



**Using morphological characteristics of the Bishop
Tuff to infer pyroclastic flow emplacement dynamics**
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 a rectangle, 6.5Km by 6Km (38 Km² area), located 20Km north of Bishop, in California. The location is shown below:

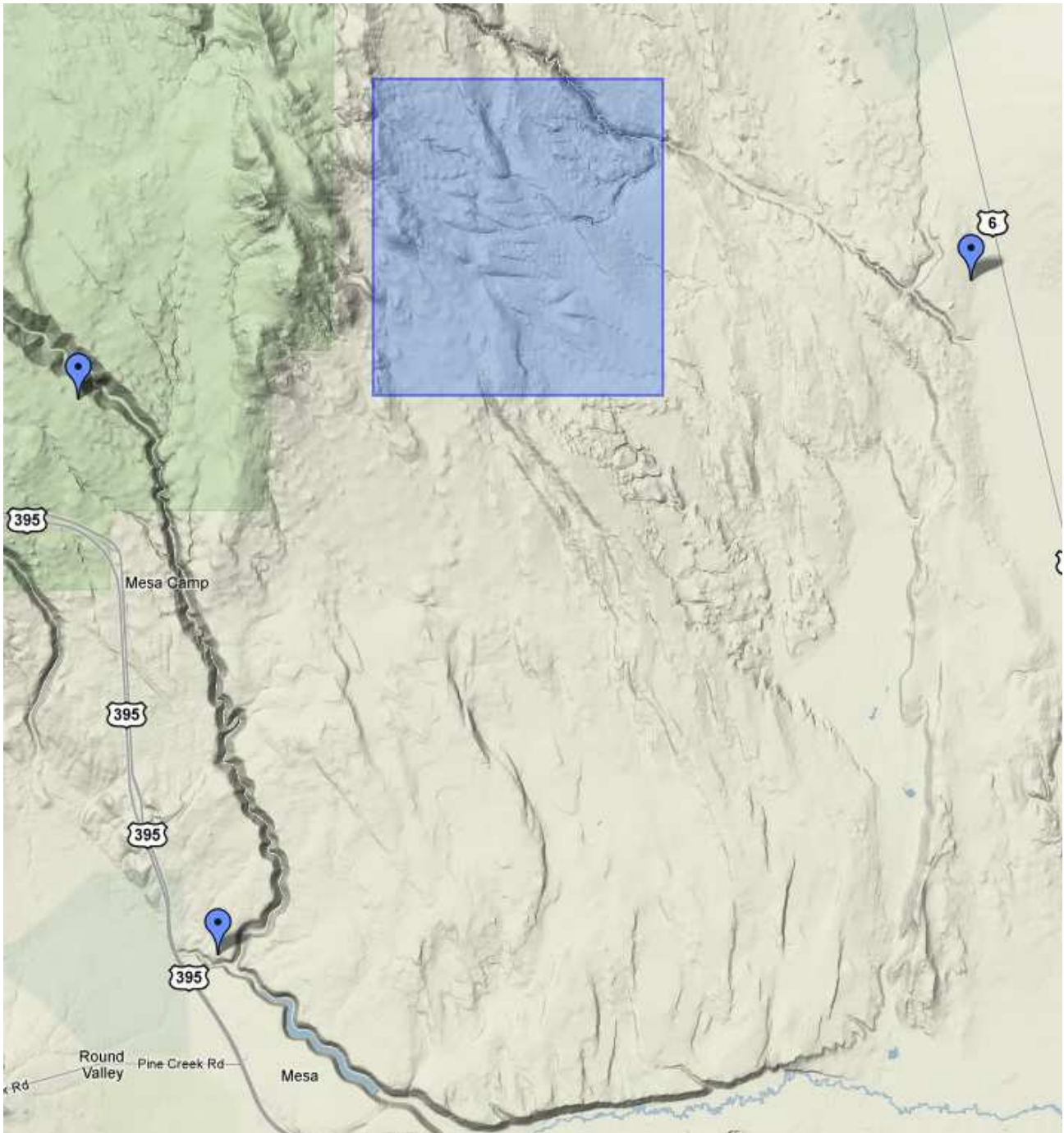


Figure 1(a) – Shape and location of survey polygon and Control GPS stations (Google Maps)

