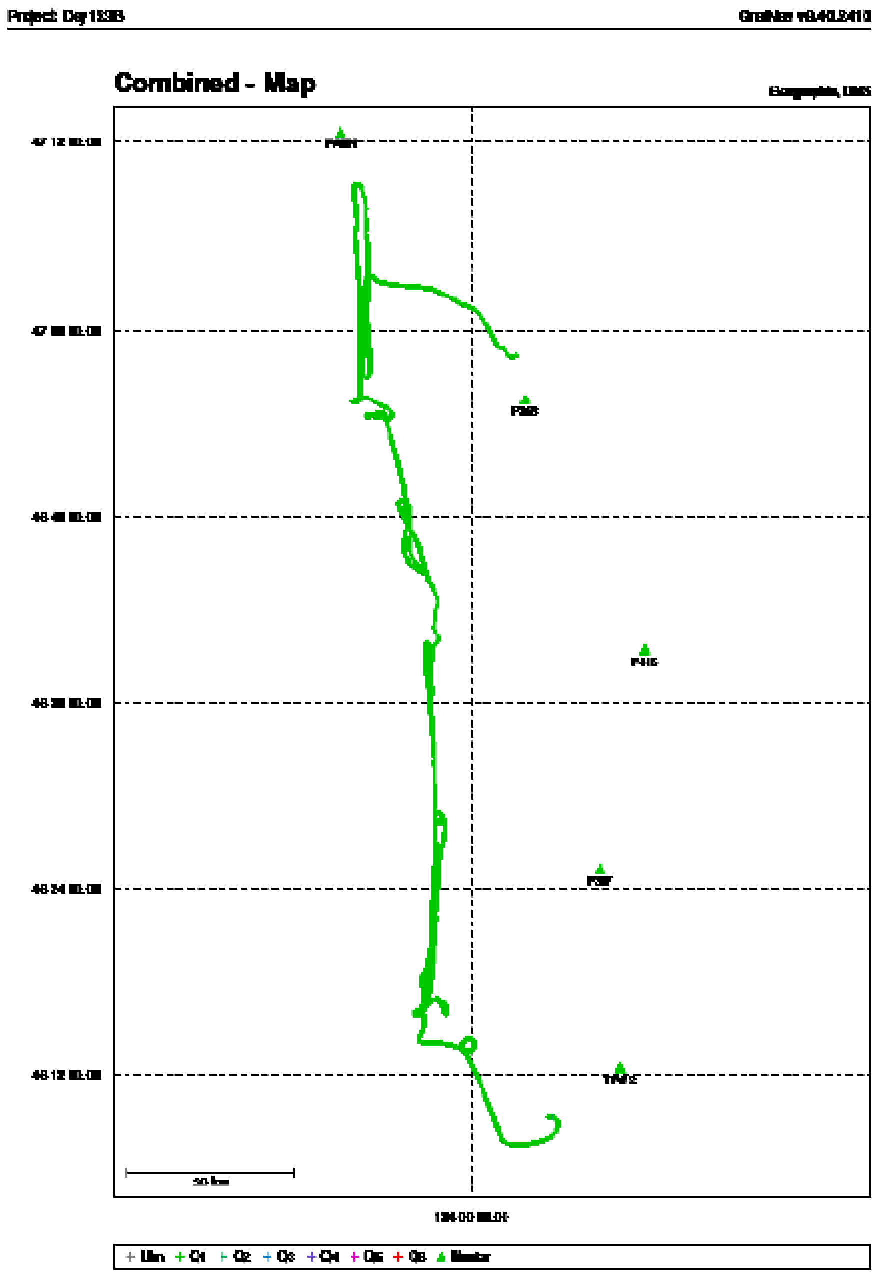

Day122c [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)
East
North
Up

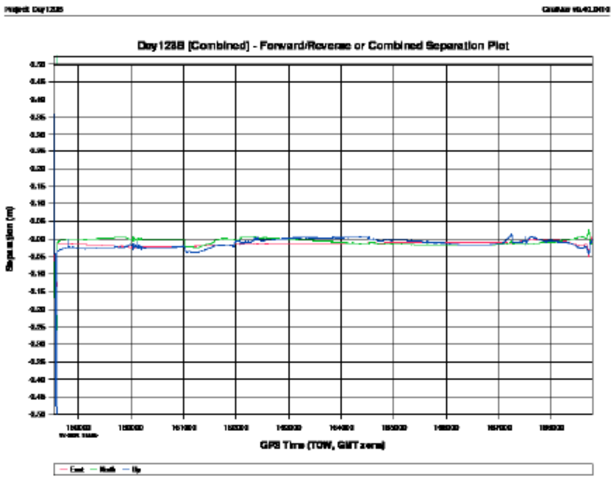

Day122c [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)
PDOP

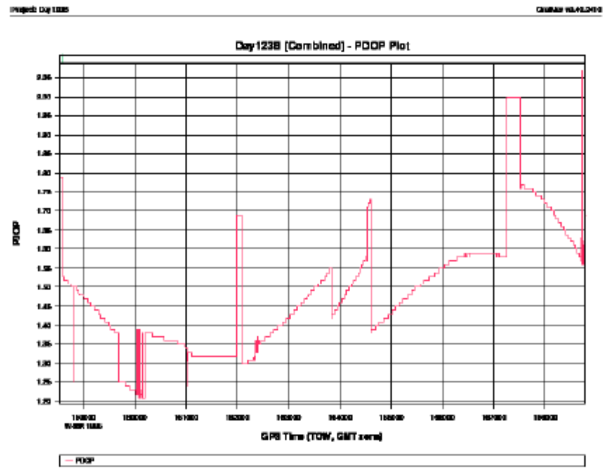

Combined - Map
Q1
Q2
Master

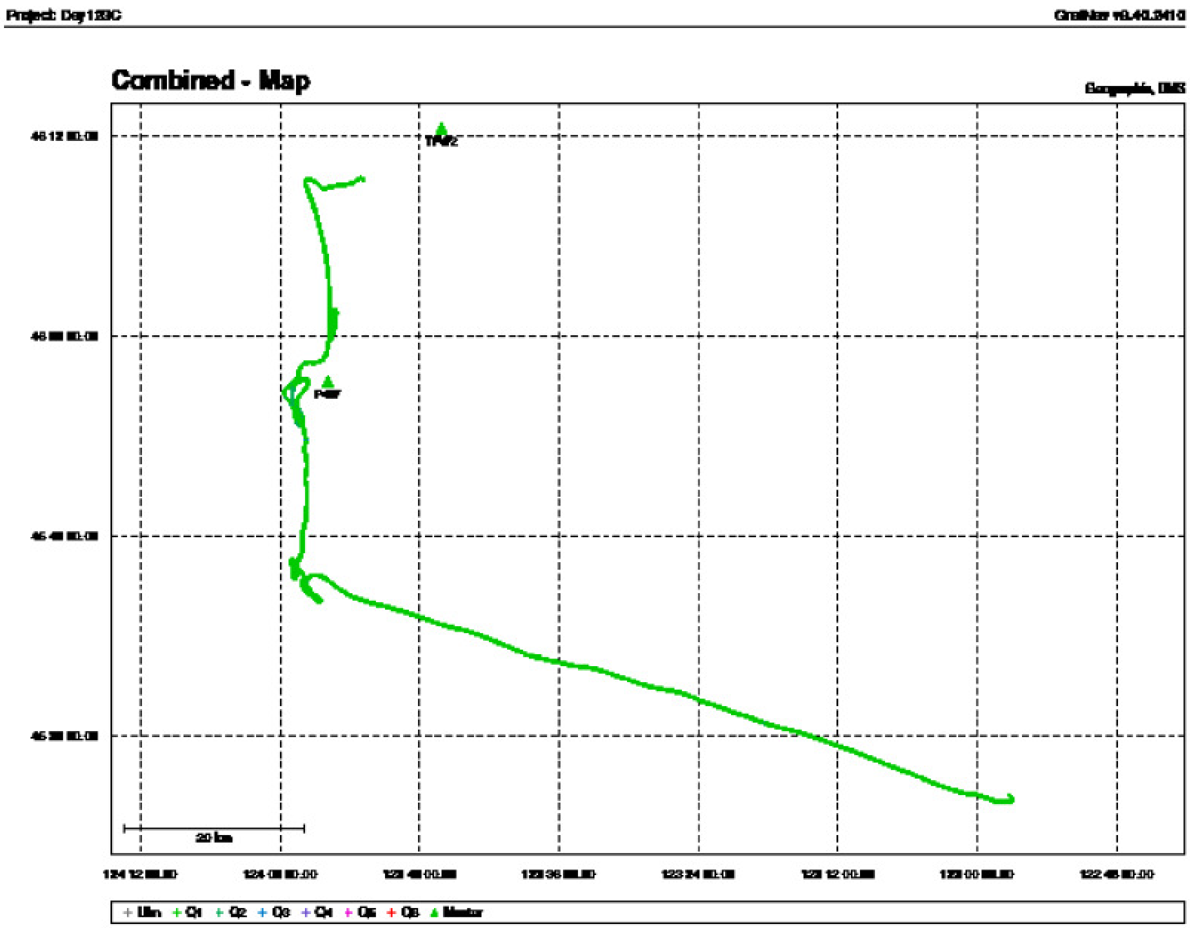

