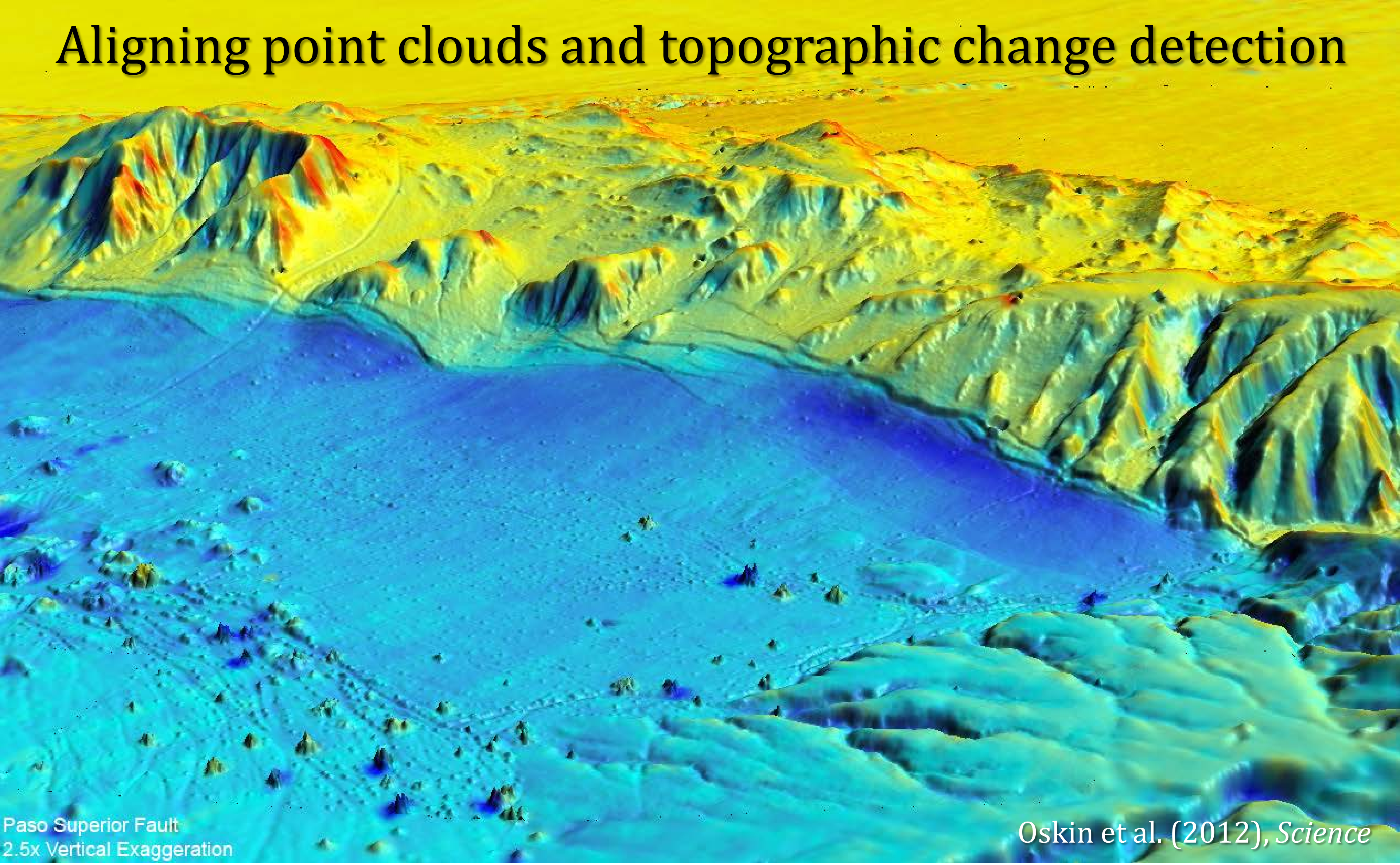
Aligning point clouds and topographic change detection



