# Spatial and Temporal Patterns of Nitrogen Export and Land Use/Cover Change in Mountainous Watershed

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## Survey Area

The survey area is an irregular polygon located 21 km west of Big Sky, Montana (Figure 1). Seven flights were made beginning on September 20, 2005 (Day 263) and completing on September 25, 2005 (Day 268). The survey was completed using an Optech 1233 Airborne Laser Terrain Mapper (http://www.optech.ca/) mounted in a twin engine Piper Chieftain (N931SA).

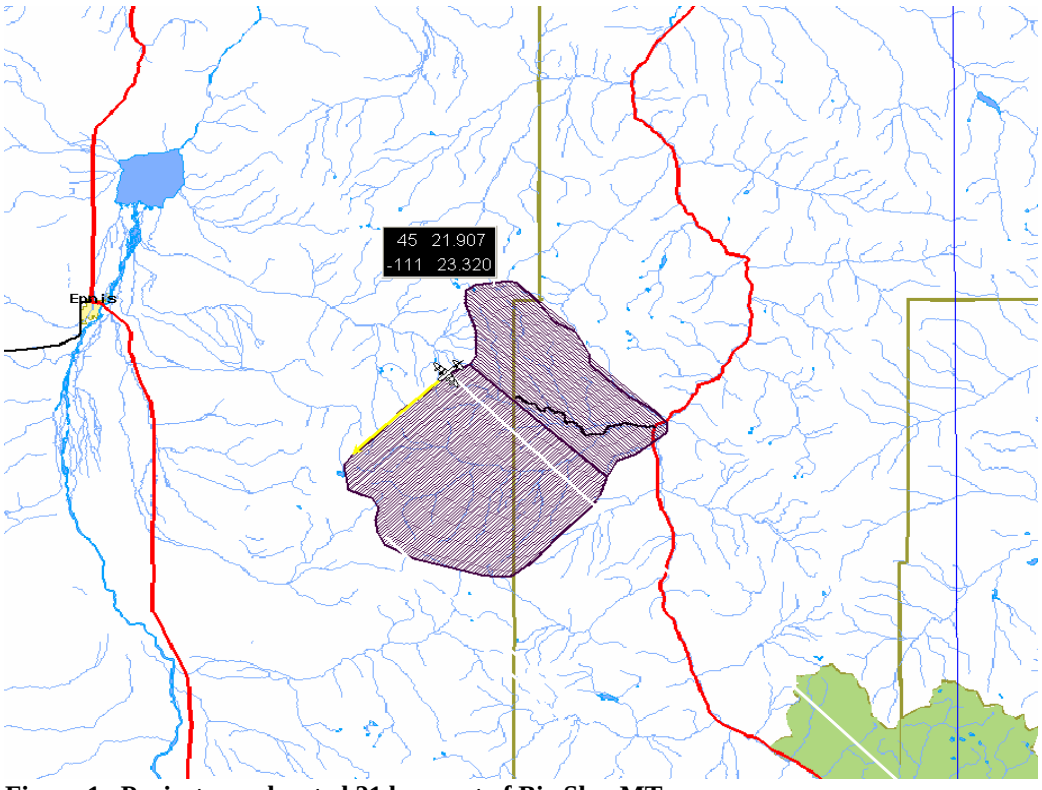



**Figure 1. Project area located 21 km west of Big Sky, MT.**

## Survey Parameters

This survey was completed following 121 flight lines in two separate polygons. The southern area (lines 1-82) is oriented southwest-northeast while the northern area (lines 83-121) is oriented southeast-northwest. Additional cross lines were flown perpendicular to the survey lines for field calibration purposes. The laser range was targeted at 600 m above ground level (AGL), but varied due to the mountainous terrain. Additional parameters are shown below in Figure 2.

