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Title: Hillslope-channel coupling in a bedrock landscape, Henry Mountains, Utah.

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). This ALTM was delivered to the UF in 2007 as the first 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 – Optech GEMINI specifications.

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

2. Survey area

The survey area is an irregular polygon in the Henry Mountains, UT and enclosing 39.7 square kilometers. The survey location is shown below in Figure 1.
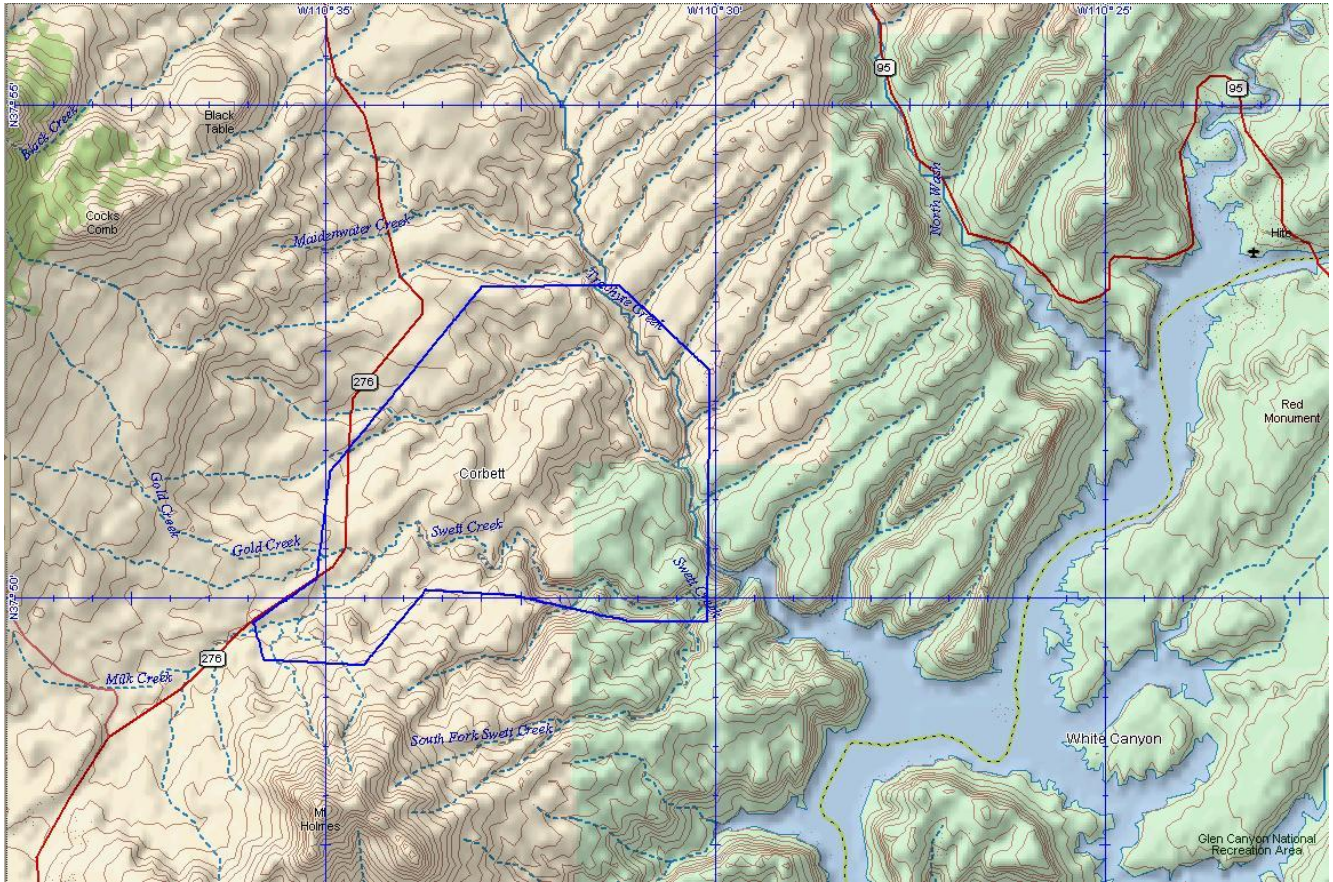

Figure 1 – Size, shape and location of survey polygon.

