Geomorphic Characterization of Precarious Rock Zones

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 1^{st}, 2^{nd}, 3^{rd}, 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 32.5 Square Kms, located 7 Kms northeast of Prescott, Arizona. Figure 1 below shows its location and extent.

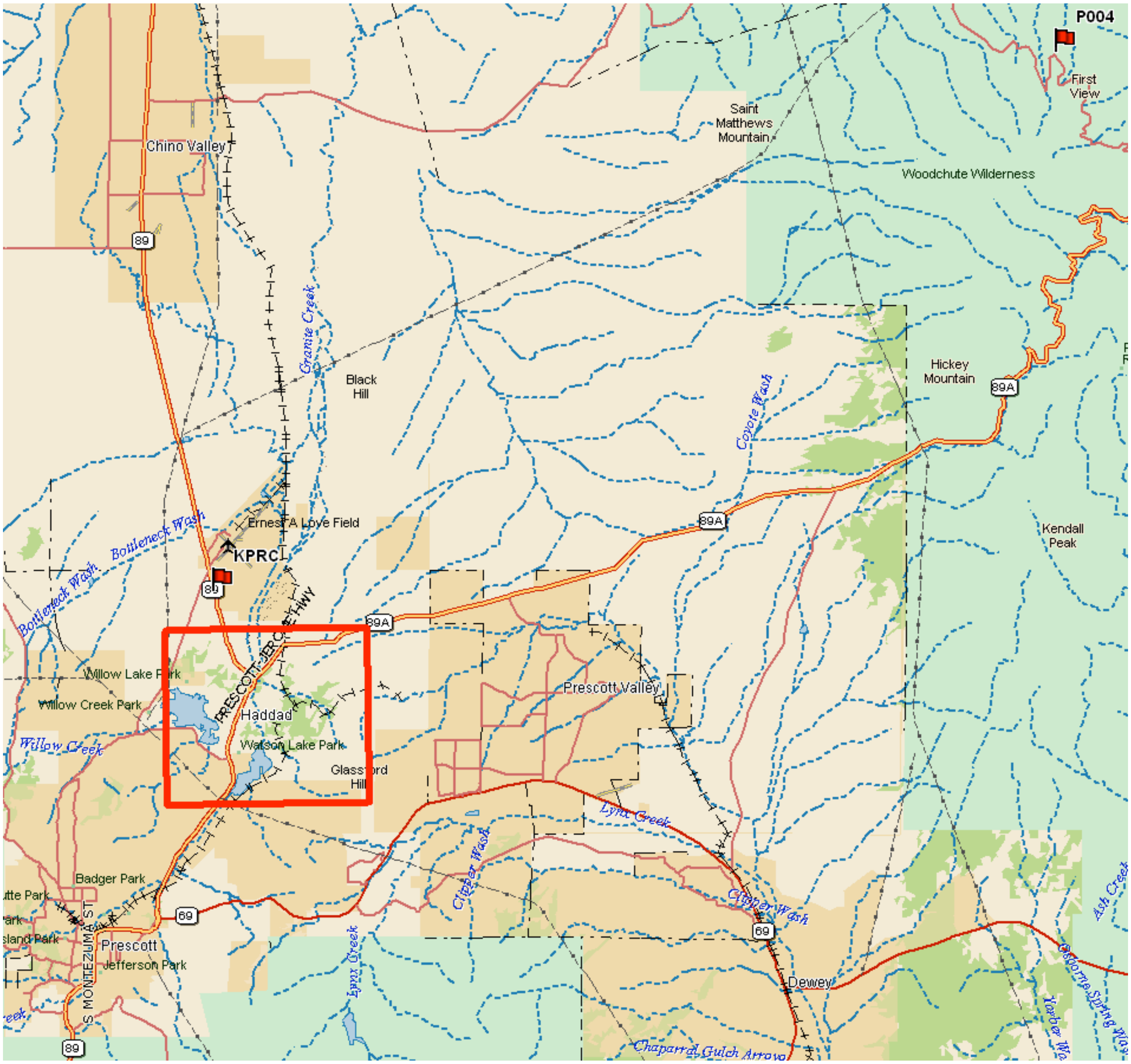

Figure 1(a) Location of survey polygon and Ground Control Stations (TopoUSA)

