Sheep Mountain Anticline
Greybull, WY
LIDAR Mapping Project Report

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1. ALTM Specifications

This survey used an Optech GEMINI Airborne Laser Terrain Mapper (ALTM) serial number 06SEN195 mounted in a twin-engine Cessna Skymaster (Tail Number N337P). System specifications appear below in Table 1.

Operating Altitude	80 - 4000 m
Horizontal Accuracy	1/11,000 x altitude; ±1-sigma
Elevation Accuracy	5 - 10 cm typical; ±1-sigma
Range Capture	Up to 4 range measurements per pulse, including last
Intensity Capture – see note below	4 Intensity readings with 12-bit dynamic range for each measurement
Scan Angle	Variable from 0 to 25 degrees in increments of ±1degree
Scan Frequency	Variable to 100 Hz
Scanner Product	Up to Scan angle x Scan frequency = 1000
Pulse Rate Frequency	33 - 167 KHz
Position Orientation System	Applanix POS/AV including internal 12-channel 10Hz GPS receiver
Laser Wavelength/Class	1047 nanometers / Class IV (FDA 21 CFR)
Beam Divergence nominal (1\e full angle)	Dual Divergence 0.25 mrad or 0.80 mrad

Table 1 Optech GEMINI specifications.

See http://www.optech.ca for more information from the manufacturer.

Please note that unfortunately, during this survey the ALTM system was malfunctioning in the following manner: alternating scan lines were recorded with either normal intensity values or unreadable (very low) intensity values. This situation could (with further processing) be correctable in at least two different ways: (1) by writing a computer program to interpolate intensity values onto alternating lines, or (2) by only using alternating lines (the ones with the normal values) for intensity analysis. Please note that this (alternating intensity) problem was confined solely to the intensity values and did not affect the range (topographic) information, or point density, or the multi-stop capability.

2. Survey Area

The survey area was located in north-central Wyoming, about 9 miles northwest of the town of Greybull. It was an rectangular polygon (below in Figure 1) encompassing an area of 60.5 Km^2

