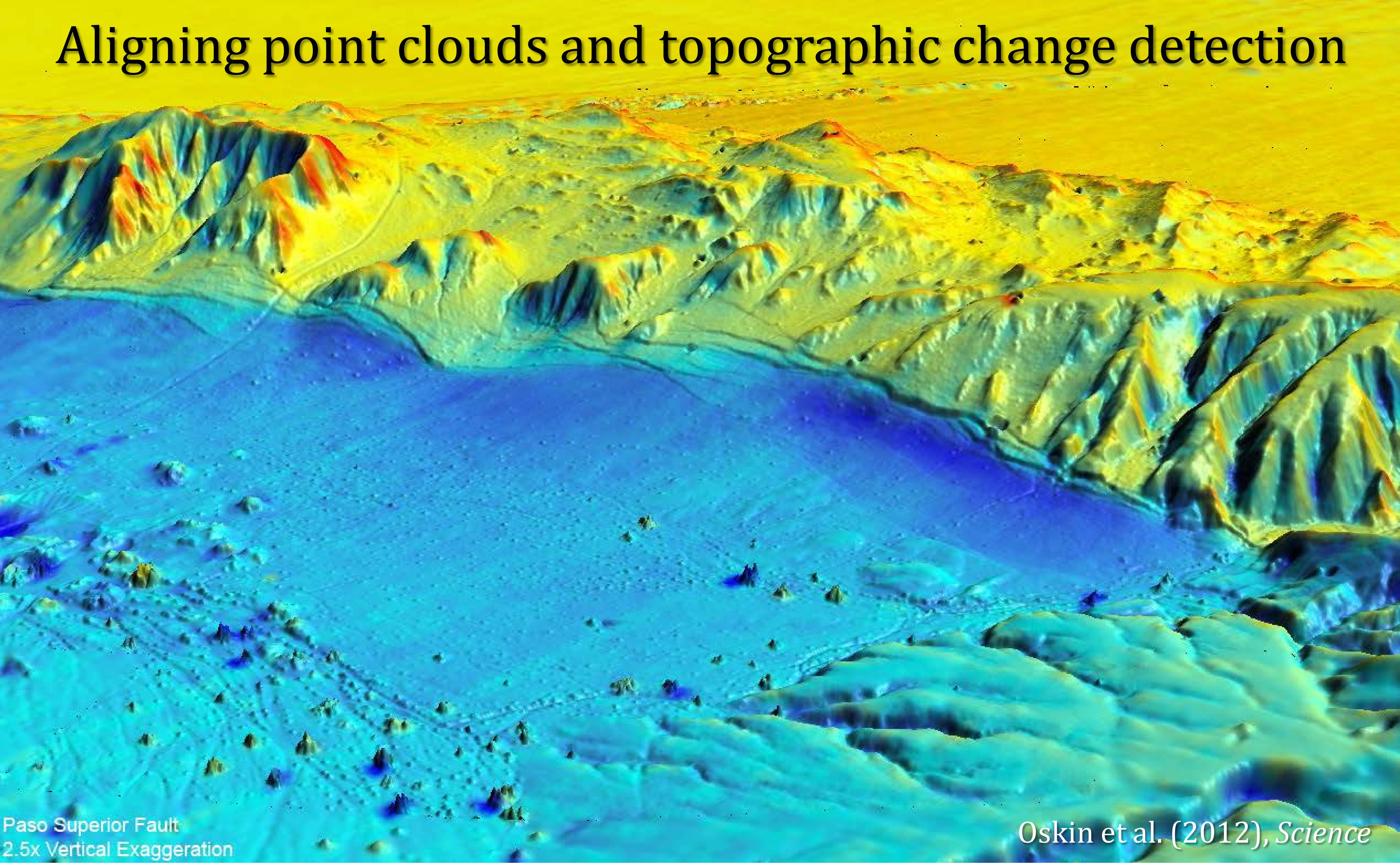
Aligning point clouds and topographic change detection



Edwin Nissen (Colorado School of Mines)

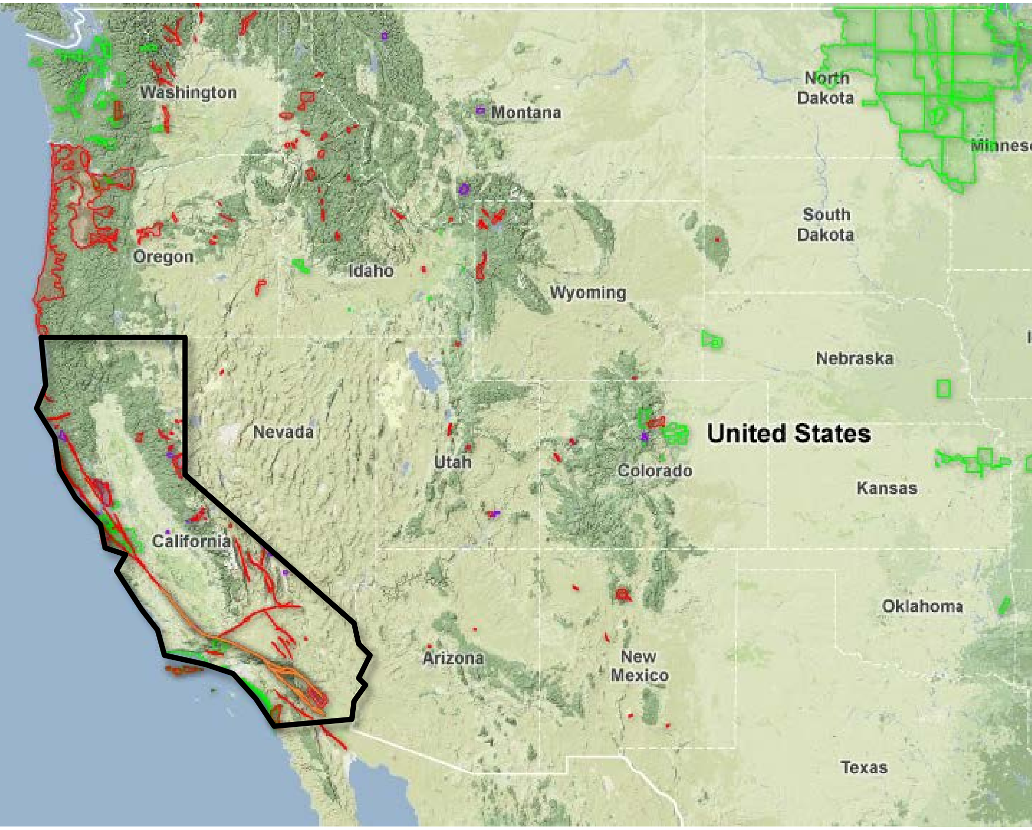
Thanks to: Ramon Arrowsmith, Srikanth Saripalli, Aravindhan Krishnan (ASU), Adrian Borsa (Scripps), Craig Glennie (Houston), Alejandro Hinojosa-Corona (CICESE), Tadashi Maruyama (AIST), Austin Elliott, Mike Oskin (UC Davis)

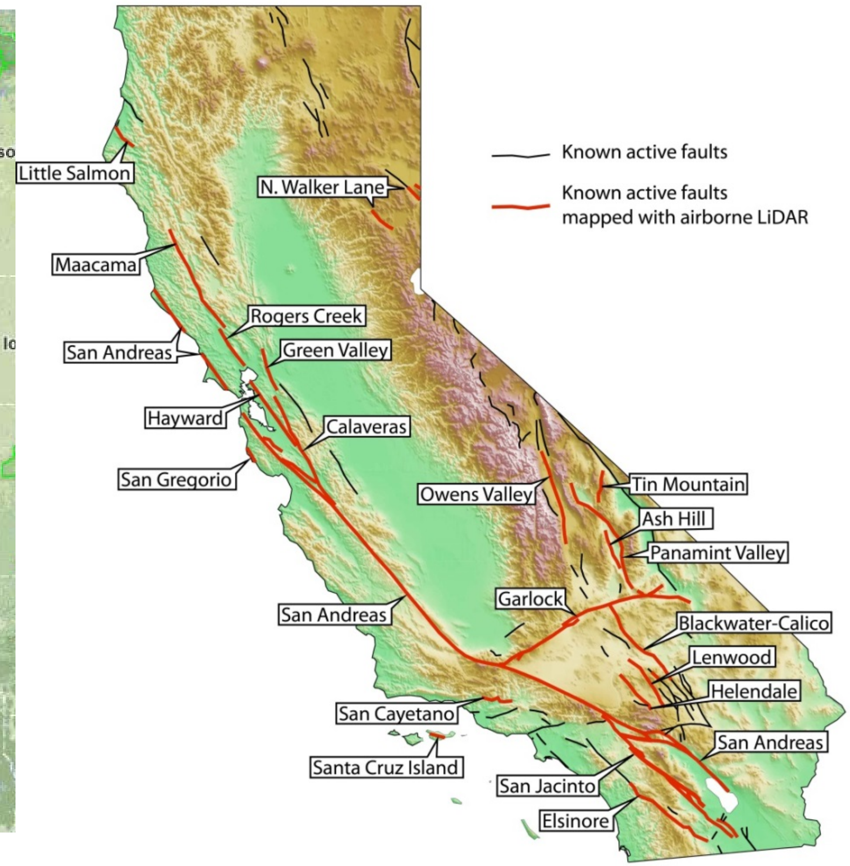
Aligning point clouds and topographic change detection

- Multi-temporal topography
- Earthquake examples:
    - scientific motivation
    - aligning (registering) topography data with ICP
    - 2008 Iwate earthquake (Japan)
    - 2011 Fukushima earthquake (Japan)
    - 2010 El Mayor Cucapah earthquake (Mexico)
- Other applications

Paso Superior Fault
2.5x Vertical Exaggeration

Aligning point clouds and topographic change detection

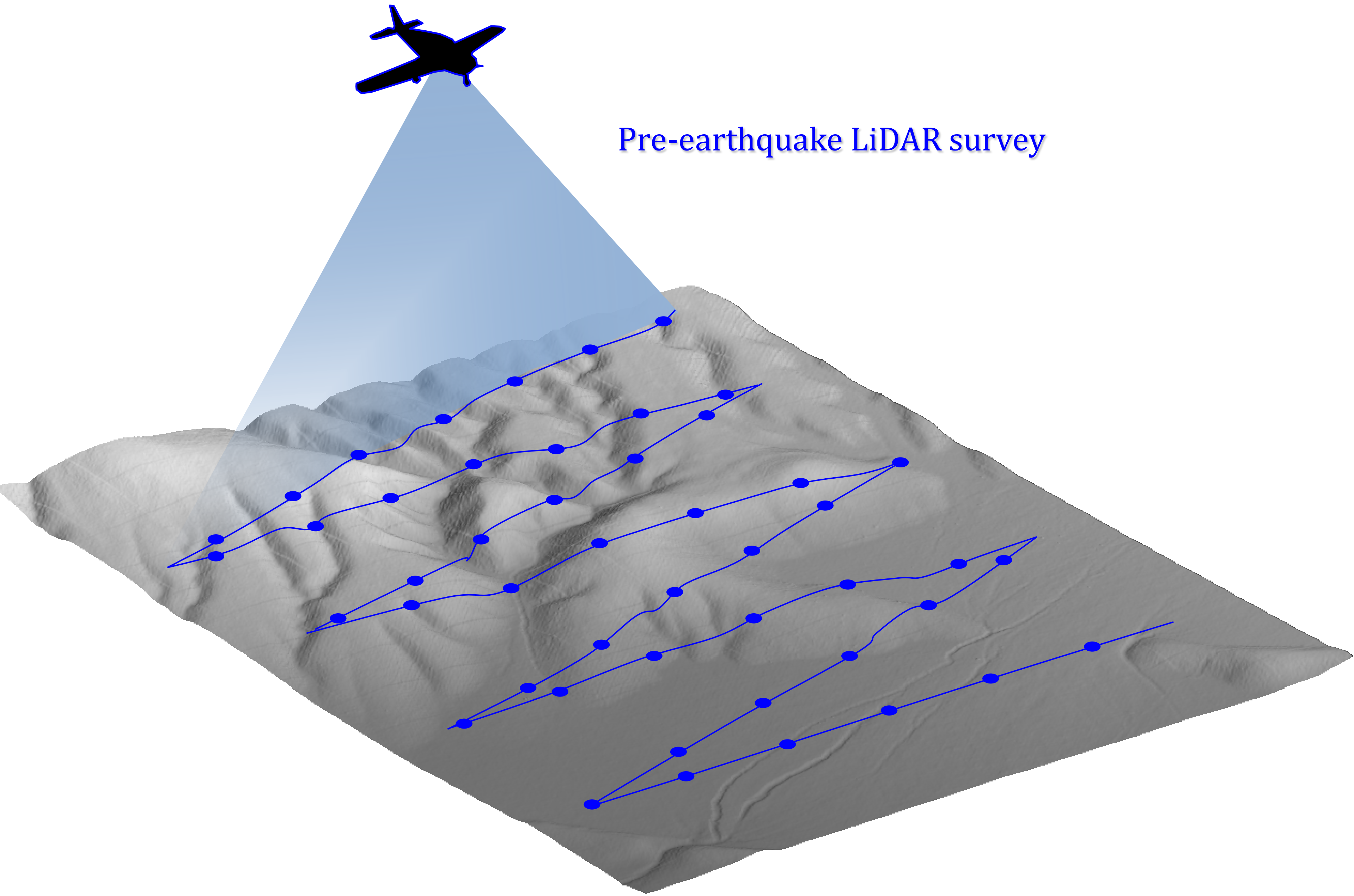




www.opentopography.org

- There is now a “baseline” of lidar topography on many active faults in the western US
- After an earthquake, repeat lidar data can be collected and differenced

3-D earthquake deformation from repeat lidar



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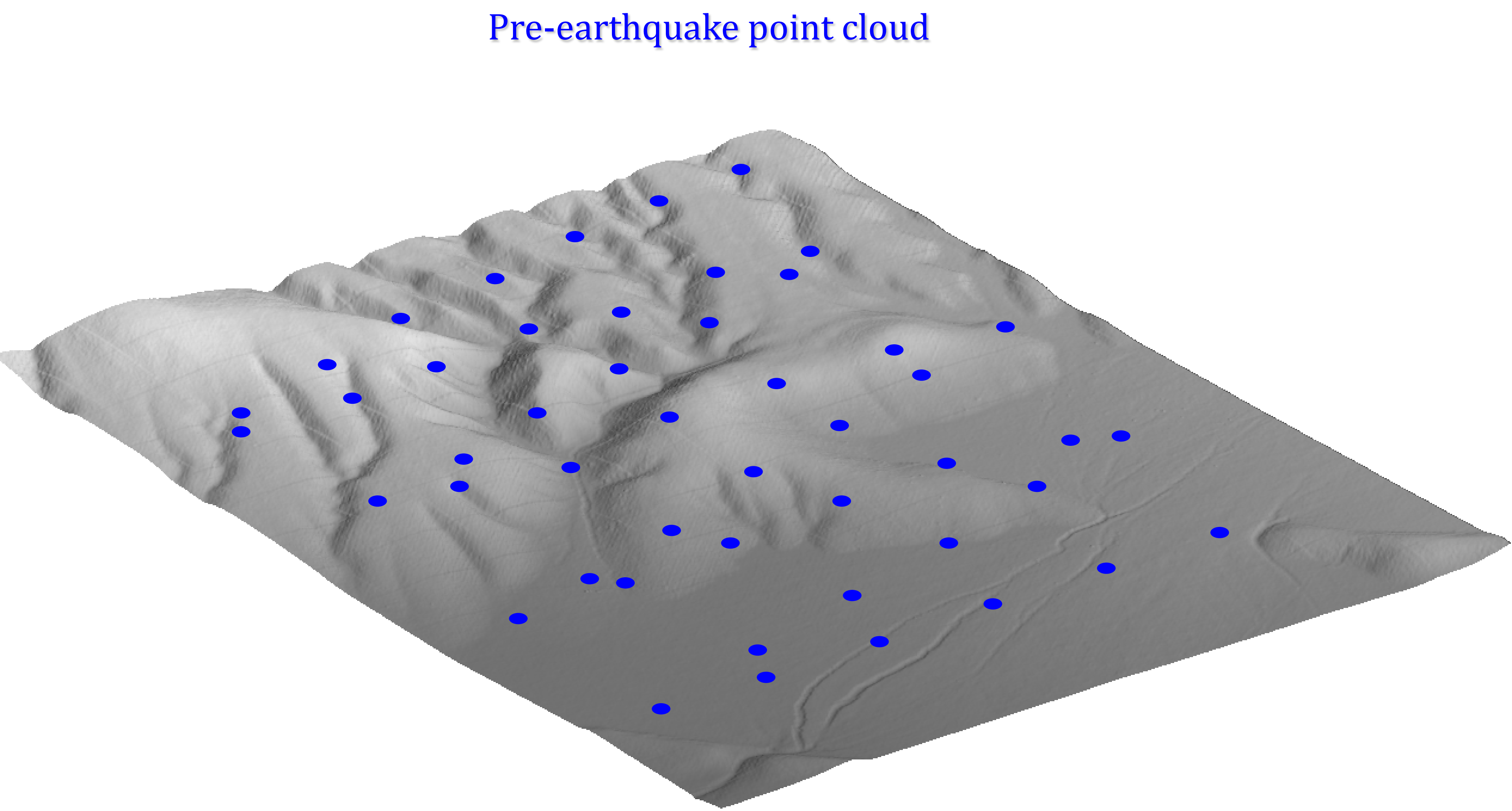

