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Project Name: West Bijou Creek, CO LiDAR Survey

1. ALTM Specifications

This survey used an Optech Gemini Airborne Laser Terrain Mapper (ALTM) serial number 06SEN195 mounted in a twin-engine Cessna Skymaster (N337P). This ALTM was delivered to the UF in 2007 as the first operational system of its kind in the United States. 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	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 – Gemini ALTM specifications.

2. Survey area

The survey area is a rectangular polygon 30 miles ESE of Aurora, Colorado enclosing approximately 19 square kilometers. The survey polygon is shown below in Figure 1.

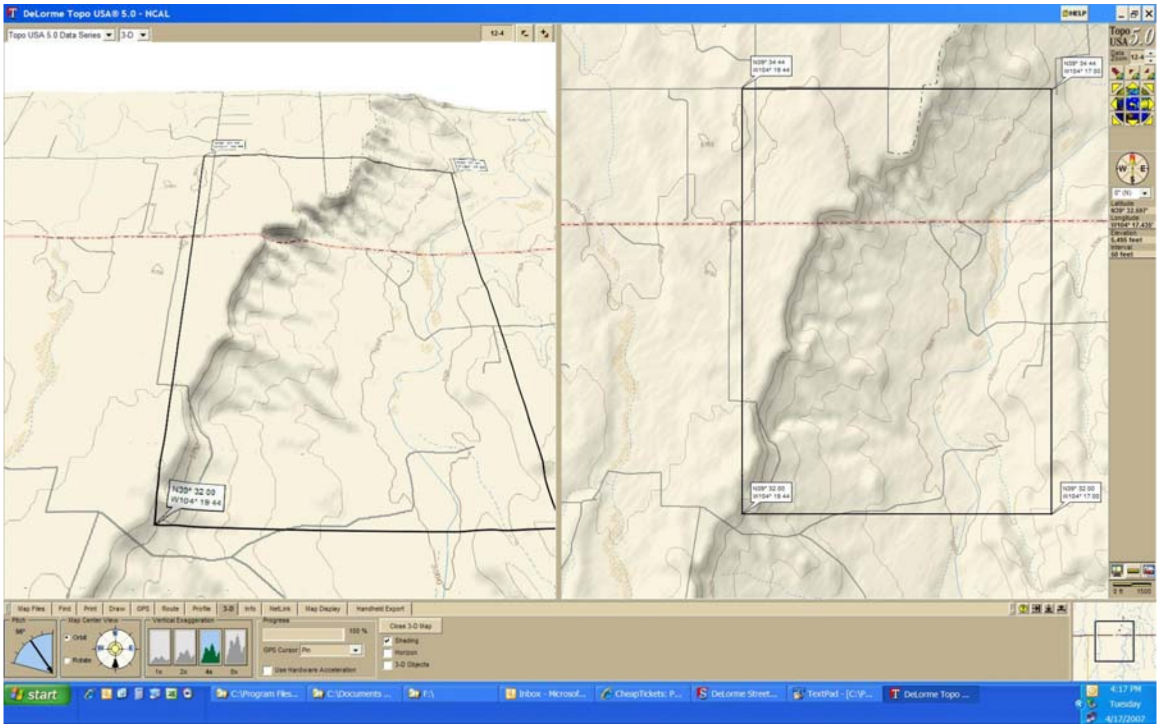


Figure 1 – Size, shape and location of survey polygon.

3. Survey Times

This area was flown on Monday April 23, 2007 in a single flight originating out of Centennial Airport in Englewood, Colorado.

4. Survey Parameters

The survey required 18 flight lines, shown below in Figure 2.

