LiDAR Data Collection and Processing Report for 2014_2015 Project: Landscape Changes in the McMurdo Dry Valleys, Antarctica

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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 de Havilland Canada DHC-6 Twin Otter (Tail Number C-GCKB). The instrument nominal specifications are listed below in Table 1.

Parameter	Specification
Operating altitude [1,2]	300 - 2500 m AGL, 1064 nm, nominal (channel 2) 300 - 2000 m AGL, 532 nm, nominal (channel 3) 300 - 2000 m AGL, 1550 nm, nominal (channel 1)
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.teledyneoptech.com/ for more information from the manufacturer.

2. Areas of Interest.

The LiDAR coverage area is organized as eight distinct polygons located in and around the McMurdo Dry Valleys in Antarctica. Figure 1 (below) is an image from Google Earth showing the shapes and locations of the survey polygons as well as the GPS Continuously Operating Reference Stations (CORS). The yellow polygon (referred to as the North section) contains parts of the Victoria, Barwick, Balham, McKelvey, and Wright Valleys. The smaller, northern purple is the Asgard Range area, the larger more southern purple polygon contains part of Beacon Valley, Orange polygon is Taylor Valley, and the pink polygon is part of Garwood Valley. Northernmost blue polygon is Cape Royds/Cape Evans area, center blue polygon is McMurdo base polygon, and the southernmost blue polygon covers the Pegasus airfield.