Day123A [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)

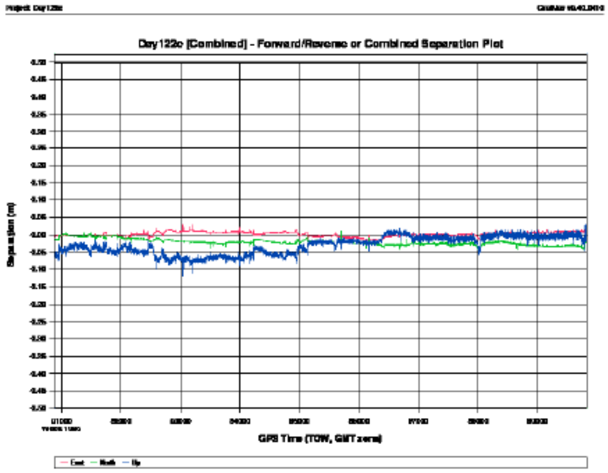

Day123A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

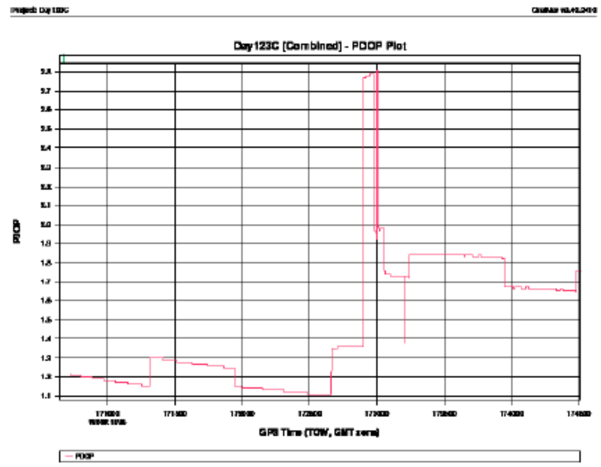

Combined - Map


Day123B (Combined) - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)


