Biocomplexity in the Environment:
Flathead Lake, Montana

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Survey Area

The survey area is an 87 km^2 box located 40 km northeast of Kalispell, Montana (Figure 1). This area was flown on September 14, 2005 (Day 257) and completed on September 15, 2005 (Day 258). The survey was completed using an Optech 1233 Airborne Laser Terrain Mapper (http://www.optech.ca/) mounted in a twin engine Piper Chieftain (N931SA).

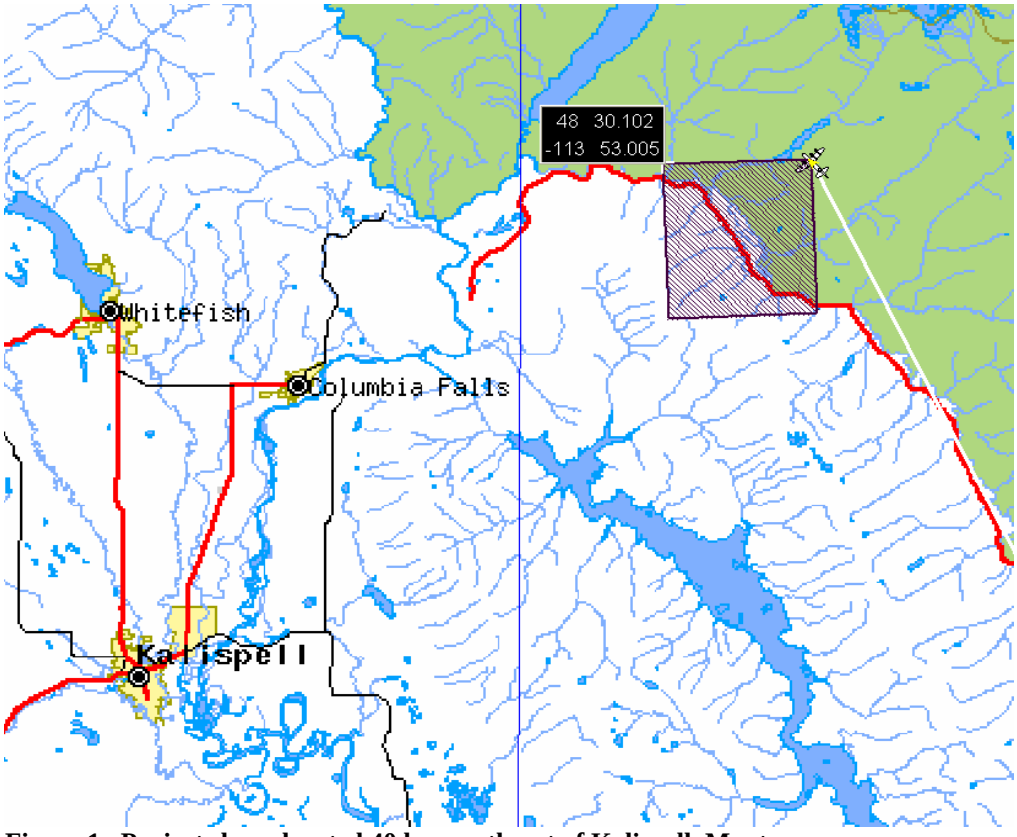


Figure 1. Project shape located 40 km northeast of Kalispell, Montana.

Survey Parameters

The project area was flown with 62 flight lines oriented northwest-southeast. Five additional cross lines were flown perpendicular to the survey lines for field calibration purposes. The flying height was targeted at 600 m above ground level (AGL), but varied during the survey due to the mountainous terrain. Additional parameters are shown below in Figure 2.

