Project Name: Wax Lake Delta, Louisiana

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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).

Operating Altitude	150 - 4000 m, Nominal
Horizontal Accuracy	1/5,500 x altitude (m AGL); 1 sigma
Elevation Accuracy	5 - 30 cm; 1 sigma
Range Capture	Up to 4 range measurements, including 1st, 2nd, 3rd, last returns
Intensity Capture	12-bit dynamic range for all recorded returns, including last returns
Scan FOV	0 - 50 degrees; Programmable in increments of ±1degree
Scan Frequency	0 – 70 Hz
Scanner Product	Up to Scan angle x Scan frequency = 1000
Roll Compensation	±5 degrees at full FOV – more under reduced FOV
Pulse Rate Frequency	33 - 167 KHz
Position Orientation System	Applanix POS/AV 510 OEM includes embedded BD950 12-channel 10Hz GPS receiver
Laser Wavelength/Class	1047 nanometers / Class IV (FDA 21 CFR)
Beam Divergence nominal (full angle)	Dual Divergence 0.25 mrad (1/e) or 0.80 mrad (1/e)

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 20 km SSE of Patterson, LA enclosing approximately 210 square kilometers. The survey polygon is shown below in Figure 1.

Figure 1 – Shape and location of survey polygon (Google Earth).

3. Survey Times

This survey was flown in two survey flights: one on January 14, 2009 (day-of-year 014), and one flight on January 15 (015). The survey required a total of 4.5 hours of laser-on time and 9.5 hours of total flying time. The flight dates and times were chosen by the team at the University of Texas in an attempt to obtain the best tidal and wind conditions for the survey: NCALM performed this survey per these instructions.

The individual flights are summarized below in Table 2.

Flight #	Date	Local Time Begin	Local Time End	Laser-On Time
1	14-Jan-08	9:03	13:56	2.32 hours
2	15-Jan-08	12:46	17:23	2.20 hours

Table 2 – Flight dates and times.

Local time is CST (Central Standard Time) is GMT – 6.0 hours.

4. Survey Parameters

The survey required 56 flight lines shown below in Figure 2. Line 1 is the most northerly line (shown in yellow).

Flight one (Jan 14): beginning in the northwest corner, lines 1-27 were flown in numerical order. Low tide at Rabbit Island was 10:30 CST, high tide at 19:31 CST.

Flight two (Jan 15) beginning in the southeast the lines were flown in reverse numerical order 56 – 28. Low tide was at 11:20 CST, high tide at 19:53 CST.

Point density over land (no water) averaged approximately 4.5 points per square meter; point density over water was variable and much less: between approximately 1 and 1.5 points per square meter. This is due to off-nadir shots on water yielding no return or yielding a return of extremely high or low energy. Very high (above 2500) and very low (below 11) intensity shots were filtered out to improve DEM quality.

