Data Collection and Processing Report for 2014 SEED Project: Degradation of the 1959 Hegben Lake rupture (Montana) and application of diffusion coefficients to undated scarps in the N Rocky Mountains and Mongolia

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1. LiDAR System Description and Specifications

This survey was performed with an Optech Titan multispectral airborne LiDAR sensor (serial number 14SEN340) mounted in a twin-engine Piper PA-31-350 Navajo Chieftain (Tail Number N640WA). The instrument nominal specifications are listed below in Table 1.

Parameter	Specification
Operating altitude [1,2]	300 - 2500 m AGL, 1064 nm, nominal 300 - 2000 m AGL, 532 nm, nominal 300 - 2000 m AGL, 1550 nm, nominal
Horizontal accuracy [2]	1/5,500 x altitude; 1 σ
Elevation accuracy [2]	< 5-15cm; 1σ
Pulse repetition frequency	Programmable; 35 – 300 kHz (each wavelength)
Scan frequency	Programmable; 0 - 70 Hz
Scan angle (FOV)	Programmable; 0 - 60° maximum
Roll compensation	Programmable; ±5° at full FOV
Position and orientation system	POSAV AP50 (OEM) 220-channel dual frequency
Minimum target separation distance	<1.0 m
Range capture	Up to 4 range measurements for each pulse, including last
Beam divergence	0.5 mrad ($1/e^2$) 1064 nm 1.0 mrad ($1/e^2$) 532 nm 0.5 mrad ($1/e^2$) 1550 nm
Laser classification	Class IV (US FDA 21 CFR 1040.10 and 1040.11; IEC/EN 60825-1)
Intensity capture	Up to 4 range measurements for each pulse, including last 12-bit dynamic measurement and data range
Data storage hard drives	Removable solid state disk SSD (SATA II)

[1]10% reflective target
[2]Dependent on selected operational parameters using nominal 50° FOV in standard atmospheric conditions

Note: To meet its stated accuracy, the ALTM must receive GPS data of sufficient quality. GPS data quality shall be viable only when all of the following conditions are met:
- At least 4 satellites are in lock (tracked by the receiver) throughout the survey
- Elevation of the satellites is above 15°
- Geometry of the satellites is good (i.e., PDOP < 4)
- Aircraft stays within 30 km of the GPS base station

If one or more of these conditions is not met, or if any source of electromagnetic interference causes the GPS receivers to repeatedly lose lock, the specified accuracy of the ALTM shall be compromised.

Table 1 – Optech TITAN specifications (http://www.optech.com/index.php/product/titan/).

See http://www.optech.com/ for more information from the manufacturer.

2. Areas of Interest.

The requested survey area consisted of a corridor polygon located 20 km NW of West Yellowstone, MT. The polygon measures about 1 km wide and encloses approximately 40 square km. Figure 1 (below) is an image from Google Earth showing the shape and location of the survey.

Figure 1 – Shape and location of survey polygon. P456, P458, and WYS indicate locations of GPS reference stations. (Google Earth).

3. Data Collection

a) Survey Dates: The survey took place on Sunday October 19, 2014 (DOY 292).

b) Airborne Survey Parameters: Survey parameters are provided in Table 2 below.

Nominal Flight Parameters		**Equipment Settings**		**Survey Totals**	
Flight Altitude	750-1200 m	Laser PRF	100 kHz	Total Flight Time	2.8 hrs.
Flight Speed	+/- 66 m/s			Total Laser Time	0.6 hrs.
Swath Width	850-1400 m	Scan Frequency	25 Hz	Total Swath Area	62.5 km^2
Swath Overlap	Min 50 %	Scan Angle	± 30°	Total AOI Area	~40 km^2
Point Density	7-11 p/m^2	Scan Cutoff	1.0°	Pass spacing	N\A m

Table 2 – Nominal flight parameters, equipment settings and survey totals; actual parameters vary with the terrain.

c) **Ground GPS:** Three GPS reference station locations were used during the survey: two of them belong to the UNAVCO PBO network (see http://pbo.unavco.org/ for more information) and the remaining one was established by NCALM at the operational airport in West Yellowstone, MT. All GPS reference observations were logged at 1 Hz. Table 3 (below) gives the coordinates of the stations and Figure 1 (above) shows the project area and the GPS reference station locations.

GPS station	KWYS	P458	P456
Agency	NCALM	UNAVCO	UNAVCO
Latitude	44.6848	44.7657	44.8235
W Longitude	111.1174	111.3015	111.2251

Table 3 – Coordinates of GPS reference stations in NAD83 (2011) Epoch 2010.0000.

4. GPS/IMU Data Processing

Reference coordinates (NAD83 (2011) Epoch 2010.0000) for all 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. 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 trajectories for this survey were processed using KARS (Kinematic and Rapid Static) software written by Dr. Gerald 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 high-accuracy fixed integer ionosphere-free differential solution at 1 Hz. All final aircraft trajectories for this project are blended solutions from at least three of the five available stations.

After GPS processing, the 1 Hz trajectory solution and the 200 Hz 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).

