2009 San Gabriel Mountains Fire

Airborne Lidar Data Collection and Processing Report

Survey conducted by NCALM for investigators Arjun Heimsath and Kelin Whipple, Arizona State University; Michael Lamb, California Institute of Technology; and Ken Hudnut, U.S. Geological Survey, through funding from their institutions to investigate tectonics and geomorphology of the San Gabriel Mountains, California.

POC: Arjun Heimsath, Associate Professor, School of Earth & Space Exploration, Arizona State University - (480)965-5855 Arjun.Heimsath@asu.edu

Data Products Summary:

Horizontal / Vertical Datum:	NAD83 / NAVD88 (GEOID03)
Projection / Units:	UTM Zone 11N / meters
Project/Raster Sections:	2 Sections designated Low (~321.4 km²) and High (89.6 km²)
Point Cloud Tiles:	418 total (325 low + 93 high) 1000 m × 1000 m tiles in LAS format (Version 1.0), classified into ground and non-ground (Default Class). Nominal laser pulse density 3.2-4.5 laser pulses /m²
Bare-Earth Elevation Model:	ESRI FLT format @ 1 m grid spacing from classified ground returns
Bare-Earth Hillshade:	ESRI created raster @ 1 m grid spacing using parameters (315° Azimuth, 45° Elev).
First-Surface Elevation Model:	ESRI FLT format @ 1 m resolution based only on first returns.
First-Surface Hillshade:	ESRI-created raster @ 1 m grid spacing using parameters (315° Azimuth, 45° Elev).

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 two survey areas are both irregular polygons. The first polygon (A.K.A the lower box) was +/-27 km long, +/-10.5 km wide and enclosed +/-282 square km. It is centered roughly on San Gabriel Peak, 14 km due north of Pasadena, CA, and contained the Mt Wilson Observatory and a portion of the Angeles Crest Highway.

The second polygon (A.K.A the higher box) was +/-13 km long, +/-5.5 km wide and enclosed +/-67 square km. It is centered roughly on Mt Hawkins, 27 km due north of San Dimas, CA, and contained portions of both the Pacific Coast Trail and the Angeles Crest Highway. Both survey polygons are shown below (outlined in green) in a screen capture from Google Earth (Figure 1), and in a screen capture from DeLorme Topo USA software (Figure 2).

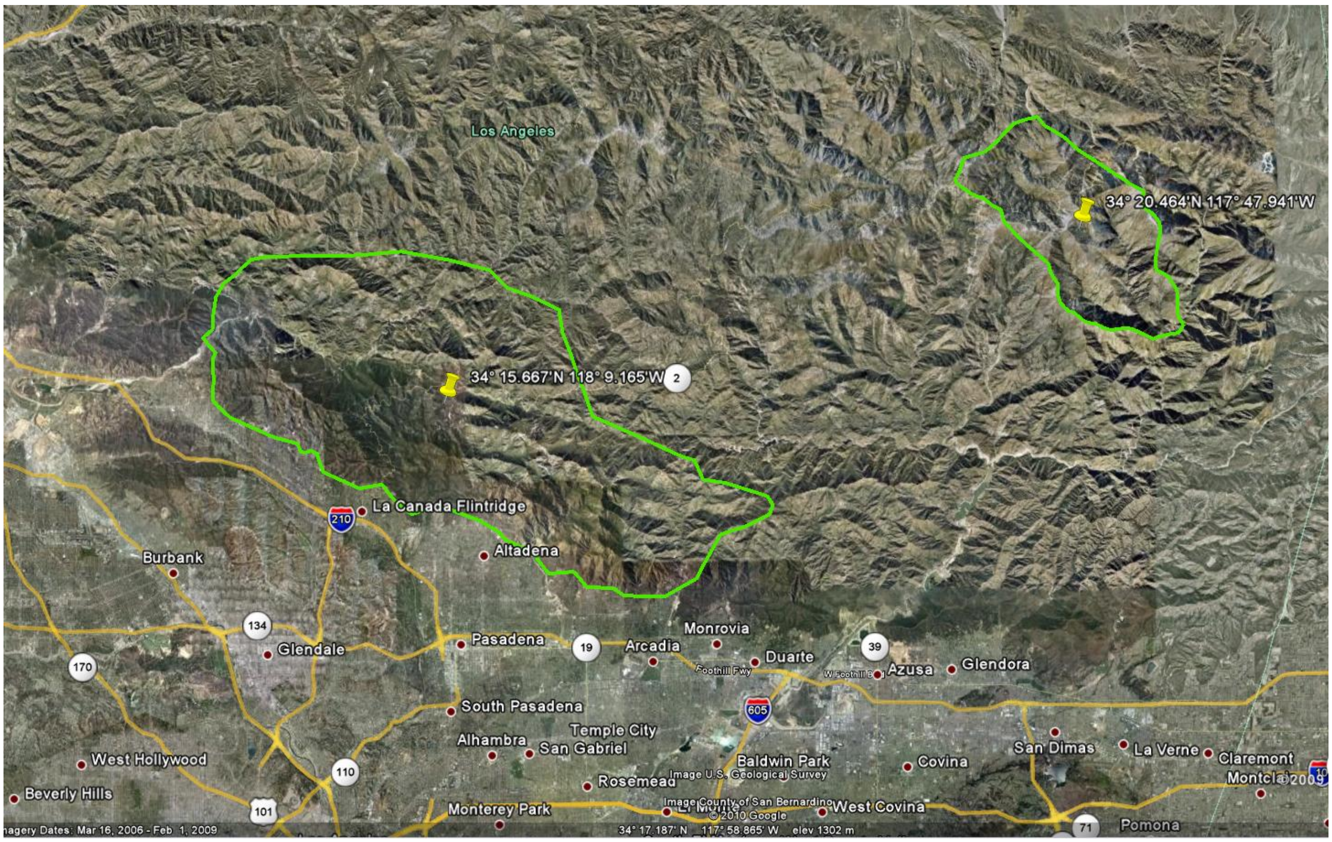

Figure 1 – Google Earth screen capture: Shape and location of the survey polygons. Total area = 349 km square.

