Contact information

Danna Truslow
d.truslow@comcast.net
Phone: 603-498-2916 **Fax:** 603-430-9102
Address: 1065 Washington Road Rye, NH 03970

Advisor: Jennifer Jacobs
Advisor's email: jennifer.jacobs@unh.edu
Advisor's Phone: 603-862-0635

Title: Understanding Hyporheic Zone Extent and Exchange in a Coastal New Hampshire Stream Using Heat as
A Tracer

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.

Gemini 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 approximately 16 km West of Portsmouth, NH and enclosing 42.5 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 November 11, 2008, day-of-year 316.

4. Survey Parameters

The survey required 15 flight lines, shown below in Figure 2.

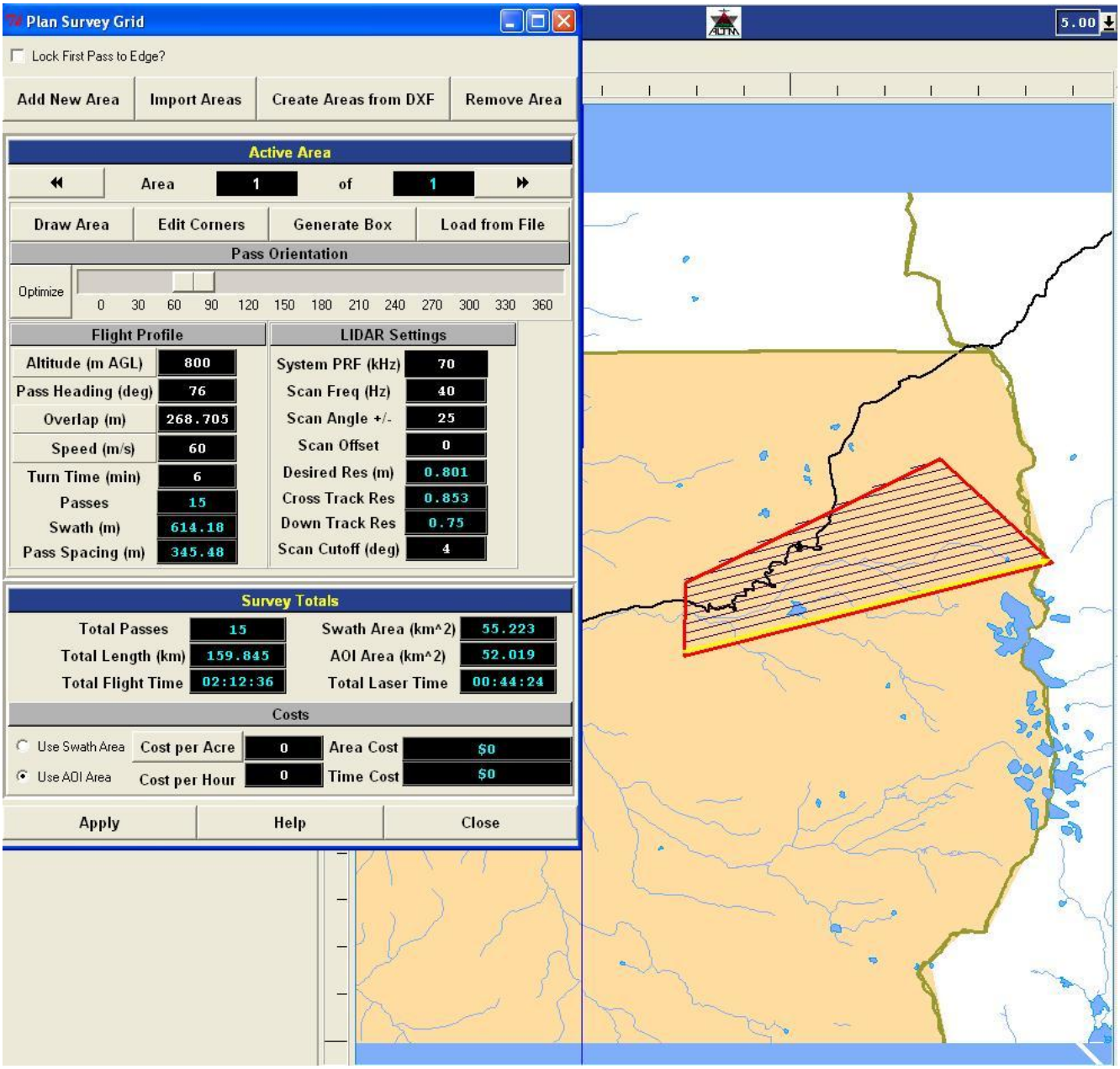


Figure 2 - Flight lines with planning parameters.

