Legg: Hazard implications of landscape response to debris flows in Mount Rainier National Park
Anderson: Assessing climatically-driven aggradation in a mountain stream, Mount Rainier, Washington
(2012 SEED Projects)

PI: Nicolas Legg - Oregon State University - Corvallis
PI: Scott Anderson - UC Boulder

Nicholas Legg Oregon State University – Corvallis Department of Geosciences 104 Wilkinson Hall, Corvallis, OR 97331-5506 leggn@geo.oregonstate.edu 763-350-3052	Scott Anderson University of Colorado at Boulder Geography Department 3380 Dartmouth Ave. Boulder, CO 80305 Scott.w.Anderson@colorado.edu 541-760-1137

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 Piper Chieftain (Tail Number N31PR). 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 BD960 72-channel 10Hz (GPS+GLONASS) 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 two separate polygons within the boundary of Mount Rainier National Park in Washington on the southwestern flank of the volcano. The two polygons are shown with red outlines below in Figure 1. Their close proximity enabled the two surveys to be flown most efficiently as a single polygon; the planned flight lines are shown below in yellow. The eastern polygon (Legg) covers the Kautz Creek watershed and is approximately 33 km². The western polygon (Anderson) covers the Tahoma Creek watershed and is approximately 37 km². The total area for the combined survey including the area between the requested polygons and the additional coverage in the northwest corner is approximately 96 km².

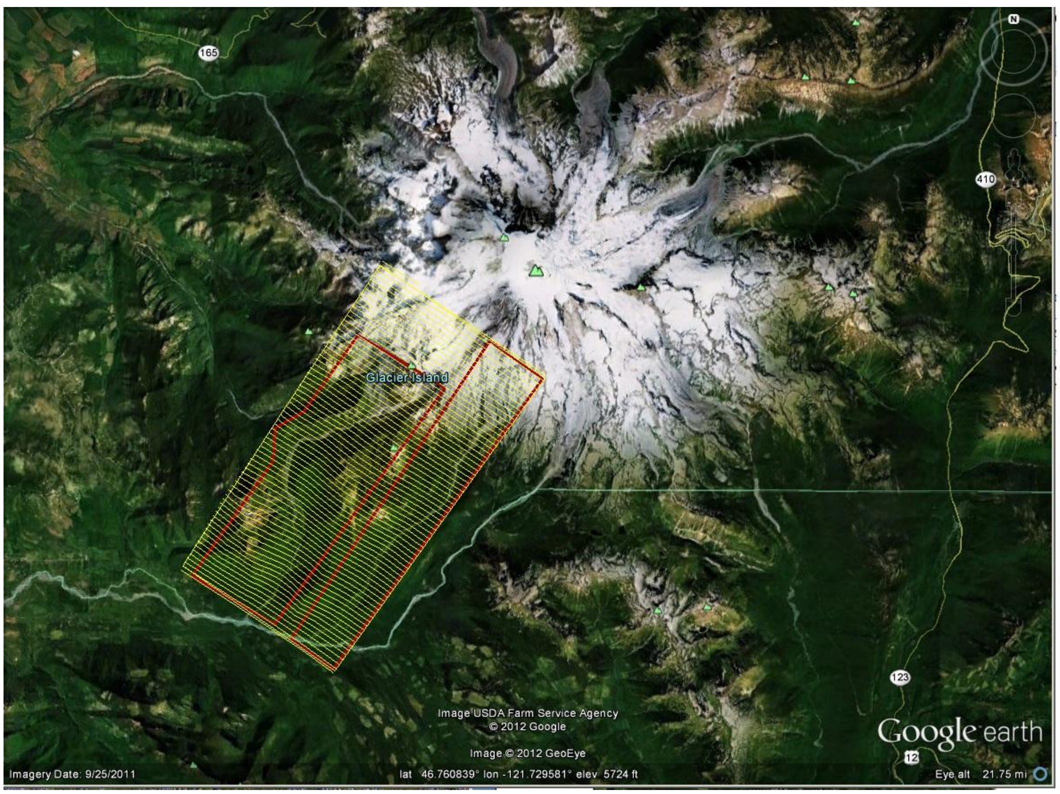

Figure 1 – Shape and location of survey polygons (red outlines) with the planned flight lines shown in yellow. (Google Earth).