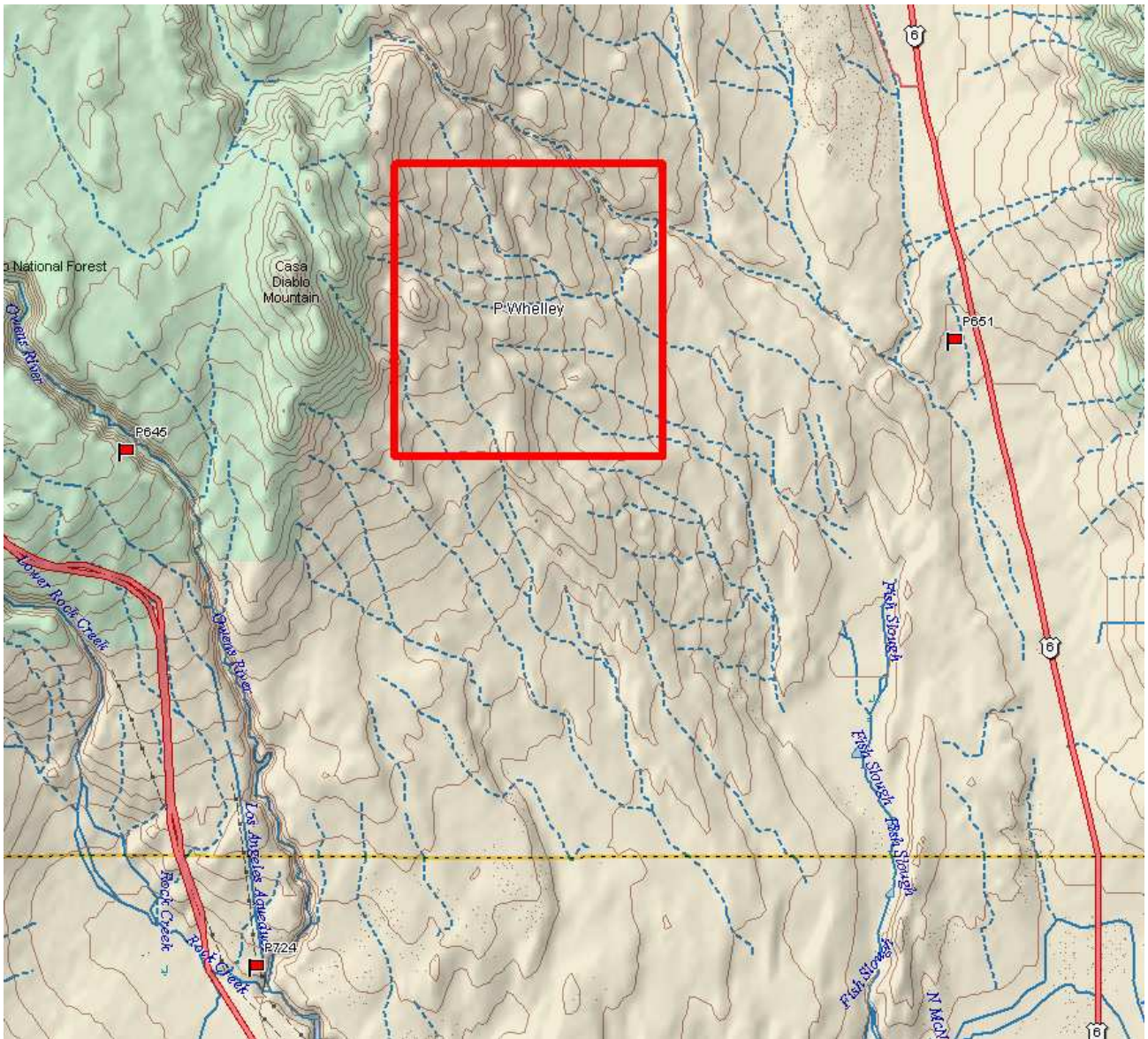


Figure 2(b) – Shape and location of survey polygon (TopoUSA)

3. Survey Planning and Parameters.

The survey composed of a 31 total passes going in North-South direction Figure 2 below shows the planning software along with the sets of planned flight lines and the survey parameters.

