

## HAWAII KAUAI Survey Report

### LIDAR System Description and Specifications

This survey used an Optech GEMINI Airborne Laser Terrain Mapper (ALTM) serial number 06SEN195 mounted in a twin-engine Navajo Piper (Tail Number N3949W). This ALTM was delivered to the UF in March, 2007 as the first of its kind in the United States. System specifications appear below in Table 1.

Operating Altitude	150 - 4000 m
Horizontal Accuracy	1/5500 x altitude; $\pm 1$ -sigma
Elevation Accuracy	5 - 30 cm typical; $\pm 1$ -sigma
Range Capture	Up to 4 range measurements per pulse, including last
Intensity Capture	4 Intensity readings with 12-bit dynamic range for each measurement
Scan Angle	Variable from 0 to 25 degrees in increments of $\pm 1$ degree
Scan Frequency	Variable to 70 Hz
Scanner Product	Up to Scan angle x Scan frequency = 1000
Pulse Rate Frequency	33 - 167 KHz
Position Orientation System	Applanix POS/AV 510 OEM including internally embedded BD950, 12-channel 10Hz GPS receiver
Laser Wavelength/Class	1047 nanometers / Class IV (FDA 21 CFR)
Beam Divergence nominal (1\e full angle)	Dual Divergence 0.25 mrad or 0.80 mrad

**Table 1 – Optech GEMINI specifications.**

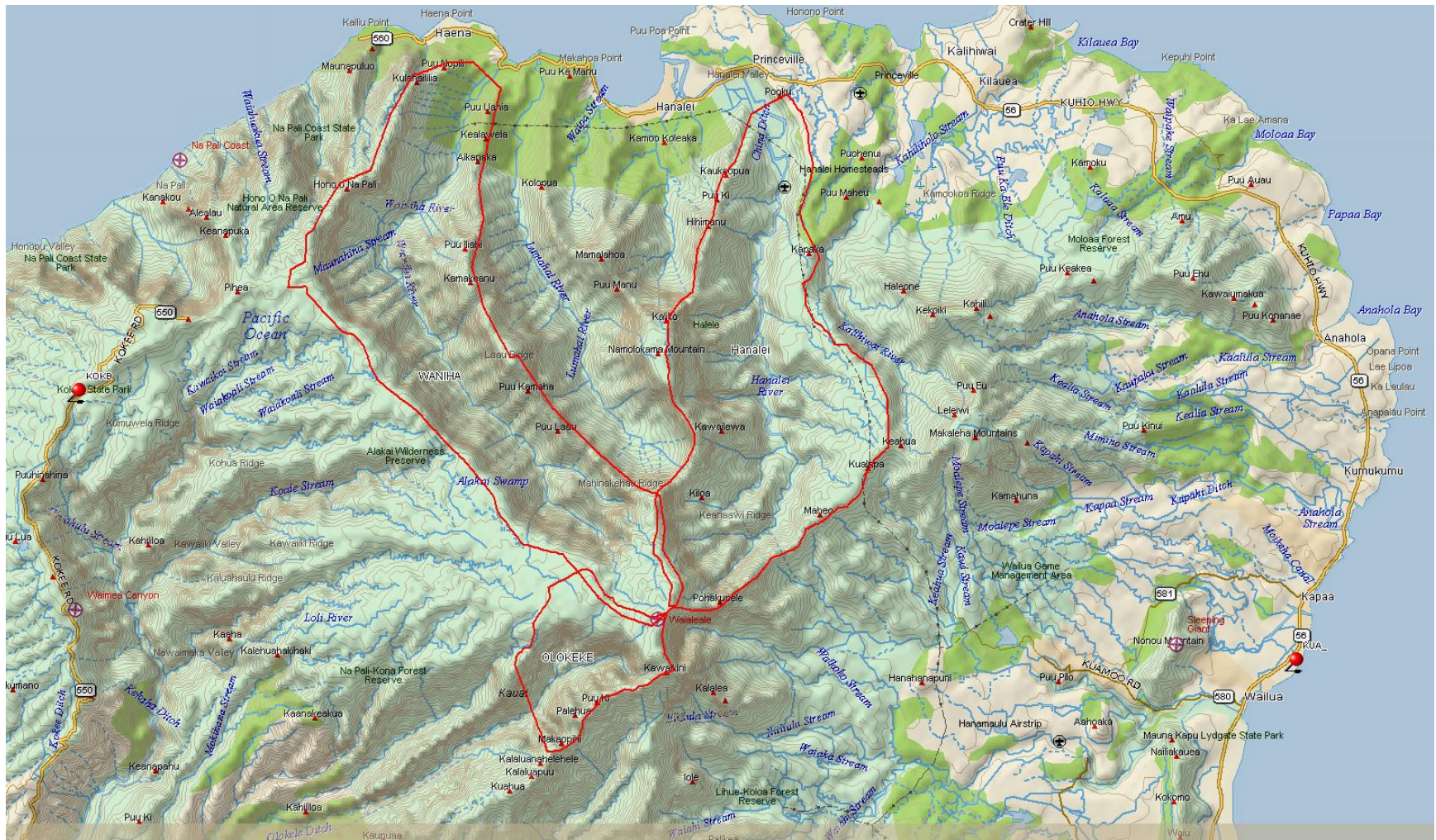
See <http://www.optech.ca> for more information from the manufacturer.

