



Landscape response to tectonics: Elucidating the coupling between channels and hillslopes during transient adjustment to an increase in uplift rate

LIDAR Mapping Project Report

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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 Skymaster (Tail Number N337P). 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 - 30 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 12-channel 10Hz GPS receiver
Laser Wavelength/Class	1047 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

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

2. Survey Area.

The survey area was 56.09 Square Kms, located 26Kms northwest of San Francisco, California. Figure 1 below shows its location and extent.

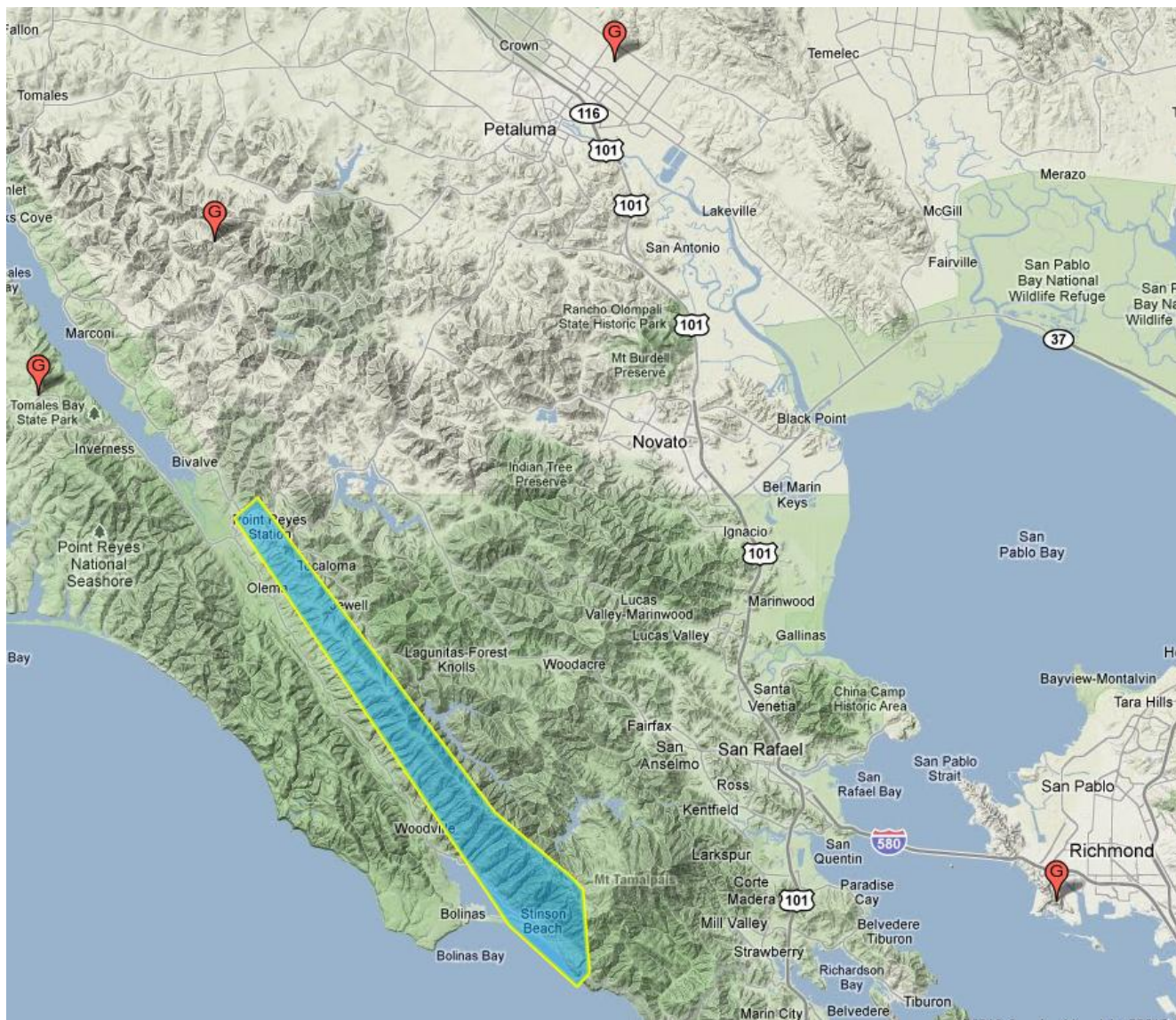


Figure 1(a) – Shape and location of survey polygon and Ground Control Stations(Google Maps)