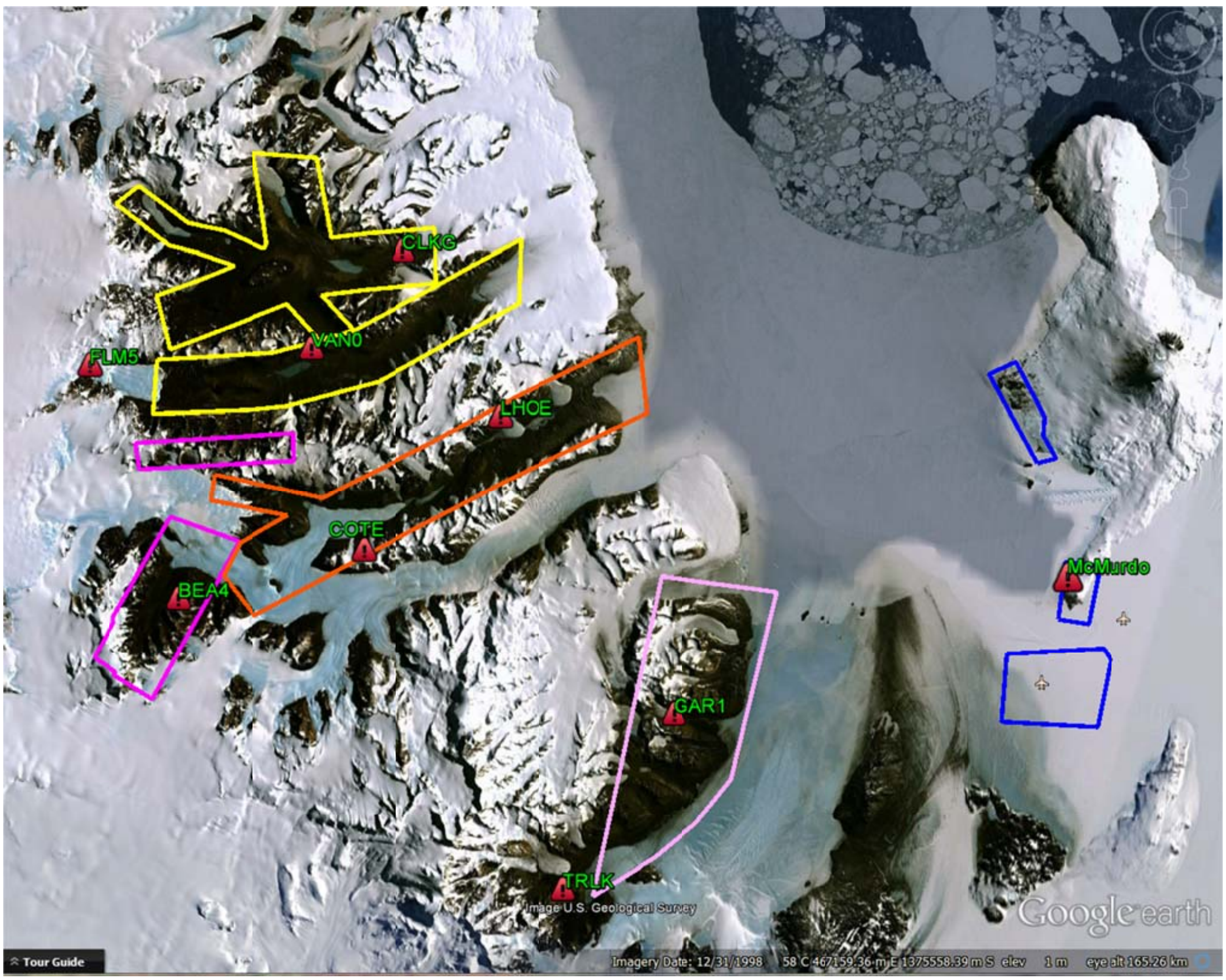

Figure 1 – Shape and location of survey polygons. The nine red triangle icons indicate locations of GPS reference stations. (Google Earth).

3. Data Collection

a) Survey Flights: The survey took place in 29 flights over 8 weeks, beginning on Thursday December 4, 2014 with a test flight over McMurdo Station and ending with the final flight on Monday January 19, 2015. Table 2 (below) gives the flight breakdown in terms of date, Day-of-Year (DOY), Engine On Time (ET), Flight Time (FT) Laser-on Time (LOT) and area mapped.

Flight	Date	DOY	ET [hr]	FT [hr]	LOT [hr]	Areas Mapped
1	4-Dec-14	338a	1.50	0.67	0.13	Test
2	5-Dec-14	339a	4.40	4.00	2.47	Taylor
3	5-Dec-14	339b	4.95	4.68	2.99	Taylor
4	8-Dec-14	342a	4.33	3.96	2.67	Taylor
5	9-Dec-14	343a	3.57	3.08	1.86	Taylor
6	9-Dec-14	343b	4.88	4.46	2.71	Taylor/Pearse
7	10-Dec-14	344a	3.97	3.54	2.14	Wright
8	11-Dec-14	345a	3.83	3.37	2.03	Wright
9	12-Dec-14	346a	2.72	2.29	0.46	McMurdo
10	14-Dec-14	348a	3.33	2.98	1.54	Wright
11	17-Dec-14	351a	4.12	3.80	2.14	Taylor/Wright
12	18-Dec-14	352a	3.98	3.58	1.98	Wright/Victoria
13	18-Dec-14	352b	3.93	3.41	1.95	Garwood
14	19-Dec-14	353a	2.67	2.24	0.86	Garwood
15	23-Dec-14	356a	3.92	3.53	1.95	Victoria
16	26-Dec-14	360a	4.57	4.22	2.75	Garwood
17	27-Dec-14	361a	4.17	2.83	2.33	Bull Pass
18	28-Dec-14	362a	3.88	3.55	2.05	Bull Pass/Victoria/Garwood
19	29-Dec-14	363a	2.27	1.94	0.64	Cape Royds/Evans
20	29-Dec-14	363b	2.18	1.76	0.82	Garwood
21	30-Dec-14	364a	4.15	3.81	1.93	Beacon/Garwood
22	31-Dec-14	365a	4.12	3.77	1.95	Victoria
23	1-Jan-15	001a	3.50	3.02	1.41	Beacon
24	4-Jan-15	004a	3.12	2.80	1.03	Victoria
25	7-Jan-15	007a	3.83	3.04	0.92	Pegasus
26	7-Jan-15	008a	4.18	3.84	1.67	Victoria/Beacon
27	11-Jan-15	011a	4.23	4.06	2.09	Victoria/Wright
28	18-Jan-15	018a	4.01	3.76	1.91	All areas (Gemini)
29	19-Jan-15	019a	1.89	1.63	0.60	Garwood (Gemini)
		Total	**106.20**	**93.62**	**49.98**	

Table 2 – Survey Flights.

b) Airborne Survey Parameters: Nominal survey parameters are provided in Table 3 below. Note that due to the extremely variable terrain actual the hardware setting for the Pulse Rate Frequency (PRF) varied significantly: from 50 KHz to 125 KHz. The aircraft height above ground varied from 400 – 1100 m. Scan angle and scan frequency did NOT vary.

