Hydrologic and topographic controls on the distribution of organic carbon in forest Soils
LIDAR Mapping Project Report

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1. LIDAR System Description and Specifications

This survey was performed with an Optech GEMINI Airborne Laser Terrain Mapper (ALTM) serial number 06SEN195 mounted in a twin-engine Cessna Skymaster (Tail Number N337P). The instrument nominal specifications are listed in table 1.

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 was 42.15 Square Kms, located 20Kms north of Plymouth, North Hampshire. Figure 1 below shows its location and extent.
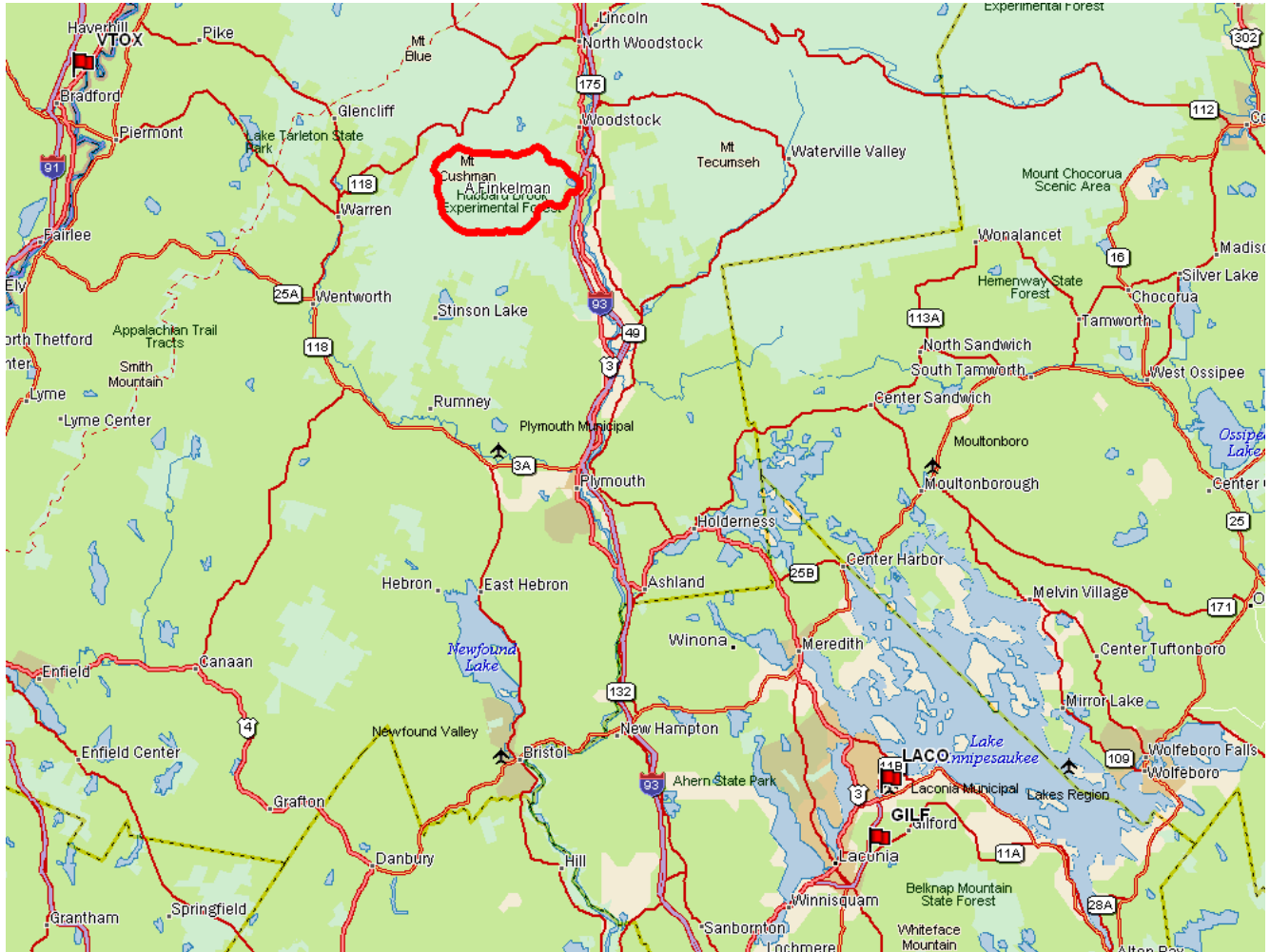

