Documentation for the analysis of the ground-based Alvord Basin LiDAR dataset

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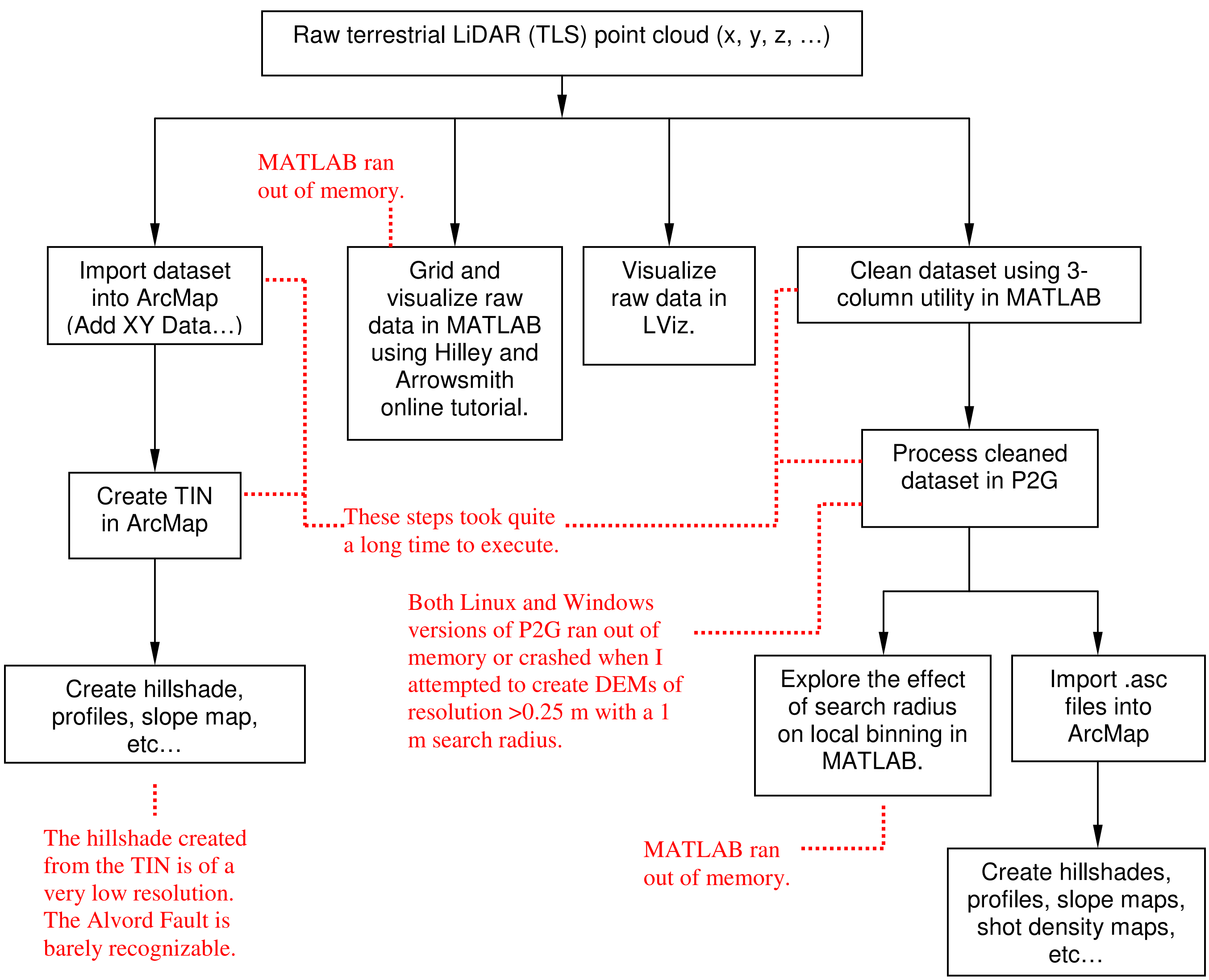
Introduction

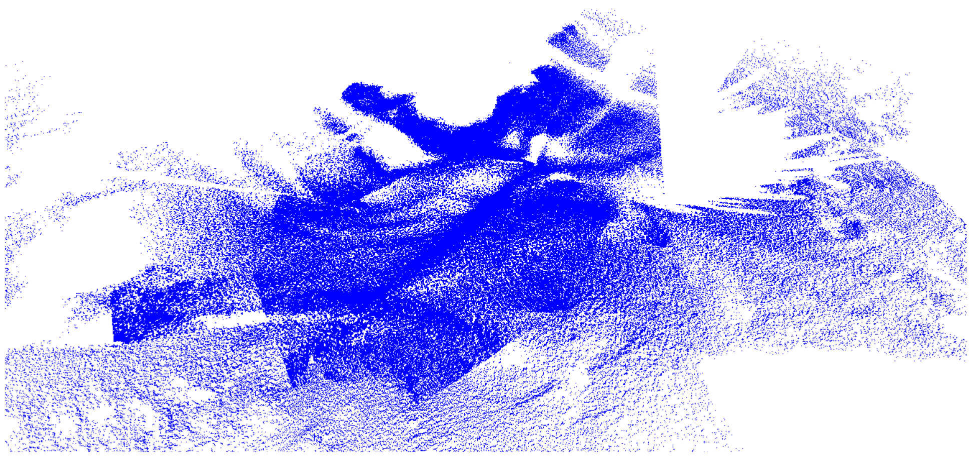
This report presents the procedures carried out, the results obtained, and the issues I ran into during my analysis of the terrestrial LiDAR dataset acquired from the Alvord Basin by John Oldow and colleagues. The following flowchart summarizes my steps in preparing the dataset, executing the necessary processes, and the issues I ran into while performing these steps.

