Undergraduate Topographic Differencing Laboratory Exercise

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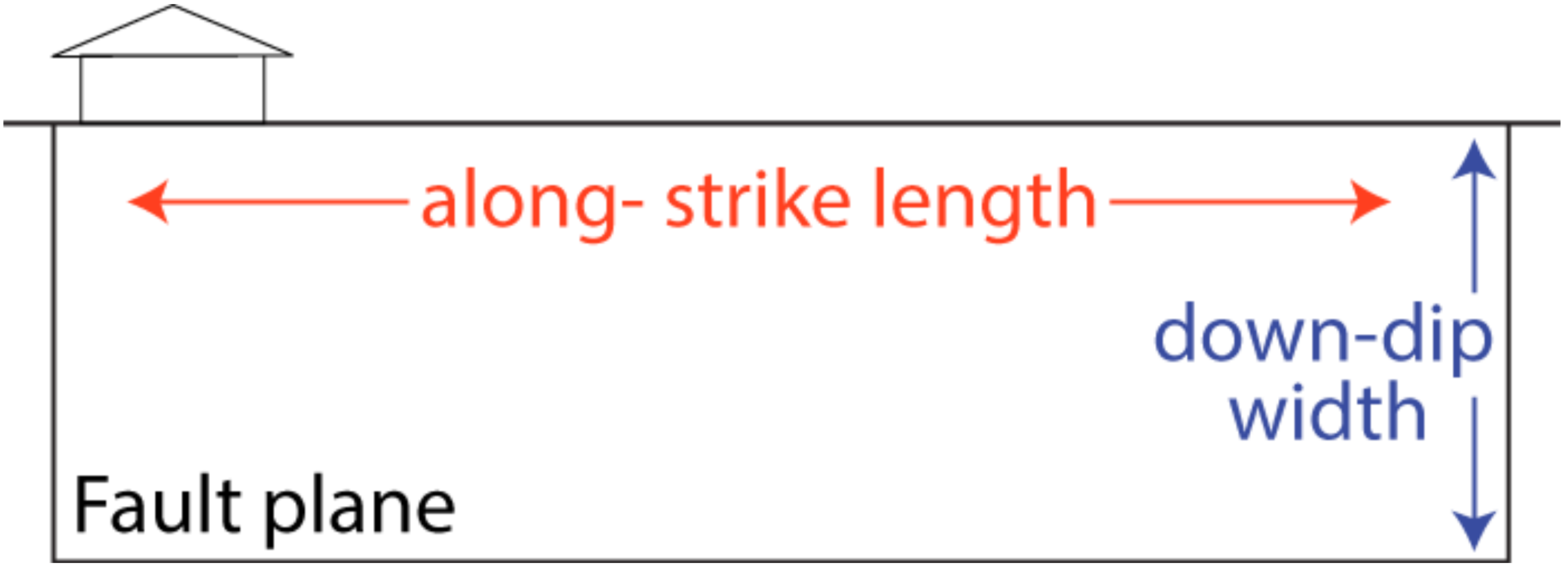
Introduction

- Undergraduate geoscience students learn about faulting processes by examining surface ruptures in high-resolution topography imagery and computing coseismic surface displacements.
- The exercise simulates a large earthquake along the Wasatch fault in Salt Lake City.
- Activities:
  - Examine and map the fault surface trace from topographic hillshades
  - Use Cloud Compare Software to calculate the 3D surface deformation
  - Determine type of fault activated and the earthquake magnitude
- ~4 hours to complete the full lab

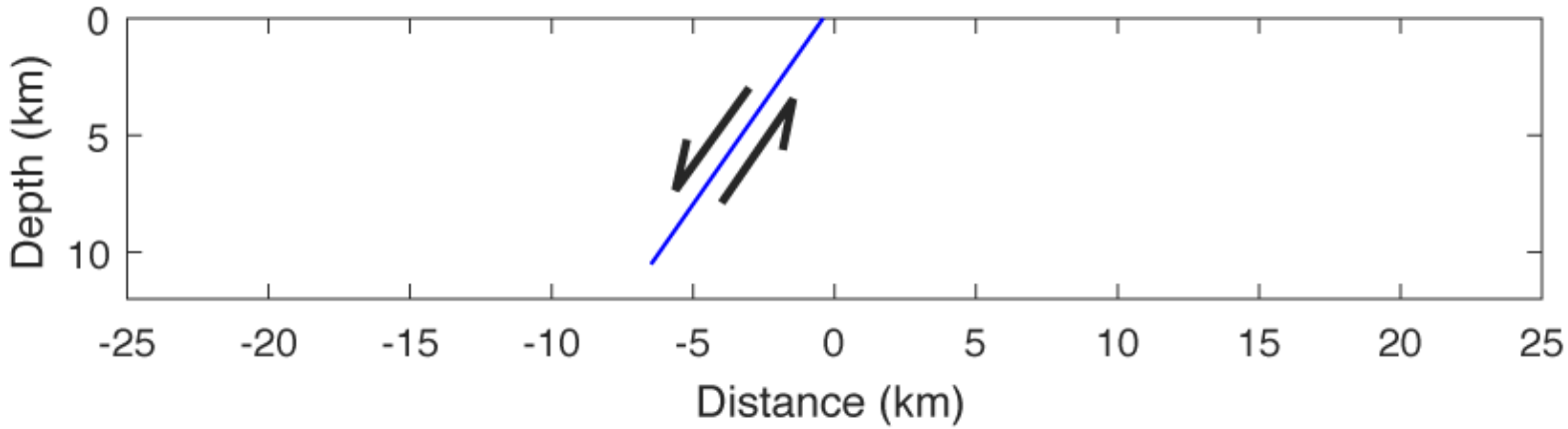
Learning goals

- Visualize how earthquakes permanently deform landscapes
- Describe the relationship between fault slip, surface displacement, and earthquake magnitude
- Interpret quantitative geospatial datasets
- Practice writing scientific methods and interpretations for an experiment with uncertainty

Earthquake background: Fault geometry



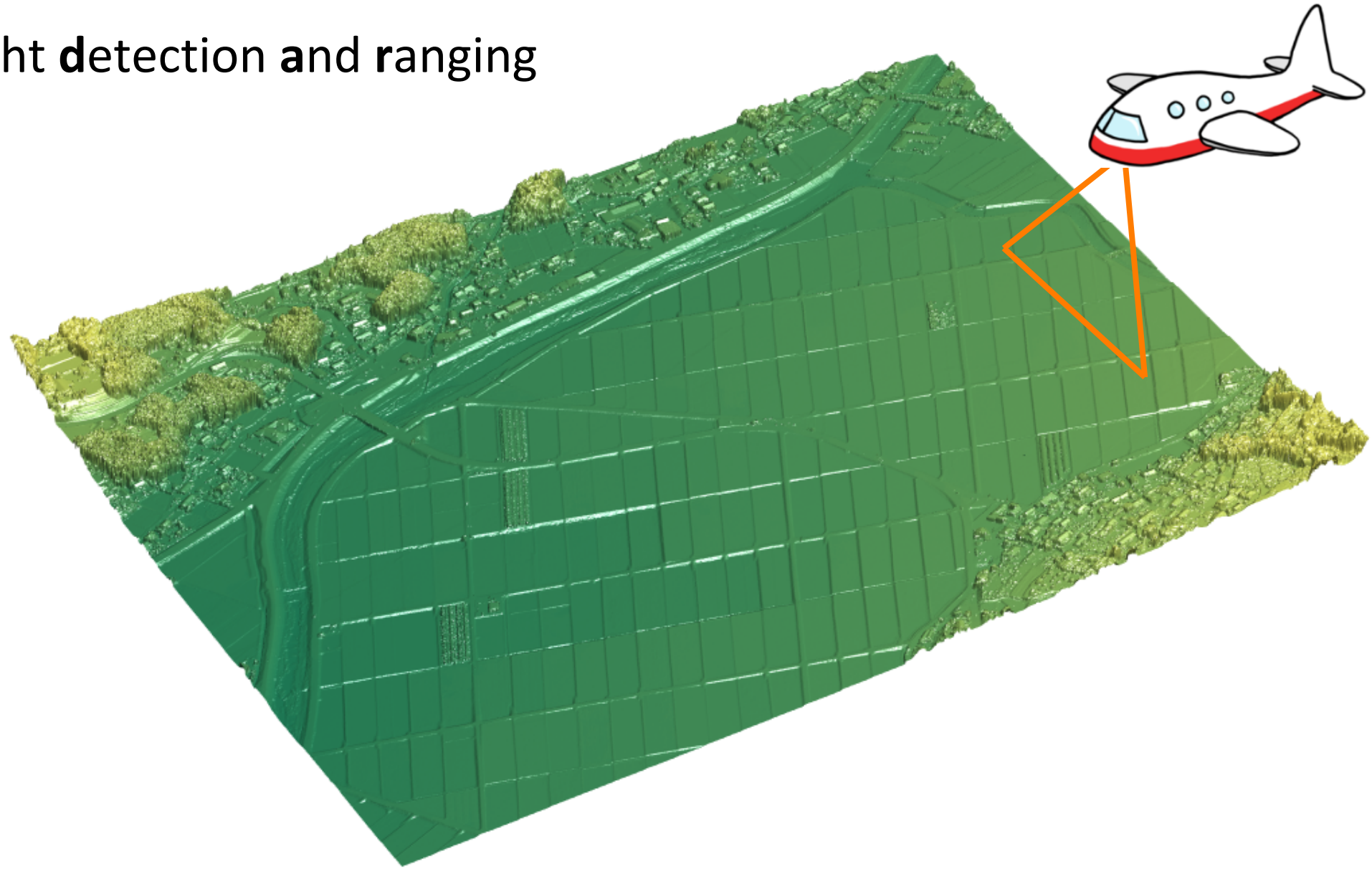
Earthquake background: Surface displacement