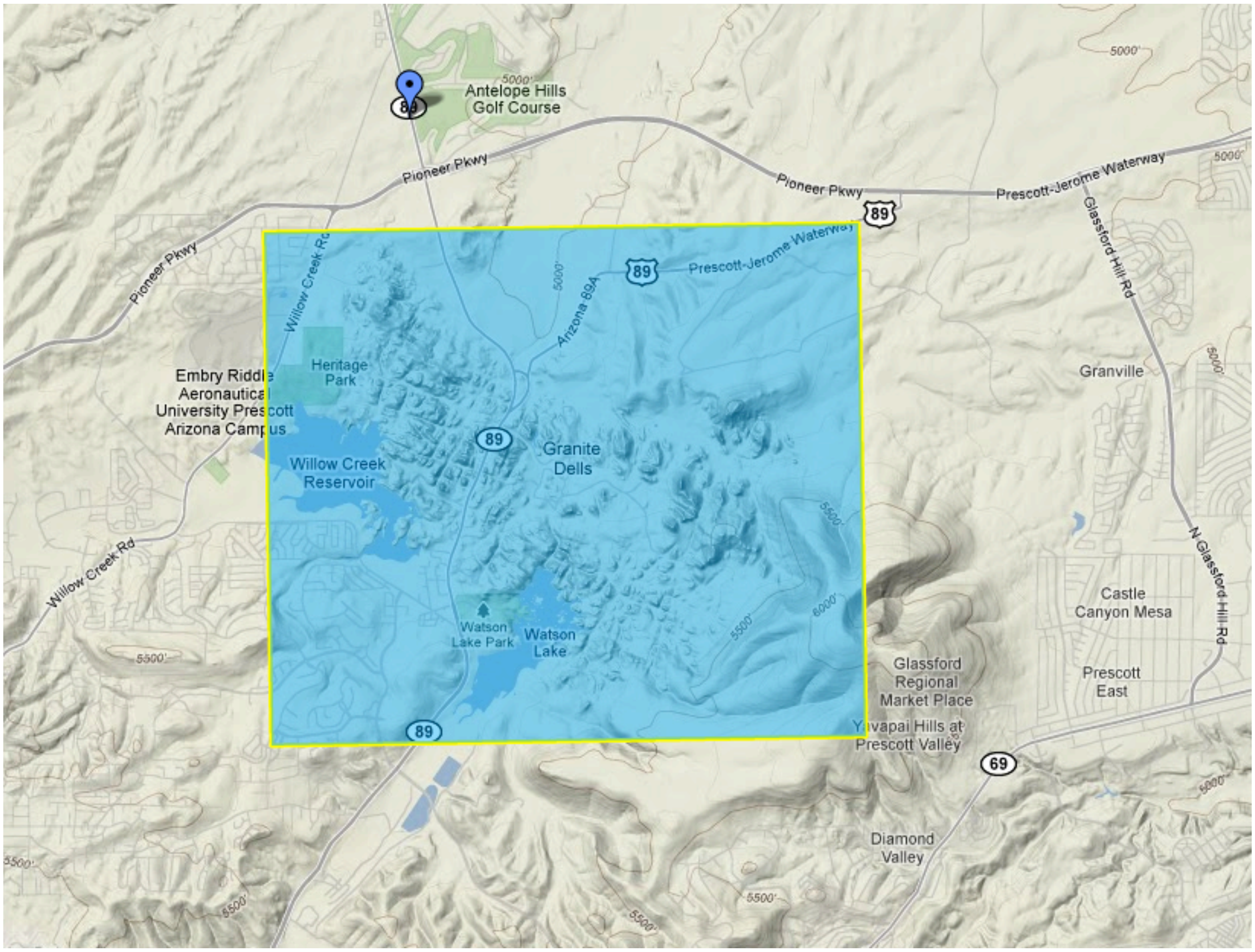

Figure 1(b) – Shape and extent of survey polygon (GoogleMaps)

3. Survey Planning and Parameters.

The survey composed of a 30 total passes going in East-West direction. Figure 2 below shows the planning software along with the sets of planned flight lines and the survey parameters.