Figure 1(a) Location of survey polygon and Ground Control Stations (TopoUSA)
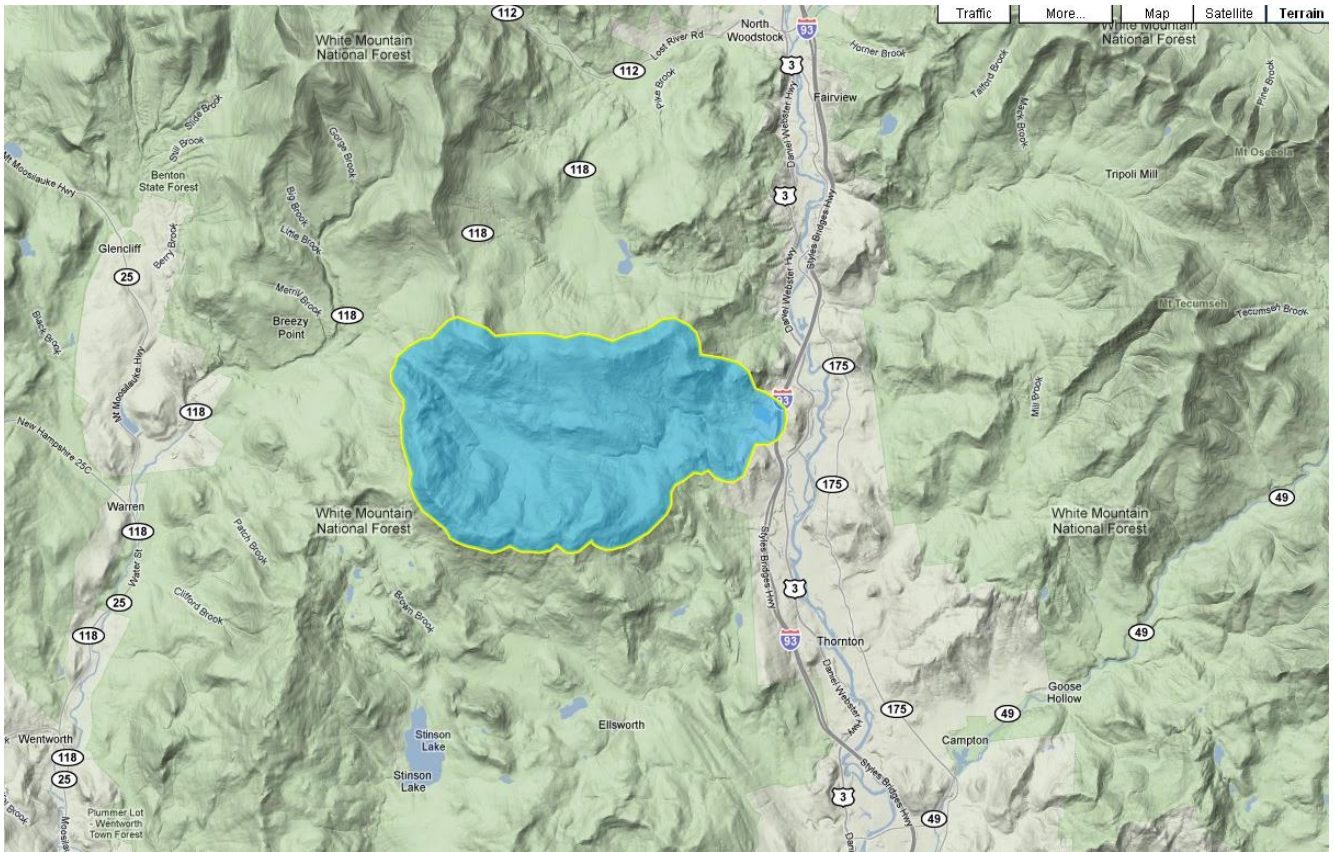
Figure 2(b) – Shape and extent of survey polygon (GoogleMaps)

