Iterative Closest Point Differencing

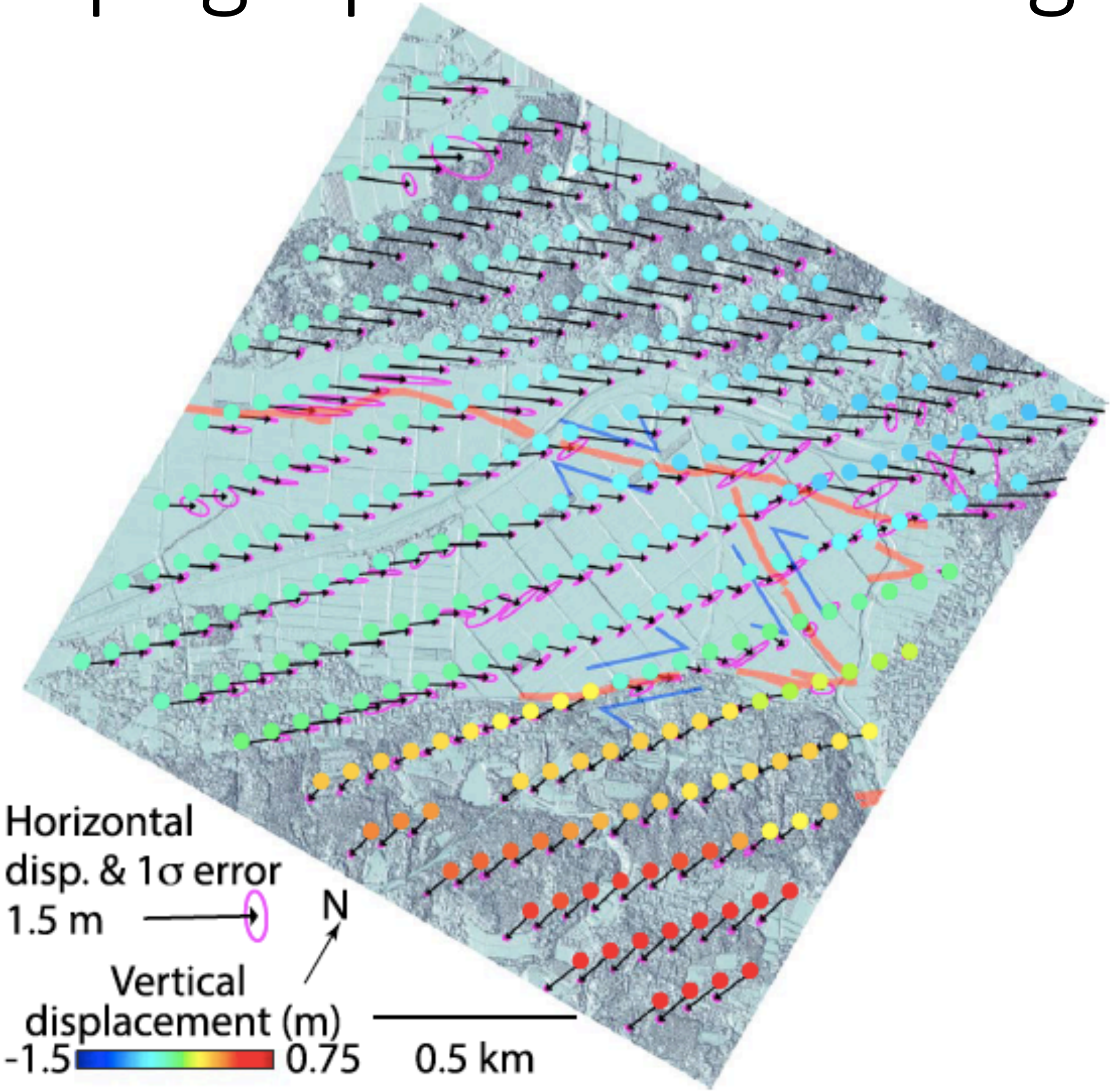
Chelsea Scott

With contributions from Edwin Nissen

Outline

- Brief motivation
- Technical introduction to differencing
- Processing Choices
  - Window size
  - Grid spacing
  - Coordinate system origin
  - Point-to-point vs. Point-to-plane error penalty
- Matlab demo
- How do I perform topographic differencing on my own datasets?
- PLEASE ASK QUESTIONS!!

Topographic differencing



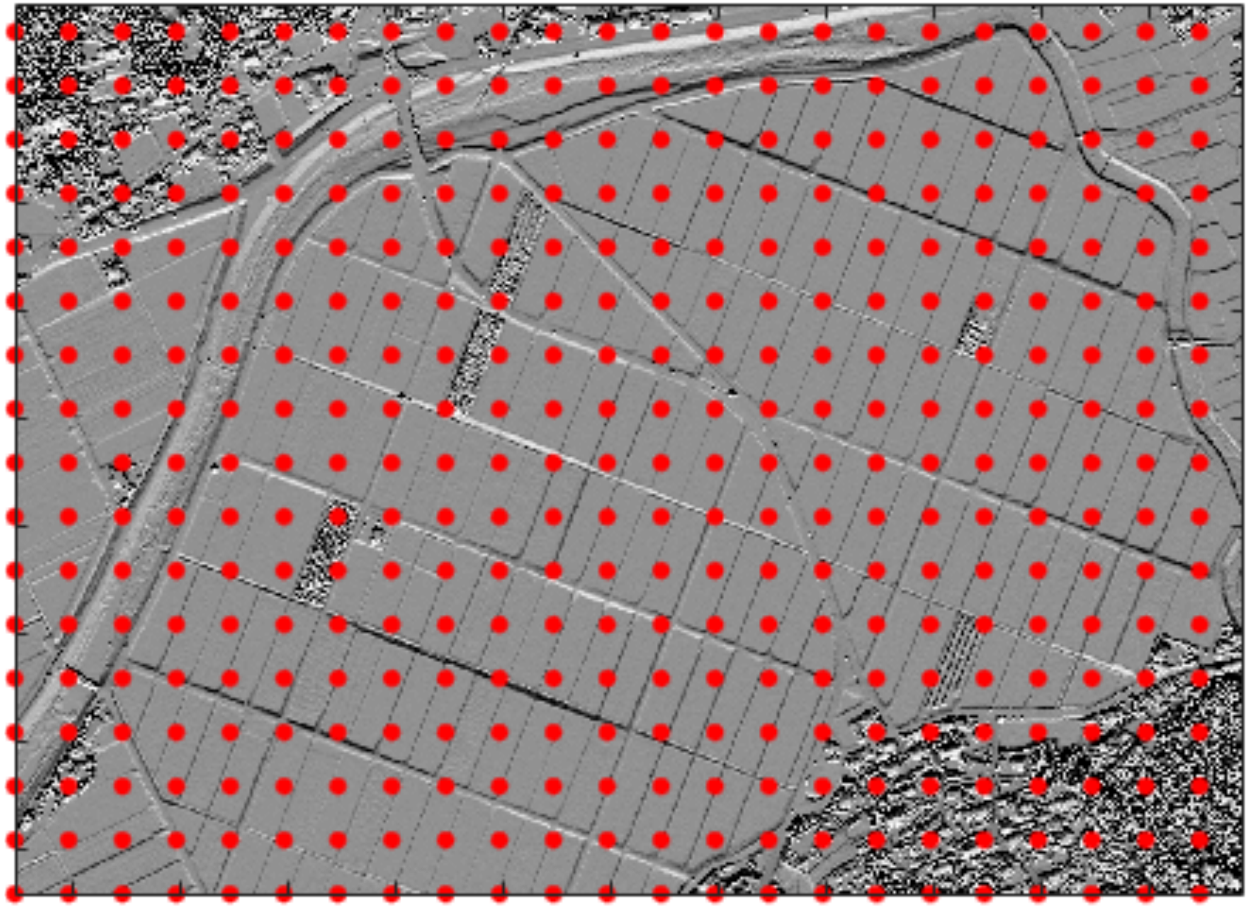
- Calculate 3D on- and off-fault deformation
- Resolves deformation along the fault where other geodetic datasets commonly lack resolution
- Method assumes a rigid deformation. Other methods (e.g., PIV) work better when assumption is invalid.