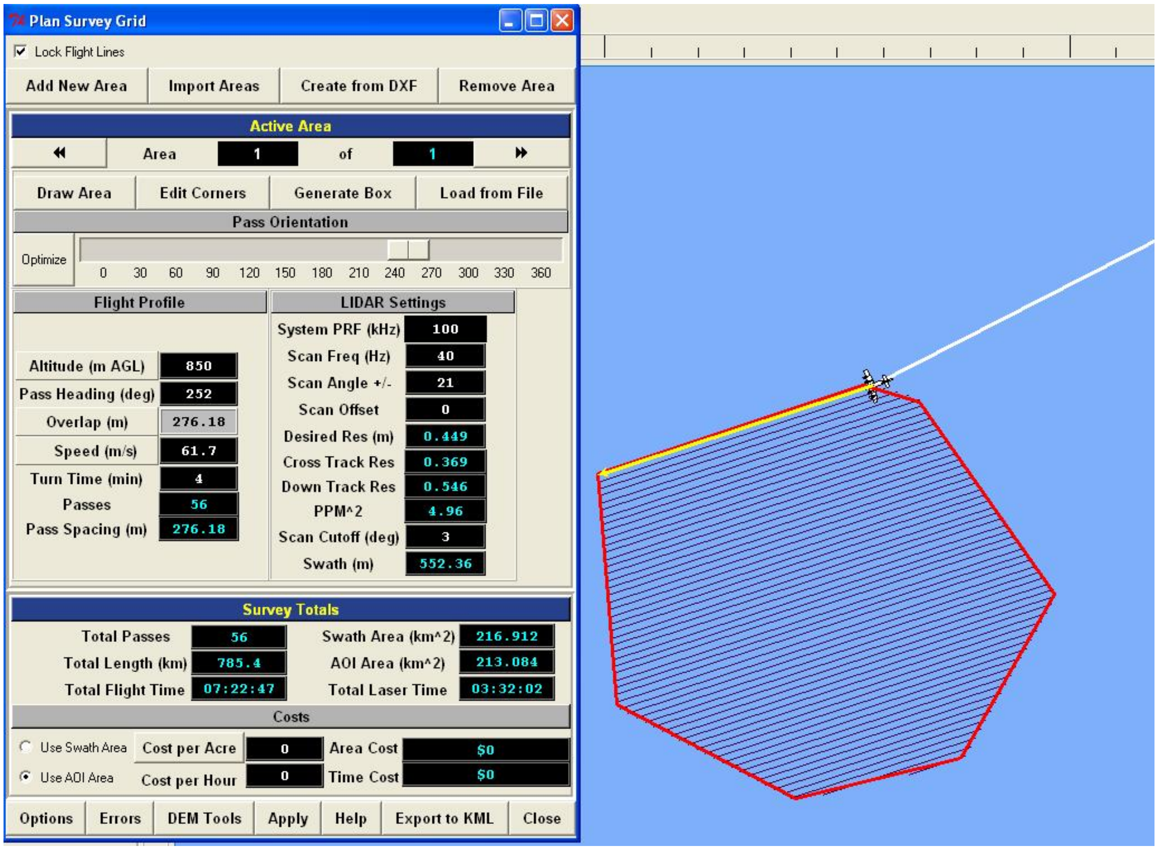

Figure 2. Flight Lines 1 (shown in yellow) through 56.

Survey parameters are also shown above in Figure 2. Note that the swath width of a single pass is 552.36 meters (nominal), and that line spacing was planned at 276 meters.

Planned overlap was 100% (50% side-lap) or 276 meters per swath. Pulse rate frequency was set at 100 KHz.

Survey totals appear below in Table 3.

Survey Totals	
Total Passes	56
Total Length	785.4 km
Total Flight Time	9.5 hrs
Total Laser Time	4.5
Total Swath Area	216.9 km^2
Total AOI Area	213.1 km^2

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

LiDAR settings are shown in Table 4.

LiDAR Settings	
Scan Frequency	40 Hz
Scan Angle	+/- 21 deg
Scan Cutoff	+/- 3.0 deg
Scan Offset	0 deg
System PRF	100 kHz
Swath Width	552.36 m

Table 4 – LiDAR settings.

In summation, the point density was much higher over land than over water. Scan frequency was held to 40 Hz and the scan angle limited to +/- 21 degrees yielding a scan product (frequency x angle) of 840, or about 84% of system limits.

5. GPS Reference Stations

Two GPS reference station locations were used during the survey, both of which were newly established NCALM stations at the Harry P Williams Memorial Airport in Patterson. These two stations were given point IDs of PTN_ and PTN0.

All reference GPS observations were logged at 1 Hz. Reference coordinates for the two NCALM stations are derived from two 5-hour observation sessions submitted to the NGS on-line processor OPUS which processes static differential baselines tied to the National CORS network. The repeat OPUS solutions for stations PTN_ and PTN0 yielded reference station coordinate solutions with differences less than 0.010 meters in both horizontal and vertical components. 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/ .

Ground equipment consisted of ASHTECH (Thales Navigation) Z-Extreme receivers, with choke ring antennas (Part# 700936.D) mounted on 1.3-meter fixed-height tripods. The airborne receiver is an integrated GPS receiver module Trimble BD950, logging at 10 Hz. See Appendix B for the OPUS solutions of stations PTN_ and PTN0 occupations.

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.

The aircraft trajectories for the survey flights on both days were processed separately using PTN_ and PTN0 reference stations and then positional differences between the separate solutions were plotted. Figure 3 (below) is a plot of the differences in Easting, Northing, and Height of the Jan 15 flight trajectory processed from the two different reference stations (PTN_ and PTN0).