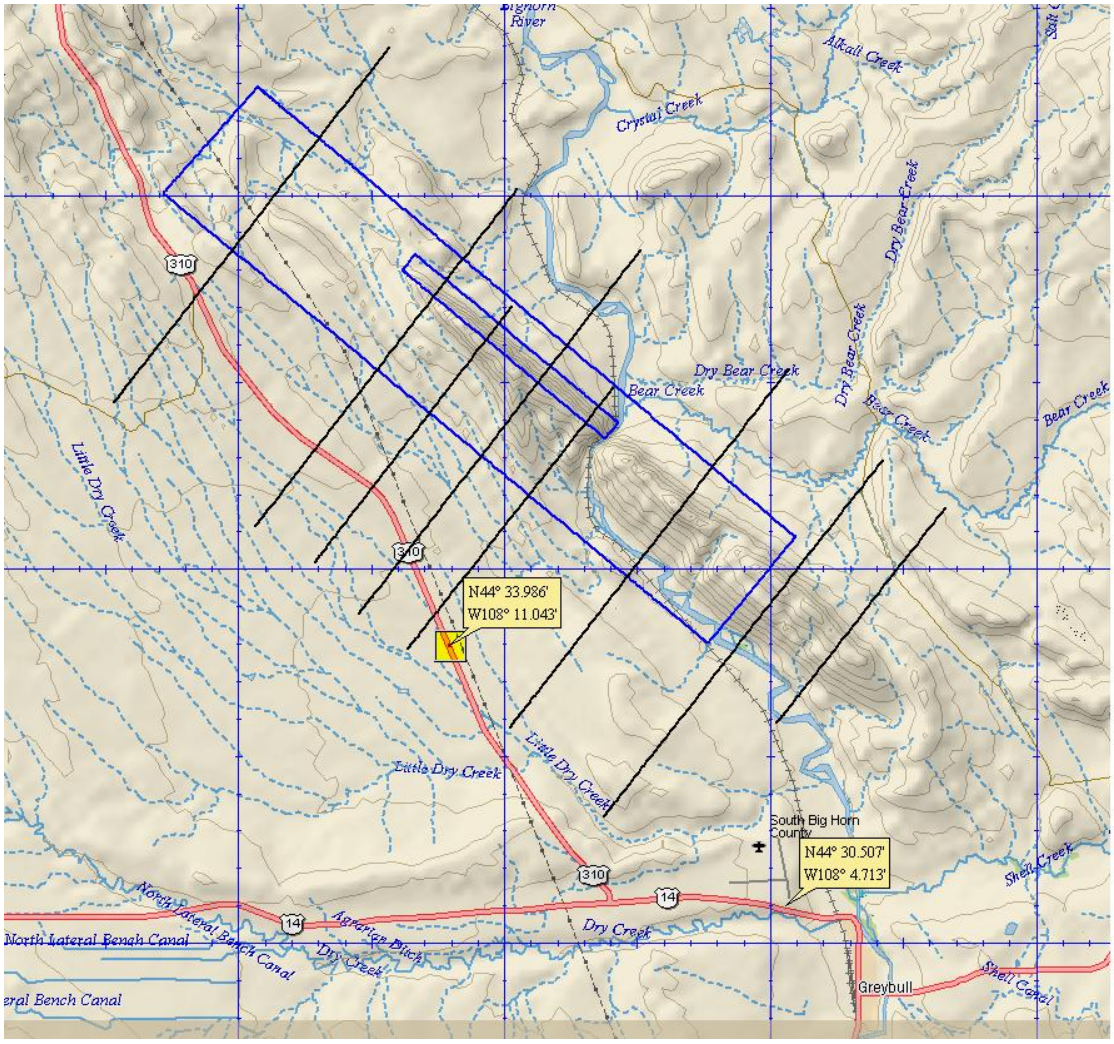


Figure 1 Survey Area. GPS reference locations are indicated by yellow text balloons with latitude, longitude coordinates.

In addition to the primary rectangular survey area there are an additional eight perpendicular transects (black lines in Figure 1) and another smaller rectangular area (blue rectangle fully contained within the larger blue rectangle) enclosing 3.3 square kilometers that contained extra flight lines in order to provide greater point density over particularly steep terrain.

3. Survey Time

The survey was carried out in two flights that took place on July 13th, 2007, day of year 194.

4. Survey Parameters

The survey required 14 flight passes for the primary box, an additional 5 lines in the smaller fully contained box, and 8 additional perpendicular transects. The flight lines for the two rectangular boxes are shown shown below in Figure 2.

