HAWAII Big Island 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; ±1-sigma
Elevation Accuracy	5 - 30 cm typical; ±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 ±1degree
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 started on June 21, 2009, Sunday and ended on June 27, 2009, Saturday. The base for the flying operations was HILO airport. A total of 9 flights took place on 6 different days totaling about 22 hrs of flying time and 6 and half hours of laser on time (LOT).

Flight Num	Date (2009)	DOY	DOW	Areas Surveyed	Flying Time	LOT
1	21-Jun	172	Sunday	Mauna Loa 1984 Flow	3:55:00	1:21:16
2	22-Jun	173	Monday	Mauna Loa Caldera	2:09:00	0:39:38
3	23-Jun	174	Tuesday	Mauna Loa 1984 Flow	0:57:00	0:12:10
4	23-Jun	174	Tuesday	Sw Rift, Muliwai _a_ Pele	2:35:00	0:56:13
5	25-Jun	176	Thursday	Kilauea 1974 Flow	0:45:00	0:04:44
6	25-Jun	176	Thursday	Kilauea 1974 Flow	3:40:00	0:48:11
7	26-Jun	177	Friday	Kilauea 1974 Flow	1:00:00	0:14:05
8	27-Jun	178	Saturday	Kilauea 1974 Flow, Kilauea Caldera, East Rift	3:30:00	1:09:42
9	27-Jun	178	Saturday	Mauna Loa 1984 Flow	3:40:00	1:12:52
Total					**22:11:00**	**6:38:51**

Table 2 Survey Flight information

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 was carried out at an above ground altitude of 700m and 100 KHz pulse frequency with 50% overlap to obtain the desired point density. This was the case with all of the sections except one: “Muliwai A Pele”. It had a steep slope facing south, making it unsafe to fly at lower altitude, hence required higher flying altitude and lower pulse frequency.

Section Name	Pulse Frequency	Scan Angle	Scan Rate	Area (SqKm)
Mauna Loa Caldera	100	21	45	37.70
Mauna Loa 84 Flow	100	21	40	131.60
Kilauea Caldera and 1974 Flow	100	21	40	101.20
East Rift	100	21	40	14.55
Muliwai A Pele	70	21	45	17.81
SW Rift	100	21	40	18.80
Total				321.66