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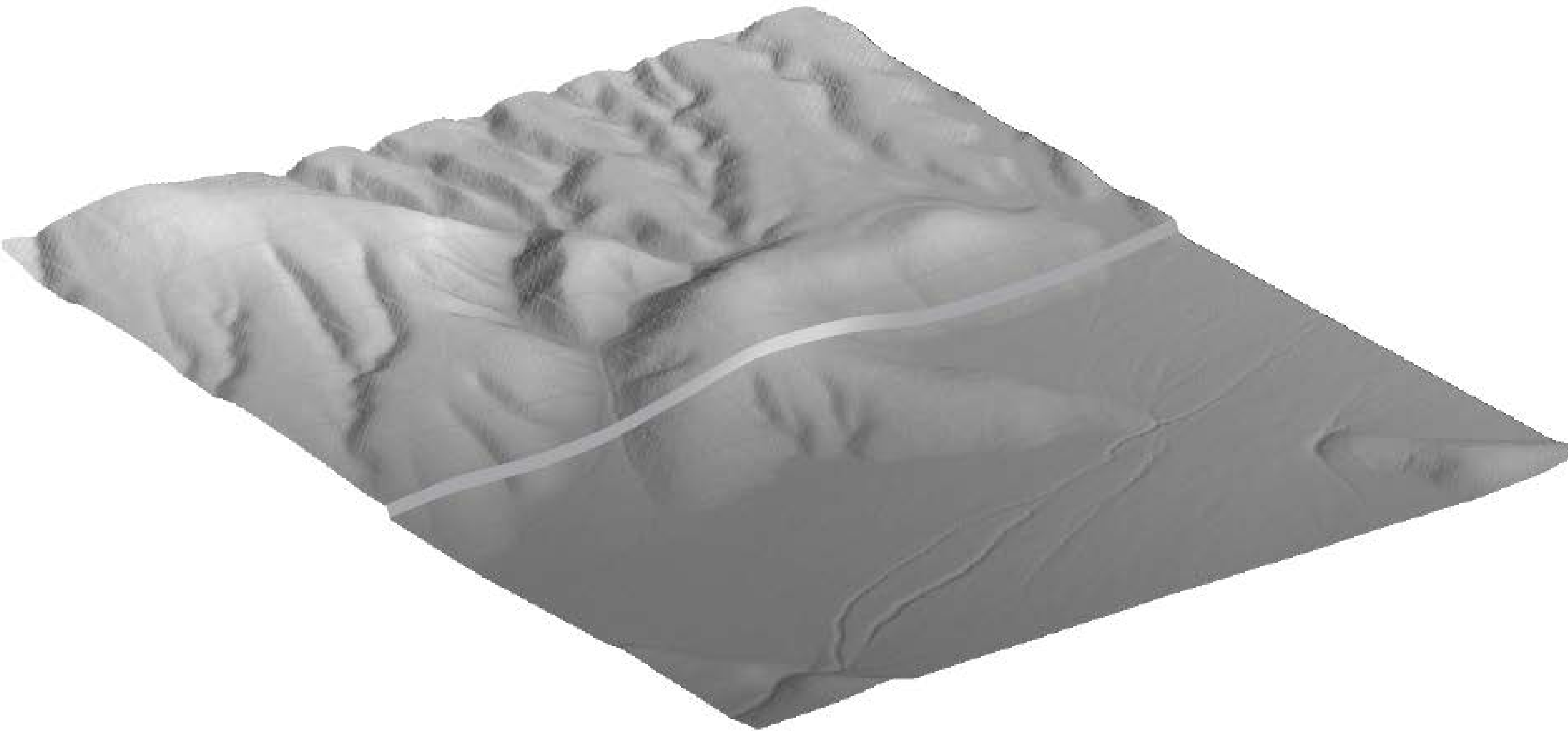

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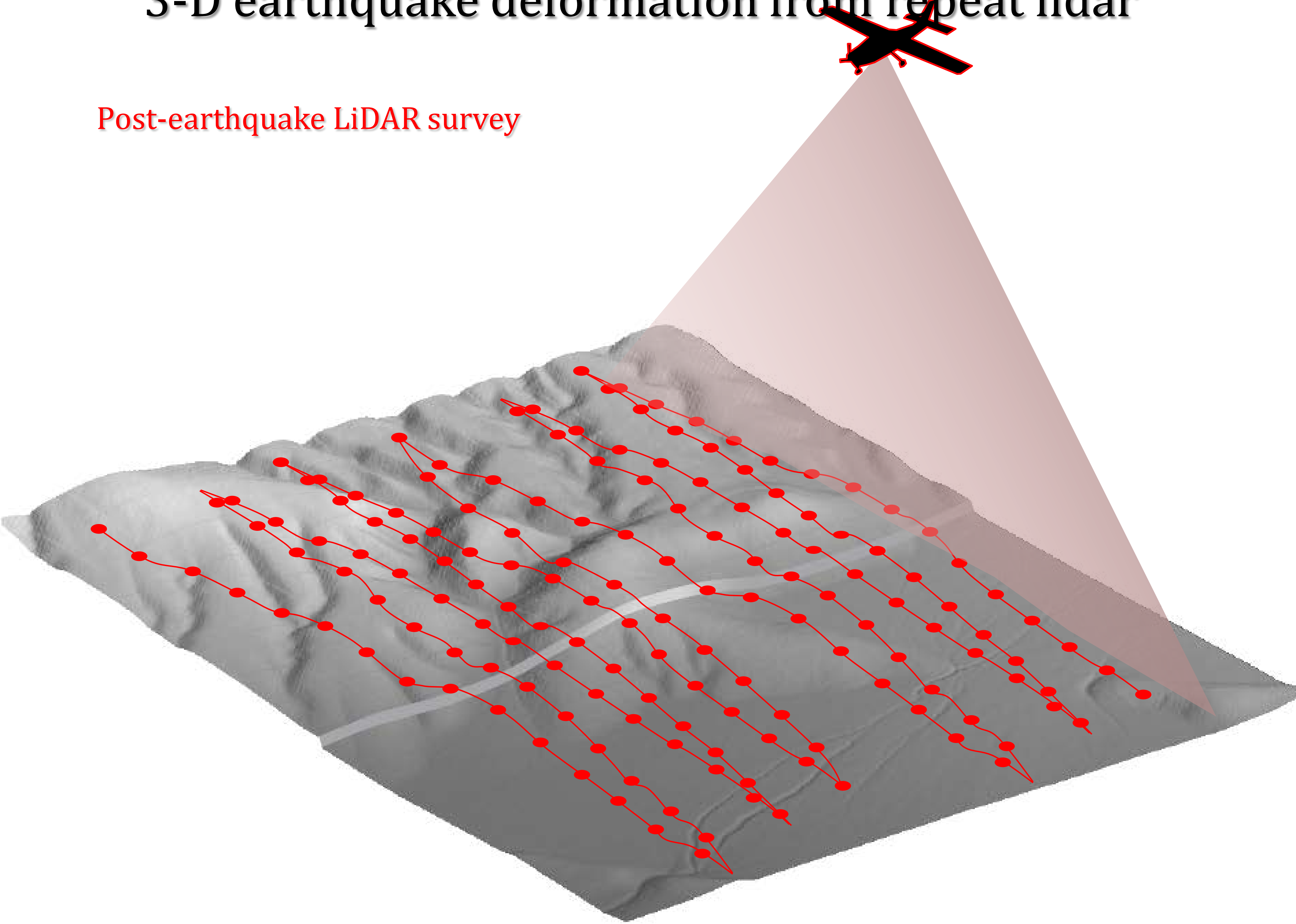

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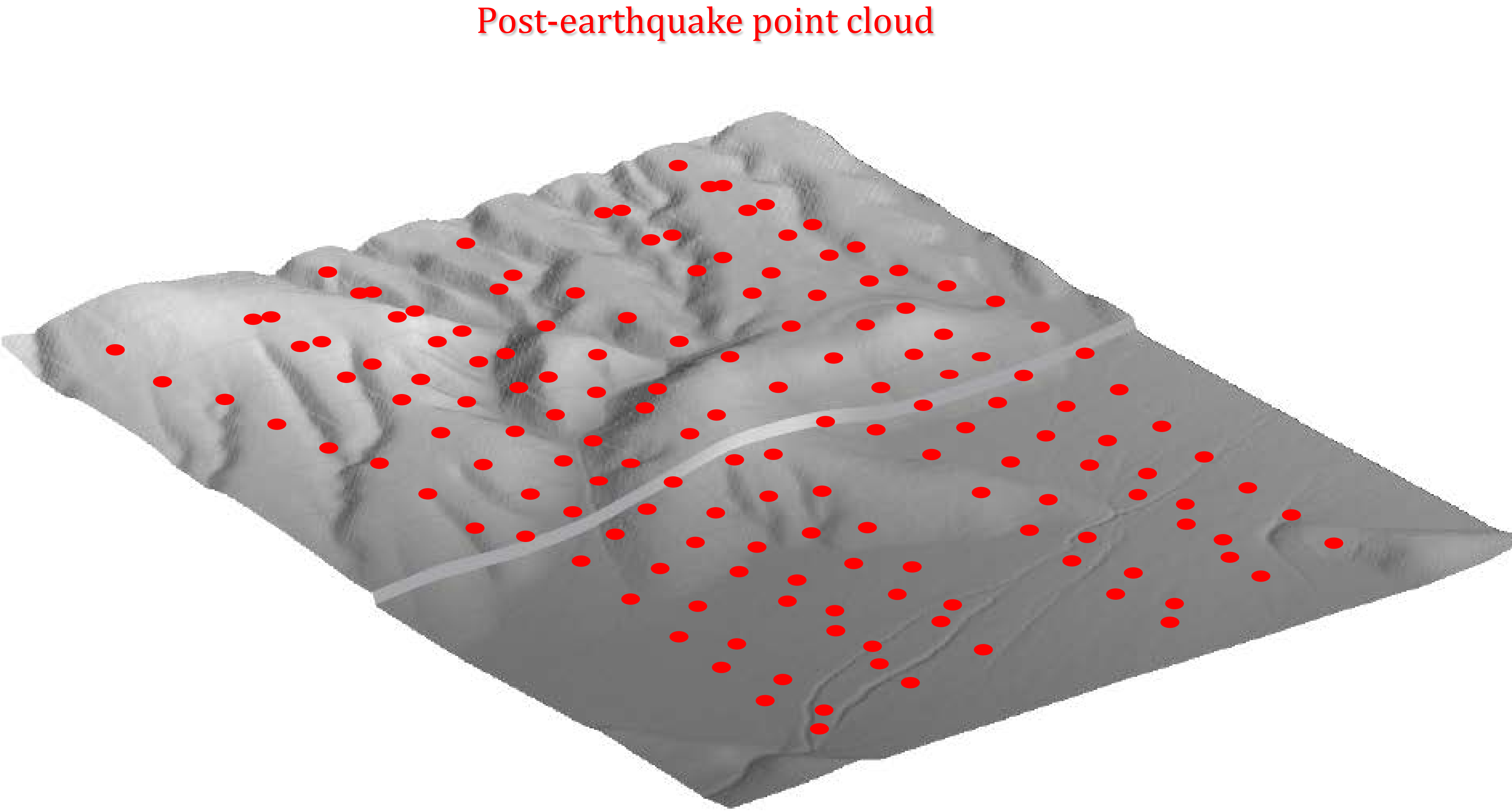

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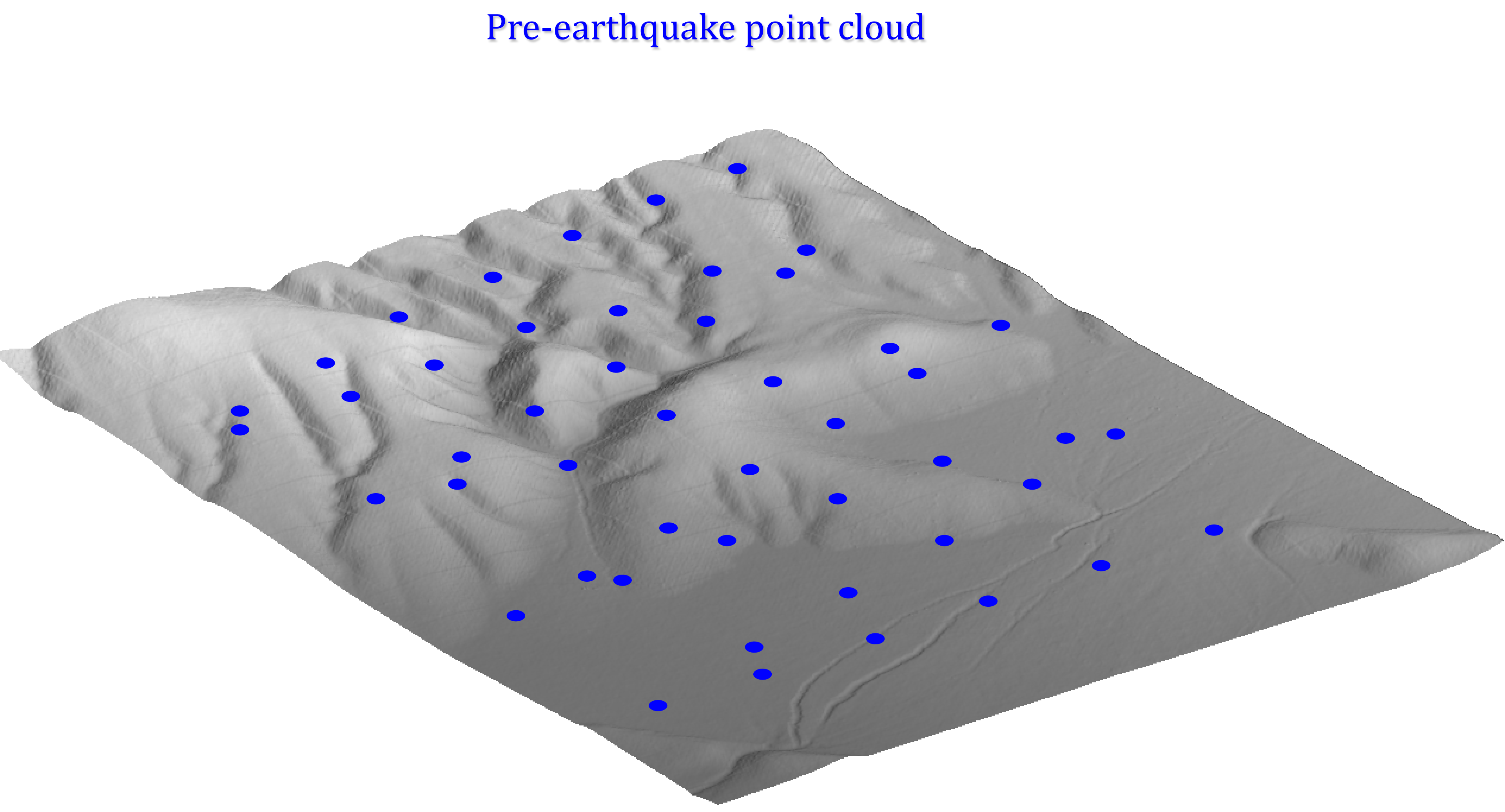
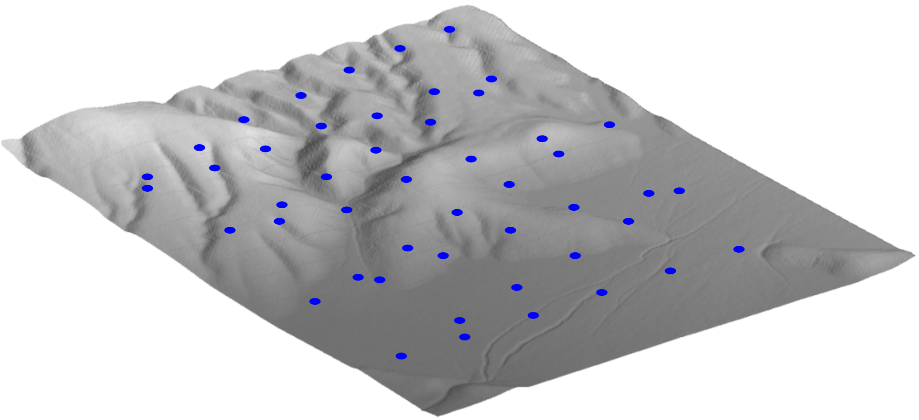
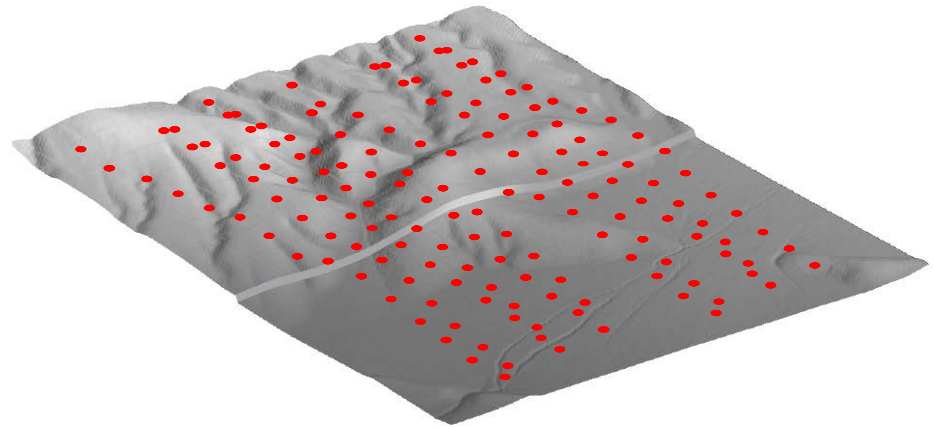