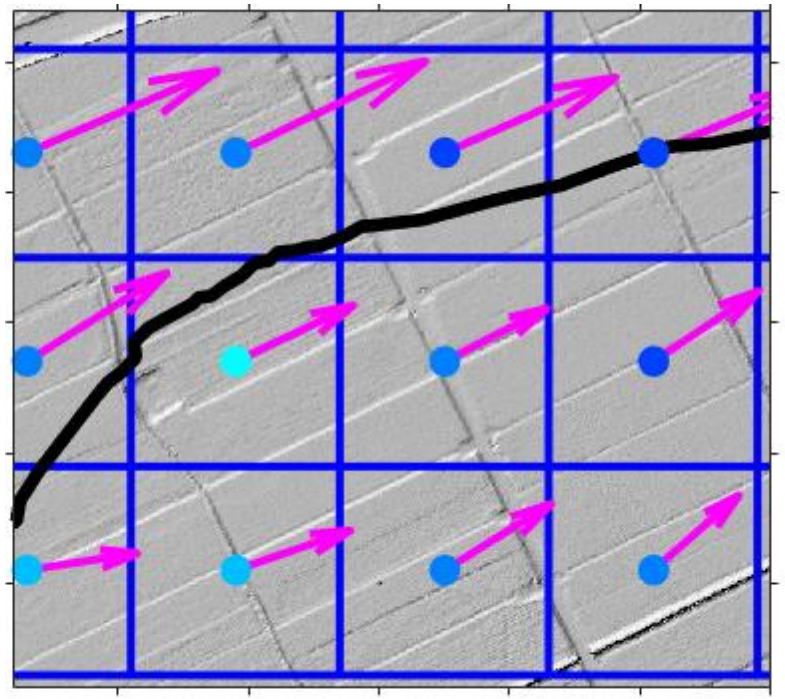
30 cm of fault slip

Topographic differencing

Lidar: **l**ight **d**etection **a**nd **r**anging

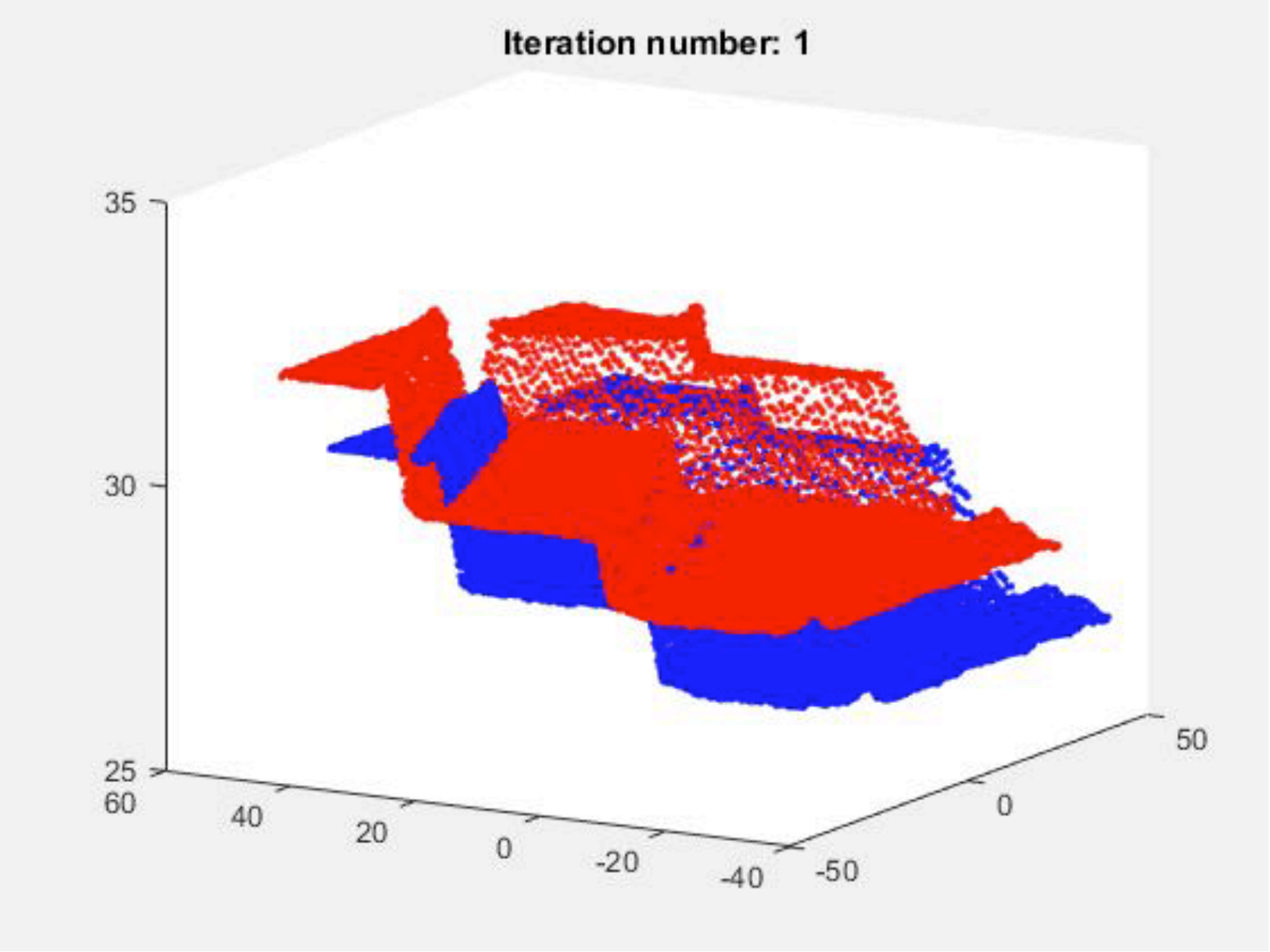


Coseismic displacement

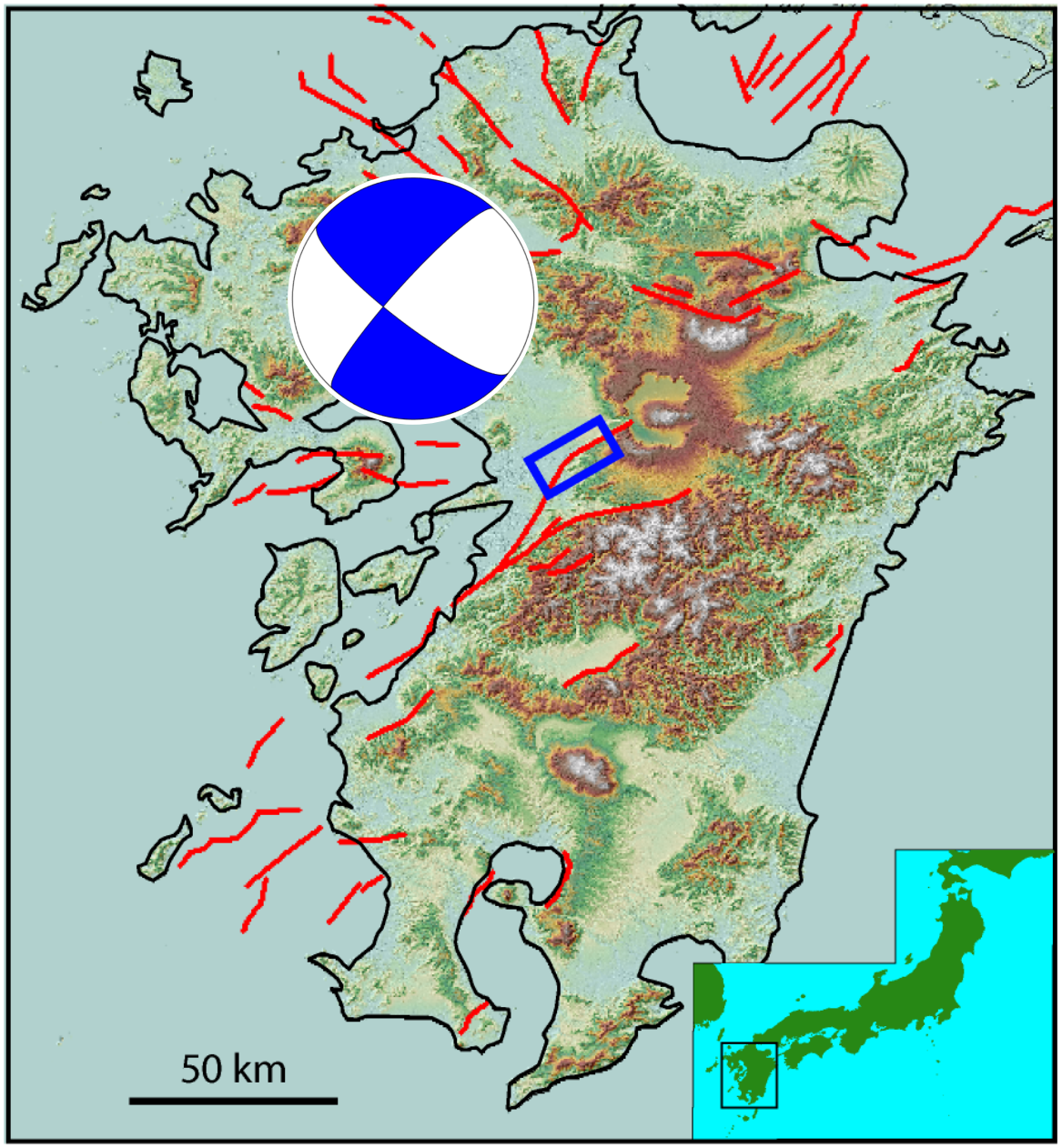


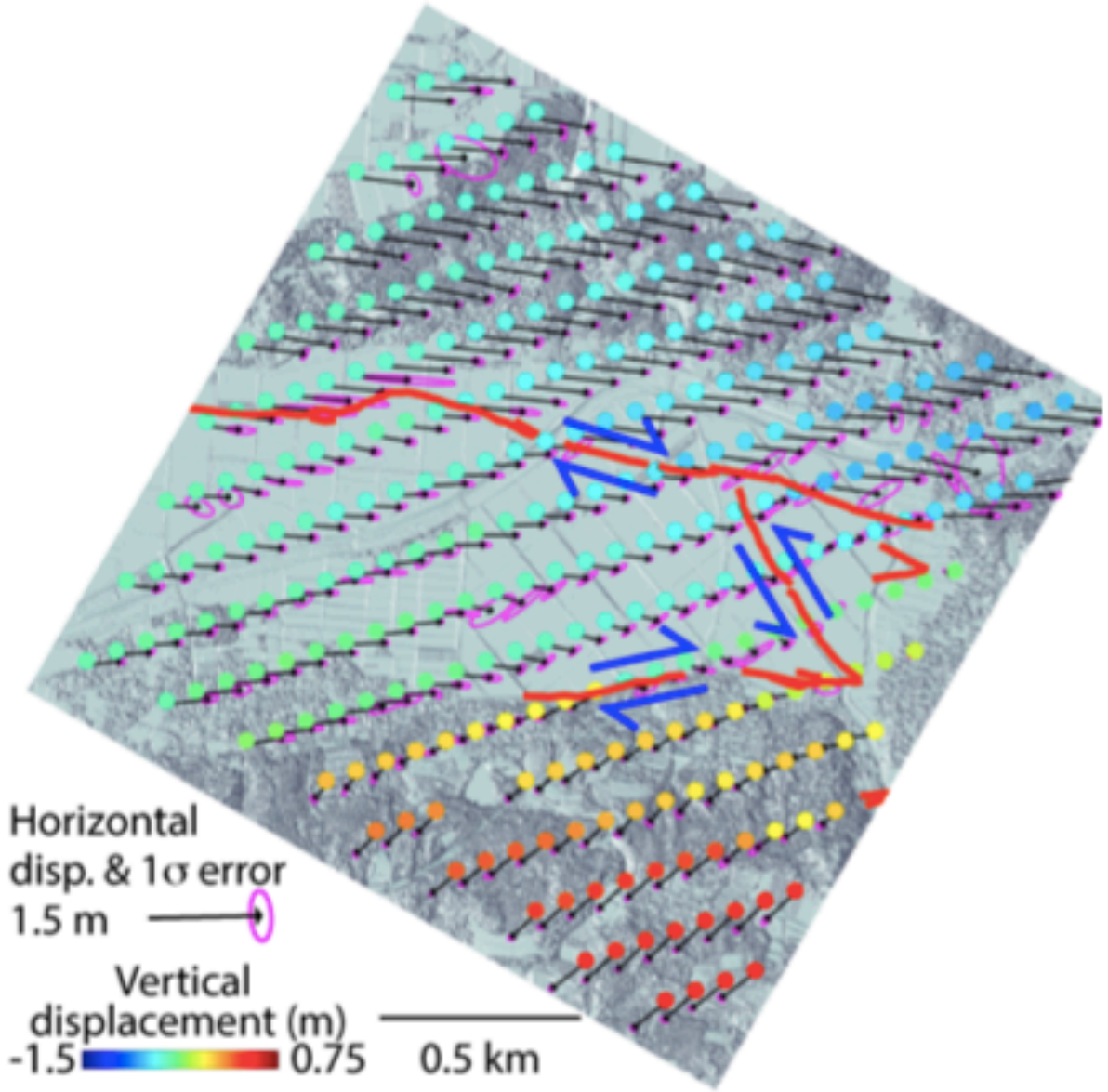
Iterative Closest Point

- https://www.youtube.com/watch?v=uzOCS_gdZuM



Align the pre-earthquake and post-earthquake topography

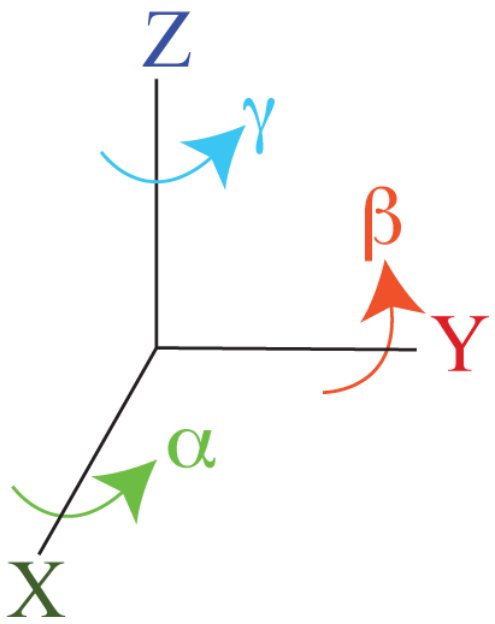

50 km


Horizontal
disp. & 1σ error
1.5 m
Vertical
displacement (m)
-1.5
0.75
0.5 km

3D rigid deformation

$$\text{Deformed point cloud} = \begin{bmatrix} 1 & -\gamma & \beta \\ \gamma & 1 & -\alpha \\ -\beta & \alpha & 1 \end{bmatrix} \begin{bmatrix} \text{Undeformed point cloud} \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix}$$

