Meteor Crater, Az

A terrestrial analog to study gully formation on Mars

Mapping Project Report

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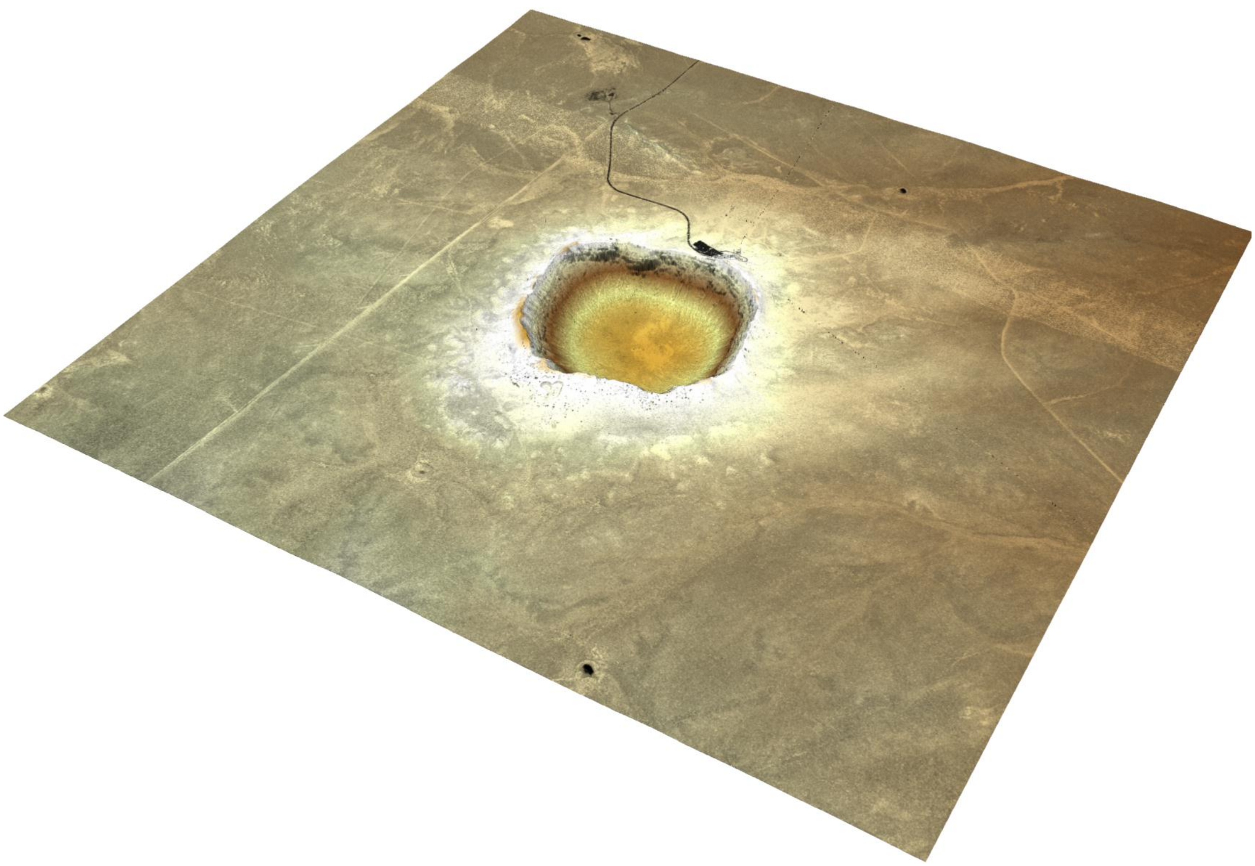

1. LiDAR System Description and Specifications

This survey was performed with an Optech GEMINI Airborne Laser Terrain Mapper (ALTM) serial number 06SEN195 mounted in a twin-engine Piper PA-31 (Tail Number N31PR). The instrument nominal specifications are listed in table 1 and Figure 1 show the system installed in the aircraft.

Table 1 – Optech GEMINI specifications.