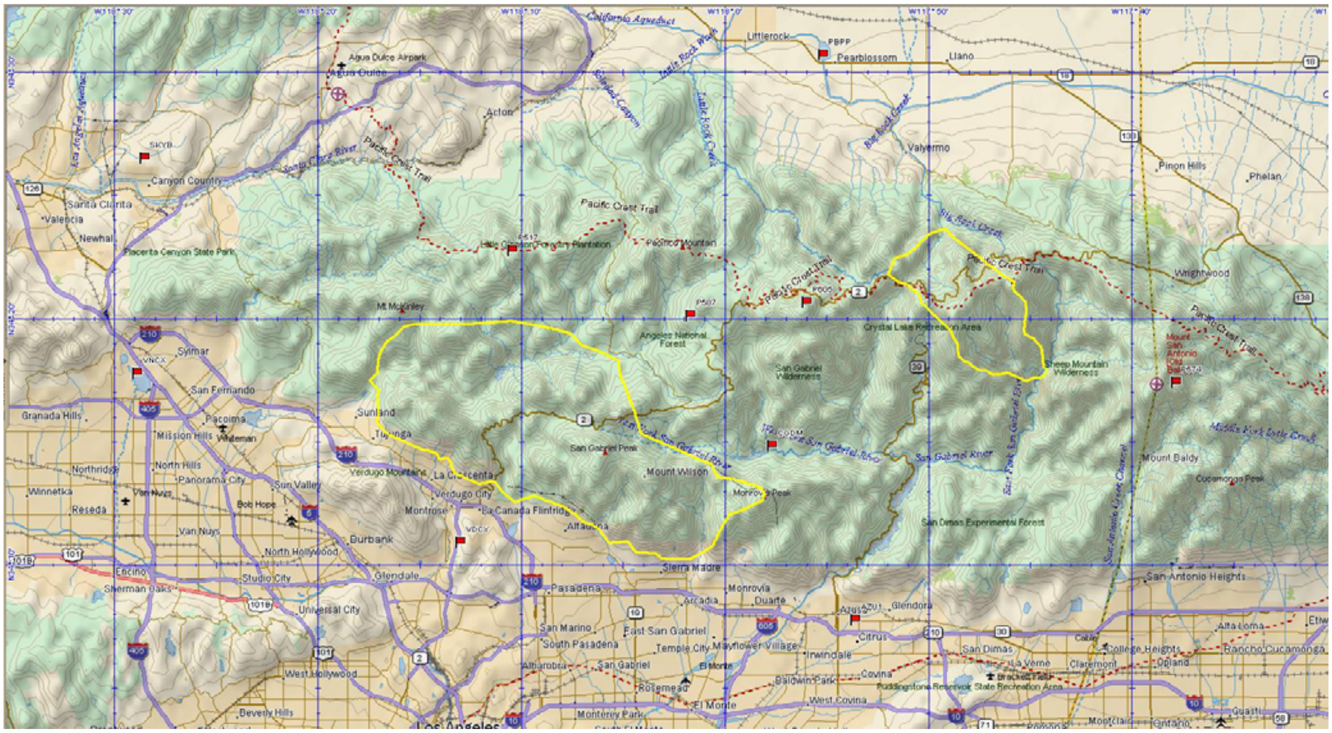

Figure 2 – DeLorme TOPO USA screen capture: Survey polygons and locations of PBO CORS (red flags).

3. Survey Times

This survey was flown in four survey flights on four consecutive days beginning on Sept 28, 2009 (day-of-year 271), with the final flight occurring on Oct 01, 2009 (day-of-year 274). The survey required a total of 9.3 hours of laser-on time and 19.17 hours of total flying time.

The individual flights are summarized below in Table 2.

Flight #	Date	GMT Begin	GMT End	Laser-On Time	Area Flown
1	28 Sept 2009	19:40	01:10	1.9	High box
2	29 Sept 2009	18:30	24:00	3.0	Low box
3	30 Sept 2009	17:40	22:20	2.3	Low box
4	01 Oct 2009	17:40	21:10	2.1	Low box

Table 2 – Flight dates and times.

Local time is PDT (Pacific Daylight Time) and is equal to GMT – 7.0 hours.

Survey Parameters

The high box survey required 34 flight lines shown below in Figure 3.

The low box survey required 64 flight lines shown below in Figure 4.

Flight parameters for the both surveys were the same except for the Pulse Rate Frequency (PRF) which was 70 KHz for the low box but had to be limited to 50 KHz for the high box due to the severe slopes.

Rapid ground slope changes cause rapid changes in the laser ranges measured from the aircraft. This limits the useable PRF due to the restriction of having only one laser pulse in transit at a time: two pulses in the air simultaneously often lead to timing and range errors in spite of the multi-pulse capability of the Gemini ALTM.