Rotation Translation



Coordinate system

ICP references: Besl and McKay (1992); Nissen et al., (2012; 2014); Scott et al., (2018)

Describing deformations with linear algebra

Full 3D rotation and translation

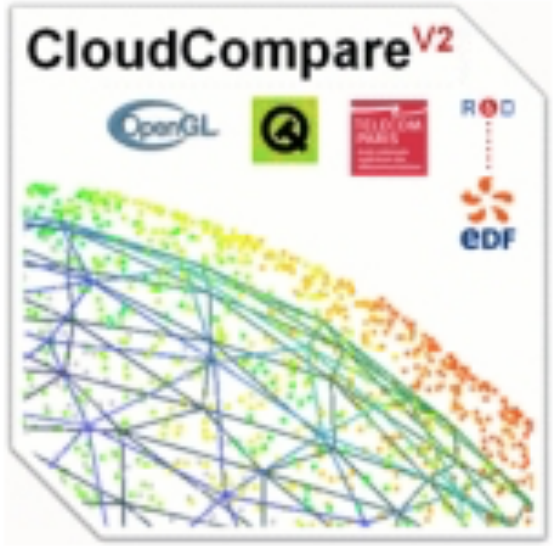
$$\varphi = \begin{pmatrix} 1 & -\gamma & \beta & t_x \\ \gamma & 1 & -\alpha & t_y \\ -\beta & \alpha & 1 & t_z \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

