Contact information

Noah Snyder [noah.snyder@bc.edu]
Dept. of Geology & Geophysics
Boston College
140 Commonwealth Avenue
Chestnut Hill, MA 02467
Tel: 617-552-0839

Project: Land use, geologic and climatic controls on stream processes in northern New England using airborne laser swath mapping

1. LiDAR System Description and 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 March, 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 areas are three irregular polygons containing the watersheds of three rivers in Maine: the Sheepscot (243 square kilometers), Narragaugus (275 square kilometers) and Pleasant (265 square kilometers).

The survey polygons are shown below in Figures 1 - 3.

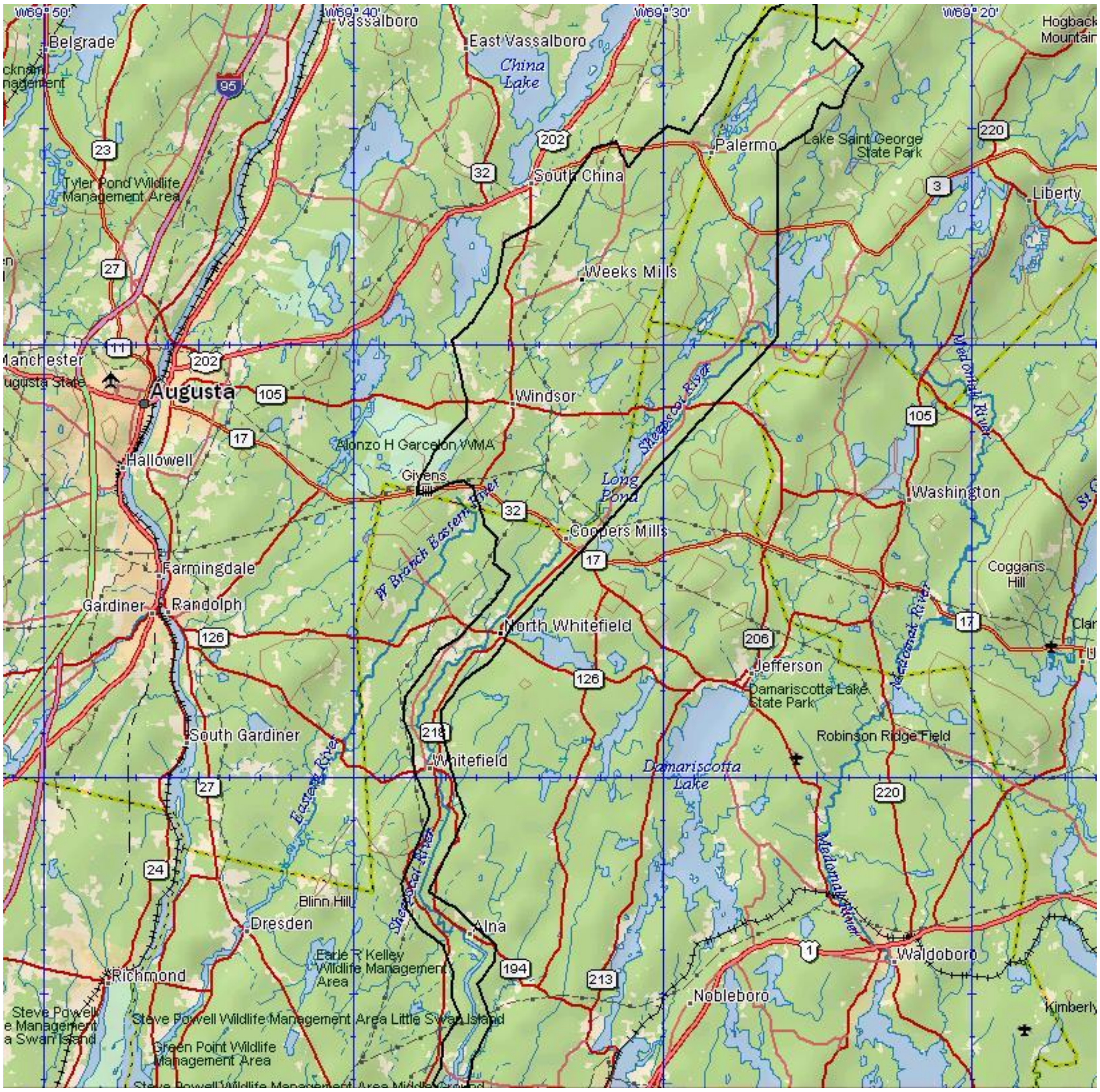

Figure 1 – Shape and location of Sheepscot River survey polygon.

