The Best Climbing Places in the Yosemite Valley, determined using LIDAR

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ABSTRACT

Detailed slopes mapping was completed to determine the best climbing walls in Yosemite Valley. The process depends on LIDAR data and the extraction of ground point data from unclassified point cloud data downloaded from OpenTopography. In order for the data to be processed in ArcGIS, it is preprocessed in PDAL using a batching approach, for memory issues. To derive the base raster files, data is imported in ArcGIS LAS dataset, then using Spatial Analyst extension it goes through a series of processes in order to obtain a cluster of climbing areas. Existing data from IRMA datastore, including trails, rivers, roads, parking, springs, is downloaded and clipped with an Area of Interest layer that was digitized. Those layers are used to create a Weighted Analysis pipeline, that assesses the best climbing locations based on a series of subjective factors. Another Weighted Analysis is being conducted to obtain a more objective cluster of climbing zones, based only on slope and slope height.

■ INTRODUCTION

Yosemite Valley

Yosemite National Park is located within the heart of the Sierra Nevada, the largest fault-block mountain range in the United States. Trending northwest–southeast for more than 480 km (300 mi), the Sierra Nevada traverses half the length of California. Comprised of granitic rocks that formed approximately 100 million years ago, the massive block forms an asymmetrical mountain range with a gentle western slope and an eastern edge that rises abruptly from adjacent desert basins, forming a nearly vertical wall of rock.

Yosemite Valley is a ~1-km-deep, glacially carved canyon in the Sierra Nevada mountains of California that hosts some of the largest granitic rock faces in the world. El Capitan is a ~1-km-tall, vertical southeast face, that making it the tallest single face in North America, Yosemite Falls is the tallest waterfall in United States, Camp 4 is regarded as the birthplace of modern rock climbing. (Geologic resources inventory report, 2012)

The primary purpose of this study is to illustrate and describe how to identify the climbing walls in Yosemite Valley using **light detection and ranging (LIDAR) point clouds**, and determine the best places for climbing using specific criteria.

LiDAR is a remote sensing technique that uses visible or near-infrared laser energy to measure the distance between a sensor and an object. LiDAR sensors are versatile and (often) mobile; they help autonomous cars avoid obstacles and make detailed topographic measurements from space. (PDAL Contributors, 2018)

In Yosemite Valley, Quaternary glaciation, river erosion, and ongoing rockfall have produced a steep-sided valley with over 1 km of local relief.
The vertical northwest cliff face of Half Dome is 680 m tall, and continuous exposure from the top of Half Dome to Tenaya Creek covers 1340 vertical meters at an average angle of 51°. This entire section is sculpted in one pluton, the Half Dome Granodiorite (Calkins, 1985). El Capitan exposes a 1-km vertical section of plutonic rocks (Calkins, 1985; Peck, 2002) in a massive cliff that is locally overhanging but is typically steeper than 75°.

Of the three main categories of rock (igneous, sedimentary, and metamorphic), igneous rocks are most common at Yosemite National Park, including the granitic salt-and-pepper-colored rocks that form such features as Half Dome, El Capitan, and the cliffs of Yosemite Valley. The park's granitic rocks can be classified more specifically as granite, granodiorite, and tonalite.

There have been other studies involving LIDAR in the area, with the focus on rock falls, geology and landslides, for example:

- Plutonism in three dimensions: Field and geochemical relations on the southeast face of El Capitan, Yosemite National Park, California
- Use of LIDAR in landslide investigations: A review
- Assessing rockfall susceptibility in steep and overhanging slopes using three-dimensional analysis of failure mechanisms

Rockfall monitoring and research is ongoing in Yosemite National Park. In 2008, the park partnered with Los Angeles–based xRez Studio to create the Yosemite Panoramic Imaging Project, which enables imagery-based rockfall monitoring in Yosemite Valley (National Park Service 2009b). The project created a 3.8-gigapixel photographic map of Yosemite Valley by combining gigapixel panoramic photography with LiDAR-based digital terrain modeling and 3-D computer rendering to capture Yosemite Valley in a single image. The image allows resource managers to examine the cliffs in detail without climbing them. (Geologic resources inventory report, 2012)

Photographs taken by climbers on the southeast face presented the means to study vertical changes in rock texture. Using the Exelis ENVI image processing package, mineral types were classified using simple quantitative thresholds in pixel value for 78 photographs taken over much of the extent of the El Capitan Granite. (Putnam et al. 2015)

That's why mapping the climbing walls in detail is beyond this paper's scope.