Nominal Flight Parameters		Equipment Settings		Survey Totals	
Flight Altitude	700	Laser PRF	100 KHz	Total Flight Time	93.6 hrs.
Flight Speed	65 m/s			Total Laser Time	50.0 hrs.
Swath Width	776	Scan Frequency	20 Hz	Total Swath Area	3421
Swath Overlap	60%	Scan Angle	+/- 30	Total AOI Area	3421
Point Density	8.8 sq. m	Scan Cutoff	2.0	Pass spacing	388 m

Table 3 – Nominal flight parameters, equipment settings and survey totals.

Table 4 (below) gives the area breakdown by polygon.

Name	**Area KM^2**
North Area - Wright Valley	517
North Area - Victoria, Barwick, Balham, Bull Pass, McKelvey Valleys	643
Asgard Range	101
Beacon Valley	294
Taylor Valley	836
Garwood Valley	741
Cape Royds/Cape Evans	63
McMurdo Base	46
Pegasus Airfield	180
TOTAL	**3421**

Table 4 – Area breakdown in square kilometers by polygon.

Point density was highly variable and is shown below in Figures 2-5.

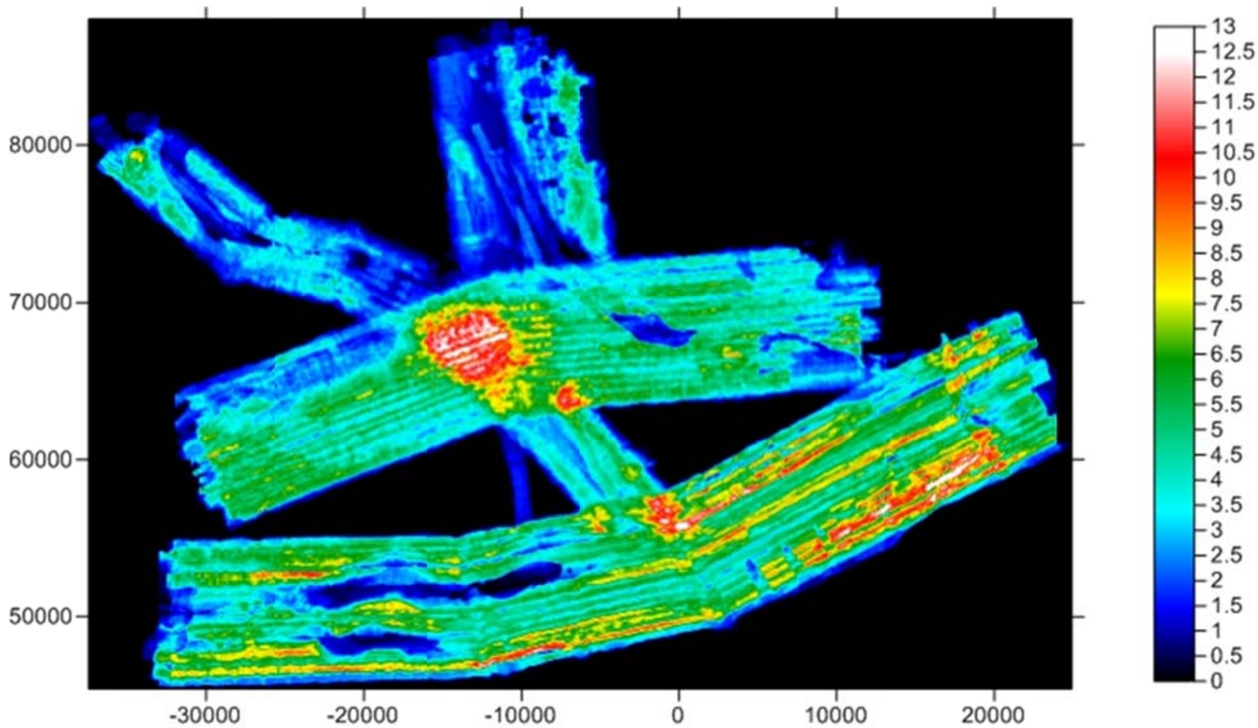

Figure 2 - Point density for Victoria, Barwick, Balham, McKelvey, Wright Valleys, and Bull Pass.

