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USGS/FEMA Region IX – Orange County, CA LiDAR

Report Produced for U.S. Geological Survey

USGS Contract: G10PC0013

Task Order: G12PD00039.

Report Date: 10/01/2012

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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 FEMA IX Orange County, California Project Area.

The LiDAR data were processed to a bare-earth digital terrain model (DTM). Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Data was formatted according to tiles with each tile covering an area of 1500m by 1500m. A total of 868 tiles were produced for the project encompassing an area of approximately 681 sq. miles.

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.

Dewberry's Steven A. Wood completed ground surveying for the project and delivered surveyed checkpoints. His task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the LiDAR-derived surface model. He also verified the GPS base station coordinates used during LiDAR data acquisition to ensure that the base station coordinates were accurate. Note that a separate Survey Report was created for this portion of the project.

Digital Mapping, Inc (DMI) completed LiDAR data acquisition and data calibration for the project area.

SURVEY AREA

The project area addressed by this report falls within the California counties of Los Angeles, Orange, Riverside, and San Bernardino.

DATE OF SURVEY

The LiDAR aerial acquisition was conducted from December 17, 2011 thru February 9, 2012.

DATUM REFERENCE

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 (NAD 83)
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 11
Units: Horizontal units are in meters, Vertical units are in meters.
Geiod Model: Geoid09 (Geoid 09 was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

For the FEMA IX Orange County, CA LiDAR Project, the tested $RMSE_z$ for checkpoints in open terrain equaled **0.10 m** compared with the 0.125 m specification; and the FVA computed using $RMSE_z$ x 1.9600 was equal to **0.19 m**, compared with the 0.245 m specification.

For the FEMA IX Orange County, CA LiDAR Project, the tested CVA computed using the 95^{th} percentile was equal to **0.17 m,** compared with the 0.363 m specification.

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 (8-bit gray scale, tiled, GeoTIFF format)
5. Breakline Data (File GDB)
6. Control & Accuracy Checkpoint Report & Points
7. Metadata
8. Project Report (Acquisition, Processing, QC)
9. Project Extents, Including a shapefile derived from the LiDAR Deliverable

PROJECT TILING FOOTPRINT

Eight hundred sixty-eight (868) tiles were delivered for the project. Each tile's extent is 1,500 meters by 1,500 meters.

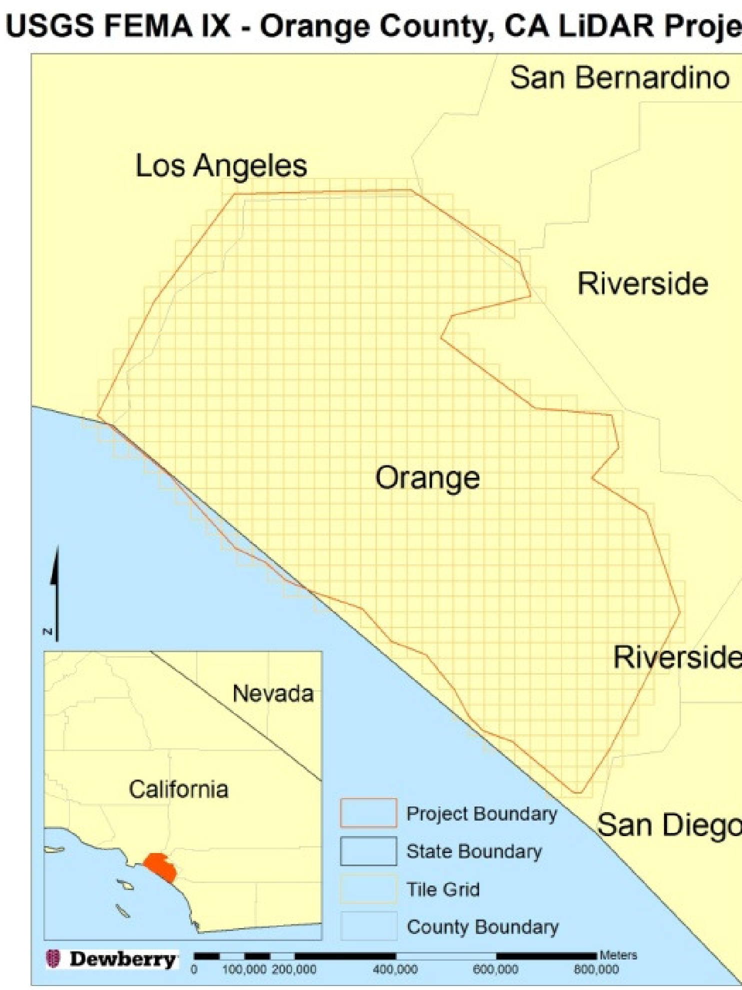

Figure 1: Project Map

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LiDAR Acquisition Report

SCOPE OF WORK

DMI acquired LiDAR data over an Area of Interest (AOI) entire of Orange County California. The acquisition plan entailed a nominal point spacing of 1.76 points per meter square and a side lap of 40% between flight lines. The AOI covers 696 square miles.

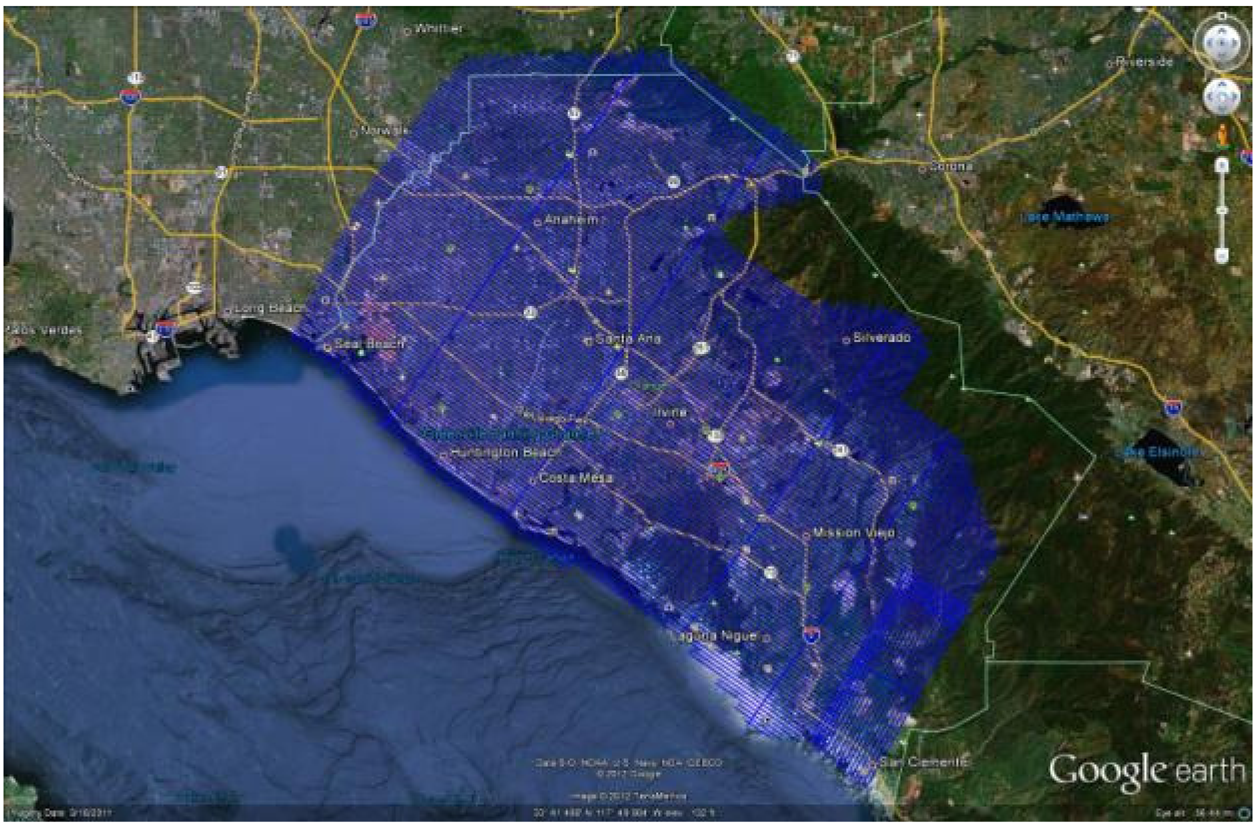


Fig. 1 Flight plan

LIDAR ACQUISITION DETAILS

Collections (Lifts): 14

Collection Dates: 2011 December 17, 20, 21, 23, 24, 26, 27, 28, 29, 30,

Field of View (FOV): 18 degrees

Average Point Density (planned): 0.75 m

Flight Level(s): 914 / 3000 m/ft

Sensor Type: Optech Gemini **Sensor Serial Number(s):** 07SEN204

All acquired LiDAR data was initially quality controlled after every mission for coverage and further verified for content and adherence to flight plan at DMI production facilities Huntington Beach, CA. All data was accepted for processing.

COLLECTION REPORT

A detailed report consisting of the GPS/IMU separation plots, trajectories, and flight information has been attached to this report in the form of attachment A. The full report has been separated from this section because of length and technical content.

SWATH ACCURACY RESULTS

Prior to additional processing, Dewberry tested the vertical accuracy of the open terrain swath data. The survey checkpoints were evenly distributed throughout the project area. There were two points with DeltaZ values greater than 10 cm. These points were not used to test the swath data due to the presence of nearby vegetation. These points will be included in the testing of the classified data. The DeltaZ values improve once the ground points are classified and the vegetation points have been removed. Dewberry tested the vertical accuracy of the swath data using the remaining nineteen open terrain control points. The vertical accuracy is tested by comparing survey checkpoints in open terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in open 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. Project specifications require a FVA of 0.245 m based on the $RMSE_z$ (0.125 m) x 1.96. The dataset for the FEMA IX Orange County, CA LiDAR Project satisfies the criteria. The raw LiDAR swath data tested 0.16 m vertical accuracy at 95% confidence level in open terrain, based on $RMSE_z$ (0.08m) x 1.9600.

LiDAR Processing & Qualitative Assessment

DATA CLASSIFICATION AND EDITING

LiDAR mass points were produced to LAS 1.2 specifications, including the following LAS classification codes:

- Class 1 = Unclassified, and used for all other features that do not fit into the Classes 2, 7, 9, 10, or 11, including vegetation, buildings, etc.
- Class 2 = Ground, includes accurate LiDAR points in overlapping flight lines
- Class 7 = Noise, low and high points
- Class 9 = Water, points located within collected breaklines
- Class 10 = Ignored Ground due to breakline proximity.
- Class 11 = Withheld, Points with scan angles exceeding +/- 20 degrees.

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 outliers in the dataset to class 7 and points with scan angles exceeding +/- 20 degrees to class 11. 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.

The following fields within the LAS files are populated to the following precision: GPS Time (0.000001 second precision), Easting (0.003 meter precision), Northing (0.003 meter precision), Elevation (0.003 meter precision), Intensity (integer value - 12 bit dynamic range), Number of Returns (integer - range of 1-4), Return number (integer range of 1-4), Scan Direction Flag (integer - range 0-1), Classification (integer), Scan Angle Rank (integer), Edge of flight line (integer, range 0-1), User bit field (integer - flight line information encoded). The LAS file also contains a Variable length record in the file header that defines the projection, datums, and units.

Once the initial ground routine has been performed on the data, Dewberry creates Delta Z (DZ) orthos to check the relative accuracy of the LiDAR data. These orthos compare the elevations of LiDAR points from overlapping flight lines on a 1 meter pixel cell size basis. If the elevations of points within each pixel are within 10 cm of each other, the pixel is colored green. If the elevations of points within each pixel are between 10 cm and 20 cm of each other, the pixel is colored yellow, and if the elevations of points within each pixel are greater than 20 cm in difference, the pixel is colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. DZ orthos can be created using the full point cloud or ground only points and are used to review and verify the calibration of the data is acceptable. Some areas are expected to show sections or portions of red, including terrain variations, slope changes, and vegetated areas or buildings if the full point cloud is used. However, 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. The DZ orthos for Orange County California showed that the data was calibrated correctly with no issues that would affect its usability. The figure below shows an example of the DZ orthos.

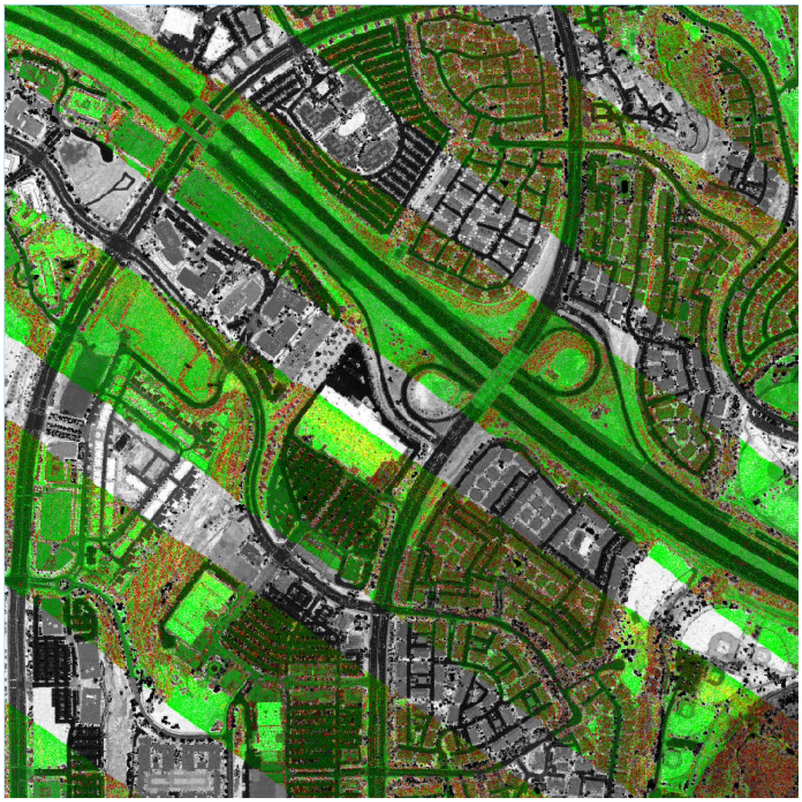


Figure 3: DZ orthos created from the full point cloud. Some red pixels are visible along embankments, sloped terrain, and in vegetated land cover, as expected. Open, flat areas are green indicating the calibration and relative accuracy of the data is acceptable.

Dewberry utilized a variety of software suites for data processing. The LAS dataset was received and imported into GeoCue task management software for processing in Terrascan. Each tile was 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. 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. The final classification routine applied to the dataset selects ground points within a specified distance of the water breaklines and classifies them as class 10, ignored ground due to breakline proximity.

QUALITATIVE ASSESSMENT

Dewberry's qualitative assessment utilizes a combination of statistical analysis and interpretative methodology to assess the quality of the data for a bare-earth digital terrain model (DTM). This process looks for anomalies in the data and also identifies areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model.

Within this review of the LiDAR data, two fundamental questions were addressed:

- Did the LiDAR system perform to specifications?
- Did the vegetation removal process yield desirable results for the intended bare-earth terrain product?

Mapping standards today address the quality of data by quantitative methods. If the data are tested and found to be within the desired accuracy standard, then the data set is typically accepted. Now with the proliferation of LiDAR, new issues arise due to the vast amount of data. Unlike photogrammetrically-derived DEMs where point spacing can be eight meters or more, LiDAR nominal point spacing for this project is 1 point per 1 square meters. The end result is that millions of elevation points are measured to a level of accuracy previously unseen for traditional elevation mapping technologies and vegetated areas are measured that would be nearly impossible to survey by other means. The downside is that with millions of points, the dataset is statistically bound to have some errors both in the measurement process and in the artifact removal process.

As previously stated, the quantitative analysis addresses the quality of the data based on absolute accuracy. This accuracy is directly tied to the comparison of the discreet measurement of the survey checkpoints and 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 with DZ orthos. Once the absolute and relative accuracy has been ascertained, the next stage is to address the cleanliness of the data for a bare-earth DTM.

By using survey checkpoints to compare the data, the absolute accuracy is verified, but this also allows us to understand if the artifact removal process was performed correctly. To reiterate the quantitative approach, if the LiDAR sensor operated correctly over open terrain areas, then it most likely operated correctly over the vegetated areas. This does not mean that the entire bare-earth was measured; only that the elevations surveyed are most likely accurate (including elevations of treetops, rooftops, etc.). In the event that the LiDAR pulse filtered through the vegetation and was able to measure the true surface (as well as measurements on the surrounding vegetation) then the level of accuracy of the vegetation removal process can be tested as a by-product.

To fully address the data for overall accuracy and quality, the level of cleanliness (or removal of above-ground artifacts) is paramount. Since there are currently no effective automated testing procedures to measure cleanliness, Dewberry employs a combination of statistical and visualization processes. 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. By creating multiple images and using overlay techniques, not only can potential errors be found, but Dewberry can also find where the data meets and exceeds expectations. This report will present representative examples where the LiDAR and post processing had issues as well as examples of where the LiDAR performed well.

ANALYSIS

Dewberry utilizes GeoCue software as the primary geospatial process management system. GeoCue is a three tier, multi-user architecture that uses .NET technology from Microsoft. .NET technology provides the real-time notification system that updates users with real-time project status, regardless of who makes changes to project entities. GeoCue uses database technology for sorting project metadata. Dewberry uses Microsoft SQL Server as the database of choice. Specific analysis is conducted in Terrascan and QT Modeler environments.

Following the completion of LiDAR point classification, the Dewberry qualitative assessment process flow for the USGS FEMA IX – Orange County, CA LiDAR project incorporated the following reviews:

1. *Format:* The LAS files are verified to meet project specifications. The LAS files for the USGS FEMA IX – Orange County, CA LiDAR project conform to the specifications outlined below.

- Format, Echos, Intensity
    - LAS format 1.2
    - Point data record format 1
    - Multiple returns (echos) per pulse
    - Intensity values populated for each point
- ASPRS classification scheme
    - Class 1 – unclassified
    - Class 2 – Bare-earth ground
    - Class 7 – Noise
    - Class 9 – Water
    - Class 10 – Ignored Ground due to breakline proximity
    - Class 11 – Withheld due to scan angles exceeding +/- 20 degrees
- Projection
    - Datum – North American Datum 1983
    - Projected Coordinate System – UTM Zone 11
    - Units – Meters
    - Vertical Datum – North American Vertical Datum 1988, Geoid 09
    - Vertical Units - Meters
- LAS header information:
    - Class (Integer)
    - GPS Week Time (0.0001 seconds)
    - Easting (0.003 meters)
    - Northing (0.003 meters)
    - Elevation (0.003 meters)
    - Echo Number (Integer 1 to 4)
    - Echo (Integer 1 to 4)
    - Intensity (8 bit integer)

- Flight Line (Integer)
- Scan Angle (Integer degree)

2. *Data density, data voids:* The LAS files are used to produce Digital Elevation Models using the commercial software package "QT Modeler" 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. For the USGS FEMA IX – Orange County, CA LiDAR project it is stipulated that the minimum post spacing in un-obscured areas should be 1 point per 1 square meter.

    a. 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. These are considered to be acceptable voids.

Bare earth quality: Dewberry reviewed the cleanliness of the bare earth to ensure the ground has correct definition, meets the project requirements, there is correct classification of points, and there are less than 5% residual artifacts.

a. *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.

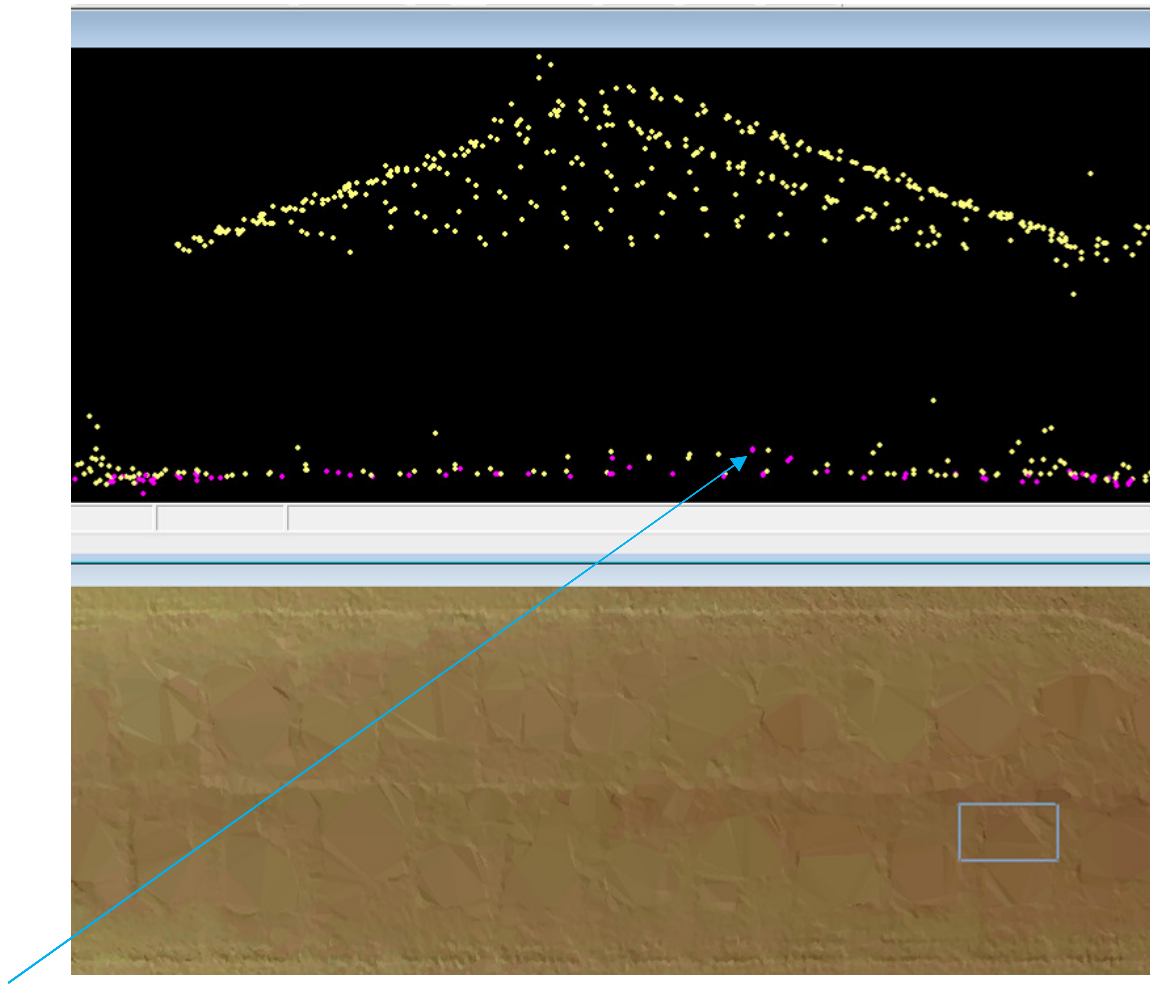


Figure 4 – Tile number 11SMT111465. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground.

b. *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 triangulate across a bridge opening from legitimate ground points on either side of the actual bridge. This can cause visual artifacts or "saddles." These "artifacts" are only visual and do not exist in the LiDAR points or breaklines.

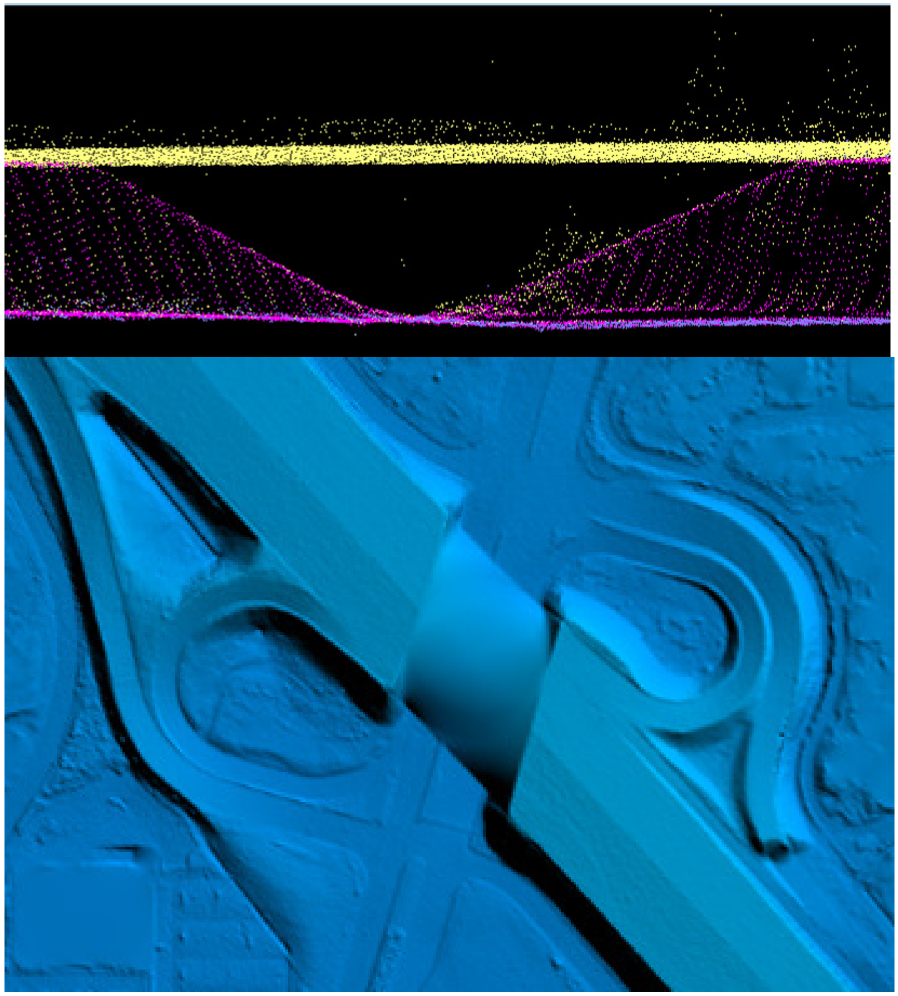


Figure 5 – Tile number 11SMT171390. The DEM in the bottom view shows a visual artifact because the surface model is interpolating from the slope leading to the bridge to the lower ground points on either side of the bridge points that were removed. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This can cause visual artifacts when there are features with large elevation differences. 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 (pink) and are unclassified (yellow). There are no ground points that can be modified to correct this visual artifact.

c. *Building Removal Artifacts:* Large buildings, unique construction, and buildings built on sloped terrain or built into the ground can make a noticeable impact on the bare earth DEM once they have been removed, often in the form of large void areas with obvious triangulation or interpolation across the area and general lack of detail in the ground where the structure stood. In a few areas, this interpolation has resulted in visual artifacts within building footprints. These "artifacts" are only visual and do not exist in the LiDAR points.

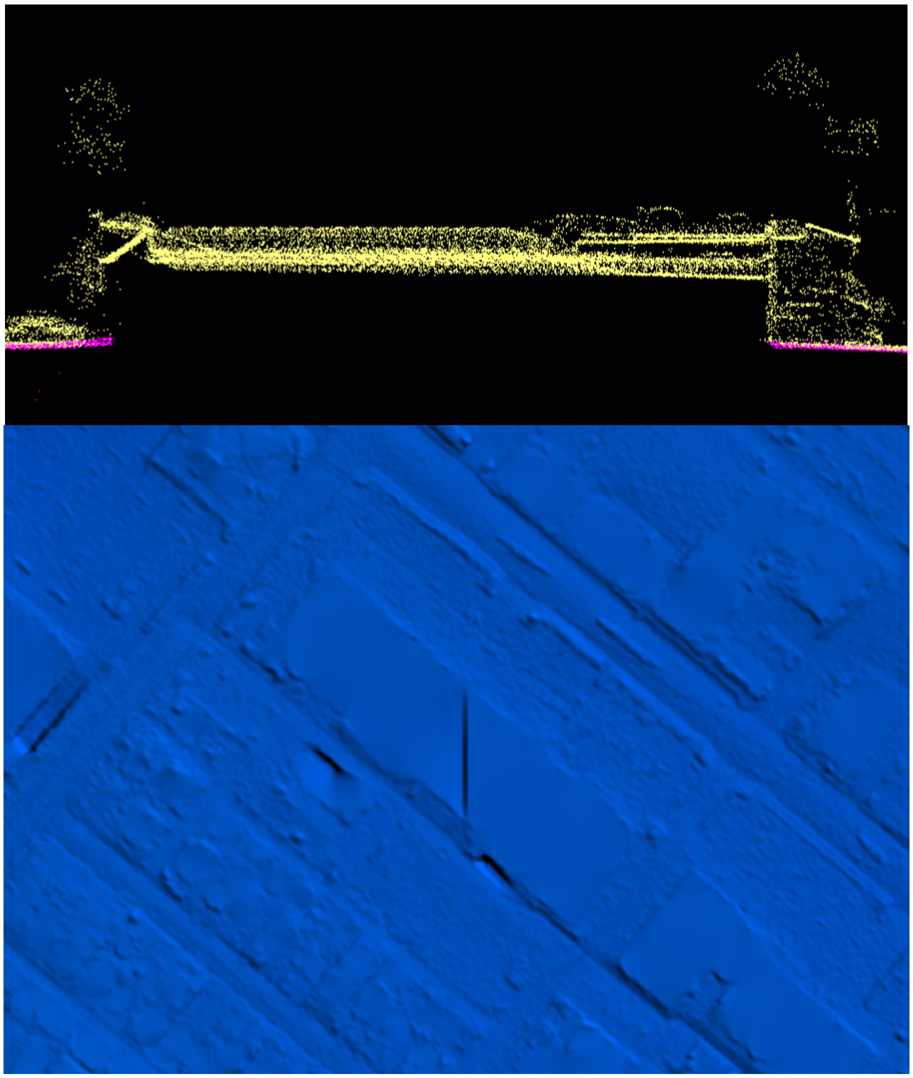


Figure 6 – Tile number 11SMT141210. The DEM in the bottom view shows a visual artifact because the surface model is interpolating between the available ground points on either side of the building points that were removed. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This can cause visual artifacts in areas where the ground elevation is slightly lower on one side of building than the other. The profile in the top view shows the LiDAR points of this particular feature colored by class. All building points have been removed from ground (pink) and are unclassified (yellow) or classified as noise (red). There are no ground points that can be modified to correct this visual artifact.

d. *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. There were also several large structures throughout the project area that Dewberry determined to be box culverts. Below is an example of a culvert that has been left in the ground surface.

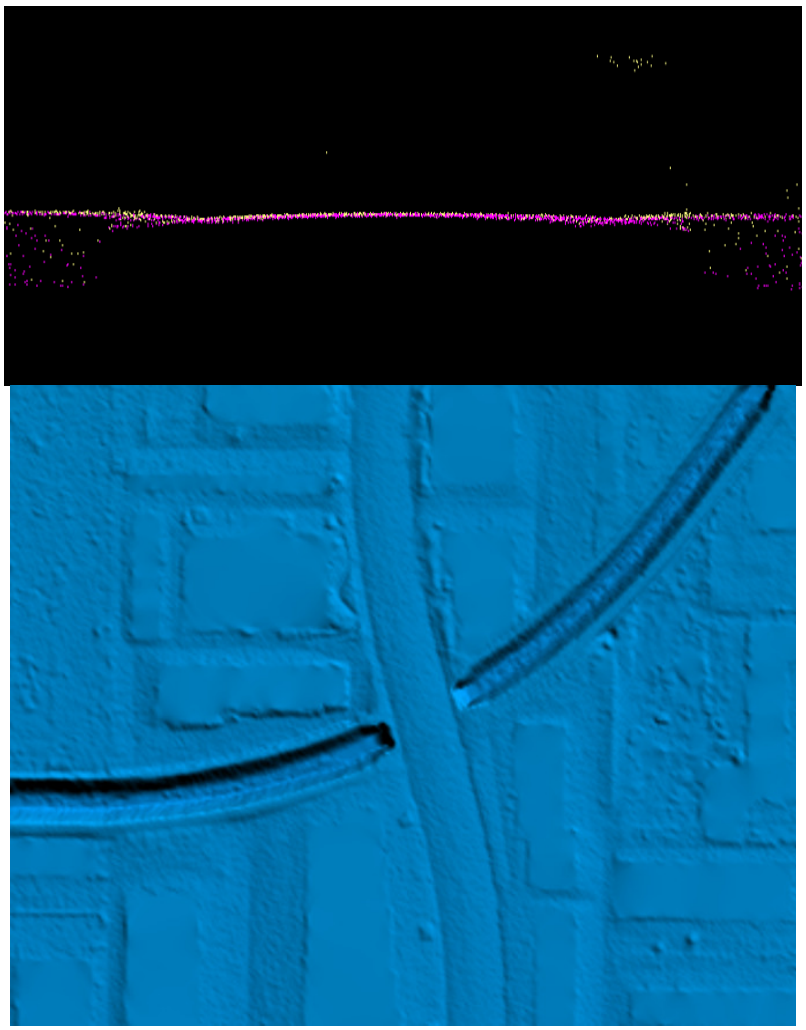


Figure 7– Tile number 11SMT186405. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 1.

e. *Concrete Railroad Tunnel:* Tunnels are generally included in the final ground model. An odd shaped precast concrete railroad tunnel that occurs within the project area is shown below.

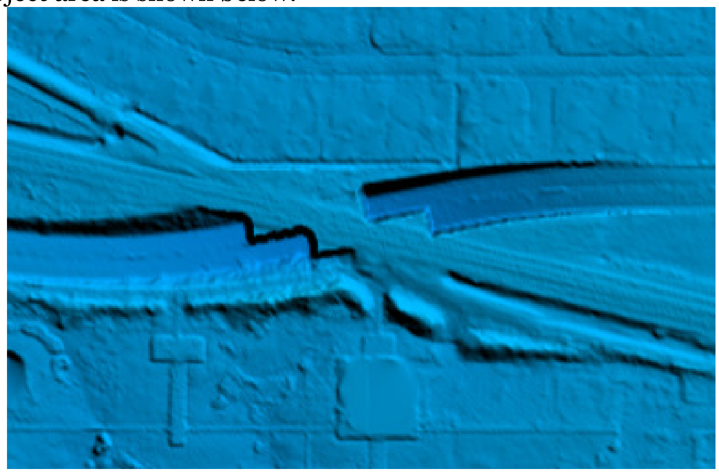


Figure 8– Tile number 11SMT111480. The tunnel shown in the above DEM, remains in the bare earth surface.

f. *In Ground Bunkers:* In ground structures exist within the project area. These occur mainly on military bases. These features are correctly included in the ground classification.

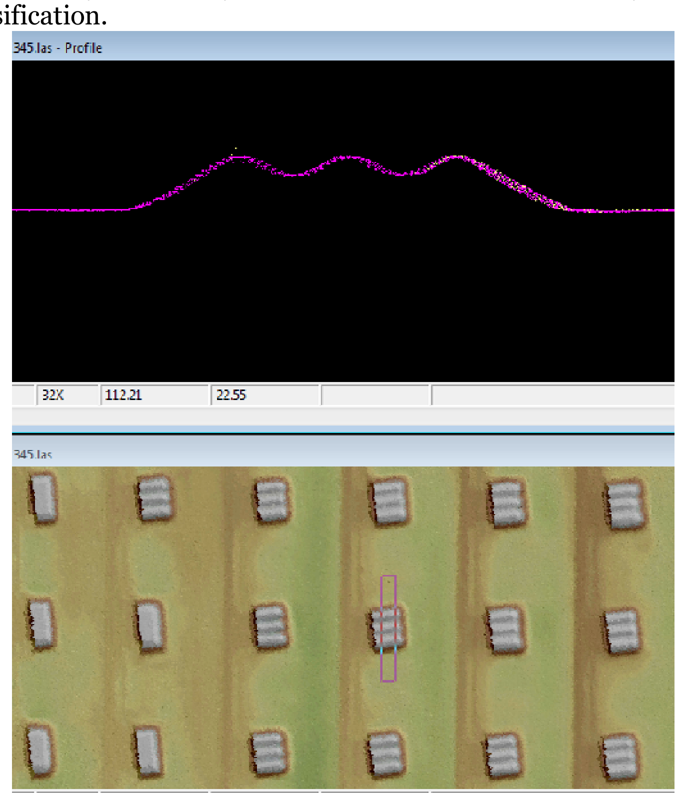


Figure 9 – Tile number 11SMT021345. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a TIN of the surface is shown in the bottom view. In ground military structures have been included in the ground classification.

g. *Elevation Change Within Breaklines:* While water bodies are flattened in the final DEMs, other features such as linear hydrographic features and tidal waters can have significant changes in elevation within a small distance. In linear hydrographic features, this is often due to the presence of a structure that affects flow such as a dam or spillway. Sudden changes in elevation occur naturally in tidally influenced areas which are present within the project area. Dewberry has gone through the DEMs making sure that changes in elevation are shown from bank to bank. These changes are often shown as steps to reduce the presence of artifacts while ensuring consistent downhill flow. Examples of elevation change due to a structure and within a tidally influenced area are shown below.

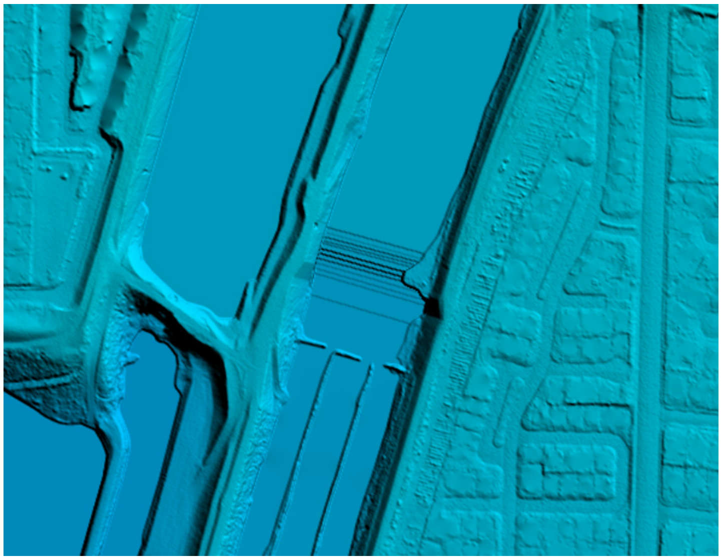


Figure 10 – Tile number 11SMT186435. Elevation change due to the structure has been stair stepped. The steps are straight across from bank to bank and flow consistently downhill.

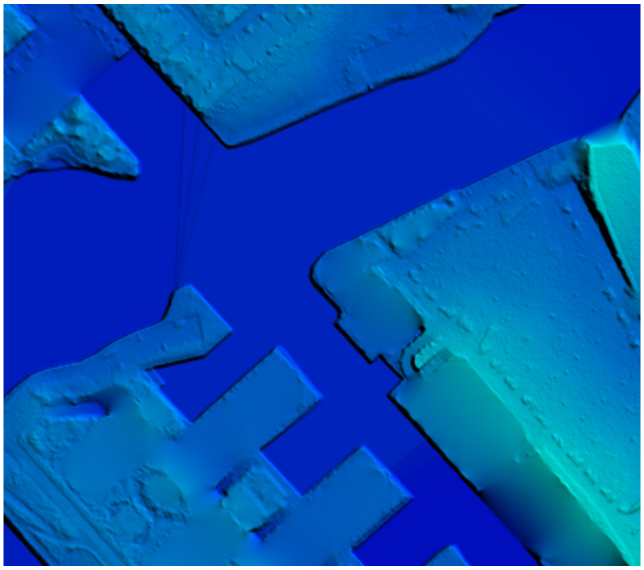


Figure 11 – Tile number 11SLT961360. Sudden changes in elevation within the tidally influenced breaklines have been stair stepped. The steps flow consistently downhill.

h. *Flightline Ridges:* Ridges occur when there is a difference between the elevations of adjoining flightlines or swaths. Some flightline ridges are visible in the final DEMs but they do not exceed the project specifications and the overall relative accuracy requirements for the project area have been met. An example of a visible ridge that is within tolerance is shown below.

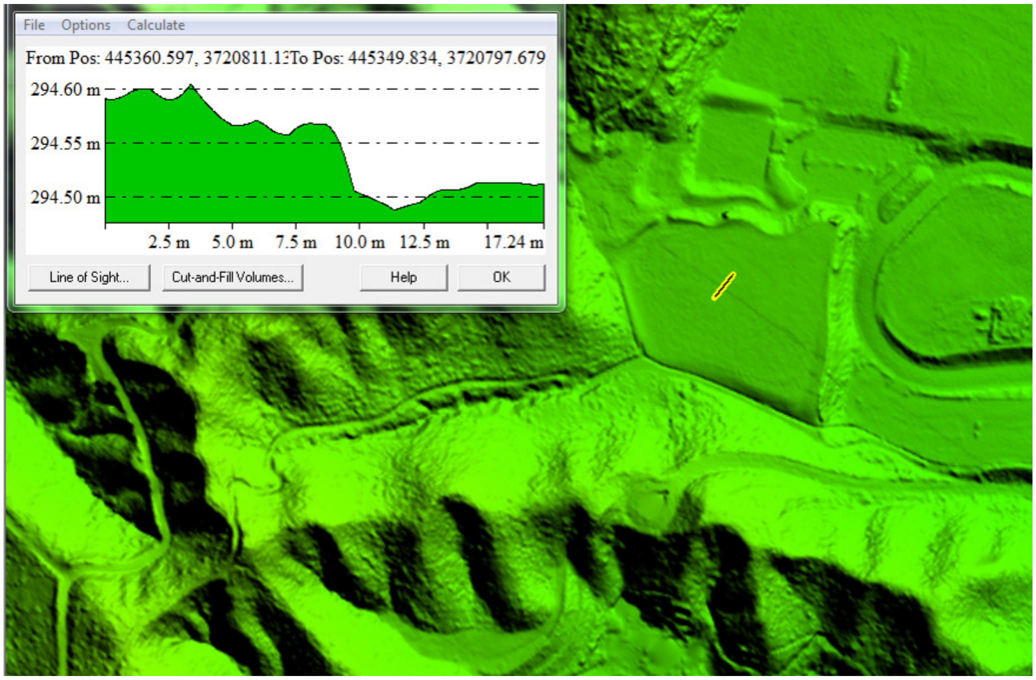


Figure 12 – Tile number 11SMT441195. The flight line ridge is less than 10 cm. Overall, the Orange County LiDAR data meets the project specifications for 10 cm RMSE relative accuracy.

CONCLUSION

The dataset conforms to project specifications for format and header values. The spatial projection information and classification of points is correct. Minor artifacts and small areas of misclassification are isolated and have minimal impact on the usability of the dataset.

Survey Vertical Accuracy Checkpoints

PT. #	EASTING	NORTHING	ELEVS.
	UTM North Zone 11		
POINT ID	**EASTING (M)**	**NORTHING (M)**	**ELEVATION (M)**
Or100_OT13	438012.729	3724661.839	221.174
Or13_OT10	426275.573	3735038.027	54.597
Or18_OT04	424644.543	3740376.689	93.865
Or22_OT11	417088.376	3730138.572	10.467
Or23_OT03	414401.835	3727697.854	12.092
Or28_OT02	405913.505	3728762.660	22.067
Or38_OT05	428144.121	3750220.401	169.177
Or43_OT09	413230.692	3747828.908	41.570
Or47_OT06	417474.859	3751257.435	137.653
Or55_OT01	407885.234	3734301.461	11.476
Or60_OT17	425207.757	3721997.253	91.421
Or61_OT22	446108.639	3734510.662	567.901
Or72_OT12	432080.668	3717316.683	190.207
Or75_OT16	445930.258	3709083.385	89.874
Or76_OT15	442323.009	3708812.603	53.261
Or79_OT07	405702.177	3739859.248	13.319
Or80_OT08	404094.319	3746020.215	14.632
Or87_OT19	434670.780	3706420.686	80.906
Or88_OT20	438963.202	3703614.154	97.036
Or91_OT18	429696.446	3720929.317	122.821
Or95_OT14	436148.223	3720575.444	124.737
Or03_B16	417186.773	3719657.949	20.642
Or06_B17	420335.305	3722229.509	30.432
Or101_B21	443533.876	3703411.049	133.315
Or12_B09	425556.625	3729116.119	17.791
Or15_B10	429253.540	3735551.163	101.830
Or17_B04	428164.414	3742582.899	139.752
Or24_B03	412926.323	3725246.850	23.566
Or26_B02	408577.584	3727018.991	16.061
Or29_B01	403778.953	3735141.169	6.275
Or36_B05	425462.436	3754121.327	227.818
Or42_B08	414552.187	3751051.455	87.258
Or44_B07	409942.117	3751030.965	95.168
Or45_B06	408867.848	3748347.427	26.008
Or62_B11	437774.844	3734522.633	307.028
Or63_B12	440641.768	3729195.902	419.832
Or65_B13	444638.023	3724027.225	288.333
Or73_B19	434444.280	3711455.974	65.234
Or82_B15	442722.854	3722284.418	256.239
Or83_B14	445003.482	3721623.581	295.417

Or89_B20	441587.895	3704515.424	73.740
Or93_B16	438805.228	3721997.928	210.623
Or96_B18	427338.383	3724083.628	58.231
Or05_F13	416521.375	3722953.070	26.592
Or19_F10	421855.612	3736582.602	55.953
Or20_F12	416906.251	3733122.349	19.937
Or21_F04	412665.469	3732620.855	15.587
Or25_F03	409892.555	3724186.045	2.141
Or32_F07	407739.403	3742788.274	21.816
Or33_F07	407055.999	3751844.146	55.837
Or34_F08	412432.847	3756075.110	124.401
Or35_F05	422537.849	3753600.315	129.710
Or49_F06	422515.967	3744593.874	99.515
Or53_F01	416045.915	3738186.776	34.934
Or54_F02	410443.187	3736184.793	18.679
Or56_F11	428948.113	3730494.298	53.647
Or59_F19	424199.179	3724839.859	30.257
Or71_F14	433428.124	3715319.792	66.972
Or90_F18	439626.509	3707103.916	29.694
Or92_F16	435433.246	3723792.701	129.317
Or94_F15	437385.865	3715887.885	108.840
Or98_F17	441258.968	3712778.254	150.106
Or50_F01A	419318.901	3741319.842	51.032
Or01_TW14	414310.974	3720509.940	3.721
Or02_TW13	418712.225	3725144.900	13.346
Or08_TW11	432926.485	3736607.702	248.494
Or10_TW20	423905.552	3727856.964	17.440
Or14_TW10	429822.478	3733317.482	82.484
Or16_TW03	429655.825	3739293.399	191.380
Or31_TW08	402642.728	3744543.059	13.065
Or39_TW05	424047.910	3750065.414	103.609
Or48_TW04	427711.641	3745291.070	133.355
Or52_TW07	411060.754	3740743.217	28.491
Or57_TW09	427543.406	3726459.284	36.908
Or58_TW17	432626.995	3729517.277	122.633
Or61_TW12	446214.928	3734567.891	573.167
Or64_TW02	406200.571	3731497.728	1.391
Or68_TW16	429516.073	3717466.744	93.587
Or69_TW15	429061.781	3714487.070	49.860
Or78_TW01	413283.759	3735869.446	22.870
Or81_TW06	414895.921	3742411.492	43.995
Or84_TW18	444918.667	3714946.274	162.958
Or97_TW19	448803.102	3710710.305	114.163
Or04_U19	432874.006	3708888.836	157.070
Or07_U10	419405.802	3727524.647	10.318

Or09_U17	420938.040	3729546.112	13.111
Or11_U09	423862.622	3732245.302	28.240
Or27_U03	410555.417	3728168.277	3.636
Or30_U08	400215.787	3739495.567	4.581
Or37_U04	434404.506	3750241.984	313.163
Or40_U05	419436.890	3746855.019	63.981
Or41_U06	417709.684	3745155.199	56.987
Or46_U16	433920.904	3726436.423	128.049
Or50_U01	419310.580	3741323.858	50.734
Or51_U07	411231.560	3743926.191	33.878
Or66_U18	432814.707	3719087.889	117.807
Or67_U11	420218.828	3719198.908	89.351
Or70_U12	424439.659	3718154.762	283.761
Or74_U15	435816.432	3708453.594	103.893
Or77_U02	410070.322	3731305.239	9.418
Or85_U14	441538.129	3716056.661	180.438
Or86_U20	443447.236	3701869.101	72.054
Or99_U13	437866.324	3727671.532	269.808

Table 6: USGS FEMA IX-Orange County, CA LiDAR surveyed accuracy checkpoints

LiDAR Vertical Accuracy Statistics & Analysis

BACKGROUND

Dewberry tests and reviews project data both quantitatively (for accuracy) and qualitatively (for usability).

For qualitative assessment (i.e. vertical accuracy assessment), One hundred and two (103) check points were surveyed for the project and are located within bare earth/open terrain, brush/small trees, forested/fully grown, tall weeds/crops and urban land cover categories. The checkpoints were surveyed for the project using RTK survey methods. A survey report was produced 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.

VERTICAL ACCURACY TEST PROCEDURES

FVA (Fundamental Vertical Accuracy) is determined with check points located only in the open terrain (grass, dirt, sand, and/or rocks) land cover category, 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 FVA 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 (RMSEz) of the checkpoints x 1.9600. For the USGS FEMA IX Orange County California LiDAR project, vertical accuracy must be 0.245 meters or less based on an RMSEz of 0.125 meters x 1.9600.

CVA (Consolidated Vertical Accuracy) is determined with all checkpoints in all land cover categories combined where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. CVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all land cover categories combined. The USGS FEMA IX Orange County California LiDAR Project CVA standard is 0.363 meters at the 95% confidence level. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the CVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from CVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas CVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

SVA (Supplemental Vertical Accuracy) is determined for each land cover category other than open terrain. SVA at the 95% confidence level equals the 95th percentile error for all checkpoints in each land cover category. The USGS FEMA IX Orange County California LiDAR Project SVA target is 0.363 meters at the 95% confidence level. Target specifications are given for SVA's as one individual land cover category may exceed this target value as long as the overall CVA is within specified tolerances. Again, $Accuracy_z$ differs from SVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas SVA 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
Fundamental Vertical Accuracy (FVA) in open terrain only using RMSEz *1.9600	0.245 meters (based on RMSEz (0.125 meters) * 1.9600)
Consolidated Vertical Accuracy (CVA) in all land cover categories combined at the 95% confidence level	0.363 meters (based on combined 95th percentile)
Supplemental Vertical Accuracy (SVA) in each land cover category separately at the 95% confidence level	0.363 meters (based on 95th percentile for each land cover category)

Table 7 – Acceptance Criteria

VERTICAL ACCURACY TESTING STEPS

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 each of the 102 checkpoints.
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 FVA, CVA, and SVA values.
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.

The figure below shows the location of the QA/QC checkpoints within the project area.

Figure 13 – Location of QA/QC Checkpoints

VERTICAL ACCURACY RESULTS

Table 8 summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the LiDAR LAS files.

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=0.245 m	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.363 m	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=0.363 m
Consolidated	103		0.17	
Bare Earth-Open Terrain	21	0.19		
Tall Weeds and Crops	20			0.12
Forested and Fully Grown	20			0.12
Brush and Small Trees	22			0.18
Urban	20			0.16

Table 8 — FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.10 meters, within the target criteria of 0.125 meters. Compared with the 0.245 meters specification, the FVA tested 0.19 meters at the 95% confidence level based on $RMSE_z$ x 1.9600.

Compared with the 0.363 meters specification, CVA for all checkpoints in all land cover categories combined tested 0.17 meters at the 95% confidence level based on the 95th percentile.

Compared with target 0.363 specification, SVA for checkpoints in the tall weeds and crops land cover category tested 0.12 meters, checkpoints in the forested and fully grown land cover category tested 0.12 meters at the 95% confidence level based on the 95th percentiles, checkpoints in the brush and small trees land cover category tested 0.18 meters at the 95% confidence level based on the 95th percentiles, and checkpoints in the urban land cover category tested 0.16 meters at the 95% confidence level based on the 95th percentiles.

Figure 14 illustrates the magnitude of the differences between the QA/QC checkpoints and LiDAR data. This shows that the majority of LiDAR elevations were within +/- 0.15 meters of the checkpoints elevations, but there were some outliers where LiDAR and checkpoint elevations differed by up to +0.35 meters.

