Characterizing the Influence of Pioneer Woody Vegetation on Barform Morphodynamics using ALSM
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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 ALTM nominal specifications are listed below 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. Area of Interest.

The survey polygon, 40KM^2 in size, is located 160 km Northwest of Phoenix, AZ in Arizona. Figure 1 shows the shape and location of the survey area.

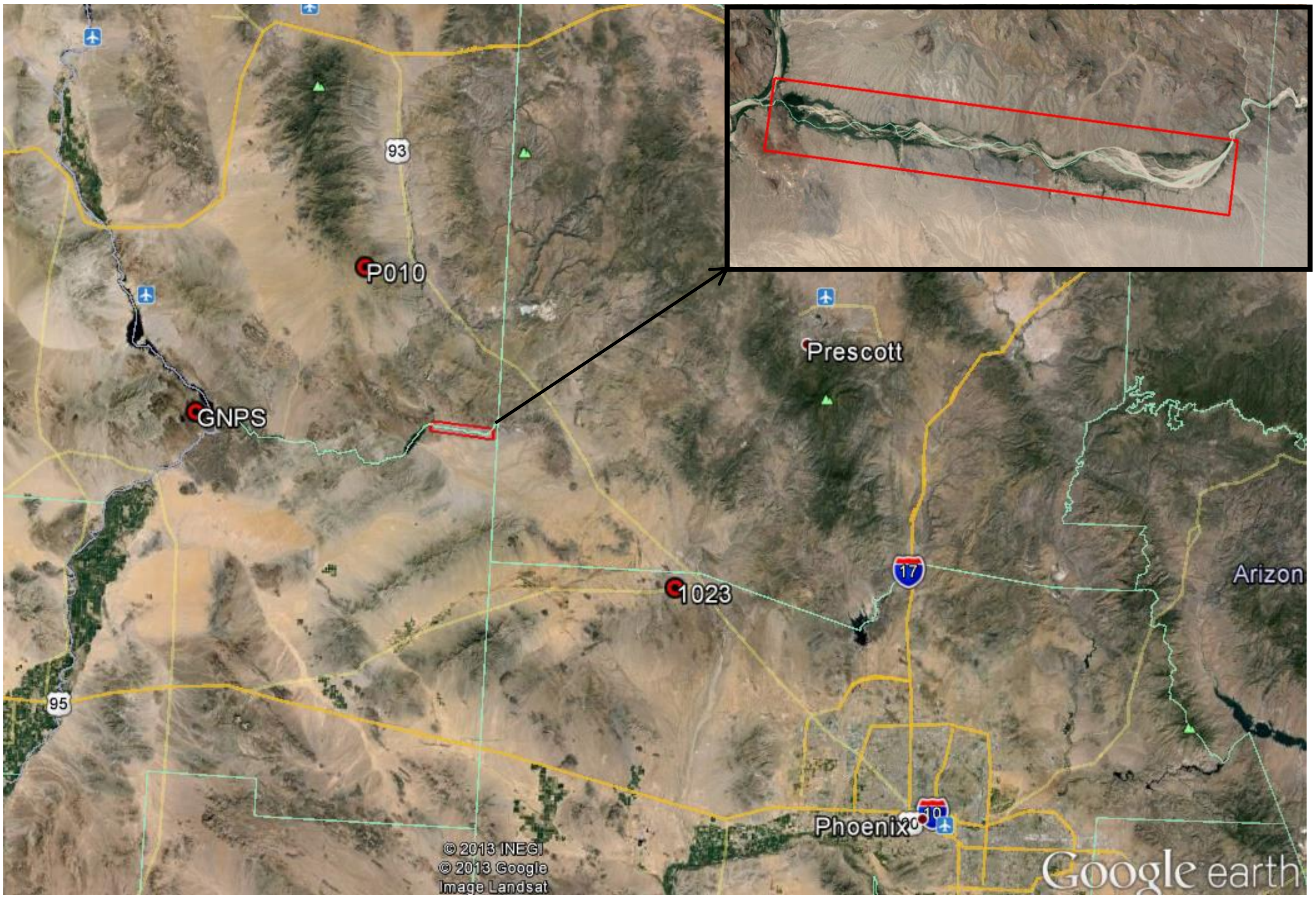

Figure 1 – Shape and location of survey polygons and GPS reference stations (Google Earth).

3. Data Collection

The survey took place on July 31, 2013 (DOY 212). The flight lasted 3.25 hrs with the total Laser on time of 1.35 hrs. Table 2 below gives the flight parameters of the survey flight.