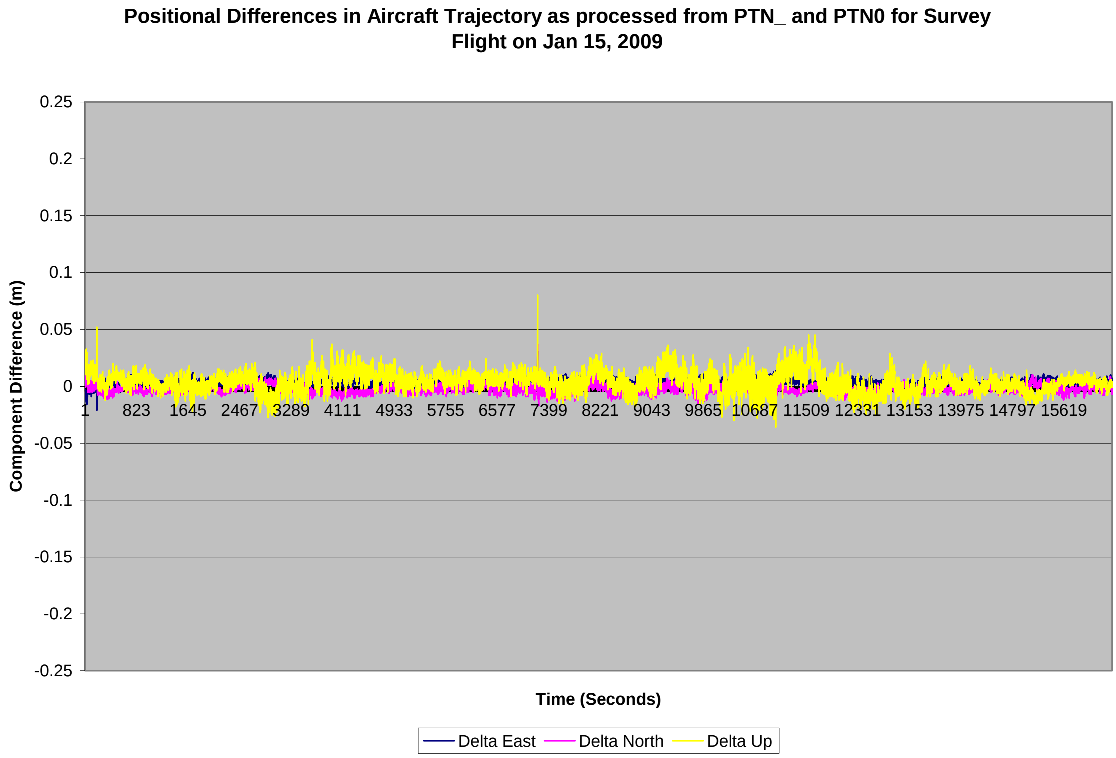

Figure 3 - Positional differences in aircraft trajectories with respect to time as processed from PTN_ and PTN0

The standard deviation of the differences in the easting position of these two trajectories is 3 mm, in northing 4 mm, and in height 9 mm. Aircraft trajectory position files are available in ASCII format, 4-columns, GPS Time (Seconds of the week); Easting; Northing; Height. These aircraft trajectory files will be sent by e-mail if requested.

After GPS processing, the trajectory and the inertial measurement unit (IMU) data collected during the flight were input into APPLANIX software POSPac MMS (Mobile Mapping Suite) (Version 5.2) 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 (Version 3.005) 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 attempted for each flight by surveying crossing flight-lines over the Patterson Airport and using TerraMatch software (http://www.terrasolid.fi/en/products/4). TerraMatch usually 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.

But on this project TerraMatch failed because the very flat terrain yielded weak solutions. Calibration was therefore done manually and was very time-consuming. The strategy employed was two-fold: (1) to extract a strip of near-nadir points from one flight strip and use it as “truth” by differencing across a perpendicular strip; and (2) to analyze water profiles and adjust the calibrations to obtain the flattest possible (and least noisy) profiles. This process eventually yielded the final point cloud.

Absolute calibration was done by establishing a calibration site consisting of 954 check points surveyed with vehicle-mounted GPS over 1.3 kilometers of paved surfaces on SR 182 near the Patterson Airport. The section of road containing these check points was then surveyed with crossing flight lines using the ALTM. This was repeated on each of the two survey flights. After comparing the heights of the check points with their nearest neighbor LiDAR shot a systematic height bias (approximately 20 cm) was calculated and removed by applying a range correction calibration parameter during processing.

The heights of over 700 LiDAR shots were compared with the height of their nearest-neighbor check point on the calibration surfaces over all of the 5 survey flights. The standard deviation of these height differences was consistent and averaged 0.055 meters.

Absolute calibration analysis can also yield an accuracy assessment for hard surfaces. The aircraft maintained a flying height of approximately 800 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. It is reasonable to use this standard deviation (0.055 meters) calculated for the calibration site 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 15, 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 652000 through 653000, and northing equals 3265000 through 3266000 then the tile filename is 652000_3266000. This is illustrated below in Figure 4.