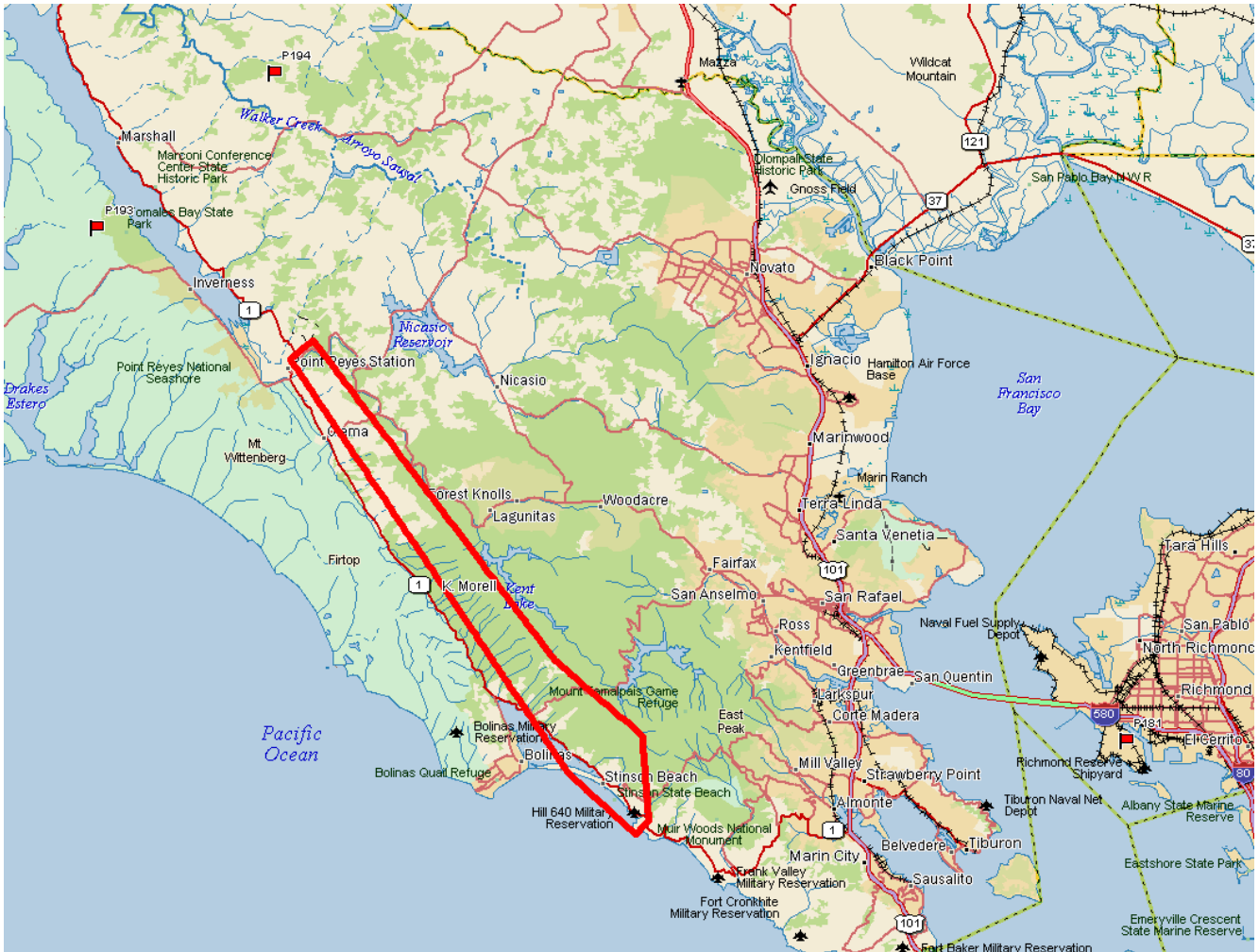


Figure 2(b) – Shape and location of survey polygon and Ground control stations (TopoUSA)

3. Survey Planning and Parameters.

The survey composed of a 19 total passes going in Northwest-Southeast direction. Figure 2 below shows the planning software along with the sets of planned flight lines and the survey parameters.