3. Survey Planning and Parameters.

The survey composed of a 32 total passes going in Northwest-Southeast direction. Figure 2 below shows the planning software along with the sets of planned flight lines and the survey parameters.
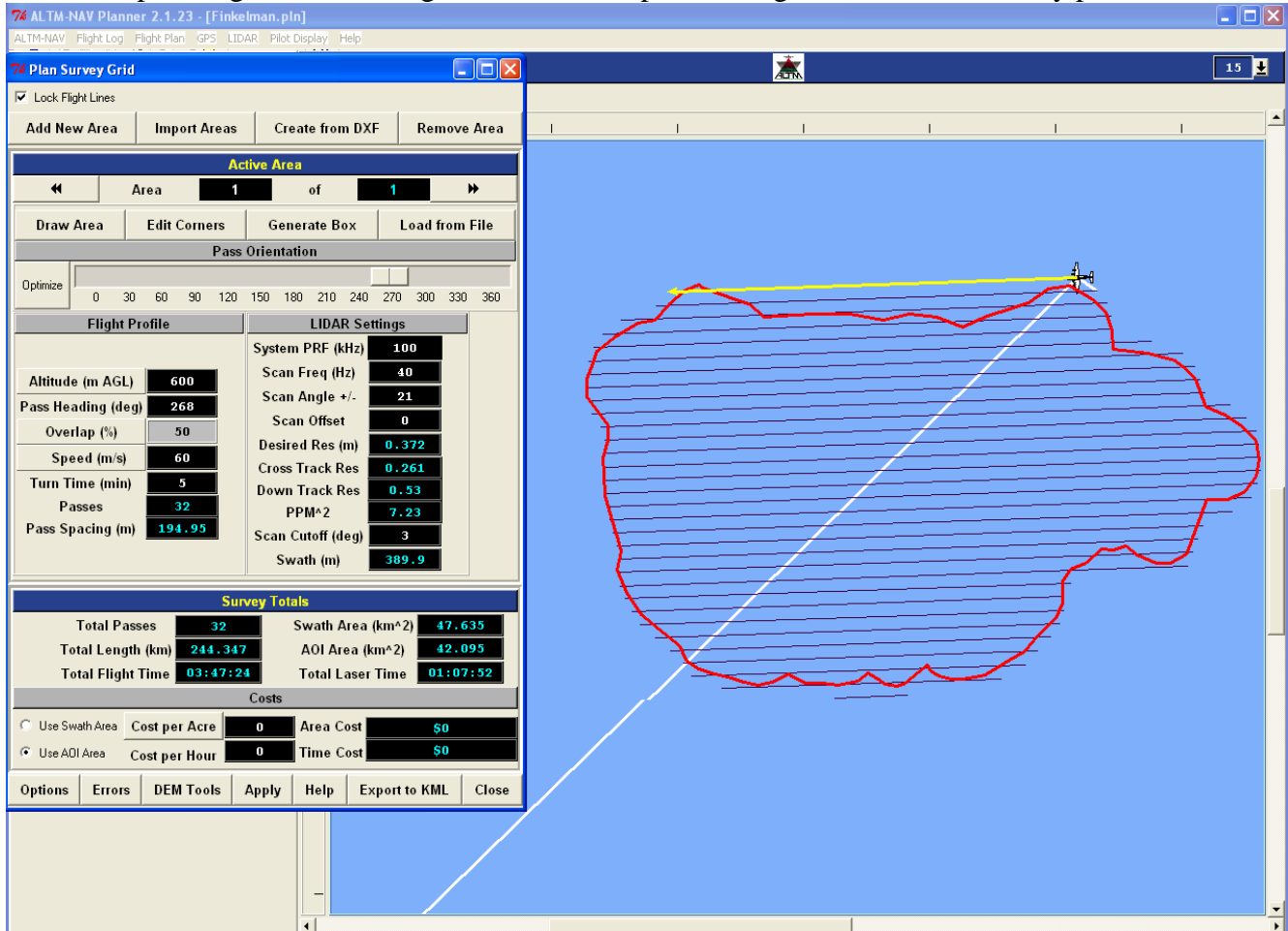

Figure 3 Flight lines from the planning software

Survey parameters are given below in Table 3.