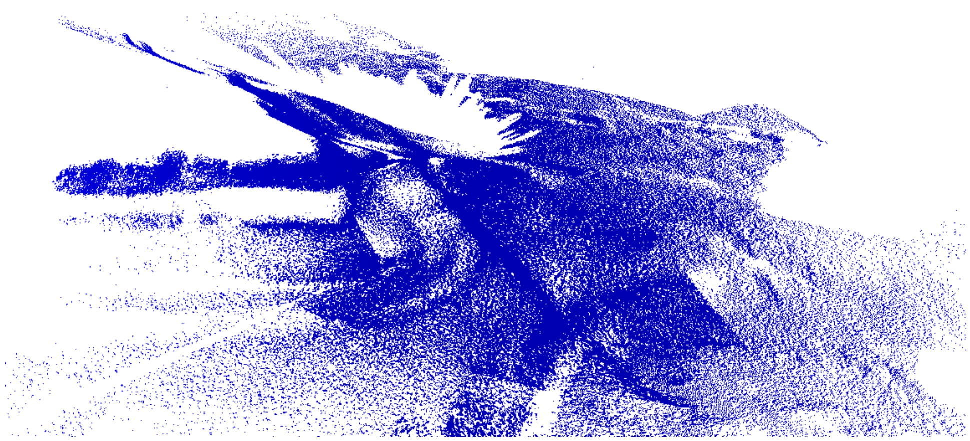


Initial visualization of the raw Alvord Basin TLS dataset

The first step in assessing the Alvord Basin dataset involved the visualization of the point cloud in LViz. LViz is a lightweight 3D visualization tool that was developed by Jeffrey Conner in the Active Tectonics Research Group at Arizona State University (now with HPC at ASU). It is designed to quickly visualize large LiDAR datasets in 3D, but can also be used to visualize any 3D point cloud.

I imported the entire point cloud for the Alvord Basin using the "Import 3D Point Cloud Data" command in LViz. The process took approximately 1 minute to execute. Data navigation and rendering was performed smoothly using a lab computer. The following are screen shots of the point cloud in LViz viewed from different perspectives. The Alvord Fault is represented by a band of dense points near the center of each image:



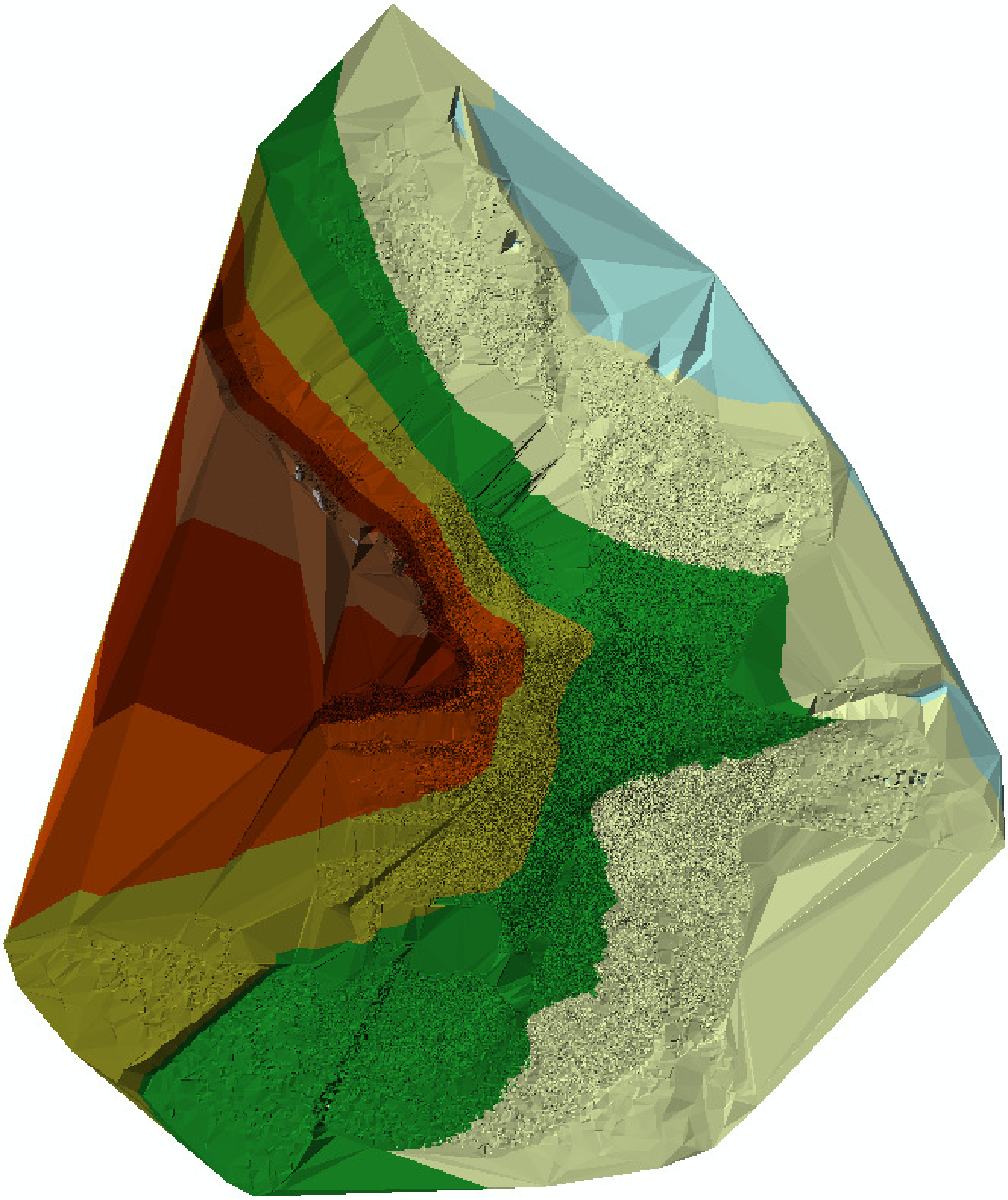


It is apparent that the point cloud contains large "holes" of no data. This illustrates the high heterogeneity in the acquisition process of the TLS data in the field.