Day123B (Combined) - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

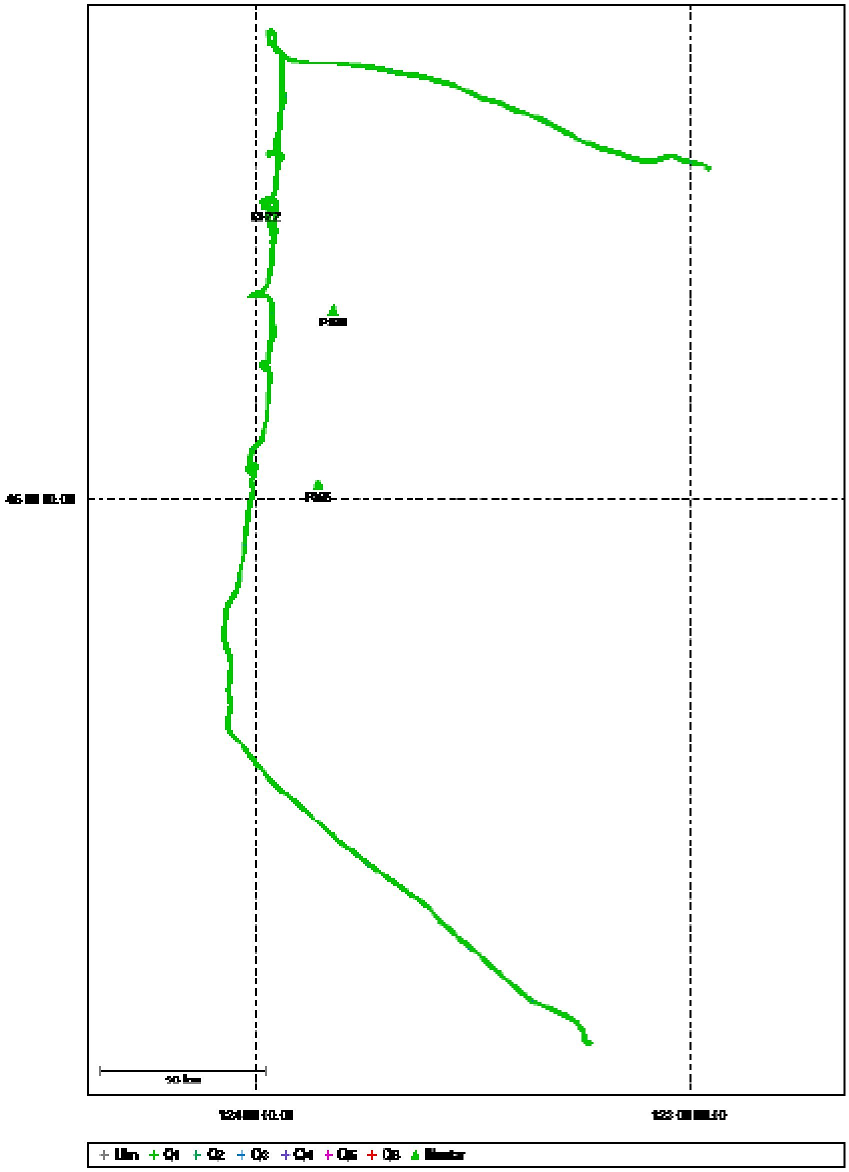

Project: Day123C
Combined - Map
20 km

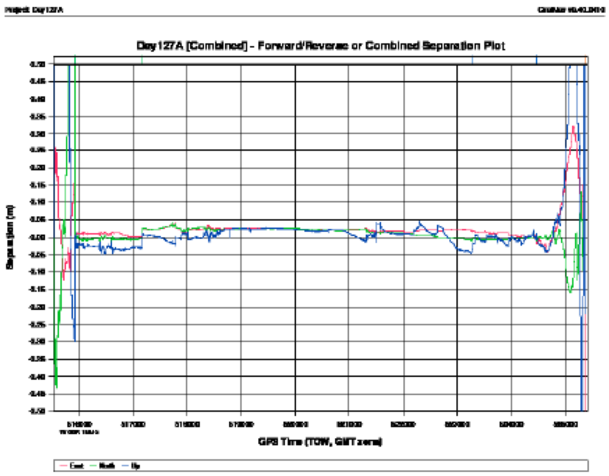

Day122c [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)
East
North
Up

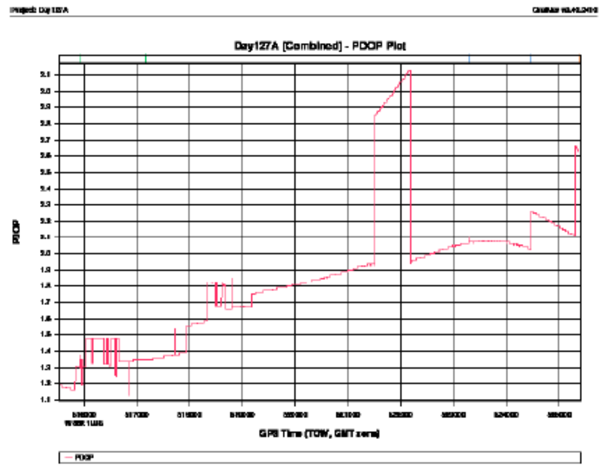

