# LiDAR survey of the Yosemite Rim Fire Area

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## 1. Sensor Systems Description and Specifications

The survey was performed with an Optech Gemini Airborne Laser Terrain Mapper (ALTM) serial number 06SEN195 mounted in a twin-engine Piper Navajo Chieftain aircraft (Tail Number N154WW). The LiDAR instrument's 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 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 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.**

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

## 2. Area of Interest.

The requested survey area consisted of a single irregular polygon of approximately 1500 $km^2$, located west of Yosemite Valley in California. The polygon covered the Yosemite Rim fire that occurred in fall 2013. The size and location of the polygon is shown in Figure 1(a) (below). Two flight strips were flown with full waveform data collection (shown in neon-green lines). A smaller polygon (Smithsonian forest plot) north of Crane Flat Fire lookout, within the larger area, was collected at a higher point density and full waveform. It is shown in the Figure 1(b).

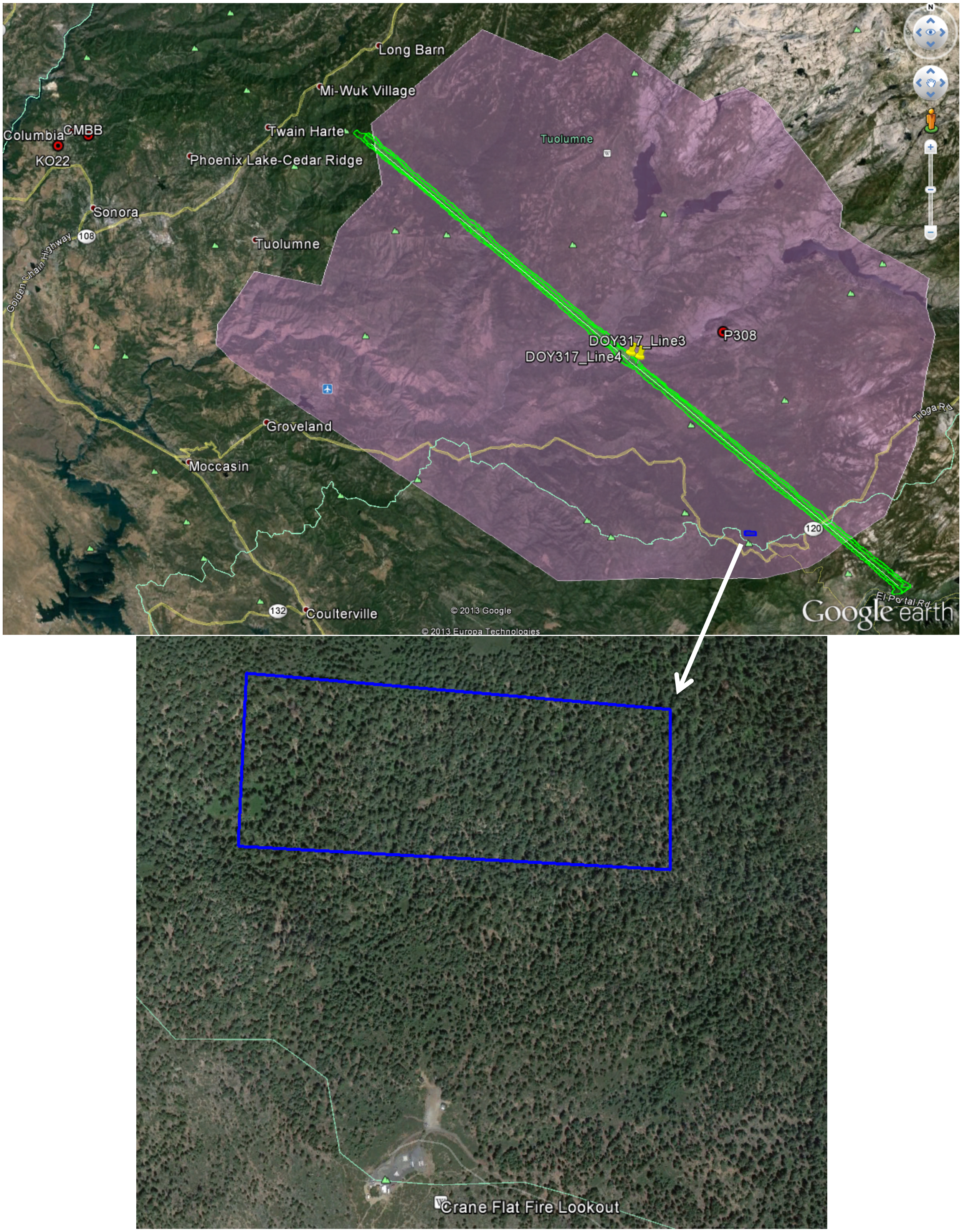


**Figure 1: (a) Shape and location of the survey polygons and location of ground GPS stations (Google Earth). (b) High point density Smithsonian forest plot.**

