Contact information
Vinton Valentine
The Ecosystems Center
Marine Biological Laboratory
Woods Hole, MA 02543
(508) 289-7727
(508) 457-1548 fax
vvalentine@mbl.edu

NCALM LIDAR Project: Plum Island, Massachusetts

1. Survey areas

The survey area is an irregular polygon (86.7 square kilometers) at the Plum Island River in northeast Massachusetts. The eastern third of the polygon was flown on Monday April 18, 2005. The central third was flown early Tuesday morning April 19, 2005 and the last third (the Parker River area) was flown on the afternoon of the 19th. Figure 1 (below) is an image showing the project shape and location.

Figure 1 - Project shape and location

Figure 2 is a plot of the flight lines colored by flight. Lines from day 108 lines are shown in blue, day 109 flight 1 lines are in red and day 109 flight 2 lines are in green.

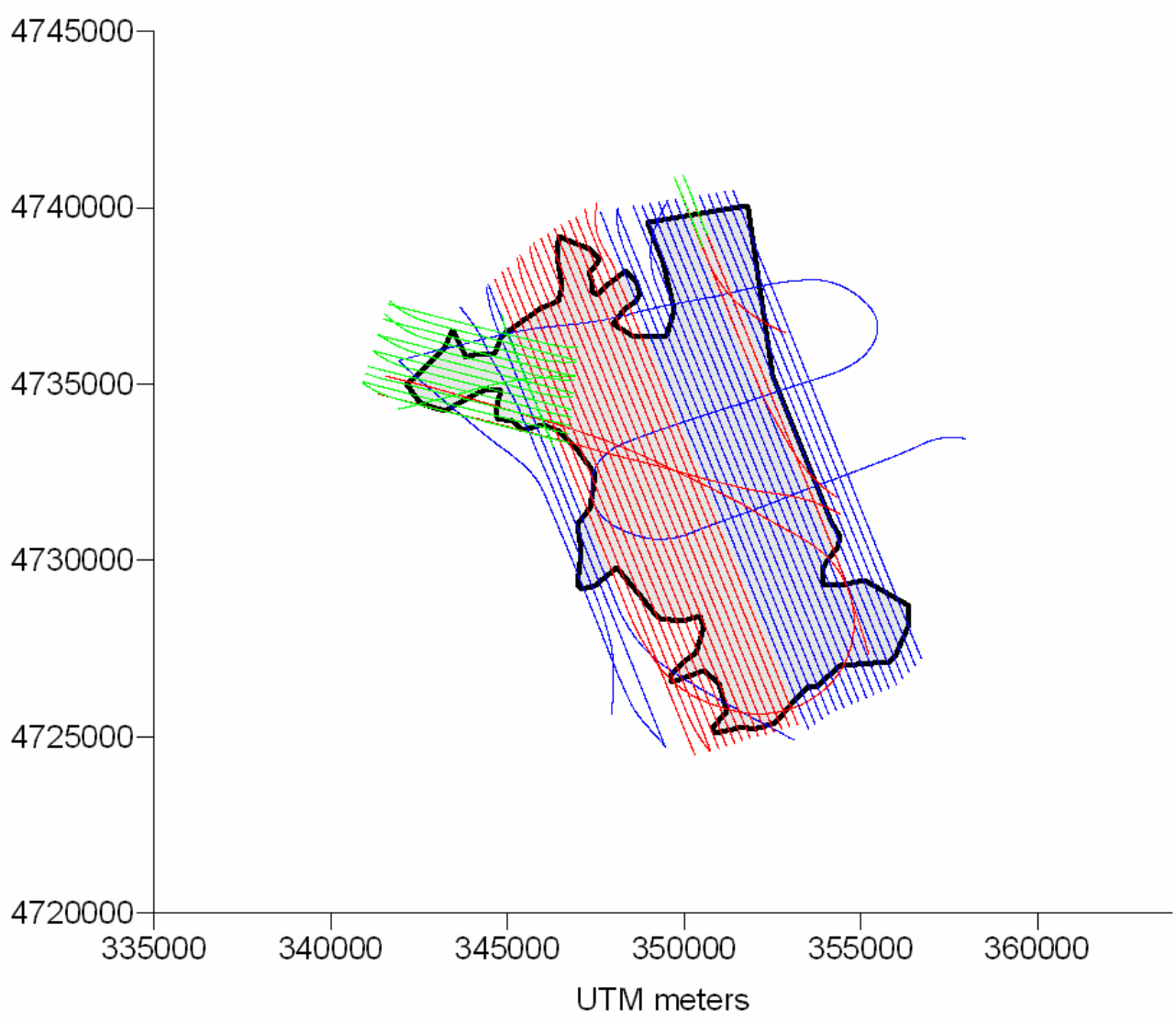

Figure 2 - Flight lines flown on separate days – blue day 108; red day 109 flight 1; green day 109 flight 2

2. Survey Parameters

The project area was flown with 48 flight lines: lines 1-36 oriented approximately north-south and lines 37-48 oriented approximately east-west. Additionally cross lines and ground truth passes were flown for field calibration purposes. The flying height was 600 meters Above Ground Level (AGL). Flying speed was variable, but targeted at 117 knots. Planned point spacing per swath was approximately 1 meter along-track at nadir, 2.1 meters at the scan edge and 0.73 meters cross-track. Overlap coverage was targeted at approximately 100%, (50% sidelap). Additional parameters are shown on the next page in Table 1.

Flying Speed (m/s)	**Scan Spacing (m)**	**Pulse Rate (p/sec)**
60.0	**2.1**	**33333.0**
Indicated Air Speed (nm/h)	**Scan Width (m)**	**Pulses Per Scan**
116.6	**436.8**	**595.2**
Scan Rate (+/- degrees)	**Scan Angle (d)**	**Distance Between Range Points Along Scan (m)**
28.0	**20.0**	**0.73**
Flying Height (meters AGL)	**Flight line Spacing (m)**	**Swath Overlap (m)**
600	**219.8**	**260.0**

Table 1 - Survey Parameters at 600 meters AGL.

Table 2 lists the survey parameters at 800 meters for comparison.