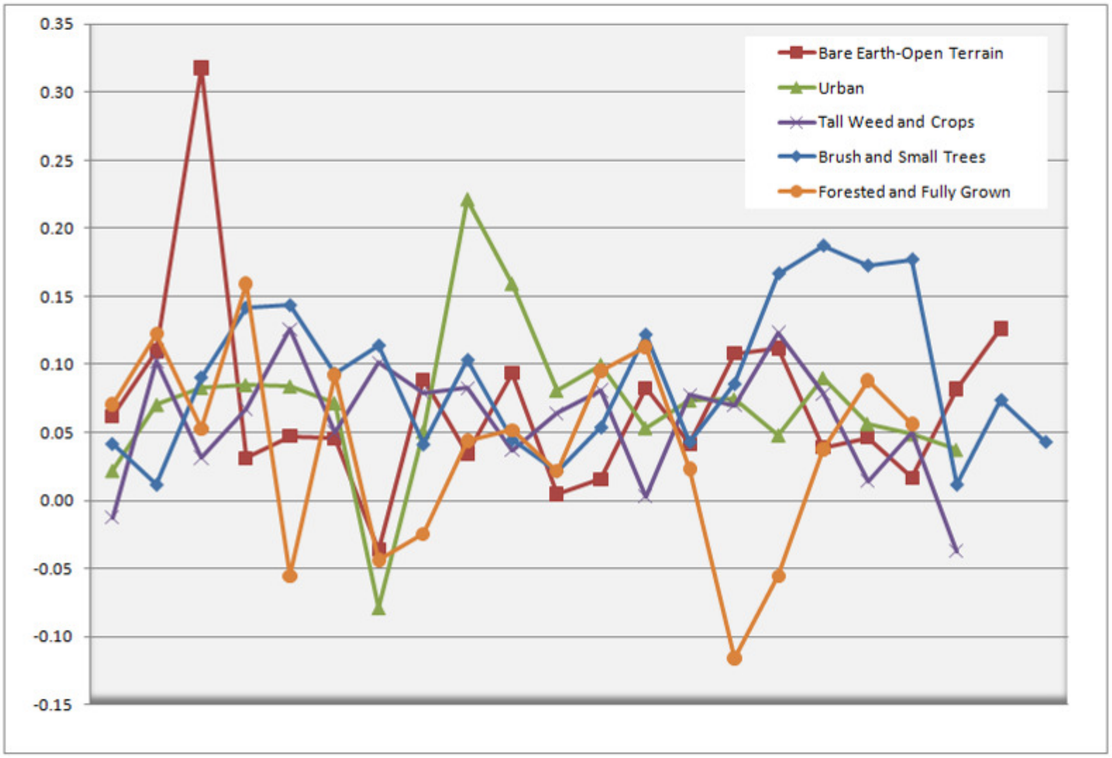


Figure 14 – Magnitude of Elevation Discrepancies

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

Point ID	NAD83 UTM North Zone 11		NAVD88	LiDAR - Z (m)	Delta Z	AbsDelta Z
	Easting - X (m)	Northing - Y (m)	Survey -Z (m)			
Or18_OT04	424644.543	3740376.689	93.865	94.1827	0.32	0.32
Or14_TW10	429822.478	3733317.482	82.484	82.61	0.13	0.13
Or69_TW15	429061.781	3714487.070	49.860	49.9833	0.12	0.12
Or19_F10	421855.612	3736582.602	55.953	56.0756	0.12	0.12
Or21_F04	412665.469	3732620.855	15.587	15.7462	0.16	0.16
Or71_F14	433428.124	3715319.792	66.972	66.8562	-0.12	0.12
Or65_B13	444638.023	3724027.225	288.333	288.4998	0.17	0.17
Or73_B19	434444.280	3711455.974	65.234	65.4212	0.19	0.19
Or82_B15	442722.854	3722284.418	256.239	256.4116	0.17	0.17
Or83_B14	445003.482	3721623.581	295.417	295.5941	0.18	0.18
Or41_U06	417709.684	3745155.199	56.987	57.2083	0.22	0.22
Or46_U16	433920.904	3726436.423	128.049	128.2083	0.16	0.16

Table 9 — 5% Outliers

Table 10 provides overall descriptive statistics.

100 % of Totals	RMSE (m) Open Terrain Spec=0.125m	Mean (m)	Mean Absolute (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated		0.07	0.08	0.07	0.41	0.06	102	-0.12	0.32
Bare Earth-Open Terrain	0.10	0.07	0.07	0.05	2.19	0.07	21	-0.04	0.32
Tall Weeds and Crops		0.06	0.06	0.07	-0.60	0.04	20	-0.04	0.13
Forested and Fully Grown		0.04	0.08	0.05	-0.59	0.07	20	-0.12	0.16
Brush and Small Trees		0.09	0.09	0.09	0.30	0.06	22	0.01	0.19
Urban		0.07	0.08	0.07	0.15	0.06	20	-0.08	0.22

Table 10 — Overall Descriptive Statistics

Figure 15 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 -0.12 meters and a high of +0.32 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.

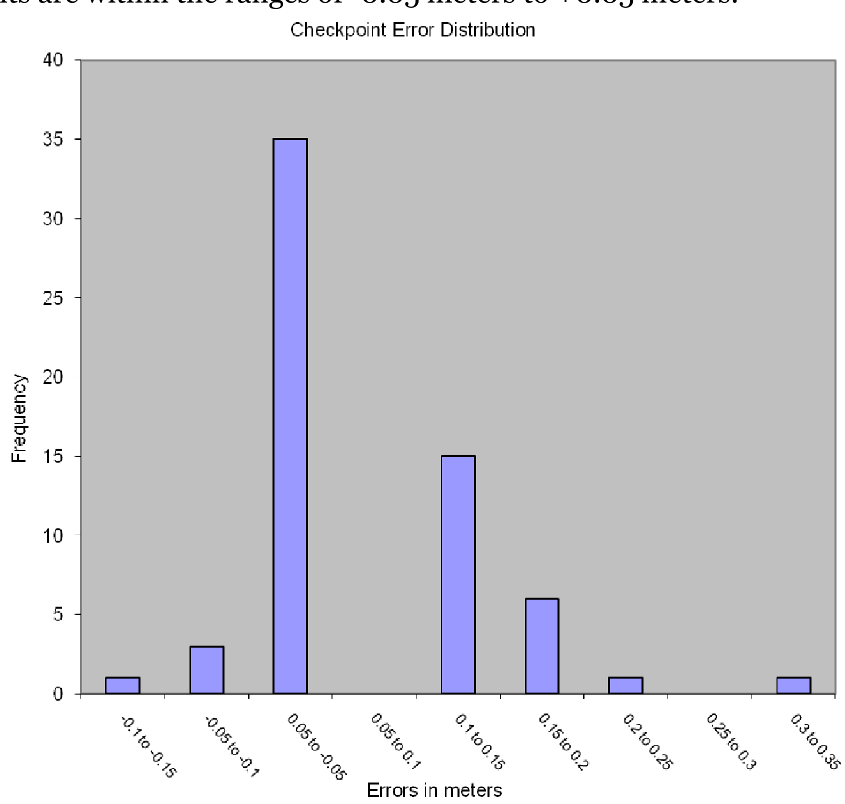


Figure 15 — Histogram of Elevation Discrepancies within errors in feet

CONCLUSION

Based on the vertical accuracy testing conducted by Dewberry, the LiDAR dataset for the USGS FEMA IX – Orange County LiDAR Project satisfies the project's pre-defined vertical accuracy criteria.

Breakline Production & Qualitative Assessment Report

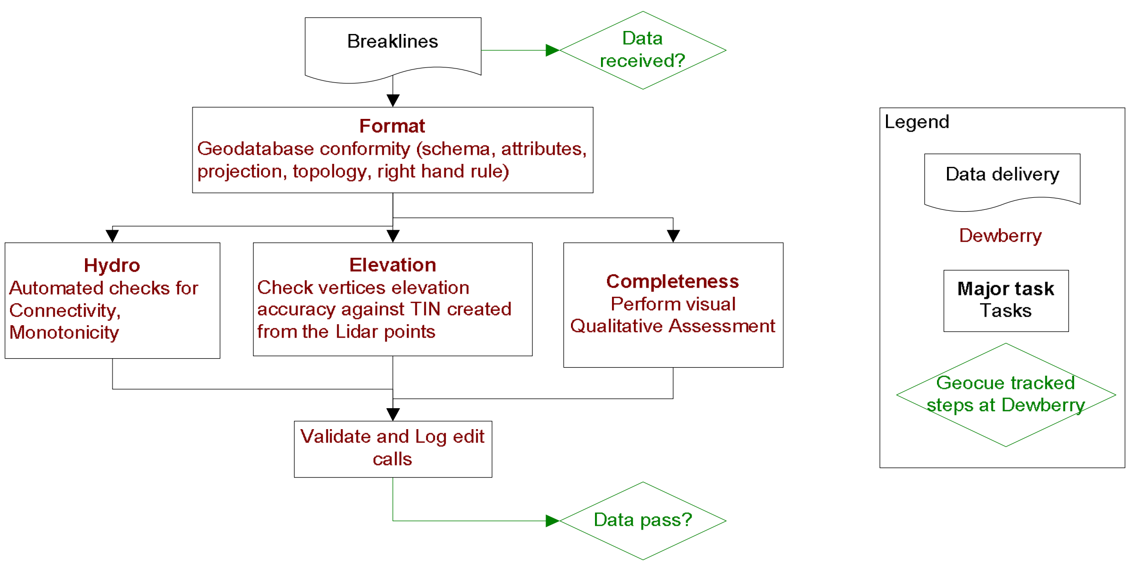
BREAKLINE PRODUCTION METHODOLOGY

Dewberry used GeoCue software to develop LiDAR stereo models of the USGS FEMA IX – Orange County 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 three types of hard breaklines in accordance with the project's Data Dictionary.

All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are reviewed in stereo and the lowest elevation is applied to the entire waterbody.

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.



BREAKLINE TOPOLOGY RULES

Automated checks are applied on hydro features to validate the 3D connectivity of the feature and the monotonicity of the hydrographic breaklines. Dewberry's major concern was that the hydrographic breaklines have a continuous flow downhill and that breaklines do not undulate. Error points are generated at each vertex not complying with the tested rules and these potential edit calls are then visually validated during the visual evaluation of the data. This step also helped validate that breakline vertices did not have excessive minimum or maximum elevations and that elevations are consistent with adjacent vertex elevations.

The next step is to compare the elevation of the breakline vertices against the 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.

Dewberry's final check for the breaklines was to perform a full qualitative analysis. Dewberry compared the breaklines against LiDAR intensity images to ensure breaklines were captured in the required locations. The quality control steps taken by Dewberry are outlined in the QA Checklist below.

BREAKLINE QA/QC CHECKLIST

Project Number/Description: TO G10PC00013 USGS FEMA IX – Orange County LiDAR

Date:______10/1/2012_____

Overview

☒ All Feature Classes are present in GDB

☒ All features have been loaded into the geodatabase correctly. Ensure feature classes with subtypes are domained correctly.

☒ The breakline topology inside of the geodatabase has been validated. See Data Dictionary for specific rules

☒ Projection/coordinate system of GDB is accurate with project specifications

Perform Completeness check on breaklines using either intensity or ortho imagery

☒ Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency (See Data Dictionary for specific collection rules). NHD data will be used to help evaluate completeness of collected hydrographic features. Features should be collected consistently across tile bounds within a dataset as well as be collected consistently between datasets.

☒ Check to make sure breaklines are compiled to correct tile grid boundary and there is full coverage without overlap

☒ Check to make sure breaklines are correctly edge-matched to adjoining datasets if applicable. Ensure breaklines from one dataset join breaklines from another dataset that are coded the same and all connecting vertices between the two datasets match in X,Y, and Z (elevation). There should be no breaklines abruptly ending at dataset boundaries and no discrepancies of Z-elevation in overlapping vertices between datasets.

Compare Breakline Z elevations to LiDAR elevations

☒ Using a terrain created from LiDAR ground points and water points and GeoFIRM tools, drape breaklines on terrain to compare Z values. Breakline elevations should be at or below the elevations of the immediately surrounding terrain. This should be performed before other breakline checks are completed.

Perform automated data checks using PLTS

The following data checks are performed utilizing ESRI's PLTS extension. These checks allow automated validation of 100% of the data. Error records can either be written to a table for future correction, or browsed for immediate correction. PLTS checks should always be performed on the full dataset.

☒ Perform "adjacent vertex elevation change check" on the Inland Ponds feature class (Elevation Difference Tolerance=.001 meters). This check will return Waterbodies whose vertices are not all identical. This tool is found under "Z Value Checks."

☒ Perform "unnecessary polygon boundaries check" on Inland Ponds and Inland Streams feature classes. This tool is found under "Topology Checks."

☒ Perform "duplicate geometry check" on (inland streams to inland streams), (inland ponds to inland ponds), (inland ponds to inland streams). Attributes do not need to be checked during this tool. This tool is found under "Duplicate Geometry Checks."

☒ Perform "geometry on geometry check" on (inland ponds to inland streams). Spatial relationship is contains, attributes do not need to be checked. This tool is found under "Feature on Feature Checks."

☒ Perform "polygon overlap/gap is sliver check" (inland streams to inland streams), (inland ponds to inland ponds), (inland ponds to inland streams). Maximum Polygon Area is not required. This tool is found under "Feature on Feature Checks."

Perform Dewberry Proprietary Tool Checks

☒ Perform monotonicity check on inland streams features using "A3_checkMonotonicityStreamLines." This tool looks at line direction as well as elevation. Features in the output shapefile attributed with a "d" are correct monotonically, but were compiled from low elevation to high elevation. These errors can be ignored. Features in the output shapefile attributed with an "m" are not correct monotonically and need elevations to be corrected. Input features for this tool need to be in a geodatabase. Z tolerance is .01 meters. Polygons need to be exported as lines for the monotonicity tool.

☒ Perform connectivity check between (inland ponds to inland streams) using the tool "07_CheckConnectivityForHydro." The input for this tool needs to be in a geodatabase. The output is a shapefile showing the location of overlapping vertices from the polygon features and polyline features that are at different Z-elevation. The unnecessary polygon boundary check must be run and all errors fixed prior to performing connectivity check. If there are exceptions to the polygon boundary rule then that feature class must be checked against itself, i.e. inland streams to inland streams.

Metadata

☒ Each XML file (1 per feature class) is error free as determined by the USGS MP tool

☒ Metadata content contains sufficient detail and all pertinent information regarding source materials, projections, datums, processing steps, etc. Content should be consistent across all feature classes.

Completion Comments: Complete – Approved

Data Dictionary

HORIZONTAL AND VERTICAL DATUM

The horizontal datum shall be North American Datum of 1983, Units in Meters. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in Meters. Geoid09 shall be used to convert ellipsoidal heights to orthometric heights.

COORDINATE SYSTEM AND PROJECTION

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

INLAND STREAMS AND RIVERS

Feature Dataset: BREAKLINES
Feature Class: STREAMS_AND_RIVERS
Feature Type: Polygon

Contains M Values: No
Contains Z Values: Yes
Annotation Subclass: None

XY Resolution: Accept Default Setting
Z Resolution: Accept Default Setting
XY Tolerance: 0.003
Z Tolerance: 0.001

Description

This polygon feature class will depict linear hydrographic features with a width greater than 100 feet.

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
Streams and Rivers	Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 100 feet in length. In the case of embankments, if the feature forms a natural dual line	Capture features showing dual line (one on each side of the feature). Average width shall be great than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity and data is required to show "closed polygon". Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot

	channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project.	of the stream or river is present. The banks of the stream must be captured at the same elevation to ensure flatness of the water feature. If the elevation of the banks appears to be different see the task manager or PM for further guidance. 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. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. 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. Every effort should be made to avoid breaking a stream or river into segments. Dual line features shall break at road crossings (culverts). In areas where a bridge is present the dual line feature shall continue through the bridge. Islands: The double line stream shall be captured around an island if the features on either side of the island meet the criteria for capture. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature.

INLAND PONDS AND LAKES

Feature Dataset: BREAKLINES
Feature Class: PONDS_AND_LAKES
Feature Type: Polygon

Contains M Values: No
Contains Z Values: Yes
Annotation Subclass: None

XY Resolution: Accept Default Setting
Z Resolution: Accept Default Setting
XY Tolerance: 0.003
Z Tolerance: 0.001

Description

This polygon feature class will depict closed water body features that are at a constant elevation.

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
Ponds and Lakes	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features 2 acres in size or greater. "Donuts" will exist where there are islands within a closed water body feature greater than ½ acre in size.	Water bodies shall be captured as closed polygons with the water feature to the right. <u>The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body.</u> 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. An Island within a Closed Water Body Feature will also have a "donut polygon" compiled. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. 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.

TIDAL WATERS

Feature Dataset: BREAKLINES
Feature Type: Polygon

Feature Class: Tidal Waters

Contains M Values: No
Annotation Subclass: None

Contains Z Values: Yes

XY Resolution: Accept Default Setting
XY Tolerance: 0.003

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
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by Dewberry
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Dewberry
SHAPE_AREA	Double	Yes			0	0		Calculated by Dewberry

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 require some feathering or edge matching to ensure a smooth transition.	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.

CONTACT INFORMATION

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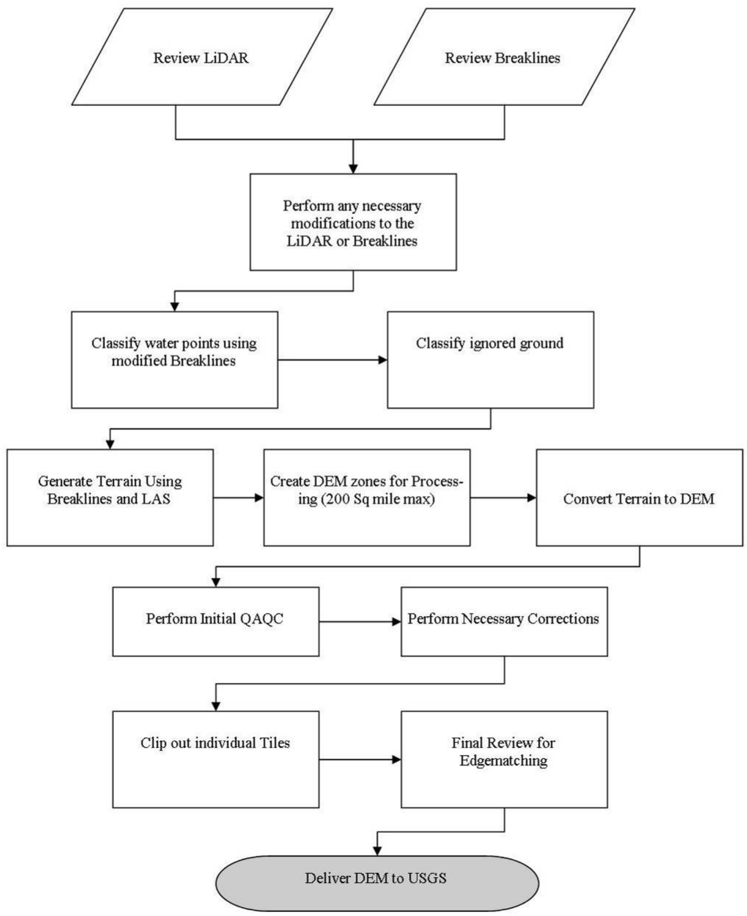
DEM Production & Qualitative Assessment

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.

Dewberry Hydro-Flattening Workflow



1. Classify Water Points: LAS point falling within hydrographic breaklines shall be classified to ASPRS class 9 using TerraScan. Breaklines must be prepared correctly prior to performing this task.
2. Classify Ignored Ground Points: Classify points in close proximity to the breaklines from Ground to class 10 (Ignored Ground). Close proximity will be defined as no more than 1x the nominal point spacing on the landward side of the breakline. Breaklines will be buffered using this specification and the subsequent file will need to be prepared in the same manner as the water breaklines for classification. This process will be performed after the water points have been classified and only run on remaining ground points.
3. Terrain Processing: A Terrain will be generated using the Breaklines and LAS data that has been imported into Arc as a Multipoint File. If the final DEMs are to be clipped to a project boundary that boundary will be used during the generation of the Terrain.

4. Create DEM Zones for Processing: Create DEM Zones that are buffered around the edges. Zones should be created in a logical manner to minimize the number of zones without creating zones too large for processing. BAE will make zones no larger than 200 square miles (taking into account that a DEM will fill in the entire extent not just where LiDAR is present). Once the first zone is created it must be verified against the tile grid to ensure that the cells line up perfectly with the tile grid edge.
5. Convert Terrain to Raster: Convert Terrain to raster using the DEM Zones created in step 6. In the environmental properties set the extents of the raster to the buffered Zone. For each subsequent zone, the first DEM will be utilized as the snap raster to ensure that zones consistently snap to one another.
6. Perform Initial QAQC on Zones: During the initial QA process anomalies will be identified and corrective polygons will be created.
7. Correct Issues on Zones: BAE will perform corrections on zones following Dewberry's correction process.
8. Extract Individual Tiles: BAE will extract individual tiles from the zones utilizing the Dewberry created tool.
9. Final QA: Final QA will be performed on the dataset to ensure that tile boundaries are seamless.

DEM QUALITATIVE ASSESSMENT

Dewberry performed a comprehensive qualitative assessment of the 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 and to review the hydro-flattened features. To perform this review Dewberry creates HillShade models and overlays a partially transparent colorized elevation model to review for these issues. Upon completion of this review the DEM data is loaded into Global Mapper to ensure that all files are readable and that no artifacts exist between tiles.

DEM VERTICAL ACCURACY RESULTS

The same 103 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.

Table 7 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	FVA – Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=0.245 m	CVA – Consolidated Vertical Accuracy (95th Percentile) Spec=0.363 m	SVA – Supplemental Vertical Accuracy (95th Percentile) Target=0.363 m
Consolidated	102		0.17	
Bare Earth-Open Terrain	21	0.18		
Tall Weeds and Crops	20			0.12
Forested and Fully Grown	20			0.13
Brush and Small Trees	22			0.20
Urban	20			0.17

Table 7 — FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.09 meters, within the target criteria of 0.125 meters. Compared with the 0.245 meters specification, the FVA tested 0.18 meters at the 95% confidence level based on $RMSE_z$ x 1.9600.

Compared with the 0.363 meters specification, CVA for all checkpoints in all land cover categories combined tested 0.17 meters at the 95% confidence level based on the 95^{th} percentile.

Compared with target 0.363 specification, SVA for checkpoints in the tall weeds and crops land cover category tested 0.12 meters, checkpoints in the forested and fully grown land cover category tested 0.13 meters at the 95% confidence level based on the 95^{th} percentiles, checkpoints in the brush and small trees land cover category tested 0.20 meters at the 95% confidence level based on the 95^{th} percentiles, and checkpoints in the urban land cover category tested 0.17 meters at the 95% confidence level based on the 95^{th} percentiles.

Table 8 lists the 5% outliers that are larger than the 95^{th} percentile.

Point ID	NAD83 UTM North Zone 11		NAVD88	DEM Z (m)	Delta Z	AbsDeltaZ
	Easting - X (m)	Northing - Y (m)	Survey Z (m)			
Or18_OT04	424644.543	3740376.689	93.865	94.158	0.29	0.29
Or65_B13	444638.023	3724027.225	288.333	288.535	0.20	0.20
Or73_B19	434444.28	3711455.974	65.234	65.428	0.19	0.19
Or101_B21	443533.876	3703411.049	133.315	133.543	0.23	0.23
Or41_U06	417709.684	3745155.199	56.987	57.240	0.25	0.25

Table 8 — 5% Outliers

Table 9 provides overall descriptive statistics.

100 % of Totals	RMSE (m) Open Terrain Spec=0.125 m	Mean (m)	Mean Absolute (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated		0.07	0.08	0.07	0.53	0.06	102	-0.12	0.29
Bare Earth-Open Terrain	0.09	0.07	0.07	0.07	2.02	0.06	21	-0.03	0.29
Tall Weeds and Crops		0.06	0.07	0.07	-0.40	0.04	20	-0.02	0.13
Forested and Fully Grown		0.04	0.08	0.05	-0.59	0.07	20	-0.12	0.16
Brush and Small Trees		0.10	0.10	0.10	0.39	0.06	22	0.01	0.23
Urban		0.07	0.08	0.07	1.26	0.06	20	-0.05	0.25

Table 9 — Overall Descriptive Statistics

DEM QA/QC CHECKLIST

Project Number/Description: TO G10PC00013 USGS FEMA IX – Orange County LiDAR
Date:______10/1/2012_____
Overview
☒ Correct number of files is delivered and all files are in ERDAS IMG format
☒ Verify Raster Extents
☒ Verify Projection/Coordinate System

Review
☒ Manually review bare-earth DEMs with a hillshade to check for issues with hydro-enforcement process or any general anomalies that may be present. Specifically, water should be flowing downhill, water features should NOT be floating above surrounding terrain and bridges should NOT be present in bare-earth DEM. Hydrologic breaklines should be overlaid during review of DEMs.
☒ Overlap points (in the event they are supplied to fill in gaps between adjacent flightlines) are not to be used to create the bare-earth DEMs
☒ DEM cell size is 1 meter
☒ Perform final overview in Global Mapper to ensure seamless product.

Metadata
☒ Project level DEM metadata XML file is error free as determined by the USGS MP tool

☒ Metadata content contains sufficient detail and all pertinent information regarding source materials, projections, datums, processing steps, etc.

Completion Comments: Complete - Approved

Appendix A: Full LiDAR Acquisition Report

Scope of Work

DMI acquired LiDAR data over an Area of Interest (AOI) entire of Orange County California. The acquisition plan entailed a nominal point spacing of 1.76 points per meter square and a side lap of 40% between flight lines. The AOI covers 696 square miles.

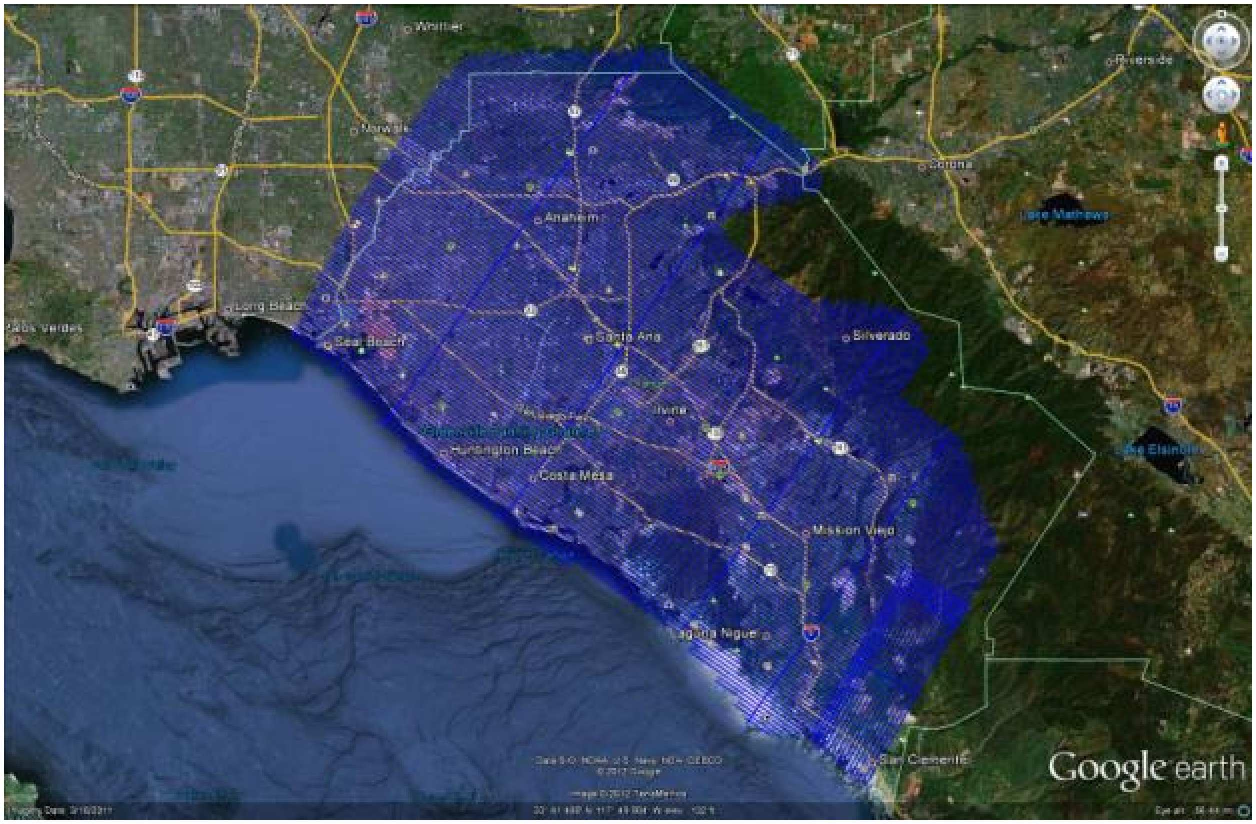


Fig. 1 Flight plan

LiDAR Acquisition Details

Collections (Lifts): 14
Collection Dates: 2011 December 17, 20, 21, 23, 24, 26, 27, 28, 29, 30,
Field of View (FOV): 18 degrees
Average Point Density (planned): 0.75 m
Flight Level(s): 914 / 3000 m/ft
Sensor Type: Optech Gemini **Sensor Serial Number(s):** 07SEN204

All acquired LiDAR data was initially quality controlled after every mission for coverage and further verified for content and adherence to flight plan at DMI production facilities Huntington Beach, CA. All data was accepted for processing.

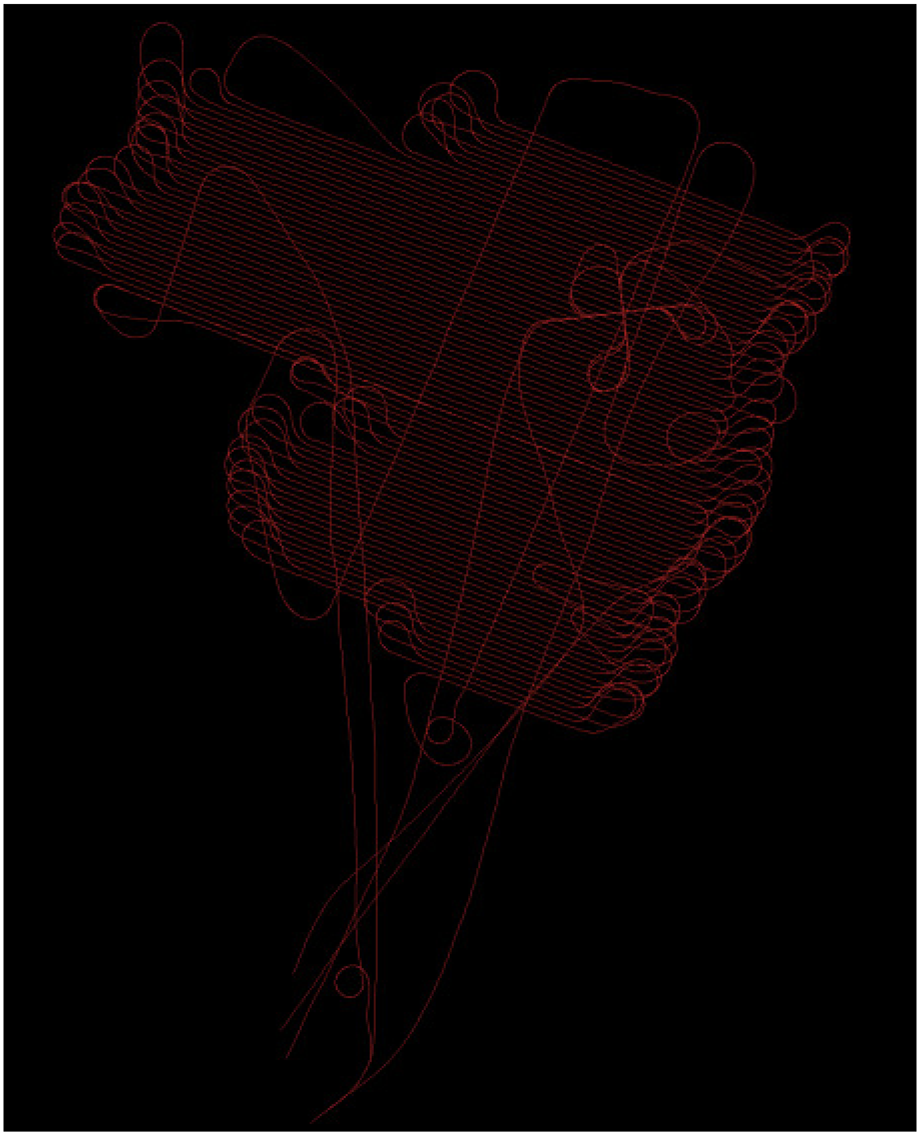
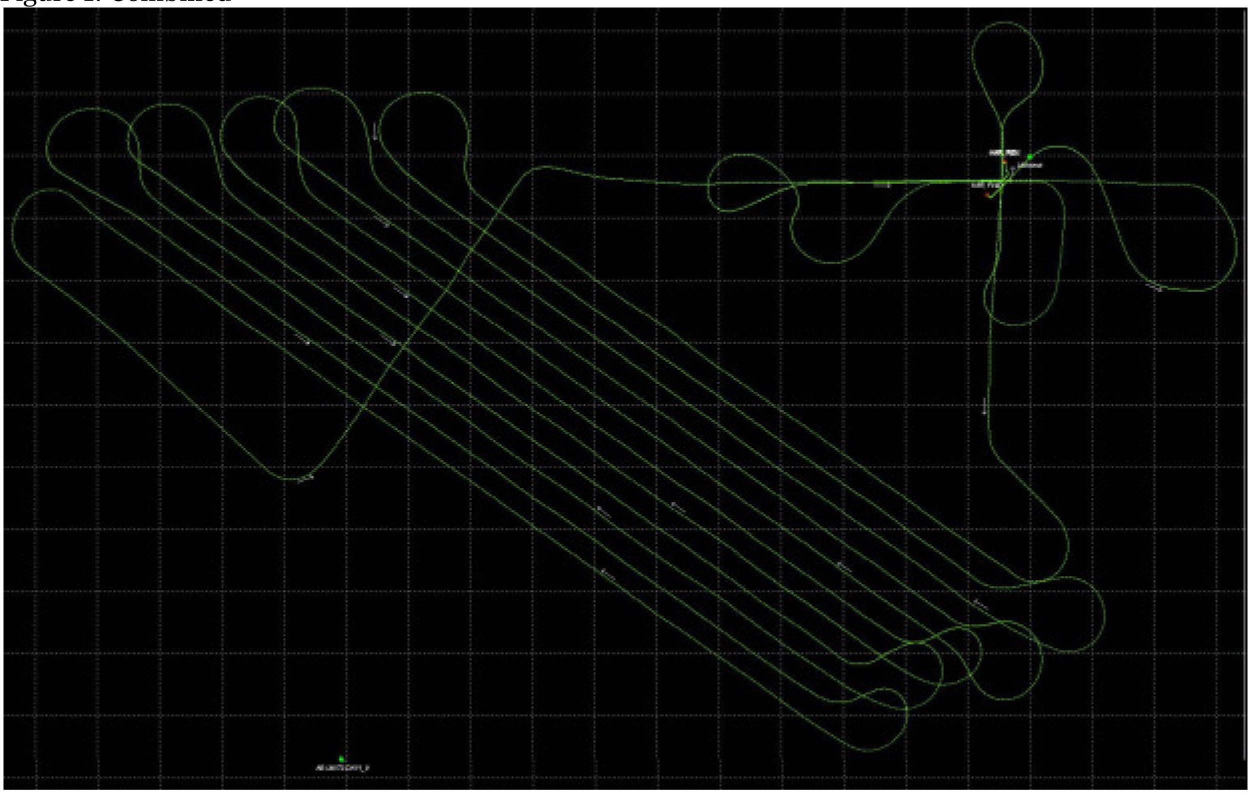


Fig. 2 Orange County AOI Flight Trajectories

Output Results for 12/17/2011AM

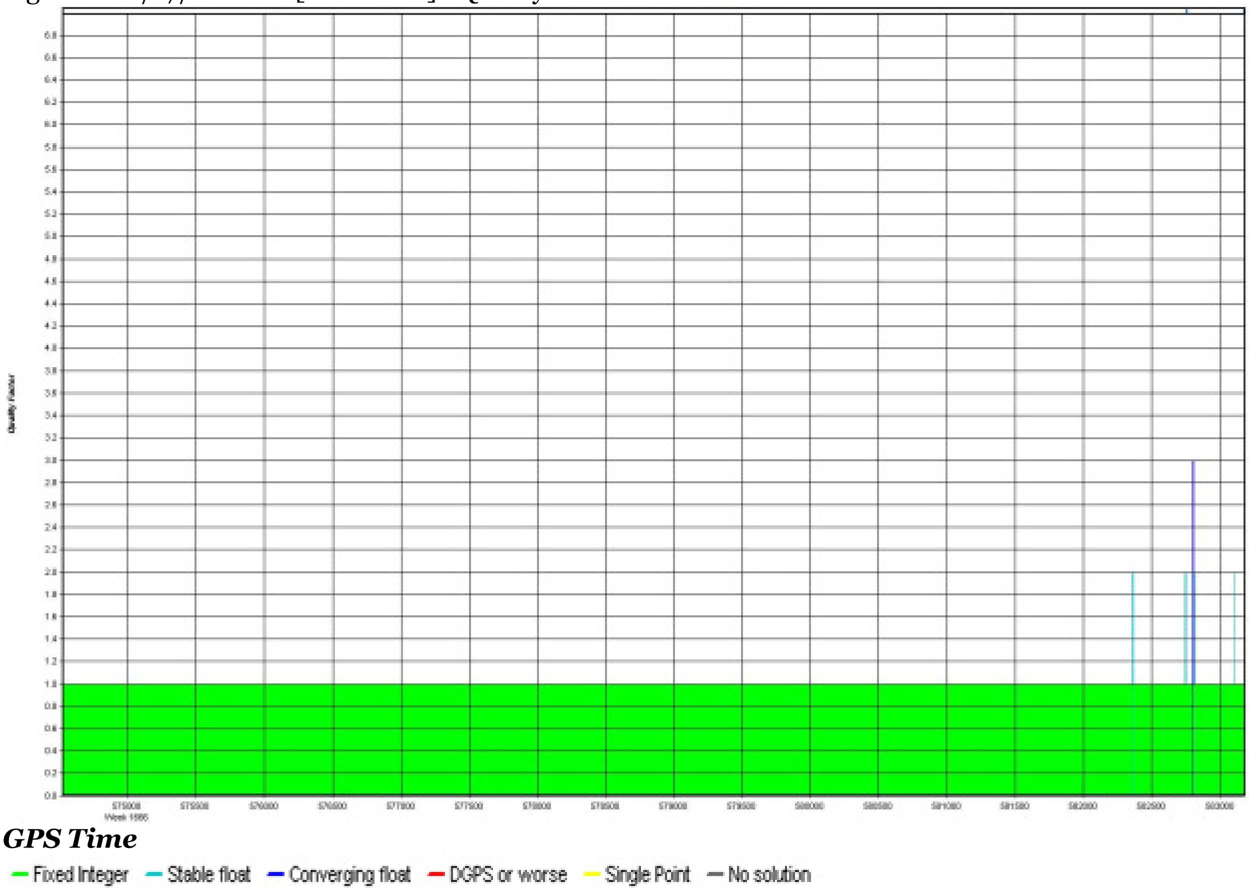
POSPAC Version 4.31

Figure 1: Combined



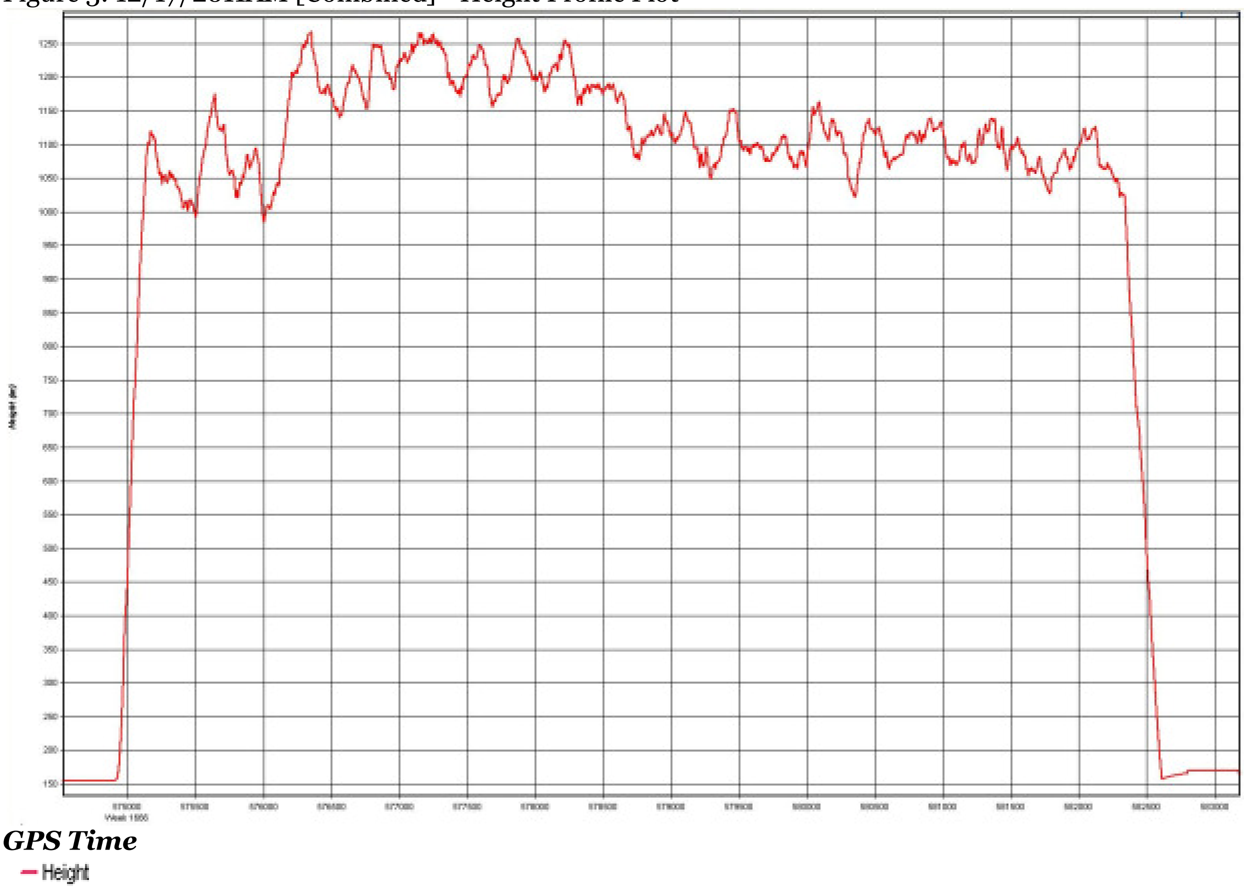
Process	Run (12)	by Unknown	on 12/17/2011	at 07:30

Figure 2: 12/17/2011AM [Combined] - Quality Factor Plot



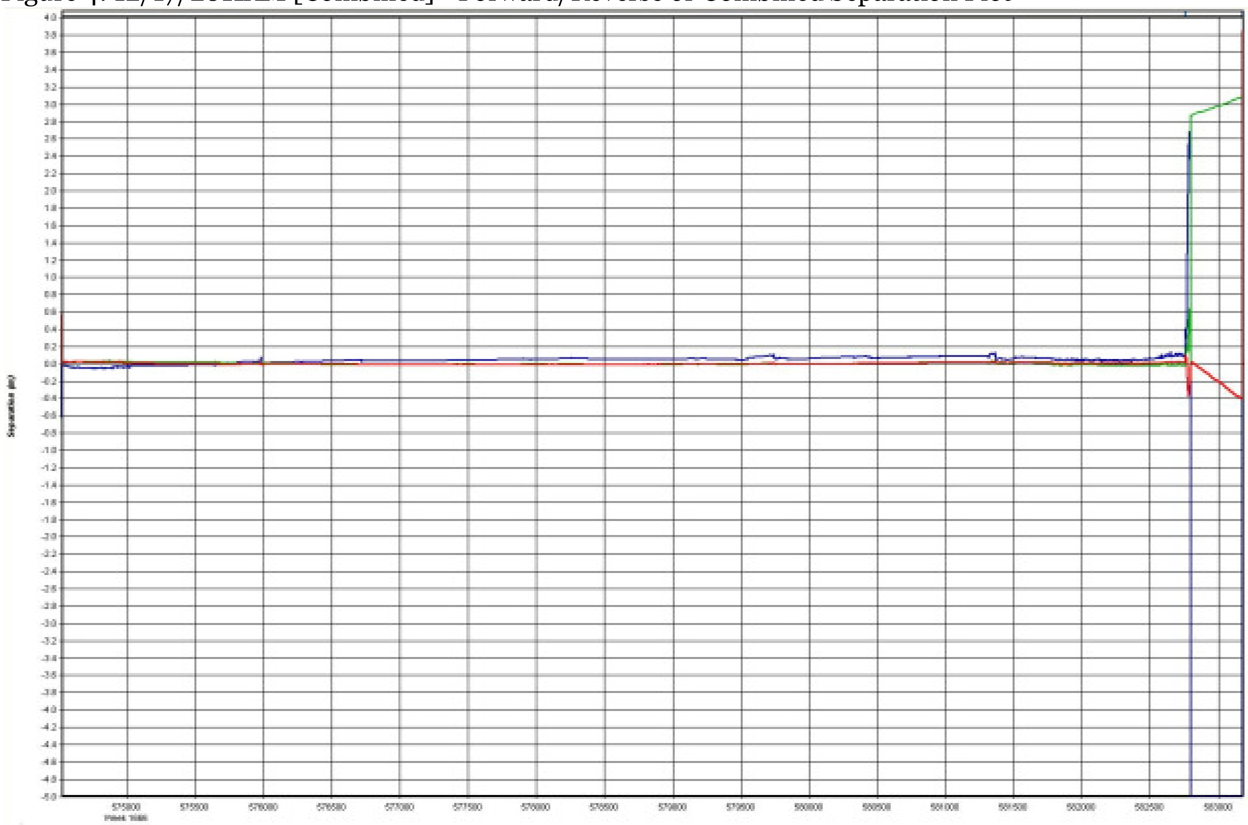
Process	Run (12)	by Unknown	on 12/17/2011	at 07:30

Figure 3: 12/17/2011AM [Combined] - Height Profile Plot



Process	Run (12)	by Unknown	on 12/17/2011	at 07:30

Figure 4: 12/17/2011AM [Combined] - Forward/Reverse or Combined Separation Plot



GPS Time

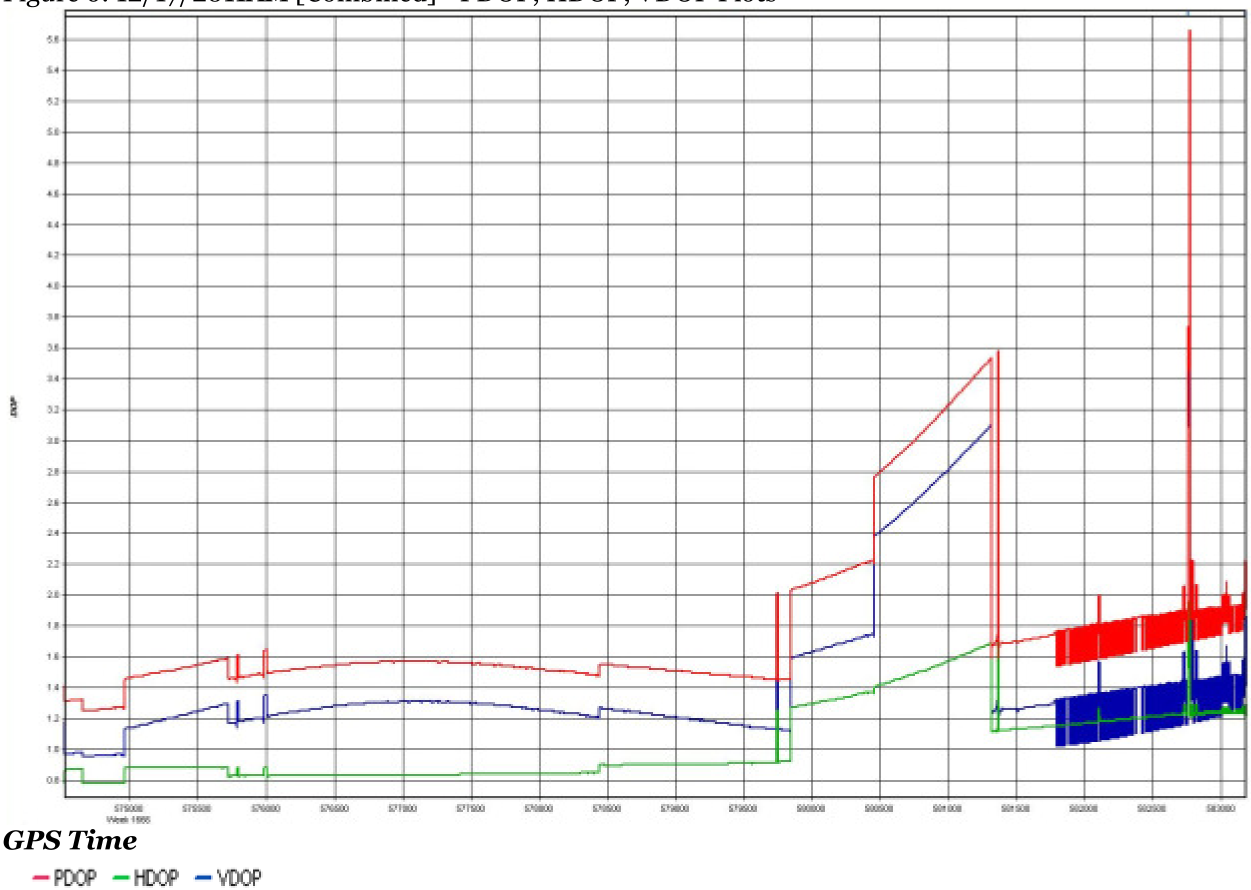
— East — North — Up

Process	Run (12)	by Unknown	on 12/17/2011	at 07:30

Figure 5: 12/17/2011AM [Combined] - Forward/Reverse or Combined Weighting Plot

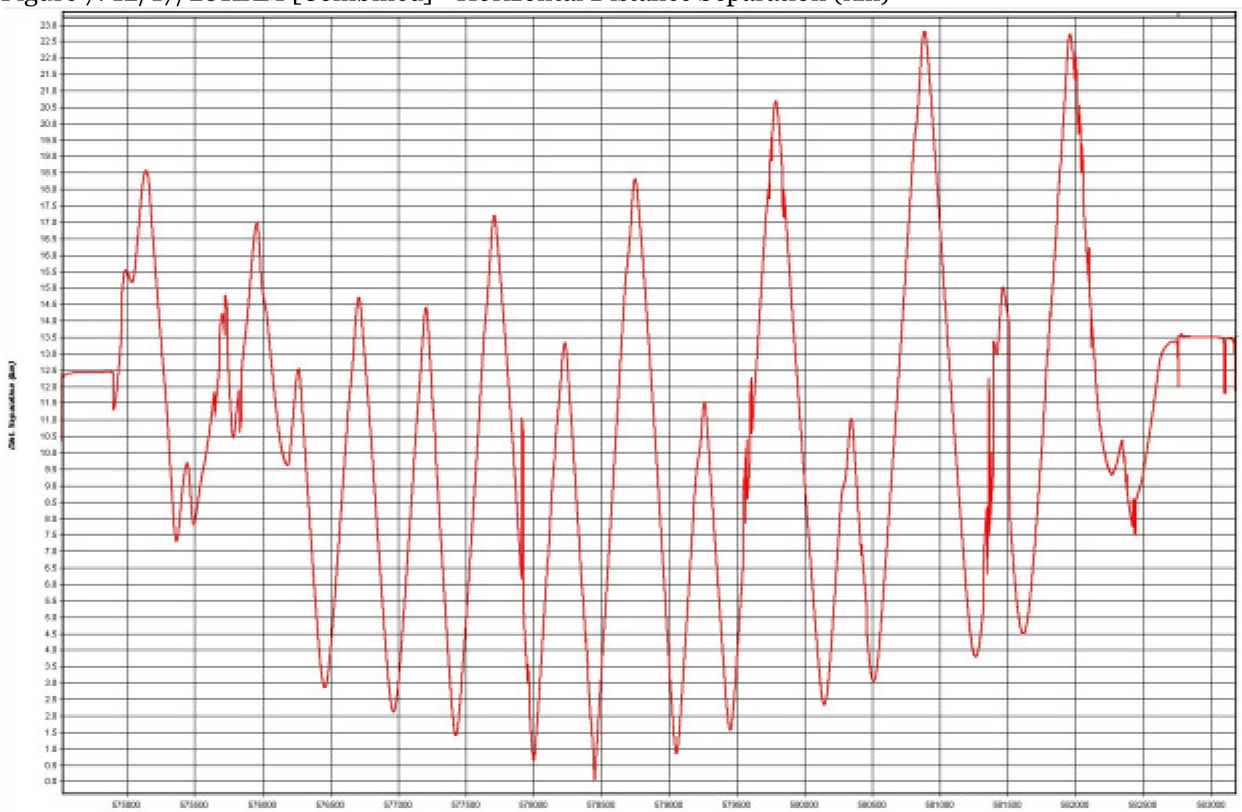
Process	Run (12)	by Unknown	on 12/17/2011	at 07:30

Figure 6: 12/17/2011AM [Combined] - PDOP, HDOP, VDOP Plots



Process	Run (12)	by Unknown	on 12/17/2011	at 07:30

Figure 7: 12/17/2011AM [Combined] - Horizontal Distance Separation (km)