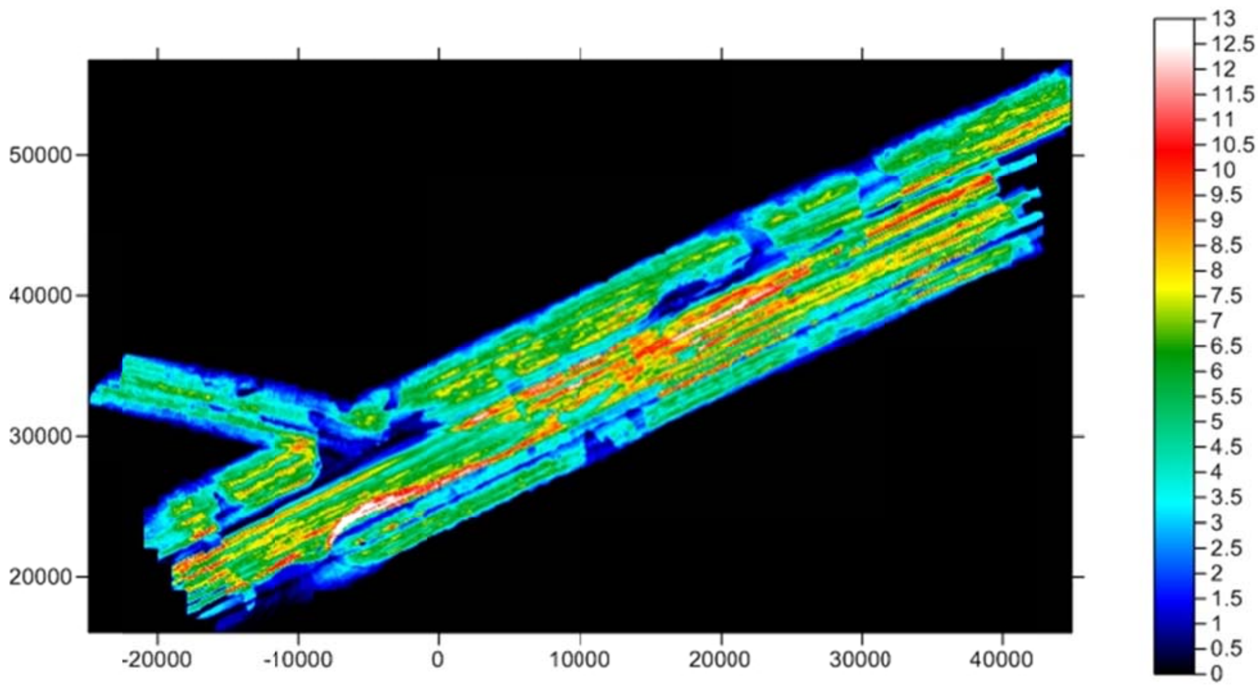

Figure 3 - Point Density for Taylor Valley.

