Automated Rockfall Feature Extraction using High-Resolution 3D Point Clouds

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Introduction

A considerable amount of research has been published on magnitude-frequency distributions and their application to quantifying the cumulative yield of rockfalls. Why ?

To upscale, in both time and space, to model cliff erosion

So…: To compensate for the difficulty in capturing regional scale observations

However…Limitation of assumptions:

- non-biased portion of an inventory is representative
- apply power laws within limits
- extrinsic controls are constant
- all rockfalls in an inventory are statistically independent *(although rockfalls exhibit some degree of spatial and/or temporal path-dependency (Rohmer and Dewez, 2015)*

Cons: **This approach loses any site specificity or individual location!**

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Now…
we need a large scale data…

24 km North Yorkshire coast, England, United Kingdom

Cliffs height:~ 150m at (a) up to ~ 20 m in (d)

Aerial photos:
(a) Boulby,
(b) Old Nab (foreground) and Staithes (background),
(c) Kettleness, and
(d) Sandsend.

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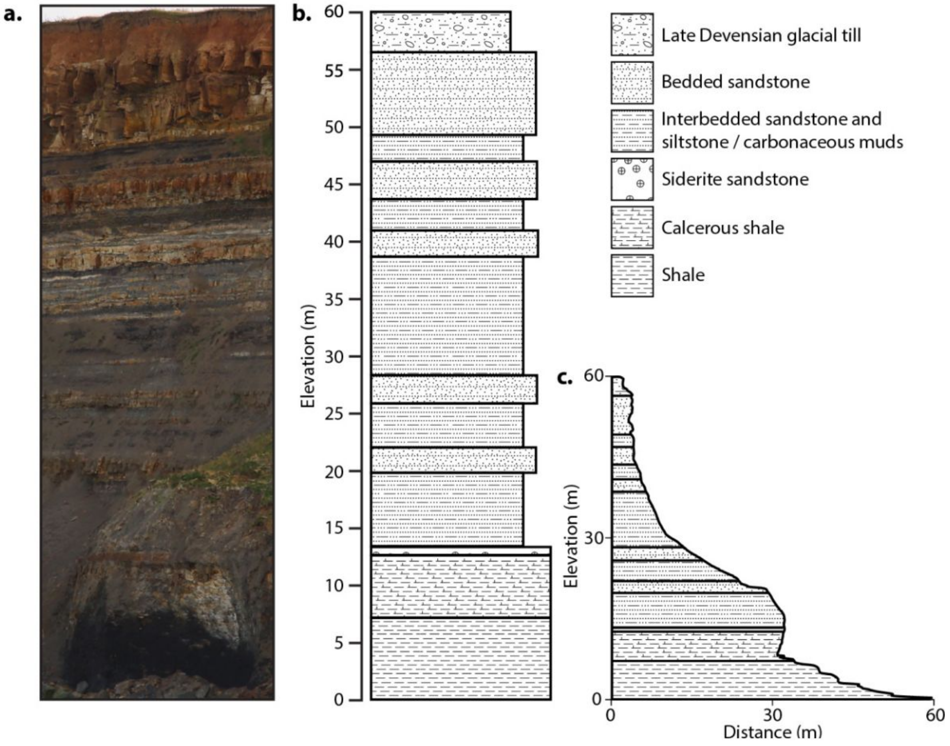

Figure 1: (a) Whitby cliff: Photo illustrates the near horizontal bedding of sandstone and sandstone interbedded with siltstone. Capped with glacial till, *(Log modified from Figure 3 in Rosser et al.(2005:365)*

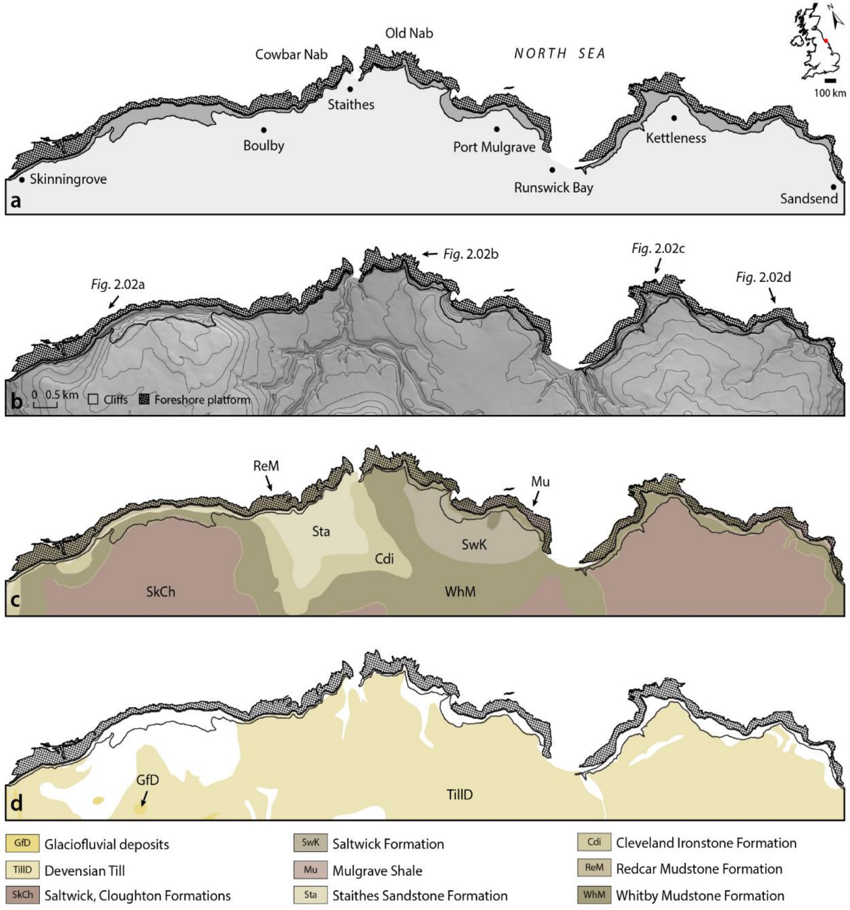

Figure 2. (a) Map of the North Yorkshire coast. (b) topographical map, with contours at 20 m intervals, (c) bedrock geology, and (d) superficial geology.*(Modified after Benjamin et al. 2016)*

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Data collection

Airborne coastal survey from Whitby to Skinningrove by GeoM for Durham University.

StreetMapper mobile mapping system (MMS) mounted onto a twin engine Jetranger helicopter.

360 degree mobile mapping scanner as opposed to a typical 60 degree field of view airborne scanner (for high resolution data of the cliff face and the ground).

Length (km) = 24 (scanned in 2 hours).

flying speed (knots) = 40, height (m) = 120

average point density (pts/sq m) = 40 (80 on the cliff faces),

average camera pixel size (cm) = 4

Vertical RMSE (m) = 0.032

Absolute accuracy (cm) = 3

Point cloud: ~45,000,000 each year (~450,000,000 before masking)

COBRA Project


Geom
Pointcloud of Runswick Bay

Now…we need large scale data…

- Coastal Cliffs Rockfalls are critical landslide phenomena that significantly impact human activities on top and along the coast. 😕
- CloudCompare to process 3D PC from TLS, are often time-consuming and introduce considerable uncertainty in area and volume estimation (2.5D). 😤
- Commercial softwares, (ex. Matlab)applying fees with restrictions on use, modification, or distribution 😕
- Automated long-term volume and erosion rate changes of coastal cliffs are rarely addressed in detail.

To streamline the detachment analysis that contribute to **flexible parameters optimisation** and **updating used data**, a **multi-phase processing** framework **unified** into a single script, **is highly needed**. 🤓

Objectives

1. Software independency (memory issues, installation or GUI)
    - **Deliverable:** Efficient interaction with a computer's hardware and resources using open-sources and bash script commands
2. Efficient handling of large scale and high resolution PC analysis
    - **Deliverable:** Python environment of dependencies installed on Cloud based computational server
3. Automation of long-term detachment detection and features geometric quantification
    - **Deliverable:** Unified multi-processes codes to calculate volume, erosion, density, area, and shapes categories with distance area segmentation capabilities