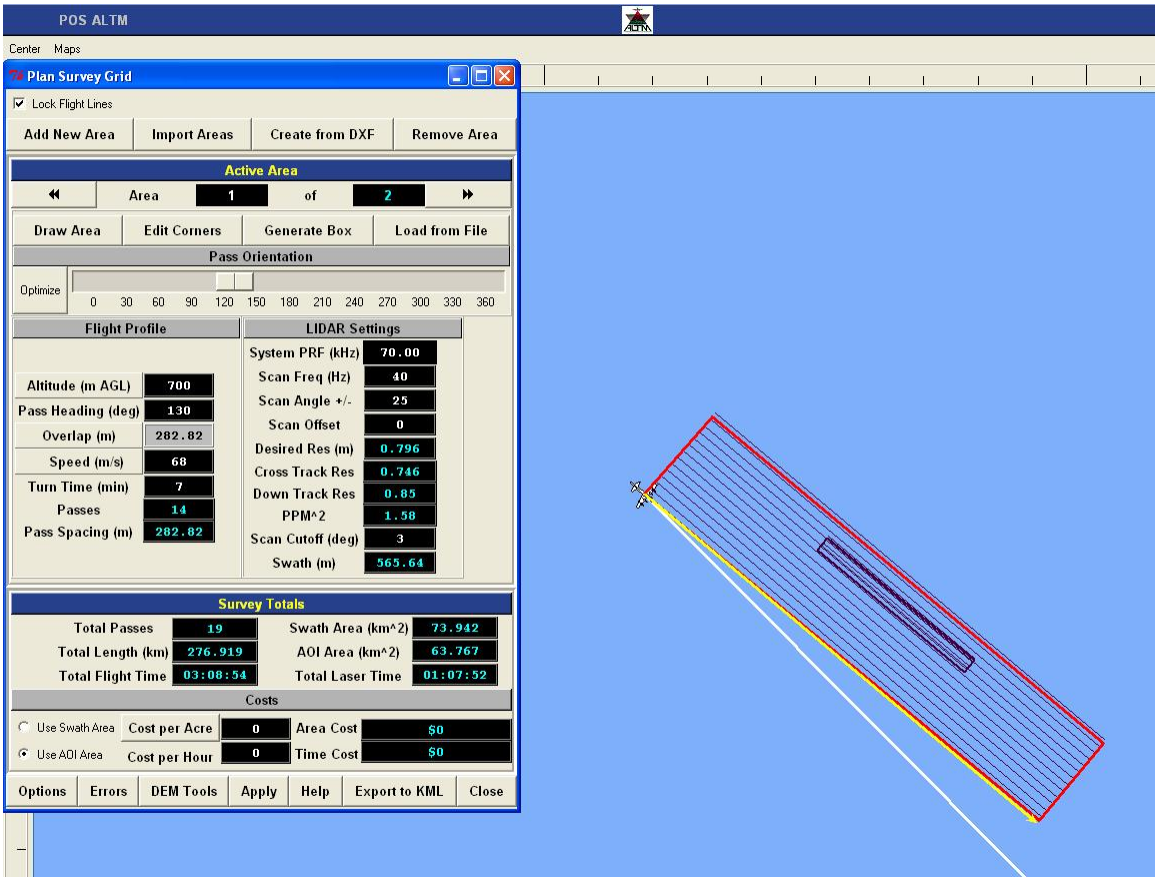


Figure 2 - Flight lines with planning parameters.

Survey totals appear below in Table 2.

Survey Totals	
Total Passes	27
Total Flight Time	05:55:57
Total Laser Time	02:27:04

Table 2 – Survey totals.

LiDAR settings are shown in Table 3.

LiDAR Settings	
Desired Resolution	0.796 m
Cross Track Resolution	0.746 m
Down Track Resolution	0.85 m
Scan Frequency	40 Hz
Scan Angle	+/- 25 deg
Scan Cutoff	+/- 3.0 deg
Scan Offset	0 deg
System PRF	70 kHz
Swath Width	565.64 m

Table 3 – LiDAR settings.

5. GPS Reference Stations

Two stations operated by NCALM were used as GPS reference stations – see Figure 1 (above) for their locations. All NCALM 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 the NCALM stations yielded reference station coordinate differences of less than 0.022 meters in both horizontal and vertical positions. Final coordinates for all NCALM reference stations were calculated from the OPUS solutions. 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/ NCALM GPS equipment consisted of ASHTECH (Thales Navigation) Z-Extreme receivers, with choke ring antennas (Part# 700936.D) mounted on fixed-height tripods.

6. 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. KARS makes use of the dual-frequency phase history files of the reference and airborne receivers to determine a fixed integer ionosphere-free differential solution. Each trajectory was processed using both ground reference stations and then coordinate differences between the separate solutions were plotted.

Figure 3 (below) is a plot of the easting, northing and height differences of the final aircraft trajectory as processed from the two base stations for the first flight on day 194. Differences are in meters (y-axis) and the time is in seconds (X-axis).