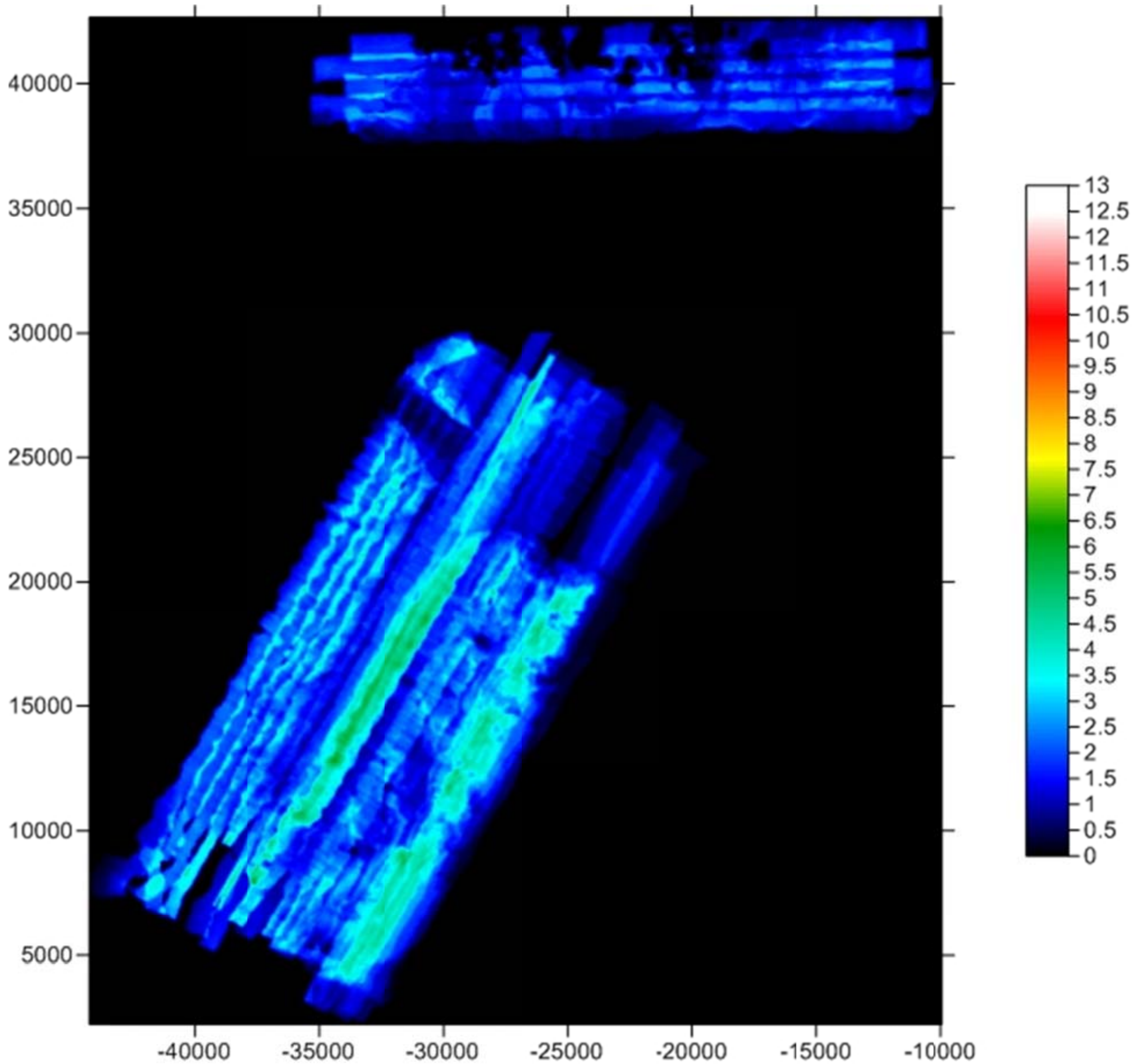

Figure 4 - Point density for Beacon Valley and Asgard Range.