Day123C [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

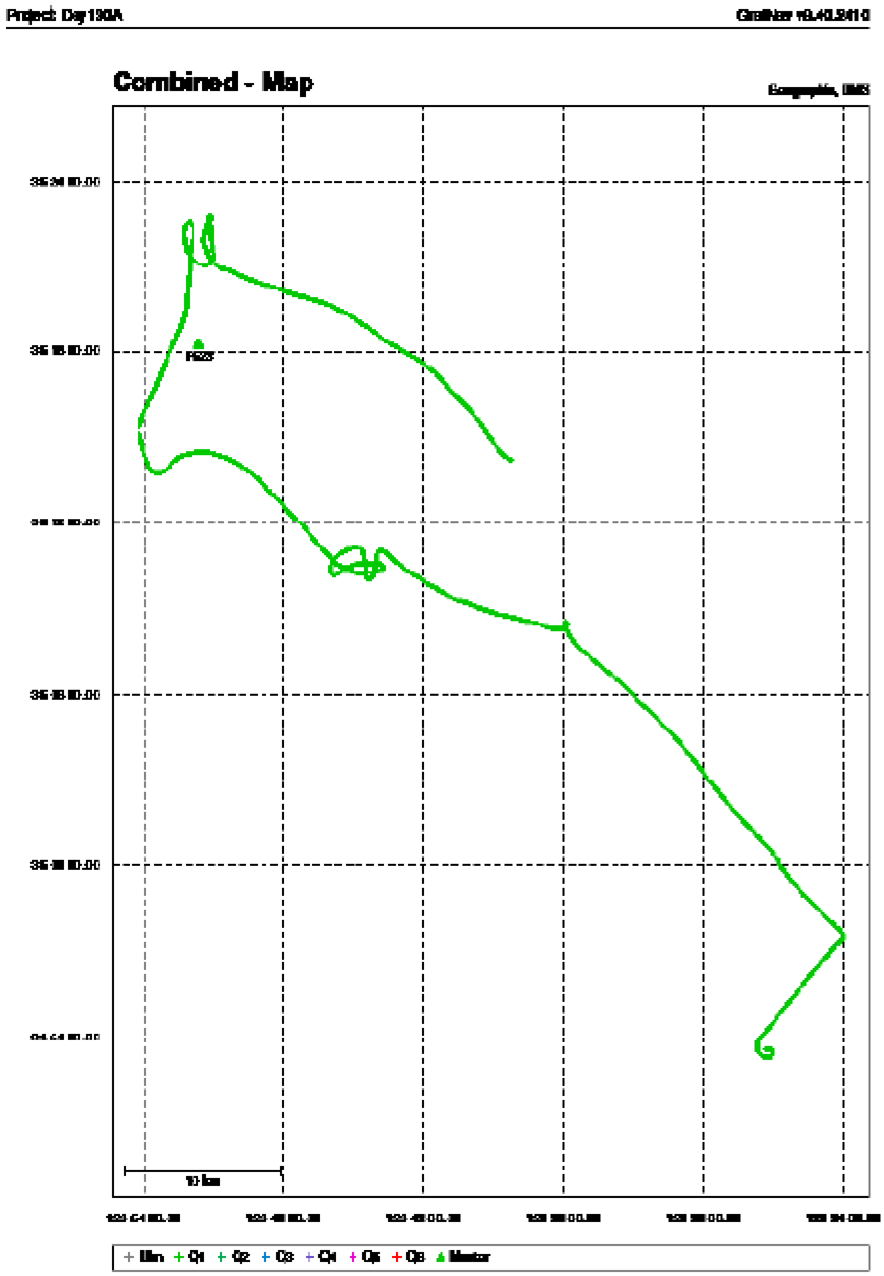
Project: Day127A

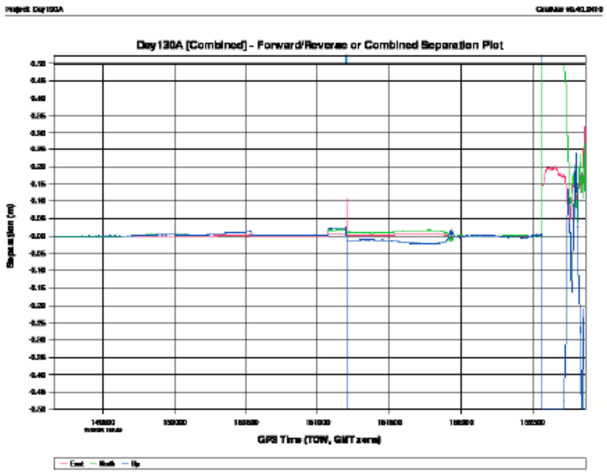
Combined - Map

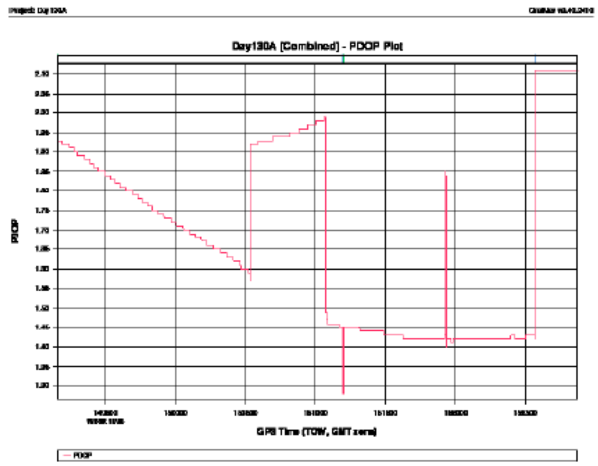


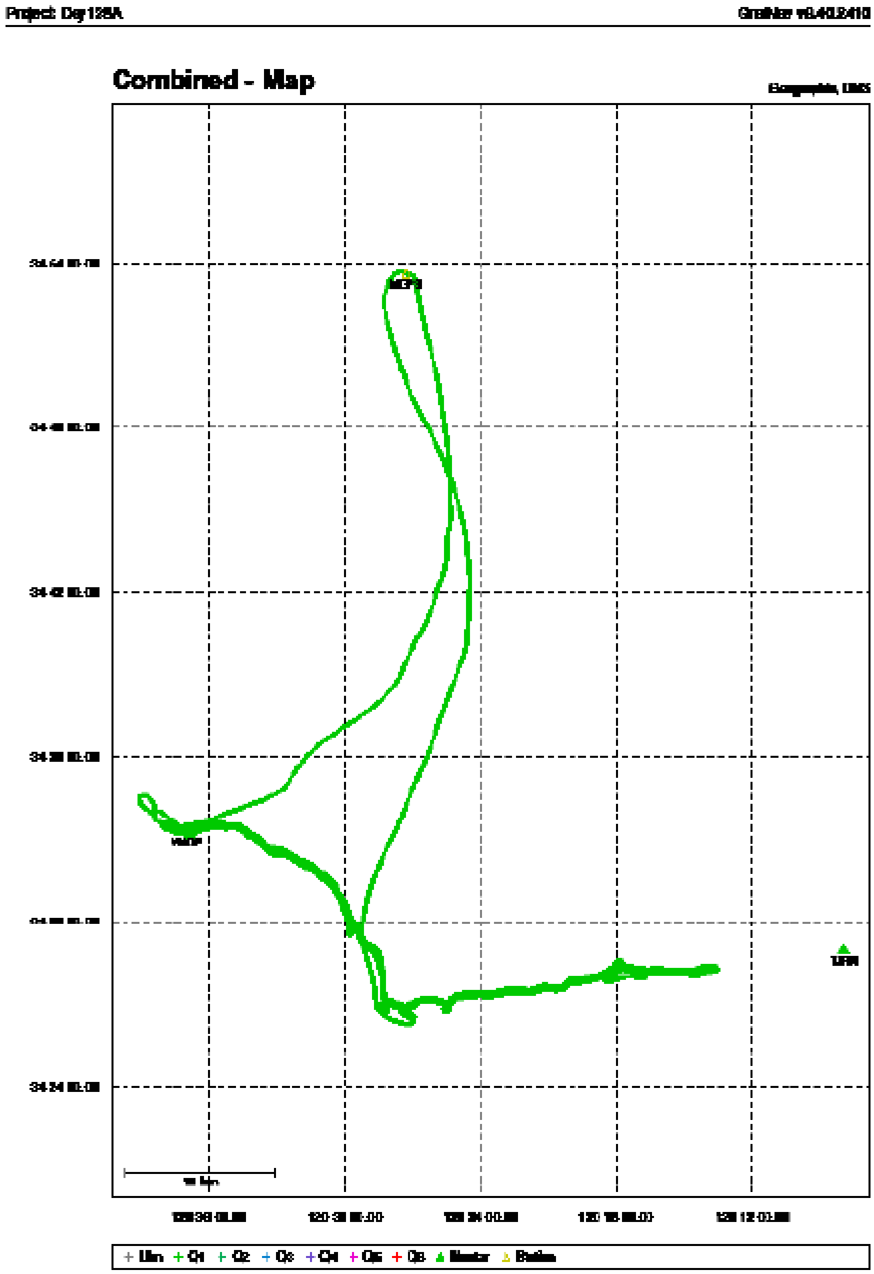

Day127A (Combined) - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)