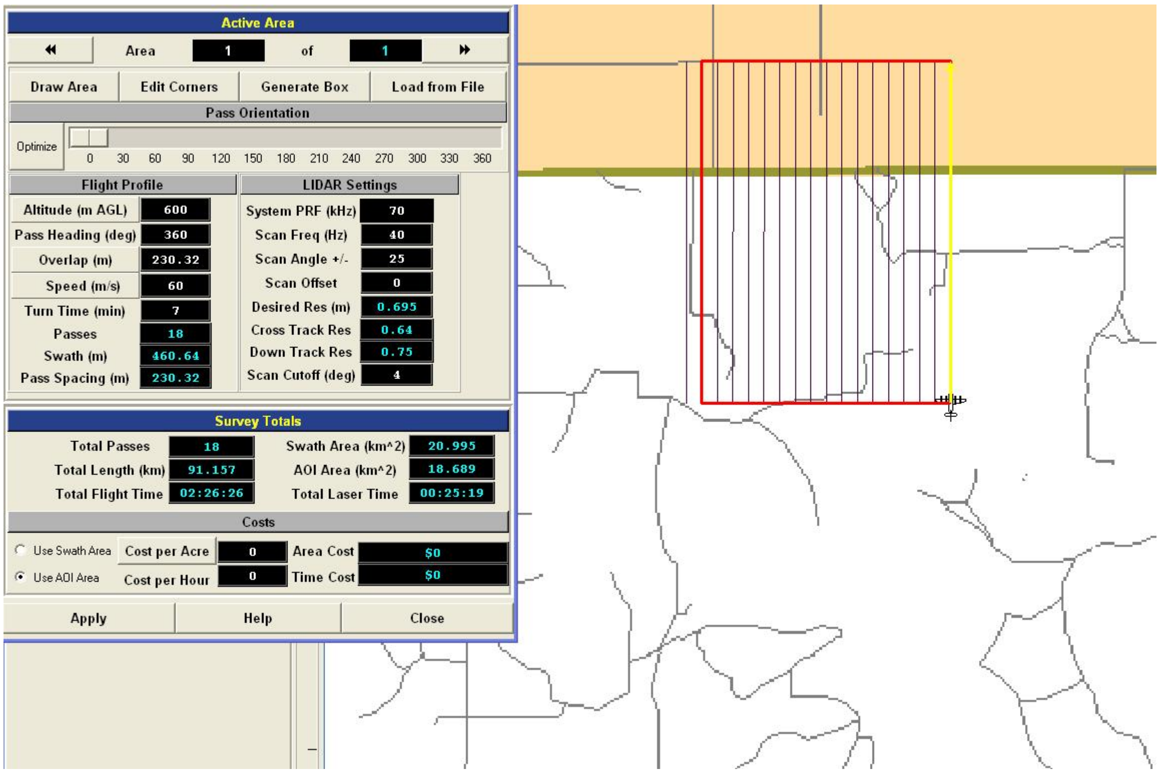


Figure 2 - Flight lines with planning parameters.

Survey totals appear below in Table 3.

Survey Totals	
Total Passes	18
Total Length	91 km
Total Flight Time	02:26:00
Total Laser Time	00:25:19
Total Swath Area	21 km^2
Total AOI Area	18.7km^2

Table 3 – Survey totals. Area of Interest is abbreviated AOI.

LiDAR settings are shown in Table 4.

LiDAR Settings	
Desired Resolution	0.69 m
Cross Track Resolution	0.63 m
Down Track Resolution	0.75 m
Scan Frequency	40 Hz
Scan Angle	+/- 25 deg
Scan Cutoff	+/- 4.0 deg
Scan Offset	0 deg
System PRF	70 kHz
Swath Width	460 m

Table 4 – LiDAR settings.

Actual point spacing and aircraft altitude varied slightly from planned settings.

5. GPS Reference Stations

Two GPS reference station locations were used during the survey, one located at the Centennial Airport (named CEN_) and the second located just west of the project polygon (named 194_). All GPS observations were logged at a 1 Hz, and submitted to the NGS on-line processor OPUS. Solution files are attached as Appendix A. Final coordinates for the both 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/ .

All GPS observations were logged at a 1 Hz. Ground equipment for the NCALM stations consisted of ASHTECH (Thales Navigation) Z-Extreme receivers, with choke ring antennas (Part# 700936.D) mounted on 1.5-meter fixed-height tripods. The airborne receiver is an internal TRIMBLE GPS receiver running at 10 Hz.

6. Navigation Processing and Calibration

Airplane trajectories for this survey were processed using both APPLANIX POGPS and KARS software (Kinematic and Rapid Static) written by Dr. Gerry Mader of the NGS Research Laboratory. Both of these kinematic processors uses the dual-frequency phase history files and yields a high-quality fixed integer ionosphere-free differential solution. Figure 3 (below) illustrates the positional difference between the aircraft trajectory solutions as processed using POSGPS and KARS.