Airborne and terrestrial LiDAR, high-resolution photography, and acoustic data were used to help analyze the initiation, dynamics, and talus deposition of the complex rockfall occurring at Ahwiyah Point on March 28, 2009 (Zimmer et al. 2012). LiDAR data accurately determined the volume and dimensions of the detached block, the orientation of fractures bounding the block, the size and dip of the ramp, the vertical ballistic distance, the mid-cliff distance, and the volume of material dislodged from the mid-cliff impact.

In this study, 3D point clouds are processed into a DTM (Digital terrain Model), then a set of conditions is applied to a slope raster in order to derive possible climbing zones. A digital elevation model (DEM) is a 3D CG representation of a terrain's surface – commonly of a planet (e.g. Earth), moon, or asteroid – created from a terrain's elevation data.

DEMs are used often in geographic information systems, and are the most common basis for digitally produced relief maps. While a digital surface model (DSM) may be useful for landscape modeling, city modeling and visualization applications, a digital terrain model (DTM) is often required for flood or drainage modeling, land-use studies, geological applications, and other applications, and in planetary science.

Data acquisition and preprocess

Data for the Yosemite Park from IRMA datastore was downloaded, merged and used in this analysis.

1. Roads - https://irma.nps.gov/DataStore/Reference/Profile/2180725
2. Trails - https://irma.nps.gov/DataStore/Reference/Profile/2170447
3. Parking - https://irma.nps.gov/DataStore/Reference/Profile/2260366
4. Geology - https://irma.nps.gov/DataStore/Reference/Profile/1047771
5. Hydrology - https://irma.nps.gov/DataStore/Reference/Profile/2170437
6. Rock fall hazard line - https://irma.nps.gov/DataStore/Reference/Profile/2188906

NAIP data from USDA-FPAC-BC Aerial Photography Field office that covers the region of interest, was used to analyze the intermediary results and better understand the region.

1. https://earthexplorer.usgs.gov/metadata/15920/2770976/
2. https://earthexplorer.usgs.gov/metadata/15920/2770977/
3. https://earthexplorer.usgs.gov/metadata/15920/2770980/
4. https://earthexplorer.usgs.gov/metadata/15920/2770981/
5. https://earthexplorer.usgs.gov/metadata/15920/2771006/
6. https://earthexplorer.usgs.gov/metadata/15920/2771007/
7. https://earthexplorer.usgs.gov/metadata/15920/2771010/
8. https://earthexplorer.usgs.gov/metadata/15920/2771011/
9. https://earthexplorer.usgs.gov/metadata/15920/2770985/
10. https://earthexplorer.usgs.gov/metadata/15920/2771015/

I have found on OpenTopography a point cloud dataset named 'Yosemite National Park, CA: Rockfall Studies' (2010), located in the grounds of the Yosemite National Park, specifically the Half Dome and the Yosemite Valley.

Because I wanted to find the best climbing places in the Yosemite Valley, and this area didn't cover El Capitan, the highest wall in the Valley, I have searched for more data. I have added more point cloud datasets from OpenTopography, 'Yosemite, CA: El Portal, Mariposa Grove, Yosemite Canyon & Tuolumne Meadows' (2006) and 'Airborne Laser Mapping of Yosemite National Park, CA, 2007' to cover El Capitan and a portion of Little Yosemite Valley:

1. http://opentopo.sdsc.edu/lidarDataset?jobId=pc1574891670287
2. http://opentopo.sdsc.edu/lidarDataset?jobId=pc1576872771428
3. http://opentopo.sdsc.edu/lidarDataset?jobId=pc1575015527554

METHODS

Mapping

Mapping was conducted using the above data sets and different techniques.

Using ESRI's ArcMap 3.7 and PDAL, a process to identify the climbing zones was developed, based on 4 free point clouds datasets from the Yosemite Valley, from OpenTopography. Spatial Analyst extension is needed.