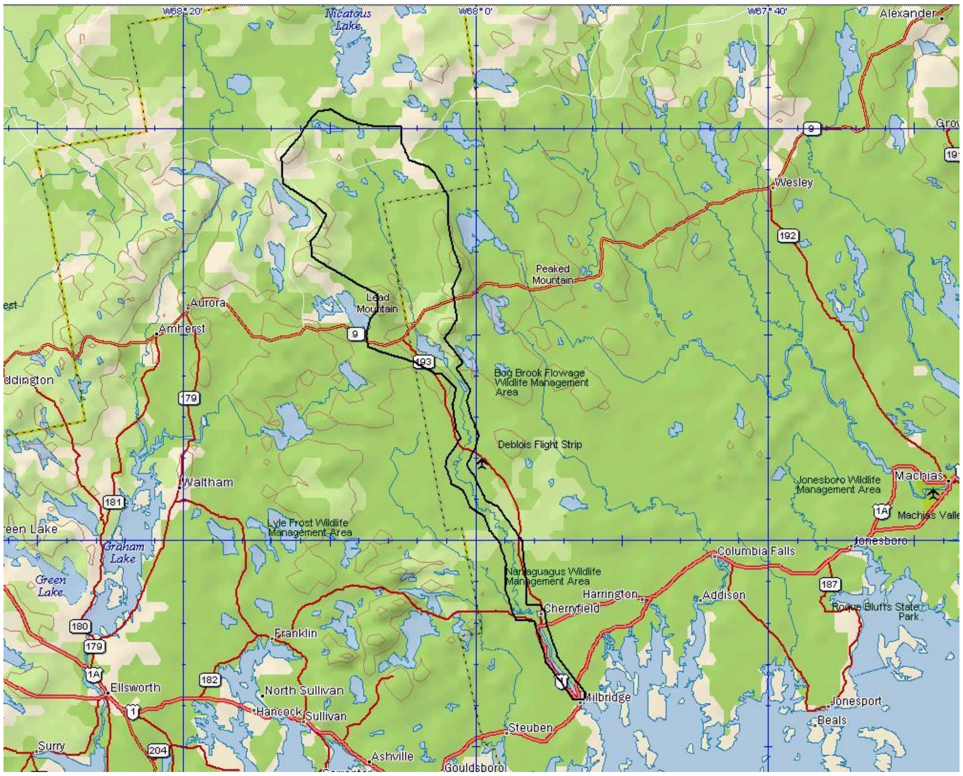

Figure 2 – Shape and location of Narragaugus River survey polygon.