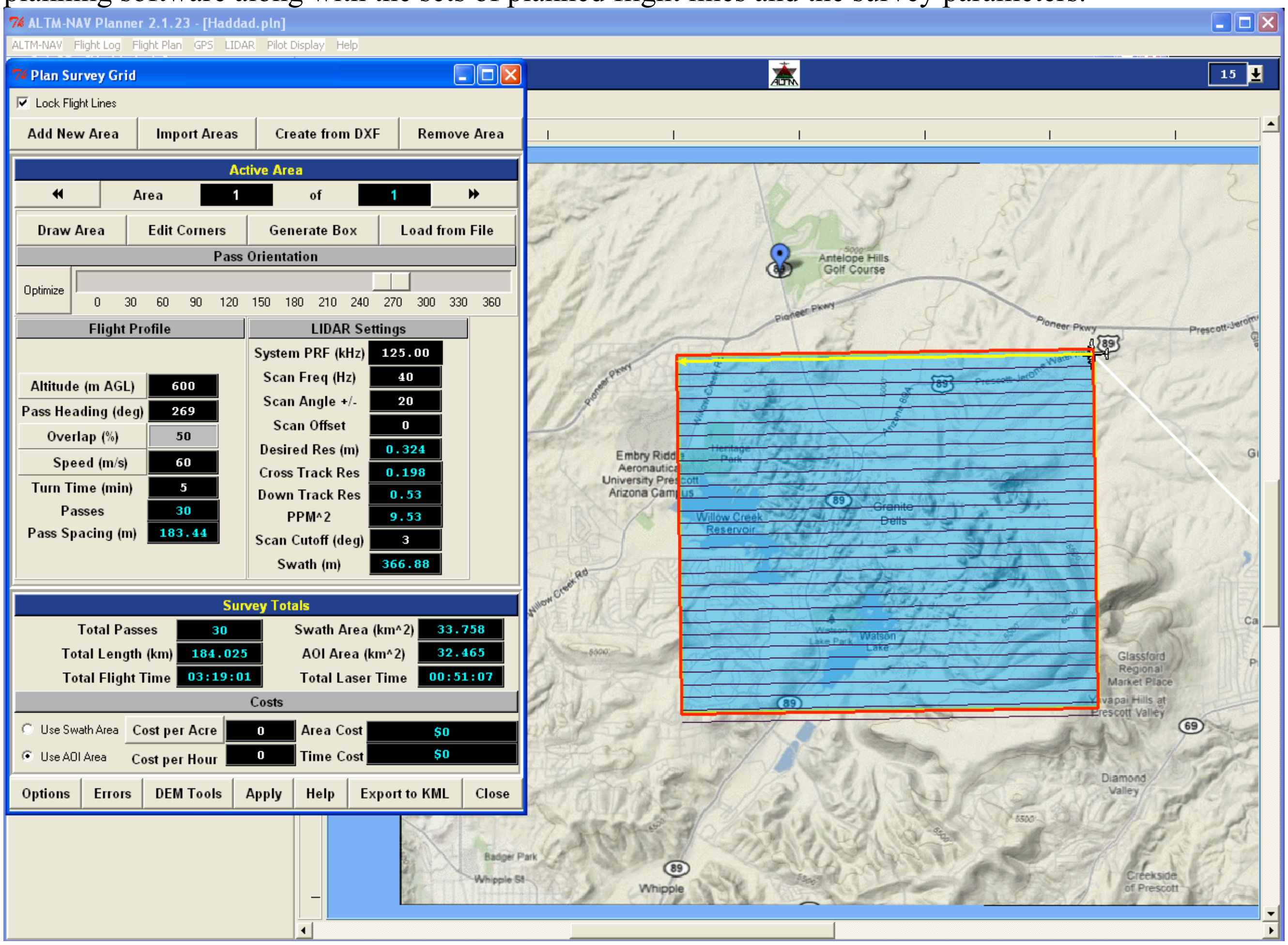

Figure 2 Flight lines from the planning software

Survey parameters are given below in Table 3.