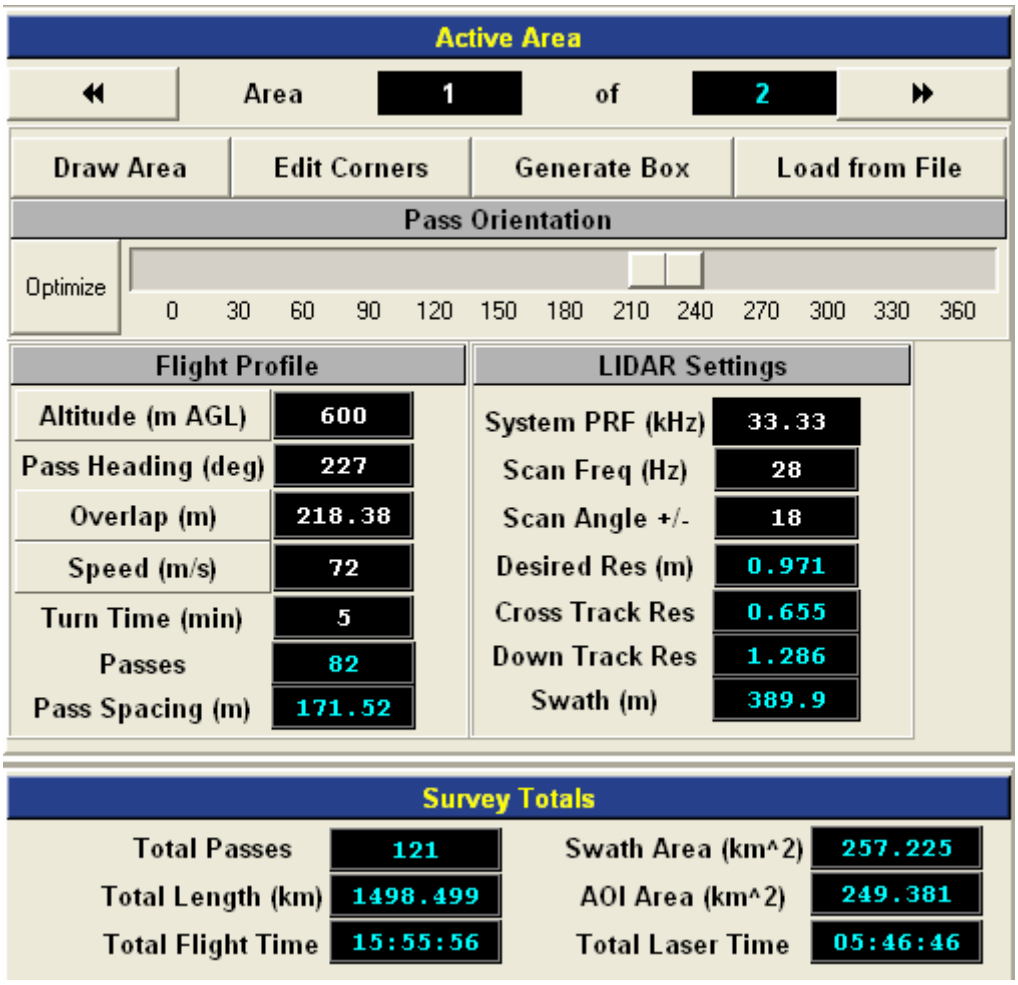



**Figure 2. Flight and data parameters.**

## GPS Reference Stations

Three GPS reference stations were established for this project: HIX located at the Holiday Inn Express in Belgrade, MT; SPAN located at the intersection of Spanish Creek and Route 191 (17 KM Northeast of the project; and BSKY located just south of Route 64 across the street from the public golf course inside the project polygon. HIX was observed for a 9 hour session on Sept 20, 2005, SPAN and BSKY were both observed multiple times, in excess of 25 hours. All GPS observations were logged at a 1-second rate and 5 sessions were submitted to the NGS online processor OPUS (solutions appear as Appendix A). Final coordinates for all 3 reference stations are based on these OPUS solutions (http://www.ngs.noaa.gov/OPUS/). For more information on the CORS network, refer to http://www.ngs.noaa.gov/CORS/. Ground equipment included ASHTECH Z-Extreme receivers and choke ring antennas (Part #700936.D) mounted on a 1.5 m fixed-height tripod.

## Navigation Processing

Airplane trajectories were processed using KARS (Kinematic and Rapid Static) software written by Dr. Gerry Mader of the NGS Research Laboratory. The KARS differential GPS solution is dual-frequency, phase-differenced, and fixed integer.