GPS Time

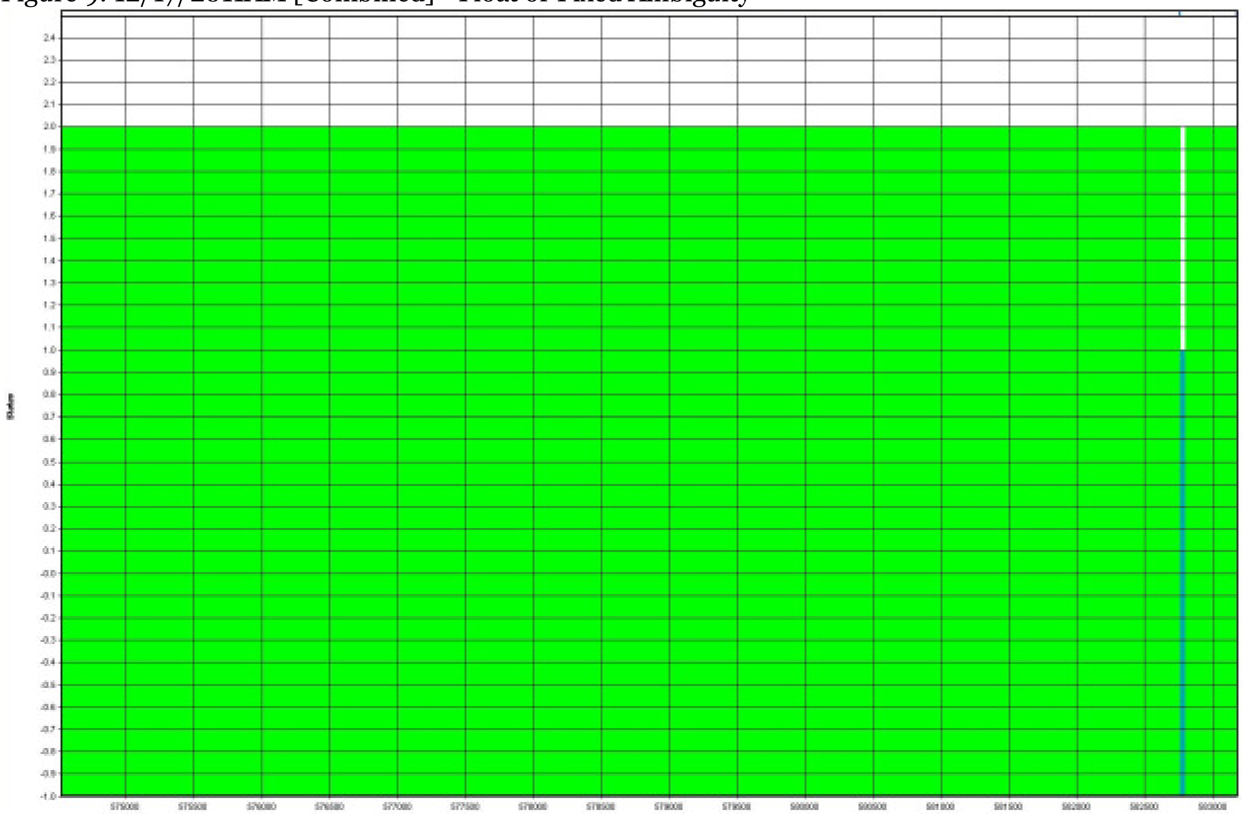
Distance

Process	Run (12)	by Unknown	on 12/17/2011	at 07:30

Figure 8: 12/17/2011AM [Combined] - Forward/Reverse or Combined RMS Plot

Process	Run (12)	by Unknown	on 12/17/2011	at 07:30

Figure 9: 12/17/2011AM [Combined] - Float or Fixed Ambiguity



GPS Time

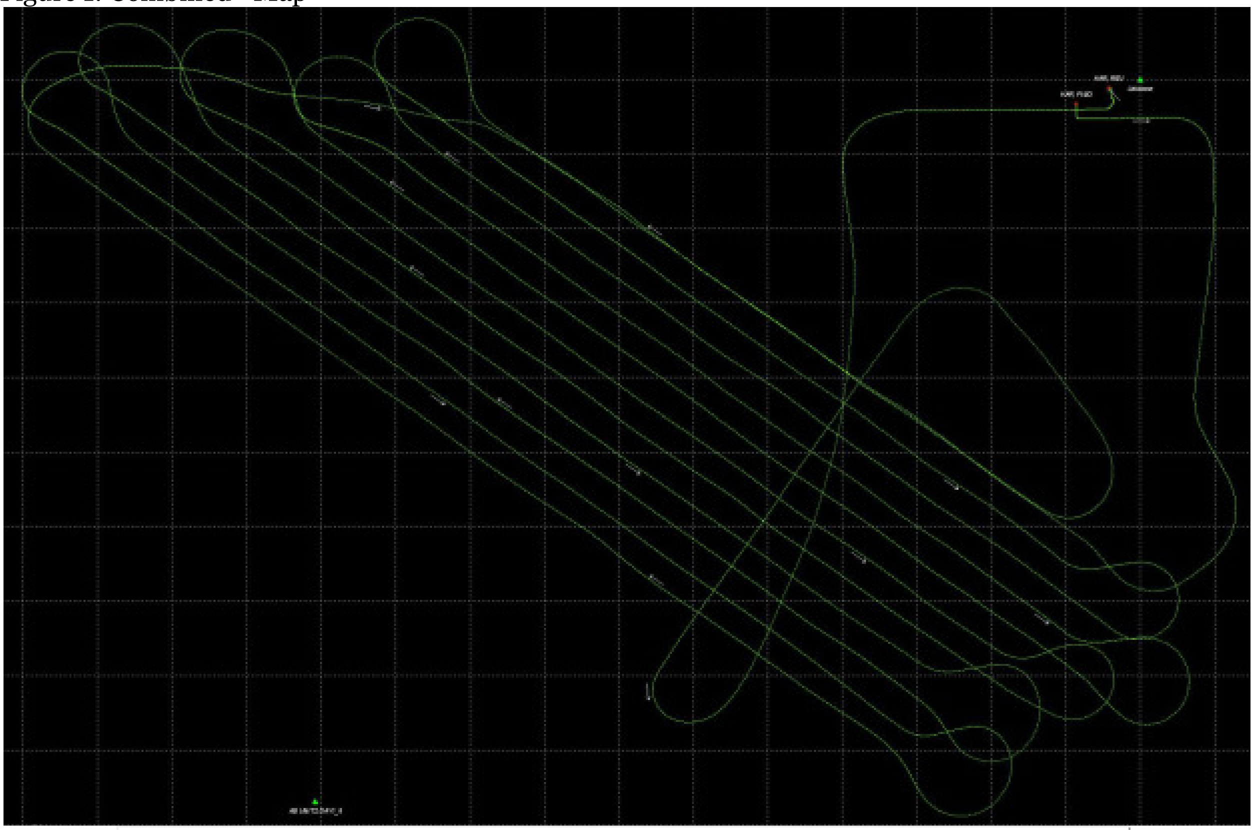
Float — Fixed (1 baseline) — Fixed (2 or more)

Process	Run (12)	by Unknown	on 12/17/2011	at 07:30

Output Results for 12/17/2011PM

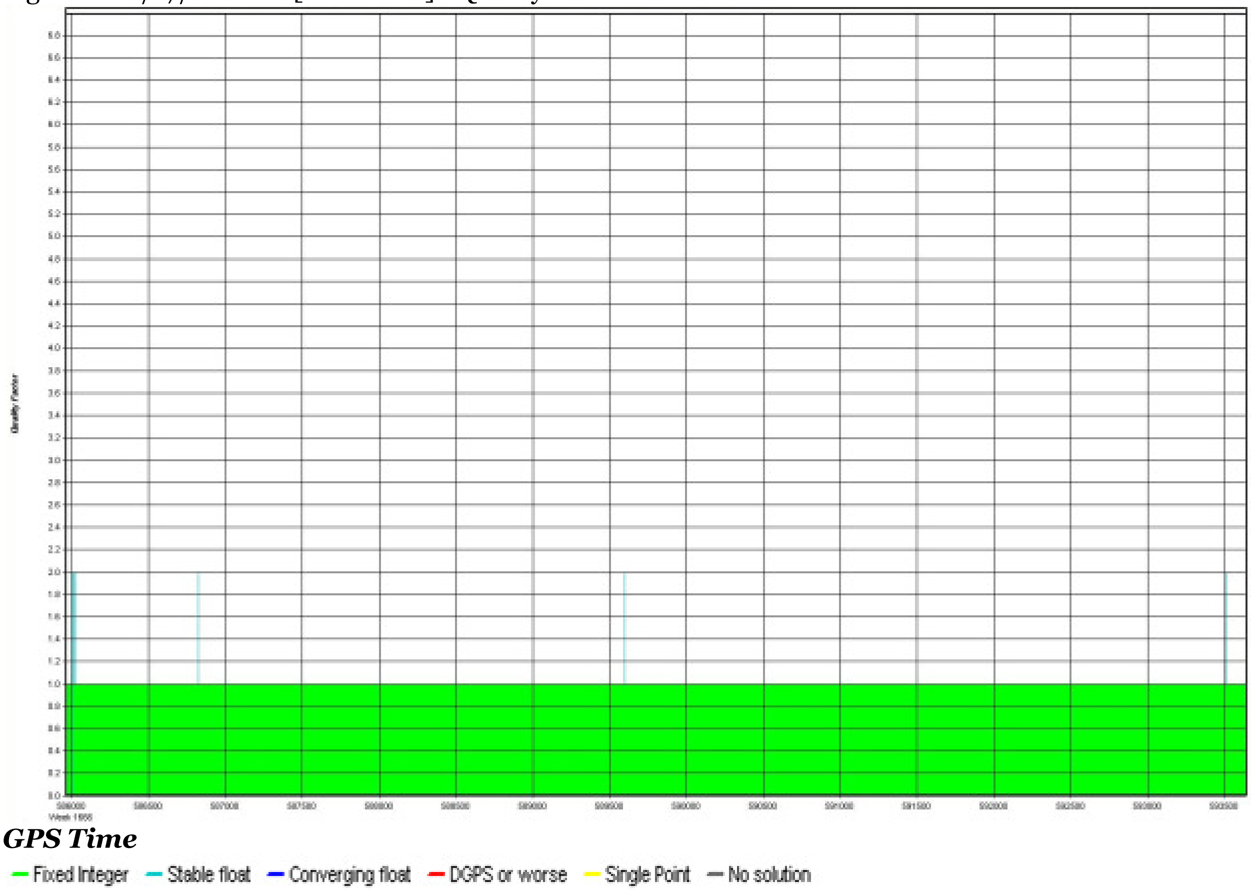
POSPAC Version 4.31

Figure 1: Combined - Map



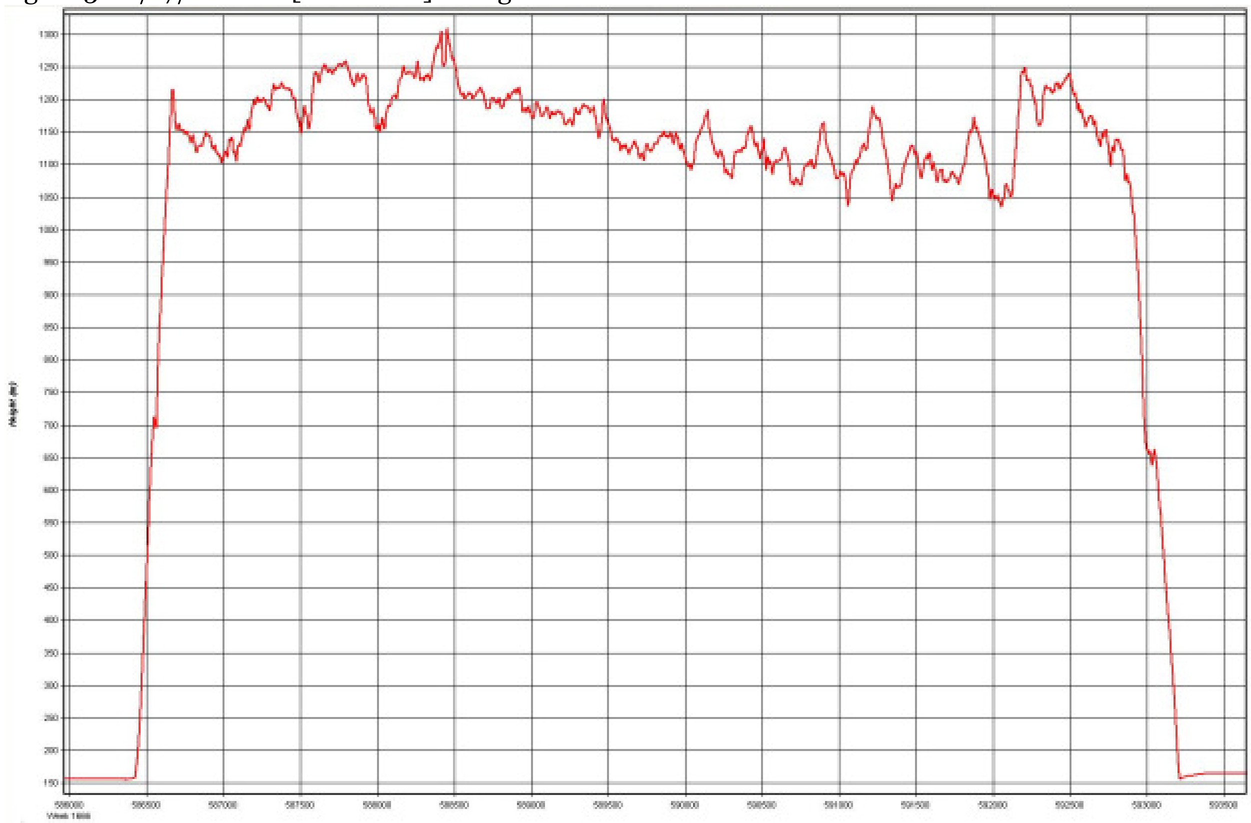
Process	Run (12)	by Unknown	on 12/17/2011	at 13:00

Figure 2: 12/17/2011PM [Combined] - Quality Factor Plot



Process	Run (12)	by Unknown	on 12/17/2011	at 13:00

Figure 3: 12/17/2011PM [Combined] - Height Profile Plot

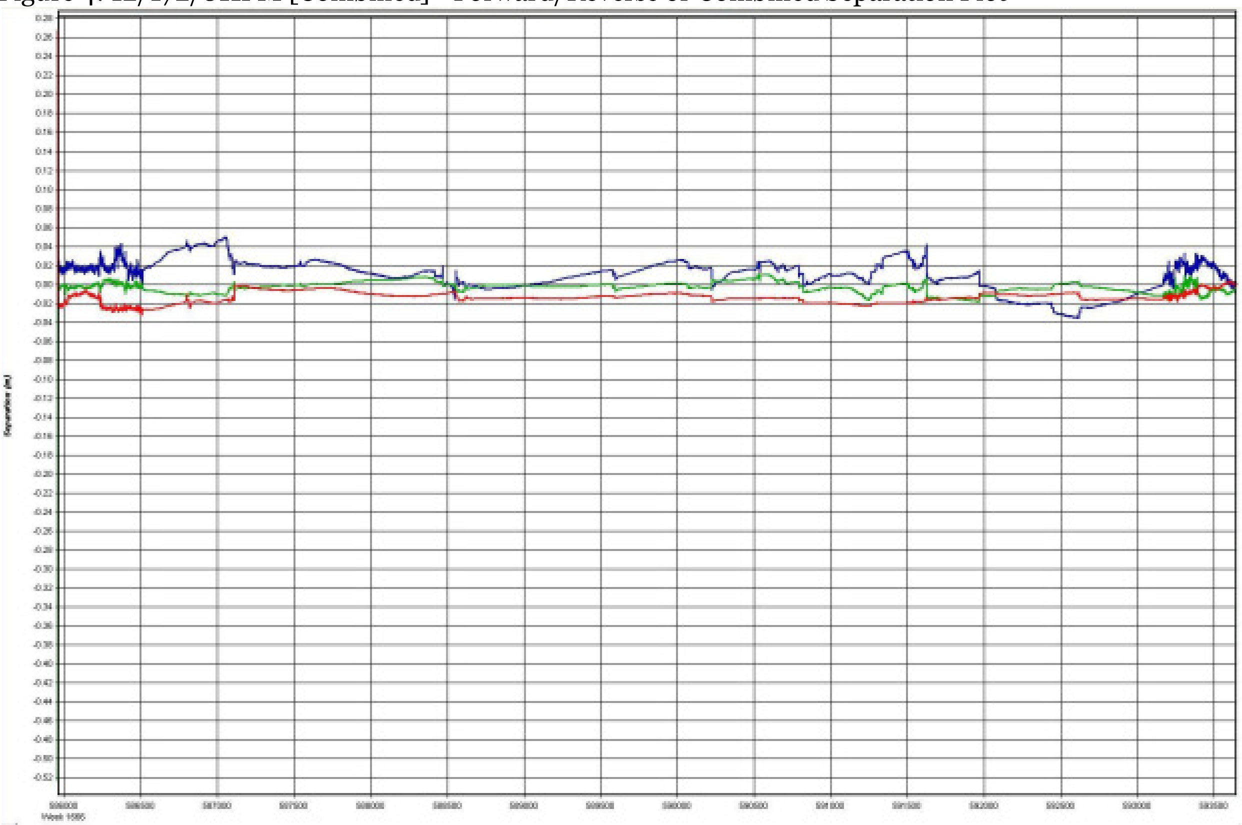


GPS Time

— Height

Process	Run (12)	by Unknown	on 12/17/2011	at 13:00

Figure 4: 12/172/011PM [Combined] - Forward/Reverse or Combined Separation Plot

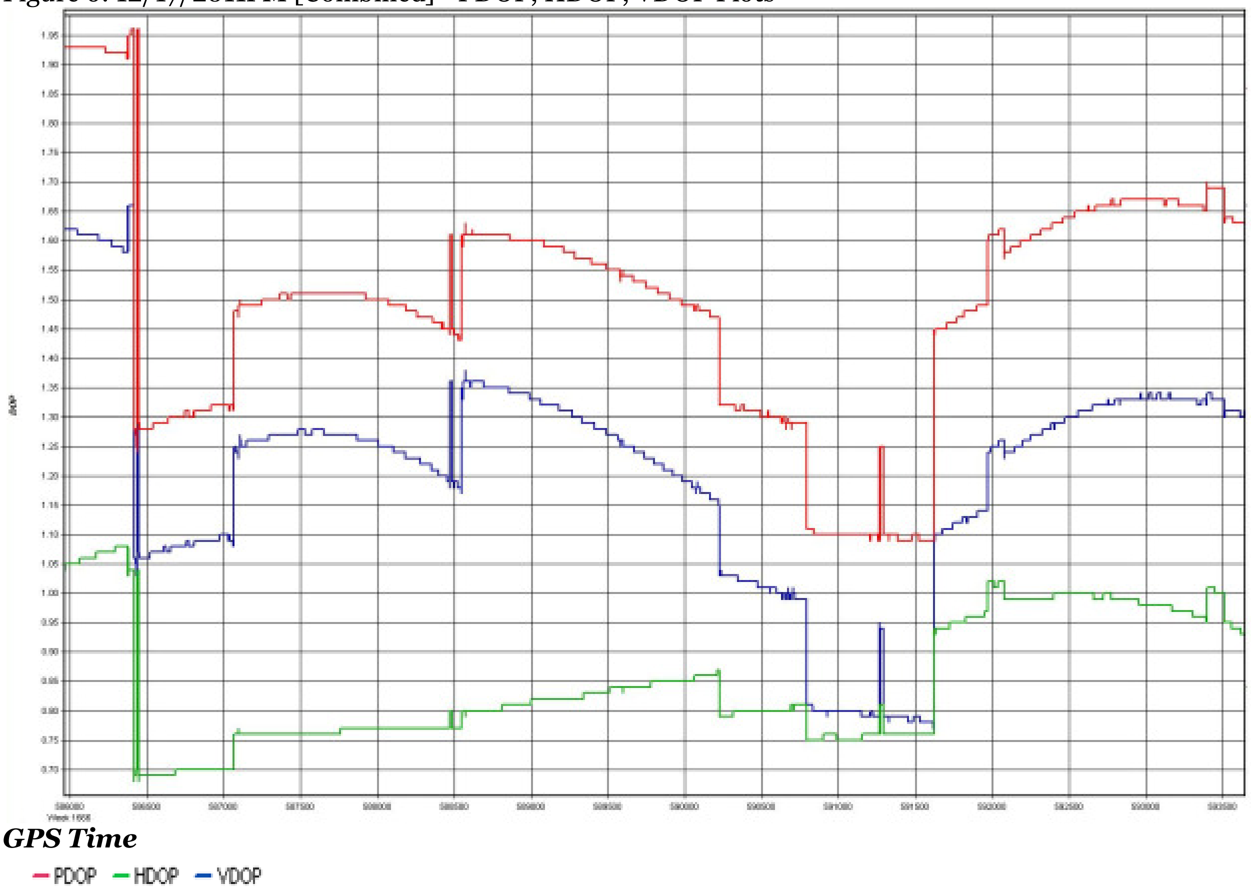


Process	Run (12)	by Unknown	on 12/17/2011	at 13:00

Figure 5: 12/17/2011PM [Combined] - Forward/Reverse or Combined Weighting Plot

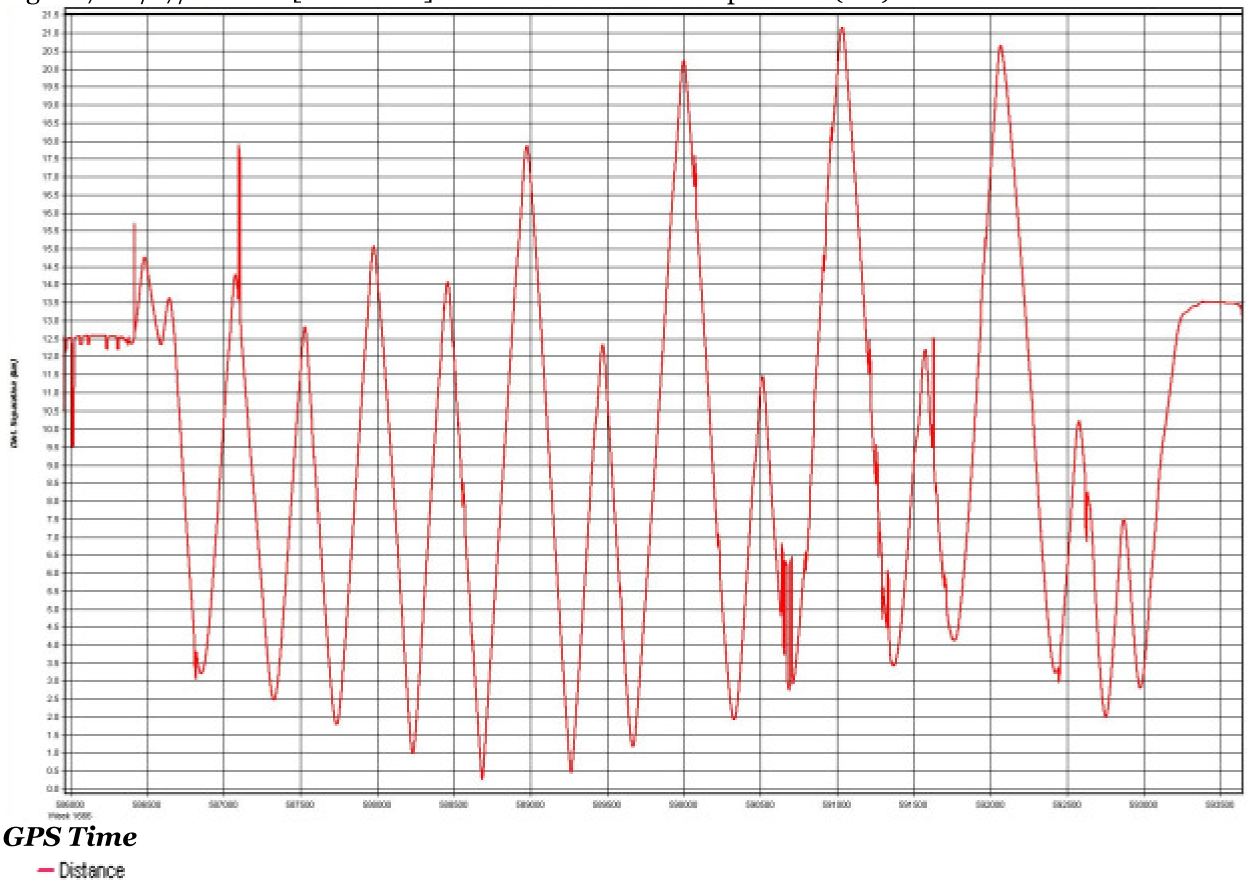
Process	Run (12)	by Unknown	on 12/17/2011	at 13:00

Figure 6: 12/17/2011PM [Combined] - PDOP, HDOP, VDOP Plots



Process	Run (12)	by Unknown	on 12/17/2011	at 13:00

Figure 7: 12/17/2011PM [Combined] - Horizontal Distance Separation (km)

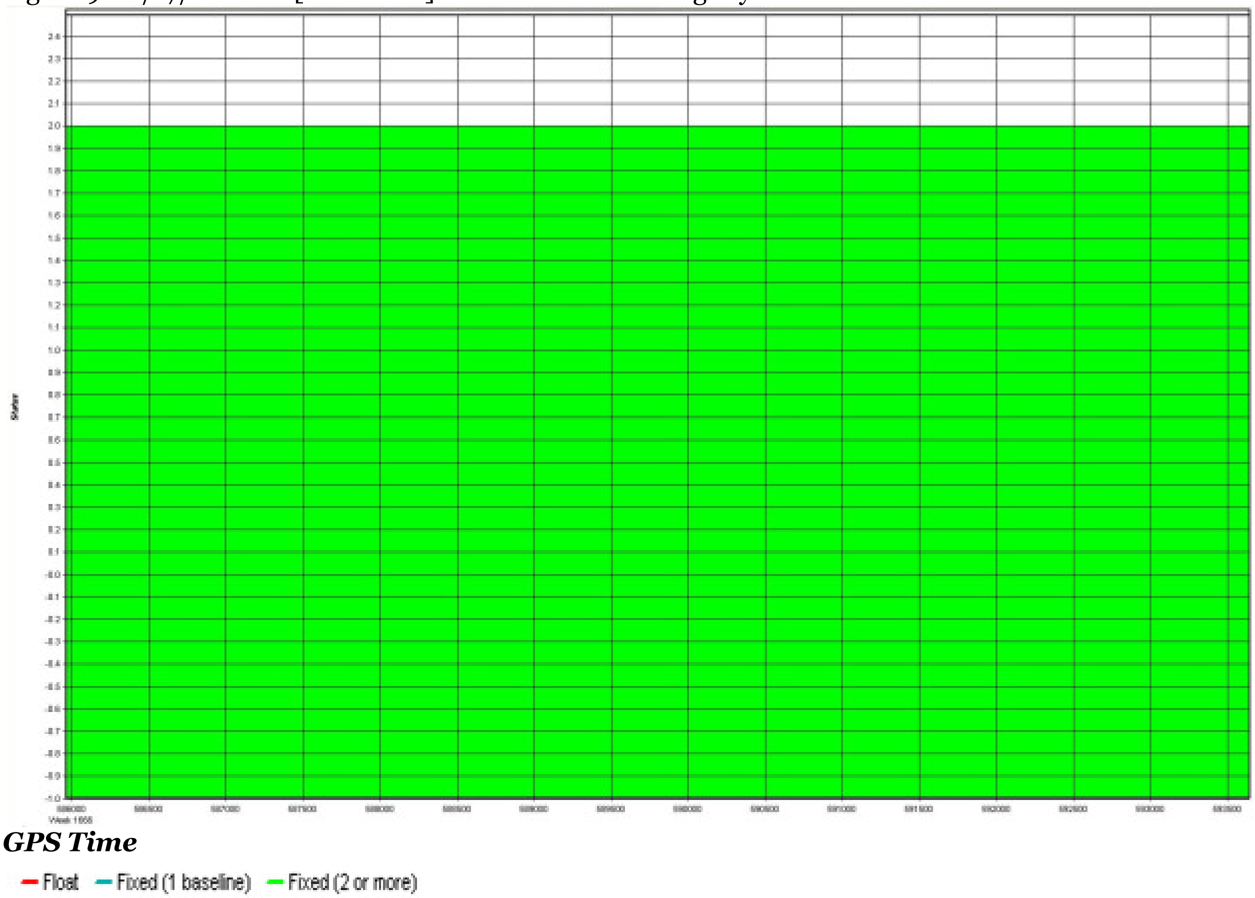


Process	Run (12)	by Unknown	on 12/17/2011	at 13:00

Figure 8: 12/17/2011PM [Combined] - Forward/Reverse or Combined RMS Plot

Process	Run (12)	by Unknown	on 12/17/2011	at 13:00

Figure 9: 12/17/2011PM [Combined] - Float or Fixed Ambiguity

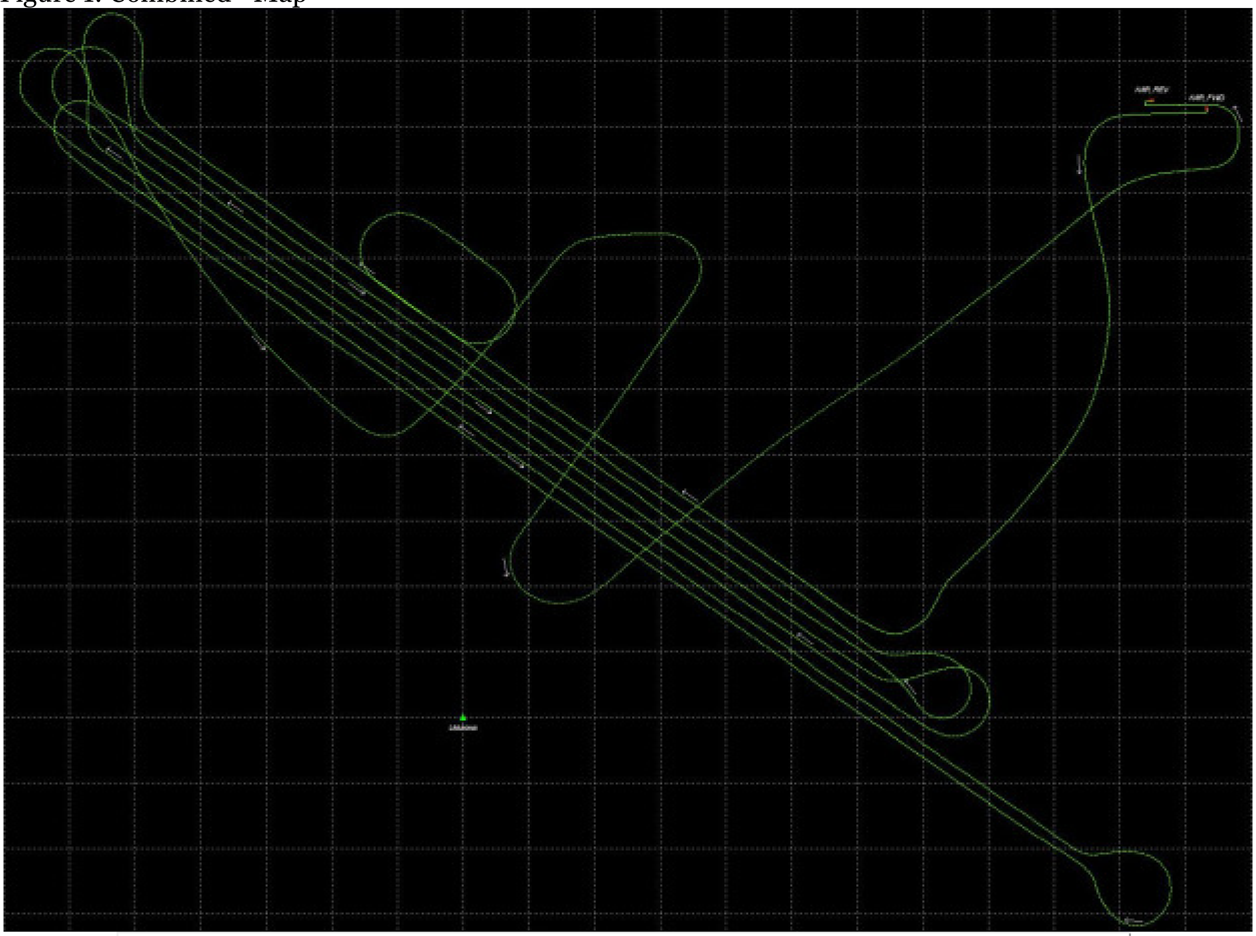


Process	Run (12)	by Unknown	on 12/17/2011	at 13:00

Output Results for 12/20/2011

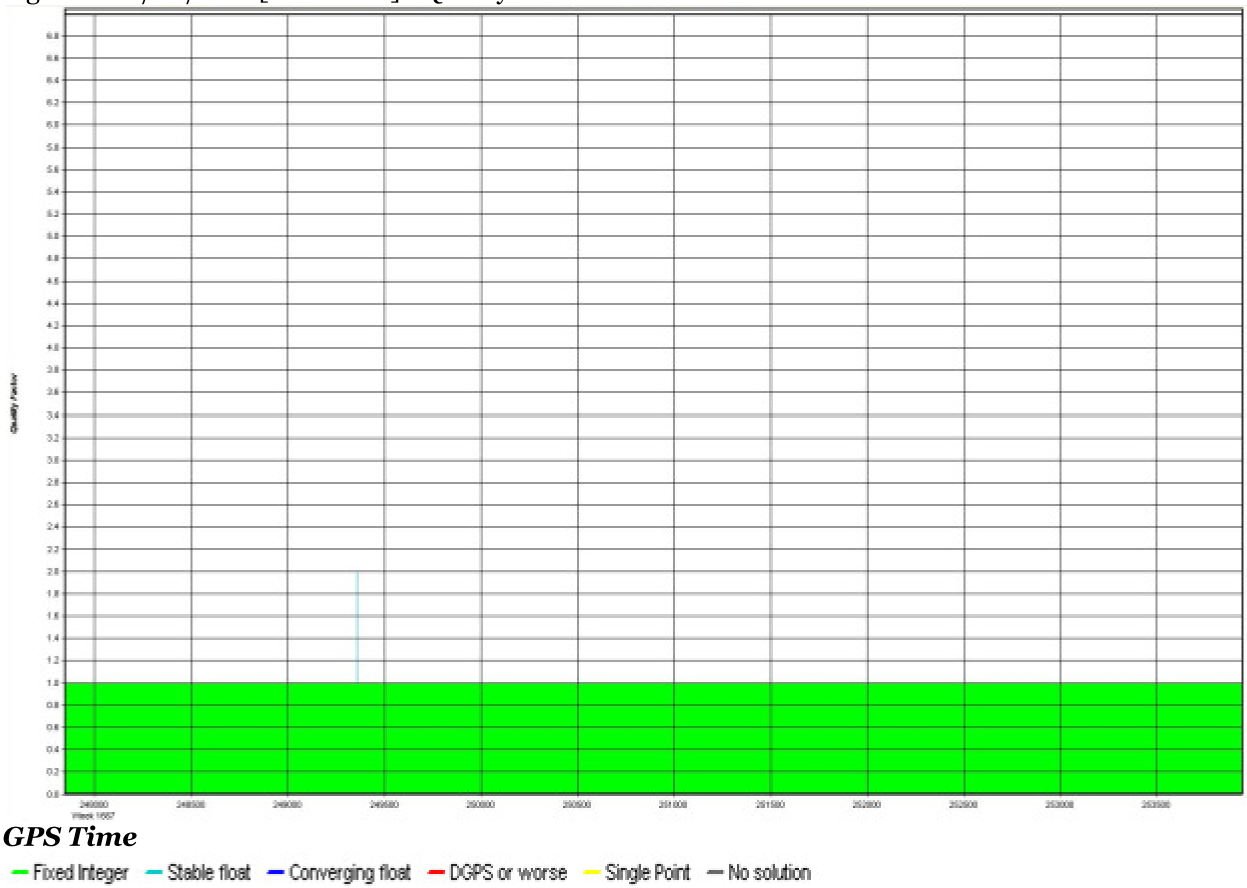
POSPAC Version 4.31

Figure 1: Combined - Map



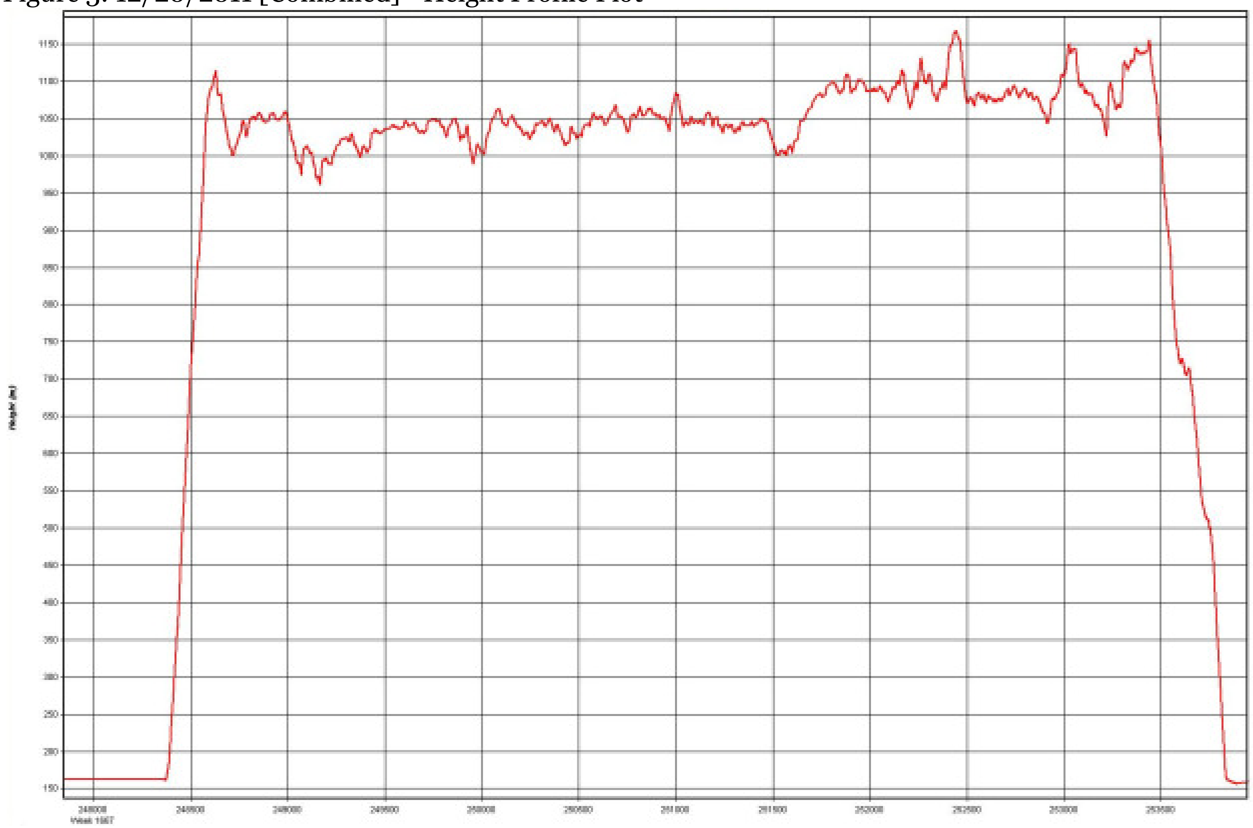
Process	Run (10)	by Unknown	on 12/20/2011	at 12:45

Figure 2: 12/20/2011 [Combined] - Quality Factor Plot



Process	Run (10)	by Unknown	on 12/20/2011	at 12:45

Figure 3: 12/20/2011 [Combined] - Height Profile Plot

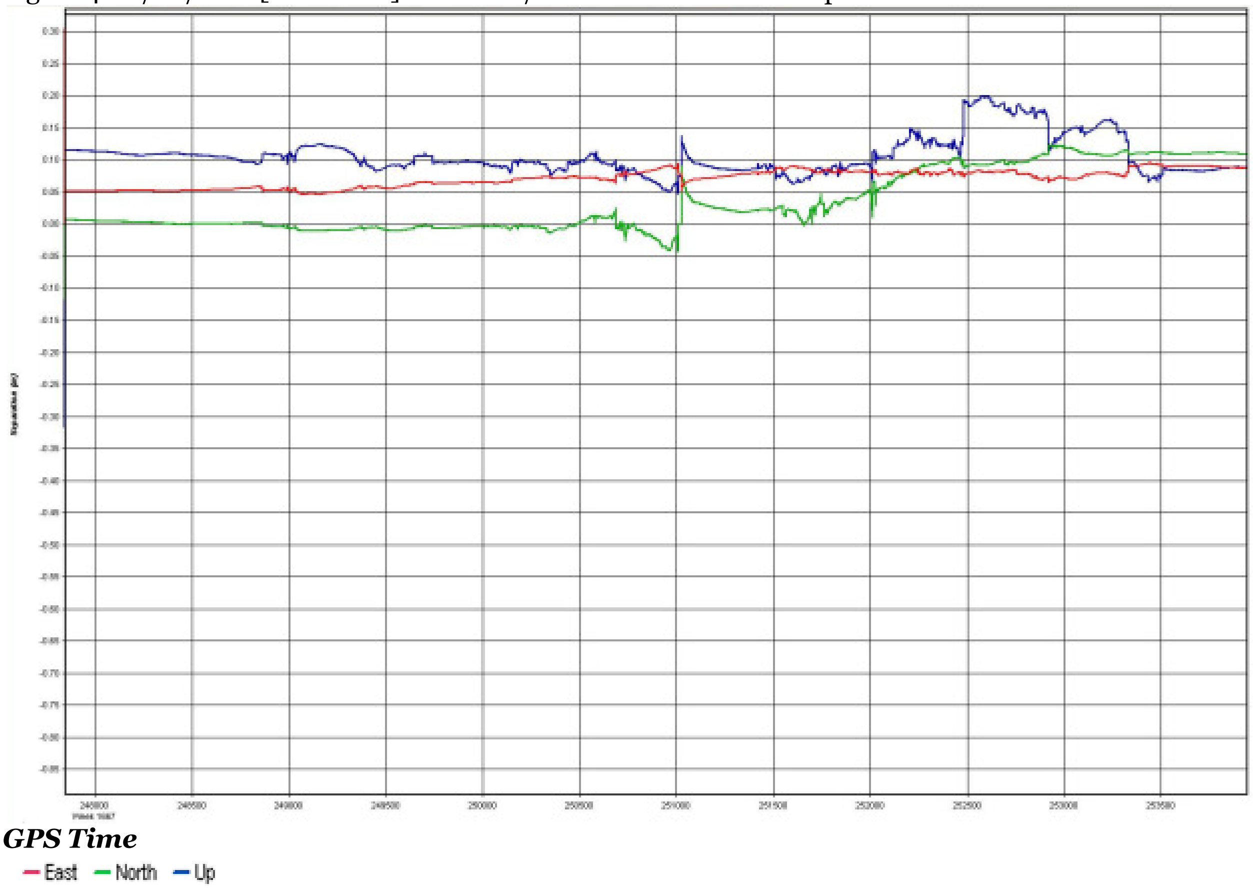


GPS Time

— Height

Process	Run (10)	by Unknown	on 12/20/2011	at 12:45

Figure 4: 12/20/2011 [Combined] - Forward/Reverse or Combined Separation Plot

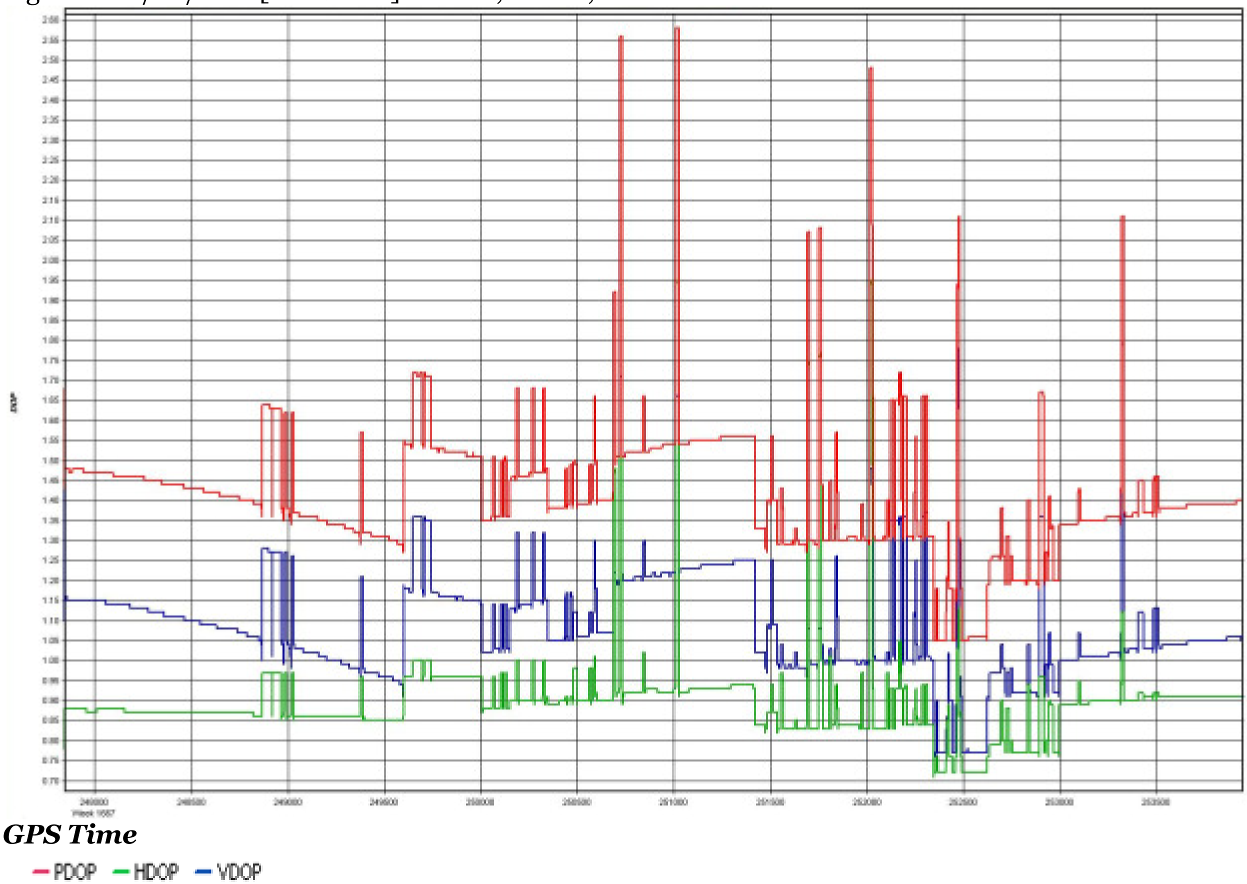


Process	Run (10)	by Unknown	on 12/20/2011	at 12:45

Figure 5: 12/20/2011 [Combined] - Forward/Reverse or Combined Weighting Plot

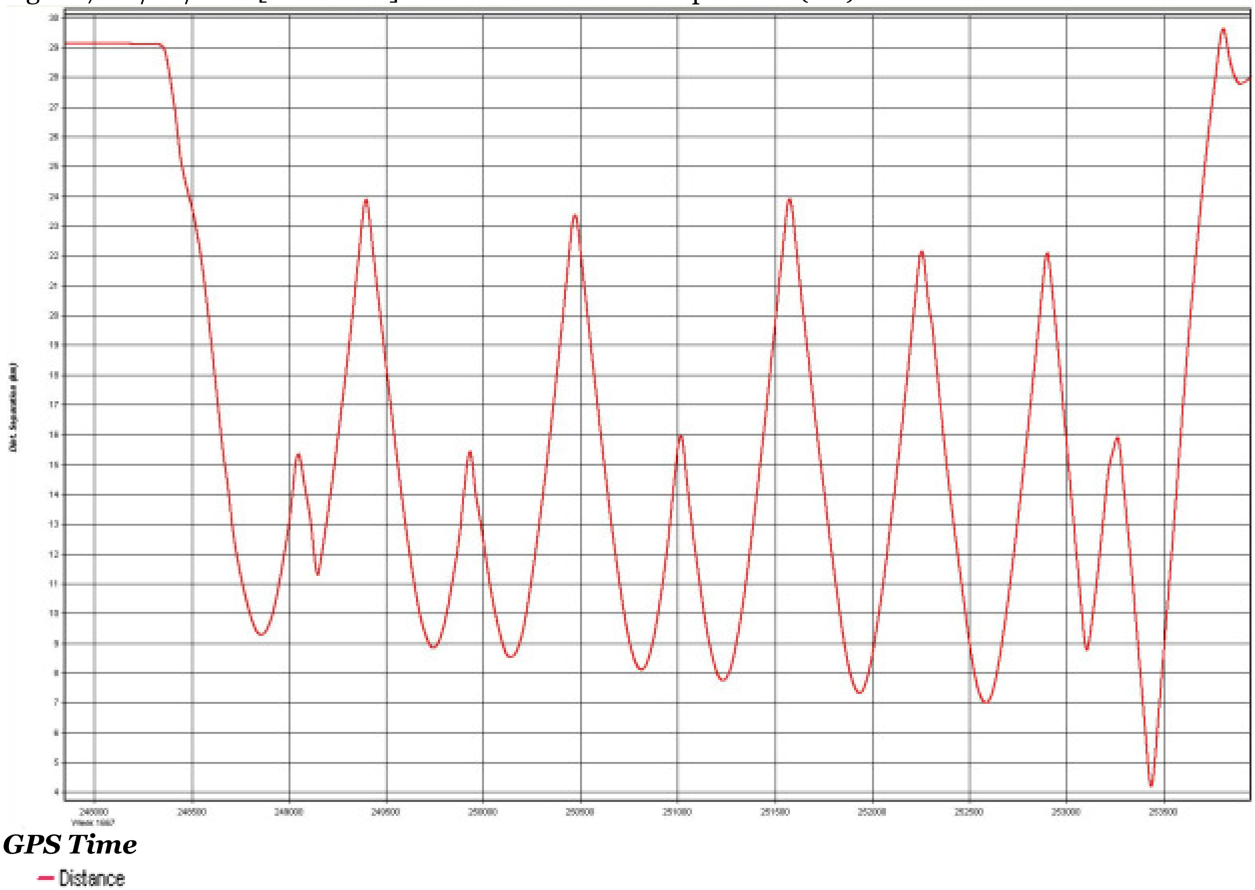
Process	Run (10)	by Unknown	on 12/20/2011	at 12:45

Figure 6: 12/20/2011 [Combined] - PDOP, HDOP, VDOP Plots



Process	Run (10)	by Unknown	on 12/20/2011	at 12:45

Figure 7: 12/20/2011 [Combined] - Horizontal Distance Separation (km)