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)

See http://www.optech.ca for more information from the manufacturer.
http://www.optech.ca/pdf/Brochures/ALTM-GEMINI.pdf

Figure 1 – NCALM Gemini ALTM installed in a Piper PA-31.

2. Description of PI's Areas of Interest.

The survey area is a rectangular polygon, roughly 5.44 km on a side, enclosing the Barringer Meteorite Crater and its ejecta blanket. The project area is located 60 km southeast of Flagstaff, AZ and 30 km west of Winslow, Az. The polygon has a surface area of 29.7 km²; the requirement indicates two point densities one for the crater walls and rim of 8 pts/ m², and one for the surrounding area of 4 pts/m².

Figure 2 – Shape and location of survey polygon (Google Earth).

3. Airborne Survey Planning and Collection

To achieve the required dual point density scheme and to maximize the possibility to map the crater walls, flight lines for two polygons were planned. The polygons are squares: one defined by the original AOI and a second one with a 2.2 km on a side co-centered with the crater. The flight lines of the main polygon are oriented east to west and the lines for the smaller polygon are oriented north to south. The orthogonal lines over the crater double the nominal point density and reduce the effects of shadowing by the crater walls. The survey planning was performed considering nominal values of 600 m for flight altitude above the terrain, a mean flying speed of 65 m/s and a swath overlap of 50%.

Because the objective of the project is to accurately map the relatively small gully features, laser Pulse Repetition Frequency (PRF) was set at 70 kHz to balance the requirements of point density and accuracy. The scan angle (Field-of-View or FOV) was limited to ± 21 degrees and the scan frequency (mirror oscillation rate) was set to 40 Hz to ensure a uniform across-track and along-track spacing and a scan product (frequency x angle) within 75-80% of system maximum of 1000). The beam divergence was set to narrow divergence (0.25 mrad). Figure 3 shows the project polygons and the planned flight lines, the nominal flight parameters, equipment settings and the survey totals are summarized in Table 2.