Two separate airplane trajectories were processed in KARS software for each flight using two reference stations, usually SPAN and BSKY. Station HIX was used as a back-up station on the first flight (September 20, 2005 only). As an illustration of typical trajectory precision, coordinate differences between the separate solutions for the second flight on September 22 were plotted, and the difference plot appears below (Figure 3). This flight was almost 4 hours in duration. Note that the height difference between the trajectories is generally less than 2 cm, growing to 3 or 4 cm for small durations of the survey.

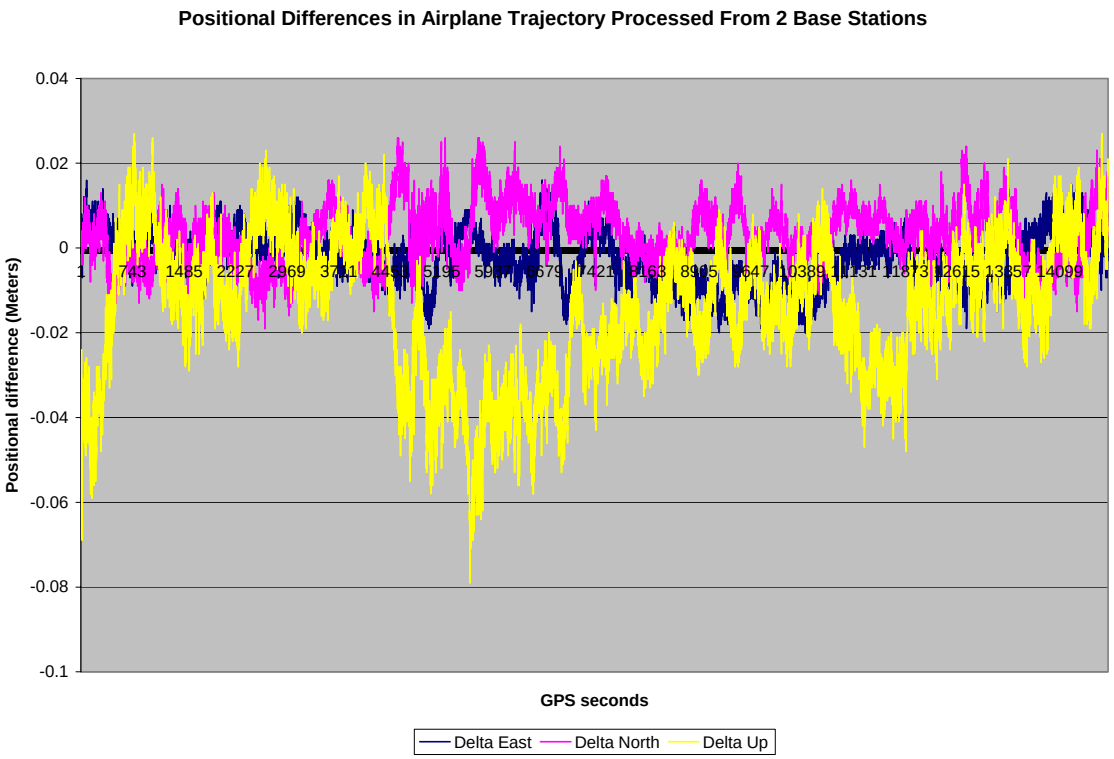



**Figure 3- Positional differences in airplane trajectory as processed from SPAN and BSKY.**

## Laser Point Processing

All coordinates were processed with respect to NAD83 and referenced to the national CORS network. The plane projection for all 9 column (flight-strip) output is UTM Zone 12, with ellipsoid heights, and units in meters. All other output was produced 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 all other output or in the 1-meter DEMs.

During processing, a scan cutoff angle of 0.5 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.

## Ground Truth and Calibration

In order to provide on-site calibration and ground truth, a section of Highway 64 running east and west through the project polygon was surveyed using vehicle-mounted GPS, and also 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 overlaid on a shaded relief image of the filtered project DEM.