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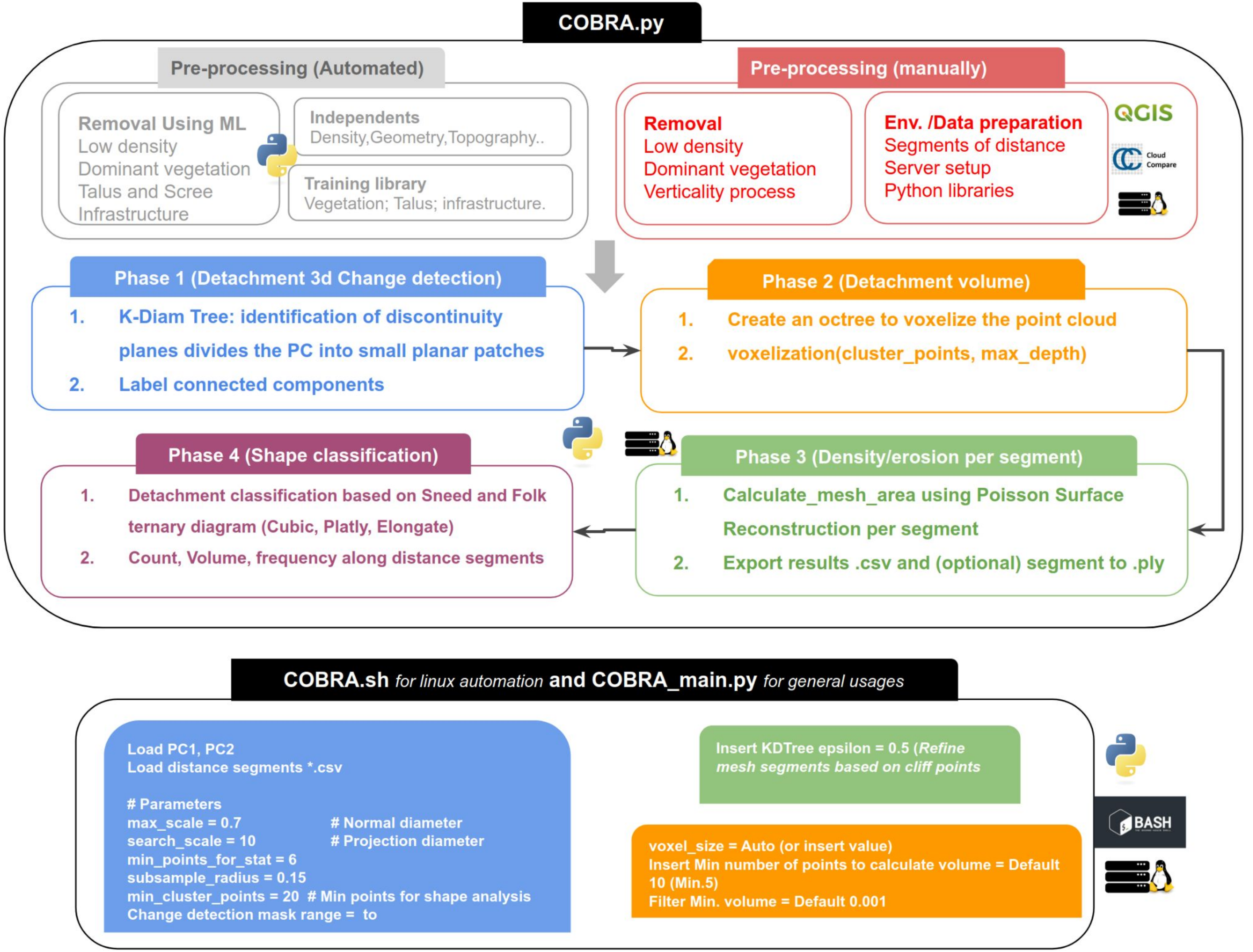
General framework

1- Change detection

2- Volume estimation

3- Density & erosion rate

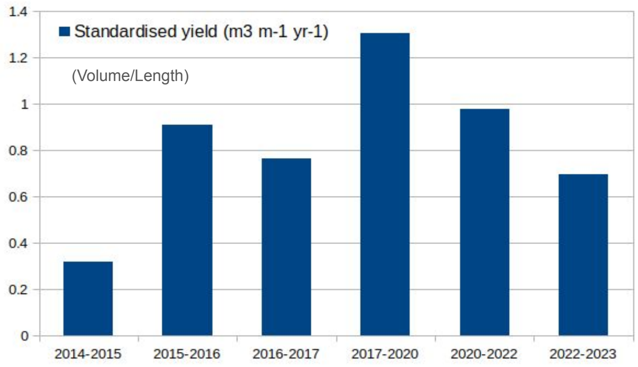
4- Detachments shape classification

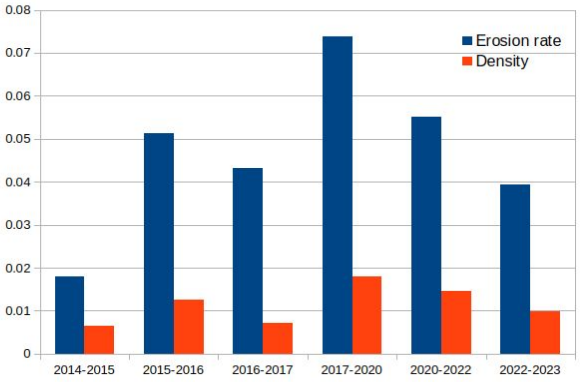


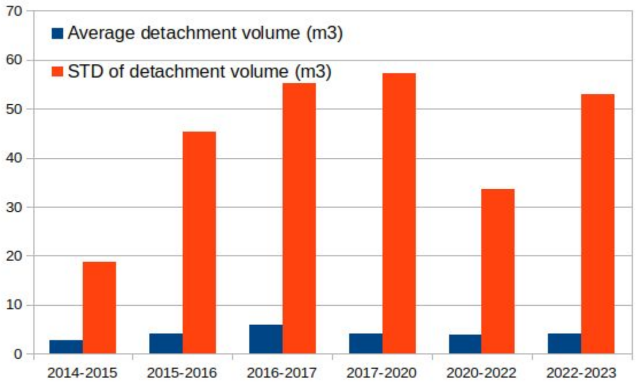
Annual statistics

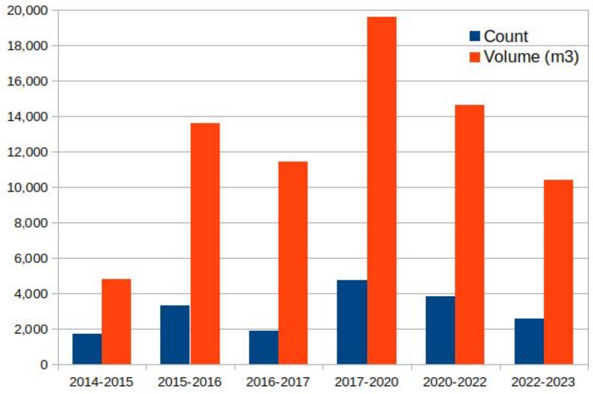
Cliff average area (m2) = 265,480

Cliff length (m) = 14,990









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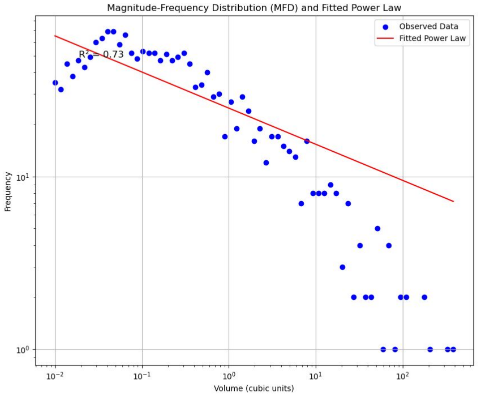
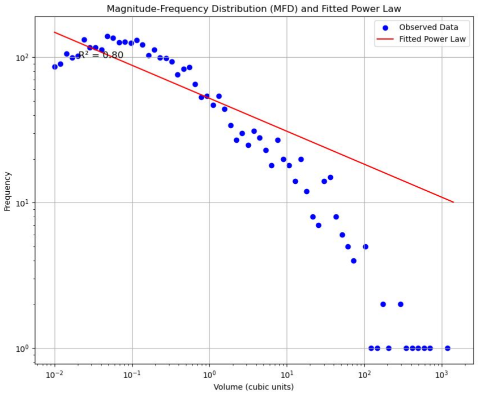
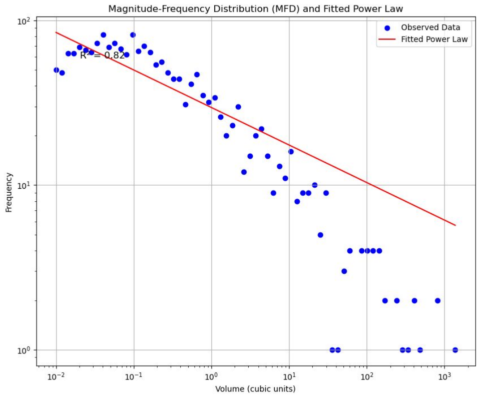
Detachment Mag.-Freq. plot