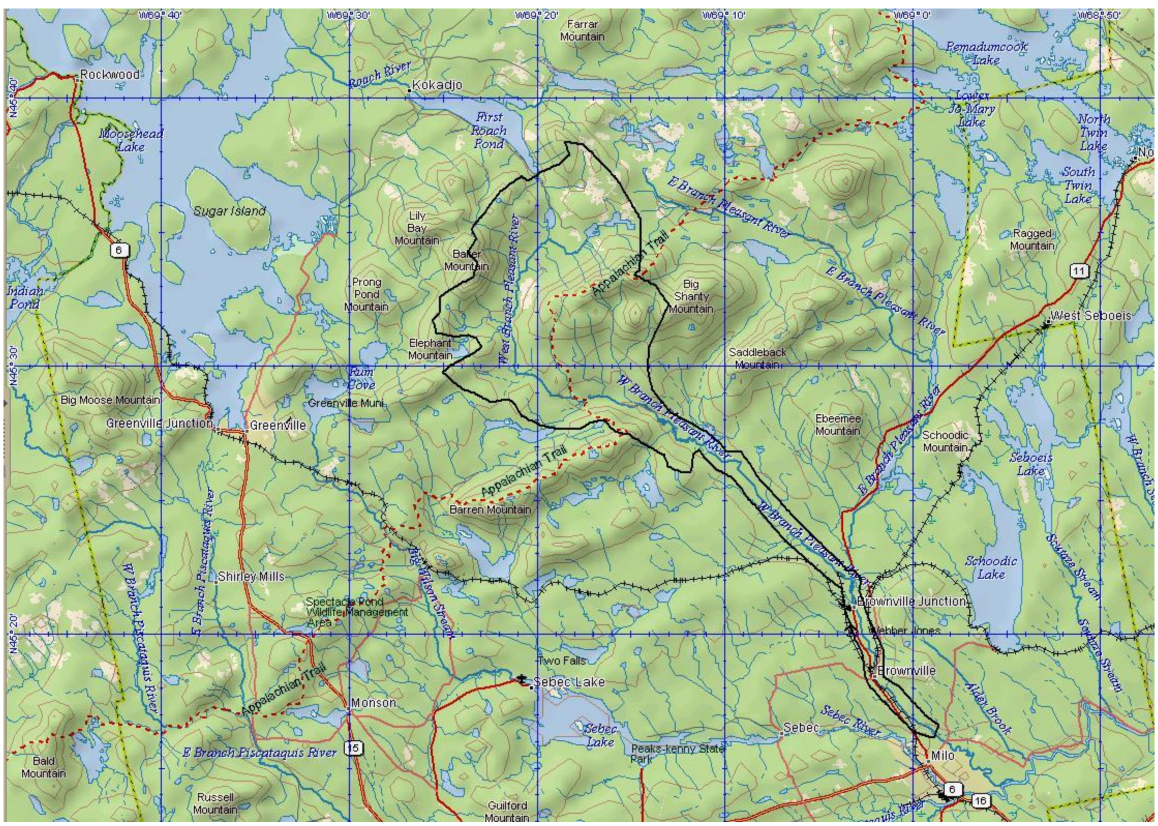

Figure 3 – Shape and location of Pleasant River survey polygon.

3. Survey Times

These areas were flown in thirteen survey flights beginning on October 31, 2007 (day-of-year 304) and were completed on November 11, 2007 (day-of-year 314).

These flights are summarized below in Table 2.

Flight #	Date	River	Start	Stop	Fly time	Laser-on
1	10/31/2007	Pleasant	16:14	19:14	3:00	0.73
2	11/2/2007	Pleasant	12:06	17:34	5:28	2.56
3	11/2/2007	Pleasant	19:15	21:59	2:44	1.17
4	11/3/2007	Pleasant	12:27	14:27	2:00	0.44
5	11/4/2007	Pleasant	19:12	21:38	2:26	0.72
6	11/5/2007	Pleasant	13:12	16:16	3:04	1.10
7	11/7/2007	Sheepscot	14:28	20:20	5:52	2.90
8	11/7/2007	Sheepscot	20:54	22:40	1:46	0.57
9	11/8/2007	Sheepscot	13:05	17:24	4:19	1.34
10	11/9/2007	Narragaugus	15:07	18:40	3:33	1.69
11	11/9/2007	Narragaugus	19:26	22:50	3:24	1.47
12	11/10/2007	Narragaugus	13:33	16:02	2:29	0.82
13	11/11/2007	Narragaugus	13:24	18:12	4:48	2.62
				TOTAL	44.53	18.13

Table 2 – Flight dates and times (GMT) Fly time and laser-on are hours:minutes.

4. Survey Parameters

The Sheepscot survey required 63 flight lines, shown below in Figure 4.