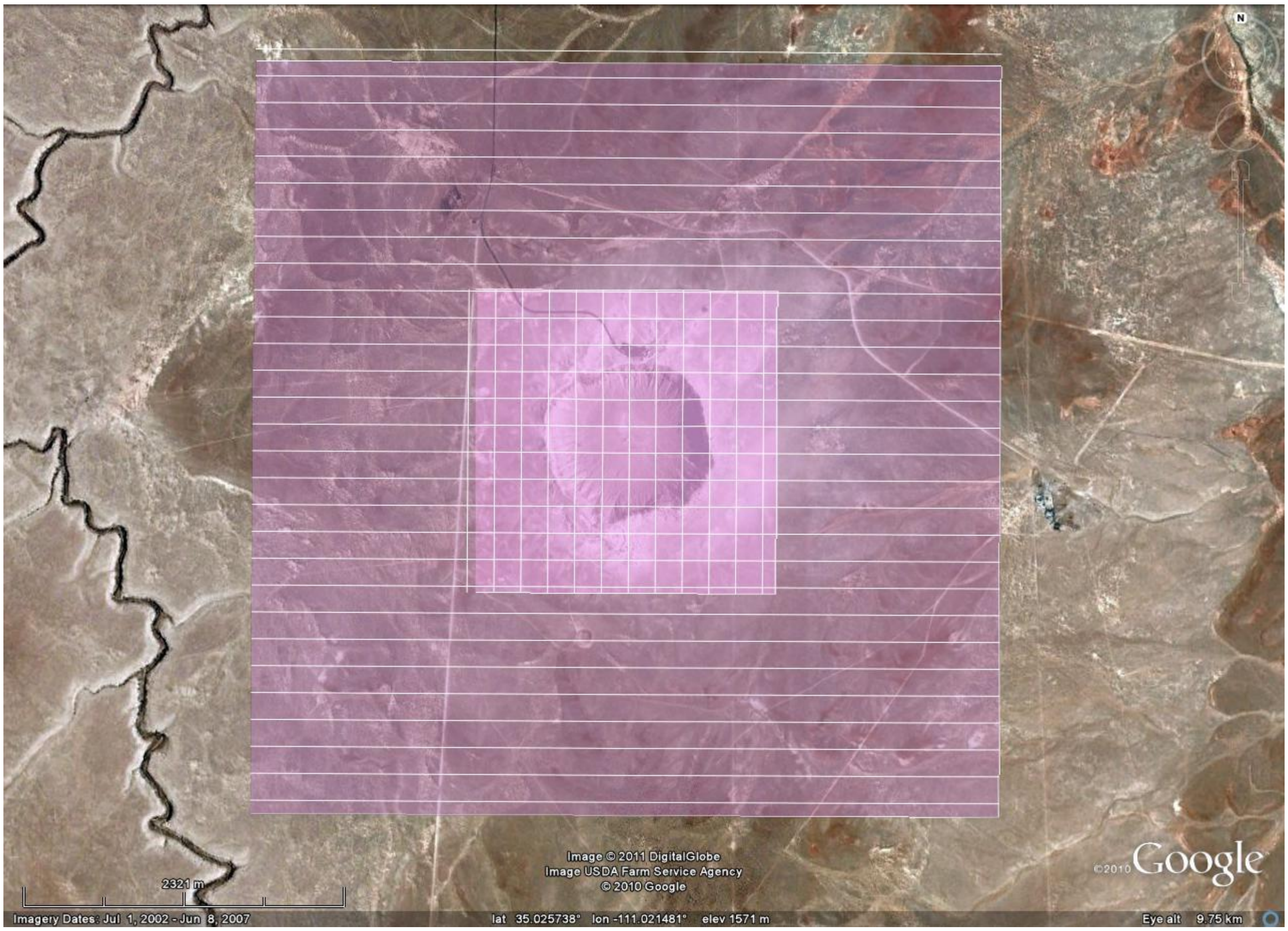

Figure 3. Project area of interest and planned flight lines.

Table 2 – Survey totals. Area of Interest is abbreviated AOI.

Nominal Flight Parameters		Equipment Settings		Survey Totals			
Flight Altitude	600 m	Laser PRF	70 kHz	Areas	Total	A	B
Flight Speed	65 m/s	Beam Divergence	0.25 mrad	Passes	41	12	29
Swath Width	389.9 m	Scan Frequency	40 Hz	Length (km)	184.06	26.42	157.64
Swath Overlap	50%	Scan Angle	± 21°	Flight Time (hr)	4.10	1.05	3.05
Point Density	4.68 p/m²	Scan Cutoff	± 3°	Laser Time (hr)	0.79	0.11	0.67
Cross-Track Res	0.47 m	Scan Offset	0	Swath Area (km²)	35.884	5.151	30.733
Down-Track Res	0.46 m	Laser Spot Size	0.15 m@600	AOI Area (km²)	34.551	4.811	29.740

This survey was flown on March 12, 2010 (DOY 71) in a single flight collecting data for consisting 41 mapping strips. The total flight time was 4.16 Hrs, with a total Laser on Time (LOT) of 1.11 Hrs.

Three GPS reference station were used during the survey, all set up by NCALM. One was located on the grounds of the Winslow-Lindbergh Regional Airport (WINS), and the other two located near the survey polygon (CRAT and BRAT). Figure 4 shows the location of the GPS stations with respect to the project polygon and their coordinates are presented in Table 3. All reference GPS observations were logged at 1 Hz using of ASHTECH Z-Extreme receivers with choke ring antennas (Part# 700936.D) mounted on 1.3-meter fixed-height tripod. The airborne receiver is an integrated GPS receiver module Trimble BD950, logging at 10 Hz.