Table 3 Survey Parameters for Areas Surveyed

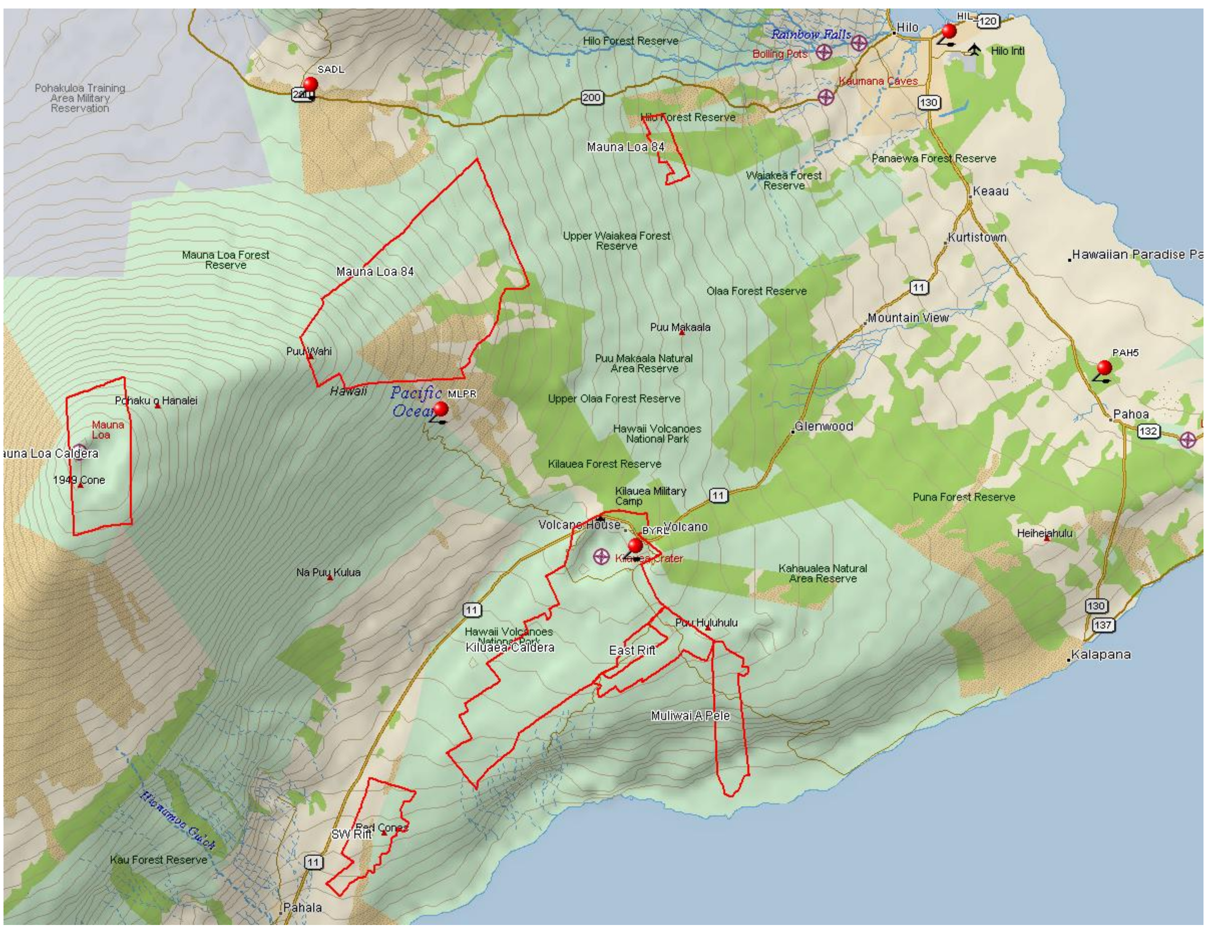

Figure 1 Areas Surveyed

Data Processing

GPS and IMU Data Processing

Five GPS stations were used as ground reference stations. Two of them were set up and operated by NCALM, one was a CORS station and 2 other were operated by USGS. Table 4 lists them and Figure 1 shows their position. The aircraft and ground reference station GPS data was processed by Dr. Gerry Mader using the KARS software in the ITRF2000 geocentric coordinate system. KARS kinematic GPS processing uses the dual-frequency phase history files of the reference and airborne receivers to determine a fixed integer ionosphere-free differential solution.

GPS Station	Latitude	Longitude	Station Type
HIL_	19.719409	-155.060134	NCALM
SADL	19.687284	-155.466505	NCALM
PAH5	19.517896	-154.961846	CORS/NOAA
BYRL	22.056468	-159.324034	USGS
MLPR	22.126255	-159.664906	USGS

Table 4 Ground reference stations

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 are in UTM Zone 5.**
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.
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 then 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. Incase of Hawaii, since lava flows were being mapped, vegetation filtering algorithms were not required. However there were instances of noise because of clouds and haze, multipath and noise due to low intensity of returns (intense black lava). These were removed using a combination of above mentioned routines.

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. The figures below show the hillshade images of all the sections.