5. LiDAR Data Processing Overview

The following diagram (Figure 2) shows a general overview of the NCALM LiDAR data processing workflow

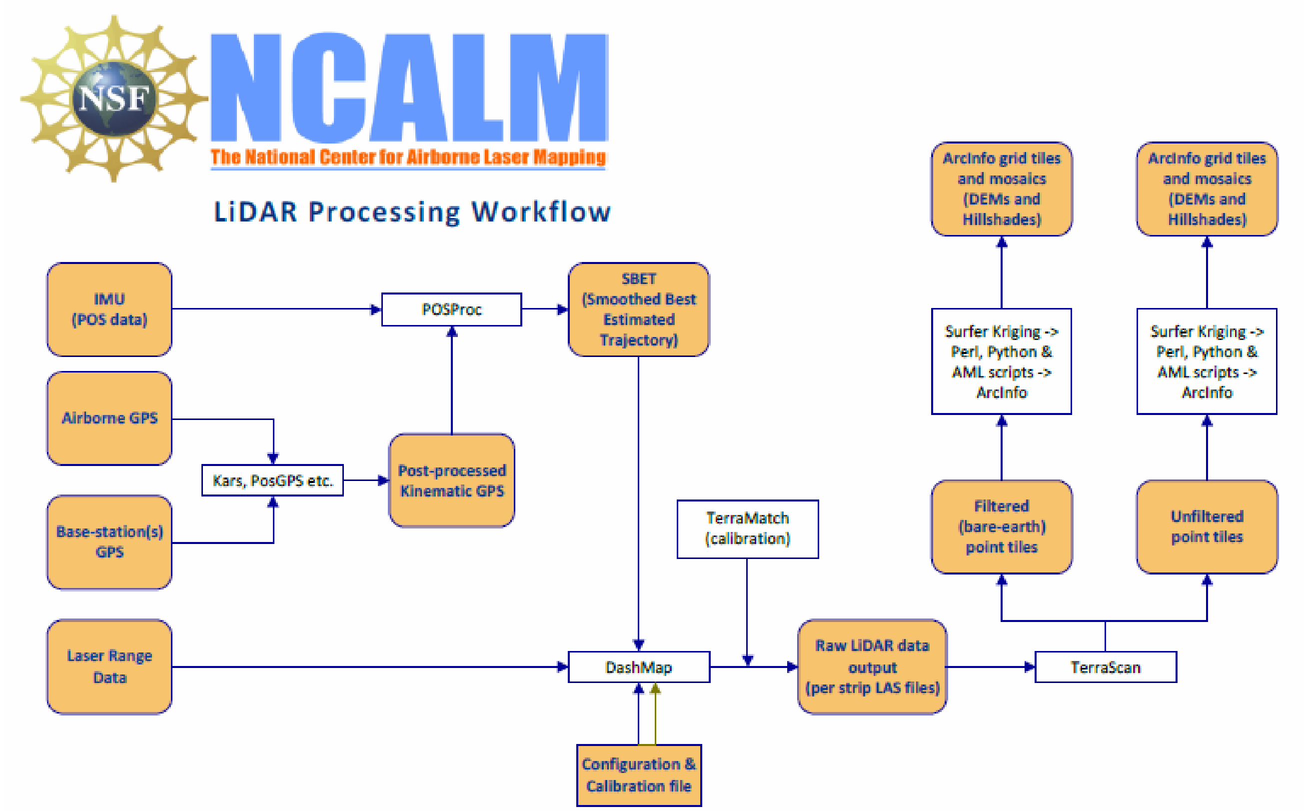

Figure 2 - NCALM LiDAR Processing Workflow

Classification done by automated means using TerraSolid software (TerraScan Version 14.017). http://www.terrasolid.com/products/terrascanpage.php

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 .
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.

6. Calibration Procedure

System calibration of the 3 sensor bore sight angles (roll, pitch, and yaw) and scanner mirror scale factor is done by automated means using LMS Pro (version 2.4.2) http://www.optech.com/index.php/product/optech-lms-pro/ software from Optech and TerraSolid Software (TerraMatch version 14.007) http://www.terrasolid.com/products/terramatchpage.php

Overlapping parallel project lines along with perpendicular cross lines and lines over developed neighborhoods with many sloping roof lines are used as input into automated optimization and calibration routines in both TerraMatch and LMS Pro. These software suites use least-squares algorithms to compute and apply optimal bore sight offsets and scale values that minimize height mismatches in overlapping flight lines. These routines are run and calibration values are updated for each flight.

No ground check points were collected for this project so it is possible that a small (<0.15m) vertical bias in the elevations of the final point cloud and DEM may exist with respect to NAVD88. Note that any LiDAR-derived DEM accuracy will usually degrade on steep terrain and under canopy.

7. Data Deliverables

a) **Horizontal Datum**: NAD83 (2011)
b) **Vertical Datum:** NAVD88 (GEOID 12a)
c) **Projection:** UTM Zone 12N
d) **Units: meters.**
e) **File Formats:**

1. Point Cloud in LAS format (version 1.2), classified as ground or non-ground, in 1 km square tiles.
2. ESRI format 0.5-m DEM from ground classified points.
3. ESRI format 0.5-m Hillshade raster from ground classified points
4. ESRI format 0.5-m DEM from all points (canopy included).
5. ESRI format 0.5-m Hillshade raster from all points (canopy included).

f) **File naming convention:** 1 Km tiles follow 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 477000 through 478000, and northing equals 4970000 through 4971000 then the tile filename incorporates 477000_4970000. The ESRI DEMs are mosaic files created by combining together the 1 km tiles.

8. Notes

This project was flown at 750-1200 m AGL due to mountainous terrain. This higher than normal flying height caused channel 2 laser (1064 nm) to have a large percentage of drop-outs due to weak signal caused by scanner mirror misalignment. This had a minor impact on point density, but the target value of 10 points/square meter was still met by flying extra passes.