### Field Campaign

The Field campaign lasted for 4 days starting on 29<sup>th</sup> June, 2009, and ending on 2<sup>nd</sup> July, 2009. Flying took place on all the four days totaling 15 hrs of flying time and 3 hours 45 minutes of laser on time.

Flight Num	Date	DOY	DOW	Areas Surveyed	Flying Time	LOT
1	29-Jun	180	Monday	Hanalei, Olokeke	2:27:00	0:24:21
2	30-Jun	181	Tuesday	Hanalei	3:19:00	1:01:00
3	1-Jul	182	Wednesday	Olokeke, Hanalei, Waniha	5:40:00	1:40:23
4	2-Jul	183	Thursday	Waniha	3:35:00	0:38:52
				<b>Total</b>	<b>15:01:00</b>	<b>3:44:36</b>

**Table 2 Survey Flight Information**



**Figure 1** Areas surveyed

## Survey Area and Parameters

ALTM NAV planner software was used to plan the surveys. They were planned to provide a point density of 6-8 points per square meter. The survey parameters for each section are given in Table 3. The pulse frequency was decided on the basis of terrain of the section. For a nominal terrain with gradual slopes, which could be followed easily, the survey is generally carried out at an above ground altitude of 700m and 100 KHz pulse frequency with 50% overlap to obtain the desired point density. However, in this case, the sections covered valley with cliffs and steep slopes. Therefore, the survey was planned at 1100 m AGL, 70 KHz and the overlap was adjusted to realize the required point density.

Section	Pulse Frequency	Scan Angle	Scan Rate	Area
Hanalei	70	18	40	56.88033
Waniha	70	18	40	62.34312
Olokeke	70	18	40	13.2039
<b>Total</b>				<b>132.4274</b>

**Table 3 Survey Parameters for Area Surveyed**

## Data Processing

### GPS and IMU Data Processing

Two GPS stations were used as ground reference stations. One was set up by NCALM, the other was operated by the IGS (International GNSS Service) and the data was downloaded from CDDIS (Crustal Dynamics Data Information System) website.

Station	Latitude	Longitude	Station Type
KUA_	19.411954	-155.260009	UF
KOKB	19.493388	-155.383238	CDDIS

**Table 4 Ground Reference Stations**

The aircraft and the ground GPS were processed by Dr. Gerry Mader using the KARS software. The resulting airplane GPS trajectories were integrated with the IMU data using the Applanix POSPac v 5.2 software to get the final SBET (Smoothed best estimate trajectory). This software employs a Kalman Filter algorithm to combine the 1-Hz final differential GPS solutions with the raw 200-Hz IMU orientation measurement data and their respective error models. The final result is a smoothed and blended solution of both aircraft position and orientation at 200 Hz, in SBET format (Smoothed Best Estimated Trajectory).