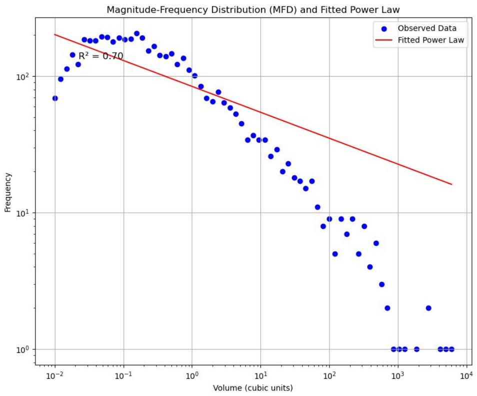
2014-2015



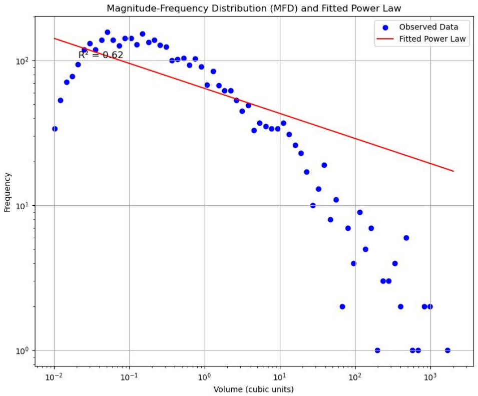
2015-2016



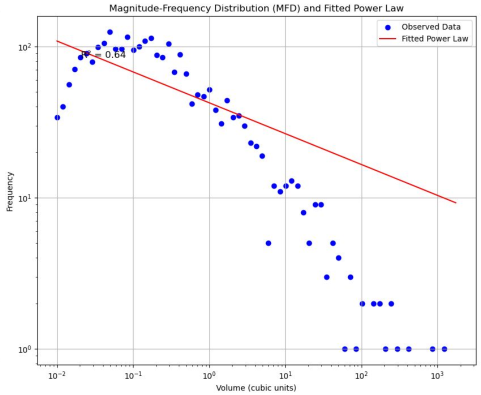
2016-2017



2017-2020



2020-2022



2022-2023

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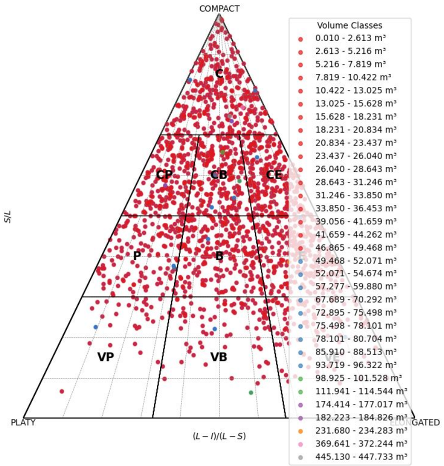
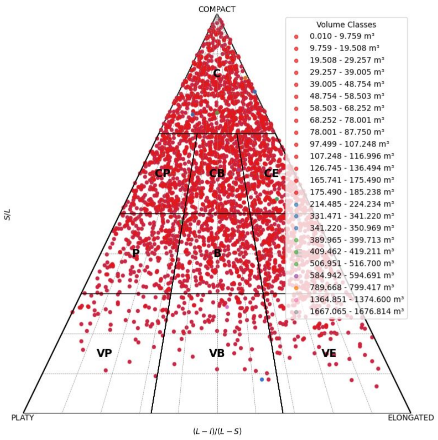
Detachment shapes classification

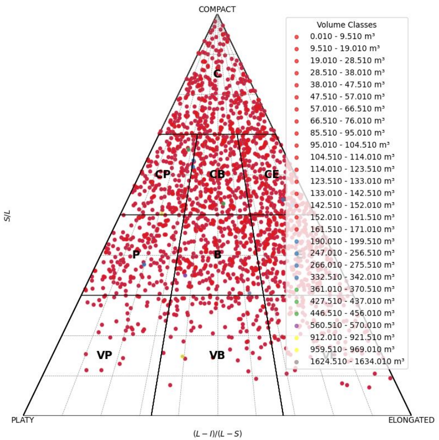
(Sneed and Folk Ternary diagram)