3-D earthquake deformation from repeat lidar

Pre-earthquake point cloud



Post-earthquake point cloud



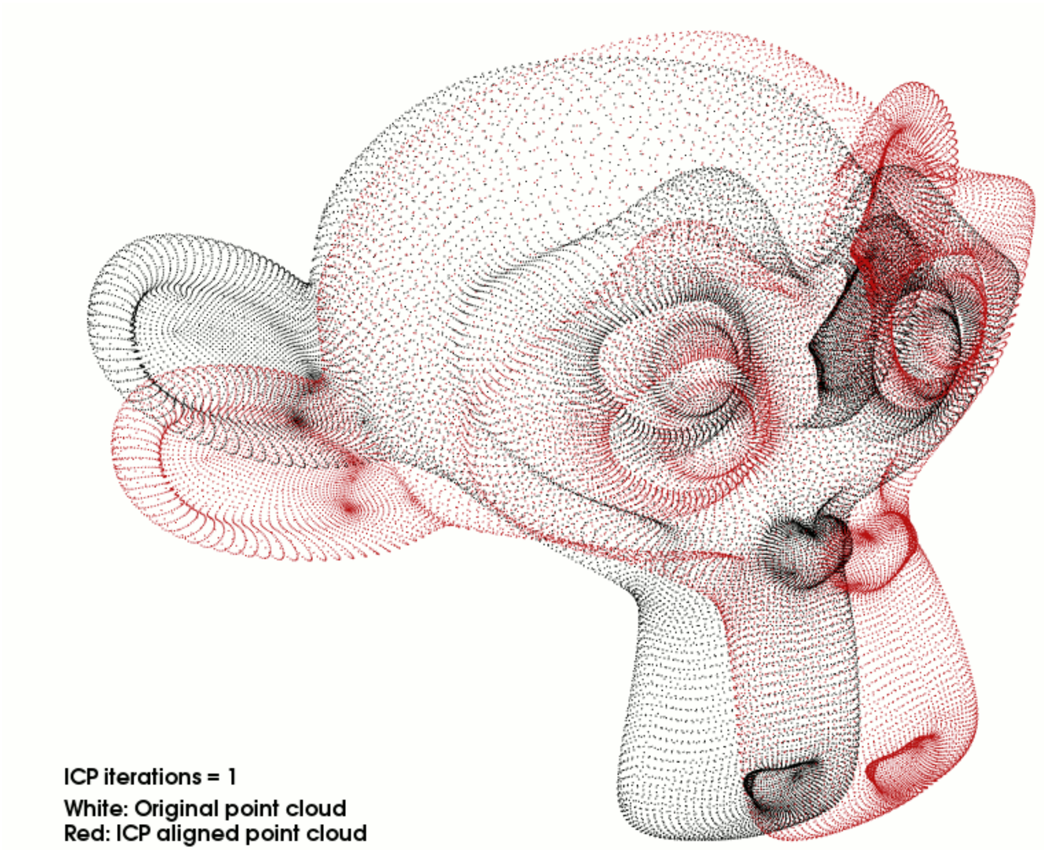
The Challenges of LiDAR differencing

- Data are irregularly spaced (we can rasterize them, but lose information doing so)
- There can be large mismatches in point density (legacy datasets vs modern surveys)
- … and mismatches in data quality and metrics (third party vs research-grade)
- Treatment of vegetation returns in forested areas

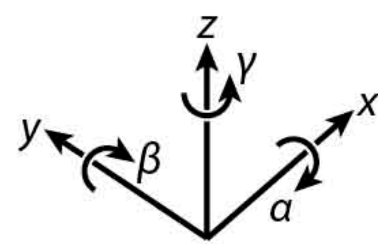
3-D earthquake deformation from repeat lidar

• The **iterative closest point** algorithm (ICP) is a method for registering (aligning) irregular point clouds, well known in computer vision and medical imaging

• ICP minimizes closest point pair distances using iterative **rigid-body transformations,** each one comprising a **translation** [t_x t_y t_z] and a **rotation** [α β γ]



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



pointclouds.org/documentation/tutorials/interactive_icp.php

3-D earthquake deformation from repeat lidar

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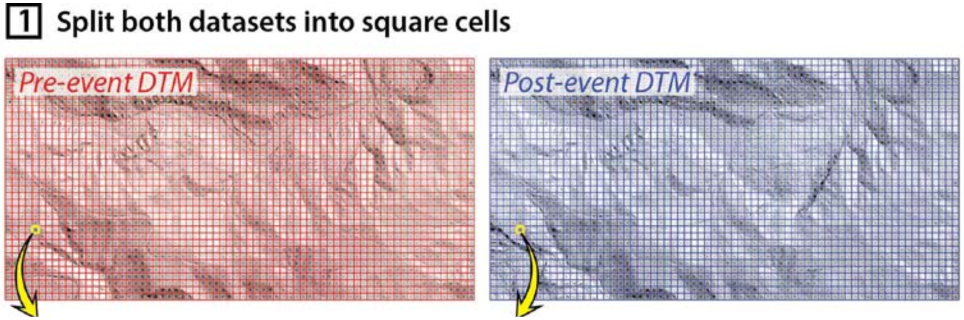


- (1) the two LiDAR datasets are first split into square “cells”

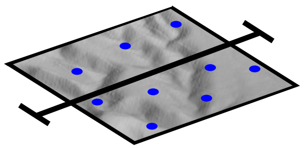
- (2) ICP is run on each equivalent pair of cells. The **translation** [t_x t_y t_z] corresponds to the cell displacement

- (3) this is repeated for the next pair of cells

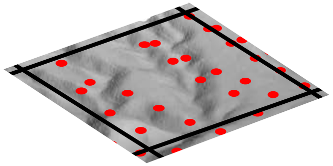
Nissen *et al.* (2012), *Geophys. Res. Lett.*

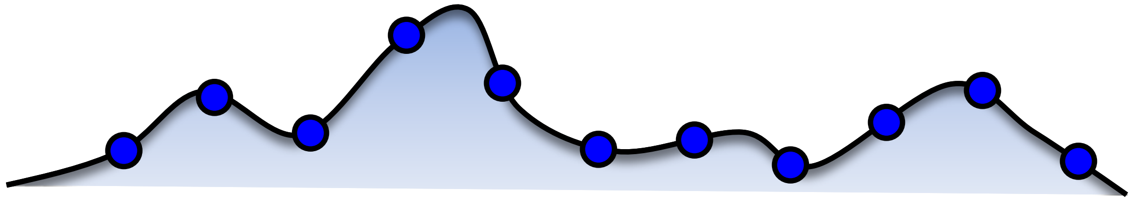
Iterative Closest Point algorithm (ICP)

Pre-earthquake cell

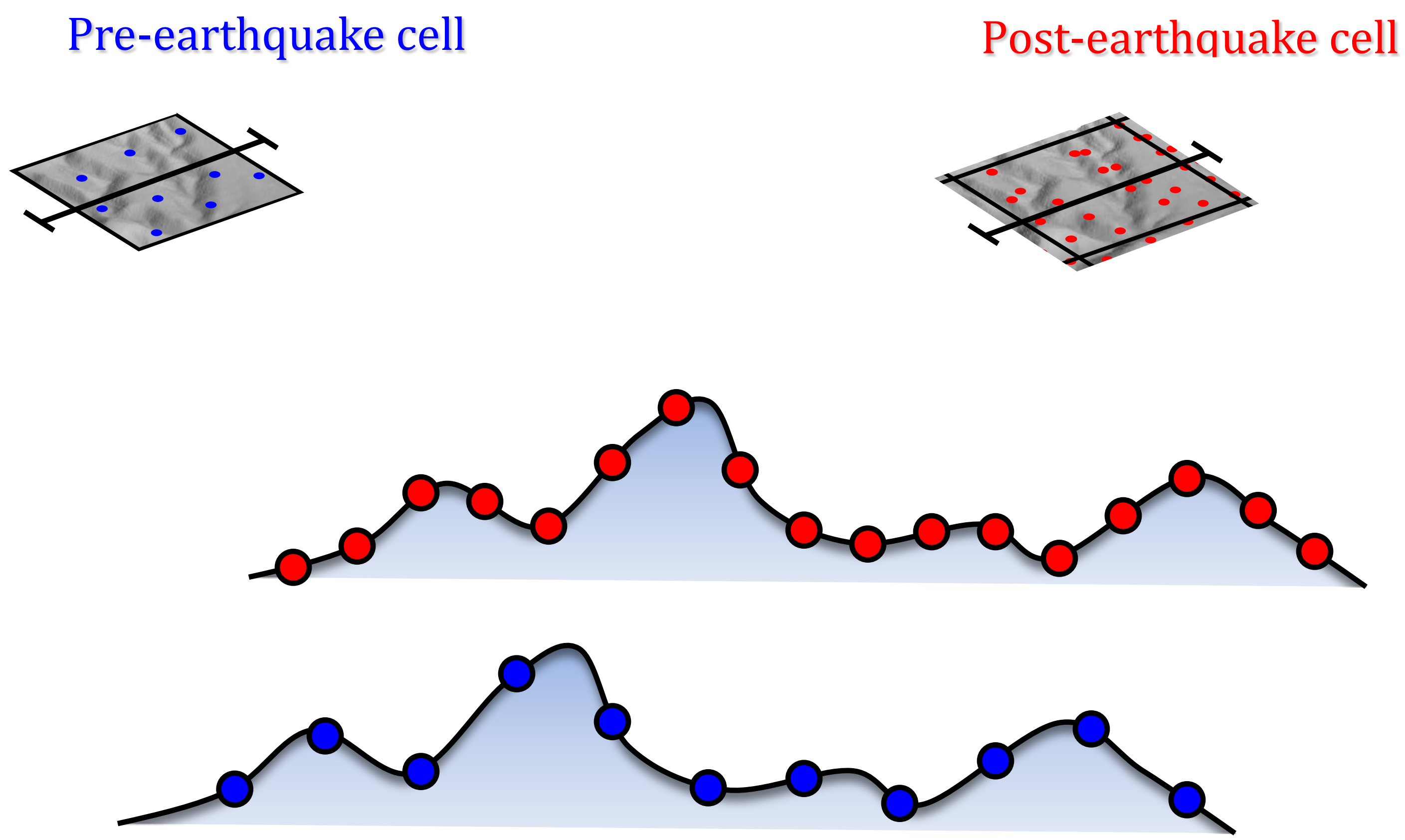


Post-earthquake cell



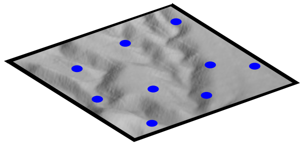


Iterative Closest Point algorithm (ICP)

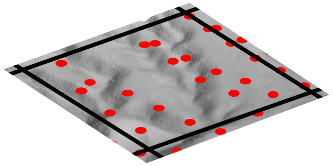


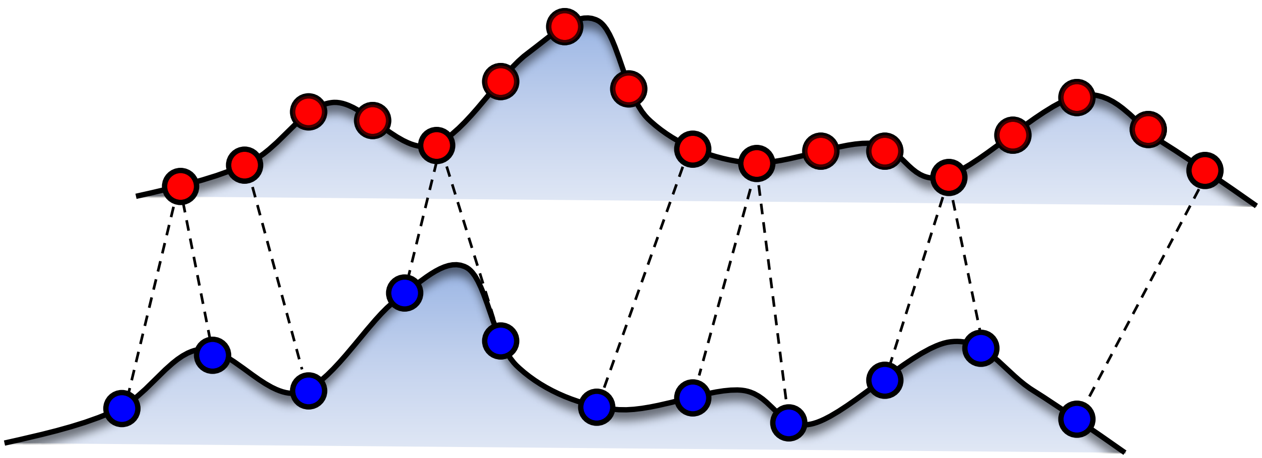
Iterative Closest Point algorithm (ICP)

Pre-earthquake cell



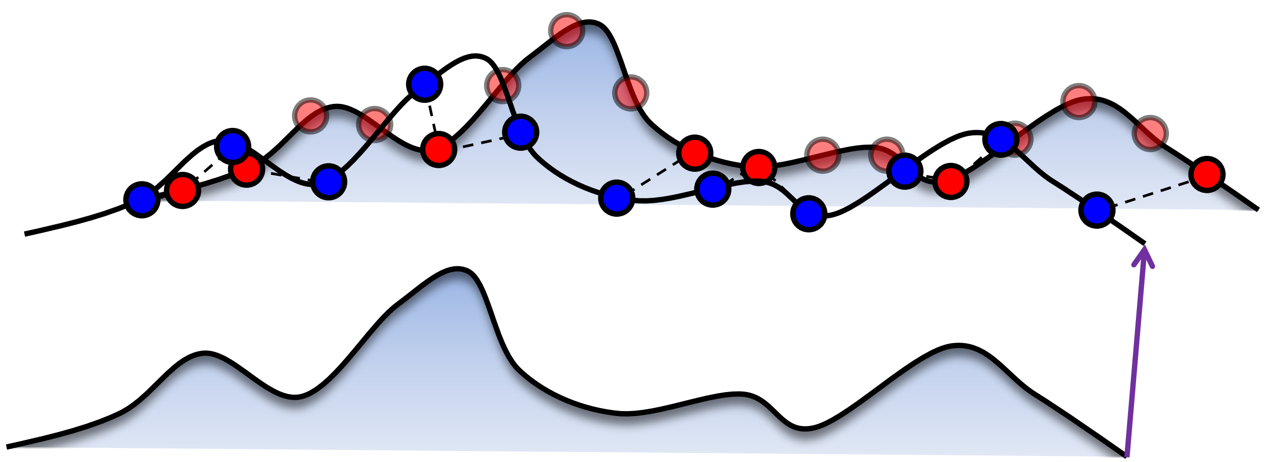
Post-earthquake cell





Find closest points

Iterative Closest Point algorithm (ICP)



