Data Collection and Processing Report for the Project:

"LiDAR Survey of Sierra Nevada, CA"

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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 337 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 - 35 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 72-channel 10Hz (GPS) receiver
Laser Wavelength/Class	1064 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 (http://www.optech.ca/pdf/Gemini_SpecSheet_100908_Web.pdf).

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

2. Areas of Interest.

The requested survey area consisted of five polygons within Sierra Nevada Mountains, CA. The size and location of each polygon is shown in Figure 1 (below). Polygon #1 and #2 (northernmost area due west of Lake Tahoe) were combined for the sake of flying efficiency. Parts of polygon #1 and polygon #2 were not surveyed due to the arrival of a snowstorm which left significant accumulations of snow not likely to melt until spring of 2013.

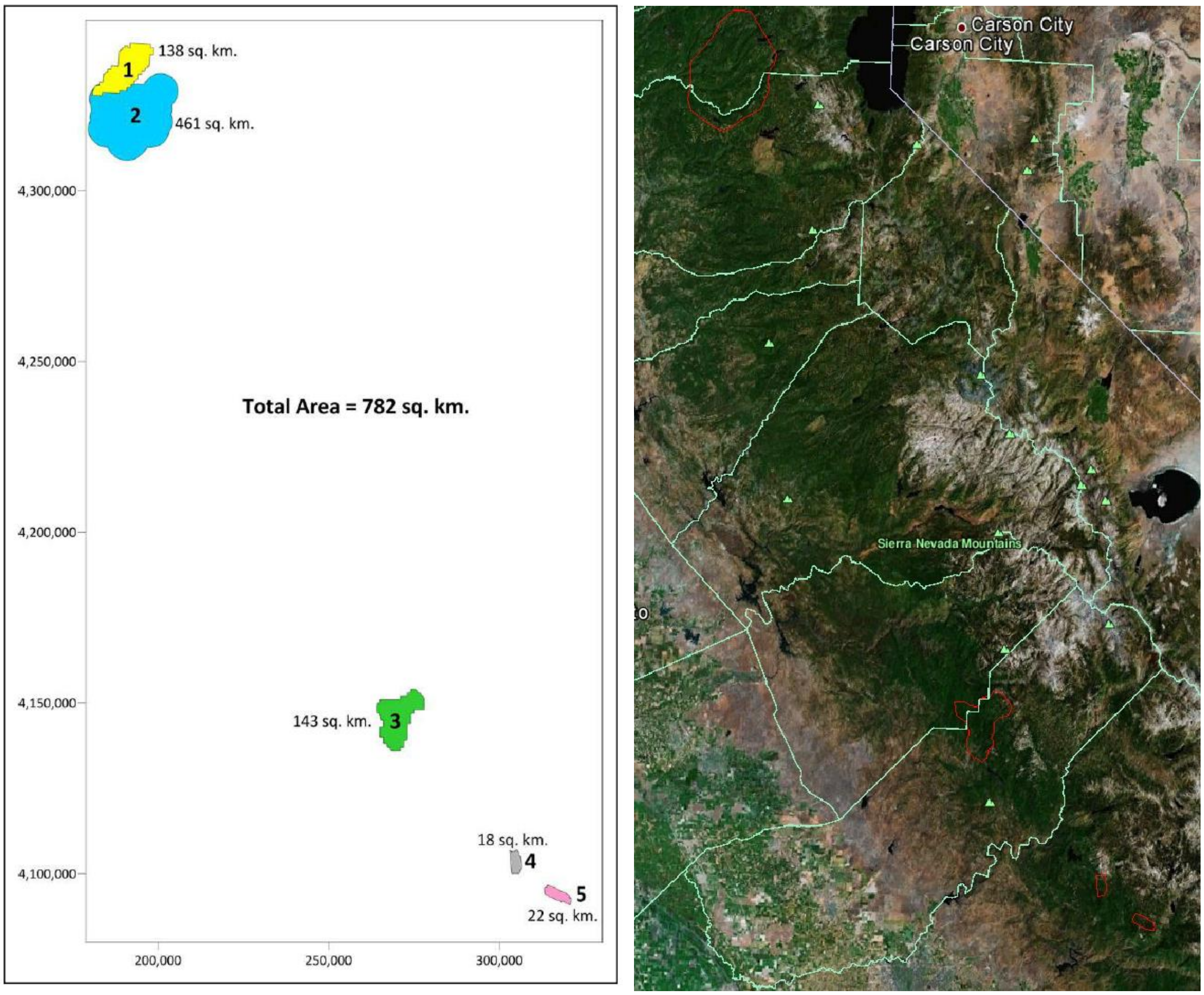

Figure 1 – Shape and location of survey polygons. (Right) polygons are shown as red outlines on Google Earth.