Survey Parameters		Survey Totals	
Altitude (m)	600	Total Length (Km)	244
Swath Width (m)	400	Swath Area (Km^2)	47.6
Overlap (%)	50	Area of Interest (Km^2)	42
Laser PRF (kHz)	100	No. of Passes	32
Scan Freq (Hz)	40		
Scan Angle (degrees)	21		
Scan Cutoff (degrees)	3		

Table 3 – Survey parameters

4. LIDAR and GPS Data Collection Campaign.

This survey was flown in November 03, 09(Day of the Year 307). It was flown out of Laconia Municipal airport, Gilford, North Hampshire. The total flight time was 5 hrs 05mins and the total Laser on time was 1 hr 46 min.

Three GPS reference stations were used for ground control. One was a CORS (Continuously Operated Reference Station) station and other two were setup and operated by NCALM. The list of the stations and their locations is given below in table 4. The airborne receiver is an integrated GPS receiver module Trimble BD950, logging at 10 Hz.

Station Name	Latitude	Longitude	Type
VTOX	44.0078	-72.1143	CORS
GILF	43.5333	-71.4391	NCALM
LACO	43.5697	-71.4295	NCALM

Table 4 Ground Control Stations

5. Data Processing

5.1. GPS & INS Navigation Solution.

Reference coordinates and the GPS data for the CORS stations was obtained from their website. Reference coordinates for the NCALM station was obtained using OPUS (Online Positioning User Service), which processes static differential baselines tied to the international CORS network. 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/

Airplane GPS trajectories for this survey were processed using KARS (Kinematic and Rapid Static), software created by Dr. Gerry Mader. KARS kinematic GPS processing uses the dual-frequency phase history files of the reference and airborne receivers to determine a high-accuracy fixed integer ionosphere-free differential solution at 1 Hz. GPS trajectories were created using all the above three mentioned ground control stations. These trajectories were then differenced to determine the best solution. Figure 3 shows the plot for positional difference between trajectories obtained from GILF and LACO

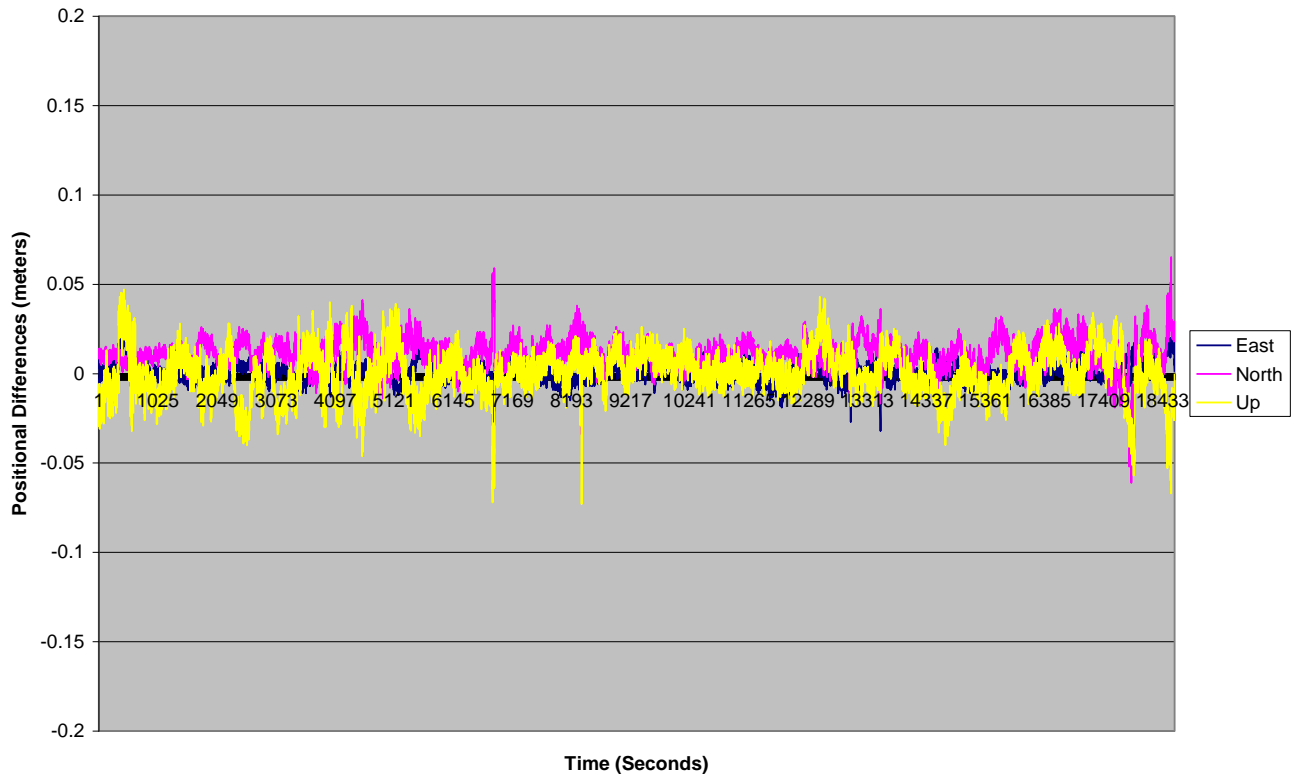**Positional differences in Aircraft Trajectory**