Iterative Closest Point

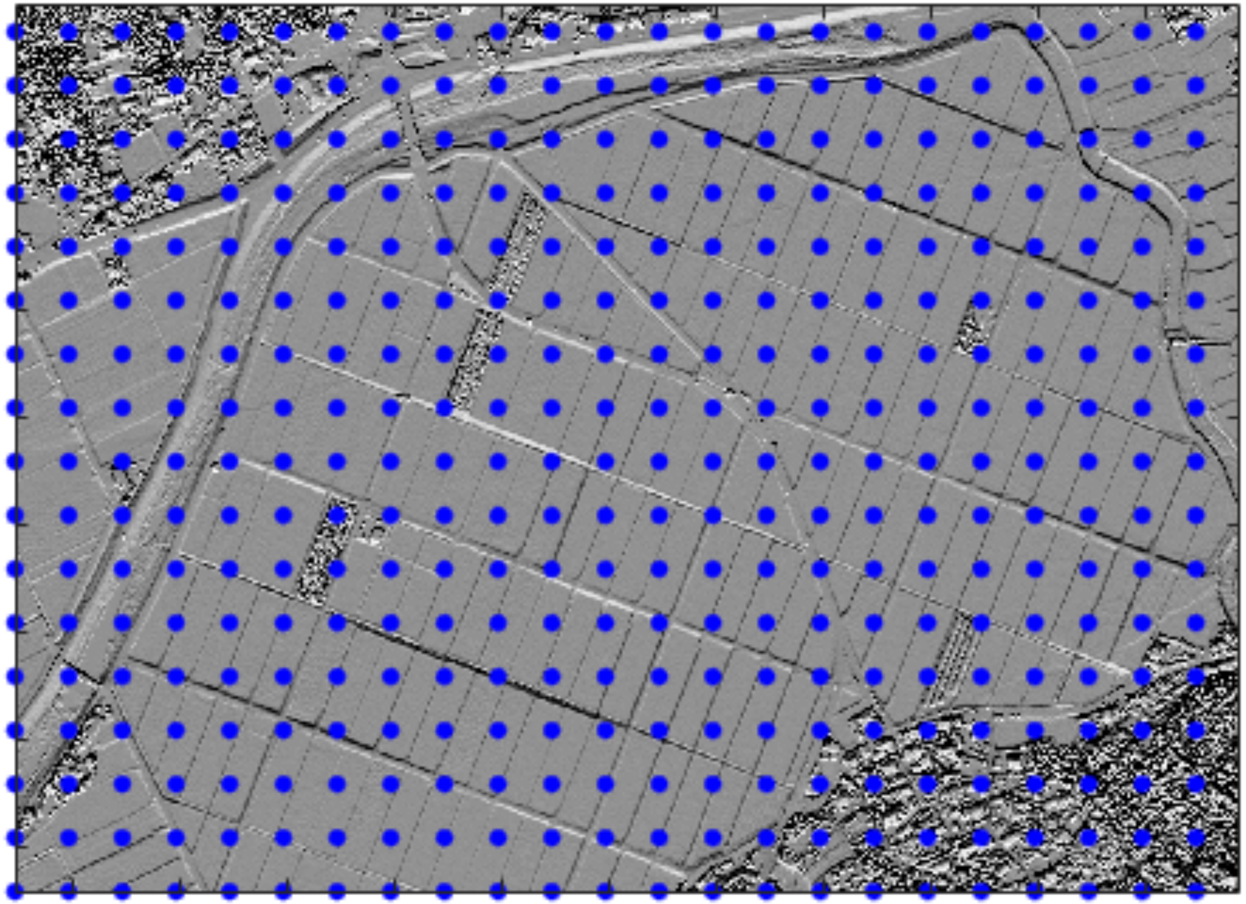
Pre-earthquake: Compare

Post-earthquake: Reference

Calculate 3D displacements at core points

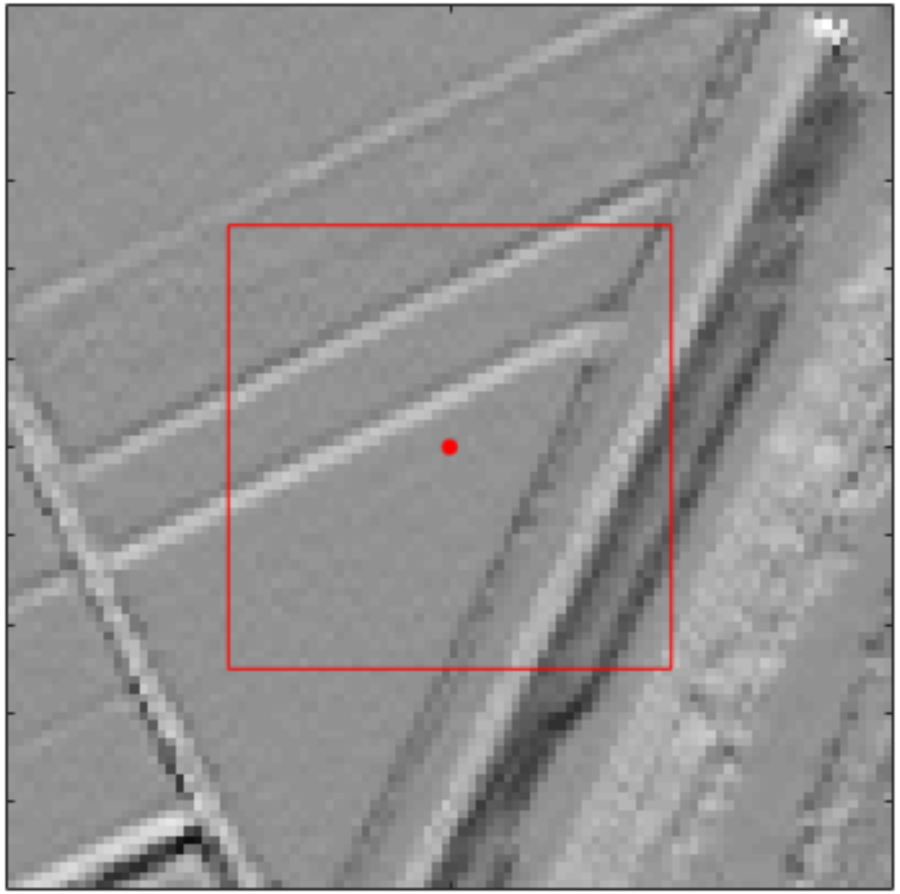


Pre-earthquake: Compare

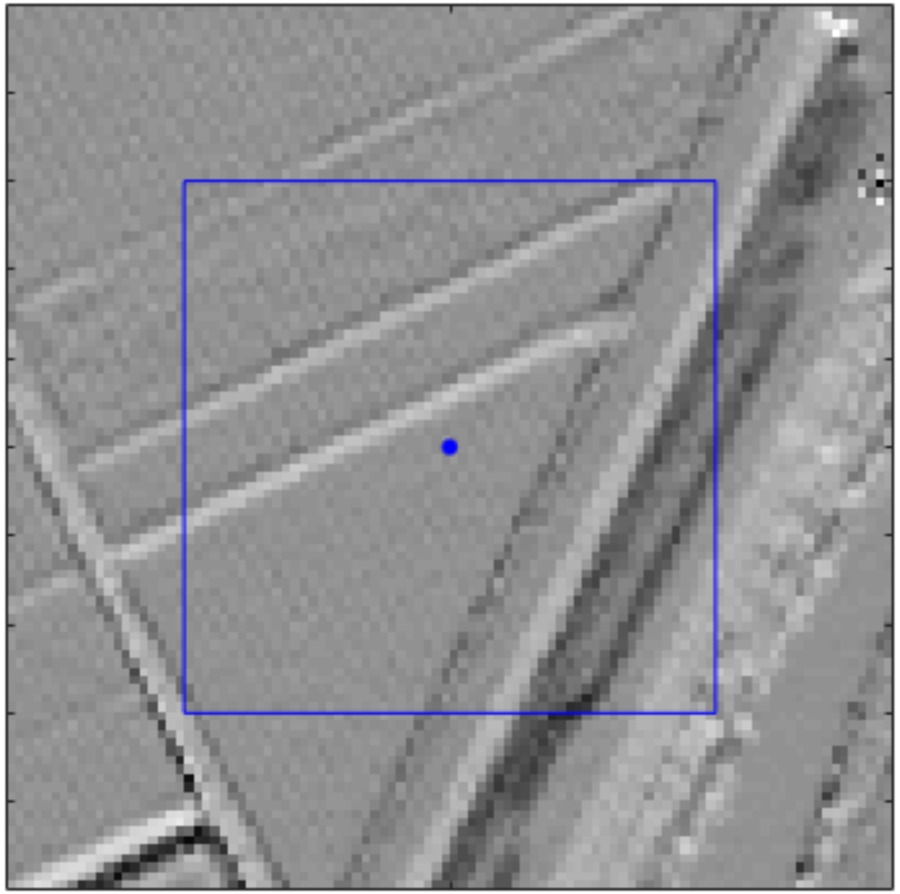


Post-earthquake: Reference

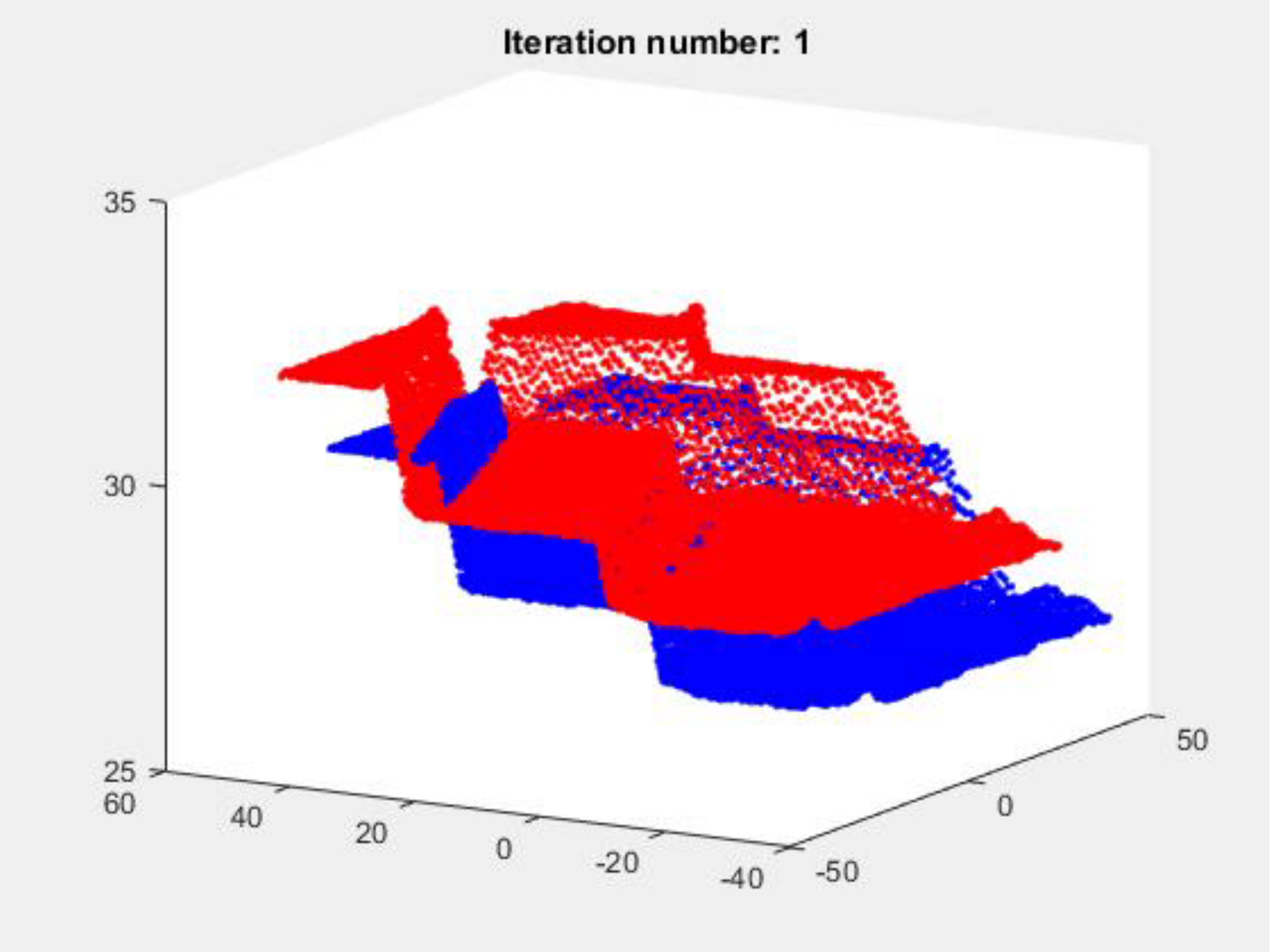
Select windowed subsets



Pre-earthquake: Compare
Width 50 m



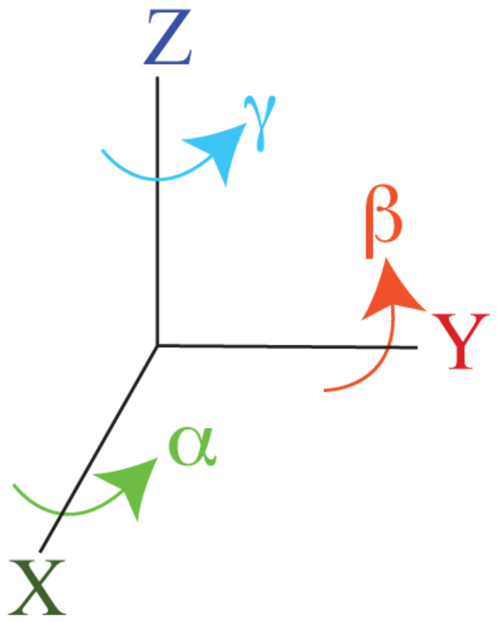
Post-earthquake: Reference
Contains an extra 10 m buffer


Iteration number: 1
35
30
25
60
40
20
0
-20
-40
-50
0
50

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

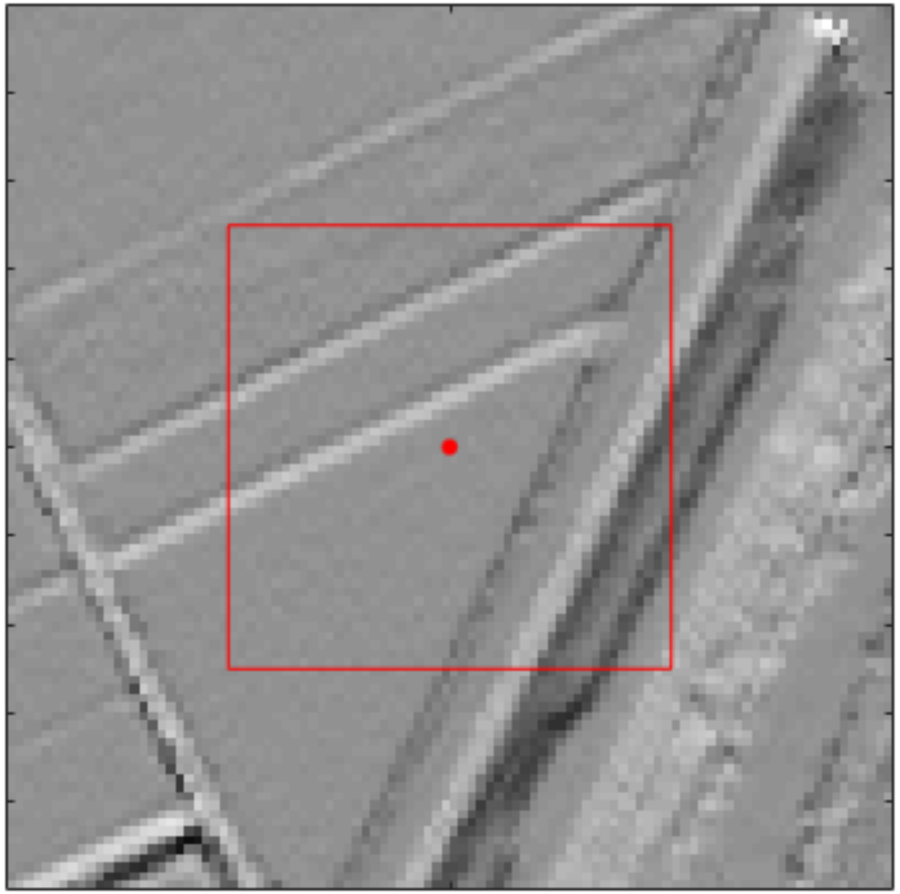
ICP references: Besl and McKay (1992); Nissen et al., (2012; 2014); Scott et al., (2018)

Processing Choices

- Window Size
- Grid Spacing
- Coordinate system origin
- Point-to-point vs. Point-to-plane error penalty