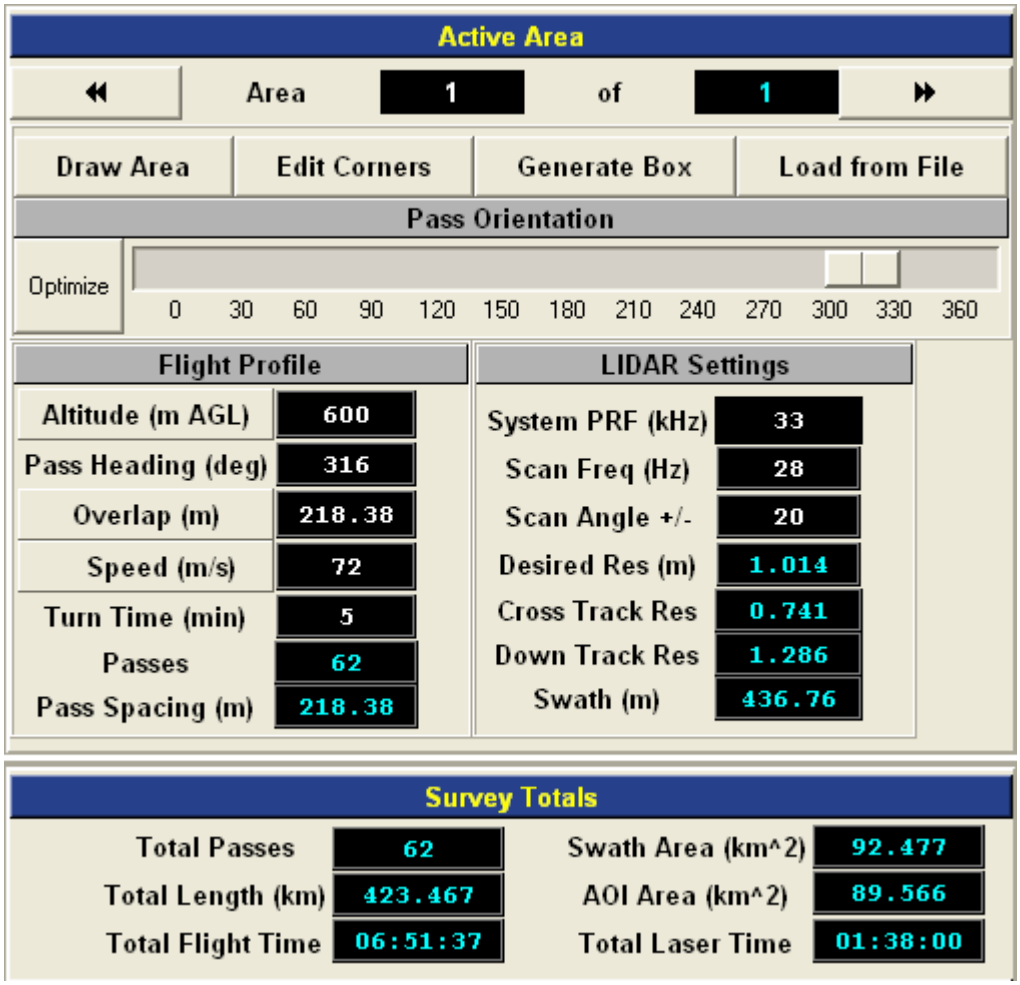


Figure 2. Flight profile and LiDAR settings.

GPS Reference Stations

Two GPS reference station locations were used during the survey. One receiver was place on a newly set mark off of US Hwy 2. This location was just west of the project boundary. The other receiver was placed on a newly set mark in the project area also off of US Hwy 2. These stations were observed on September 14, 2005 (Day 257) and September 15, 2005 (Day 258) for a total of 30 hours. All GPS observations were logged at a 1-second rate and submitted to the NGS online processor OPUS (Appendix A). Final coordinates for reference stations nrth and soth were 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 conventional tripod.

Navigation Processing

The airplane trajectory for this survey was processed using KARS software (Kinematic and Rapid Static) by Dr. Gerry Mader of the NGS Research Laboratory.