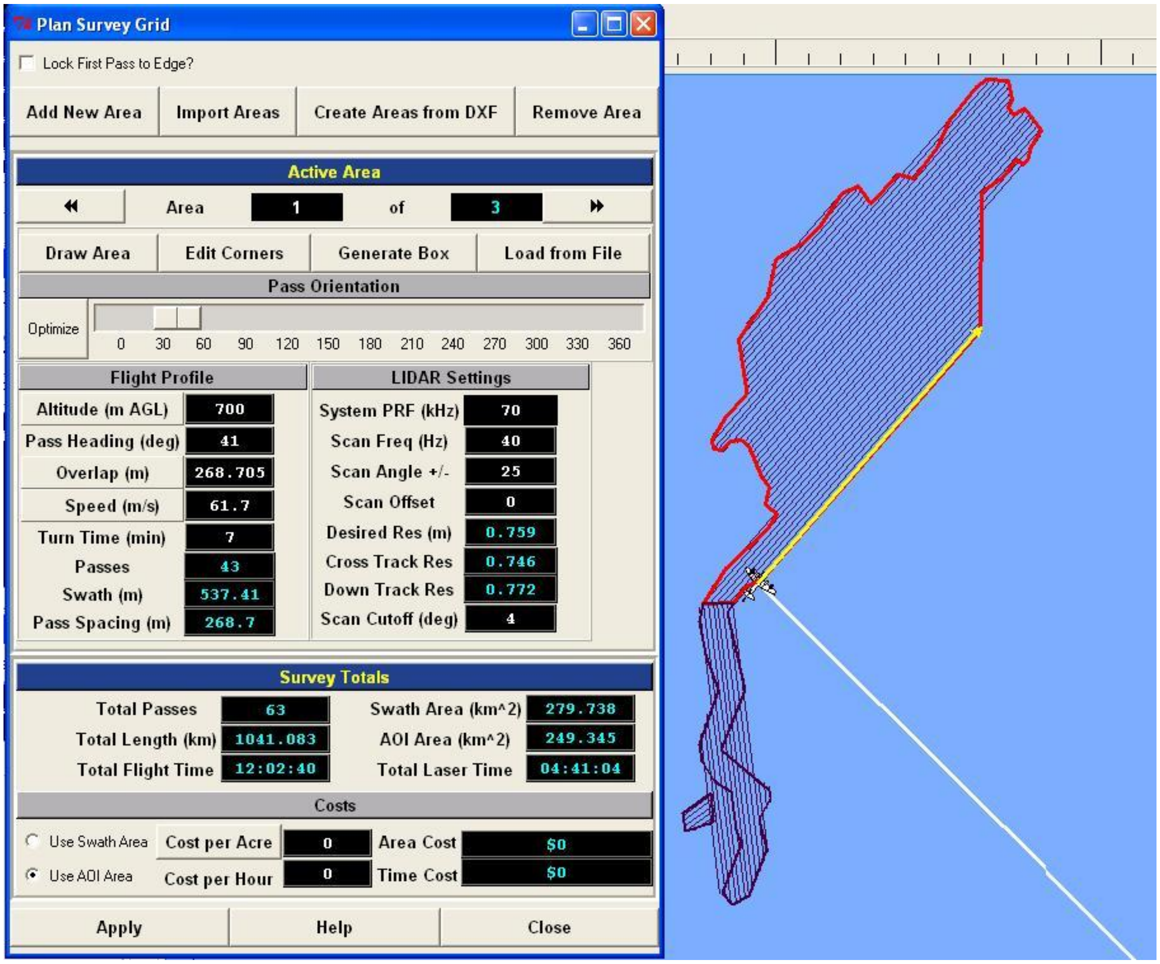

Figure 4. Flight lines for the Sheepscot survey, including the small add-on

Survey parameters are also shown above in Figure 4. Note that the swath width of a single pass averaged 537.41 meters, and that line spacing was planned at 268.7 meters. Planned overlap was also 268 meters: all of the ground area is covered with shots from at least 2 different swaths.

Below in Figure 5 are the flight lines for Narragaugus.