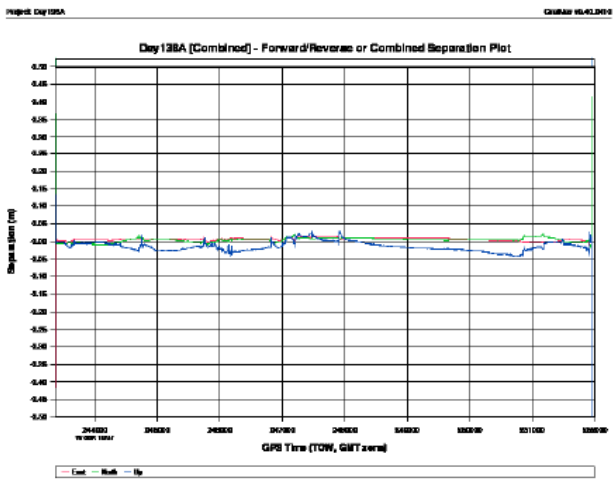

Day127A (Combined) - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

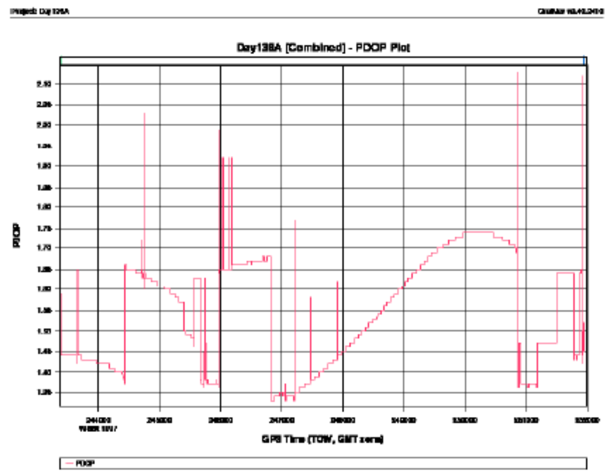

Combined - Map
10 km
Q1
Q2
Q3
Q4
Q5
Q6

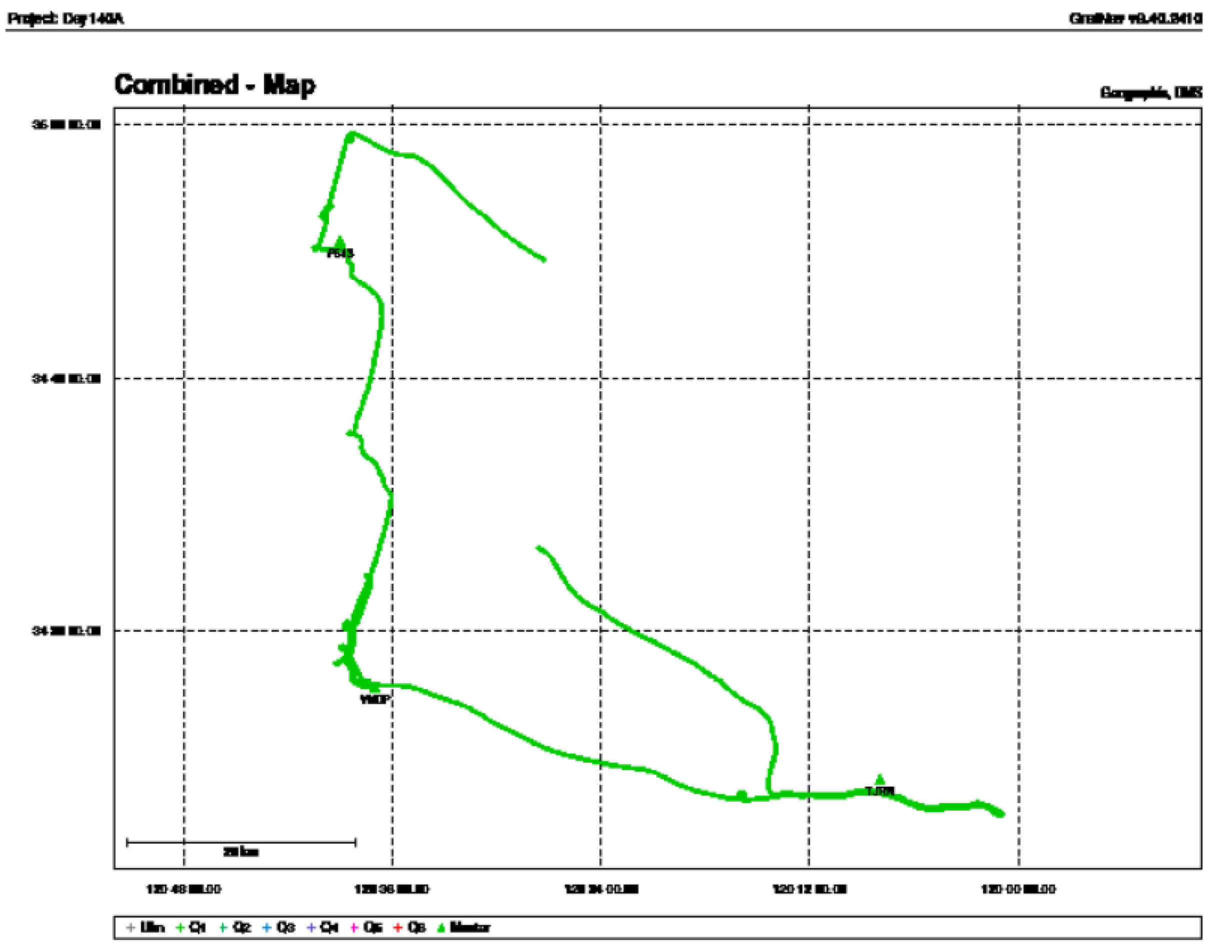

Day130A [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)