3. Data Collection

a) Survey Dates: The survey required 4 flights which took place from August 28, 2012 – September 1, 2012 (DOY 241-245).

b) Airborne Survey Parameters: Survey parameters varied considerably due to the mountainous terrain and are provided in Table 2 below.

Nominal Flight Parameters		Equipment Settings		Survey Totals	
Flight Altitude	700-1500 m	Laser PRF	70,100,125 kHz	Total Flight Time	10.5 hrs
Flight Speed	60 m/s	Beam Divergence	0.25 mrad	Total Laser Time	2.5 hrs
Swath Width	480-760 m	Scan Frequency	45 Hz	Total Swath Area	99.2 km^2
Swath Overlap	Min 50 %	Scan Angle	± 19-20°	Total AOI Area	96 km^2
Point Density	7.5 p/m^2	Scan Cutoff	1.0°		

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

c) Ground GPS: Five GPS reference station locations were used during the survey: one station (PARA) was set and operated by NCALM at the lower parking area of the Paradise Inn while the remaining four stations are part of UNAVCO's PBO network (see http://pbo.unavco.org/ for more information from UNAVCO). All GPS reference observations were logged at 1 Hz. Table 3 (below) gives the coordinates of the stations and Figure 2 shows the project area and the GPS reference station locations.

GPS station	PARA	P421	P431	P432	CPXX
Agency	NCALM	UNAVCO	UNAVCO	UNAVCO	UNAVCO
Latitude	46.78431	46.53185	46.57208	46.62285	46.84008
W Longitude	121.74201	122.42921	121.98844	121.68321	122.25650
GRS80 Height	1618.821	220.946	1423.978	319.241	533.982

Table 3 – Coordinates of GPS reference stations in NAD83 (2011) Epoch 2010.0000 - Ellipsoid Height in meters.