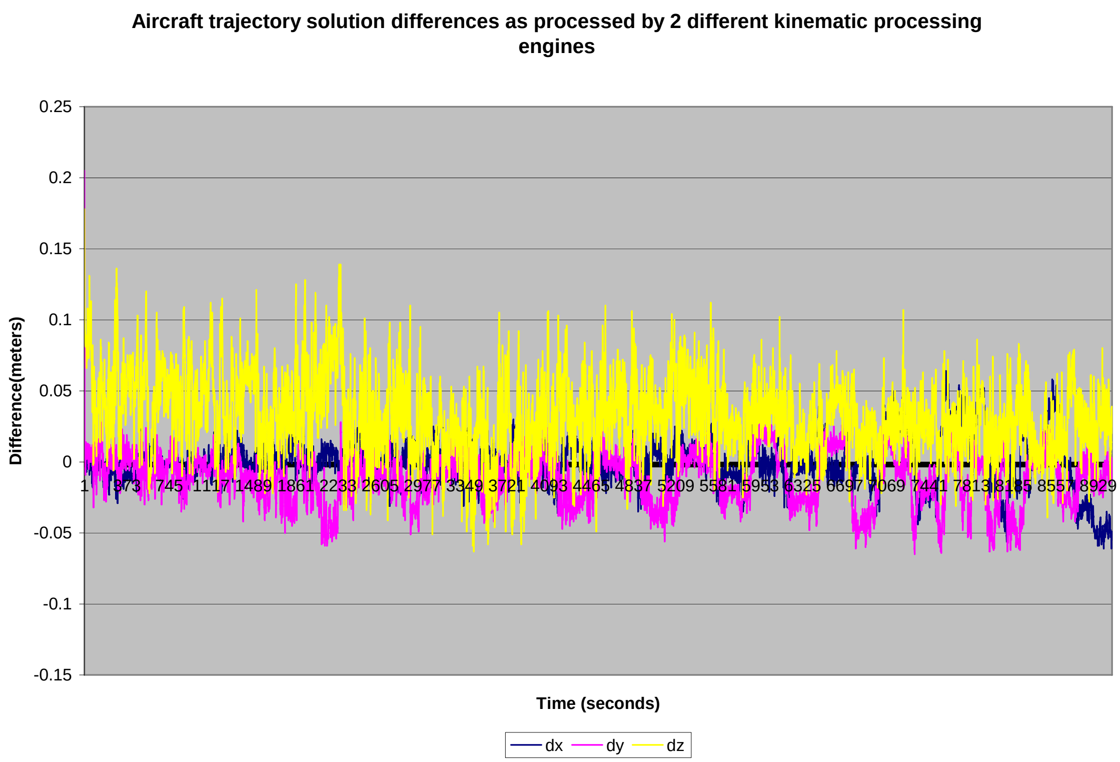


Figure 3 - Positional differences in the aircraft trajectory. Yellow line is the height difference.

The RMS of the height differences is 27 mm.

After GPS processing, the trajectory and the inertial measurement unit (IMU) data collected during the flights were input into APPLANIX software POSPROC which implements a Kalman Filter algorithm to produce a final, smoothed, and complete navigation solution including both aircraft position and orientation at 200 Hz. This final solution is known as the SBET (Smoothed Best Estimated Trajectory).

The SBET and the raw laser range data were combined using Optech's DashMap processing software to generate the laser point dataset. A few small test sites containing crossing flight-lines were initially extracted and used for relative calibration with TerraSolid's TerraMatch software. This application measures the differences between laser surfaces from overlapping flight lines and translates them into correction values for the system orientation -- easting, northing, elevation, heading, roll and/or pitch. After obtaining adjustments to calibration values using TerraMatch, laser point processing was re-done and the calibration rechecked. Calibration values for this flight are archived at UC Berkeley along with all raw data.

Absolute ground calibration was performed on these data by collecting test points by vehicle mounted GPS some sections of roads near the project. Analysis of 130 test point elevation versus the nearest-neighbor laser point elevation differences yielded an RMS of 39 mm. Figure 4 (below) is a shaded relief image showing the calibration cross lines and the ground truth near Walker Field.

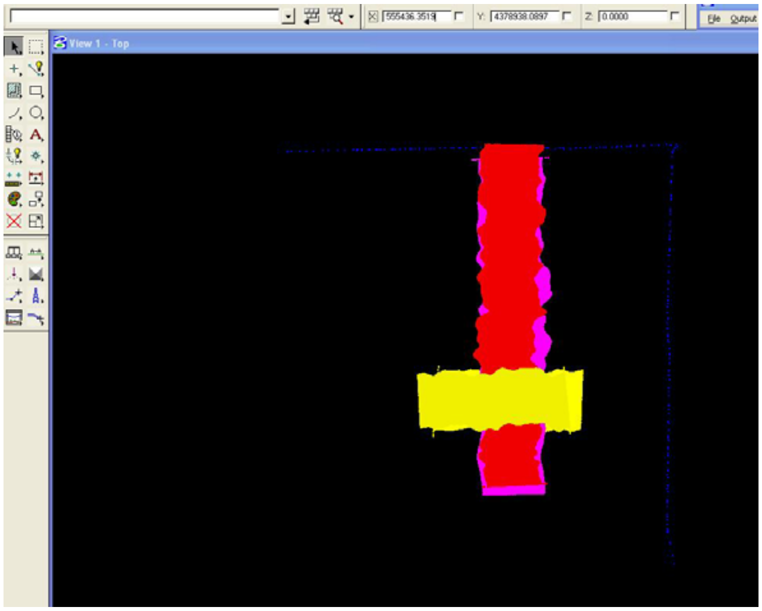


Figure 4 – Cross lines and ground truth points (in blue) near Tucker Project area.