Survey totals appear below in Table 3.

Survey Totals	
Total Passes	15
Total Length	159.8 km
Total Flight Time	03:25:00
Total Laser Time	01:05:00
Total Swath Area	55.2 km^2
Total AOI Area	52.0 km^2

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

LiDAR settings are shown in Table 4.

LiDAR Settings	
Desired Resolution	0.80 m
Cross Track Resolution	0.85 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	614.0 m

Table 4 – LiDAR settings.

5. GPS Reference Stations

Three GPS reference station locations were logging data during the survey: RMD1, RMD2, and one Continuously Operating Reference Station (CORS) REDM which is located at the Redmond Airport and operated by UNAVCO (see http://www.unavco.org/aboutus/aboutus.html). See http://www.ngs.noaa.gov/CORS/ for more information on the CORS network.

REDM logged data at a 15 second rate, and these observations were interpolated to a 1 Hz rate by an NGS (National Geodetic Survey) utility program (INTERPO.EXE).

Stations RMD1 and RMD2 were established by NCALM at the Redmond Airport (Roberts Field) and logged data for four hours at 1 Hz. These observations were submitted to the NGS on-line processor OPUS (see http://www.ngs.noaa.gov/OPUS/ for more information. 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.

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 all three reference stations: RMD1, RMD2 and REDM. Trajectory solutions from RMD1 and REDM were differenced and Figure 3 (below) is a plot of these positional differences.