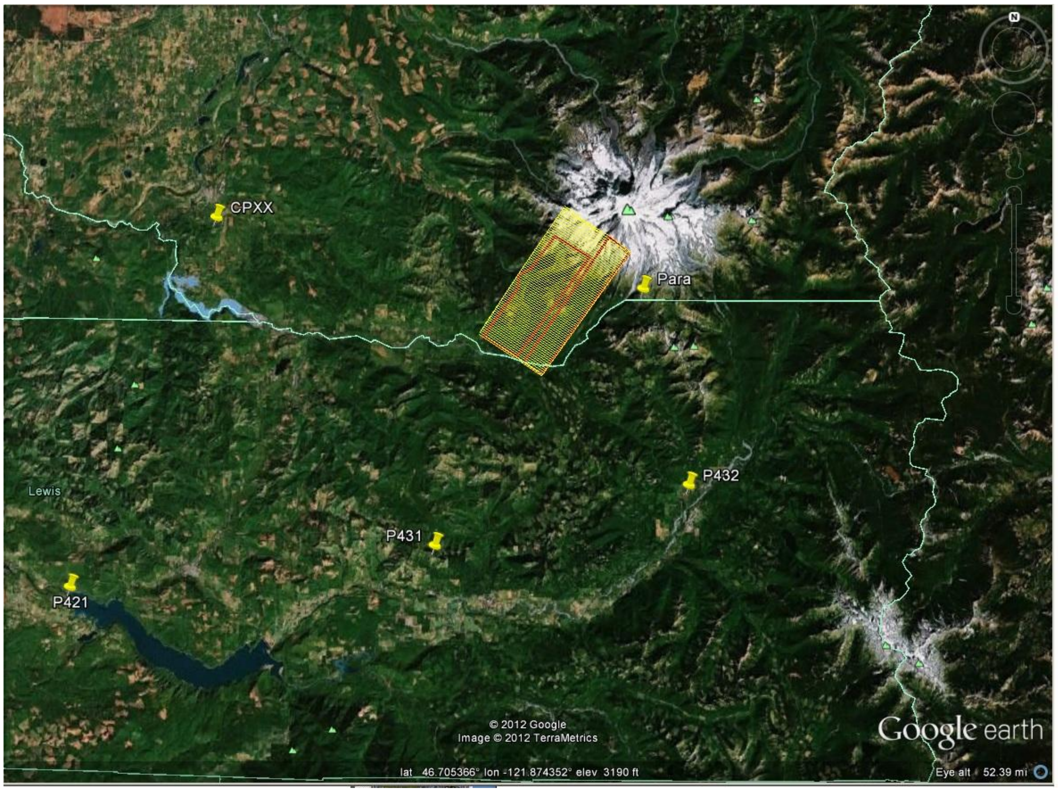

Figure 2 - Project area and GPS reference locations.

4. GPS/IMU Data Processing

Reference coordinates (NAD83 (2011) Epoch 2010.0000) 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 five 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 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 3) shows a general overview of the NCALM LiDAR data processing workflow