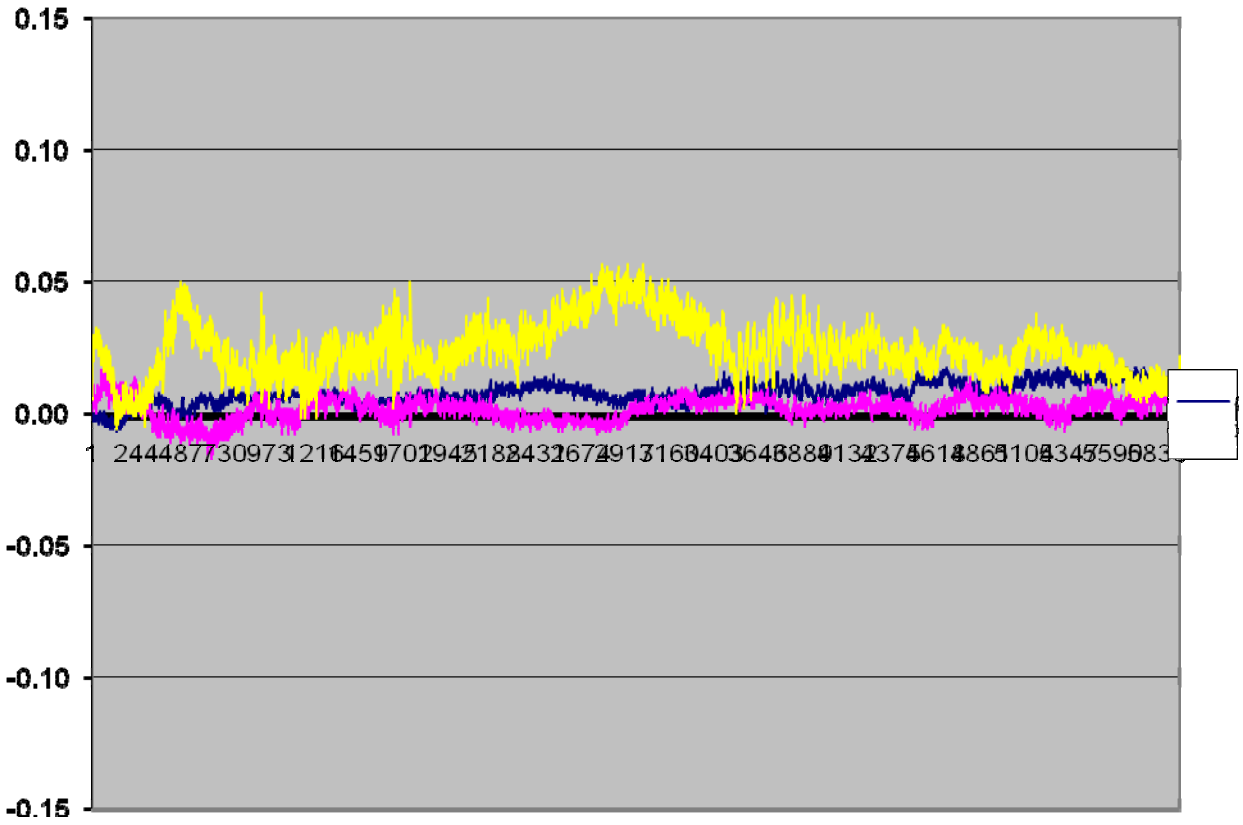


Figure 3 - Positional differences in aircraft trajectories with respect to time as processed from 2 base stations (GEY and M329) for flight on day 194.

	dx	dy	dz
average	-0.008	0.002	0.025
std	0.004	0.004	0.011

Table 5 Positional difference values statistics for day 194

7. Laser Point Processing and Calibration

After GPS processing was completed for all flights, the final GPS trajectories and the raw IMU (Inertial Measurement Unit) data collected during each flight were input into APPLANIX software POSPROC. This software employs a Kalman Filter algorithm to combine the 1-Hz final differential GPS solutions with the raw 200-Hz IMU orientation measurement data and their respective error models. The final result is a smoothed and blended solution of both aircraft position and orientation at 200 Hz, in SBET format (Smoothed Best Estimated Trajectory). The SBET, laser range, and mirror-angle measurement data were combined using Optech's DASHMap processing suite to generate point clouds in selected calibration areas, usually locations where cross-lines were flown or ground truth was collected.