Window Size

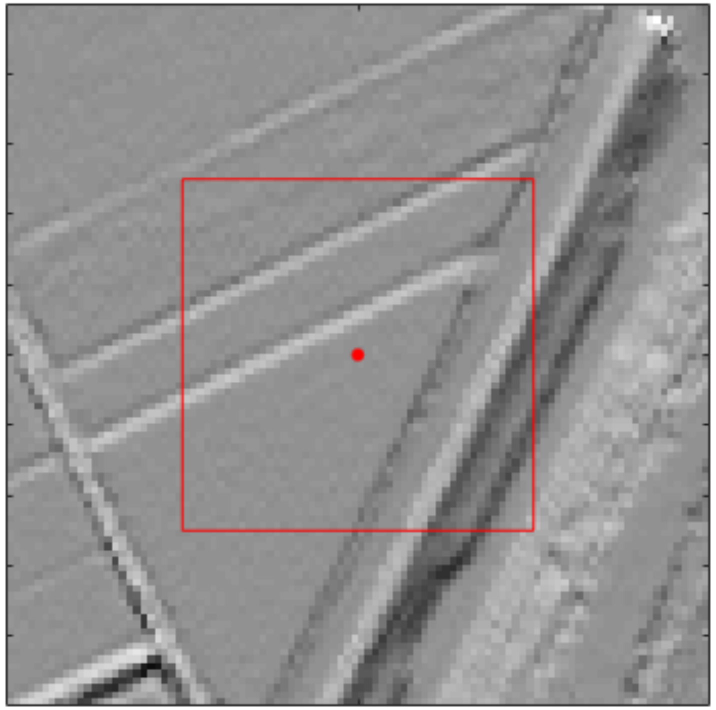
- Large enough that there is sufficient topographic relief to produce an accurate alignment
- Smaller windows have better resolution and a lower violation of the rigid body assumption
- In my experience, 30-50 m window size are best with 1-4 shots/m^2 lidar imagery



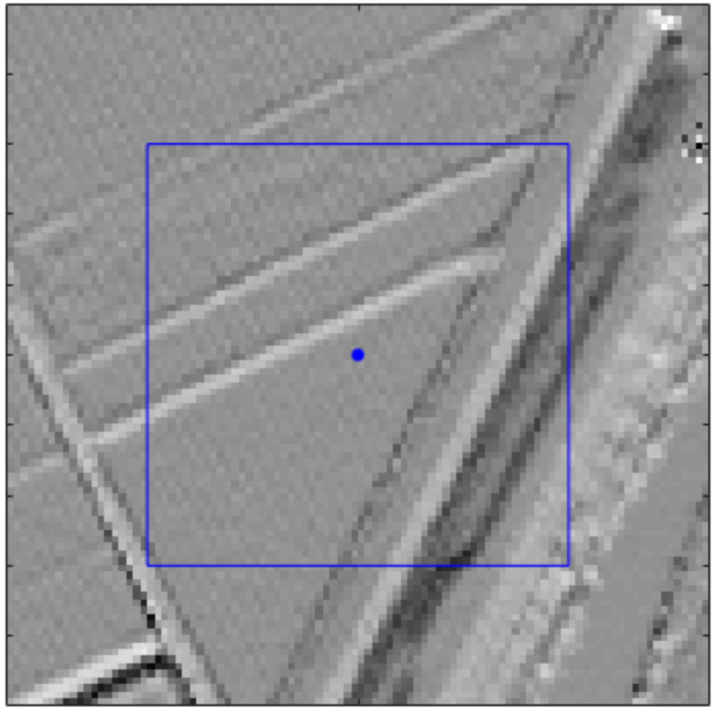
Canal and field boundaries provide topographic relief

Window size of reference dataset

Add buffer to the reference point cloud so that the deformed reference point cloud fits entirely into the compare point cloud.



Pre-earthquake: Compare
Width 50 m

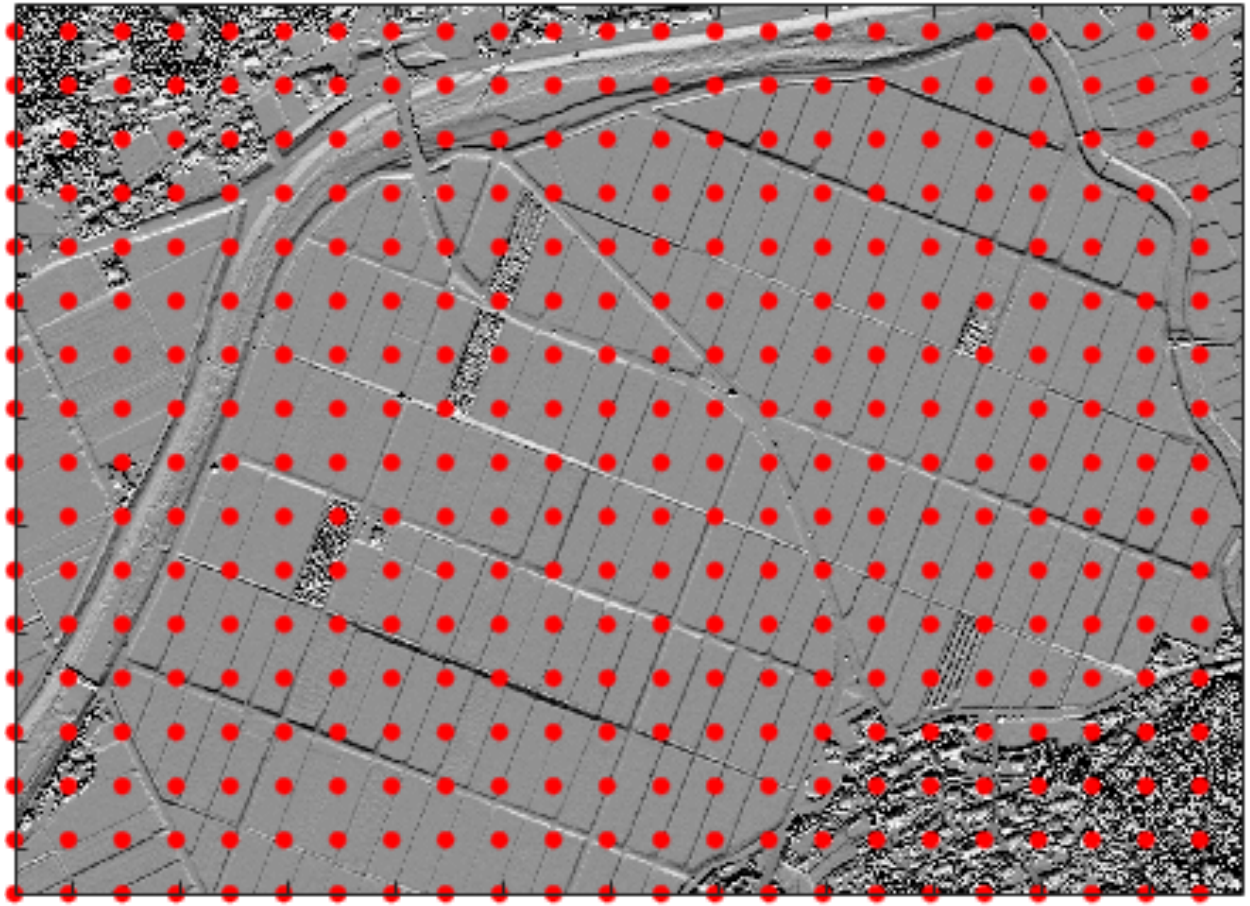


Post-earthquake: Reference
Contains an extra 10 m buffer

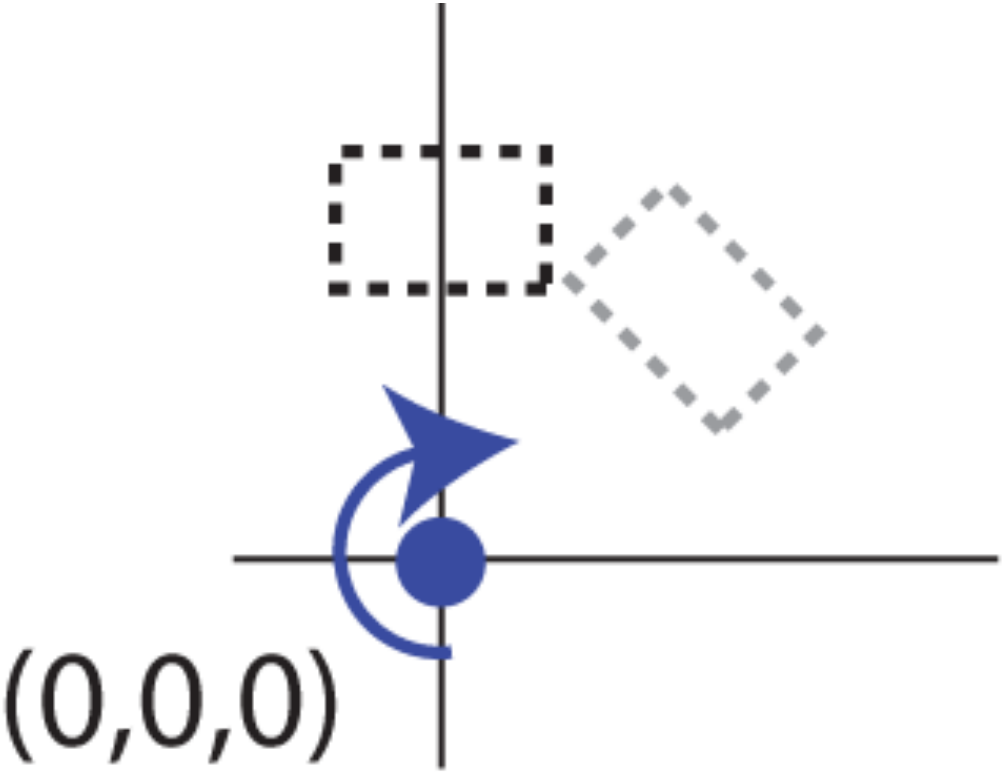
Grid spacing

Commonly equal to full or half of the window size

For efficiency, grid spacing can be much larger. This is the case for today's demo.

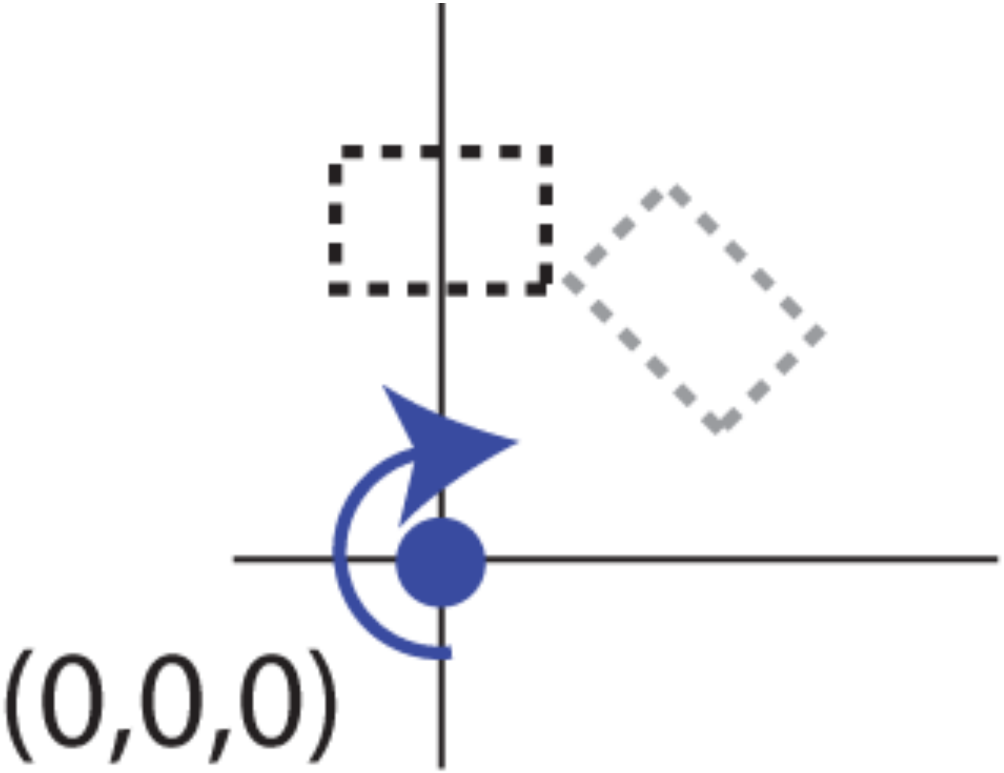


Coordinate system origin

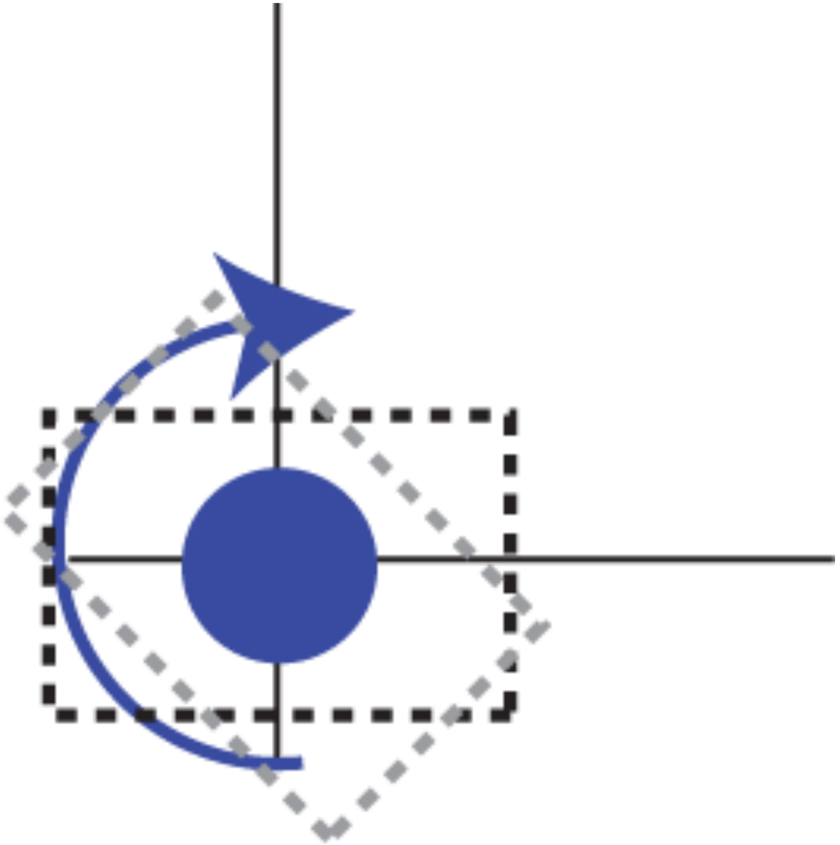


When the origin is offset from the point cloud window, the rotation and translation trade-off.