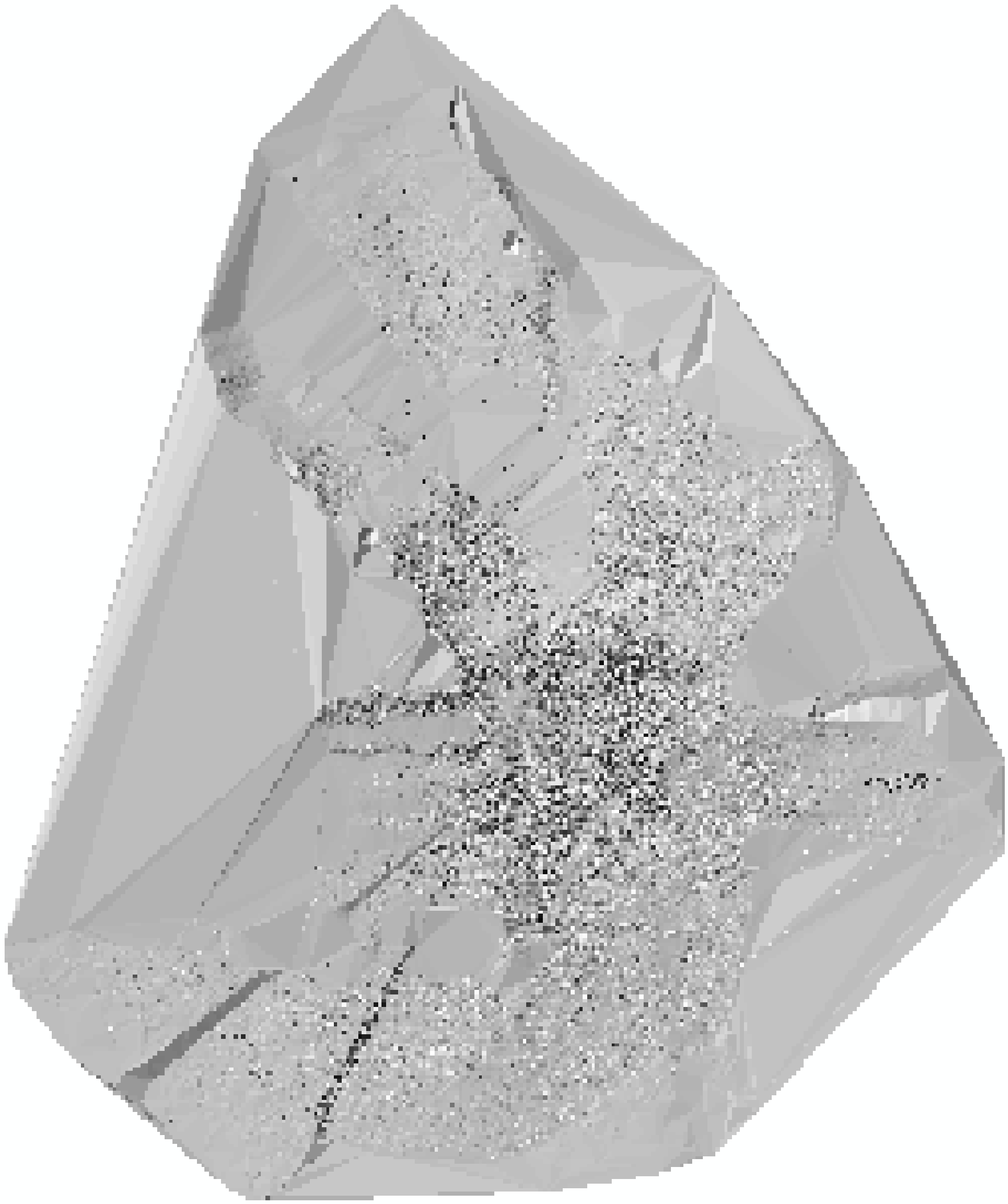
Processing and displaying the raw TLS LiDAR dataset in ArcMap

This step involved importing the full dataset into ArcMap using the "Add XY Data…" command:

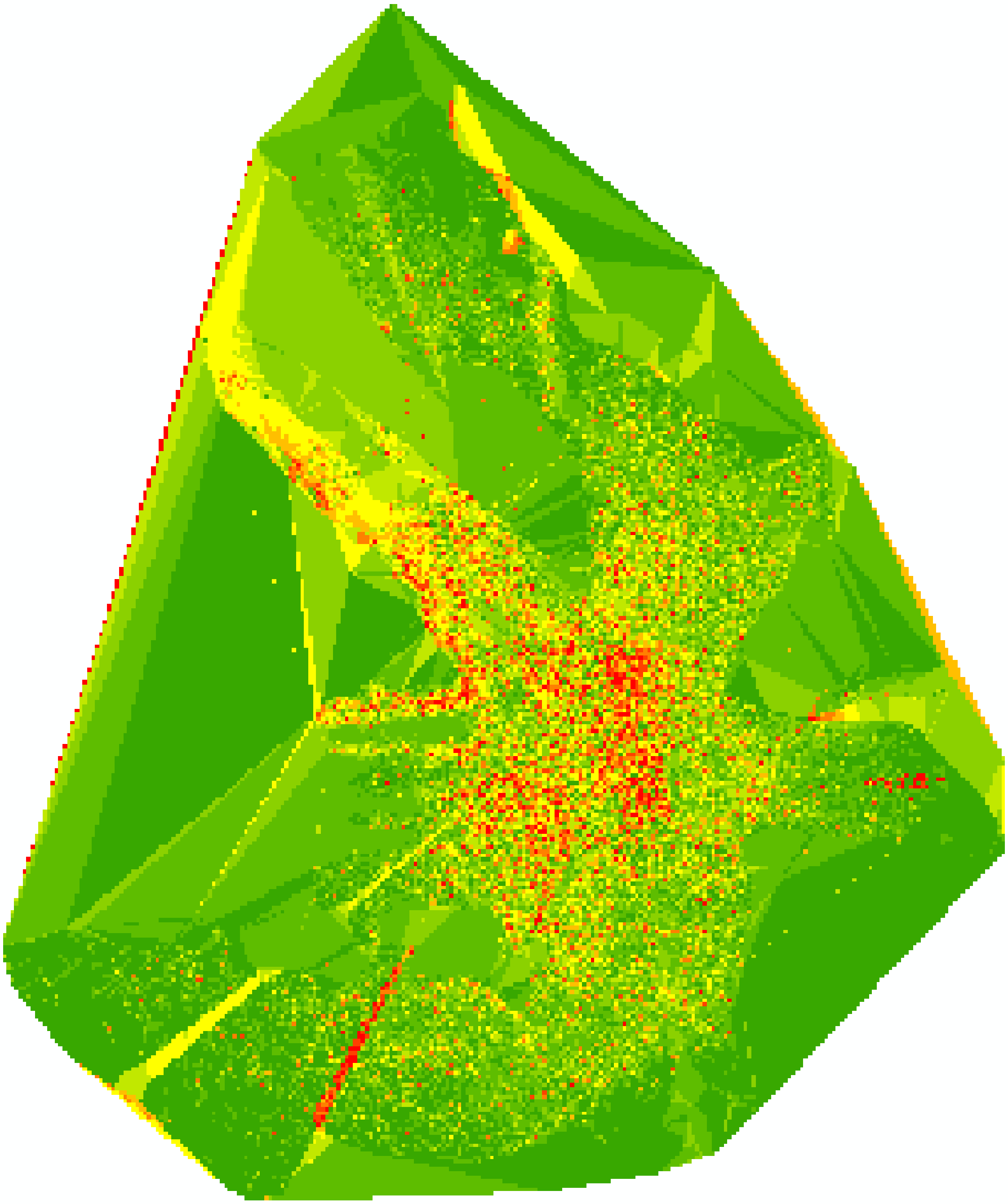
A triangular irregular network (TIN) was created from the dataset. This process took quite some time, and I suspect this was due to the large size of the dataset (~16 million data points, ~0.6 Gb text file):



A hillshade was created from this TIN. The quality of this hillshade is far inferior to the quality of the hillshades created from the DEMs that were produced by P2G:



Slope map of the TIN:



Processing and displaying the raw TLS LiDAR dataset in MATLAB

I was unable to perform this step for the entire Alvord Basin LiDAR dataset because MATLAB seemed to run out of memory. This is the error that MATLAB returned when I tried running the "plot_data.m" script on the full dataset:

```
>> plot_data
??? Error using ==> horzcat
Out of memory. Type HELP MEMORY for your options.

Error in ==> griddata at 85
sxyz = sortrows([x y z],[2 1]);

Error in ==> plot_data at 29
[xi,yi,zi] = griddata(X,Y,Z,easting,northing');

>>
```

Processing and displaying the raw dataset in MATLAB, P2G, and ArcMap

This is where the bulk of my analysis took place. I first processed the raw TLS LiDAR data using the "three_column_utility_efficient.m" utility script to clean the dataset by first loading the original TLS text file and writing the first three columns (x, y, and z) into two new ASCII text files; one with a header ("x, y, z") to be used in ArcMap (and other applications that may require a header), and another without a header. This took quite some time to process (~39 minutes on the lab machine). The final size of the two new text files was ~0.3 Gb each.

Next, I used the "get_extents.m" utility script in MATLAB to find the minimum and maximum values of the x, y, and z columns. I did this because processing time of the P2G application may be reduced by 20% (according to the documentation of the Linux P2G), which may be a few minutes for large datasets such as the Alvord Basin point cloud. Here are the extents of the x, y, and z columns for the Alvord Basin dataset:

Extent	Value
Minimum x	-1011.1
Minimum y	-737.0
Minimum z	-46.764
Maximum x	543.43
Maximum y	1116.6
Maximum z	123.51

The data were now ready to be processed in P2G in order to create DEMs of various resolutions using the IDW method with various search radii. I ran the Linux and Windows versions of P2G. The following lists the P2G runs that I made to generate these DEMs:

P2G Linux		P2G Windows	
Grid resolution (m)	Search radius (m)	Grid resolution (m)	Search radius (m)
1	0.707	0.5	1
1	1		
0.5	0.3535		
0.5	0.707		
0.5	1		
0.3	1		
0.26	1		

The highest-quality DEM that the Linux P2G was able to produce had a grid resolution of 0.26 m and a search radius of 1 m. I was unable to create DEMs of resolutions greater than 0.26 m because the Windows version of P2G crashed, while the Linux version of P2G produced an error message saying it ran out of memory.