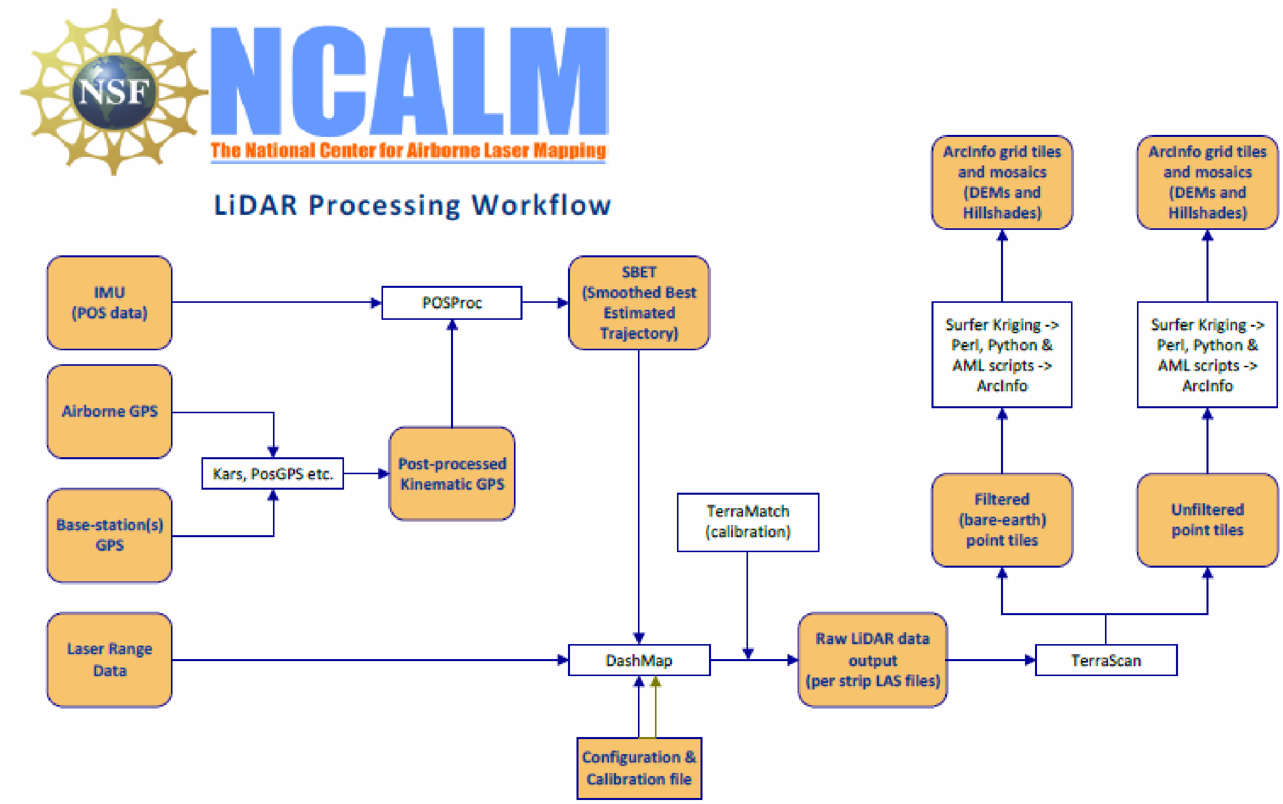

Figure 3 - NCALM LiDAR Processing Workflow

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.

Classification done by automated means using TerraSolid Software (TerraScan Version 12.016). http://www.terrasolid.fi/en/products/4

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. Data Deliverables

a) **Horizontal Datum**: NAD83 (2011)
b) **Vertical Datum:** NAVD88 (GEOID 03) The GEOID03 model is outdated. It was used in order to maintain maximum compatibility with 2007/2008 WS LiDAR survey which also used GEOID03.
c) **Projection:** UTM Zone 10N – 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).

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 396000 through 397000, and northing equals 4444000 through 4445000 then the tile filename incorporates 396000_4444000. 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. 'ume396000'. The hillshade files have a prefix 'sh' after the name, for e.g. 'ume396000sh'

7. Notes

a) The 2007/2008 Watershed Sciences LiDAR (WS2008) was used as control to vertically adjust the 2012 NCALM LiDAR (NC2012). Using profiles cut along roads from WS2008 as ground truth, the NC2012 was found to be biased (too high) by 0.151 m with respect to WS2008 and this adjustment was then applied to NC2012 effectively lowering NC2012 by 0.151 m.
b) The Horizontal Datum for NC2012 is the current iteration of NAD83, namely NAD83 (2011) Epoch 2010.0000. The WS2008 survey used a previous iteration of NAD83 namely (CORS96) Epoch 2002.0000. Although there is NO defined systematic horizontal shift between NAD83 (CORS96) and NAD83 (2011) there is some modeled tectonic

movement between these NAD83 iterations (velocities are 5.15 mm/yr north; 5.08 mm/yr east). The epoch difference of 8 years (Epoch 2010.0000 vs. Epoch 2002.0000) at the modeled velocity is equal to horizontal shifts of approximately 0.041 m in northing and 0.041m in easting (2012 being more northerly and easterly than 2008). An analysis was performed at the conclusion of NC2012 LiDAR processing whereby the WS2008 bare-earth DEM was subtracted from the NC2012 bare-earth DEM. This analysis revealed a mismatch in the horizontal alignment between the 2 DEMs that is substantially greater than the modeled tectonic shift and in the opposite direction: NC2012 must be shifted to the north and east in order to better fit WS2008. The precise magnitude of the shift (it appears to be around a meter) could be calculated using the WS2008 DEM and the NC2012 point cloud, but a more precise magnitude might be determined given access to the WS2008 point cloud. Unfortunately this point cloud is not currently available to download from the Puget Sound LiDAR Consortium. If the WS2008 point cloud were available, one way of precisely determining shift values would be to create intensity images from both surveys showing road paint stripes and directly measuring the shift.

c) LiDAR data ground classification is the (mostly) automated process whereby a subset of the entire point cloud is selected as bare-earth measurements vs. measurements deemed not to have penetrated all the way to the ground. Heavy vegetation, extreme relief, fast-forming clouds, and flying time budget constraints are all factors that limit the density of these critical bare-earth measurements. When dealing with a suboptimal number of ground class points (as is the case in both the WS2008 and NC2012 surveys), there is a trade-off between DEM smoothness and information degradation. It could be argued that Watershed Sciences made a choice to be more aggressive in their classification scheme to the point where they sacrifice some information to gain a smoother DEM. While the WS2008 DEM is smoother (less noisy -fewer bumps) than the NC2012 DEM, the smoothness has come at the price of eroded edges of steep slopes, eroded cliffs, and most importantly, eroded water channels causing distortions in their true dimensions. The 3 figures below (Figures 4-6) are shaded relief images of a 750 meter section of Kaust creek.