Nominal Flight Parameters		Equipment Settings	
Flight Altitude	600 m	Laser PRF	100 kHz
Flight Speed	60 m/s	Beam Divergence	0.25 mrad
Swath Width	344m	Scan Frequency	50 Hz
Swath Overlap	50 %	Scan Angle	± 16°
Point Density	8 p/m²	Scan Cutoff	1.0°

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

Three GPS reference station locations were used during the survey; 2 of them being part of UNAVCO's PBO network (see http://pbo.unavco.org/ for more information from UNAVCO). The remaining 1 station was set by the NCALM field crew at the Wickenburg Municipal Airport, AZ. All GPS reference observations were logged at 1 Hz with geodetic-grade GPS receivers and antennas. Table 3 (below) gives the coordinates of the stations. Figure 1 (above) shows the relative locations of the reference stations.

GPS station	**1023**	**GNPS**	**P010**
Operating Agency	NCALM	UNAVCO	UNAVCO
Latitude	33.96557°	34.30855°	34.66725°
W Long	112.80435°	114.18943°	113.73133°
Ellipsoid Height(m)	696.238	233.181	1399.868

Table 3 – GPS Stations

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

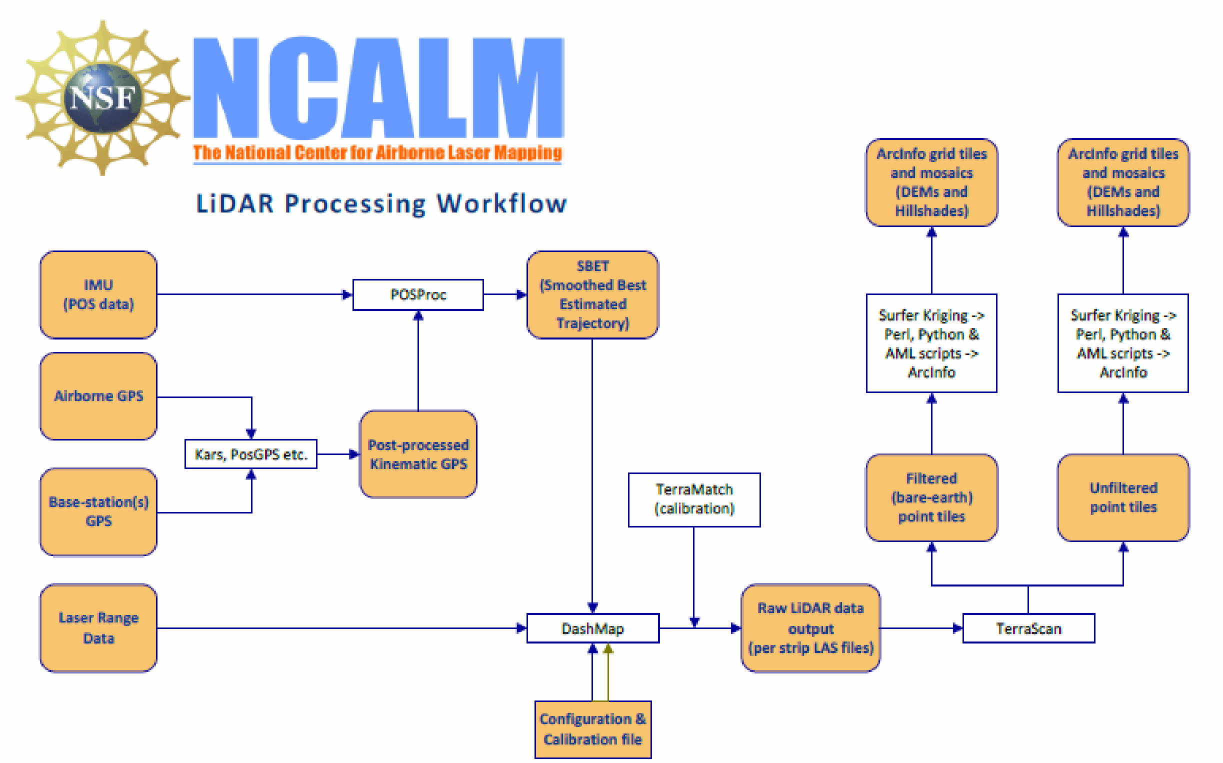

Figure 2 - NCALM LiDAR Processing Workflow

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 13.014). http://www.terrasolid.fi/en/products/4

6. Accuracy assessment

6.1 Relative accuracy

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 13.006). 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 0.037 meters with a standard deviation of 0.016 meters.

6.2 Absolute accuracy

This project was flown as part of a larger campaign covering different projects in the same region. For the campaign, 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. Absolute accuracy is certainly less on steep terrain and under canopy.

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 12N
d) **Units:** Meters.
e) **File Formats:**

1. Discrete return 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).

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 278000 through 279000, and northing equals 3798000 through 3799000 then the tile filename incorporates 278000_3798000. These tile footprints are available as an AutoCAD DXF, Bentley DGN, or ESRI shape-file. The ESRI DEMs are single mosaic files created by combining together the 1KM tiles.