Flying Speed (m/s)	**Scan Spacing (m)**	**Pulse Rate (p/sec)**
60.0	**2.1**	**33333.0**
Indicated Air Speed (nm/h)	**Scan Width (m)**	**Pulses Per Scan**
116.6	**582.4**	**595.2**
Scan Rate (+/- degrees)	**Scan Angle (d)**	**Distance Between Range Points Along Scan (m)**
28.0	**20.0**	**0.98**
Flying Height (meters AGL)	**Flight line Spacing (m)**	**Swath Overlap (m)**
800	**219.8**	**363.0**

Table 2 - Survey Parameters at 800 meters AGL.

Table 3 (below) gives the combined laser-on and air time totals for the project.

Laser-on	**3.59**	**Hours**
Air Time(Laser-off)	**6.83**	**Hours**
Total Flight Time	**10.42**	**Hours**

Table 3 - Laser–on time, air time, and total flight time.

3. GPS Reference Stations

Two GPS reference station locations were used during the survey; both at the north end of the polygon. Both stations were located in the parking lot of the Plum Island Airport, located on the Plum Island Turnpike. Both stations were marked with nails set by U of Florida personnel. These marks were observed for a total of about 17.5 hours each in three sessions over 2 days. All GPS observations were logged at a 1-second rate, and were submitted to the NGS on-line processor OPUS with solution files included as Appendix A. The repeat session results on both marks yielded reference station coordinate differences of less than 0.023 meters in both horizontal and vertical positions. Final coordinates for the reference stations PLM1 and PLM2 were calculated from the OPUS solutions as an average of the first two sessions (the third session was only 4 hours long and was not used in for determining final coordinates). For further information on OPUS see http://www.ngs.noaa.gov/OPUS/ and for more information on the CORS network see http://www.ngs.noaa.gov/CORS/ . Ground equipment consisted

of ASHTECH (Thales Navigation) Z-Extreme receivers, with choke ring antennas (Part# 700936.D) mounted on 2-meter fixed-height tripods.

4. Navigation Processing

Airplane trajectories for this survey were processed using both KARS software (Kinematic and Rapid Static) written by Dr. Gerry Mader of the NGS Research Laboratory, and REALM processing software by Optech, Inc. The KARS solution is dual-frequency phase-differenced fixed integer, while the REALM solution is phase-differenced L1 only, without fixing phase ambiguities; these types of solutions (REALM) are generally less suitable over long baseline lengths (over 25 kilometers) but usually very good over short baseline separation distances. Day 109 trajectories were processed separately in KARS software using our two reference stations and then coordinate differences between the separate solutions were plotted. Figure 3 (below) is a plot of the first day 109 flight (the second day 109 flight showed similar results). Here differences in Easting, Northing, and Height of two trajectories, one using PLM1 as the reference and the other using PLM2 have been shown.

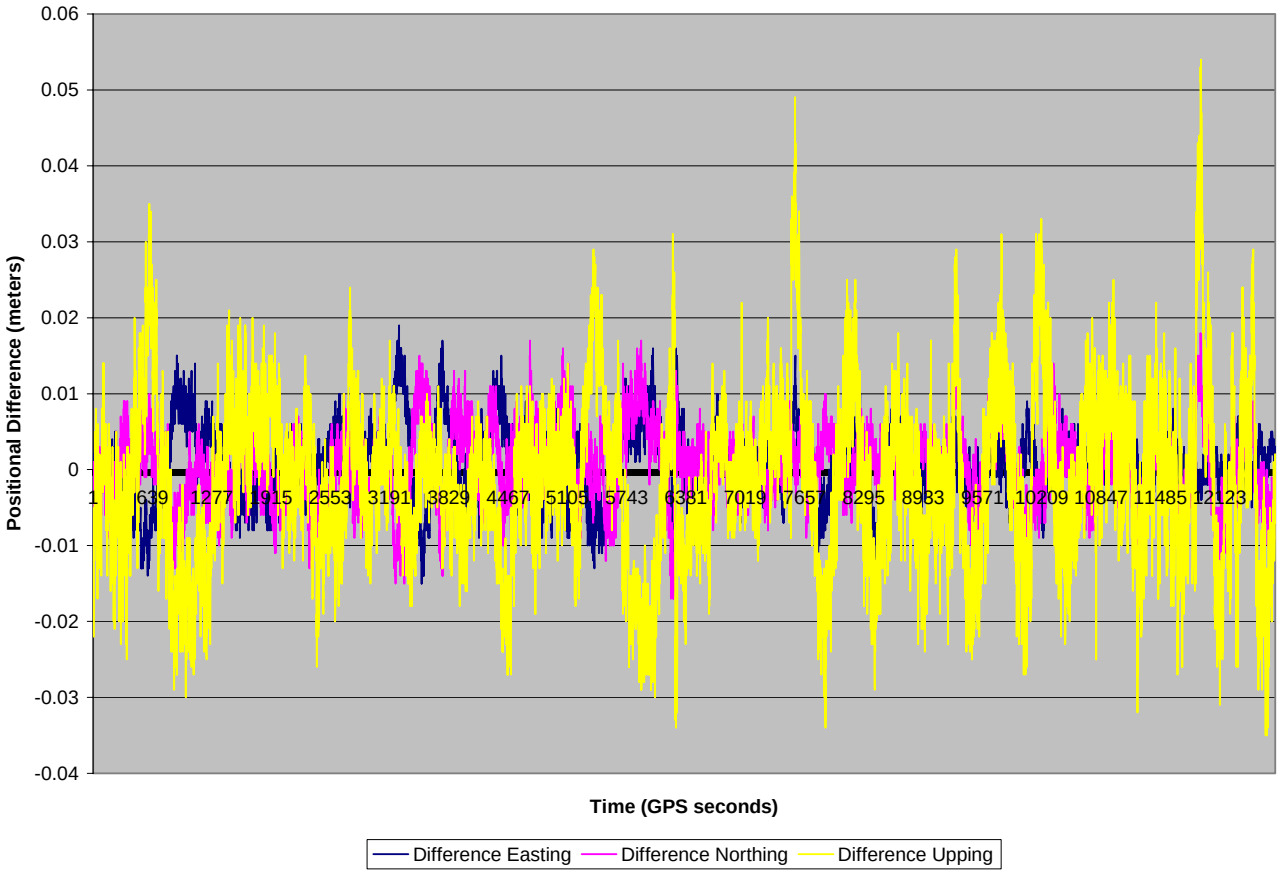

Figure 3 - Positional differences in aircraft trajectories with respect to time.