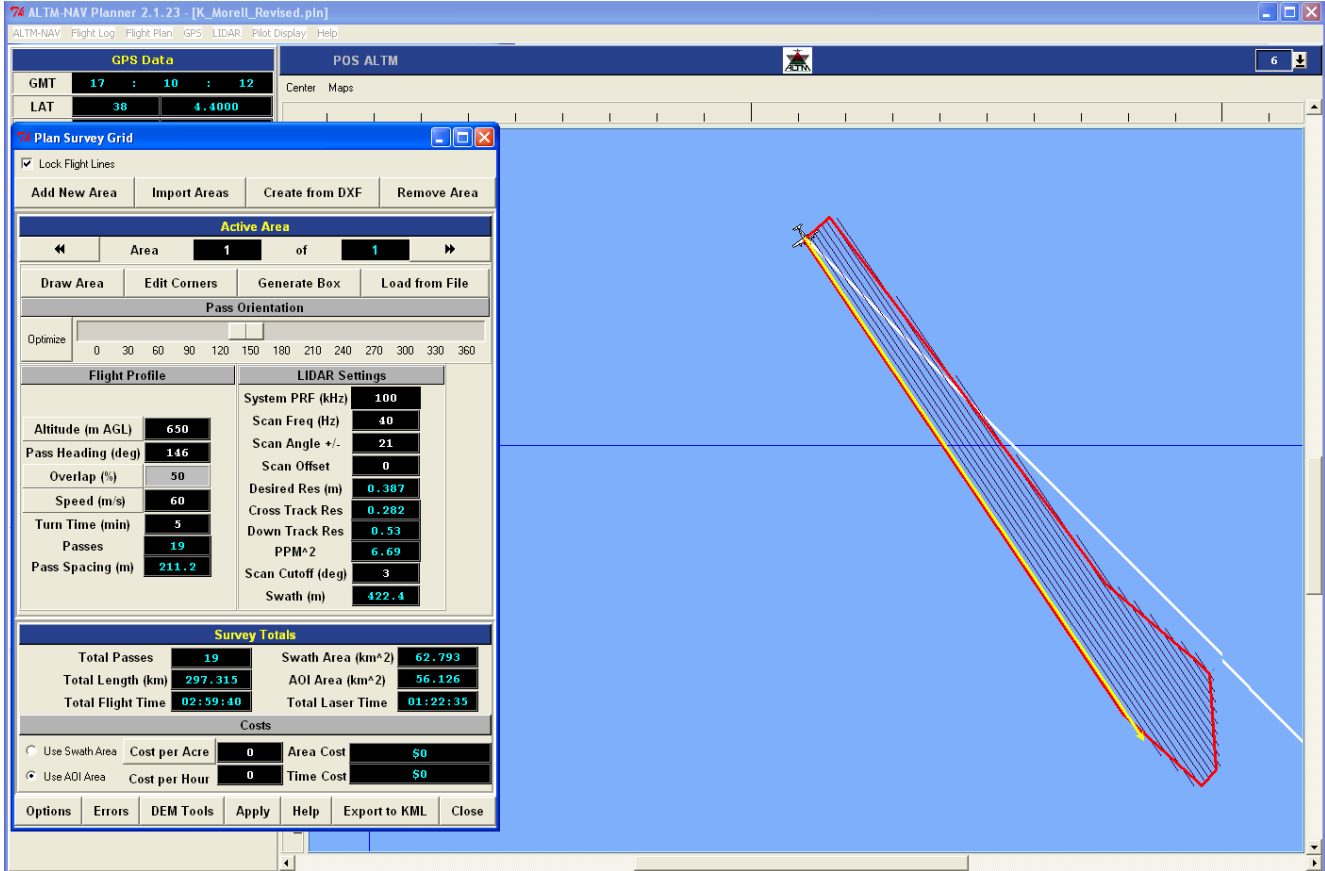


Figure 3 Flight lines from the planning software
Survey parameters are given below in Table 3.

Survey Parameters		Survey Totals	
Altitude (m)	650	Total Length (Km)	297
Swath Width (m)	422	Swath Area (Km ²)	62.8
Overlap (%)	50	Area of Interest (Km ²)	56
Laser PRF (kHz)	100	No. of Passes	19
Scan Freq (Hz)	40		
Scan Angle (degrees)	21		
Scan Cutoff (degrees)	3		

Table 3 – Survey parameters

4. LIDAR and GPS Data Collection Campaign.

This survey was flown as a part of Seed Money Survey Campaign that took place in Aug-Sept 2009. This section was surveyed on two days: Sept 8, 09 (Day of the Year 251) and Sept 9, 09 (Day of the Year 252). It was flown out of Ukiah Municipal Airport, California. The total flight time was 4 hrs 35 mins and the total Laser on time was 1 hr 42 min.