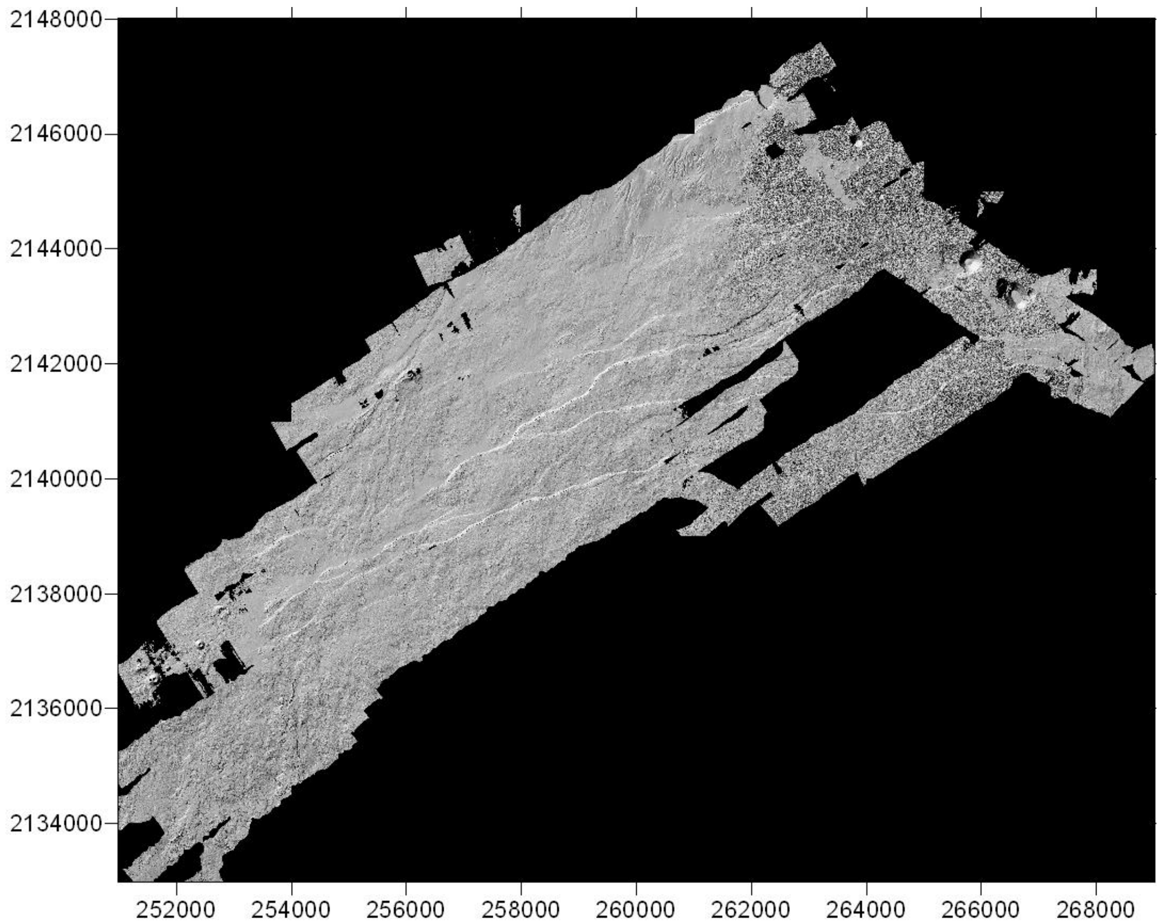

Figure 2 1974 Flow

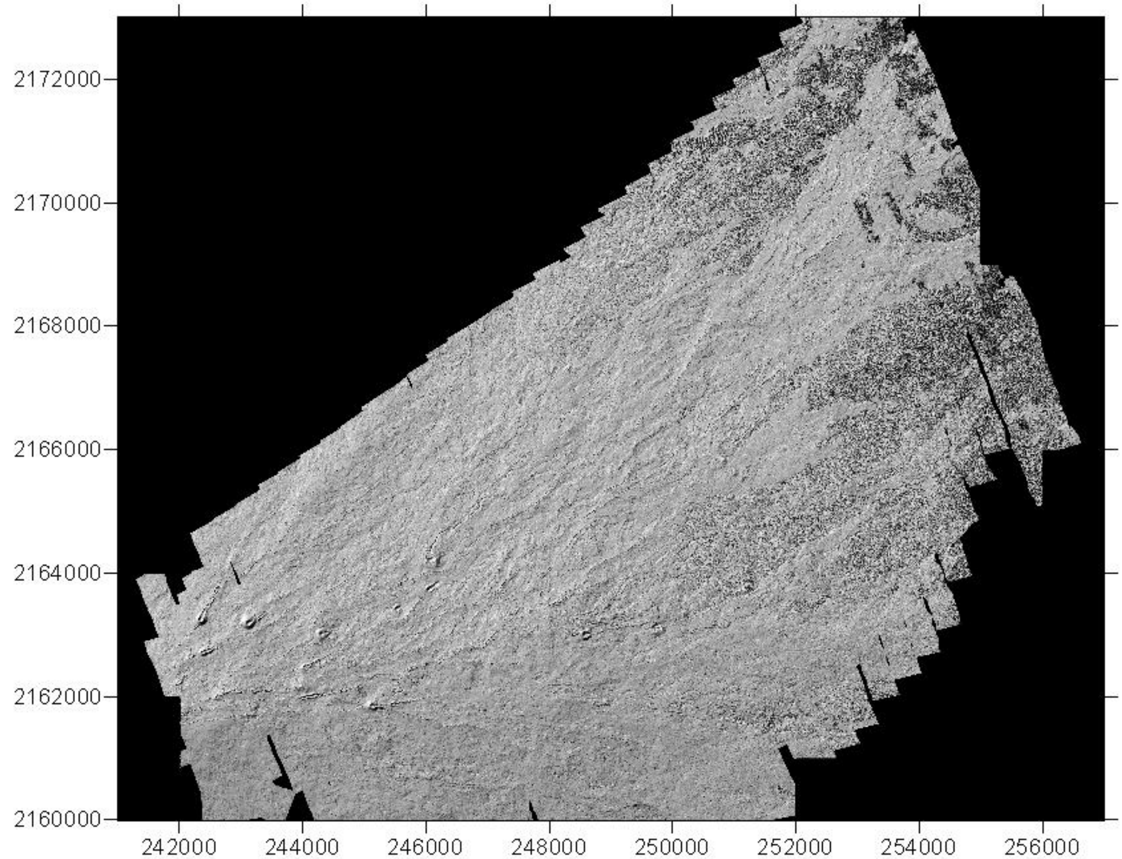