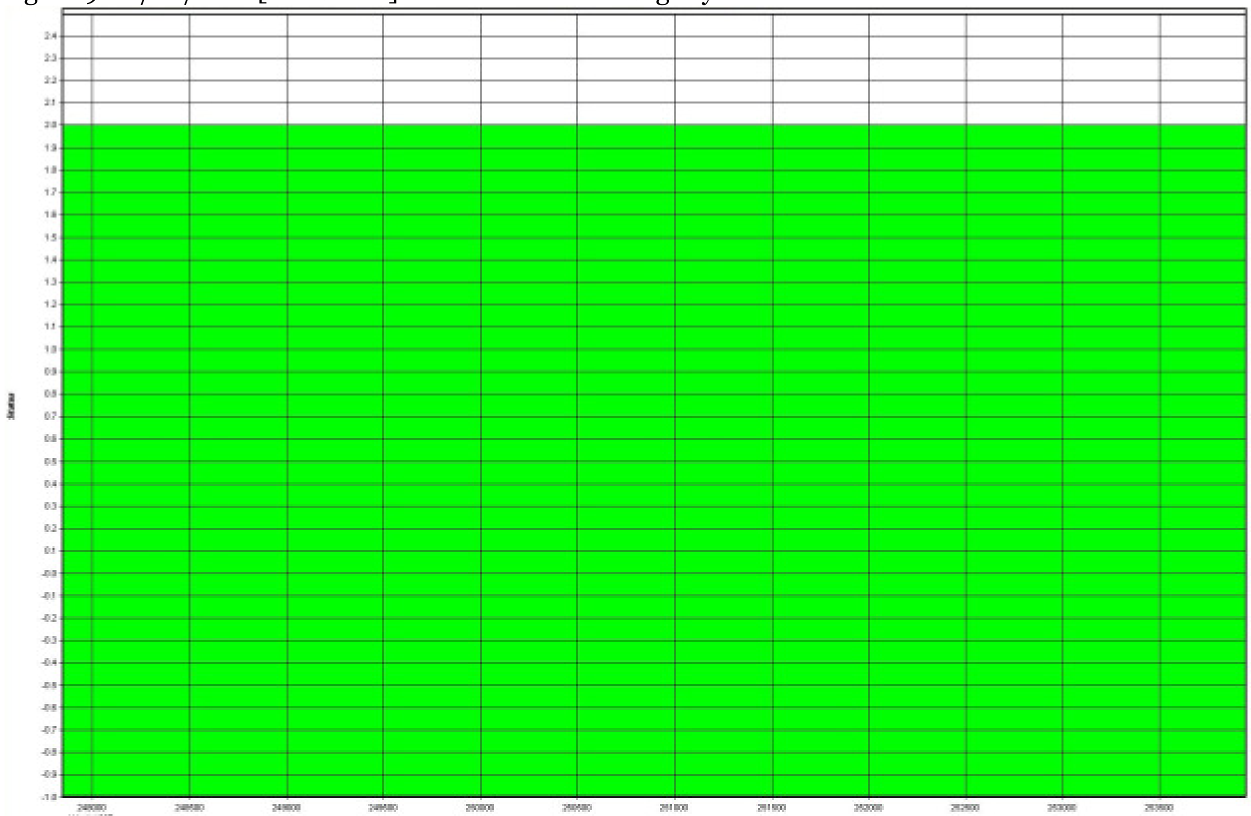


Process	Run (10)	by Unknown	on 12/20/2011	at 12:45

Figure 8: 12/20/2011 [Combined] - Forward/Reverse or Combined RMS Plot

Process	Run (10)	by Unknown	on 12/20/2011	at 12:45

Figure 9: 12/20/2011 [Combined] - Float or Fixed Ambiguity



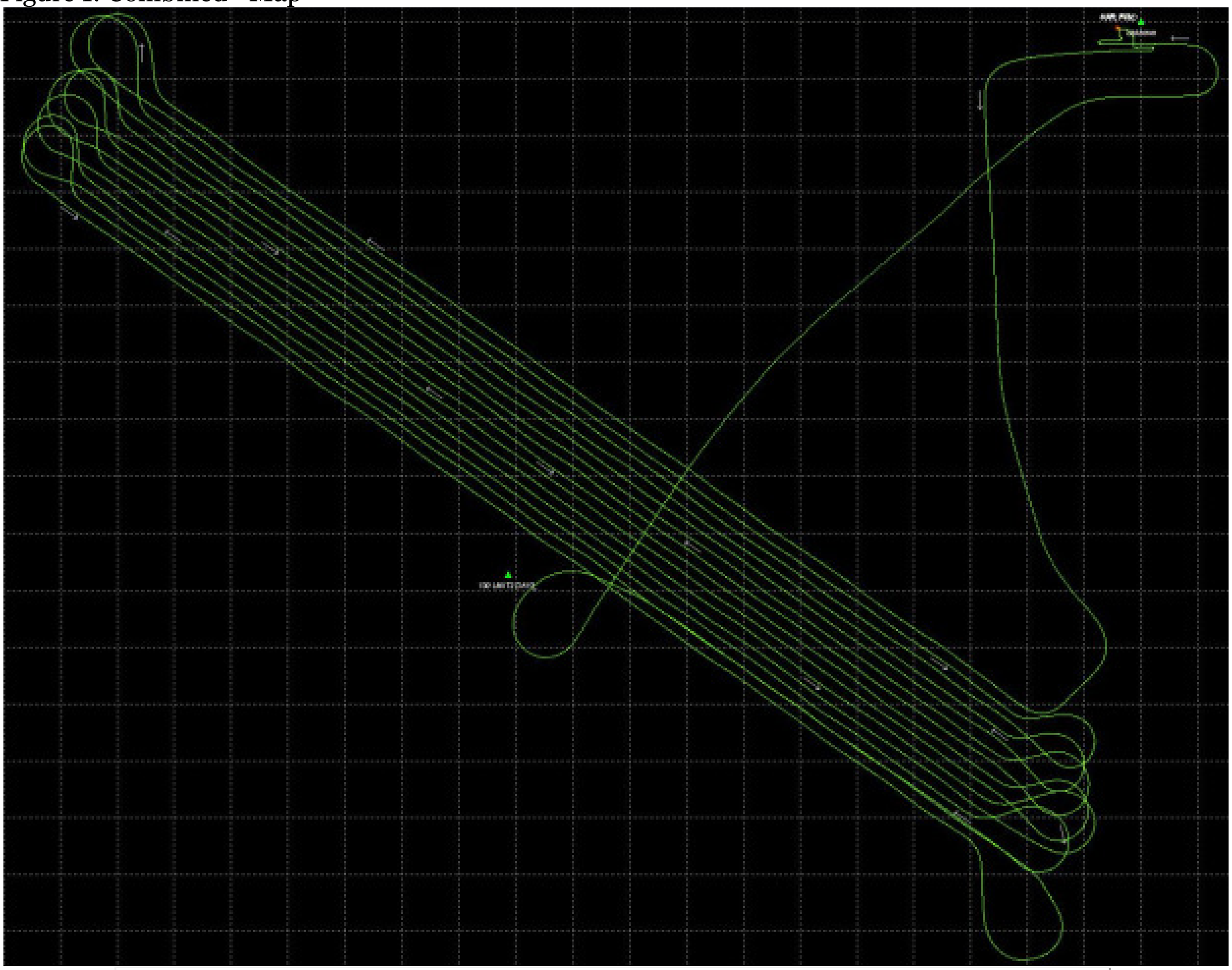
GPS Time

— Float — Fixed (1 baseline) — Fixed (2 or more)

Process	Run (10)	by Unknown	on 12/20/2011	at 12:45

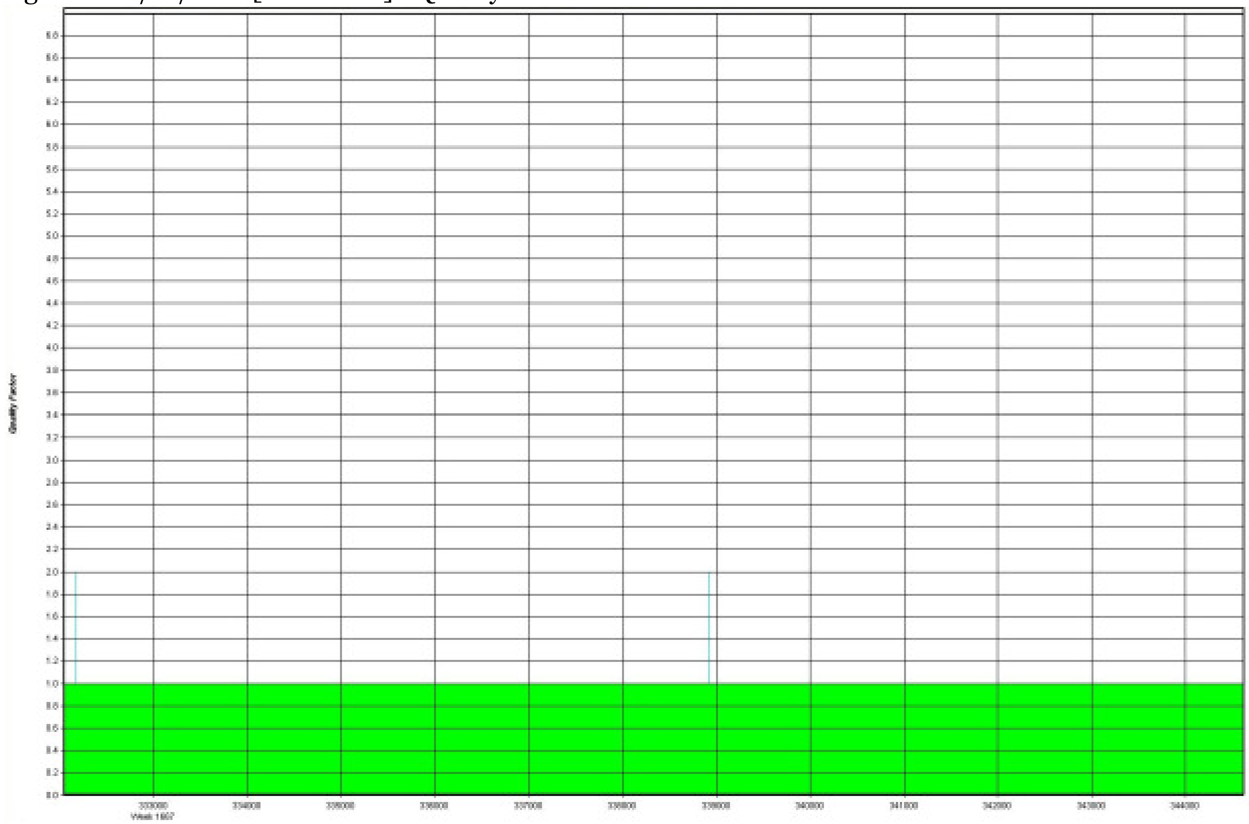
Output Results for 12/21/2011
POSPAC Version 4.31

Figure 1: Combined - Map



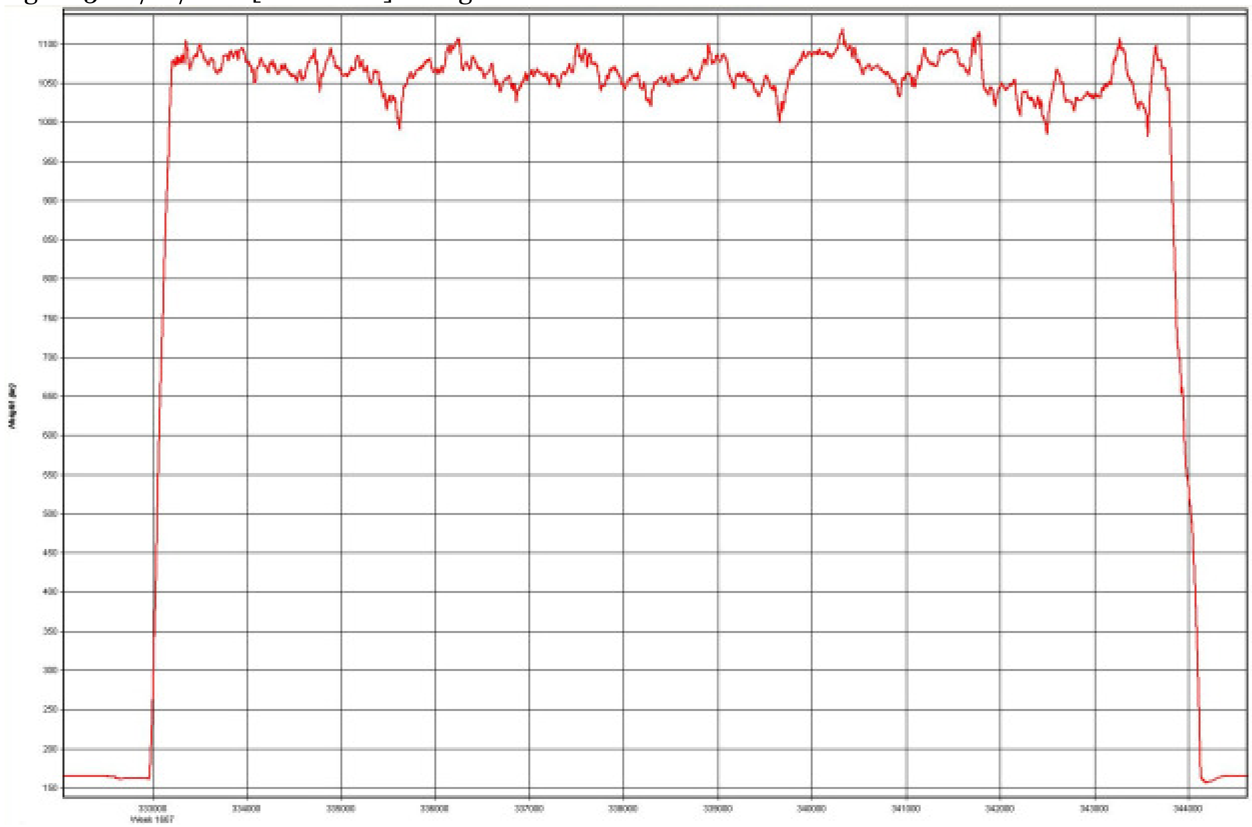
Process	Run (16)	by Unknown	on 12/21/2011	at 12:20

Figure 2: 12/21/2011 [Combined] - Quality Factor Plot



Process	Run (16)	by Unknown	on 12/21/2011	at 12:20

Figure 3: 12/21/2011 [Combined] - Height Profile Plot

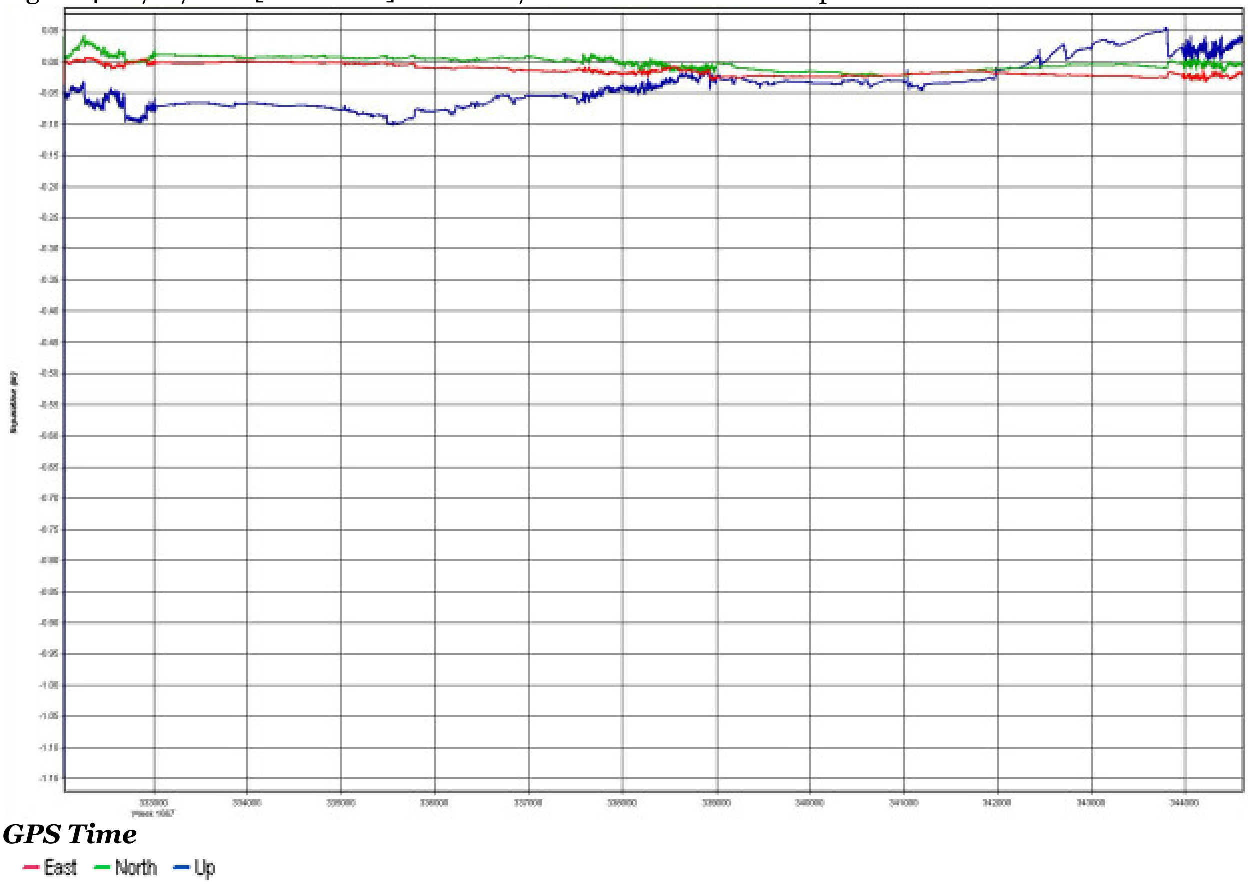


GPS Time

— Height

Process	Run (16)	by Unknown	on 12/21/2011	at 12:20

Figure 4: 12/21/2011 [Combined] - Forward/Reverse or Combined Separation Plot

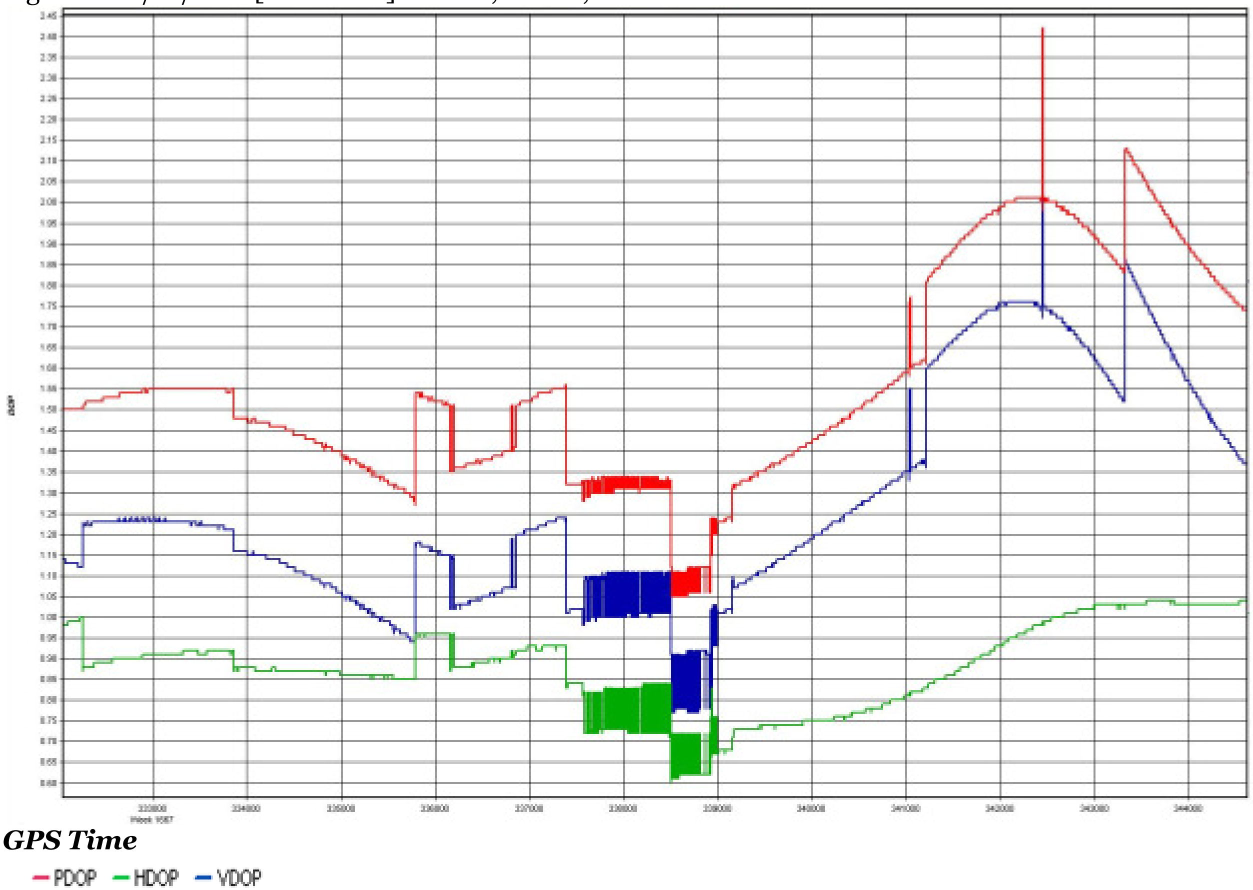


Process	Run (16)	by Unknown	on 12/21/2011	at 12:20

Figure 5: 12/21/2011 [Combined] - Forward/Reverse or Combined Weighting Plot

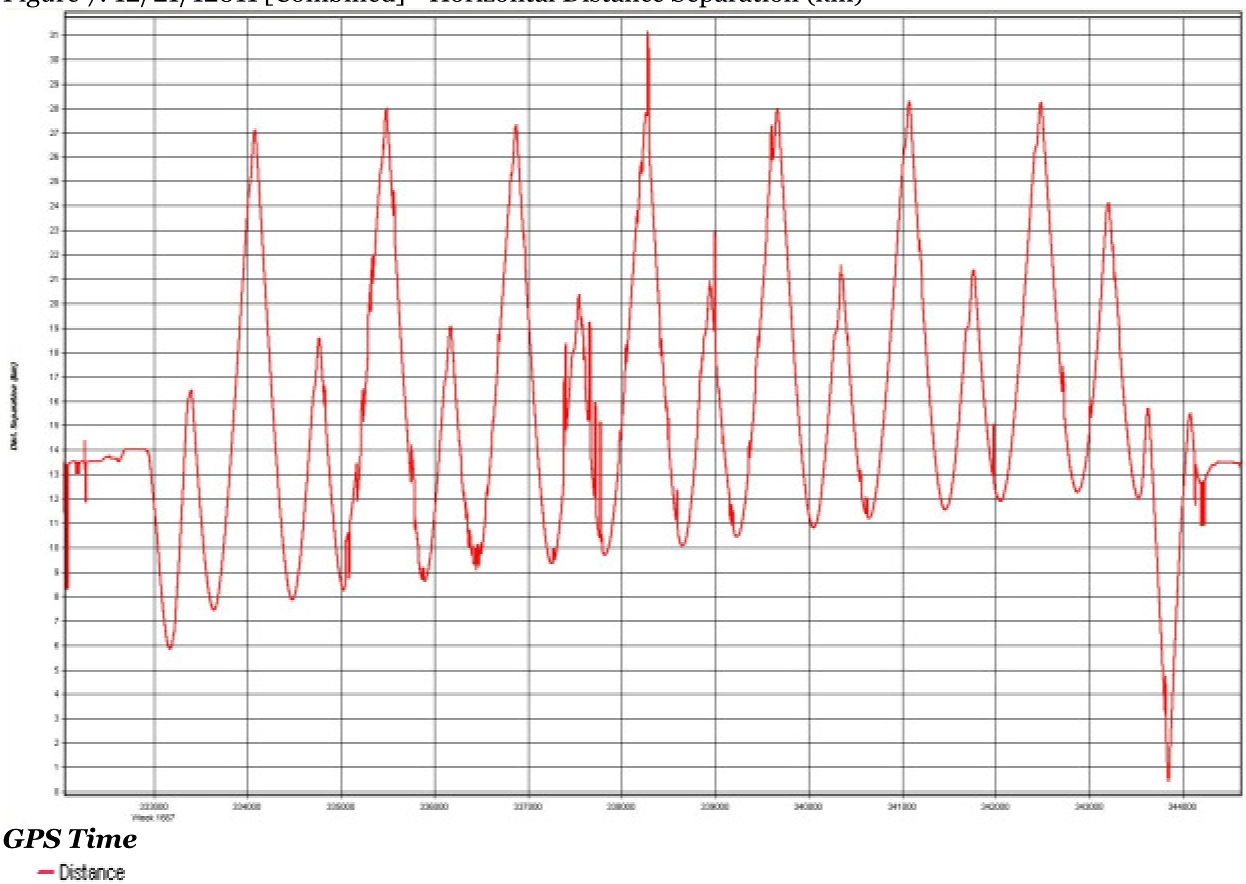
Process	Run (16)	by Unknown	on 12/21/2011	at 12:20

Figure 6: 12/21/2011 [Combined] - PDOP, HDOP, VDOP Plots



Process	Run (16)	by Unknown	on 12/21/2011	at 12:20

Figure 7: 12/21/12011 [Combined] - Horizontal Distance Separation (km)

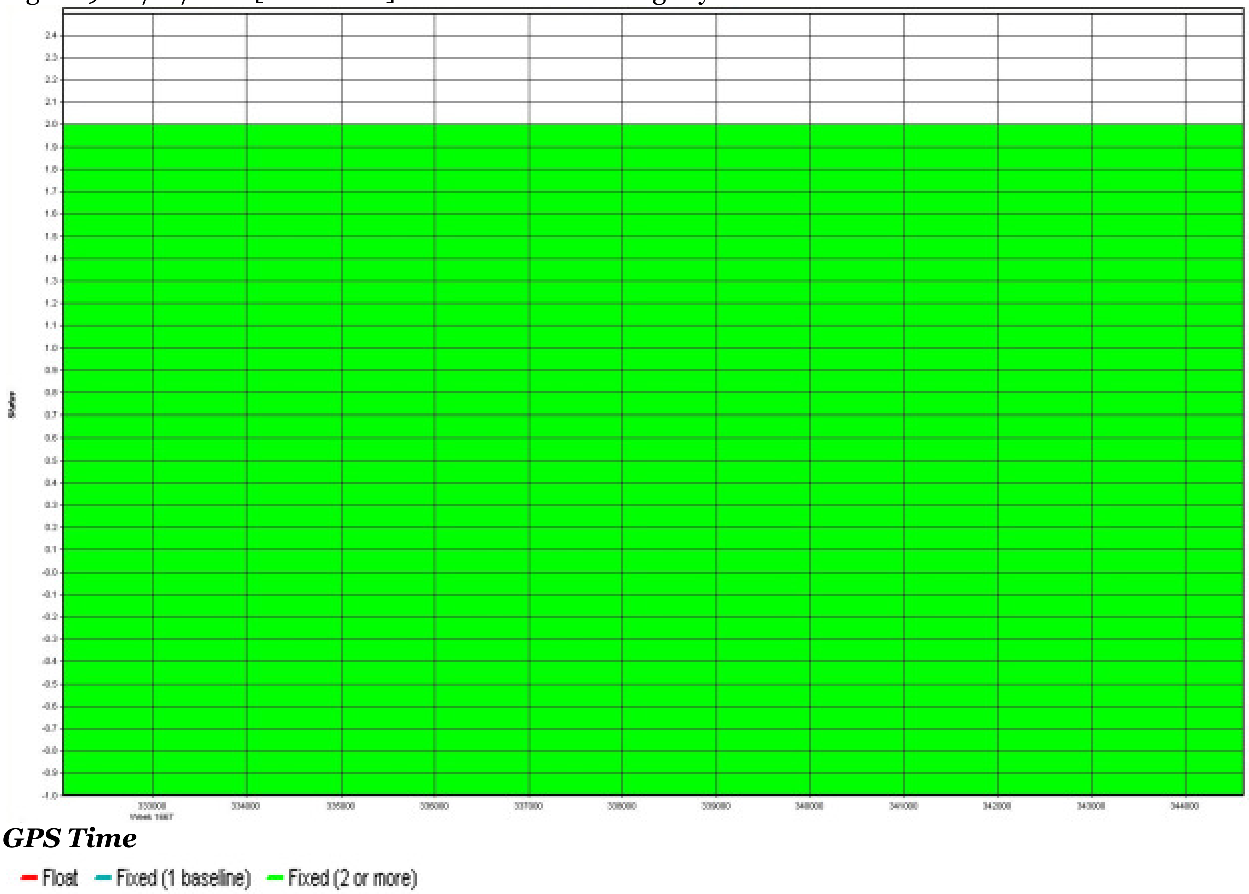


Process	Run (16)	by Unknown	on 12/21/2011	at 12:20

Figure 8: 12/21/2011 [Combined] - Forward/Reverse or Combined RMS Plot

Process	Run (16)	by Unknown	on 12/21/2011	at 12:20

Figure 9: 12/21/2011 [Combined] - Float or Fixed Ambiguity

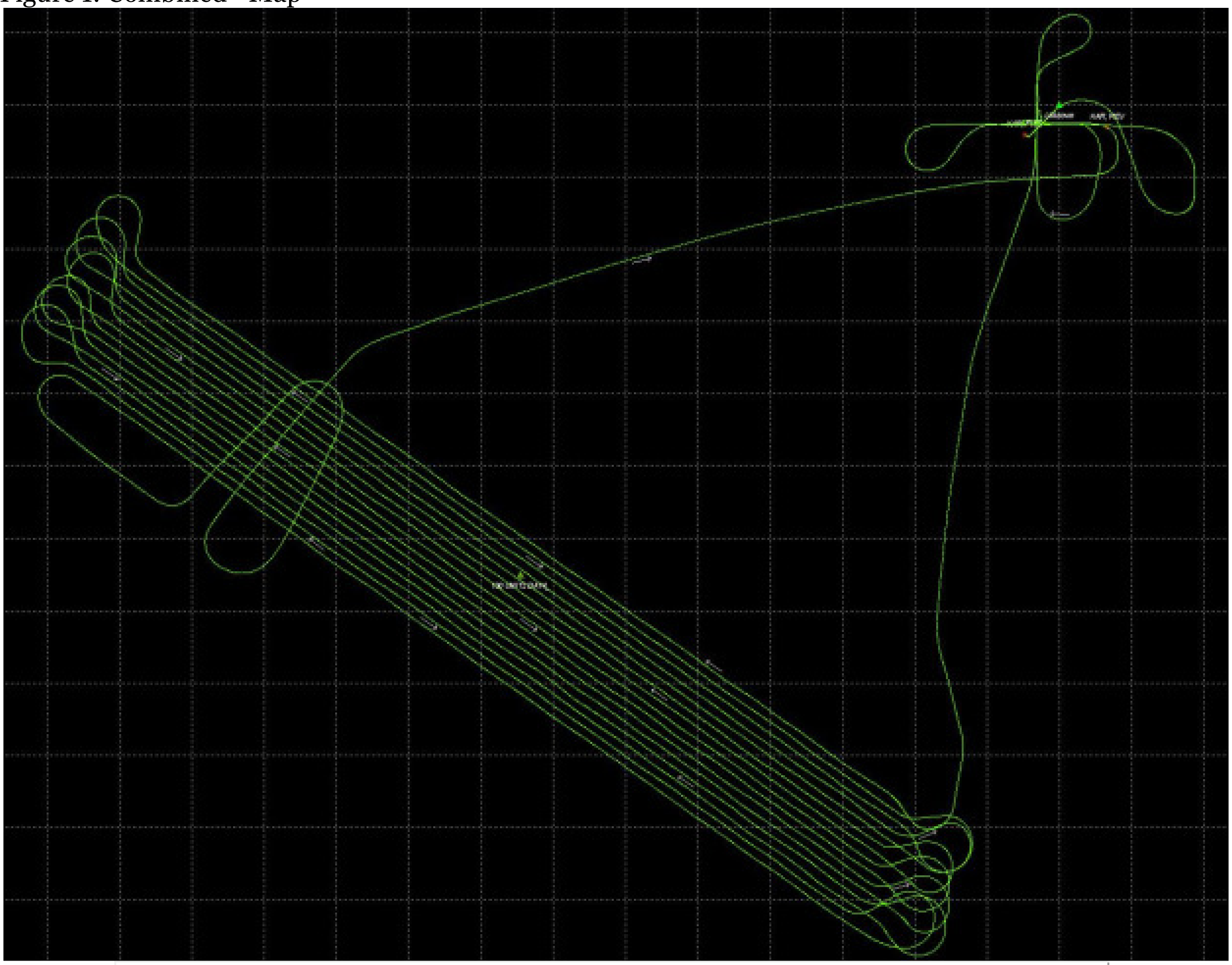


Process	Run (16)	by Unknown	on 12/21/2011	at 12:20

2.7 Output Results for 12/23/2011

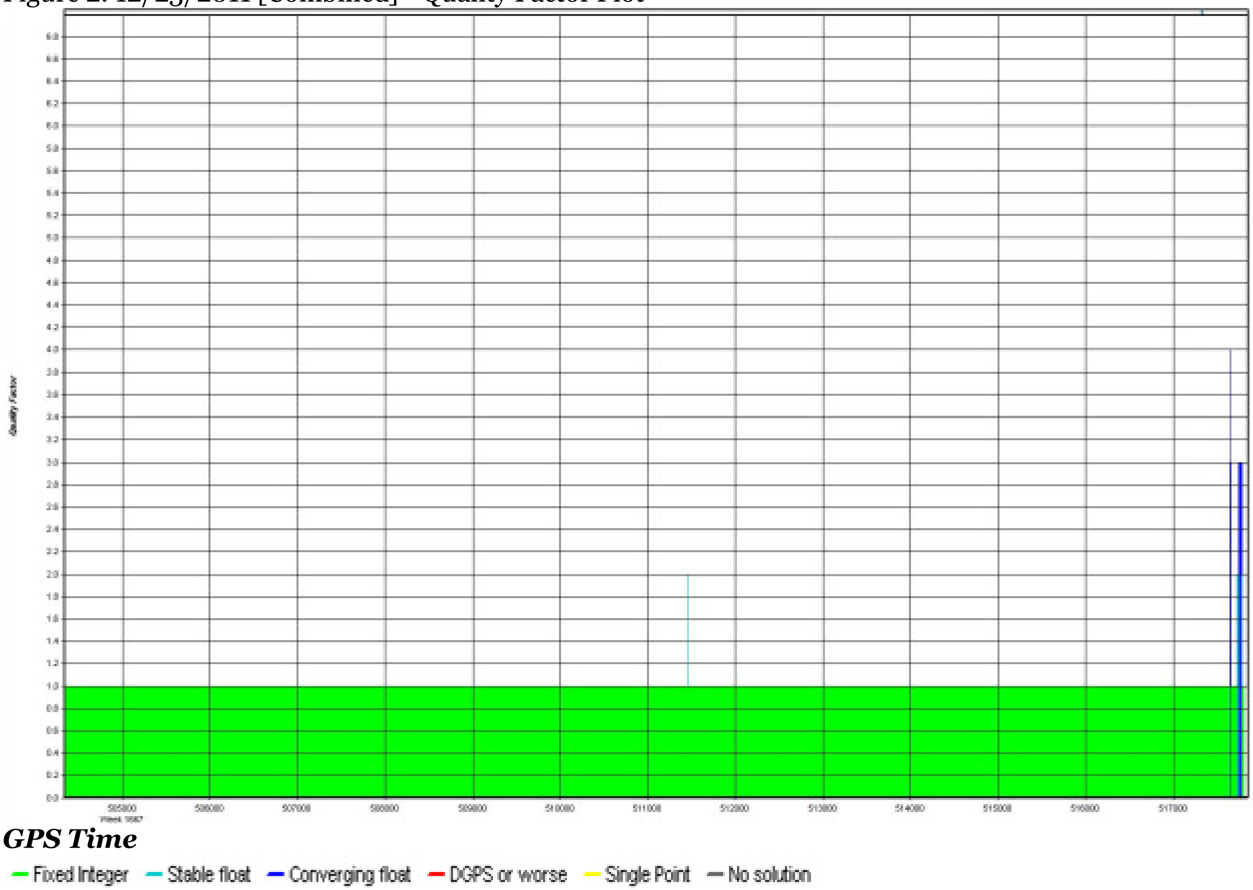
POSPAC Version 4.31

Figure 1: Combined - Map



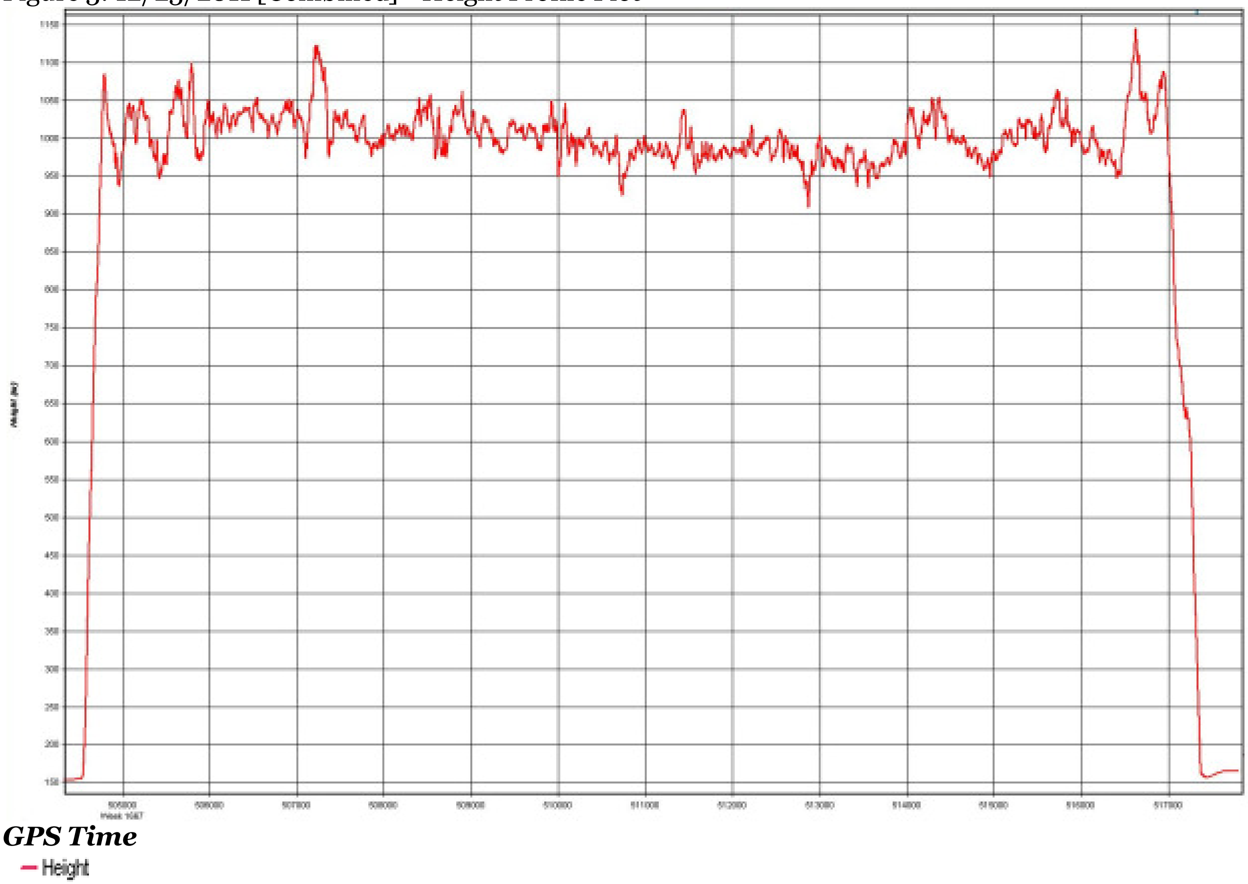
Process	Run (17)	by Unknown	on 12/23/2011	at 12:05

Figure 2: 12/23/2011 [Combined] - Quality Factor Plot



Process	Run (17)	by Unknown	on 12/23/2011	at 12:05

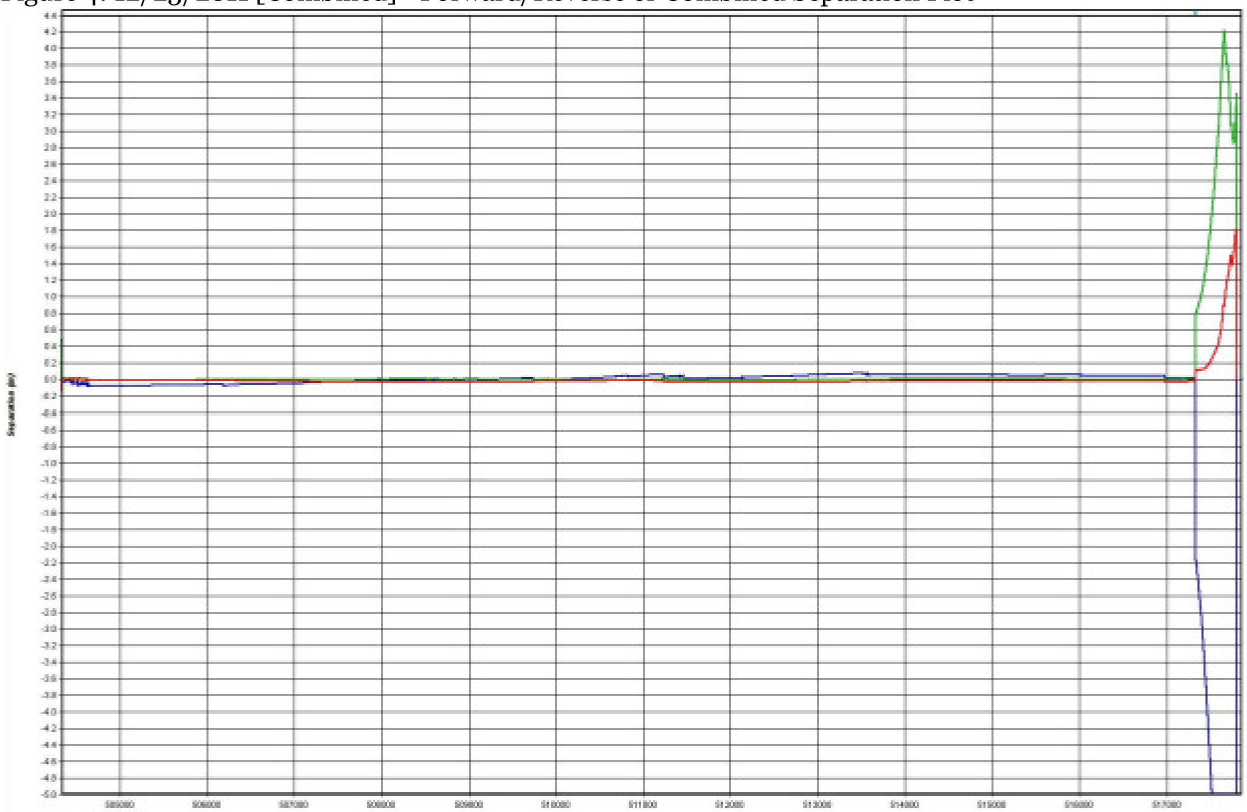
Figure 3: 12/23/2011 [Combined] - Height Profile Plot



GPS Time

Process	Run (17)	by Unknown	on 12/23/2011	at 12:05

Figure 4: 12/23/2011 [Combined] - Forward/Reverse or Combined Separation Plot



GPS Time

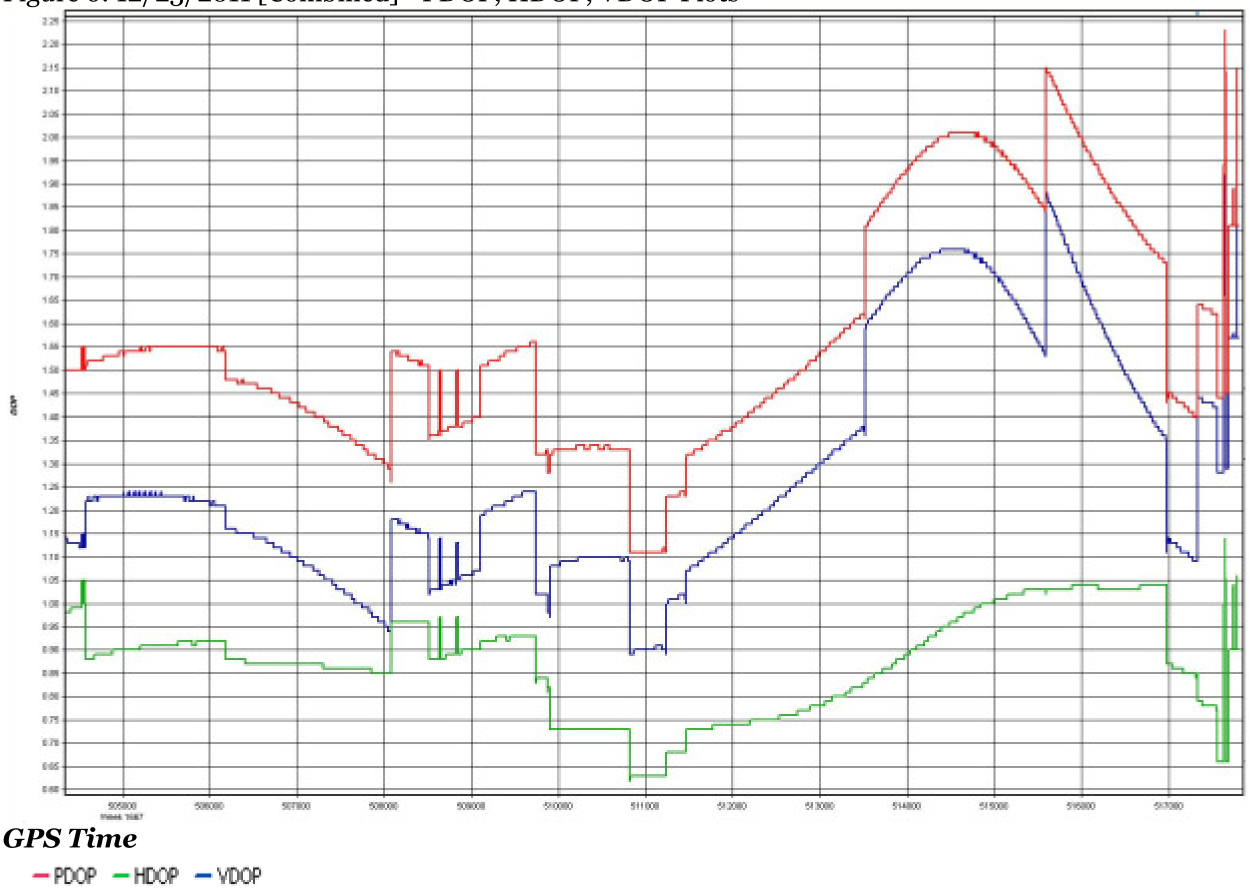
East North Up

Process	Run (17)	by Unknown	on 12/23/2011	at 12:05

Figure 5: 12/23/2011 [Combined] - Forward/Reverse or Combined Weighting Plot

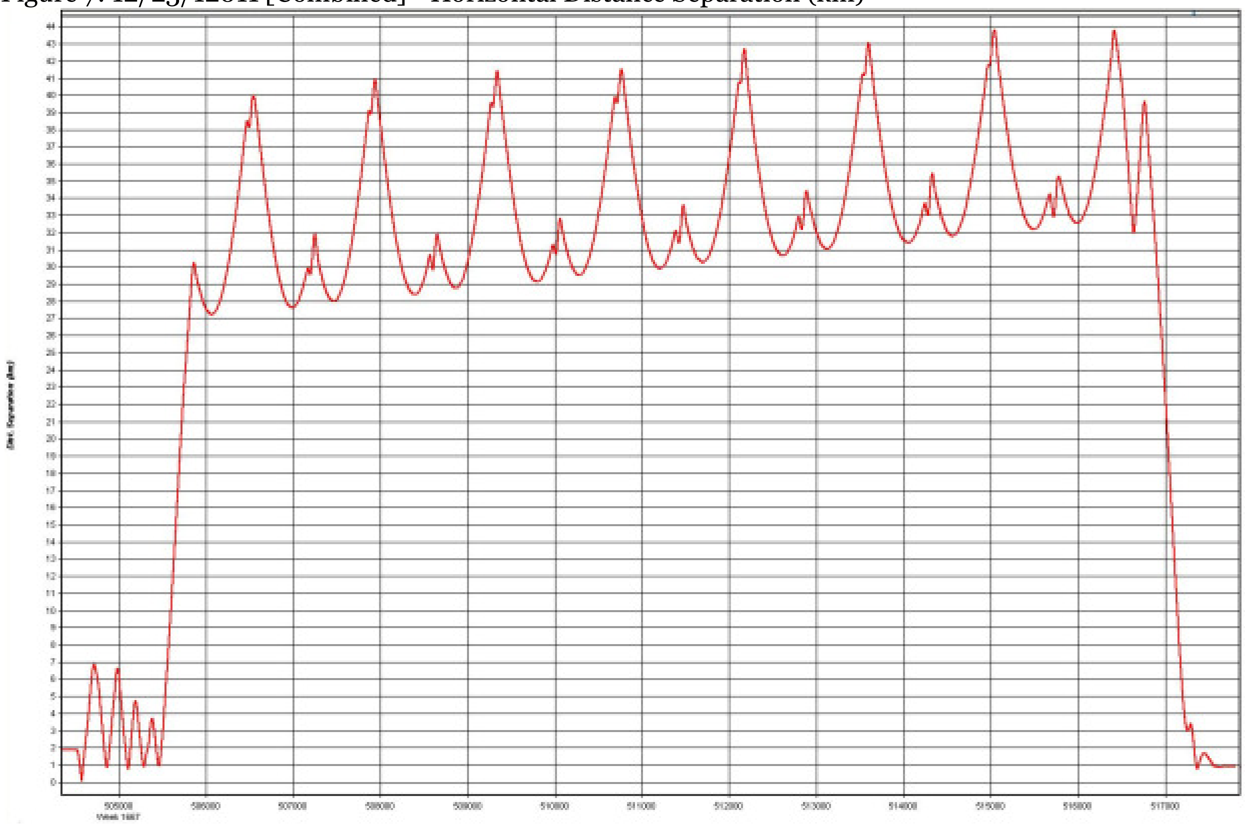
Process	Run (17)	by Unknown	on 12/23/2011	at 12:05

Figure 6: 12/23/2011 [Combined] - PDOP, HDOP, VDOP Plots



Process	Run (17)	by Unknown	on 12/23/2011	at 12:05

Figure 7: 12/23/12011 [Combined] - Horizontal Distance Separation (km)