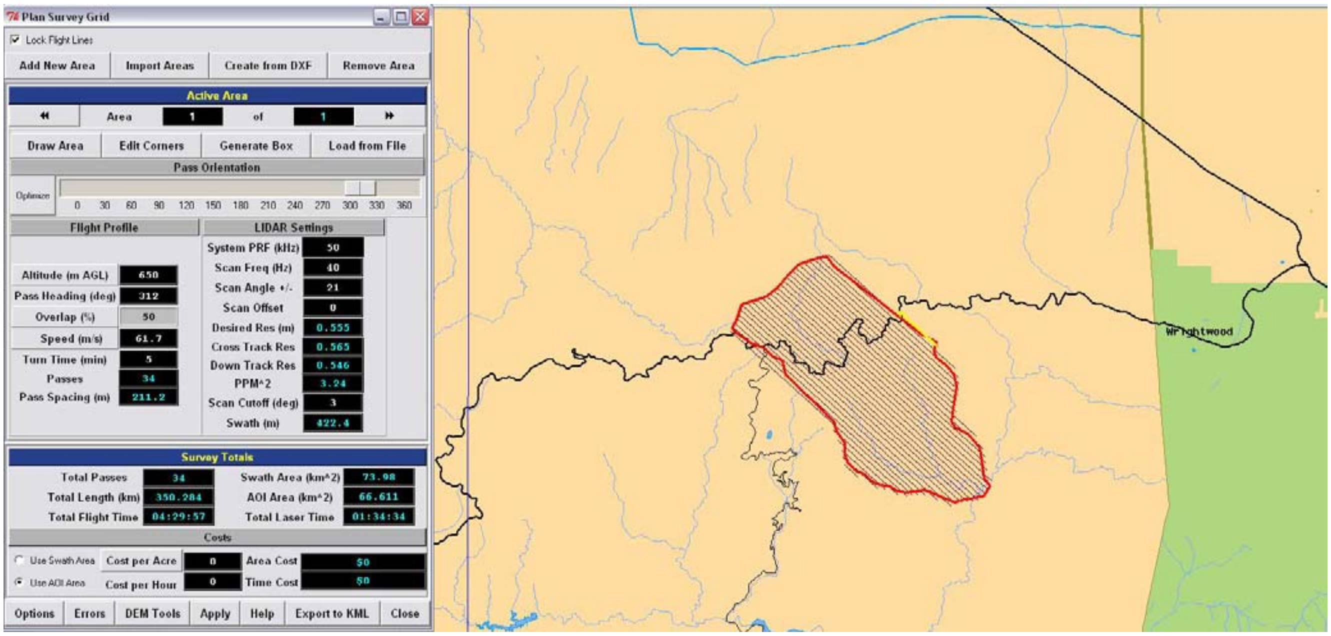

Figure 3 - high box flight lines and survey parameters.

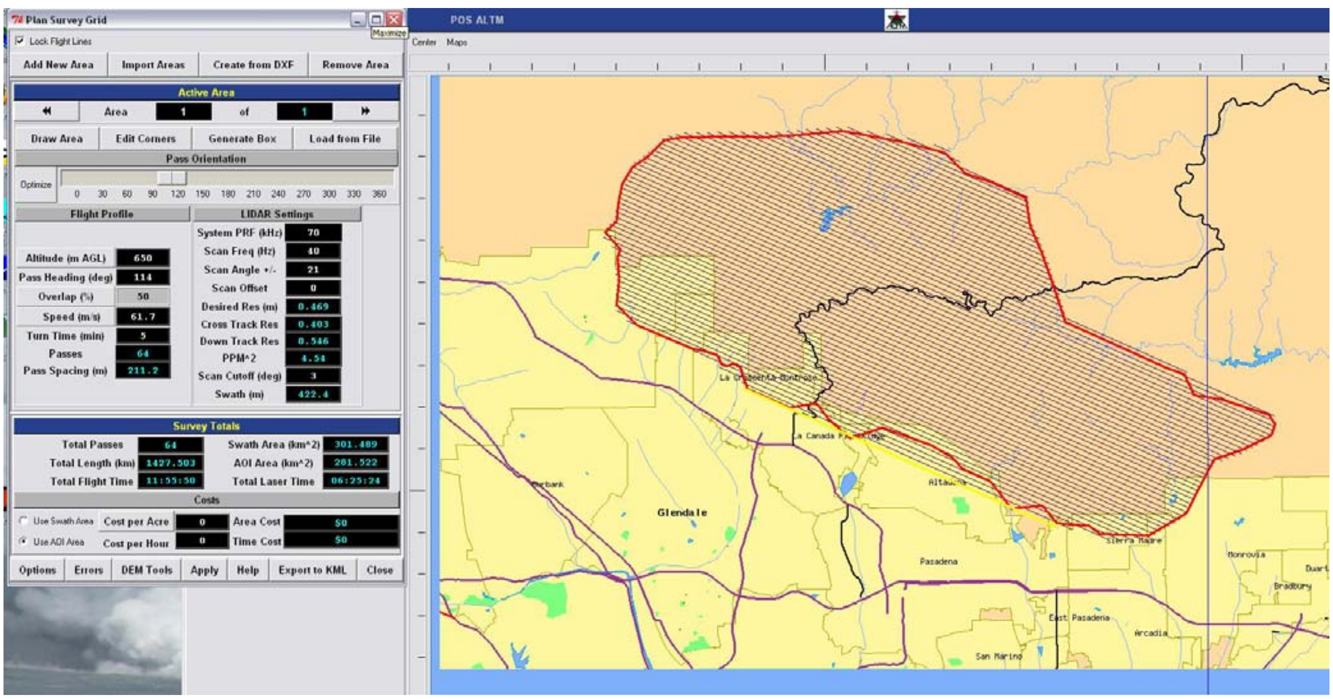

Figure 4 - low box flight lines and survey parameters.

Note that the swath width of a single pass is 422 meters (nominal), and that line spacing was planned at 211 meters.

Planned overlap was 100% (50% side-lap) or 211 meters per swath. Pulse rate frequency was set at 70 KHz. for the low box and 50 KHz for the high box.

Point density over land averaged approximately 3.1 points per square meter before classification.

Survey totals appear below in Table 3.

Survey Totals	
Total Passes	98
Total Length	1777.8 km
Total Flight Time	19.2 hrs
Total Laser Time	9.3
Total Swath Area	375.5 km^2
Total AOI Area	348.1 km^2

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

LiDAR settings are shown below in Table 4.