α: *x axis rotation*
β: *Y axis rotation*
γ: *Z axis rotation*

t_x: *x translation*
t_y: *y translation*
t_z: *z translation*

Differencing on the Wasatch fault

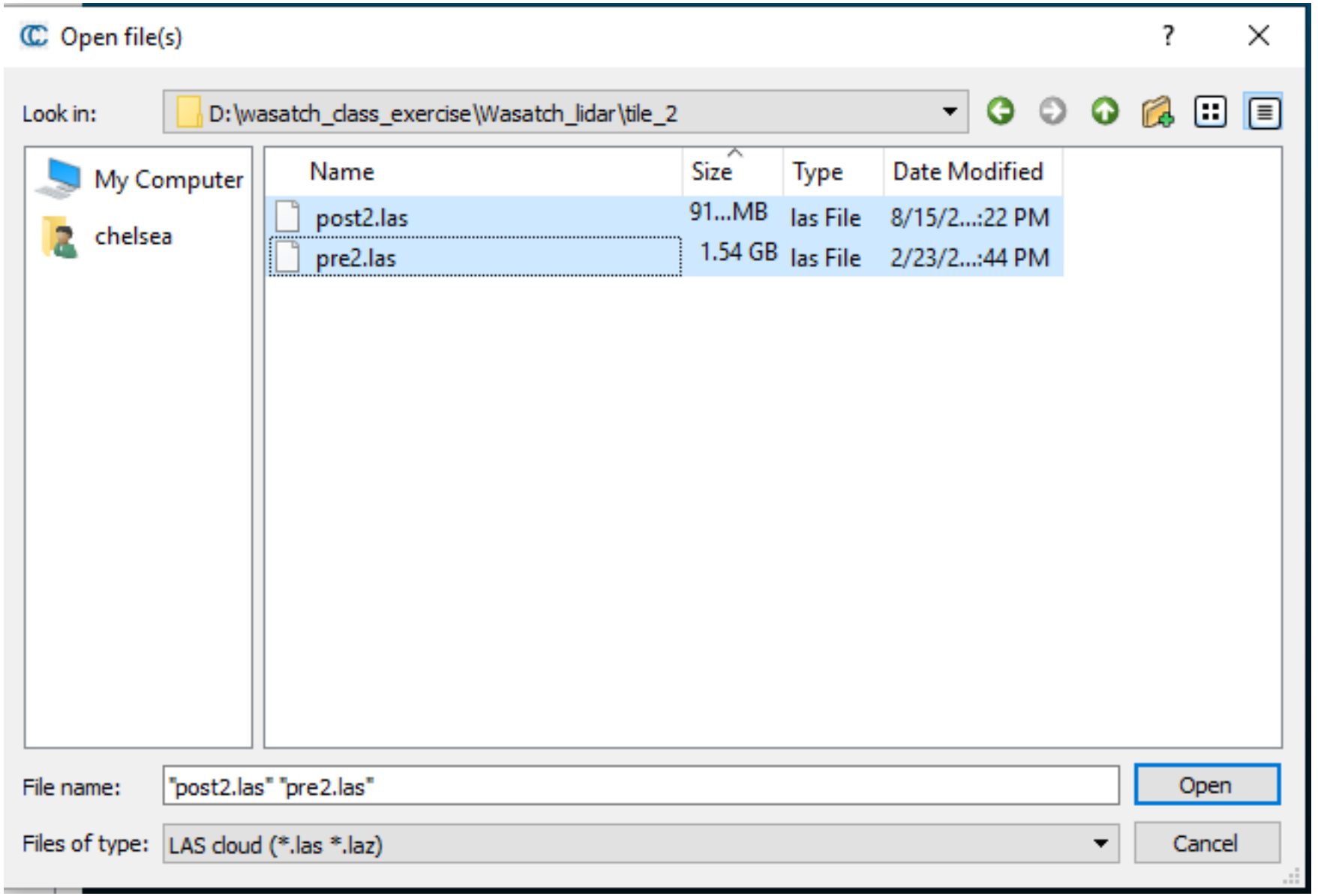
Cloud Compare



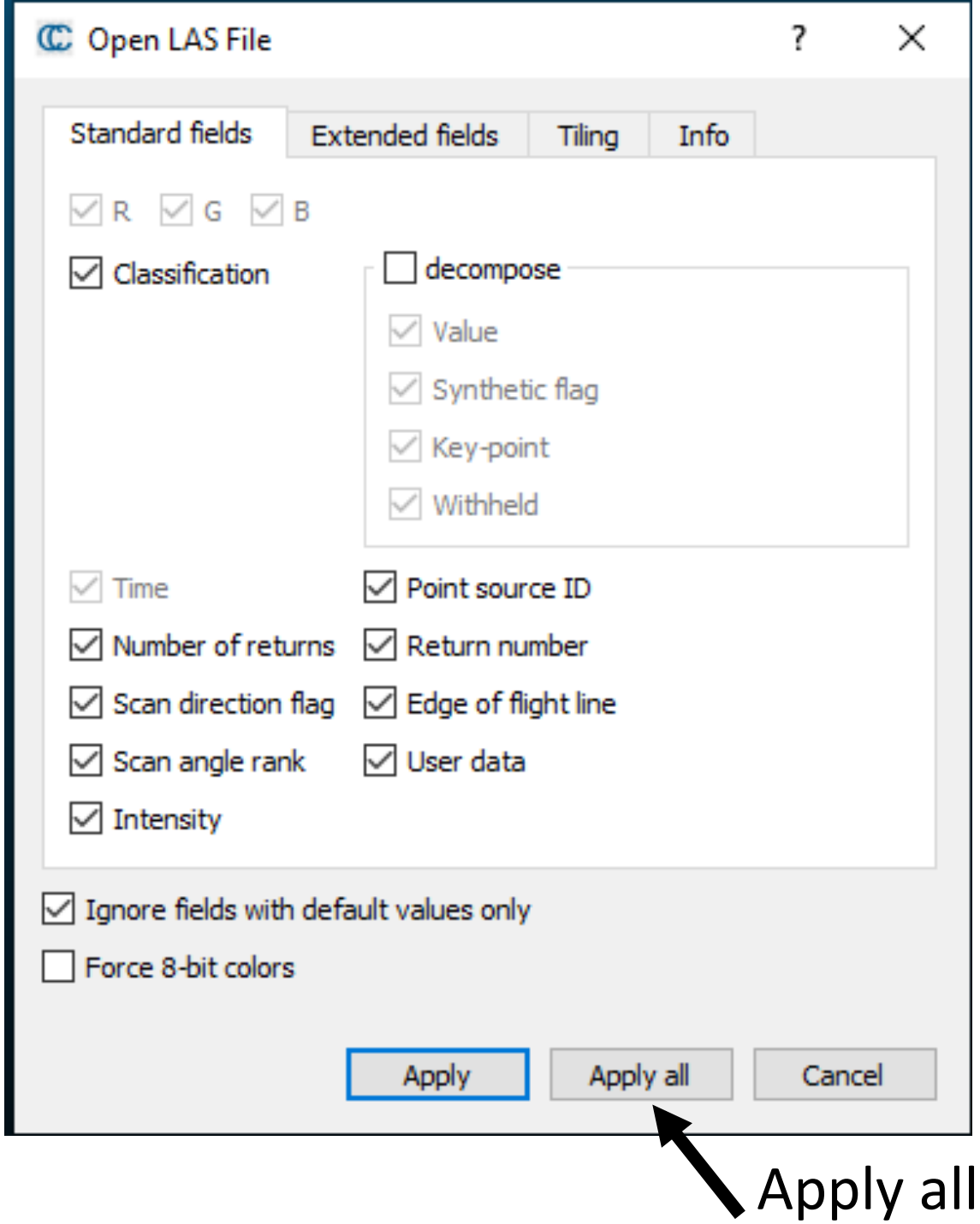
CloudCompare

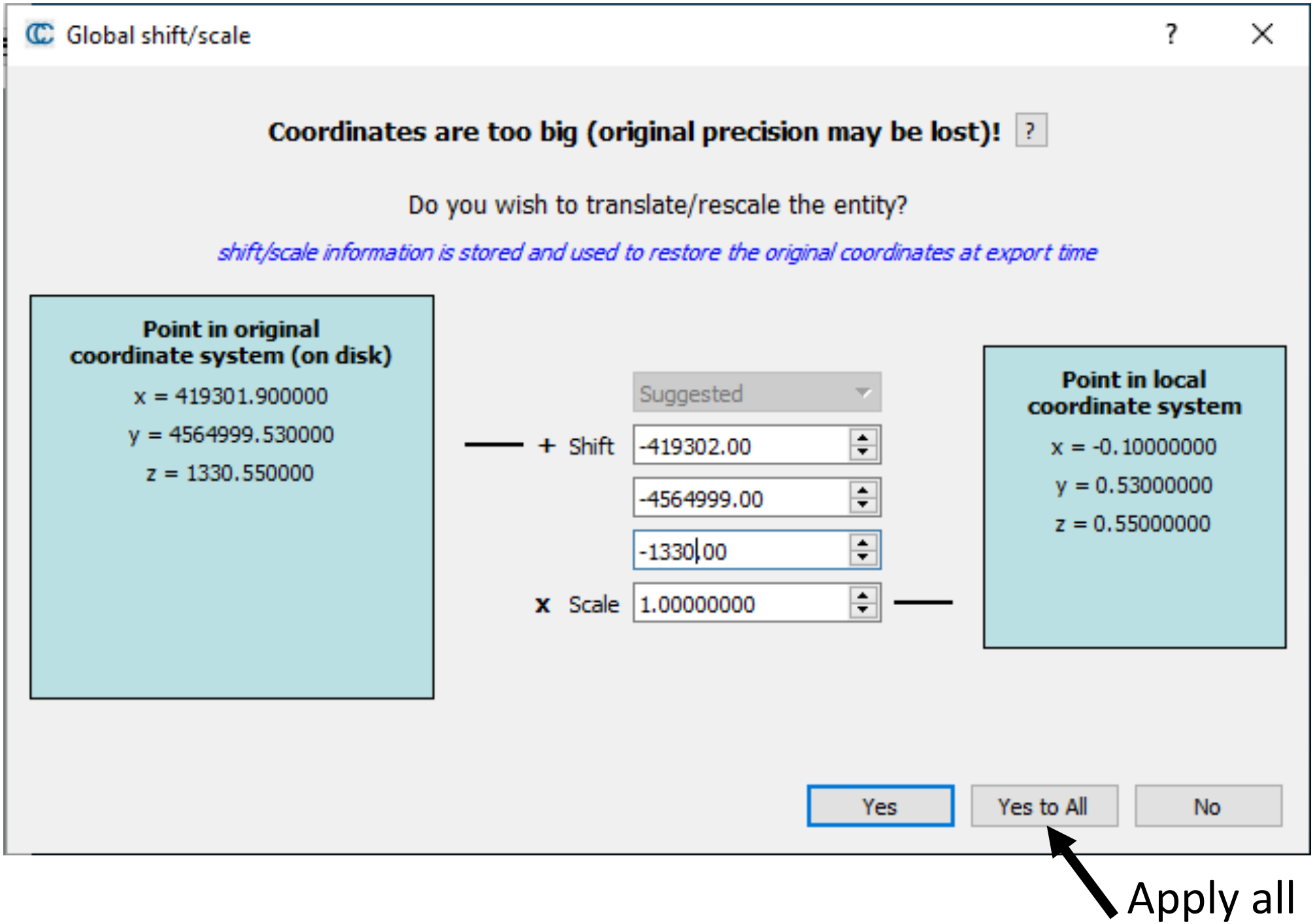
3D point cloud and mesh processing software
Open Source Project

Daniel Girardeau-Montaut
www.danielgm.net/cc/



Open pre- and post-earthquake .las files at the same time


Open LAS File
Standard fields
Extended fields
Tiling
Info
R
G
B
Classification
decompose
Value
Synthetic flag
Key-point
Withheld
Time
Point source ID
Number of returns
Return number
Scan direction flag
Edge of flight line
Scan angle rank
User data
Intensity
Ignore fields with default values only
Force 8-bit colors
Apply
Apply all
Cancel
Apply all

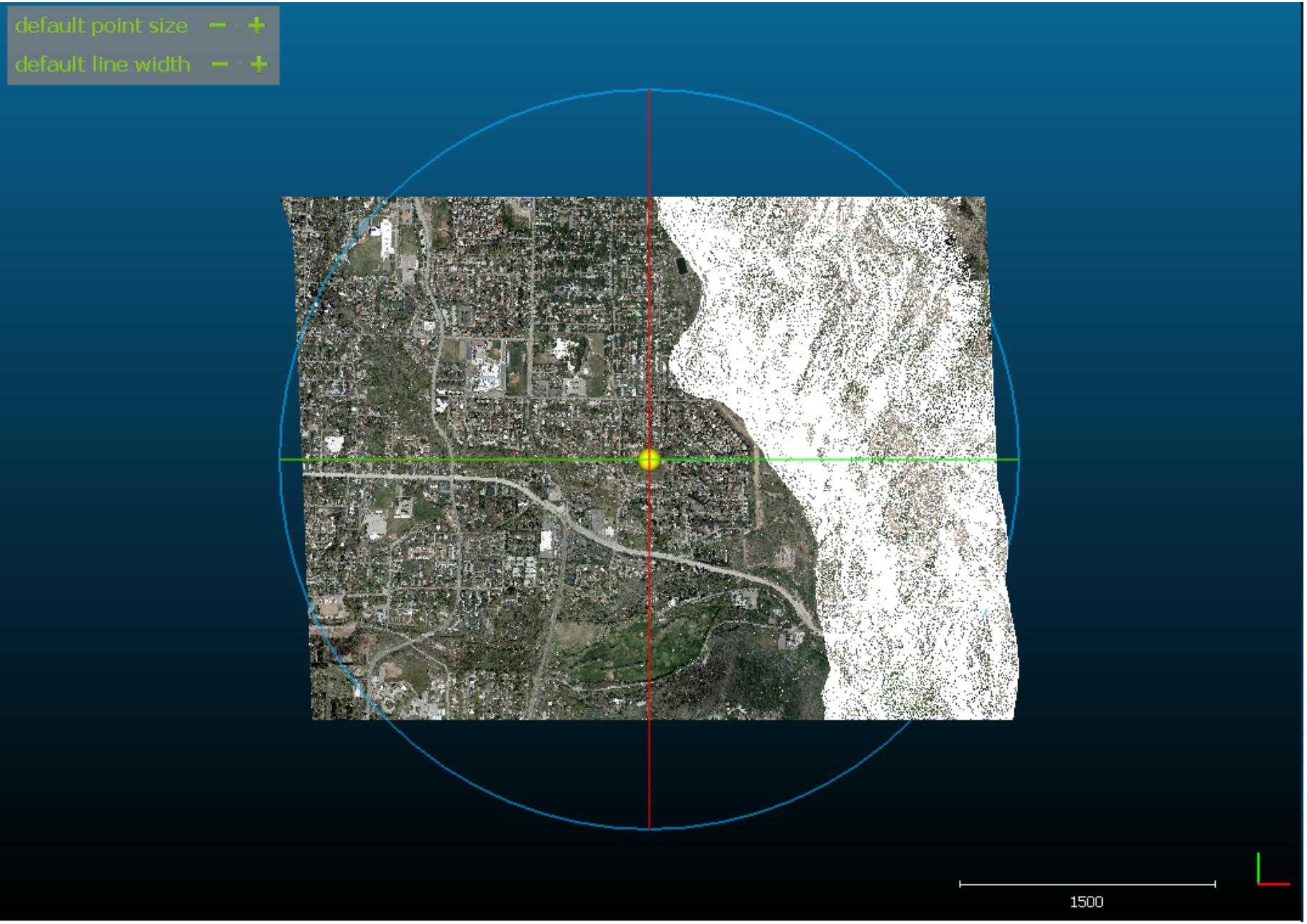


Apply a coordinate system shift to transform the point to ~(0,0,0).

Why?

1. Coordinates are too big.
2. Center of ICP rotation needs to be within the tile.

Apply all

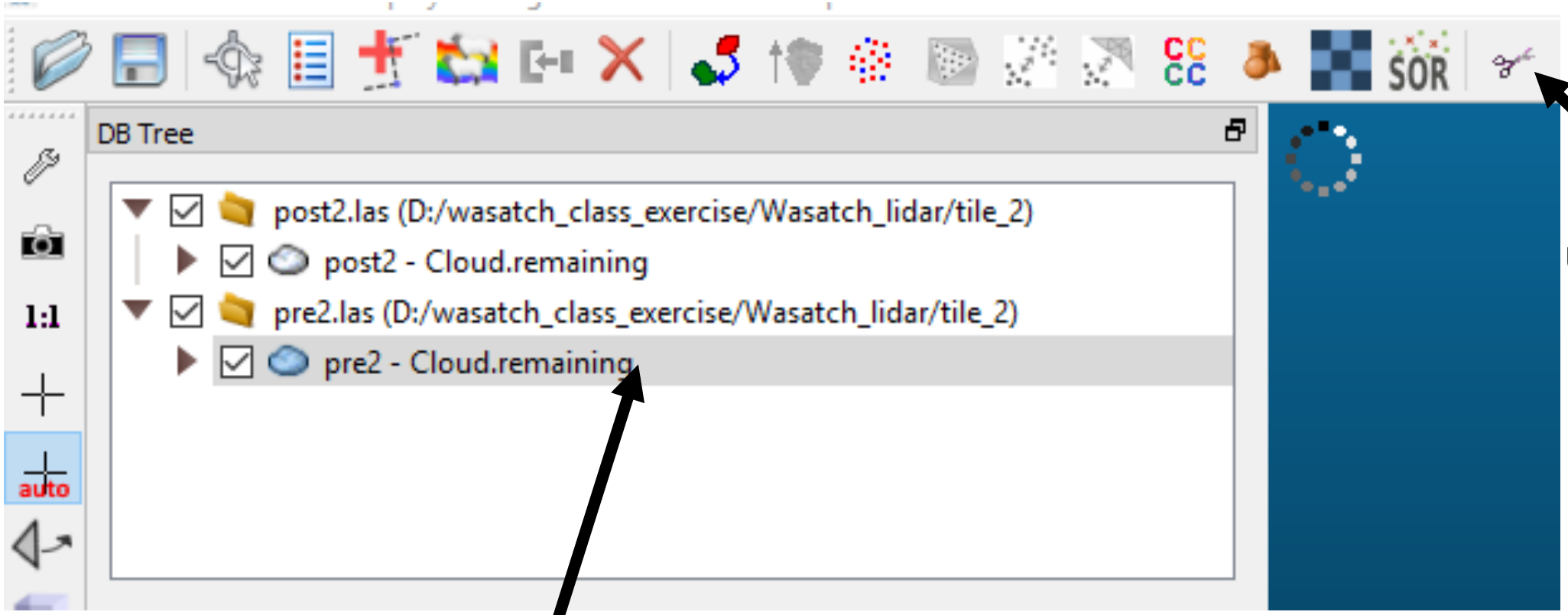


Point clouds:

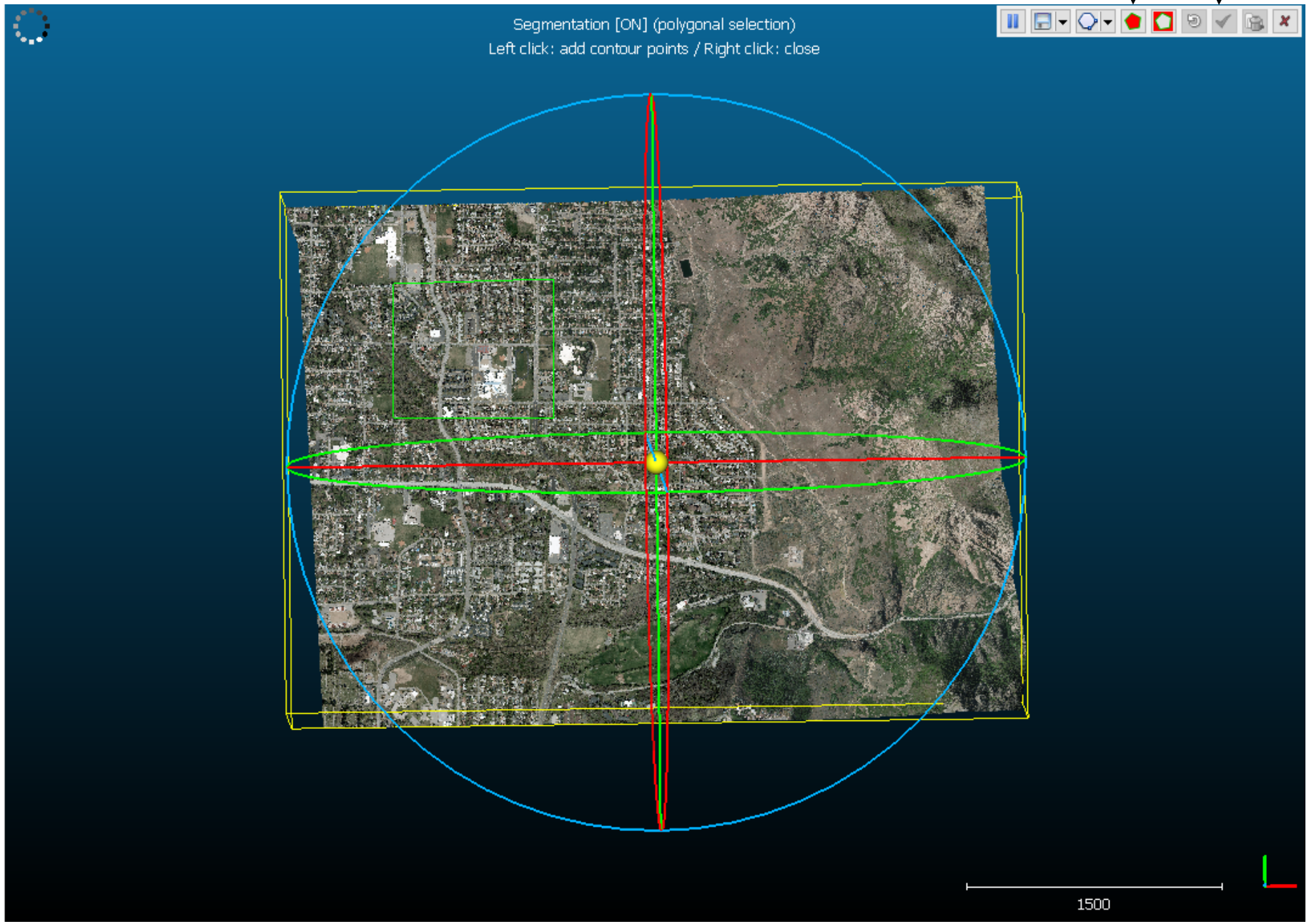
RGB: Pre-earthquake

White: Post-earthquake

Cut window for topographic differencing



Segment in ↓ ↓ Green check

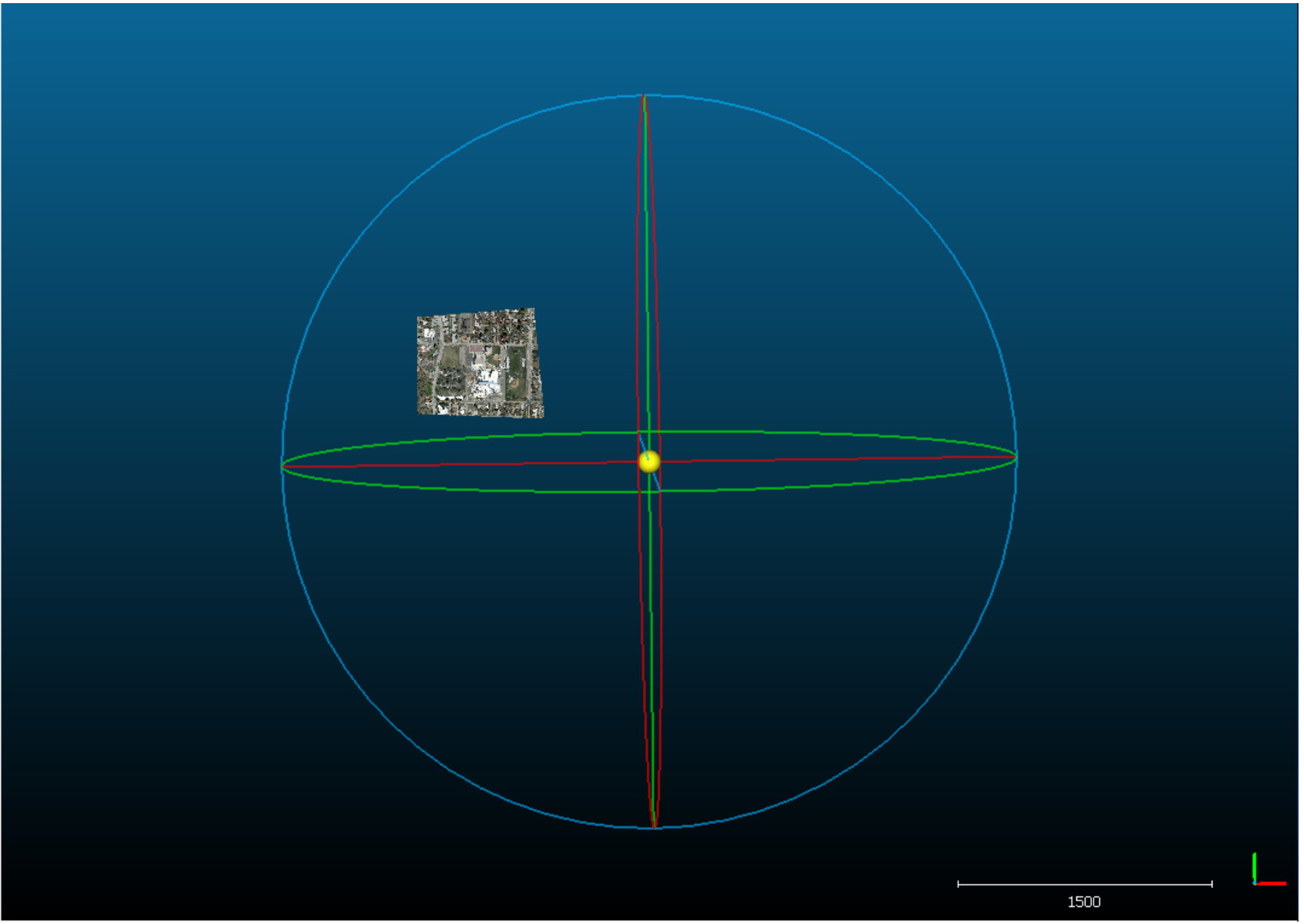


Cut a box for ICP

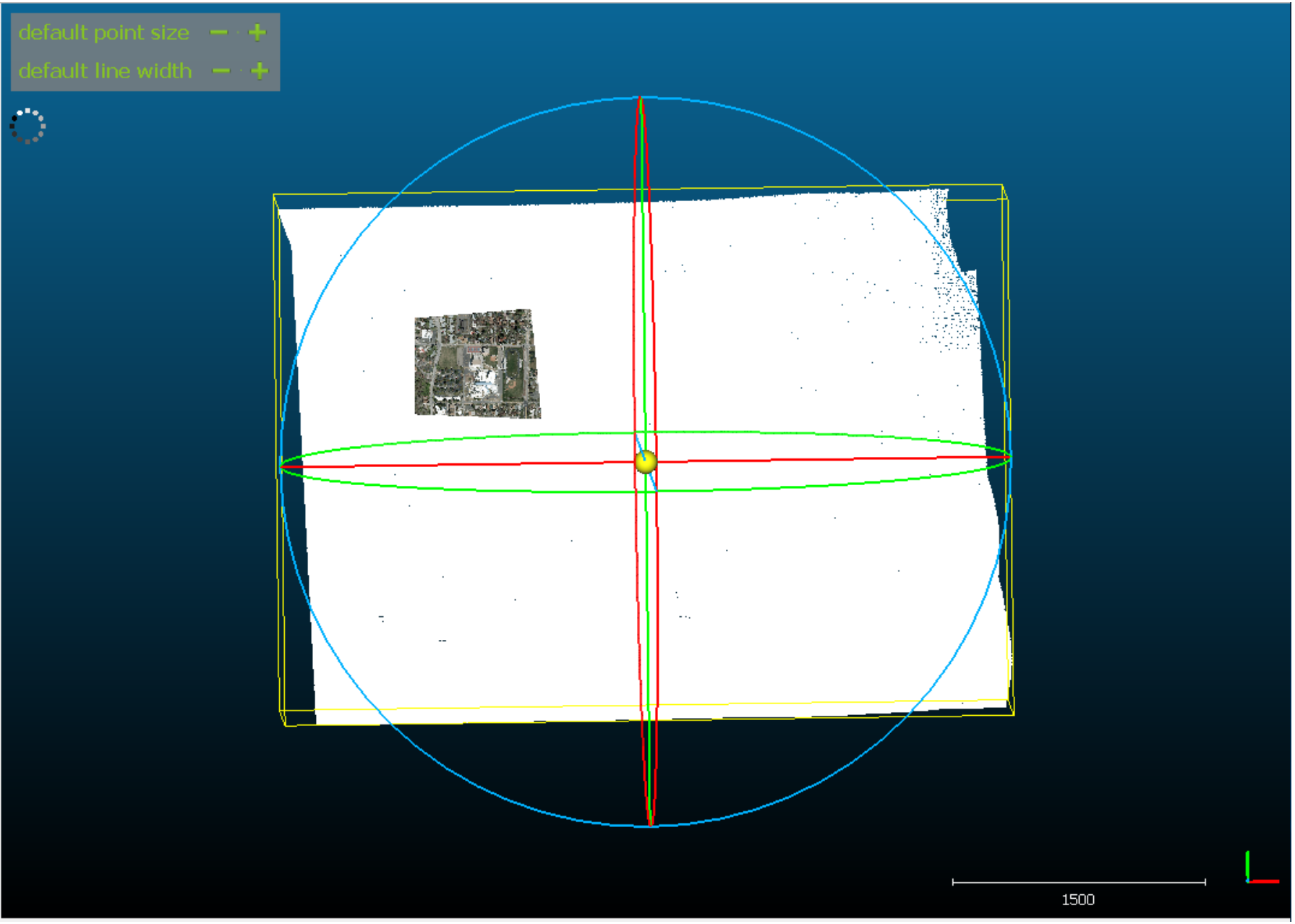
Length: 500 m – 1km

Steps:

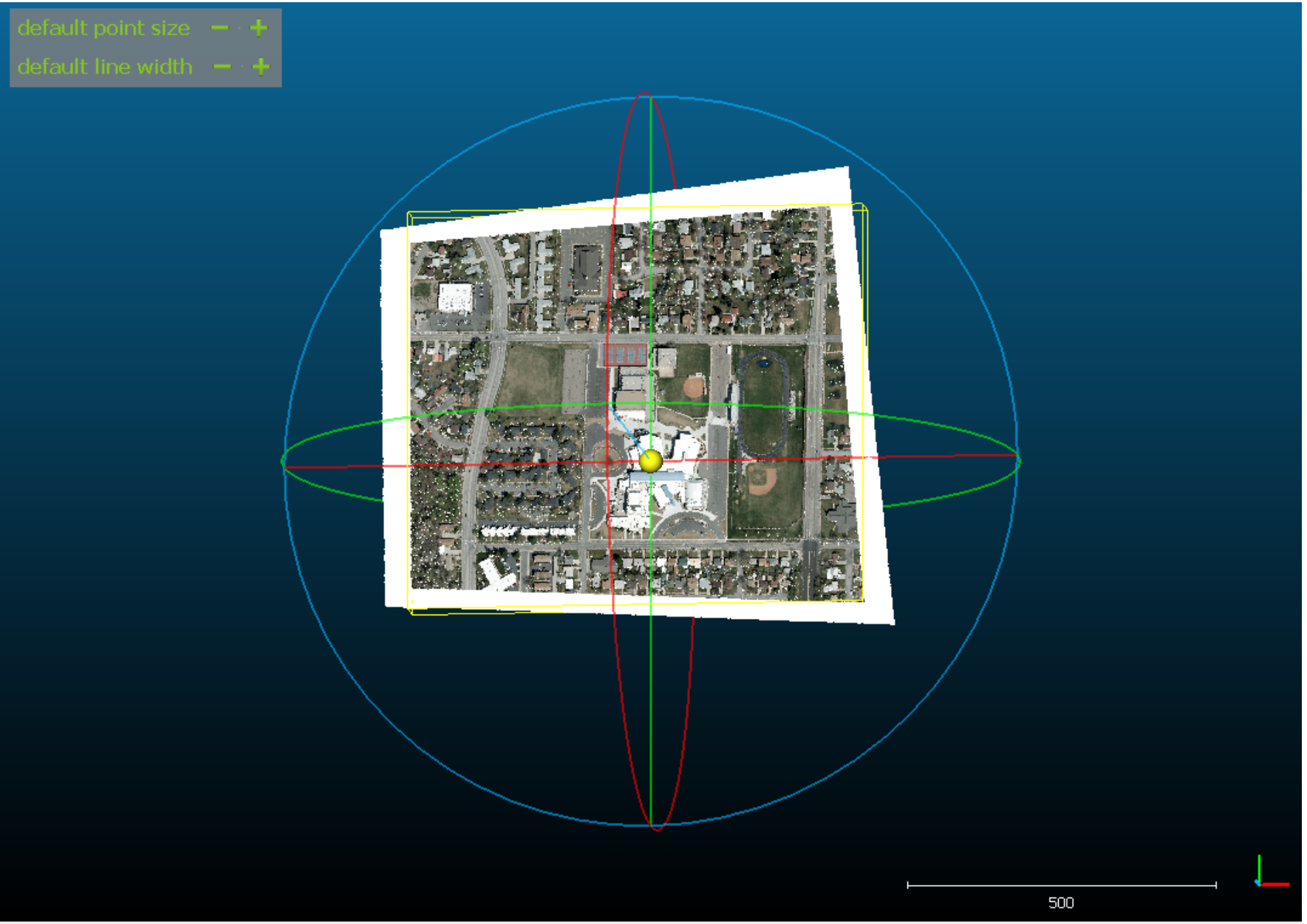
1. Left click to outline the square
2. Right click when done
3. Segment in
4. Green check



Cutting tool result



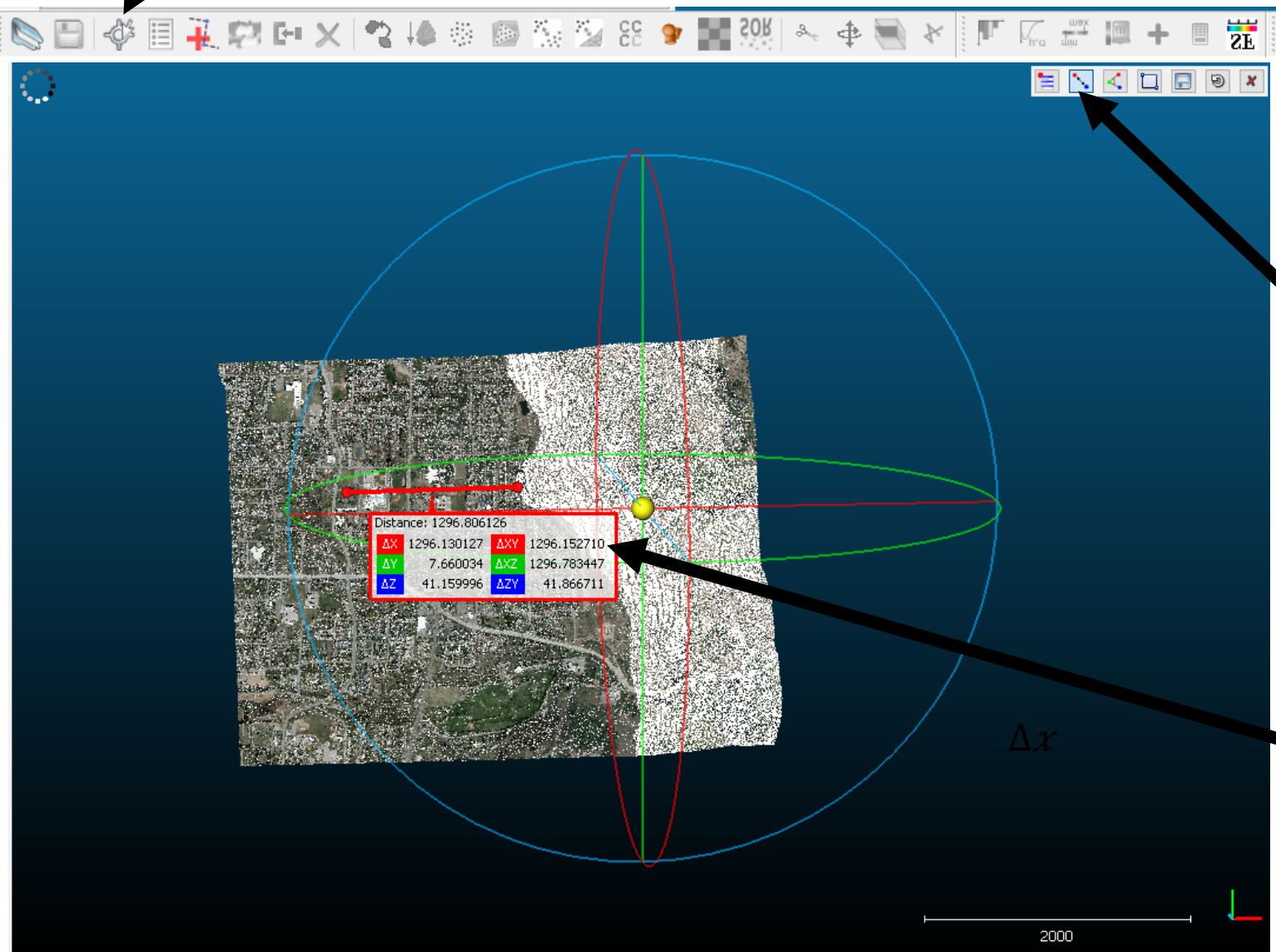
Show the cut pre-earthquake (RGB) with the full post-earthquake (White)



Cut the post-earthquake point cloud to be a little bit larger than the pre-earthquake point cloud.