Survey Parameters		Survey Totals	
Altitude (m)	600	Total Length (Km)	184
Swath Width (m)	400	Swath Area (Km^2)	33.8
Overlap (%)	50	Area of Interest (Km^2)	32.5
Laser PRF (kHz)	125	No. of Passes	30
Scan Freq (Hz)	40		
Scan Angle (degrees)	20		
Scan Cutoff (degrees)	3		

Table 3 – Survey parameters

4. LIDAR and GPS Data Collection Campaign.

This survey was flown in September 11, 09(Day of the Year 254). It was flown out of Earnest A Love field public airport, Prescott, Arizona. The total flight time was 3 hrs 34mins and the total Laser on time was 1 hr 09 min.

Two GPS reference stations were used for ground control. One was part of the PBO (Plate Boundary Observation) network, operated by UNAVCO. The other one was setup and operated by NCALM. List of 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
KPRC	34.6374	-112.4308	NCALM
P004	34.7843	-112.1519	PBO

Table 4 Ground Control Stations

5. Data Processing

5.1. GPS & INS Navigation Solution.

The GPS data for the PBO station was downloaded from their website. Reference coordinates for both the stations were 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/ , for more information on the CORS network see http://www.ngs.noaa.gov/CORS/ and for PBO see UNAVCO website http://pboweb.unavco.org/.

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 both the ground control stations. These trajectories were then differenced to check for agreement between the solutions. Figure 3 shows the plot for positional difference between trajectories obtained from KPRC and P004