ArcGIS is a geographic information system (GIS) for users/organizations to create, manage, share, and analyze spatial data. It consists of server components, mobile and desktop applications, and developer tools. This platform can be deployed on-premises or in the cloud (Amazon, Azure) with ArcGIS Enterprise, or used via ArcGIS Online which is hosted and managed by Esri.

PDAL is Point Data Abstraction Library. It is a C/C++ open source library and applications for translating and processing point cloud data. It is not limited to LiDAR data, although the focus and impetus for many of the tools in the library have their origins in LiDAR.

The coordinate system for the project was taken from the LIDAR files:

- Horizontal: UTM Zone 11N NAD83 (CORS) [EPSG: 26911]
- Vertical: NAVD88 (GEOID 03) [EPSG: 5703]

One file was in WGS84N and had to be reprojected in PDAL during merge.

Preliminary step

The working environment was prepared, and an area of interest was manually digitized:

- Created a File Geodatabase named scratch.gdb, to keep track of all the files and store all the intermediate results, and set geoprocessing workspace to this geodatabase.
- Created a new polygon file, drew the area of interest.
- Created Models that do specific tasks in order to separate functionality.

Extract shapefiles for Yosemite Valley

File geodatabase or shapefile data were downloaded from IRMA Data Store, merged and used in this analysis.

Clipped the data for Yosemite Park to an area of interest in the Yosemite Valley:

- Downloaded the data.
- Created a new file geodatabase named park_data.gdb, and imported specific data to it, for example roads, rivers, springs, trails.

- Created a new file geodatabase named valley_data.gdb, iterated through park_data.gdb, clipped the files using an AOI layer, and saved the results.

Create a mosaic of aerial images

Used NAIP data from USDA-FPAC-BC Aerial Photography Field office that covers the region of interest, to analyze the intermediary results and better understand the region.

Mosaic data from https://earthexplorer.usgs.gov:

Downloaded the files and mosaicked:

- Created a file geodatabase named AerialCollection
- Created Mosaic Dataset
- Added the raster files to Mosaic

Create base raster files

There are three point cloud files of las type for this zone on Opentopography. In order to conduct this study in the area, the files were downloaded, merged and transformed into raster files that could be easier analyzed using Spatial Analyst tools or 3D tools. One file was too large, it was splitted in two for download, resulting four files for processing.

Downloaded the files, merged all las files into a single file, then the tiles into a LAS dataset:

- Used PDAL to merge the four files, reproject to the same coordinate system, create tiles, then extracted ground and denoised the tiles using a batch command.
- Imported all resulting ground tiles to a new LAS dataset.

Generated the primary raster files:

- Created Raster from the LAS dataset, using LAS To Raster. Because the average point density was around 0.5, this value was used as base cell resolution for all the derived products.
- Create Slope in degrees.

Extract Climbing Walls

This section focuses on a set of threshold operations on the primary rasters, to determine areas where is very likelihood of long and steep walls. The main declivity should be above 75°, but the intention is to include the intercalated smaller zones on the walls, too.

This was achieved using generalization algorithms to create a mask for the zones that include faces with high declivity. Also, there was an operation to extract the approximate difference in altitude for the walls, that was achieved using sections of streams that cross the walls.

Went through a set of operations to extract the possible climbing faces:

A. Selected the areas that are usually considered steep slopes, extracted only faces above 35° using Con.

B. Generalized the extracted data for slope, in order to get a cluster of similar slope and aspect.

- Did a Boundary Clean and a Majority Filter to generalize the results.
- Boundary Clean sorting technique 'ASCEND'
- Created a mask from the previous result, then refined it through a smoothing process.
- Removed data smaller than 1000 sqm, then use this mask to extract data from the slope raster.
- Used Region Group tool

C. Extracted portions of streams that intersected with the walls, to approximate the difference in elevation.

- Created the stream network from the Elevation raster resulted earlier, using Flow Accumulation, Stream Order, Stream Links, Stream to Feature.
- Intersected the Streams raster with a raster buffer following the resulting Slope raster, then with the Elevation raster using summary statistics, and got the elevation range per stream.

Get the best Yosemite Valley climbing places

Deriving datasets, such as slope, is the first step when building a suitability model. Each cell in the study area will need to have a value for each input criteria. There is the need to combine the derived datasets in order to create a suitability map, which will identify the potential locations for the climbing routes.