GPS Time

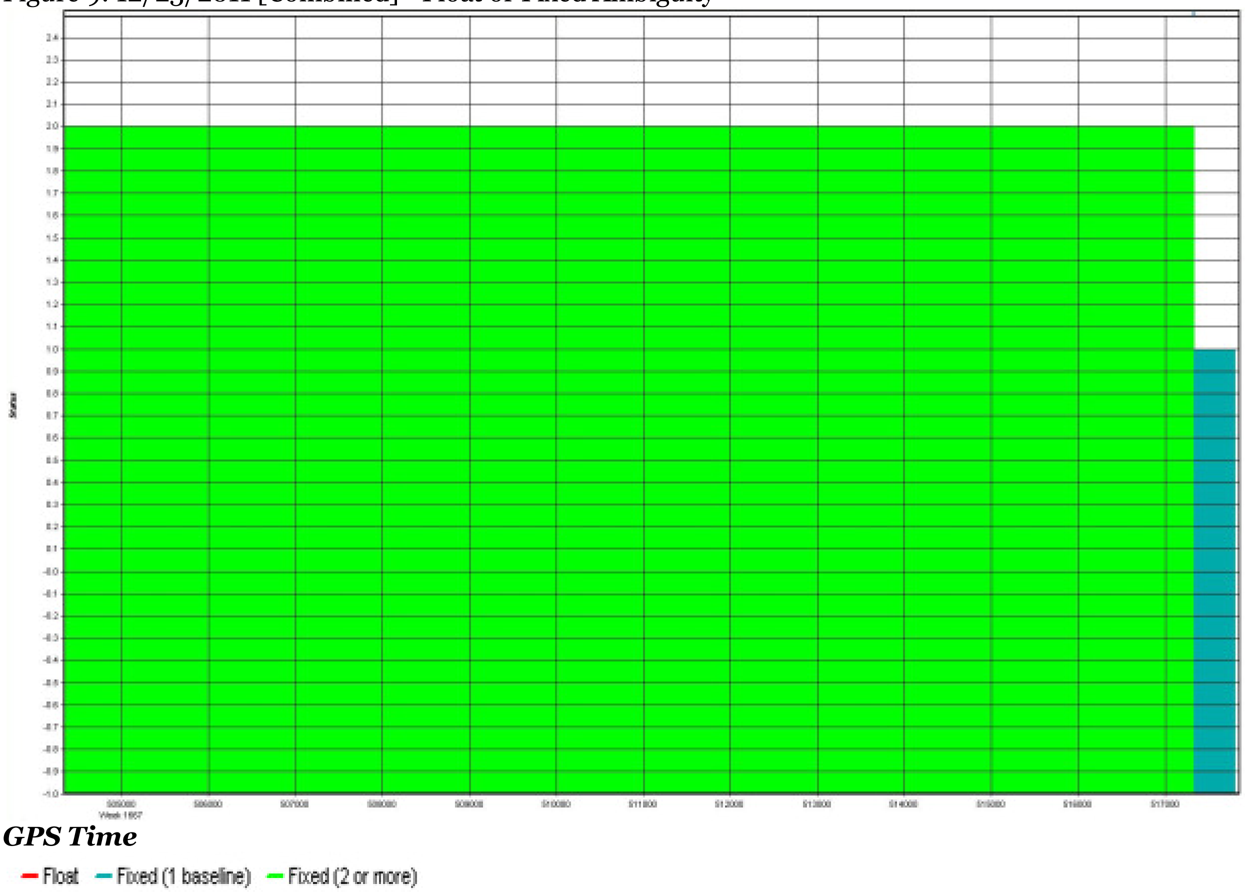
— Distance

Process	Run (17)	by Unknown	on 12/23/2011	at 12:05

Figure 8: 12/23/2011 [Combined] - Forward/Reverse or Combined RMS Plot

Process	Run (17)	by Unknown	on 12/23/2011	at 12:05

Figure 9: 12/23/2011 [Combined] - Float or Fixed Ambiguity

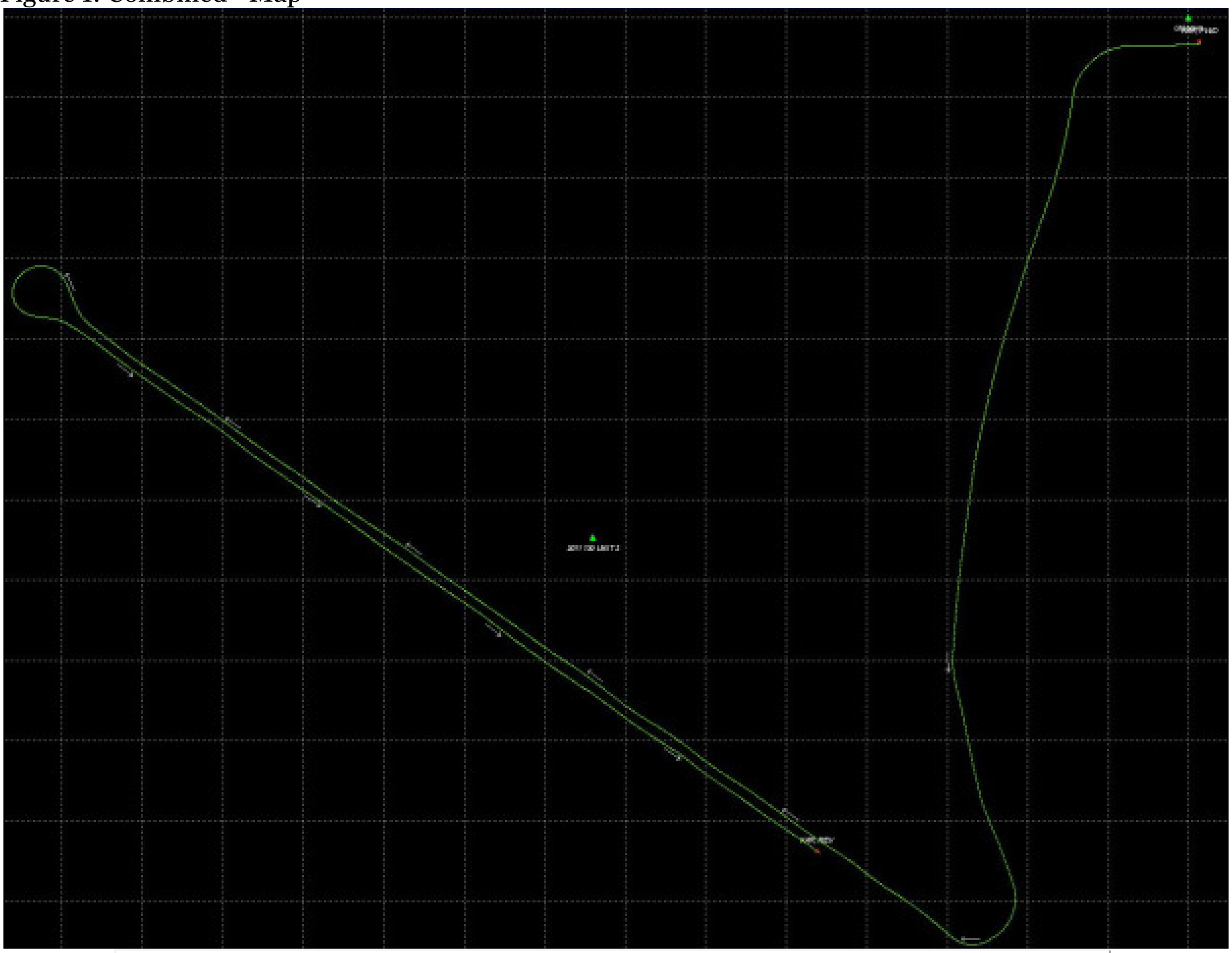


Process	Run (17)	by Unknown	on 12/23/2011	at 12:05

2.8 Output Results for 12/24/2011AM

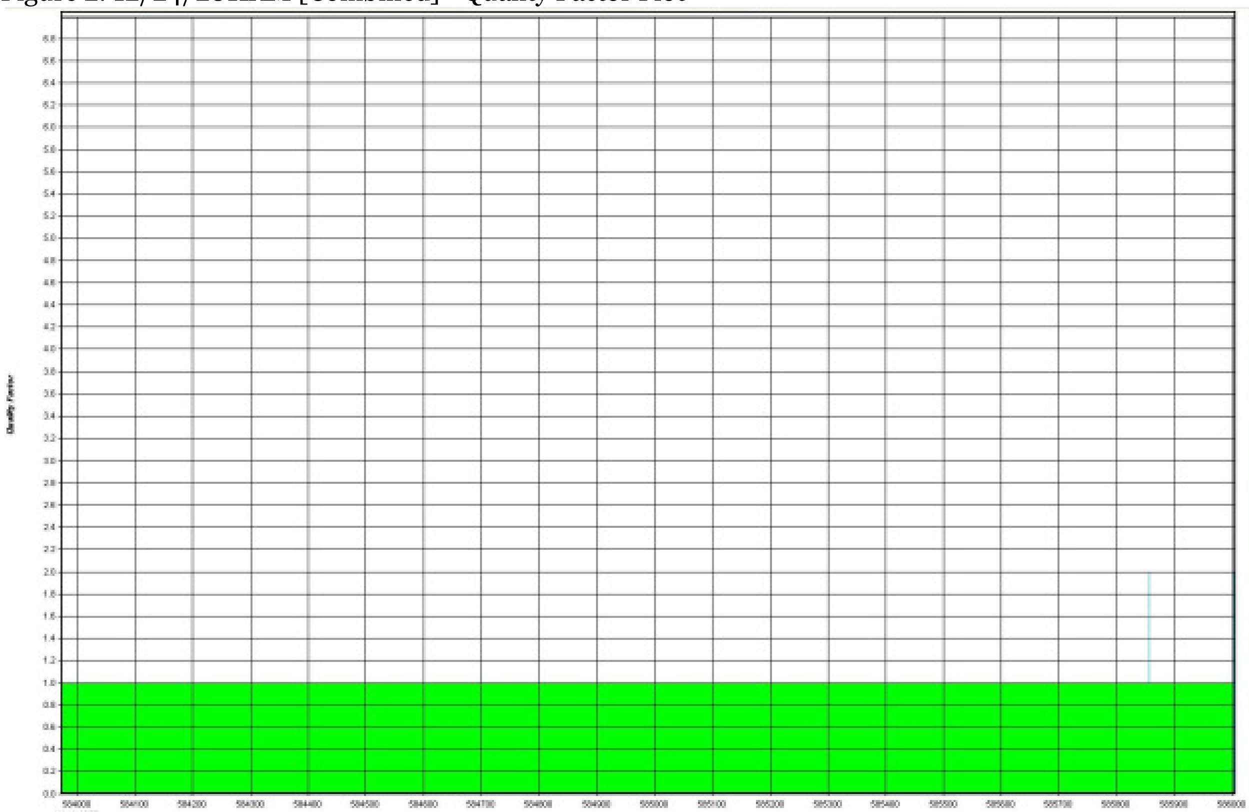
POSPAC Version 4.31

Figure 1: Combined - Map



Process	Run (2)	by Unknown	on 12/24/2011	at 10:20

Figure 2: 12/24/2011AM [Combined] - Quality Factor Plot

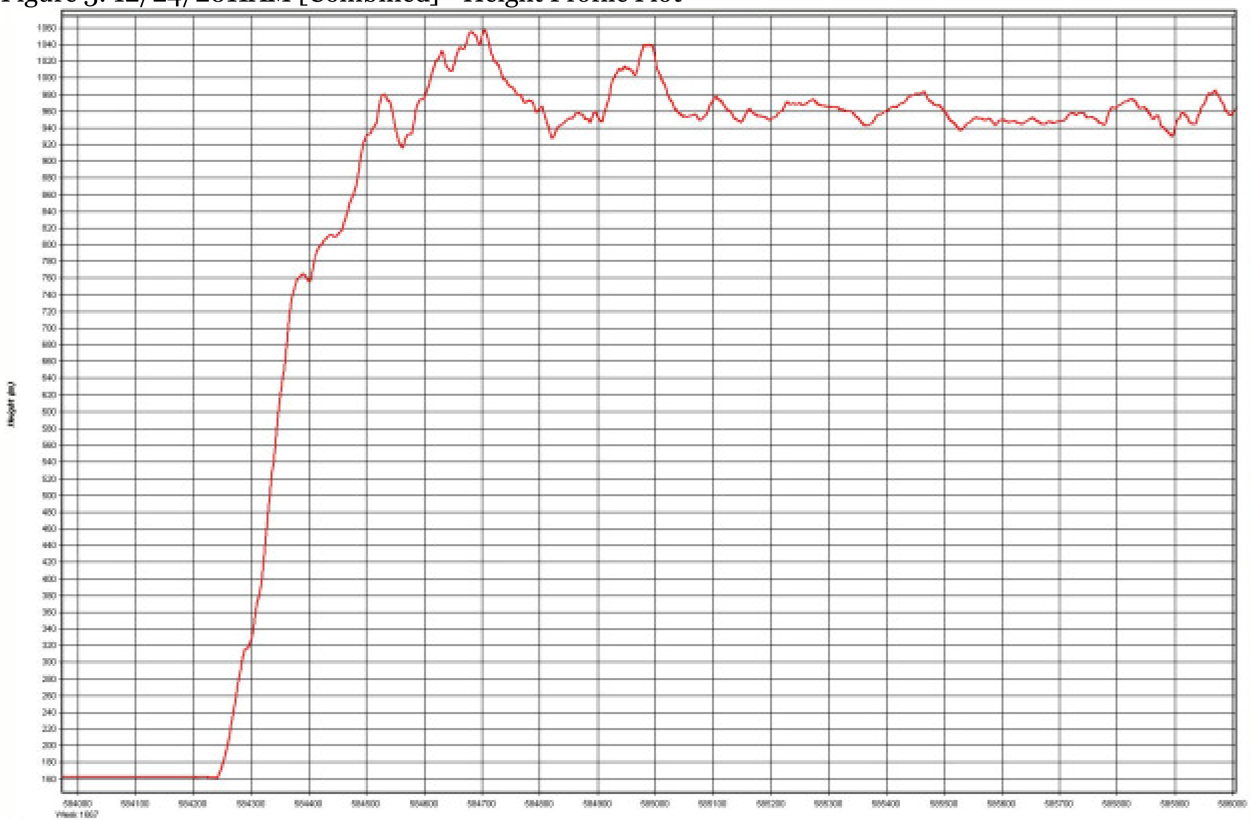


GPS Time

— Fixed Integer — Stable float — Converging float — DGPS or worse — Single Point — No solution

Process	Run (2)	by Unknown	on 12/24/2011	at 10:20

Figure 3: 12/24/2011AM [Combined] - Height Profile Plot

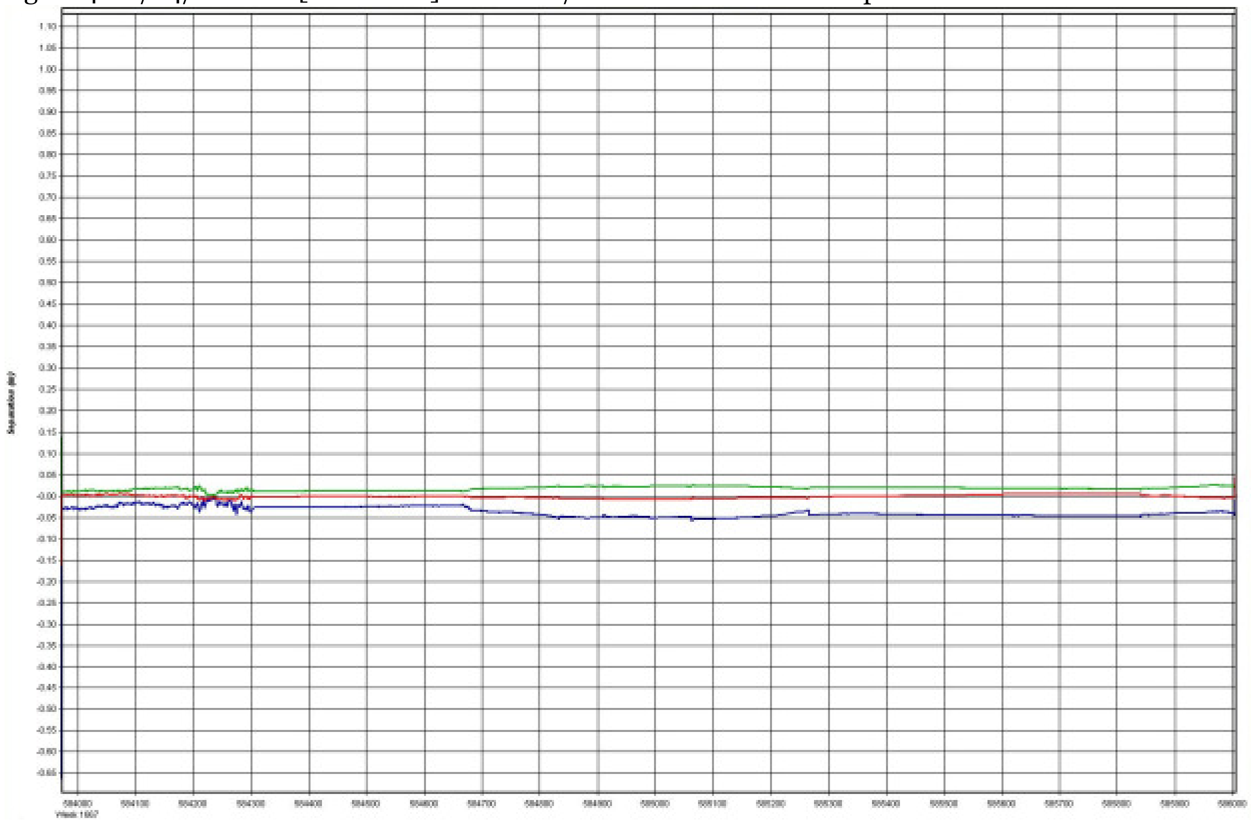


GPS Time

— Height

Process	Run (2)	by Unknown	on 12/24/2011	at 10:20

Figure 4: 12/24/2011AM [Combined] - Forward/Reverse or Combined Separation Plot

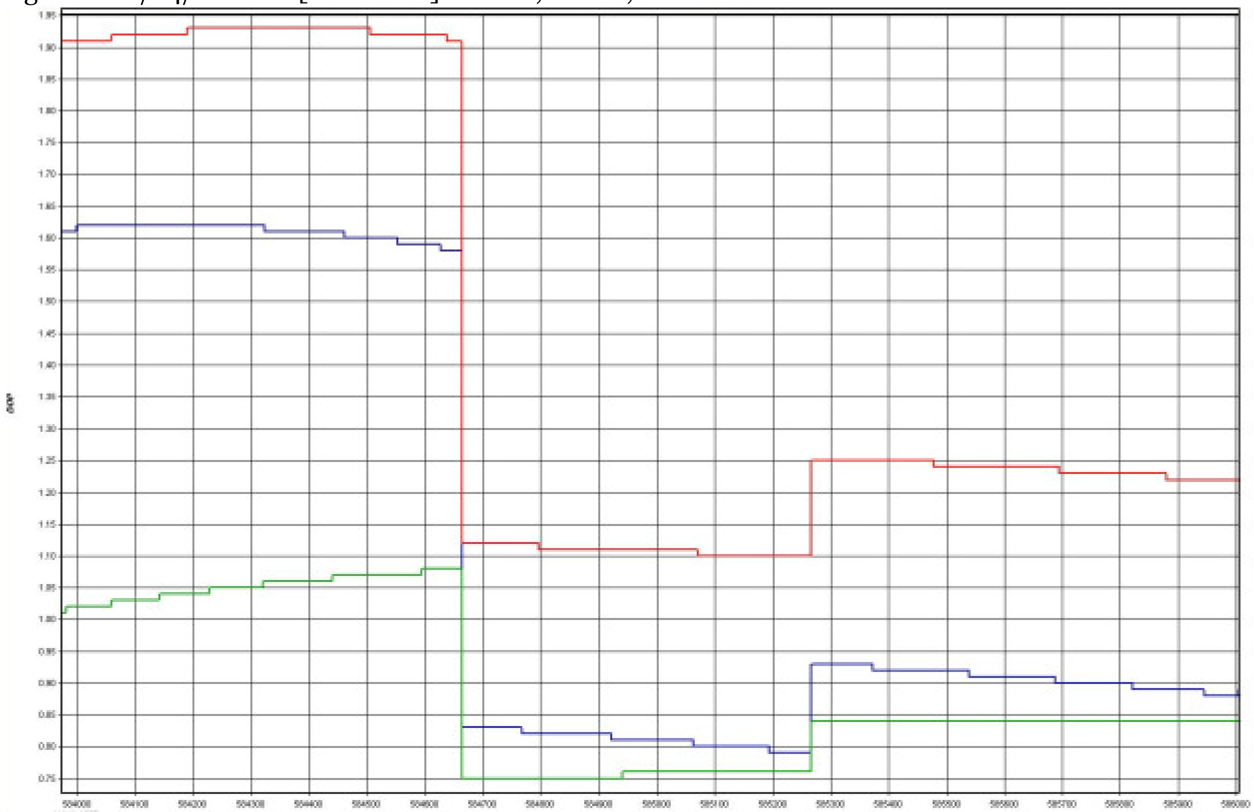


Process	Run (2)	by Unknown	on 12/24/2011	at 10:20

Figure 5: 12/24/2011AM [Combined] - Forward/Reverse or Combined Weighting Plot

Process	Run (2)	by Unknown	on 12/24/2011	at 10:20

Figure 6: 12/24/2011AM [Combined] - PDOP, HDOP, VDOP Plots



GPS Time

— PDOP — HDOP — VDOP

Process	Run (2)	by Unknown	on 12/24/2011	at 10:20

Figure 7: 12/24/2011AM [Combined] - Horizontal Distance Separation (km)

GPS Time

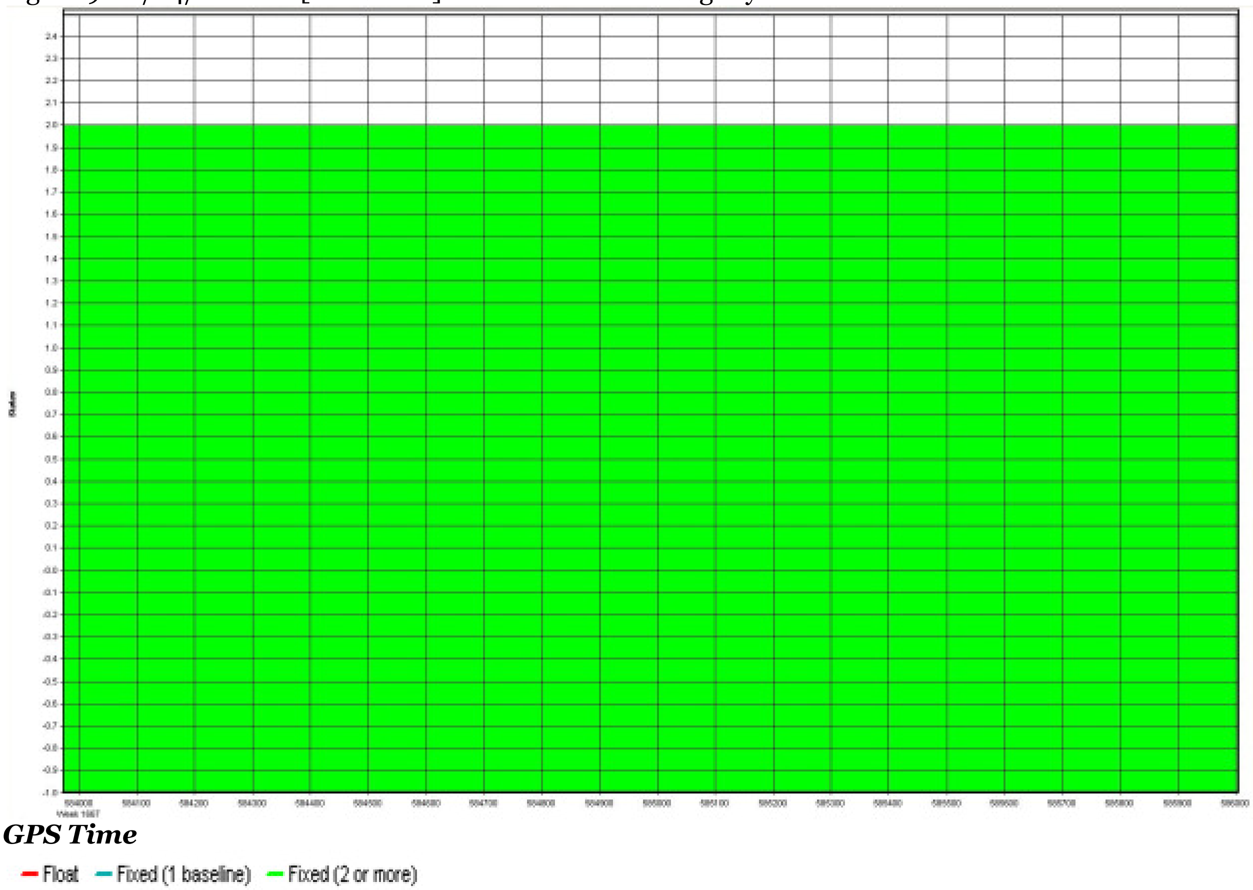
Distance

Process	Run (2)	by Unknown	on 12/24/2011	at 10:20

Figure 8: 12/24/2011AM [Combined] - Forward/Reverse or Combined RMS Plot

Process	Run (2)	by Unknown	on 12/24/2011	at 10:20

Figure 9: 12/24/2011AM [Combined] - Float or Fixed Ambiguity

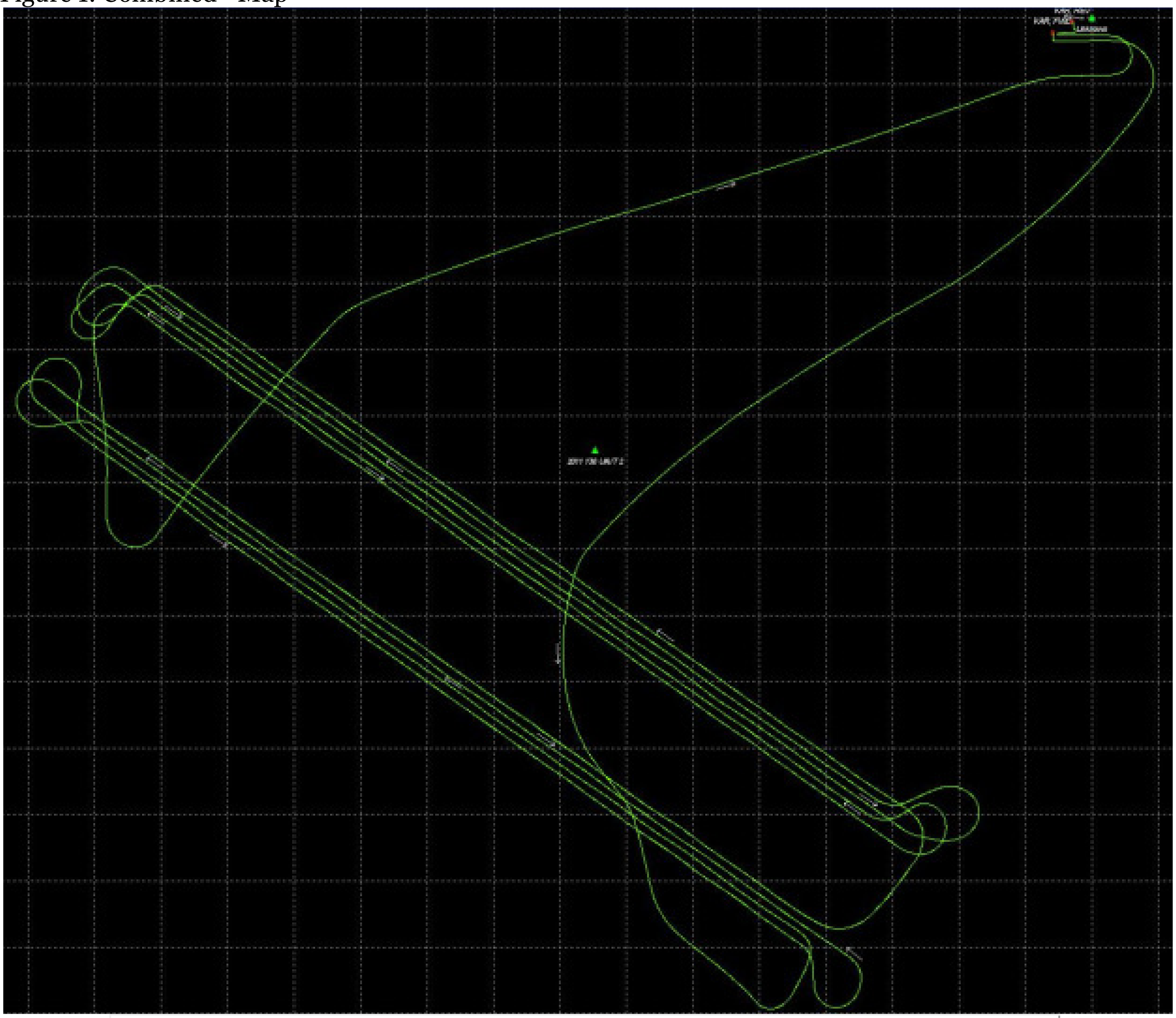


Process	Run (2)	by Unknown	on 12/24/2011	at 10:20

2.9 Output Results for 12/24/2011PM

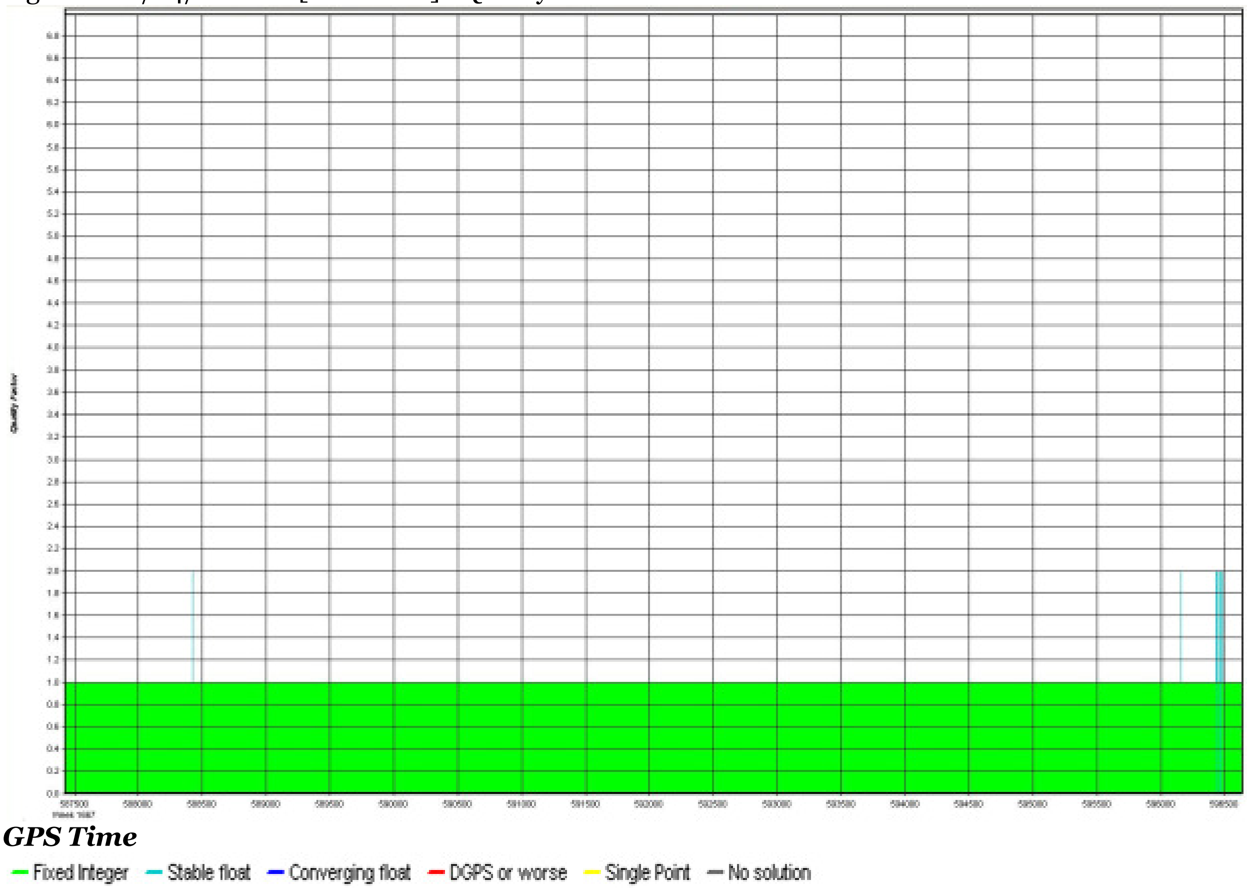
POSPAC Version 4.31

Figure 1: Combined - Map



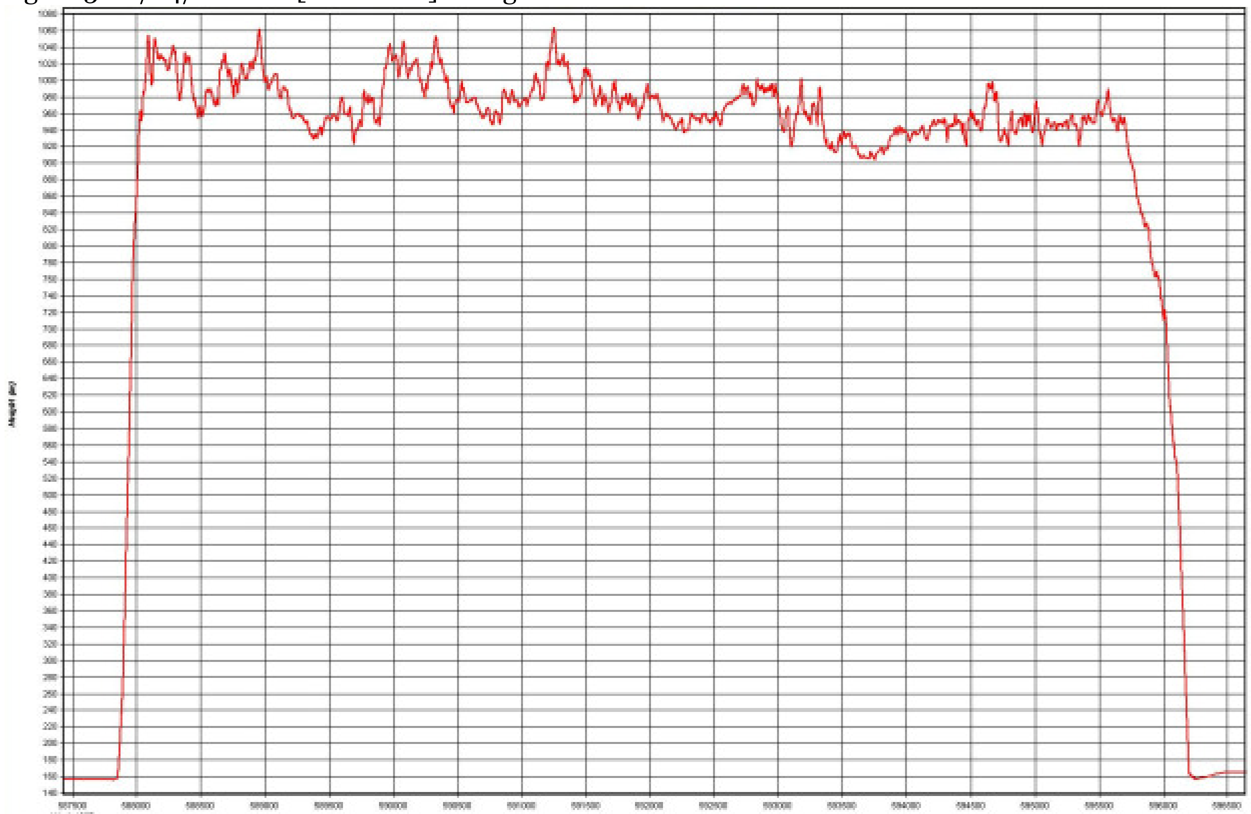
Process	Run (10)	by Unknown	on 12/24/2011	at 13:55

Figure 2: 12/24/2011PM [Combined] - Quality Factor Plot



Process	Run (10)	by Unknown	on 12/24/2011	at 13:55

Figure 3: 12/24/2011PM [Combined] - Height Profile Plot

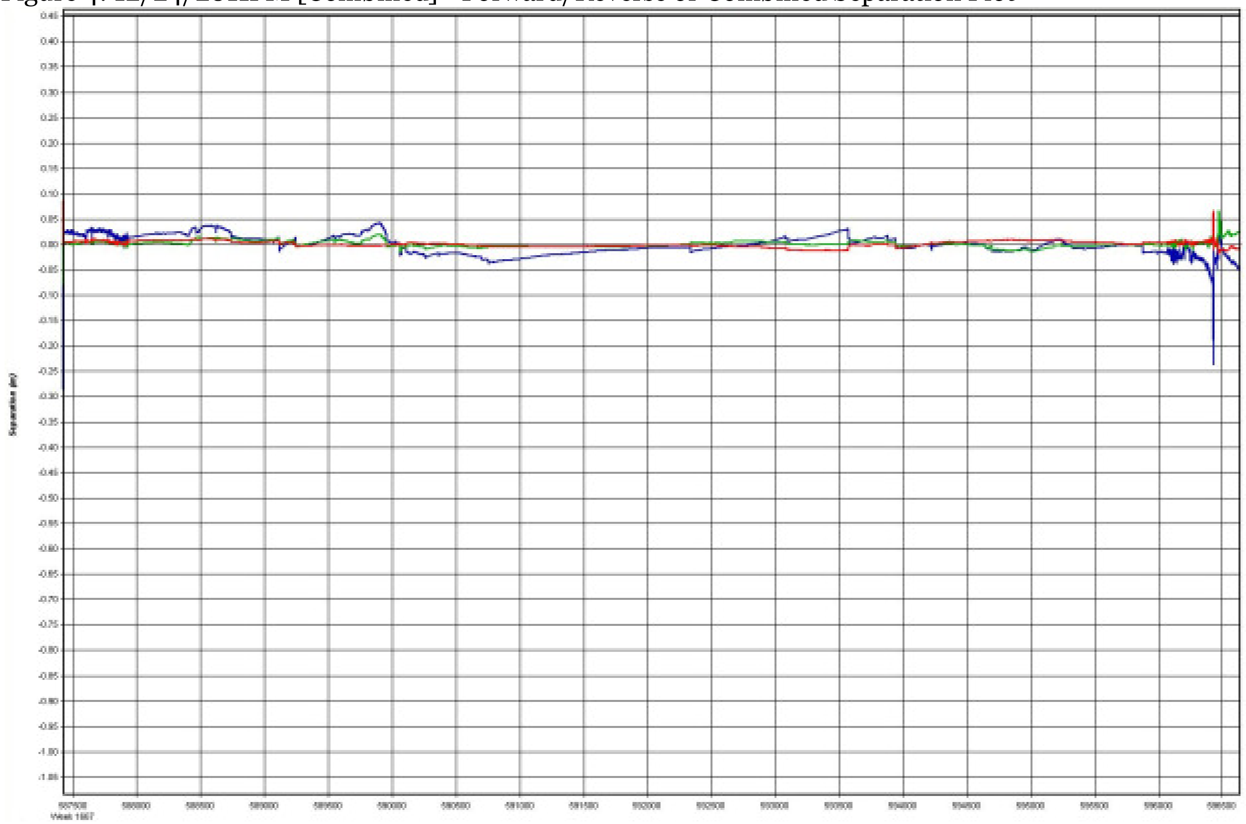


GPS Time

— Height

Process	Run (10)	by Unknown	on 12/24/2011	at 13:55

Figure 4: 12/24/2011PM [Combined] - Forward/Reverse or Combined Separation Plot



GPS Time

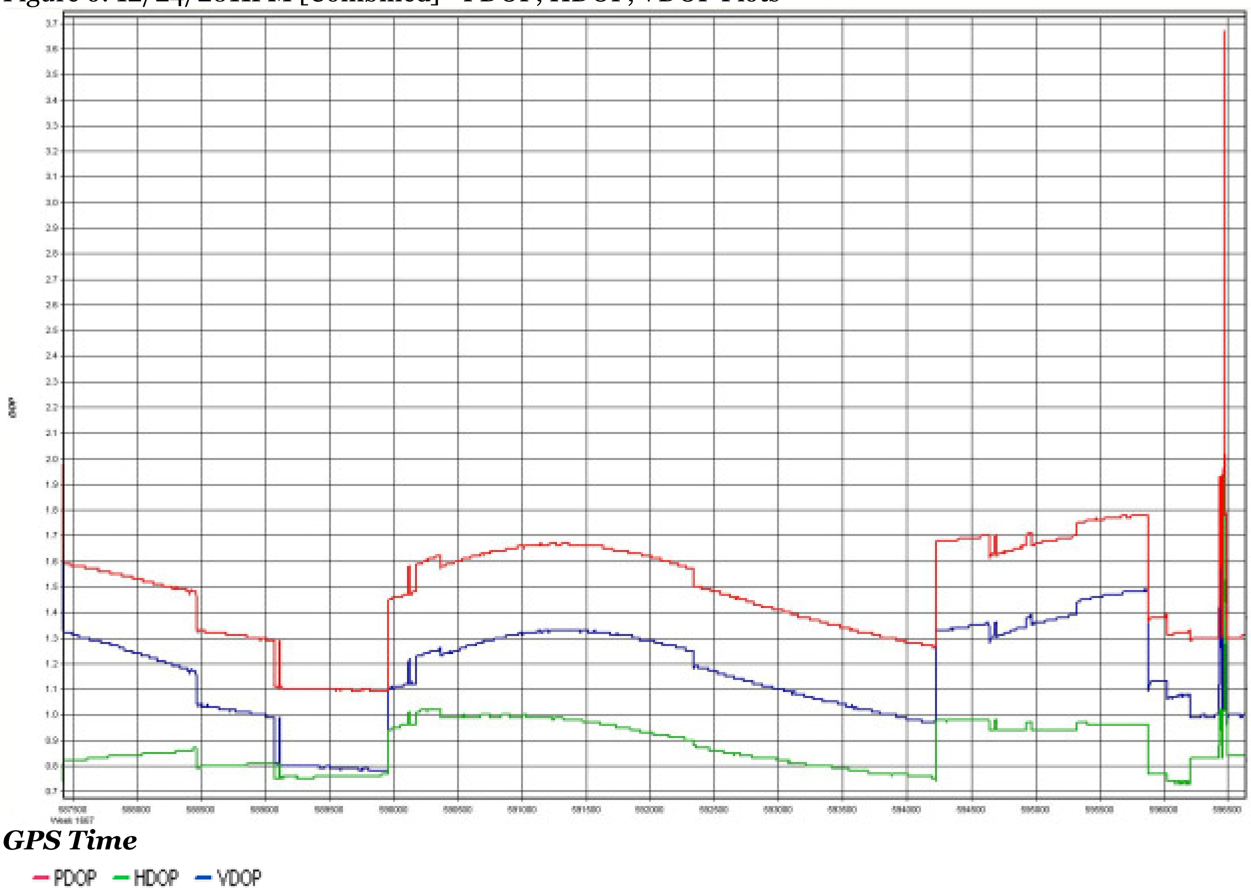
East North Up

Process	Run (10)	by Unknown	on 12/24/2011	at 13:55

Figure 5: 12/24/2011PM [Combined] - Forward/Reverse or Combined Weighting Plot

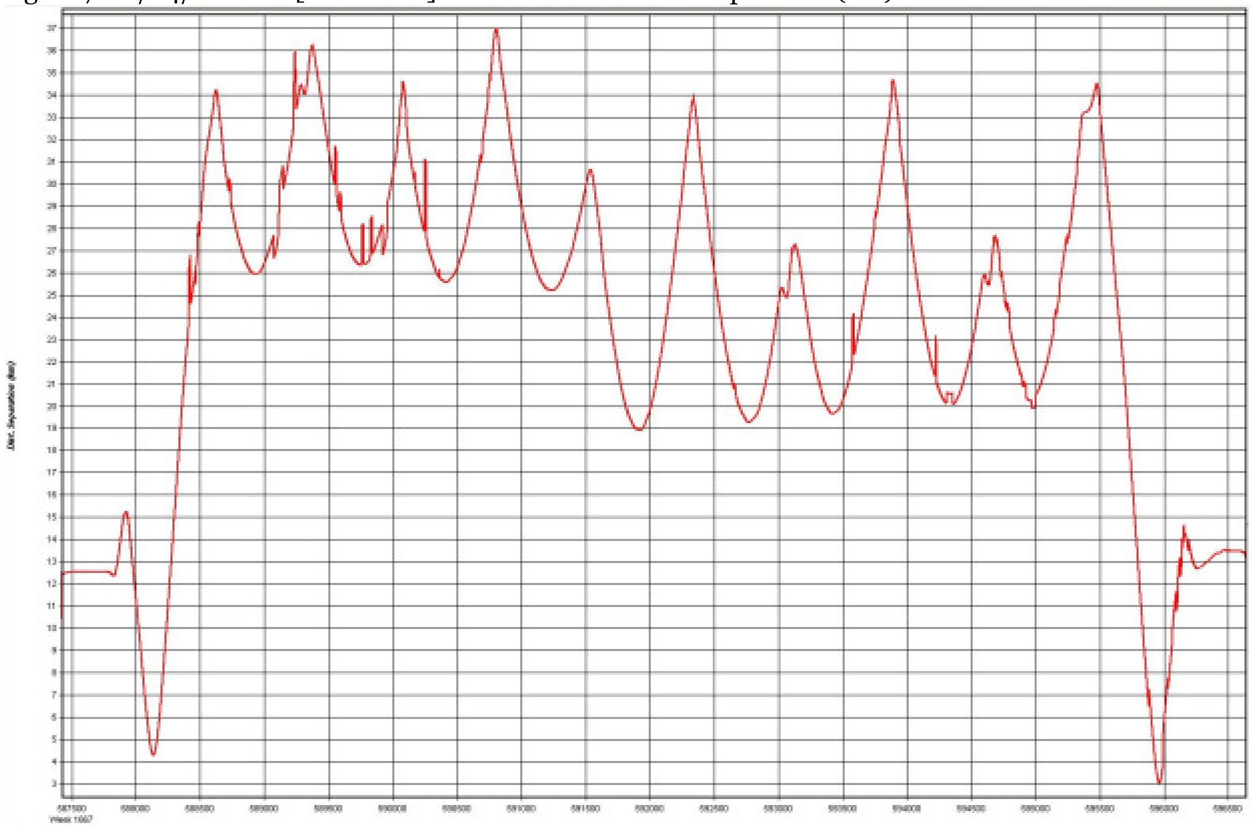
Process	Run (10)	by Unknown	on 12/24/2011	at 13:55

Figure 6: 12/24/2011PM [Combined] - PDOP, HDOP, VDOP Plots



Process	Run (10)	by Unknown	on 12/24/2011	at 13:55

Figure 7: 12/24/2011PM [Combined] - Horizontal Distance Separation (km)



GPS Time

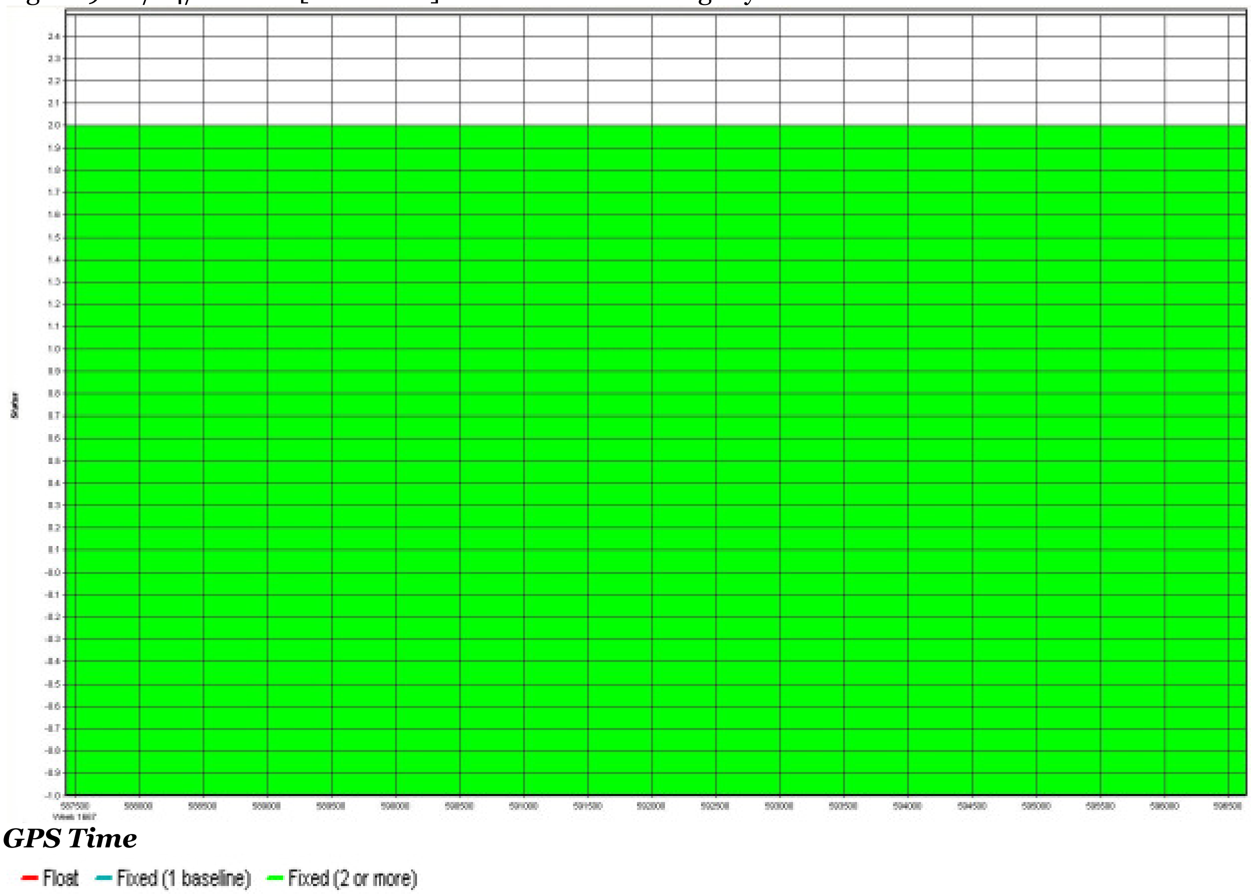
— Distance

Process	Run (10)	by Unknown	on 12/24/2011	at 13:55

Figure 8: 12/24/2011PM [Combined] - Forward/Reverse or Combined RMS Plot

Process	Run (10)	by Unknown	on 12/24/2011	at 13:55

Figure 9: 12/24/2011PM [Combined] - Float or Fixed Ambiguity

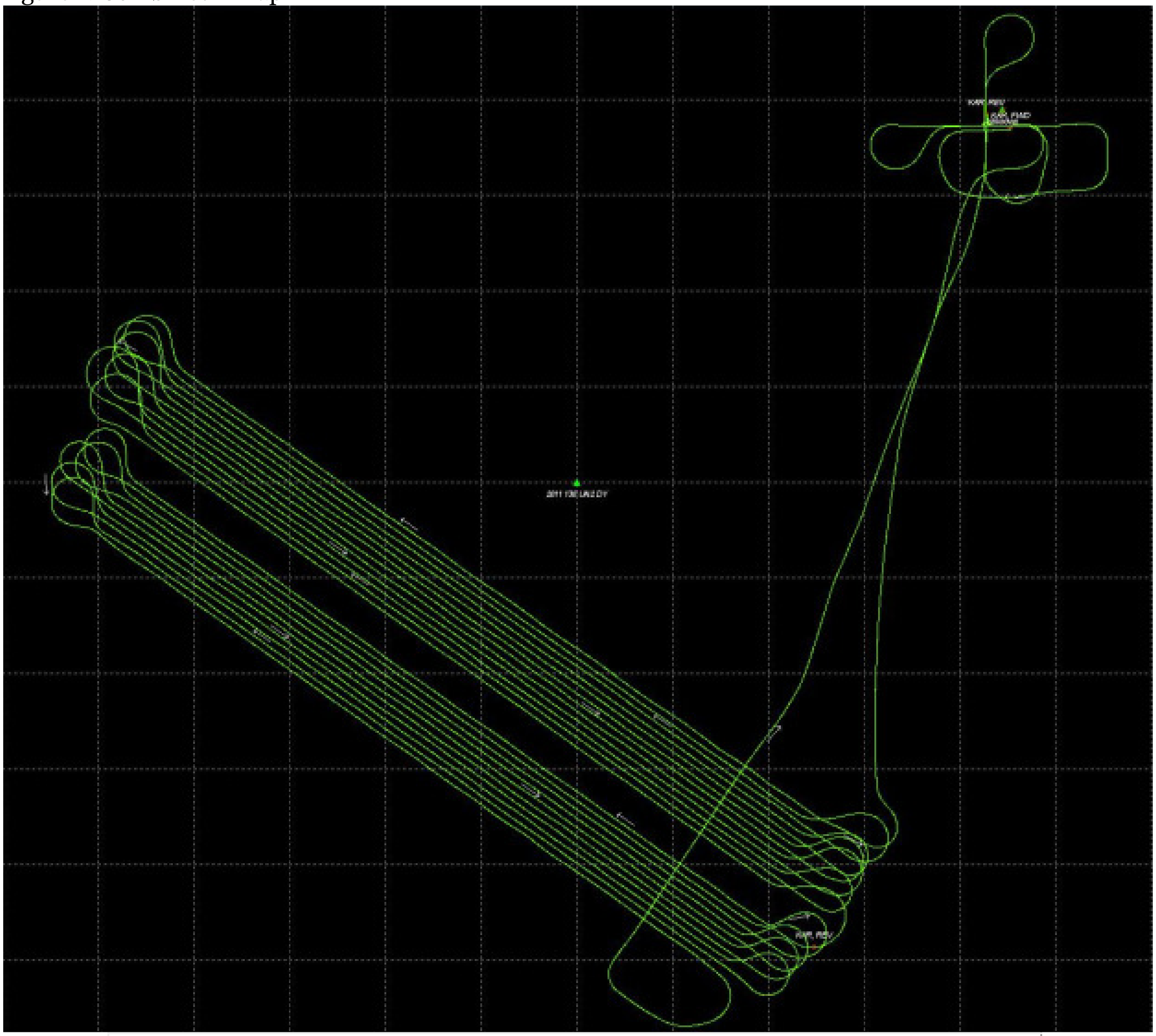


Process	Run (10)	by Unknown	on 12/24/2011	at 13:55

2.10 Output Results for 12/26/2011

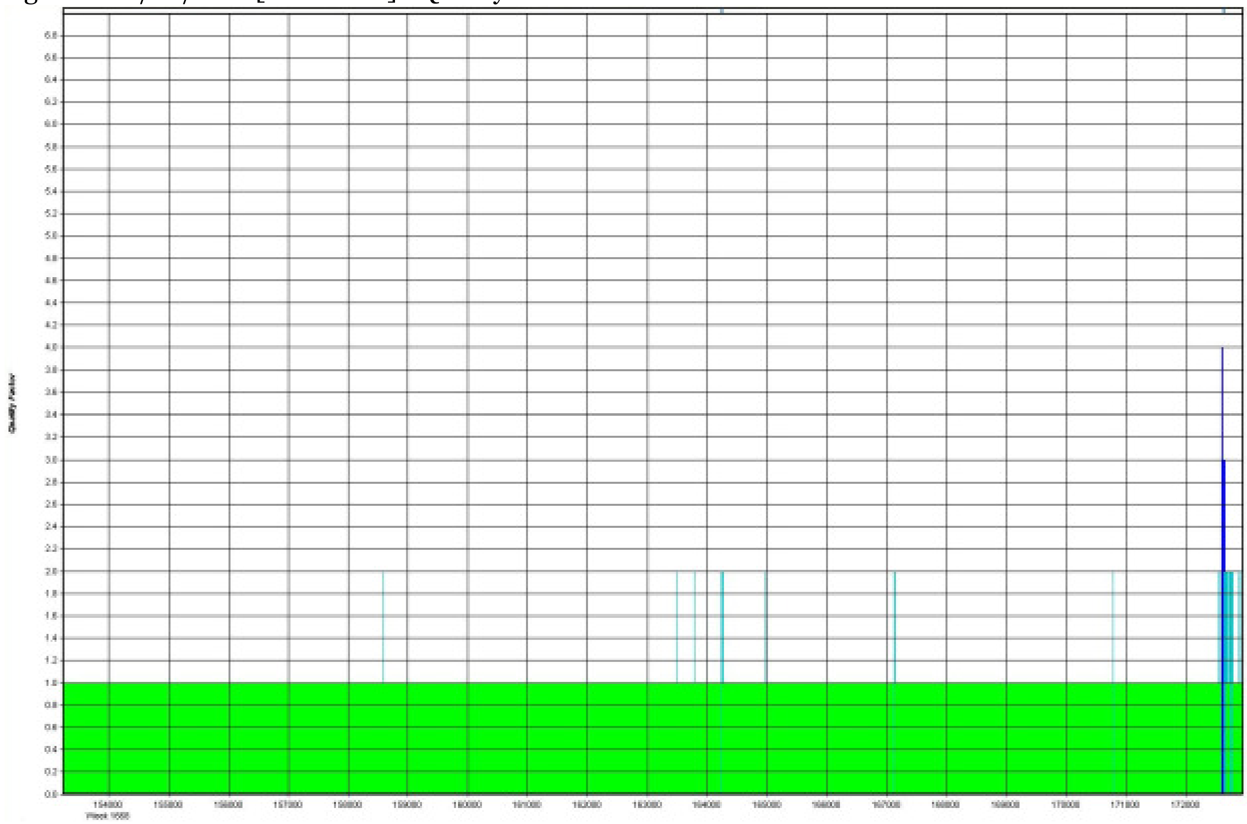
POSPAC Version 4.31

Figure 1: Combined - Map



Process	Run (23)	by Unknown	on 12/26/2011	at 10:40

Figure 2: 12/26/2011 [Combined] - Quality Factor Plot



GPS Time

— Fixed Integer — Stable float — Converging float — DGPS or worse — Single Point — No solution