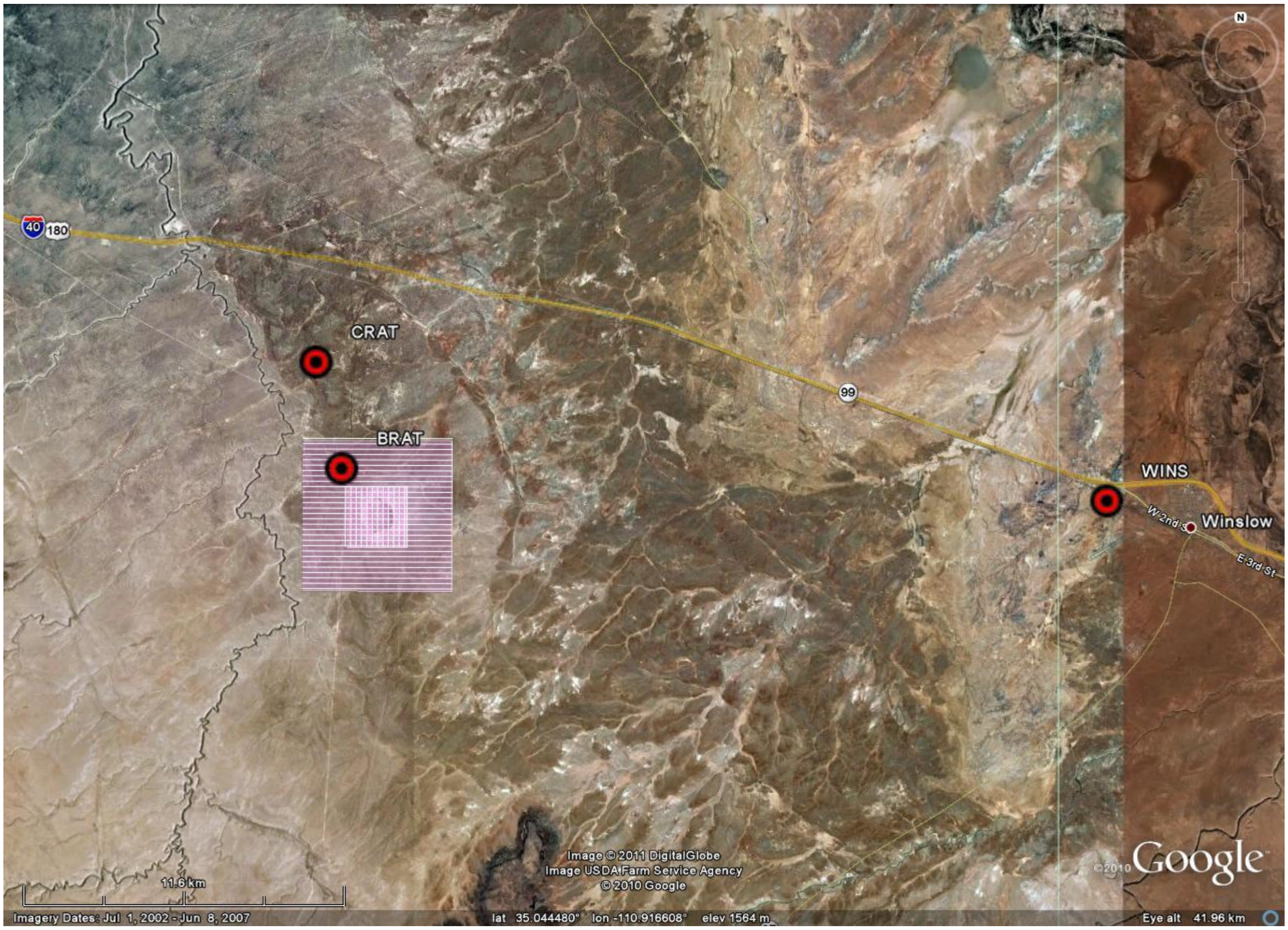

Figure 4. Location of the GPS stations used to derive the aircraft trajectory.

Table 3. Coordinates of GPS stations used to derive aircraft trajectories.