The REALM L1 trajectory was used for the processing of the final navigation for the day 108 trajectory because the L1/L2 solution was not available due to a problem with the aircraft GPS antenna. The L1 solution will not vary significantly with the dual frequency solution over the short baselines seen on this flight, as verified in many previous analyses. KARS L1/L2 solutions were able to be computed for portions of the day 108 flight. These portions were compared to the entire REALM L1 solution and similar results with a consistent z bias of about 11 cm which was removed.

After GPS processing was complete, the final trajectories (1 Hz) were combined with raw IMU measurements (50 Hz) and a final navigation solution was developed using Applanix POSPAC software. This software employs a Kalman Filter and various smoothing algorithms to determine a best estimate of trajectory (50 Hz).

5. Laser Point Processing

All coordinates were processed with respect to NAD83 and referenced to the national CORS96 network. The projection for the 9 column output is UTM Zone 19, with ellipsoid heights, and units in meters. All other output is in MA-Mainland State Plane Coordinates with orthometric heights in NAVD88, computed using NGS GEOID03 model.

The most complete output format is nine-column ASCII (space delimited), one file per flight strip. The nine columns are as follows: 1. GPS time (seconds of week); 2. Easting last stop; 3. Northing last stop; 4. Height last stop; 5. Intensity last stop; 6. Easting first stop; 7. Northing first stop; 8. Height first stop; 9. Intensity first stop. . Note that in these 9-column files no geoid model has been applied - height values are ellipsoid heights and these height values will NOT match orthometric heights (elevations) found in the 4-column output or in the 1-meter DEM grid nodes.

During processing, a scan cutoff angle of 4.0 degrees was used to eliminate points at the edge of the scan lines. This was done to improve the overall DEM accuracy (points farthest from the scan nadir are the most affected by small errors in pitch, roll and scanner mirror angle measurements). Points with very low intensity values were also filtered out (intensity values less than 7), because these points also tend to be the least accurate. This is due to the fact that very weak return pulses yield the noisiest range measurements. These points represent a very small percentage of the total number of points, usually in the neighborhood of a few hundredths of one percent.

All calibration files as well as all raw observation files (both GPS and ALTM) necessary to reprocess this project in its entirety are archived by UC Berkeley.

6. Ground Truth and Calibration

In order to provide on-site calibration and ground truth, a section of the Plum Island Turnpike running east and west just north of the project polygon was surveyed using vehicle-mounted GPS, and then surveyed with the ALTM during the flight. Comparisons were made between the heights of the vehicle-collected GPS and the airborne laser scanner. This allowed for a check on the calibration of the airborne scanner as well as a measure of the accuracy of the scanner heights. Figure 4 shows a plot of the vehicle-mounted GPS ground truth points in relation to the project boundary.

