High Resolution Topography of a Portion of the House Range Fault and Pleistocene Lake Bonneville Shorelines, Sevier Desert, Utah, USA

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Introduction

This document accompanies a high-resolution topographic data set and orthomosaic that cover ~ 4.5 km of the House Range fault and shoreline features of late Pleistocene Lake Bonneville in the Sevier Desert, eastern Basin and Range, Utah, USA. A point cloud, digital surface model (DSM) and the orthomosaic were generated from low-altitude aerial photographs using Structure-from-Motion and multi-view stereo processing (SfM) (Table 1). The data have been used by Stahl et al. (in review) to aid analysis of extensional processes near the eastern margin of the Basin and Range in the Sevier Desert. The data set and supporting tables of photograph positions and georeferencing information are available free-to-public on OpenTopography. An overview of the dataset and methods used to create it is provided here.

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Background

The House Range fault (HRF) is a range-bounding, west-dipping normal fault in the western Sevier Desert, within the Basin and Range province (Figure 1). There is up to 1600 m of vertical relief across the fault, and it displays characteristics typical of tectonically – driven extensional faulting, in contrast to extension that is associated with volcanism in the eastern Sevier Desert (Stahl and Niemi, 2017; Stahl et al., in review). We used unoccupied aerial systems (UAS) to acquire aerial photographs, which were combined with ground control georeferencing to create a point cloud that models the topography at high resolution ($\leq$ 10 cm) along the central portion of the fault.

Data Description (Table 1)

1. Point cloud model, containing 1.969×10^9 points, each with a color attribute. Points are unclassified and include both ground and vegetation. The point cloud covers approximately 5.05 km^2, for an average point density of 389 points/m^2. The reference frame for the point cloud is NAD83(2011) UTM zone 12 (EPSG 6341), epoch 2010.000, and NAVD88 (orthometric heights determined using GEOID 12B, units of meters).
2. Digital surface model (DSM), with a 0.10-m pixel size. The DSM was derived from the point cloud and covers the same area. Rasterization was performed

in Agisoft Metashape (v1.5.1), using a ‘binning’ algorithm, wherein each DSM pixel value (elevation) is calculated as an average of the elevations of points located within the pixel area (average of 3.89 points per pixel). The DSM reference frame is the same as the point cloud, NAD83(2011) UTM zone 12 (EPSG 6341), epoch 2010.000, and NAVD88 (i.e., orthometric heights determined using GEOID 12B, units of meters).

3. Orthomosaic, with a 0.05-m pixel size. The orthomosaic was constructed from the aerial imagery in Agisoft Metashape, using the DSM to project the imagery. The reference frame is the same as the other data, NAD83(2011) UTM zone 12 (EPSG 6341), epoch 2010.000.
4. Table of camera locations. The point cloud was constructed from low-altitude aerial photographs taken from UAS. The positions from which the photographs were taken were estimated during processing in Agisoft Metashape, and a table of these locations is provided as a comma-delimited file. The reference frame is NAD83(2011) UTM zone 12 (EPSG 6341), epoch 2010.000, and NAVD88 (i.e., orthometric heights determined using GEOID 12B, units of meters).
5. Table of ground control point locations. The point cloud was georeferenced using ground control points (GCPs), which are markers placed on the ground (visible in aerial photographs) and the positions of which were surveyed with differential GNSS (see georeferencing section below). A table of the locations of the GCPs is provided as a comma-delimited digital file. The reference frame is NAD83(2011) UTM zone 12 (EPSG 6341), epoch 2010.000, and NAVD88 (i.e., orthometric heights determined using GEOID 12B, units of meters).
6. Table of check point locations. Checkpoints were measured and used to assess the vertical uncertainty of the modeled topography (see georeferencing section below for more information). Checkpoints were measured on relatively flat, bare ground, away from vegetation using dGNSS. A table of the checkpoint locations is provided as a comma-delimited file. The reference frame is NAD83(2011) UTM zone 12 (EPSG 6341), epoch 2010.000, and NAVD88 (i.e., orthometric heights determined using GEOID 12B, units of meters).

Data Collection Overview

Field work to acquire the high-resolution topography was conducted in May 2016, and followed the methods of Bunds et al. (2015). The survey area was divided into 4 subsections (‘polygons’) to organize field work and facilitate processing. Each polygon contains at least nine ground control points and each was surveyed so as to ensure overlap in aerial photography and imaging of GCPs across polygons. The polygons were merged into a single model during processing.

The point cloud model was made from a total of 7,980 low altitude aerial photographs. UAS were DJI Phantom 2 v2 quadcopters, equipped with Sony A5100 cameras (16 mm prime lens) using a custom, fixed mount. The fixed camera mount (as opposed to a gimbal), caused the camera orientation to change with the orientation of the UAS, and to vary from nadir by up to ~36°. Average photograph ground sample distance is ~2.62 cm. Photograph overlap as calculated by Agisoft is > 9 throughout most of the survey area. Areas that lack sufficient overlap have poorer quality reconstruction which is evident in the resulting model. An additional measure of overlap is the number of photographs in which GCPs appear, which averages 33.7 photographs/GCP. The DJI Phantom was piloted and navigated manually, without calculated flight plans generated by software. A table of camera positions for the photographs is included. The positions are estimates calculated during SfM processing.