Three GPS reference stations were used for ground control. All three were PBO (Plate Boundary Observation) stations maintained and operated by UNAVCO. The list of the stations and their locations is given below in table 4. The airborne receiver is an integrated GPS receiver module Trimble BD950, logging at 10 Hz.

Station Name	Lat	Long
P194	38.18571	-122.816241
P193	38.12293	-122.908124
P181	37.91454	-122.376739

Table 4 Ground Control Stations

5. Data Processing

5.1. GPS & INS Navigation Solution.

GPS data for the UNAVCO stations was obtained from their website (<http://facility.unavco.org/data/>). Reference coordinates were determined using OPUS (Online Positioning User Service), 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 GPS trajectories for this survey were processed using KARS (Kinematic and Rapid Static), software created by Dr. Gerry Mader. 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. GPS trajectories are created using all the above four mentioned ground control stations. These trajectories are then differenced to determine the best solutions. Figure 3 shows the plot for positional difference between trajectories obtained from P194 and P193.

Positional Differences in the Aircraft Trajectory

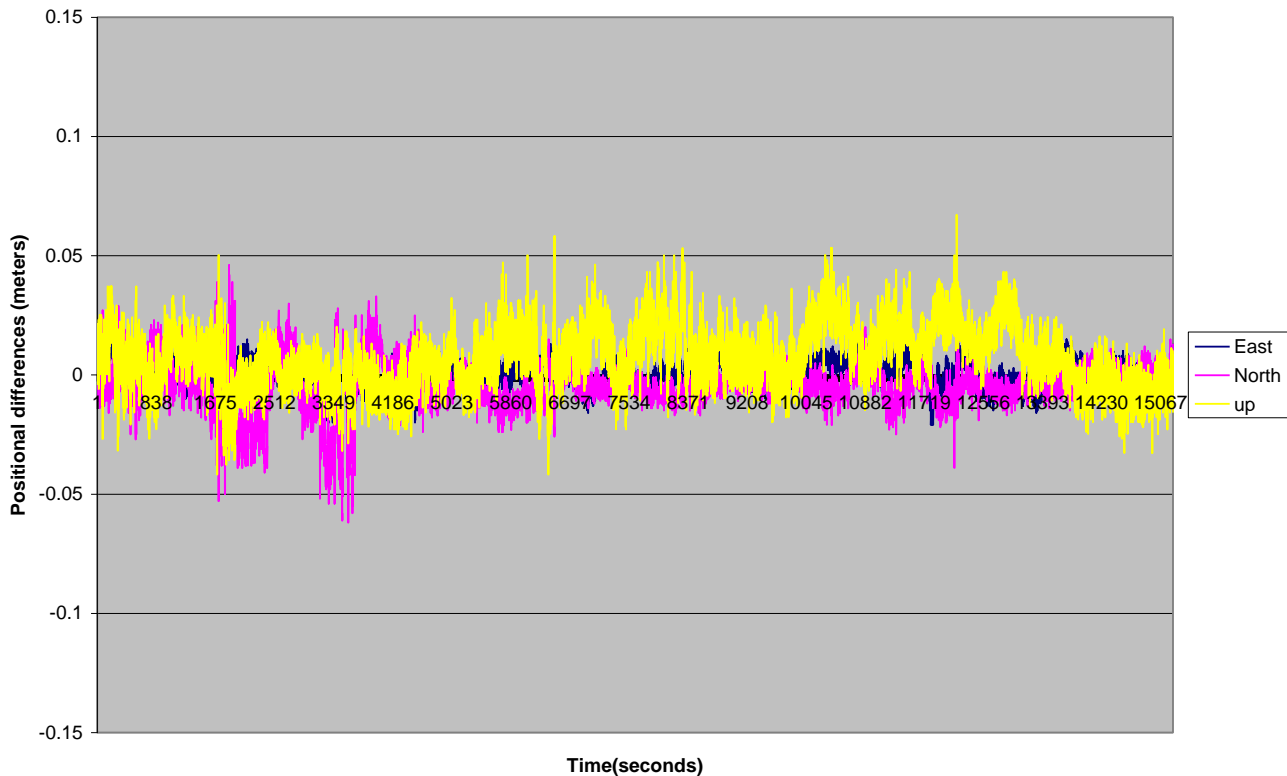


Figure 3 Positional differences between the two trajectories

After GPS processing, the 1Hz differential GPS trajectory and the Inertial Measurement Unit (IMU) datasets are processed together in the POSProc software (version 5.2). POSProc software combines GPS trajectory with the orientation information in a Kalman Filter to produce a final, smoothed and complete navigation solution at 200Hz. This final solution is known as the SBET (Smoothed Best Estimated Trajectory).

5.2 Strip Laser Point Processing

An SBET together with laser ranges and mirror angles are finally combined in Optech's DashMap software (Version 4.1) to generate a flight-strip point cloud in LAS format. All point cloud coordinates were processed with respect to **NAD83** and referenced to the international CORS network. The projection is UTM Zone 10, with units in meters. **Heights are NAVD88** orthometric heights computed using the **NGS GEOID 03**. Scan angle cut-offs are done to improve the overall DEM accuracy as points farthest from the scan nadir are the most affected by small errors in pitch, roll and scanner mirror angle measurements. Moreover, scan angle cut-offs are done to eliminate points at the edge of the scan lines for improving the overall DEM accuracy as the points farthest from the scan nadir are the most affected by small errors in pitch, roll and scanner mirror angle measurements. A scan cutoff angle of 3 degrees was used.

5.3. Calibration

Relative calibration is done for each flight by the following method:

1. Planning and flying swaths with 50% side lap.
2. Surveying crossing flight-lines over calibration areas and over the project polygon.
3. Analyzing these overlaps and cross-lines in TerraMatch software. (see <http://www.terrasolid.fi/en/products/4>).