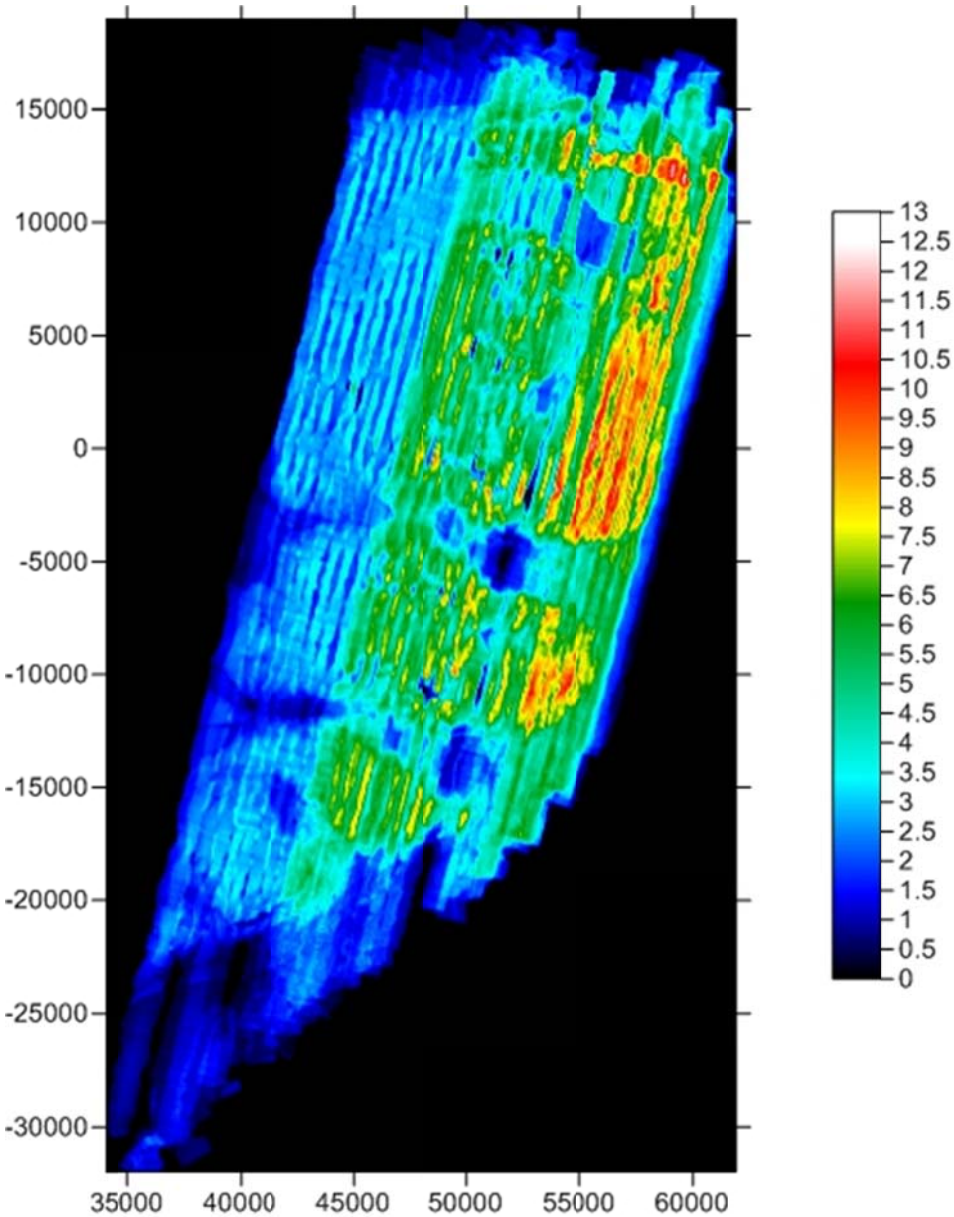

Figure 5 - Point density for Garwood Valley.

c) **Reference CORS** (supported by NSF and UNAVCO):

GPS station	Latitude	Longitude	Height
BEA4	-77 51 45.33669	160 45 35.41685	2141.922
CLKG	-77 23 24.58081	162 17 43.15149	778.378
COTE	-77 48 21.25052	161 59 52.11842	1878.354
FLM5	-77 31 57.82967	160 16 17.08137	1869.695
GAR1	-78 2 24.26835	164 2 46.77308	816.524
LHOE	-77 37 23.28472	162 54 4.76741	29.127
TRLK	-78 17 3.70694	163 17 35.53629	889.237
VAN0	-77 31 20.53913	161 41 23.58556	42.037
MCMD	-77 50 18.06134	166 40 9.59802	98.026

Table 5 – Coordinates of GPS reference stations in IGS08 (EPOCH:2015.0014)

4. GPS/IMU Data Processing

Reference coordinates in the IGS08 (EPOCH:2015.0014) 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 nine 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 7.1). 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 6) shows a general overview of the NCALM LiDAR data processing workflow.