3. Survey Times
This area was flown in a single survey flight on February 07, 2008, day-of-year 038.

4. Survey Parameters

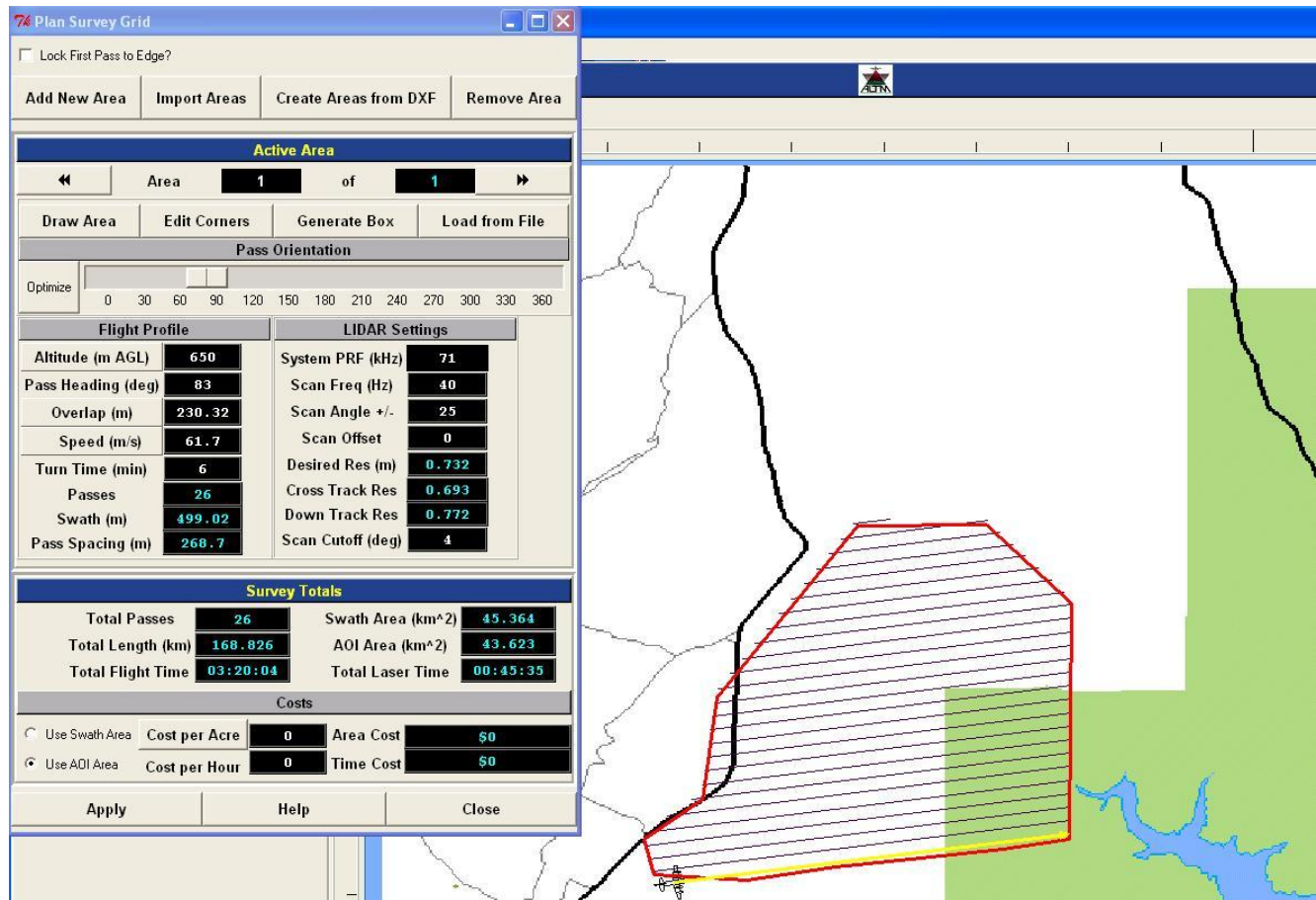The survey required 26 flight lines, shown below in Figure 2.