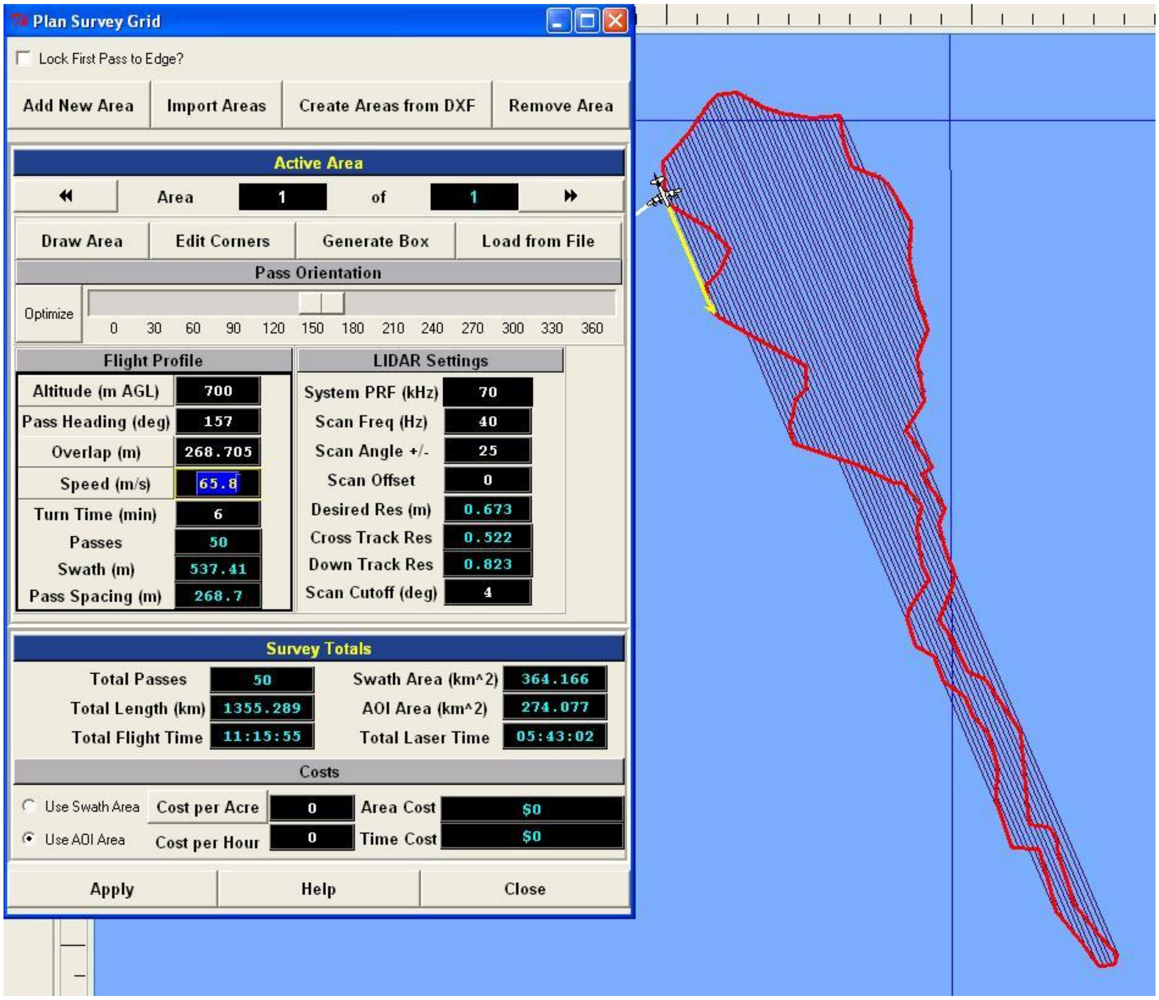

Figure 5 Narragaugus flight lines and survey parameters.

Below in Figure 6 are the flight lines and survey parameters for the Pleasant River.