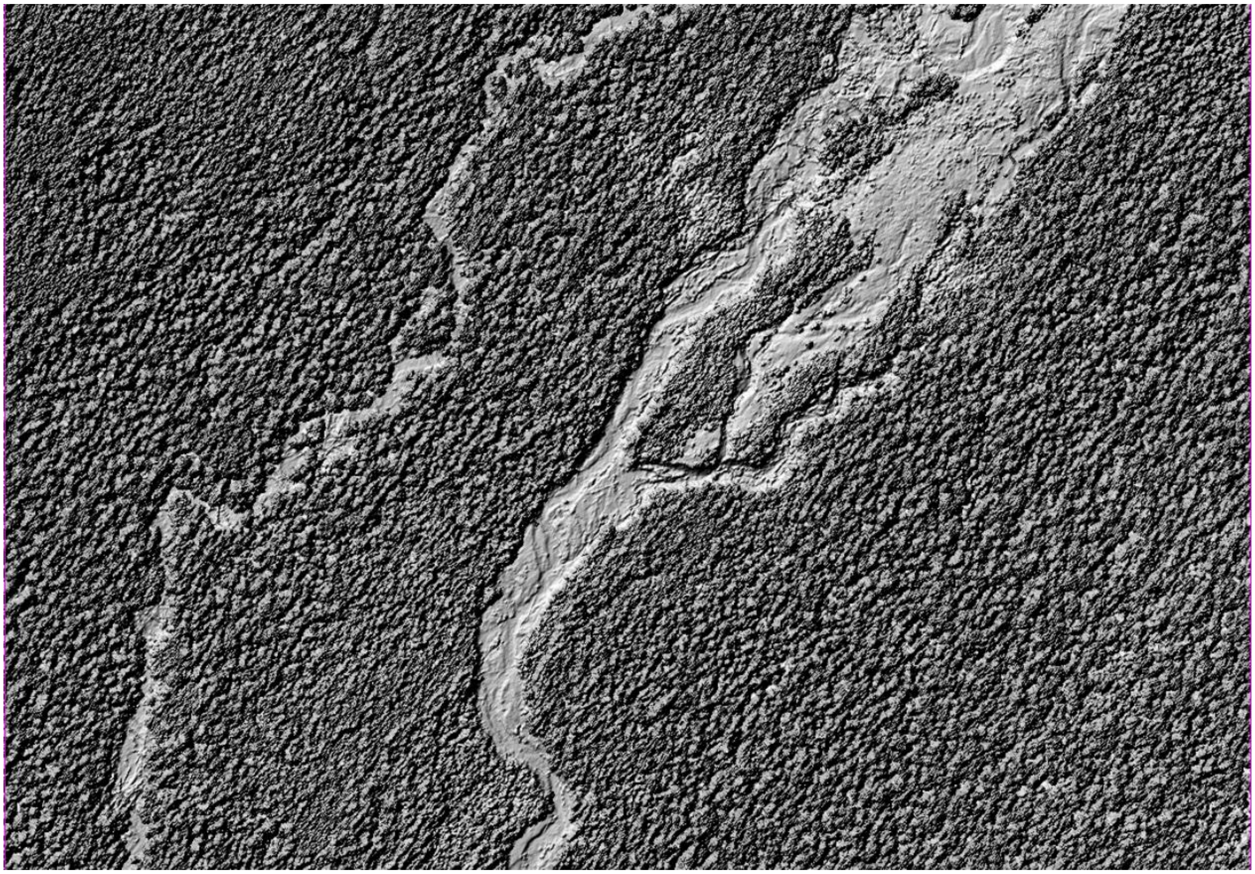

Figure 4 - Shaded relief image of DEM made from the unclassified LiDAR point cloud (NC2012) on a portion of Kaust Creek. Native point density >8 per m^2