LiDAR Settings	
Scan Frequency	40 Hz
Scan Angle	+/- 21 deg
Scan Cutoff	+/- 3.0 deg
Scan Offset	0 deg
System PRF	70 kHz & 50 KHz
Swath Width	423 m

Table 4 – LiDAR settings.

5. GPS Reference Stations

Nine GPS reference station locations were used during the survey, eight of these reference stations were PBO CORS logging at 1 Hz thanks to a special request granted by UNAVCO. The PBO station names and coordinates are listed below in Table 5. See Figure 2 (above) for an image of a map showing the locations of the PBO CORS.

	ECEF Coordinate			Latitude			Longitude			Height
PBO	**X**	**Y**	**Z**							
AZU1	-2472979.462	-4671337.945	3558107.843	34	7	33.66852	-117	53	47.35440	144.743
CGDM	-2475328.155	-4662294.280	3569248.583	34	14	38.37521	-117	57	53.80475	704.697
P517	-2489193.051	-4646692.087	3582087.059	34	22	34.91686	-118	10	39.25861	1959.175
P587	-2478484.892	-4655208.101	3577842.081	34	19	56.04018	-118	1	52.81249	1600.767
P605	-2470845.584	-4659402.644	3579118.959	34	20	28.05919	-117	56	11.99493	2419.720
PBPP	-2464204.734	-4649642.597	3593555.015	34	30	29.61756	-117	55	21.25730	901.951
VDCY	-2497836.477	-4654543.295	3563028.969	34	10	42.83696	-118	13	12.00013	318.188
VNCX	-2515892.449	-4636680.583	3573547.419	34	17	35.49625	-118	29	4.34382	328.595

Table 5 – PBO CORS coordinates for stations logging at 1 Hz and used as references for 1 or more flights of this survey. Coordinates in ITRF00 (EPOCH:2009.7474).

The ninth and final station (SDIM) was newly established by NCALM at Brackett Field. Coordinates appear below.

SDIM	-2465016.553	-4678282.082	3554774.475	34	5	20.0297	-117	47	6.11199	280.575

Reference coordinates for SDIM were derived from multiple 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 SDIM 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 for the Brackett Field station consisted of an ASHTECH (Thales Navigation) Z-Extreme receiver, with choke ring antenna (Part# 700936.D) mounted on 1.5-meter fixed-height tripods. The airborne receiver is an integrated GPS receiver module Trimble BD950, logging at 10 Hz.

6. Navigation Processing

All trajectories for this survey were processed using PosGNSS version 5.10.2421 (NovAtel Inc. 2008). This software uses the dual-frequency phase history files of multiple reference and one airborne receiver to determine a simultaneous multi-base fixed integer ionosphere-free differential solution.

After GPS processing, the trajectory and the inertial measurement unit (IMU) data collected during the flights were input into APPLANIX software POSPac MMS (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.

Figures 5 – 8 (below) are images of the aircraft trajectory for each of the four flights.

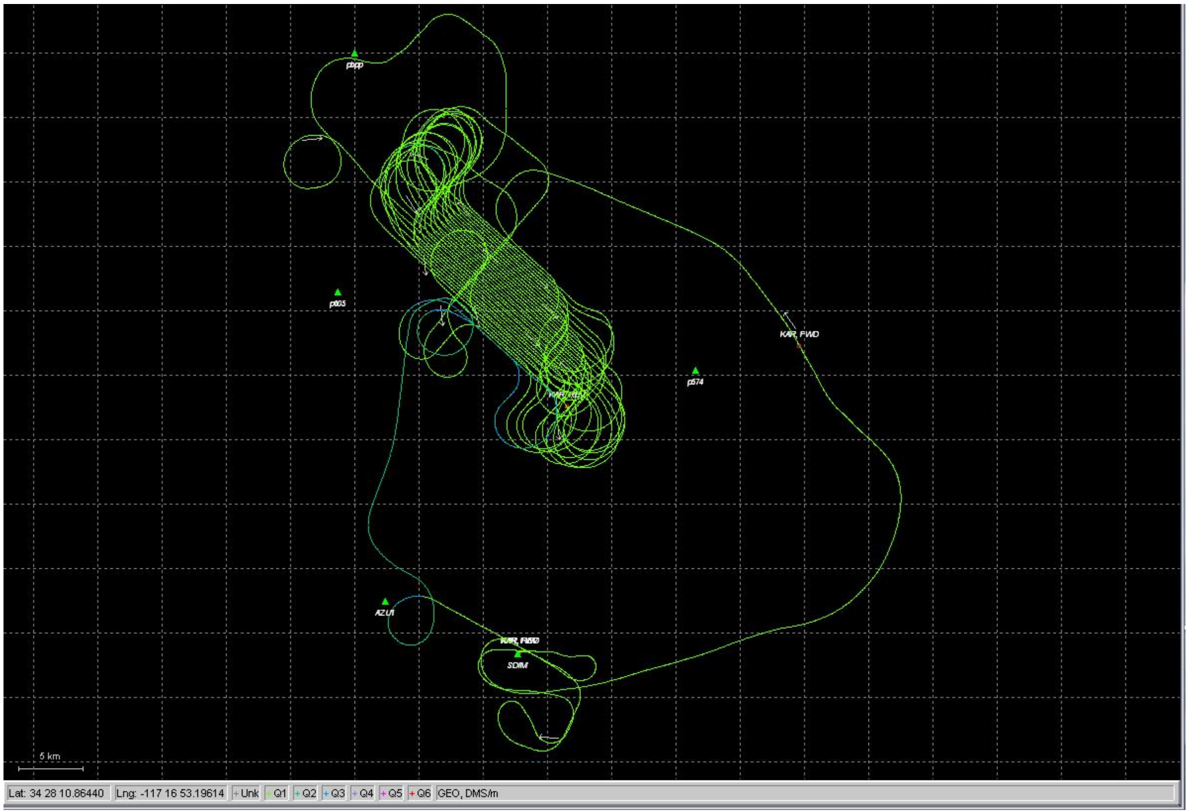

Figure 5 - Trajectory and reference stations for flight on day 271 – high box complete.