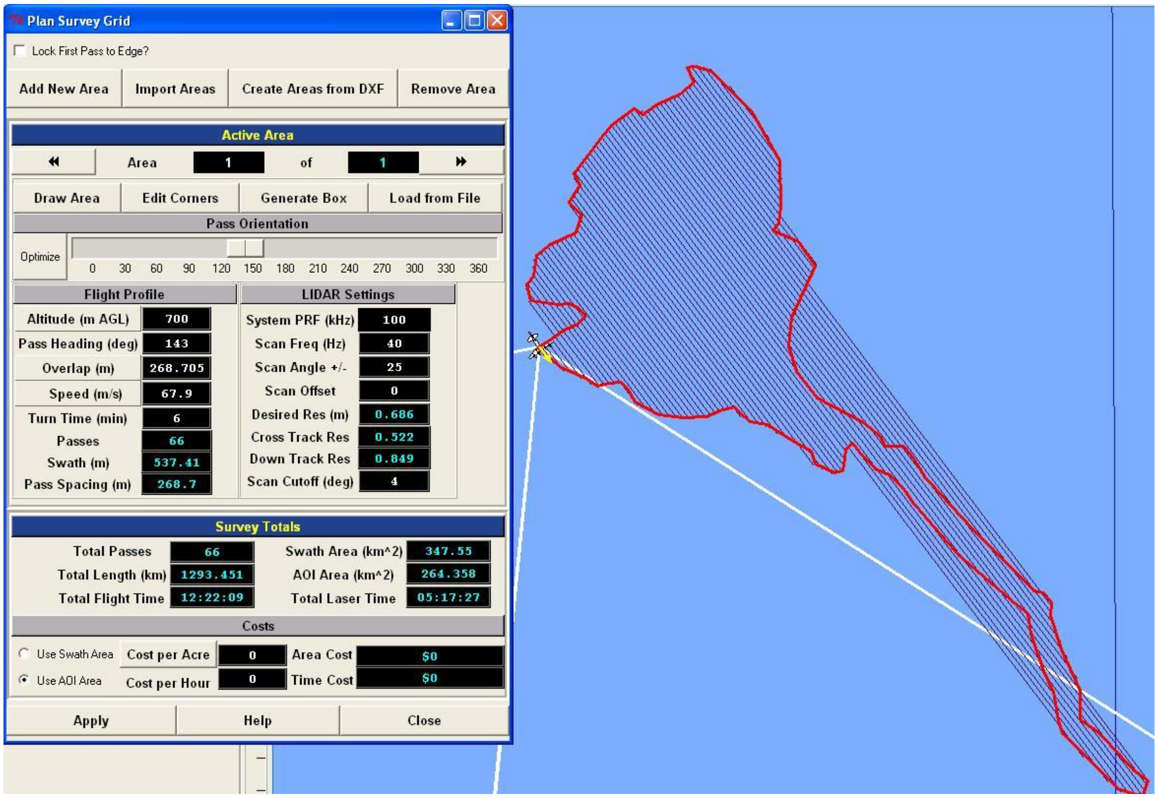

Figure 6 - Pleasant River flight lines and Survey parameters.

The southern portion of this watershed was flown first, and when completed, the heading of the remaining lines was adjusted to increase efficiency. The northern portion of the plan is shown below in Figure 7.

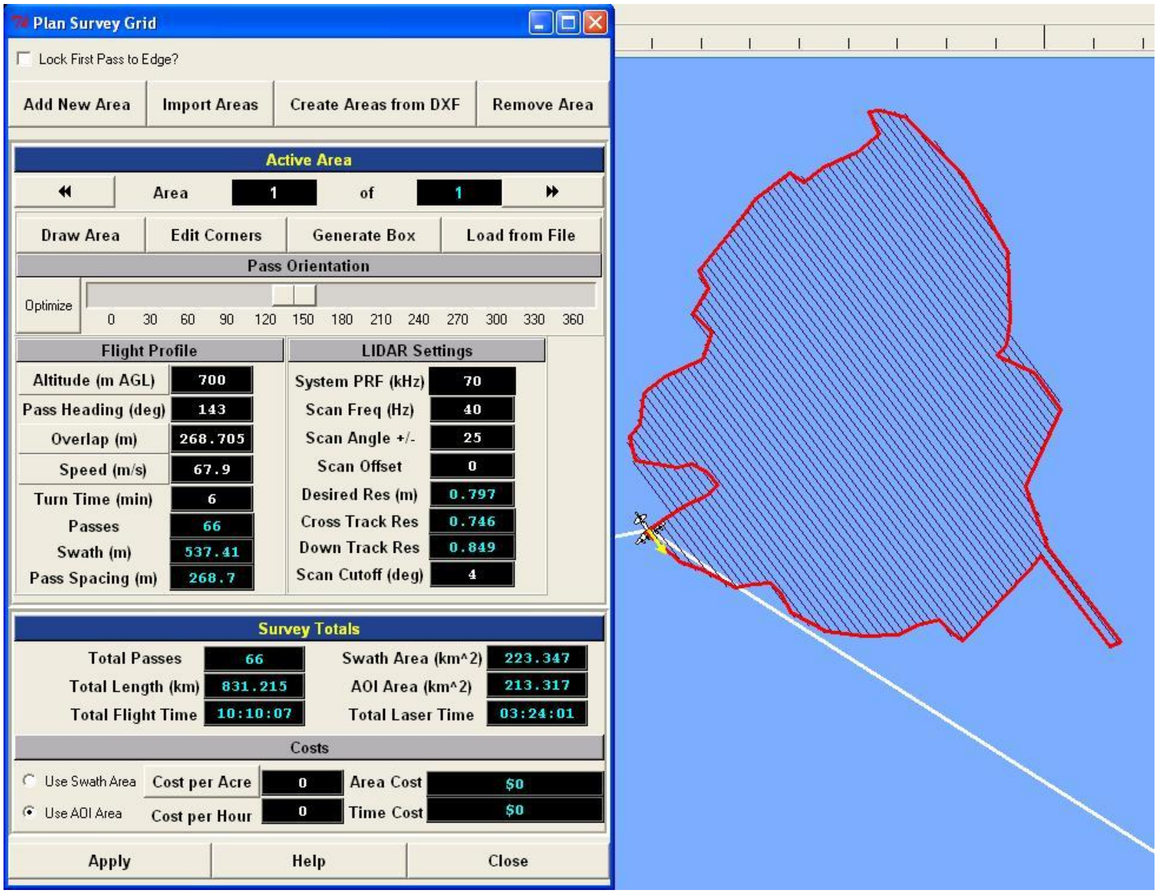

Figure 7 - Flight lines for the northern portion of the Pleasant River survey.