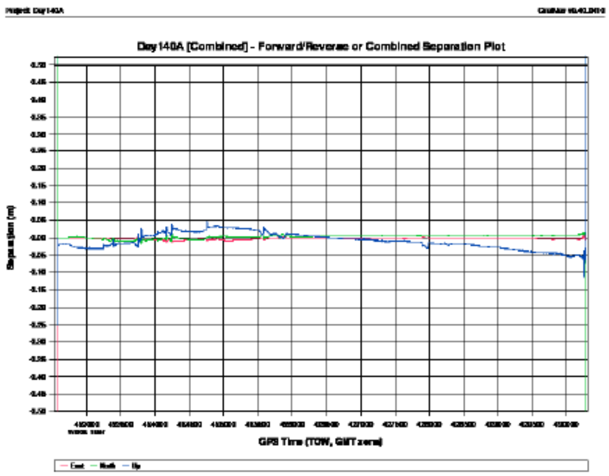

Day130A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

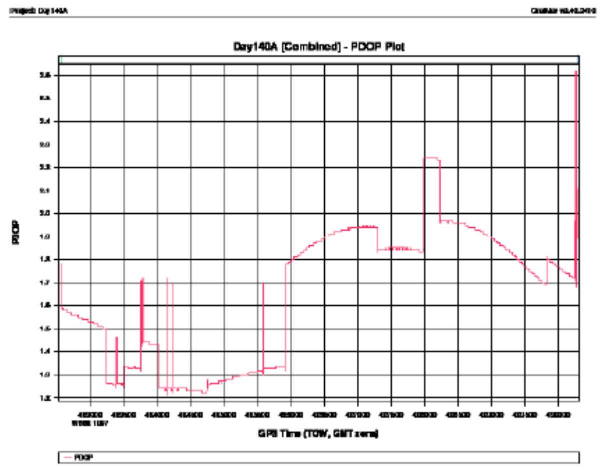

Combined - Map

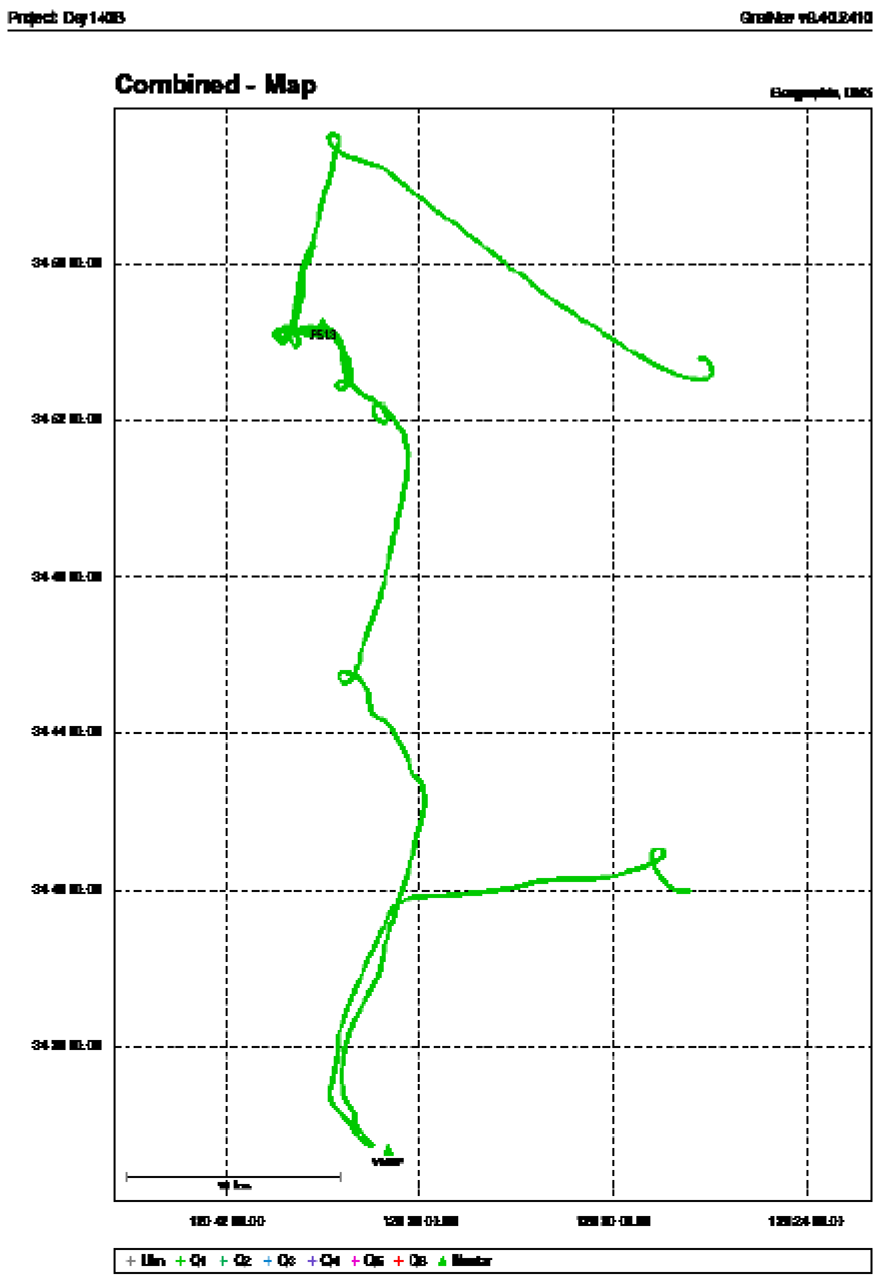

Day138A [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)