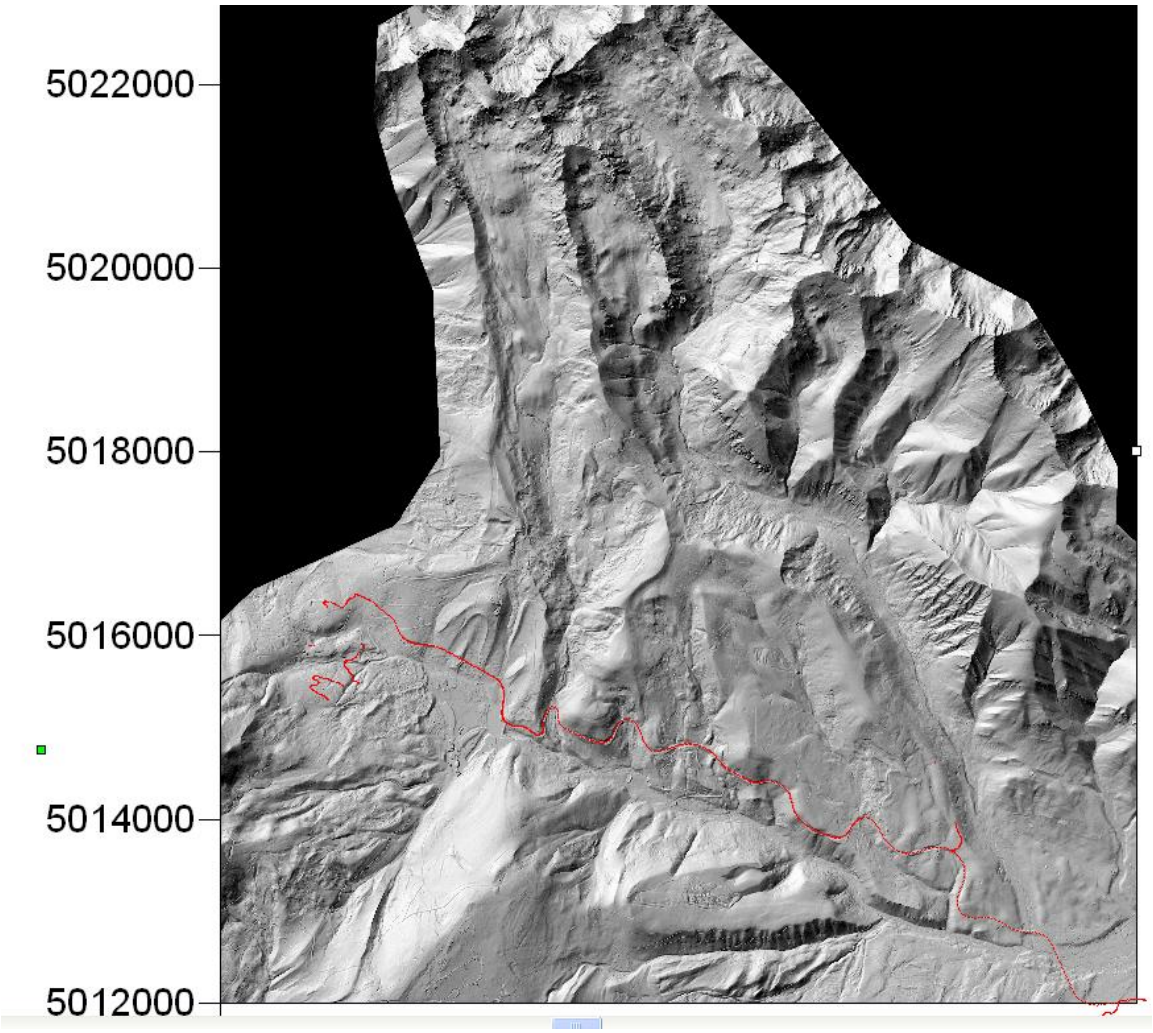



**Figure 4- Ground Truth Points.**

The standard deviation of the differences between the ALTM nearest neighbor shot and the ground truth points was about 7 cm on all flights.