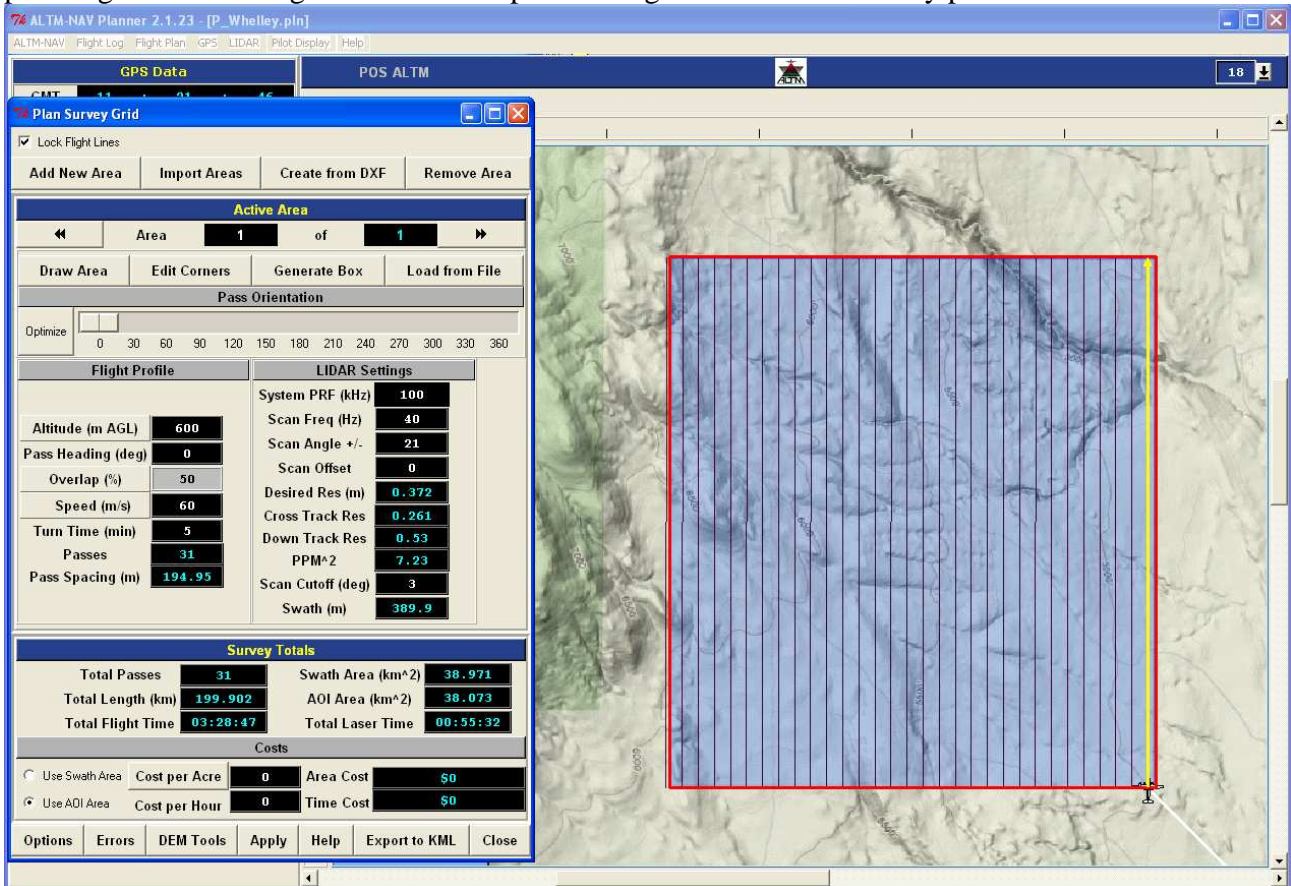


Figure 3 Flight lines from the planning software

Survey parameters are given below in Table 3.

Survey Parameters		Survey Totals	
Altitude (m)	600	Total Length (Km)	200
Swath Width (m)	400	Swath Area (Km ²)	39
Overlap (%)	50	Area of Interest (Km ²)	38
Laser PRF (kHz)	100	No. of Passes	31
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 as a part of Seed Money Survey Campaign that took place in Aug-Sept 2009. This section was surveyed on Sept 9, 09(Day of the Year 252). The airport used was Ukiah Municipal Airport in Ukiah California. The total flight time was 3 hrs and the total Laser on time was 1 hrs 8 min.

