ESRM433/SEFS533
Lab 8

Objectives:

- *Voxels*
  - *Introduction*
  - *Normalizing TLS point clouds*
  - *Subjective assessment of ground cover*
  - *Quantifying ground cover with voxels*
    - *Identifying issues with occlusion*
- *Stitching point clouds and volume change*
  - *Comparison to drone Digital Aerial Photogrammetry (dDAP)*
  - *Quantifying coastal cliff erosion*

Data and Software:

- *LAB8_DATA:*
    - *FARO s350*
      - *Plot1.laz*
      - *Plot2.laz*
      - *Plot3.laz*
      - *Plot4.laz*
      - *Plot5.laz*
      - *FARO Discovery Park Cliff 2019_1.laz*
      - *FARO Discovery Park Cliff 2019_2.laz*
    - *dDAP*
      - *dDAP Discovery Park Cliff 2018.laz*
- *Washington DRN lidar Portal*
    - *Loomis Loop Loop*
- *CloudCompare software*

What you will turn in:

- *Submission Template as PDF*

Welcome to Lab 8 for ESRM433/SEFS533

We are going to be downloading A LOT of data for this lab. Take a moment and delete old files that you are no longer using to free up space in your Madrona instance.

This lab is all about Terrestrial Lidar Scanning (TLS). Unlike aerial lidar which is acquired from airplanes or drones, TLS is acquired from scanners on the ground. TLS point clouds tend to be much denser and more detailed than ALS.

Generally speaking, TLS has typically referred to a stationary scanner mounted to a tripod. The biggest advantage of being stationary on a tripod is that scanlines can be tightly packed together and objects can be scanned with tens of thousands of points per square meter, depending on the distance of the object from the scanner. Metrics like pulses per meter^2 that are commonly used for ALS, aren't as meaningful for TLS. Pulses per meter^2 will decrease as distance between the scanner and the object increases. Pulses per meter^2 at 100m can be used as it defines the distance from the scanner. Also, multiple scans can be stitched together to create a larger scene. TLS scenes can be comprised of 2 or 3 scans stitched together, or 100+ scans stitched together. TLS can be time of fight or phase based. https://lidarmag.com/2013/04/06/the-reality-tof-vs-phased-based-scanners-2/

For this lab, you will be creating voxel counts from single point TLS scans to quantify the amount of understory vegetation. You will then be comparing point clouds created by drone digital aerial photogrammetry (DDAP) to TLS and determining the volume of erosion from a cliff face at Discovery Park in Seattle.

Information on the scanner that were used to collect the lidar data is included in the appendix.

Georeferencing

While ALS data is dependent on being accurately georeferenced, TLS data often doesn't need to be placed accurately. TLS data most often is only related to the relative location of object within the scan rather than the geographic locations. An example is the costal cliff face erosion. All the point clouds are aligned to each other and it doesn't matter if they are located geographically.

However, if we are going to derive forest plot information from TLS to be scaled up to ALS or satellite data, we do need to know the precise locations of the scans. This initial georeferencing step I did for you.
To georeference the data. There are a few different ways that this can be done. Using survey grade GPS receivers marking the location of targets that can be identified in the lidar point cloud. Targets that are used to TLS scanning are often spheres or checkerboard patterns that can be seen in the point cloud.

Another way that TLS scans can be georeferenced is to match the point cloud with an ALS cloud. Identifying features in both clouds and transforming the TLS to match. Ideally the features are things that don't move or grow (i.e. not trees) but trees can be used if there are not better options. This second method is what was used to georeference the TLS scans to the Loomis Loop Loop ALS acquisition.

PART 1: VOXELS

This part is going to be a very brief work flow to introduce the idea of voxels. The term voxel is a combination of Volume and pixel. They are essentially 3D pixels. They are defined by XYZ coordinates, an area value, and additional user defined values.

With TLS data, voxels are typically used in two distinctly different ways. The first way is to normalize the point density of a TLS scan. There are more points per unit area close to the scanner. A wall 3m from a TLS scanner could have a million points per m^2 while a wall 100m from the scanner may only have 100s or dozens of points per m^2 depending on the scan resolution set on the scanner. To normalize the point density is to decimate the point cloud so there are an equal amount of points per m^2 on the wall 3m from the scanner and the wall 100m from the scanner.

A 3D voxel grid can be imposed on the scan area with a user defined area or side length. Lets use the value of 10cm per side. Within this voxel grid, if there is a single lidar return within the area the voxel value becomes 1. If there are 1000s of lidar returns, the voxel value is still just 1. We are only interested in the question, “Is there at least one lidar return within this area?”. If there are no lidar returns, then the voxel value becomes 0. This decimated lidar point cloud can then be represented by a single point at the center of the voxel. It creates an odd looking point cloud of points all distributed evenly spaced.

The second way voxels are used is by imposing a voxel grid on an area and then counting the number of points within each voxel. This method typically is run on an already decimated point cloud. The output of this method is a table of “voxel metrics”.

Voxel metrics have been used extensively in quantifying how much “stuff” is in an area. Voxels are one of the best ways to estimate biomass and biomass change due to some disturbance event such as fire. In my own work I use voxels as a way to quantify the amount of cover in an area for habitat quality assessment.

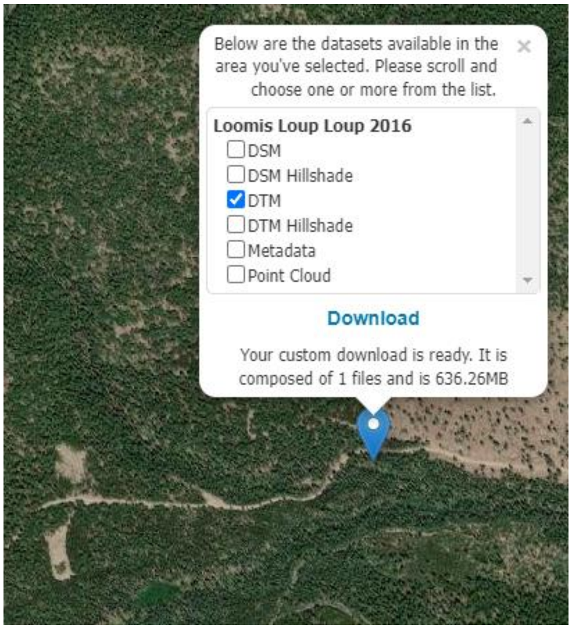
Typically, you need to have multiple scans stitched together to create full 3D models of vegetation for volume estimates. With single point scans, occlusion becomes a major issue. Very dense vegetation will have a high amount of occlusion which essentially hides most of the vegetation from the view of the scanner. We are going to experiment with using single point scans to generate voxel estimates, but keep in mind that our results will likely be heavily impacted by the amount of occlusion that is present with a single TLS scan.

For this part of the lab, we are going to look at 2D depth maps generated from TLS scans and do an subjective, qualitative assessment of the amount of understory vegetation present. We then going to normalize the height of the TLS scans using an ALS DTM, Normalize the point distributions of the TLS scans with 10cm voxels, then preform voxel metrics with 50cm voxels. We will see how well our voxel metrics align with our subjective assessments of cover amount. This analysis by itself isn’t very useful, but the intention is to introduce you to the process of normalizing both the height and point distributions of TLS scans as well as how to create voxels.

The TLS data is provided for you via canvas but you will need to get the DTM from the DNR lidar portal. You will need one DTM from the DNR site:
EPSG 3857

- 48.79235, -119.79638
  - loomis_loup_loup_2016_dtm_10.tif

You only want the DTM which should be 636.26MB in size. Make sure it is the correct DTM or none of the following steps will work.



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As always, set up a LAB8 folder in your Desktop/ESRM433 for your data. Put your download there as well as the LAB8.zip file from canvas. Unzip all of the data.

As always, the best way to get a good look at the lidar data is to open up the files in CloudCompare.

Let's take a look at TLS data. When the data is collected from the scanner, there is a lot of noise present. I have done the initial filtering of the point cloud and added the color to the point cloud. I also decimated the point cloud a little already to reduce the file size. The original TLS scans had between 13 and 20 million points each. If you are interested in seeing what the data looks like straight from the scanner, let me know and I can provide you with an unfiltered point cloud to experiment with.

QUESTION 1: Take a screenshot of one of the TLS scans rendered in a cool way. Discuss some of the similarities and differences between the TLS and ALS. What happens to point density at greater distances from the TLS scaner? Why is there a circular gap in the TLS point clouds below the sanner location?

Below are depth maps created from the TLS scans. The depth maps are 2D representations of the 3D point clouds with the colors representing distance from scanner. These depth maps are colored in the magma gradient up to 10m from scanner with all points beyond 10m in green. You can compare the depth maps to the point clouds to see how they are similar and different. The depth maps are 2D representations of a spherical image. You can clip one out and view it in a spherical image viewer to see what the viewpoint from the scanner looked like. Here is an online version you can check out:

https://renderstuff.com/tools/360-panorama-web-viewer/

QUESTION 2: Use the table in the submission template to rate the ammount of vegetation cover within 10m of the scaner for the five sample plots. We are going to use 3 categories of vegetation amount; Low, Medium, and High. This is a purely subjective assessment and we will be returning to this table later in the lab to fill out the other cells.

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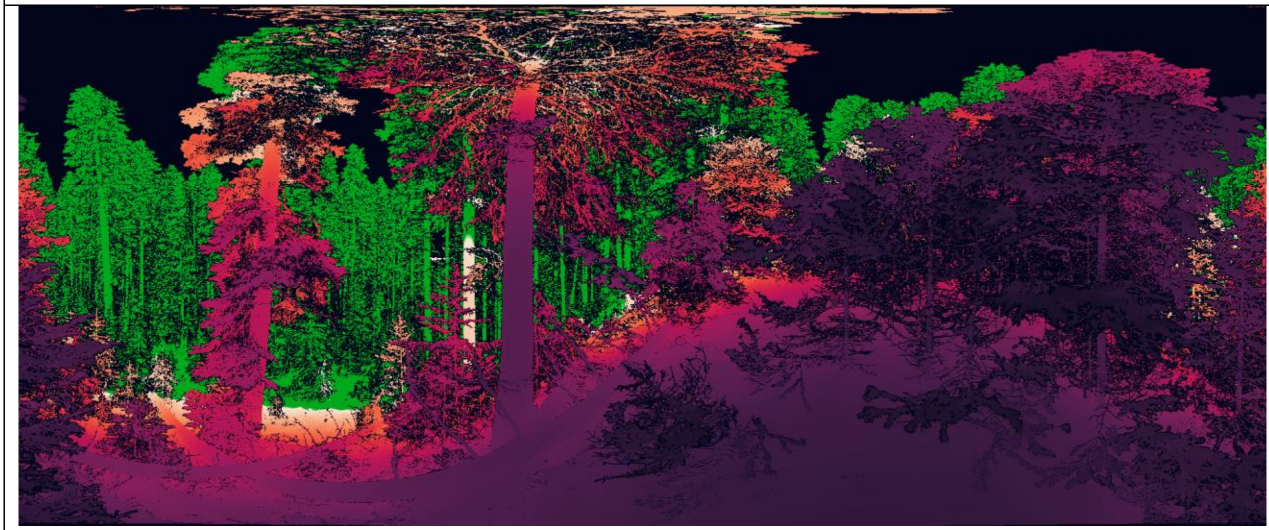
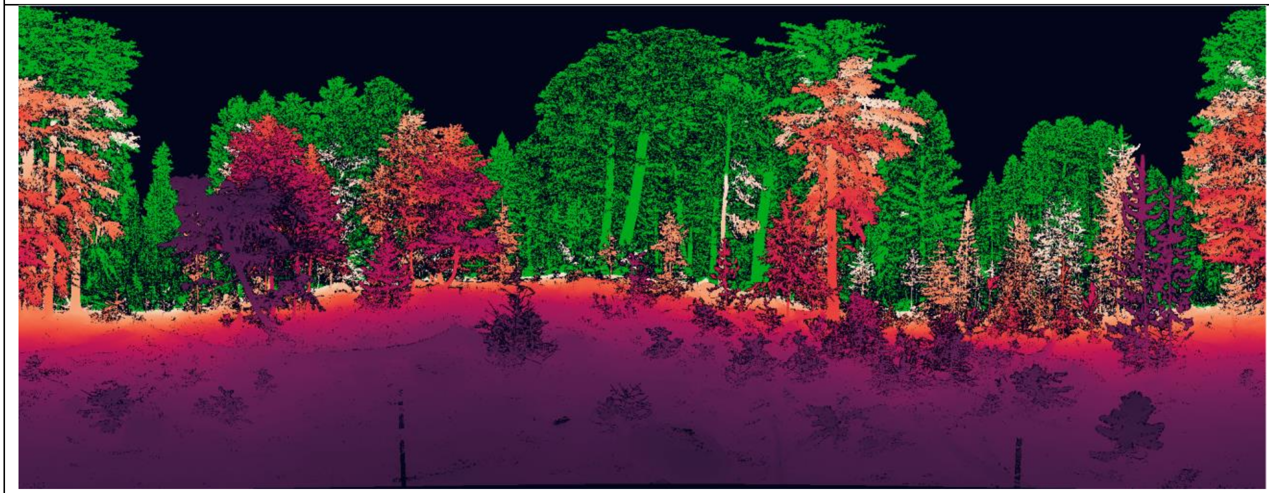
Plot Number	Visual Estimate	Voxel Count 0.5 to 2m	Total Voxels > 0.5
Plot 1			
Plot 2			
Plot 3			
Plot 4			
Plot 5			

Plot coordinates are EPSG 2927, X Y and Z coordinates of scanner.