Figure 3 Positional differences between the two trajectories

After GPS processing, the 1Hz differential GPS trajectory and the Inertial Measurement Unit (IMU) datasets are processed together in the POSProc software (version 5.2). POSproc software combines GPS trajectory with the orientation information in a Kalman Filter to produce a final, smoothed and complete navigation solution at 200Hz. This final solution is known as the SBET (Smoothed Best Estimated Trajectory).

5.2 Strip Laser Point Processing

An SBET together with laser ranges and mirror angles are finally combined in Optech's DashMap software (Version 4.1) to generate a flight-strip point cloud in LAS format. All point cloud coordinates were processed with respect to **NAD83** and referenced to the international CORS network. The projection is UTM Zone 19, with units in meters**. Heights are NAVD88** orthometric heights computed using the **NGS GEOID 03.** Scan angle cut-offs are 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. Moreover, scan angle cut-offs are done to eliminate points at the edge of the scan lines for improving the overall DEM accuracy as the points farthest from the scan nadir are the most affected by small errors in pitch, roll and scanner mirror angle measurements. A scan cutoff angle of 3 degrees was used.

5.3. Calibration

Relative calibration is done for each flight by the following method:

1. Planning and flying swaths with 50% side lap.
2. Surveying crossing flight-lines over calibration areas and over the project polygon.
3. Analyzing these overlaps and cross-lines in TerraMatch software. (see http://www.terrasolid.fi/en/products/4).

TerraMatch employs a least-squares approach (minimizing the height differences between computed laser surfaces from individual crossing and/or overlapping flight lines) to calculate the best-fit values for four parameters: three bore sight angle alignments (roll, pitch, and yaw), and the scanner mirror-angle scale factor.

TerraMatch was run to a convergent solution on every flight line. Values for height disagreements between individual flight line surfaces ranged from a high of 10 cm to a low of 3 cm. Individual swath height disagreements averaged approximately 7.0 cm. The values obtained for different lines were then averaged to get the correction for roll, pitch and yaw values and the final configuration file is created to be used for outputting files in DashMap. Below is a typical TerraMatch report for one of the flight lines:

```
Used loaded points
Trajectories: D:\_Seed_09\09_307_Fnklmn\SBET
967 known points from D:\_Seed_09\09_307_Fnklmn\Calibration\car.txt
Observe every 2th point
Solution for whole data set

Starting dz RMS:        0.0862
Final dz RMS:           0.0720

Standard error of unit  0.0328

Execution time: 196.0 sec
Number of iterations: 8

Points          1856772
Z shift          +0.419     Std dev  0.0002
H shift         -0.0101     Std dev  0.0004
R shift         +0.0104     Std dev  0.0001
P shift         +0.0486     Std dev  0.0002
Scale           +0.00036
```

Note that the initial average height difference between individual swath surfaces was found to be 8.6 cm. After best-fitting the bore sight angles for heading (yaw), roll, pitch, and mirror-angle scale factor the final average height difference improved to 7.2 cm.