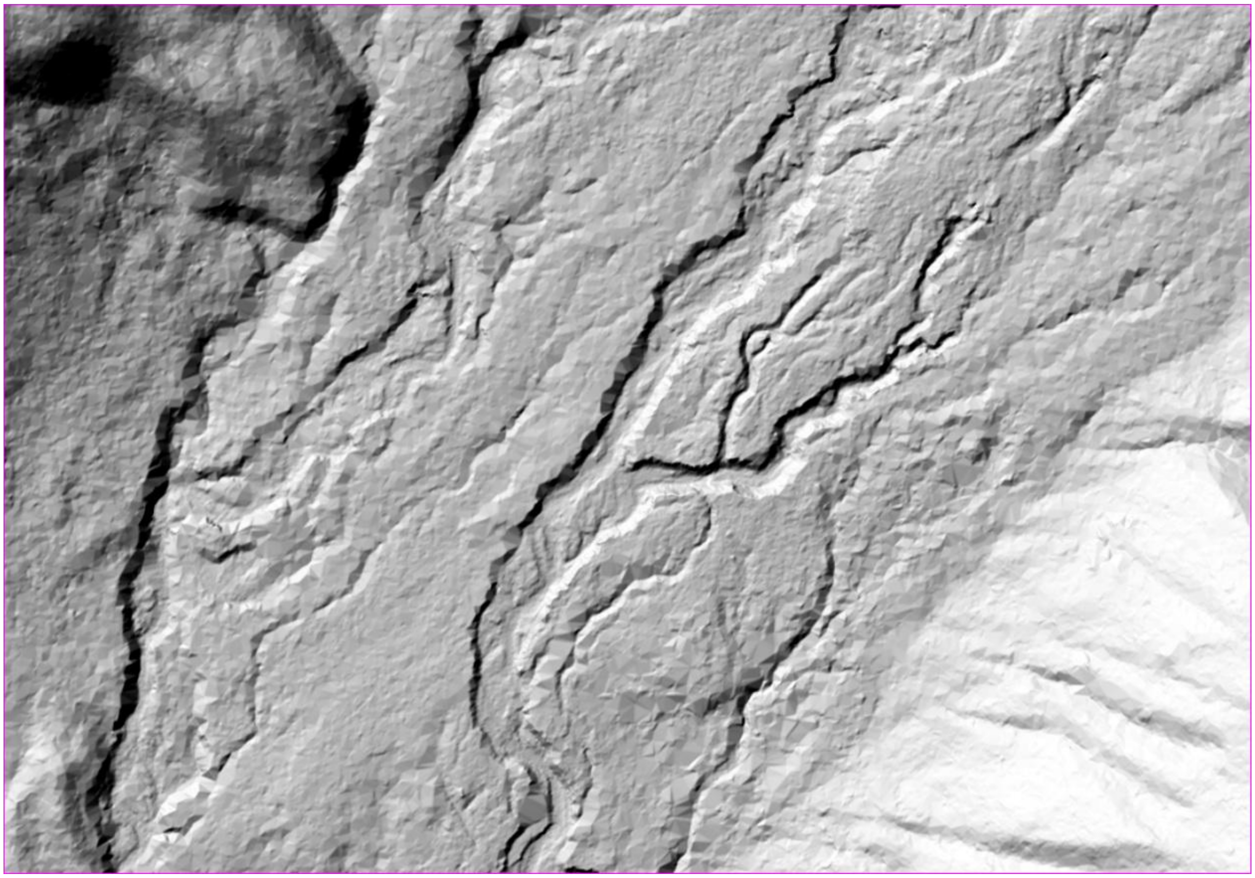

Figure 5 - Shaded relief image of DEM made from the ground-classified LiDAR point cloud (WS2008) on the same portion of Kaust Creek. This DEM was created with a TIN interpolation algorithm. Ground class point density <1.0 per m^2 per WS report dated 3/25/2009 p14.