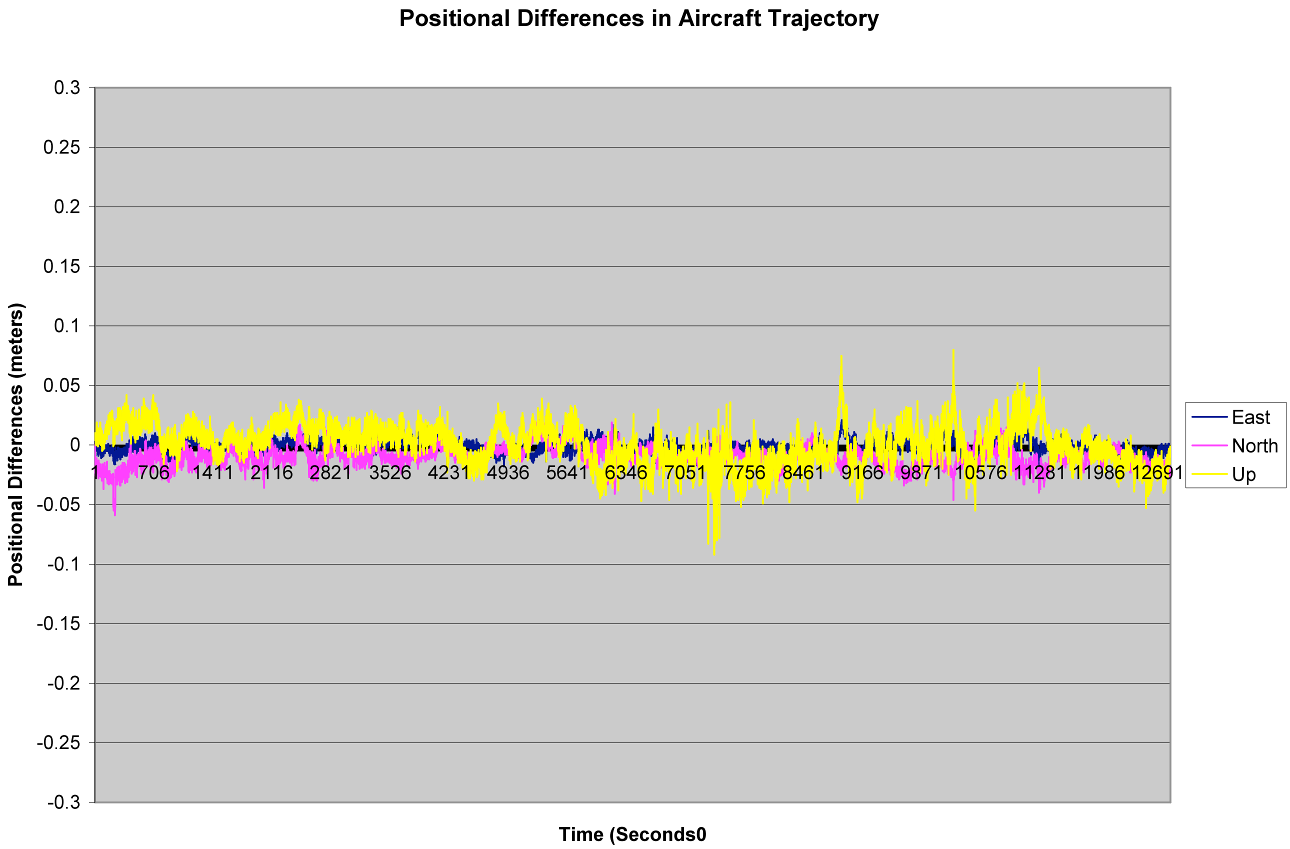

Figure 3 Positional differences between the two trajectories

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 12, 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_254_Haddad\SBET
No known points
Observe every 1th point
Solution for whole data set