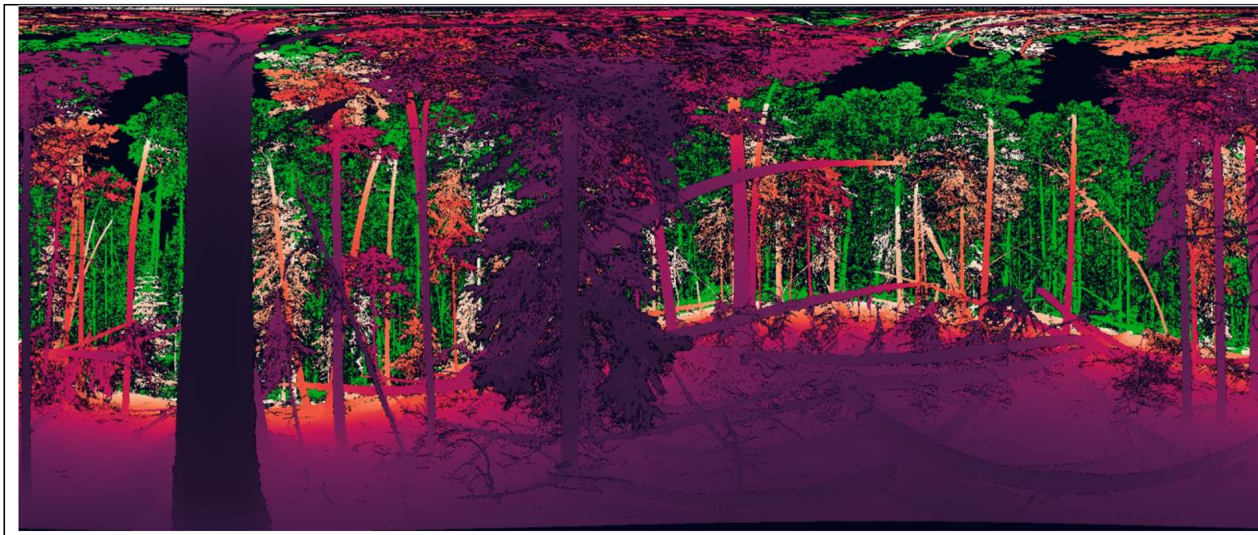
Plot 1 1802812.608 1255802.834 5349.696



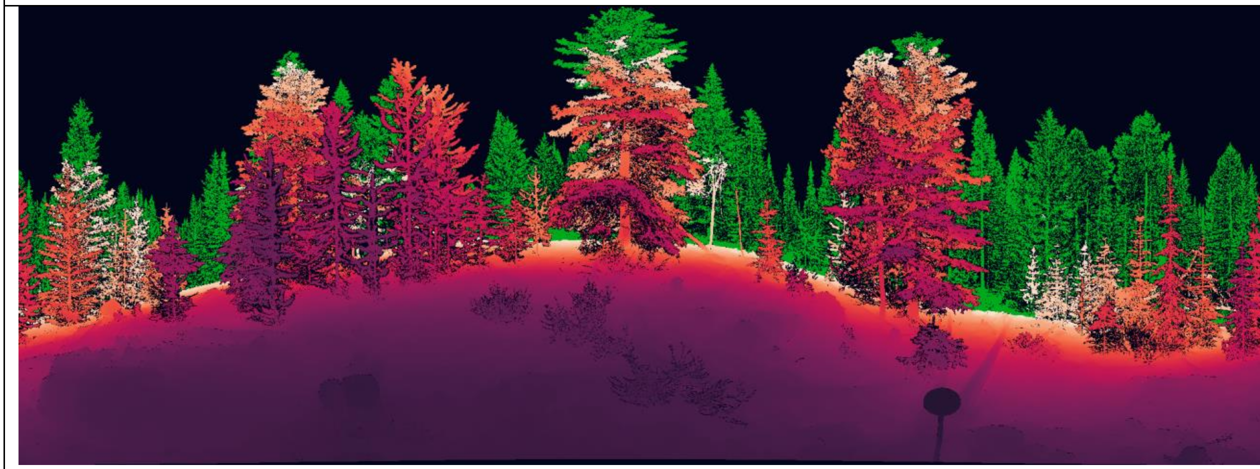
Plot 2 1814786.997 1260991.466 4275.601



Plot 3 1807317.333 1263542.463 5044.303



Plot 4 1808798.994 1266139.443 5295.859



Plot 5 1811814.714 1266173.833 5382.354

Let's get started with R. As always, download and unzip the lab data into a lab 8 folder on your desktop. Open R and set your working directory and load up your libraries.

If you are having issues with rgl, try reinstalling it.

```
setwd("//fs-persona.sefs.uw.edu/student_redirect$/jonbatch/Desktop/ESRM433/Lab8/")
#install.packages("rgl")
library(lidR)
library(terra)
library(rgl)
```

I am going to work though 2 plots. You will have to write the code for the other 3 plots based on the code for the first two. We are going to read in the DTM that we downloaded from the DNR site as well as all **5** of the TLS scans (I am only showing the code for the first two).

```
DTM <- rast("loomis_loup_loup_2016_dtm_10.tif")
Plot1 <- readLAS("Plot1.laz")
Plot2 <- readLAS("Plot2.laz")
```

We need to do check and set the CRS for the data. Remember the command to change the CRS for a raster dataset is different than a point cloud.

```
projection(DTM)
crs(DTM) <-"epsg:2927"
projection(Plot1)
st_crs(Plot1) <- 2927
st_crs(Plot2) <- 2927
```

We are only interested in the vegetation within 10m of the scan position so we need to create 10m radius clips around our scanners position. The scanner has a range of 350m but occlusion becomes an issue at further distances from the scanner. You can plot the full scan and the points within 10m of the scan to compare.

```
Plot1C<-clip_circle(Plot1,1802812.608,1255802.834,32.8)
plot(Plot1)
plot(Plot1C)
Plot2C<-clip_circle(Plot2,1814786.997,1260991.466,32.8)
plot(Plot2)
plot(Plot2C)
```

We are now going to normalize the height of the point clouds in the same manner as we did in previous labs by using the vendor supplied DTM.

```
Plot1N <- normalize_height(Plot1C,DTM)
Plot2N <- normalize_height(Plot2C,DTM)
```

QUESTION 3. The DTM from the ALS data will have some ammount of registration error from my georeferancing the TLS scans, but this is still preferable to trying to create a DTM from a single TLS scan. What issues do you think there would be in creating a DTM from a TLS scan?

Take a moment to check out the documentation for the voxel tools in lidR.

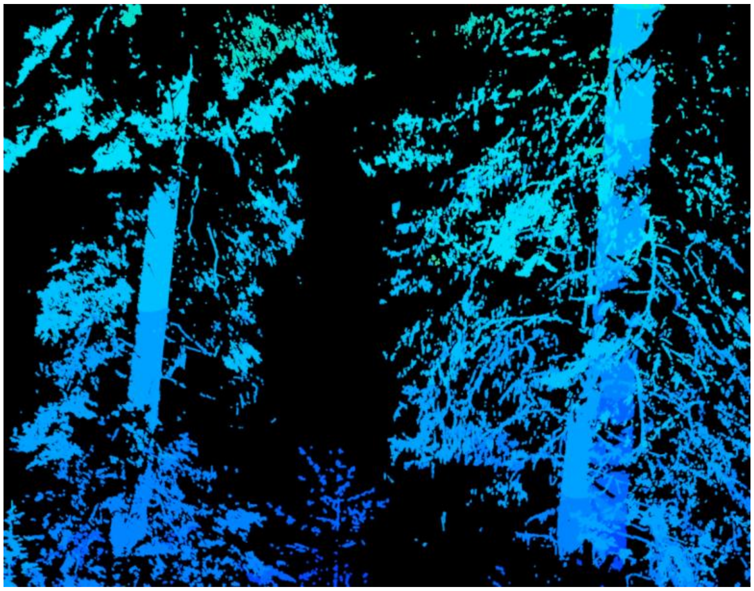
```
?voxelize_points
?voxel_metrics
```

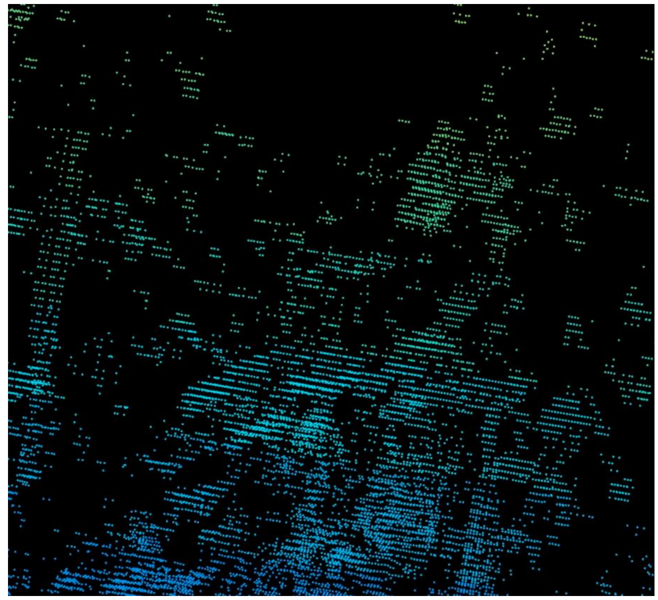
We are ready to decimate the point cloud and normalized the point density using a voxel approach.

```
Plot1NV <- voxelize_points(Plot1N, .328)
Plot2NV <- voxelize_points(Plot2N, .328)
```

Voxelize_points creates that 3D grid at a user defined resolution. In this case we are using 0.328 feet as our resolution. This of course equals 10cm. There is no ideal resolution. It fully depends on the ecological application.

QUESTION 4: Submit 2 screen shots. Pick plot 3, 4, or 5. Take a screen shot of the output from normalize_height and a screen shot of the output from voxelize_points. Provide a caption for the screenshot as if it were a figure in a paper you are writing. Discribe the differeances and what the voxelizing process is doing to create the decimated point cloud. Make sure to directly refer to the screen shots in your caption. Also make sure the grided nature of the voxelized point cloud is visible in the screen shot (example is the lower right figure below).



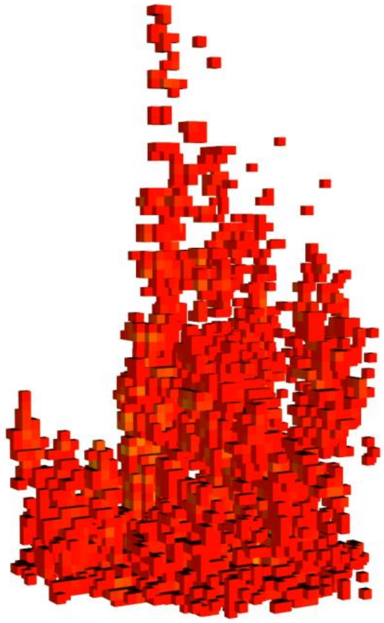


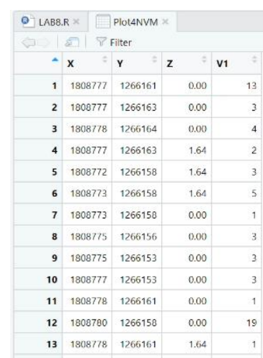
Voxel_metrics uses a 3D and provides a count of all points within each cube. We are using 0.5m (1.64ft). These metrics are similar to cloud metrics as we can derive any number of statistics about the points. Mean, Max, Sum, average at different distances from plot center… etc. We are going to keep things simple for this lab and focus on the sum of all points at each height interval.

```
Plot1NVM <- voxel_metrics(Plot1NV, length(Z), 1.64)
Plot2NVM <- voxel_metrics(Plot2NV, length(Z), 1.64)
```

We can check out our voxel metrics by plotting them as a continuous grid (voxel = TRUE), and applying a color heat map based on the number of points within each voxel (color="v1")

```
plot(Plot1NVM,color="V1", pal = heat.colors(50), size = 1, bg = "white", voxel = TRUE)
plot(Plot2NVM,color="V1", pal = heat.colors(50), size = 1, bg = "white", voxel = TRUE)
```





	X	Y	Z	V1
1	1808777	1266161	0.00	13
2	1808777	1266163	0.00	3
3	1808778	1266164	0.00	4
4	1808777	1266163	1.64	2
5	1808772	1266158	1.64	3
6	1808773	1266158	1.64	5
7	1808773	1266158	0.00	1
8	1808775	1266156	0.00	3
9	1808775	1266153	0.00	3
10	1808777	1266153	0.00	3
11	1808778	1266161	0.00	1
12	1808780	1266158	0.00	19
13	1808778	1266161	1.64	1

The voxel metrics output is a data frame in R. You can view it in table form by clicking on it in the environment tab. There are thousands of rows of data. You should recognize the column names as position information. XYZ. The V1 is the number of points inside each voxel metric cube. There are likely to be some Z values with a negative value as our normalization process created some errors. The rows that have a Z value of 0 are the cubes between 0 and 1.68m. We are interested in the number of 10cm voxels that has at least one point return, but we shouldn't count the 0 to 1.68 height bin as the majority of those points are likely to be the ground and not vegetation. For ground vegetation we will want to get the count of voxels between 0.5m and 2m. We can also get a count of the total number of voxels at each plot. Luckily in R this is very easy code to write.