Note that water channels in Figure 5 (WS2008) show significant distortions (try zooming to 200%) as evidenced by the planar triangular surfaces that are artifacts of the TIN algorithm and caused by a sub-optimal ground class point density of less than 1 point per meter square.

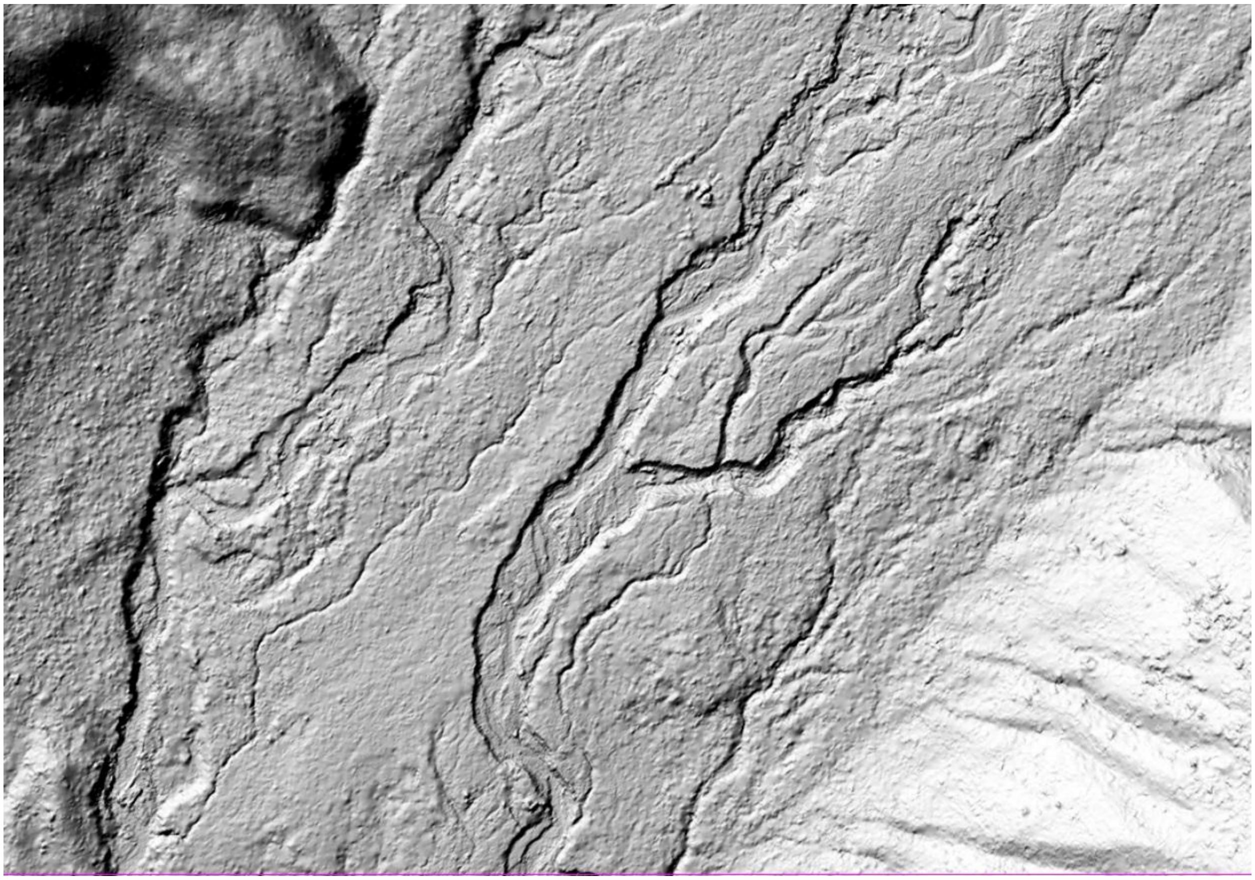

Figure 6 - Shaded relief image of DEM made from the ground-classified LiDAR point cloud (NC2012) on the same portion of Kaust Creek. This DEM was created with a krigging interpolation algorithm. Ground class point density is still sub-optimal but improved from WS2008 to >1.2 per m^2

