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Title: Linking biogeochemical and hydrological perspectives to model coastal plain wetland ecosystems

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). See http://www.optech.ca/prodaltm.htm for information from the manufacturer.

Gemini ALTM System specifications appear below in Table 1, and also here: http://www.optech.ca/pdf/Brochures/ALTM-GEMINI.pdf

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.

2. Survey area

The survey area is an irregular polygon east from Columbia, NC and enclosing 21 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 18, 2008 = day-of-year 323.

4. Survey Parameters

The survey required 23 flight lines, shown below in Figure 2.

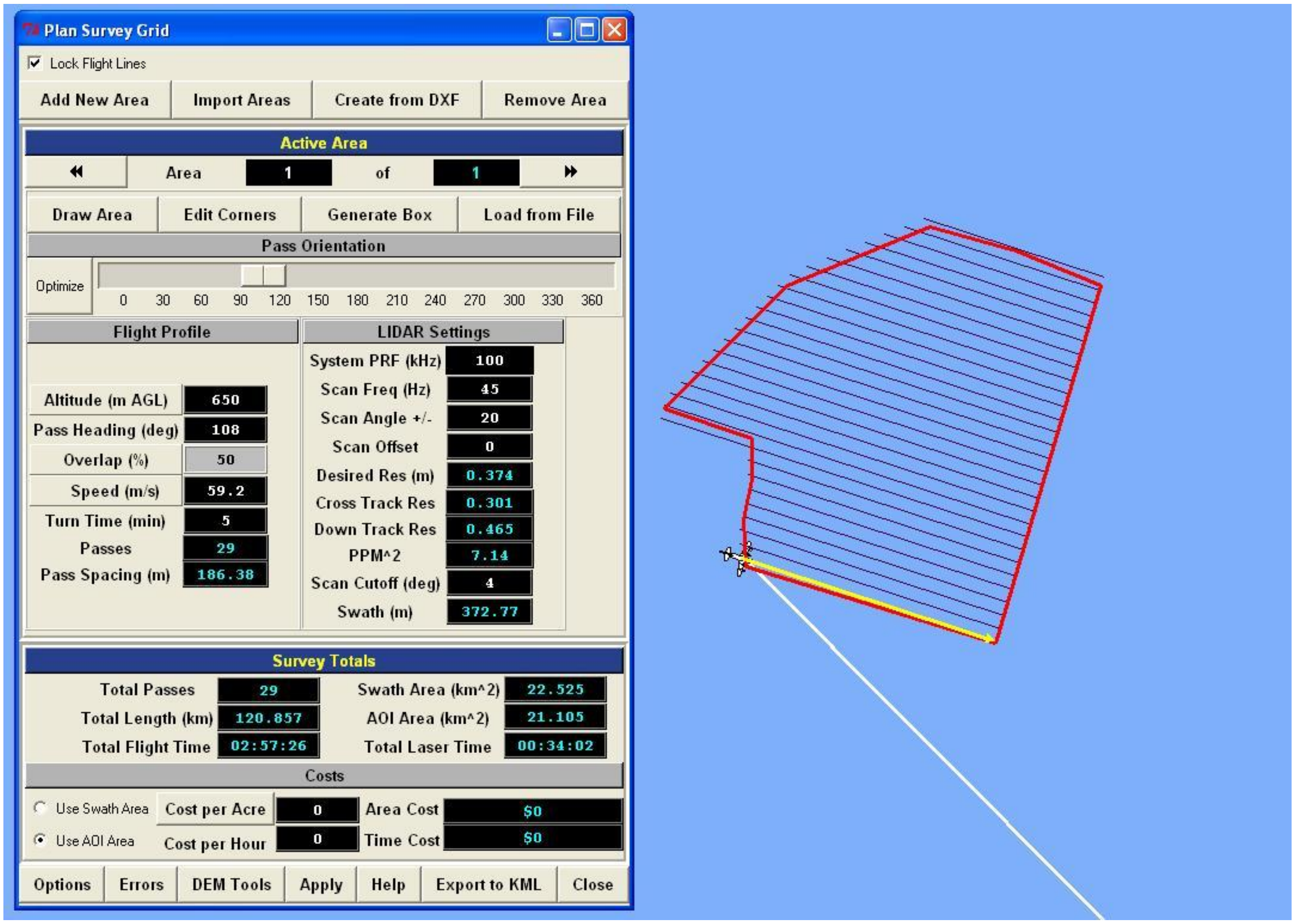

Figure 2 - Flight lines with planning parameters.