For total number of voxels, we want the sum of all the values in the 4th column where the Z column is greater than 0. This excludes all rows where the Z value is equal to, or less than 0. Remember that 0 in the Z column represents the height bin between 0m and 0.5m so by stating "> 0" we are actually saying all voxels at height bins greater than 0.5m.

```
Plot1_Total <- sum(Plot1NVM[which(Plot1NVM$Z > '0' ), 4])
```

For voxel counts of all points greater than 0 but less than 2m we can add an "&".

```
Plot1_2m <- sum(Plot1NVM[which(Plot1NVM$Z > '0'& Plot1NVM$Z <= '6.6' ), 4])
```

QUESTION 5: Determine the count of Total voxels > 0.5m and the Voxel Count 0.5 to 2m and fill in the table from question 2. Do your sites with "high" ammounts of vegetation have a

higher voxel count? If not, how do you think occlusion and the fact we are only using a single point TLS scan affected your results?

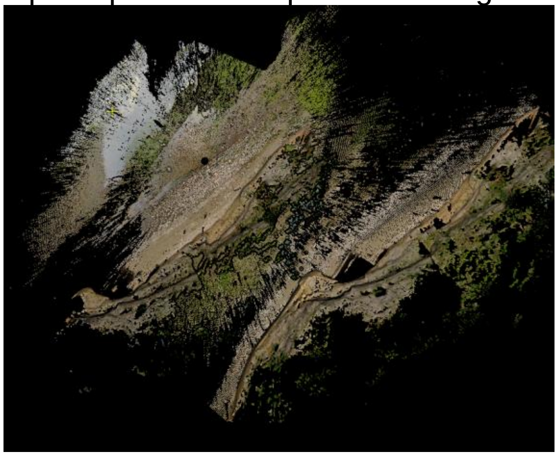
PART 2 Volume from Surface

Another application of TLS data is to monitor change in volume. TLS has been used to monitor fine scale glacier expansion/contraction, to quantify amount of material moved/excavated at mine sites, and to monitor erosion of cliffs.

We are going to bring some DAP data back into the labs by comparing a point cloud generated from drone Digital Aerial Photogrammetry (dDAP) to a point cloud generated by a stationary TLS scanner. The dDAP was from 2018 and the TLS was from 2019. We will be able to derive a volume estimate of the amount of cliff face that eroded in one year.
All the dDAP has been processed for you and you will be handed the data in a complete form. The data is from Dr. David Sheen's advanced surveying class. An excellent class for more in-depth coverage of dDAP, TLS, and survey grade GPS.

Our location of interest is 47.657798, -122.425993 (EPSG 3857). You can check out the site using google maps.

Open up CloudCompare and bring in both of the FARO scans.



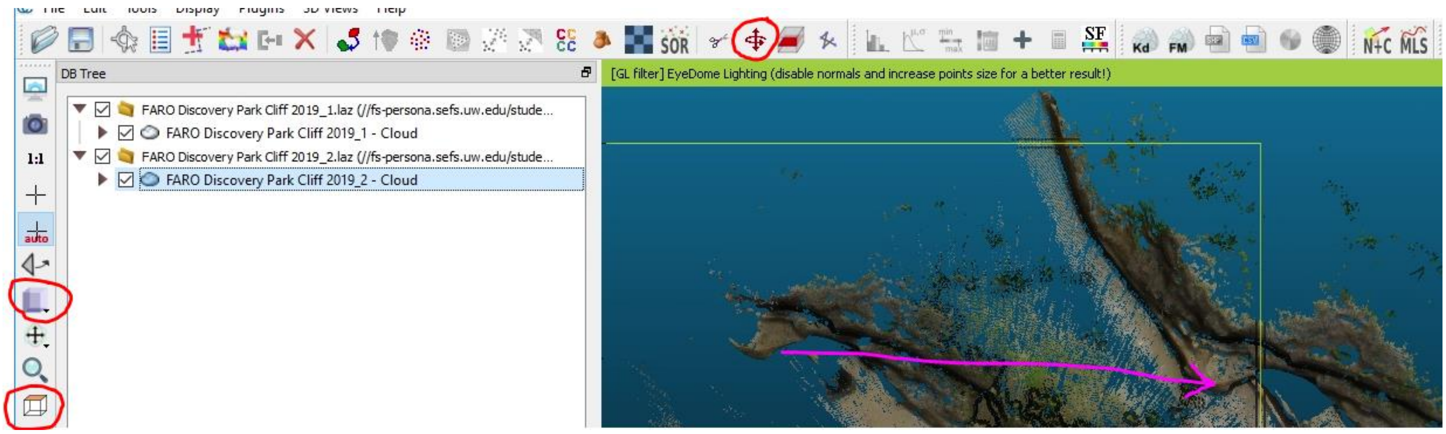
Take a moment to check out the cloud. They obviously are not co-regestered at the moment, and they have no geographic location. Find a few similarites between the two scans. These are only of the orginal scan. I removed about half the points by clipping to just this one area of interest. You can see the locaiton of the scanner in the point clouds by the locaiton of the round hole in the “ground”. The scans are aligned where the hole is (i.e. where the scanner was located during the scanning). You will also see outlines of me standing near the hole while I waited for the scanner.

QUESTION 6: How does the TLS scanner apply color to the scans? Does it get color values from the laser pulse returns?

You can see me standing but I'm colored like a photo of a beach. You can also see a target sphere in the image below.

QUESTION 7: Find another sphere in the point cloud (not the one I am standing near in the image above) and grab a screenshot of it. Make sure to increase your point size for a good rendering of the point cloud at close range.

We want to first move the scans so they are roughly aligned. This will make our future steps easier. You want to use an 'Orthographic projection' view so you will be looking straight down on the point clouds. Click the 'Set top view' button and then the Translate/Rotate tool



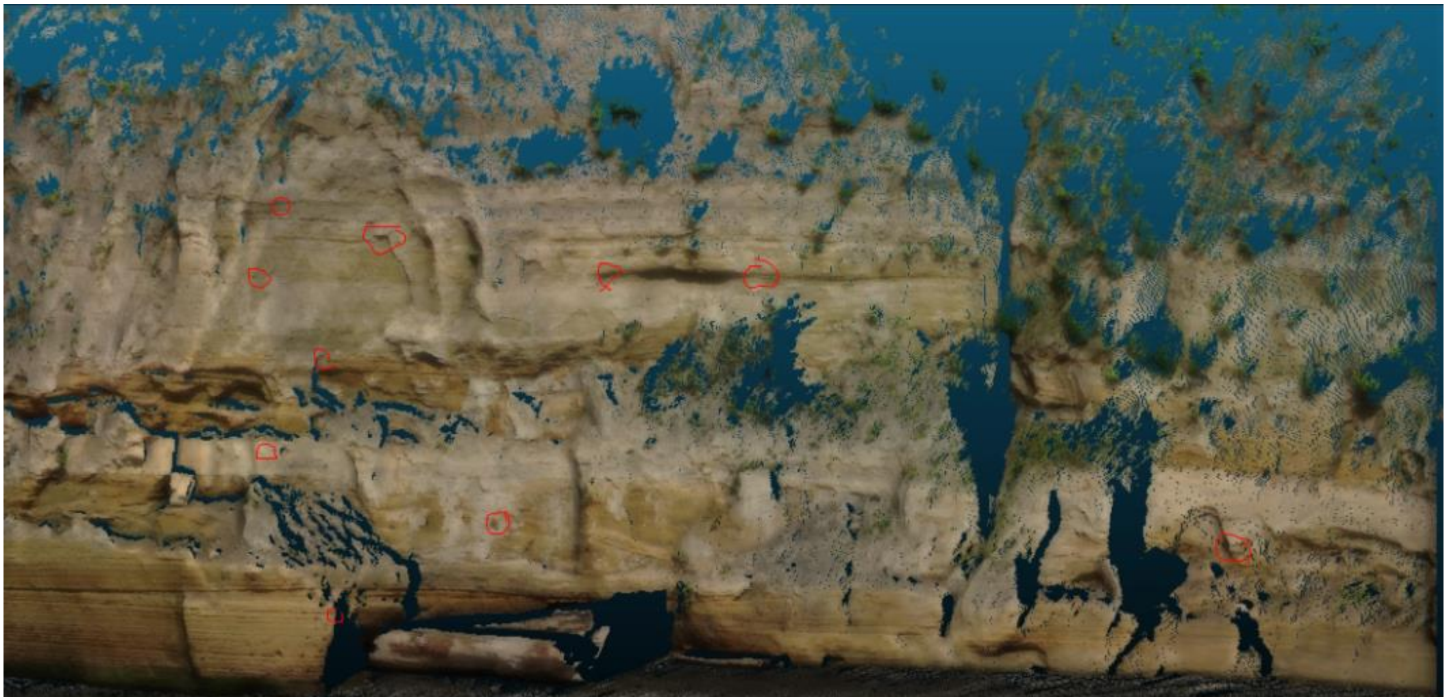
Because the TLS data doesn't have georeferanced coordinate systems, it doesn't matter which one we move. You need to find similar features In the two scans and then match them up. You can pivot and roate the sellected point cloud with the left mouse button, and you can move it using the right mouse button.

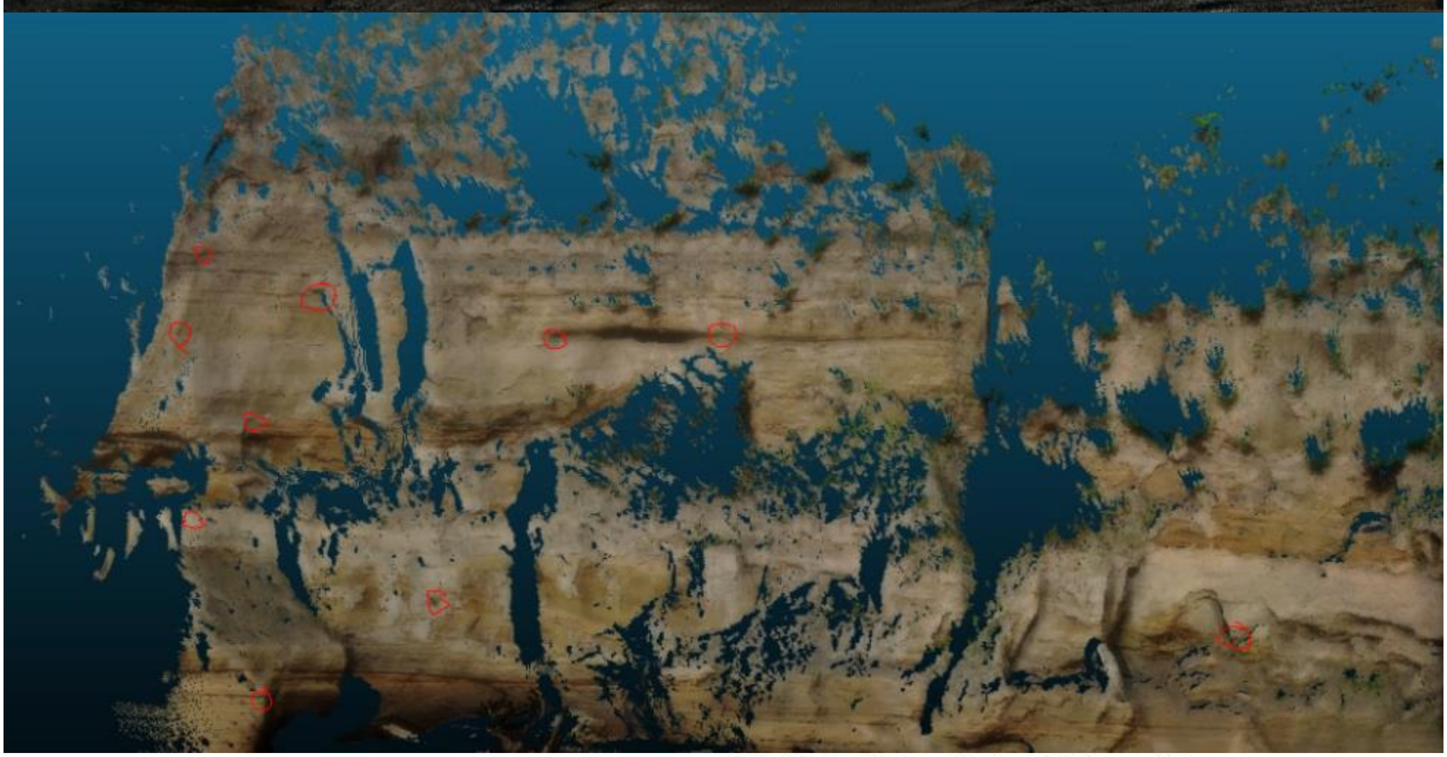
USE ONLY YOUR RIGHT MOUSE BUTTON. You want want to pivot or rotate, just move. You can click the undo arrow button to reset the tool. This is only a rough alignment so don't spend too much time trying to make it purfect at this step.

When you are statisfied, click the green button.

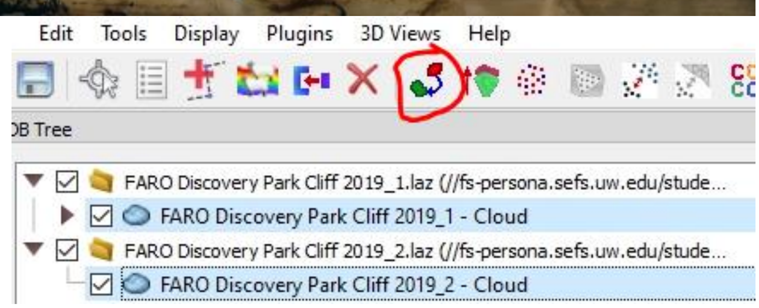
Two methods commonly used to align point clouds are target based, or cloud to cloud. For cloud to cloud to work, the two scans need to have a majority of area scanned shared between the two scans. In this instance, we don't have enough shared area between our two scans, so we will have to use target based.

Targets can be placed or features in the scan can be used. While there were spheres in the scans, we are going to instead use features on the cliff to regitster our scans.Find locations that appear in both scans. It is like one of those "find the difference" image pairs, but this time, it is "find the the same".