Calculate distance to fault

Point picker

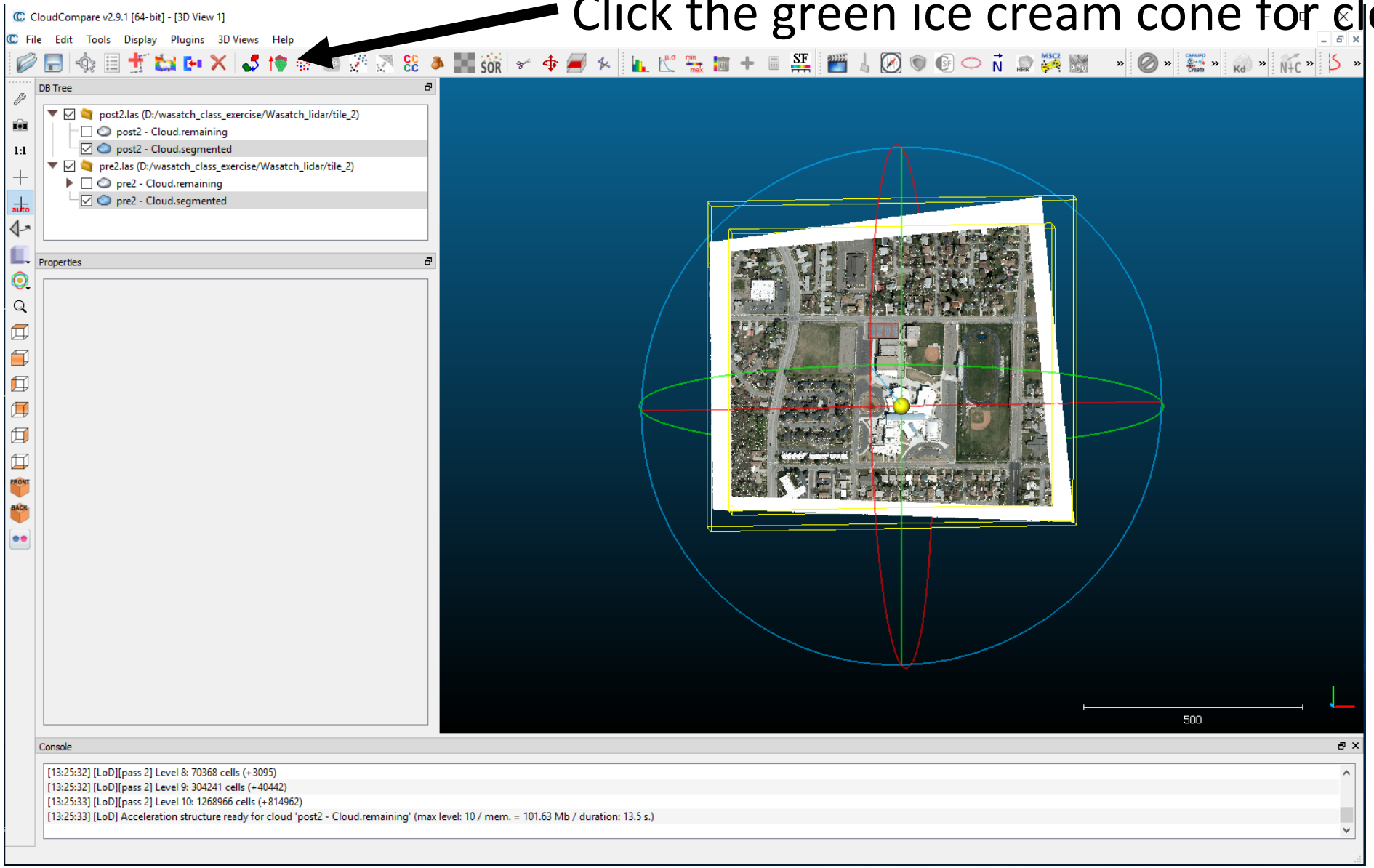


Measure distance between two point

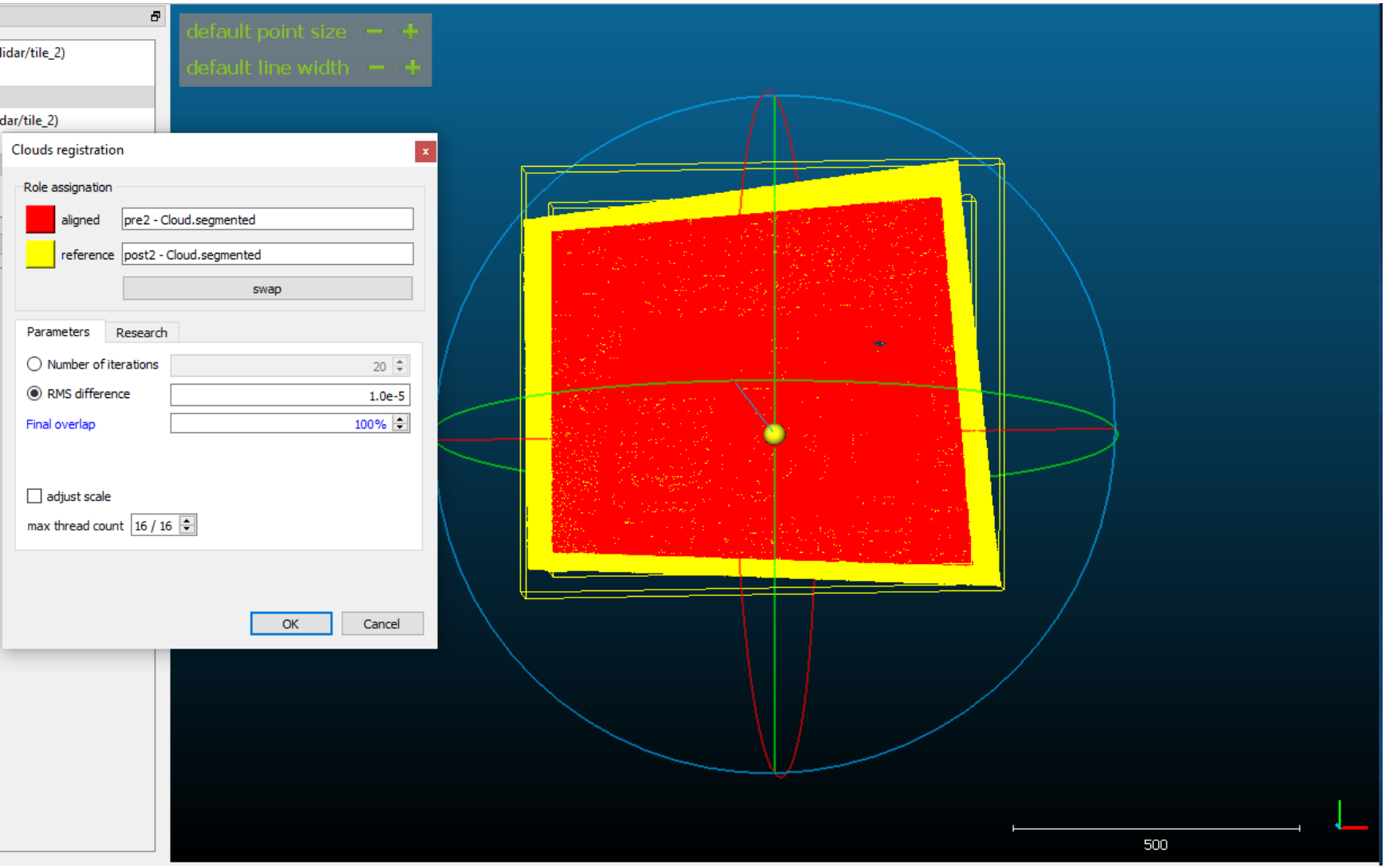
ICP differencing

Select cut point clouds

Click the green ice cream cone for cloud registration



ICP differencing

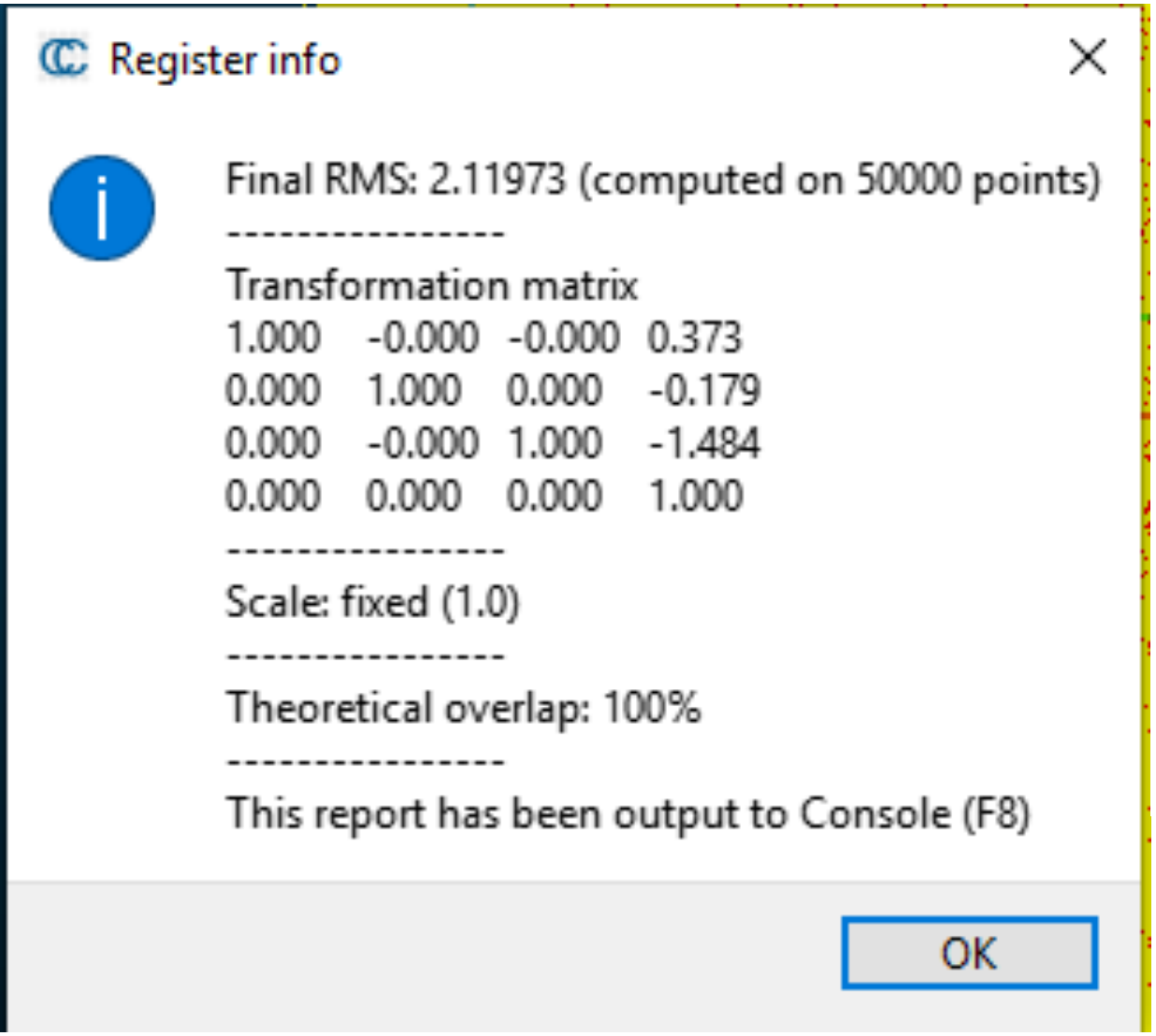


Role assignment

Aligned: Pre-earthquake
Reference: Post-earthquake

Swap to switch, if needed

ICP differencing



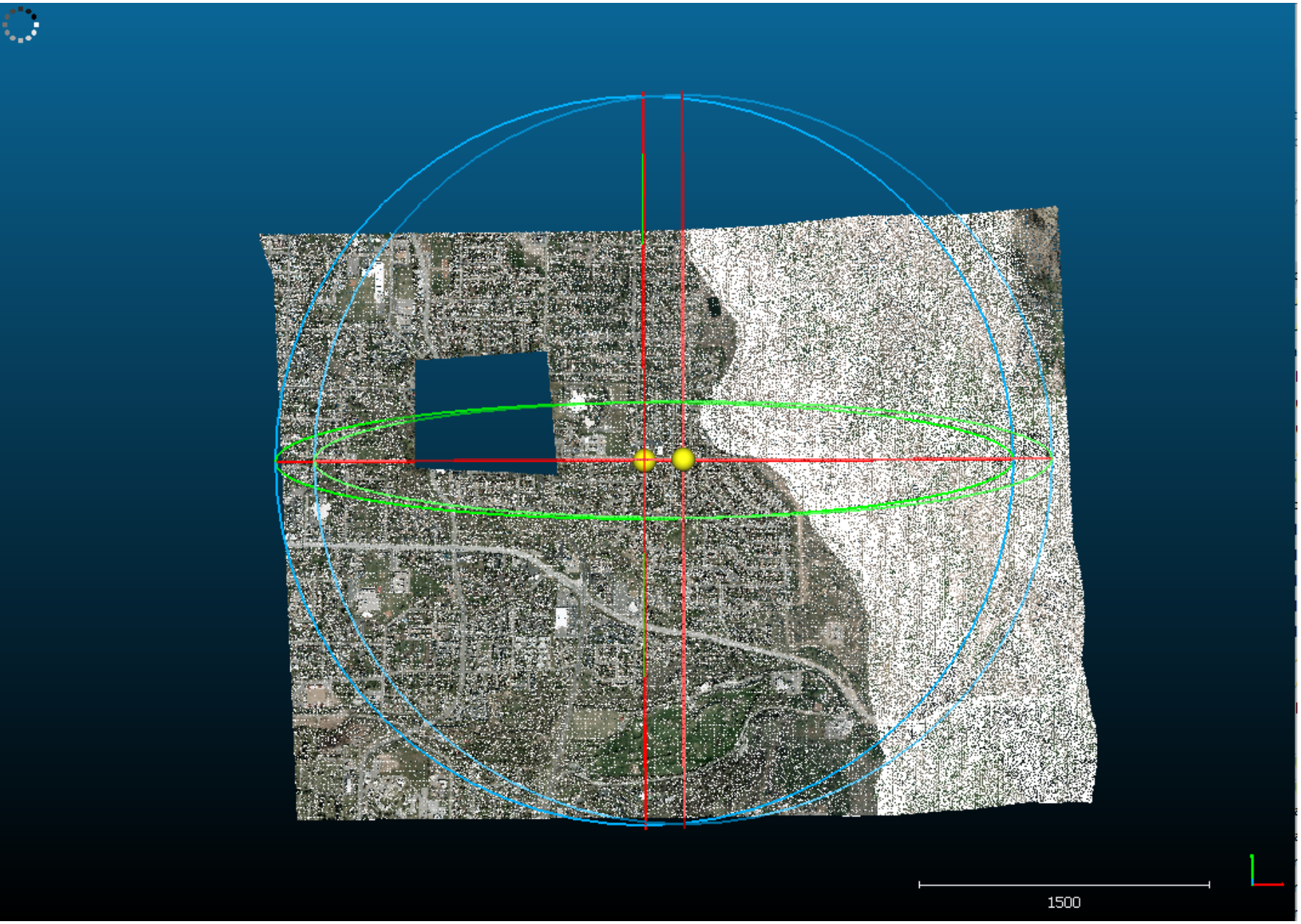
Full 3D rotation and translation

$$\varphi = \begin{pmatrix} 1 & -\gamma & \beta & t_x \\ \gamma & 1 & -\alpha & t_y \\ -\beta & \alpha & 1 & t_z \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

α: *x axis rotation*
β: *Y axis rotation*
γ: *Z axis rotation*

t_x: *x translation*
t_y: *y translation*
t_z: *z translation*

t_x: E-W displacement (positive East)
t_y: N-S displacement (positive North)
t_z: Vertical displacement (positive Up)



For organization, delete the tile once finished with ICP.