DEM comparison

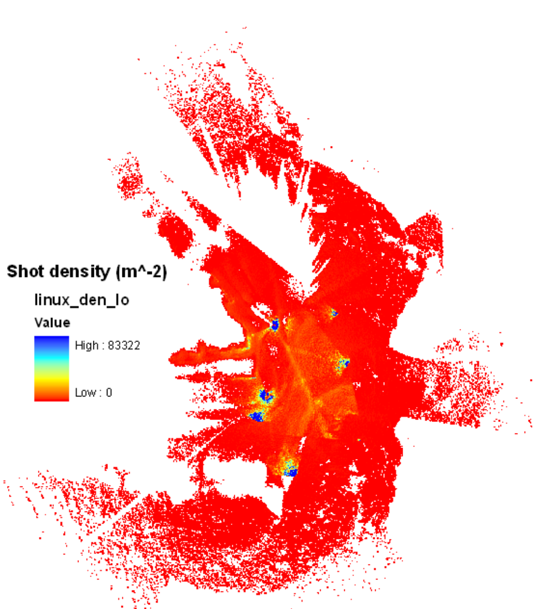
I compared the DEMs produced by the Linux and Windows versions of P2G using grid resolutions of 0.5 m and 0.26 m with a search radius of 1 m. The following are hillshades of these DEMs:

Hillshade created from DEM produced by Windows version of P2G
Resolution: 0.5 m
Search radius: 1 m

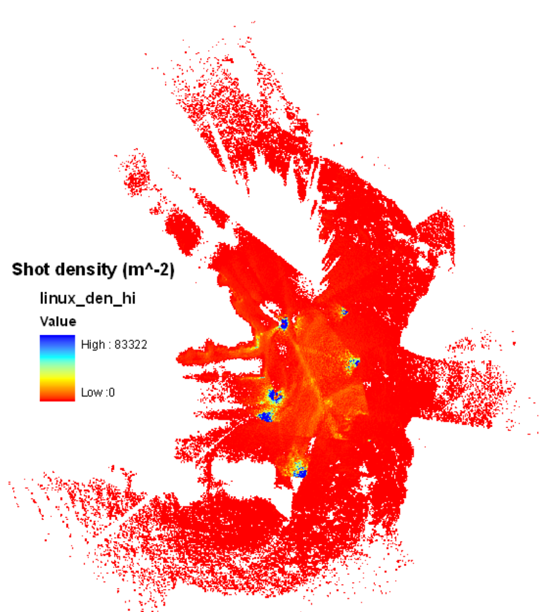
Hillshade created from DEM produced by Windows version of P2G
Resolution: 0.26 m
Search radius: 1 m

I also compared the shot density maps produced by the Linux and Windows versions of P2G using the same grid resolutions and search radius as above. The following are shot density maps displaying shot counts per square meter:

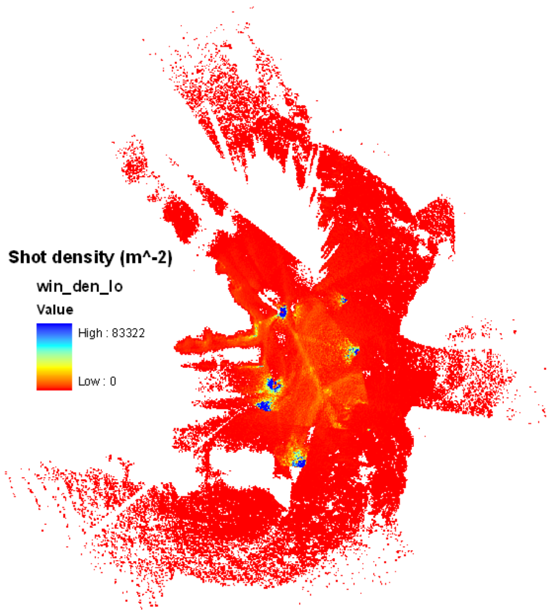
Shot density of DEM produced by Linux version of P2G
Resolution: 0.5 m
Search radius: 1 m



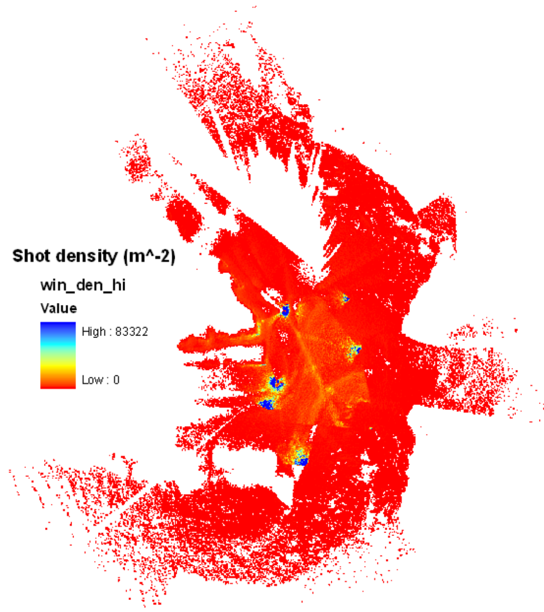
Shot density of DEM produced by Linux version of P2G
Resolution: 0.26 m
Search radius: 1 m



Shot density of DEM produced by Windows version of P2G
Resolution: 0.5 m
Search radius: 1 m



Shot density of DEM produced by Windows version of P2G
Resolution: 0.26 m
Search radius: 1 m



There is no apparent difference between the DEMs and the shot density maps created by the Linux and Windows versions of P2G (as expected).