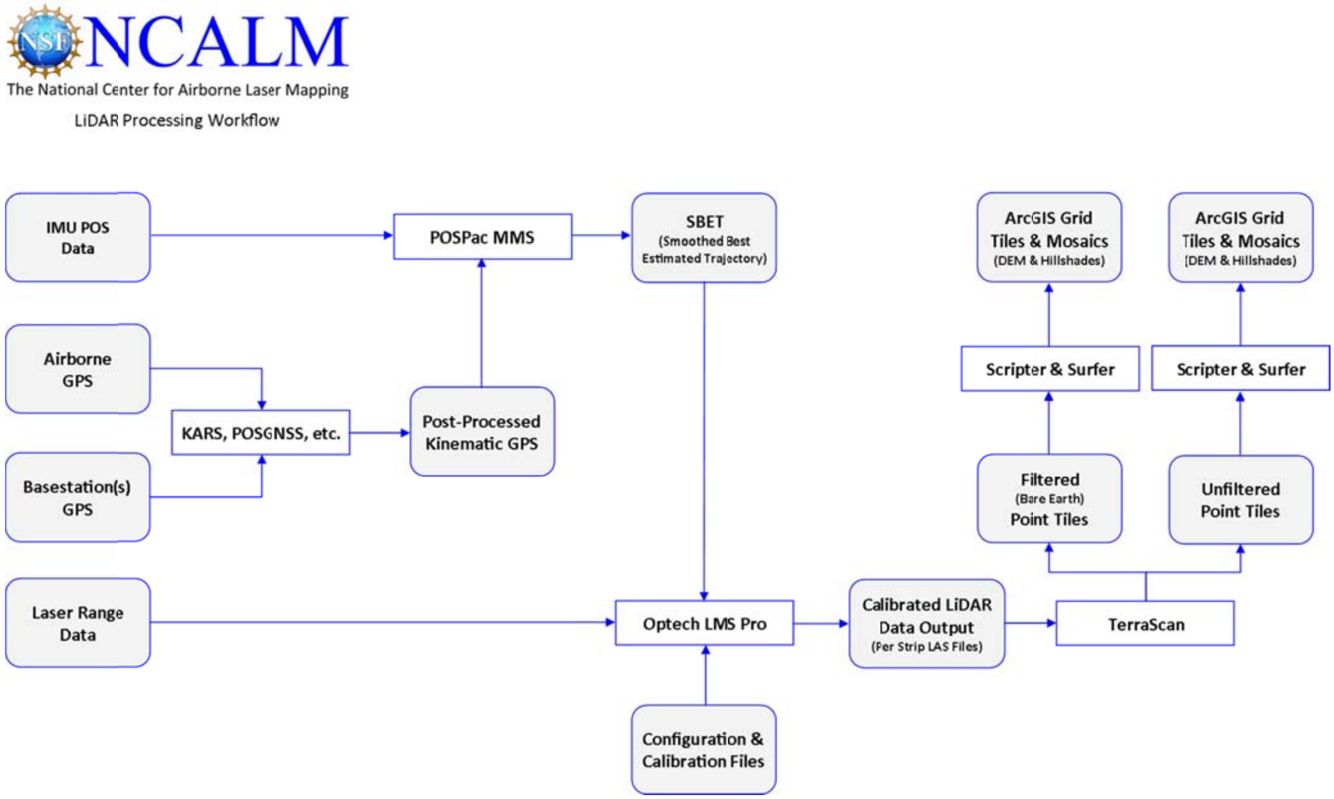

Figure 6 - NCALM LiDAR Processing Workflow

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

Calibration was done by automated means in Optech LMS PRO software version 2.4.2.14565

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.

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

Horizontal Datum: REF FRAME: IGS08 (EPOCH:2015.0233)
Vertical Datum: WGS84 Ellipsoid height
Projection: EPSG 3294 - USGS Transantarctic Mountains.
Units: meters.

File Formats:

1. Point cloud in LAS format (version 1.2), unclassified (noise removed) in one km square tiles.
2. ESRI format 1.0-m DEM from all points.
3. ESRI format 1.0-m Hillshade raster from all points

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 382000 through 383000, and northing equals 4130000 through 4131000 then the tile filename incorporates 382000_4130000. The ESRI DEMs are mosaic files created by combining together the 1 km tiles.

8. Notes

a) No classification or filtering (other than removal of atmospheric noise/outlier points) was done due to the complete absence of vegetation in project area.

b) Channel three LiDAR data (532 nm) was corrupted by excessive scattered light from ubiquitous ice and snow surfaces and was not useable.

c) A five degree cutoff angle was applied to the LiDAR in an effort to reduce the corduroy artifact.

d) Imagery processing not covered in this report.