Figure 3 1984 Flow

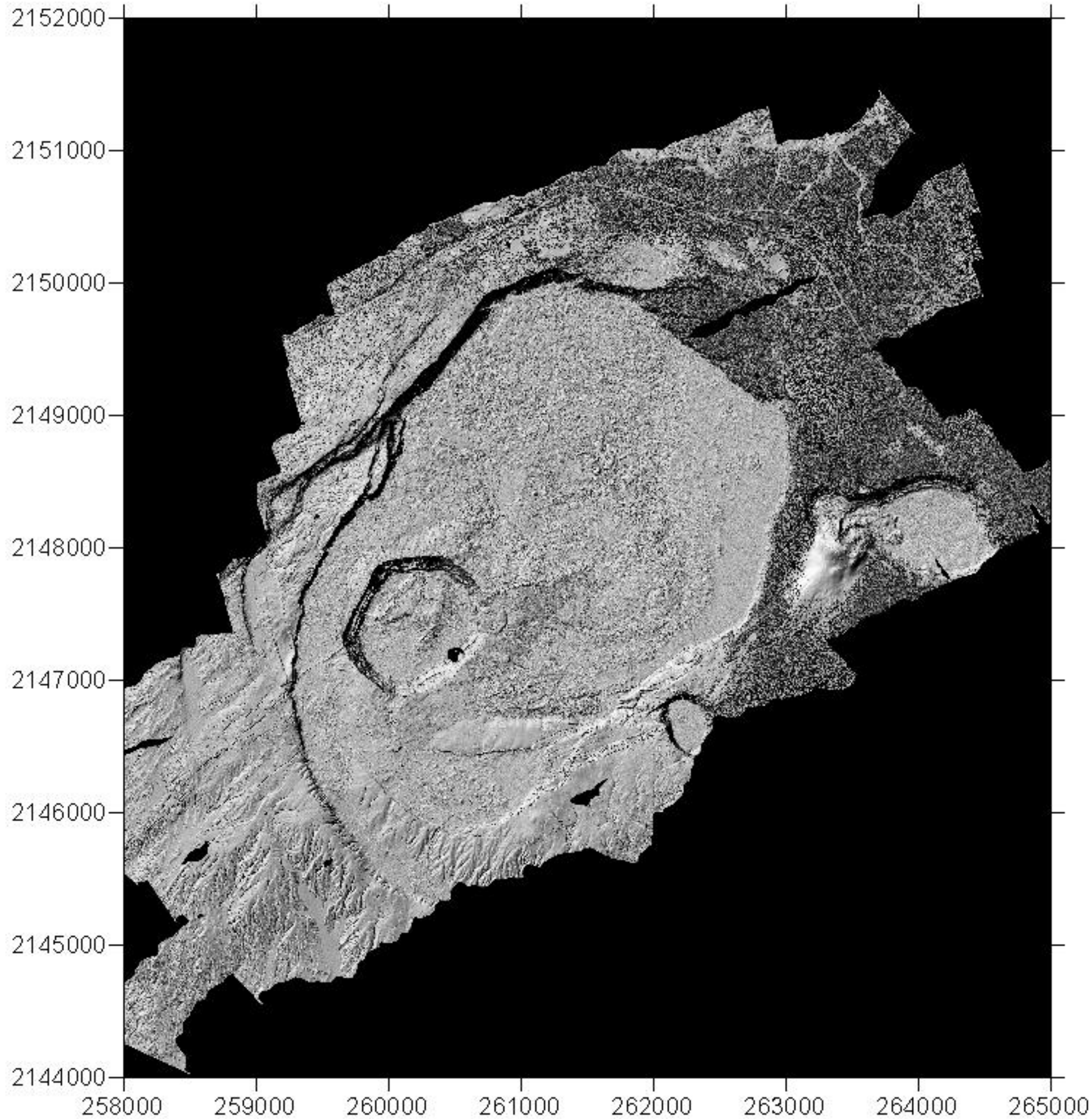

Figure 4 Kilauea Caldera

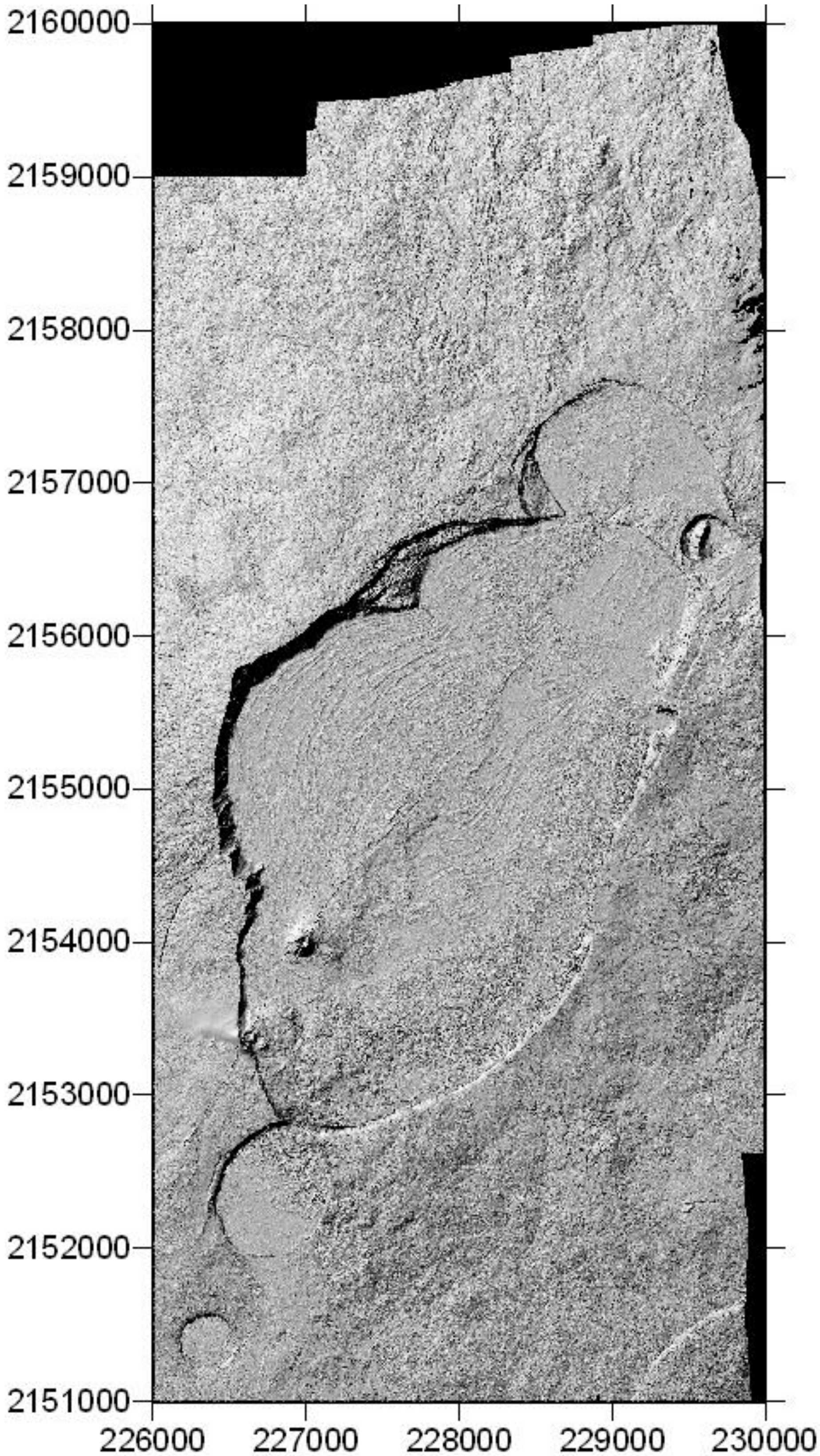