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Processing

Processing of the aerial photographs to produce point clouds was done with Agisoft Metashape (v1.5.1). Each of the 4 polygons that compose the covered area was initially processed independently, including georeferencing, to produce a sparse cloud and camera models. The sparse clouds and camera models were georeferenced and optimized using locations of GCPs (described below). The polygons were then merged using both ground control and point cloud information. The sparse cloud was filtered to remove large uncertainty points and the model was re-optimized. A dense point cloud was then generated for the entire, merged model. The sparse point cloud and camera models were made using the ‘highest’ setting in Agisoft, and the dense cloud was built using the ‘high’ setting (i.e., photographs were downsampled x2). DSMs were made in Agisoft Metashape, which averaged elevations of points within each DSM pixel to calculate the pixel elevations.

Georeferencing and Accuracy

All data (point cloud, DSM, orthomosaic, and accompanying GCP and camera locations), are in NAD83(2011) UTM Zone 12 (EPSG 6341) coordinates, with elevations given as NAVD88 orthometric heights in meters determined using GEOID 12B. All data were processed in epoch 2010.0000.

The point clouds were georeferenced using GCPs. GCPs consisted of markers placed on the ground, the positions of which were measured using differential GNSS (dGNSS). A total of 22 GCPs were used and a table of their positions is included.

dGNSS was done in kinetic mode using a local reference station and a single rover. The reference station consisted of a Trimble 5700 receiver and Trimble Zephyr Geodetic I antenna. Reference station location was determined using the National Geodetic Survey’s Online Positioning User Service (OPUS) and over 16 hours occupation time. OPUS results in epoch 2010.0000 were used, so effectively the entire data set is in that epoch. Reference station uncertainty is estimated to be approximately +/- 0.003 and 0.006 m horizontal and vertical respectively. A Trimble R8 rover was used to occupy the GCPs (and checkpoints). Rover accuracy generally degrades towards the east, where proximity to the House Range limited satellite visibility and decreased measurement precision. GCP location uncertainty is estimated to vary from +/- 0.01 (horizontal) and +/- 0.015 (vertical) up to approximately +/- 0.02 (horizontal) and +/- 0.04 (vertical). Orthometric heights in NAVD88 were determined by applying GEOID 12B in Trimble Business Center software.

The position of every GCP was manually marked by hand in every photograph in which it clearly appears using Agisoft Metashape prior to optimization of the sparse point cloud and camera models.

The final point cloud, DSM and orthomosaic were cropped prior to export from Agisoft Metashape. Cropping was done to include the area reasonably well covered by GCPs and photographs.

Vertical uncertainty of the final DSMs were assessed using checkpoints (Bunds et al., 2015). Checkpoints are dGNSS measurements taken on bare, relatively flat ground away from GCPs and vegetation. Checkpoints measured too close to vegetation, in areas of notably poor model reconstruction (evident in the DSM and derivatives of it), and with large measurement uncertainty (greater than ~ 5 cm) were excluded. A total of 63 checkpoints were used to confirm vertical accuracy. The elevation predicted for each checkpoint was extracted from the DSM using ArcMAP, and a residual calculated as the difference between the DSM elevation and the directly measured elevation for each checkpoint. Root-mean-square error (RMSe; 1-sigma error) for all checkpoints relative to the DSM is 6.7 cm. GCPs and checkpoints were measured using the same reference stations as the GCPs, so some additional error in accuracy should be present in the data set due to error in the absolute positions of the reference station, however based on the quality of the OPUS solutions this is likely to be small relative to the checkpoint RMSe. Note that misfit of the point clouds to GCPs (as measured by Agisoft) is much less than checkpoint error, and reflects the fact that GCP misfit as calculated in Agisoft is not a reliable measure of model accuracy across the survey area.

DSM and point cloud error should be expected to vary across the surveyed area, and may deviate significantly from the checkpoint - derived RMSe. Larger errors should be expected at large distances from GCPs, outside of flight lines or good camera coverage, and in areas of poor model reconstruction. SfM processing using GCPs typically results in a model with good fit to GCPs, and potential warping between GCPs (in this case, probably mostly <6.7 cm based on checkpoints), as well as significant potential warping in areas not surrounded by GCPs (i.e., areas on the edge of the data set or outside of GCP coverage) (e.g., Bunds et al., 2015). Photograph coverage and model reconstruction also affect error, and portions of the model that extend beyond flight lines are likely to contain larger than average error. There are areas in the data set with relatively poor camera coverage and reconstruction; it should be expected that error in these areas is much greater than the overall RMSe. These areas are apparent in the DSM and derivatives made from it such as hillshades. The tables of GCP and camera locations are included to aid identification of areas prone to relatively large error. Lastly, although extensive efforts have been made to minimize and quantify error in the data set, no guarantee of accuracy is given nor implied.

Figure 1. Location map showing approximate areas covered by data set (outlined in red), the House Range fault, the Wasatch fault, and other Quaternary faults. Faults from USGS Quaternary Fault and Fold Database, imagery from Google Earth.

Table 1. Summary of Topographic Model Parameters

Parameter	Topographic model
Total points	1.969 x 10^9
Coverage area	5.05 km^2
Point density	389 points/m^2
Number photographs	7,980
Average GSD	0.0262 m
Number GCPs	22
Number checkpoints	63
Checkpoint RMSerror	0.067 m
DSM resolution	0.10 m
Orthomosaic resolution	0.05 m
Horizontal reference frame – point clouds, DSMs and orthomosaics	NAD83(2011) UTM Zone 12 (EPSG 6341) epoch 2010.0000
Vertical reference frame	NAVD88 (GEOID12B)
Field data collection date	May, 2016

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