Precipitation effects on landscape evolution: Quantifying the role of spatially variable climate in bedrock fluvial incision, Kohala Peninsula, Hawaii

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1. Sensor Systems Description and Specifications

The **LiDAR** data for this survey were collected with an Optech Gemini Airborne Laser Terrain Mapper (ALTM) serial number 06SEN195 mounted in a twin-engine Aero Commander 500S (piloted by Air Flight Service; Tail Number N500SJ). 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 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 (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 requested survey area consisted of a single irregular polygon of approximately 40 km^2 on the island of Hawaii covering two distinct watersheds on the Kohala peninsula. Repeated efforts were made to survey this area over an 8-day span. Unfortunately the ever-present cloud cover on the wet side prevented the completion of the survey. The requested polygon is shown below in Figure 1 with a red outline; the actual coverage is shown with a blue outline.

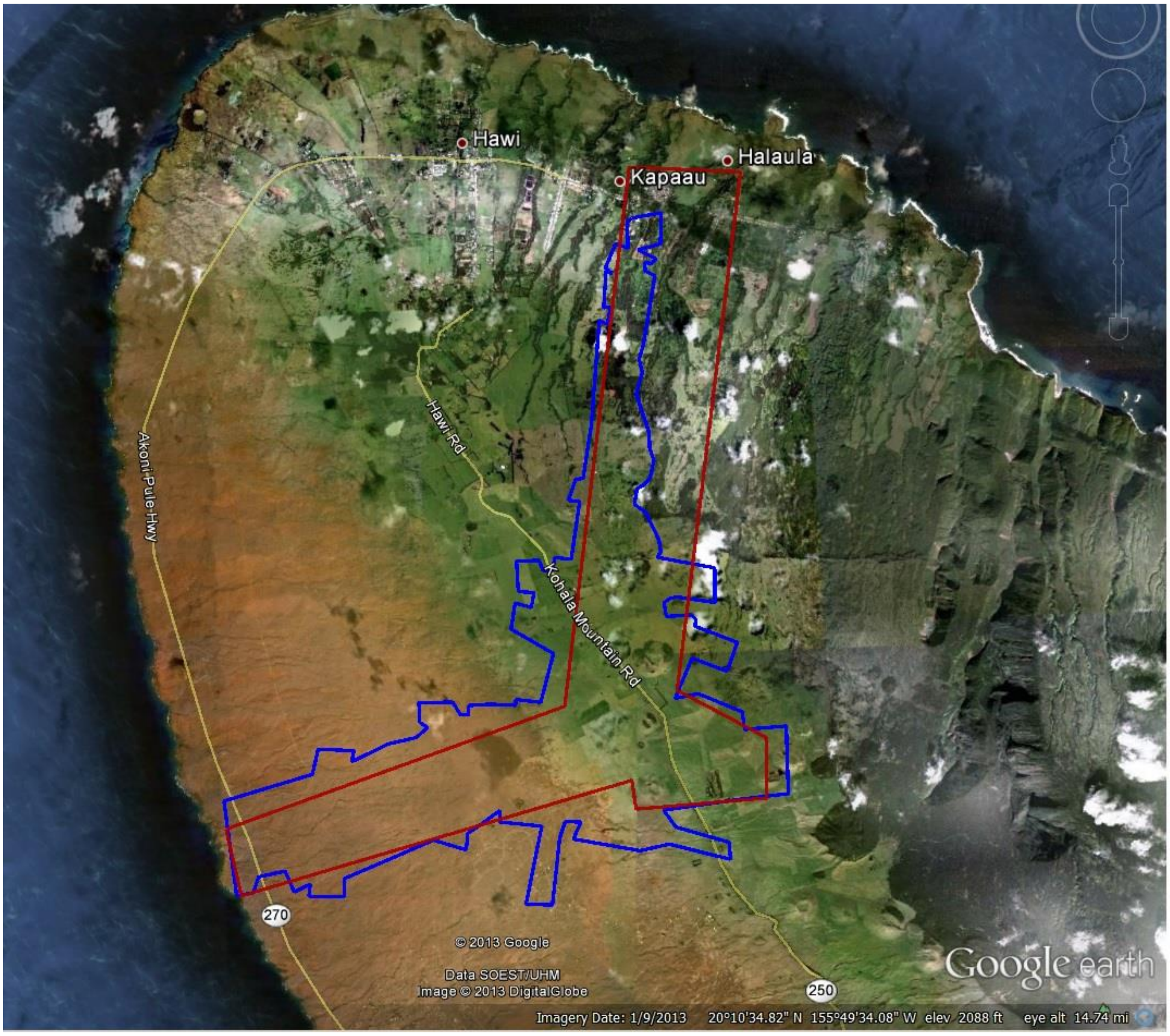

Figure 1 – Shape and location of the requested survey polygon shown as red outline; blue outline shows the area actually surveyed. (Google Earth).