Process	Run (23)	by Unknown	on 12/26/2011	at 10:40

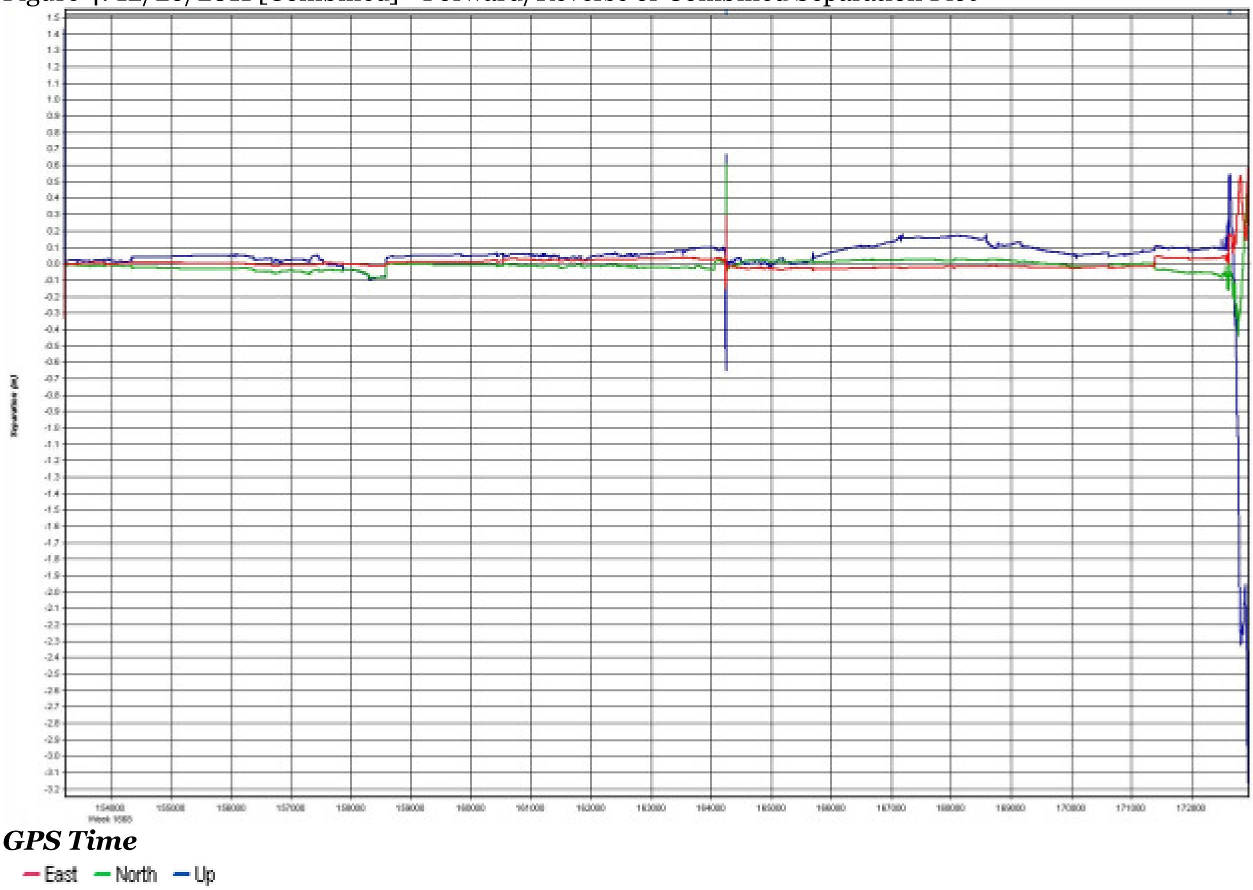
Figure 3: 12/26/2011 [Combined] - Height Profile Plot

GPS Time

— Height

Process	Run (23)	by Unknown	on 12/26/2011	at 10:40

Figure 4: 12/26/2011 [Combined] - Forward/Reverse or Combined Separation Plot

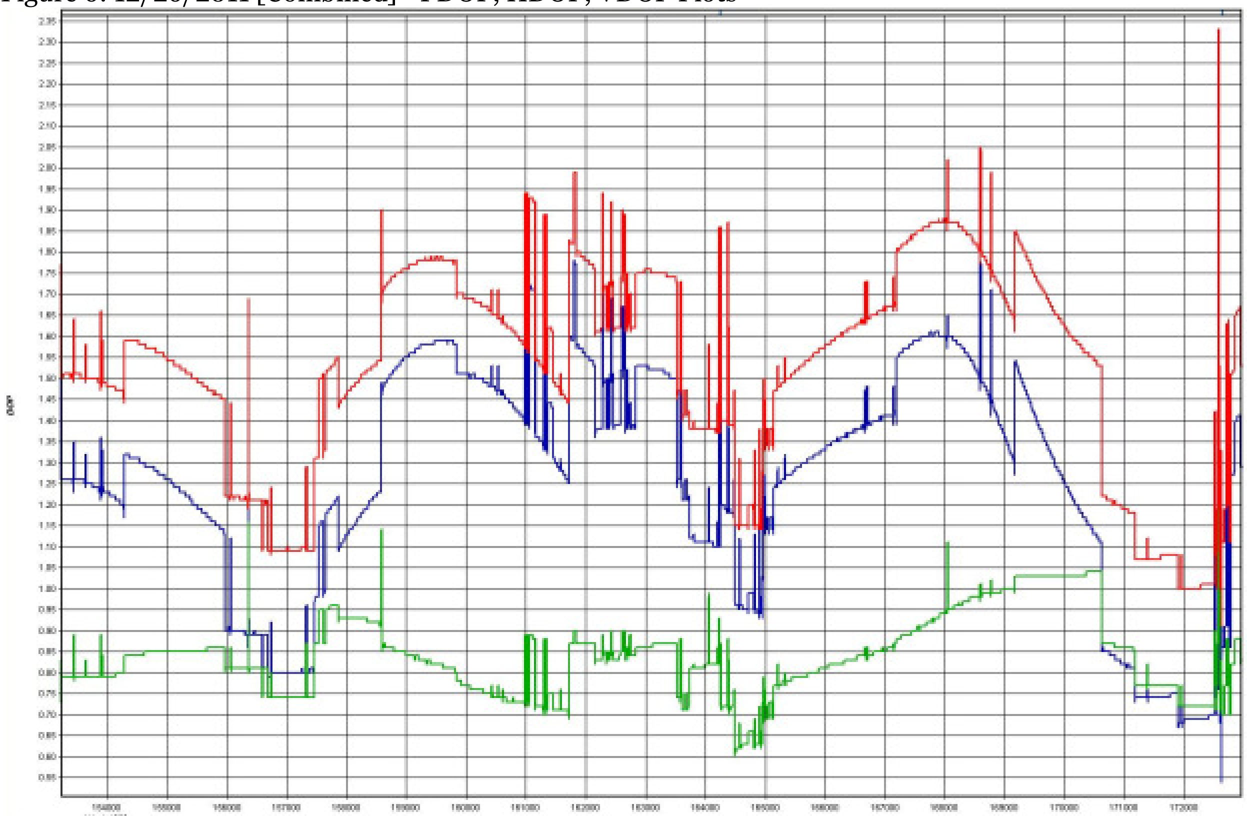


Process	Run (23)	by Unknown	on 12/26/2011	at 10:40

Figure 5: 12/26/2011 [Combined] - Forward/Reverse or Combined Weighting Plot

Process	Run (23)	by Unknown	on 12/26/2011	at 10:40

Figure 6: 12/26/2011 [Combined] - PDOP, HDOP, VDOP Plots

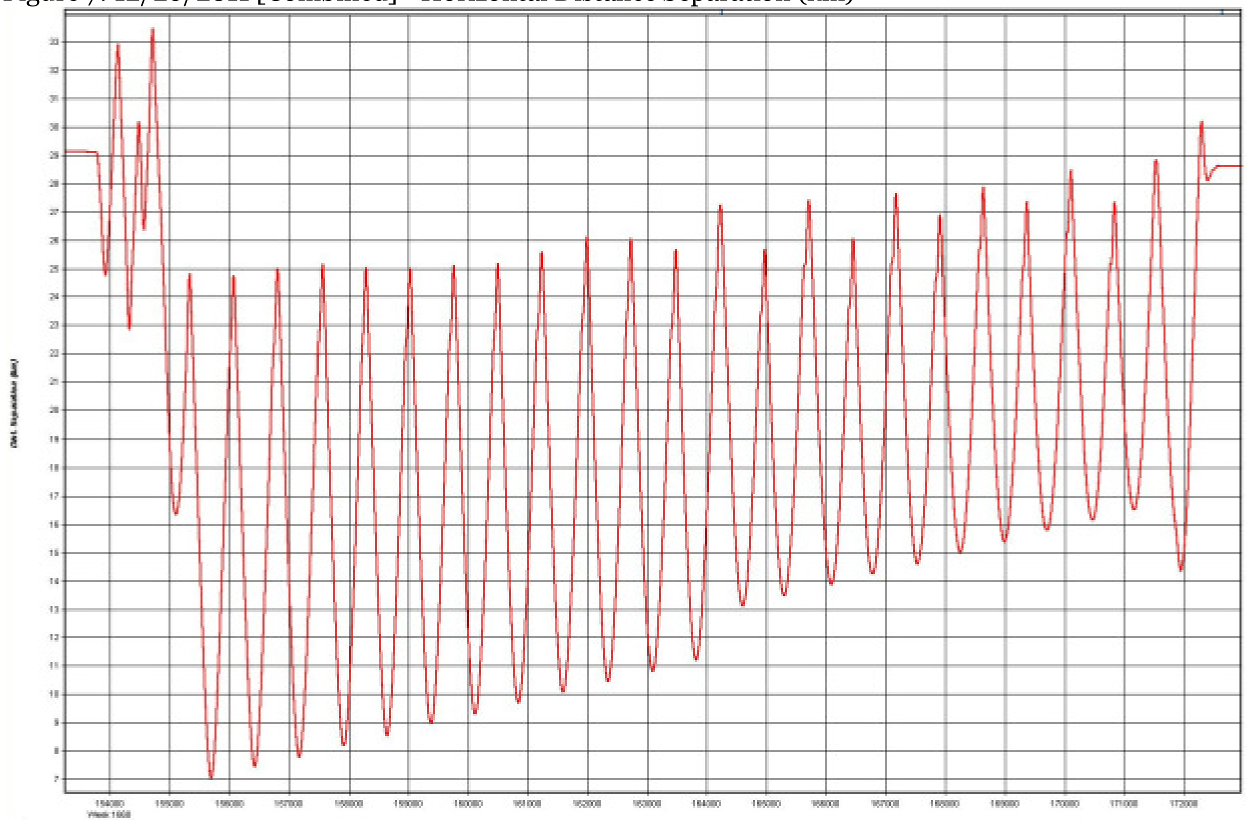


GPS Time

— PDOP — HDOP — VDOP

Process	Run (23)	by Unknown	on 12/26/2011	at 10:40

Figure 7: 12/26/2011 [Combined] - Horizontal Distance Separation (km)

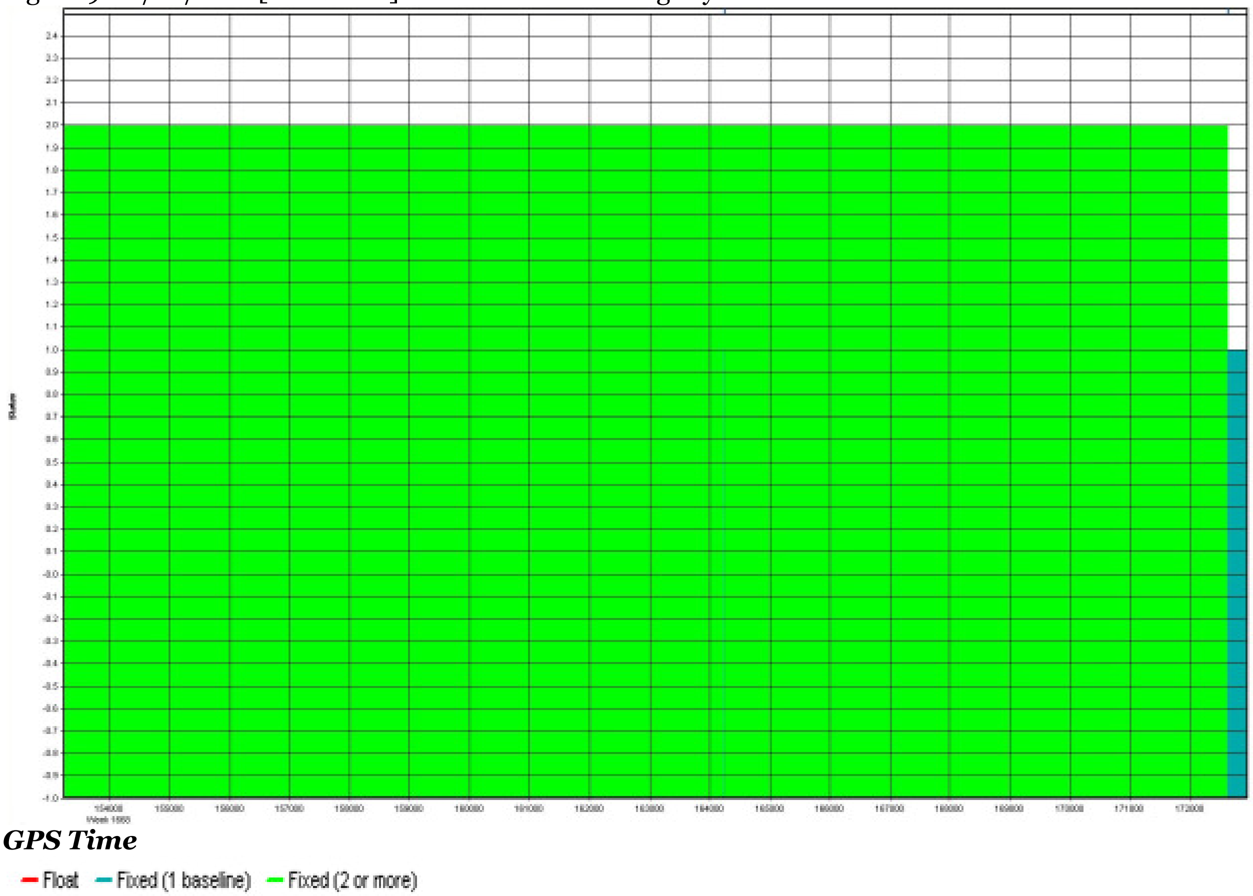


Process	Run (23)	by Unknown	on 12/26/2011	at 10:40

Figure 8: 12/26/2011 [Combined] - Forward/Reverse or Combined RMS Plot

Process	Run (23)	by Unknown	on 12/26/2011	at 10:40

Figure 9: 12/26/2011 [Combined] - Float or Fixed Ambiguity

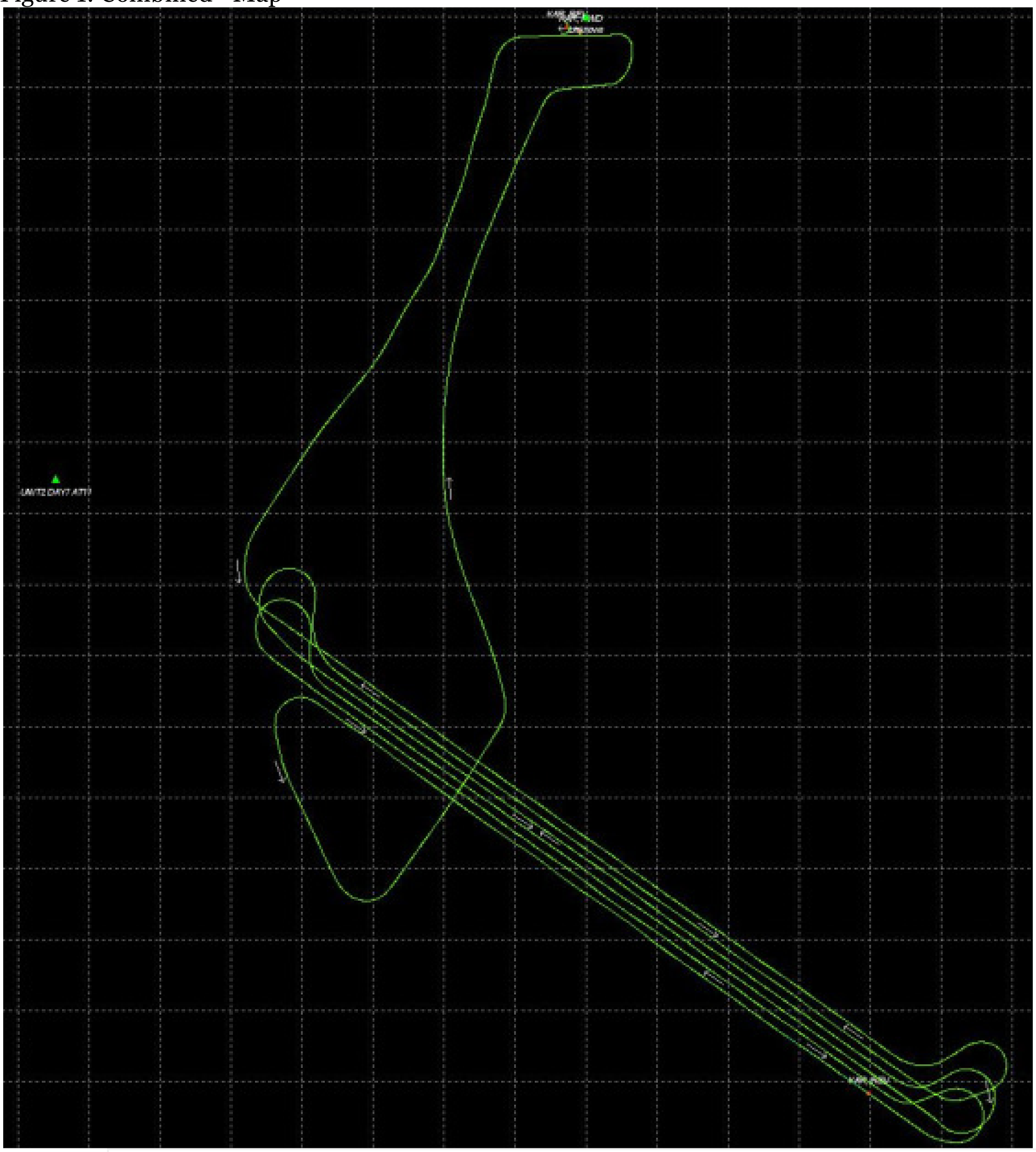


Process	Run (23)	by Unknown	on 12/26/2011	at 10:40

2.11 Output Results for 12/27/2011AM

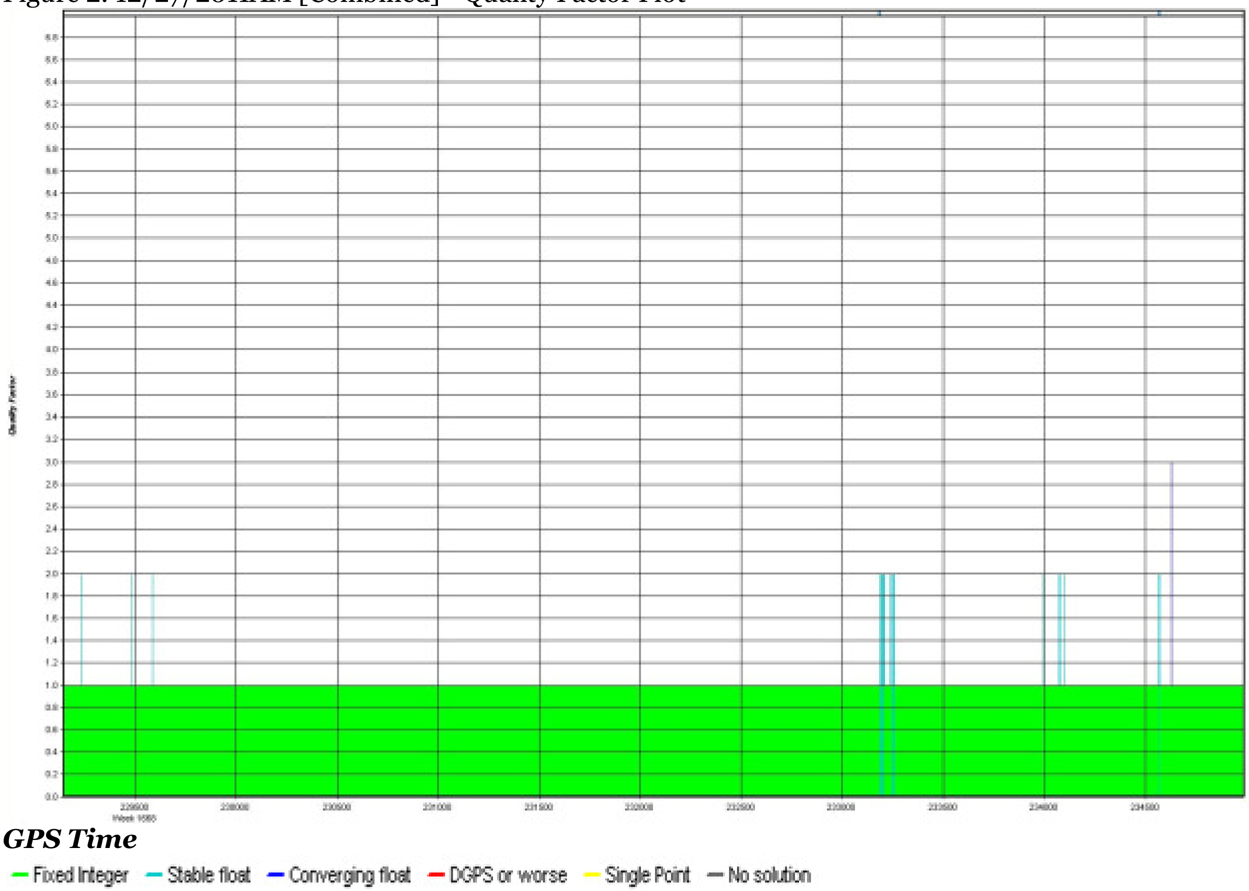
POSPAC Version 4.31

Figure 1: Combined - Map



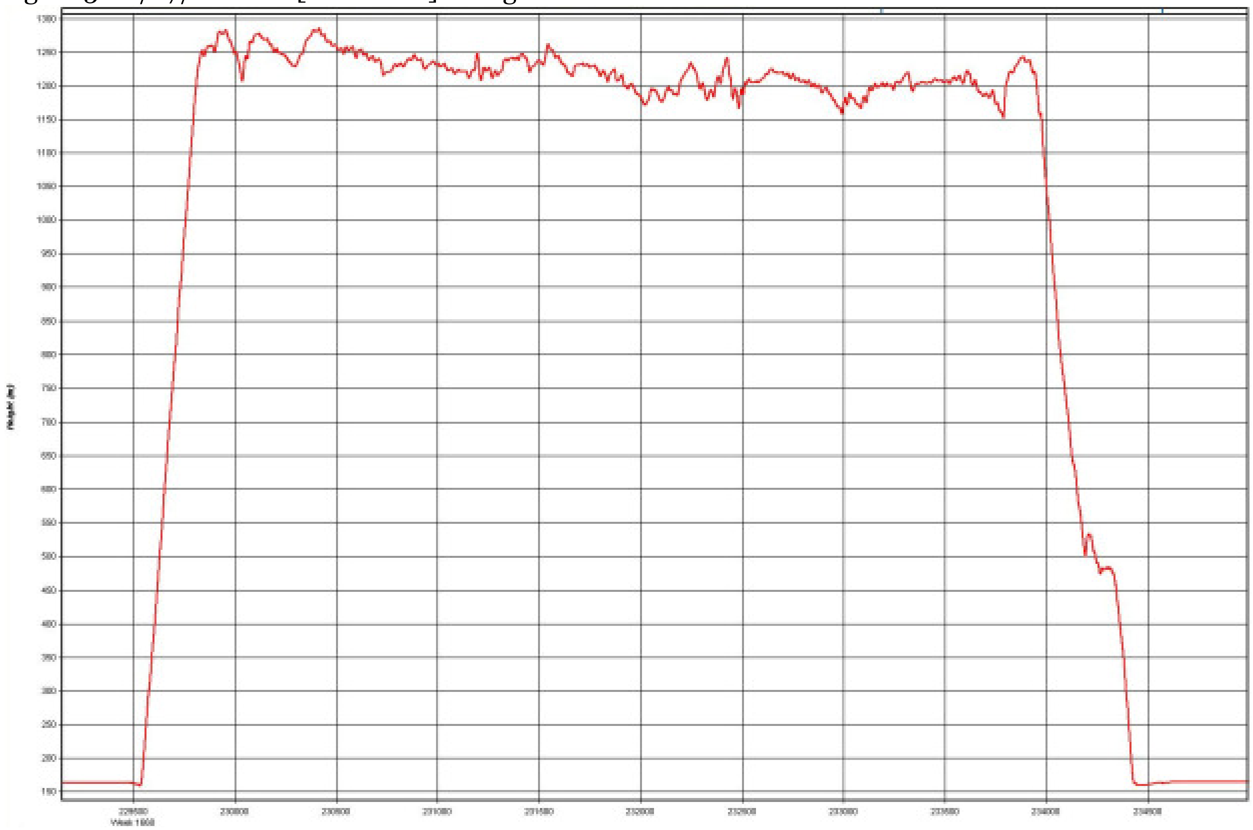
Process	Run (7)	by Unknown	on 12/27/2011	at 06:50

Figure 2: 12/27/2011AM [Combined] - Quality Factor Plot



Process	Run (7)	by Unknown	on 12/27/2011	at 06:50

Figure 3: 12/27/2011AM [Combined] - Height Profile Plot

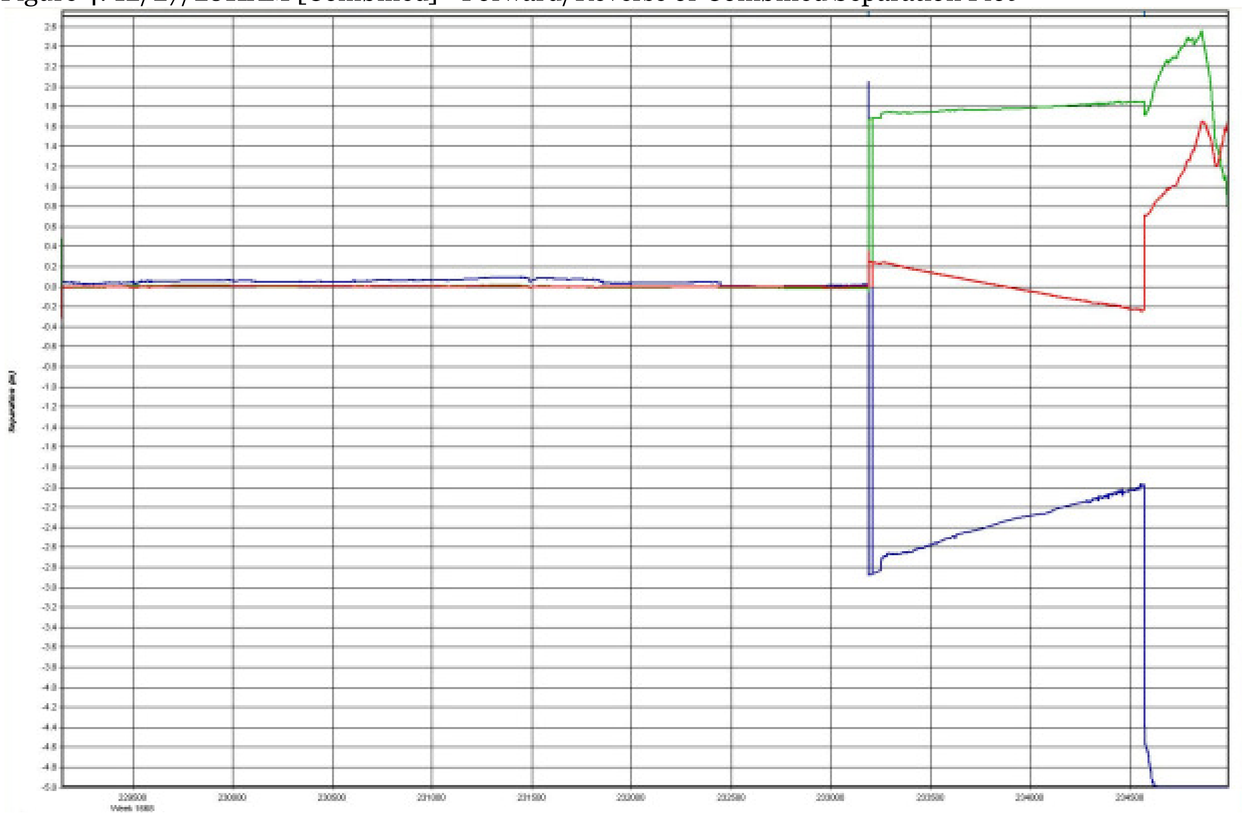


GPS Time

– Height

Process	Run (7)	by Unknown	on 12/27/2011	at 06:50

Figure 4: 12/27/2011AM [Combined] - Forward/Reverse or Combined Separation Plot



GPS Time

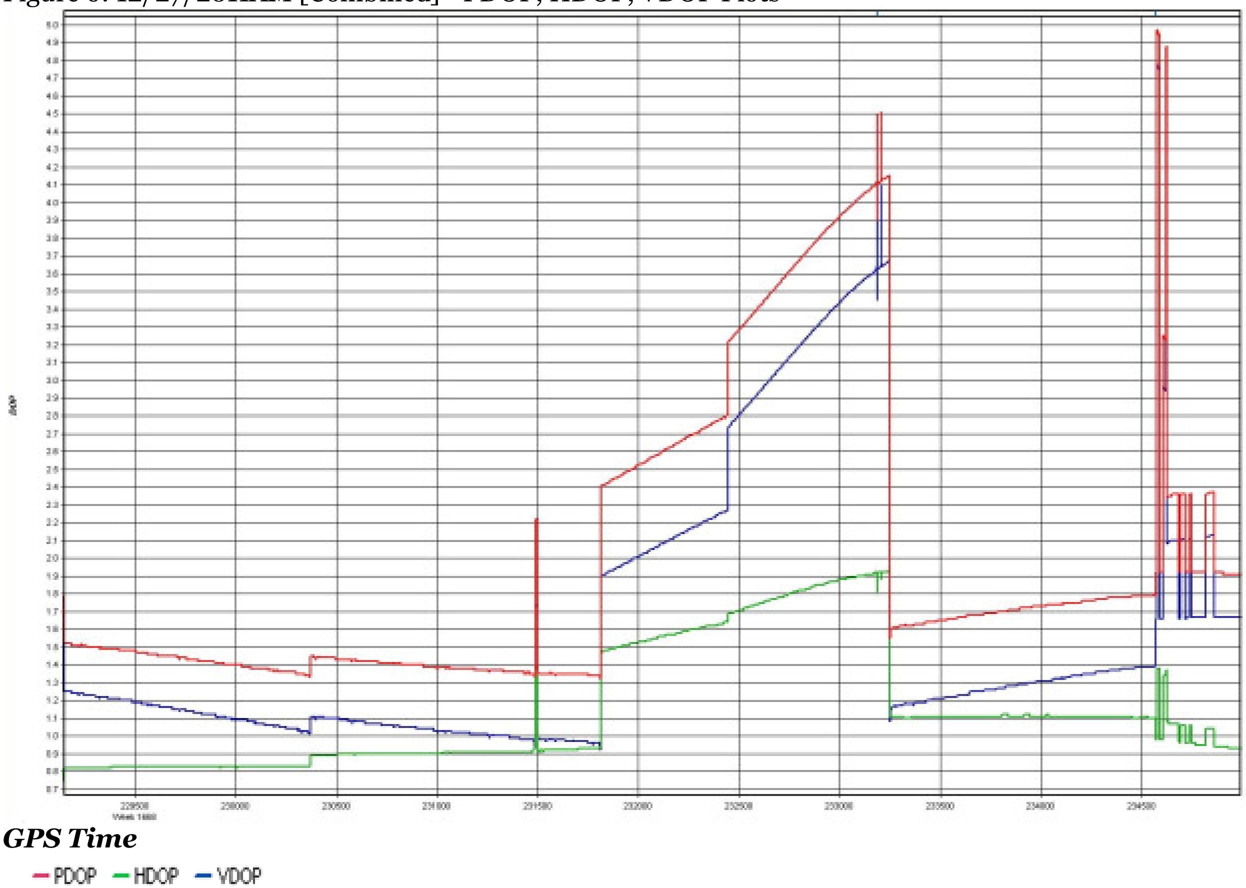
East North Up

Process	Run (7)	by Unknown	on 12/27/2011	at 06:50

Figure 5: 12/27/2011AM [Combined] - Forward/Reverse or Combined Weighting Plot

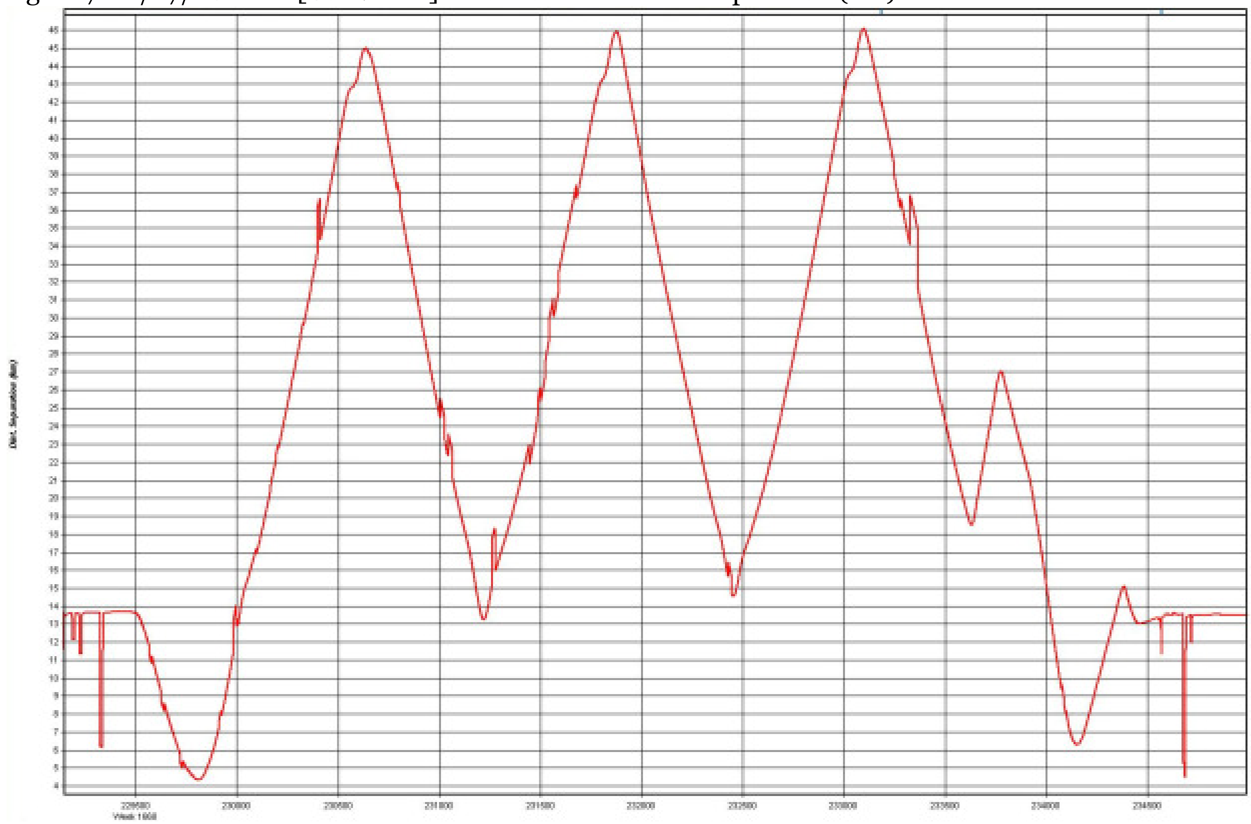
Process	Run (7)	by Unknown	on 12/27/2011	at 06:50

Figure 6: 12/27/2011AM [Combined] - PDOP, HDOP, VDOP Plots



Process	Run (7)	by Unknown	on 12/27/2011	at 06:50

Figure 7: 12/27/2011AM [Combined] - Horizontal Distance Separation (km)

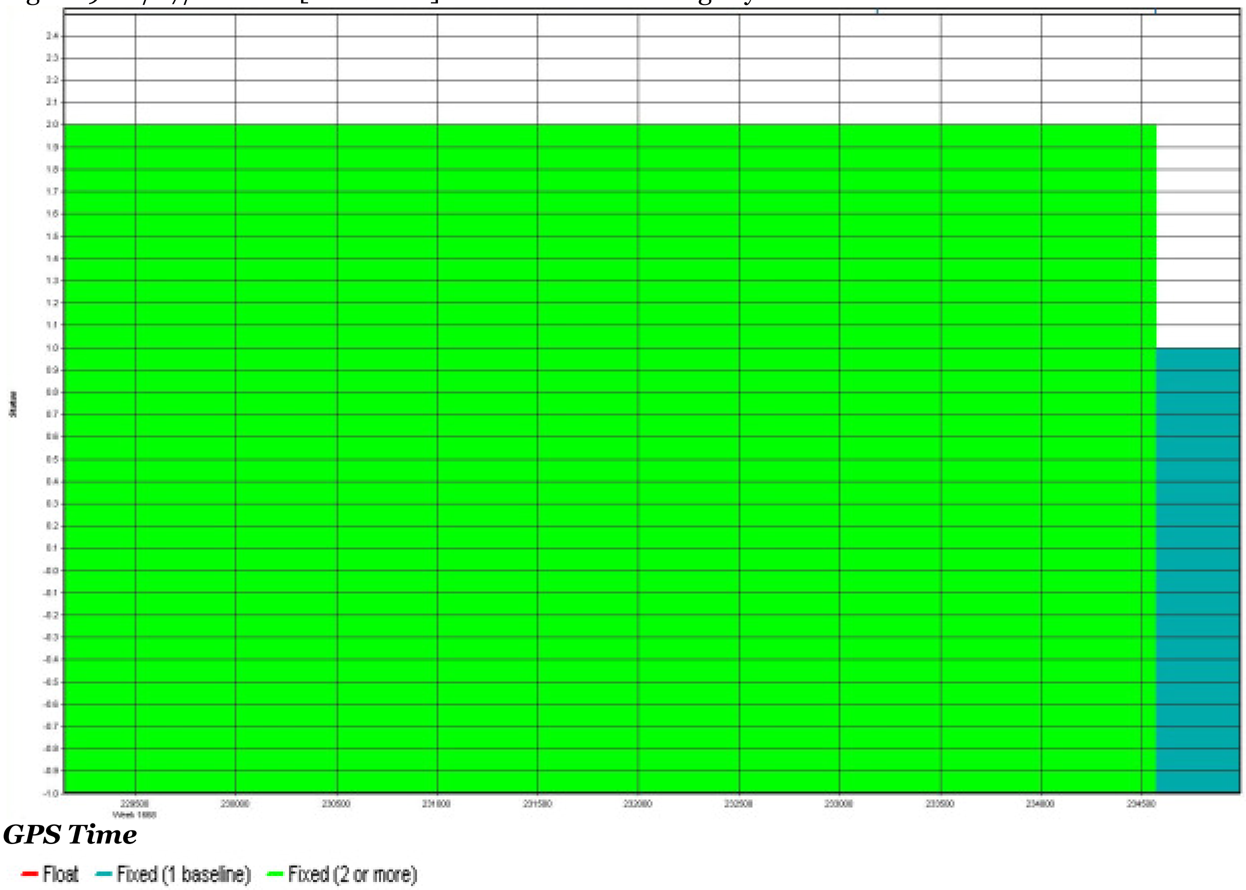


Process	Run (7)	by Unknown	on 12/27/2011	at 06:50

Figure 8: 12/27/2011AM [Combined] - Forward/Reverse or Combined RMS Plot

Process	Run (7)	by Unknown	on 12/27/2011	at 06:50

Figure 9: 12/27/2011AM [Combined] - Float or Fixed Ambiguity

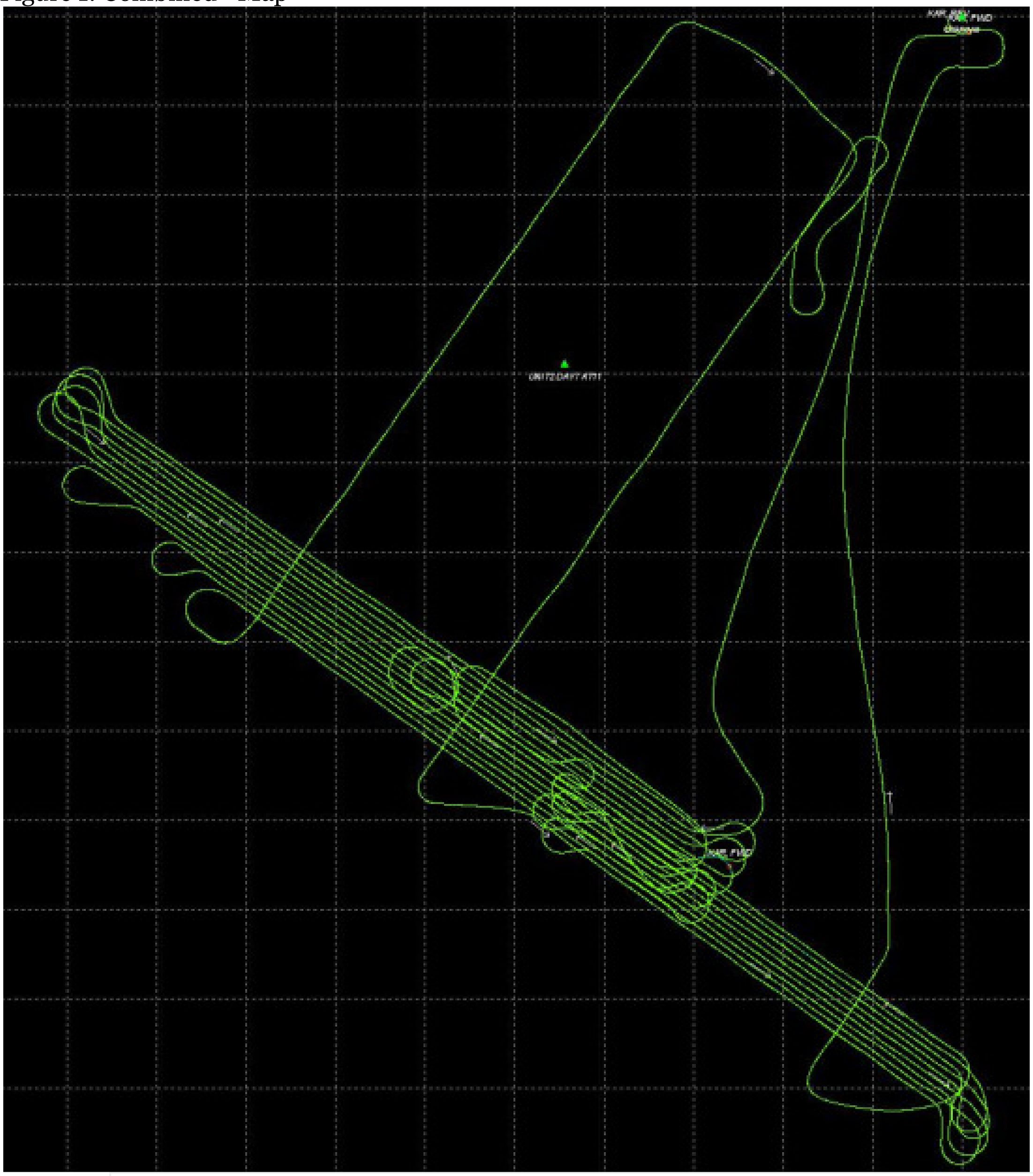


Process	Run (7)	by Unknown	on 12/27/2011	at 06:50

2.12 Output Results for 12/27/2011PM

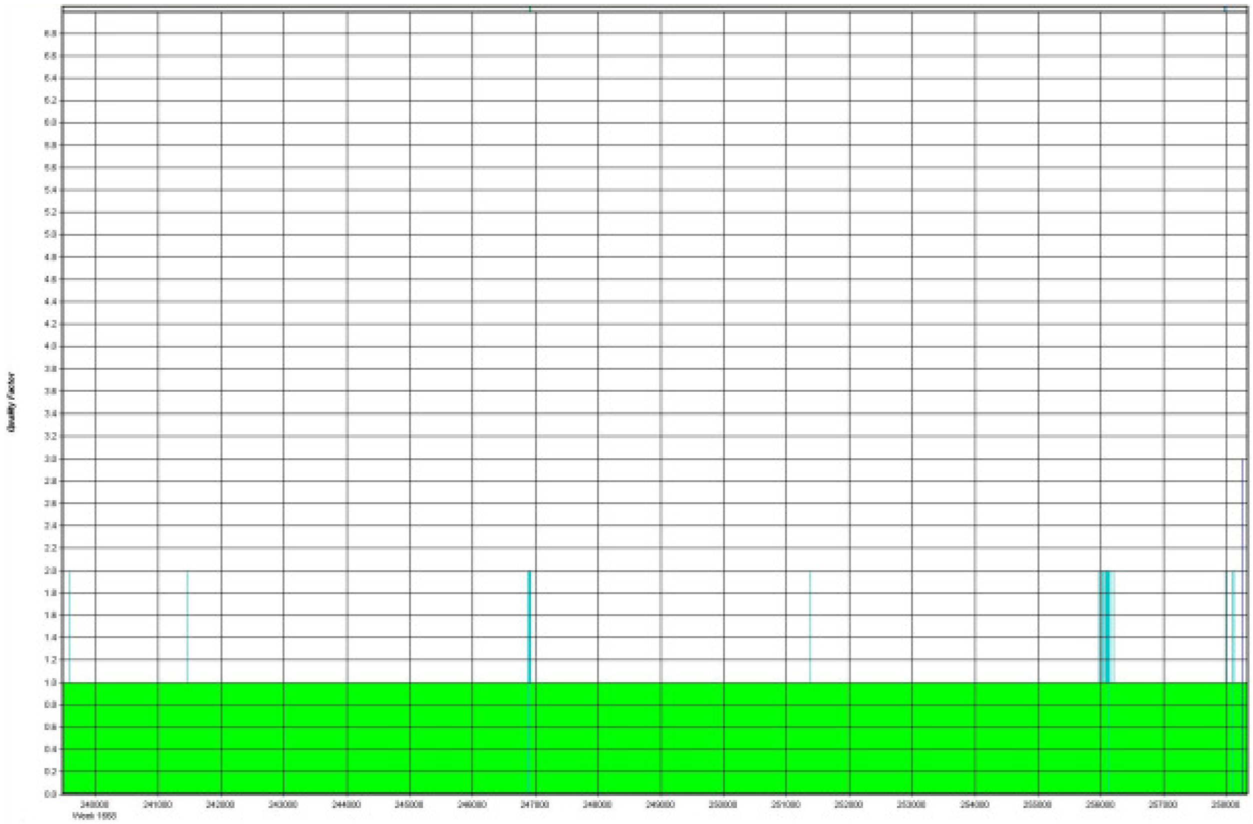
POSPAC Version 4.31

Figure 1: Combined - Map



Process	Run (29)	by Unknown	on 12/27/2011	at 10:30

Figure 2: 12/27/2011PM [Combined] - Quality Factor Plot

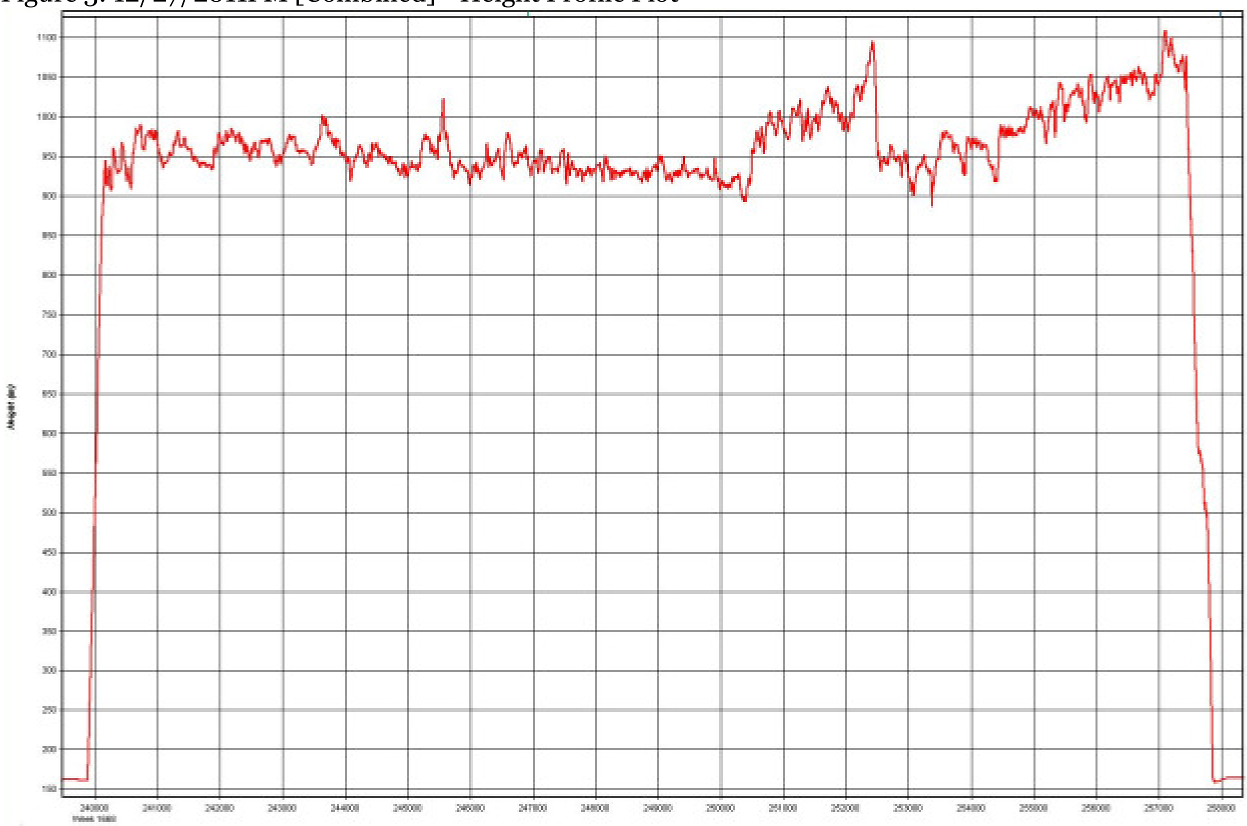


GPS Time

— Fixed Integer — Stable float — Converging float — DGPS or worse — Single Point — No solution