Coordinate system origin

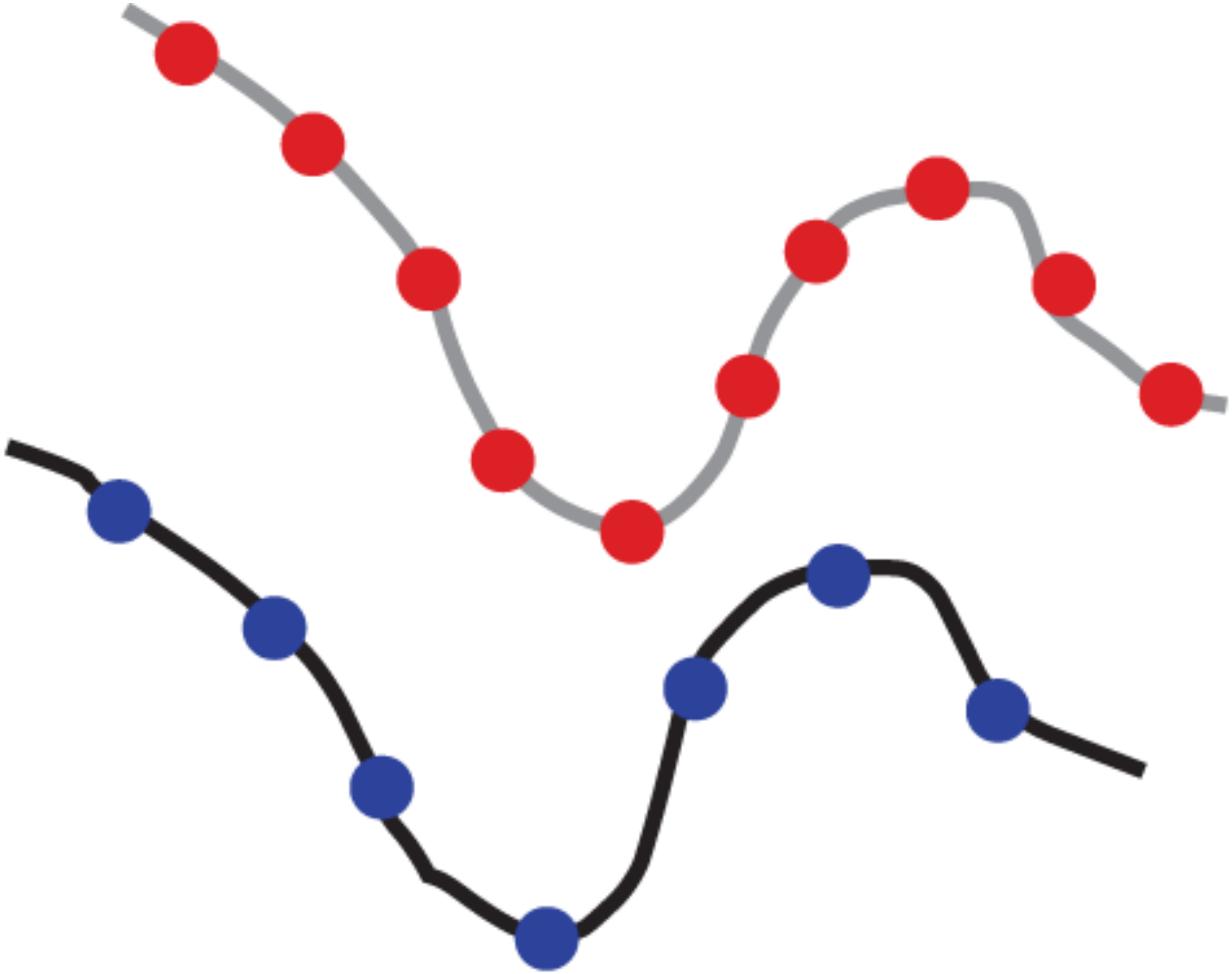


When the origin is offset from the point cloud window, the rotation and translation trade-off.



Shift the coordinate system origin (0,0,0) to the window center.