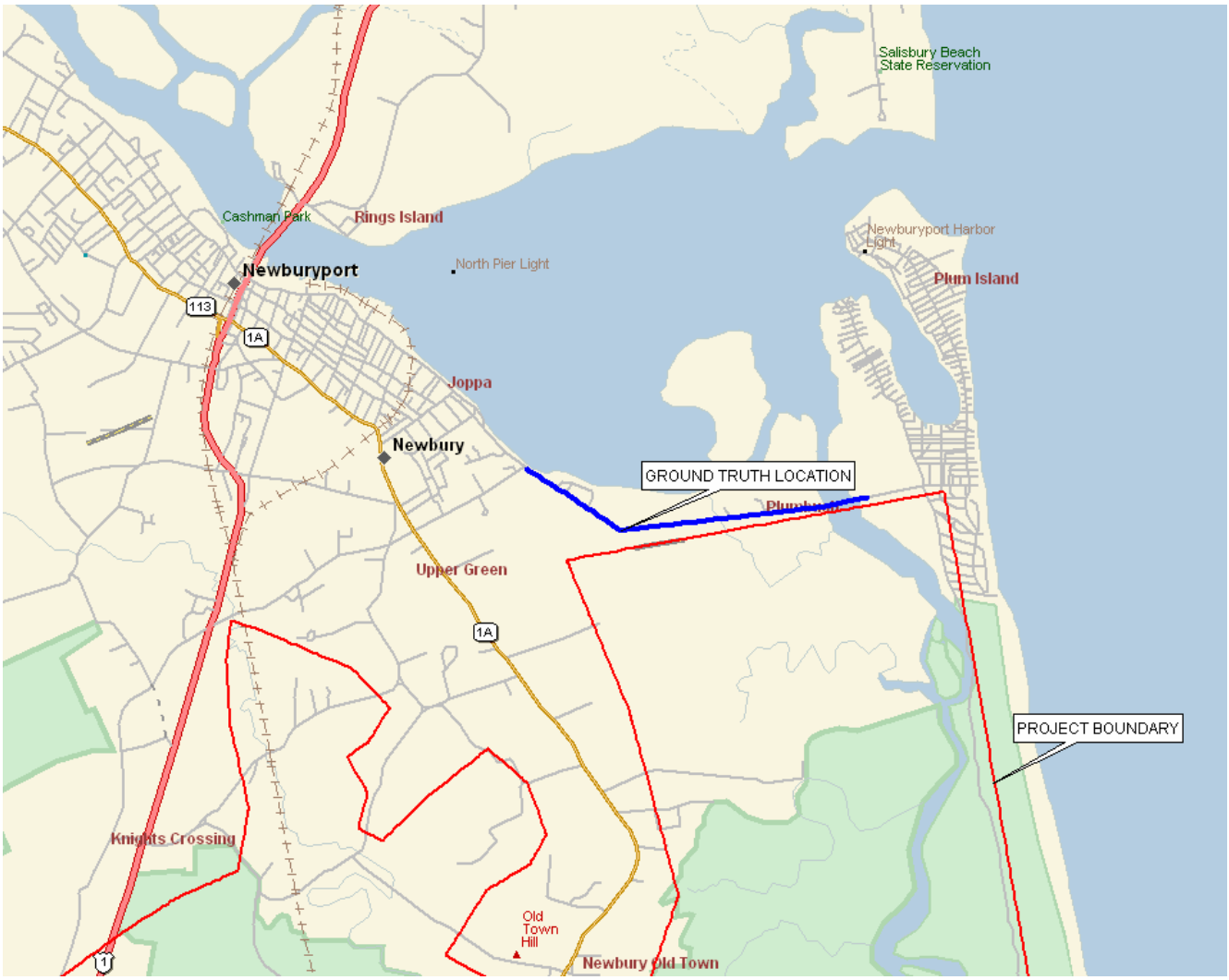

Figure 4 - Location of GPS ground truth points

The standard deviation of the differences between the ALTM nearest neighbor shot and the ground truth points was about 9 cm on all flights. After analysis, all trajectories showed height shifts of between 10 and 15 cm.

7. Filtering and DEM Production

Terrasolid's TerraScan (http://terrasolid.fi) software was used to classify the last return LIDAR points (already projected in state plane coordinates) and generate the "bare-earth" dataset. The classification process was executed in two phases:

1) **Automatic ground classification**. The following classification routines were run on the entire dataset:
   a. "Low Points" Removal. This routine was used to search for possible error points which are clearly below the ground surface. The elevation of each point is compared with every other point within a given neighborhood and if the initially selected point is clearly lower then any other point it will be classified as a "low point" and not be considered as potential ground in the next step. This routine can also search for groups of low points where the whole group is lower than other points in the vicinity. The routine was run 4 times in a row with slightly different parameters. The parameters were experimentally determined using a test block covering an area where these low outliers are most likely to occur (urban settings).

      Parameters Used:

	1st pass	2nd pass	3rd pass	4th pass
Search for	group	group	group	single
Max count	6	6	6	1
More than (min height diff)	10.0 m	5.0 m	5.0 m	5.0 m
Within (xy search range)	50 m	30 m	20 m	20 m

   b. Ground Classification. This routine classifies ground points by iteratively building a triangulated surface model. The algorithm starts by selecting some local low points assumed as sure hits on the ground, within a specified windows size. This makes the algorithm particularly sensitive to low outliers in the initial dataset, hence the requirement of removing as many erroneous low points as possible in the first step.

      The routine builds an initial model from selected low points. Triangles in this initial model are mostly below the ground with only the vertices touching ground. The routine then starts molding the model upwards by iteratively adding new laser points to it. Each added point makes the model follow ground surface more closely. Iteration parameters determine how close a point must be to a triangle plane so that the point can be accepted to the model. "Iteration angle" is the maximum angle between point, its projection on triangle plane and closest triangle vertex. The smaller the Iteration angle, the less eager the routine is to follow changes in the point cloud. "Iteration distance" parameter makes sure that the iteration does not make big jumps upwards when triangles are large. This helps to keep low buildings out of the model. The routine can also help avoiding adding unnecessary point density into the ground model by reducing the eagerness to add new points to ground inside a triangle with all edges shorter than a specified length.

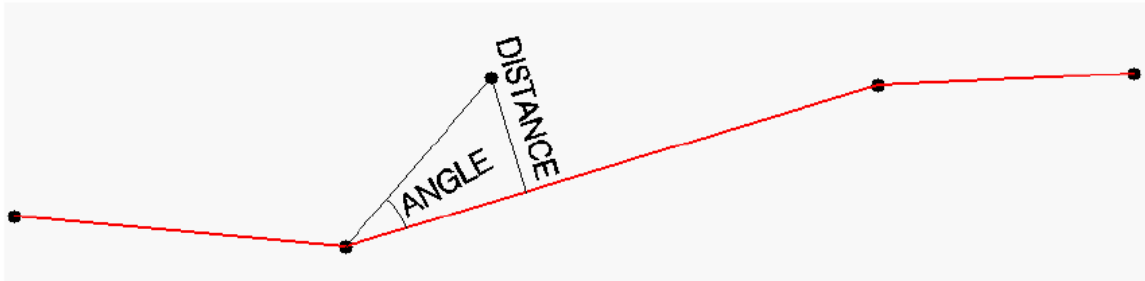

Figure 5 – Ground classification parameters

Ground classification parameters used:
Max Building Size (window size): 60.0 m
Terrain Angle: 80.0
Iteration Angle: 6.0
Iteration Distance: 1.4 m
Reduce iteration angle when edge length < : 5.0 m

c. Below Surface removal. This routine classifies points which are lower than other neighboring points and it is run after ground classification to locate points which are below the true ground surface. For each point in the source class, the algorithm finds up to 25 closest neighboring source points and fits a plane equation through them. If the initially selected point is above the plane or less than "Z tolerance", it will not be classified. Then it computes the standard deviation of the elevation differences from the neighboring points to the fitted plane and if the central point is more than "Limit" times standard deviation below the plane, the algorithm it will classify it into the target class.

Parameters used:
Source Class: Ground
Target Class: Low Point
Limit: 6.00 * standard deviation
Z tolerance: 0.10 m

2) **Visual validation and refining of the ground model**. After ground classification, a thorough visual inspection of the triangulated surface generated by the ground points was performed block by block in order to clean-up and refine the automatic filter results. The inspection was focused in particular on the marshes areas where the filter occasionally removed small lumps of ground, usually at the interface between higher ground and water. The areas that needed improvement were identified by visually comparing the triangulated ground surface with the pattern of the ground point cloud and the unfiltered shaded relief map image (see snapshots below). Then by using TerraScan's profile tools and the "Add point to the ground…" routine, these areas were refined to include the chopped-off ground features. Once a point is added to the ground model the routine reprocess the surroundings (50m) with the ground classification algorithm (same parameters as the first step) and includes other potential ground points. This process is iterated until the complete feature is added to the ground surface model. Manual inclusion of features was performed on 113 small areas.