Three GPS reference stations, all of them part of the CORS (Continuously operated Reference system) network were used during the survey. The list of the station 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	Lat	Long
P645	37.5412	-118.5934
P651	37.5631	-118.3869
P724	37.4394	-118.5610

Table 4 Ground Control Stations

5. Data Processing

5.1. GPS & INS Navigation Solution.

Reference coordinates for the stations were obtained from the CORS website. The GPS data required for differential processing was also downloaded from their website. For further 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 are created using all the above four mentioned ground control stations. These trajectories are then differenced to determine the best solutions. Figure 3 shows the plot for positional difference between trajectories obtained from P651 and P724. The table below gives the mean and standard deviation of the differences between the two trajectory positions.

	Easting	Northing	Up
Mean (m)	-0.007	0.020	0.012
Standard dev.(m)	0.006	0.007	0.014

Table 5 Mean and Standard Deviation for positional differences between the two trajectories

Positional Differences in Aircraft Trajectory

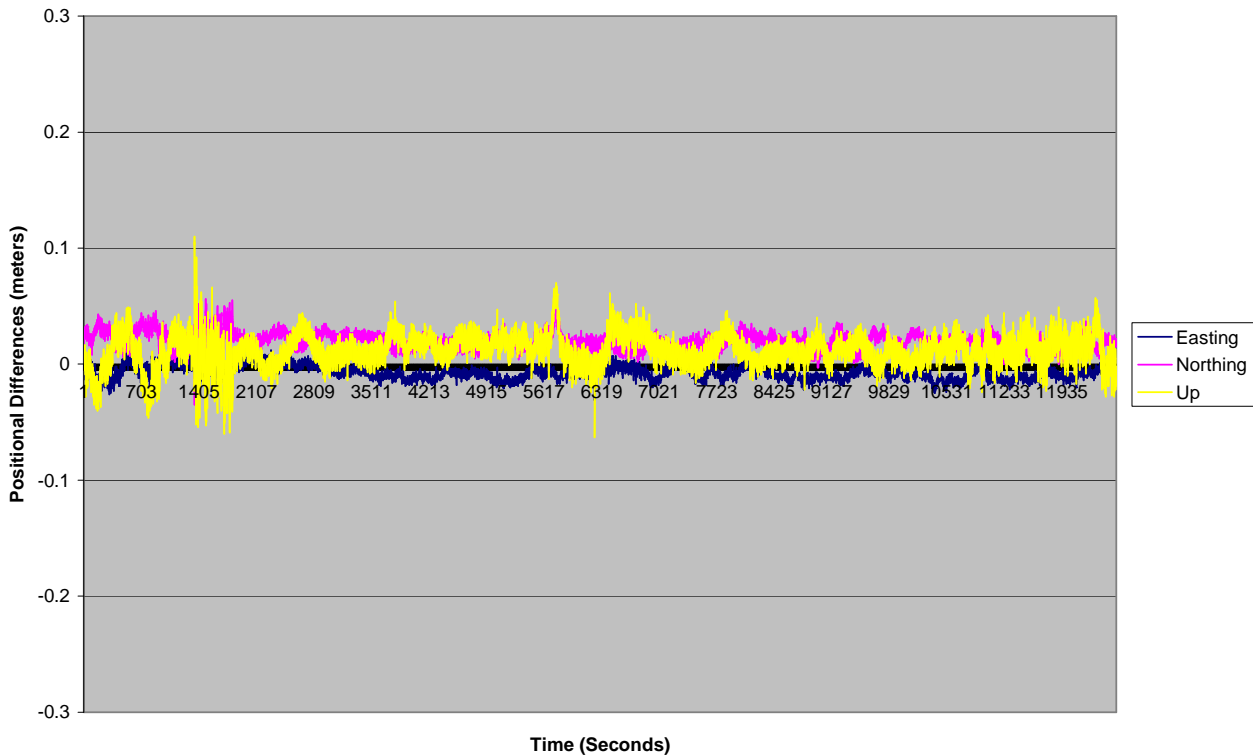


Figure 3 Positional differences between the two trajectories

After GPS processing, the 1Hz differential GPS trajectory and the Inertial Measurement Unit (IMU) data 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 11, 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 9 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 the TerraMatch report for the calibration site:

```
Used loaded points
Trajectories: E:\09_252_Whelley\TerraScan\trj
No known points
Observe every 1th point
Solution for whole data set

Starting dz RMS:      0.0442
Final dz RMS:        0.0376

Standard error of unit  0.0168

Execution time: 16259.1 sec
Number of iterations: 21

Points      16449509
H shift     +0.0028      Std dev  0.0002
R shift     +0.0024      Std dev  0.0001
P shift     -0.0069      Std dev  0.0001
Scale       -0.00039
```