To combine the datasets, they first need to be set to a common measurement scale, such as 1 to 10.

Using the Weighted Overlay tool, the values of each dataset can be weighted and combined.

Two main resulting raster files were derived using the results from the previous operations.

One raster represents zones that combine steep slopes with elevation ranges from 100 to more than 900 m, and answers the question ‘Where are the possible climbing routes in Yosemitte Valley’.

The other raster is an attempt to combine specific suitability factors, that would answer questions like ‘Where is the longest climbing route in less than 500 m from the main road, and no more than 100 m from a trail’. The decision to go to one climbing place or another can be influenced by many factors. Distances to roads, streams, springs, parking, and the overlap with specific geologic areas were taken into account.

Created Euclidean Distance Rasters:

A. Using data from step II, created Euclidean Distance rasters for roads, streams, climbing areas, parking lots, springs, trails.

Reclassified the Rasters:

B. The values in the datasets derived in previous steps were all floating-point, continuous datasets, categorized into ranges, and they had to be reclassified so that each range of values was assigned one discrete integer value. Reclassified each derived dataset to a common measurement scale, giving each range a discrete integer value between 1 and 10. Higher values would be given to attributes within each dataset that were more suitable for locating the climbing route.
    - Slope: reclassified the slope output, slicing the values into equal intervals. Assigned a value of 10 to the most suitable range of slopes (those with the lowest angle of slope) and 1 to the least suitable range of slopes (those with the steepest angle of slope) and linearly rank the values in between.
    - Roads:
    - Geology: reclassified the raster, keeping the granite and granodiorite related values.

C. Used Weighted Overlay on previous results:
    - The reclassified datasets and geology were ready to be combined to find the most suitable locations. The values have all been reclassified to a common measurement scale (more suitable cells have higher values). The geology dataset was still in its original form because we could weigh the cell values for this dataset as part of the weighted overlay process. All the inputs could be weighted assigning each a percentage of influence. The higher the percentage, the more influence a particular input will have in the suitability model.
    - Percentages of influence:
        1. Reclassed slope: 50%
        2. Reclassed distance to roads: 5%
        3. Reclassed distance to trails: 10%

4. Reclassed distance to rivers: 5%
5. Reclassed distance to springs: 2%
6. Reclassed distance to parking: 1%
7. Reclassed distance to climbing areas: 10%
8. Reclassed distance from clipped streams: 15%
9. Geology: 2%

D. A scale of 1 to 10 was used when reclassifying datasets, so before adding input rasters to the Weighted Overlay tool, we have set the evaluation scale from 1 to 10 by 1.
E. The results should include slopes greater than about 70 percent, even if all other conditions are ideal. Made values from 1 to 6 restricted, since these values represent slopes from 0 to 70.

On the resulting layer, each pixel has a value that indicates how suitable that location is for a new route. Pixels with the value of 9 are most suitable, and pixels with the value of 0 are not suitable. Therefore, the optimal site location for a new route has the value of 9.

- Extracted optimal sites using the Con tool, with the condition 'Value = 9'

■ RESULTS

Files

The final result is a file geodatabase named final, containing:

- AOI (digitized)
- yose_valley_tiles_rst05
- yose_valley_rst05_hillshade
- Possible_Climbing_Criteria
- Simple_Climbing_Criteria
- Best_Climbing_Criteria
- Simple_Climbing_Criteria.clr (colormap)
- Best_Climbing_Criteria.clr
- Rivers_clp (data from NAIP, clipped with AOI)
- Springs_clp (data from NAIP)
- Trails_clp (data from NAIP)
- yoseglg_clp (data from NAIP)
- Yosemite_Roads_clp (data from NAIP)
- YOSE_Parking_20190521_clp (data from NAIP)

- Yosemite_Climbing_Areas_clp (data from NAIP)

The first file represents the Area of Interest for the study. It can be obtained by rasterizing the LAS files and converting to vector, too, but I have needed to draw a more granular contour.

The second file represents the Elevation raster that has been obtained from the LAS tiles dataset. It has a resolution of 0.5 (cell size).

The third file is a hillshade, a derived raster representing a grayscale 3D representation of the terrain surface.