Figure 2 - Flight lines with planning parameters.

Survey totals appear below in Table 3.

Survey Totals

Total Passes	26
Total Length	168.8 km
Total Flight Time	04:10:00
Total Laser Time	01:32:16
Total Swath Area	45.3 km^2
Total AOI Area	43.6 km^2

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

LiDAR settings are shown in Table 4.

LiDAR Settings

Desired Resolution	0.73 m
Cross Track Resolution	0.69 m
Down Track Resolution	0.77 m
Scan Frequency	40 Hz
Scan Angle	+/- 25 deg
Scan Cutoff	+/- 4.0 deg
Scan Offset	0 deg
System PRF	70 kHz
Swath Width	499.0 m

Table 4 – LiDAR settings.

5. GPS Reference Stations

Two GPS reference station locations were used during the survey: ROW_ and COL_. Station COL_ is located on a hilltop near the bridge crossing the Colorado River on SR 95 and was set by the field crew. Station ROW_ is a recovered Right-of-Way capped iron rod 30 meters south of the airstrip at Hite, 15 Km east-northeast of the project.

Both stations are outside the project boundary and within 14 Km of the center of the survey polygon.

GPS observations at both reference stations logged data for over 4.5 hours at 1 Hz and these observations were submitted to the NGS on-line processor OPUS. OPUS processes static differential baselines and provides accurate control coordinates relative to the National CORS network. Final reference station coordinates for this survey were determined from the OPUS solutions and are included in this report as Appendix A. For further information on the CORS network or OPUS see http://www.ngs.noaa.gov/CORS/ or http://www.ngs.noaa.gov/OPUS/ .

The airborne receiver is an integrated BD-950 Trimble GPS receiver module logging at 10 Hz.