Starting dz RMS:        0.0503
Final dz RMS:           0.0467

Standard error of unit  0.0209

Execution time: 605.8 sec
Number of iterations: 15

Points       2951904
H shift      +0.0064    Std dev  0.0006
R shift      +0.0020    Std dev  0.0002
P shift      -0.0058    Std dev  0.0002
Scale       -0.00043
```

As shown above, the initial average height difference between individual swath surfaces was found to be 5 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 4.6 cm. Thus, the calibration was good initially and did not require any adjustment to the parameters

Absolute Calibration was done by establishing a calibration site consisting of 645 check points surveyed with vehicle-mounted GPS over a portion of SR-89 road close to the Earnest A. Love Field 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 shots within a radius of 20cm to look for any systematic height bias. The plot below shows the differences in elevation between the laser points and check points. A systematic height bias of 10cms was found and was applied to the laser points.

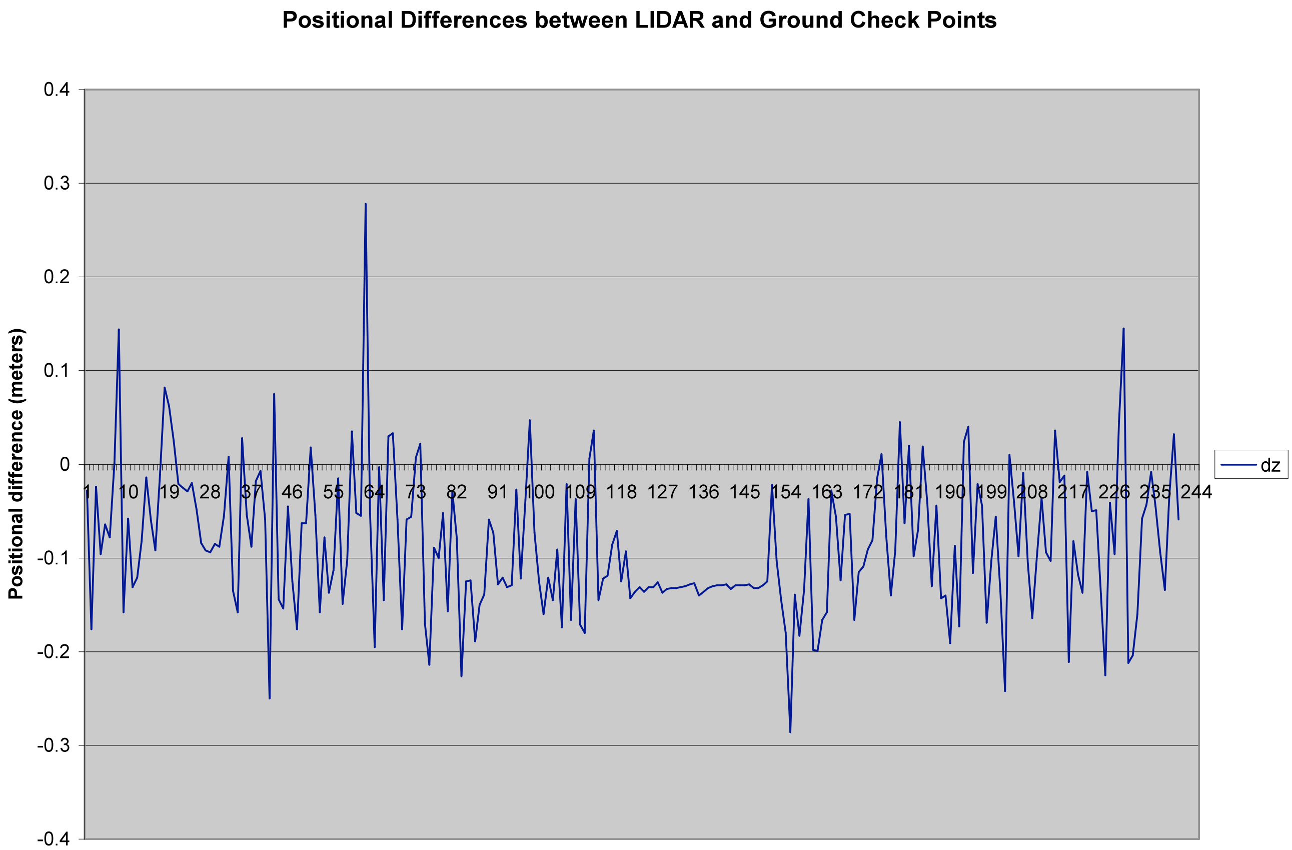

Figure 4 Positional differences between LIDAR and ground check points

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) 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.

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 5 below shows the unfiltered and filtered bare earth shaded relief models

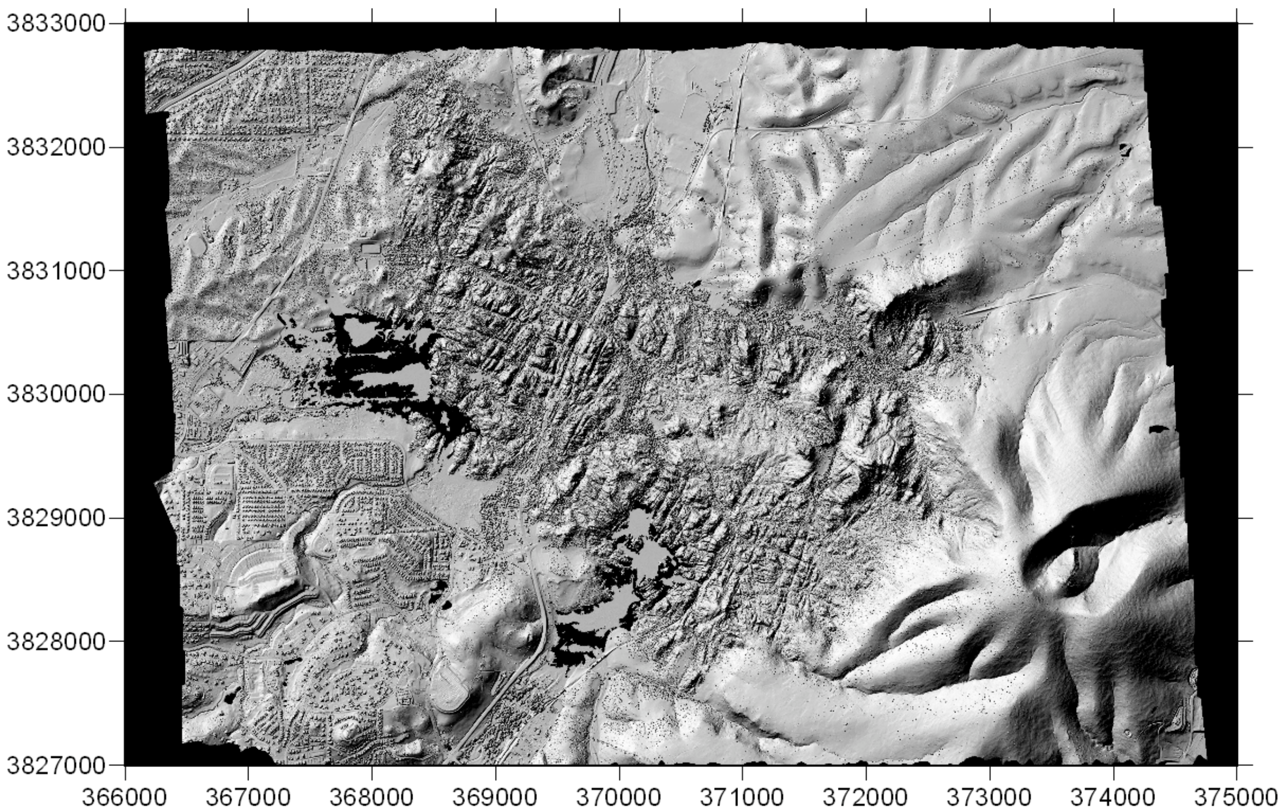