System calibration was then performed as a 2-step process: step one (relative calibration) is to adjust the bore sight values of heading, roll, pitch, and scanner mirror scale such that systematic positional errors are minimized; and step two is an absolute calibration such that the laser DEM will match the height values of ground truth collected by vehicle-mounted GPS.

Step 1: Relative calibration was performed in TerraMatch software please see (http://terrasolid.fi/ENG/Products.htm) for detailed information.

A general description of the relative calibration procedure follows.

1. Cross-lines are flown for every flight with a heading perpendicular to the project flight line heading.
2. Small polygons containing these cross lines along with project flight lines are processed using approximate calibration values for heading, roll, pitch, and scanner mirror scale. Each line is processed separately.
3. Continuing to process each line separately, all lines are filtered (if necessary) to remove vegetation; then individual flight line surfaces are created.
4. Using TerraMatch, an iterative algorithm is applied to compute the best-fit between the individual flight line surfaces: simultaneously solving for the optimal bore sight values of heading, roll, pitch, and scanner mirror scale.
5. These updated bore sight values are then entered into DASHMap; new output is produced and checked for all flights.
6. Complete and final output is run using the optimized calibration values for each flight.

Stable calibration values were observed during the processing of this project for the day 194 (July 13). Computed optimal bore sight calibration values for this day showed no significant change in any bore sight calibration value relative to previous values. Final average DZ values for cross line surfaces versus project swath surfaces was 0.049 meters. Below is text from the final calibration iteration:

Starting average dz: 0.0501
Final average dz: 0.0488

Standard error of unit 0.0218

Execution time: 404.8 sec
Number of iterations: 5

Points 3894389
H shift -0.0001 Std dev 0.0000
R shift +0.0024 Std dev 0.0000
P shift -0.0007 Std dev 0.0000
Scale -0.00007

Step 2: Absolute calibration is done by comparing the height of the nearest neighbor laser point to the height of a set of check points that are collected by vehicle-mounted GPS.

Over 800 check points were collected on a portion of US 310 south and west of the primary polygon.

RMS of the differences between the check points and the LiDAR shots was 0.059 meters.

Once the calibration was process was finished the laser points for the whole project were processed through DashMap. 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 as points farthest from the scan nadir are the most affected by small errors in pitch, roll and scanner mirror angle measurements.

All coordinates were processed with respect to NAD83. The projection is UTM Zone 12, with units in meters. Heights are NAVD88 orthometric heights computed using NGS GEOID03 model.

The eight transects and the main survey area were outputted as individual datasets and post-processed separately.

8. Classification and DEM Production

TerraSolid's TerraScan (http://cdn.terrasolid.fi/TerraScan_eng_2.pdf) software was used to classify the ground points from the LiDAR points and generate the "bare-earth" dataset. The same classification macro was run on all datasets.

The classification routine consists of following algorithms:

1) Removal of Low Points: This routine is used to search for possible error points which are clearly below the ground surface. The elevation of each point (=center) is compared with every other point within a given neighborhood and if the center point is clearly lower then any other point it will be classified as a "low point". This routine can also search for groups of low points where the whole group is lower than other points in the vicinity.