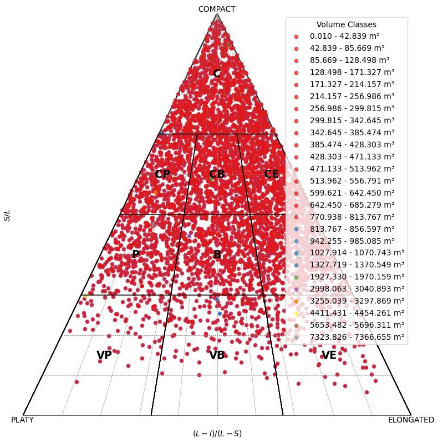
2014-2015



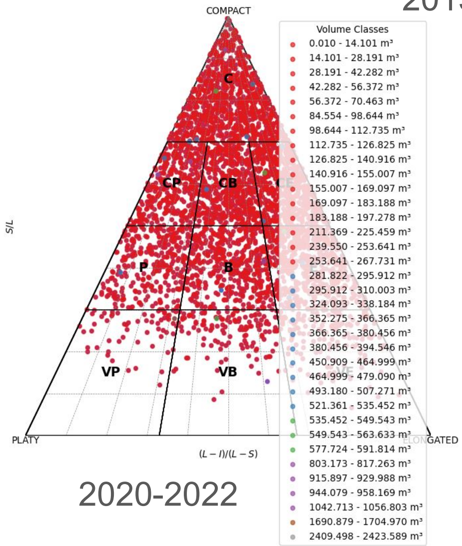
2015-2016



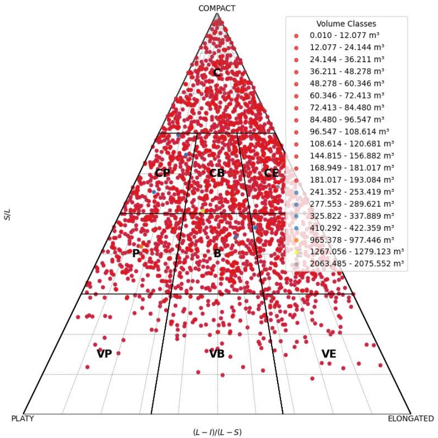
2016-2017



2017-2020

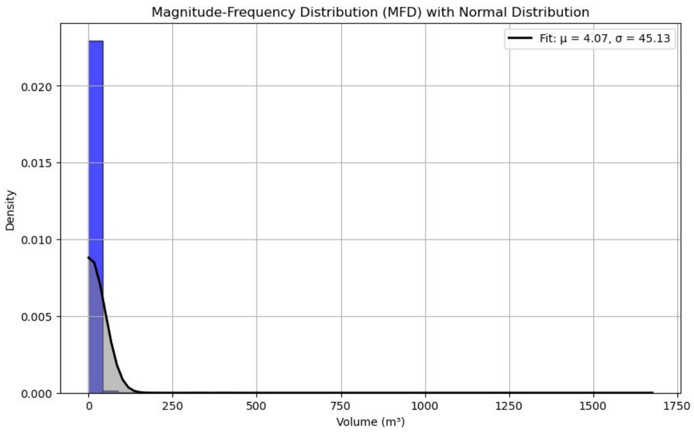


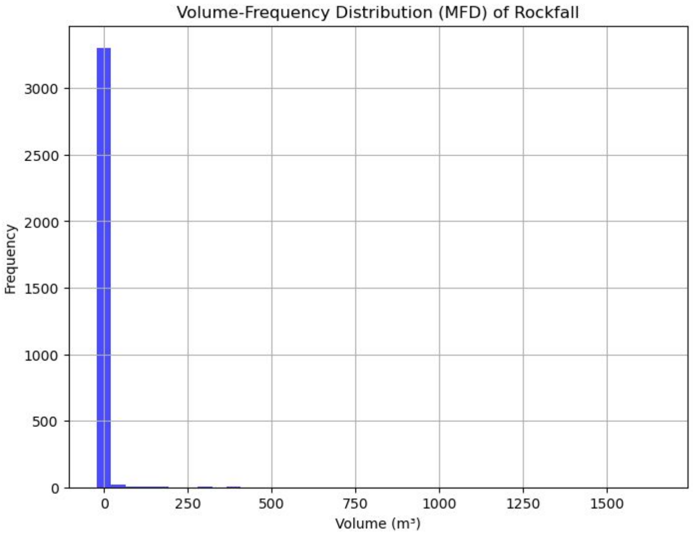
2020-2022

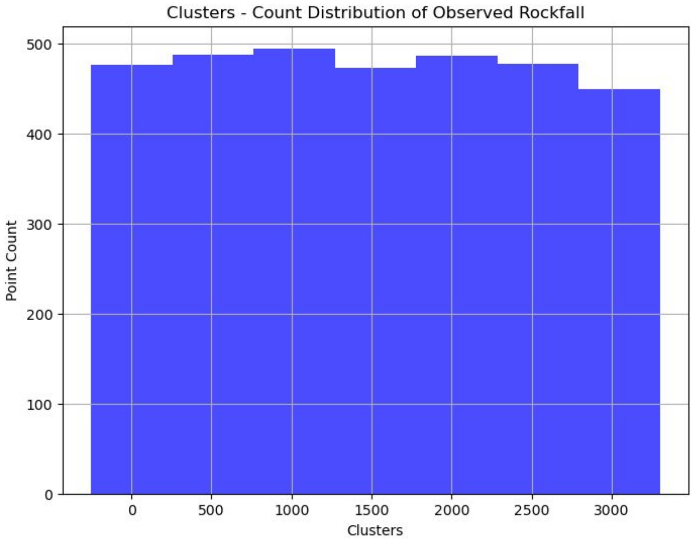


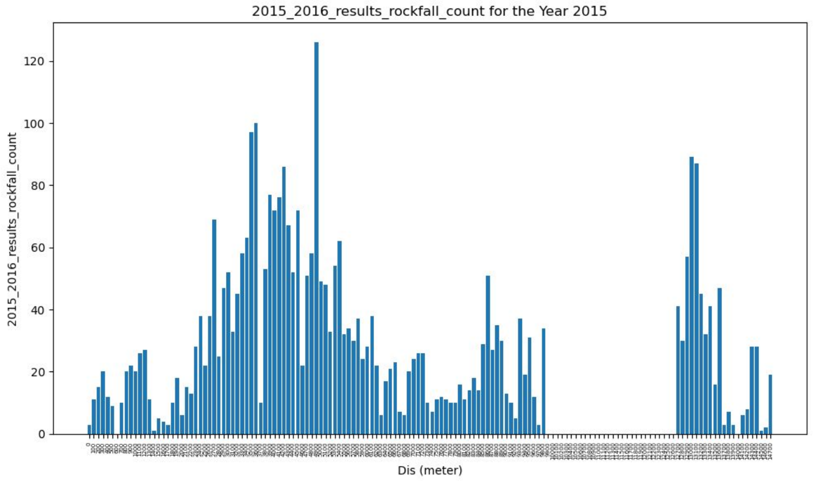
2022-2023

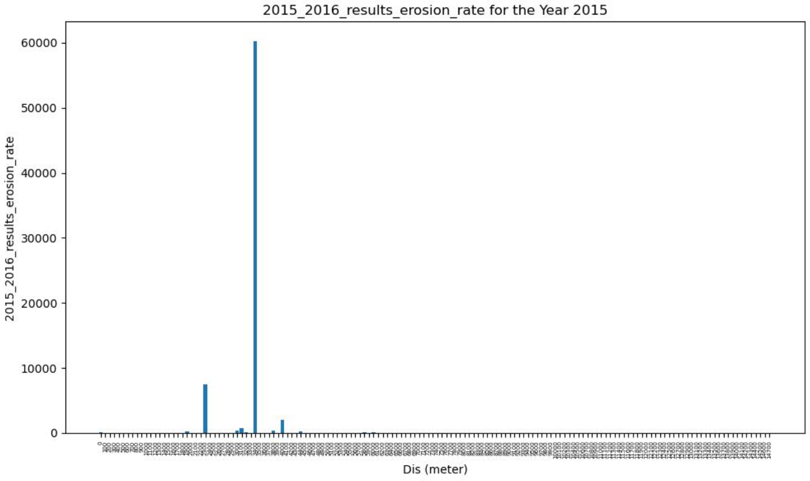
2015-2016 results

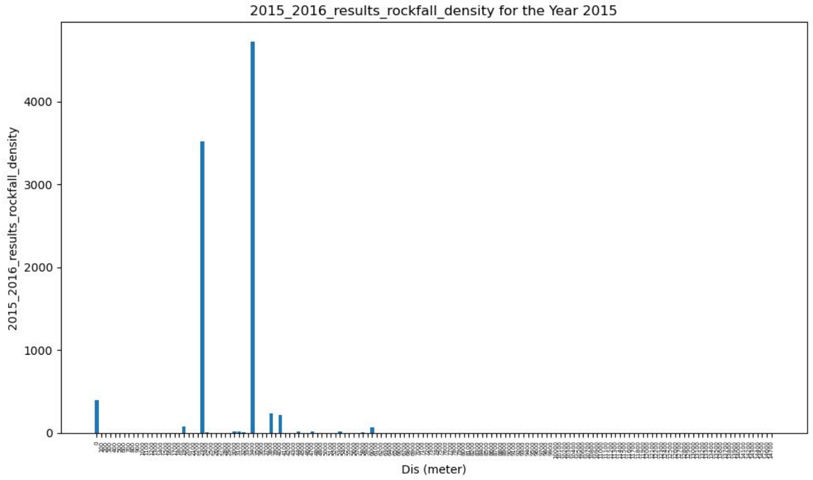


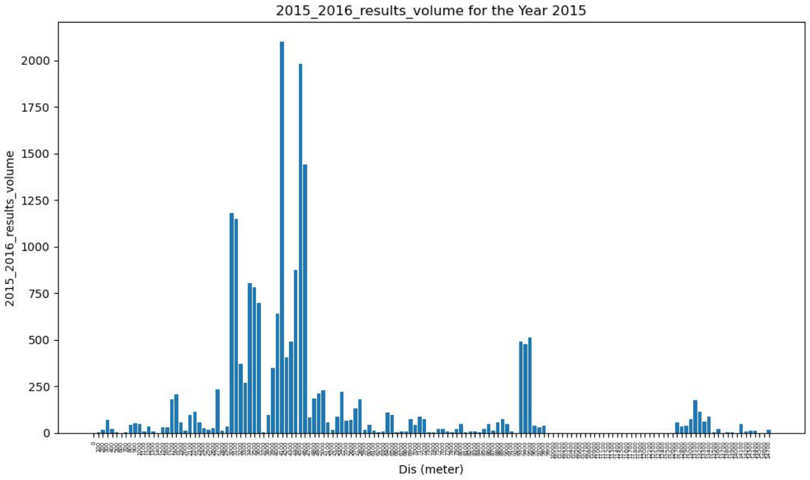




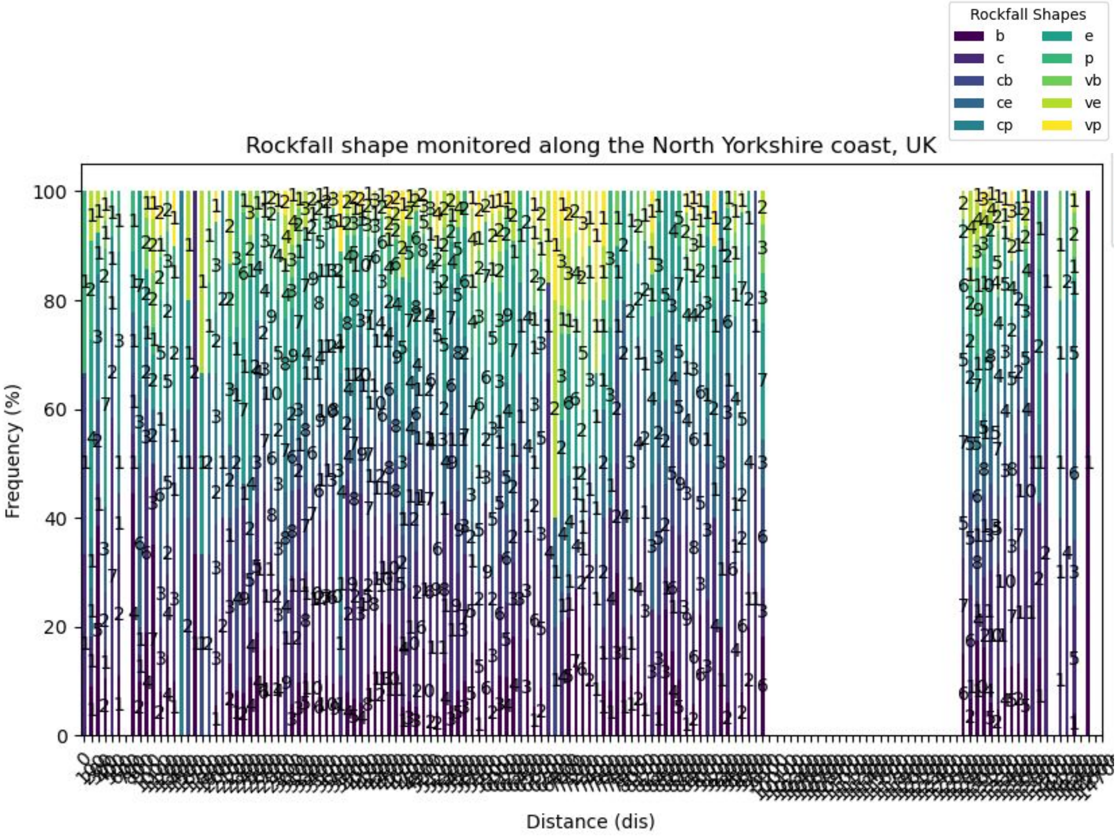

2015_2016_results_rockfall_count for the Year 2015
2015_2016_results_rockfall_count
Dis (meter)