TerraMatch employs a least-squares approach (minimizing the height differences between computed laser surfaces from individual crossing and/or overlapping flight lines) to calculate the best-fit values for four parameters: three bore sight angle alignments (roll, pitch, and yaw), and the scanner mirror-angle scale factor.

TerraMatch was run to a convergent solution on every flight line. Values for height disagreements between individual flight line surfaces ranged from a high of 10 cm to a low of 3 cm. Individual swath height disagreements averaged approximately 7.0 cm. The values obtained for different lines were then averaged to get the correction for roll, pitch and yaw values and the final configuration file is created to be used for outputting files in DashMap. Below is a typical TerraMatch report for one of the flight lines:

```
Used loaded points
Trajectories: D:\_Seed_09\09_251_Morre1\SBET
No known points
Observe every 1th point
Solution for whole data set

Starting dz RMS:      0.0497
Final dz RMS:        0.0373

Standard error of unit 0.0167

Execution time: 766.3 sec
Number of iterations: 14

Points      3575069
H shift     +0.0177   Std dev  0.0004
R shift     +0.0046   Std dev  0.0001
P shift     -0.0093   Std dev  0.0001
Scale       -0.00035
```

Note that the initial average height difference between individual swath surfaces was found to be 4.9 cm. After best-fitting the bore sight angles for heading (yaw), roll, pitch, and mirror-angle scale factor the final average height difference improved to 3.7 cm.

Absolute Calibration was done by establishing a calibration site consisting of 468 check points surveyed with vehicle-mounted GPS over a taxiway at the Ukiah Municipal Airport.). The road containing these check points was then surveyed with crossing flight lines using the ALTM. The heights of the check points were then compared to the heights of the nearest neighbor LIDAR shots within a radius of 20cm to look for any systematic height bias. No systematic height bias was found.

5.4 Classification and Filtering

TerraSolid's TerraScan (<http://terrasolid.fi>) software was used to classify the LIDAR points and generate the "bare-earth" dataset.

The classification used for this project consists of two algorithms:

- 1) Removal of isolated points. This routine removes points that have no close neighbors (within 5 meters).
- 2) 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. Iteration parameters determine how close a point must be to a triangle plane so that the point can be accepted to the model. Iteration angle is the maximum angle between point, its projection on triangle plane and closest triangle vertex. The smaller the Iteration angle, the less eager the routine is to follow changes in the point cloud. Iteration distance parameter makes sure that the iteration does not make big jumps upwards when triangles are large. This helps to keep low buildings out of the model. The routine can also help avoid adding unnecessary points to the ground model by reducing the eagerness to add new points to ground inside a triangle with all edges shorter than a specified length.