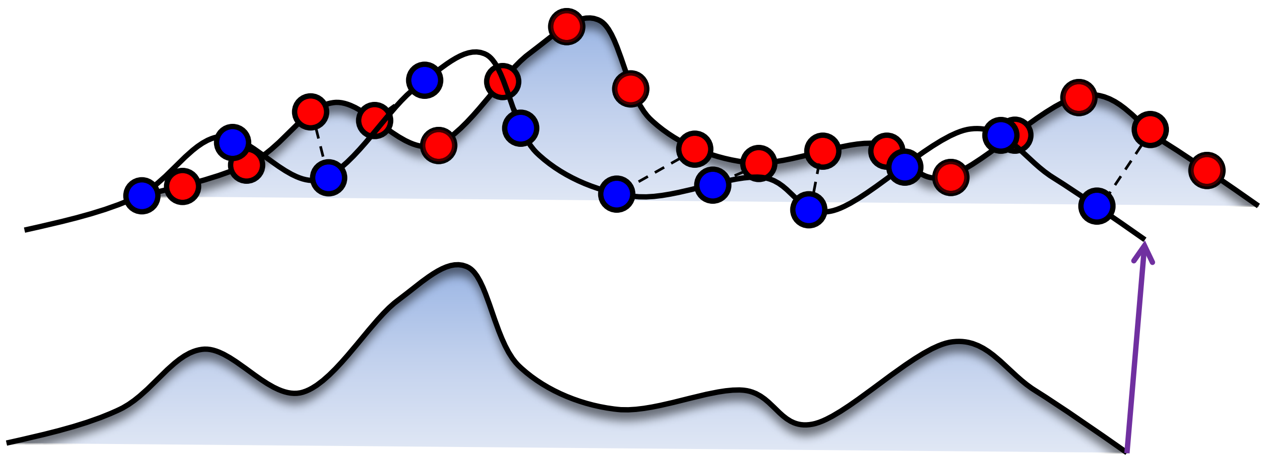
Iterate

Find closest points

Transform point cloud

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

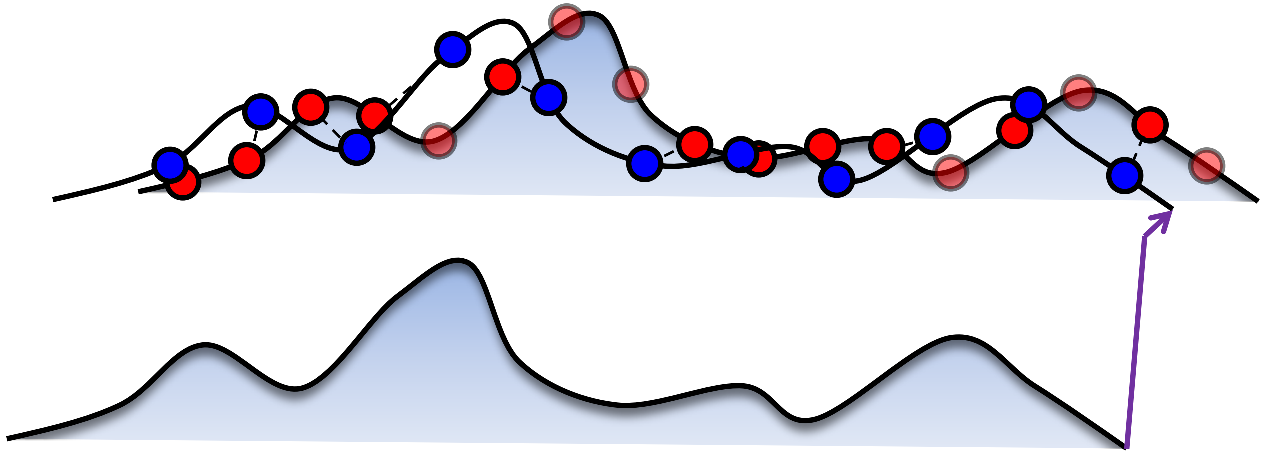
Iterative Closest Point algorithm (ICP)



Find closest points

Transform point cloud

Iterative Closest Point algorithm (ICP)



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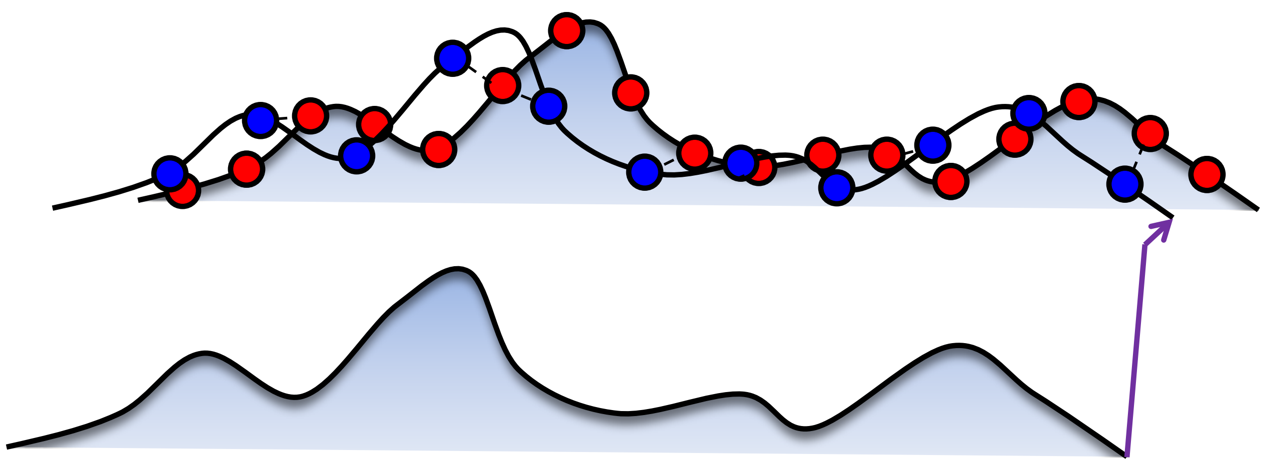

Find closest points

Transform point cloud

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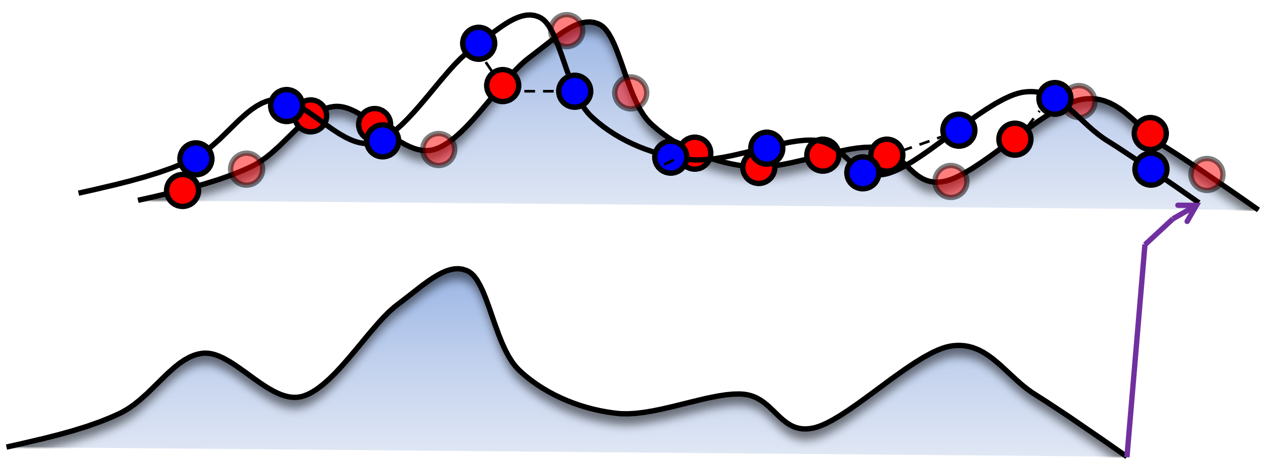

Find closest points

Transform point cloud

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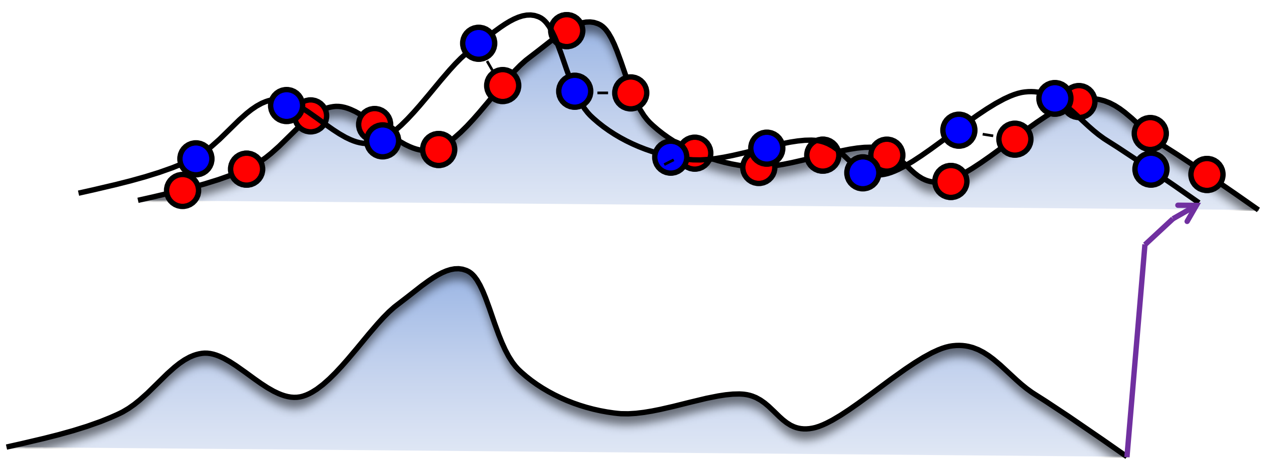

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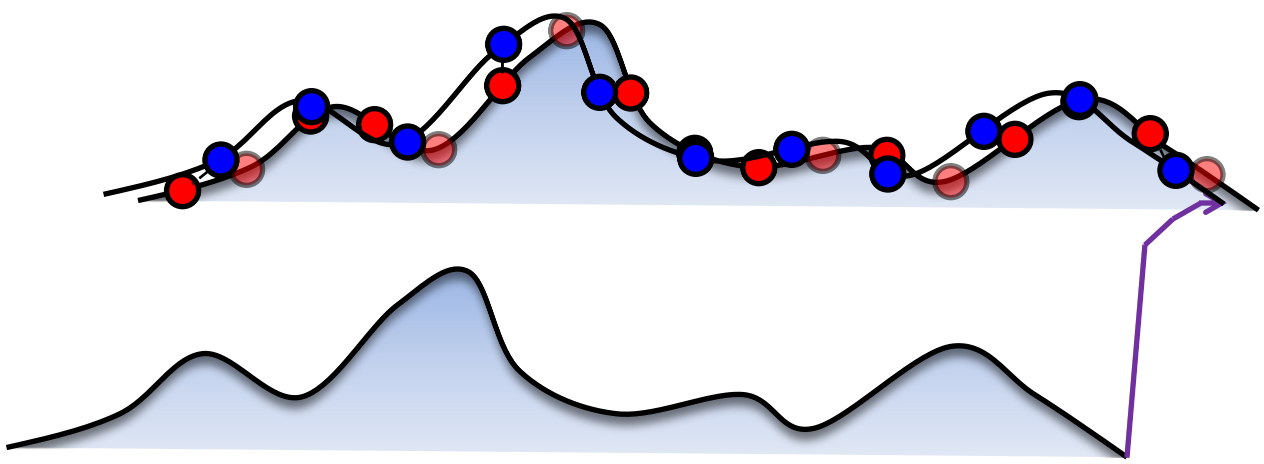

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Transform point cloud

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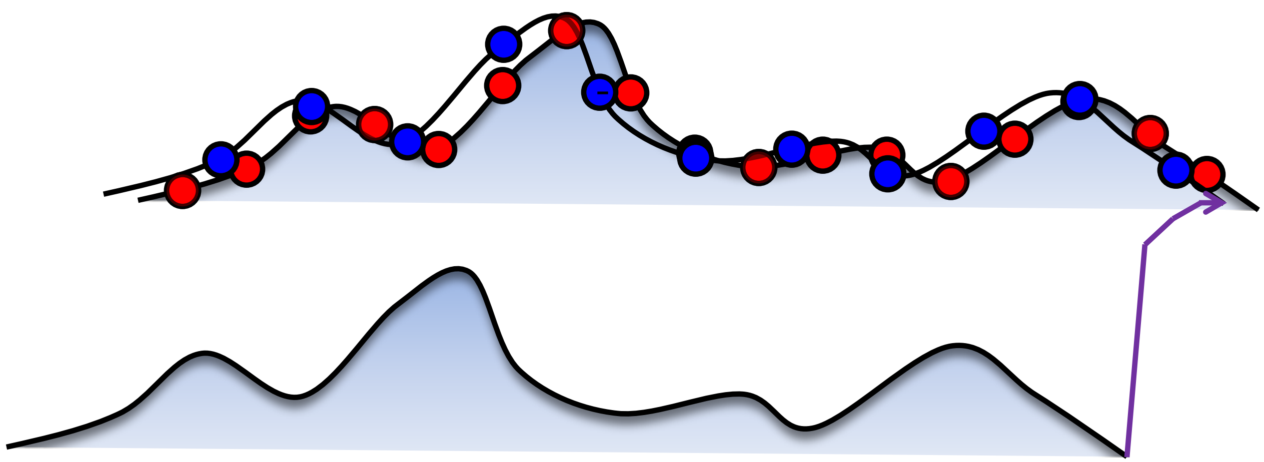

Find closest points

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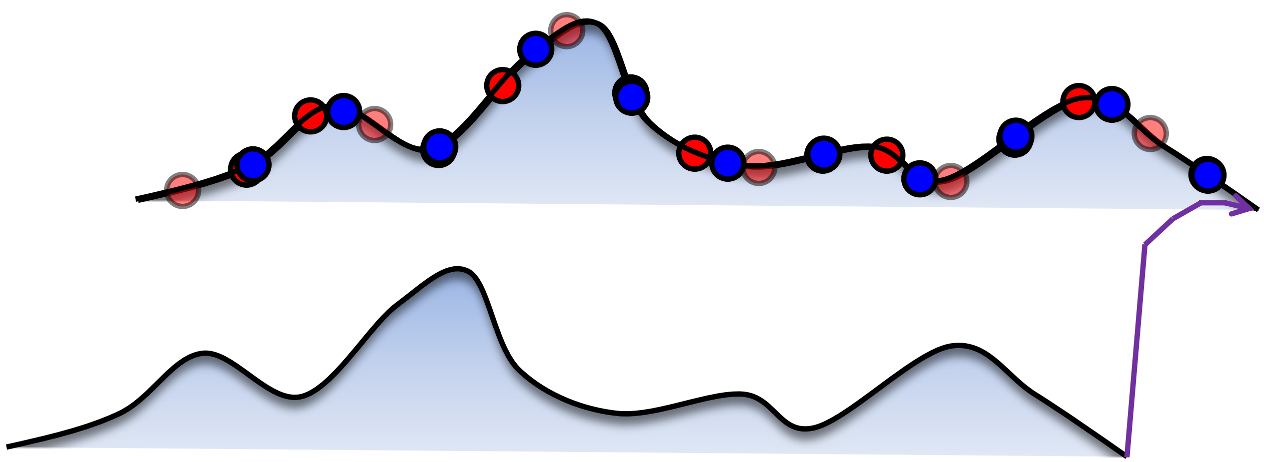

Find closest points

Transform point cloud

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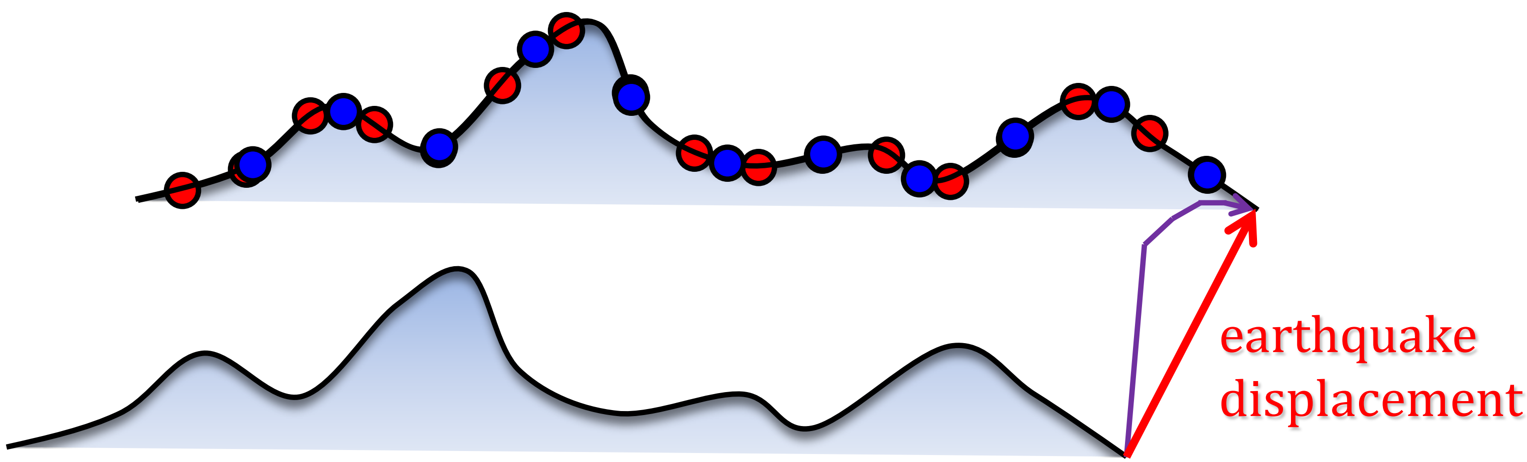