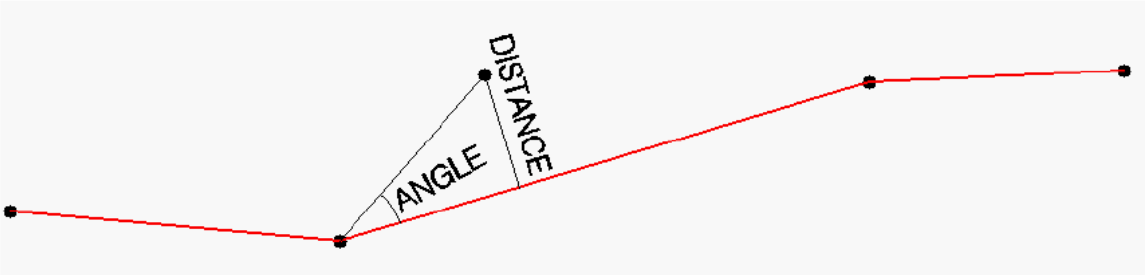
```
Max count:  6 points
More than:  0.5m lower
Within:     5.0m search window
```

2) 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 avoid adding unnecessary points to the ground model by reducing the eagerness to add new points to ground inside a triangle with all edges shorter than a specified length. Ground classification parameters used:

```
Max Building Size (window size): 40.0 m
Max Terrain Angle: 88
Iteration Angle: 6.0
Iteration Distance: 1.4 m
```



3) 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. Below Surface classification parameters used:

```
Source Class: Ground
Target Class: Low Point
Limit: 8.00 * standard deviation
Z tolerance: 0.10 m
```

Digital Elevation Models were produced at 1.0 meter spacing for all areas from last stop elevations using SURFER (Golden Software) Version 8.04. See http://www.goldensoftware.com/products/surfer/surfer.shtml

Interpolation parameters were as follows in Table 5.

Algorithm	Kriging
Variogram	Linear
Nugget Variance	0.07 meters
MicroVariance	0.00 meters
Search Radius	40m
Minimum points per quadrant	5
Maximum points per quadrant	10

Table 4 - Gridding parameters.

Digital Elevation Models (DEMs) for both filtered and unfiltered tiles are provided in ESRI format.

APPENDIX GPS Reference Station Coordinates from OPUS

```
NGS OPUS SOLUTION REPORT
                        ========================

      USER: michaels@ufl.edu                       DATE: July 16, 2007
RINEX FILE: gey_195a.07o                           TIME: 17:48:53 UTC


  SOFTWARE: page5  0612.06 master12.pl            START: 2007/07/14  00:09:00
 EPHEMERIS: igr14356.eph [rapid]                   STOP: 2007/07/14  03:11:00
  NAV FILE: brdc1950.07n                       OBS USED:  7227 /  7343   :  98%
  ANT NAME: ASH700936D_M    NONE             # FIXED AMB:    21 /    30   :  70%
ARP HEIGHT: 1.500                            OVERALL RMS: 0.015(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2007.5317)

         X:     -1414097.538(m)   0.032(m)          -1414098.279(m)   0.032(m)
         Y:     -4331926.700(m)   0.035(m)          -4331925.447(m)   0.035(m)
         Z:      4449385.885(m)   0.023(m)           4449385.858(m)   0.023(m)

       LAT:   44 30 30.43877      0.015(m)        44 30 30.45997      0.015(m)
     E LON:  251 55 17.20130      0.028(m)       251 55 17.15182      0.028(m)
     W LON:  108  4 42.79870      0.028(m)       108  4 42.84818      0.028(m)
    EL HGT:         1180.577(m)   0.045(m)             1179.873(m)   0.045(m)
 ORTHO HGT:         1193.216(m)   0.051(m) [Geoid03 NAVD88]

                       UTM COORDINATES    STATE PLANE COORDINATES
                        UTM (Zone 12)         SPC (4902 WYEC)
Northing (Y) [meters]     4932500.354           545514.057
Easting (X)  [meters]      732216.584           340745.070
Convergence  [degrees]     2.04888739          -0.52242648
Point Scale                1.00026320           0.99998066
Combined Factor            1.00007807           0.99979559

US NATIONAL GRID DESIGNATOR: 12TYQ3221732500(NAD 83)


                             BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
AI5647 MAWY MAMMOTH WYOMING CORS ARP       N445824.318 W1104121.434  213162.0
DG9745 MTEI ENGINC CORS ARP                N454447.035 W1083600.737  143588.9
DI3062 BIL5 BILLINGS 5 CORS ARP            N455816.237 W1075947.299  162711.5

                NEAREST NGS PUBLISHED CONTROL POINT
PX0003          GREYBULL  AIRPORT  RM  1                N443033.       W1080452.             217.8
```