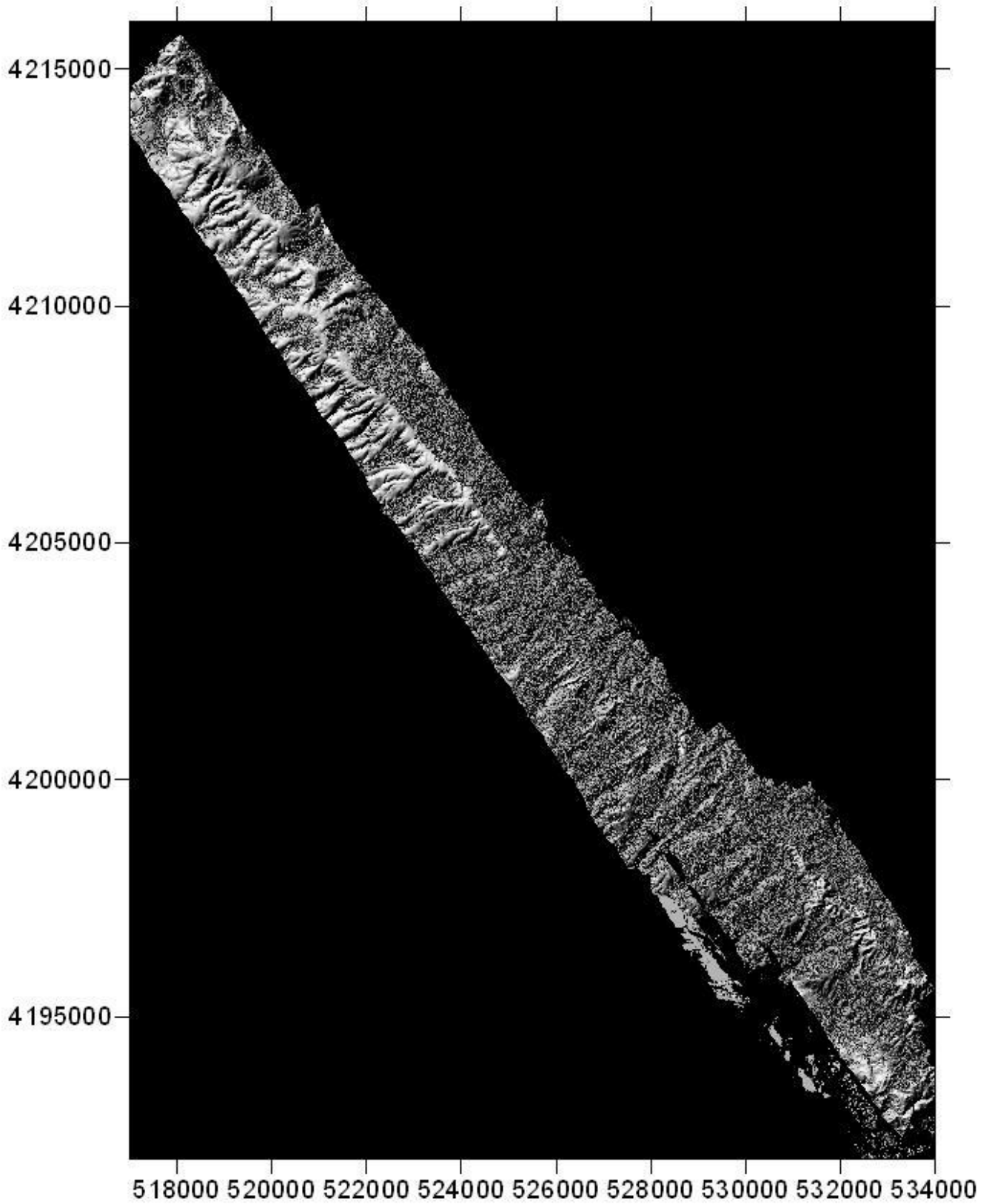


Figure 4a Unfiltered DEM

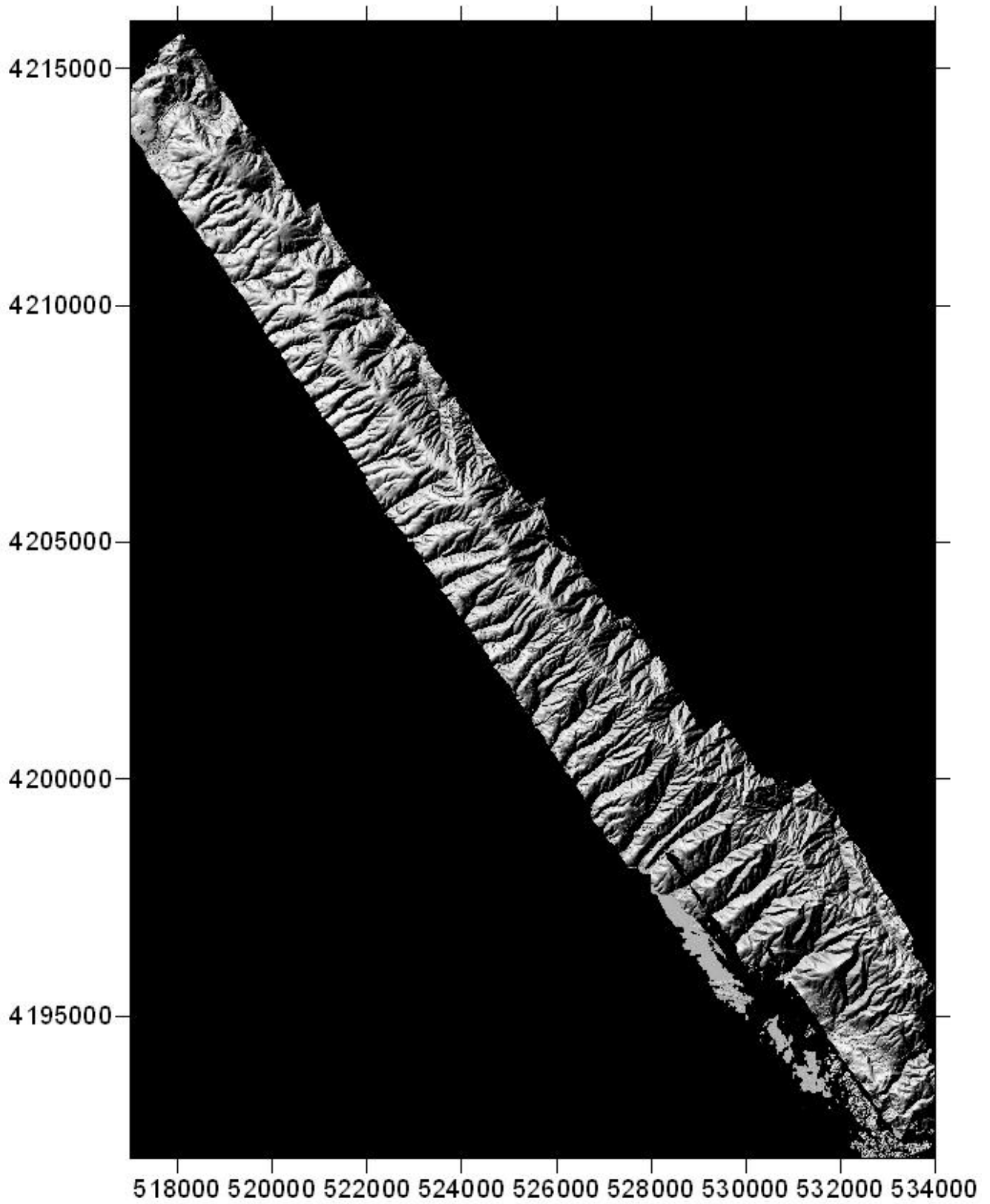


Figure 4b Filtered DEM

5.5 Gridding and Tiling.

The flight strip point cloud files were tiled into 1 kilometer square blocks, illustrated in the figure below