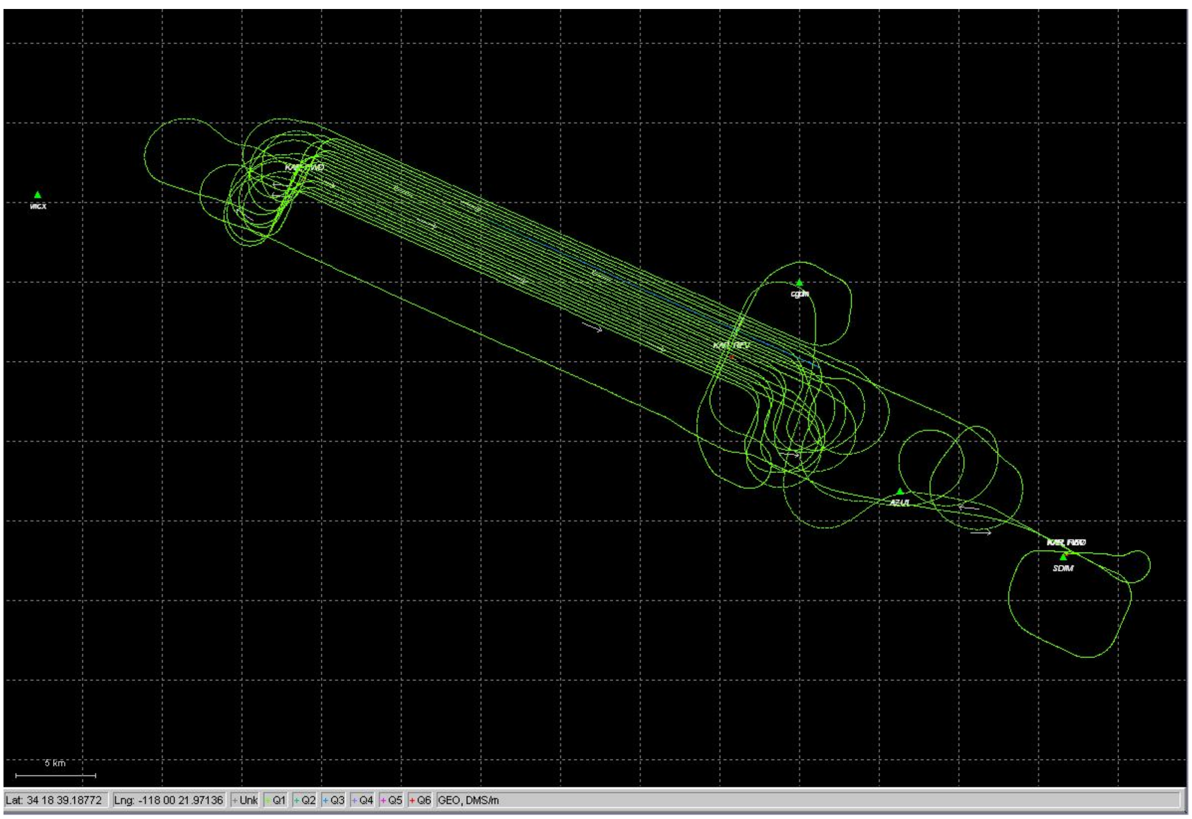

Figure 6 - Trajectory and reference stations for flight on day 272 – low box.