Figure 5a Unfiltered Shaded Relief Image

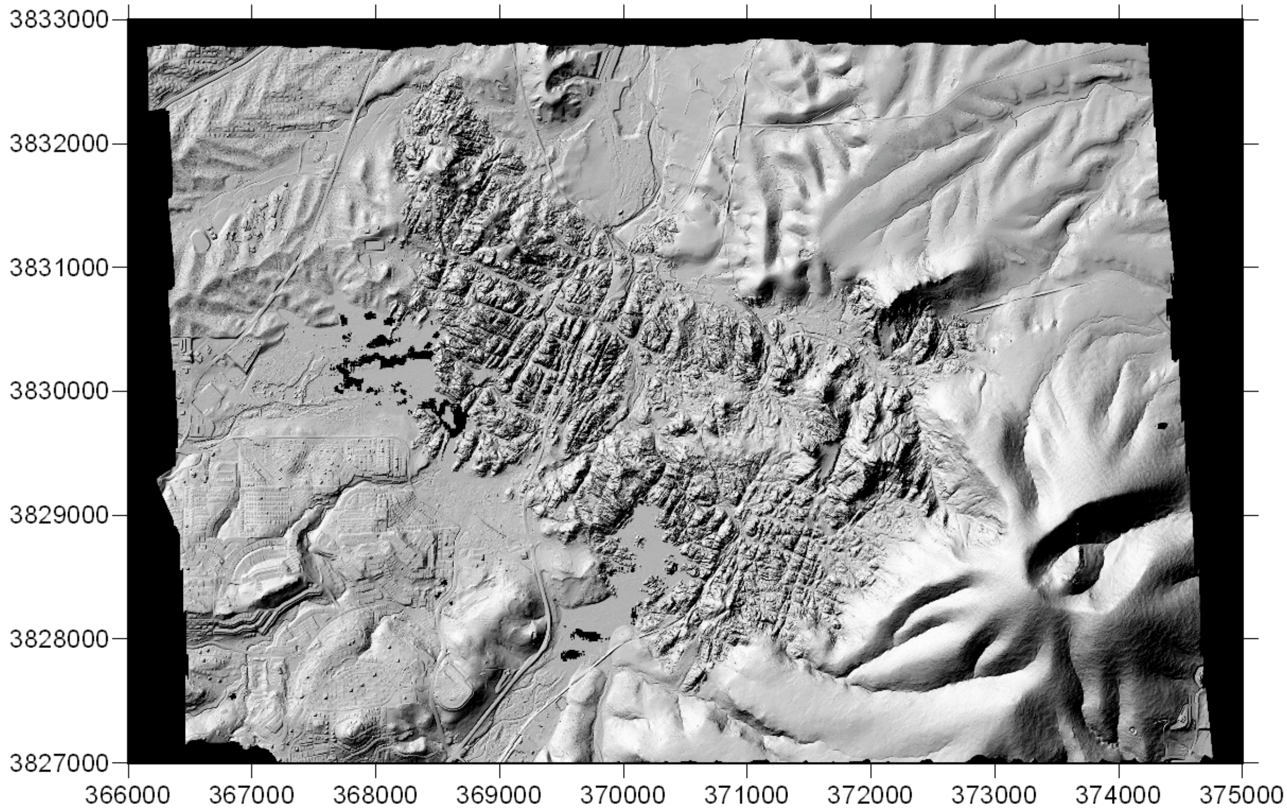

Figure 5b Filtered Bare earth shaded relief image

5.5 Gridding and Tiling.

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

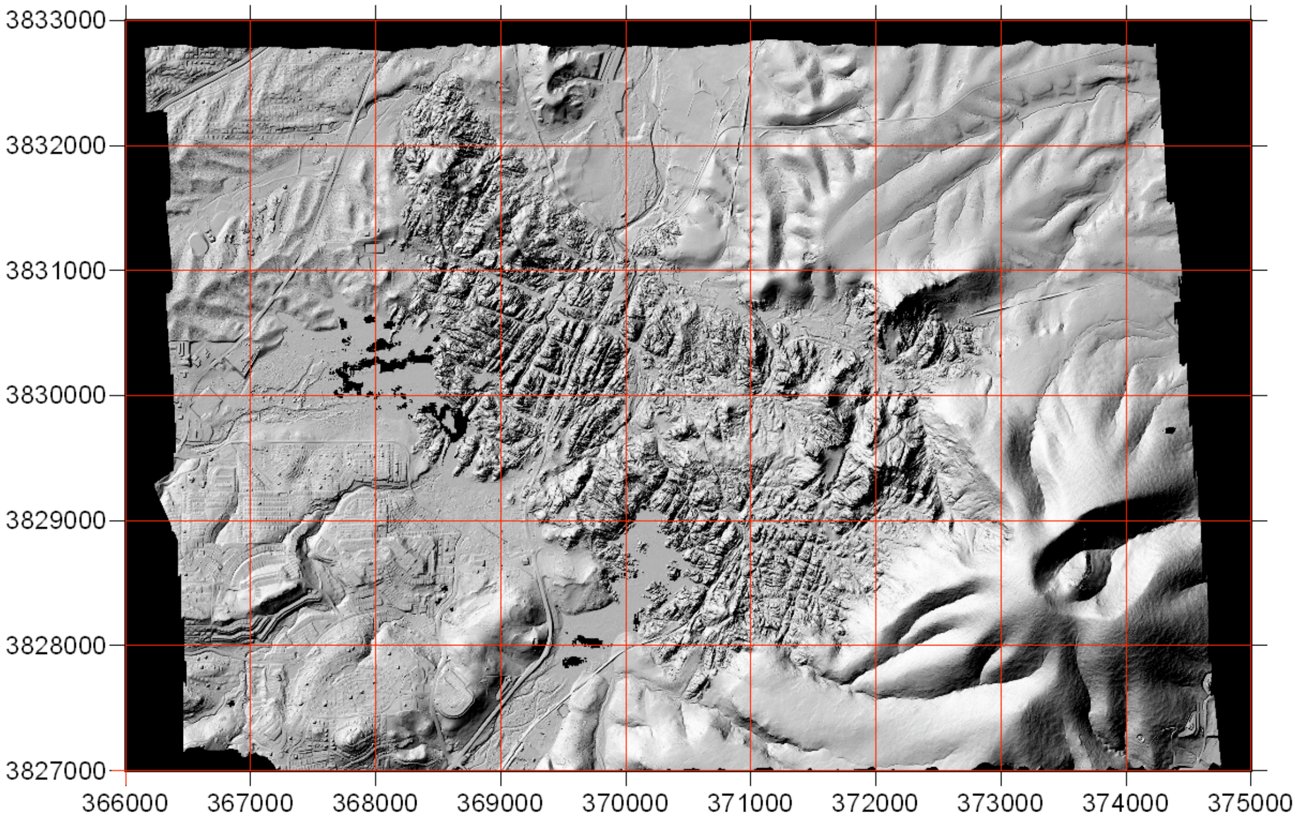

Figure 6 - Tile footprints overlaid on bare-earth shaded relief image.

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 368000 through 369000, and northing equals 3829000 through 3830000 then the tile is named as '368000_3829000'. The project totaled 54 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 1000mX1000m 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 12N. The elevations are NAVD88 orthometric heights computed using the NGS GEOID 03. All units are in meters.