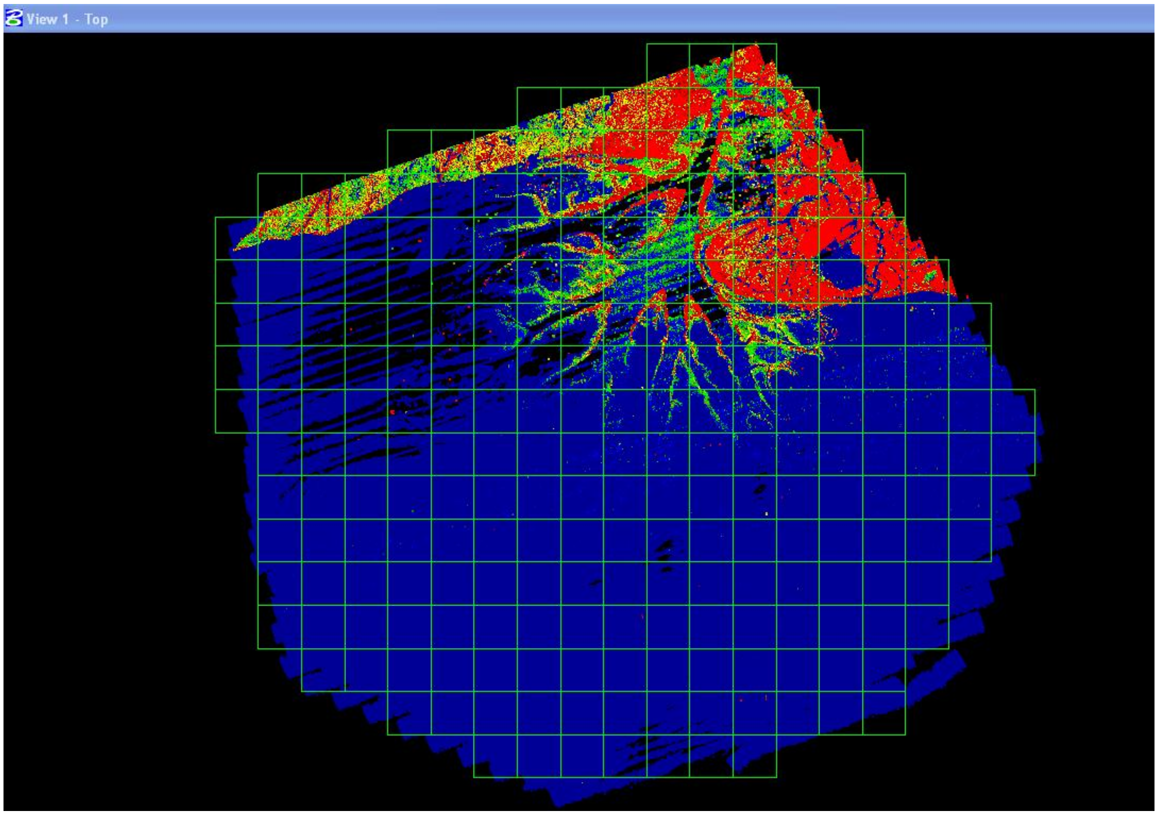

Figure 4 - Tile footprints overlaid on the point cloud colored by elevation.

These tile footprints are available as an AutoCAD DXF or ESRI shape file. The project totaled 241 tiles.

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 the following two algorithms:

1) Removal of isolated points. This routine removes points that have no close neighbors (within 5 meters).

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.

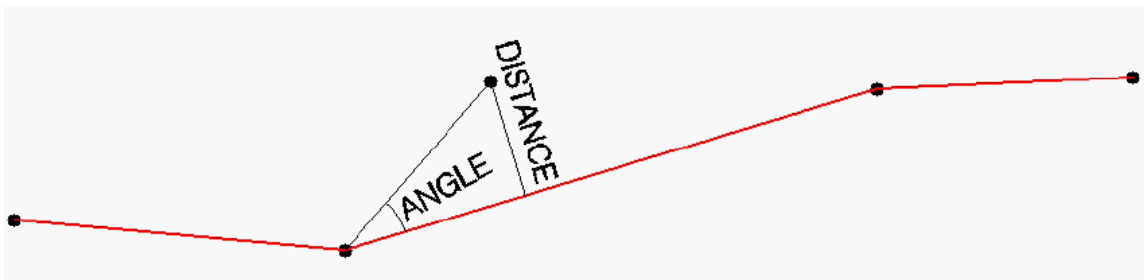

Figure 5 – Ground classification tuning parameters

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: 89.5
Iteration Angle: 6.0
Iteration Distance: 1.4 m

Please note that the bare-earth filtering algorithm is not designed to distinguish between water and ground surfaces. As a result, the noisy returns off the water surface are also mostly present in the "filtered" point dataset.

10. Ground coverage analysis

In order to better asses the quality of the laser shots that hit the ground surface our team used aerial photography to guide the differentiation between water and land areas. Unfortunately the best color, high resolution aerial coverage available to us at the time of the analysis was from a NAIP survey in 2005, which does not describe the water-land interface at the exact time of the survey. This image also covers only the northern half of the project area.

That being said, the match between the lidar data and the 2005 aerial photography is extremely high in many parts of the survey area and we believe this to be a very useful procedure in determining the lidar data quality over land. A selection of these images is included below and the full resolution maps are provided on the data DVDs.

The composite images were produced in Photoshop by determining a mask for the water area based on various shades of blue and extracting that mask from the overlayed shaded relief images of the unfiltered and filtered LiDAR DEMs.

[Images following on the next page]