After ground filtering was performed in TerraScan (see next section) it was observed that the relative calibration was still not optimal and artifacts were visible in the filtered shaded relief map, due to flight lines misfit.

The relative swath calibration was improved by running TerraMatch again on a small site (Fig 5) within the project boundary where crossing flight-lines are also present.

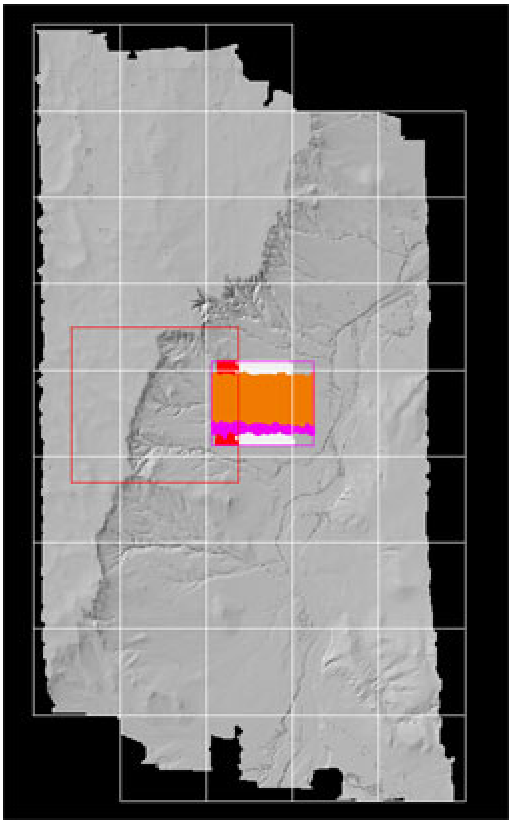


Figure 5 – location of the second calibration site.

7. Filtering and DEM Production

Terrasolid's TerraScan (http://terrasolid.fi) software was used to classify the laser points and generate the "bare-earth" dataset.
Only the first two returns were used for classifying the bare-earth points. The last two returns are usually much nosier and contain many more low points (multipath) than the first two, and represent only a very small percentage of all recorded points (typically, for a sparsely vegetated area such as this, the last two returns represent only about 1% or less)

The classification routine consists of three algorithms:

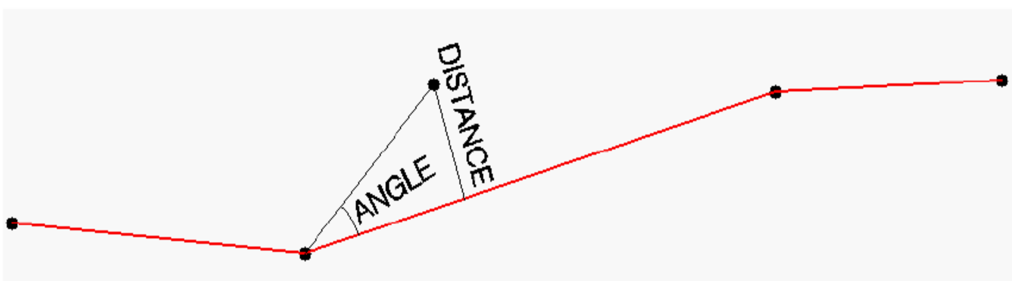
1) Removal of "Low Points". This routine was used to search for possible error points which are clearly below the ground surface. The elevation of each point (=center) is compared with every other point within a given neighborhood and if the center point is clearly lower then any other point it will 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. The parameters used on this dataset were:

```
Search for: Groups of Points
Max Count (maximum size of a group of low points): 6
```

```
More than (minimum height difference): 0.5 m
Within (xy search range):  5.0 m
```

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 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.