Survey totals appear below in Table 3.

Survey Totals	
Total Passes	23
Total Length	120.9 km
Total Flight Time	04:05:00
Total Laser Time	00:53:40
Total Swath Area	22.5 km^2
Total AOI Area	21.1 km^2

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

LiDAR settings are shown in Table 4.

LiDAR Settings	
Desired Resolution	0.37 m
Cross Track Resolution	0.30 m
Down Track Resolution	0.46 m
Scan Frequency	45 Hz
Scan Angle	+/- 20 deg
Scan Cutoff	+/- 4.0 deg
Scan Offset	0 deg
System PRF	100 kHz
Swath Width	372.8 m

Table 4 – LiDAR settings.

Point density averaged approximately 10 points per square meter.

5. GPS Reference Stations

Three GPS reference station locations were utilized during the survey, two of them Continuously Operating Reference Stations (CORS see http://www.ngs.noaa.gov/CORS/). The CORS used were (1) NCDU located 47 Km NE of the project in Duck, NC; and (2) NCPI located 68 Km SE of the project on Pea Island, NC. The third reference station (named MAN_) was set by NCALM at the Dare County Regional Airport, 42 KM east of the project. GPS observations at all three reference locations were logged at 1 Hz and the observations from MAN_ 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 MAN_ were determined from the OPUS solution; the two CORS have published values. For more information on OPUS see http://www.ngs.noaa.gov/OPUS/ . The airborne GPS receiver is an integrated BD-950 Trimble GPS receiver module logging at 10 Hz.

6. Navigation Processing and Calibration

Kinematic differential GPS solutions for the aircraft trajectory were processed using KARS software (Kinematic and Rapid Static) written and run 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. Dr Mader used his KARS software to process kinematic aircraft trajectories from all three reference stations: MAN_, NCDU, and NCPI, then combined the solutions using a weighting scheme based on their RMS.

Average PDOP during the flight was 2.2; and the RMS of the solution averaged 21 millimeters: these values give a high confidence of a good quality solution.

After GPS processing, the 1 Hz differential trajectory and the 200 Hz Inertial Measurement Unit (IMU) data collected during the flight were input into APPLANIX software PosPAC MMS (see http://www.applanix.com/products/airborne/pospac-mms.html) These software suites use processing algorithms which 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 (roll, pitch, and heading) at 200 Hz. This final solution is known as the SBET (Smoothed Best Estimated Trajectory). See http://www.applanix.com/media/downloads/products/specs/posav_specs.pdf for more information from the manufacturer.

The SBET and the raw laser range data were combined using Optech's DashMap (http://www.optech.ca/pdf/Brochures/DASHMap.pdf) processing suite to generate the laser point cloud, flightline by flightline in LAS format.

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 were less than 7 cm.

Below is the TerraMatch report from this flight.

```
Starting average dz:     0.0673
Final average dz:        0.0669

Standard error of unit   0.0299

Execution time: 96.0 sec
Number of iterations: 5

Points        1507904
H shift       +0.0014    Std dev   0.0006
R shift       -0.0004    Std dev   0.0002
P shift       -0.0018    Std dev   0.0002
Scale        -0.00063
```

Absolute calibration was done by establishing a calibration site consisting of over 100 check points surveyed with vehicle-mounted GPS on Highway 12 adjacent to the Pea Island CORS. The highway 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 100 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 47 mm (1-sigma).

8. Laser Point Processing

All coordinates were processed with respect to NAD83 and referenced to the national CORS network. The projection is UTM Zone 18, 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 394000 through 395000, and northing equals 3975000 through 3976000 then the tile filename is 394000_3975000. This is illustrated below in Figure 4.