Figure 5 Mauna Loa Caldera

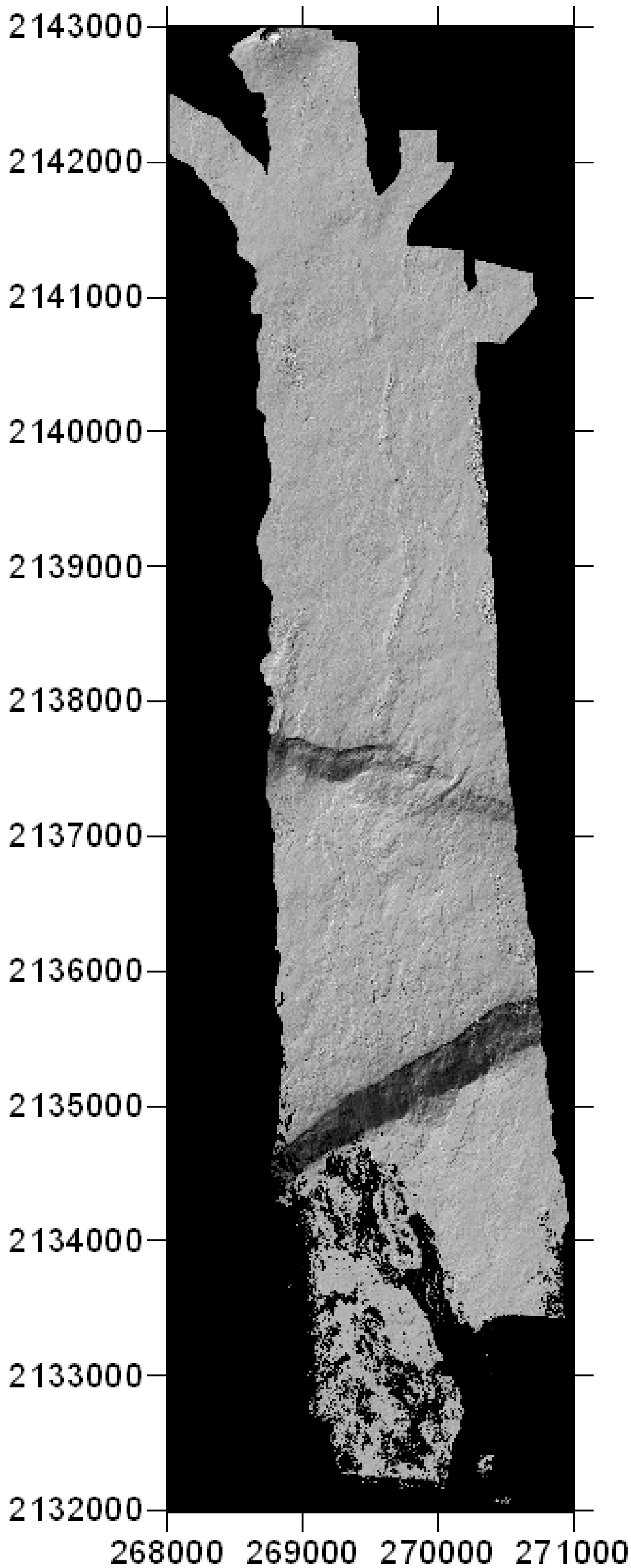

Figure 6 Muliwai a Pele