# 3. Data Collection

**a) Survey Dates**: The survey took placed from November 6, 2013 through November 24, 2013 (DOY 310 through 328). More information for individual flights are given below in Table 2

| Date | DOY | Flight Time(hrs) | Laser On Time |
|---|---|---|---|
| 11/6/2013 | 310 | 5.75 | 2.75 |
| 11/7/2013 | 311 | Airplane down for Maintenance | |
| 11/8/2013 | 312 | 6 | 3.17 |
| 11/9/2013 | 313 | 6.1 | 3.75 |
| 11/10/2013 | 314 | 6.5 | 4.2 |
| 11/11/2013 | 315 | 6.5 | 4.51 |
| 11/12/2013 | 316 | 5.25 | 3.5 |
| 11/13/2013 | 317 | 6.9 | 4.75 |
| 11/14/2013 | 318 | 6.5 | 4.5 |
| 11/15/2013 | 319 | 6.5 | 4.3 |
| 11/16/2013 | 320 | 6.2 | 3.6 |
| 11/17/2013 | 321 | 6.3 | 4.25 |
| 11/18/2013 | 322 | 6.5 | 4.5 |
| 11/19/2013 | 323 | 6.5 | 4.5 |
| 11/20/2013 | 324 | Weather | |
| 11/21/2013 | 325 | Weather | |
| 11/22/2013 | 326 | 4.75 | 2.7 |
| 11/23/2013 | 327 | Weather | |
| 11/24/2013 | 328 | 2.1 | 0.5 |
| | **Total** | **88.35** | **49.56** |

**Table 2 – Survey Flights**

**b) Airborne Survey Parameters:** Nominal survey parameters for the LiDAR collection and Survey Totals are provided in Table 3 below. For the Smithsonian area, the point density is 40 points/ m² and laser PRF used was 100 kHz.

| Nominal Flight Parameters | | Equipment Settings | | Survey Totals | |
|---|---|---|---|---|---|
| Flight Altitude | 600m | Laser PRF | 125 kHz | Total Swath Area | 1481 $km^2$ |
| Flight Speed | 65 m/s | Beam Divergence | 0.25 mRad (narrow) | Total AOI Area | 1461 $km^2$ |
| Swath Width | 277 m | Scan Frequency | 60 Hz | | |
| Swath Overlap | Min 50 % | Scan Angle | ± 14° | | |
| Point Density | 12 p/m² | Scan Cutoff | 1.0° | | |

**Table 3 – 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, CMBB, KO22 and P308: CMBB is part of the National Geodetic Survey's (NGS) network of Continuously Operating Reference Stations (CORS). KO22 was set by the NCALM field crew at the Columbia Municipal Airport. P308 is part of the UNAVCO PBO network (see http://pbo.unavco.org/ for more information from UNAVCO). All reference observations were logged at 1 Hz. GPS reference station locations are shown in Figure 1 above and Table 4 gives the coordinates of the stations

| GPS station | KO22 | CMBB | P308 |
|---|---|---|---|
| Operating Agency | NCALM | CORS | PBO |
| Latitude(DegMinSec) | 38 01 37.156 | 38 02 03.021 | 37 54 4.128 |
| W Long(DegMinSec) | 120 24 44.71 | 120 23 09.69 | 119 50 24.66 |
| Ellipsoid Height(m) | 606.68 | 696.37 | 1502.46 |

**Table 4 – GPS Coordinates of ground reference stations. NAD_83 (PA11) (EPOCH: 2010.0000)**

# 4. Data Processing Overview

Figure 2 shows a general flowchart of the NCALM LiDAR data processing workflow.