GPS station	BRAT	CRAT	WINS
Operating agency	NCALM	NCALM	NCALM
Latitude	35.033529	35.068290	35.023379
Longitude	- 111.022969	-111.033399	-110.716983
Ellipsoid Height (m)	1686.038	1644.974	1465.209

4. Data Processing and Final Product Generation.

The following diagram (Figure 4) shows a general overview of the NCALM LiDAR data processing workflow:

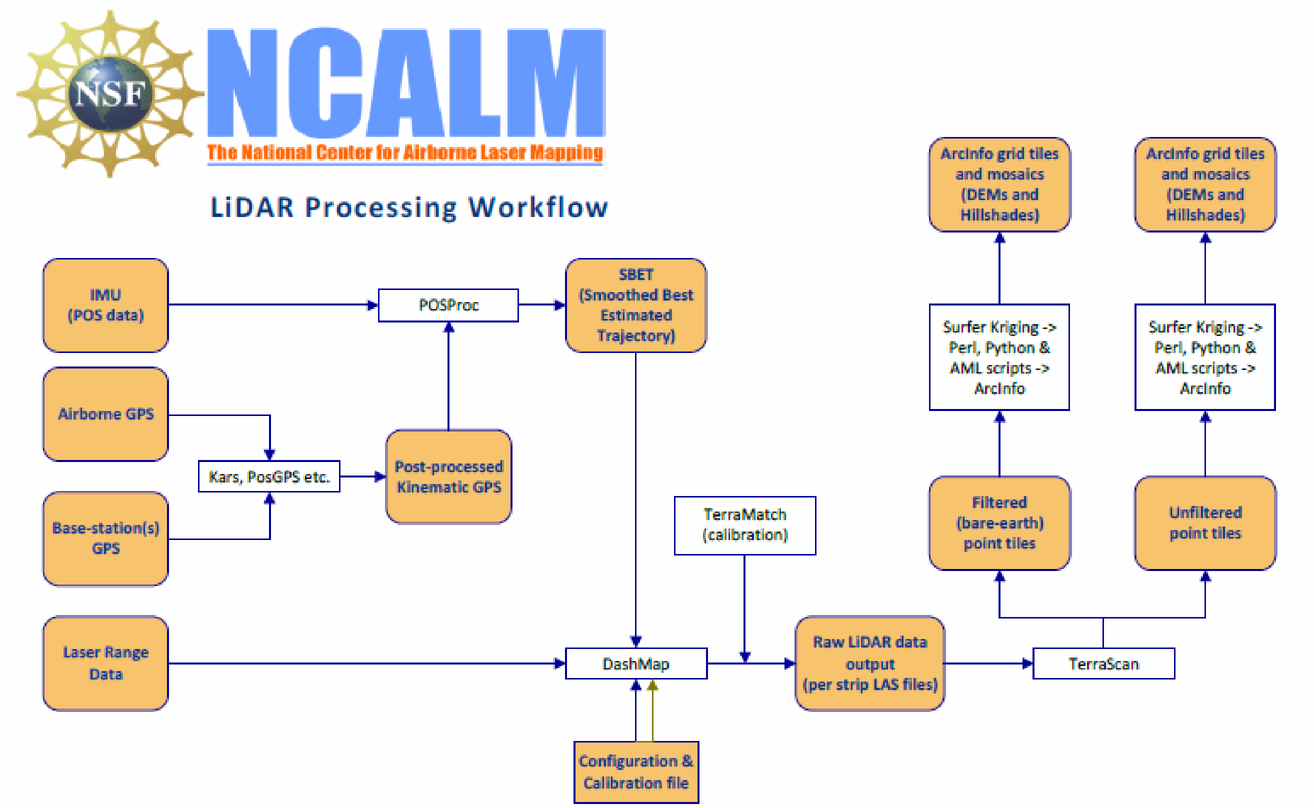

Figure 5 NCALM processing workflow

4.1. GPS & INS Navigation Solution.

Reference coordinates for all NCALM stations are derived from observation sessions taken over the project duration and submitted to the NGS on-line processor OPUS which processes static differential baselines tied to the international CORS network. All coordinates are relative to the NAD83 (CORS96) Reference Frame.

Airplane trajectories for all survey flights are 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 to determine a fixed integer ionosphere-free differential solution. All available GPS reference stations are used to create individual differential solutions and then these solutions are differenced and compared for consistency. The standard deviation of the component differences (Easting, Northing, and Height) between individual solutions is generally between 5 – 25 mm horizontally and 15 – 55 mm vertically

After GPS processing, the trajectory solution and the raw inertial measurement unit (IMU) data collected during the flights are combined in APPLANIX software POSPac MMS (Mobile Mapping

Suite Version 5.2). POSPac MMS 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 an SBET (Smoothed Best Estimated Trajectory). The SBET and the raw laser range data were combined using Optech's DashMap processing program to generate the laser point dataset in LAS format.