Better water channel definition can be seen in Figure 6 (NC2012). Several factors explain why: more shots per square meter were fired; more ground class points through a less aggressive classification scheme (though their density is still sub-optimal) and the use of a krigging interpolation algorithm.

d) Figures 7 and 8 below are point-density images from the NC2012 survey.

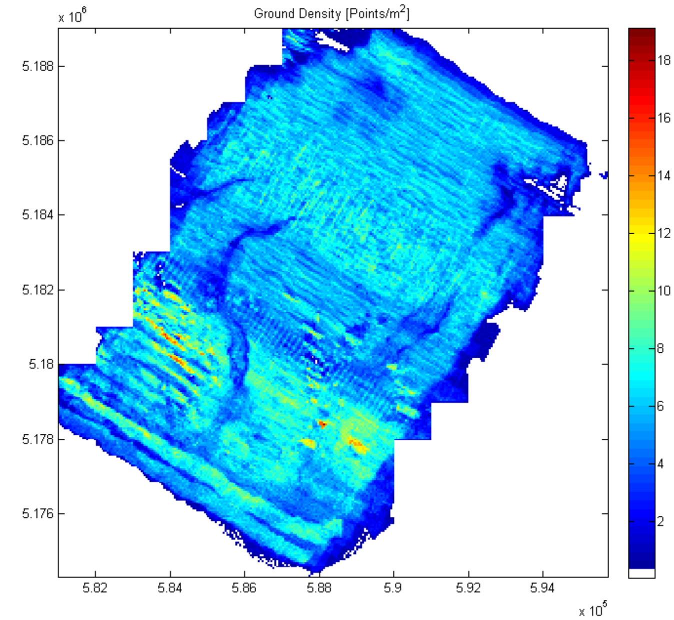

Figure 7 - Laser shots fired per square meter.

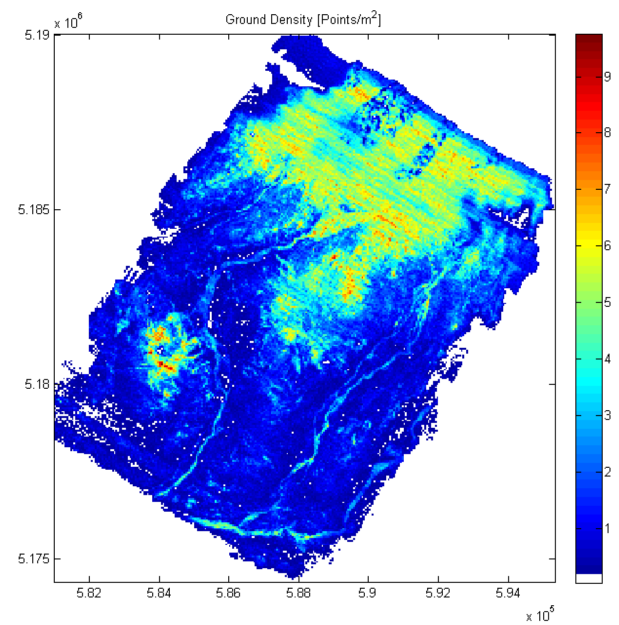

Figure 8 - Ground class points per square meter.