Absolute Calibration was done by establishing a calibration site consisting of 967 check points surveyed with vehicle-mounted GPS over a portion of the Lily Pond Road close to the Laconia municipal airport. The same portion was then surveyed with crossing flight lines using the ALTM. The heights of the check points were then compared to the heights of the nearest neighbor LIDAR

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shots within a radius of 20cm to look for any systematic height bias. No systematic height bias was found.

5.4 Classification and Filtering

TerraSolid's TerraScan (http://terrasolid.fi) software was used to classify the LIDAR points and generate the "bare-earth" dataset.

The classification used for this project consists of two algorithms:

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

2) <u>Ground Classification</u>. 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.

Figure 4 below shows the unfiltered and filtered bare earth shaded relief models
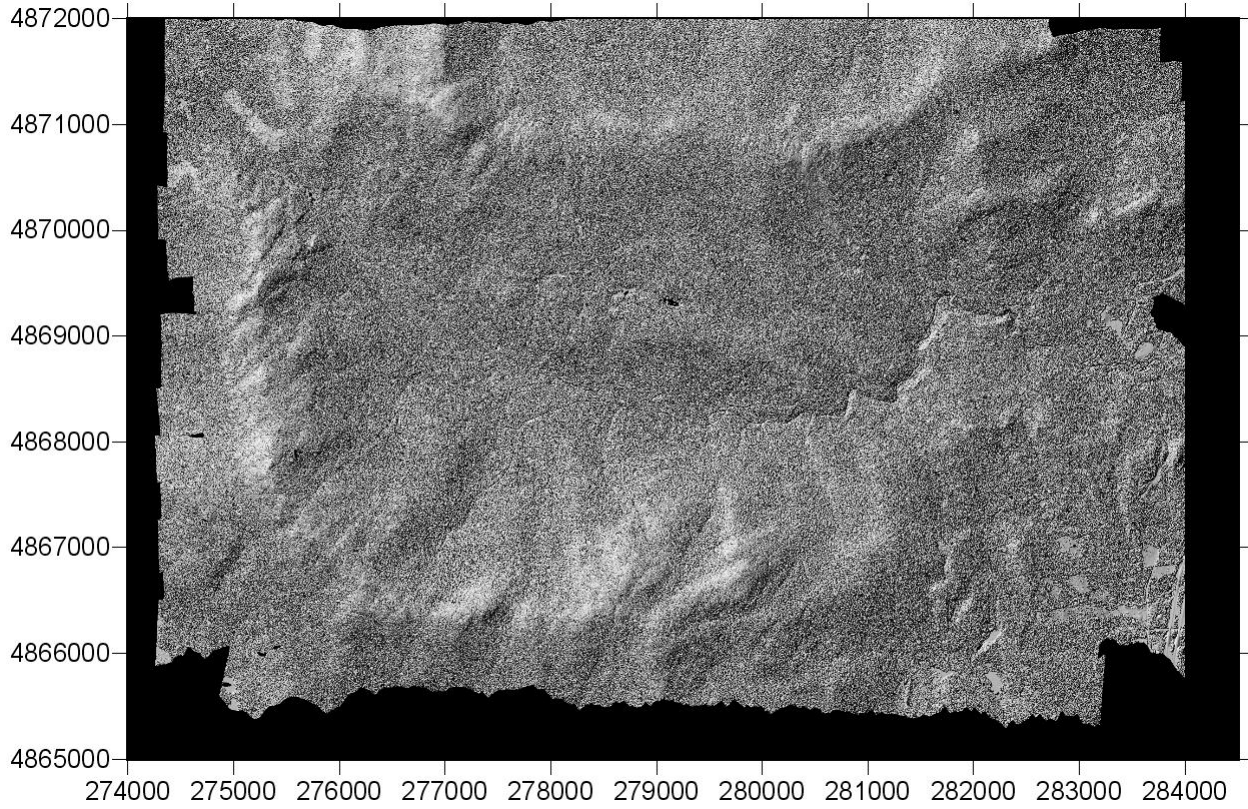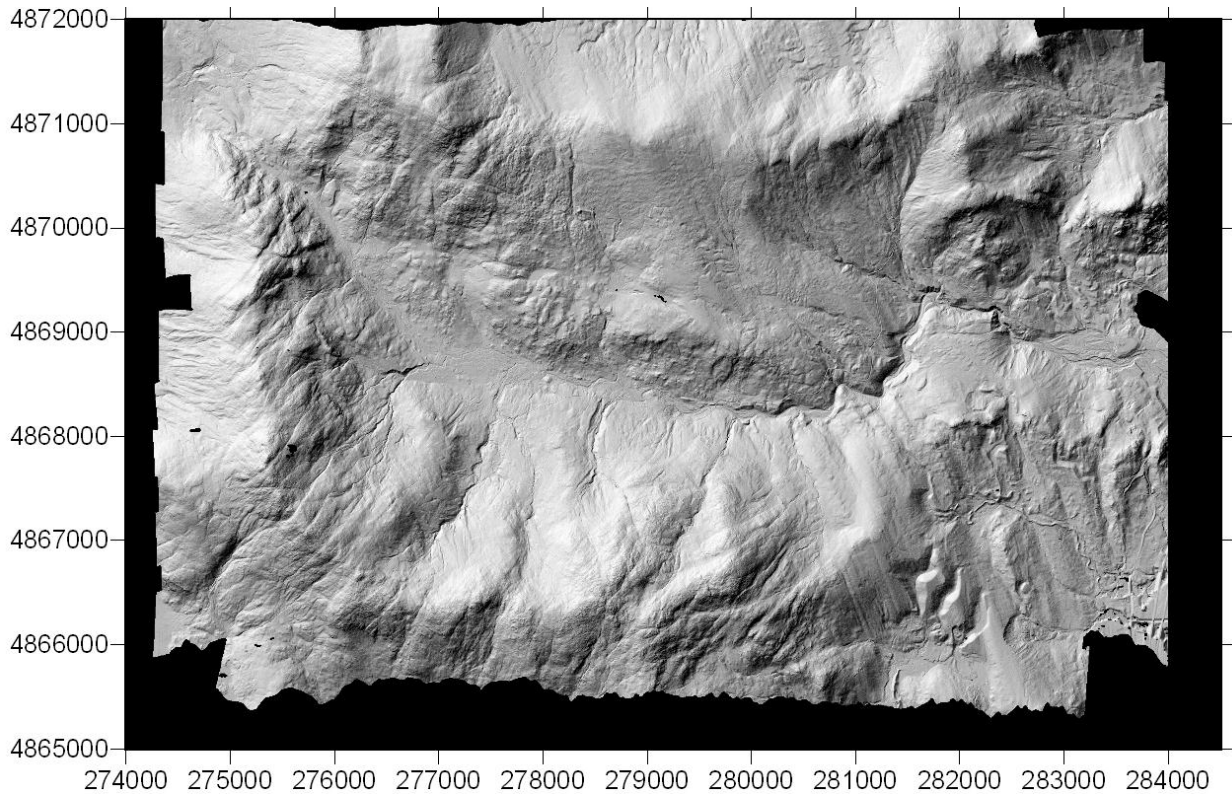
Figure 4a Unfiltered Shaded Relief Image