Possible_Climbing_Criteria is a file representing a generalization of zones that include steep slopes. In reality, the climbing walls contain more types of slopes intercalated, this file could mimic a collection of climbing zones.

Simple_Climbing_Criteria is the first file obtained from the Weighted Overlay between Possible_Climbing_Criteria and the streams that were used to approximate the height of a wall. The Brighter red represents stepper and longer walls.

Best_Climbing_Criteria is a more complex variant of Simple_Climbing_Criteria, where we took into account distances to roads, trails, rivers, springs, parking, the geology type and the walls length.

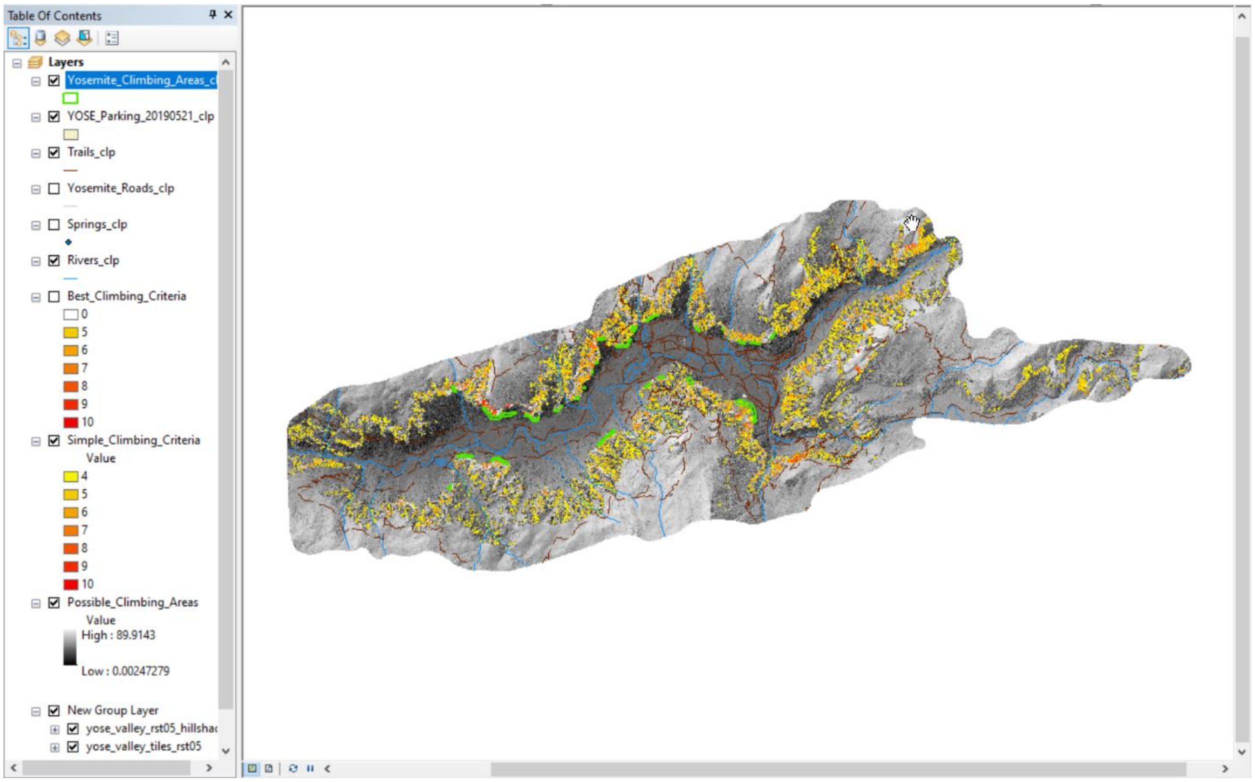

Fig.2 Final climbing areas raster files, comparation with existing climbing areas layer.