Find closest points

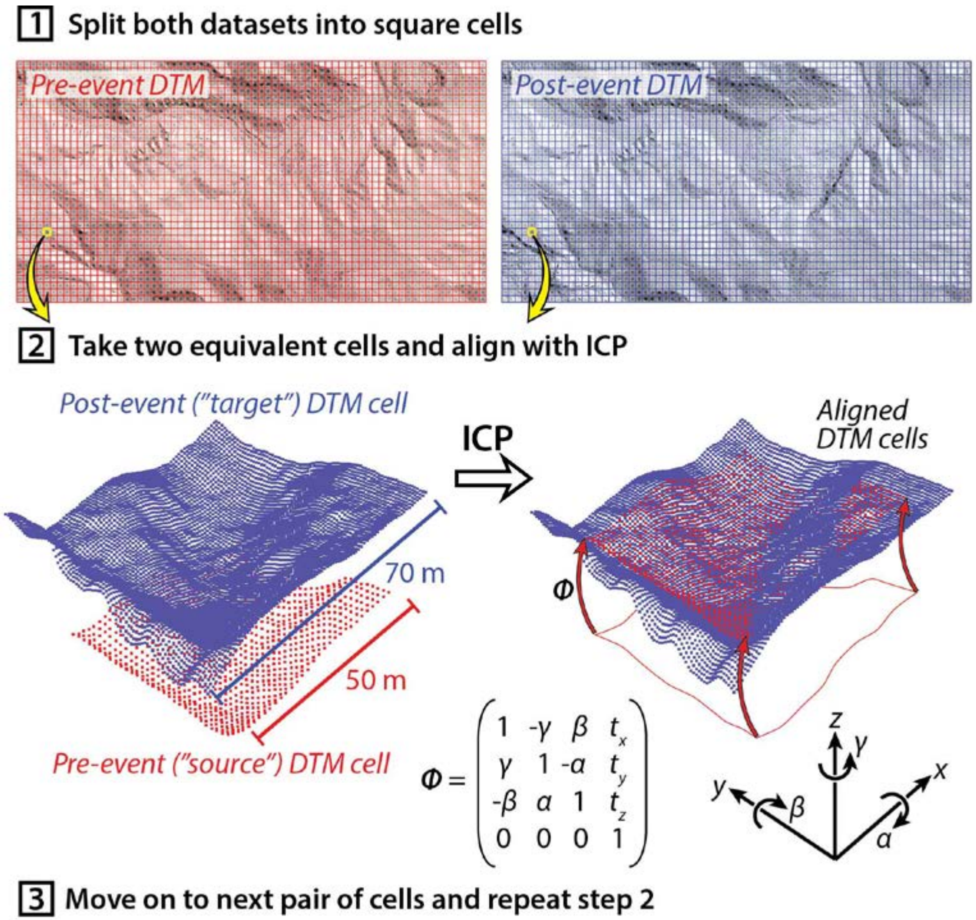
Transform point cloud

3-D earthquake deformation from repeat LiDAR point clouds

Caveats

• ICP will not work if there are large changes to the shape of the cell, e.g. through landsliding

• ICP will generate spurious results in areas that are very planar



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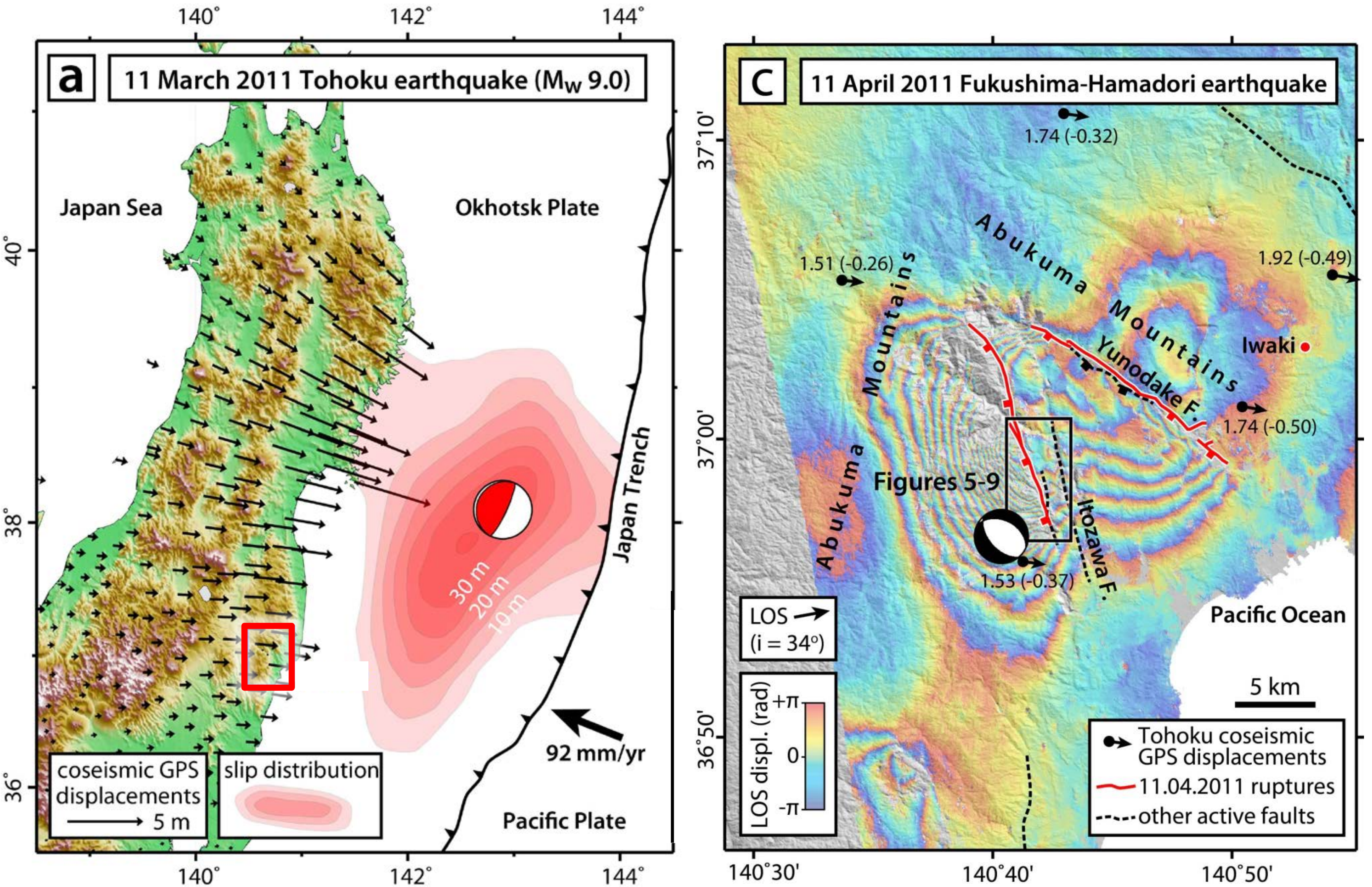
Nissen *et al.* (2012), *Geophys. Res. Lett.*

11 April 2011 Fukushima-Hamadori earthquake



Nissen *et al.* (2014), *Earth Planet. Sci. Lett.*

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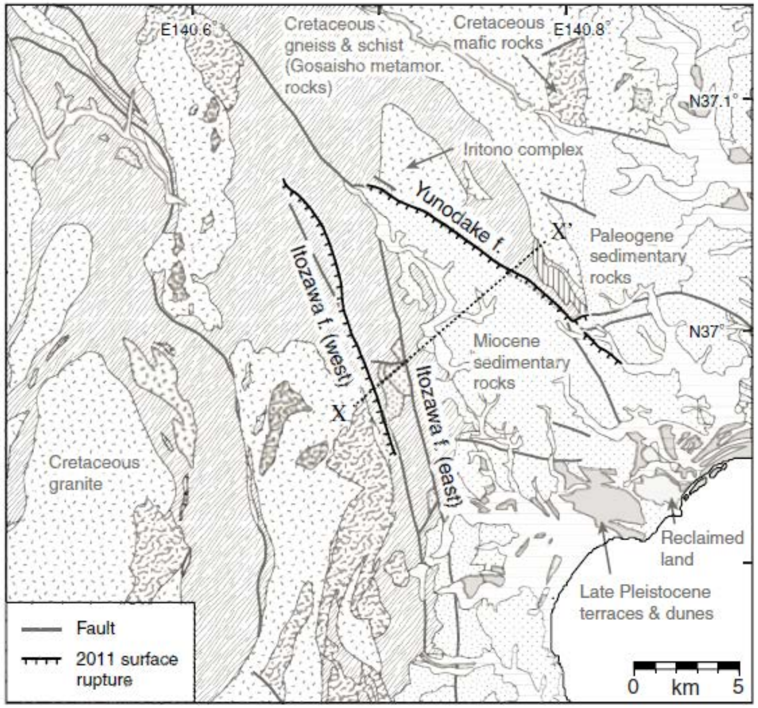
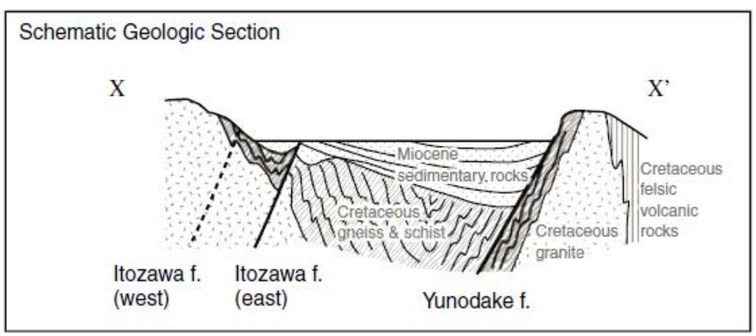
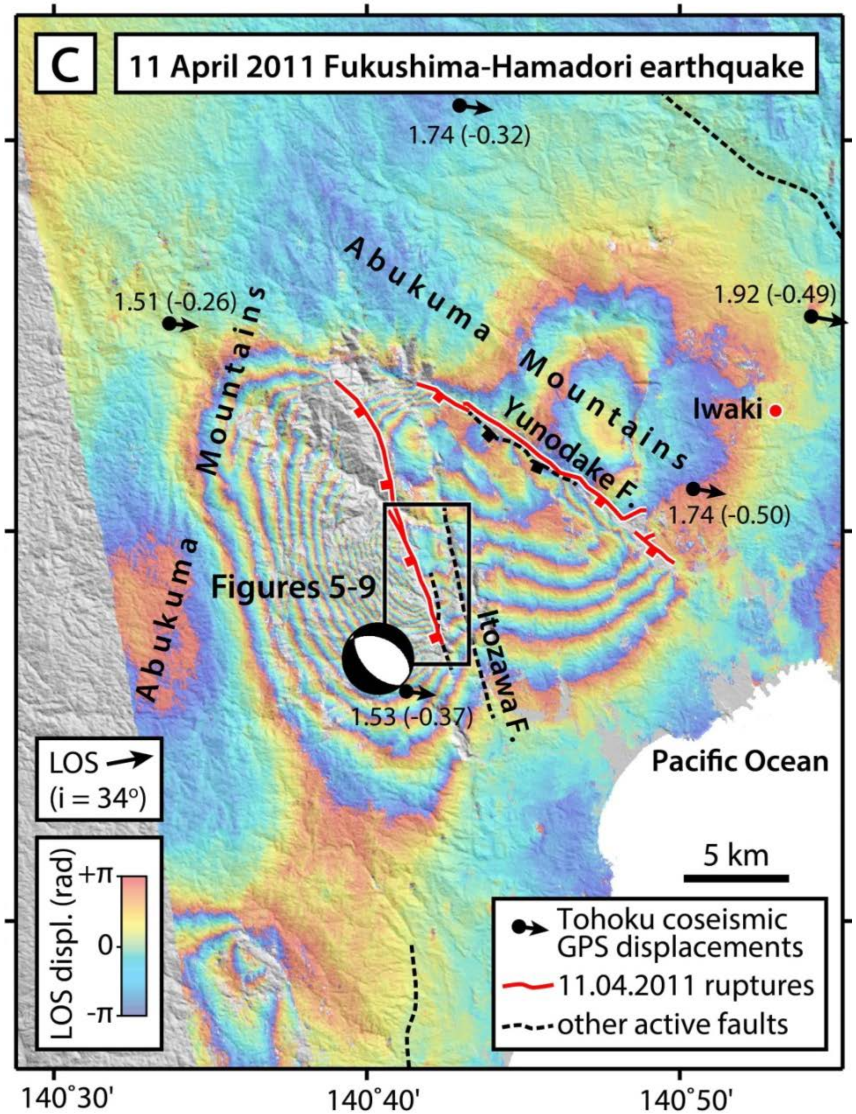




Toda & Tsutsumi (2013), *BSSA*



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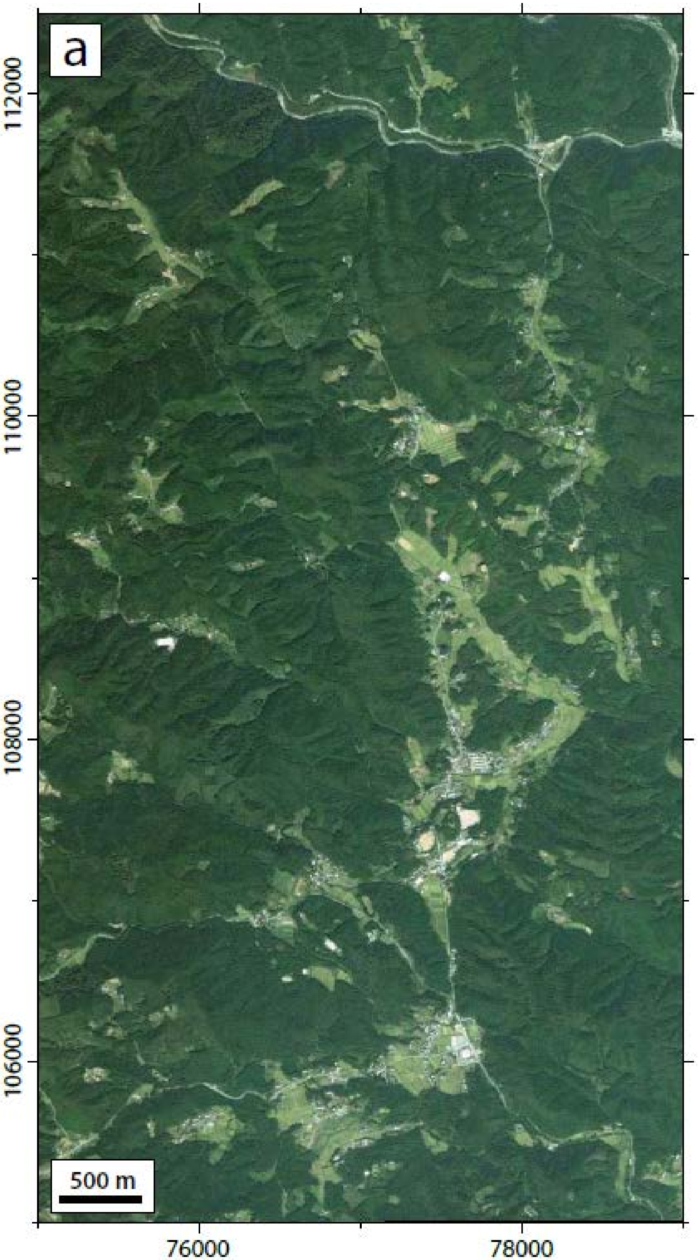