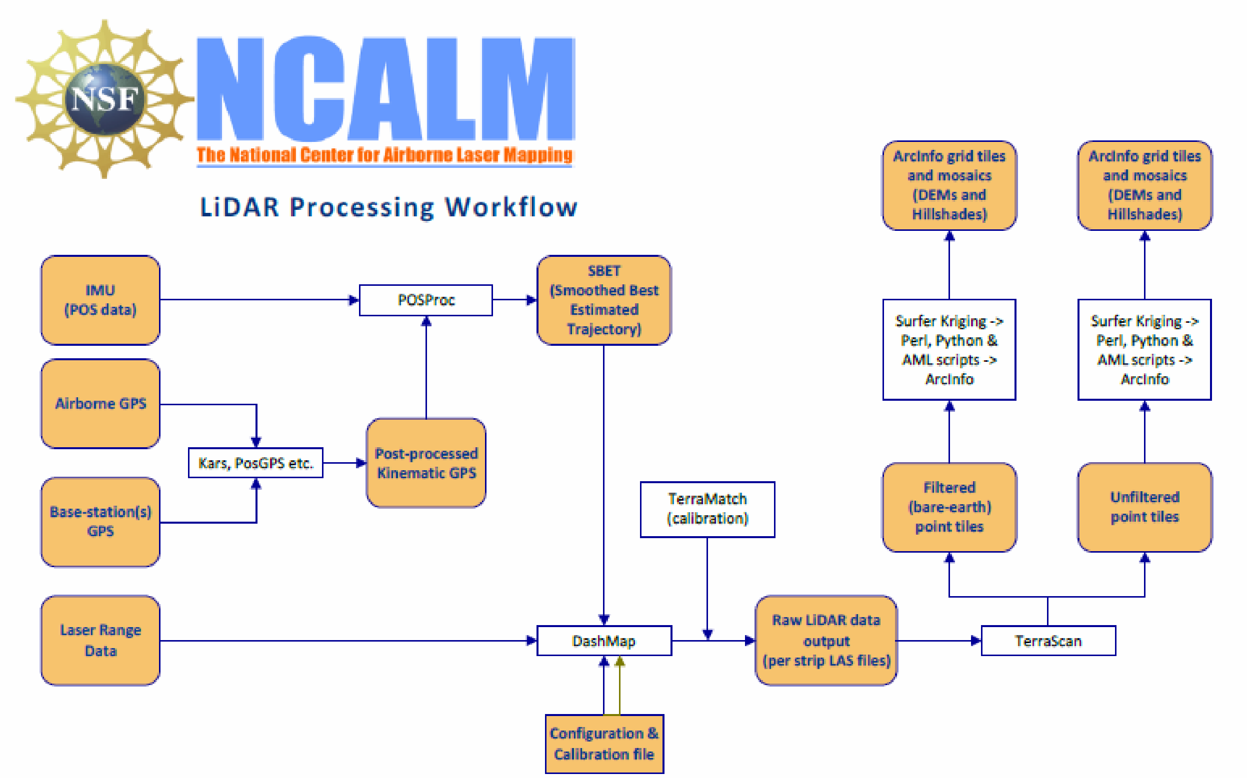


**Figure 2 - NCALM LiDAR Processing Workflow**

### a) GPS/IMU Data Processing

GPS positions for P308 and KO22 are derived from multiple 24-hour observation sessions. Data from these sessions was submitted to the NGS on-line processor OPUS which processes static differential baselines tied to the CORS network. The final coordinate value for these two stations is an average of these OPUS results. Reference coordinates for CMBB were downloaded from their respective NGS data sheets. 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 three 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).

**b) LIDAR Point cloud processing:**

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 (http://www.terrasolid.fi/en/products/4) is used to do the point classification. The classification process filters out points into noise (due to air moisture, birds; multipath effects etc) and ground class. For noise filtering, algorithms used are isolated points (points which do not have very many other points within a 3D search radius), air points (points which are clearly higher than the median elevation of surrounding points) and low points (possible error points which are clearly below the adjacent ground surface). Ground classification is carried out using an iterative algorithm which involves building a triangulated surface model. The algorithm starts by selecting some local low points assumed as sure hits on the ground, within a specified window size, for the initial triangulation model. Then it classifies more points as ground based on parameters such as distance from the surface model (iteration distance) and angle from the closest node (iteration angle). It iterates the above mentioned steps of triangulation and addition of laser points, making the model follow the ground surface more closely with each iteration. The limiting values of these parameters are chosen depending on the characteristics of the mapped area such as extent of urbanization, vegetation (type and density), and terrain (flat, rugged). The smaller the iteration angle, the less eagerly routine follows changes in the point cloud such as in case of flat area with lot of vegetation whereas a higher iteration angle is desirable in case of rugged terrain with steep slopes. Iteration distance parameter makes sure that the iteration does not make big jumps upwards when triangles are large for e.g. to keep low buildings out of the model. On the other hand if the terrain consists of near vertical cliffs, a higher iteration distance might be required. The initial window size is determined based on building sizes and vegetation densities to prevent returns from buildings and trees to be classified as ground in the first round of iteration.
Ground classification in areas with low lying shrubs and other vegetation poses some issues. Because of the limit on range resolution of the LIDAR system (1.5 m), it cannot register multiple returns in low vegetation height areas. Therefore the only returns that come from actual ground would be from laser shots which penetrate the shrubs without hitting them which depend on the extent and thickness of shrubs. This leads to some spots where there will be very few or no ground points leading to small voids and noisy ground DEM.