Urban areas were also analyzed for cleaning-up the ground surface model, usually by removing left-over trouble points near building footprints (like points hitting basement entrances or slightly climbing the building walls).

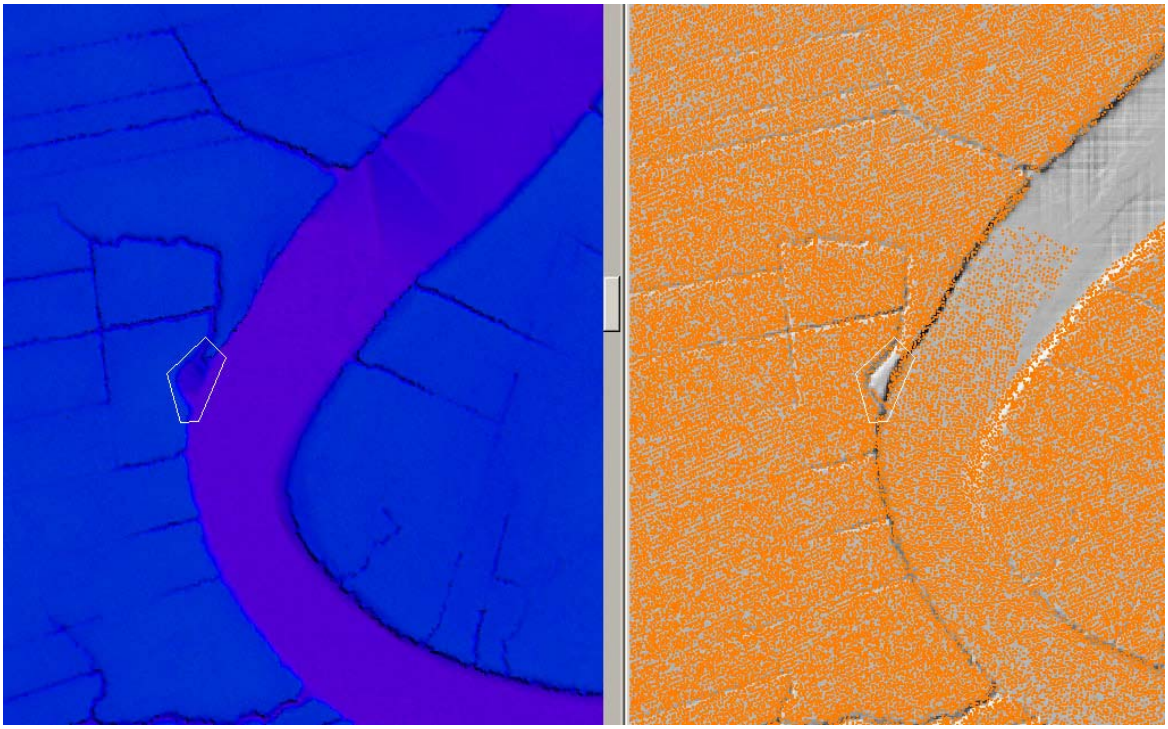

Figure 6 - Visual inspection reveals land features that were mistakenly removed by the ground classification routine. Left: triangulated ground surface model shaded and colored by elevation; Right: Ground point cloud (orange) on top of unfiltered shaded relief image

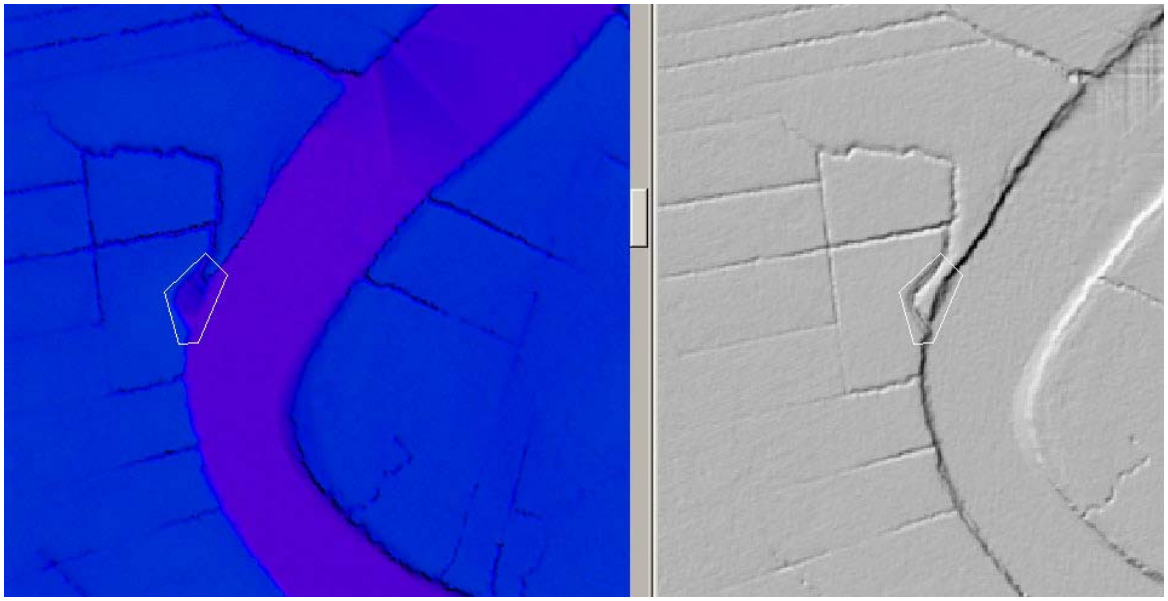

Figure 7 – Triangulated ground surface model before correction (left) vs. unfiltered shaded relief map image (right)