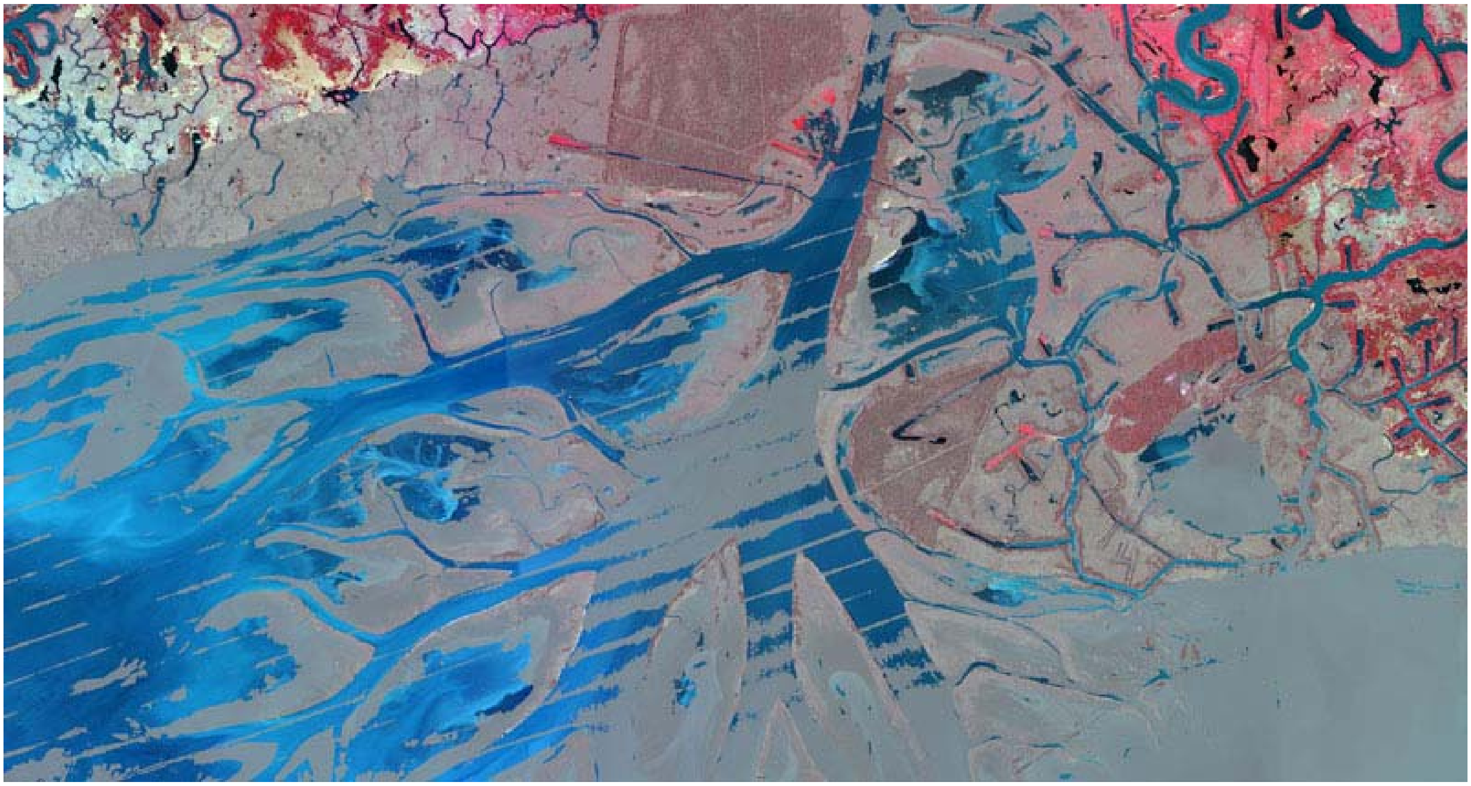

Figure 6 – Unfiltered LiDAR shaded relief map (20% transparency) overlayed on top of the 2005 aerial image.