6. Navigation Processing and Calibration

Airplane trajectories for this survey were processed using KARS software (Kinematic and Rapid Static) written by Dr. Gerry Mader of the NGS Research Laboratory. KARS kinematic GPS processing uses the dual-frequency phase history files of the reference and airborne receivers to determine a fixed integer ionosphere-free differential solution. KARS software was used to process kinematic aircraft trajectories from both reference stations: COL_ and ROW_. These two trajectories were differenced and Figure 3 (below) is a plot of these positional differences.
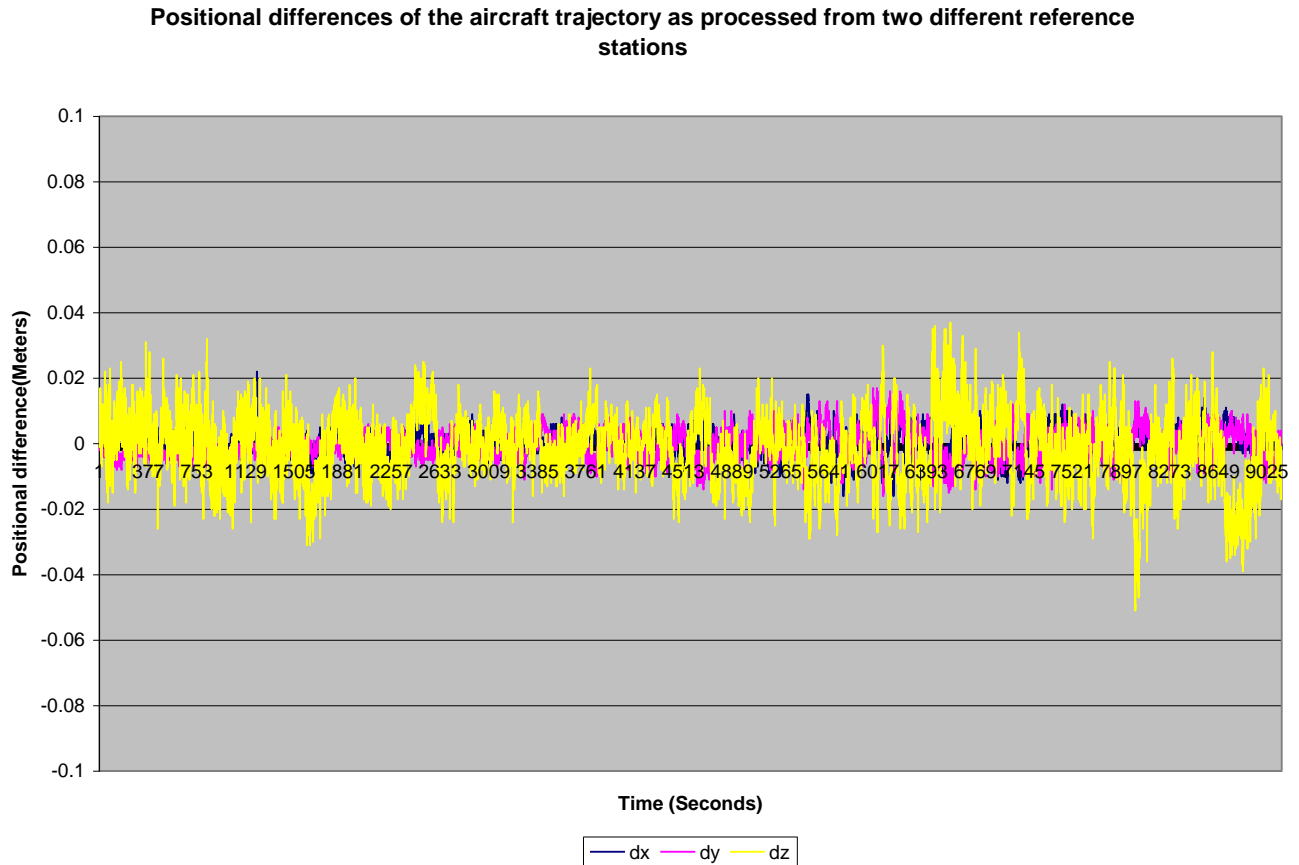
Positional differences of the aircraft trajectory as processed from two different reference stations

Figure 3 - Positional differences in aircraft trajectories with respect to time as processed from 2 base stations.

The standard deviation of the differences in the easting position of these two trajectories is 4 mm, in northing 5 mm, and in height 10 mm.

After GPS processing, the 1 Hz differential trajectory and the Inertial Measurement Unit (IMU) data collected during the flight were input into APPLANIX software POSPROC. POSPROC processing algorithms combine GPS positions and IMU orientations in a Kalman Filter 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). See http://www.applanix.com/products/posav_index.php for more information from the manufacturer.

The SBET and the raw laser range data were combined using Optech's DashMap processing suite to generate the laser point dataset.

Two types of calibration procedures were used on this project: relative calibration and absolute calibration.

Relative calibration was done by surveying crossing flight-lines over the project polygon and using TerraMatch software (http://www.terrasolid.fi/en/products/4). TerraMatch finds the best-fit values for roll, pitch, yaw, and scanner mirror scale by analyzing the height differences between computed laser surfaces from individual crossing and/or overlapping flight lines. TerraMatch was run successfully on this flight: values for height disagreements between individual flight line surfaces ranged from an average high of 80 mm before adjustment to an average low of 72 mm after adjustment. Below is the TerraMatch report from this flight.

```
Starting average dz:     0.0804
Final average dz:        0.0723

Standard error of unit   0.0323

Execution time: 2253.9 sec
Number of iterations: 13

Points          2368327
Z shift          -0.047     Std dev   0.0009
H shift          +0.0256    Std dev   0.0003
R shift          -0.0069    Std dev   0.0002
P shift          -0.0011    Std dev   0.0001
Scale           -0.00022
```