3. Data Collection

a) **Survey Dates**: The survey took placed from November 01, 2012 through November 07, 2012. (DOY 306 through 312).

b) **Airborne Survey Parameters:** Survey parameters are provided in Table 2 below. Note that the actual point density for polygons #1 & 2 are different from the original flight planning, so an image of the actual LiDAR point density for these polygons is shown in Figure 2.

Nominal Flight Parameters		Equipment Settings		Survey Totals	
Flight Altitude	600-800 m	Laser PRF	100 kHz	Total Flight Time	34.27 hrs
Flight Speed	+/- 60 m/s	Beam Divergence	0.25 mrad	Total Laser Time	16.86 hrs
Swath Width	390-520m	Scan Frequency	45 Hz	Total Swath Area (polygon #1,2)	200.1 km^2
Swath Overlap	Min 50 %	Scan Angle	± 16°	Total Swath Area (polygon #3,4,5)	436.6 km^2
Point Density (polygon #3,4,5)	9.6 p/m^2	Scan Cutoff	1.0°	Total AOI Area (polygon #1,2)	185.0 km^2
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Table 2 – Nominal flight parameters, equipment settings and survey totals; actual parameters vary with the terrain.

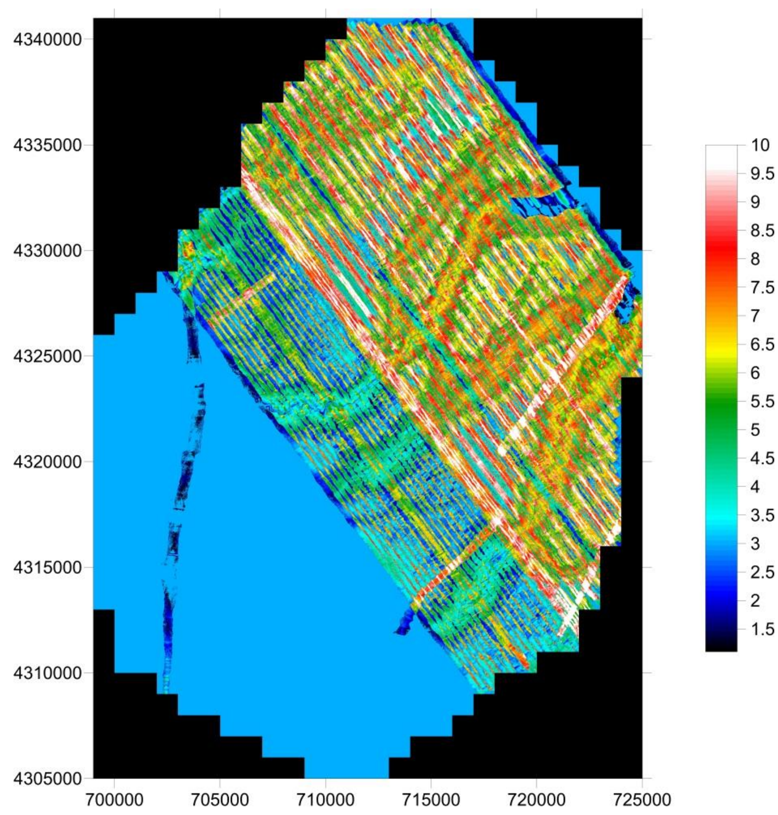

Figure 2 – Laser shots fired per square meter for polygons #1 and #2.

c) **Ground GPS:** Seven GPS reference station locations were used during the survey; five of them being part of UNAVCO's PBO network (see http://pbo.unavco.org/ for more information from UNAVCO). The remaining 2 stations were set by the NCALM field crew at the operational airports. All GPS reference observations were logged at 1 Hz. Table 3 (below) gives the coordinates of the stations and Figure 3 shows the project area and the GPS reference station locations.