Process	Run (29)	by Unknown	on 12/27/2011	at 10:30

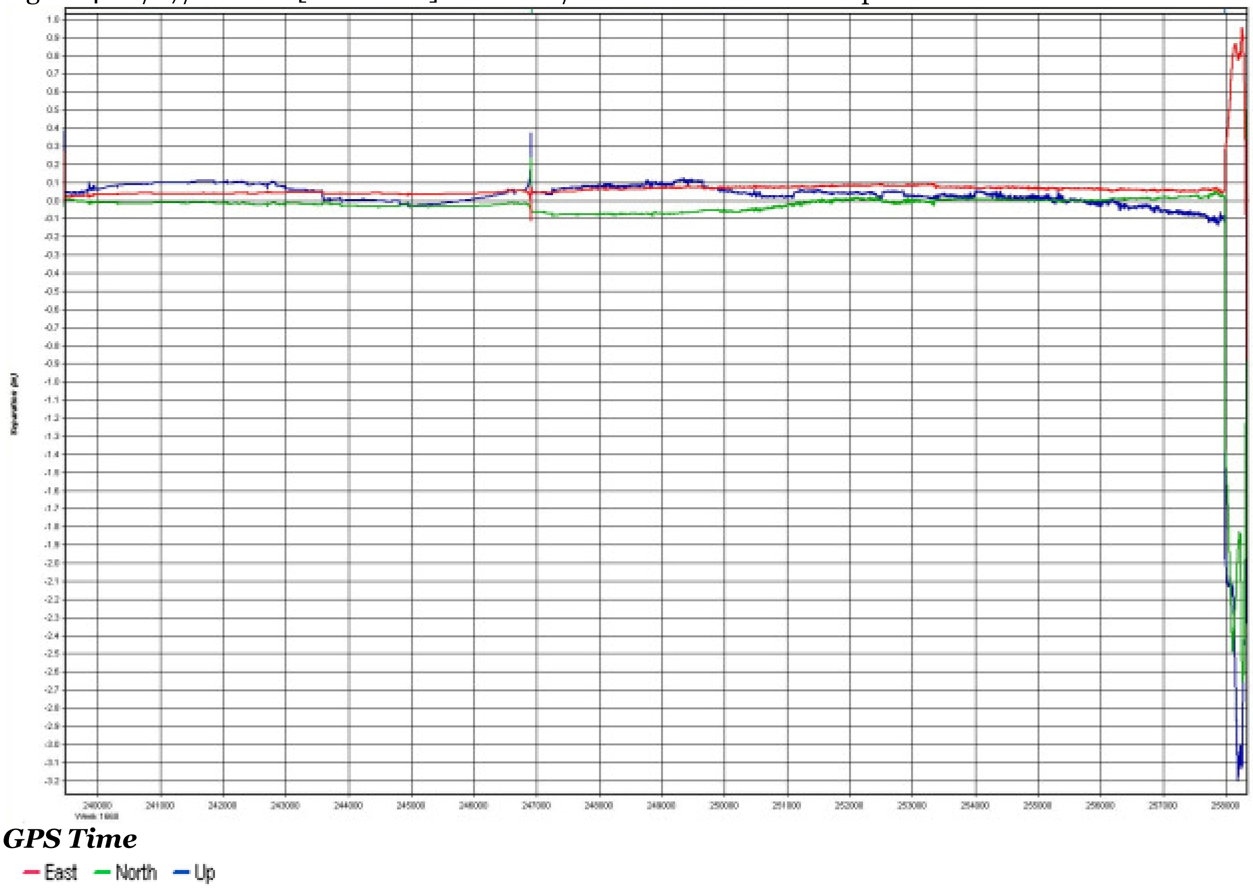
Figure 3: 12/27/2011PM [Combined] - Height Profile Plot



GPS Time

Process	Run (29)	by Unknown	on 12/27/2011	at 10:30

Figure 4: 12/27/2011PM [Combined] - Forward/Reverse or Combined Separation Plot

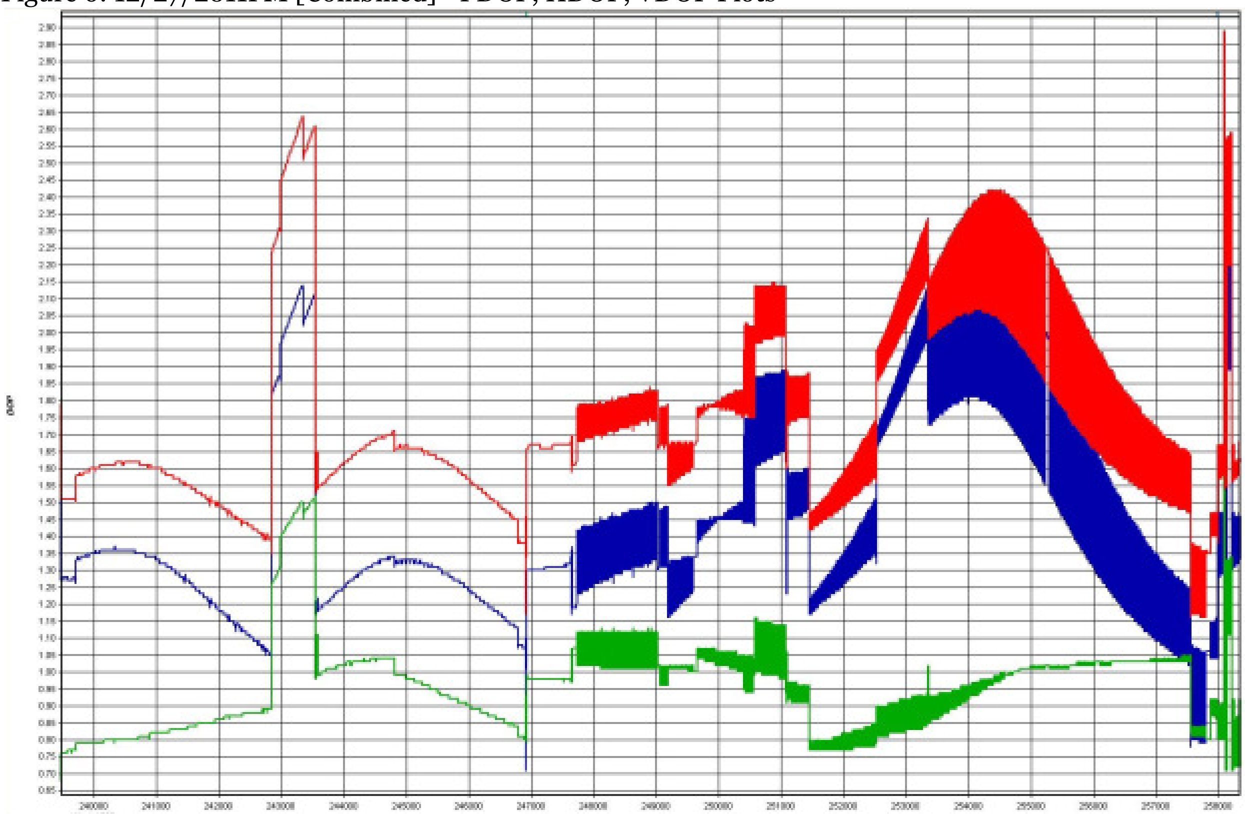


Process	Run (29)	by Unknown	on 12/27/2011	at 10:30

Figure 5: 12/27/2011PM [Combined] - Forward/Reverse or Combined Weighting Plot

Process	Run (29)	by Unknown	on 12/27/2011	at 10:30

Figure 6: 12/27/2011PM [Combined] - PDOP, HDOP, VDOP Plots

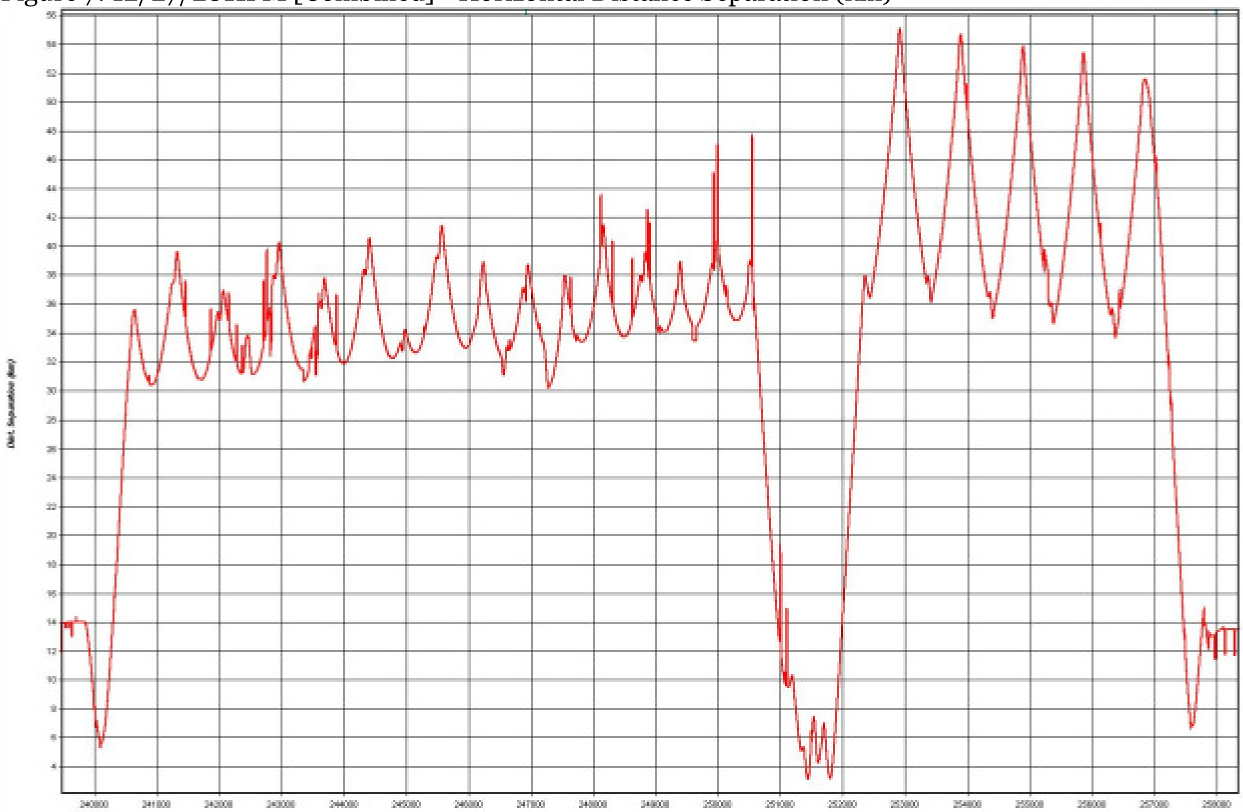


GPS Time

— PDOP — HDOP — VDOP

Process	Run (29)	by Unknown	on 12/27/2011	at 10:30

Figure 7: 12/27/2011PM [Combined] - Horizontal Distance Separation (km)



GPS Time

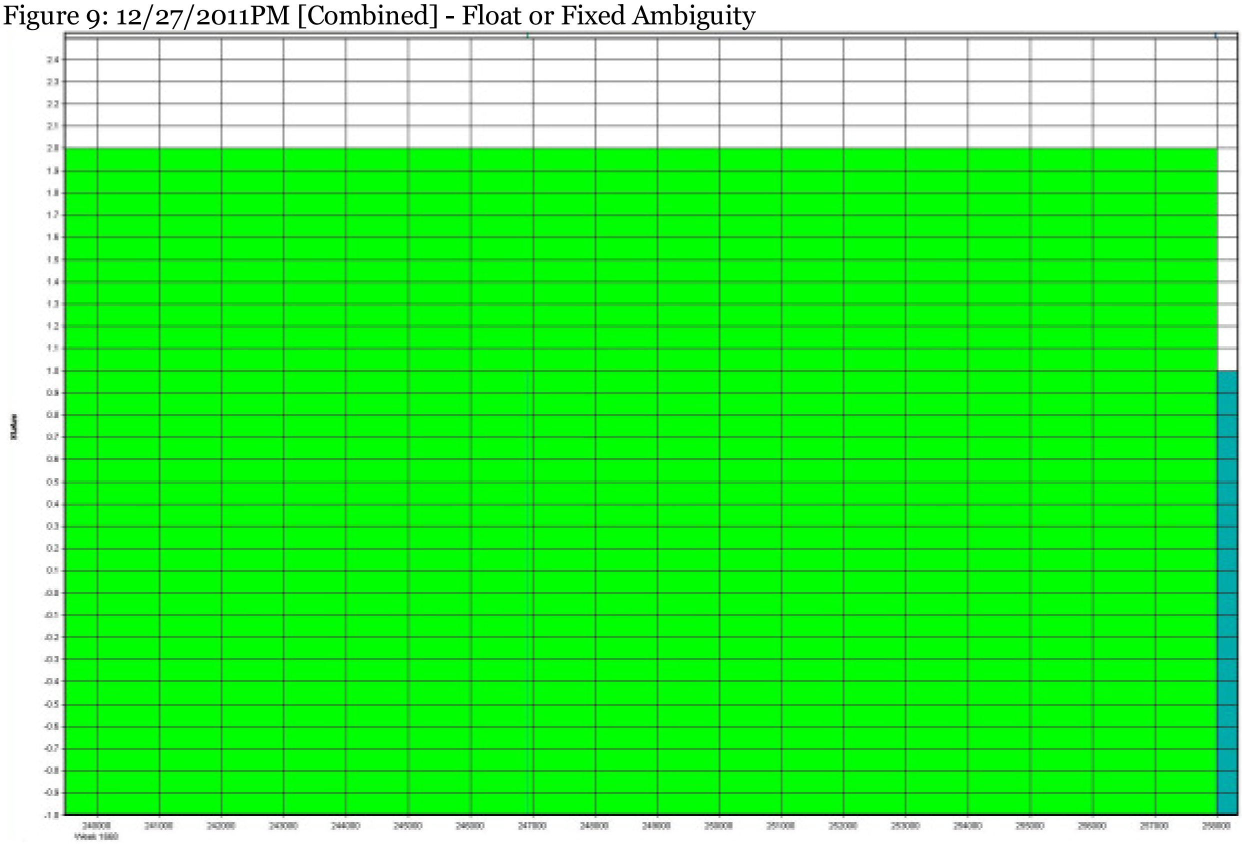
— Distance

Process	Run (29)	by Unknown	on 12/27/2011	at 10:30

Figure 8: 12/27/2011PM [Combined] - Forward/Reverse or Combined RMS Plot

Process	Run (29)	by Unknown	on 12/27/2011	at 10:30

Figure 9: 12/27/2011PM [Combined] - Float or Fixed Ambiguity



GPS Time

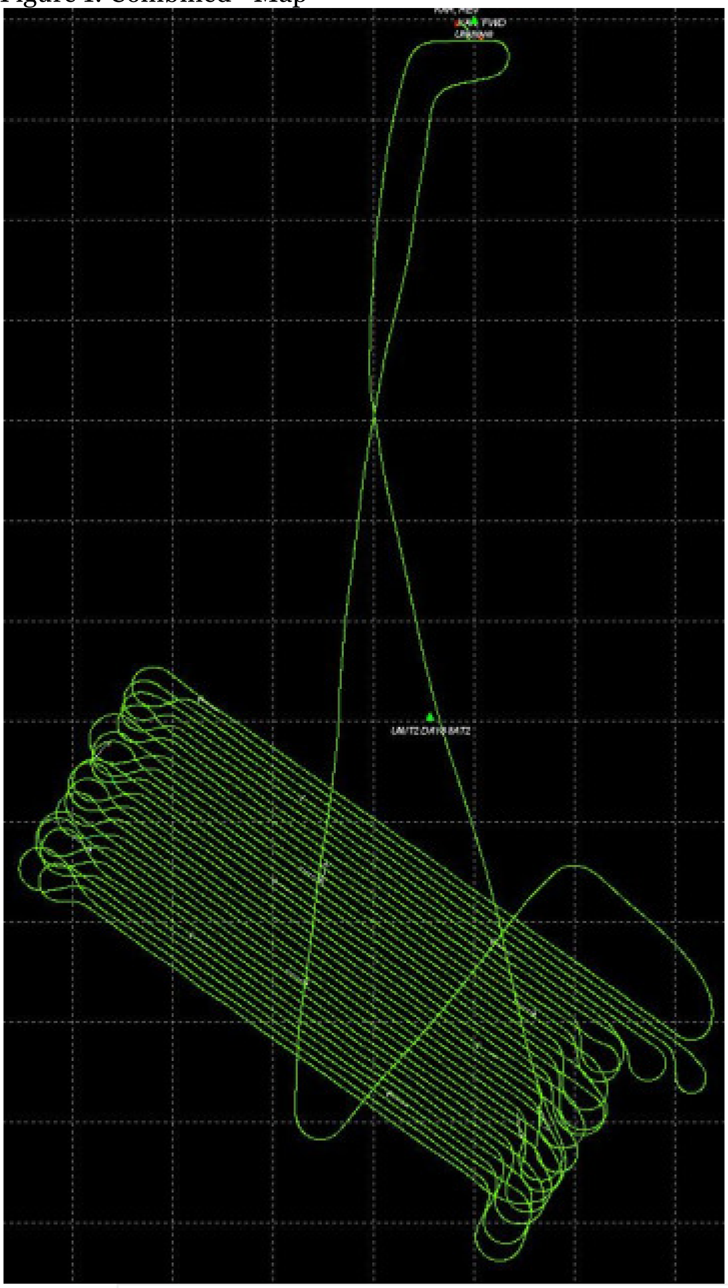
— Float — Fixed (1 baseline) — Fixed (2 or more)

Process	Run (29)	by Unknown	on 12/27/2011	at 10:30

2.13 Output Results for 12/28/2011

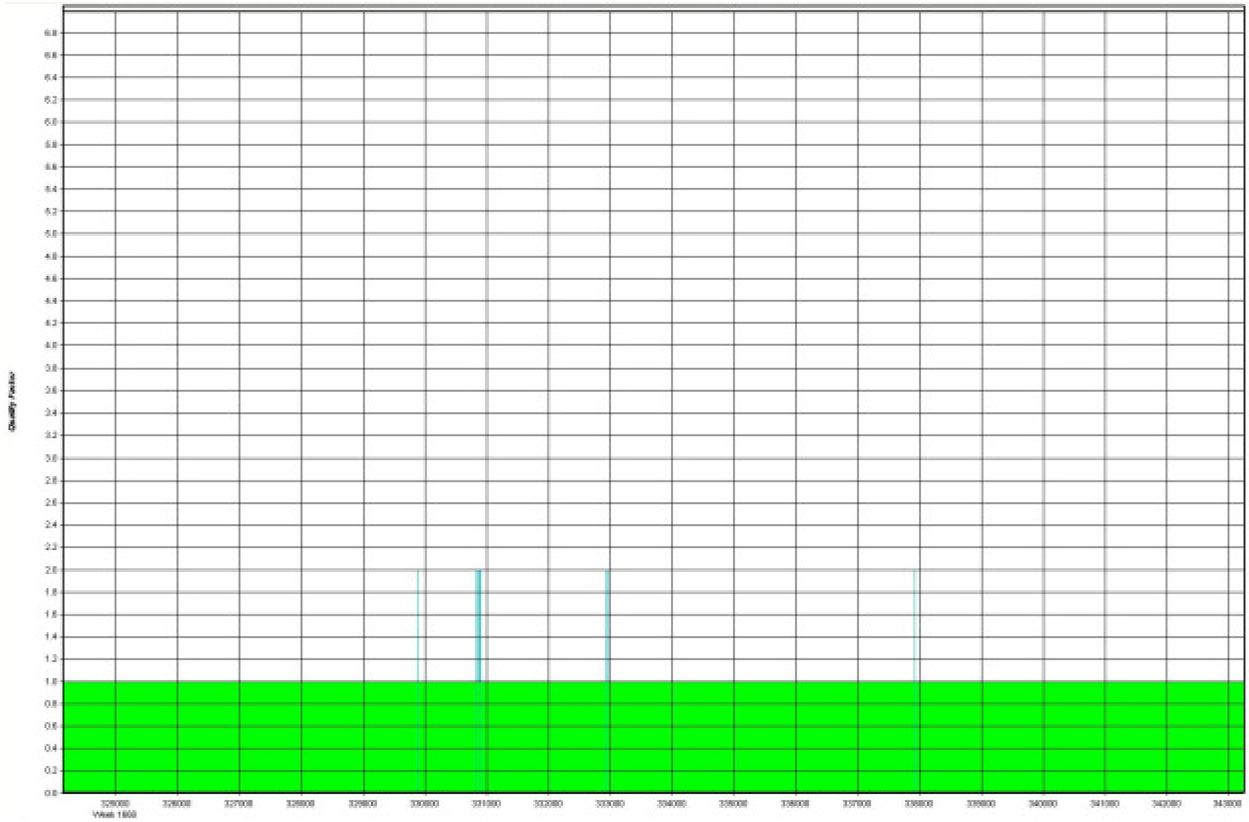
POSPAC Version 4.31

Figure 1: Combined - Map



Process	Run (33)	by Unknown	on 12/28/2011	at 10:00

Figure 2: 12/28/2011 [Combined] - Quality Factor Plot

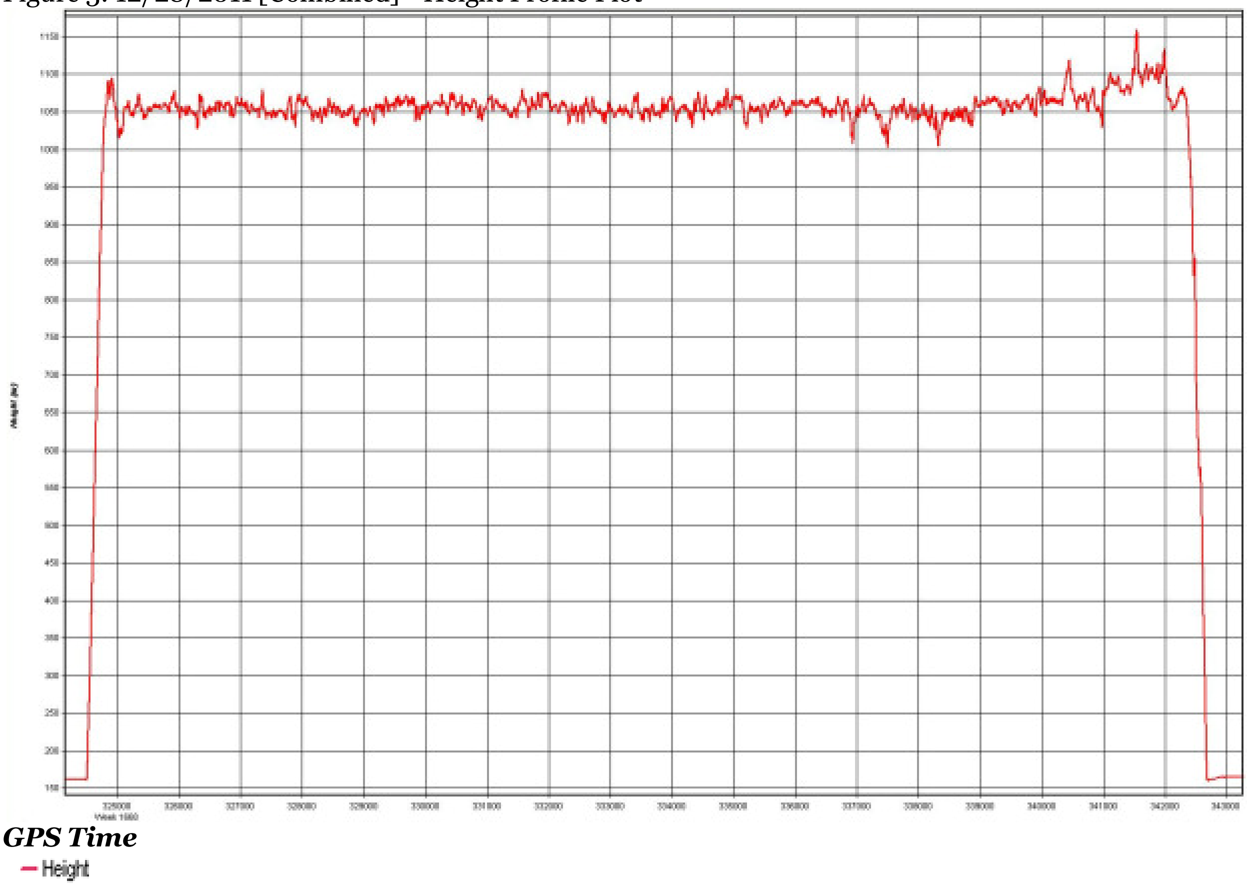


GPS Time

— Fixed Integer — Stable float — Converging float — DGPS or worse — Single Point — No solution

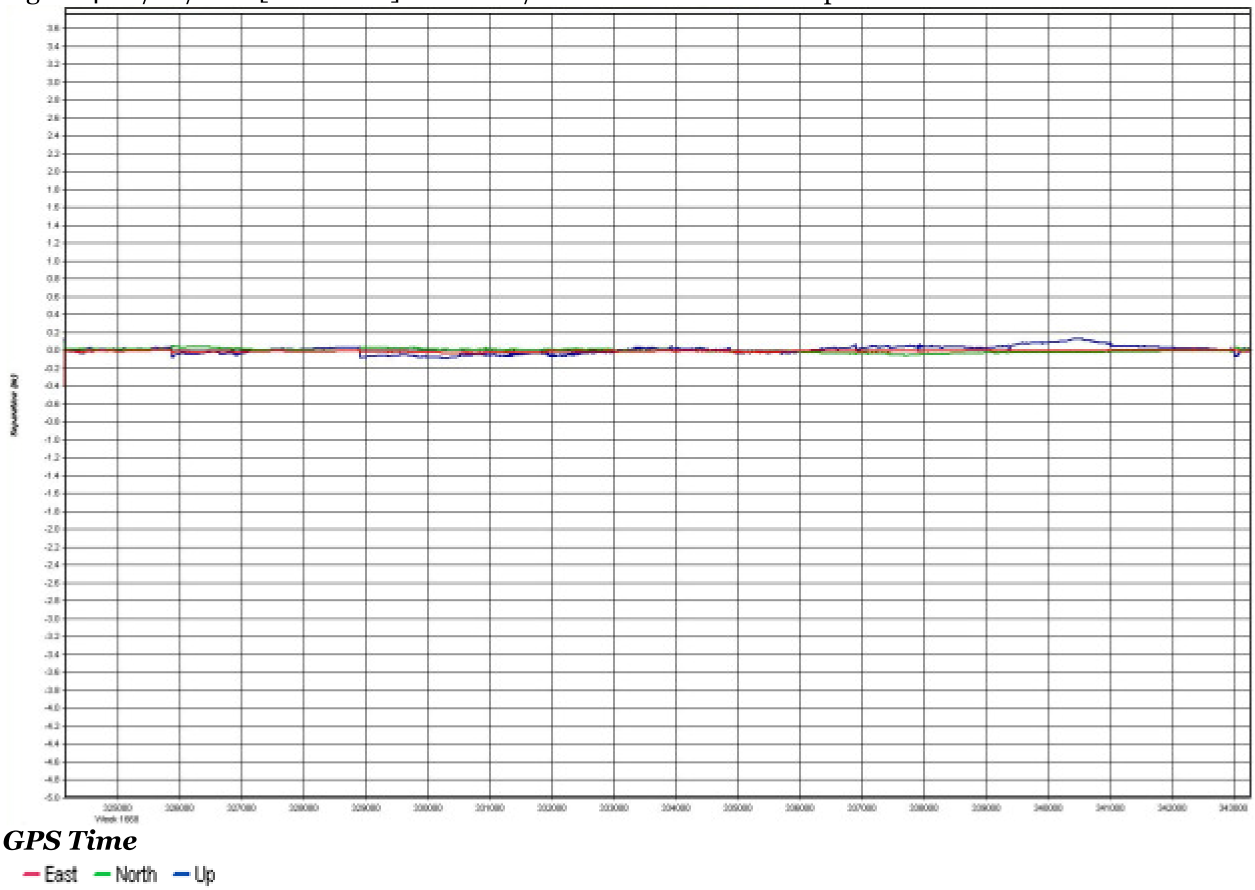
Process	Run (33)	by Unknown	on 12/28/2011	at 10:00

Figure 3: 12/28/2011 [Combined] - Height Profile Plot



Process	Run (33)	by Unknown	on 12/28/2011	at 10:00

Figure 4: 12/28/2011 [Combined] - Forward/Reverse or Combined Separation Plot

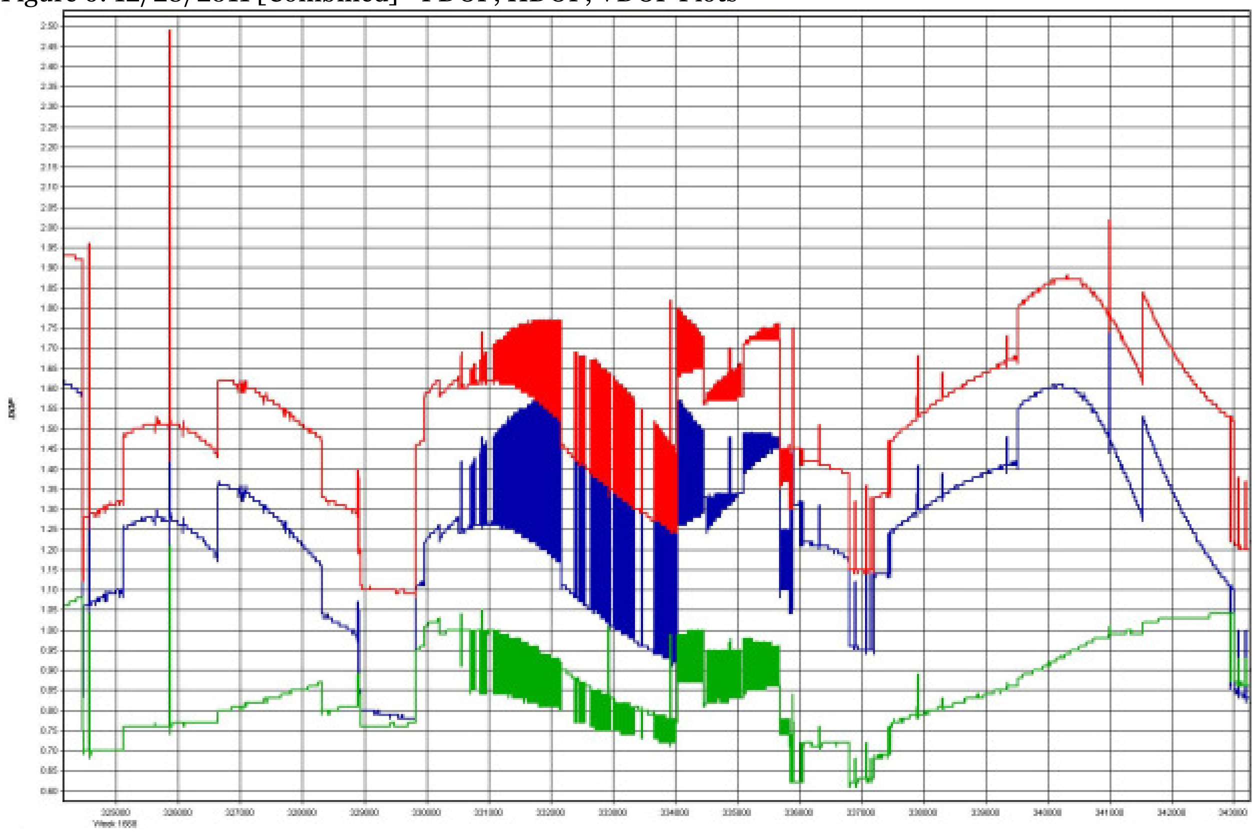


Process	Run (33)	by Unknown	on 12/28/2011	at 10:00

Figure 5: 12/28/2011 [Combined] - Forward/Reverse or Combined Weighting Plot

Process	Run (33)	by Unknown	on 12/28/2011	at 10:00

Figure 6: 12/28/2011 [Combined] - PDOP, HDOP, VDOP Plots

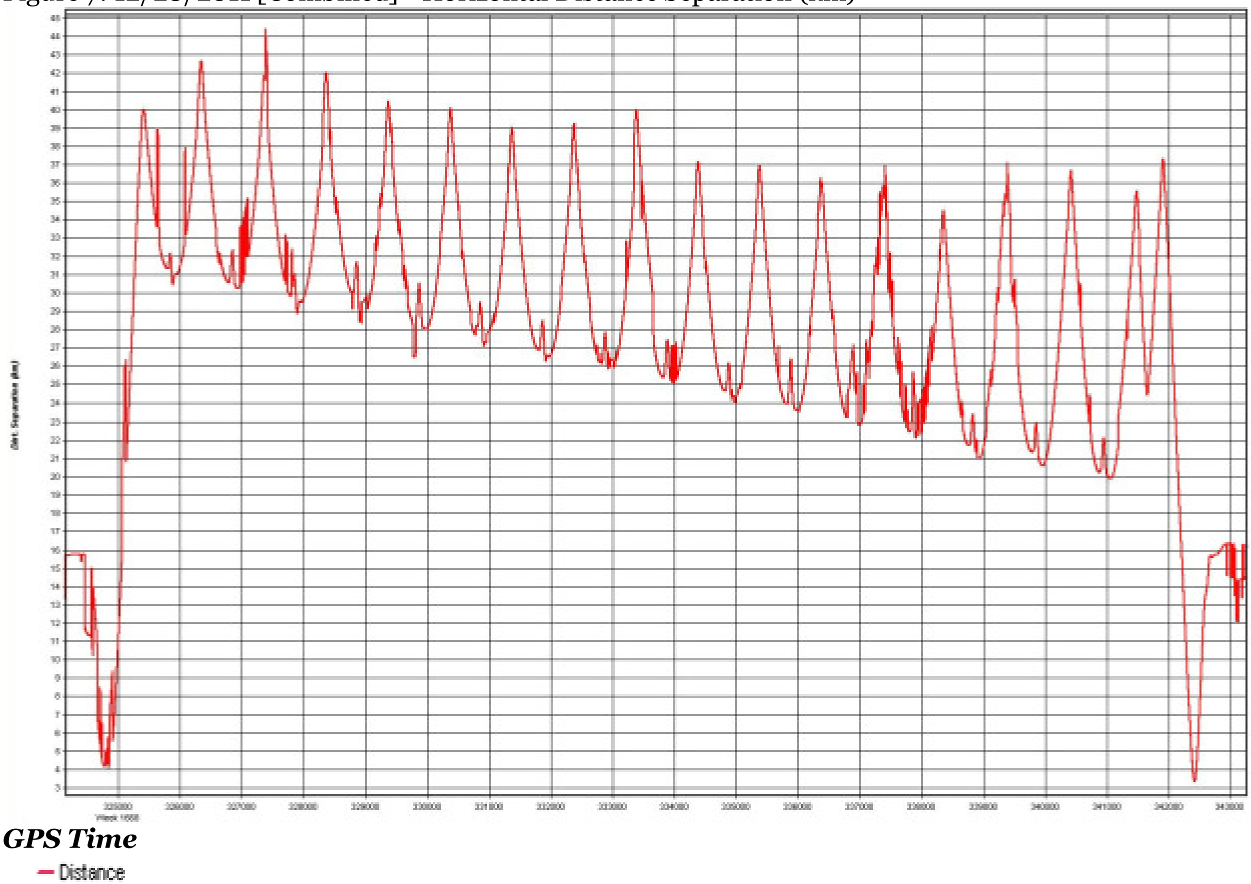


GPS Time

PDOP HDOP VDOP

Process	Run (33)	by Unknown	on 12/28/2011	at 10:00

Figure 7: 12/28/2011 [Combined] - Horizontal Distance Separation (km)

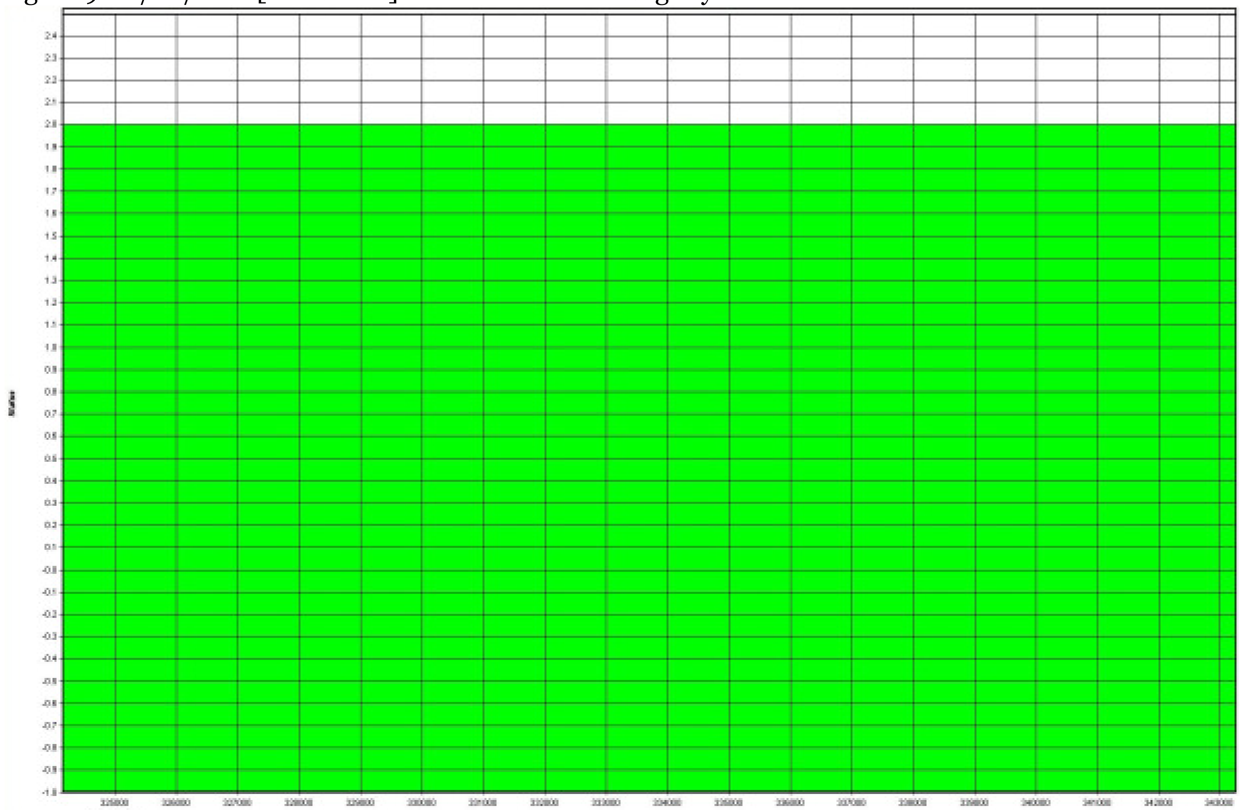


Process	Run (33)	by Unknown	on 12/28/2011	at 10:00

Figure 8: 12/28/2011 [Combined] - Forward/Reverse or Combined RMS Plot

Process	Run (33)	by Unknown	on 12/28/2011	at 10:00

Figure 9: 12/28/2011 [Combined] - Float or Fixed Ambiguity



GPS Time

Float — Fixed (1 baseline) — Fixed (2 or more)

Process	Run (33)	by Unknown	on 12/28/2011	at 10:00

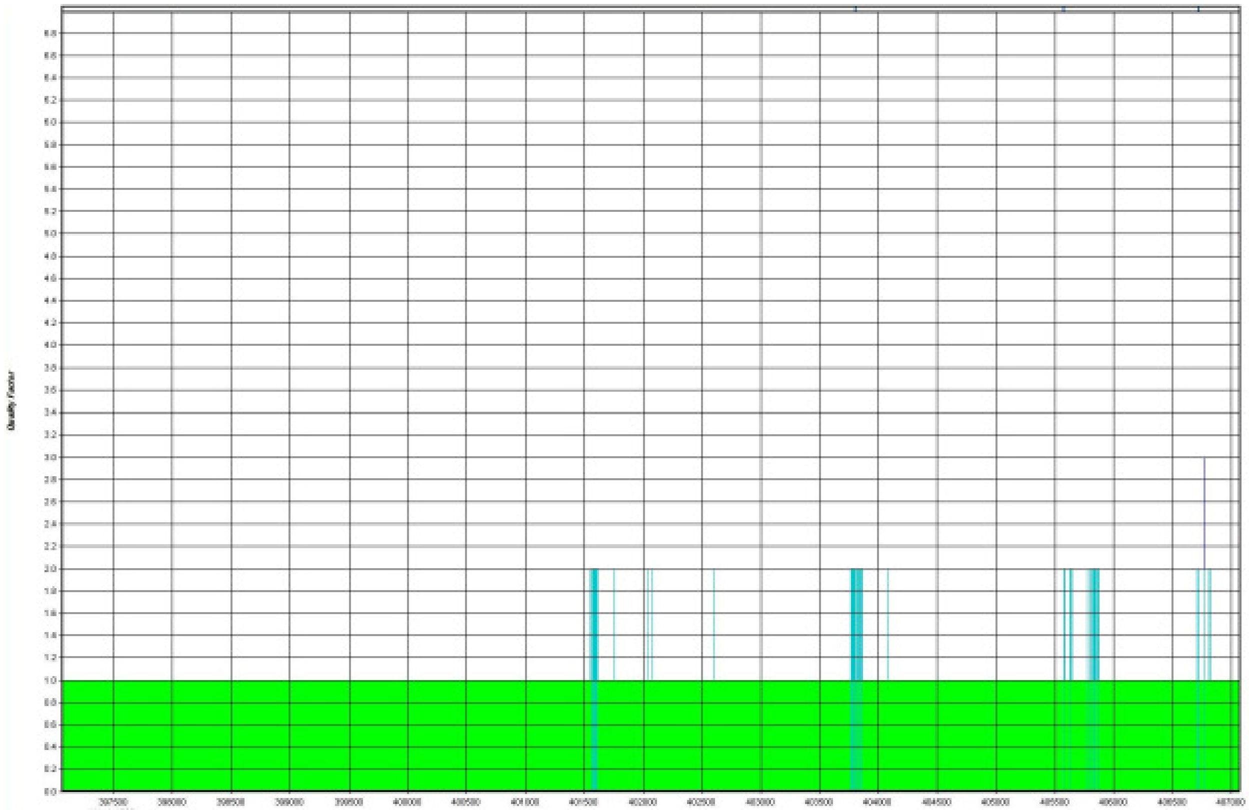
2.14 Output Results for 12/29/2011AM

POSPAC Version 4.31

Figure 1: Combined - Map

Process	Run (14)	by Unknown	on 12/29/2011	at 06:20

Figure 2: 12/29/2011AM [Combined] - Quality Factor Plot

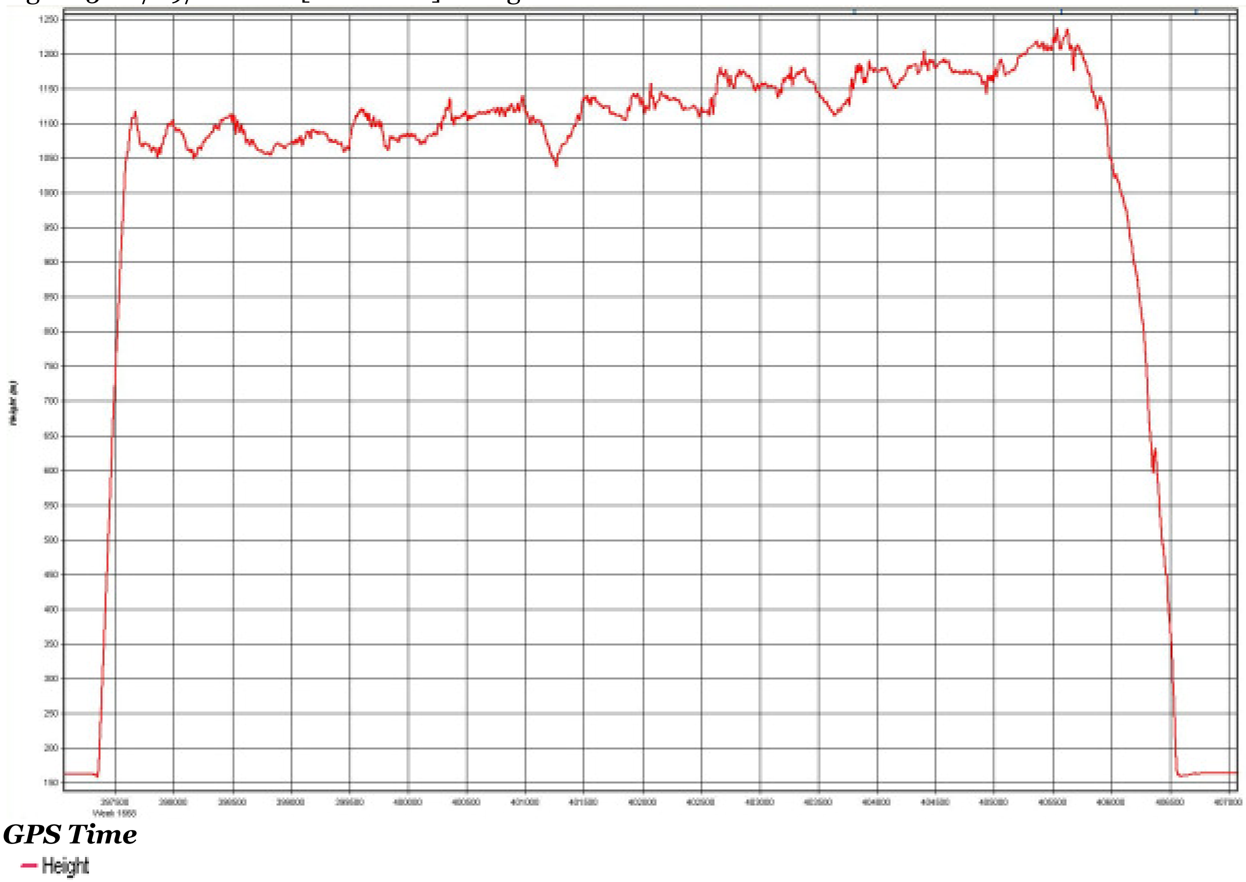


GPS Time

— Fixed Integer — Stable float — Converging float — DGPS or worse — Single Point — No solution

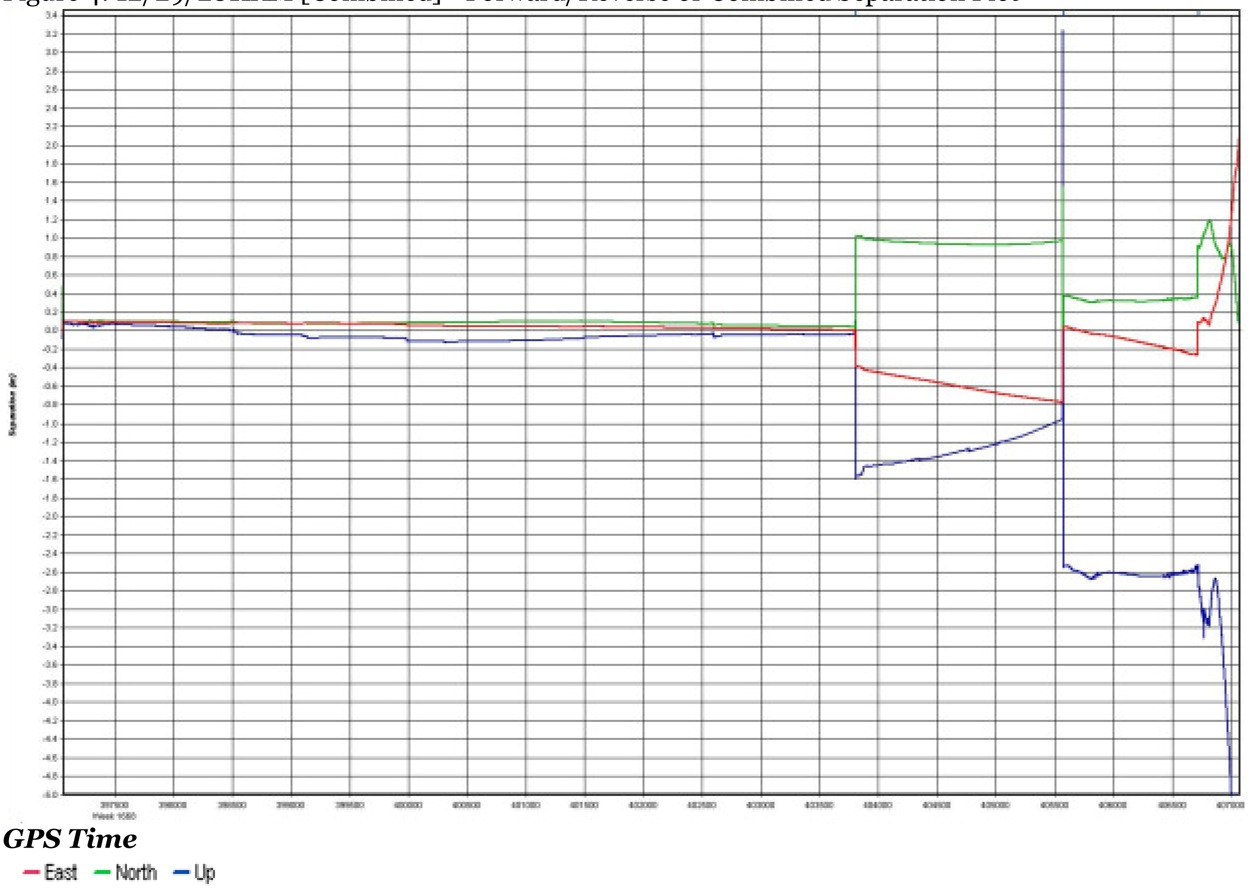
Process	Run (14)	by Unknown	on 12/29/2011	at 06:20

Figure 3: 12/29/2011AM [Combined] - Height Profile Plot



Process	Run (14)	by Unknown	on 12/29/2011	at 06:20

Figure 4: 12/29/2011AM [Combined] - Forward/Reverse or Combined Separation Plot



Process	Run (14)	by Unknown	on 12/29/2011	at 06:20

Figure 5: 12/29/2011AM [Combined] - Forward/Reverse or Combined Weighting Plot

Process	Run (14)	by Unknown	on 12/29/2011	at 06:20

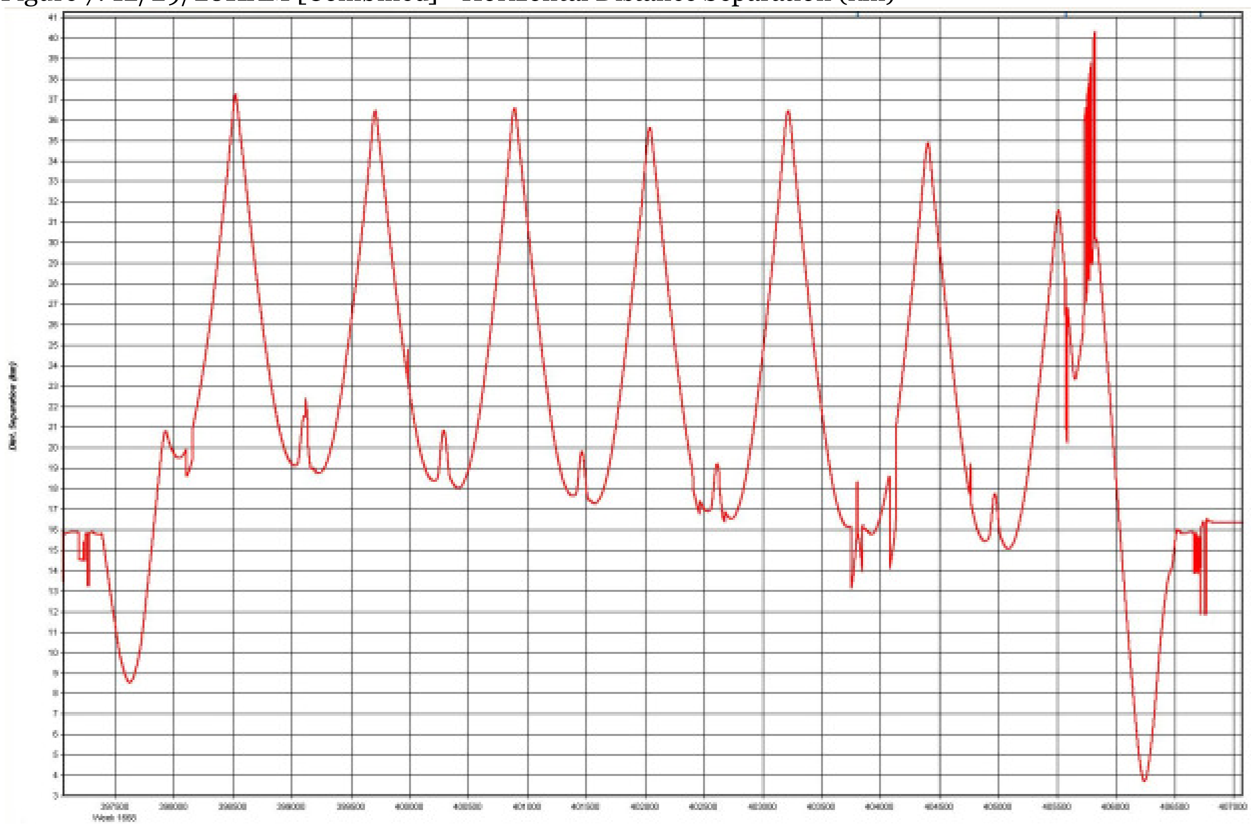
Figure 6: 12/29/2011AM [Combined] - PDOP, HDOP, VDOP Plots