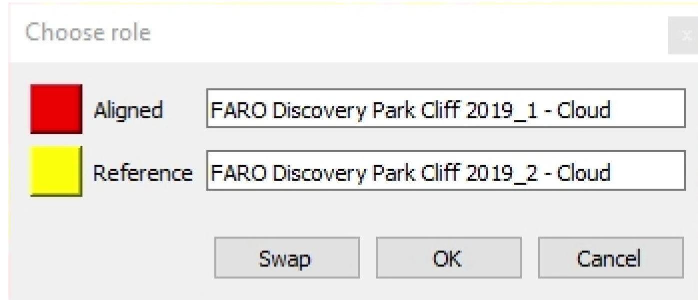




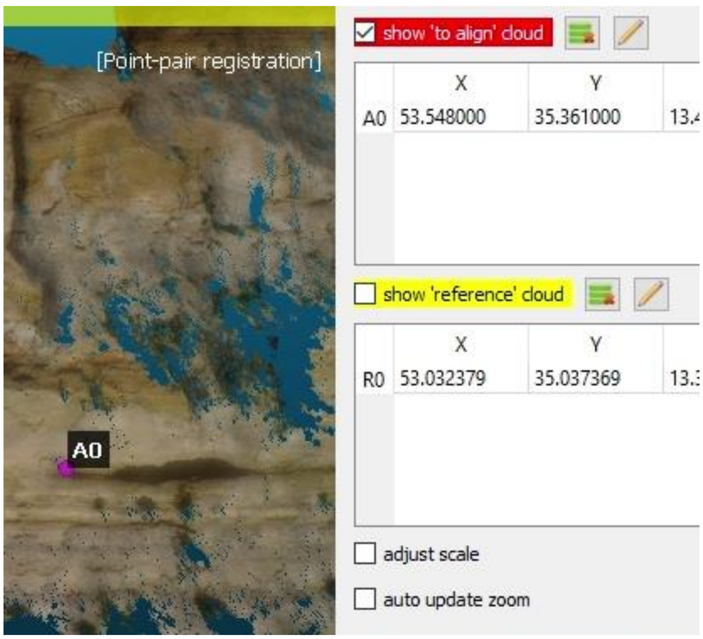
Now that you have an idea of what you are looking for, highlight both point clouds and sellect the Alight via point tool.

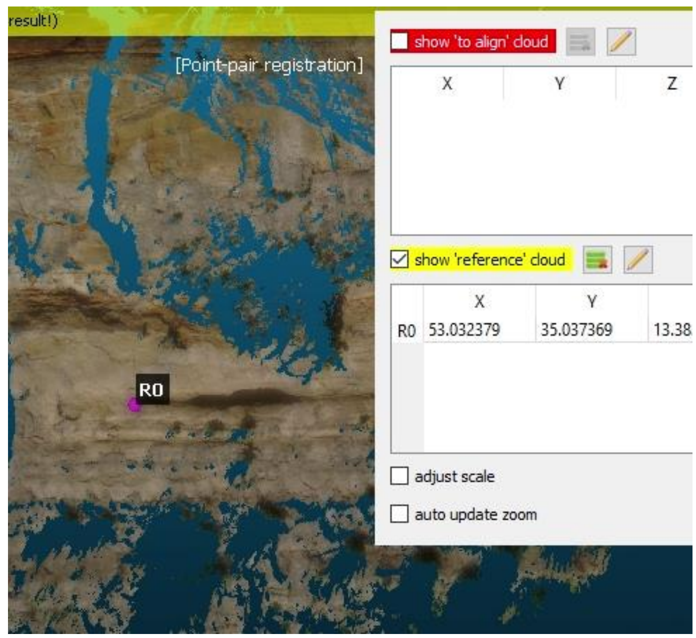


One layer will stay in it’s location (reference) and the other cloud will be moved to it’s location based on on where the targets are identified (aligned). If you had one cloud that was georeferanced, you would want that cloud to be your referance so it wouldn’t move. In this case, it doesn’t mater what cloud is our aligned and which one is our referace.



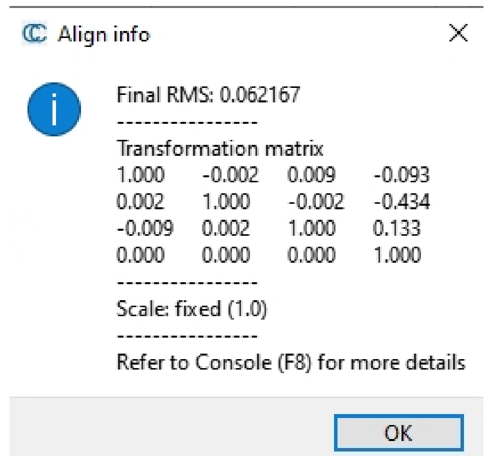
Those shared points you identified before, you are going to use those (and other) to match the clouds together. Turn one cloud off, select a point, turn that cloud off, turn on the other cloud, and sellect the same spot as best you can. Do this for ~15 points in the clouds. Distribut the points across the entire extent, but make sure to get several on the right side of cloud 2.





You will want to unckeck the adjust scale and auto update zoom boxes. You will also want to hit align after each point, once you have at least 4 points.

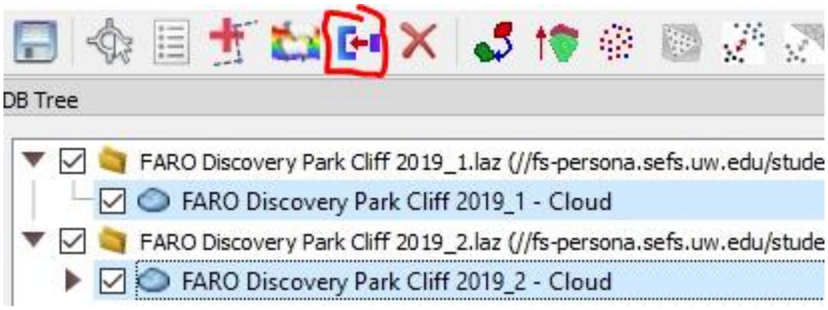
Once you have ~15 points, take a look at the ‘Error’. Your first few points likely had a larger error than your later points. In my example, my 0 point (A0 & R0) has an error of ~0.47. I am going to delete it and see if that improves the other points. Delete points that have an error of more than 0.1, but also insure that you have atleast 10 points. Note your RMS. Click on the green check box.



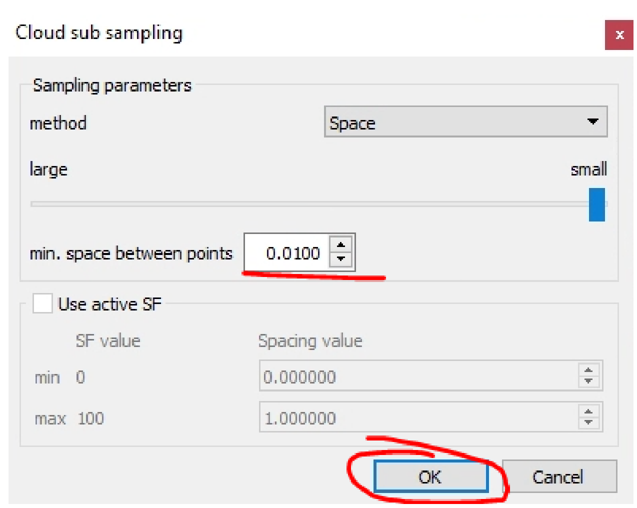
QUESTION 8: What is your RMS for your points? How many points did you use?

This is a measurement of how close your two points are that were used in your registration.

Once you are satisfied with the alignment, merge the two clouds together. You do not want a new scalar field.



TLS data is incredibly dense. Merging two or more clouds together creates a point density much higher than we need, and can bog down processing. We are going to subsample our data so that there are no two points closer than 1cm.



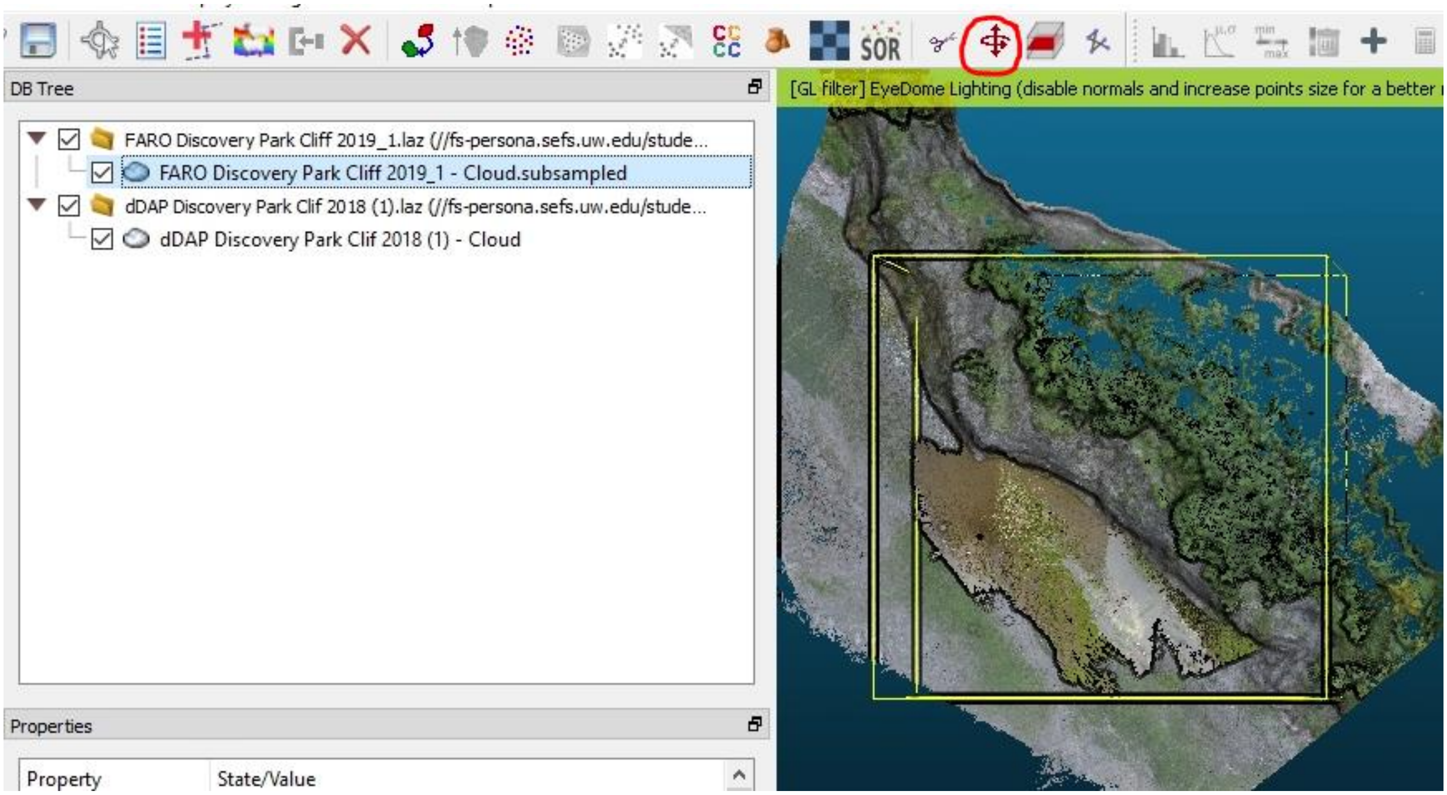
QUESTION 9: How many points did your original cloud have? How many points does yoru resampled cloud have?

Consider how many points there were per cm before you subsampled the cloud to 1cm spacing…. Go ahead and remove the original FARO point cloud from CloudCompare. You may want to save it to have a copy of the full point cloud that is registered.

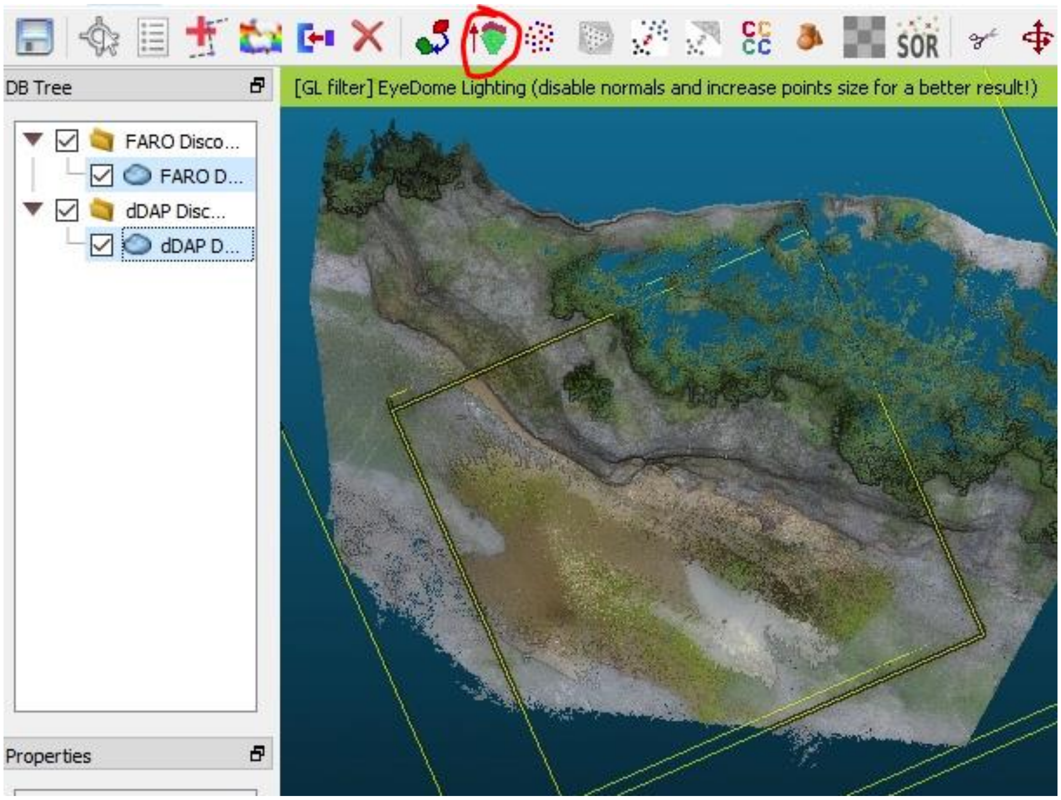
dDAP

Finally time to bring the 2018 dDAP data into CloudCompare. Drag and drop the dDAP file into CloudCompare, this is also a point cloud clip from a much larger dataset. Keep in mind when looking at this data, it was created using simple photos from a drone that you could buy at a department store.