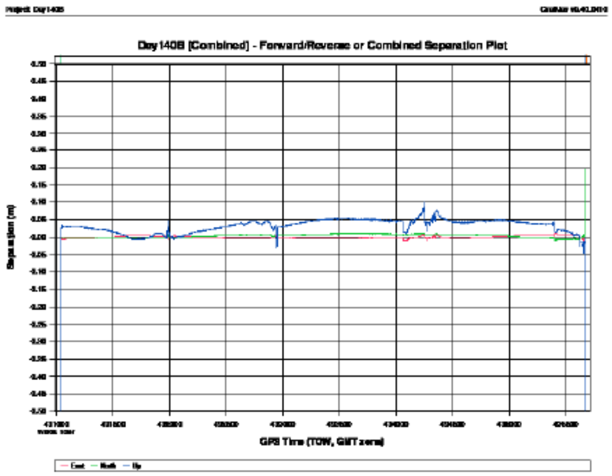

Day138A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

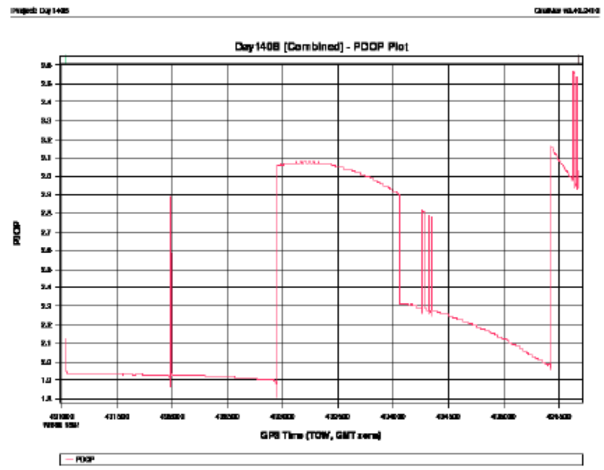

Project: Day 140A
GrafNav v8.40.2410
Combined - Map
Geographic, DMS
Master

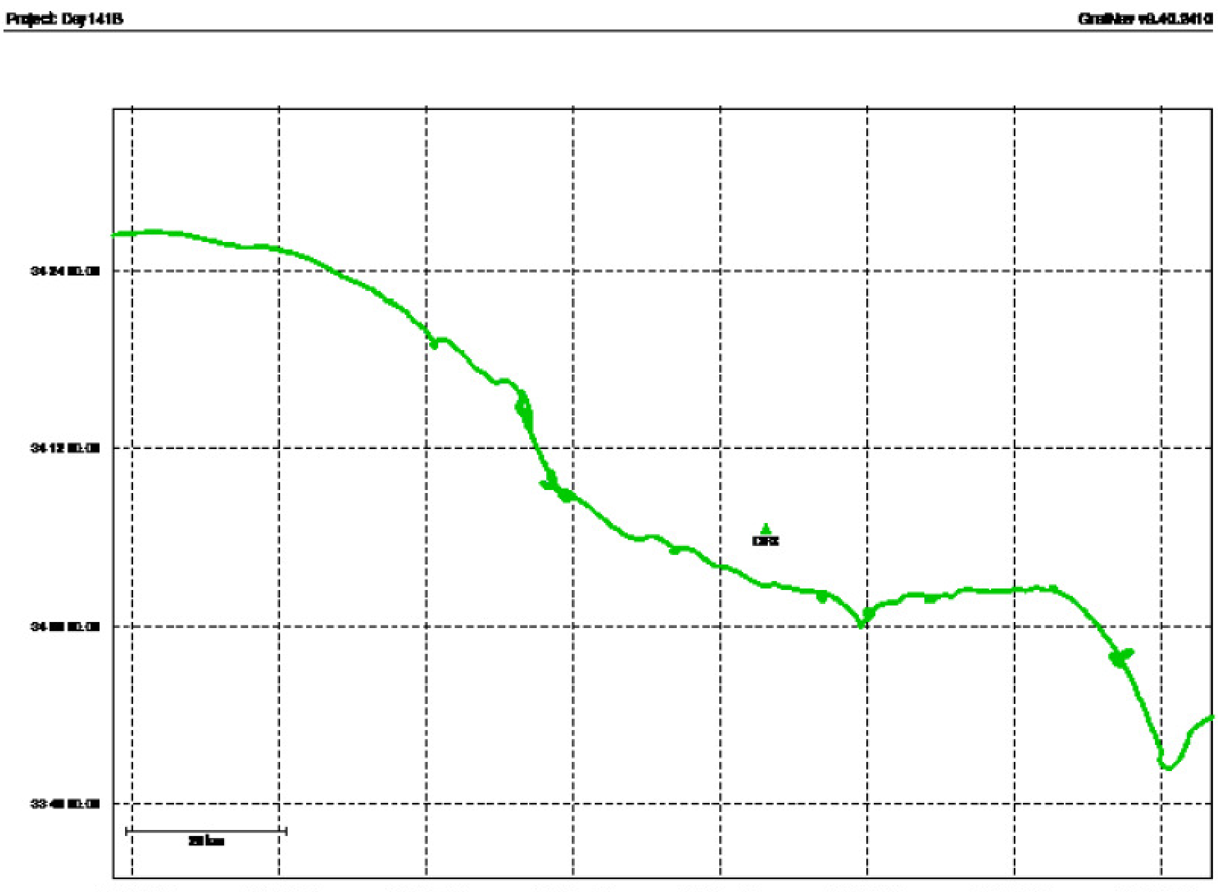

Day140A [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)
East
North
Up

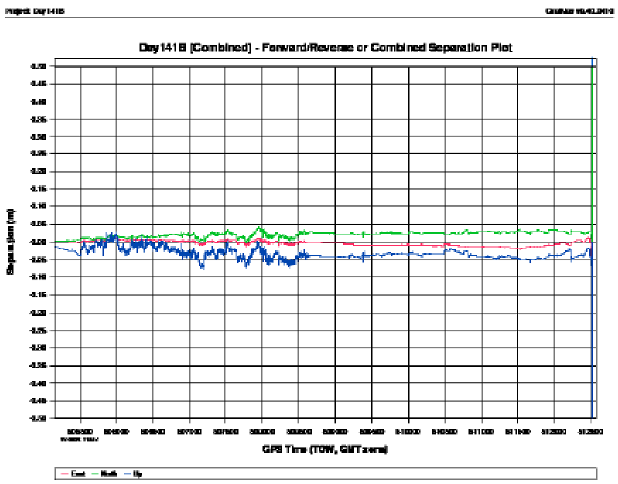

Day140A [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)
PDOP

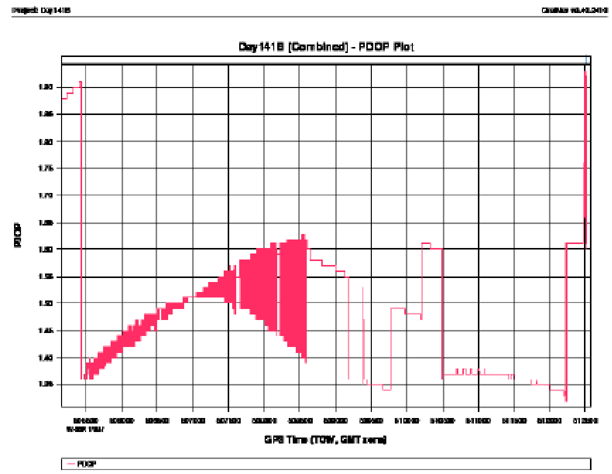

Combined - Map

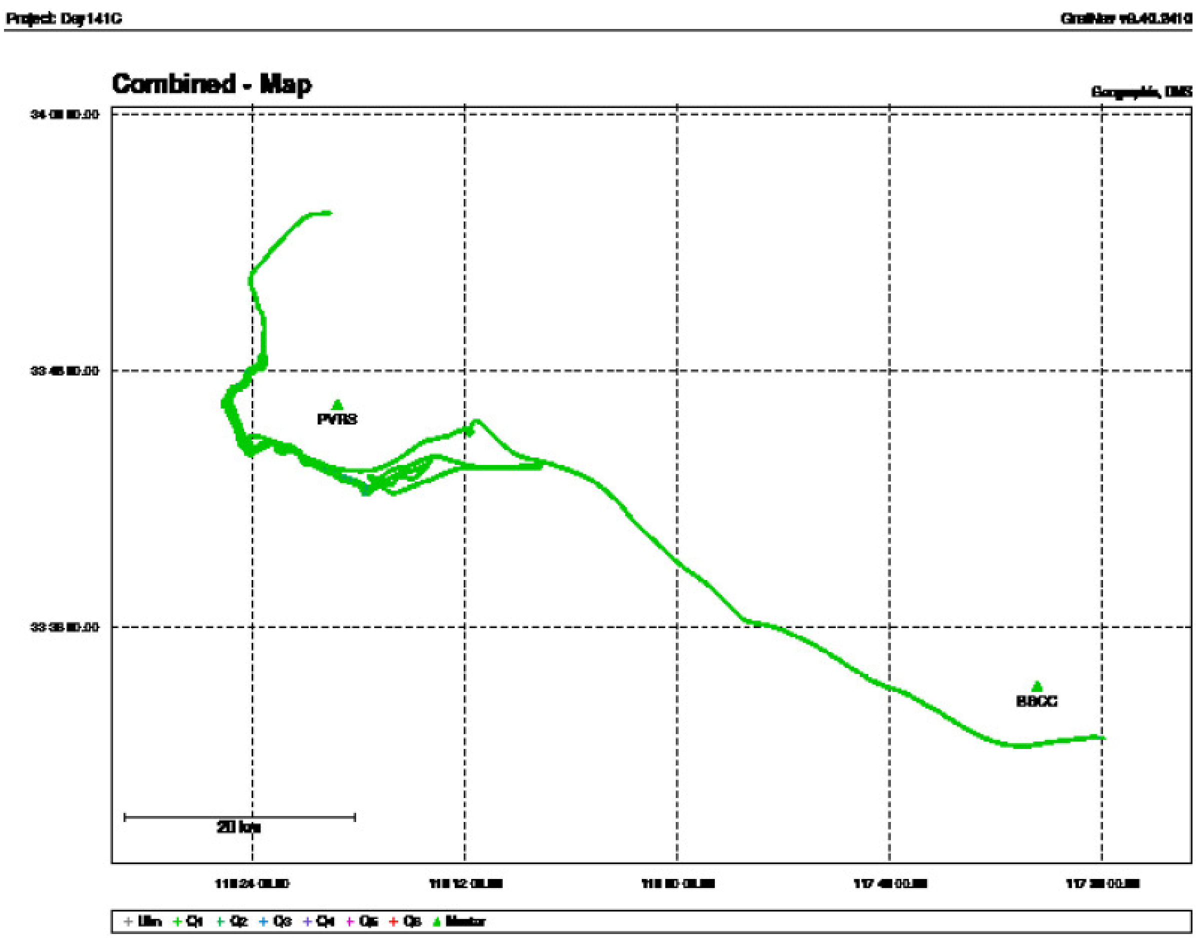