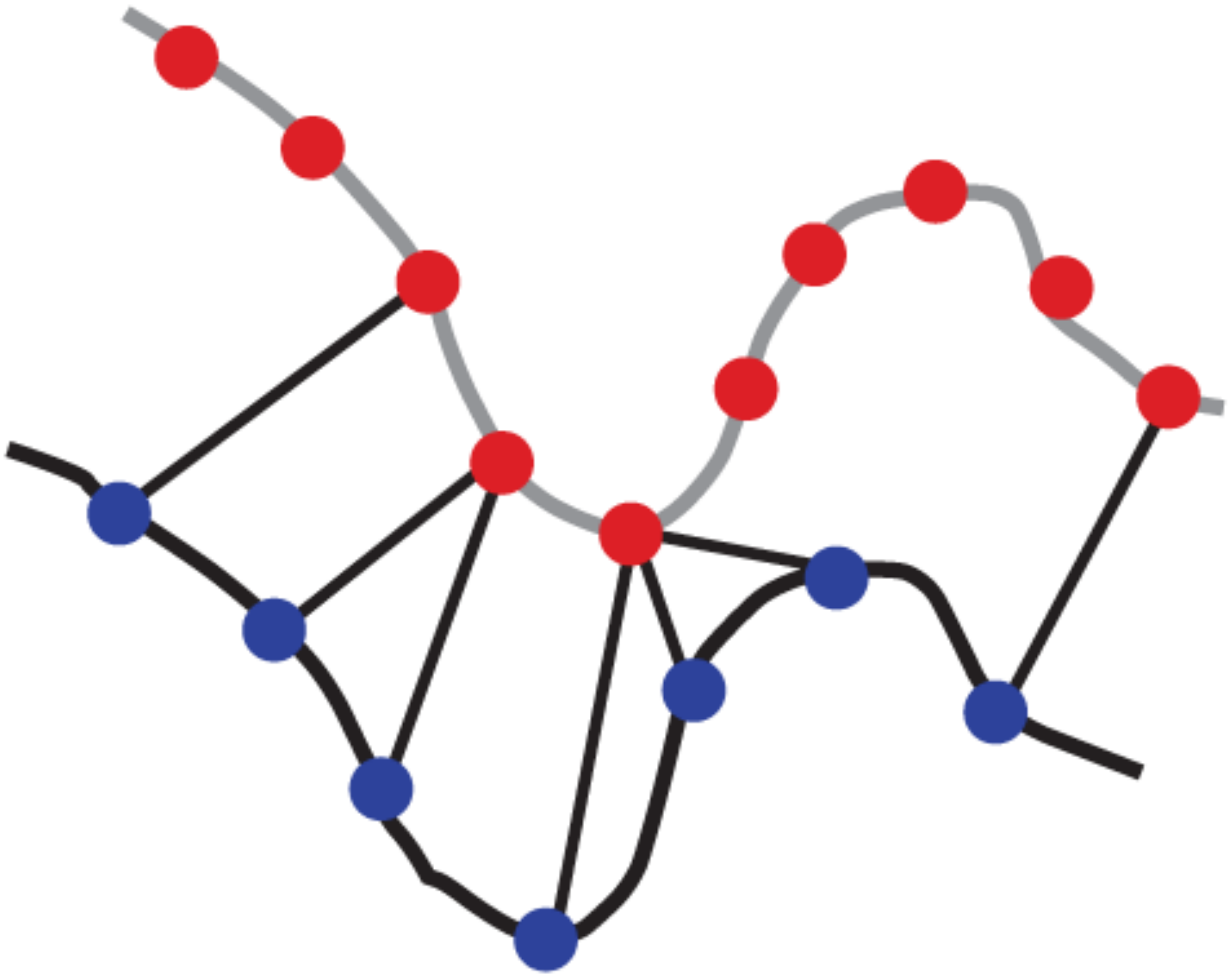
Point Cloud Alignment and ICP Error



Pre-earthquake/
Compare

Post-earthquake/
Reference

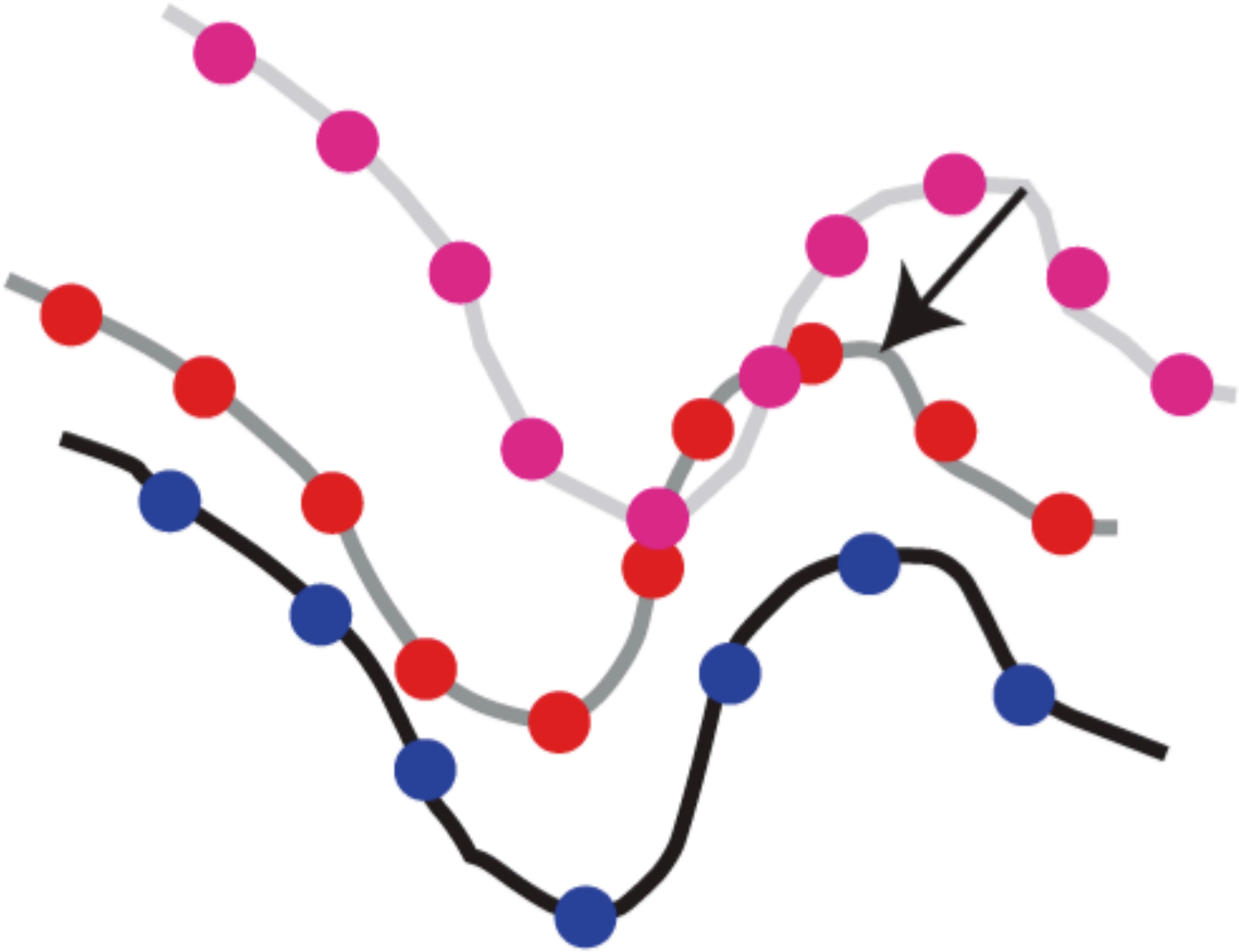
Point Cloud Alignment and ICP Error



Pre-earthquake/
Compare

Post-earthquake/
Reference

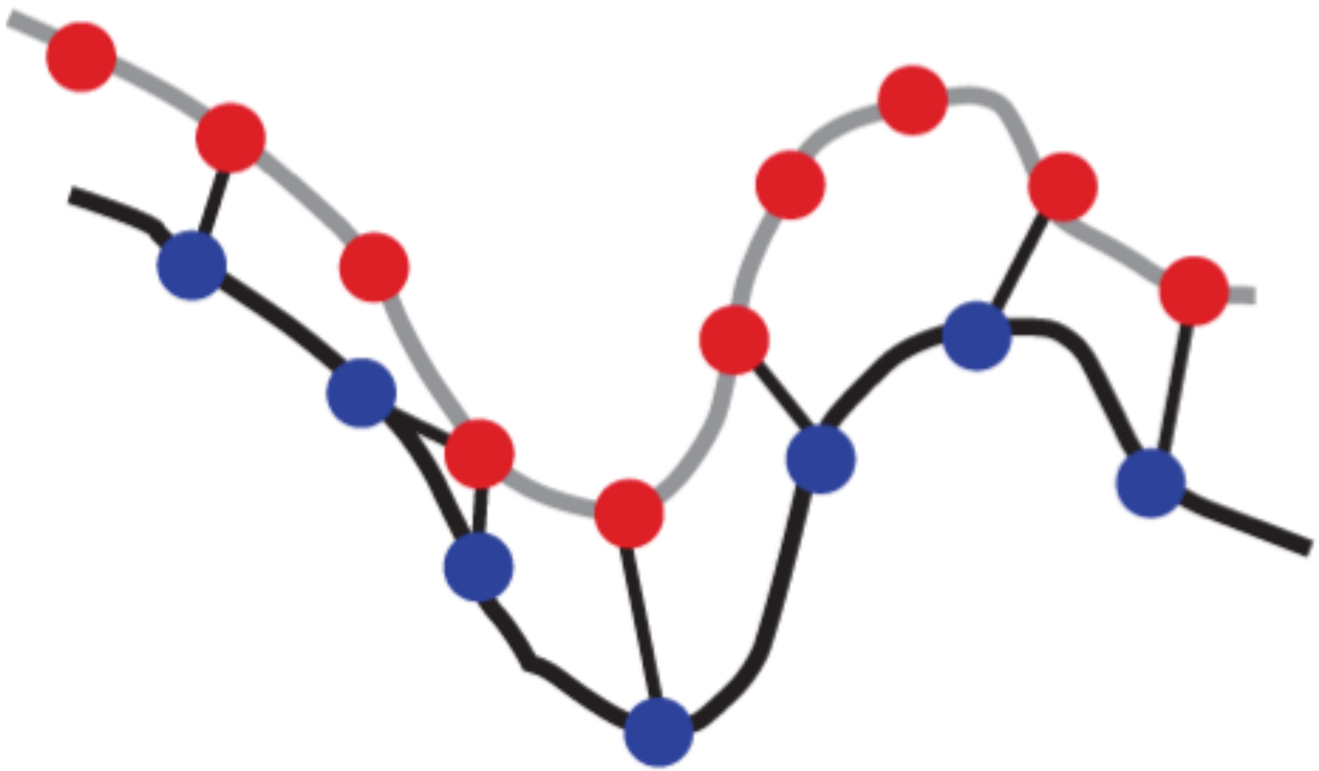
Point Cloud Alignment and ICP Error



Pre-earthquake/
Compare

Post-earthquake/
Reference

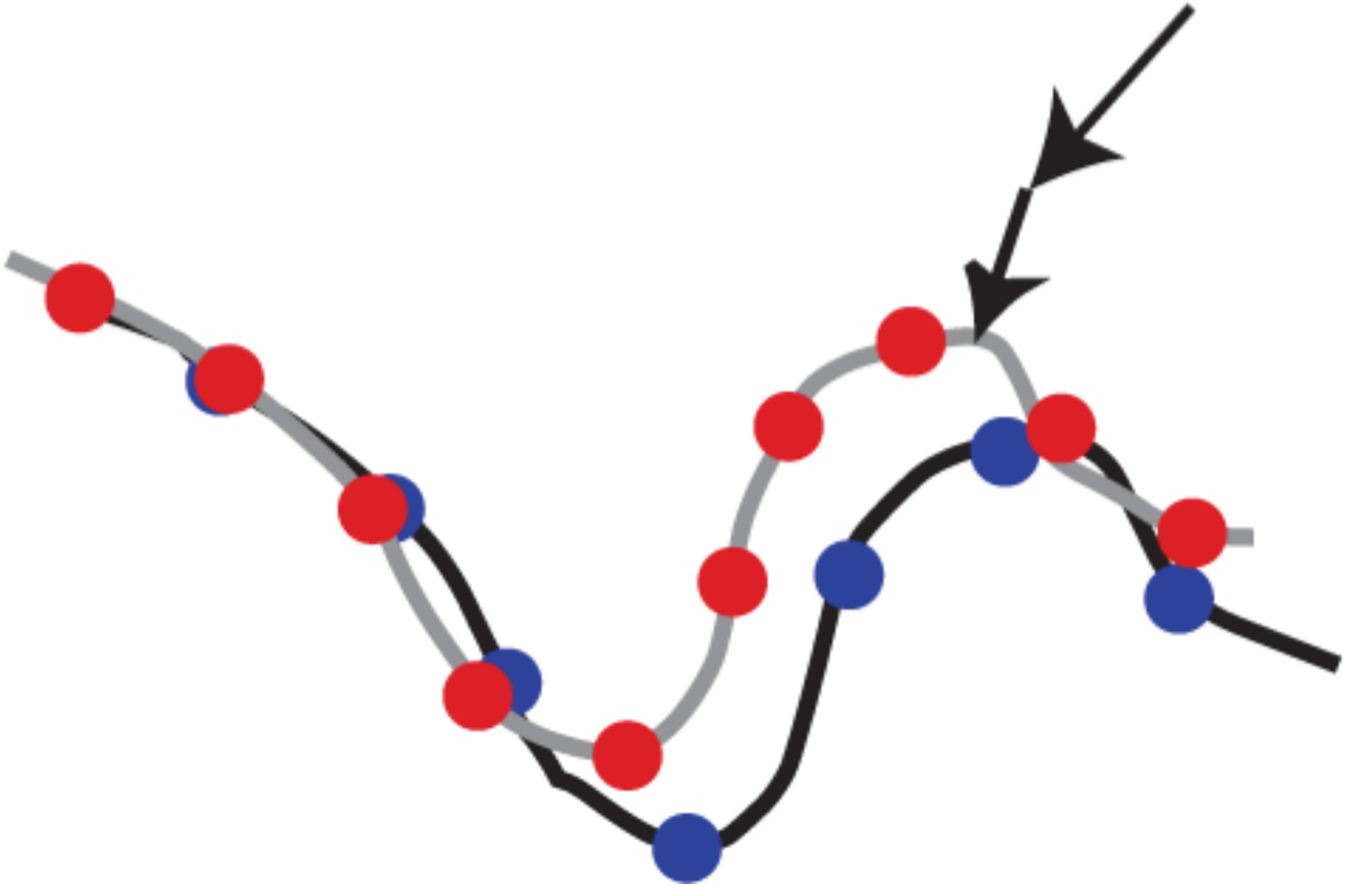
Point Cloud Alignment and ICP Error



Pre-earthquake/
Compare

Post-earthquake/
Reference

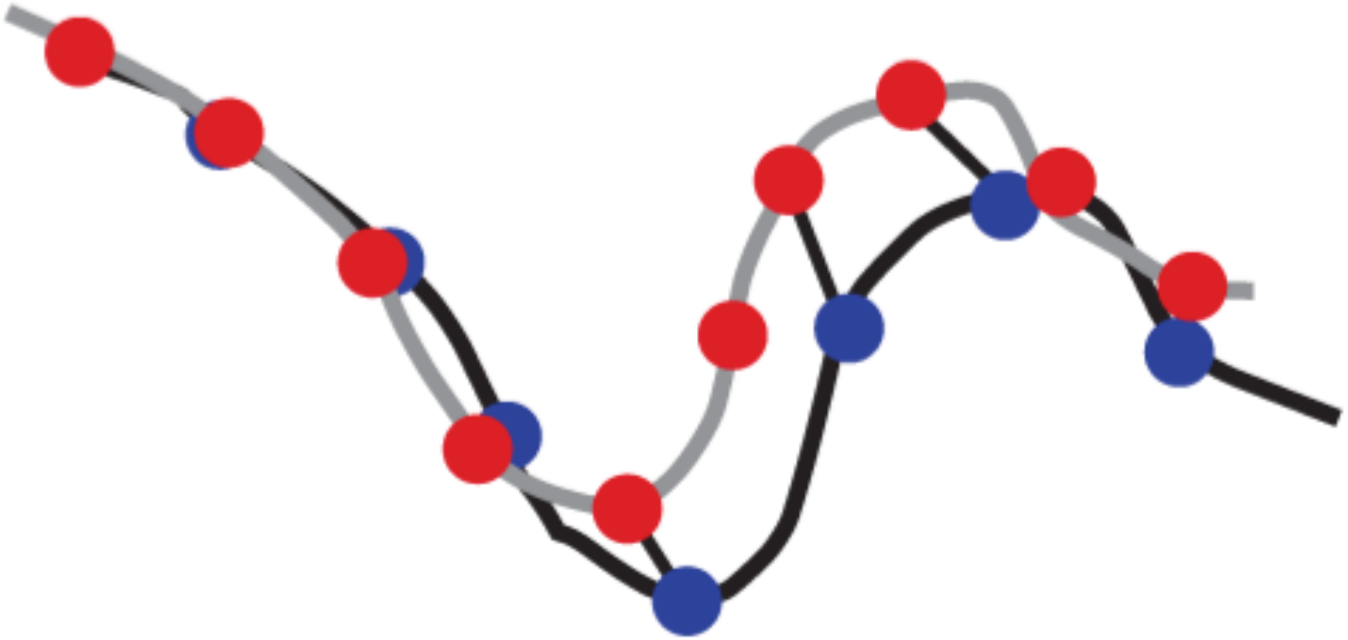
Point Cloud Alignment and ICP Error



Pre-earthquake/
Compare

Post-earthquake/
Reference

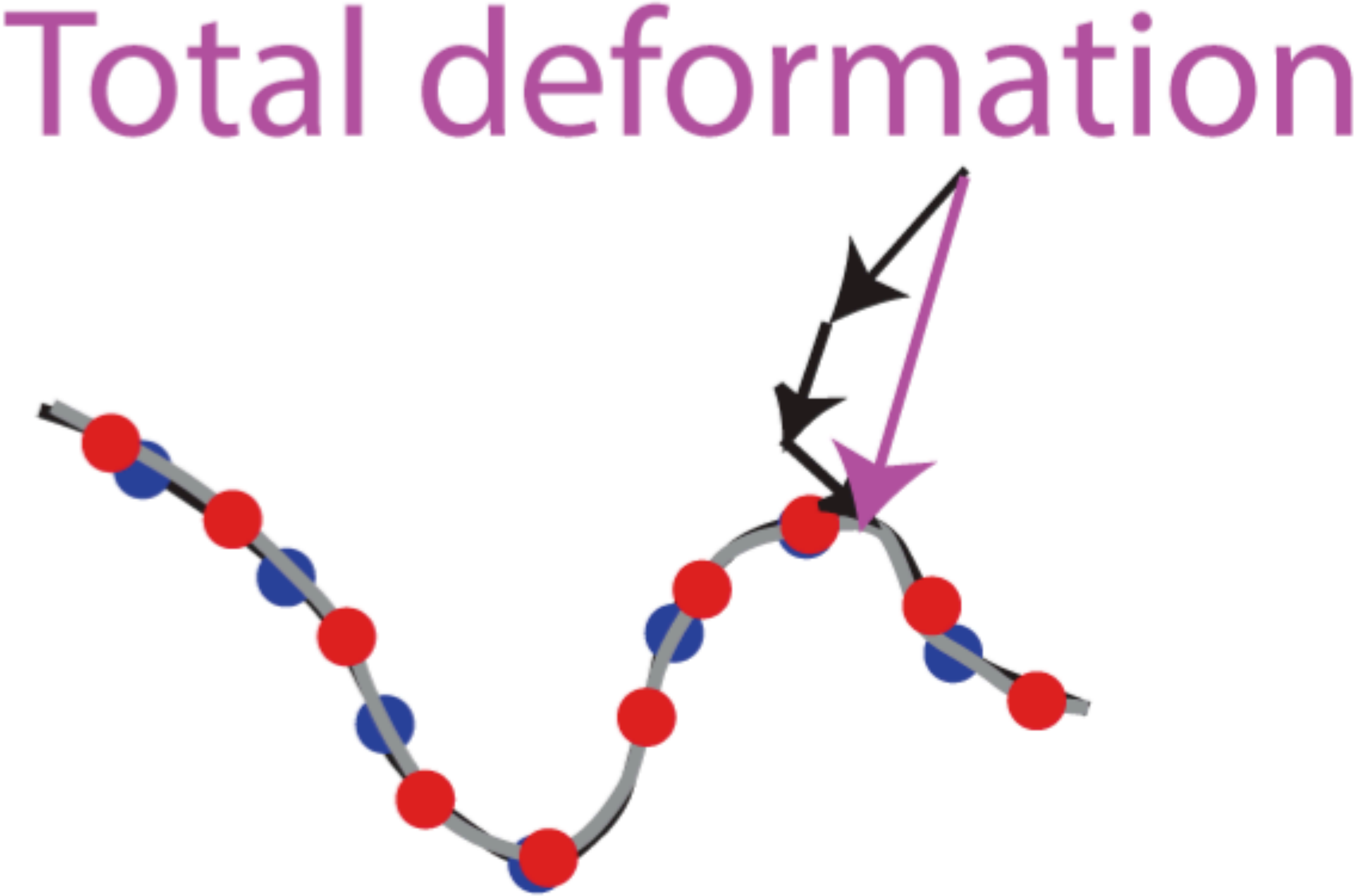
Point Cloud Alignment and ICP Error



Pre-earthquake/
Compare

Post-earthquake/
Reference

Point Cloud Alignment and ICP Error



Pre-earthquake/
Compare

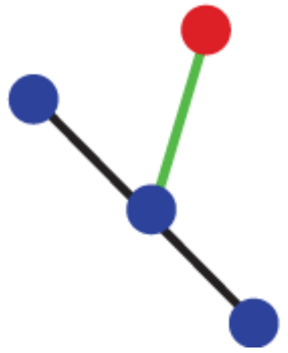
Post-earthquake/
Reference

Point cloud alignment error metrics

Point-to-Point Error

oints in the REF *cloud*▒$|(\varphi \mathrm{COMPARE}\downarrow i \;\; -\mathrm{REF}\downarrow i)|\uparrow 2$