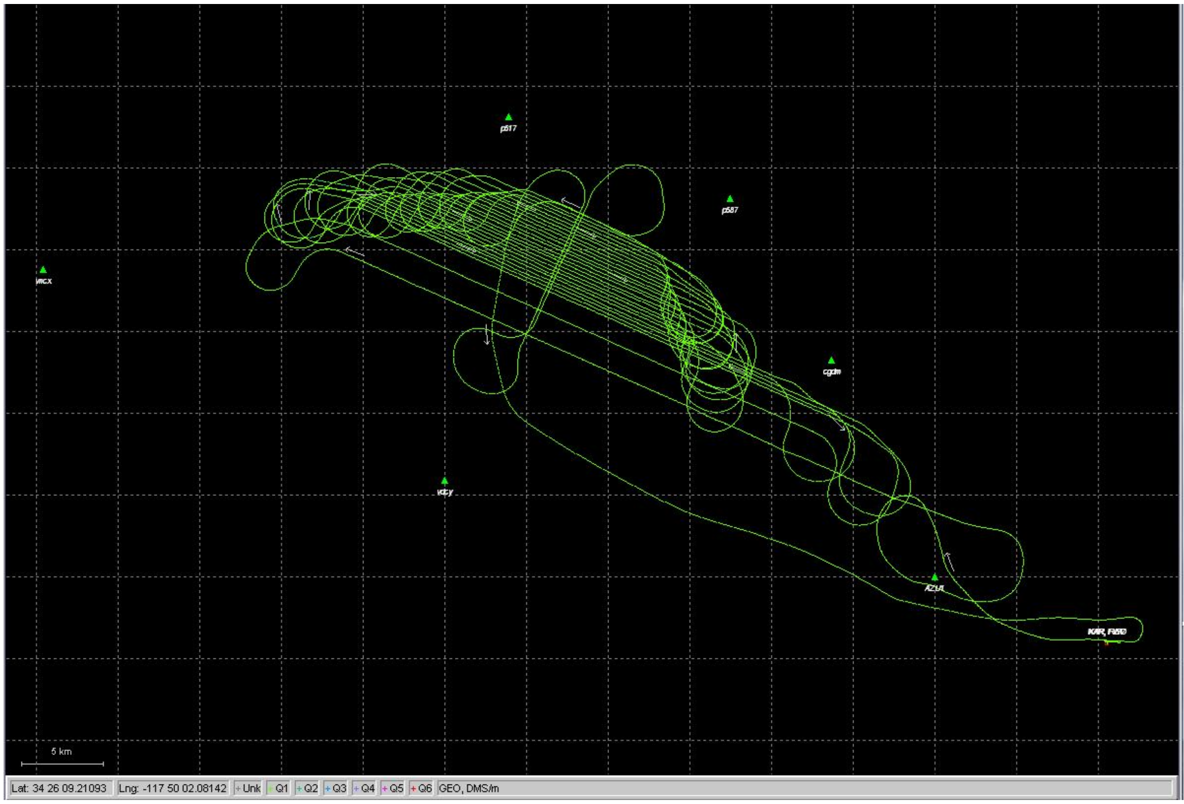

Figure 7 - Trajectory and reference stations for flight on day 273 – low box.

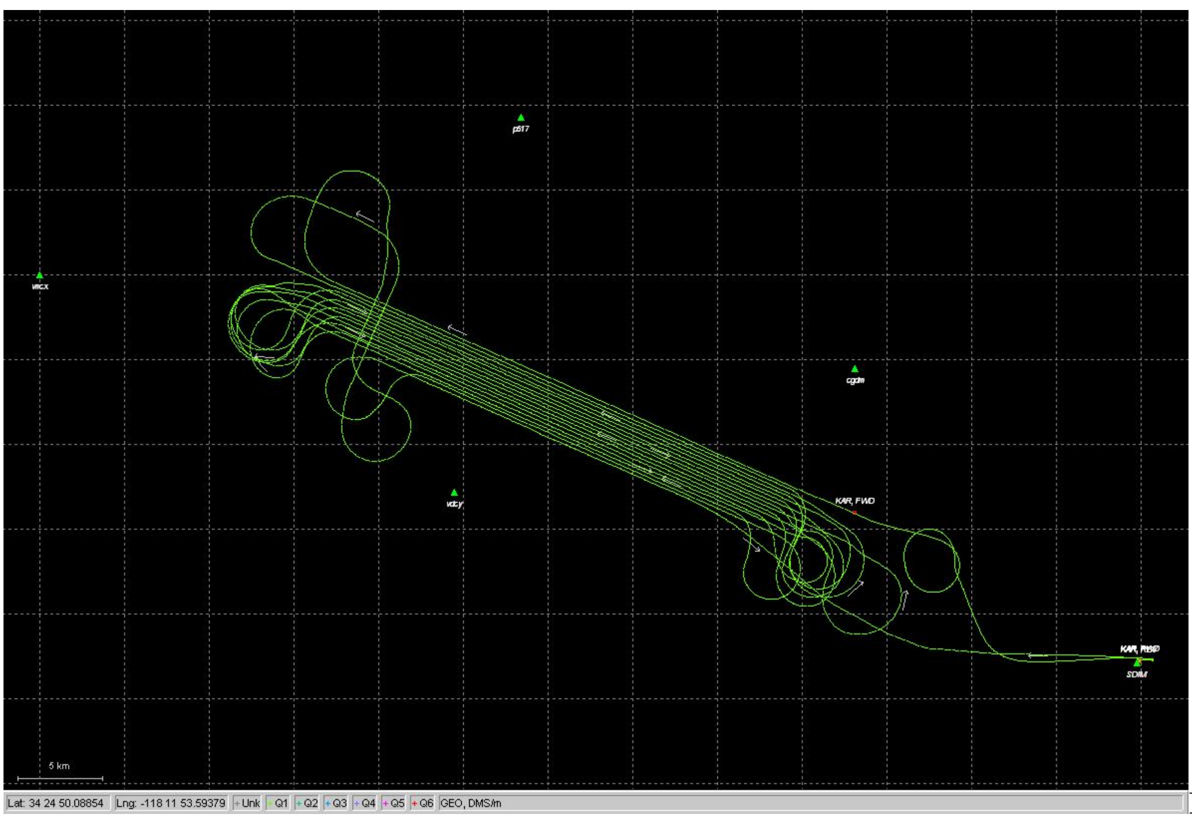

Figure 8 –

Figure 8 - Trajectory and reference stations for flight on day 274 – low box complete.

7. Calibration, Validation, and Accuracy Assessment

Two types of calibration procedures were used on this project: relative calibration and absolute calibration.

Relative calibration was computed for each flight by surveying crossing flight-lines over the project flight lines 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.

Absolute calibration was done by establishing a calibration site consisting of 575 check points surveyed with vehicle-mounted GPS over 0.9 kilometers of paved surfaces on Fairplex drive, a local road directly east of the Brackett Field. The section of road containing these check points was then surveyed with crossing flight lines using the ALTM. This was repeated on each survey flight.
The heights of several thousand LiDAR shots were compared with the height of their nearest-neighbor check point on the calibration surfaces over all of the 8 survey flights. The standard deviation of these height differences was consistent and averaged less than 0.050 meters.

8. Laser Point Processing

All coordinates were processed with respect to ITRF00, then shifted to NAD83 and referenced to the national CORS network. The projection is UTM Zone 11N, 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 422000 through 423000, and northing equals 3803000 through 3804000 then the tile filename is 422000_3803000. This is illustrated below in Figure 9 for the high box and Figure 10 for the low box.