After GPS processing, the trajectory and the (Inertial Measurement Unit) data collected during the flight were input into APPLANIX software POSPROC which uses a Kalman Filter to produce a final navigation solution (aircraft position and orientation) at 50 Hz, in SBET format (Smoothed Best Estimated Trajectory).

Figure 3 (below) is a plot of the differences in Easting, Northing, and Height of two trajectories, one using PLM1 as the reference and the other using PLM2 have been shown.

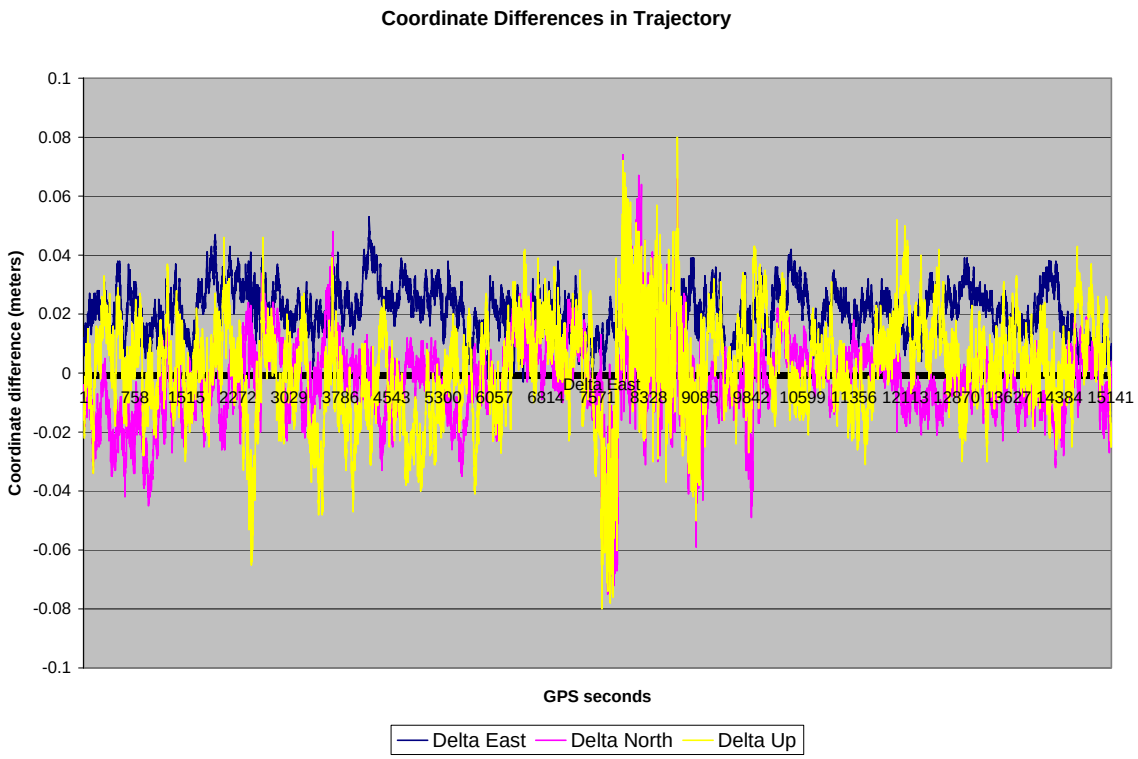


Figure 3. Positional differences in trajectory processed from Day 257.

Calibration and Laser Point Processing

The SBET and the raw laser range data were combined using Optech's REALM processing suite 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.

No absolute ground calibration was performed on these data, so a bias may be present with respect to ellipsoid heights obtained by GPS during ground surveys. If this bias exists it should be in the range of +/- 0.15 meters.

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 11, with ellipsoid heights, and units in meters. The last return data was extracted from the 9-column format and the heights reprojected to orthometric heights in NAVD88, computed using NGS GEOID03 model with the Corpscon v6.0 software (Corps of Engineers Coordinate Conversion).