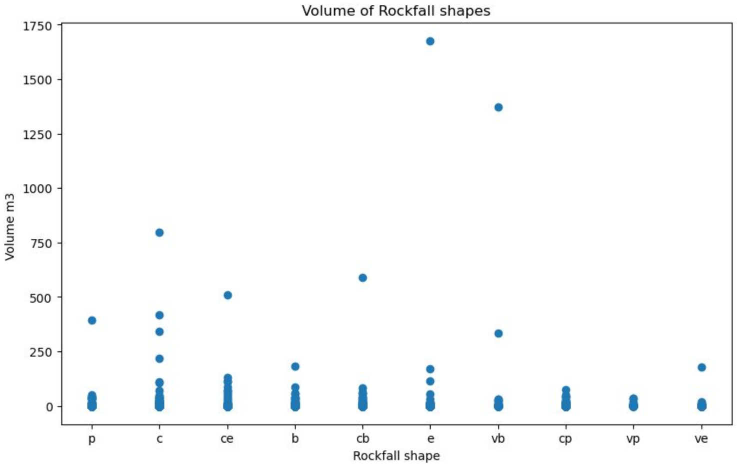

2015_2016_results_erosion_rate for the Year 2015
2015_2016_results_erosion_rate
Dis (meter)

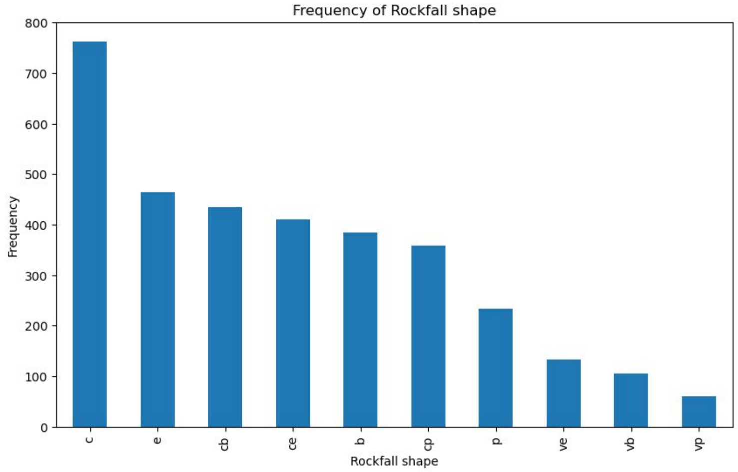

2015_2016_results_rockfall_density for the Year 2015
2015_2016_results_rockfall_density
Dis (meter)


2015_2016_results_volume for the Year 2015
2015_2016_results_volume
Dis (meter)

2015-2016 (continue)







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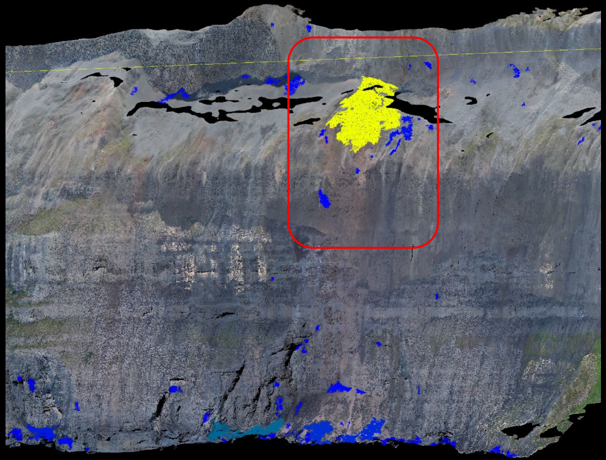
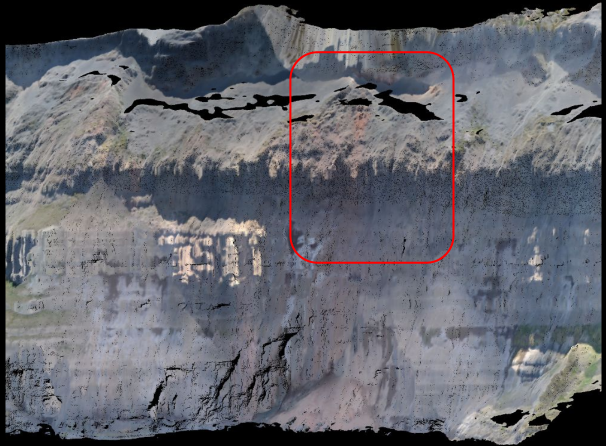
Example of Detachments 2014-2015

Detected detachments
Vol= 447 m3



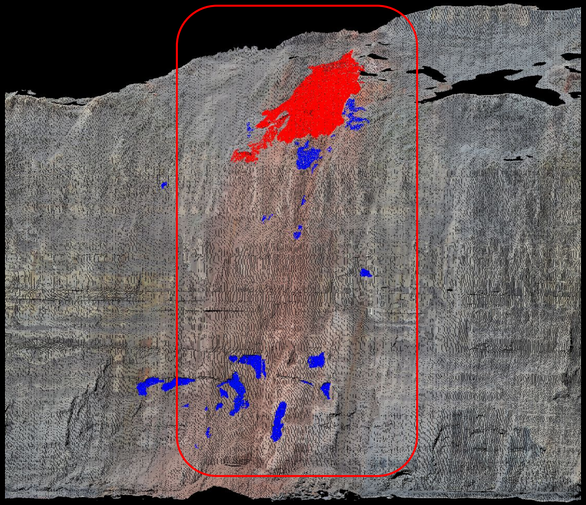
2014 (before)

2015 (after)



Example of Detachments 2015-2016

Detected detachments
Vol= 797 m3 (red)



2015 (before)

2016 (after)

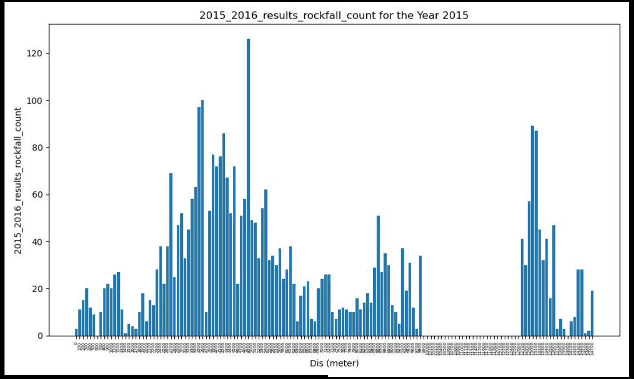
Challenges with **large scale** areas..!

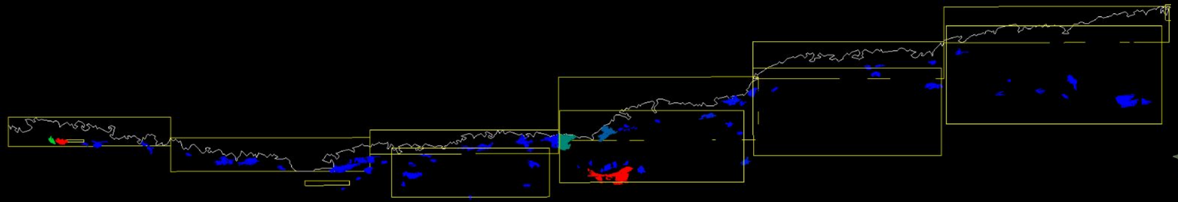
Mesh error with complex shapes

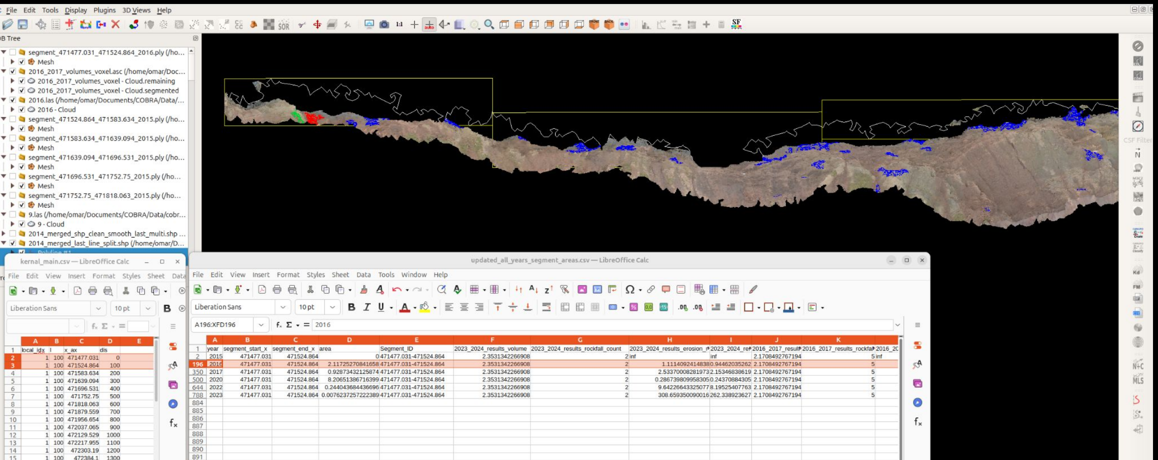
Count :calculated based on items within Length Segment, Area :calculated based on Area Segment.