GPS Time

— PDOP — HDOP — VDOP

Process	Run (14)	by Unknown	on 12/29/2011	at 06:20

Figure 7: 12/29/2011AM [Combined] - Horizontal Distance Separation (km)



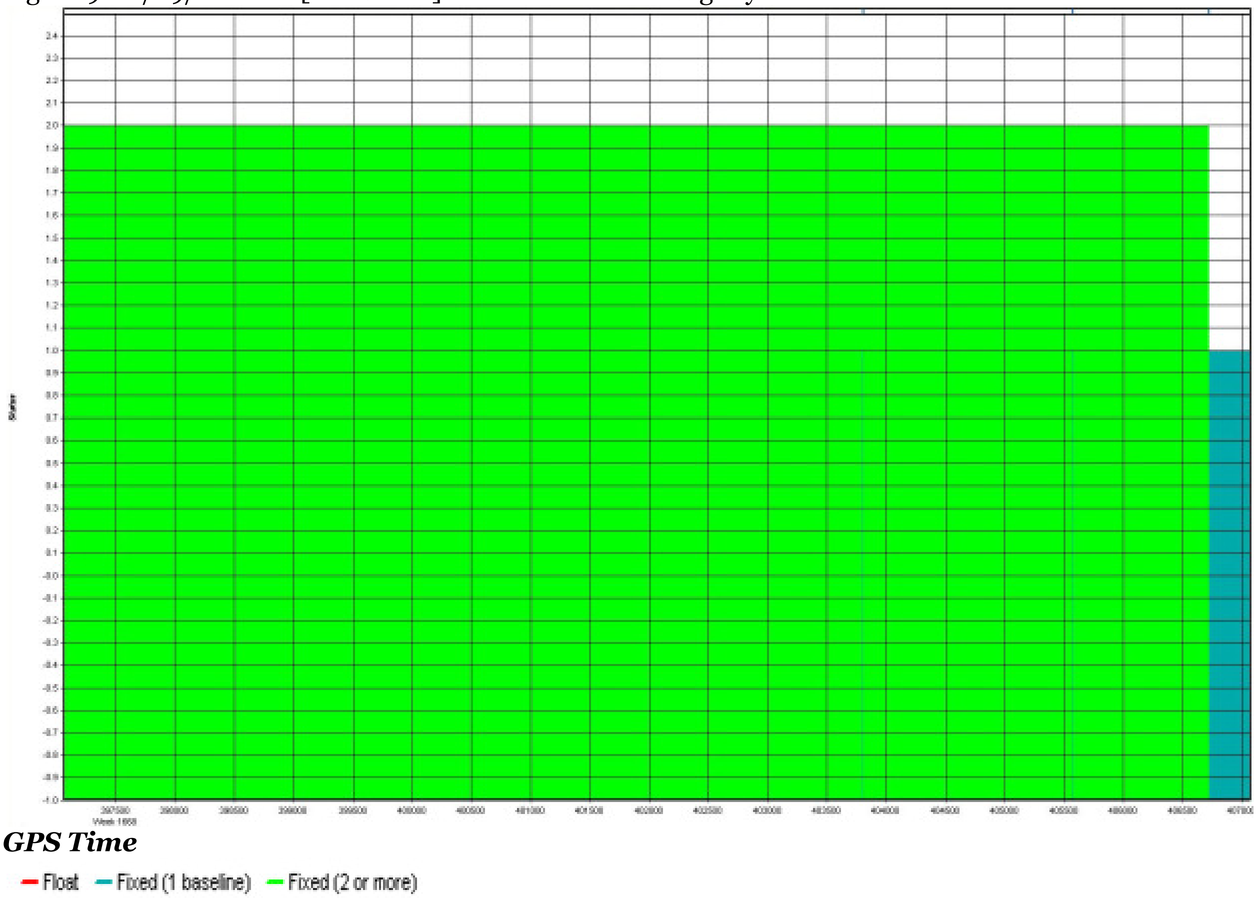
GPS Time

Process	Run (14)	by Unknown	on 12/29/2011	at 06:20

Figure 8: 12/29/2011AM [Combined] - Forward/Reverse or Combined RMS Plot

Process	Run (14)	by Unknown	on 12/29/2011	at 06:20

Figure 9: 12/29/2011AM [Combined] - Float or Fixed Ambiguity

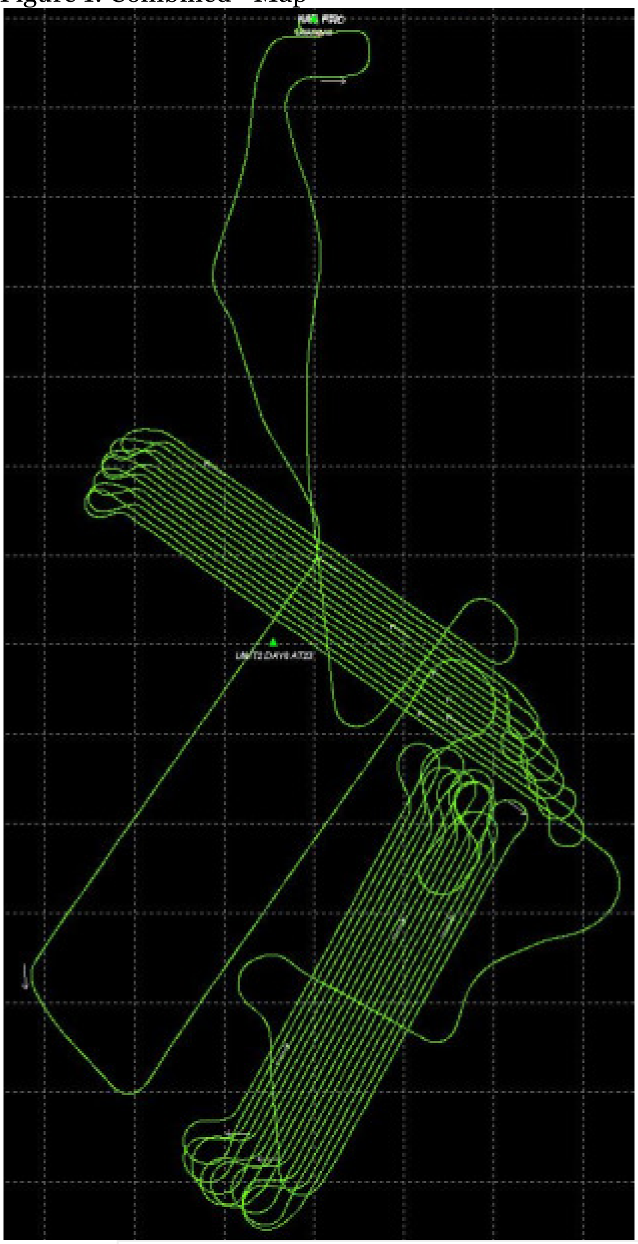


Process	Run (14)	by Unknown	on 12/29/2011	at 06:20

2.15 Output Results for 12/29/2011PM

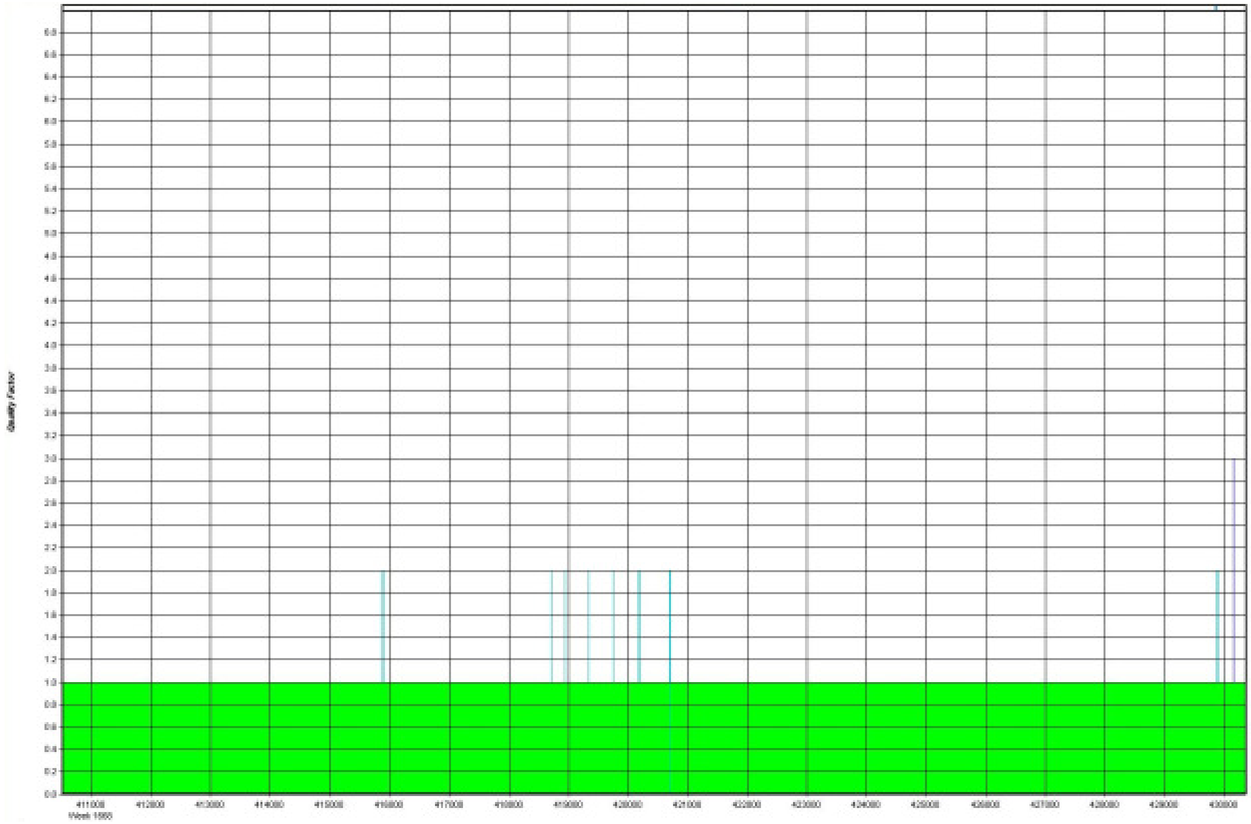
POSPAC Version 4.31

Figure 1: Combined - Map



Process	Run (33)	by Unknown	on 12/29/2011	at 10:00

Figure 2: 12/29/2011PM [Combined] - Quality Factor Plot

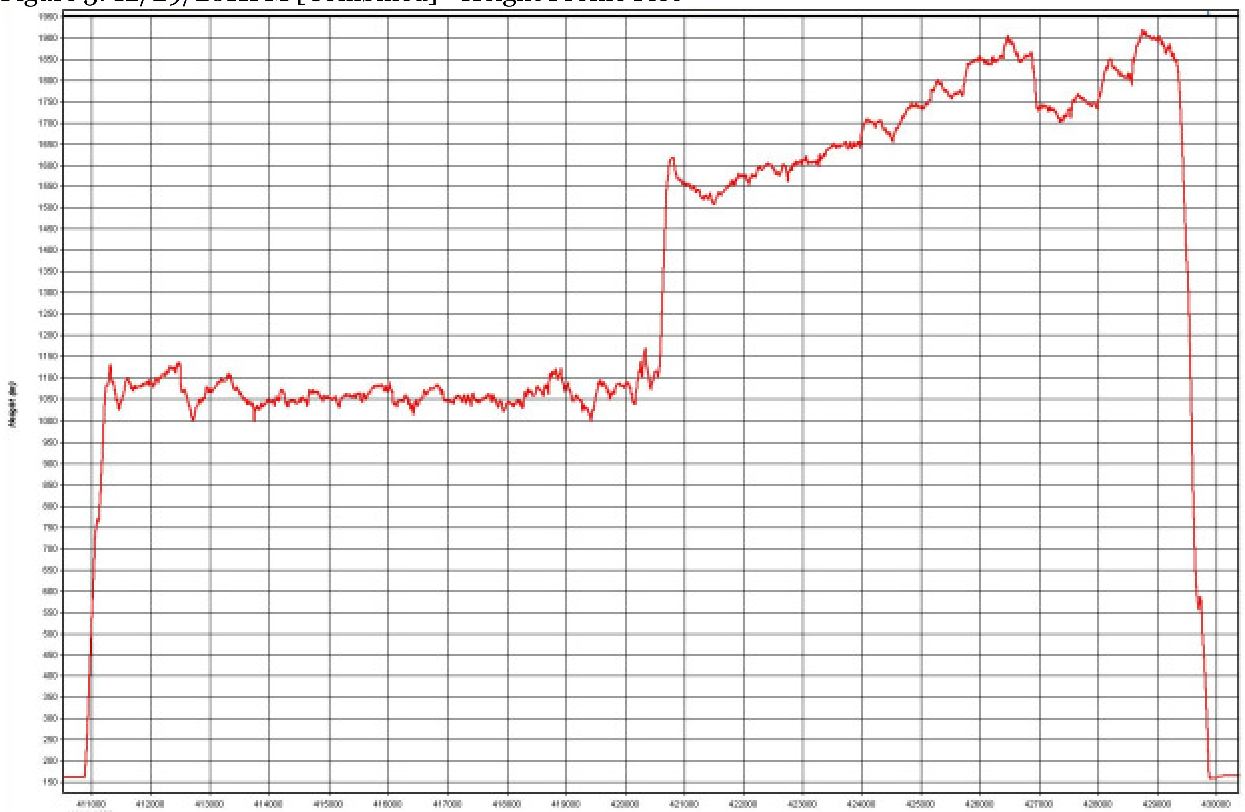


GPS Time

— Fixed Integer — Stable float — Converging float — DGPS or worse — Single Point — No solution

Process	Run (33)	by Unknown	on 12/29/2011	at 10:00

Figure 3: 12/29/2011PM [Combined] - Height Profile Plot

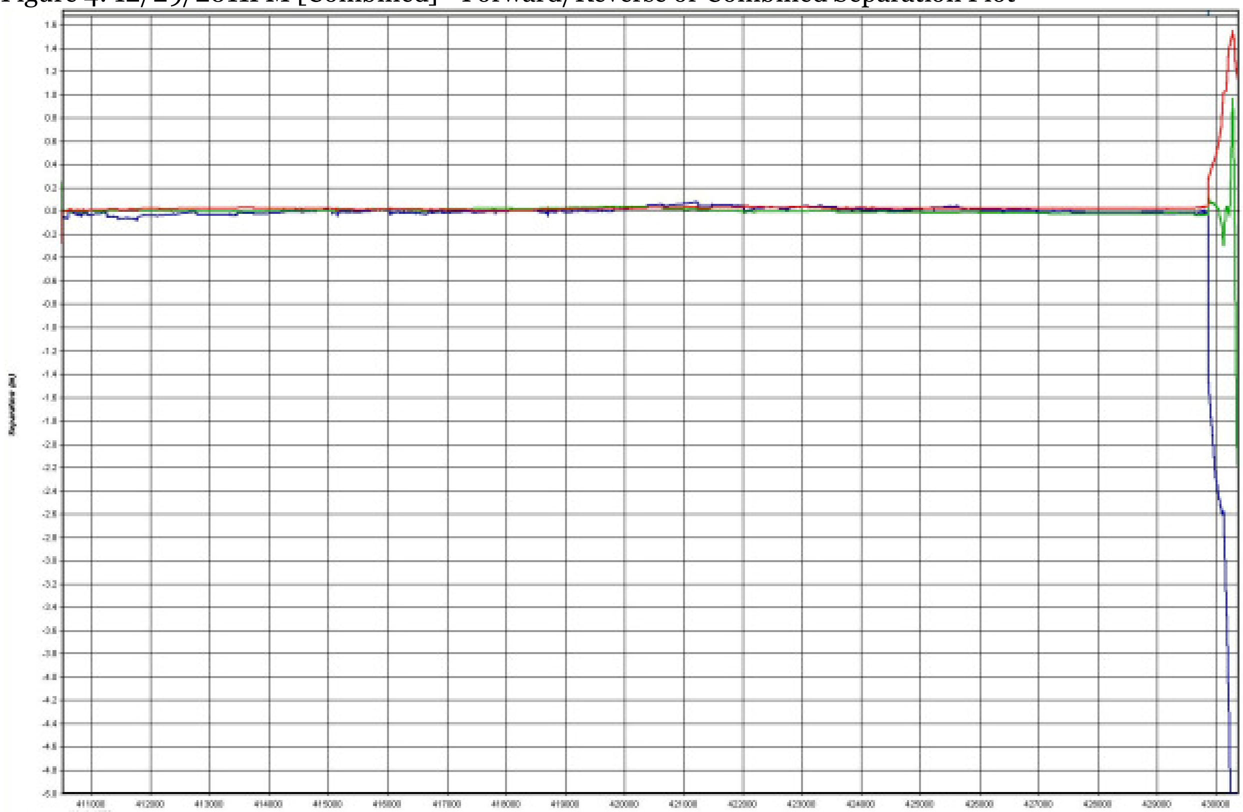


GPS Time

— Height

Process	Run (33)	by Unknown	on 12/29/2011	at 10:00

Figure 4: 12/29/2011PM [Combined] - Forward/Reverse or Combined Separation Plot



GPS Time

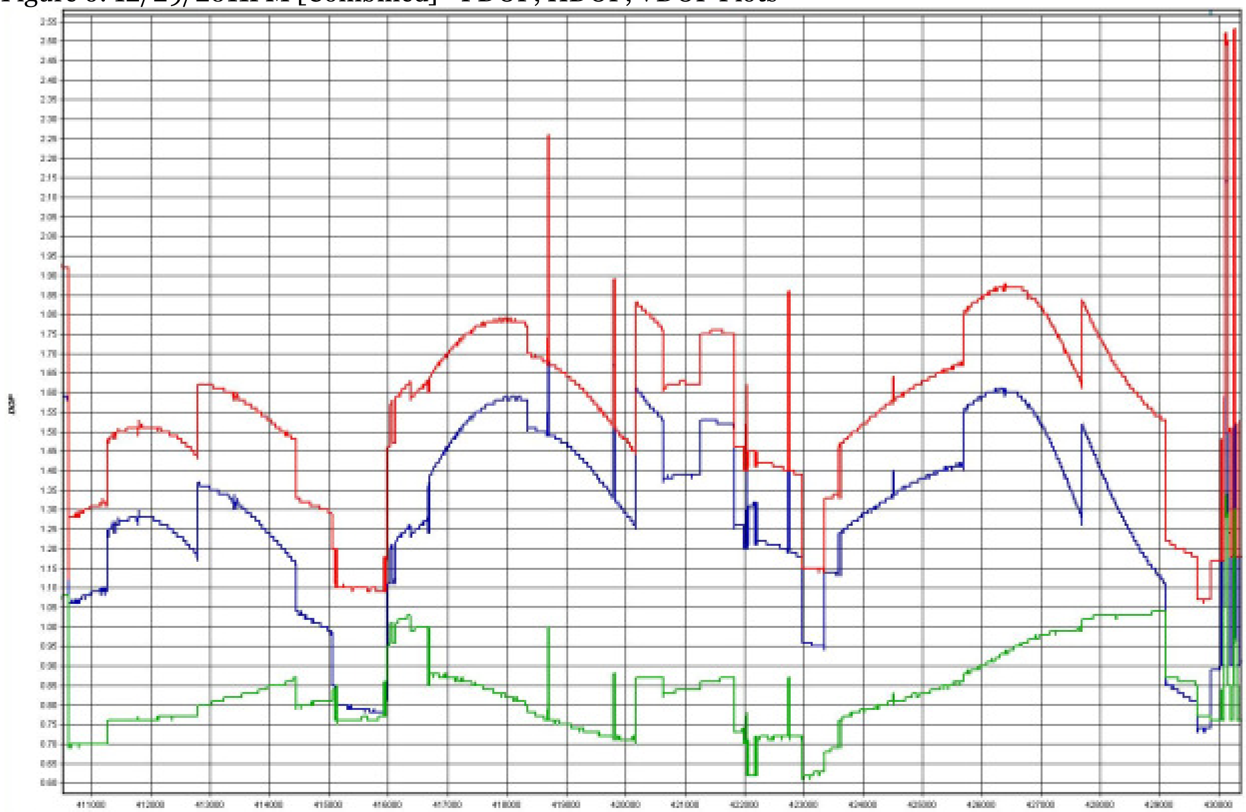
— East — North — Up

Process	Run (33)	by Unknown	on 12/29/2011	at 10:00

Figure 5: 12/29/2011PM [Combined] - Forward/Reverse or Combined Weighting Plot

Process	Run (33)	by Unknown	on 12/29/2011	at 10:00

Figure 6: 12/29/2011PM [Combined] - PDOP, HDOP, VDOP Plots

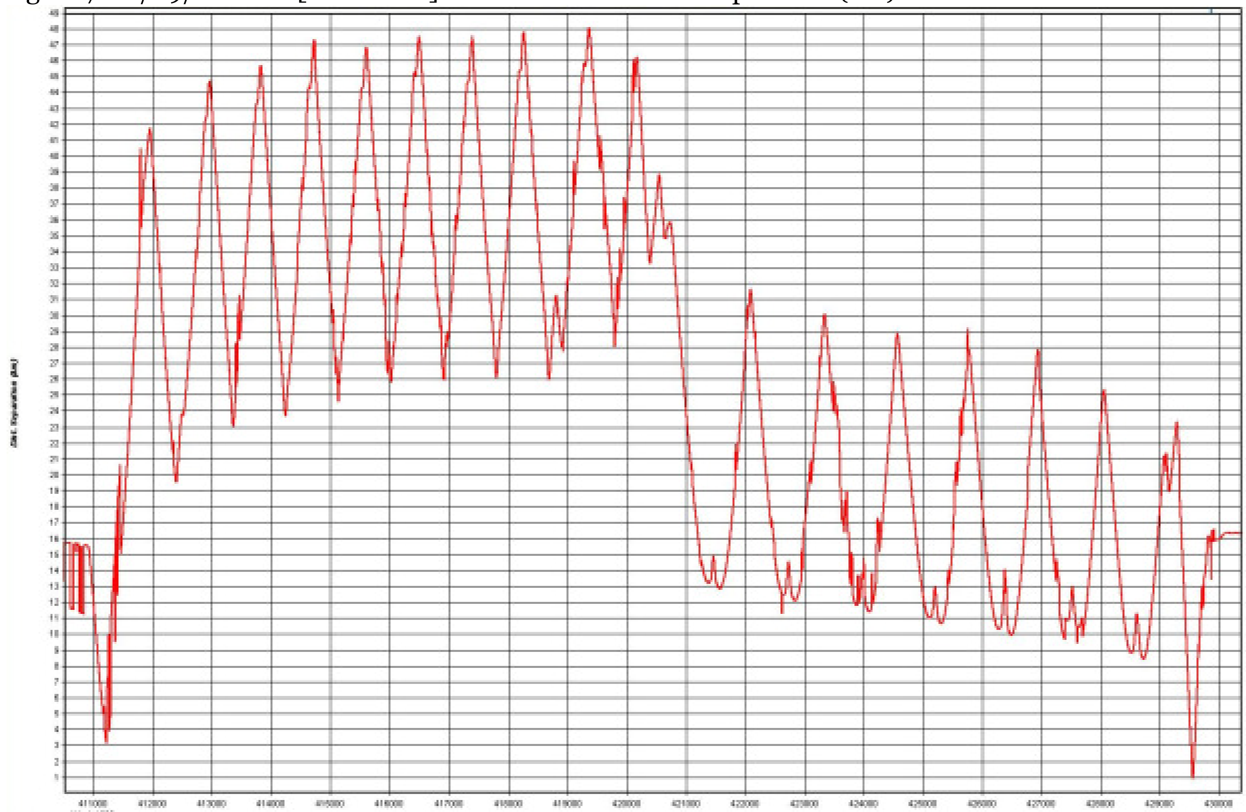


GPS Time

— PDOP — HDOP — VDOP

Process	Run (33)	by Unknown	on 12/29/2011	at 10:00

Figure 7: 12/29/2011PM [Combined] - Horizontal Distance Separation (km)

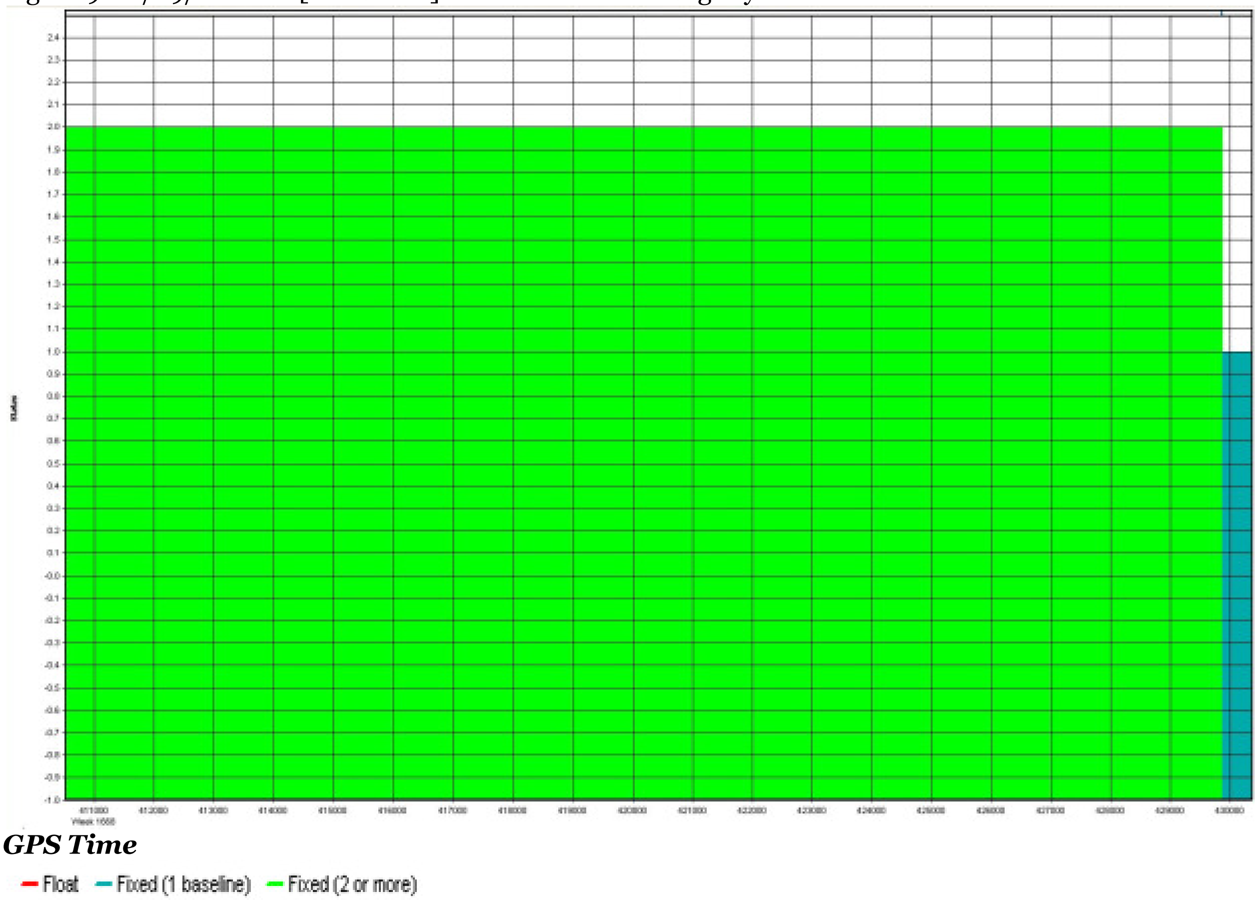


Process	Run (33)	by Unknown	on 12/29/2011	at 10:00

Figure 8: 12/29/2011PM [Combined] - Forward/Reverse or Combined RMS Plot

Process	Run (33)	by Unknown	on 12/29/2011	at 10:00

Figure 9: 12/29/2011PM [Combined] - Float or Fixed Ambiguity

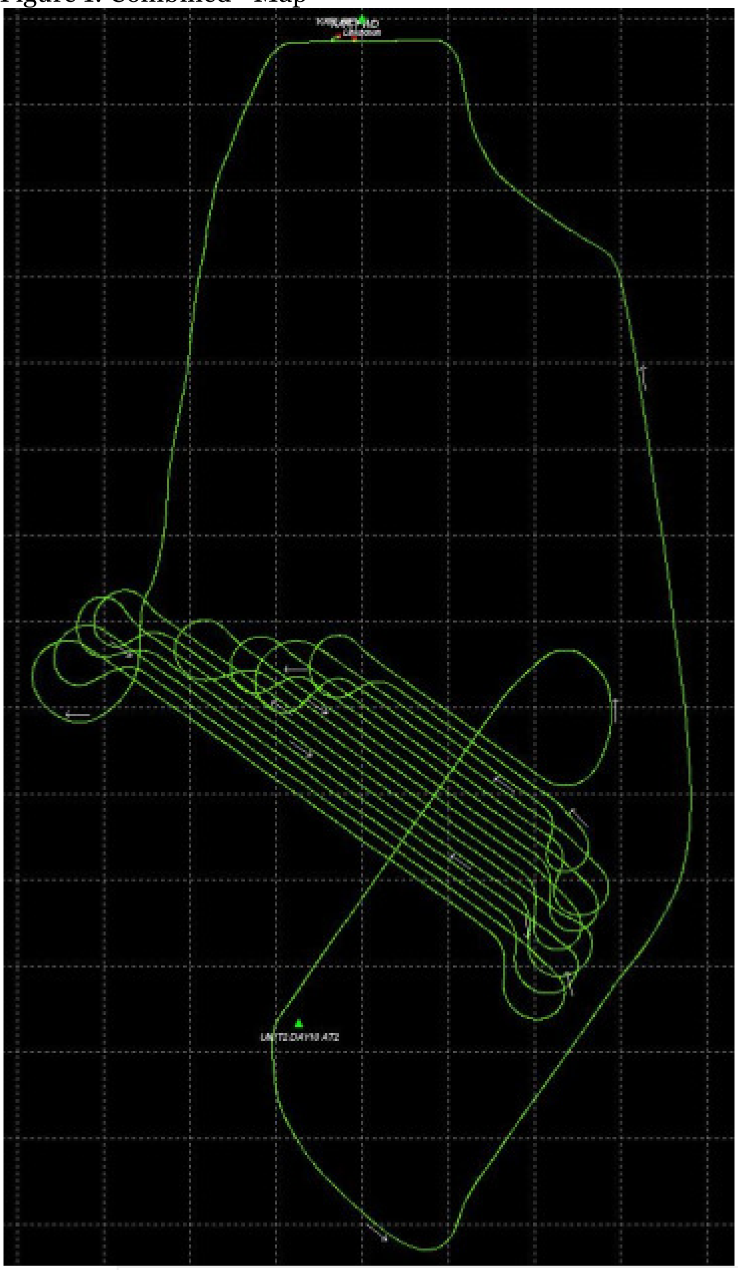


Process	Run (33)	by Unknown	on 12/29/2011	at 10:00

2.16 Output Results for 12/30/2011

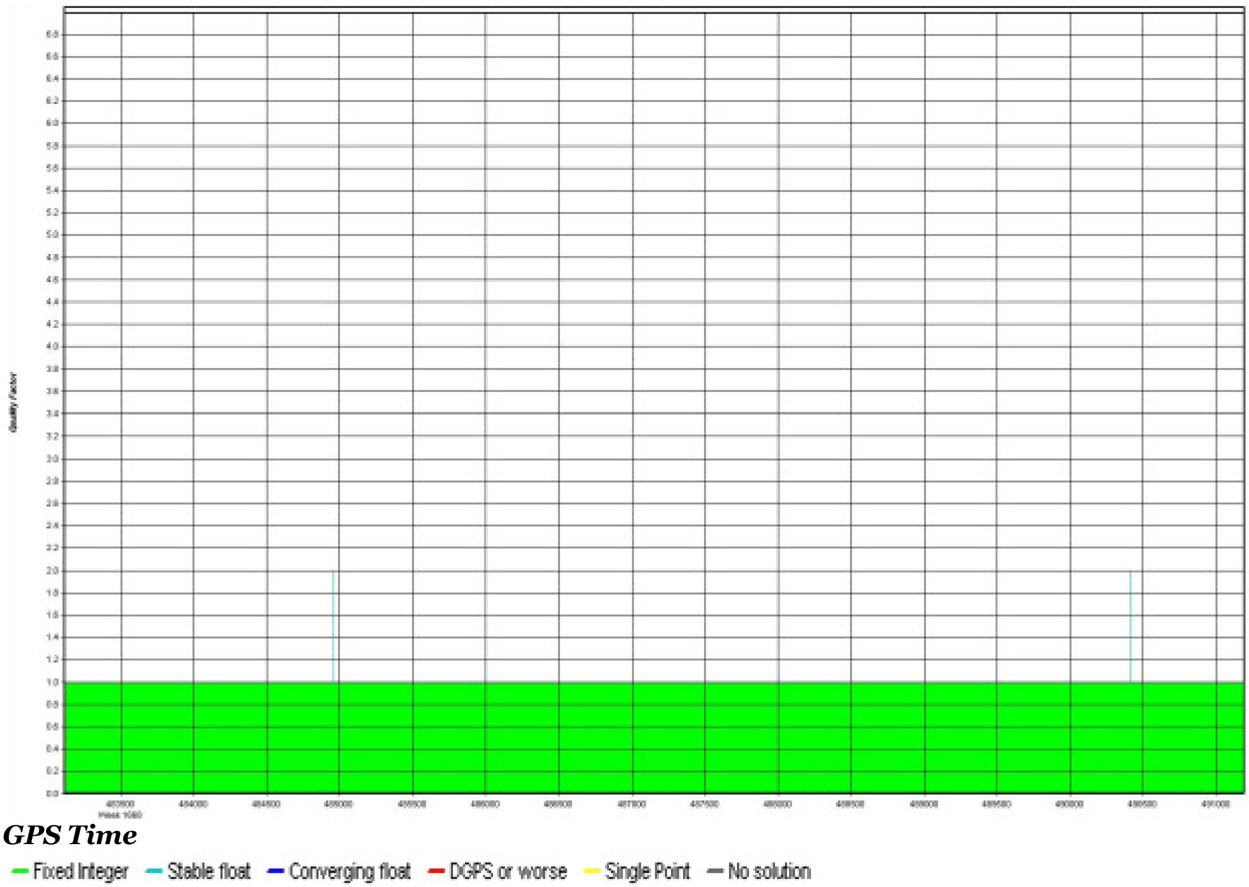
POSPAC Version 4.31

Figure 1: Combined - Map



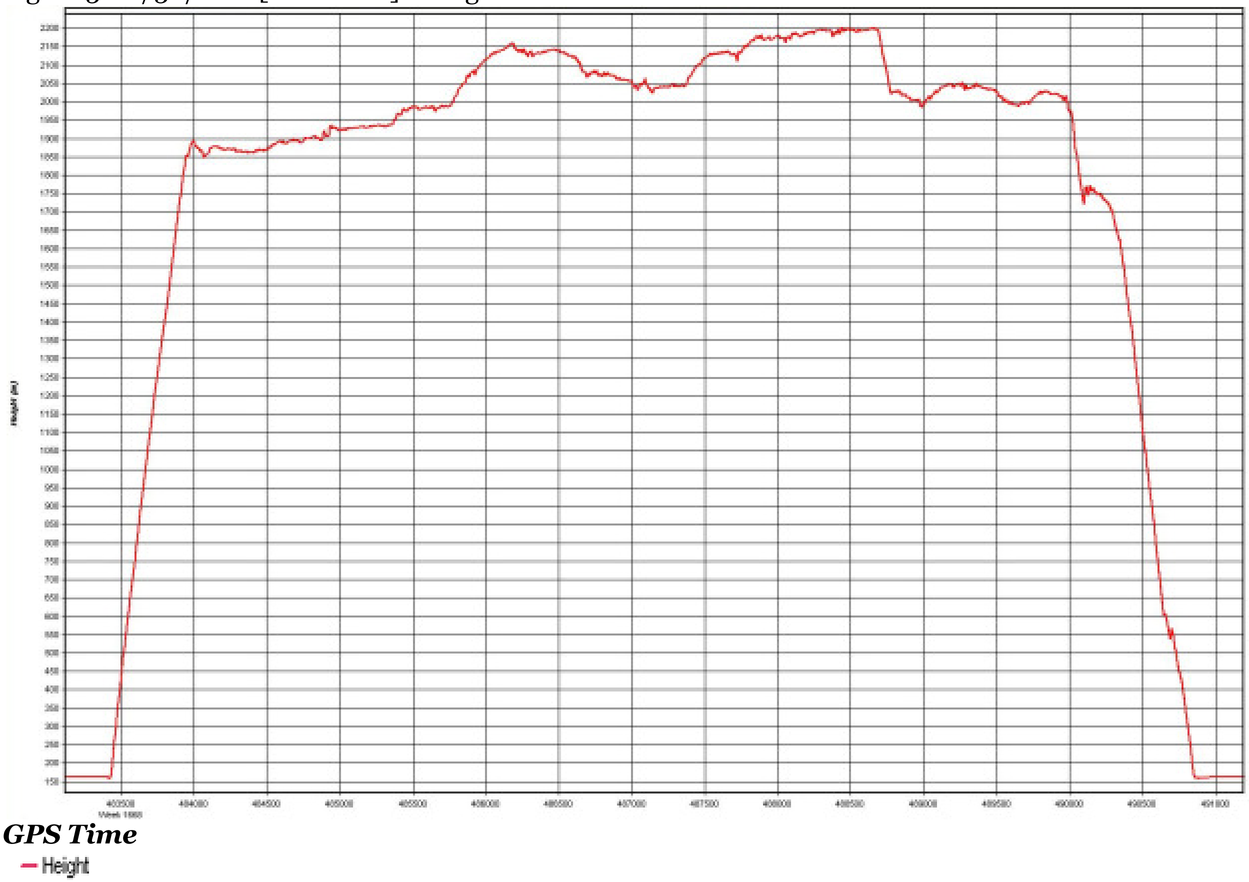
Process	Run (17)	by Unknown	on 12/30/2011	at 06:15

Figure 2: 12/30/2011 [Combined] - Quality Factor Plot



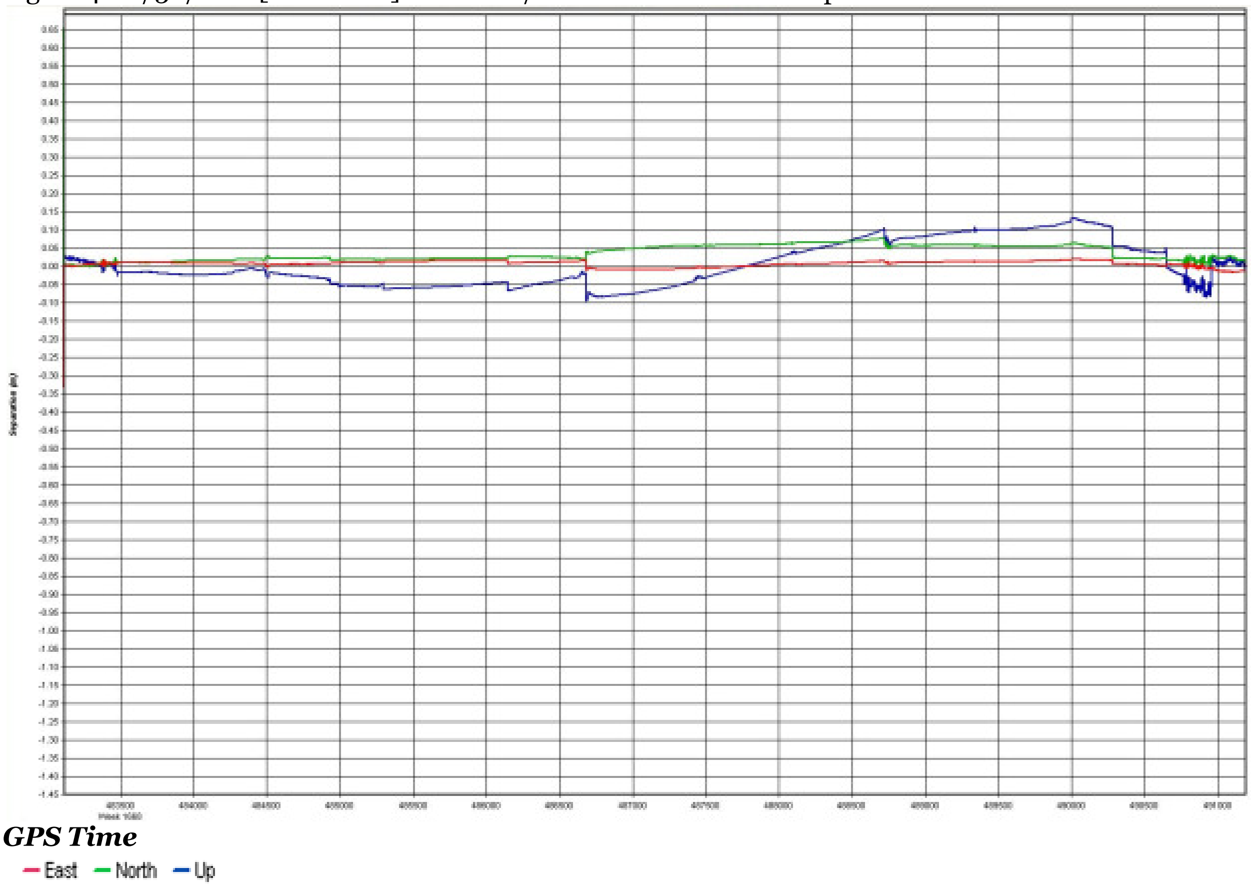
Process	Run (17)	by Unknown	on 12/30/2011	at 06:15

Figure 3: 12/30/2011 [Combined] - Height Profile Plot



Process	Run (17)	by Unknown	on 12/30/2011	at 06:15

Figure 4: 12/30/2011 [Combined] - Forward/Reverse or Combined Separation Plot

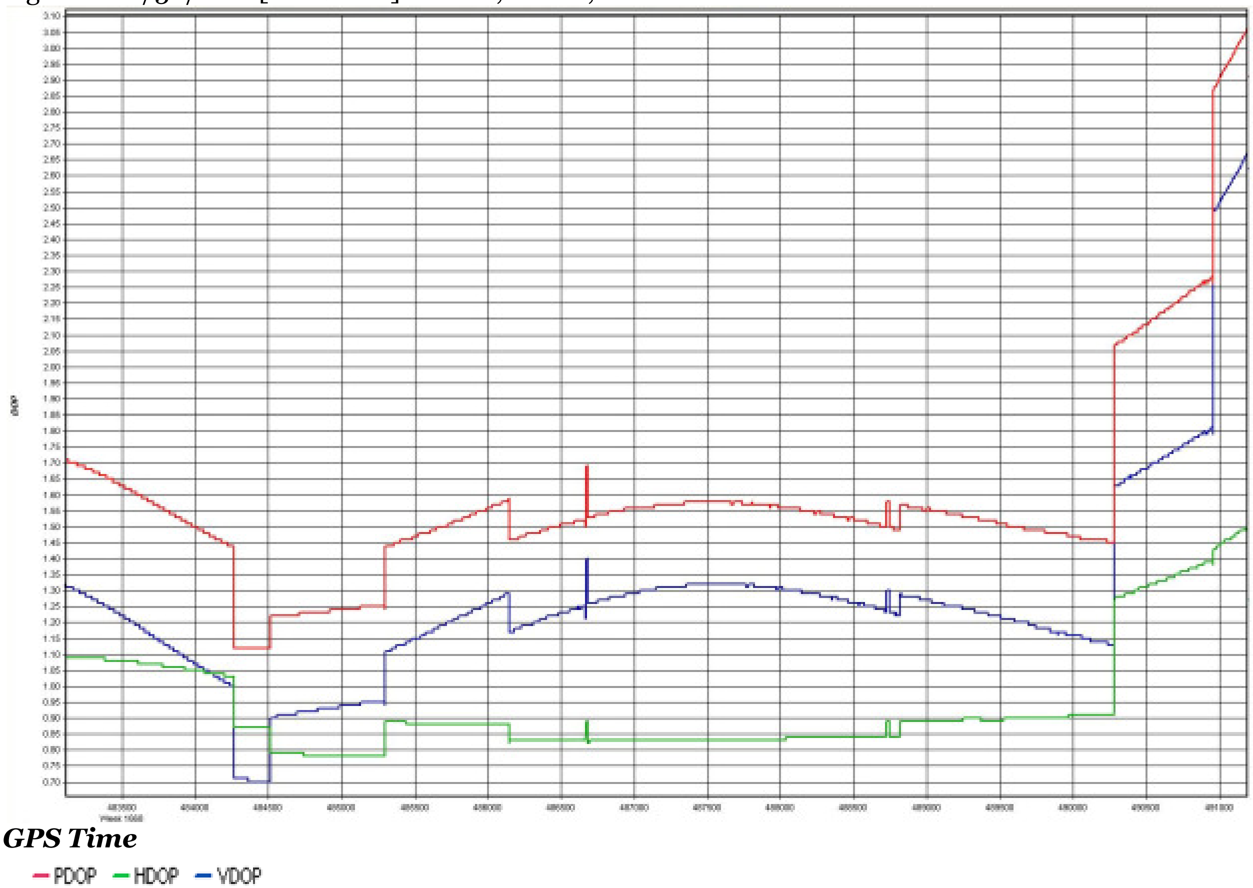


Process	Run (17)	by Unknown	on 12/30/2011	at 06:15

Figure 5: 12/30/2011 [Combined] - Forward/Reverse or Combined Weighting Plot

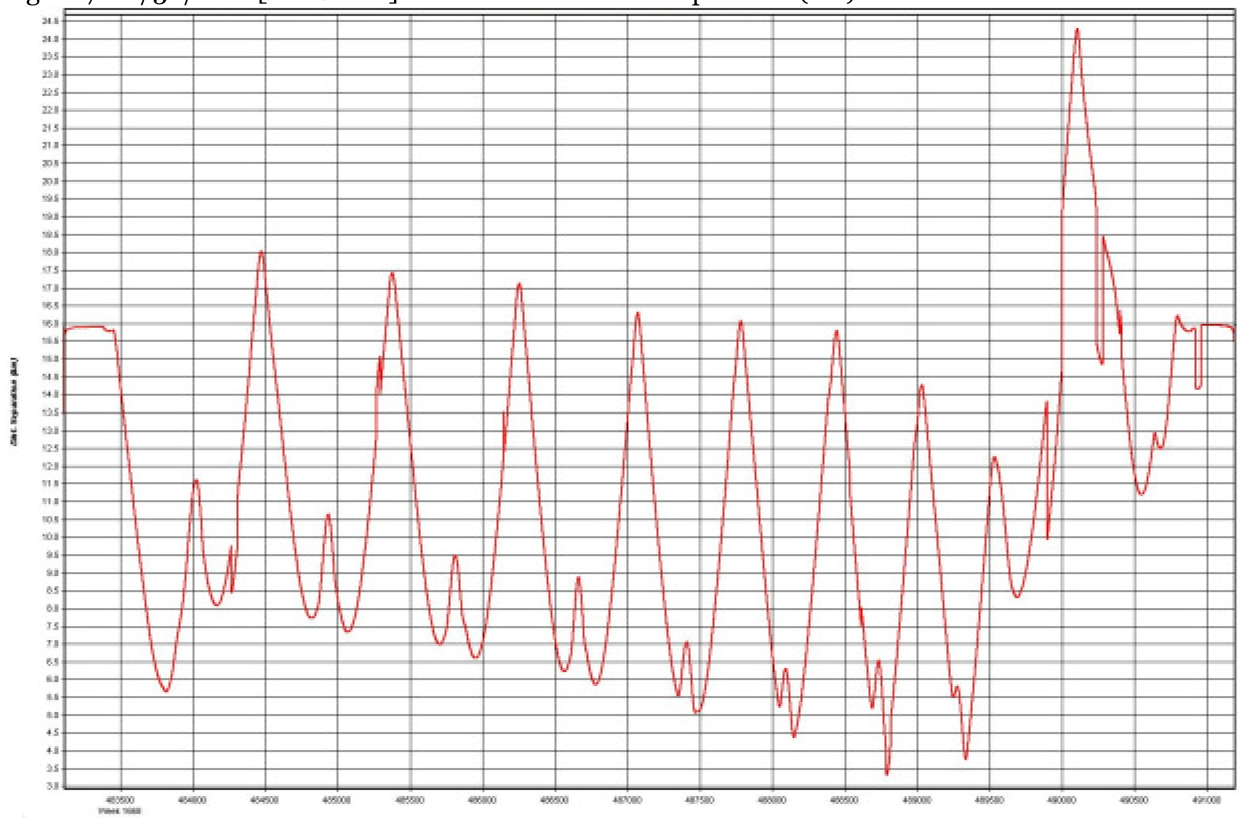
Process	Run (17)	by Unknown	on 12/30/2011	at 06:15

Figure 6: 12/30/2011 [Combined] - PDOP, HDOP, VDOP Plots



Process	Run (17)	by Unknown	on 12/30/2011	at 06:15

Figure 7: 12/30/2011 [Combined] - Horizontal Distance Separation (km)

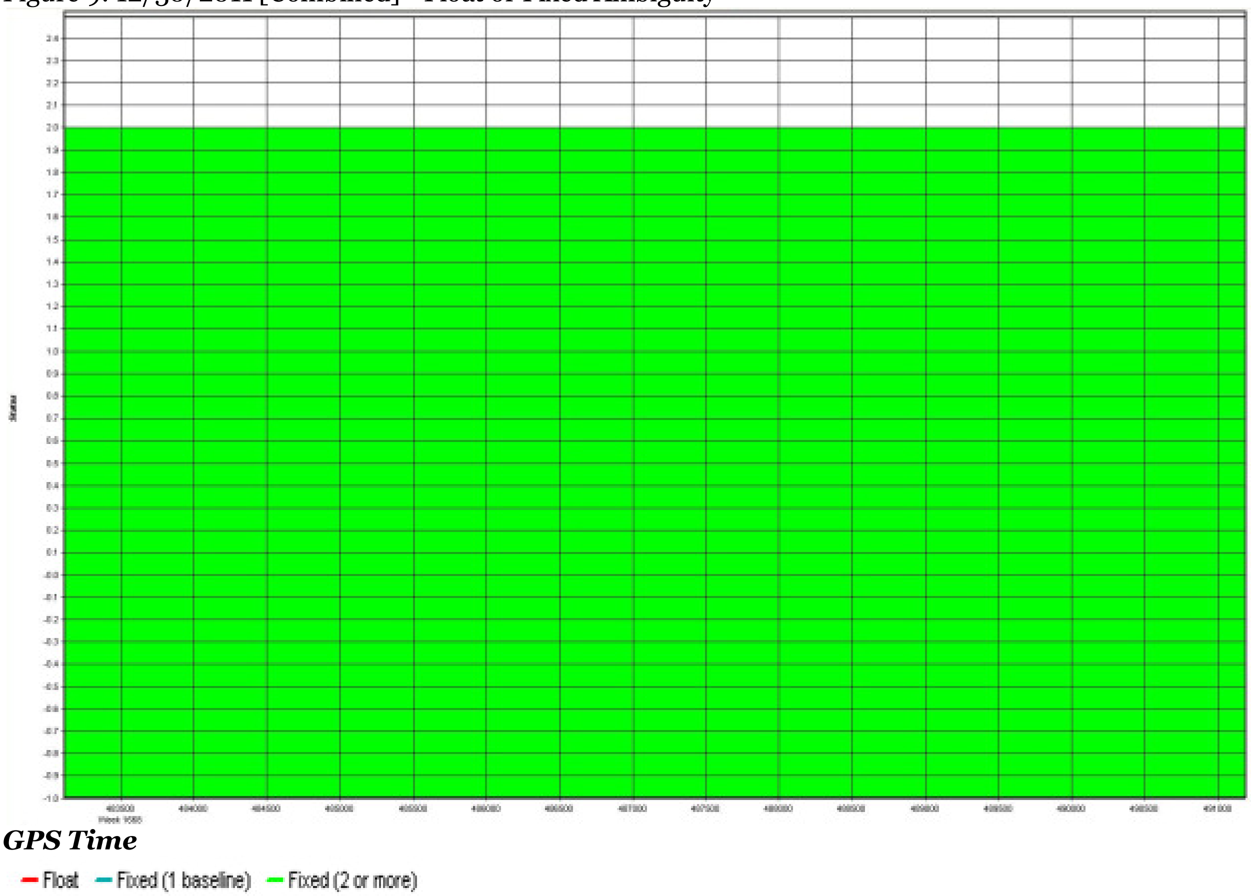


Process	Run (17)	by Unknown	on 12/30/2011	at 06:15

Figure 8: 12/30/2011 [Combined] - Forward/Reverse or Combined RMS Plot

Process	Run (17)	by Unknown	on 12/30/2011	at 06:15

Figure 9: 12/30/2011 [Combined] - Float or Fixed Ambiguity



Process	Run (17)	by Unknown	on 12/30/2011	at 06:15