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 return
3. Northing last return
4. Height last return
5. Intensity last return
6. Easting first return
7. Northing first return
8. Height first return
9. Intensity first return
```

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 3-column files or in the 1-meter DEM grid nodes.

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.

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 two algorithms:

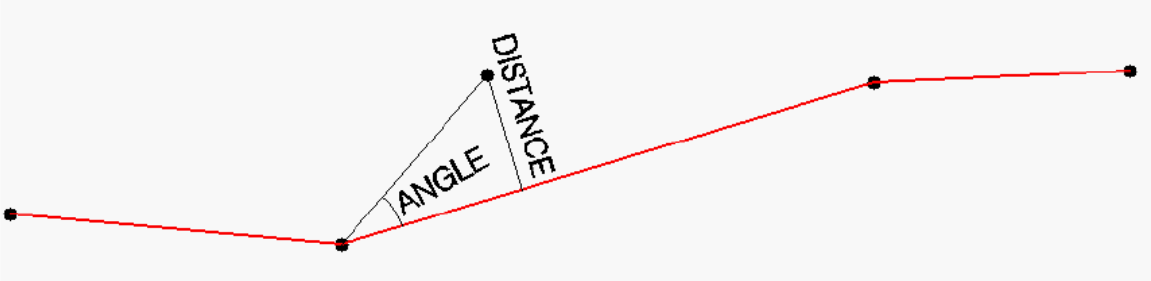
1) Removal of "Low Points". This routine was used to search for possible error points which are clearly below the ground surface. The elevation of each point (=center) is compared with every other point within a given neighborhood and if the center point is clearly lower then any other point it will 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): 40.0 m
Max Terrain Angle: 88.0
Iteration Angle: 6.0
Iteration Distance: 1.4 m
Reduce iteration angle when edge length < : 5.0 m
```

After classification the ground points were outputted in 2km x 2km overlapping tiles (60m 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 include:

```
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 floating 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.

APPENDIX A.
GPS Reference Station Coordinates from OPUS

NGS OPUS SOLUTION REPORT
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```
      USER: michaels@ufl.edu                    DATE: November 18, 2005
RINEX FILE: nrth257t.05o                        TIME: 14:28:31 UTC

  SOFTWARE: page5  0411.19 master24.pl    START: 2005/09/14  19:01:00
 EPHEMERIS: igs13403.eph [precise]         STOP: 2005/09/15  00:43:00
  NAV FILE: brdc2570.05n               OBS USED: 12482 / 12762   :  98%
  ANT NAME: ASH700936D_M            # FIXED AMB:    47 /    47   : 100%
ARP HEIGHT: 1.5                     OVERALL RMS: 0.012(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)    ITRF00 (EPOCH:2005.7039)

         X:     -1712318.828(m)  0.003(m)     -1712319.554(m)  0.003(m)
         Y:     -3876595.343(m)  0.004(m)     -3876594.146(m)  0.004(m)
         Z:      4751964.185(m)  0.003(m)      4751964.231(m)  0.003(m)

       LAT:    48 27 49.11529    0.001(m)   48 27 49.13570     0.001(m)
     E LON:   246 10  7.04157    0.004(m)  246 10  6.98571     0.004(m)
     W LON:   113 49 52.95843    0.004(m)  113 49 53.01429     0.004(m)
    EL HGT:         997.157(m)   0.004(m)          996.660(m)  0.004(m)
 ORTHO HGT:        1012.162(m)   0.025(m)              [Geoid03 NAVD88]

                         UTM COORDINATES    STATE PLANE COORDINATES
                          UTM (Zone 12)         SPC (2500 MT)
Northing (Y) [meters]     5371706.811           477083.253
Easting (X)  [meters]      290701.585           279930.686
Convergence  [degrees]    -2.12015078          -3.16842073
Point Scale                1.00013824           0.99971519
Combined Factor            0.99998197           0.99955898

US NATIONAL GRID DESIGNATOR: 12UTU9070271707(NAD 83)


                                BASE STATIONS USED
PID       DESIGNATION             LATITUDE    LONGITUDE     DISTANCE(m)
DG9747    MTFV FLAT HEAD          N481338.890 W1141936.543  45155.2
          COMMUNI CORS ARP
AJ1818    PLS1 POLSON 1 CORS ARP  N473949.553 W1140650.078  91411.9
DE8232    MSOL MISSOULA CORS ARP  N465545.837 W1140631.846  171871.6
```