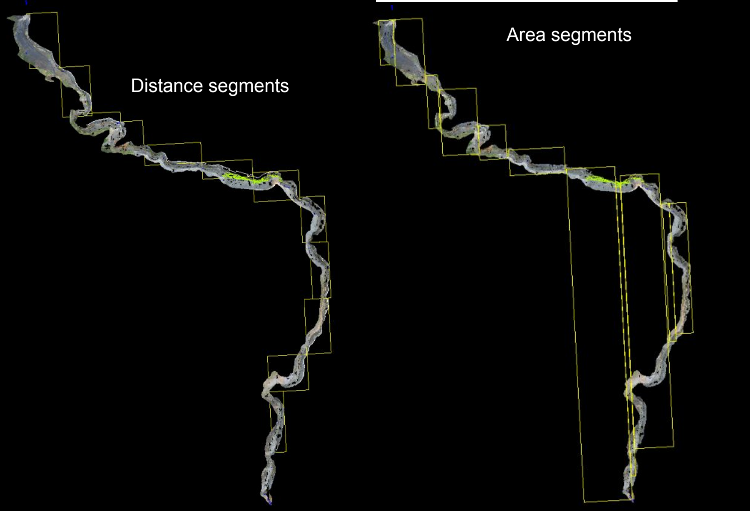
Areas segments value are misrepresented towards the Edges.Slope with a single segment and with less complex facets have better area representation

The areas segments are not equal, it built on concept of dividing the shape into mesh to measure the areas (x-axis represents the center of area segment)







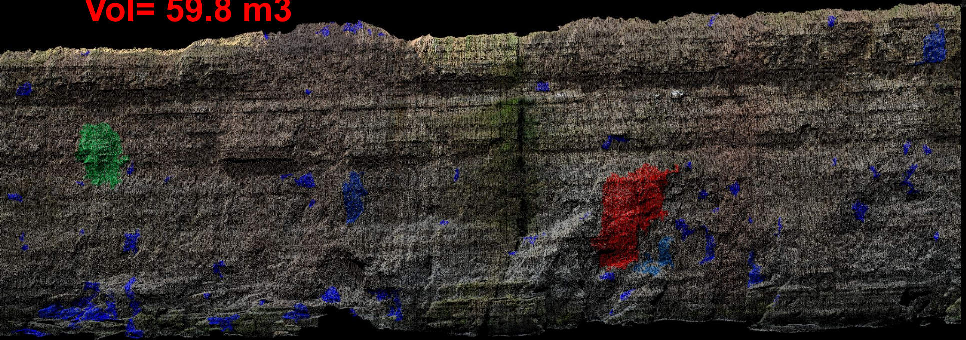


Visibility Issue

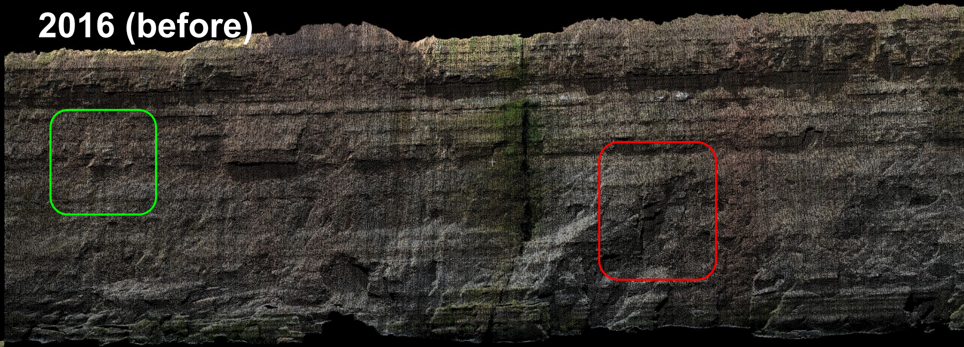
Detected detachments

Vol= 23.5 m3

Vol= 59.8 m3



2016 (before)



2017 (after)

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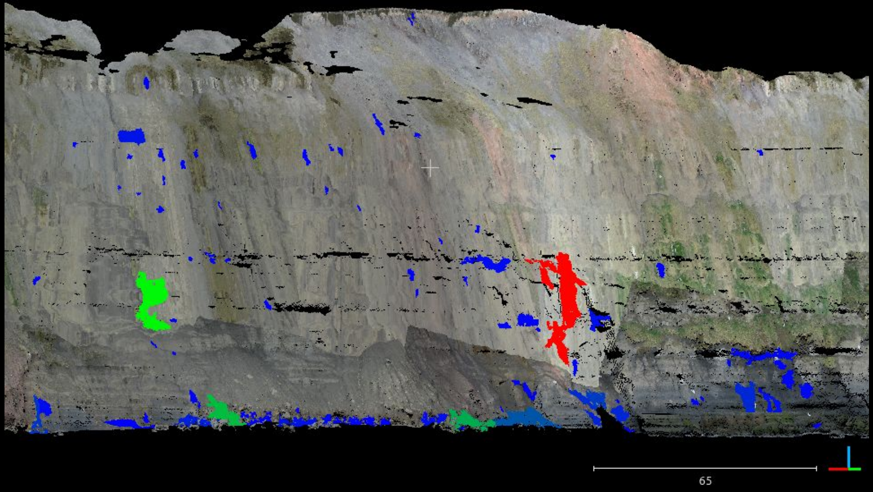
Detected detachments

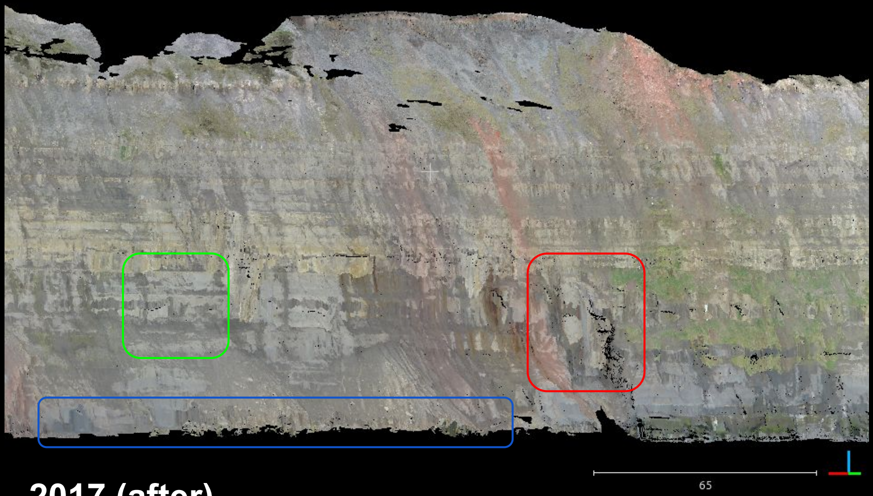
Vol= 28.5 m3

Vol= 87 m3 (red)

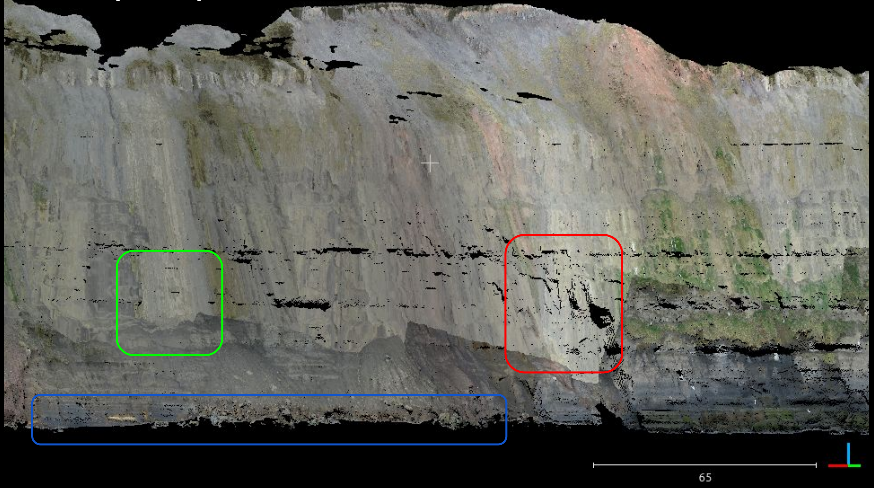


Talus Slopes *(large, boulders that have accumulated on a hillside from higher up cliffs)*
Scree field *(small rocks accumulated on a hillside from higher up cliffs)*

2016 (before)



2017 (after)



Validation

LiDAR

using StreetMapper mobile mapping system (MMS)