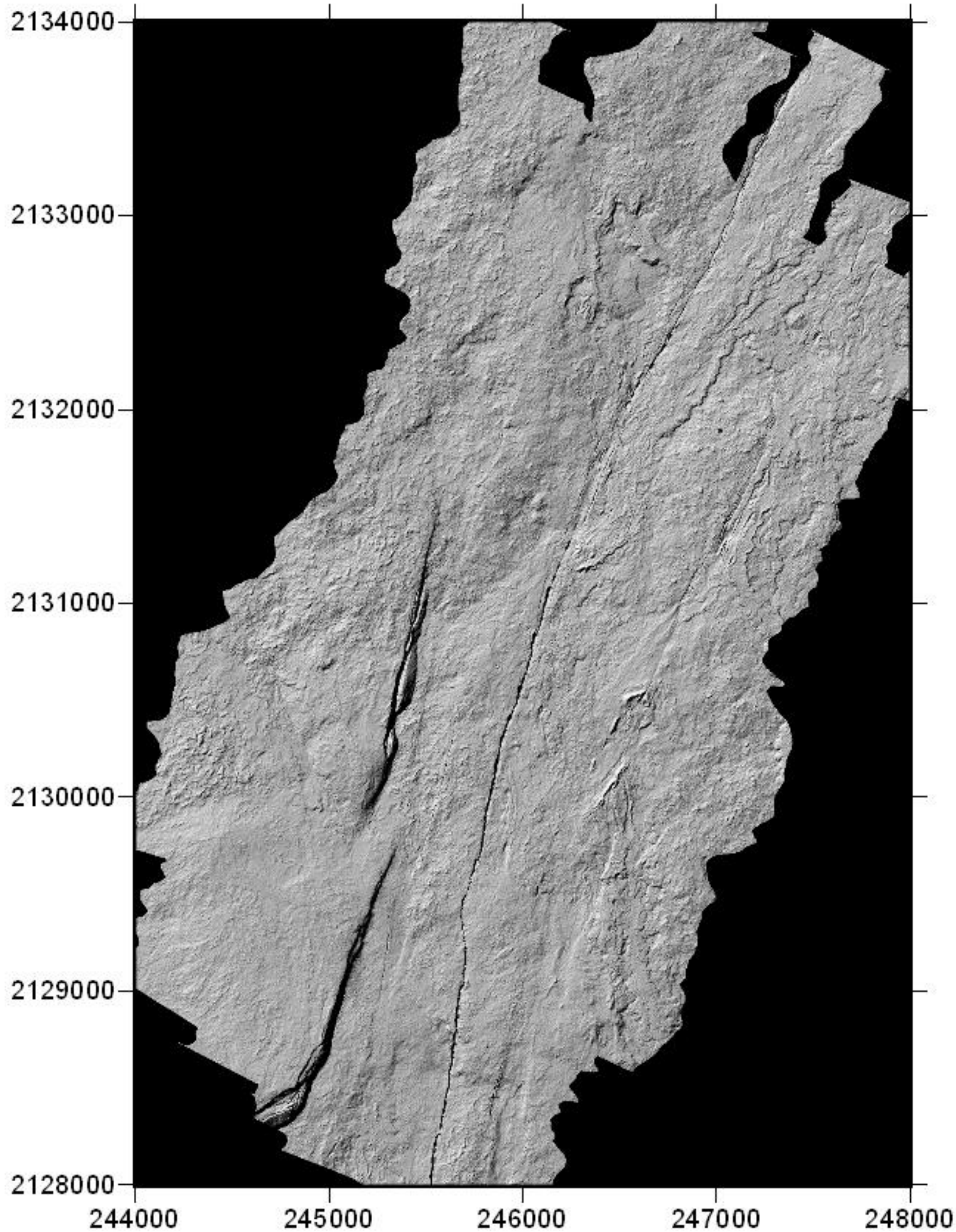

Figure 7 SW Rift

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. Incase of sections smaller than 10Km in size, a single ArcInfo grid and hillshade file is delivered.