NEAREST NGS PUBLISHED CONTROL POINT

TM0758	A 500	N482753.	W1134955.	127.2

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	DATE:	November 18, 2005
RINEX FILE:	nrth258p.05o	TIME:	14:29:08 UTC

SOFTWARE:	page5 0411.19 master25.pl	START:	2005/09/15 15:04:00
EPHEMERIS:	igs13404.eph [precise]	STOP:	2005/09/16 00:22:00
NAV FILE:	brdc2580.05n	OBS USED:	19828 / 20049 : 99%
ANT NAME:	ASH700936D_M	# FIXED AMB:	70 / 70 : 100%
ARP HEIGHT:	1.5	OVERALL RMS:	0.014(m)

	REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)		ITRF00 (EPOCH:2005.7064)	
X:	-1712318.811(m)	0.008(m)	-1712319.537(m)	0.008(m)
Y:	-3876595.356(m)	0.004(m)	-3876594.159(m)	0.004(m)
Z:	4751964.182(m)	0.007(m)	4751964.228(m)	0.007(m)
LAT:	48 27 49.11510	0.007(m)	48 27 49.13551	0.007(m)
E LON:	246 10 7.04258	0.006(m)	246 10 6.98672	0.006(m)
W LON:	113 49 52.95742	0.006(m)	113 49 53.01328	0.006(m)
EL HGT:	997.158(m)	0.007(m)	96.661(m)	0.007(m)
ORTHO HGT:	1012.163(m)	0.026(m)	[Geoid03 NAVD88]	

	UTM COORDINATES (Zone 12)	STATE PLANE COORDINATES SPC (2500 M)
Northing (Y) [meters]	5371706.804	477083.247
Easting (X) [meters]	290701.605	279930.706
Convergence [degrees]	-2.12015056	-3.16842053
Point Scale	1.00013824	0.99971519
Combined Factor	0.99998197	0.99955898

US NATIONAL GRID DESIGNATOR: 12UTU9070271707(NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE(m)
DG9747	MTFV FLAT HEAD COMMUNI CORS ARP	N481338.890	W1141936.543	45155.2
AJ1818 PLS1	POLSON 1 CORS ARP	N473949.553	W1140650.078	91411.9
DE8232 MSOL	MISSOULA CORS ARP	N465545.837	W1140631.846	171871.6

NEAREST NGS PUBLISHED CONTROL POINT

TM0758	A 500	N482753.	W1134955.	127.2

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: November 18, 2005
RINEX FILE: soth257t.05o                        TIME: 14:29:12 UTC


  SOFTWARE: page5  0411.19 master23.pl    START: 2005/09/14  19:28:00
 EPHEMERIS: igs13403.eph [precise]         STOP: 2005/09/15  00:27:30
  NAV FILE: brdc2570.05n               OBS USED: 11126 / 11432   :  97%
  ANT NAME: ASH700936D_M            # FIXED AMB:    46 /    46   : 100%
ARP HEIGHT: 1.5                     OVERALL RMS: 0.014(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)    ITRF00 (EPOCH:2005.7039)

         X:     -1707677.557(m)  0.006(m)    -1707678.283(m)   0.006(m)
         Y:     -3882894.542(m)  0.008(m)    -3882893.344(m)   0.008(m)
         Z:      4748640.736(m)  0.008(m)     4748640.781(m)   0.008(m)