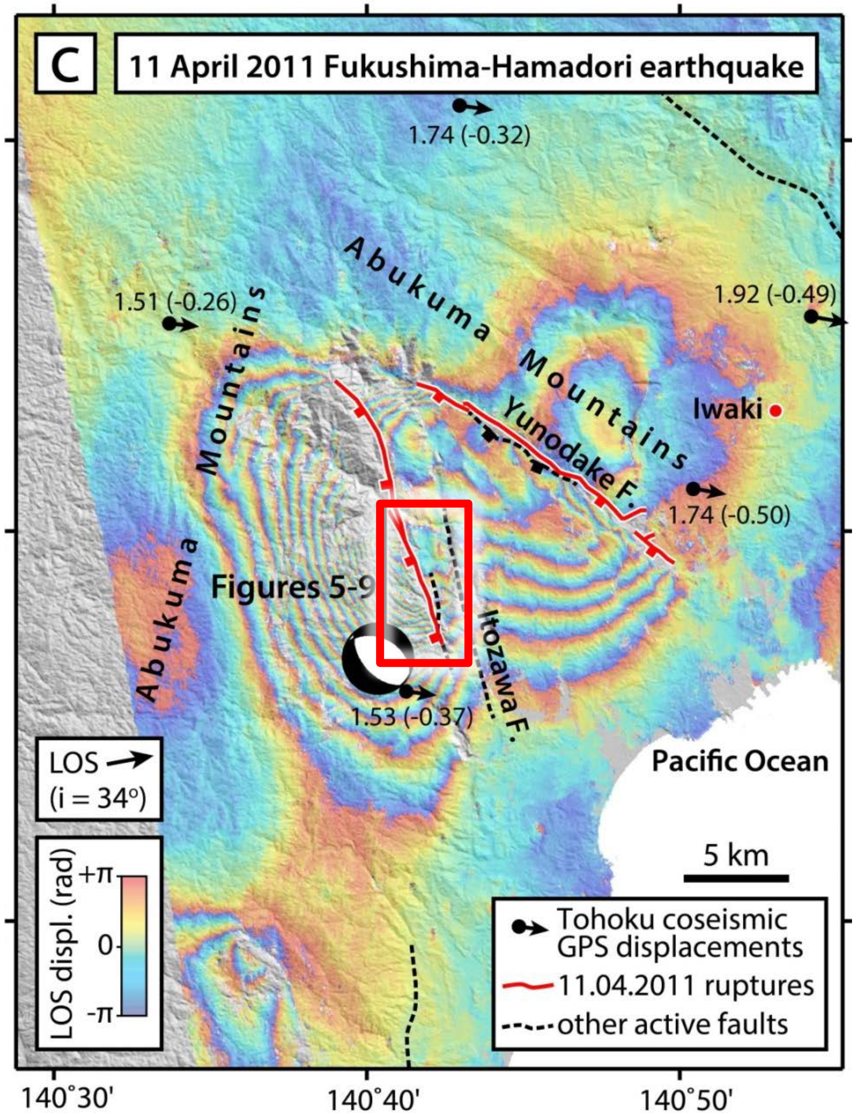

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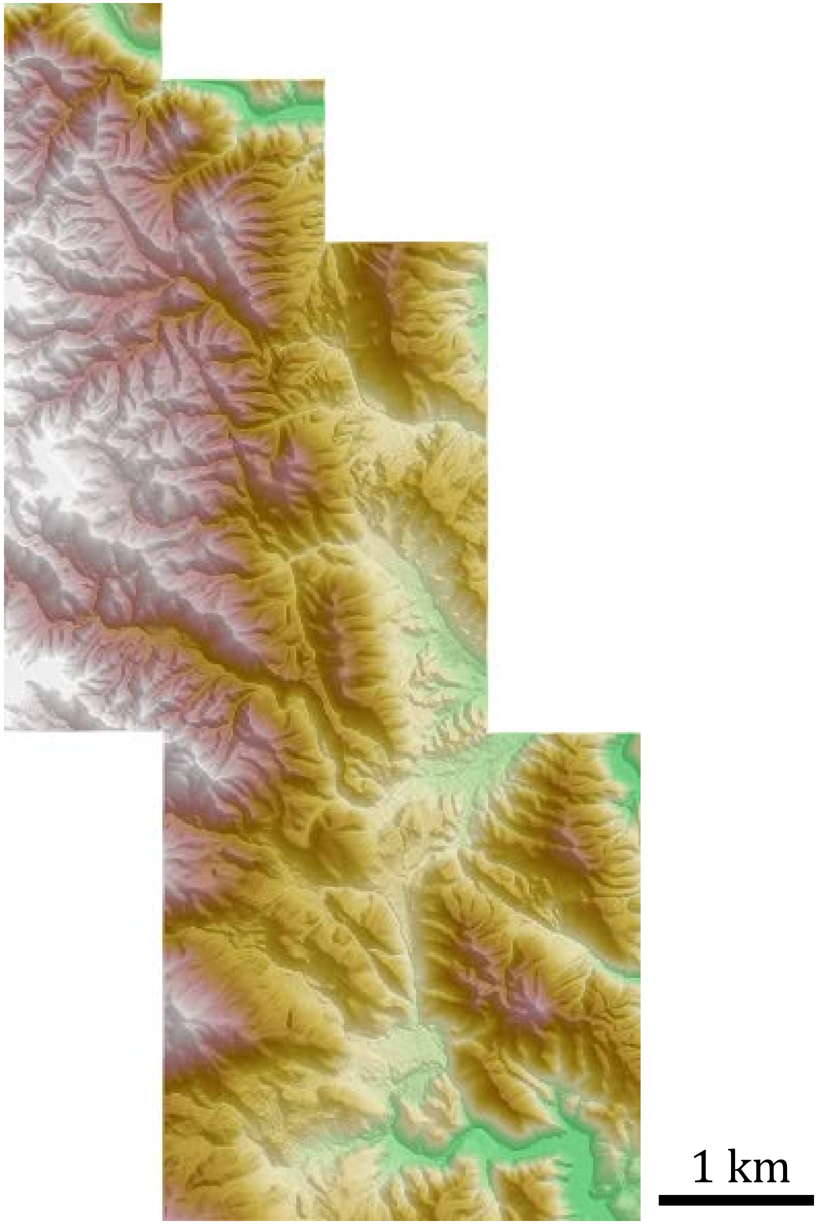
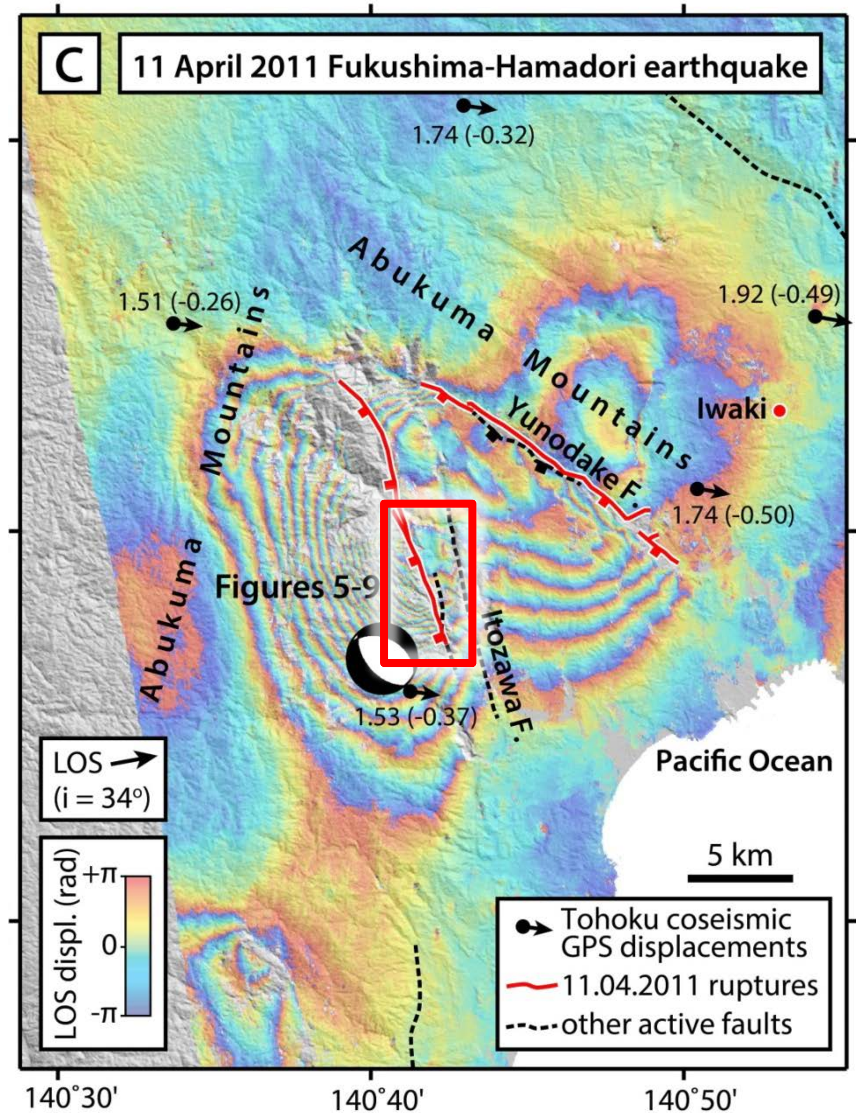


2006 pre-event 2 m DEM KOKUSAI KOGYO GROUP



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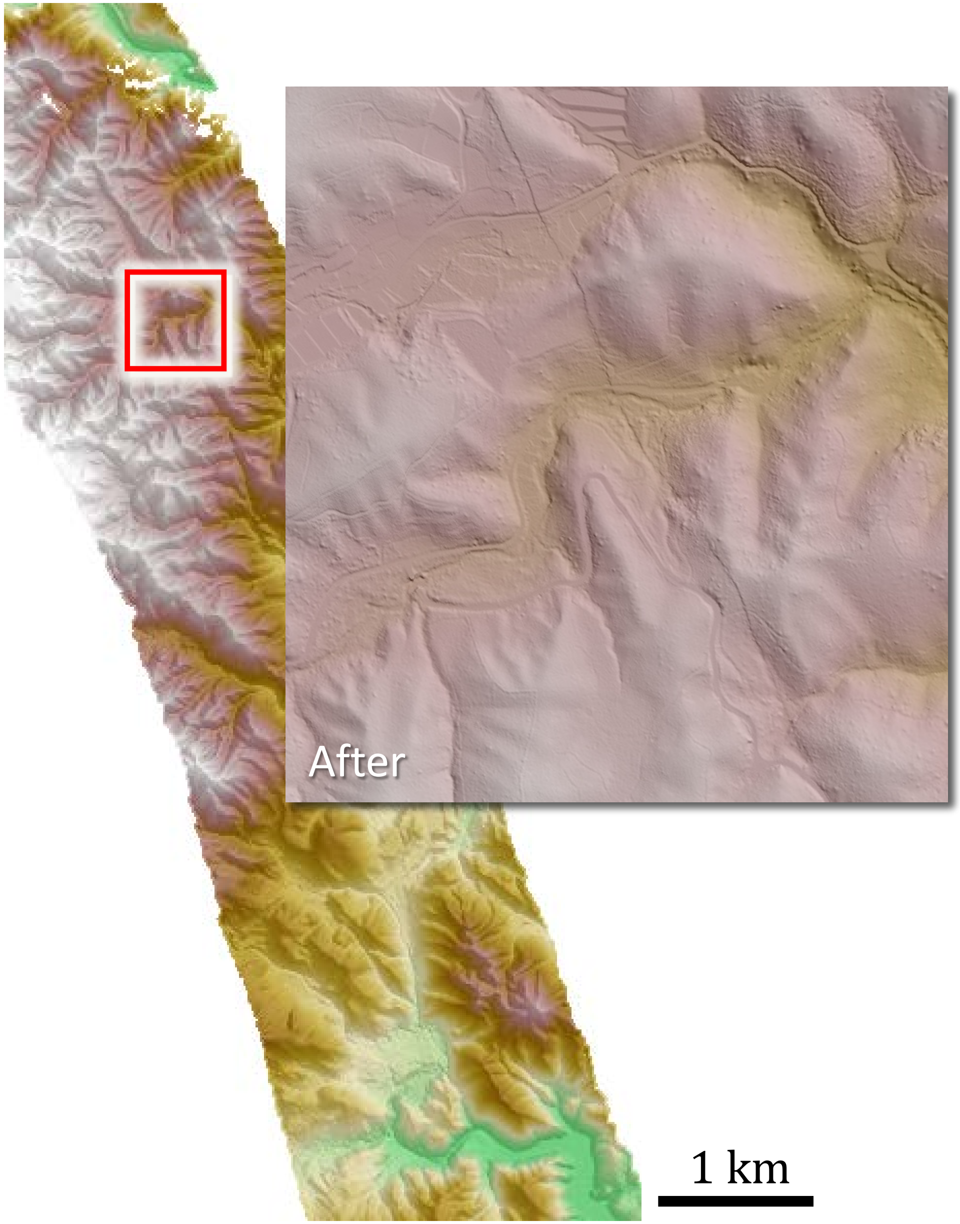
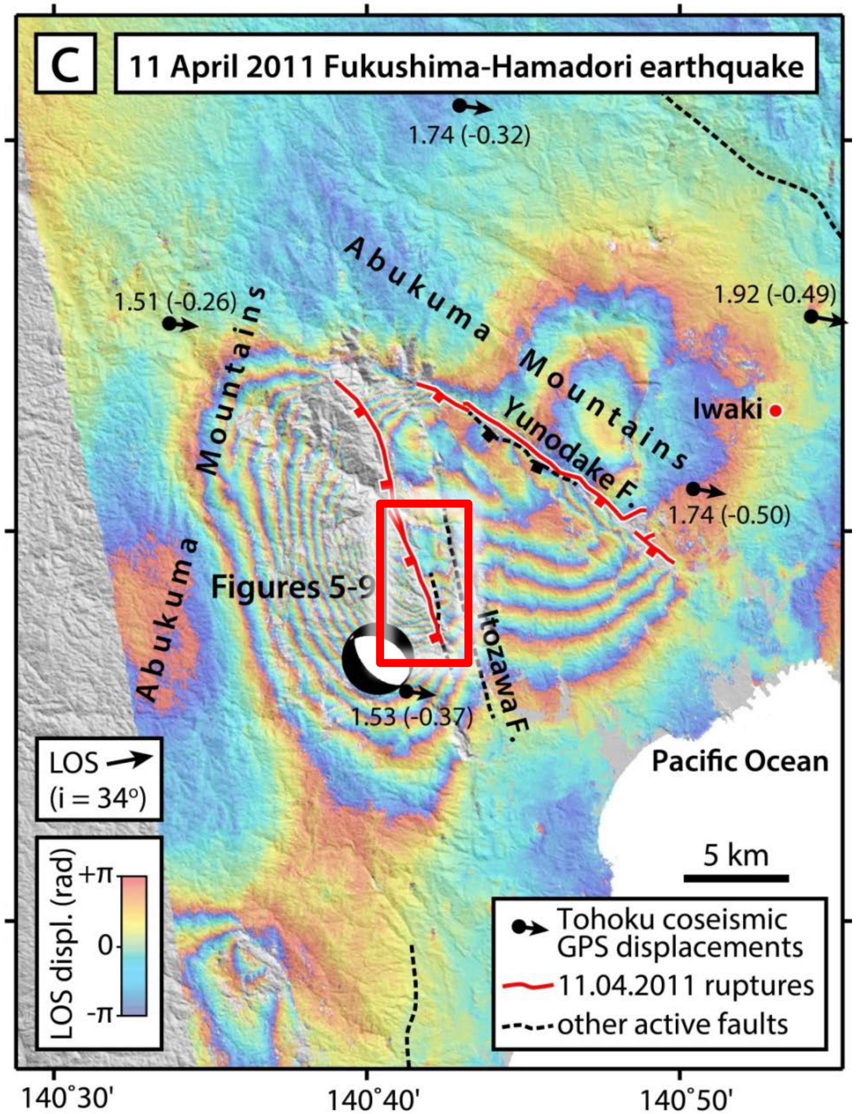
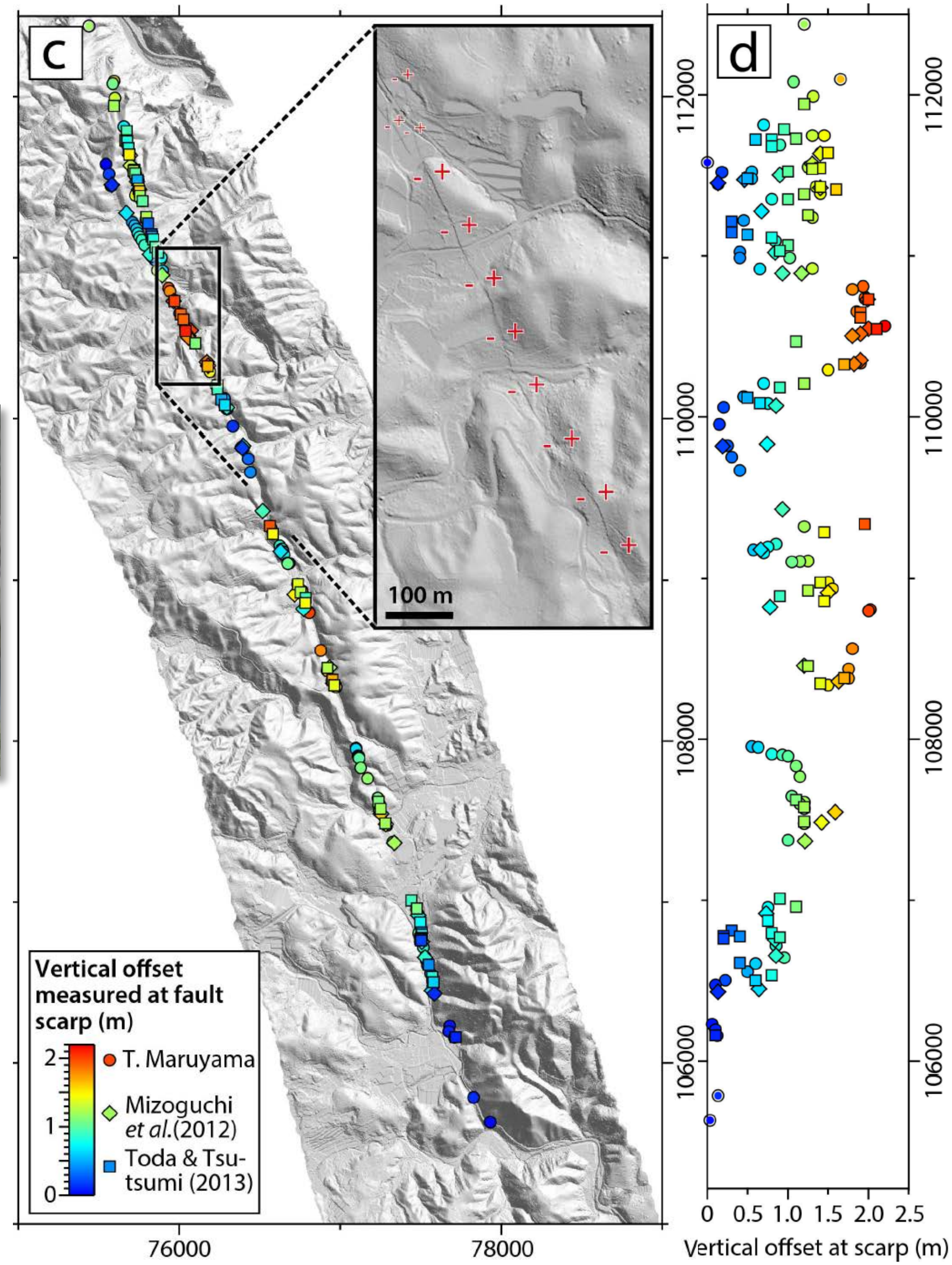