### Laser Point Processing

The laser ranging files and post processed aircraft navigation data (SBET) are combined using Optech's DashMap software (version 4) to produce the laser point cloud in the form of LAS files. **The laser point coordinates in these LAS files are in UTM Zone 4.**

DashMap was run with the following processing filters enabled: *scan angle cut-off* (varying 0.5-4.0 deg), *minimum range* (typically 400m) and *intensity normalization* enabled (1000m normal range). The temperature and pressure values were adjusted based on the recorded values from the airport at the time of the flight and the average altitude above ground.

The IMU misalignment angles (roll, pitch, heading), scanner scale and pulse range offsets are specified via the calibration file. The closest previously known good configuration file is used as a starting point for the calibration procedure and provides baseline values for the misalignment parameters. Using these baseline parameters data is output (point cloud) at the calibration site.

The calibration site typically consists of two sets of overlapping perpendicular flight lines. For this purpose, during each flight, laser data is collected in perpendicular direction to the survey lines i.e. a cross-line is flown across the survey area. Calibration is performed using TerraSolid's TerraMatch software. TerraMatch measures the differences between laser surfaces from overlapping flightlines or differences between laser surfaces and known points. These observed differences are translated into overall correction values for the system orientation (roll, pitch, heading) and mirror scale. The values reported by TerraMatch represent shifts from the baseline parameters used to output the calibration site data from DashMap. 3 to 4 such perpendicular sections are checked for consistency and an average value is used for calibration parameters.

The user should be aware that these calibration procedures determine a set of best global parameters that are equally applied to all swaths from a given laser range file. This means that the final swath misfit will vary slightly from place to place and swath to swath depending on how well the global calibration parameters are reducing the local misalignment. Some swaths or swath sections may exhibit worse than average alignment with their neighbors and the swath edge may become detectable in the DEMs.

The vertical accuracy of the LiDAR data was checked using a set of ground-truth points surveyed using vehicle-mounted GPS. Comparisons were made between the heights of the vehicle-collected GPS and the nearest neighbor processed points collected by the airborne laser scanner. The average offset between the ground truth and laser data was used to adjust the pulse range parameters in the DashMap calibration file.

The resulting orientation, mirror scale and range offsets are used to create a new DashMap calibration file that is used to output the calibrated, complete laser point dataset in LAS format, one file per flight strip. The LAS files contain all four pulses data recorded by the scanner as well as additional information like the intensity value and scan angle.

## **Classification**

TerraSolid's TerraScan software was used to classify the raw laser point into the following categories: ground, non-ground (default), aerial points and low points. The processing is done by dividing each section into 1000m X 1000m tiles. A macro containing the classification steps is created, which is run on each tile with a 40 m buffer. This overlap ensures consistent results for corners and edges of the tile.

Various classification algorithms which were used are given below:

**1) Isolated Points:** This routine classifies points which do not have very many other points within a 3D search radius. This routine is useful for finding isolated points up in

the air (fog) or below the ground (multipath). When possibly classifying one point, this routine will find how many neighbouring points there are within a given 3D search radius. It will classify the point if it does not have enough neighbours.

**2) Air points:** It classifies points which are clearly higher than the median elevation of surrounding points. It can be used to classify noise up in the air. When possibly classifying one point, this routine will find all the neighboring source points within a given search radius. It will compute the median elevation of the points and the standard deviation of the elevations. The point will be classified only if it is more than a certain limit (user defined) times the standard deviation above the median elevation. Comparison using standard deviation results in the routine being less likely to classify points in places where there is greater elevation variation.

**3) Low Points:** This routine was used to search for possible error points which are clearly below the ground surface. The elevation of each point (=center) is compared with every other point within a given neighborhood and if the center point is clearly lower than any other point it will be classified as a “low point”. This routine can also search for groups of low points where the whole group is lower than other points in the vicinity. Input parameters used were:

**4) Ground Classification:** This routine classifies ground points by iteratively building a triangulated surface model. The algorithm starts by selecting some local low points assumed as sure hits on the ground, within a specified windows size. This makes the algorithm particularly sensitive to low outliers in the initial dataset, hence the requirement of removing as many erroneous low points as possible in the first step. The routine builds an initial model from selected low points. Triangles in this initial model are mostly below the ground with only the vertices touching ground. The routine then starts molding the model upwards by iteratively adding new laser points to it. Each added point makes the model follow ground surface more closely.