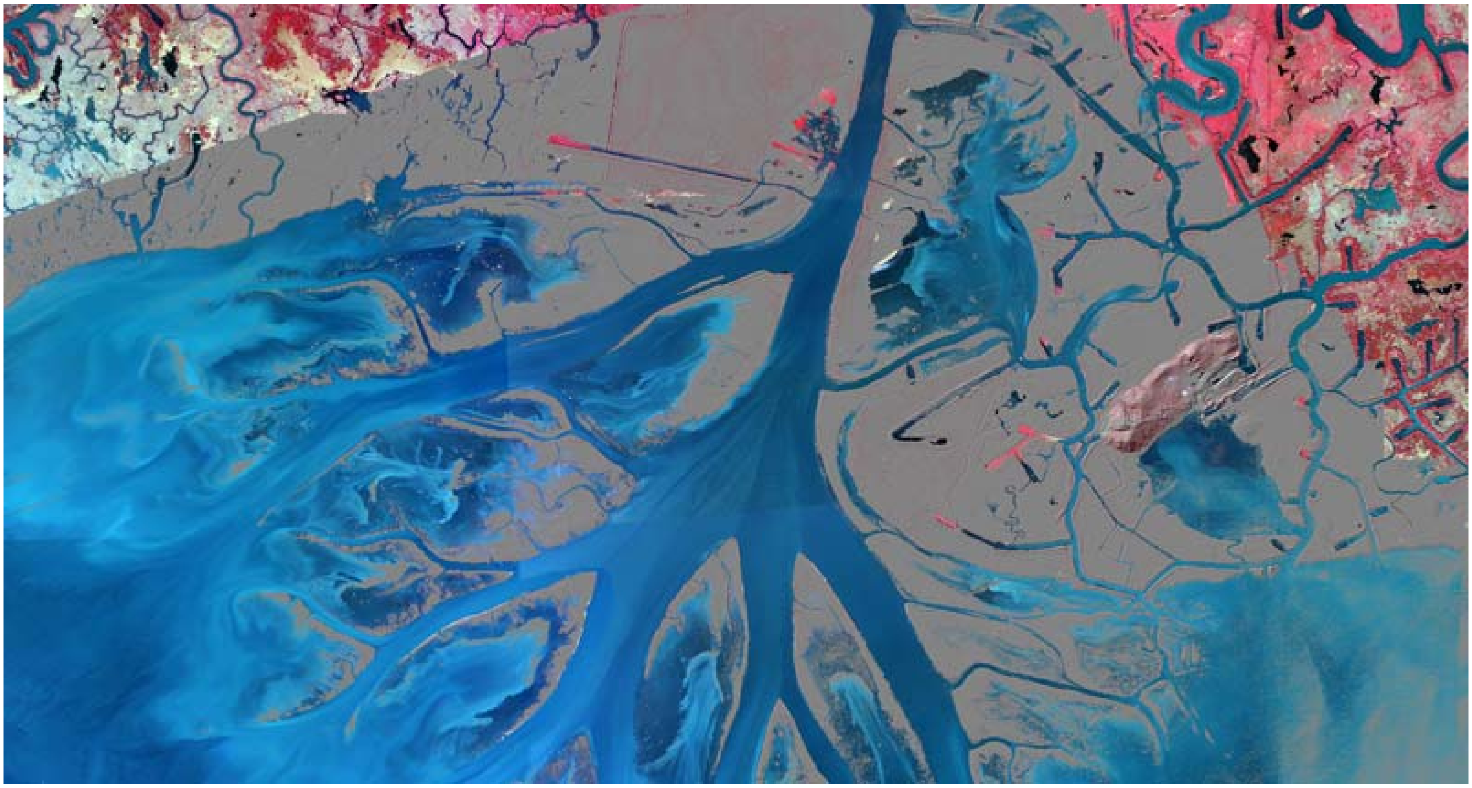

Figure 7 – Filtered composite LiDAR shaded relief map overlayed on top of the 2005 aerial image. The water areas are extracted from the hillshade image using a water-color mask.

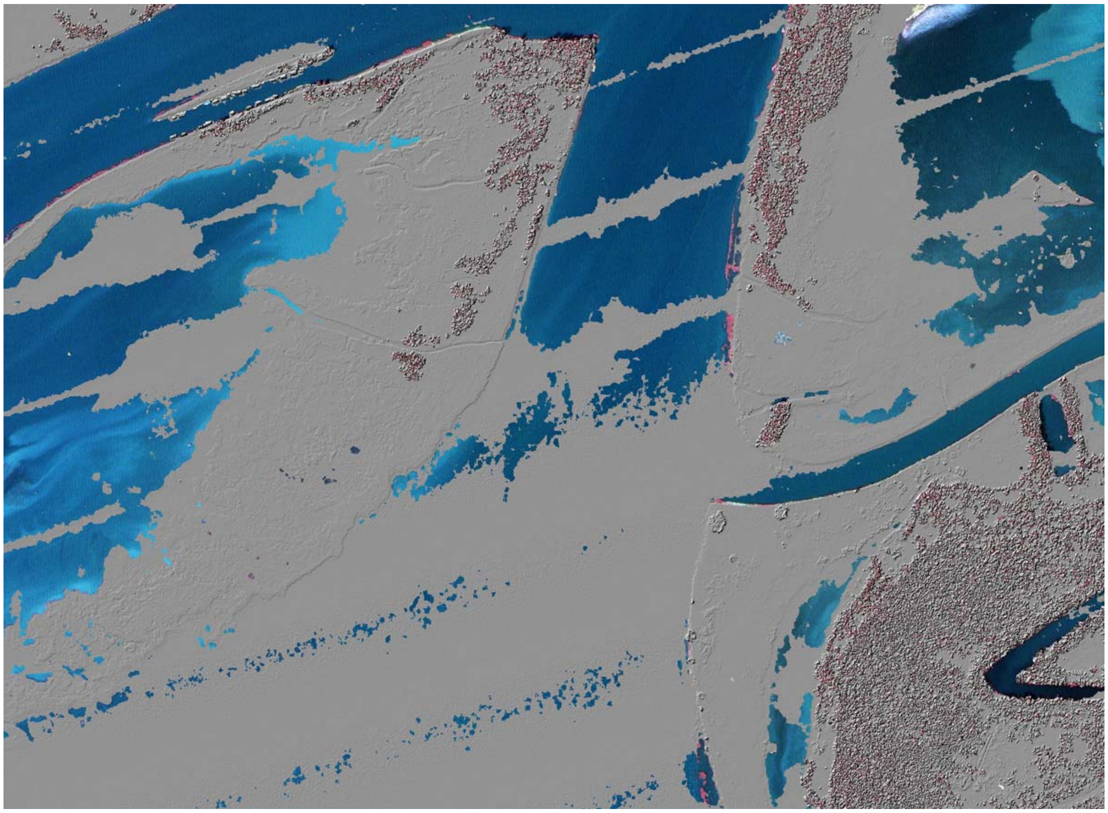

Figure 8 – Detail showing the full unfiltered LiDAR shaded relief, with gaps and artifacts over the water surface