       LAT:   48 25  3.47527     0.007(m)  48 25  3.49571      0.007(m)
     E LON:  246 15 37.25049     0.006(m) 246 15 37.19472      0.006(m)
     W LON:  113 44 22.74951     0.006(m  113 44 22.80528      0.006(m)
    EL HGT:         1092.437(m)  0.008(m)        1091.937(m)   0.008(m)
 ORTHO HGT:         1107.228(m)  0.026(m)              [Geoid03 NAVD88]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 12)         SPC (2500 MT)
Northing (Y) [meters]     5366346.251           471605.012
Easting (X)  [meters]      297298.239           286425.312
Convergence  [degrees]    -2.04996087          -3.10132373
Point Scale                1.00010485           0.99969496
Combined Factor            0.99993365           0.99952383

US NATIONAL GRID DESIGNATOR: 12UTU9729866346(NAD 83)


                                BASE STATIONS USED
PID       DESIGNATION            LATITUDE     LONGITUDE     DISTANCE(m)
DG9747    MTFV FLAT HEAD         N481338.890  W1141936.543  48413.9
          COMMUNI CORS ARP
AJ1818    PLS1 POLSON 1 CORS ARP N473949.553  W1140650.078  88360.2
DE8232    MSOL MISSOULA CORS ARP N465545.837  W1140631.846  167795.8

                NEAREST NGS PUBLISHED CONTROL POINT
```

TM0752 G 500 N482507. W1134413. 27.8

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: November 18, 2005
RINEX FILE: soth258p.05o TIME: 14:27:59 UTC

SOFTWARE: page5 0411.19 master.pl START: 2005/09/15 15:18:00
EPHEMERIS: igs13404.eph [precise] STOP: 2005/09/16 00:37:00
NAV FILE: brdc2580.05n OBS USED: 19420 / 20237 : 96%
ANT NAME: ASH700936D_M # FIXED AMB: 90 / 90 : 100%
ARP HEIGHT: 1.5 OVERALL RMS: 0.016(m)

REF FRAME:	NAD_83(CORS96)(EPOCH:2002.0000)		ITRF00 (EPOCH:2005.7064)	
X:	-1707677.557(m)	0.010(m)	-1707678.283(m)	0.010(m)
Y:	-3882894.543(m)	0.008(m)	-3882893.345(m)	0.008(m)
Z:	4748640.734(m)	0.007(m)	4748640.779(m)	0.007(m)
LAT:	48 25 3.47520	0.013(m	48 25 3.49564	0.013(m)
E LON:	246 15 37.25051	0.008(m)	246 15 37.19474	0.008(m)
W LON:	113 44 22.74949	0.008(m)	113 44 22.80526	0.008(m)
EL HGT:	1092.436(m)	0.005(m)	1091.936(m)	0.005(m)
ORTHO HGT:	1107.227(m)	0.025(m)	[Geoid03 NAVD88]	

	UTM COORDINATES (UTM (Zone 12))	STATE PLANE COORDINATES (SPC (2500 MT))
Northing (Y) [meters]	5366346.248	471605.010
Easting (X) [meters]	297298.239	286425.312
Convergence [degrees]	-2.04996086	-3.10132373
Point Scale	1.00010485	0.99969496
Combined Factor	0.99993365	0.99952383

US NATIONAL GRID DESIGNATOR: 12UTU9729866346(NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE(m)
DG9747	MTFV FLAT HEAD COMMUNI CORS ARP	N481338.890	W1141936.543	48413.9
AJ1818	PLS1 POLSON 1 CORS ARP	N473949.553	W1140650.078	88360.2
DE8232	MSOL MISSOULA CORS ARP	N465545.837	W1140631.846	167795.8

NEAREST NGS PUBLISHED CONTROL POINT

TM0752 G 500 N482507. W1134413. 227.8

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.