**5) Classify By Height Above Ground:** It classifies points which are within a given height range compared to the ground points surface model. The routine requires that you have already classified ground points successfully. This routine will build a temporary triangulated surface model from ground points and compare other points against the elevation of the triangulated model. This routine was used to filter out the noise because of clouds hovering above the ground surface around a constant altitude.

**6) Classify Below Surface:** This routine classifies points which are lower than neighbouring points in the source class. This routine was run after ground classification to locate points which were below the true ground surface

The use of these classification algorithms depends on the nature of topography, vegetation characteristics and extent of urbanization. All the sections in Kauai were river valleys. They consisted of steep slopes, cliff edges and dense vegetation requiring extensive use of ground classification algorithms. However, care was taken not to erode ground points from the steep slopes and edges while using them.

## DEM Production

The 1000m tiles were gridded using Golden Software's Surfer Version 8 Krigging routine at 1m resolution. The resulting tiles surfer grids were transformed into corresponding ArcInfo grids and hillshades using in-house Perl and AML scripts. Due to the large area covered by some segments and the ArcInfo software limitations it is not possible to create one large mosaic for the entire area. Therefore, 10 KM wide segment mosaics are produced in the same ArcInfo format. Figures below give a snapshot of the

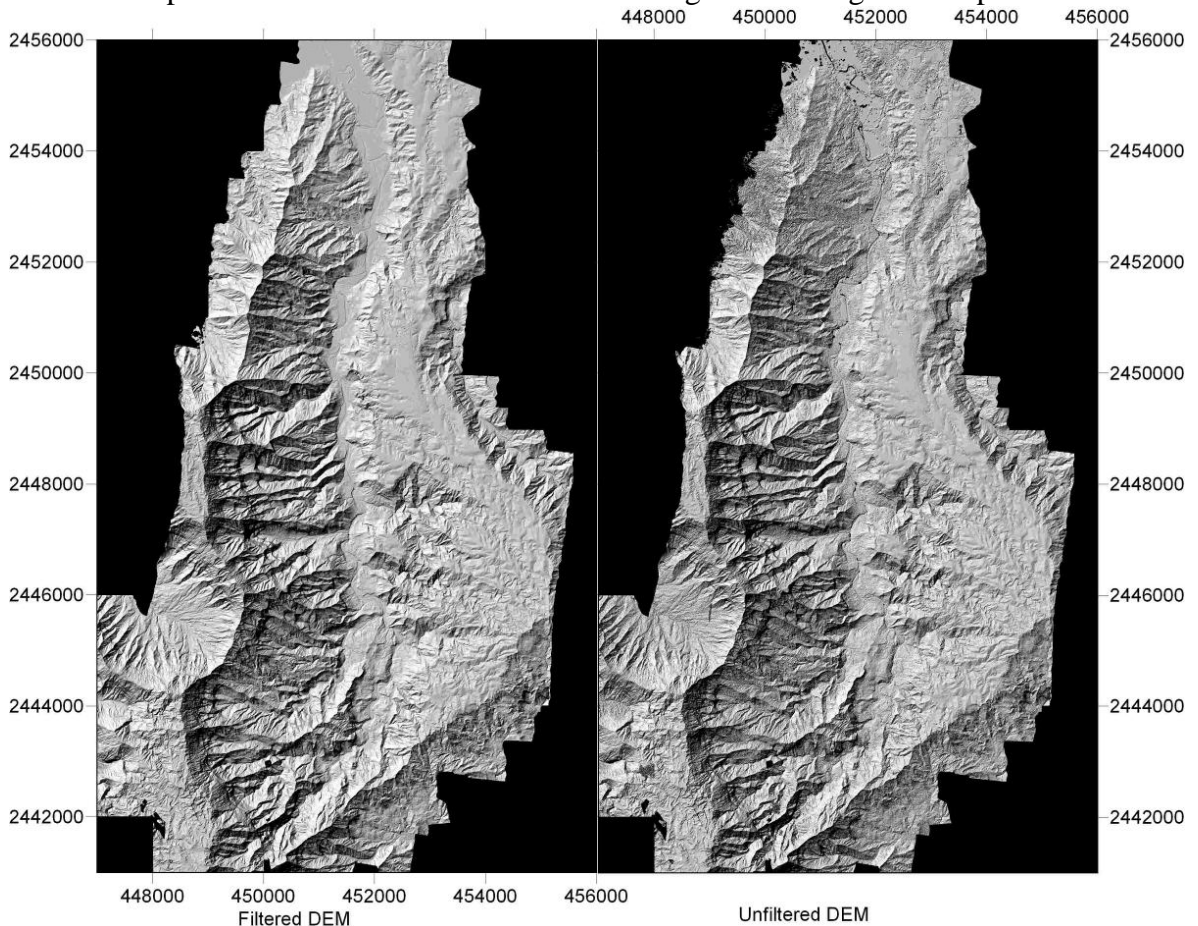


Figure 2 Hanalei, Filtered and Unfiltered

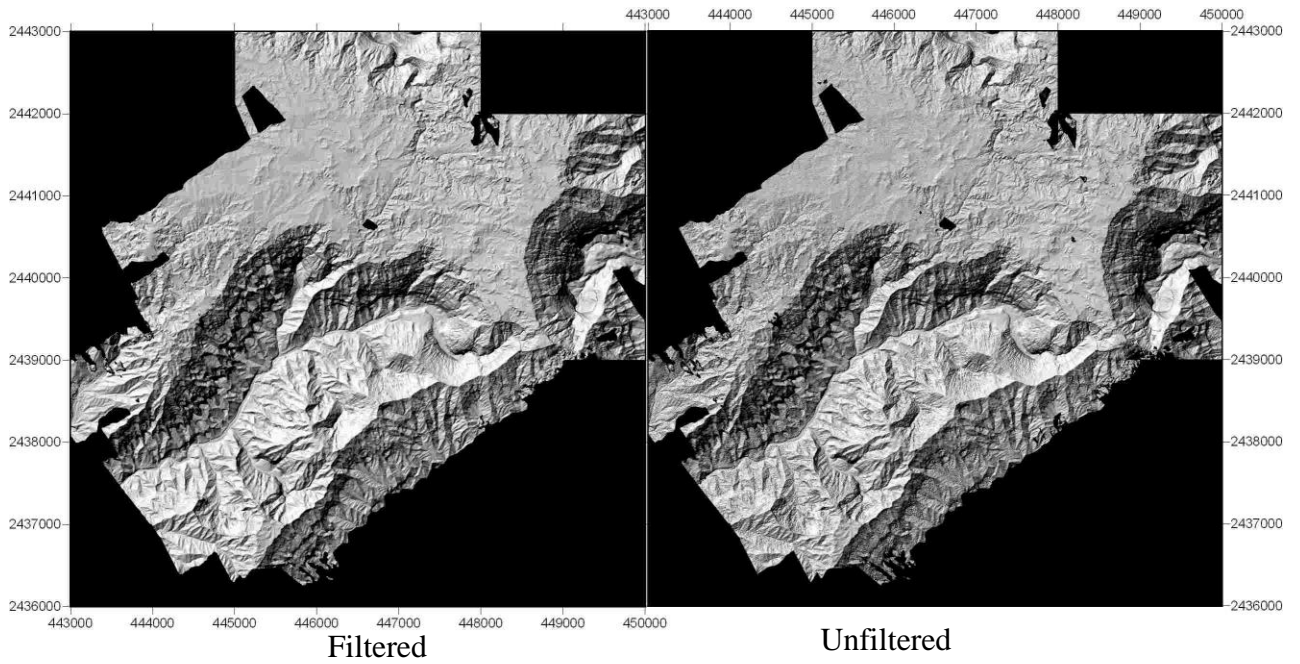


Figure 3 Olokeke