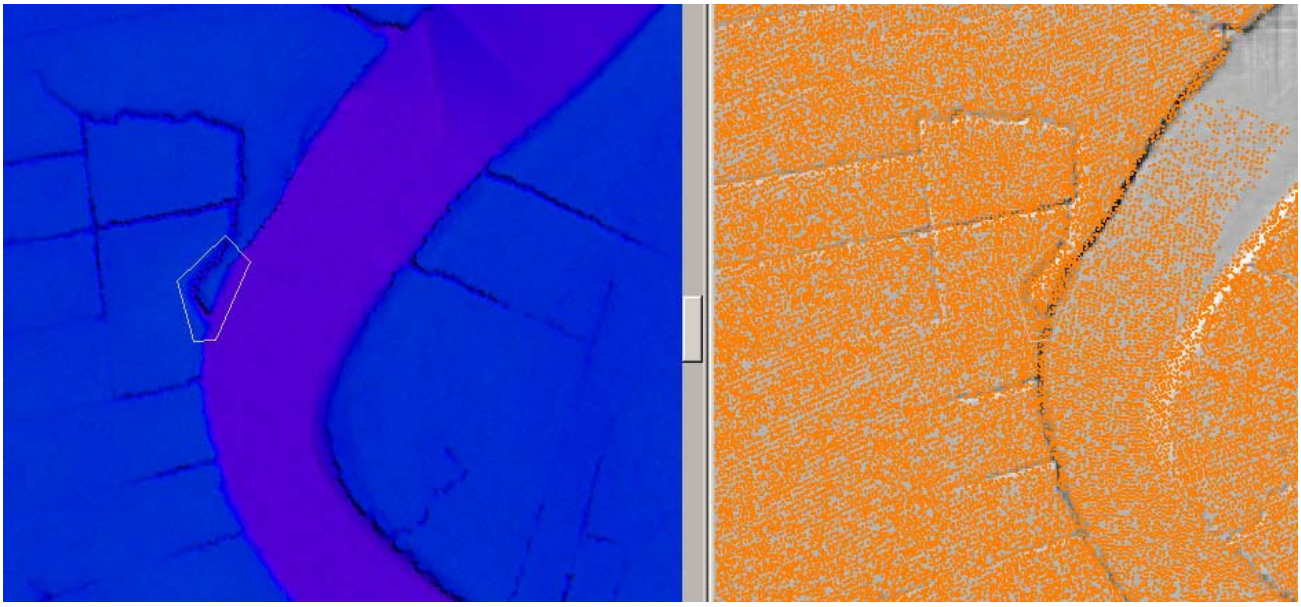

Figure 8 – Triangulated ground surface model after correction (left) vs. ground point cloud (orange, left) on top of the unfiltered shaded relief image

After classification the ground points were outputted in 2km x 2km overlapping tiles (100m overlap), ASCII format (XYZI), and gridded at 1m cell size using Golden Software's SURFER ver. 8.01. The tiles need to overlap in order to obtain consistent transitions from one tile to the adjacent ones.
Gridding parameters:

Gridding Algorithm: Kriging
Variogram: Linear
Nugget Variance: 0.07 m
MicroVariance: 0.00 m
SearchDataPerSector: 10
SearchMinData: 5
SearchMaxEmpty: 1
SearchRadius: 40m

The resulted Surfer grid tile set was exported to ESRI ArcInfo floting point binary format and using an in-house C++ application the overlap was trimmed from each tile. The trimmed tiles were exported to ESRI ArcInfo GRID format and merged into one seamless raster dataset.

A similar process was used to generate the unfiltered seamless grid.

APPENDIX A.

GPS Reference Station Coordinates from OPUS

```
                    NGS OPUS SOLUTION REPORT (PLM1 DAY 108)
                        ========================

     USER: mcoles@ufl.edu                          DATE: April 25, 2005
RINEX FILE: plm1108p.05o                            TIME: 16:56:21 UTC


 SOFTWARE: page5  0411.19 master22.pl             START: 2005/04/18  15:30:00
EPHEMERIS: igr13191.eph [rapid]                   STOP: 2005/04/18  21:56:00
 NAV FILE: brdc1080.05n                       OBS USED: 12541 / 12859   :  98%
 ANT NAME: ASH700936D_M                     # FIXED AMB:    56 /    57   :  98%
ARP HEIGHT: 2.00                             OVERALL RMS: 0.012(m)


REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2005.2953)

        X:      1538426.478(m)   0.022(m)           1538425.784(m)   0.022(m)
        Y:     -4427725.595(m)   0.010(m)          -4427724.162(m)   0.010(m)
        Z:      4310866.013(m)   0.029(m)           4310865.943(m)   0.029(m)

      LAT:   42 47 44.83310      0.013(m)        42 47 44.86625      0.013(m)
    E LON:  289  9 35.76901      0.019(m)       289  9 35.76086      0.019(m)
    W LON:   70 50 24.23099      0.019(m)        70 50 24.23914      0.019(m)
   EL HGT:          -24.417(m)   0.029(m)               -25.625(m)   0.029(m)
ORTHO HGT:            2.485(m)   0.038(m) [Geoid03 NAVD88]

                       UTM COORDINATES    STATE PLANE COORDINATES
                        UTM (Zone 19)         SPC (2001 MA M)
Northing (Y) [meters]     4739779.605           949673.070
Easting (X)  [meters]      349521.634           253990.131
Convergence  [degrees]    -1.25035028           0.44329782
Point Scale                0.99987858           1.00001847
Combined Factor            0.99988241           1.00002230

US NATIONAL GRID DESIGNATOR: 19TCH4952239780(NAD 83)



                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DF9215 ZBW1 BOSTON WAAS 1 CORS ARP         N424408.559 W0712849.518   52836.3
AJ1830 BARN BARTLETT CORS ARP              N440556.684 W0710934.400  147086.9
AJ8472 ACU1 ACUSHNET 1 CORS ARP            N414436.796 W0705313.026  116942.6

                NEAREST NGS PUBLISHED CONTROL POINT
AI5536      2B2 A                          N424744.629 W0705025.746      35.0

This position was computed without any knowledge by the National Geodetic
Survey regarding the equipment or field operating procedures used.
```