The large variability in the spatial distribution of shot counts in the Alvord Basin TLS dataset is nicely illustrated in the shot density maps. It is apparent that at least six "hot spots" of high-density shot counts exist in the dataset (blue regions). Each "hot spot" may be the result of multiple overlaps of the laser swaths during data acquisition in the field. My first-order qualitative assessment indicates that shot density decreases rapidly with distance from these "hot spots". This indicates that the laser swaths overlap multiple times nearer to the terrestrial scanner, and that the magnitude of shot returns decreases very rapidly as distance increases away from the laser scanner. This makes me ponder the following:

What controls the geometry (radius, diameter, etc.) of these shot count "hot spots"?

What can they tell us about the data acquisition process in the field?

Can they be controlled, minimized or completely avoided, or are they purely an artifact of the data acquisition process (similar to overlapping swaths in airborne LiDAR datasets and the "corduroy effect")?

Do they affect the quality of the DEM produced? If so, can we establish TLS data acquisition standards or field protocols that strategically determine the placement of the scanner, or is it entirely dependant on the landform being assessed?

Exploring the effects of search radius on local binning

IN PROGRESS

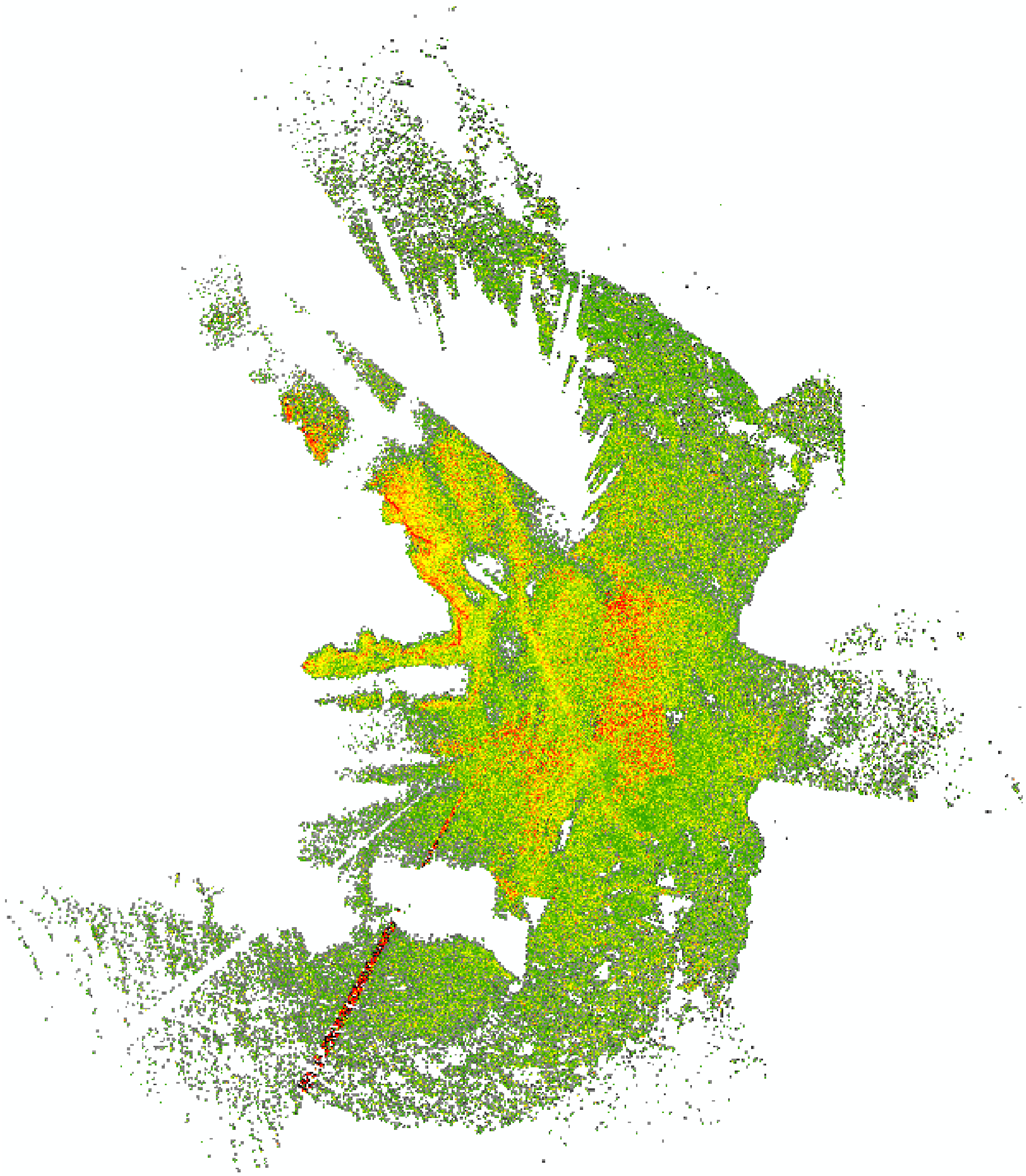
I was unable to explore the effects of varying the search radius on the local binning of the 0.5 m DEM in MATLAB because of the following error:

```
>> analyze_radius

i =

     1


i =

     2

??? Error using ==> unknown
Out of memory. Type HELP MEMORY for your options.

Error in ==> gradient at 75
      g(2:n-1,:) = (f(3:n,:)-f(1:n-2,:))./h(:,ones(p,1));

Error in ==> LoadFile at 30
        [dElev_dx, dElev_dy]   = gradient(Elevation,dx,dy);

Error in ==> analyze_radius at 52
[X, Y, Easting, Northing, Elevation, dElev_dx, dElev_dy, nulls_count] =
LoadFile('05Res1SR.idw.arc.asc');

>>
```

I have not tried running this script using the 0.26 m DEM because I suspect this error is due to the large size of the .asc file that P2G created.