Absolute calibration was done by establishing a calibration site consisting of 900 check points surveyed with vehicle-mounted GPS over airstrip at Hite (cracked asphalt). The runway containing these check points was then surveyed with crossing flight lines using the ALTM. After comparing the heights of the check points with their nearest neighbor LiDAR shot no systematic height bias was found.

Absolute calibration analysis can also yield an accuracy assessment for similar surfaces on the project polygon. The aircraft maintained a flying height of approximately 650 meters Above Ground Level (AGL) while surveying cross lines above the calibration site, and fired the laser at 70 KHz, the same parameters that were maintained over the project polygon. Nearest neighbor check point heights were differenced with LiDAR shots. The standard deviation of these differences was 32 mm. This is a good estimate of 1-sigma accuracy on similar surfaces inside the project.

8. Laser Point Processing

All coordinates were processed with respect to NAD83 and referenced to the national CORS network. The projection is UTM Zone 12, with units in meters. Heights are NAVD88 orthometric heights computed using NGS GEOID03 model. The flight strip point cloud files were tiled into 1 kilometer square blocks with a naming convention using the lower left coordinate (minimum X, Y) as the seed for the file name as follows: XXXXXX_YYYYYY. For example if the tile bounds coordinate values from easting equals 540000 through 541000, and northing equals 4190000 through 4192000 then the tile filename is 540000_4192000. This is illustrated below in Figure 4.
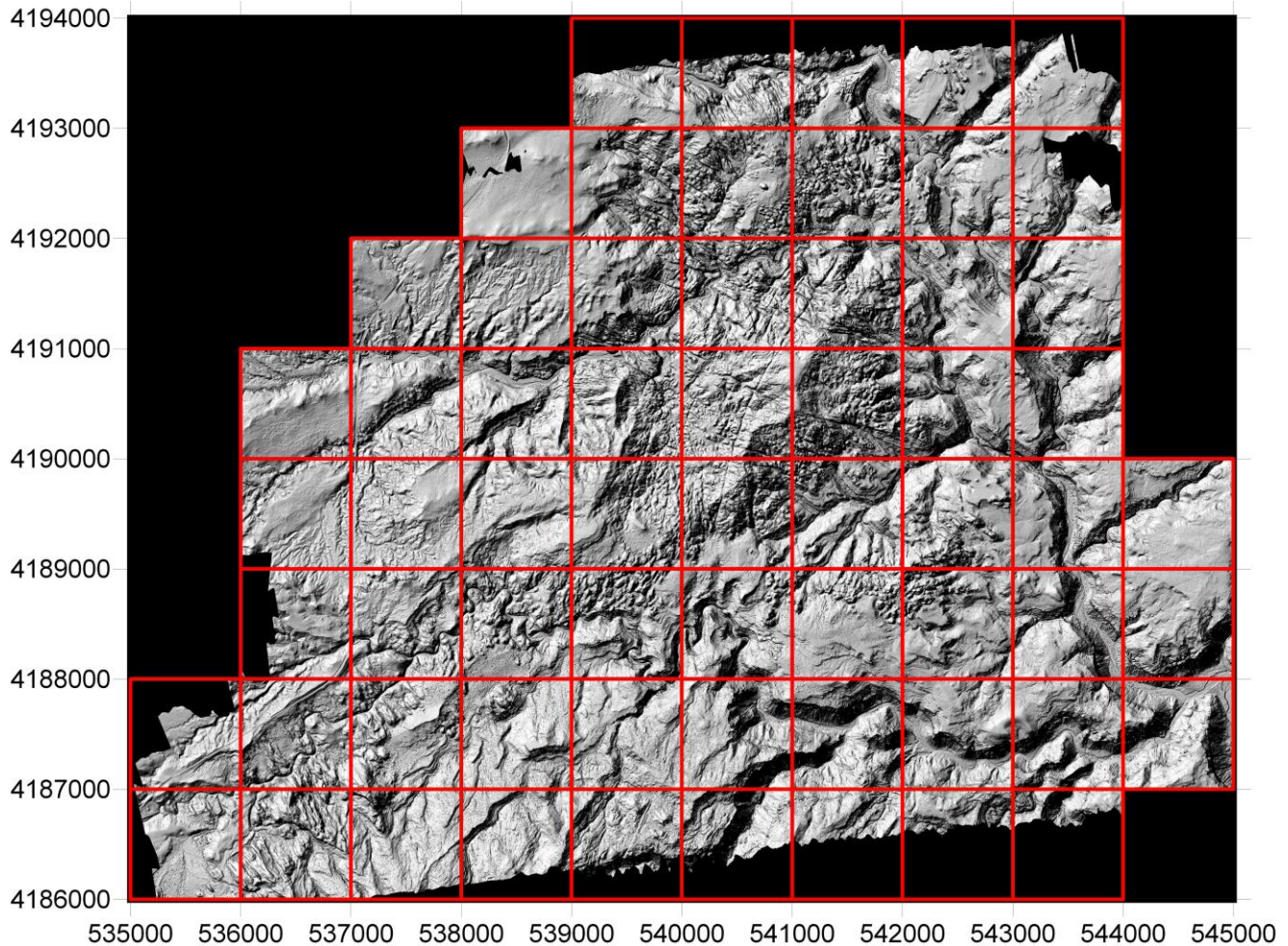