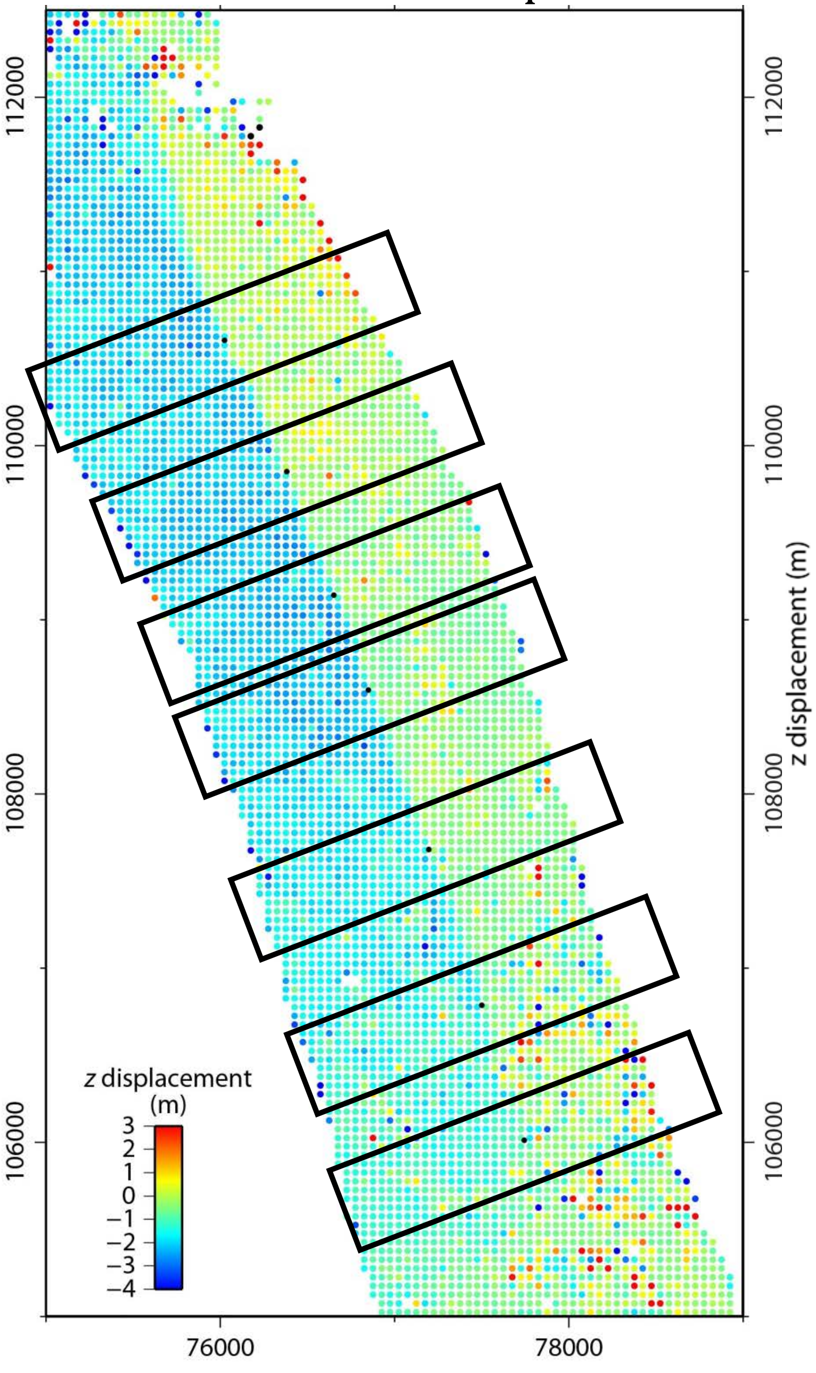
2011 post-event 1 m DEM AERO ASAHI CORPORATION

11 April 2011 Fukushima-Hamadori earthquake

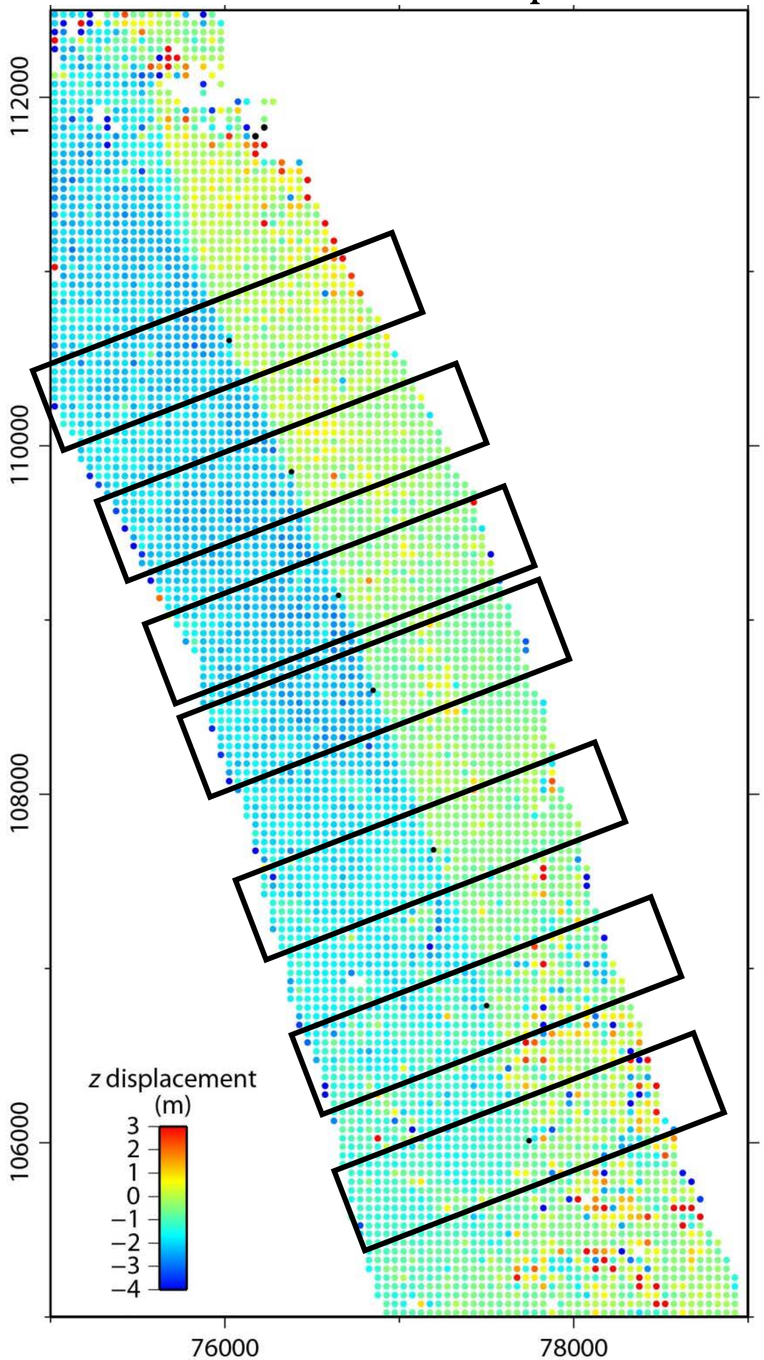


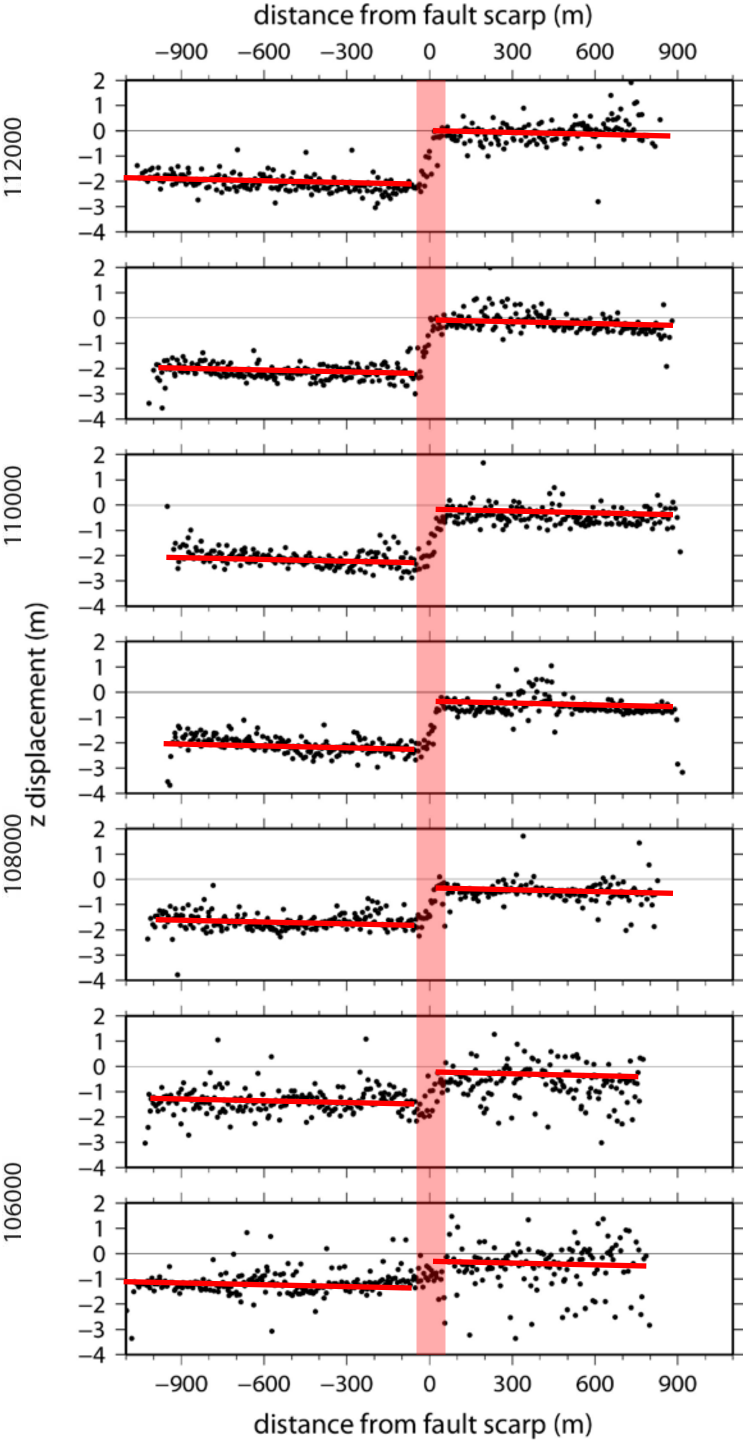
Photos from Toda & Tsutsumi (2013), *BSSA*

2005-2011 vertical displacements



2005-2011 vertical displacements





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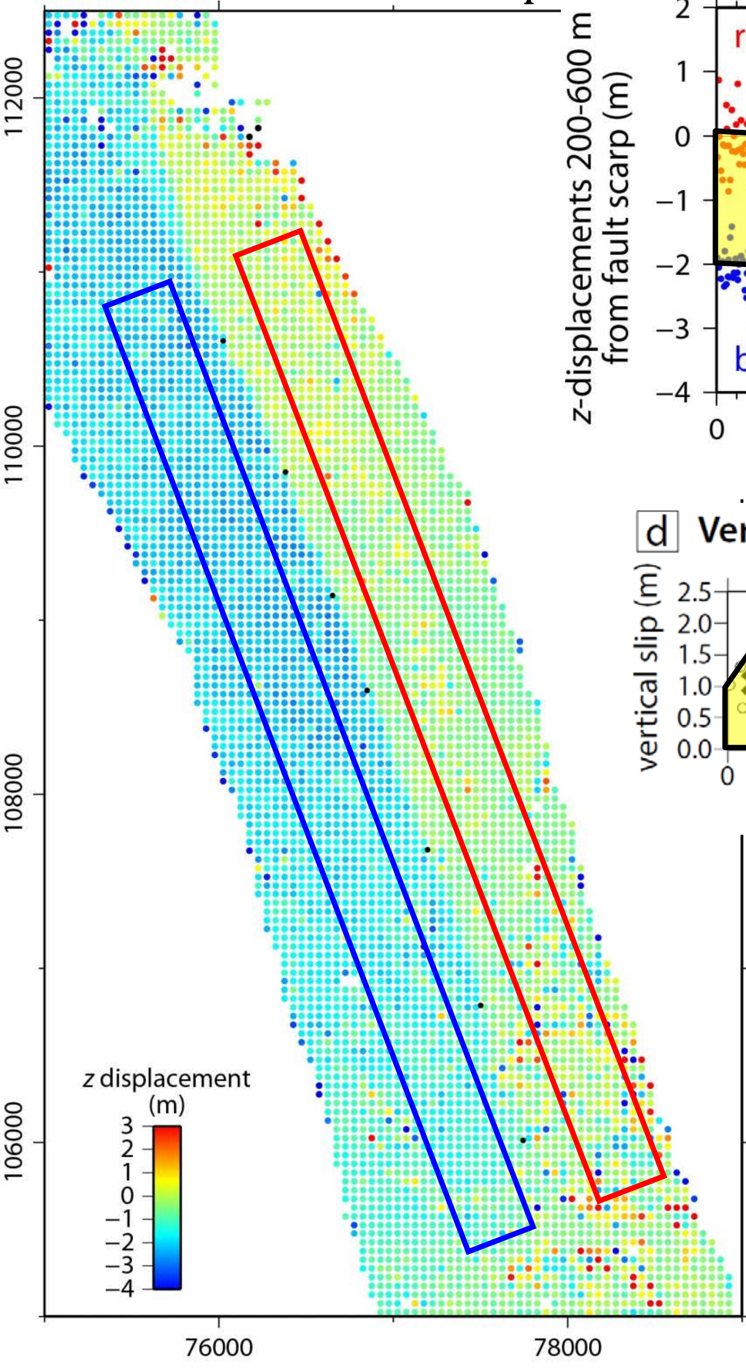
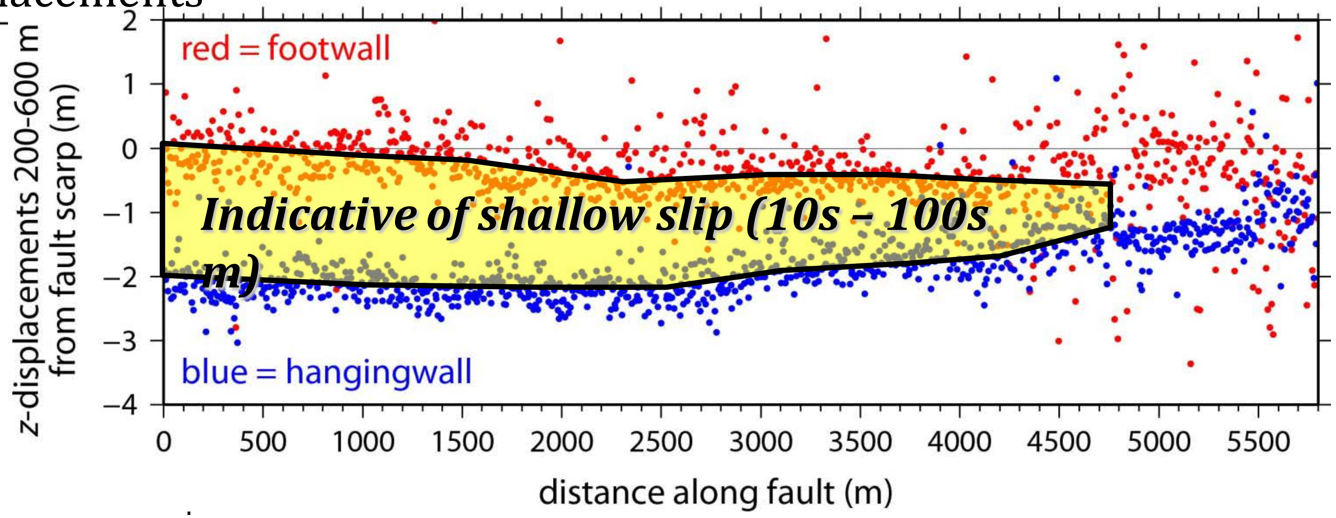
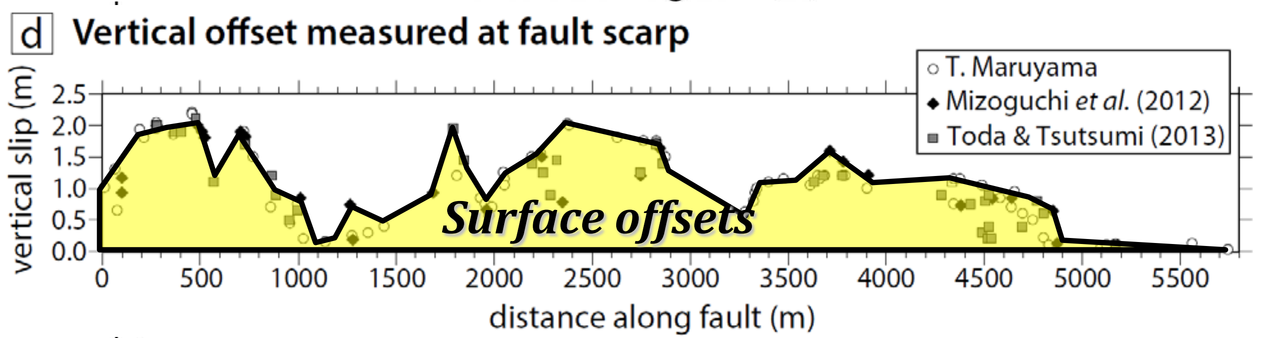
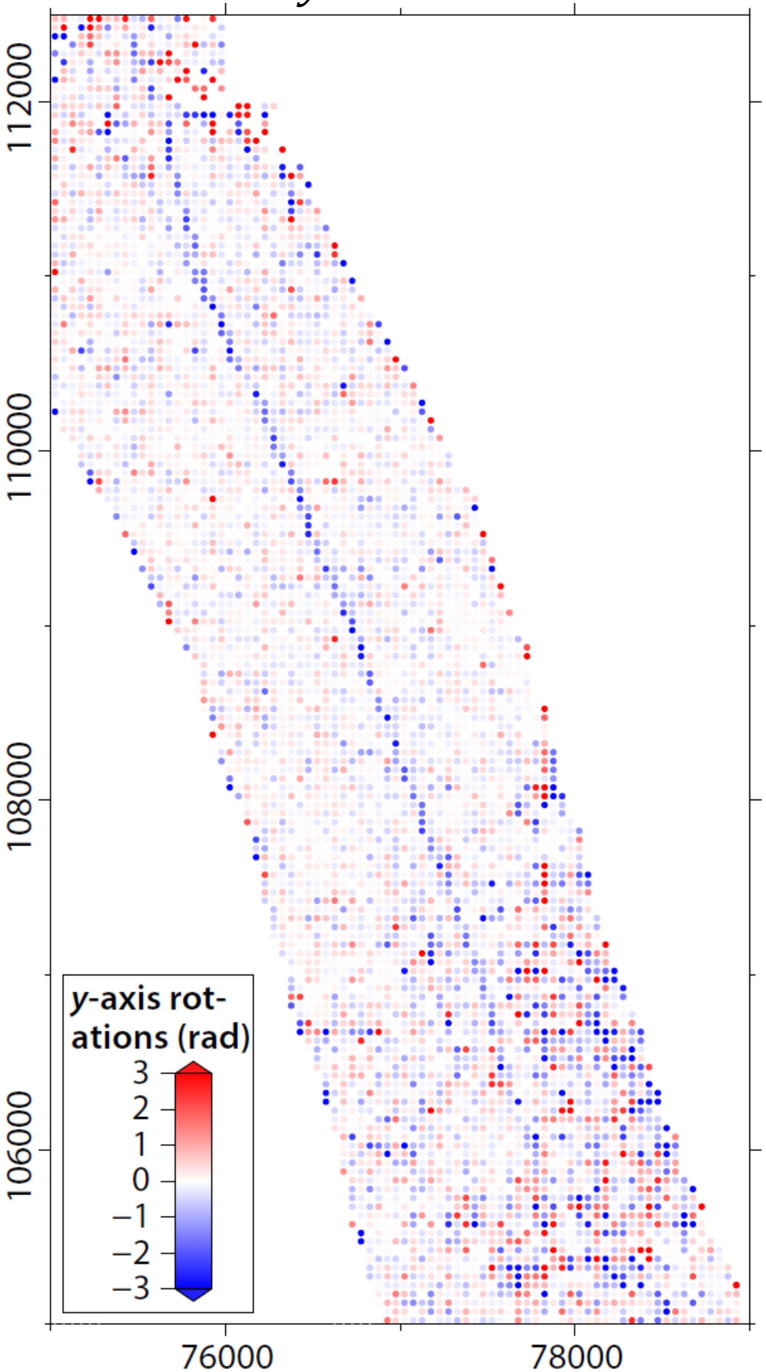