Points: **152,650**

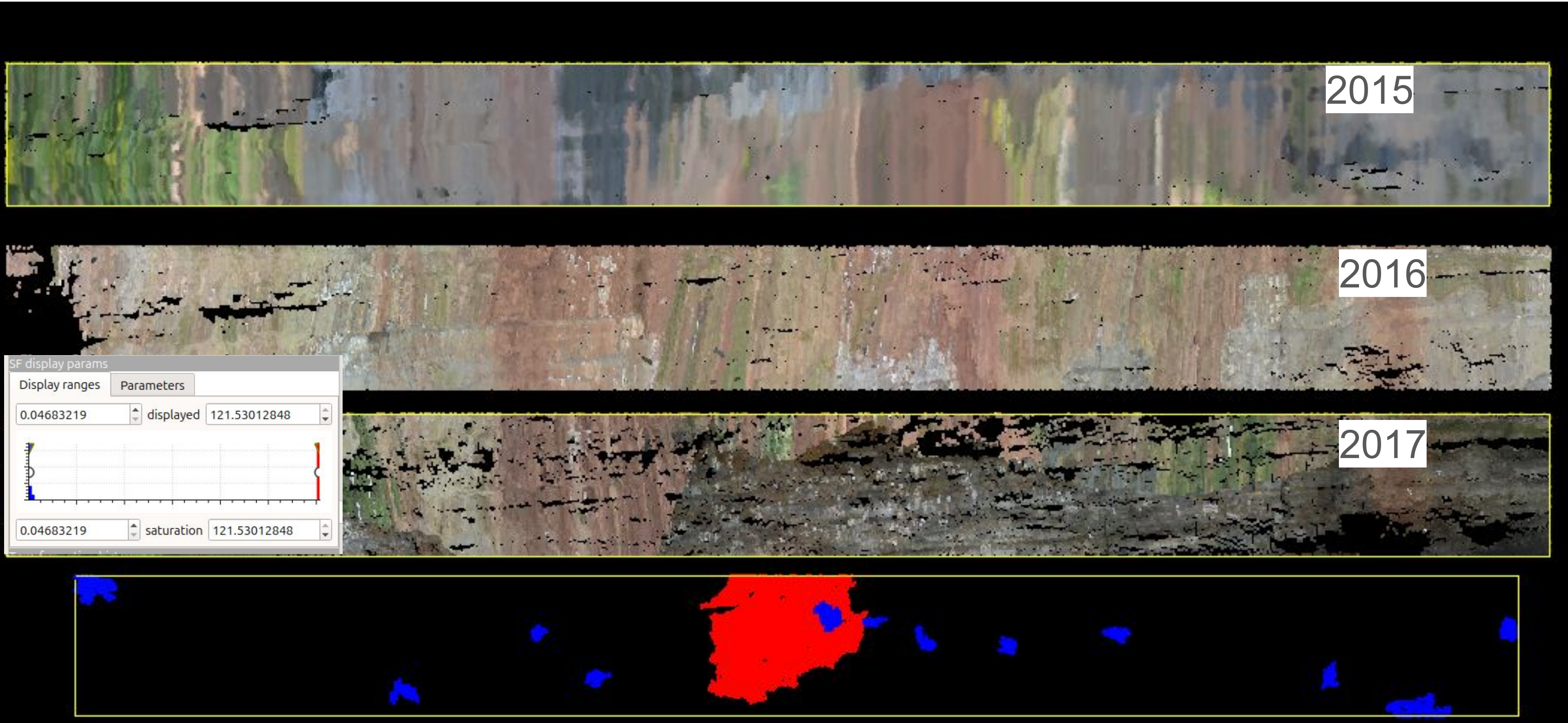
TLS

using A Riegl VZ-1000 instrument-target range of 2.5 – 1 400 m, an accuracy of 0.008 m, and an 0.005 m

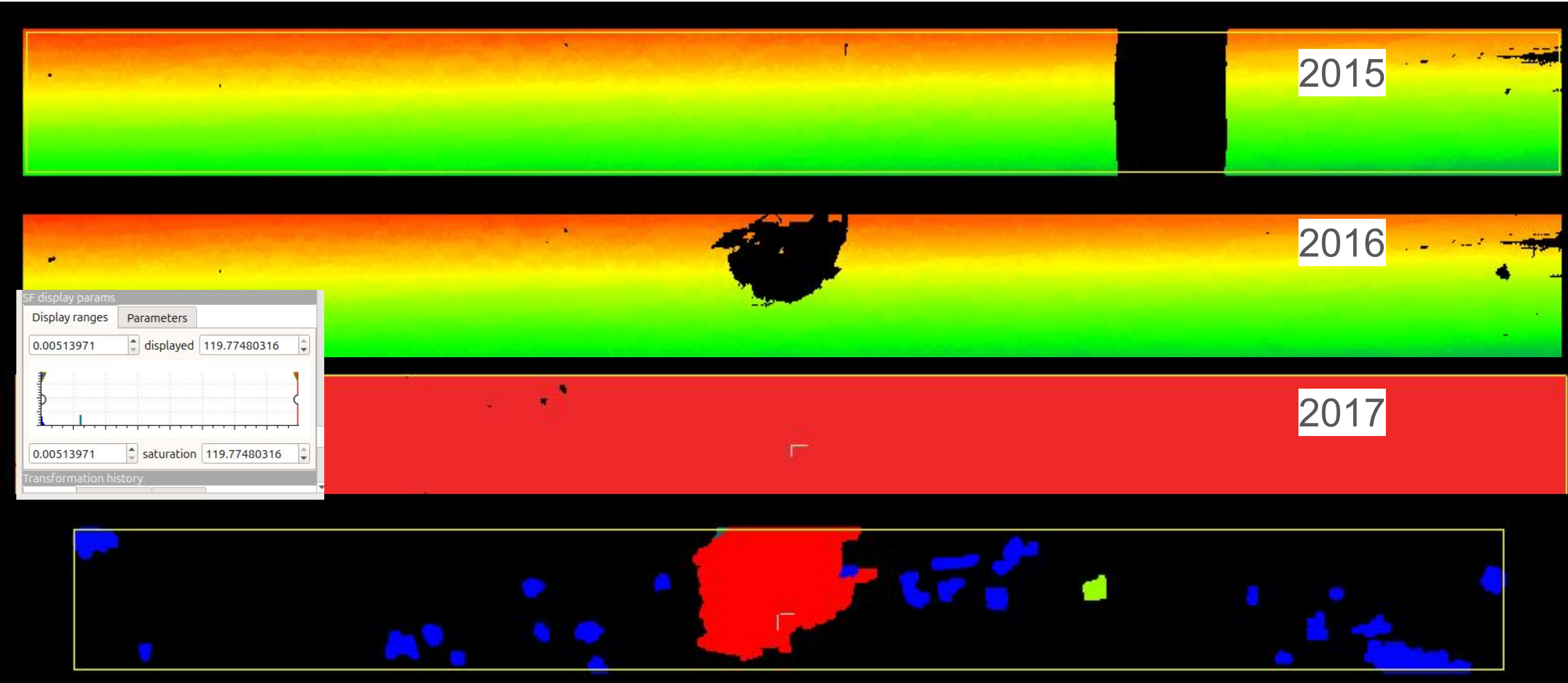
Points: **903,161**

* Both scan have different dates, therefore, we extended the detection span for years **2015,2016,2017**.

Detachments Volume validation (LiDAR)