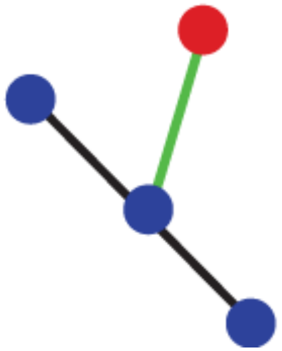
φ: Rigid deformation



Point cloud alignment error metrics

Point-to-Point Error

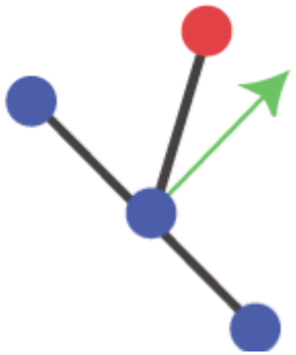
$$\text{oints in the REF cloud}\ |(\varphi\text{COMPARE}_i - \text{REF}_i)|^2$$



φ: Rigid deformation

Point-to-Plane Error

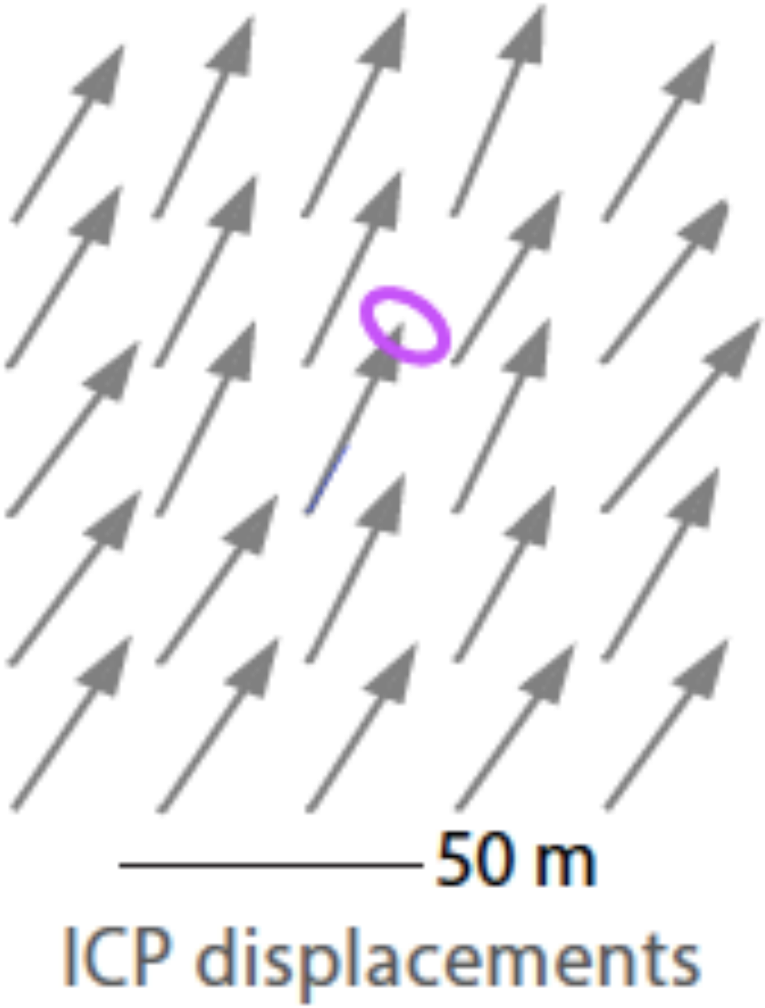
$$\text{points in the REF cloud}\ |(\varphi\text{COMPARE}_i - \text{REF}_i)\cdot n_i|^2$$

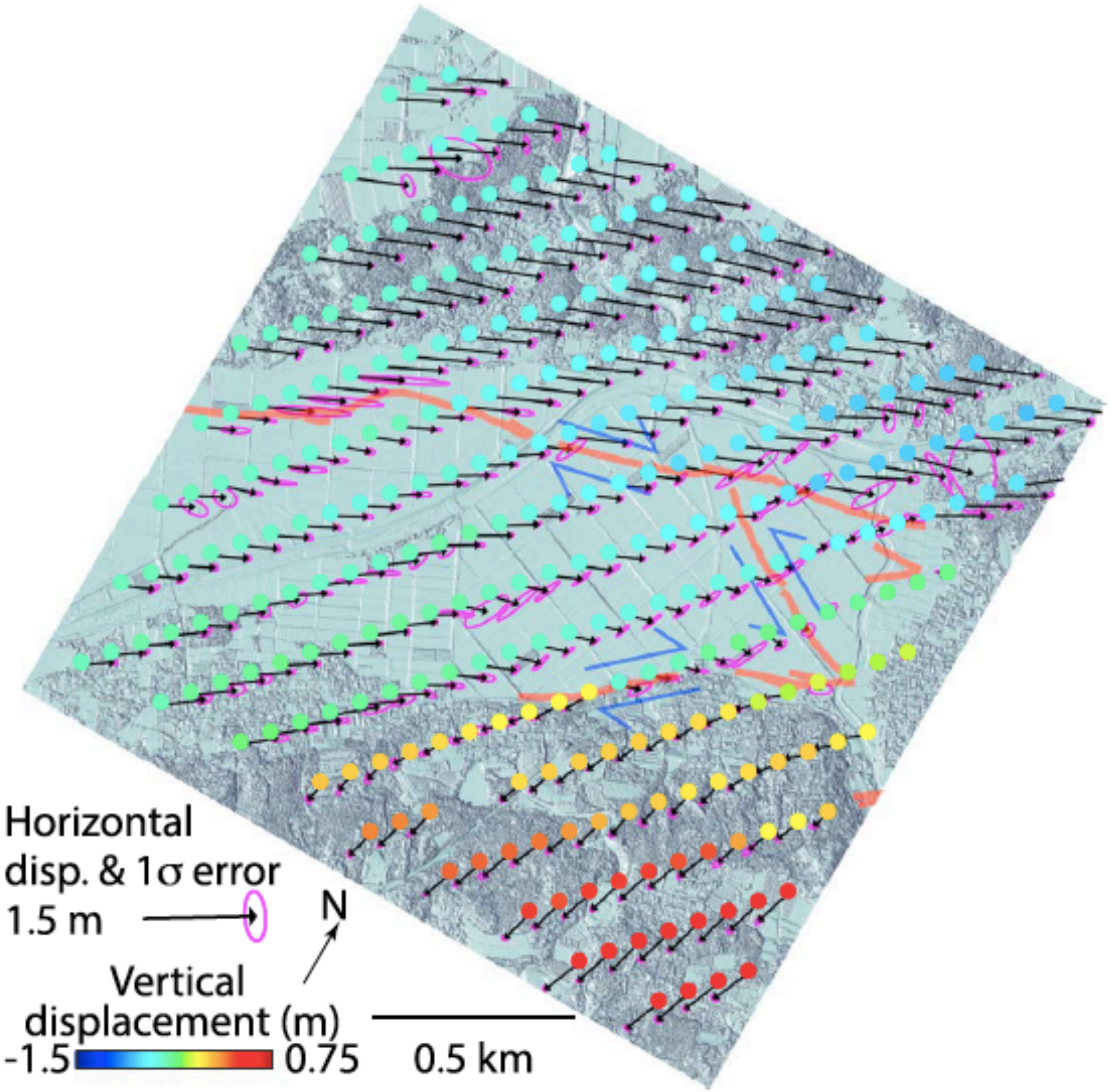


n_i: Vector normal to surface

Point-to-plane works better for geological applications

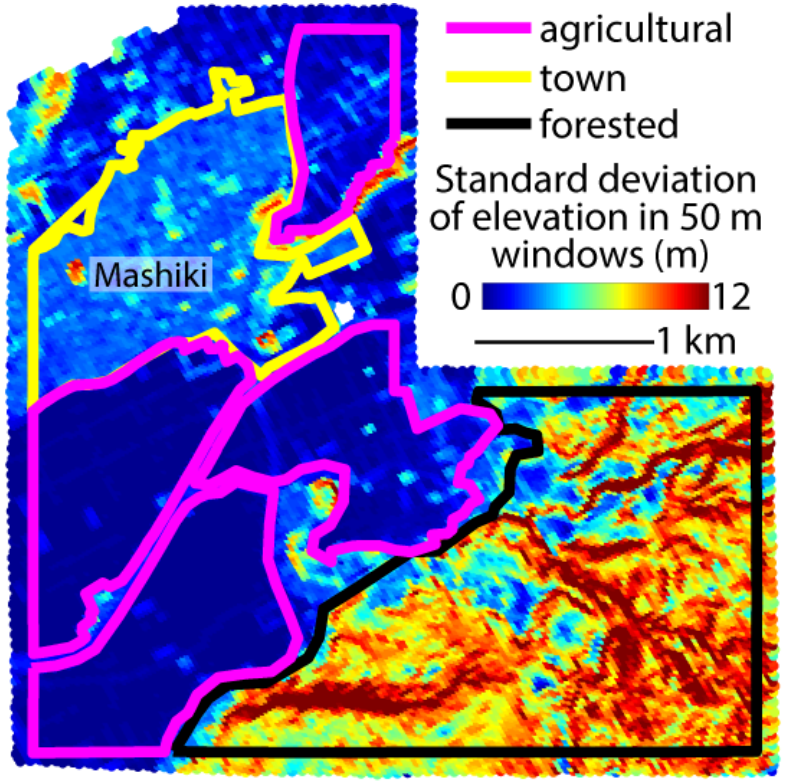
Correlation Error



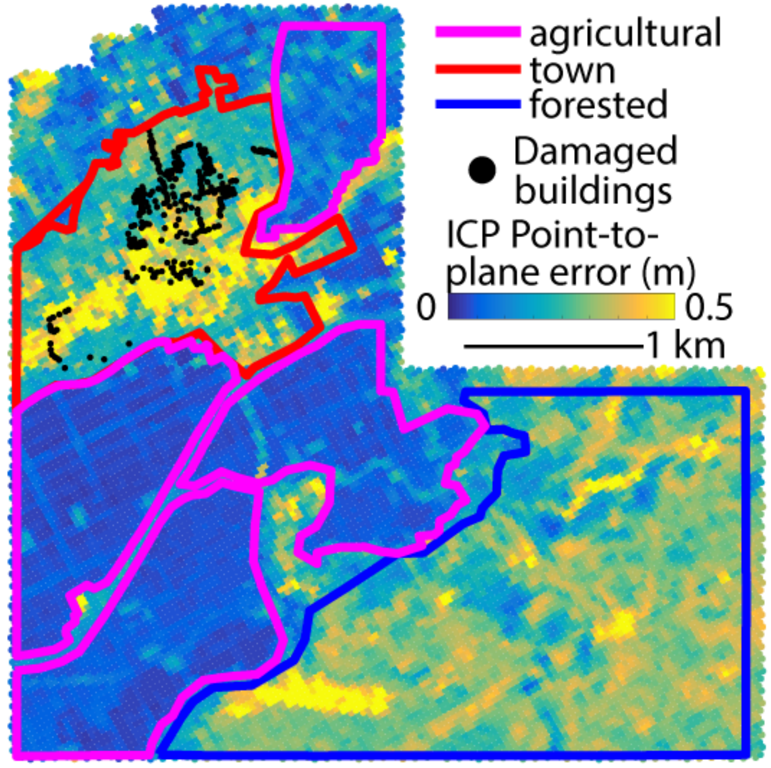


Scott et al., (2018)