Survey totals for the entire project appear below in Table 3.

Survey Totals	
Total Passes	179
Total Length	3689 km
Total Swath Area	991 km^2
Total AOI Area	788 km^2

Table 3 – Project survey totals. Area of Interest is abbreviated AOI.

LiDAR settings are shown in Table 4.

LiDAR Settings	
Desired Resolution	0.635m
Cross Track Resolution	0.499 m
Down Track Resolution	0.772 m
Scan Frequency	40 Hz
Scan Angle	+/- 24 deg
Scan Cutoff	+/- 4.0 deg
Scan Offset	0 deg
System PRF	100 kHz
Swath Width	509.56 m

Table 4 – LiDAR settings.

Beam divergence was set at the narrow setting for all flights in order to utilize full laser power. The UF Gemini has since been adjusted (December 2007- January 2008) to allow full power on the broad divergence setting as well.

5. GPS Reference Stations

A total of seven GPS reference station locations were used for the three surveys. Two GPS reference stations for the Sheepscot survey, both located at the Augusta airport. A pair of GPS reference stations was used for the Pleasant survey, both located at the Greenville airstrip. Finally three reference stations were used for the Narragaugus survey: one at the airstrip in Trenton, ME, another on-site at the Deblois flight strip, and the third station being the CORS BARH at Bar Harbor.

All of these stations (except the CORS) were set by the field crew then occupied and observed by GPS for the days of each survey. All GPS observations were logged at a 1 Hz and daily sessions averaging approximately ten hours were submitted to the NGS on-line processor OPUS which processes static differential baselines tied to the National CORS network. The repeat OPUS solutions yielded reference station solutions with positional differences of less than 2 cm in both horizontal and vertical components. Final coordinates for these reference stations were calculated as a weighted average 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/ .

Reference station coordinates appear below in Table 5.

Station	X	Y	Z	Latitude			Longitude			Height
3B1-	1565456.140	-4198831.188	4524044.862	45	27	54.79343	69	33	10.67381	400.969
3B1_	1565456.359	-4198834.533	4524041.617	45	27	54.64558	69	33	10.71815	400.908
AUG-	1578788.246	-4289556.320	4433544.335	44	19	6.94544	69	47	37.18065	80.080
AUG_	1578784.435	-4289559.710	4433542.409	44	19	6.85859	69	47	37.39488	80.069
BHB_	1681660.656	-4239662.794	4443507.148	44	26	41.30650	68	21	51.35852	-6.490
BARH	1693645.537	-4239069.007	4439567.286	44	23	42.13778	68	13	18.08017	7.920
43B_	1701455.775	-4208338.856	4465609.540	44	43	25.20459	67	59	10.43221	39.246

Table 5 – GPS reference station coordinates.

Ground equipment 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 integrated GPS receiver module Trimble BD950, logging at 10 Hz.

6. Navigation Processing

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 determine a fixed integer ionosphere-free differential solution. Trajectories for each flight were processed separately using all of the reference stations that logged data during the survey and then coordinate differences between the solutions were plotted. Figure 8 (below) is a plot typical of the differences in Easting, Northing, and Height of two trajectories and is taken from flight 7 on November 07, 2007.