NGS OPUS SOLUTION REPORT (PLM2 DAY 108)

```
     USER: mcoles@ufl.edu                          DATE: April 25, 2005
RINEX FILE: plm2108p.05o                            TIME: 16:58:33 UTC


 SOFTWARE: page5  0411.19 master25.pl             START: 2005/04/18  15:51:00
EPHEMERIS: igr13191.eph [rapid]                    STOP: 2005/04/18  22:03:00
 NAV FILE: brdc1080.05n                       OBS USED: 12046 / 12334   :  98%
 ANT NAME: ASH700936D_M                     # FIXED AMB:    54 /    54   : 100%
ARP HEIGHT: 2.00                             OVERALL RMS: 0.013(m)


REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2005.2953)

        X:      1538426.693(m)   0.021(m)           1538425.999(m)   0.021(m)
        Y:     -4427717.815(m)   0.006(m)          -4427716.382(m)   0.006(m)
        Z:      4310874.145(m)   0.022(m)           4310874.075(m)   0.022(m)

      LAT:   42 47 45.18672      0.011(m)        42 47 45.21987      0.011(m)
    E LON:  289  9 35.89031      0.018(m)       289  9 35.88216      0.018(m)
    W LON:   70 50 24.10969      0.018(m)        70 50 24.11784      0.018(m)
   EL HGT:          -24.233(m)   0.021(m)               -25.441(m)   0.021(m)
ORTHO HGT:            2.668(m)   0.033(m) [Geoid03 NAVD88]

                       UTM COORDINATES    STATE PLANE COORDINATES
                        UTM (Zone 19)         SPC (2001 MA M)
Northing (Y) [meters]     4739790.452           949684.004
Easting (X)  [meters]      349524.627           253992.803
Convergence  [degrees]    -1.25032969           0.44332046
Point Scale                0.99987857           1.00001849
Combined Factor            0.99988237           1.00002229

US NATIONAL GRID DESIGNATOR: 19TCH4952539790(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DF9215 ZBW1 BOSTON WAAS 1 CORS ARP         N424408.559 W0712849.518   52840.4
AJ1830 BARN BARTLETT CORS ARP              N440556.684 W0710934.400  147076.6
AJ8472 ACU1 ACUSHNET 1 CORS ARP            N414436.796 W0705313.026  116953.6

                NEAREST NGS PUBLISHED CONTROL POINT
AI5536      2B2 A                          N424744.629 W0705025.746      40.9

This position was computed without any knowledge by the National Geodetic
Survey regarding the equipment or field operating procedures used.
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NGS OPUS SOLUTION REPORT (PLM 1 DAY 109 SESSION 1)

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     USER: mcoles@ufl.edu                          DATE: April 25, 2005
RINEX FILE: plm1109e.05o                            TIME: 17:19:05 UTC


 SOFTWARE: page5  0411.19 master23.pl             START: 2005/04/19  04:15:00
EPHEMERIS: igr13192.eph [rapid]                    STOP: 2005/04/19  11:13:30
 NAV FILE: brdc1090.05n                       OBS USED: 14187 / 14526   :  98%
 ANT NAME: ASH700936D_M                     # FIXED AMB:    57 /    57   : 100%
ARP HEIGHT: 2.00                             OVERALL RMS: 0.015(m)


REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2005.2968)

        X:      1538426.485(m)   0.017(m)           1538425.791(m)   0.017(m)
        Y:     -4427725.596(m)   0.010(m)          -4427724.163(m)   0.010(m)
        Z:      4310866.018(m)   0.015(m)           4310865.948(m)   0.015(m)

      LAT:   42 47 44.83314      0.017(m)        42 47 44.86630      0.017(m)
    E LON:  289  9 35.76929      0.013(m)       289  9 35.76114      0.013(m)
    W LON:   70 50 24.23071      0.013(m)        70 50 24.23886      0.013(m)
   EL HGT:          -24.411(m)   0.011(m)               -25.619(m)   0.011(m)
ORTHO HGT:            2.491(m)   0.027(m) [Geoid03 NAVD88]

                       UTM COORDINATES    STATE PLANE COORDINATES
                        UTM (Zone 19)         SPC (2001 MA M)
Northing (Y) [meters]     4739779.606           949673.072
Easting (X)  [meters]      349521.640           253990.137
Convergence  [degrees]    -1.25035023           0.44329788
Point Scale                0.99987858           1.00001847
Combined Factor            0.99988241           1.00002230

US NATIONAL GRID DESIGNATOR: 19TCH4952239780(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DF9215 ZBW1 BOSTON WAAS 1 CORS ARP         N424408.559 W0712849.518   52836.3
AJ8472 ACU1 ACUSHNET 1 CORS ARP            N414436.796 W0705313.026  116942.6
AF9487 BRU1 BRUNSWICK 1 CORS ARP           N435323.306 W0695647.665  141494.3

                NEAREST NGS PUBLISHED CONTROL POINT
AI5536      2B2 A                          N424744.629 W0705025.746      35.0

This position was computed without any knowledge by the National Geodetic
Survey regarding the equipment or field operating procedures used.
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NGS OPUS SOLUTION REPORT (PLM2 DAY 109 SESSION 1)

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     USER: mcoles@ufl.edu                          DATE: April 25, 2005
RINEX FILE: plm2109e.05o                            TIME: 17:22:02 UTC


 SOFTWARE: page5  0411.19 master25.pl             START: 2005/04/19  04:30:00
EPHEMERIS: igr13192.eph [rapid]                    STOP: 2005/04/19  11:19:00
 NAV FILE: brdc1090.05n                       OBS USED: 13816 / 14143   :  98%
 ANT NAME: ASH700936D_M                     # FIXED AMB:    47 /    47   : 100%
ARP HEIGHT: 2.00                             OVERALL RMS: 0.015(m)


REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2005.2968)

        X:      1538426.699(m)   0.018(m)           1538426.005(m)   0.018(m)
        Y:     -4427717.816(m)   0.013(m)          -4427716.383(m)   0.013(m)
        Z:      4310874.150(m)   0.013(m)           4310874.080(m)   0.013(m)

      LAT:   42 47 45.18677      0.015(m)        42 47 45.21993      0.015(m)
    E LON:  289  9 35.89055      0.013(m)       289  9 35.88240      0.013(m)
    W LON:   70 50 24.10945      0.013(m)        70 50 24.11760      0.013(m)
   EL HGT:          -24.228(m)   0.016(m)               -25.436(m)   0.016(m)
ORTHO HGT:            2.673(m)   0.030(m) [Geoid03 NAVD88]

                       UTM COORDINATES    STATE PLANE COORDINATES
                        UTM (Zone 19)         SPC (2001 MA M)
Northing (Y) [meters]     4739790.454          949684.005
Easting (X)  [meters]      349524.633          253992.809
Convergence  [degrees]    -1.25032965          0.44332050
Point Scale                0.99987857          1.00001849
Combined Factor            0.99988237          1.00002229

US NATIONAL GRID DESIGNATOR: 19TCH4952539790(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DF9215 ZBW1 BOSTON WAAS 1 CORS ARP         N424408.559 W0712849.518   52840.4
AJ8472 ACU1 ACUSHNET 1 CORS ARP            N414436.796 W0705313.026  116953.6
AF9487 BRU1 BRUNSWICK 1 CORS ARP           N435323.306 W0695647.665  141483.5

                NEAREST NGS PUBLISHED CONTROL POINT
AI5536      2B2 A                          N424744.629 W0705025.746      40.9

This position was computed without any knowledge by the National Geodetic
Survey regarding the equipment or field operating procedures used.
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NGS OPUS SOLUTION REPORT (PLM1 DAY 109 SESSION 2)