# 5. Calibration and Accuracy assessment

System calibration of the three sensor boresight angles (roll, pitch, and yaw) and the scanner mirror scale factor is done over project lines and off-project lines flown with opposite headings combined with perpendicular cross lines Surfaces are constructed from the ground-class points of all individual flight lines from each survey flight and then a best-fit solution of the roll, pitch, yaw, and scanner mirror scale factor is computed through an iterative algorithm. This procedure is run on a flight-by-flight basis and all calibration values were found to have remained stable for every survey flight on this project. This process is done using TerraSolid Software (TerraMatch module).

After optimal calibration values are determined, these are used to output project flight line point clouds in their final form and then checked for internal consistency. This is done by computing an average mismatch in surfaces constructed from only ground-class points of individual flight lines in overlap areas. The following project statistics are compiled on all tiles and for the entire project.

1. Magnitude: Absolute value of the elevation difference between a flight strip and the mean surface.
2. Average magnitude: Mean value of absolute elevation difference values.
3. DZ: Mean value of the elevation difference between a strip and the mean surface.

Table 5 (below) gives the statistics for the project area.

| Min magnitude for individual flight strip | Max magnitude for individual flight strip | Average Magnitude all flight strips | Min DZ for individual flight strip | Max DZ for individual flight strip |
|---|---|---|---|---|
| 0.062 | 0.167 | 0.101 | -0.09 | 0.117 |

**Table 5 Flight line elevation mismatch statistics.**

In order to assess the absolute accuracy of the LiDAR more than 3000 check points were collected by mounting a GPS antenna on a vehicle over Grass valley Municipal airport. (Figure 3). LiDAR data was collected over the airport and residuals were computed from the check point values with respect to the bare-earth DEM. Results are presented below in Table 6

| | |
|---|---|
| Average height residual | 0.047 |
| Standard deviation of height residual | 0.045 |
| RMSE of height residuals | 0.065 |

**Table 6 – Statistics on Residual Values of the Check Points With Respect to the Bare-Earth DEM.**

**Figure 3 – Check points at Grass Valley Municipal Airport**

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.

## 6. Data Deliverables

a) Datums and Projections
   i. Horizontal Datum: NAD_83 (EPOCH: 2010.0000)
   ii. Vertical Datum: NAVD88 (GEOID 12a)
   iii. Projection: UTM Zone 10 North
   iv. Units: Meters

b) Files and Formats:
   i. Discrete return Point Cloud in LAS format (Version 1.2), classified as ground (classification code 2), vegetation (classification code 4), and outliers ( classification code 9) in 1 km square tiles

ii. Unclassified individual flight strips in LAS format (Version 1.2)
iii. Bare-earth model at 1-m resolution in ESRI GRID float format
iv. Highest hit model at 1-m resolution ESRI GRID float format
v. Normalized intensity images at 1-m resolution ESRI GRID float format
vi. Site boundary index in ESRI shapefile
vii. Tile index (1kmx1km) in ESRI shapefile
viii. DEM/DSM index in ESRI shapefile
ix. Smooth best estimate trajectory in ESRI shapefile
x. Smooth best estimate trajectory in ASCII format file
xi. Optech Binary format ('.idf') full waveform files
xii. Optech Binary format ('.csd': Corrected Sensor Data ) individual flight strip data corresponding to full waveform data

c) File descriptions and naming Conventions:

i. **LAS Format Point Cloud Tiles** are 1 Km tiles follow a naming convention using the lower left coordinate (minimum X, Y) as the seed for the file name as follows: cXXXXXX_YYYYYYY, where .'c' is a prefix. For example if the tile bounds coordinate values from easting equals 762000 through 763000, and northing equals 4208000 through 4209000 then the tile filename incorporates c762000_4208000.
ii. **The ESRI grid tiles** are mosaics with their names also using the lower left coordinate. However it uses only the first three digits for easting and first four digits of northing. For e.g. for the mosaic with lower left corner with easting 738000 and northing 418000, the name will be f738_4180. The prefixes used are 'f' for bare earth DEMs, 'z' for maximum elevation grids and 'i' for intensity grids.
iii. **SBETS** are named with the day of the year of that flight.

Two spreadsheets are included:

1) Digitizer Files Index to relate the digitizer files to corresponding flight lines in CSD as well as LAS format
2) Flight Line index which gives the flight line ID for each flight line in the classified point clouds