3. Data Collection

a) Survey Dates: The survey attempts took placed from February 5, 2013 through February 12, 2013 (DOY 036 through 043).

b) Airborne Survey Parameters: Nominal survey parameters for the LiDAR collection are provided in Table 2 below. The survey was attempted eight different times, four of which resulted in some successful data collection.

Nominal Flight Parameters		Equipment Settings		Survey Totals	
Flight Altitude	600-800 m	Laser PRF	100 kHz	Total Flight Time(all attepts)	7.3 hrs.
Flight Speed	+/- 60 m/s	Beam Divergence	0.25 mRad (narrow)	Total Laser Time	1.7 hrs.
Swath Width	366 m	Scan Frequency	45 Hz	Total Swath Area	48 km^2
Swath Overlap	Min 50 %	Scan Angle	± 19°	Total AOI Area	40 km^2
Point Density	2 -10 p/m²	Scan Cutoff	1.0°		

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

c) Ground GPS: Four GPS reference station locations were used during the survey: MKEA, UPO5, PMAU, and ST1_. Two of the four (MKEA and UPO5) are part of the National Geodetic Survey's (NGS) network of Continuously Operating Reference Stations (CORS). The third station (PMAU) is part of the USGS Hawaiian Volcano Observatory network (many thanks to Asta Miklius of the USGS HVO for her help in obtaining high-rate data) and the fourth station (ST1_) was set by the NCALM field crew 30 km southeast of the project site. MKEA, PMAU, and ST1_ reference observations were logged at 1 Hz; UPO5 logged at a 5-second rate and was interpolated to 1 Hz. Table 3 (below) gives the coordinates of the stations and Figure 2 (following page) shows the project area and the GPS reference station locations.

GPS station	ST1_	PMAU	MKEA	UPO5
Operating Agency	NCALM	USGS HVO	CORS	CORS
Latitude	19 54 9.51004	19 40 37.86549	19 48 04.84680	20 14 45.16697
W Long	155 40 37.39570	155 49 3.62055	155 27 22.74526	155 53 01.65401
Ellipsoid Height(m)	1024.927	2033.047	3754.486	78.143

Table 3 – GPS Coordinates of ground reference stations. NAD_83 (PA11) (EPOCH: 2010.0000)