A relative calibration of roll, pitch, and mirror angle scale was also done using TerraMatch (TerraSolid) software. Table 1 (below) summarizes these results.

| | Flight number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 263a | 263b | 264a | 264b | 265a | 265b | 268a | Average | STDEV |
| **Roll Shift** | -0.041 | -0.046 | -0.064 | -0.053 | -0.067 | -0.054 | -0.076 | -0.0574 | 0.012 |
| **Pitch Shift** | 0.012 | 0.006 | -0.006 | 0.019 | 0.017 | 0.020 | 0.022 | 0.0131 | 0.010 |
| **Scale Shift** | -0.008 | -0.009 | -0.010 | -0.008 | -0.007 | -0.009 | -0.008 | -0.0083 | 0.001 |

**Table 1 – TerraMatch calibration summary.**

Note that the standard deviation on the shifts in roll, pitch, (degrees) and mirror scale (scalar) is small, indicating good agreement between flights.

## Filtering and DEM Production

Terrasolid's TerraScan (http://terrasolid.fi) software was used to classify the last return LIDAR points and generate the "bare-earth" dataset.

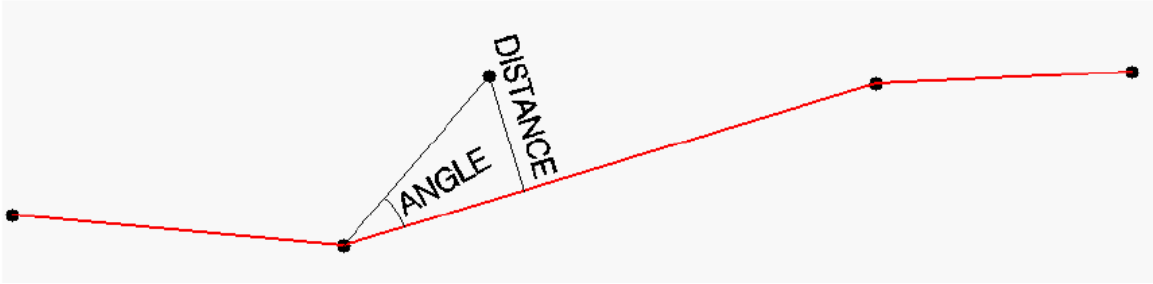
The classification routine consists of three algorithms:

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):  10.0 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): 55.0 m
Max Terrain Angle: 88.0
Iteration Angle: 6.0
Iteration Distance: 1.2 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 2km x 2km overlapping tiles (60m 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.

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 grids. The unfiltered points were krigged using a 5m Search Radius because of the higher data density.

# APPENDIX A.
# GPS Reference Station Coordinates from OPUS

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

```
      USER: michaels@ufl.edu                      DATE: November 15, 2005
RINEX FILE: span265o.05o                          TIME: 14:59:18 UTC


  SOFTWARE: page5  0411.19 master25.pl            START: 2005/09/22  14:44:00
 EPHEMERIS: igs13414.eph [precise]                 STOP: 2005/09/23  00:32:00
  NAV FILE: brdc2650.05n                      OBS USED: 20224 / 20848   :  97%
  ANT NAME: ASH700936D_M                   # FIXED AMB:    81 /    85   :  95%
ARP HEIGHT: 1.5                            OVERALL RMS: 0.016(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2005.7255)

         X:     -1625345.753(m)   0.020(m)          -1625346.460(m)   0.020(m)
         Y:     -4174668.687(m)   0.012(m)          -4174667.460(m)   0.012(m)
         Z:      4526929.431(m)   0.013(m)           4526929.436(m)   0.013(m)

       LAT:   45 29 29.23214      0.009(m)        45 29 29.25274      0.009(m)
     E LON:  248 43 38.21518      0.019(m)       248 43 38.16435      0.019(m)
     W LON:  111 16 21.78482      0.019(m)       111 16 21.83565      0.019(m)
    EL HGT:         1579.002(m)   0.016(m)             1578.384(m)   0.016(m)
 ORTHO HGT:         1588.937(m)   0.030(m) [Geoid03 NAVD88]

                       UTM COORDINATES    STATE PLANE COORDINATES
                        UTM (Zone 12)         SPC (2500 MT  )
Northing (Y) [meters]     5037583.167          139543.079
Easting (X)  [meters]      478690.193          461474.611
Convergence  [degrees]    -0.19448845         -1.29675067
Point Scale                0.99960558          0.99974056
Combined Factor            0.99935819          0.99949314

US NATIONAL GRID DESIGNATOR: 12TVR7869037583(NAD 83)



                             BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
AI5647 MAWY MAMMOTH WYOMING CORS ARP       N445824.318 W1104121.434   73596.3
DG8532 TSWY TSWY_EBRY_WY2001               N434026.703 W1103550.864  209002.5
DG9745 MTEI ENGINC CORS ARP                N454447.035 W1083600.737  210378.5

                  NEAREST NGS PUBLISHED CONTROL POINT
QX0268      J 160                          N452935.    W1111619.        188.3
```