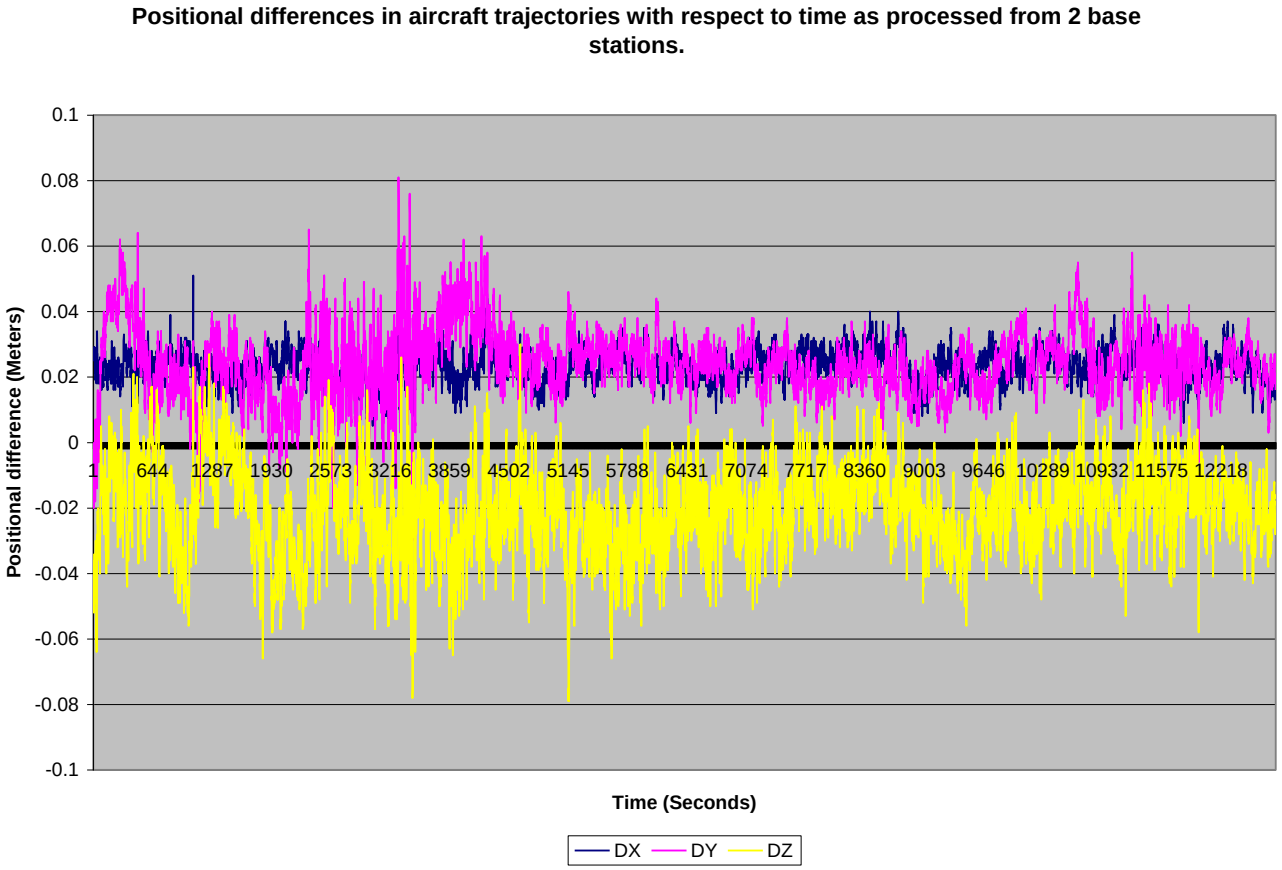


Figure 3 - Positional differences in aircraft trajectories with respect to time as processed from 2 base stations.

The standard deviation of the differences in the easting position of these two trajectories is 5 mm, in northing 10 mm, and in height 13 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.

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 74 mm before adjustment to an average low of 54 mm after adjustment. Below is the TerraMatch report from this flight.

```
Starting average dz:    0.0738
Final average dz:       0.0541

Standard error of unit  0.0242

Execution time: 1126.8 sec
Number of iterations: 9

Points       4977429
H shift      +0.0033    Std dev  0.0005
R shift      +0.0138    Std dev  0.0001
P shift      -0.0058    Std dev  0.0002
Scale       +0.00013
```

No independent ground truth was collected on this project; it is possible that a small (< 0.15 meters) height bias may exist between the ALTM DEM and other independent survey data. The relative vertical height accuracy of the ALTM DEM is within system specifications as verified by the relative calibration results.

8. Laser Point Processing

All coordinates were processed with respect to NAD83 and referenced to the national CORS network. The projection is UTM Zone 19, 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_YYYYYYY. For example if the tile bounds coordinate values from easting equals 590000 through 591000, and northing equals 4892000 through 4893000 then the tile filename is 590000_4192000. This is illustrated below in Figure 4.