Good lesson

- If you do something wrong, it is often best to quit and restart Cloud Compare.
- No undo tool

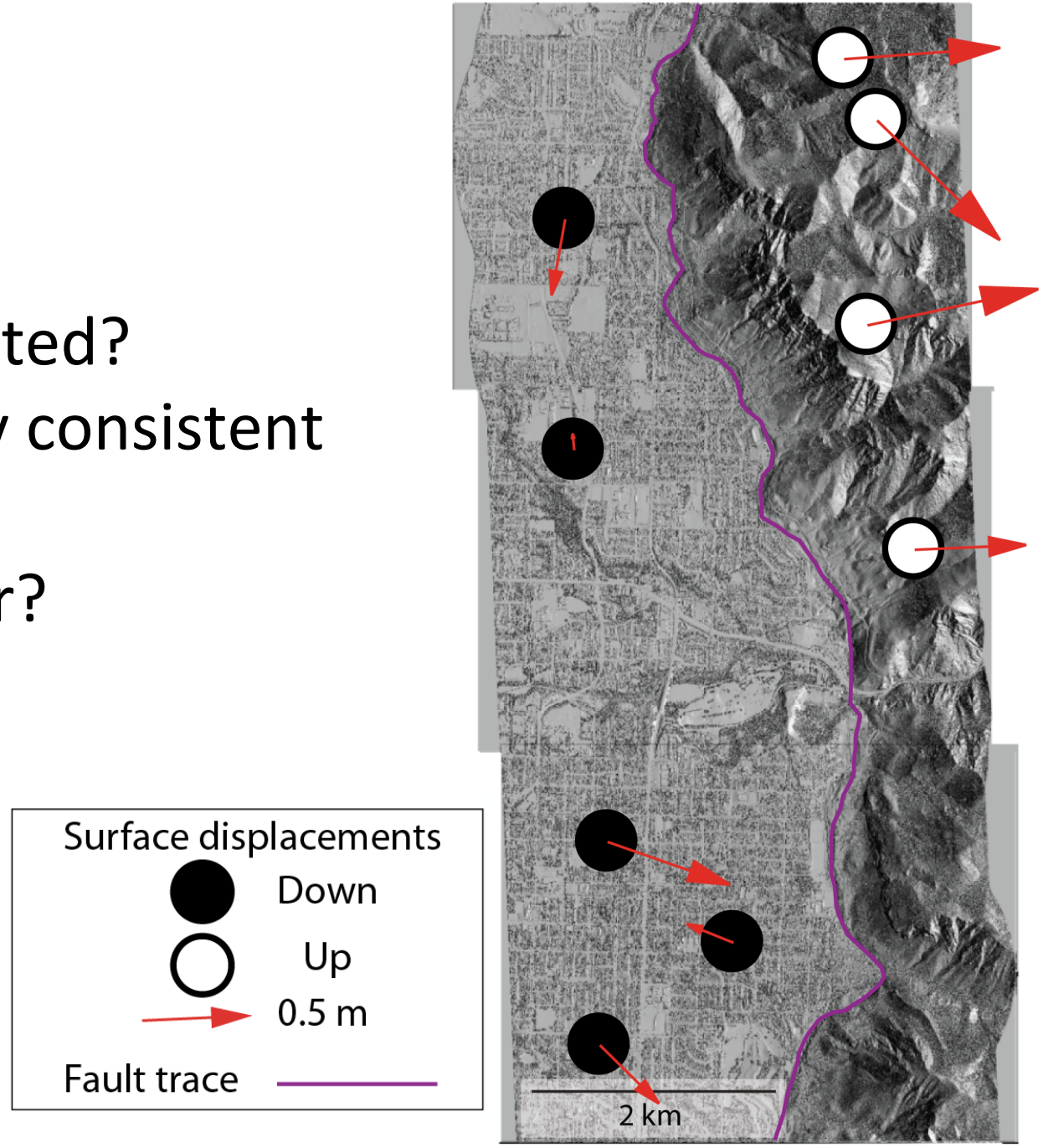
Pre-earthquake

Post-earthquake

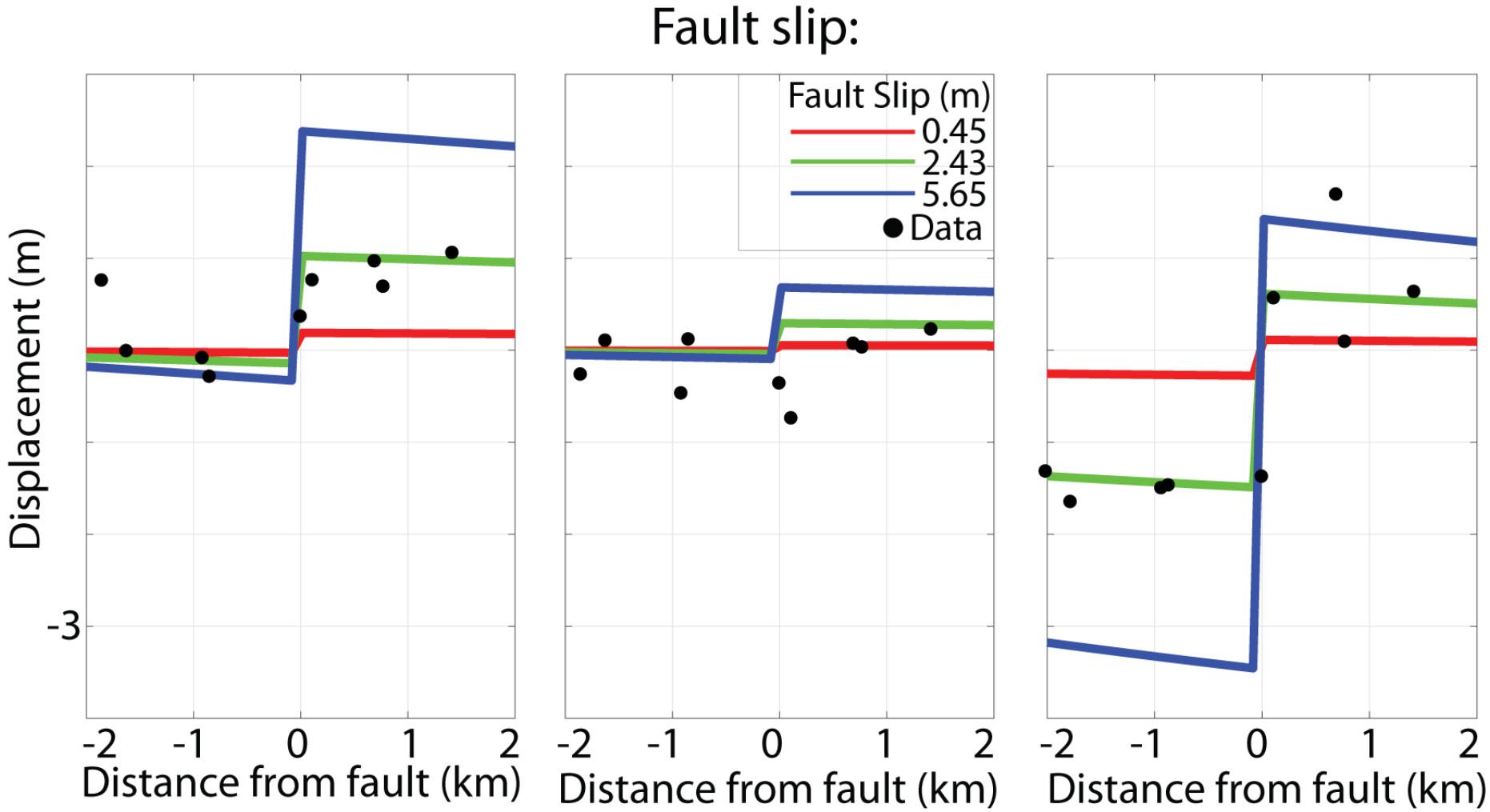
Mapped rupture

ICP results

What type of fault was activated?
Are all measurements exactly consistent with this type of fault?
What are the sources of error?

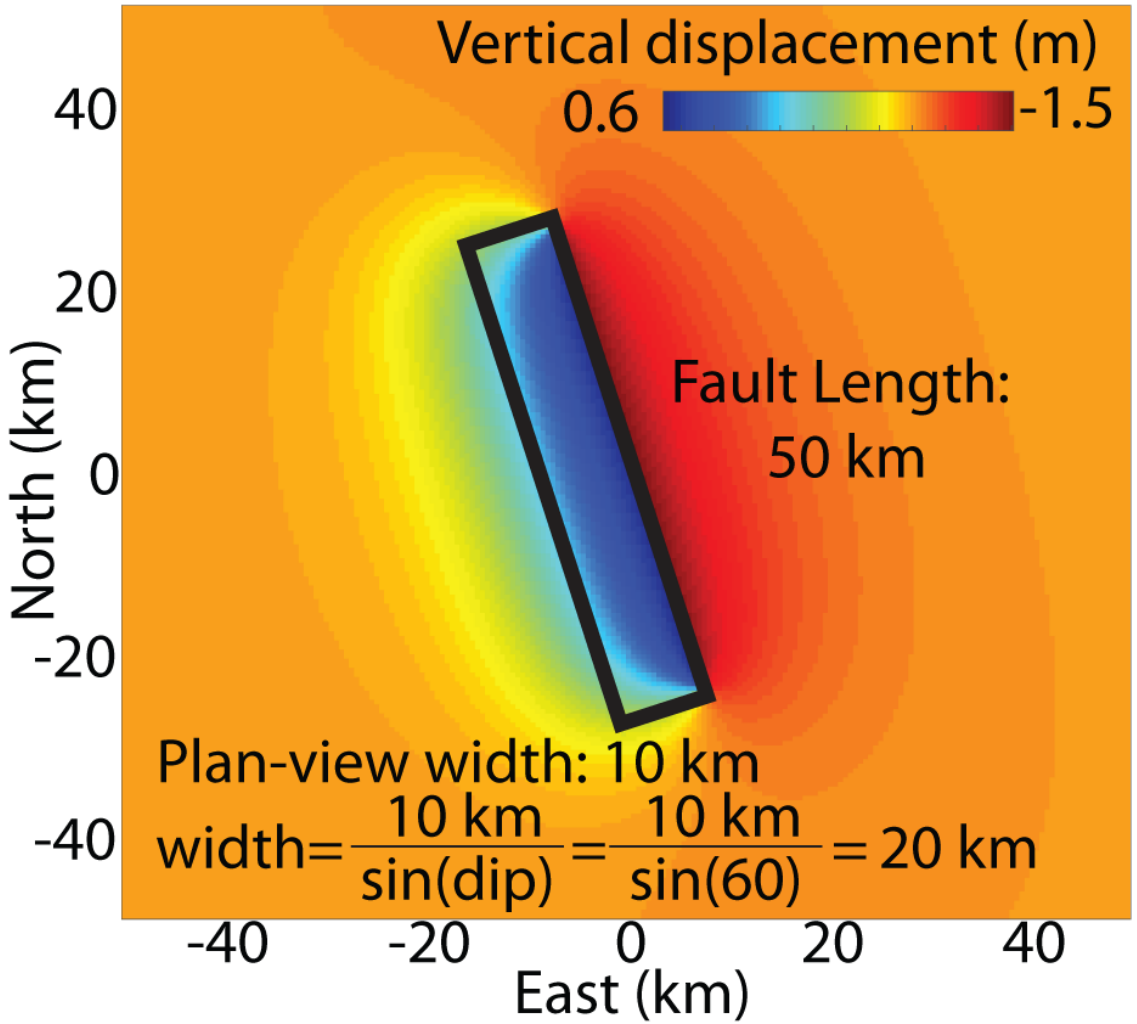


Fault slip



The surface displacements align with 2.43 m of fault slip.

Fault area:



Fault outline in black

Magnitude calculation:

Slip=2.43 m

Area=20 km x 50 km=1000km^2

M_o=7.7x10^{19} Nm

M_w=7.2