Absolute Calibration was done by establishing a calibration site consisting of 768 check points surveyed with vehicle-mounted GPS over a taxiway at the Ukiah Municipal Airport.). The road containing these check points 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. No systematic height bias was found.

5.4 Classification and Filtering

TerraSolid's TerraScan software was used to classify the raw laser point into the following categories: ground, non-ground (default), aerial points and low points. The processing is done by dividing each section into 1000m X 1000m tiles. A macro containing the classification steps is created, which is run on each tile with a 40 m buffer. This overlap ensures consistent results for corners and edges of the tile.

Various classification algorithms which were used are given below:

1) Isolated Points: This routine classifies points which do not have very many other points within a 3D search radius. This routine is useful for finding isolated points up in the air (fog) or below the ground (multipath). When possibly classifying one point, this routine will find how many neighboring points there are within a given 3D search radius. It will classify the point if it does not have enough neighbors.

2) Air points: It classifies points which are clearly higher than the median elevation of surrounding points. It can be used to classify noise up in the air. When possibly classifying one point, this routine will find all the neighboring source points within a given search radius. It will compute the median elevation of the points and the standard deviation of the elevations. The point will be classified only if it is more than a certain limit (user defined) times the standard deviation above the median elevation. Comparison using standard deviation results in the routine being less likely to classify points in places where there is greater elevation variation.

3) 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 than 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. Input parameters used were:

4) 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.

Ground classification parameters used:

```
Max Building Size (window size): 20.0 m
Max Terrain Angle: 88.0
Iteration Angle: 6.0
Iteration Distance: 1.4 m
```

5) Classify By Height Above Ground: It classifies points which are within a given height range compared to the ground points surface model. The routine requires that you have already classified ground points successfully. This routine will build a temporary triangulated surface model from ground

points and compare other points against the elevation of the triangulated model. This routine was used to filter out the noise because of clouds hovering above the ground surface around a constant altitude.

6) Classify Below Surface: This routine classifies points which are lower than neighboring points in the source class. This routine was run after ground classification to locate points which were below the true ground surface

The use of these classification algorithms depends on the nature of topography, vegetation characteristics and extent of urbanization.

The flight strip point cloud files were tiled into 63 1 kilometer square blocks, illustrated in the figure below. The clean-up and classification algorithms were run as a macro on each tile with a buffer of 40m from the neighboring blocks in order to ensure consistent results across tile boundaries.