Slope map of the 0.26 m DEM

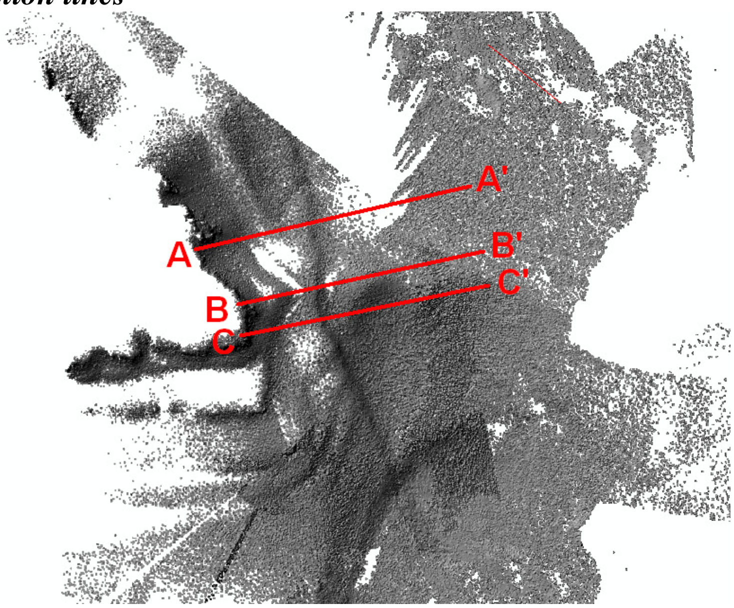
The following is a slope map that was created from the 0.26 m DEM in ArcMap. The Alvord Fault can clearly be seen as a northwest-trending band of yellow points near the center of the image.