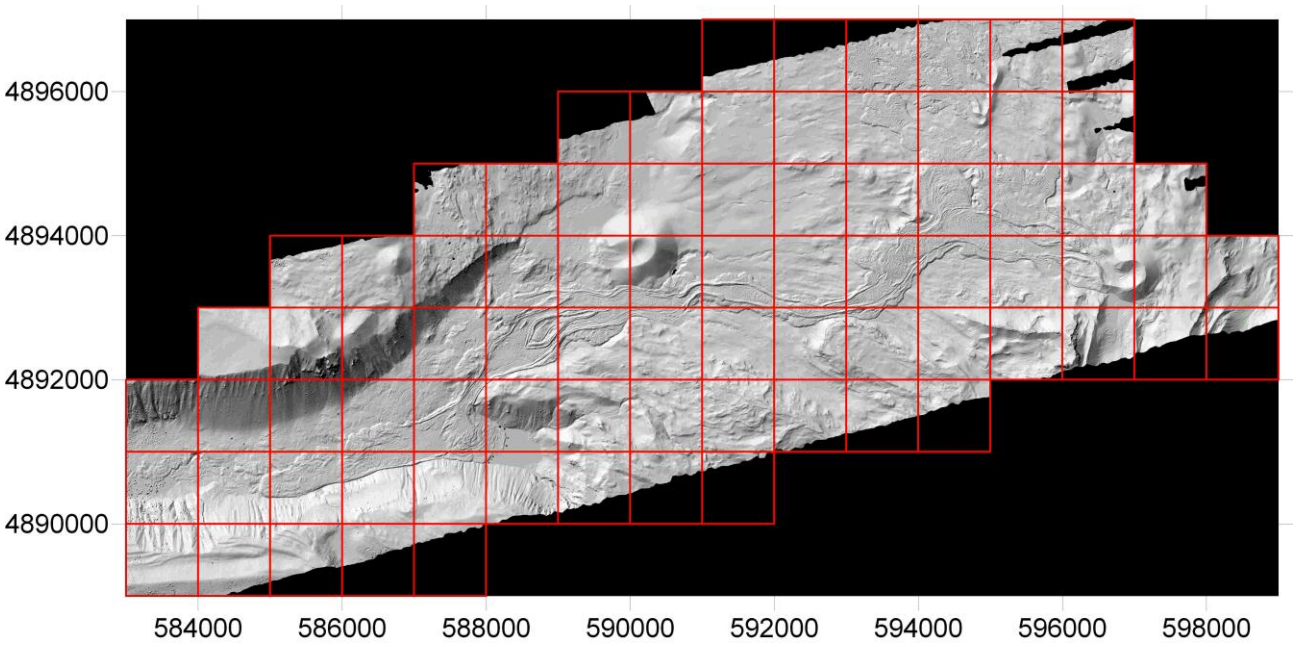


Figure 4 - Tile footprints overlaid onto a shaded relief image of the DEM. Tile foot prints are in red.

These tile footprints are available as an AutoCAD DXF or ESRI shape file. The project totaled 80 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. Filtering and 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	0.15 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.

Terrasolid's TerraScan (http://terrasolid.fi) software was used to classify the last return LiDAR points and generate the "bare-earth" dataset. All 80 tiles were processed individually.

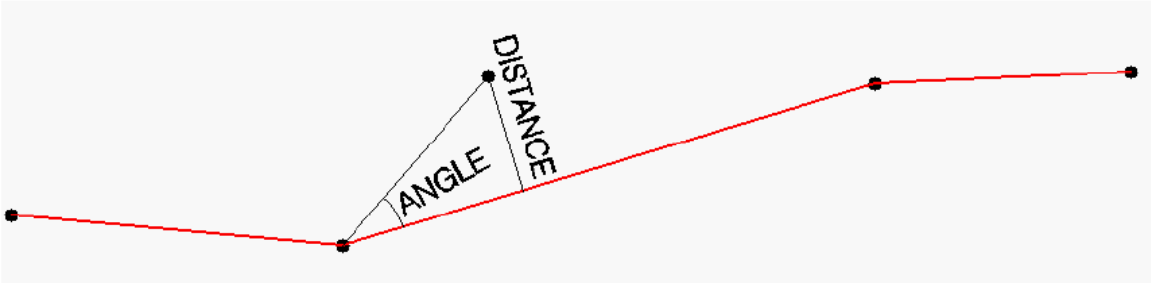
The classification routine consists of three algorithms:

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): 5
More than (minimum height difference): 0.1 m
Within (xy search range):  2.0 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): 10.0 m
Max Terrain Angle: 88.0
Iteration Angle: 9.0
Iteration Distance: 1.4 m
(Tiles with lava)
```

```
Max Building Size (window size): 10.0 m
Max Terrain Angle: 88.0
Iteration Angle: 6.0
Iteration Distance: 1.4 m
(Tiles without lava)
```

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: 5.00 * standard deviation
Z tolerance: 0.10 m
```

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

APPENDIX A. – OPUS Solutions

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

USER: michaels@ufl.edu DATE: November 19, 2007
RINEX FILE: rmd1209u.07o TIME: 20:34:28 UTC

SOFTWARE: page5 0612.06 master.pl START: 2007/07/28 20:05:00
EPHEMERIS: igs14376.eph [precise] STOP: 2007/07/29 00:01:00
NAV FILE: brdc2090.07n OBS USED: 9770 / 9858 : 99%
ANT NAME: ASH700936D_M NONE # FIXED AMB: 39 / 40 : 98%
ARP HEIGHT: 1.500 OVERALL RMS: 0.017(m)

	REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)		ITRF00 (EPOCH:2007.5724)	
X:	-2367840.030(m)	0.011(m)	-2367840.798(m)	0.011(m)
Y:	-3916128.495(m)	0.010(m)	-3916127.283(m)	0.010(m)
Z:	4429143.506(m)	0.017(m)	4429143.544(m)	0.017(m)
LAT:	44 15 21.58120	0.004(m)	44 15 21.59655	0.004(m)
E LON:	238 50 28.49467	0.006(m)	238 50 28.43678	0.006(m)
W LON:	121 9 31.50533	0.006(m)	121 9 31.56322	0.006(m)
EL HGT:	909.390(m)	0.022(m)	908.958(m)	0.022(m)
ORTHO HGT:	930.499(m)	0.033(m)	[Geoid03 NAVD88]	

	UTM COORDINATES UTM (Zone 10)	STATE PLANE COORDINATES SPC (3602 OR S)
Northing (Y) [meters]	4901954.724	287856.419
Easting (X) [meters]	646984.963	1447388.346
Convergence [degrees]	1.28517293	-0.45068309
Point Scale	0.99986571	1.00007516
Combined Factor	0.99972315	0.99993258

US NATIONAL GRID DESIGNATOR: 10TFQ4698501955(NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE(m)
DH4503	P376 EOLARESVR_OR2004 CORS ARP	N445628.313	W1230608.100	172073.3
AF9636	GWEN APPLETON CORS ARP	N454657.461	W1211939.167	170195.8
DG8527	ORS1 SENECA 1 CORS ARP	N440951.272	W1190331.461	168170.0

NEAREST NGS PUBLISHED CONTROL POINT

QD0847	D 478	N441529.	W1210915.	431.6

NGS OPUS SOLUTION REPORT

USER: michaels@ufl.edu
RINEX FILE: rmd2209u.07o
DATE: November 19, 2007
TIME: 20:31:12 UTC

SOFTWARE: page5 0612.06 master22.pl
EPHEMERIS: igs14376.eph [precise]
NAV FILE: brdc2090.07n
ANT NAME: ASH700936D_M NONE
ARP HEIGHT: 1.500
START: 2007/07/28 20:07:00
STOP: 2007/07/29 00:05:00
OBS USED: 9885 / 10001 : 99%
FIXED AMB: 44 / 45 : 98%
OVERALL RMS: 0.018(m)

	REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)		ITRF00 (EPOCH:2007.5724)	
X:	-2367839.450(m)	0.005(m)	-2367840.218(m)	0.005(m)
Y:	-3916132.289(m)	0.017(m)	-3916131.077(m)	0.017(m)
Z:	4429140.538(m)	0.015(m)	4429140.576(m)	0.015(m)
LAT:	44 15 21.44573	0.008(m)	44 15 21.46108	0.008(m)
E LON:	238 50 28.60552	0.008(m)	238 50 28.54763	0.008(m)
W LON:	121 9 31.39448	0.008(m)	121 9 31.45237	0.008(m)
EL HGT:	909.429(m)	0.020(m)	908.998(m)	0.020(m)
ORTHO HGT:	930.538(m)	0.032(m)	[Geoid03 NAVD88]	

	UTM COORDINATES UTM (Zone 10)	STATE PLANE COORDINATES SPC (3602 OR S)
Northing (Y) [meters]	4901950.600	287852.218
Easting (X) [meters]	646987.514	1447390.772
Convergence [degrees]	1.28519356	-0.45066202
Point Scale	0.99986571	1.00007515
Combined Factor	0.99972316	0.99993256

US NATIONAL GRID DESIGNATOR: 10TFQ4698801951(NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE(m)
DH4503	P376 EOLARESVR_OR2004 CORS ARP	N445628.313	W1230608.100	172077.4
AF9636	GWEN APPLETON CORS ARP	N454657.461	W1211939.167	170200.2
DG8527	ORS1 SENECA 1 CORS ARP	N440951.272	W1190331.461	168167.4

NEAREST NGS PUBLISHED CONTROL POINT

QD0847	D 478	N441529.	W1210915.	431.7