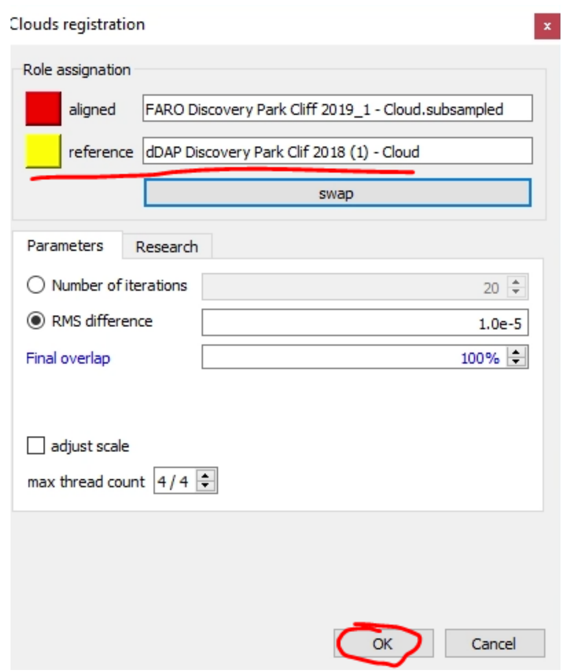
You are going to roughly align the point clouds just as you did with the two TLS scans. You should do a top down alignment and then a side view alignment.



Because these two point clouds cover the same area (even though there has been erosion), we can still just use the fine alignment automatic tool.



This time we do want to keep the dDAP as reference.



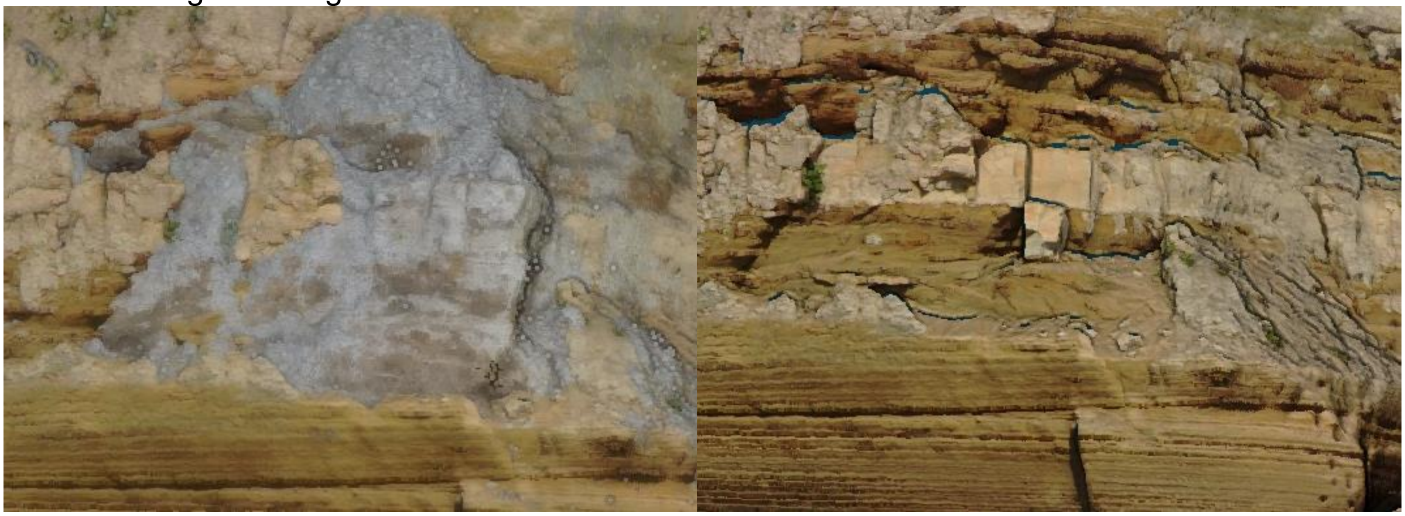
QUESTION 10: What was your final RMS? This time the RMS is not calculated from you identifying ~10 points, but rather from a subsection of 50,000 points.

You can do a quick check for areas that had erroded by toggling the 2018 data on and off. You should be able to see where that large driftwood log was in 2018 compared to where it was in 2019.

ESRM433/SEFS533

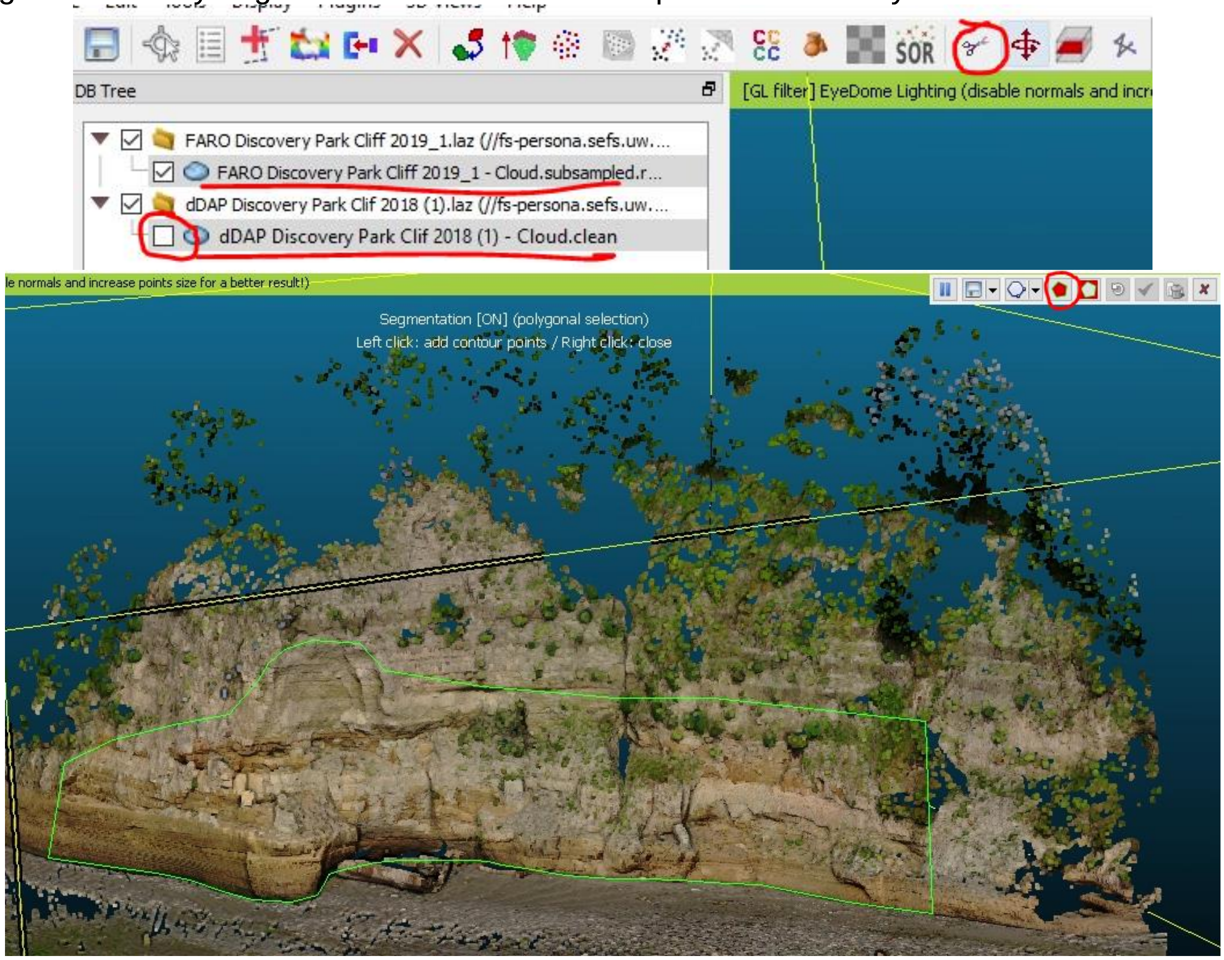
Lab 8

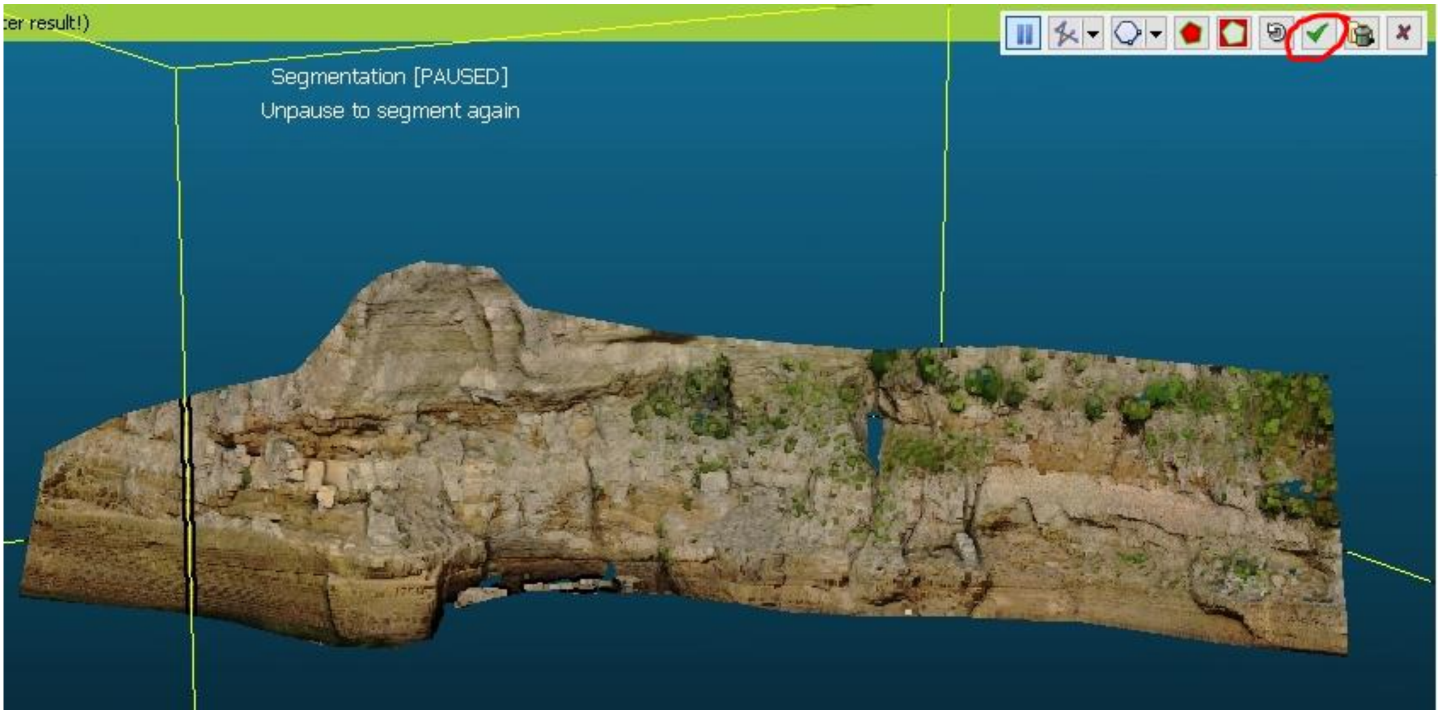
One of the bigest changes in the cliff was at the ‘nose’ of the cliff.