Figure 4b Filtered Bare earth shaded relief image

5.5 Gridding and Tiling.

The flight strip point cloud files were tiled into 1000m x 500m rectangular blocks, illustrated in the figure below
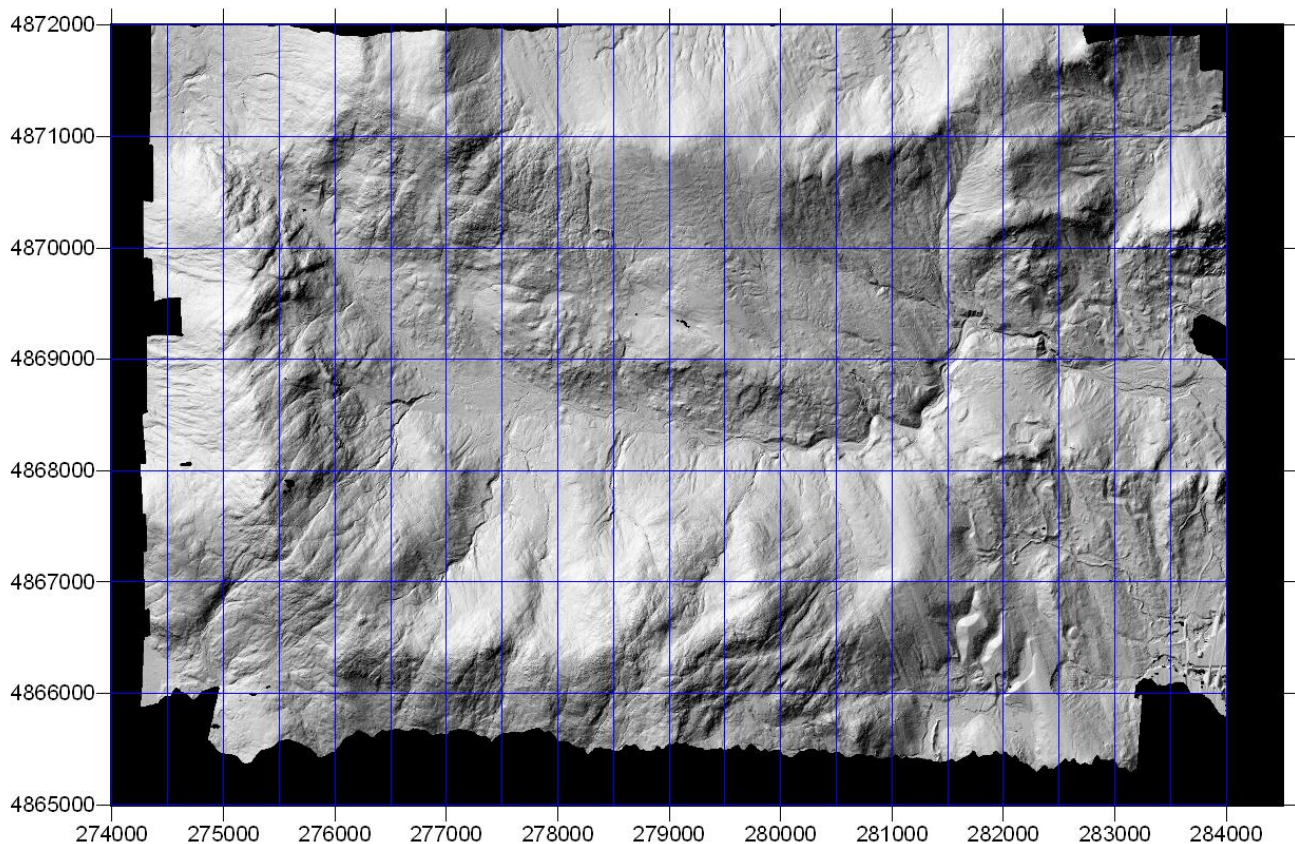

Figure 5 - Tile footprints overlaid on bare-earth shaded relief image.

Tiles follow a naming convention using the lower left coordinate (minimum X, Y) as follows: XXXXXX_YYYYYYY. For example if the tile bounds coordinate values from easting equals 275500 through 276000, and northing equals 4867000 through 4868000 then the tile is named as '275500_4867000'. The project totaled 140 tiles.
Digital Elevation Models were produced in SURFER (Golden Software) Version 8 at 1.0 meter resolution using krigging routine.

6 File Formats

The point cloud files are delivered in the 1000mX500m tiles in ".Las" format. It is a binary format contains all the information associated with each point i.e. its position in X,Y,Z, intensity, flight line, timestamp, scan angle etc. The individual Las files can be converted to ASCII using the LAS to ASCII converter tool developed by the UNC. It can be accessed at   http://www.cs.unc.edu/~isenburg/lastools . It gives users the freedom to create ASCII files with whichever point features they want to access. Raster grids are delivered in ArcInfo grid and hillshade format as 10KM mosaics. Incase of sections smaller than that in size, a single ArcInfo grid and hillshade file is delivered. The point tiles, the corresponding grids and mosaics are all positioned in the NAD83 reference frame and projected into

UTM coordinates Zone 19N. The elevations are NAVD88 orthometric heights computed using the NGS GEOID 03. All units are in meters.