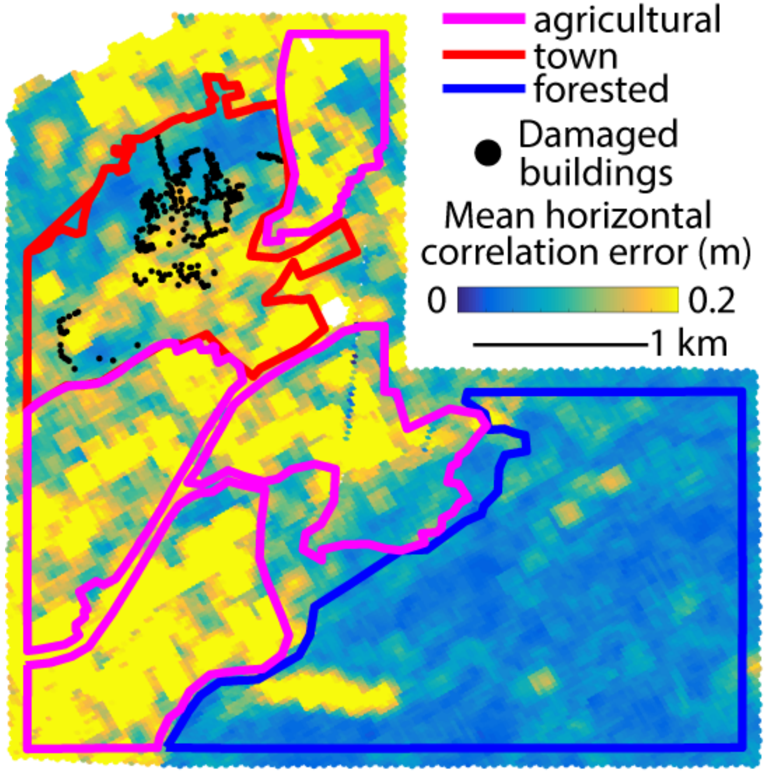
Compare Different Error Measurements



Standard deviation of Topography

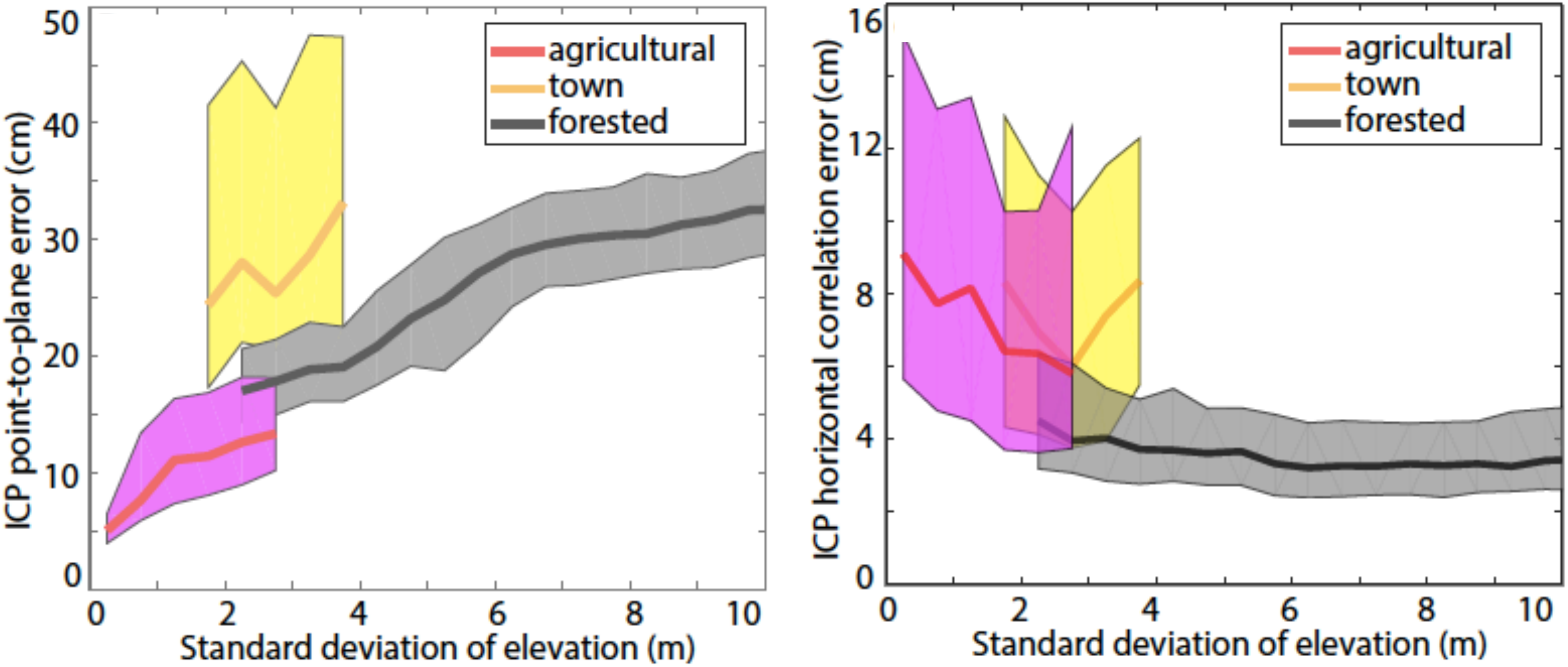


ICP point-to-plane error



Horizontal correlation error

Scott et al., (2018)



ICP point-to-plane error and ICP horizontal correlation error are anti-correlated.

Scott et al., (2018)

ICP Differencing Demo

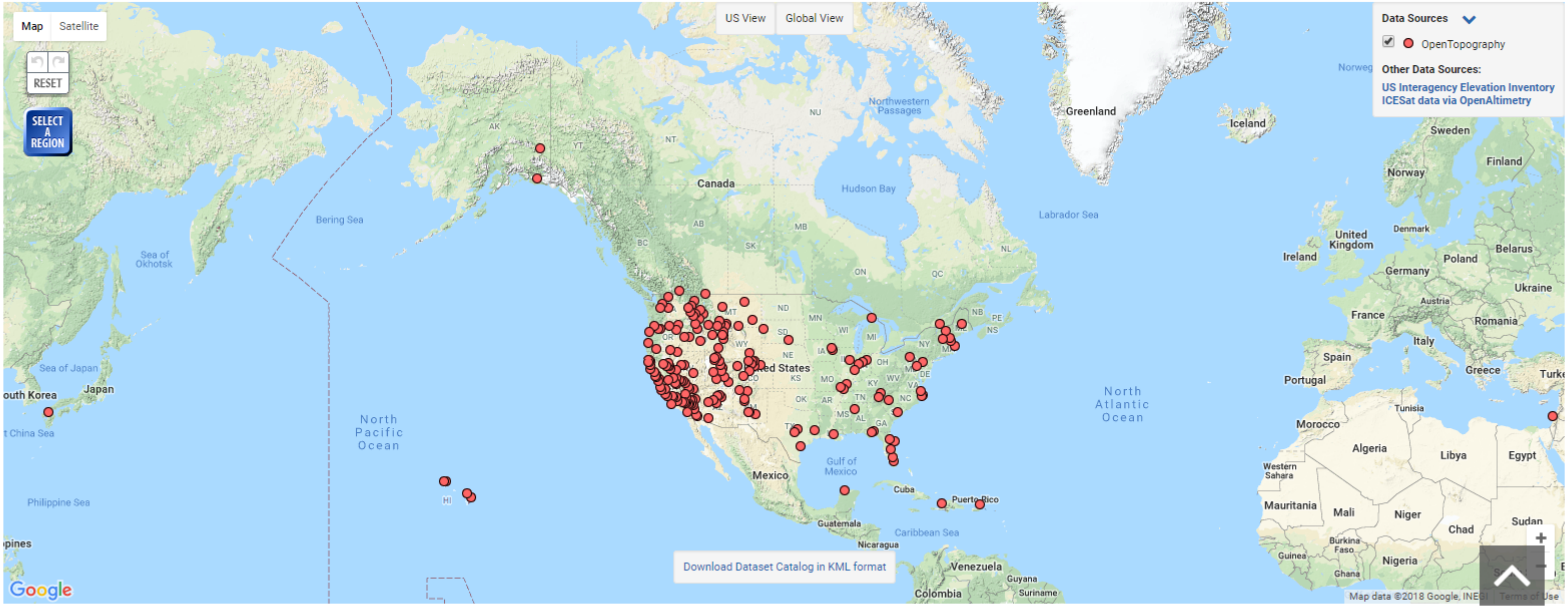
- Requirements
  - Matlab
  - ICP script for exercise
  - Matlab ICP File Exchange (Jacob Wilm): https://www.mathworks.com/matlabcentral/fileexchange/27804-iterative-closest-point
  - Matlab Las file reader (Teemu Kumpumäki): https://www.mathworks.com/matlabcentral/fileexchange/48073-lasdata