Day140B [Combined] - Forward/Reverse or Combined Separation Plot
GPS Time (TOW, GMT zero)

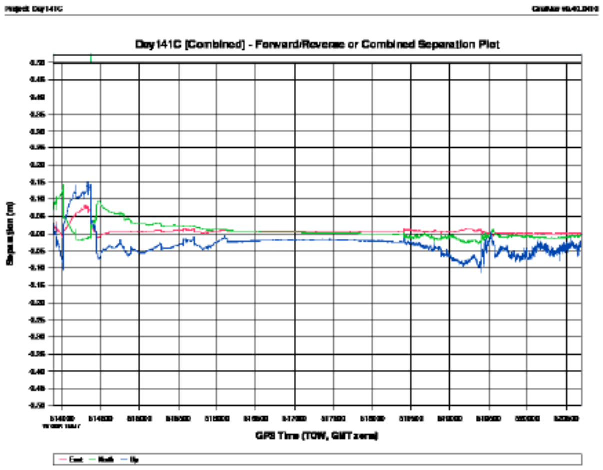

Day140B [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)

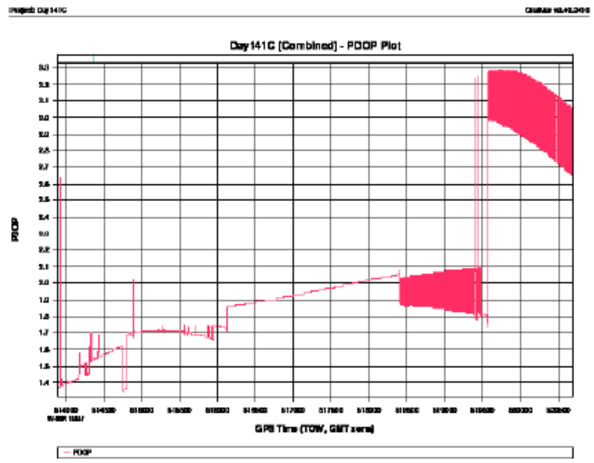

Project: Day141B


Day141B [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)


Day141B [Combined] - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)


Project: Day141C
Combined - Map
PVRS
BBCC
20 km


Day141C (Combined) - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zero)
East
North
Up


Day141C (Combined) - PDOP Plot
PDOP
GPS Time (TOW, GMT zero)
PDOP