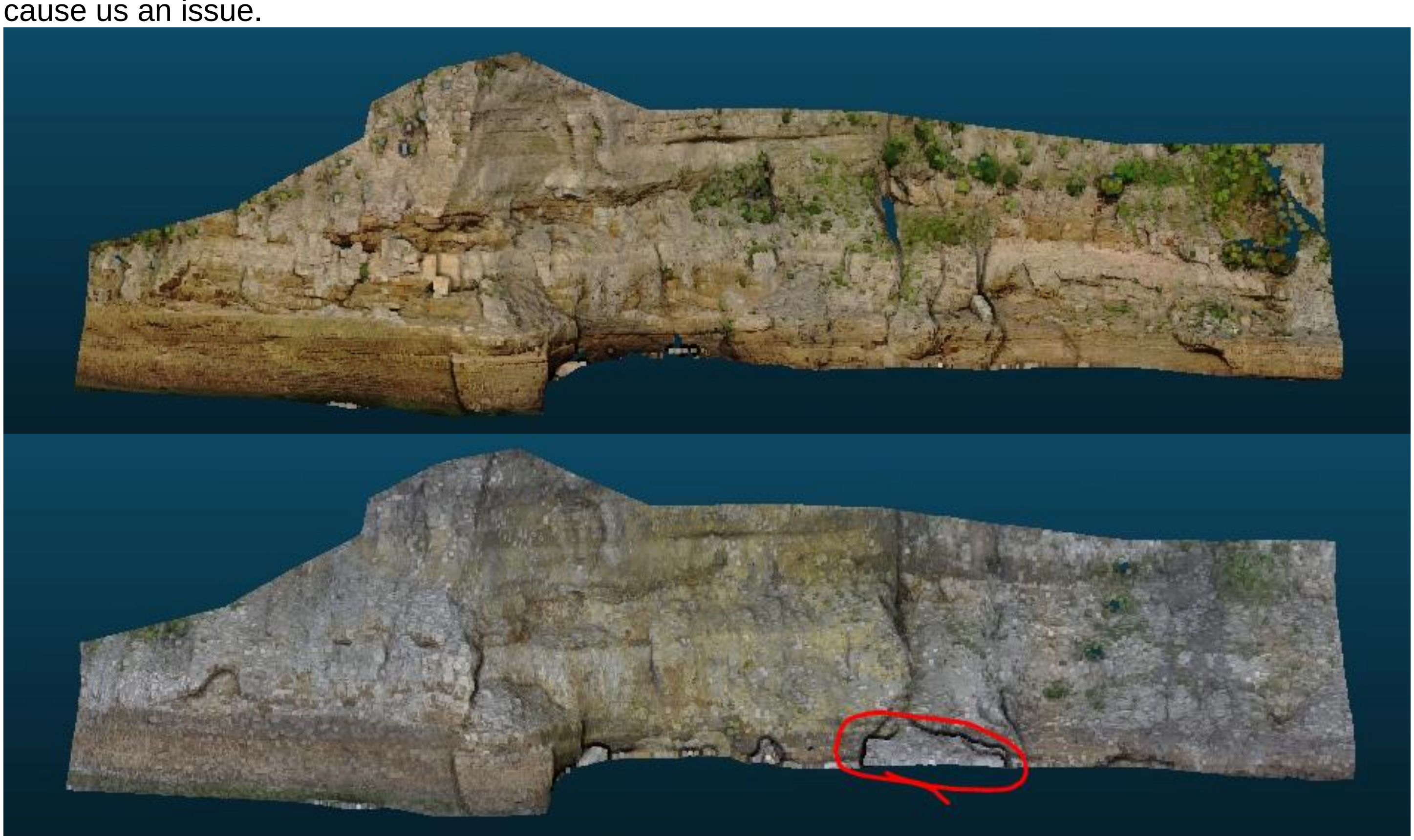
Lets quantify the area that errored. We can compare the two surfaces and determine the volume of the area in 2018 that dropped off.

First we want to clip the point clouds to only the area of the cliff of interest to us. We want the area that is clearly captured with the two TLS scans. To do this, sellect both scans but unclick the dDAP layer. The use the clipping tool to draw a polygon around the area of the cliff that has errored and we have a good scan. Try to get rid of as much beach as possible. We only want the cliff.



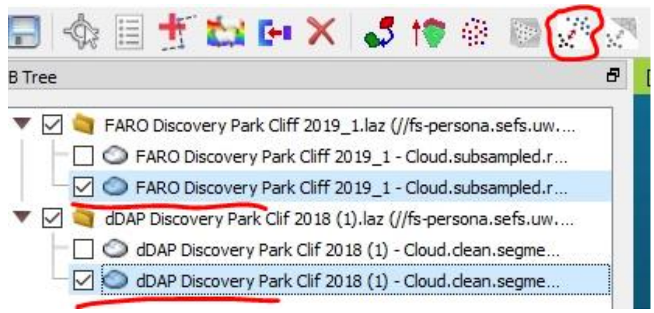


You should now have the same section cut from the TLS data and the dDAP data. The log may cause us an issue.

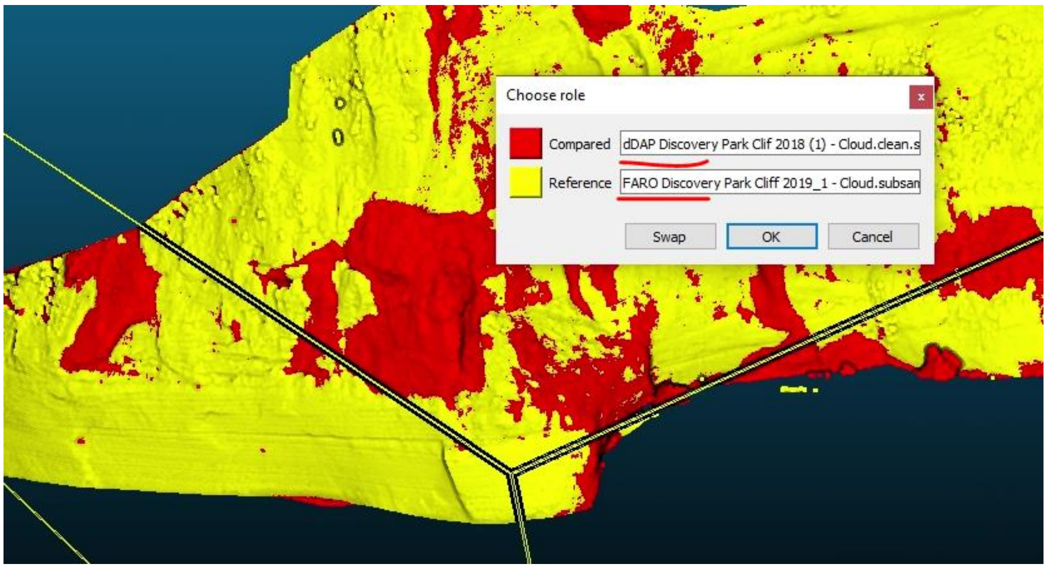


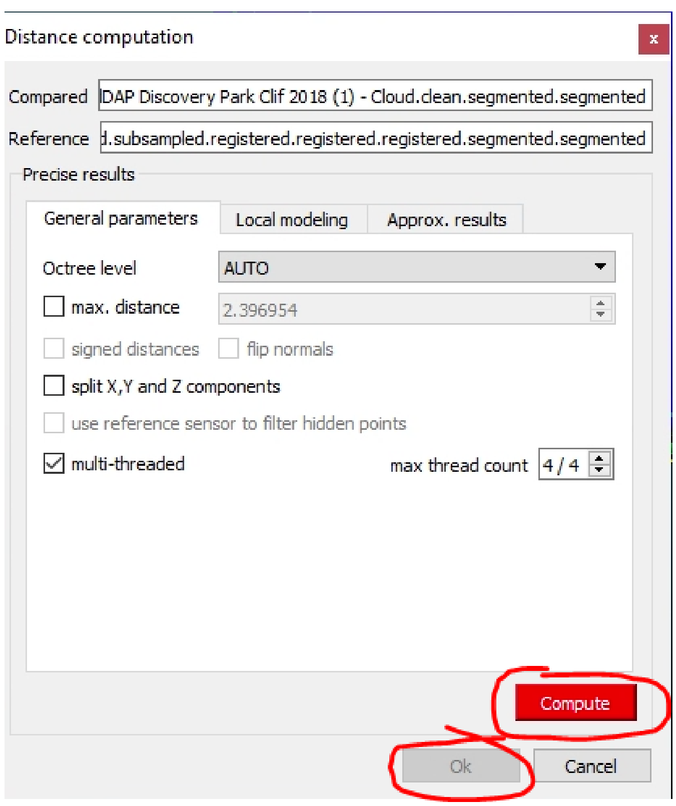
Create an image like the one above (minus the red scribble) and save it. You'll need it for the last question.

Let's now identify the areas of greatest change. We are going to find the distance between the two clouds. Sellect both of your segmented clouds in your menu and then the 'Compute cloud/cloud distance' tool.

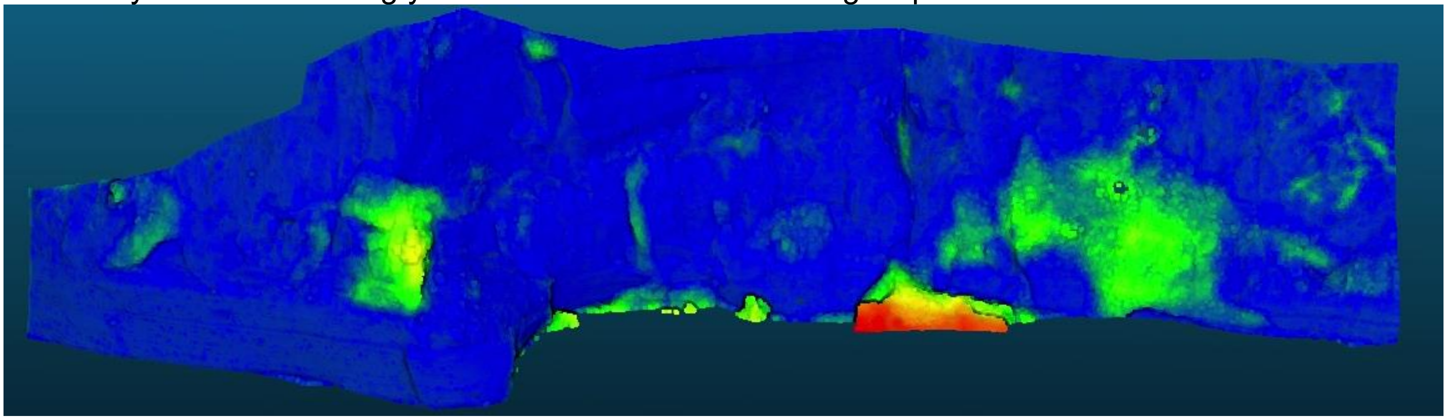


For this we want the FARO TLS cloud to be the referance. You can think of it as being the ground and the dDAP being piles of rock on top of the ground. The default values work fine for this tool.



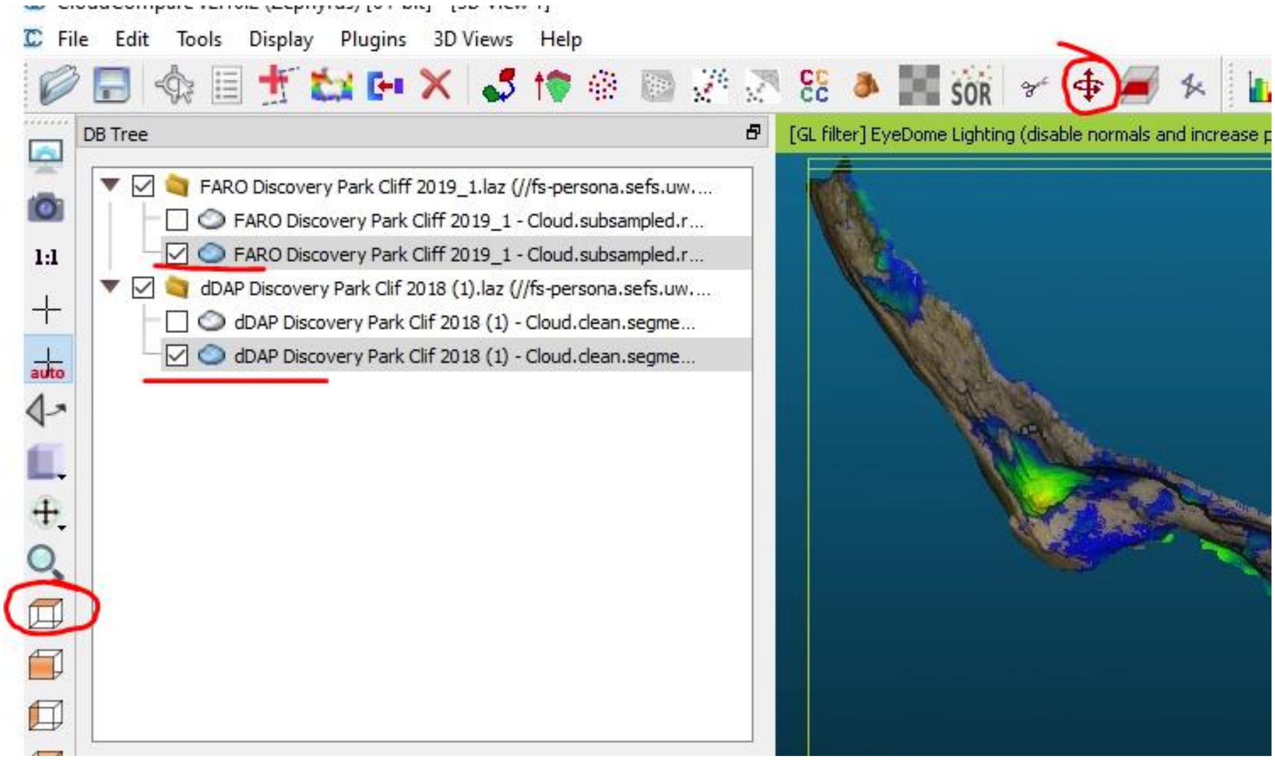


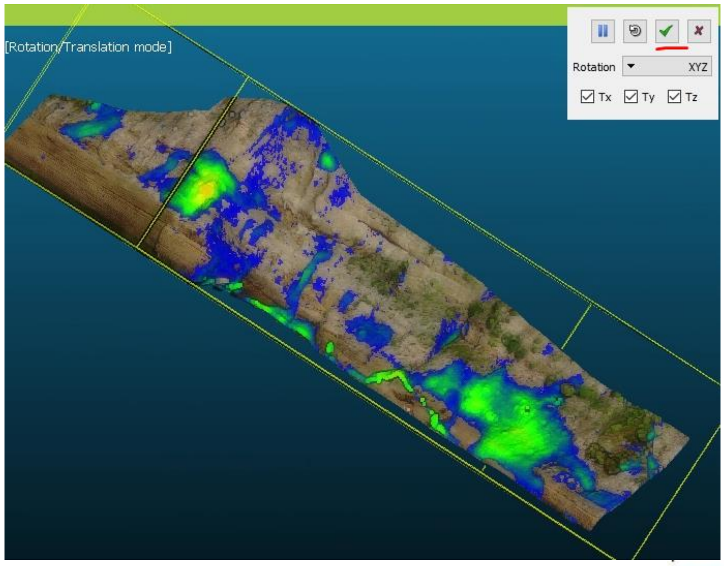
You now have a visual map of the differences between the two clouds (i.e. areas of greatest errosion). I knew that log would cause us problems….. Save your two clipped layers in case you accidently delete something you didn't intend in the following steps



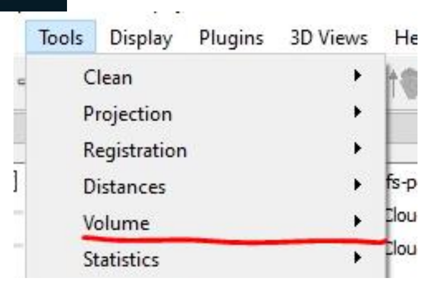
QUESTION 11: Take a moment to clean up the data a little more, remove the log from the point cloud and any other clumps of points that apear green or red that aren't acutally part of the cliff. When you are done with your clean up, run the 'Compute cloud/cloud distance' tool again just as we did above and submit a screenshot of your cleaned up cloud distance vidualization.