OpenTopography

High-Resolution Topography Data and Tools

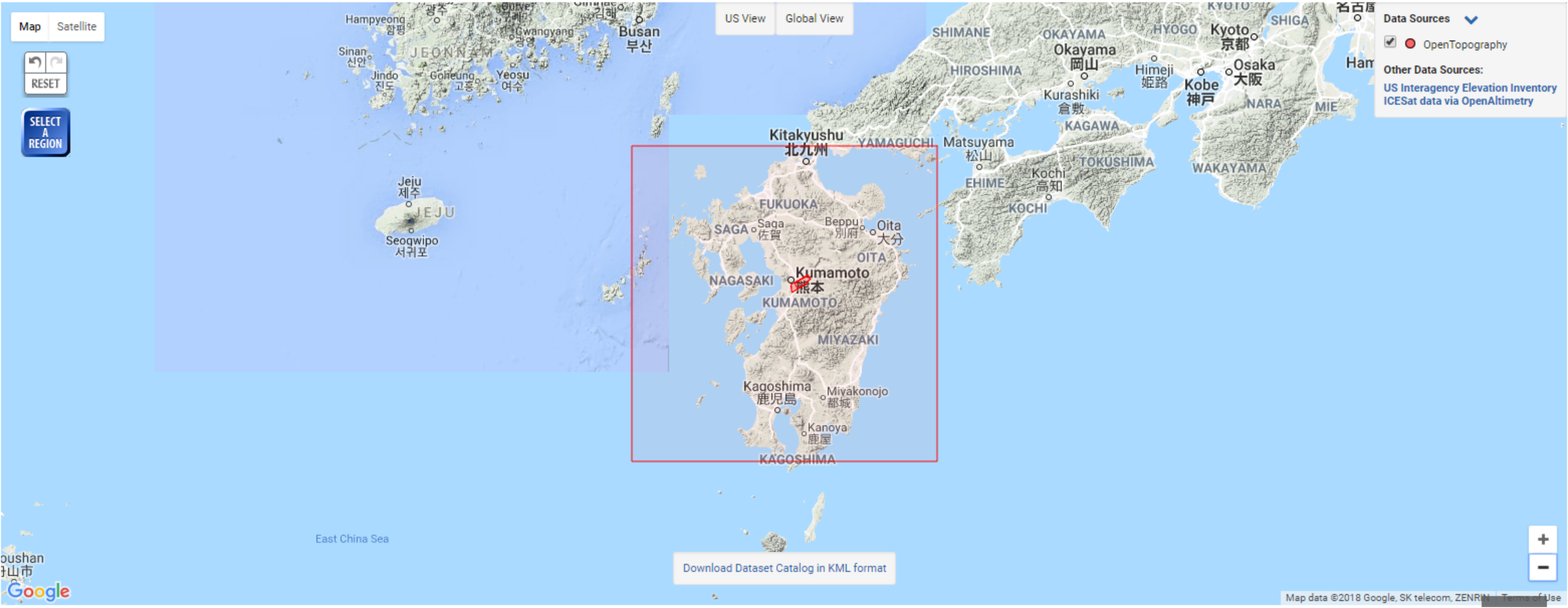
Find Topography Data

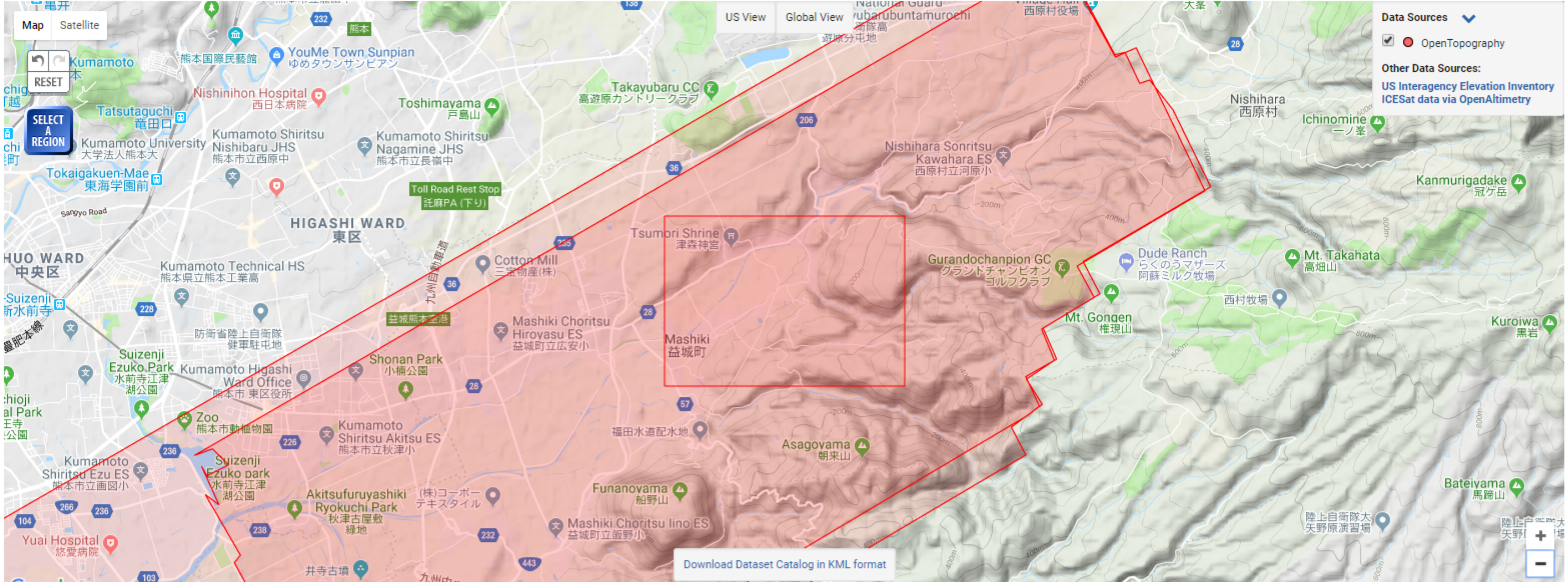
Information and Instructions



Find Topography Data

Information and Instructions





OpenTopography: 5 datasets found

Datasets listed below are hosted by OpenTopography and are available in point cloud format for download and processing (e.g., creating custom DEMs). In some cases derived data products such as raster and Google Earth Image overlays are also available. Click the button to the right of the dataset name to access the available data products.

High Resolution Data | **Global Data**

1	Post-Kumamoto Earthquake (16 April 2016) Rupture Lidar Scan	Point Cloud Data
2	Pre-Kumamoto Earthquake (16 April 2016) Rupture Lidar Scan	Point Cloud Data

Pre-Kumamoto Earthquake (16 April 2016) Rupture Lidar Scan

Overview

The 16 April 2016 M7 Kumamoto earthquake ruptured the Futagawa- Hinagu fault zone on Kyushu Island of southwestern Japan. The lidar dataset collected by Air Survey Co., Ltd., of Japan covers the western half of the rupture zone. The acquisition of the imagery closely brackets the timing of the earthquake: The pre-earthquake dataset was acquired on 15 April 2016 and the post-earthquake dataset was acquired on 23 April 2016.

ASIA AIR SURVEY CO.,LTD.

Platform: Airborne Lidar
Full Metadata

Survey Area: 151.56 km^2
Dataset Acknowledgement

Point Density: 2.94 pts/m^2
Funder: AAS

Survey Date: 04/15/2016

Other Available Data Products: Point Cloud Bulk Download

1. Coordinates & Classification

Horizontal Coordinates: Japan Plane Rectangular Coordinate System (system 2) [EPSG: 2444]
Vertical Coordinates: JDG2000 [EPSG: 6694]

Data Selection Coordinates: ☐ Manually enter selection coordinates (in the horizontal coordinate system listed above)

X_{min} = -15924.418161 Y_{min} = -24166.962709 X_{max} = -12080.574676 Y_{max} = -21500.178931

The selection area contains approximately 17,431,000 points.

Choose Return Classification ☑ Ground ☑ Unclassified ☑ Vegetation

2. Point Cloud Data Download

☑ Point cloud data in LAS format ☐ Point cloud data in LAZ format ☐ Point cloud data in ASCII format

3A. DEM Generation (Streaming TIN)

Gridding Method
☑ Calculate TIN

Gridding Parameters
Grid Resolution (Default = 1 meter) 1
Max. triangle size (Default 50 units) 50

Grid Format
GeoTiff

Job Id	Dataset	Title	Submission	Completion	Duration	Num points	Final Status
pc1534078635822	JN16_KumapreEQ	pre_kumamoto_aug_2_1	2018-08-12 05:57:16	2018-08-12 05:58:37	81 secs	8,764,396	Done ✔

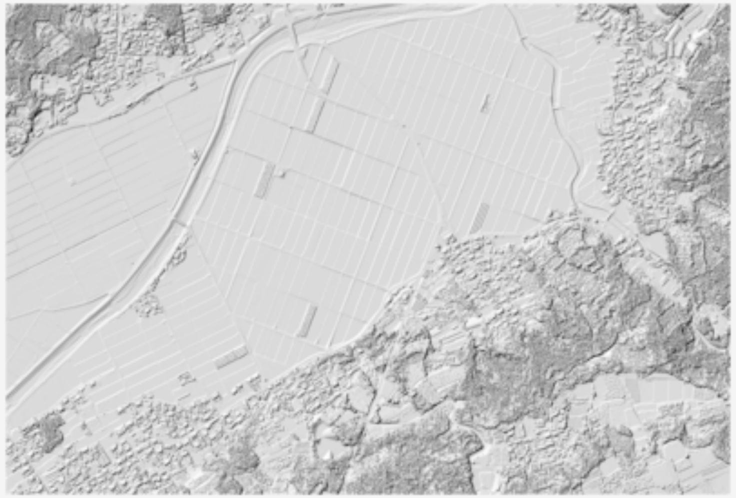
Download Data

Point Cloud Results	• Download point cloud data in LAS format points.las (234 MB)
DEM Results	• Download DEM (TIN) output.tin.tar.gz (8.4 MB)
Derivative Products	• Download Hillshade & Slope Products (TIN) viz.tar.gz (11.1 MB)

Visualization Products

Ztin

- View with Google Map



Repeat for the post-earthquake data

DEMO

How do I perform topographic differencing on my own datasets?

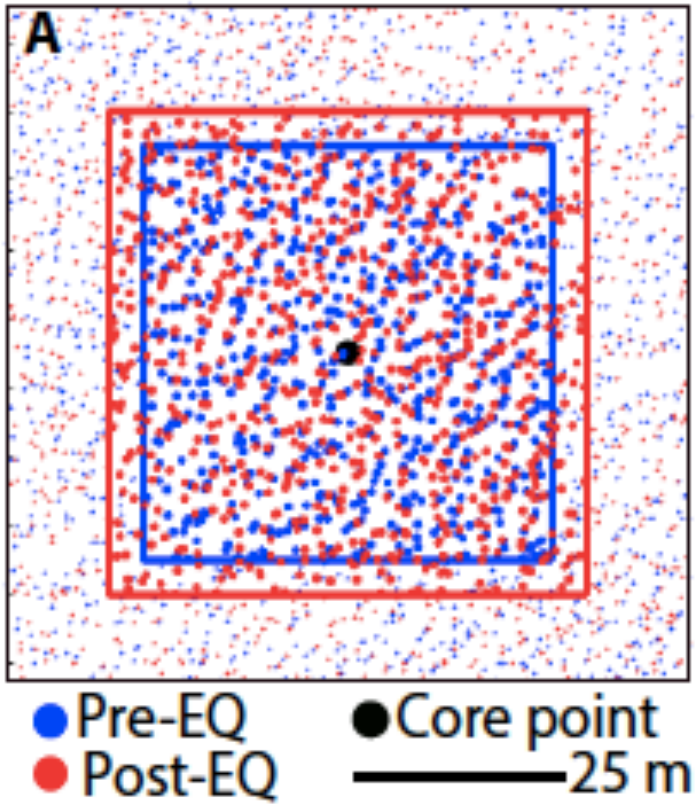
- Datasets
  - “Before” or “compare”
  - “After” or “reference”
- Datasets must be in the same reference frame
  - See lecture by Craig Glennie
- Datasets are big
  - Use lastile (lastools) to tile the big dataset into many smaller data files. Add a for for loop to loop through the smaller data files.
- Datasets available on OpenTopography
  - 2010 El Mayor Cucapah earthquake
  - 2016 Kumamoto earthquake
  - ~12 OT datasets already in the same reference frame

Software options

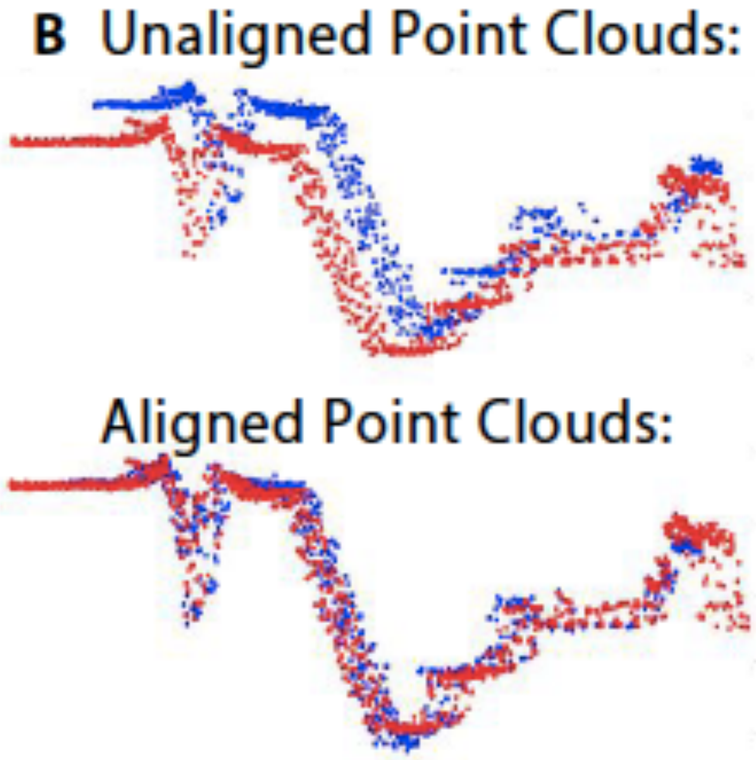
- Windowed ICP
  - LIBICP (http://www.cvlibs.net/software/libicp/): C++ code with Matlab wrappers
  - Matlab ICP File Exchange (Jacob Wilm): https://www.mathworks.com/matlabcentral/fileexchange/27804-iterative-closest-point
  - PDAL: https://pdal.io (Point Data Abstraction Library)
- Global ICP
  - Point Cloud Tools File Exchange: https://www.mathworks.com/matlabcentral/fileexchange/54412-point-cloud-tools-for-matlab
  - 2018 Matlab built in functions: https://www.mathworks.com/help/vision/ref/pcregrigid.html

Thank you!

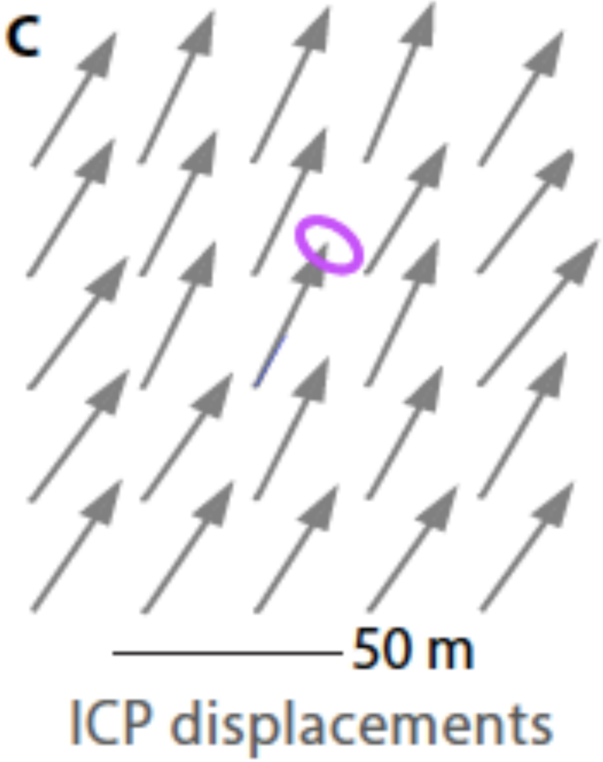
3D coseismic displacement: Iterative closest point (ICP)



Windowed subset



3D rigid-body deformation



Uncertainty

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