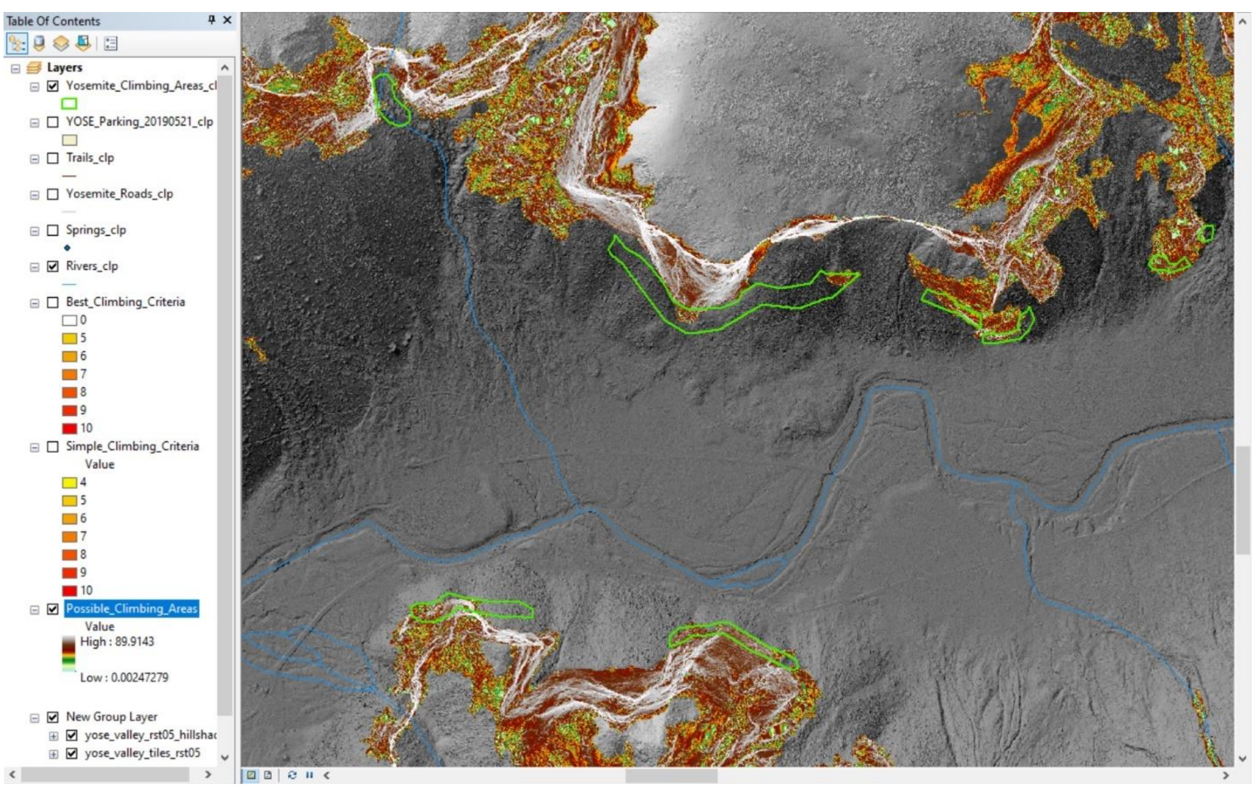

Fig.3 Possible climbing areas raster file, comparation with existing climbing areas layer.