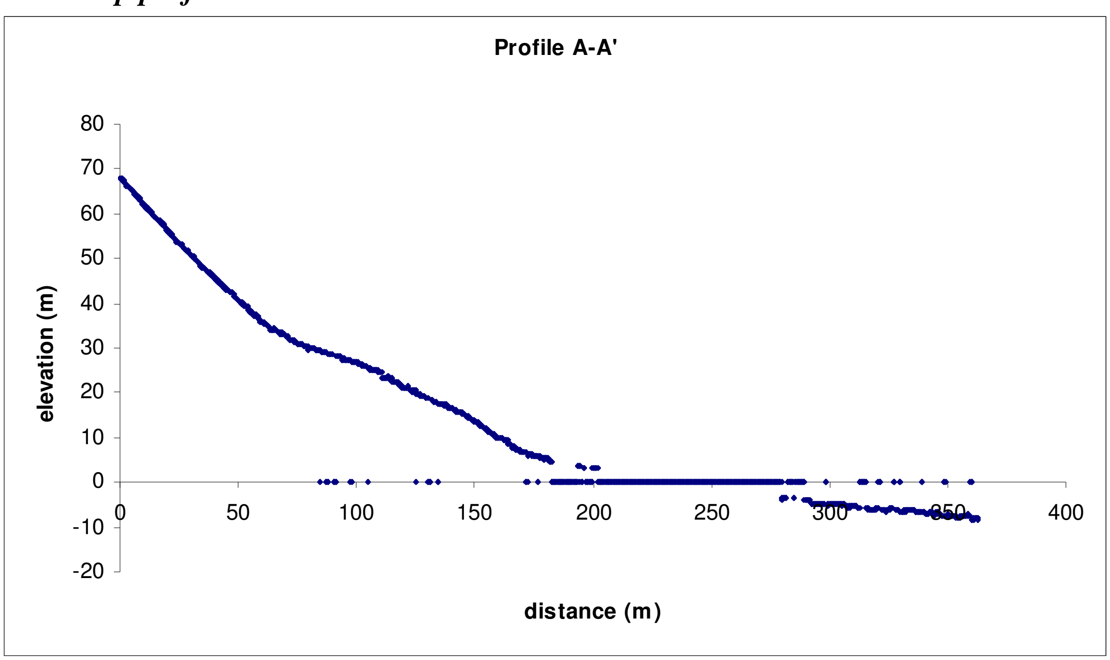
Fault scarp profiles

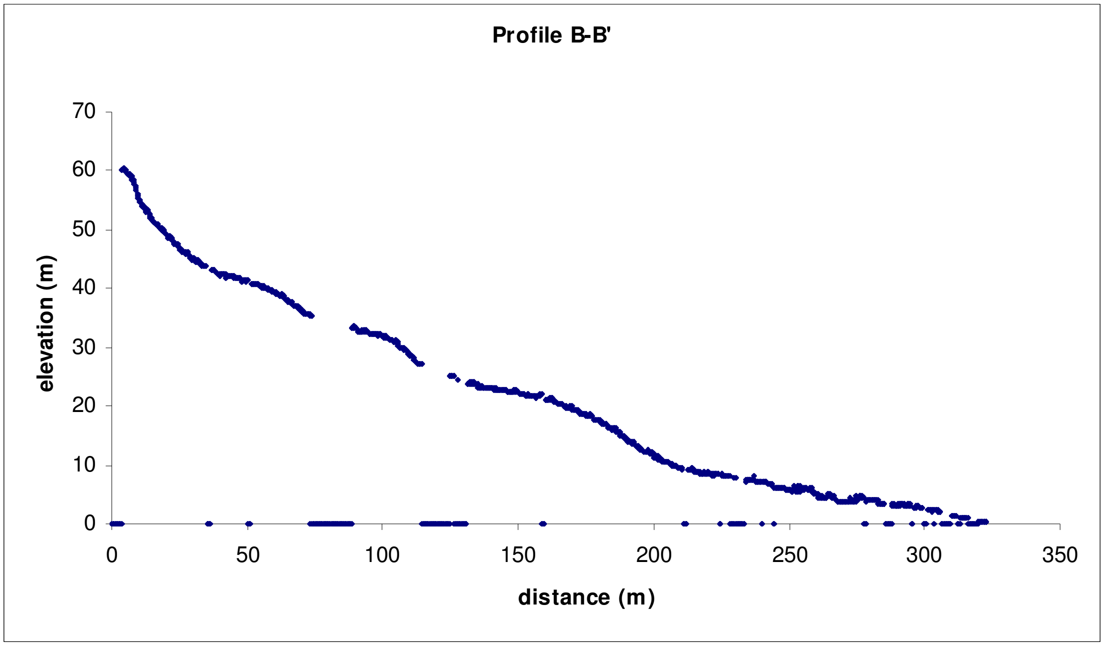
The following images are fault scarp profiles generated using the 0.26 m DEM and the LiDAR Data Handler extension in ArcMap. I note that the "null" cells in the DEM have the value of -3.4×10^{38} for elevation. I replaced these null cells with the value of 0. However, it may be useful to write a MATLAB script that "cleans" the profile data points extracted by the LiDAR Data Handler prior to plotting the fault scarp profiles.

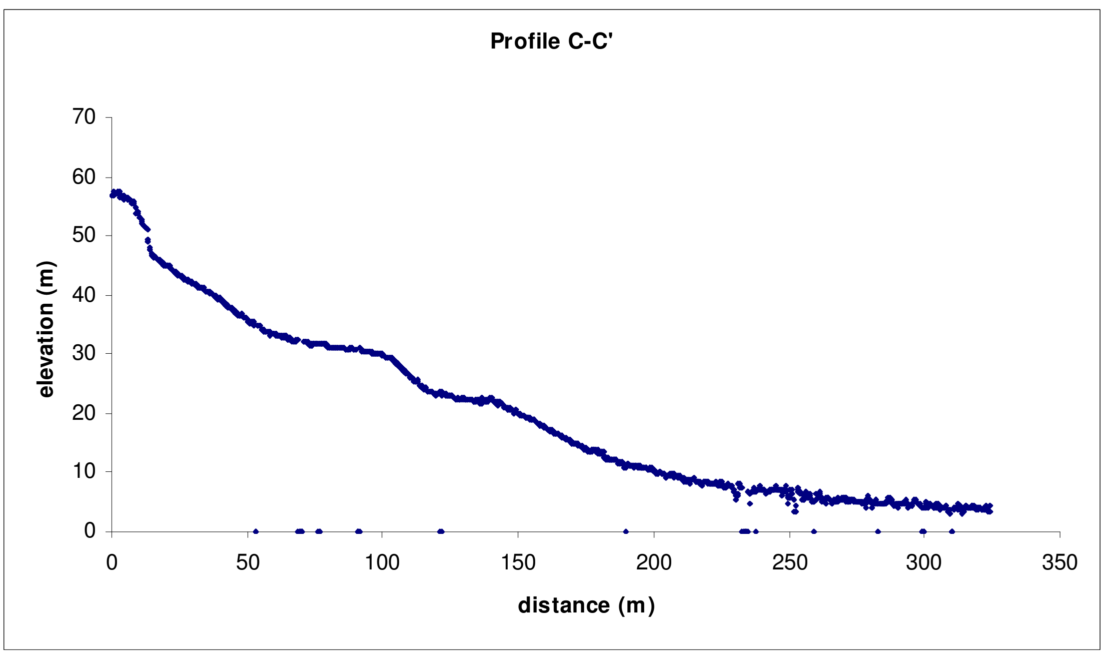
Map of cross-section lines



Fault scarp profiles




Profile B-B'
elevation (m)
distance (m)
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350


Profile C-C'
elevation (m)
distance (m)
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350

Conclusions and next steps

We developed and used several computational processing tools to assess the Alvord Basin TLS dataset. Most of the processes were executed successfully and produced high-resulition DEMs that will be essential to the geomorphic assessment of this segment of the Alvord Fault. The processes that were unsuccessfully executed in this analysis (running out of memory in MATLAB, running out of memory in the Linux version of P2G, and crashing the Windows version of P2G) may be attributed to the large volume of the Alvord Basin TLS dataset. However, this should motivate the increased efficiency of the P2G application and MATLAB utilities at processing large LiDAR point clouds, especially since future acquired TLS point clouds will undoubtedly be large. Another process that will be essential to the geomorphic analysis of the Alvord Basin dataset is the georeferencing of the point cloud to a true coordinate system. Ramon Arrowsmith and I have discussed a suitable approach for said process (rotation and translation of the point cloud into a "real" coordinate system), but this will require the true coordinates of at least three data points in the point cloud.