# NGS OPUS SOLUTION REPORT

USER: michaels@ufl.edu
RINEX FILE: bsky264p.05o
DATE: November 15, 2005
TIME: 14:59:13 UTC

SOFTWARE: page5 0411.19 master4.pl
EPHEMERIS: igs13413.eph [precise]
NAV FILE: brdc2640.05n
ANT NAME: ASH700936D_M
ARP HEIGHT: 1.5
START: 2005/09/21 15:12:00
STOP: 2005/09/21 23:44:00
OBS USED: 16756 / 17121 : 98%
# FIXED AMB: 62 / 65 : 95%
OVERALL RMS: 0.015(m)

| REF FRAME: | NAD_83(CORS96)(EPOCH:2002.0000) | | ITRF00 (EPOCH:2005.7228) | |
|---|---|---|---|---|
| X: | -1633964.686(m) | 0.028(m) | -1633965.391(m) | 0.028(m) |
| Y: | -4191132.192(m) | 0.012(m) | -4191130.963(m) | 0.012(m) |
| Z: | 4509154.617(m) | 0.014(m) | 4509154.620(m) | 0.014(m) |
| LAT: | 45 15 39.22067 | 0.006(m) | 45 15 39.24119 | 0.006(m) |
| E LON: | 248 42 3.82239 | 0.024(m) | 248 42 3.77181 | 0.024(m) |
| W LON: | 111 17 56.17761 | 0.024(m) | 111 17 56.22819 | 0.024(m) |
| EL HGT: | 1901.759(m) | 0.023(m) | 1901.136(m) | 0.023(m) |
| ORTHO HGT: | 1910.844(m) | 0.034(m) | [Geoid03 NAVD88] | |

| | UTM COORDINATES (Zone 12) | STATE PLANE COORDINATES SPC (2500 MT ) |
|---|---|---|
| Northing (Y) [meters] | 5011976.612 | 113977.688 |
| Easting (X) [meters] | 476546.265 | 458837.699 |
| Convergence [degrees] | -0.21234253 | -1.31593087 |
| Point Scale | 0.99960676 | 0.99985342 |
| Combined Factor | 0.99930881 | 0.99955539 |

US NATIONAL GRID DESIGNATOR: 12TVR7654611977(NAD 83)

## BASE STATIONS USED

| PID | DESIGNATION | LATITUDE | LONGITUDE | DISTANCE(m) |
|---|---|---|---|---|
| AI5647 | MAWY MAMMOTH WYOMING CORS ARP | N445824.318 | W1104121.434 | 57652.3 |
| DG8532 | TSWY TSWY_EBRY_WY2001 | N434026.703 | W1103550.864 | 185003.8 |
| DG9745 | MTEI ENGINC CORS ARP | N454447.035 | W1083600.737 | 217735.5 |

## NEAREST NGS PUBLISHED CONTROL POINT

| | | | | |
|---|---|---|---|---|
| QX0293 | X 160 | N451517. | W1111513. | 3617.7 |

# NGS OPUS SOLUTION REPORT

USER: michaels@ufl.edu
RINEX FILE: bsky265p.05o
DATE: November 15, 2005
TIME: 14:57:30 UTC