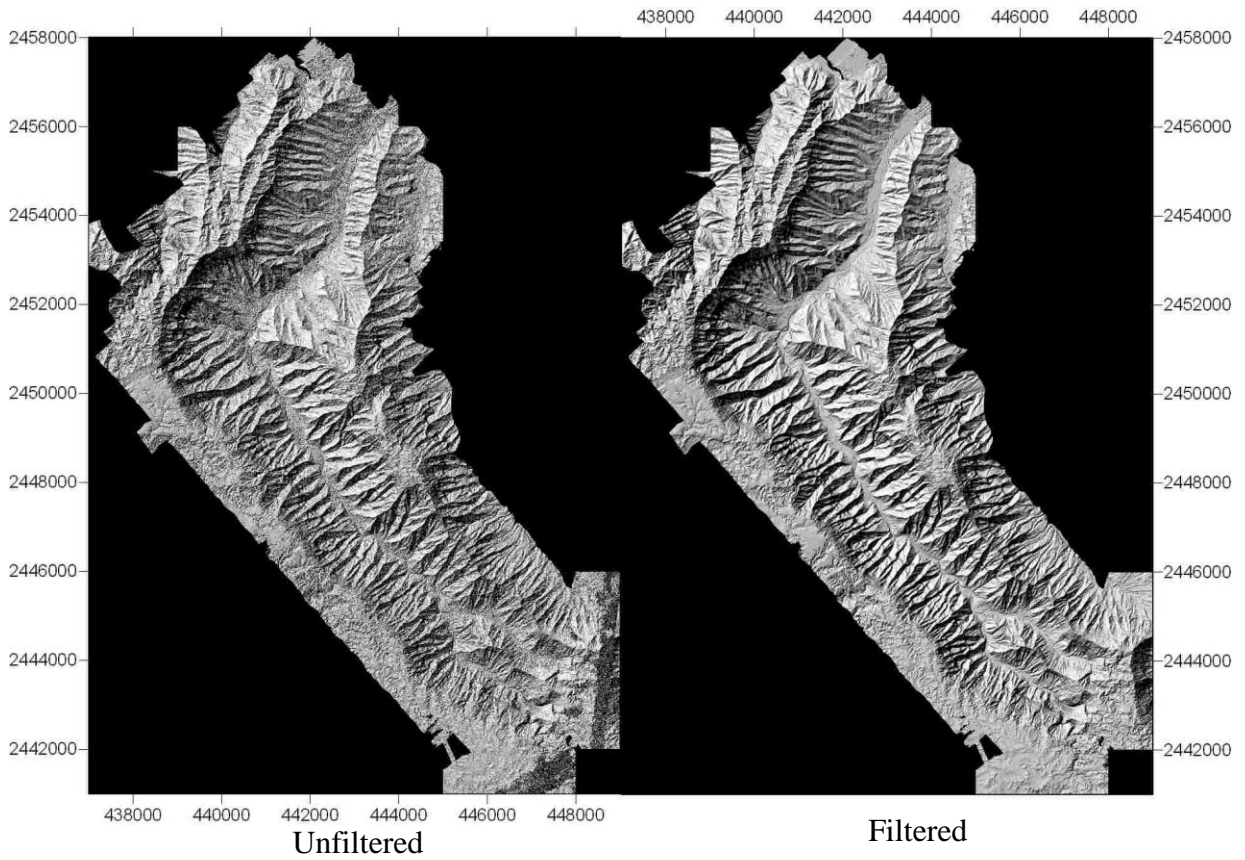


Figure 4 Waniha

## File Formats and Naming Conventions

The point cloud files are delivered in the 1000mX1000m tiles in “.Las” format. This format contains all the information associated with each point i.e. its position in X,Y,Z, intensity, flight line, timestamp, scan angle etc. The individual Las files can be converted to ASCII using the LAS to ASCII converter tool developed by the UNC. It can be accessed at <http://www.cs.unc.edu/~isenburg/lastools> . It gives the user the freedom to create ASCII files with whichever point features they want to access. Raster grids are delivered in ArcInfo grid and hillshade format as tiles corresponding to the point cloud tiles. 10KM mosaics are also included. In case of sections smaller than that in size, a single ArcInfo grid and hillshade file is delivered. The figure below shows an example of tiling scheme on the Waniha section