NGS OPUS SOLUTION REPORT
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USER: michaels@ufl.edu DATE: July 16, 2007
RINEX FILE: gey_194p.07o TIME: 17:51:05 UTC

SOFTWARE: page5 0612.06 master30.pl START: 2007/07/13 15:08:00
EPHEMERIS: igr14355.eph [rapid] STOP: 2007/07/13 19:59:00
NAV FILE: brdc1940.07n OBS USED: 9853 / 9955 : 99%
ANT NAME: ASH700936D_M NONE # FIXED AMB: 41 / 41 : 100%
ARP HEIGHT: 1.500 OVERALL RMS: 0.015(m)

REF FRAME:	NAD_83(CORS96)(EPOCH:2002.0000)		ITRF00 (EPOCH:2007.5308)	
X:	-1414097.532(m)	0.020(m)	-1414098.273(m)	0.020(m)
Y:	-4331926.685(m)	0.021(m)	-4331925.432(m)	0.021(m)
Z:	4449385.870(m)	0.026(m)	4449385.843(m)	0.026(m)
LAT:	44 30 30.43879	0.031(m)	44 30 30.45999	0.031(m)
E LON:	251 55 17.20135	0.016(m)	251 55 17.15187	0.016(m)
W LON:	108 4 42.79865	0.016(m)	108 4 42.84813	0.016(m)
EL HGT:	1180.555(m)	0.023(m)	1179.851(m)	0.023(m)
ORTHO HGT:	1193.194(m)	0.034(m)	[Geoid03 NAVD88]	

	UTM COORDINATES (Zone 12)	STATE PLANE COORDINATES SPC (4902 WYEC)
Northing (Y) [meters]	4932500.355	545514.058
Easting (X) [meters]	732216.585	340745.071
Convergence [degrees]	2.04888740	-0.52242647
Point Scale	1.00026320	0.99998066
Combined Factor	1.00007808	0.99979560

US NATIONAL GRID DESIGNATOR: 12TYQ3221732500(NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE(m)
AI5647	MAWY MAMMOTH WYOMING CORS ARP	N445824.318	W1104121.434	213162.0
DG9745	MTEI ENGINC CORS ARP	N454447.035	W1083600.737	143588.9
DI3062	BIL5 BILLINGS 5 CORS ARP	N455816.237	W1075947.299	162711.5

NEAREST NGS PUBLISHED CONTROL POINT

PX0003	GREYBULL AIRPORT RM 1	N443033.	W1080452.	217.8

This position and the above vector components were computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.

NGS OPUS SOLUTION REPORT
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USER: michaels@ufl.edu DATE: July 16, 2007
RINEX FILE: m329194p.07o TIME: 17:52:38 UTC

SOFTWARE: page5 0612.06 master30.pl START: 2007/07/13 15:36:00
EPHEMERIS: igr14355.eph [rapid] STOP: 2007/07/14 00:17:30
NAV FILE: brdc1940.07n OBS USED: 18791 / 18983 : 99%
ANT NAME: ASH700936D_M NONE # FIXED AMB: 56 / 62 : 90%
ARP HEIGHT: 1.915 OVERALL RMS: 0.020(m)