GPS station	Operating Agency	Latitude	W Longitude	Ellipsoid Height(m)
KFAT	NCALM	36 46 16.29645	119 43 33.40892	68.224
KPVF	NCALM	38 43 28.89377	120 45 14.81659	761.286
MUSB	UNAVCO	37 10 11.77402	119 18 33.61129	2043.234
P140	UNAVCO	38 49 45.23224	120 41 35.44721	1079.767
P141	UNAVCO	39 2 47.86415	120 23 8.04880	2170.926
P512	UNAVCO	37 33 45.47281	119 41 39.95702	1345.325
P725	UNAVCO	37 5 20.00878	119 44 44.13025	1345.325

Table 3 – GPS Coordinates of ground reference stations. NAD_83 (2011) (EPOCH: 2010.0000)

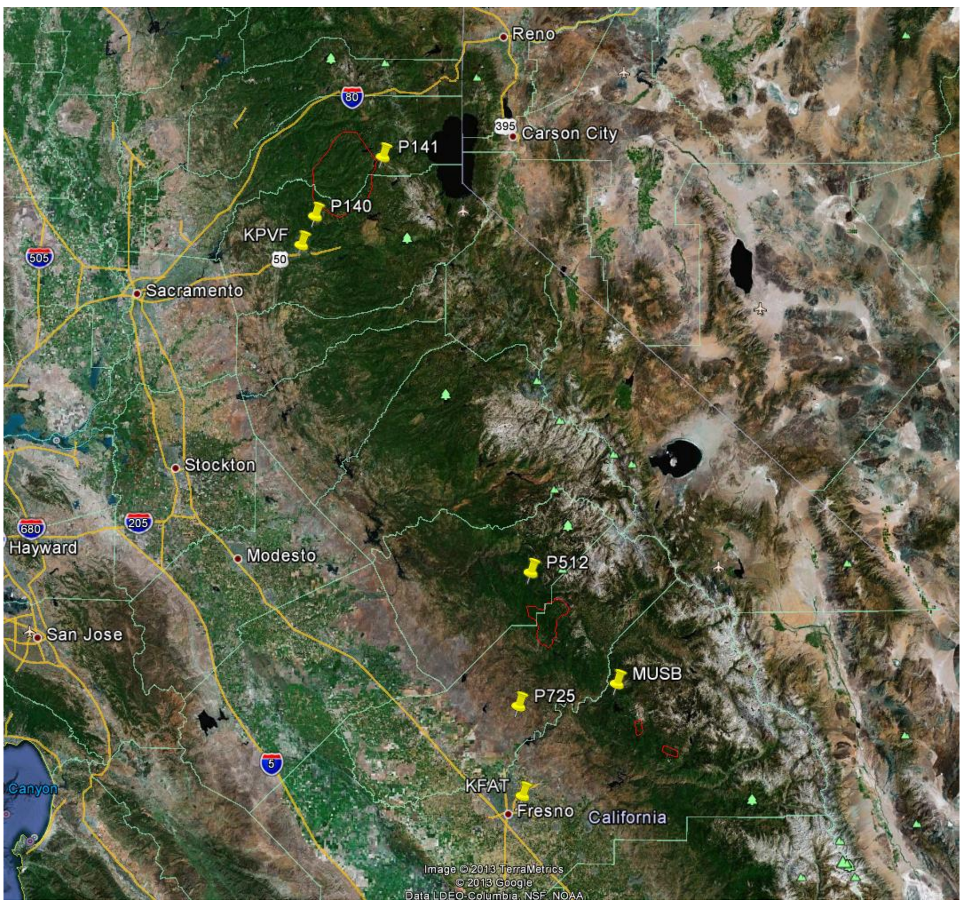

Figure 3 - Project area and GPS reference locations.

4. GPS/IMU Data Processing

Reference coordinates 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 the appropriate stations.

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).