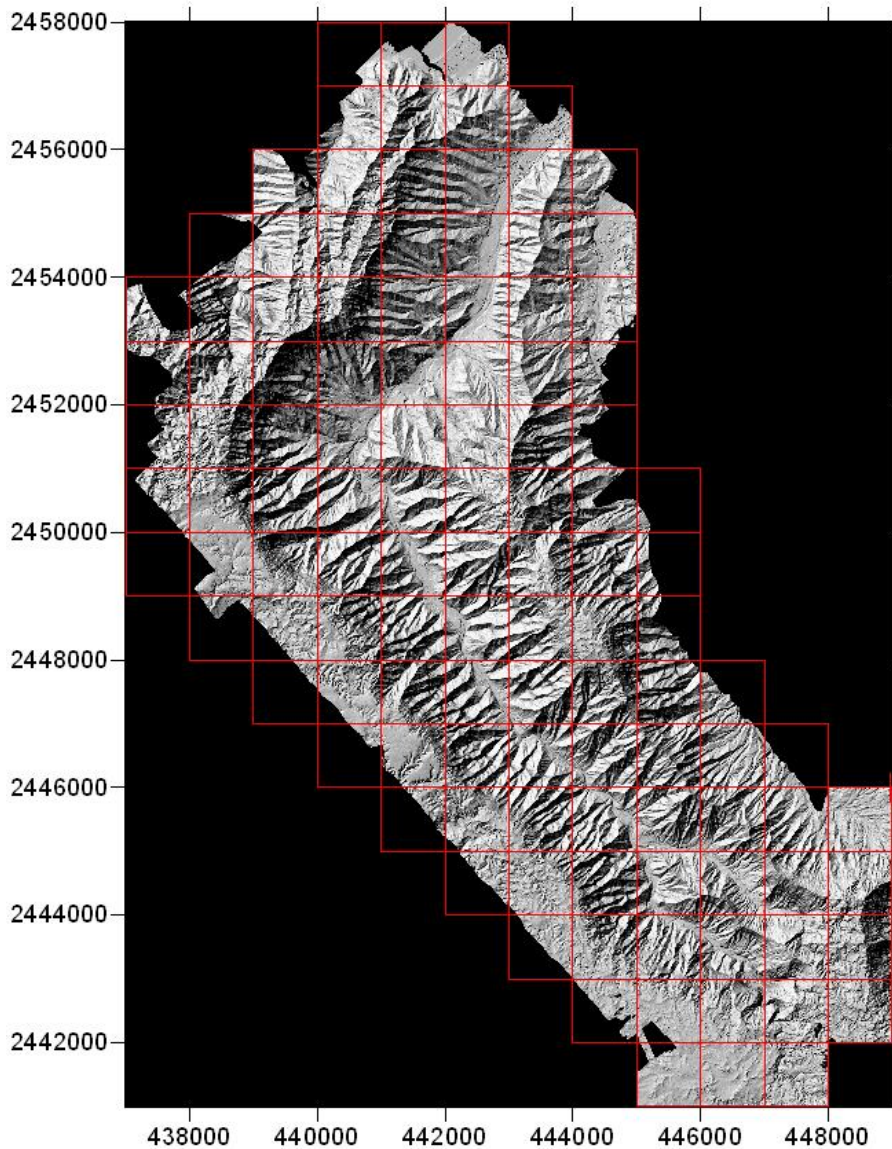


Figure5 Tiling procedure



Thus the grid tile with coordinates lying between 445000 and 446000 in easting and 2441000 to 2442000 in Northing would be named as “u445000\_2441000.grd” where the prefix ‘u’ represents that it is unfiltered. It is replaced by ‘f’ for filtered tiles.

The point tiles, the corresponding grids and mosaics are all positioned in the ITRF2000 reference frame and projected into UTM coordinates Zone 4N. All units are in meters.

The elevations are heights above the ellipsoid.