REF FRAME:	NAD_83(CORS96)(EPOCH:2002.0000)		ITRF00 (EPOCH:2007.5311)	
X:	-1420666.400(m)	0.028(m)	-1420667.142(m)	0.028(m)
Y:	-4325037.318(m)	0.025(m)	-4325036.066(m)	0.025(m)
Z:	4453996.692(m)	0.043(m)	4453996.666(m)	0.043(m)
LAT:	44 33 59.19282	0.024(m)	44 33 59.21399	0.024(m)
E LON:	251 48 57.39779	0.024(m)	251 48 57.34815	0.024(m)
W LON:	108 11 2.60221	0.024(m)	108 11 2.65185	0.024(m)
EL HGT:	1204.712(m)	0.038(m)	1204.011(m)	0.038(m)
ORTHO HGT:	1217.592(m)	0.046(m)	[Geoid03 NAVD88]	

	UTM COORDINATES (UTM (Zone 12))	STATE PLANE COORDINATES (SPC (4902 WYEC))
Northing (Y) [meters]	4938647.026	552039.273
Easting (X) [meters]	723608.298	332423.451
Convergence [degrees]	1.97686496	-0.59700526
Point Scale	1.00021493	0.99999364
Combined Factor	1.00002603	0.99980478

US NATIONAL GRID DESIGNATOR: 12TYQ2360838647(NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE(m)
AI5647	MAWY MAMMOTH WYOMING CORS ARP	N445824.318	W1104121.434	203441.4
DG9745	MTEI ENGINC CORS ARP	N454447.035	W1083600.737	135175.5
DI3062	BIL5 BILLINGS 5 CORS ARP	N455816.237	W1075947.299	156832.4

NEAREST NGS PUBLISHED CONTROL POINT

PX0282	M 329	N443400.	W1081103.	26.5

This position and the above vector components were computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.

NGS OPUS SOLUTION REPORT
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USER: michaels@ufl.edu DATE: July 16, 2007
RINEX FILE: m329195a.07o TIME: 17:51:30 UTC

SOFTWARE: page5 0612.06 master3.pl START: 2007/07/14 00:19:00
EPHEMERIS: igr14356.eph [rapid] STOP: 2007/07/14 03:12:00
NAV FILE: brdc1950.07n OBS USED: 6797 / 7030 : 97%
ANT NAME: ASH700936D_M NONE # FIXED AMB: 29 / 30 : 97%
ARP HEIGHT: 1.915 OVERALL RMS: 0.014(m)

REF FRAME:	NAD_83(CORS96)(EPOCH:2002.0000)		ITRF00 (EPOCH:2007.5317)	
X:	-1420666.409(m)	0.027(m)	-1420667.151(m)	0.027(m)
Y:	-4325037.310(m)	0.032(m)	-4325036.058(m)	0.032(m)
Z:	4453996.671(m)	0.050(m)	4453996.645(m)	0.050(m)
LAT:	44 33 59.19244	0.021(m)	44 33 59.21361	0.021(m)
E LON:	251 48 57.39729	0.036(m)	251 48 57.34764	0.036(m)
W LON:	108 11 2.60271	0.036(m)	108 11 2.65236	0.036(m)
EL HGT:	1204.694(m)	0.051(m)	1203.993(m)	0.051(m)
ORTHO HGT:	1217.574(m)	0.056(m)	[Geoid03 NAVD88]	

	UTM COORDINATES (Zone 12)	STATE PLANE COORDINATES (4902 WYEC)
Northing (Y) [meters]	4938647.014	552039.262
Easting (X) [meters]	723608.288	332423.440
Convergence [degrees]	1.97686486	-0.59700535
Point Scale	1.00021493	0.99999364
Combined Factor	1.00002603	0.99980478

US NATIONAL GRID DESIGNATOR: 12TYQ2360838647(NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE(m)
AI5647	MAWY MAMMOTH WYOMING CORS ARP	N445824.318	W1104121.434	203441.3
DG9745	MTEI ENGINC CORS ARP	N454447.035	W1083600.737	135175.5
DI3062	BIL5 BILLINGS 5 CORS ARP	N455816.237	W1075947.299	156832.4

NEAREST NGS PUBLISHED CONTROL POINT

PX0282	M 329	N443400.	W1081103.	26.5

This position and the above vector components were computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.