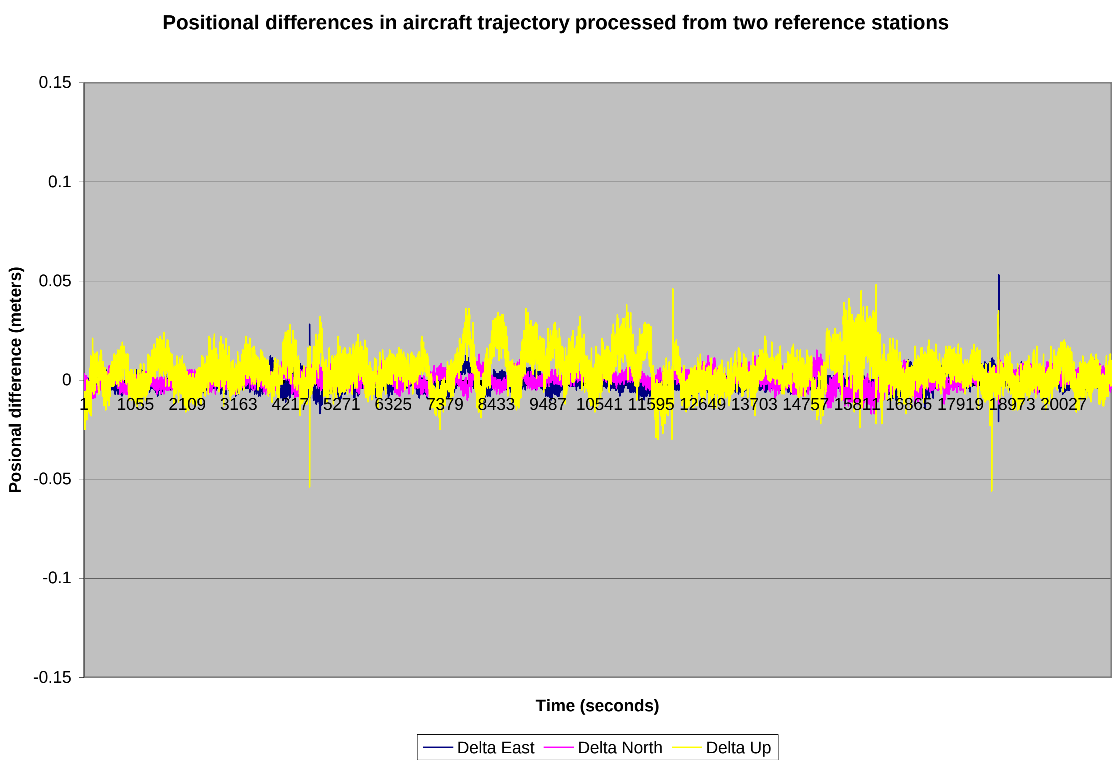

Figure 8 - Positional differences in aircraft trajectories with respect to time as processed from AUG- and AUG_.

The standard deviation of the differences in the easting position of these two trajectories is 3 mm, in northing 3 mm, and in height 9 mm.

After GPS processing, the trajectory and the inertial measurement unit (IMU) data collected during the flight 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 navigation 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 program to generate the laser point dataset in LAS format.

7. Calibration, Validation, and Accuracy Assessment

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

Relative calibration was done for each flight 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 every flight: values for height disagreements between individual flight line surfaces ranged from a high of 9 cm to a low of 3 cm. Individual swath height disagreements averaged approximately 5 cm. Below is TerraMatch report from the flight of November 8, 2007.

```
Starting average dz:    0.0395
Final average dz:       0.0260

Standard error of unit  0.0119

Execution time: 358.3 sec
Number of iterations: 13

Points        1016331
H shift       +0.0192    Std dev  0.0007
R shift       -0.0120    Std dev  0.0002
P shift       -0.0017    Std dev  0.0004
Scale        +0.00032
```

Below is the text report from TerraMatch from the last of the 13 flights.

```
Starting average dz:    0.0671
Final average dz:       0.0510

Standard error of unit  0.0228

Execution time: 1086.4 sec
Number of iterations: 10

Points        3539042
H shift       +0.0016    Std dev  0.0005
R shift       -0.0173    Std dev  0.0001
P shift       +0.0184    Std dev  0.0002
Scale        +0.00006
```

These results are typical for all of the flights.

Absolute calibration was done by establishing a check points surveyed with vehicle-mounted GPS over sections of road near the project airports. These sections of road were then surveyed with crossing flight lines using the ALTM. This procedure was repeated for each of the 13 flights. 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 hard surfaces. The aircraft maintained a flying height of approximately 700 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 from all thirteen flights. Over 2700 check-point-to-LiDAR-point differences were computed and the average difference was 20 mm. The standard deviation of these differences was 41 mm. It is reasonable to use this standard deviation as a vertical accuracy assessment (1-sigma) to similar hard surfaces on the project polygon.

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 269000 through 270000, and northing equals 4947000 through 4948000 then the tile filename is 269000_4947000.

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.

9. Filtering

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 the Pleasant River 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

Run again with these parameters:
Max Count (maximum size of a group of low points): 6
More than (minimum height difference): 0.3 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 avoid adding unnecessary points to 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
Iteration Angle: 8.0
Iteration Distance: 1.4 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.

Below Surface classification parameters used:
Source Class: Ground
Target Class: Low Point
Limit: 4.00 * standard deviation
Z tolerance: 0.10 m

Filter macros have been saved and available for review.