   Ground classification parameters used:

```
Max Building Size (window size): 40.0 m
Max Terrain Angle: 88.0
Iteration Angle: 6.10
Iteration Distance: 2.0 m
Reduce iteration angle when edge length < : 5.0 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.

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

After classification the ground points were outputted in 1km x 1km overlapping tiles (40m overlap), ASCII format (XYZ), 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 when merged.

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
OPUS Solutions

```
                          NGS OPUS SOLUTION REPORT

      USER: michaels@ufl.edu                          DATE: May 29, 2007
RINEX FILE: 194_113p.07o                              TIME: 19:31:07 UTC


  SOFTWARE: page5  0612.06 master11.pl               START: 2007/04/23  15:30:00
 EPHEMERIS: igs14241.eph [precise]                    STOP: 2007/04/23  18:46:00
  NAV FILE: brdc1130.07n                          OBS USED:  8786 /  8880   :
99%
  ANT NAME: ASH700936D_M    NONE               # FIXED AMB:    42 /    42   :
100%
ARP HEIGHT: 1.500                              OVERALL RMS: 0.009(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2007.3088)

         X:     -1221932.759(m)   0.011(m)          -1221933.475(m)   0.011(m)
         Y:     -4771028.003(m)   0.021(m)          -4771026.687(m)   0.021(m)
         Z:      4041891.571(m)   0.013(m)           4041891.487(m)   0.013(m)

       LAT:   39 33 50.46549      0.016(m)        39 33 50.48605      0.016(m)
     E LON:  255 38  4.09013      0.008(m)       255 38  4.04740      0.008(m)
     W LON:  104 21 55.90987      0.008(m)       104 21 55.95260      0.008(m)
    EL HGT:         1736.635(m)   0.021(m)              1735.735(m)   0.021(m)
 ORTHO HGT:         1754.747(m)   0.032(m) [Geoid03 NAVD88]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 13)         SPC (0502 CO C)
Northing (Y) [meters]     4379561.535           497531.834
Easting (X)  [meters]      554501.195          1011886.245
Convergence  [degrees]     0.40412891           0.71549805
Point Scale                0.99963657           0.99996850
Combined Factor            0.99936429           0.99969613

US NATIONAL GRID DESIGNATOR: 13SED5450179562(NAD 83)



                             BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
AI2151 DSRC BOULDER CORS ARP               N395929.129 W1051539.675   90230.4
DG7429 P041 MARSHALL FIELD CORS ARP        N395658.150 W1051139.316   82939.0
AF9517 PLTC PLATTEVILLE CORS ARP           N401053.712 W1044333.333   75201.9

                 NEAREST NGS PUBLISHED CONTROL POINT
KK0087      849 AX 2 A                     N393447.    W1042750.       8619.1
```

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

      USER: michaels@ufl.edu                      DATE: May 29, 2007
RINEX FILE: cen_113o.07o                          TIME: 19:36:48 UTC


  SOFTWARE: page5  0612.06 master11.pl           START: 2007/04/23  14:37:00
 EPHEMERIS: igs14241.eph [precise]                STOP: 2007/04/23  19:11:00
  NAV FILE: brdc1130.07n                      OBS USED: 12813 / 12859   :
100%
  ANT NAME: ASH700936D_M    NONE           # FIXED AMB:    54 /    54   :
100%
ARP HEIGHT: 1.500                          OVERALL RMS: 0.010(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2007.3088)

         X:     -1261523.417(m)   0.012(m)          -1261524.134(m)   0.012(m)
         Y:     -4759915.273(m)   0.020(m)          -4759913.960(m)   0.020(m)
         Z:      4042850.234(m)   0.017(m)           4042850.152(m)   0.017(m)

       LAT:   39 34 30.33967      0.017(m)        39 34 30.36004      0.017(m)
     E LON:  255  9 22.07633      0.009(m)       255  9 22.03321      0.009(m)
     W LON:  104 50 37.92367      0.009(m)       104 50 37.96679      0.009(m)
    EL HGT:         1753.041(m)   0.021(m)              1752.152(m)   0.021(m)
 ORTHO HGT:         1770.318(m)   0.033(m) [Geoid03 NAVD88]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 13)         SPC (0502 CO C)
Northing (Y) [meters]     4380610.220           498356.429
Easting (X)  [meters]      513409.648           970775.057
Convergence  [degrees]     0.09947033           0.41381580
Point Scale                0.99960221           0.99997008
Combined Factor            0.99932737           0.99969514

US NATIONAL GRID DESIGNATOR: 13SED1341080610(NAD 83)



                             BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
AI2151 DSRC BOULDER CORS ARP               N395929.129 W1051539.675   58442.7
DG7429 P041 MARSHALL FIELD CORS ARP        N395658.150 W1051139.316   51291.7
AF9517 PLTC PLATTEVILLE CORS ARP           N401053.712 W1044333.333   68109.4

                 NEAREST NGS PUBLISHED CONTROL POINT
AI5877      APA E                          N393423.979 W1045056.911     493.5
```