SOFTWARE: page5 0411.19 master12.pl
EPHEMERIS: igs13414.eph [precise]
NAV FILE: brdc2650.05n
ANT NAME: ASH700936D_M
ARP HEIGHT: 1.5
START: 2005/09/22 15:18:00
STOP: 2005/09/23 00:02:00
OBS USED: 17838 / 18253 : 98%
# FIXED AMB: 70 / 73 : 96%
OVERALL RMS: 0.015(m)

| REF FRAME: | NAD_83(CORS96)(EPOCH:2002.0000) | | ITRF00 (EPOCH:2005.7255) | |
|---|---|---|---|---|
| X: | -1633964.685(m) | 0.020(m) | -1633965.390(m) | 0.020(m) |
| Y: | -4191132.200(m) | 0.013(m) | -4191130.971(m) | 0.013(m) |
| Z: | 4509154.611(m) | 0.012(m) | 4509154.614(m) | 0.012(m) |
| LAT: | 45 15 39.22037 | 0.011(m) | 45 15 39.24089 | 0.011(m) |
| E LON: | 248 42 3.82257 | 0.019(m) | 248 42 3.77198 | 0.019(m) |
| W LON: | 111 17 56.17743 | 0.019(m) | 111 17 56.22802 | 0.019(m) |
| EL HGT: | 1901.760(m) | 0.016(m) | 1901.137(m) | 0.016(m) |
| ORTHO HGT: | 1910.845(m) | 0.030(m) | [Geoid03 NAVD88] | |

| | UTM COORDINATES (Zone 12) | STATE PLANE COORDINATES SPC (2500 MT ) |
|---|---|---|
| Northing (Y) [meters] | 5011976.603 | 113977.679 |
| Easting (X) [meters] | 476546.269 | 458837.702 |
| Convergence [degrees] | -0.21234250 | -1.31593084 |
| Point Scale | 0.99960676 | 0.99985342 |
| Combined Factor | 0.99930881 | 0.99955539 |

US NATIONAL GRID DESIGNATOR: 12TVR7654611977(NAD 83)

## BASE STATIONS USED

| PID | DESIGNATION | LATITUDE | LONGITUDE | DISTANCE(m) |
|---|---|---|---|---|
| AI5647 | MAWY MAMMOTH WYOMING CORS ARP | N445824.318 | W1104121.434 | 57652.3 |
| DG8532 | TSWY TSWY_EBRY_WY2001 | N434026.703 | W1103550.864 | 185003.8 |
| DG9745 | MTEI ENGINC CORS ARP | N454447.035 | W1083600.737 | 217735.5 |

## NEAREST NGS PUBLISHED CONTROL POINT

| | | | | |
|---|---|---|---|---|
| QX0293 | X 160 | N451517. | W1111513. | 3617.7 |

# NGS OPUS SOLUTION REPORT

USER: michaels@ufl.edu
RINEX FILE: hix_263p.05o
DATE: November 15, 2005
TIME: 14:59:46 UTC

SOFTWARE: page5 0411.19 master13.pl
EPHEMERIS: igs13412.eph [precise]
NAV FILE: brdc2630.05n
ANT NAME: ASH700936D_M
ARP HEIGHT: 1.5
START: 2005/09/20 15:45:00
STOP: 2005/09/21 00:50:00
OBS USED: 18371 / 18864 : 97%
# FIXED AMB: 71 / 72 : 99%
OVERALL RMS: 0.013(m)

| REF FRAME: | NAD_83(CORS96)(EPOCH:2002.0000) | | ITRF00 (EPOCH:2005.7202) | |
|---|---|---|---|---|
| X: | -1611291.495(m) | 0.014(m) | -1611292.203(m) | 0.014(m) |
| Y: | -4156933.431(m) | 0.004(m) | -4156932.205(m) | 0.004(m) |
| Z: | 4547773.044(m) | 0.004(m) | 4547773.051(m) | 0.004(m) |
| LAT: | 45 45 41.72937 | 0.004(m) | 45 45 41.75012 | 0.004(m) |
| E LON: | 248 48 46.44372 | 0.014(m) | 248 48 46.39268 | 0.014(m) |
| W LON: | 111 11 13.55628 | 0.014(m) | 111 11 13.60732 | 0.014(m) |
| EL HGT: | 1357.771(m) | 0.001(m) | 1357.157(m) | 0.001(m) |
| ORTHO HGT: | 1369.139(m) | 0.025(m) | [Geoid03 NAVD88] | |

| | UTM COORDINATES UTM (Zone 12) | STATE PLANE COORDINATES SPC (2500 MT ) |
|---|---|---|
| Northing (Y) [meters] | 5067576.246 | 169403.057 |
| Easting (X) [meters] | 485450.399 | 468810.523 |
| Convergence [degrees] | -0.13404600 | -1.23411999 |
| Point Scale | 0.99960260 | 0.99962833 |
| Combined Factor | 0.99938987 | 0.99941559 |