```
     USER: mcoles@ufl.edu                          DATE: April 25, 2005
RINEX FILE: plm1109s.05o                            TIME: 17:37:23 UTC


 SOFTWARE: page5  0411.19 master13.pl             START: 2005/04/19  18:12:00
EPHEMERIS: igr13192.eph [rapid]                    STOP: 2005/04/19  22:02:00
 NAV FILE: brdc1090.05n                        OBS USED:  8092 /  8250   :  98%
 ANT NAME: ASH700936D_M                     # FIXED AMB:    33 /    35   :  94%
ARP HEIGHT: 2.00                             OVERALL RMS: 0.014(m)


REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2005.2982)

        X:      1538426.474(m)   0.015(m)           1538425.780(m)   0.015(m)
        Y:     -4427725.593(m)   0.004(m)          -4427724.160(m)   0.004(m)
        Z:      4310866.001(m)   0.025(m)           4310865.931(m)   0.025(m)

      LAT:   42 47 44.83288      0.020(m)        42 47 44.86603      0.020(m)
    E LON:  289  9 35.76887      0.015(m)       289  9 35.76072      0.015(m)
    W LON:   70 50 24.23113      0.015(m)        70 50 24.23928      0.015(m)
   EL HGT:          -24.428(m)   0.016(m)               -25.636(m)   0.016(m)
ORTHO HGT:            2.474(m)   0.029(m) [Geoid03 NAVD88]

                       UTM COORDINATES    STATE PLANE COORDINATES
                        UTM (Zone 19)         SPC (2001 MA M)
Northing (Y) [meters]     4739779.598           949673.064
Easting (X)  [meters]      349521.630           253990.128
Convergence  [degrees]    -1.25035031           0.44329780
Point Scale                0.99987858           1.00001847
Combined Factor            0.99988241           1.00002231

US NATIONAL GRID DESIGNATOR: 19TCH4952239780(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DF9215 ZBW1 BOSTON WAAS 1 CORS ARP         N424408.559 W0712849.518   52836.3
AJ1830 BARN BARTLETT CORS ARP              N440556.684 W0710934.400  147086.9
AJ8472 ACU1 ACUSHNET 1 CORS ARP            N414436.796 W0705313.026  116942.6

                NEAREST NGS PUBLISHED CONTROL POINT
AI5536      2B2 A                          N424744.629 W0705025.746      35.0

This position was computed without any knowledge by the National Geodetic
Survey regarding the equipment or field operating procedures used.
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NGS OPUS SOLUTION REPORT (PLM2 DAY 109 SESSION 2)

```
     USER: mcoles@ufl.edu                          DATE: April 25, 2005
RINEX FILE: plm2109t.05o                            TIME: 17:32:07 UTC


 SOFTWARE: page5  0411.19 master25.pl             START: 2005/04/19  19:09:00
EPHEMERIS: igr13192.eph [rapid]                    STOP: 2005/04/19  22:01:00
 NAV FILE: brdc1090.05n                       OBS USED:  4567 /  4861   :  94%
 ANT NAME: ASH700936D_M                     # FIXED AMB:    44 /    45   :  98%
ARP HEIGHT: 2.00                             OVERALL RMS: 0.016(m)


REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2005.2982)

        X:      1538426.700(m)   0.012(m)           1538426.006(m)   0.012(m)
        Y:     -4427717.827(m)   0.039(m)          -4427716.394(m)   0.039(m)
        Z:      4310874.167(m)   0.031(m)           4310874.097(m)   0.031(m)

      LAT:   42 47 45.18694      0.028(m)        42 47 45.22009      0.028(m)
    E LON:  289  9 35.89043      0.018(m)       289  9 35.88228      0.018(m)
    W LON:   70 50 24.10957      0.018(m)        70 50 24.11772      0.018(m)
   EL HGT:          -24.208(m)   0.036(m)               -25.416(m)   0.036(m)
ORTHO HGT:            2.693(m)   0.044(m) [Geoid03 NAVD88]

                       UTM COORDINATES    STATE PLANE COORDINATES
                        UTM (Zone 19)         SPC (2001 MA M)
Northing (Y) [meters]     4739790.459           949684.010
Easting (X)  [meters]      349524.630           253992.806
Convergence  [degrees]    -1.25032967           0.44332048
Point Scale                0.99987857           1.00001849
Combined Factor            0.99988237           1.00002229

US NATIONAL GRID DESIGNATOR: 19TCH4952539790(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DF9215 ZBW1 BOSTON WAAS 1 CORS ARP         N424408.559 W0712849.518   52840.4
AJ8472 ACU1 ACUSHNET 1 CORS ARP            N414436.796 W0705313.026  116953.6
AF9487 BRU1 BRUNSWICK 1 CORS ARP           N435323.306 W0695647.665  141483.5

                NEAREST NGS PUBLISHED CONTROL POINT
AI5536      2B2 A                          N424744.629 W0705025.746      40.9
```

This position was computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.