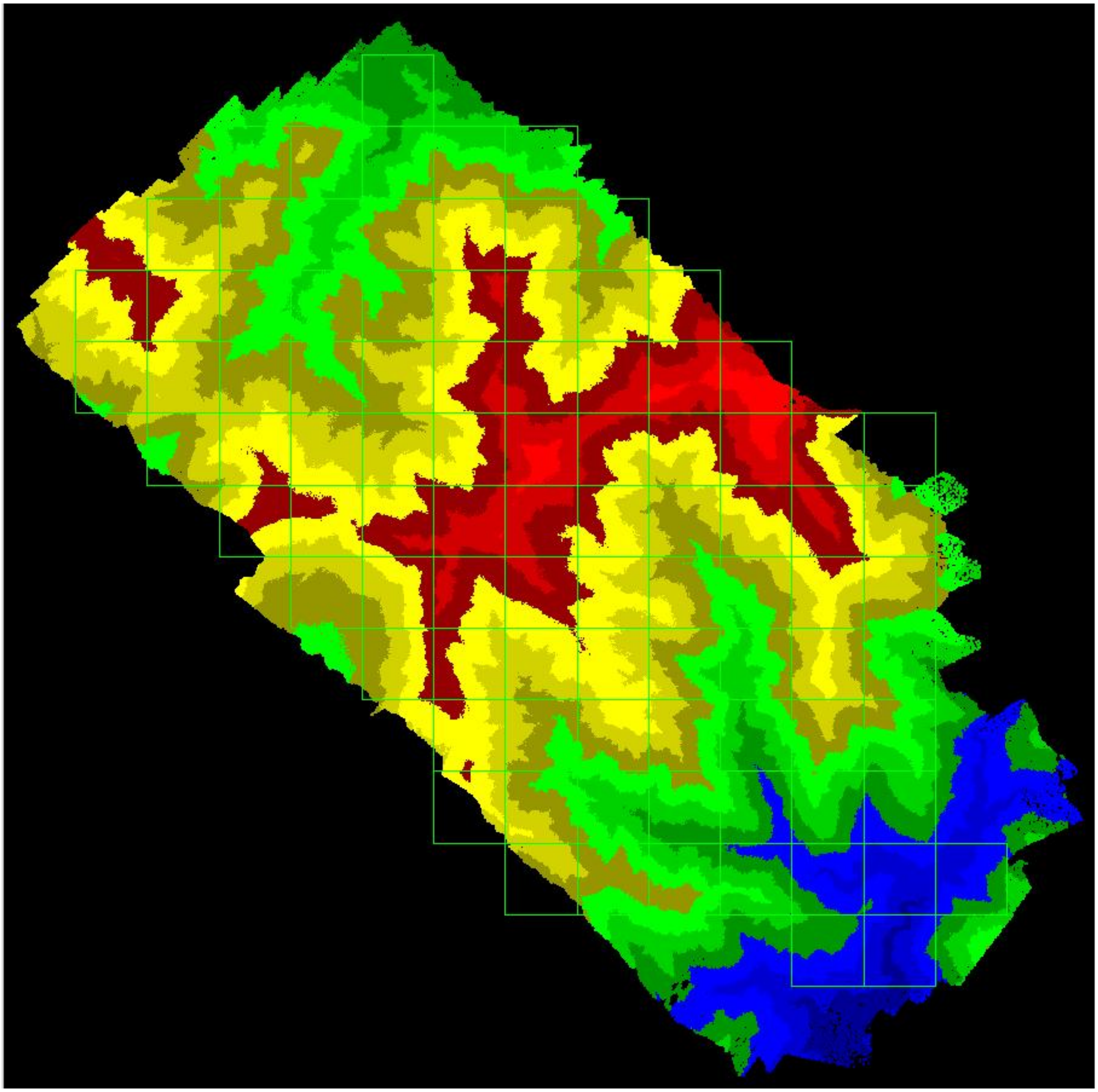

Figure 9 – 1 km tile footprints overlaid on the high box point cloud colored by elevation.