US NATIONAL GRID DESIGNATOR: 12TVR8545067576(NAD 83)

## BASE STATIONS USED

| PID | DESIGNATION | LATITUDE | LONGITUDE | DISTANCE(m) |
|---|---|---|---|---|
| AI5647 | MAWY MAMMOTH WYOMING CORS ARP | N445824.318 | W1104121.434 | 95909.3 |
| DG9745 | MTEI ENGINC CORS ARP | N454447.035 | W1083600.737 | 201302.6 |
| DF8970 | ZBI1 BILLINGS WAAS 1 CORS ARP | N454813.548 | W1083212.748 | 206172.1 |

## NEAREST NGS PUBLISHED CONTROL POINT

| | | | | |
|---|---|---|---|---|
| QX0626 | BELGRADE PRESB CHURCH SPIRE | N454626.112 | W1111047.385 | 1484.0 |

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

USER: michaels@ufl.edu
RINEX FILE: span263q.05o
DATE: November 15, 2005
TIME: 14:57:49 UTC

SOFTWARE: page5 0411.19 master4.pl
EPHEMERIS: igs13412.eph [precise]
NAV FILE: brdc2630.05n
ANT NAME: ASH700936D_M
ARP HEIGHT: 1.5
START: 2005/09/20 16:31:00
STOP: 2005/09/21 00:20:30
OBS USED: 15708 / 16126 : 97%
# FIXED AMB: 57 / 57 : 100%
OVERALL RMS: 0.016(m)

| REF FRAME: | NAD_83(CORS96)(EPOCH:2002.0000) | | ITRF00 (EPOCH:2005.7202) | |
|---|---|---|---|---|
| X: | -1625345.759(m) | 0.032(m) | -1625346.466(m) | 0.032(m) |
| Y: | -4174668.704(m) | 0.022(m) | -4174667.477(m) | 0.022(m) |
| Z: | 4526929.450(m) | 0.015(m) | 4526929.455(m) | 0.015(m) |
| LAT: | 45 29 29.23216 | 0.012(m) | 45 29 29.25275 | 0.012(m) |
| E LON: | 248 43 38.21521 | 0.021(m) | 248 43 38.16438 | 0.021(m) |
| W LON: | 111 16 21.78479 | 0.021(m) | 111 16 21.83562 | 0.021(m) |
| EL HGT: | 1579.028(m) | 0.034(m) | 1578.410(m) | 0.034(m) |
| ORTHO HGT: | 1588.963(m) | 0.042(m) | [Geoid03 NAVD88] | |

| | UTM COORDINATES UTM (Zone 12) | STATE PLANE COORDINATES SPC (2500 MT ) |
|---|---|---|
| Northing (Y) [meters] | 5037583.168 | 139543.079 |
| Easting (X) [meters] | 478690.193 | 461474.611 |
| Convergence [degrees] | -0.19448845 | -1.29675067 |
| Point Scale | 0.99960558 | 0.99974056 |
| Combined Factor | 0.99935819 | 0.99949313 |

US NATIONAL GRID DESIGNATOR: 12TVR7869037583(NAD 83)

## BASE STATIONS USED

| PID | DESIGNATION | LATITUDE | LONGITUDE | DISTANCE(m) |
|---|---|---|---|---|
| AI5647 | MAWY MAMMOTH WYOMING CORS ARP | N445824.318 | W1104121.434 | 73596.3 |
| DG8532 | TSWY TSWY_EBRY_WY2001 | N434026.703 | W1103550.864 | 209002.5 |
| DG9745 | MTEI ENGINC CORS ARP | N454447.035 | W1083600.737 | 210378.5 |

## NEAREST NGS PUBLISHED CONTROL POINT

| | | | | |
|---|---|---|---|---|
| QX0268 | J 160 | N452935. | W1111619. | 188.3 |