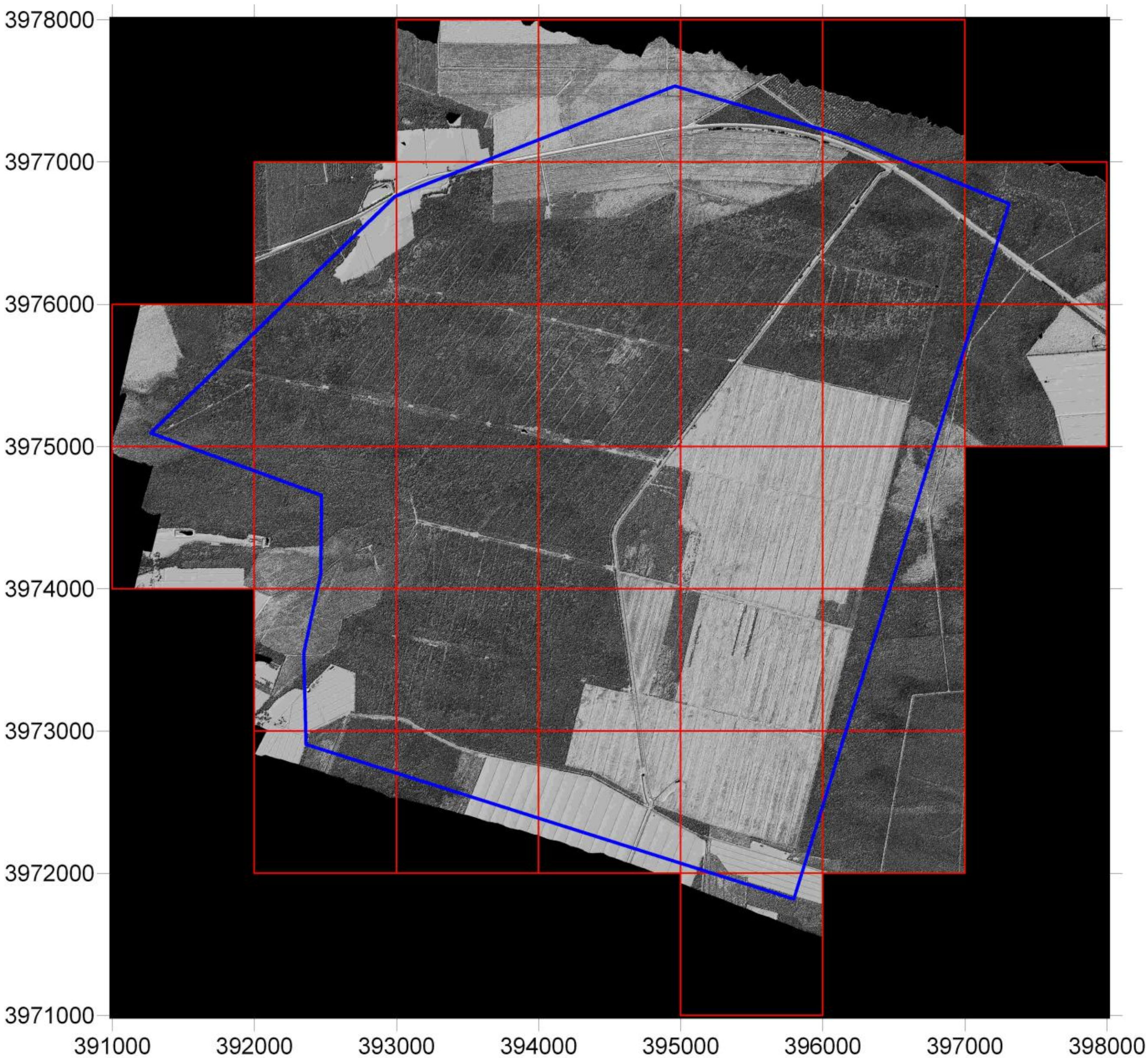

Figure 4 - Tile footprints overlaid onto a shaded relief image of the DEM. Tile foot prints are in red, the survey polygon is in blue.

These tile footprints are available as an AutoCAD DXF or ESRI shape file. The project totaled 34 tiles and is in LAS format (see http://liblas.org/raw-attachment/wiki/WikiStart/asprs_las_format_v11.pdf). Software tools for working with LAS format can be found here - http://www.cs.unc.edu/~isenburg/lastools/ among other places.

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. Classification and DEM Production

TerraSolid's TerraScan (http://cdn.terrasolid.fi/TerraScan_eng_2.pdf) software was used to classify the ground points from the LiDAR points and generate the "bare-earth" dataset.

The classification routine consists of following algorithms:

1) Removal of Isolated Points: Isolated points routine classifies points which do not have very many other points within a 3Dsearch radius. This routine is useful for finding isolated points up in the air or below the ground. Parameters used for this routine were:

```
Fewer than: 1 point
Within: 5m
```

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: 6.0
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: 3.00 * standard deviation
Z tolerance: 0.10 m
```

Digital Elevation Models were produced at 1.0 meter spacing for all areas from last stop elevations using SURFER (Golden Software) Version 8.04. See http://www.goldensoftware.com/products/surfer/surfer.shtml

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.

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