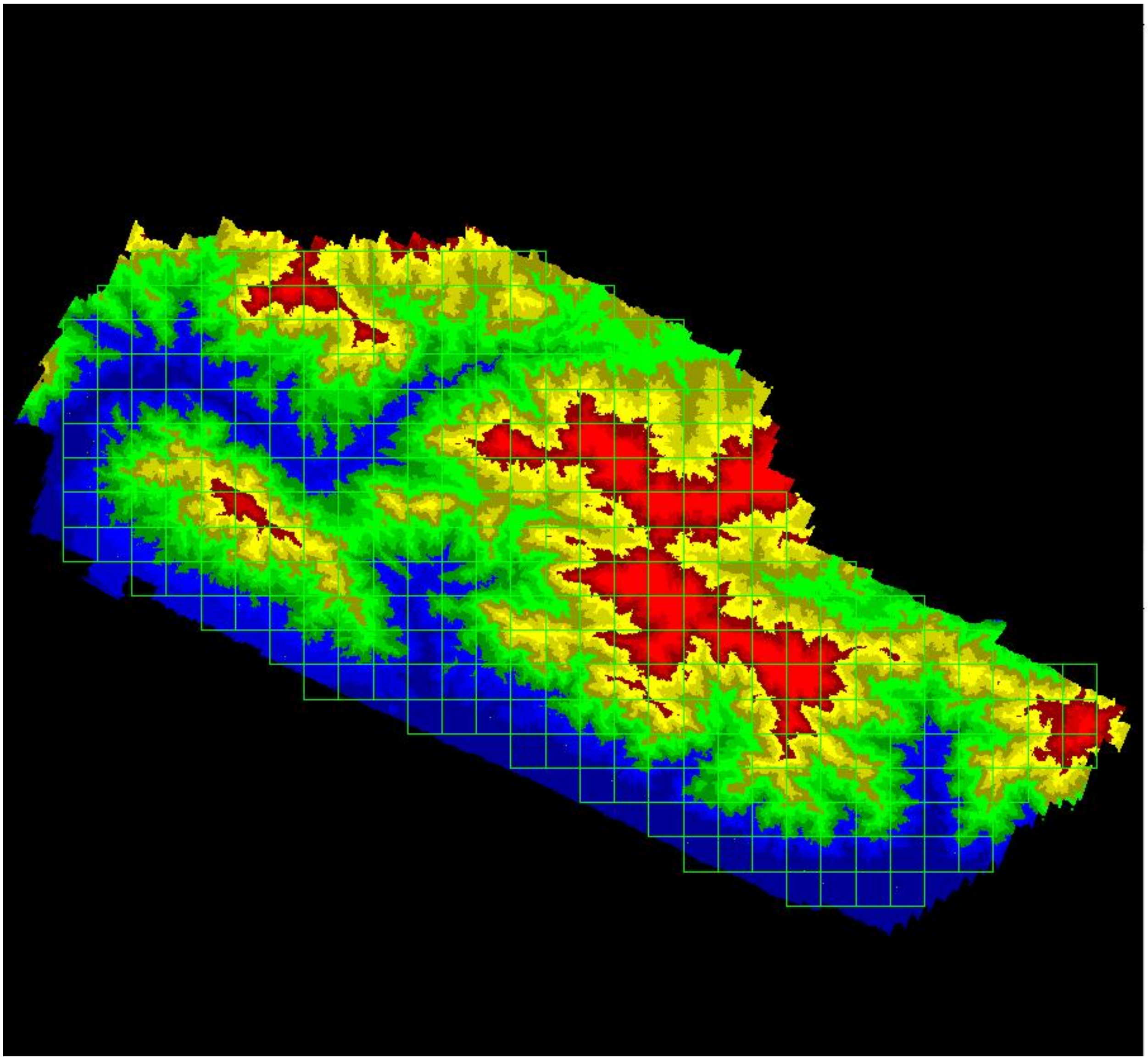

Figure 10 – 1 Km tile footprints overlaid on the low box point cloud colored by elevation.

During processing, a scan cutoff angle of 3.0 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. Classification

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.
Because of the large size of the LiDAR data the processing had to be done in tiles. Each survey segment was imported into TerraScan projects consisting of 1000m x 1000m tiles aligned with the 1000 units in UTM coordinates.

The classification process was executed by a TerraScan macro that was run on each individual tile data and the neighboring points within a 20m buffer. The overlap in processing ensures that the filtering routine generate consistent results across the tile boundaries.

The classification macros consist of a core of three algorithms:

1) *Removal of "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 then 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:

Search for: Groups of Points
Max Count (maximum size of a group of low points): 6
More than (minimum height difference): 0.3 m
Within (xy search range): 5.0 m

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.

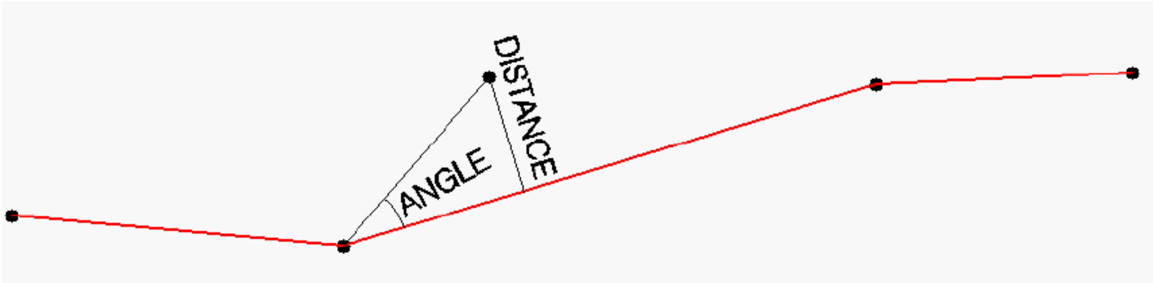

Figure 6 Ground classification parameters

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.

The various input parameters are
Max Building Size (window size): 10m
Max Terrain Angle: 89
Iteration Angle 10
Iteration Distance 1.6

These parameters depend on the properties of the area such as extent of urbanization, vegetation density and terrain (flat/rugged). 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.

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 will classify it into the target class.

Below Surface classification parameters used:

Source Class: Ground
Target Class: Low Point
Limit: 8.00 * standard deviation
Z tolerance: 0.10 m

10. DEM Production

The point data is output from TerraScan in 1000m x 1000m tiles, with 20m overlap. Two sets of files are generated, in XYZ ASCII format: filtered (ground class) and unfiltered (ground and "default" classes). In the unfiltered dataset the outlier classes are excluded from output (aerial and low points). The overlap is needed in order to generate a consistent interpolation across tile edges and it will be trimmed in the final tile DEMs.

The point tiles are gridded using Golden Software's Surfer 8 Kriging at 1.0m cell size, using a 5m search radius for the unfiltered point data and 10m for the filtered.

The gridding parameters are:
Gridding Algorithm: Kriging
Variogram: Linear
Nugget Variance: 0.15 m
MicroVariance: 0.00 m
SearchDataPerSector: 7
SearchMinData: 5
SearchMaxEmpty: 1
SearchRadius: 5m (unfiltered), 10m (filtered)

The resulting tiled Surfer grid sets are transformed using in-house Perl and AML scripts into ArcInfo binary seamless tiles at 1.0m cell size. Due to the large area covered by the segments and the ArcInfo software limitations it is not possible to create one large mosaic for the entire area so the 1.0m tiles are mosaiced at 1m resolution into 10Km wide segments.

11. Available Deliverables

Available deliverables include all of the following data products:

1. Flight Strips (LAS format).
2. 1 KM Tiles (LAS format) – per flight – classified and unclassified.
3. 1 KM Tiles (ASCII format) – per flight – classified and unclassified.
4. ESRI DEMs, (1m x 1m) -per flight - classified and unclassified.
5. Surfer Binary Grids, - per flight - classified and unclassified.