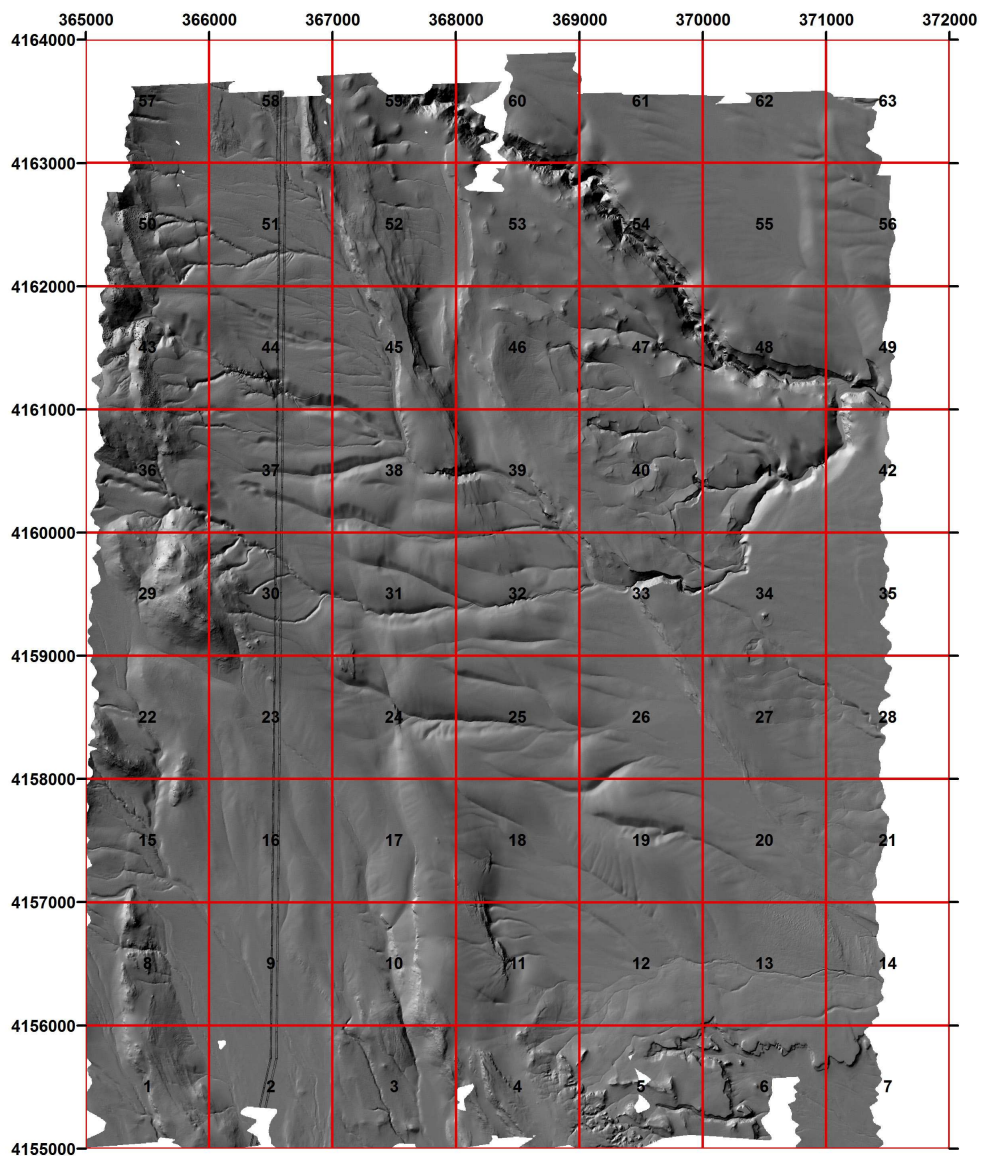


Figure 4 - Tile footprints overlaid on the unfiltered shaded relief map.

5.5 DEM production

After classification two separate sets of overlapping (40m overlap) data tiles were outputted in ASCII XYZ format: one for the ground points (filtered) and one for ground and non-ground points combined (unfiltered). The ASCII tiles were gridded using Kriging interpolation at 1m cell size resolution using Golden Software's SURFER ver. 8.01. The tile overlap is required in order to obtain a consistent surface transition from one tile to the adjacent ones when merged.

The following parameters were used for Kriging:

```
Variogram type: Linear
Nugget Variance: 0.15 m
MicroVariance: 0.00 m
SearchDataPerSector: 7
SearchMinData: 5
SearchMaxEmpty: 1
SearchRadius: 5m (unfiltered), 40m (filtered)
```

The resulted Surfer binary grids were converted to ArcInfo raster format and mosaicked together into a seamless DEM using in-house Perl and AML scripts. Two separate mosaics were produced: one for the bare-earth surface (filtered) and one for the unfiltered (default) surface.

6. File Formats and naming conventions

The point cloud files are delivered in the 1000mX1000m tiles in LAS 1.1 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.

The complete LAS 1.1 specification can be found at this address:

http://liblas.org/raw-attachment/wiki/WikiStart/asprs_las_format_v11.pdf

The point classes used for this project are slightly different from the ASPRS list found in the LAS 1.1 specification. The following values can be found in the LAS Classification field:

- 1 - unclassified
- 2 - ground
- 7 - low point
- 9 - aerial point
- 10 - isolated point

The file naming convention for the LAS tiles is the following: pXXXXXX_YYYYYYY.las, where (XXXXXX, YYYYYYY) is the lower left corner tile coordinate in UTM projection.

Raster grids are delivered in ArcInfo grid and hillshade format as 10KM mosaics. In case 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 11N. The elevations are NAVD88 orthometric heights computed using the NGS GEOID 03. All units are in meters.