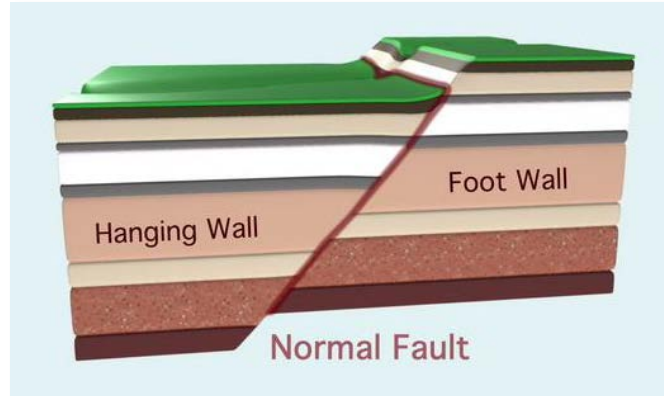


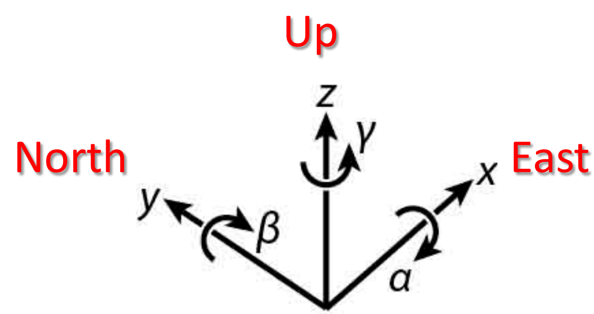


- Slip at depths of a few hundred meters appears to vary smoothly
- In many places, only a small proportion of the slip makes it to the surface

2005-2011 *y*-axis rotations







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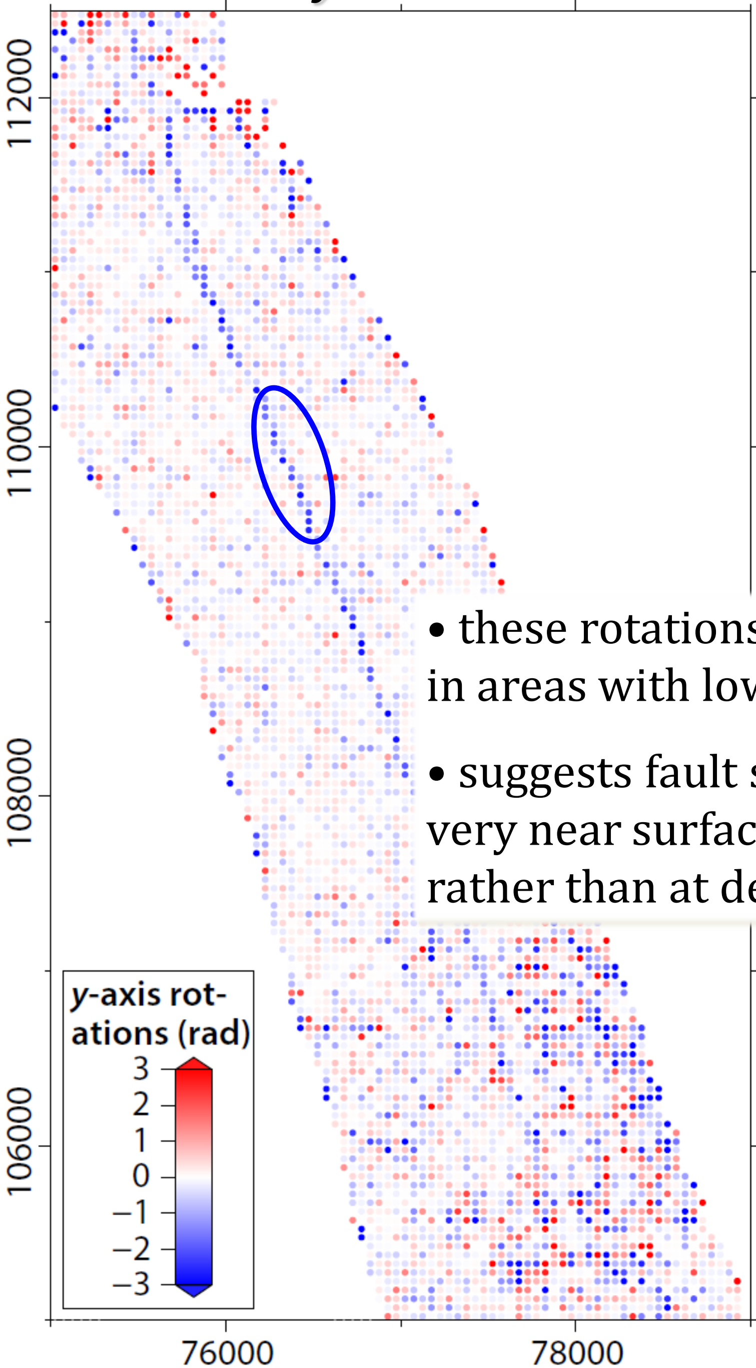
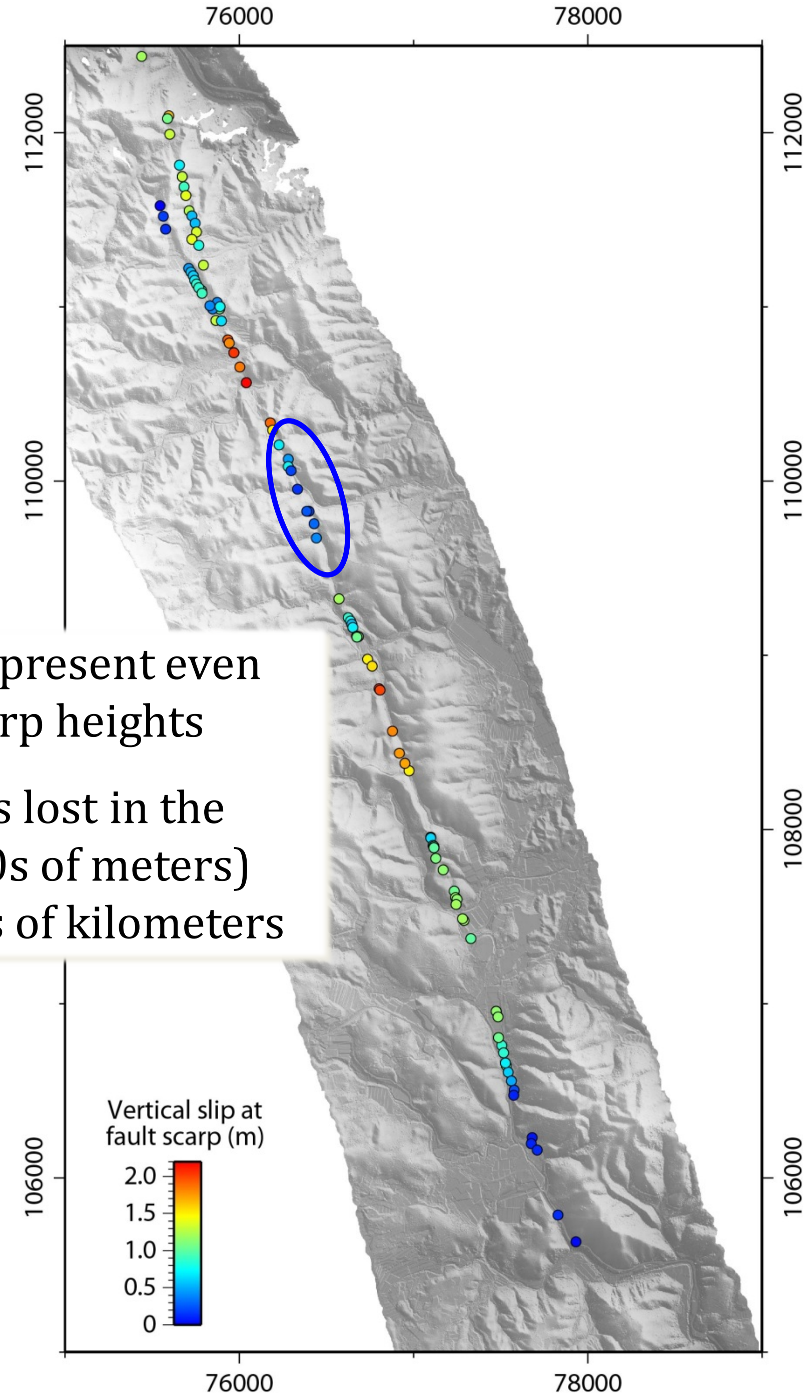
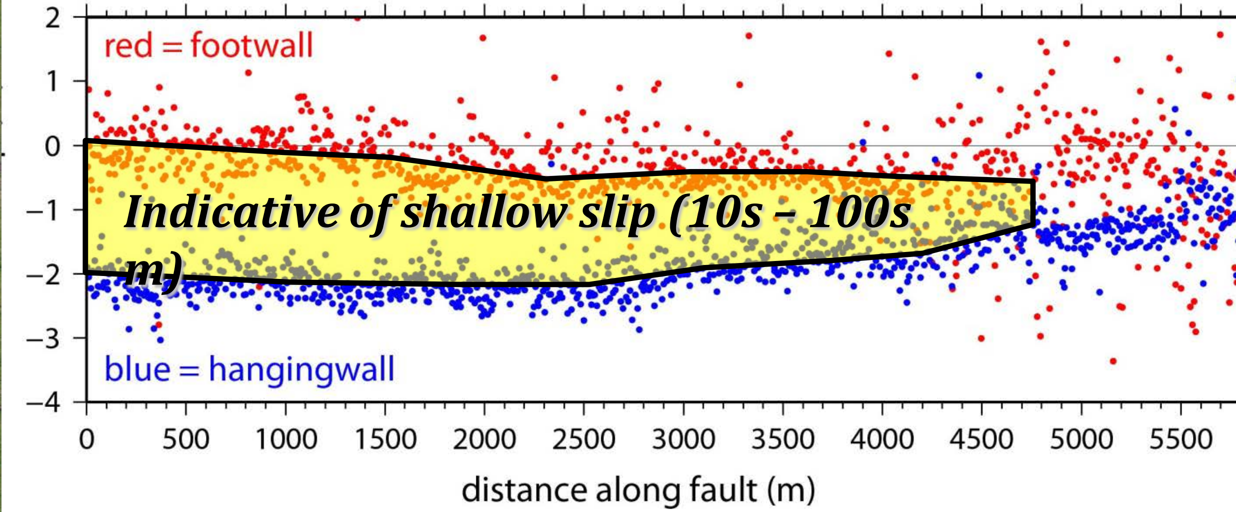
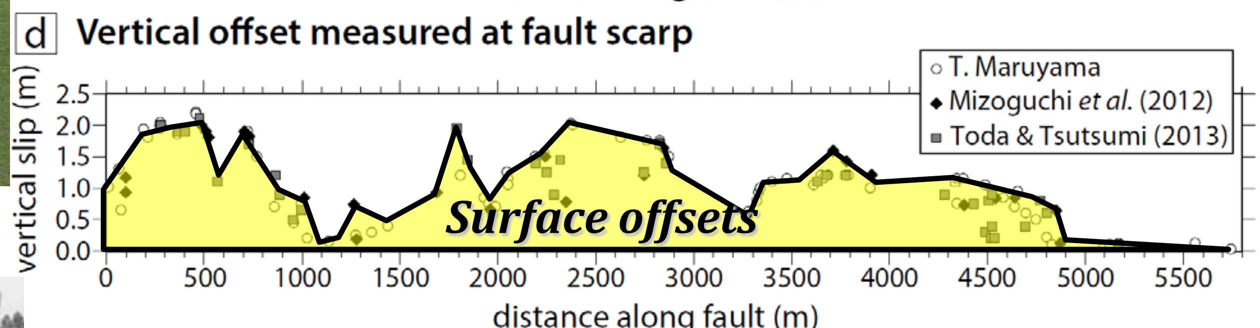




- these rotations are present even in areas with low scarp heights
- suggests fault slip is lost in the very near surface (10s of meters) rather than at depths of kilometers

Darfield rupture (Quigley *et al.* 2010)





Izmit rupture (Rockwell *et al.* 2002)

- Slip at depths of a few hundred meters appears to vary smoothly
- In many places, only a small proportion of the slip makes it to the surface
- Reflects off-fault deformation in the shallow subsurface?