4.2. Calibration, Matching, Validation, and Accuracy Assessment

Bore sight calibration was done by surveying crossing flight-lines with the ALTM over near-by residential neighborhoods and also on the project polygon and using TerraMatch software (http://www.terrasolid.fi/en/products/terramatch) to calculate calibration values. Residential neighborhoods are utilized because building rooftops provide ideal surfaces (exposed, solid, and sloped in different aspects) for automated calibration.

TerraMatch uses least-squares methods to find the best-fit values for roll, pitch, yaw, and scanner mirror scale by analyzing the height differences between computed laser surfaces of rooftops and ground surfaces from individual crossing and/or overlapping flight lines. TerraMatch is generally run on several different areas. TerraMatch routines also provide a measurement for the mismatch in heights of the overlapped portion of adjacent flight strips. This value is generally in the range of 0.05 – 0.10 meters.

A scan cutoff angle of 2.0 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 scanner errors and errors in heading, pitch, and roll.

NCALM makes every effort to produce the highest quality LiDAR data possible but every LiDAR point cloud and derived DEM will have visible artifacts if it is examined at a sufficiently fine level. Examples of such artifacts include visible swath edges, corduroy (visible scan lines), and data gaps.
A detailed discussion on the causes of data artifacts and how to recognize them can be found here:
http://ncalm.berkeley.edu/reports/GEM_Rep_2005_01_002.pdf ,
and a discussion of the procedures NCALM uses to ensure data quality can be found here:
http://ncalm.berkeley.edu/reports/NCALM_WhitePaper_v1.2.pdf
NCALM cannot devote the required time to remove all artifacts from data sets, but if researchers find areas with artifacts that impact their applications they should contact NCALM and we will assist them in removing the artifacts to the extent possible – but this may well involve the PIs devoting additional time and resources to this process.

5.4 Classification and Filtering

TerraSolid's TerraScan (http://terrasolid.fi) software was used for splitting the project area into 36 1 sq.km tiles. No bare-earth extraction was performed on the point cloud because the area is only sparsely vegetated and because the bare-earth classification algorithm would have smoothed-out the small scale topographic details inside the crater.

The elevation and intensity data was output into two separate sets of ASCII XYZ (and respectively, XYI) files and interpolated at 25cm cell size using Kriging.

The rasters are first created using Golden Software's Surfer 8 Kriging algorithm using the following parameters:

```
Gridding Algorithm: Kriging
Variogram: Linear
Nugget Variance: 0.15 m
MicroVariance: 0.00 m
SearchDataPerSector: 7
SearchMinData: 5
SearchMaxEmpty: 1
SearchRadius: 25m
```

The resulting Surfer grids are transformed into ArcInfo binary DEMs and hillshades using in-house Python and AML scripts.

5. Deliverables Description.

All deliverables were processed with respect to NAD83 (CORS96) reference frame. The projection is UTM zone 12N with units in meters. Heights are NAVD88 orthometric heights computed from GRS80 ellipsoid heights using NGS GEOID09 model.

Deliverable 1 is the point cloud in LAS v1.2 format. The tiles follow a naming convention using the lower left UTM 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 752000 through 753000, and northing equals 3313000 through 3314000 then the tile filename incorporates 752000_3313000.

Deliverable 2 is the ESRI format DEM mosaic with 25cm cell size and the associated raster hillshade. The DEM was obtained by interpolating all the laser points using Kriging and the parameters described in Section 4.

Deliverable 3 is the ESRI format intensity raster with 25cm cell size.

Note on LAS files: the LAS binary files can be transformed into ASCII files using the command line tools from the libLAS package (http://www.liblas.org/) or using Martin Isenburg's LAStools utilities (http://www.cs.unc.edu/~isenburg/lastools/)