We can now compute the volume of the changeThe volume tool assumes that the volume to be measured has it's height in the z direction. Think a big pile of gravel that an operator wants to measure the volume change. To "trick" the volume tool, we can rotate the point clouds so the cliff face becomes the ground. A 90 degree rotation so the majority of the cliff face changes are in the z direction.

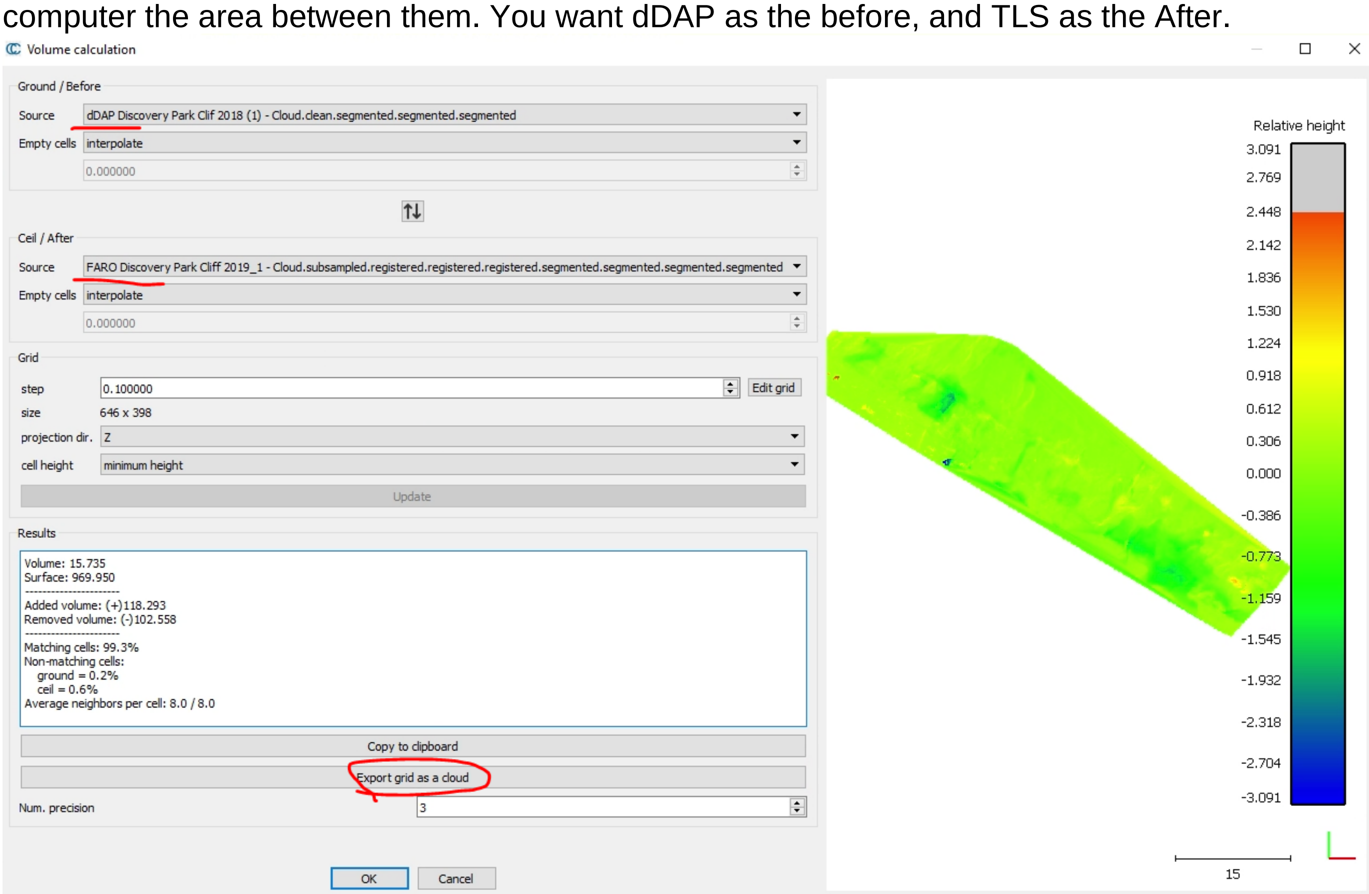




When you click on the ‘set top view’ button now, you should see the cliff layed out as the above image.

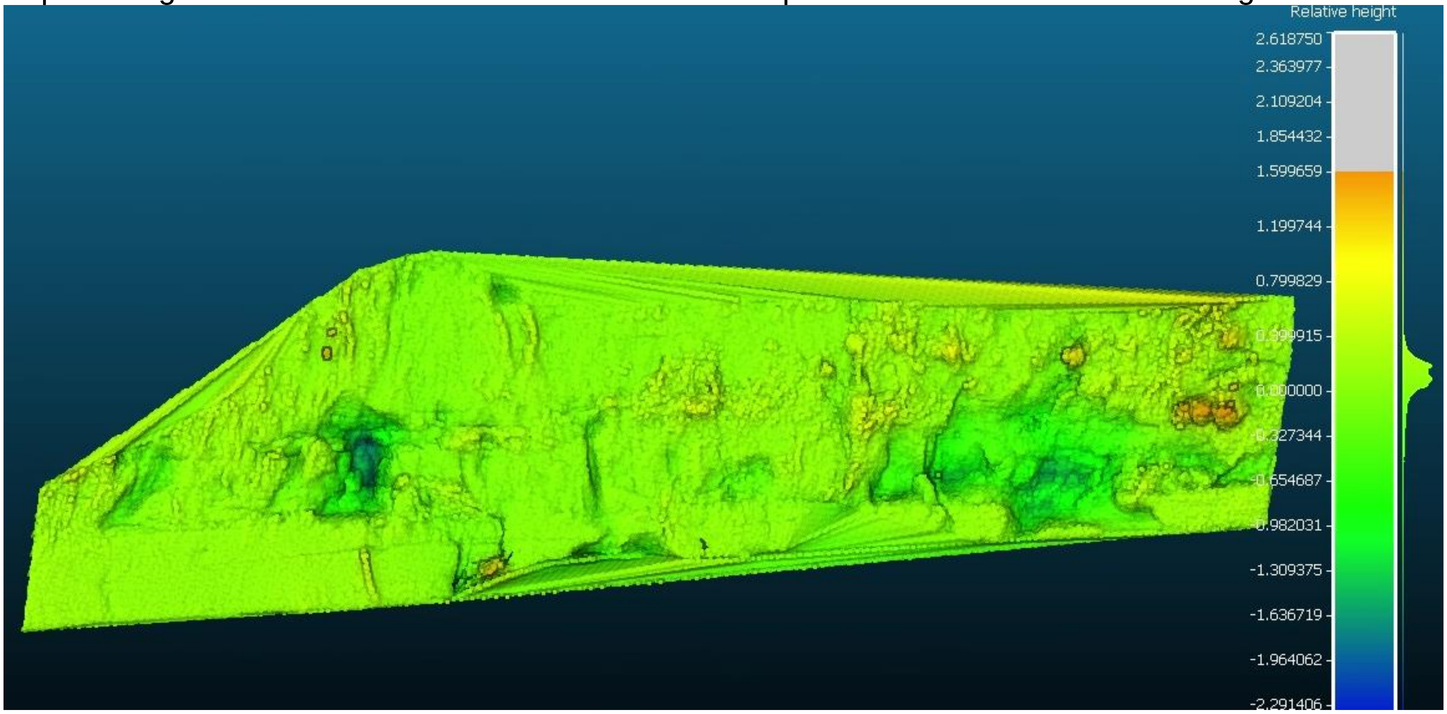


Let’s look at the total area removed/added for our clip. With both clips sellected, Go to Tools > Volume > Compute 2.5D Volume
This tool is very similar to the create raster tool we worked with previously. You are essentially going to make two DEMs and computer the area between them. You want dDAP as the before, and TLS as the After.



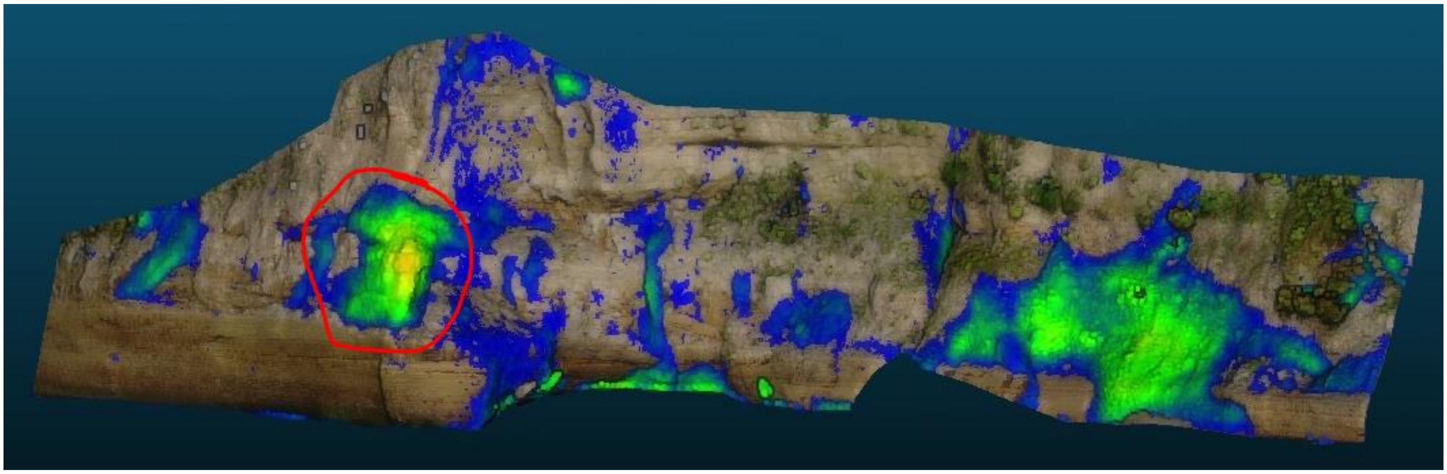
There is added volume, and removed volume. The combined is the total change. According to my results, the clif added 15.7m^2 of volume… Possible explanations for this are that we didn't remove vegetation from the cliff face, and that debris falling down the cliff could potintially accumulate at the base. There is also more noise in the dDAP data and our registration between the dDAP and TLS may be off. We want to know about how much cliff face has fallen off in a year.

Export the grid as a cloud and take a look at a visual representation of the volume change.



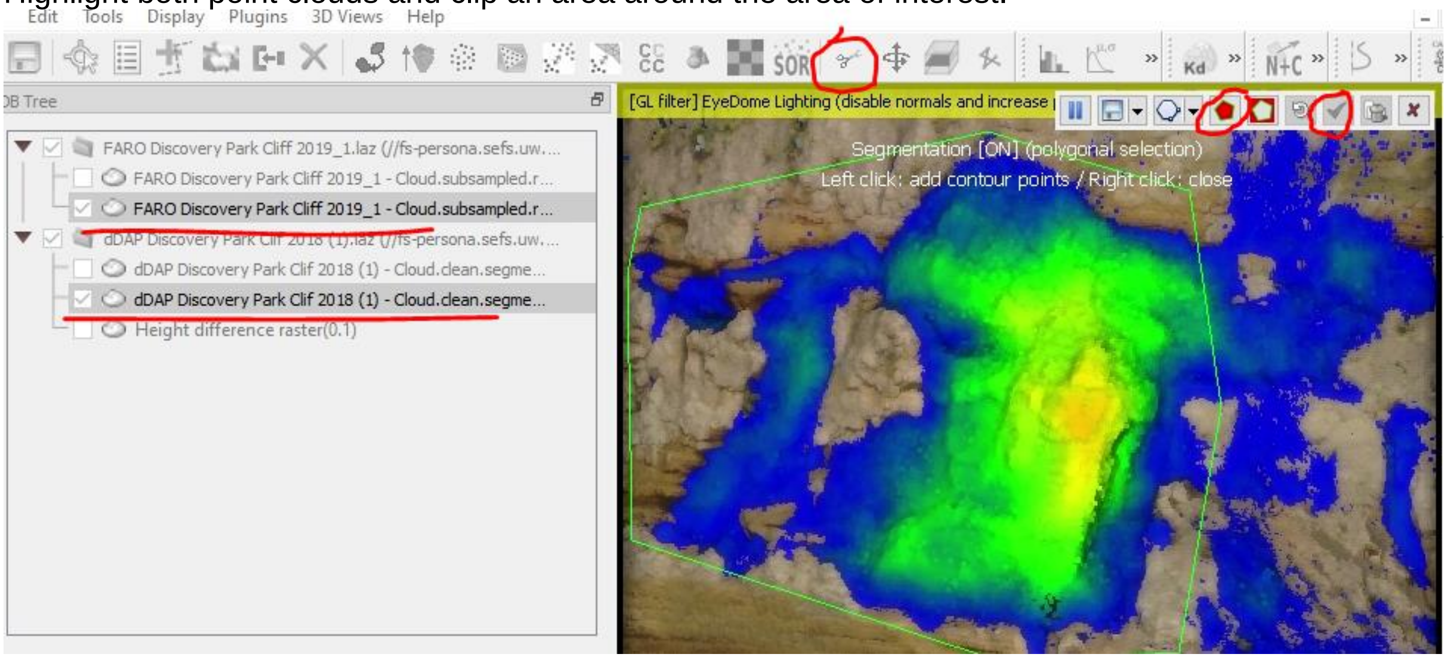
QUESTION 12: Include a screen shot of your volume change as represented by a cloud. What area seems to have had the greatest decrease in volume? What area had an increase? What happened in the areas with a decrease? What potintially caused an increase in the areas with the greatest increase?