Figure 4 - Tile footprints overlaid onto a shaded relief image of the DEM. Tile foot prints are in red, the survey polygon is in blue.

These tile footprints are available as an AutoCAD DXF or ESRI shape file. The project totaled 56 tiles and is ASCII format with three columns: Easting, Northing, and NAVD88 elevation.

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.

8. DEM Production

Digital Elevation Models were produced at 1.0 meter spacing for all areas from last stop elevations using SURFER (Golden Software) Version 8.04. Interpolation parameters were as follows in Table 5.

Algorithm	Kriging
Variogram	Linear
Nugget Variance	0.50 meters
MicroVariance	0.00 meters
Quadrant Search	4
Search Radius	variable
Minimum points per quadrant	5
Maximum points per quadrant	7

Table 5 - Gridding parameters.

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

APPENDIX A. – OPUS Solutions

```
                                 NGS OPUS SOLUTION REPORT
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      USER: michaels@ufl.edu                   DATE: February 18, 2008
RINEX FILE: row_038s.08o                       TIME: 19:28:32 UTC


  SOFTWARE: page5  0612.06 master30.pl        START: 2008/02/07  18:48:00
 EPHEMERIS: igr14654.eph [rapid]               STOP: 2008/02/07  23:27:00
  NAV FILE: brdc0380.08n                    OBS USED: 12066 / 12196  :  99%
  ANT NAME: ASH700936D_M    NONE          # FIXED AMB:   49 /   49  : 100%
ARP HEIGHT: 1.500                         OVERALL RMS: 0.009(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)        ITRF00 (EPOCH:2008.1035)

        X:     -1755058.596(m)   0.013(m)        -1755059.330(m)   0.013(m)
        Y:     -4725163.488(m)   0.020(m)        -4725162.183(m)   0.020(m)
        Z:      3896892.437(m)   0.011(m)         3896892.357(m)   0.011(m)

      LAT:   37 53 38.84510      0.007(m)       37 53 38.86232      0.007(m)
    E LON:  249 37 24.91487      0.014(m)      249 37 24.86812      0.014(m)
    W LON:  110 22 35.08513      0.014(m)      110 22 35.13188      0.014(m)
   EL HGT:        1165.233(m)    0.020(m)            1164.420(m)    0.020(m)
ORTHO HGT:        1186.317(m)    0.032(m) [Geoid03 NAVD88]

                    UTM COORDINATES    STATE PLANE COORDINATES
                     UTM (Zone 12)        SPC (4303 UT S)
Northing (Y) [meters]    4194251.185        3136821.606
Easting (X)  [meters]     554828.202         598822.158
Convergence  [degrees]    0.38301962         0.68840781
Point Scale               0.99963702         0.99995313
Combined Factor           0.99945428         0.99977033

US NATIONAL GRID DESIGNATOR: 12SWG5482894251(NAD 83)



                        BASE STATIONS USED
PID        DESIGNATION                    LATITUDE    LONGITUDE DISTANCE(m)
DI2242 P009 MARYSVALE_UT2006 CORS ARP     N382847.732 W1121321.725  174363.2
AJ2124 PUC1 CARBON COUNTY COU CORS ARP    N393557.066 W1104831.329  193010.6
DI3419 P012 MONTICELLOUT2006 CORS ARP     N380550.740 W1092001.762   94340.2

             NEAREST NGS PUBLISHED CONTROL POINT
DH5741     HITE 3                         N375239.371 W1102253.304    1892.0
```