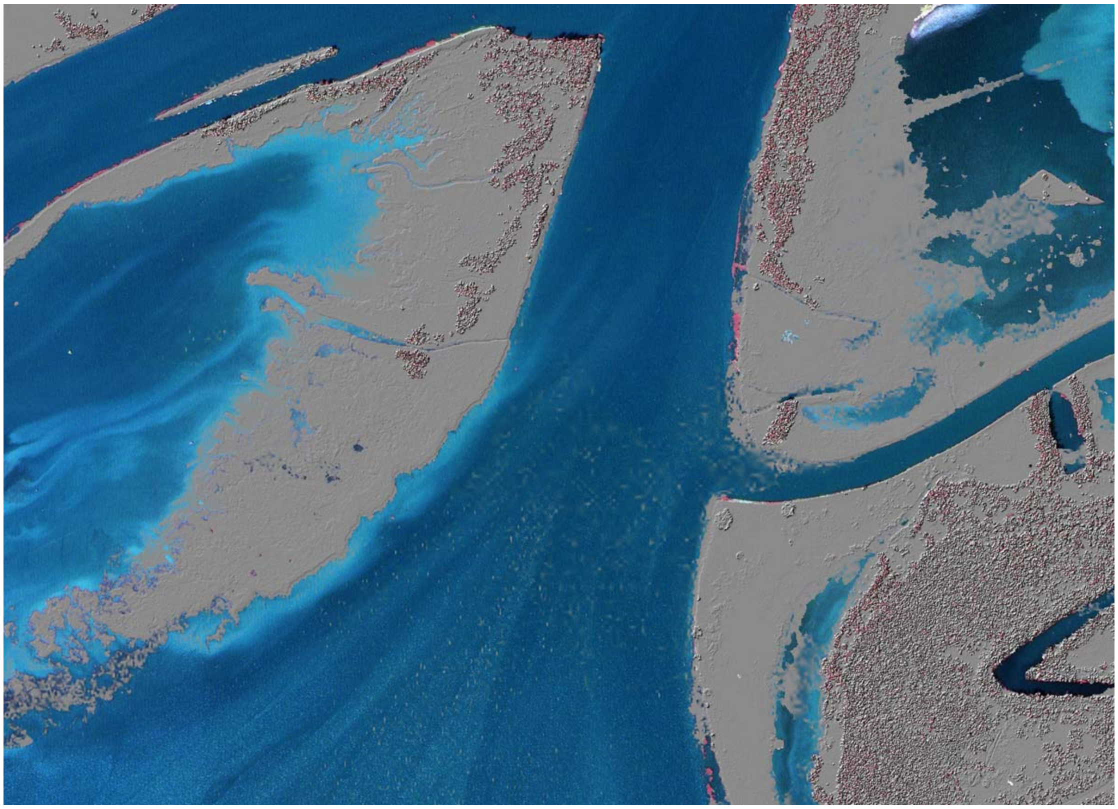

Figure 9 – Same area as Fig 8 but with the water surface removed from the unfiltered LiDAR shaded relief

APPENDIX A – OPUS Solutions for GPS Reference Stations

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NGS OPUS SOLUTION REPORT
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All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: www.ngs.noaa.gov/OPUS/Using_OPUS.html#accuracy

      USER: michaels@ufl.edu                        DATE: February 12, 2009
RINEX FILE: ptn_015s.09o                            TIME: 19:26:08 UTC


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 EPHEMERIS: igs15144.eph [precise]                  STOP: 2009/01/15  23:21:00
  NAV FILE: brdc0150.09n                        OBS USED: 14035 / 14086   : 100%
  ANT NAME: ASH700936D_M    NONE             # FIXED AMB:    49 /    50   :  98%
ARP HEIGHT: 1.300                            OVERALL RMS: 0.010(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)            ITRF00 (EPOCH:2009.0407)

         X:      -128921.893(m)   0.026(m)           -128922.587(m)   0.026(m)
         Y:     -5542602.815(m)   0.031(m)          -5542601.324(m)   0.031(m)
         Z:      3142719.460(m)   0.008(m)           3142719.258(m)   0.008(m)

       LAT:   29 42 44.90733      0.015(m)        29 42 44.92537      0.015(m)
     E LON:  268 40  3.11017      0.026(m)       268 40  3.08306      0.026(m)
     W LON:   91 19 56.88983      0.026(m)        91 19 56.91694      0.026(m)
    EL HGT:          -24.695(m)   0.026(m)               -26.076(m)   0.026(m)
 ORTHO HGT:            0.923(m)   0.076(m) [NAVD88 (Computed using GEOID03)]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 15)         SPC (1702 LA S)
Northing (Y) [meters]     3288089.493           134396.410
Easting (X)  [meters]      661302.738          1000083.592
Convergence  [degrees]     0.82668659           0.00043198
Point Scale                0.99992103           0.99993833
Combined Factor            0.99992491           0.99994221

US NATIONAL GRID DESIGNATOR: 15RXN6130388089(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DK8249 LAKJ KJUN 2 CORS ARP               N301316.947 W0920242.387   88956.0
DG5315 HOUM HOUMA CORS ARP                N293532.109 W0904324.988   60437.4
DF5771 LMCN LUMCON CORS ARP               N291517.904 W0903940.653   82512.9
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                              NGS OPUS SOLUTION REPORT
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All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: www.ngs.noaa.gov/OPUS/Using_OPUS.html#accuracy

      USER: michaels@ufl.edu                         DATE: February 12, 2009
RINEX FILE: ptn_014o.09o                             TIME: 19:26:06 UTC


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  NAV FILE: brdc0140.09n                        OBS USED: 13153 / 13406   :  98%
  ANT NAME: ASH700936D_M    NONE             # FIXED AMB:    45 /    47   :  96%
ARP HEIGHT: 1.300                            OVERALL RMS: 0.012(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)            ITRF00 (EPOCH:2009.0376)

         X:      -128921.893(m)   0.022(m)           -128922.586(m)   0.022(m)
         Y:     -5542602.821(m)   0.014(m)          -5542601.330(m)   0.014(m)
         Z:      3142719.459(m)   0.012(m)           3142719.257(m)   0.012(m)