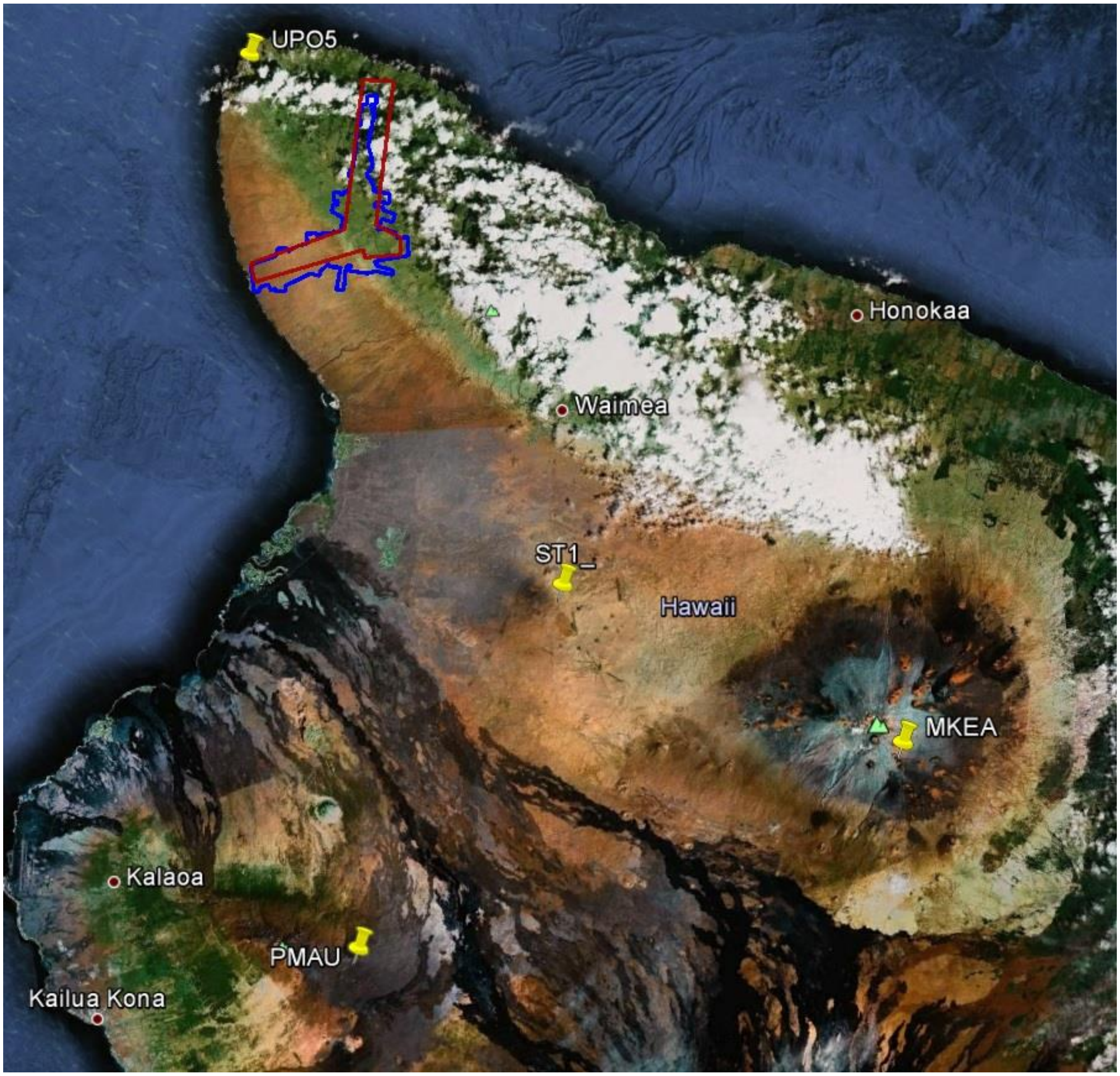

Figure 2 - Project area and GPS reference locations. Red lines illustrate the area of the virtual GPS network.

d) **Reference coordinates** for ST1_ and PMAU 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 MKEA and UPO5 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/

4. GPS/IMU Data Processing

Airplane trajectories for this survey were processed using Applanix PosPAC Mobile Mapping Suite (MMS) version 5.2. This software package enables a user to employ a network of GPS reference stations to construct a virtual reference station solution that computes a set of corrections for a roving receiver anywhere within the network. The advantage of this virtual base station approach is that within the network the atmospheric and other errors are estimated to a level such that the ppm effects remain equivalent to that of a short baseline even when the reference stations themselves are separated by a much longer distance.

Applanix kinematic processing also uses what has come to be known as a "tightly coupled" integration approach: first a single Kalman Filter estimates both the inertial system (IMU) errors and the GPS floated ambiguities and then a proprietary algorithm fixes the ambiguities as integers to obtain centimeter level positioning. The final result is a smoothed navigation solution including both aircraft position and orientation at 200 Hz. This final navigation solution is known as an SBET (Smoothed Best Estimated Trajectory). See http://www.applanix.com/articles-and-papers/pos-av.html#.UVYDuxyG0Z4 for additional information.

5. LiDAR Data Processing Overview

The following diagram (Figure 3) shows a general overview of the NCALM LiDAR data processing workflow.