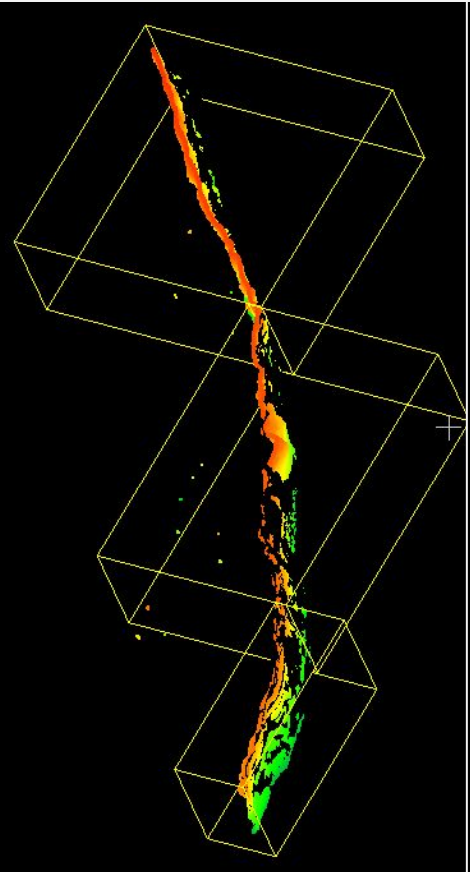


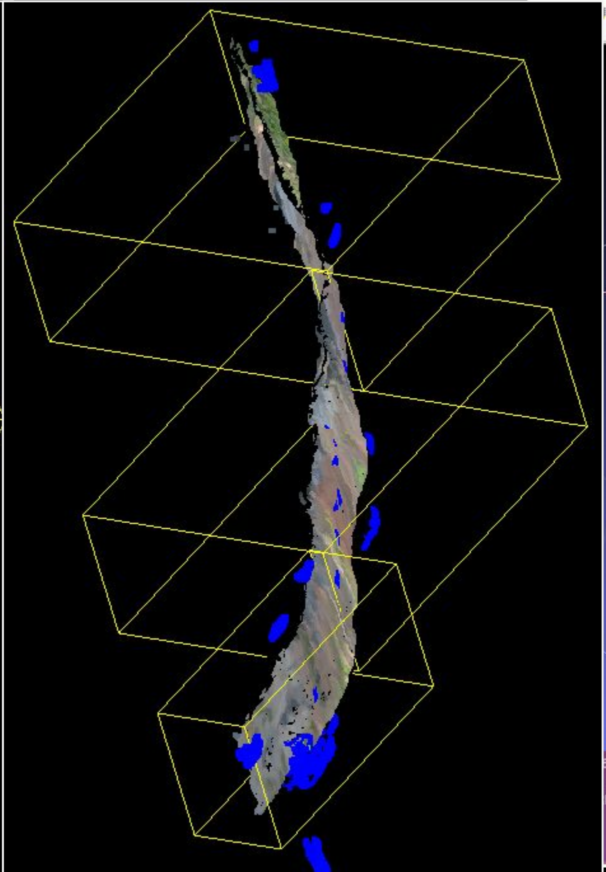
Detachments Volume validation (TLS)

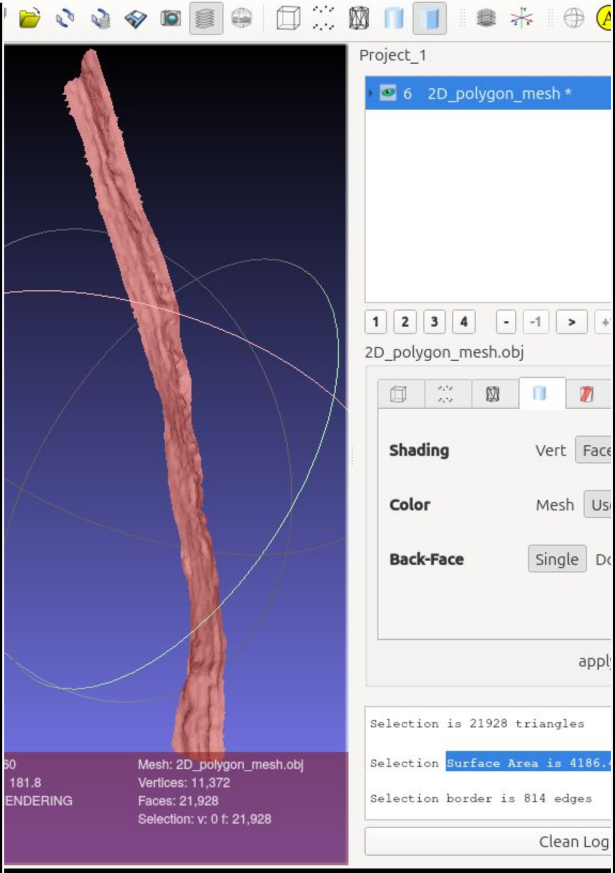


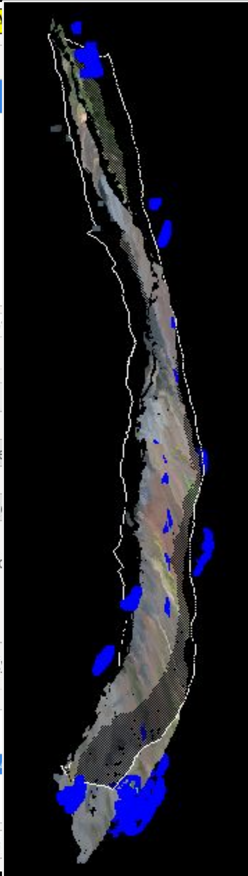
Detachments Area (m2) validation (LiDAR-TLS) using different measures

COBRA.py TLS (4182.31) | COBRA.py LiDAR (4182.13) | CC & Meshlab (4186) |CC & Facet (2210)

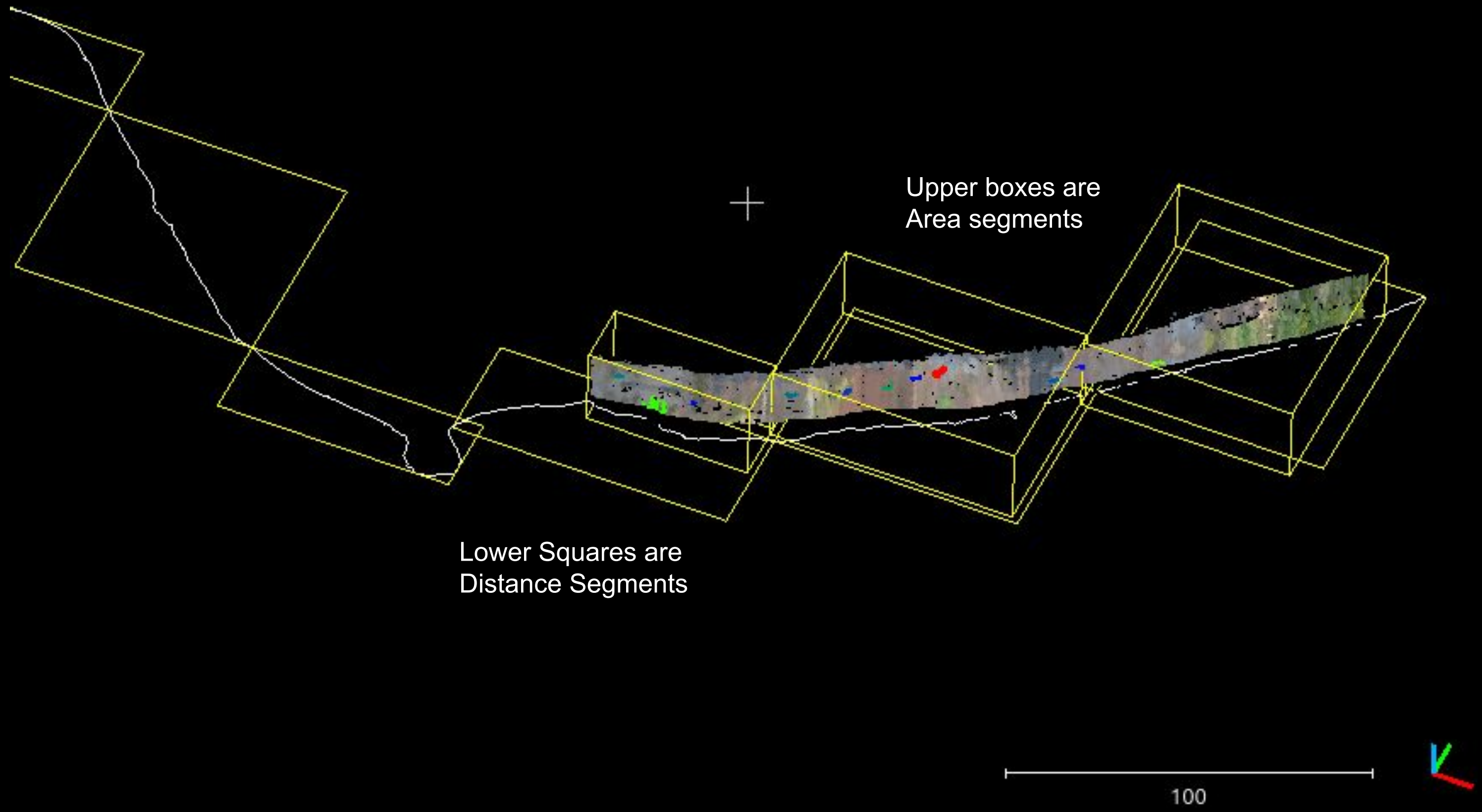








No obvious mesh error



Final remarks

- Slope with a single segment and with less complex facets have better area representation

- algorithm selection criteria considered the processing cost and speed

- CC CANUPO plugin is effective, but it causes reduction in PC where vegetation is low or not correctly presented (interference between training data).

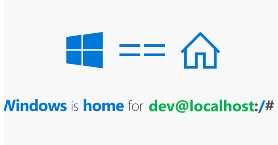
- Processing speed: ~5 mins (80,000 Points using Laptop) to ~18 hours (40,000,000 points using Server)

Ongoing work:

- Library of Slope cover features (different vegetation, talus, scree, buildings..etc)

- Vegetation, Talus and Scree extraction using ML with auxiliary data

- parameterization using bash script, toward friendly usages experience



Windows Subsystem For Linux

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