       LAT:   29 42 44.90721      0.013(m)        29 42 44.92524      0.013(m)
     E LON:  268 40  3.11017      0.022(m)       268 40  3.08311      0.022(m)
     W LON:   91 19 56.88983      0.022(m)        91 19 56.91689      0.022(m)
    EL HGT:          -24.690(m)   0.015(m)               -26.071(m)   0.015(m)
 ORTHO HGT:            0.928(m)   0.073(m) [NAVD88 (Computed using GEOID03)]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 15)         SPC (1702 LA S)
Northing (Y) [meters]     3288089.489           134396.406
Easting (X)  [meters]      661302.738          1000083.592
Convergence  [degrees]     0.82668659           0.00043198
Point Scale                0.99992103           0.99993833
Combined Factor            0.99992491           0.99994221

US NATIONAL GRID DESIGNATOR: 15RXN6130388089(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DK8249 LAKJ KJUN 2 CORS ARP                N301316.947 W0920242.387   88956.0
DG5315 HOUM HOUMA CORS ARP                 N293532.109 W0904324.988   60437.4
DF5771 LMCN LUMCON CORS ARP                N291517.904 W0903940.653   82512.9
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                              NGS OPUS SOLUTION REPORT
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All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: www.ngs.noaa.gov/OPUS/Using_OPUS.html#accuracy

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RINEX FILE: ptn0015s.09o                            TIME: 19:26:06 UTC


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 EPHEMERIS: igs15144.eph [precise]                  STOP: 2009/01/15  23:24:00
  NAV FILE: brdc0150.09n                        OBS USED: 14106 / 14201   :  99%
  ANT NAME: ASH700936D_M    NONE             # FIXED AMB:    51 /    52   :  98%
ARP HEIGHT: 1.300                            OVERALL RMS: 0.010(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)            ITRF00 (EPOCH:2009.0407)

         X:      -128918.844(m)   0.020(m)           -128919.538(m)   0.020(m)
         Y:     -5542604.477(m)   0.028(m)          -5542602.986(m)   0.028(m)
         Z:      3142716.683(m)   0.007(m)           3142716.481(m)   0.007(m)

       LAT:   29 42 44.80339      0.012(m)        29 42 44.82143      0.012(m)
     E LON:  268 40  3.22501      0.020(m)       268 40  3.19791      0.020(m)
     W LON:   91 19 56.77499      0.020(m)        91 19 56.80209      0.020(m)
    EL HGT:          -24.690(m)   0.025(m)               -26.071(m)   0.025(m)
 ORTHO HGT:            0.928(m)   0.075(m) [NAVD88 (Computed using GEOID03)]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 15)         SPC (1702 LA S)
Northing (Y) [meters]     3288086.338           134393.210
Easting (X)  [meters]      661305.870          1000086.679
Convergence  [degrees]     0.82670168           0.00044793
Point Scale                0.99992105           0.99993834
Combined Factor            0.99992492           0.99994221

US NATIONAL GRID DESIGNATOR: 15RXN6130688086(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DK8249 LAKJ KJUN 2 CORS ARP                N301316.947 W0920242.387   88960.4
DG5315 HOUM HOUMA CORS ARP                 N293532.109 W0904324.988   60433.7
DF5771 LMCN LUMCON CORS ARP                N291517.904 W0903940.653   82508.5
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                              NGS OPUS SOLUTION REPORT
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All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: www.ngs.noaa.gov/OPUS/Using_OPUS.html#accuracy

      USER: michaels@ufl.edu                        DATE: February 12, 2009
RINEX FILE: ptn0014o.09o                            TIME: 19:25:03 UTC


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 EPHEMERIS: igs15143.eph [precise]                  STOP: 2009/01/14  20:08:00
  NAV FILE: brdc0140.09n                        OBS USED: 13072 / 13338   :  98%
  ANT NAME: ASH700936D_M    NONE             # FIXED AMB:    53 /    53   : 100%
ARP HEIGHT: 1.300                            OVERALL RMS: 0.012(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)            ITRF00 (EPOCH:2009.0376)

         X:      -128918.848(m)   0.025(m)           -128919.541(m)   0.025(m)
         Y:     -5542604.479(m)   0.018(m)          -5542602.988(m)   0.018(m)
         Z:      3142716.685(m)   0.012(m)           3142716.483(m)   0.012(m)

       LAT:   29 42 44.80342      0.016(m)        29 42 44.82146      0.016(m)
     E LON:  268 40  3.22486      0.025(m)       268 40  3.19780      0.025(m)
     W LON:   91 19 56.77514      0.025(m)        91 19 56.80220      0.025(m)
    EL HGT:          -24.687(m)   0.014(m)               -26.068(m)   0.014(m)
 ORTHO HGT:            0.931(m)   0.072(m) [NAVD88 (Computed using GEOID03)]

                        UTM COORDINATES    STATE PLANE COORDINATES
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Northing (Y) [meters]     3288086.338           134393.211
Easting (X)  [meters]      661305.866          1000086.675
Convergence  [degrees]     0.82670166           0.00044791
Point Scale                0.99992105           0.99993834
Combined Factor            0.99992492           0.99994221

US NATIONAL GRID DESIGNATOR: 15RXN6130688086(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DK8249 LAKJ KJUN 2 CORS ARP                N301316.947 W0920242.387   88960.4
DG5315 HOUM HOUMA CORS ARP                 N293532.109 W0904324.988   60433.7
DF5771 LMCN LUMCON CORS ARP                N291517.904 W0903940.653   82508.5
```