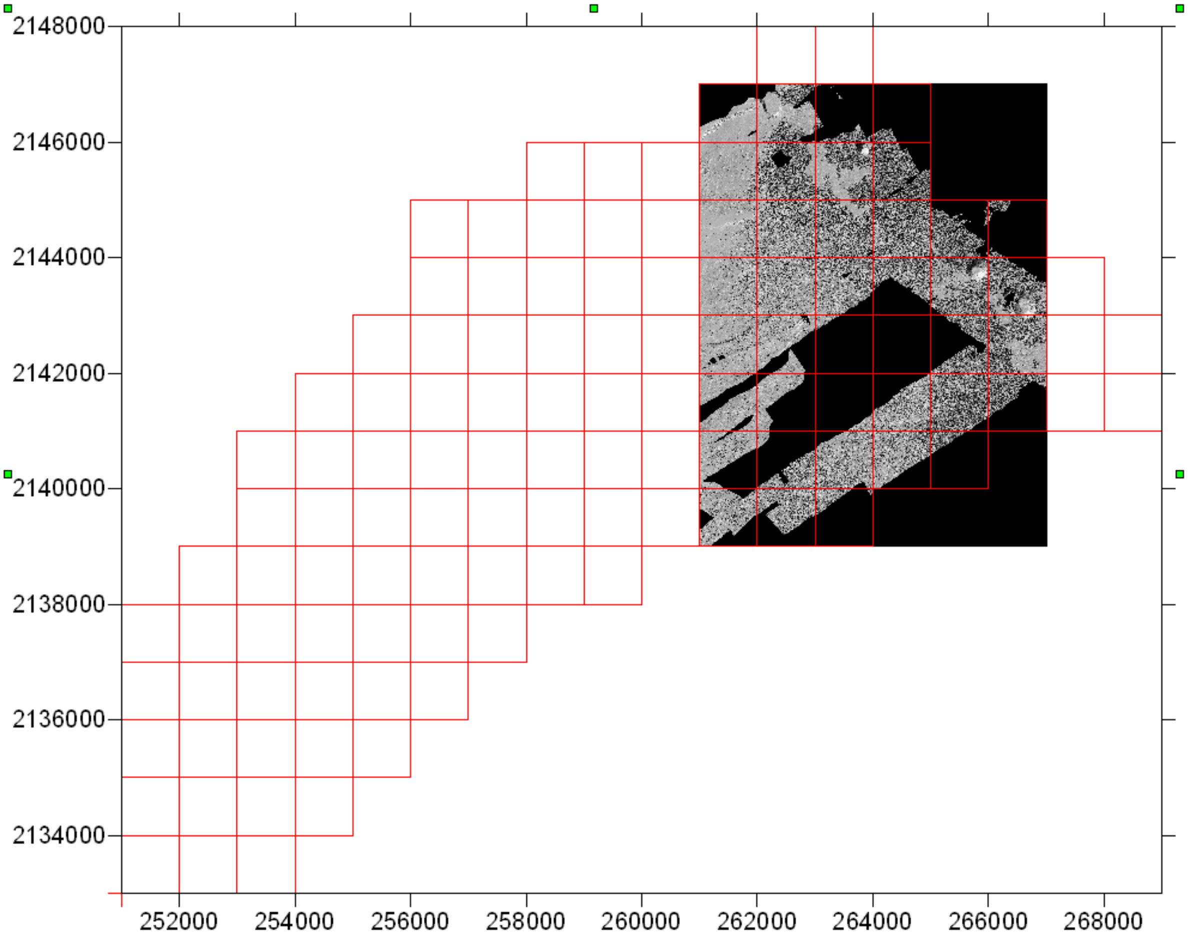

Figure 2 Tiling and Naming Convention

The naming convention followed involves naming each tile with its lowest X and Y value. Therefore, a point cloud tile which has X extent from 264000 to 265000 and Y extent from 2139000 to 2140000, will be named as “264000_2139000.las”. Incase of filtered and unfiltered grid datasets, the name is prefixed with ‘f’ and ‘u’ correspondingly.

The point tiles, the corresponding grids and mosaics are all positioned in the ITRF2000 reference frame and projected into UTM coordinates Zone 5N. All units are in meters and the elevations are heights above the ellipsoid.