5. LiDAR Data Processing Overview

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

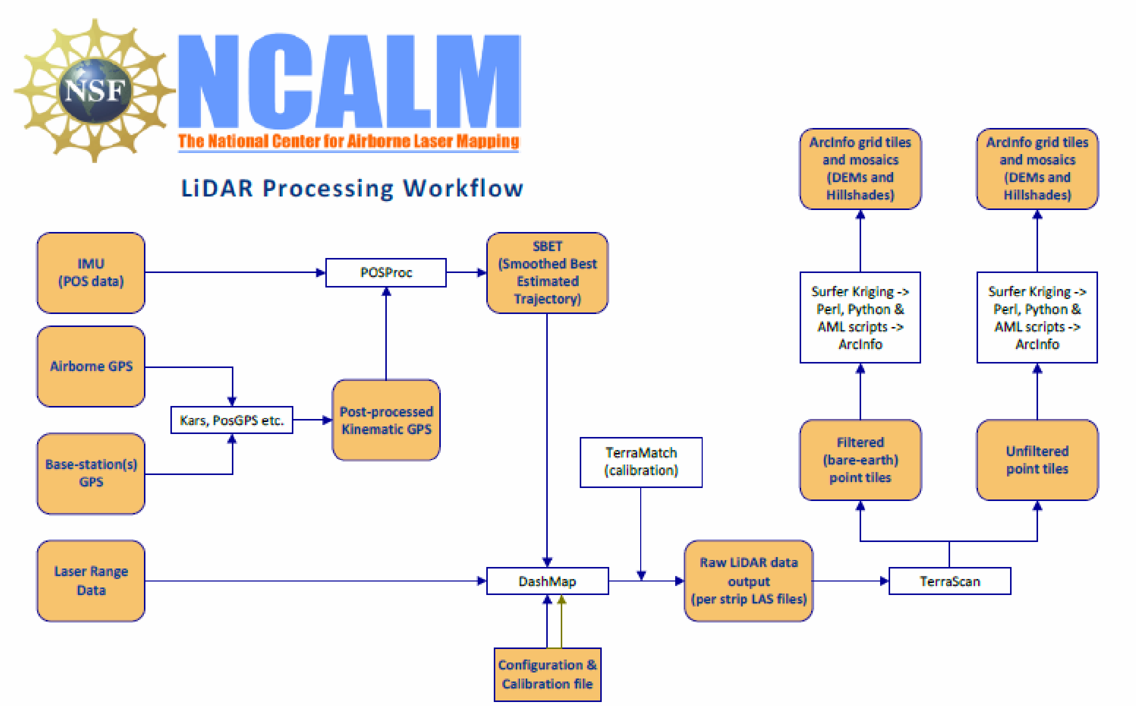

Figure 4 - NCALM LiDAR Processing Workflow

These LiDAR data were collected in flight strips and the initial observations are of course not classified but are associated with certain collection attributes such as time stamp, scan angle, intensity value, echo number (only echo, first of many, intermediate, last echo) etc. TerraSolid software is used to do the ground point classification, the emphasis being on first removing blunder points and outliers and then finding the final set of ground class points from which the bare-earth DEM is constructed. Classification of the ground-class points is done by automated routines using TerraSolid Software (TerraScan Version 12.017). http://www.terrasolid.fi/en/products/4

6. Accuracy Assessment

System calibration of the 3 sensor boresight angles (roll, pitch, and yaw) and scanner mirror scale factor is done by automated means using TerraSolid Software (TerraMatch). Project lines and off-project lines flown with opposite headings combined with perpendicular cross lines are used as input to TerraMatch (Version 12.009). The calibration values are checked on a flight-flight basis. After calibration values are determined project flight lines are checked for average mismatch. For this project the average delta Z for project flight lines is approximately 8.6 centimeters.

Check points were collected on Highway 41 south of Oakhurst, CA in order to assess the absolute accuracy of the LiDAR. NCALM field personnel mounted a GPS antenna on a vehicle and drove a 5 km section of this highway. During a survey flight the aircraft collected LiDAR over this section of road and the nearest neighbor LiDAR shot elevation was differenced from 865 check points. The RMSE of these differences was found to be 0.042 meters.

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.

7. Data Deliverables

a) **Horizontal Datum**: NAD83 (2011)
b) **Vertical Datum:** NAVD88 (GEOID 12a)
c) **Projection:** UTM Zone 10N & 11N – meters.
d) **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 1-m DEM from ground classified points.
3. ESRI format 1-m Hillshade raster from ground classified points
4. ESRI format 1-m DEM from all points (canopy included).
5. ESRI format 1-m Hillshade raster from all points (canopy included).
6. Digitizer files which include the raw intensity – time waveform data as collected by the digitizer in DF2 / IX2 formats.
7. Corrected Sensor Data (CSD) files in flight strips which contain timing, navigation, scan angle, and discrete return information (range and intensity) for each fired laser pulse as obtained from the discrete ALTM system.

e) **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 702000 through 703000, and northing equals 4328000 through 4329000 then the tile filename incorporates 702000_4328000. These tile footprints are available as an AutoCAD DXF or ESRI shapefile. The ESRI DEMs are single mosaic files created by combining together the 1KM tiles. Their name consists of prefix 'ume' and the lowest Easting coordinate rounded to the nearest 1000, for e.g. 'ume702000'. The hillshade files have a prefix 'sh' after the name, for e.g. 'ume702000sh'.