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


        USER: michaels@ufl.edu                DATE: February 18, 2008
  RINEX FILE: col_038s.08o                     TIME: 19:21:55 UTC


    SOFTWARE: page5  0612.06 master2.pl        START: 2008/02/07  18:33:00
   EPHEMERIS: igr14654.eph [rapid]              STOP: 2008/02/07  23:16:30
    NAV FILE: brdc0380.08n                  OBS USED: 12438 / 12508   :  99%
    ANT NAME: ASH700936D_M    NONE        # FIXED AMB:    48 /    48  : 100%
  ARP HEIGHT: 1.500                       OVERALL RMS: 0.009(m)


   REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)        ITRF00 (EPOCH:2008.1035)

          X:    -1754637.353(m)    0.013(m)       -1754638.087(m)    0.013(m)
          Y:    -4725415.079(m)    0.017(m)       -4725413.774(m)    0.017(m)
          Z:     3896746.350(m)    0.009(m)        3896746.270(m)    0.009(m)

        LAT:   37 53 33.33000      0.007(m)       37 53 33.34723     0.007(m)
      E LON:  249 37 44.65820      0.014(m)      249 37 44.61146     0.014(m)
      W LON:  110 22 15.34180      0.014(m)      110 22 15.38854     0.014(m)
     EL HGT:         1145.899(m)    0.017(m)             1145.086(m)  0.017(m)
   ORTHO HGT:        1166.982(m)    0.030(m) [Geoid03 NAVD88]

                     UTM COORDINATES     STATE PLANE COORDINATES
                     UTM (Zone 12)         SPC (4303 UT S)
  Northing (Y) [meters]    4194084.448        3136657.396
  Easting (X)  [meters]     555311.550         599306.541
  Convergence  [degrees]    0.38637505         0.69176795
  Point Scale               0.99963768         0.99995308
  Combined Factor           0.99945797         0.99977331

  US NATIONAL GRID DESIGNATOR: 12SWG5531294084(NAD 83)



                          BASE STATIONS USED
  PID        DESIGNATION                    LATITUDE    LONGITUDE DISTANCE(m)
  DI2242 P009 MARYSVALE_UT2006 CORS ARP     N382847.732 W1121321.725  174873.9
  AJ2124 PUC1 CARBON COUNTY COU CORS ARP    N393557.066 W1104831.329  193270.6
  DI3419 P012 MONTICELLOUT2006 CORS ARP     N380550.740 W1092001.762   93914.4

                  NEAREST NGS PUBLISHED CONTROL POINT
  HN0848      ET U 180                      N375321.349 W1102108.080    1682.7
```