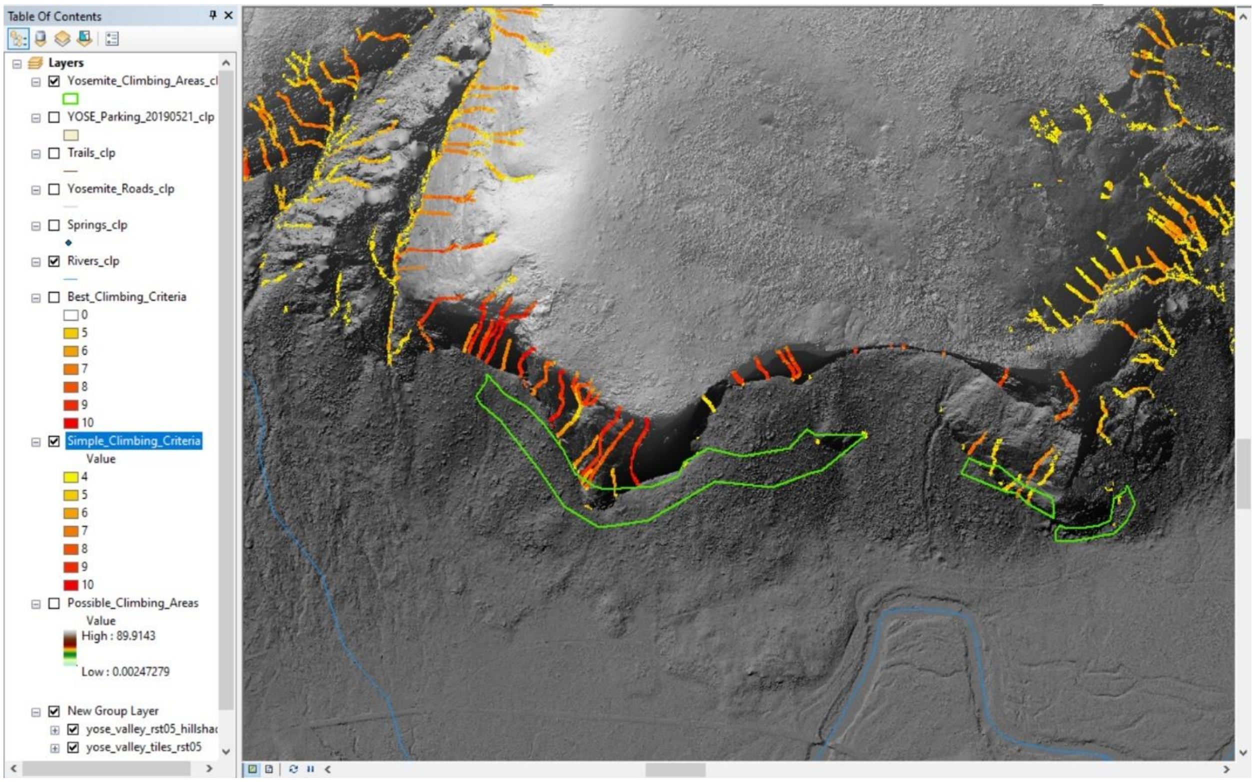

Fig.4 Simple climbing criteria raster file, comparation with existing climbing areas layer.