Lets look at a few areas in detail.

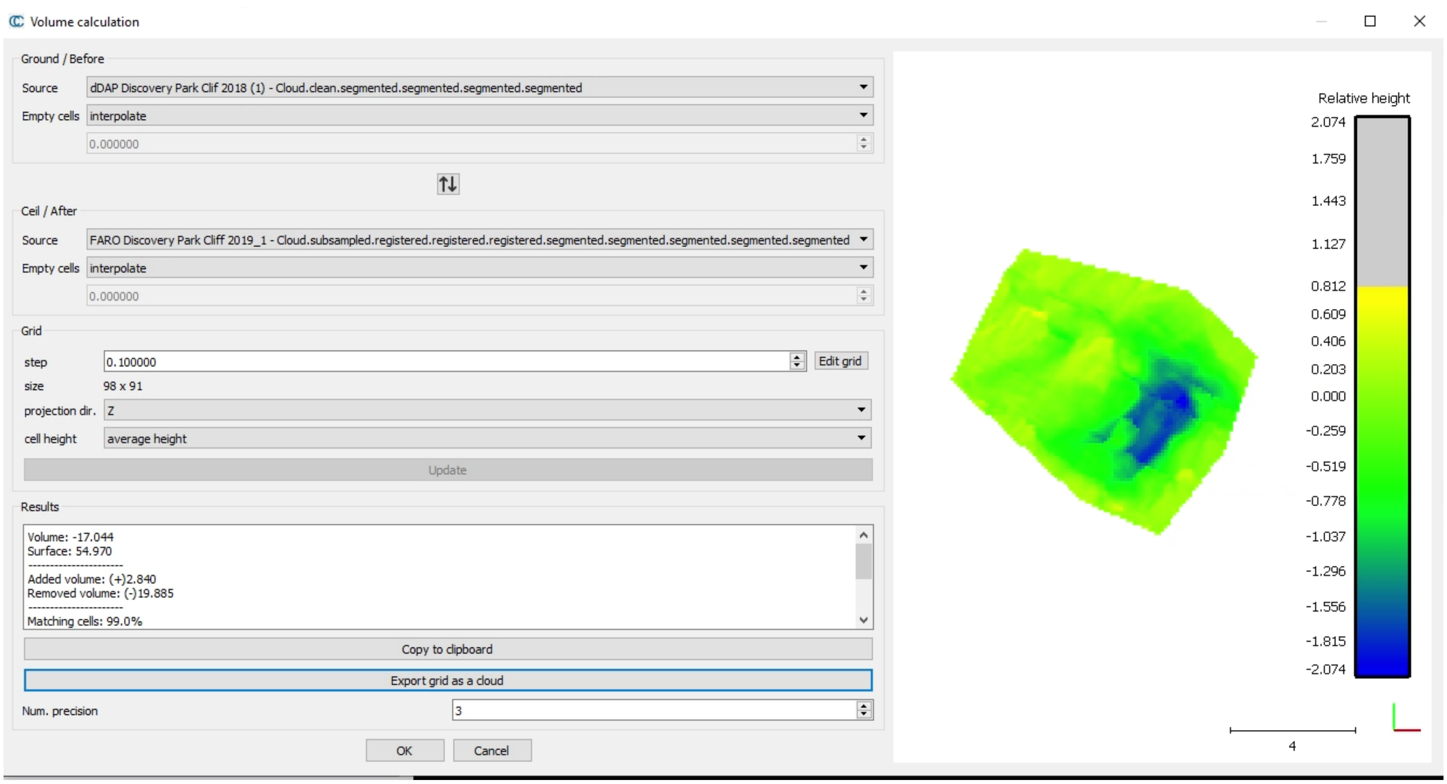


The area circled lost a large section in one year. Lets measure how much fell from the location.

Highlight both point clouds and clip an area around the area of interest.



Perform your volume measurment on the clip now. According to my volume measurement, 17m^3 were lost at that location in one year! Go look up how big one cubic meter is, if you need help visualizing (I did).



QUESTION 13: Identify the 3 location that have erroded the most on the cliff (the example above can be one of the three but make sure you come up with your own answer). Create a figure like the one below with the three areas identified on before and after images and include a caption that gives the volume lost at each of the three locations. The example below is the bare minimum. You are incouraged to make the figure as fancy as you like, but a bare bones figure will be accepted.

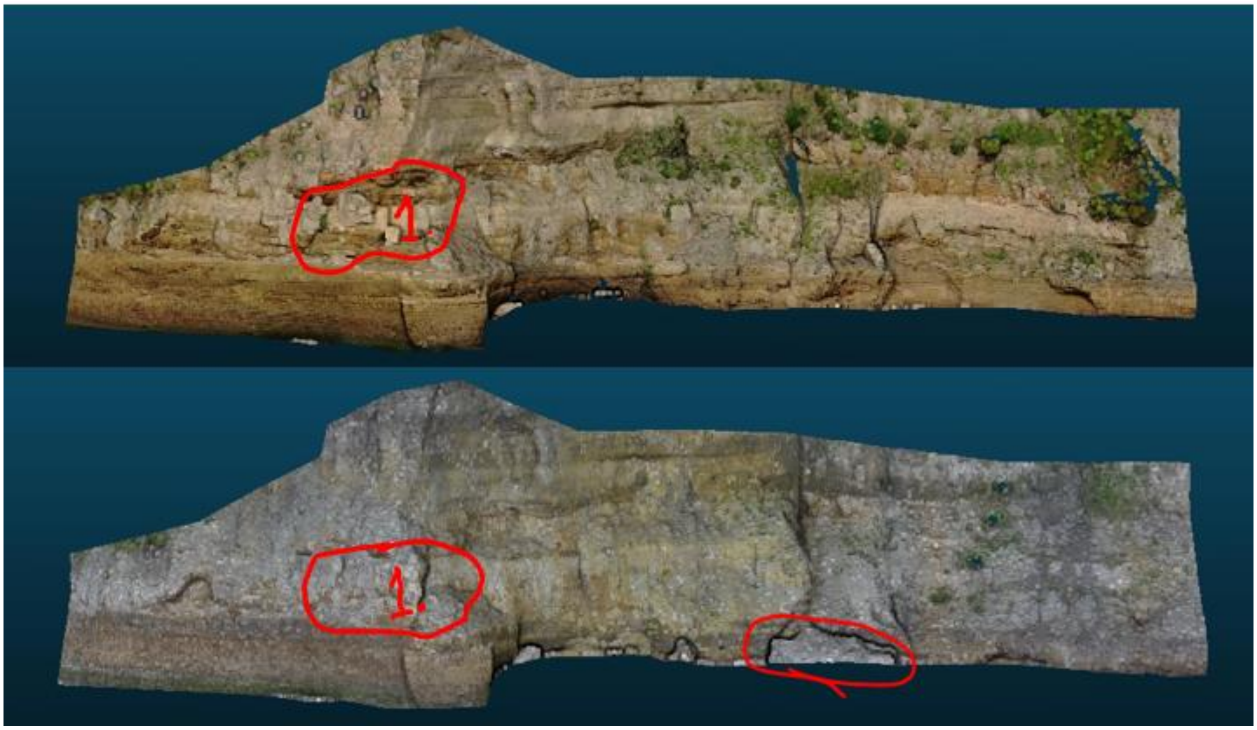


Figure _. Discription of the images and how they were created. In area one, 17m^3 of material errored from the cliff. In area 2….. In area 3…..

GRADUATE STUDENTS: No additional steps this week!

ESRM433/SEFS533
Lab 8
FARO S 350:

Performance Specifications

	Focus^S Series S 350 | S 150 | S 70				Focus^M 70 Series			
Ranging Unit								
Unambiguity interval	614m for 122 to 488 kpts/s 307m for 976 kpts/s				614m for 122 to 488 kpts/s			
Range[1]								
90% reflectivity (white)	0.6-350m | 0.6-150m | 0.6-70m				0.6 - 70m			
10% reflectivity (dark-gray)	0.6-150m | 0.6-150m | 0.6-70m				0.6 - 70m			
2% reflectivity (black)	0.6- 50m | 0.6- 50m | 0.6-50m				0.6 - 50m			
Ranging noise[2]	@10m	@10m noise reduction[3]	@25m	@25m noise reduction[3]	@10m	@10m noise reduction[3]	@25m	@25m noise reduction[3]
	in mm							
90% reflectivity (white)	0.30	0.15	0.30	0.15	0.70	0.40	0.70	0.40
10% reflectivity (dark-gray)	0.40	0.20	0.50	0.25	0.80	0.40	0.80	0.40
2% reflectivity (black)	1.30	0.65	2.00	1.00	1.50	0.80	2.10	1.10
Measurement speed (pts/sec)	122,000 / 244,000 / 488,000 / 976,000				122,000 / 244,000 / 488,000			
Ranging error[4]	±1mm				±3mm			
Angular accuracy[5]	19 arcsec for vertical / horizontal angles				not specified			
3D position accuracy[6]	10m: 2mm / 25m: 3.5mm				not specified			
Color Unit								
Resolution	Up to 165-megapixel color							
High Dynamic Range (HDR)	Exposure Bracketing 2x, 3x, 5x							
Parallax	Minimized due to co-axial design							
Deflection Unit								
Field of view:	300° vertical[7] / 360° horizontal							
Step size:	0.009° (40,960 3D-pixel on 360°) vertical/ 0.009° (40,960 3D-pixel on 360°) horizontal							
Max scan speed	97Hz (vertical)							
Laser (Optical Transmitter)								
Laser class	Laser class 1							
Wavelength	1550nm							
Beam divergence	0.3mrad (1/e)							
Beam diameter at exit	2.12mm (1/e)							
Data handling and control								
Data storage	SD, SDHC™, SDXC™; 32GB card							
Scanner control	Via touchscreen display and WLAN connection. Access by mobile devices with HTML5							

	Focus^S Series S 350 | S 150 | S 70	Focus^M 70 Series
Interface Connection		
WLAN	802.11n (150Mbit/s), as access point or client in existing networks	
Additional Features		
Dual axis compensator	Performs a leveling of each scan with an accuracy of 19 arcsec valid within ±2°	
Height sensor	Via an electronic barometer the height relative to a fixed point can be detected and added to a scan	
Compass[8]	The electronic compass gives the scan an orientation	
GNSS:	Integrated GPS & GLONASS	
On-site compensation	Creates current quality report and improves compensation automatically	–
Accessory bay	The accessory bay connects versatile accessories to the scanner	–
Inverse mounting	Yes	
Real-time, on-site registration in SCENE	Connects to SCENE, real-time scan processing and registration, overview map	–
Electronic Automation Interface	Available as option, only at point of sale	–
Digital Hash Function	Scans are cryptographically hashed and signed by the scanner	
Rescanning of Distant Targets	Defined areas recaptured in higher resolution at a greater distance	
Retake Photos	Select individual photographs with unwanted objects and retake them	
General specifications		
Power supply	19V (external supply), 14.4V (internal battery)	
Power consumption:	15W idle, 25W scanning, 80W charging	
Battery service life	4.5 hours	
Temperature	Operating: 5 – 40°C, extended operating[9]: -20 – 55°C, storage: -10 – 60°C	
Ingress protection (IP) rating class	IP54	
Humidity Resistance	Non-condensing	
Weight	4.2kg (incl. battery)	
Size/Dimensions	230 x 183 x 103mm	
Maintenance / calibration	Annual	

CLASS 1 LASER PRODUCT

1 For a Lambertian scatterer. **2** Ranging noise is defined as a standard deviation of values about the best-fit plane for measurement speed of 122,000 points/sec. **3** A noise-reduction algorithm may be activated by averaging raw data. **4** Ranging error is defined as a systematic measurement error at around 10m and 25m. **5** On-site compensation required. **6** For distances larger 25m add 0.1mm/m of uncertainty. **7** 2x150°, homogeneous point spacing is not guaranteed. **8** Ferromagnetic objects can disturb the earth magnetic field and lead to inaccurate measurements. **9** Low temperature operation: scanner has to be powered on while internal temperature is at or above 15°C, high temperature operation: additional accessory required. All accuracy specifications are one sigma, after warm-up and within operating temperature range; unless otherwise noted. Subject to change without prior notice.