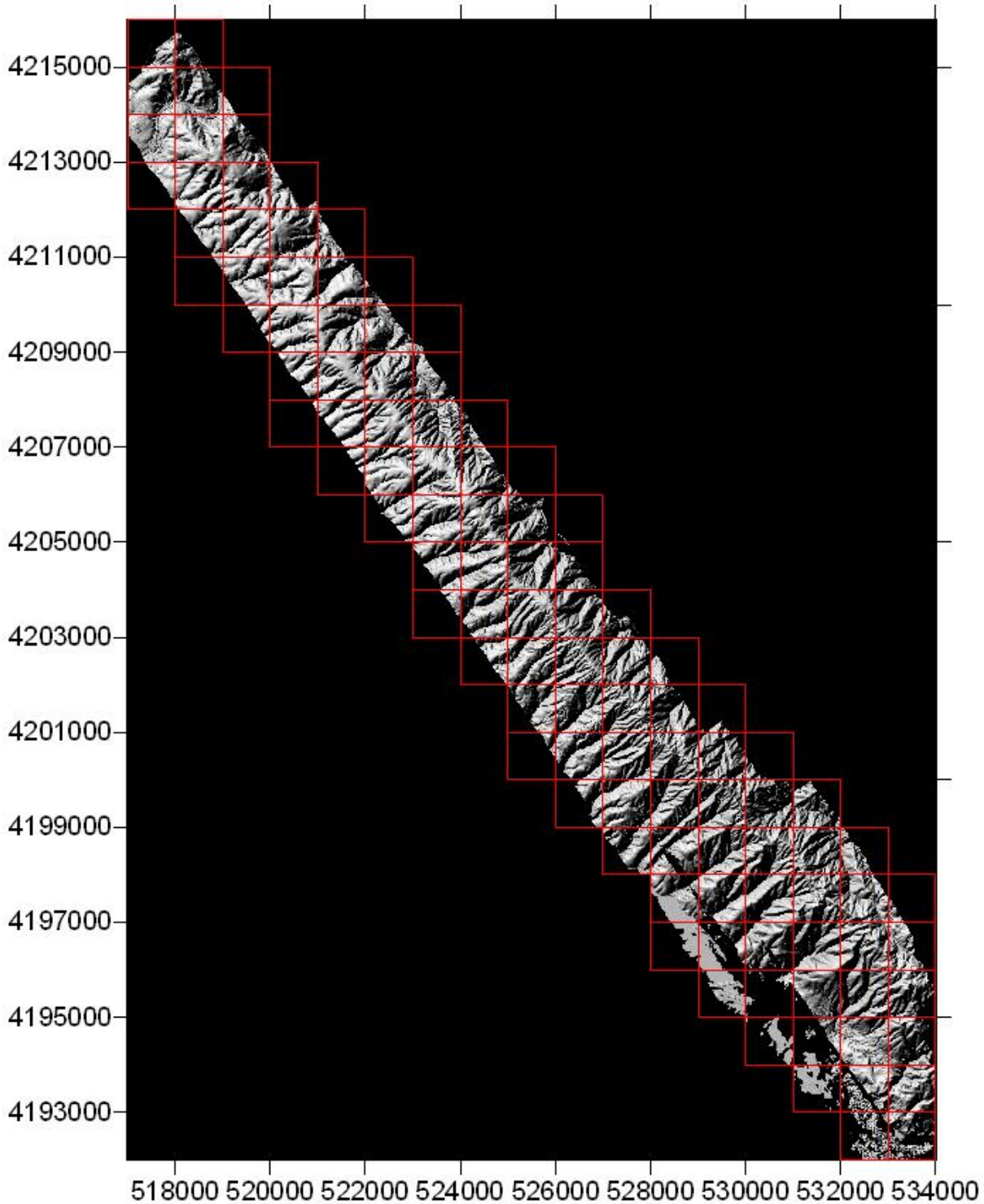


Figure 5 - Tile footprints overlaid on bare-earth shaded relief image.

Tiles follow a naming convention using the lower left coordinate (minimum X, Y) as follows: XXXXXX_YYYYYYY. For example if the tile bounds coordinate values from easting equals 519000 through 520000, and northing equals 4195000 through 4196000 then the tile is named as '519000_4195000'. The project totaled 108 tiles.

Digital Elevation Models were produced in SURFER (Golden Software) Version 8 at 1.0 meter resolution using krigging routine.

6 File Formats

The point cloud files are delivered in the 1000mX1000m tiles in “.Las” format. It is a binary 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 users 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 10KM mosaics. Incase of sections smaller than that in size, a single ArcInfo grid and hillshade file is delivered. The point tiles, the corresponding grids and mosaics are all positioned in the NAD83 reference frame and projected into UTM coordinates Zone 10N. The elevations are NAVD88 orthometric heights computed using the NGS GEOID 03. All units are in meters.