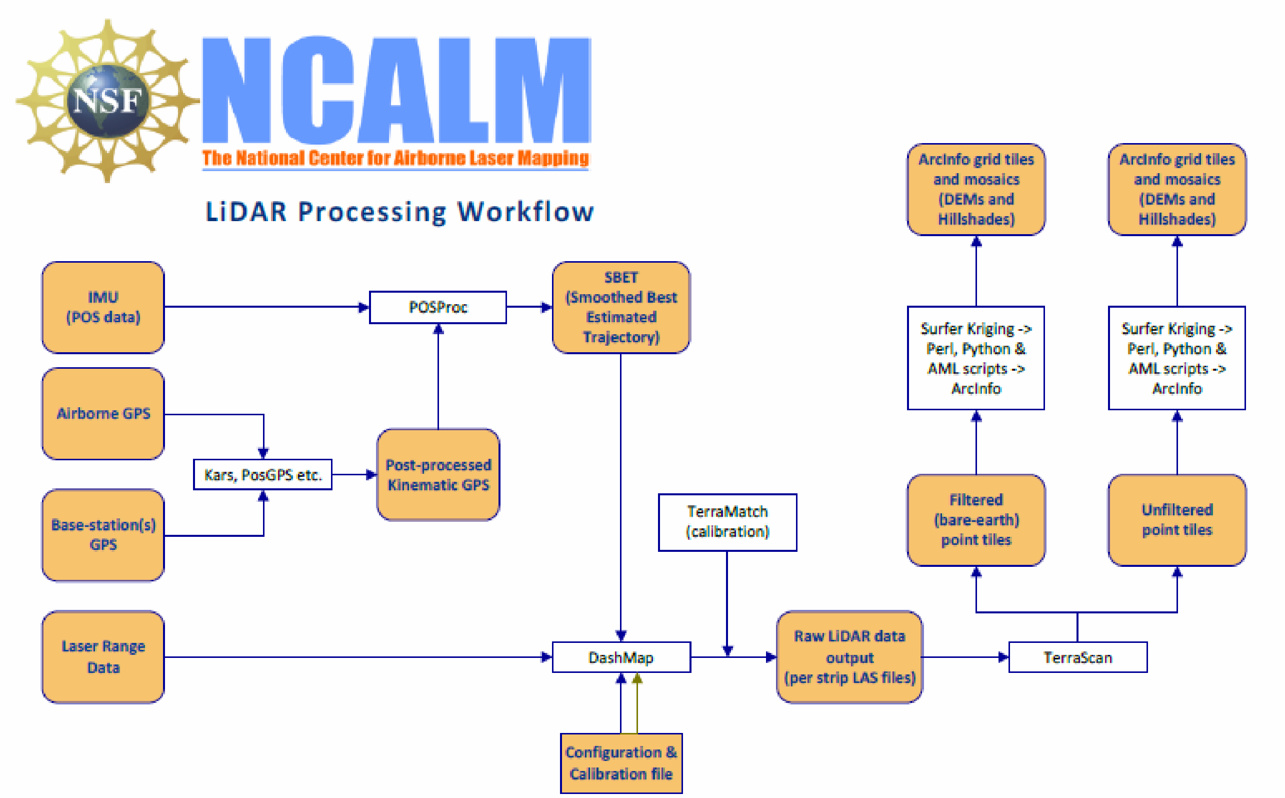

Figure 3 - NCALM LiDAR Processing Workflow

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 Digital Elevation Model (DEM) is constructed. Classification of the ground-class points is done by automated routines using TerraSolid Software (TerraScan Version 13.004). http://www.terrasolid.fi/en/products/4

6. Accuracy assessment

a) Internal Reproducibility

System calibration of the three sensor boresight angles (roll, pitch, and yaw) and the 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 13.002). 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.

After optimal calibration values are determined, project flight line point clouds are output in their final form and then checked for internal consistency. This is done by computing an average mismatch in surfaces again constructed from only ground-class points of individual flight lines in overlap areas. **Average project mismatch (individual flight line overlap areas) magnitude: 0.043 meters**

b) Absolute Accuracy

In order to assess the absolute accuracy of the LiDAR more than 8000 check points were collected by mounting a GPS antenna on a vehicle and driving 13 km on Saddle Road. During the survey flights the aircraft collected LiDAR over this section of road.
Residuals were computed from the check point values with respect to the LiDAR bare-earth DEM. Results are presented below in Table 7.

Average height residual	0.034 m
Standard deviation of height residuals	0.050 m
RMSE of height residuals	0.060 m

Table 4 – Statistics on Residual Values of the Check Points With Respect to the Bare-Earth DEM.

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(PA11)(Epoch: 2010)
b) **Vertical Datum:** GEOID 12A
c) **Projection:** UTM Zone 04 N
d) **Units:** Meters
e) **File Formats:**

1. Classified Point Cloud in LAS 1.2 format in 1 km square tiles.
2. ESRI format 1-m DEM from default-class points.
3. ESRI format 1-m DEM from ground-class points.
4. ESRI format 1-m Hillshade raster from default-class points.
5. ESRI format 1-m Hillshade raster from ground-class points.

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 830000 through 831000, and northing equals 2227000 through 2228000 then the tile filename incorporates 830000_2227000. 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

7. Notes

NCALM gave this project our best effort over 8 days but the clouds just wouldn’t allow the wet watershed to get surveyed.