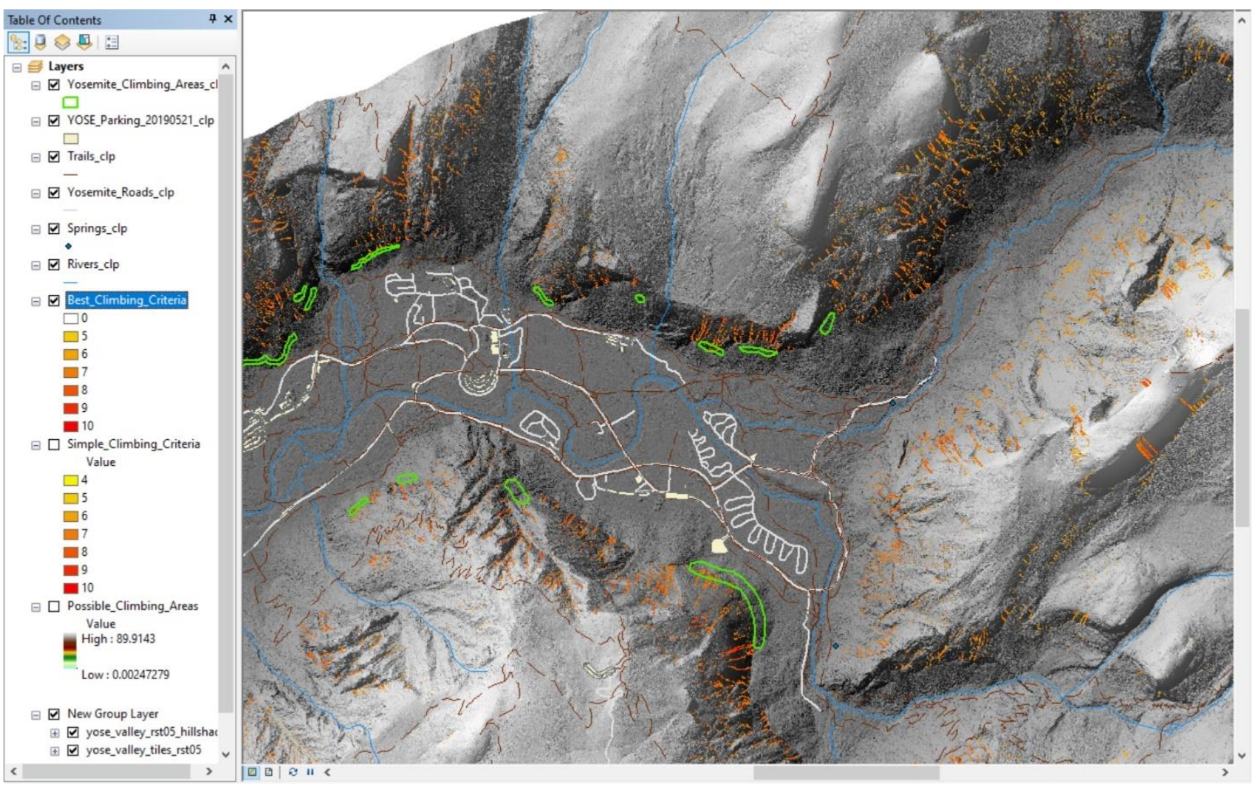

Fig.5 Best climbing criteria raster file, comparation with existing climbing areas layer.

DISCUSSION

The project results depend much both on the quality of the acquired data, and the whole processing that took place in ArcGIS.

The data had an average point spacing of about 0.5 meters, so there is enough accuracy for conducting a slope analysis, but data quality depends on the **extraction** of the ground points.

Not all LIDAR data was classified, so in order to get more data I have used PDAL to extract the ground points. The **Simple Morphological Filter (SMRF)**, that classifies ground points based on the approach outlined in [Pingel2013], was chosen. Maybe another method would work better, and this should be tested. For example, The **Progressive Morphological Filter (PMF),** a method of segmenting ground and non-ground returns, an implementation of the method described in [Zhang2003].

I could have classified ground using ArcGIS 'Classify LAS Ground', but PDAL seemed to consume less memory for batch processing.

Another issue could be that the data from OpenTopography was from different years and partially **overlapped**. LAS Tiles in ArcGIS solves the overlapping issue, but I still have to research how PDAL behaves when tiling merged point clouds.

This study aims to delineate Yosemite's Climbing walls, but with its scope is not to map the walls in detail, because this cannot be accomplished using **Airborne LiDAR scanning (ALS)** only. Usually a project for mapping walls is being driven using airborne LIDAR in conjunction with **Terrestrial LiDAR Scanning (TLS)** or **Mobile LiDAR scanning (MLS)**, because on steep walls there usually are overhangs, that cause a 'shadow' error when the airplane collects the points, that results in zones with no data.

This study is based on existing data, better results would be obtained if it was doubled by onsite research and data collection.

In order to approximate the **walls length**, the approach was to derive streamlines, cut them when they intersect the possible climbing zones buffer, then get the attributes from the Elevation raster and compute the range for elevation. So, the final length taken into account is the difference in altitude, rather than the combined slopes length. There are other approaches better than the one in this paper, for example using cost path, that would assess a more accurate wall length, and testing them is a subject for further studies.

Another point to take into account is that not all climbing walls are being crossed by pseudo-streams, there are isolated rocks, or rocks where the streams go around, that would not show up in the final results because we combine the climbing zone filter with the length filter.

Above all, this is not a climbing guide and should not be followed by climbers who want to discover new routes or explore new walls, this is only a starting point for further scientific analysis regarding delineation of climbing walls using LIDAR from airborne scanners.

Still, the method used in this study would give enough results to delineate a generalized climbing zone.

CONCLUSIONS

Even if there are still many ways to improve this project results, what we have achieved until now demonstrates that LIDAR is a great source for DEM creation and 3D modelling. The primary input for Digital Terrain Model generation was a set of point clouds with ground classifications.

PDAL is a great library for processing point cloud data using just the terminal, and helped with the memory issues in this project's case.

ArcGIS is also a sophisticated software that allowed us to analyze the LIDAR point clouds and derive complicated layers like streamlines and hillshade.

This new detailed map of climbing zones helps once more to identify the Yosemite Valley steep-sided valley and observe the pattern carved by the geologic past and polished by the ongoing climatic processes.

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