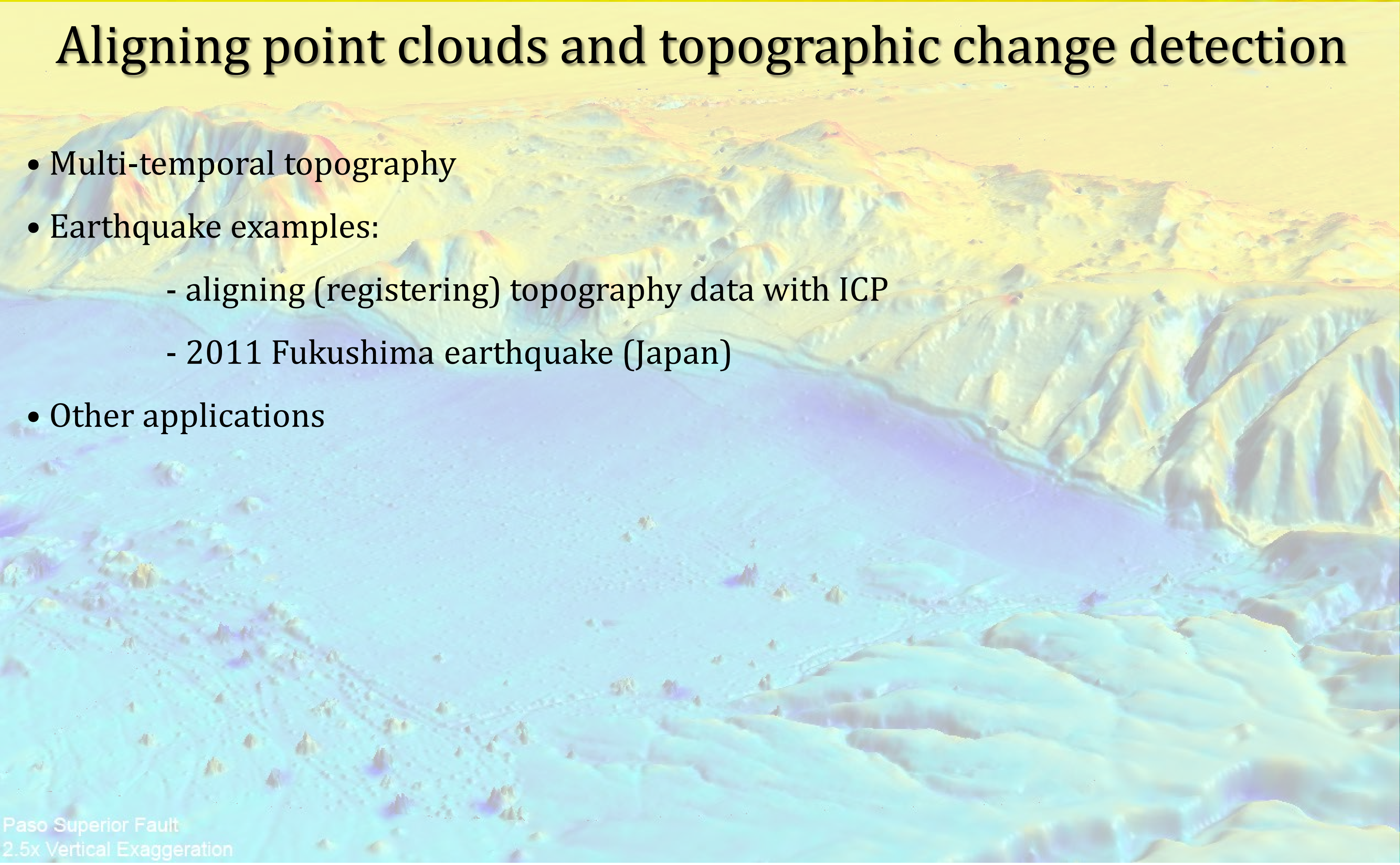
Oskin et al. (2012), *Science*

Edwin Nissen (Colorado School of Mines)

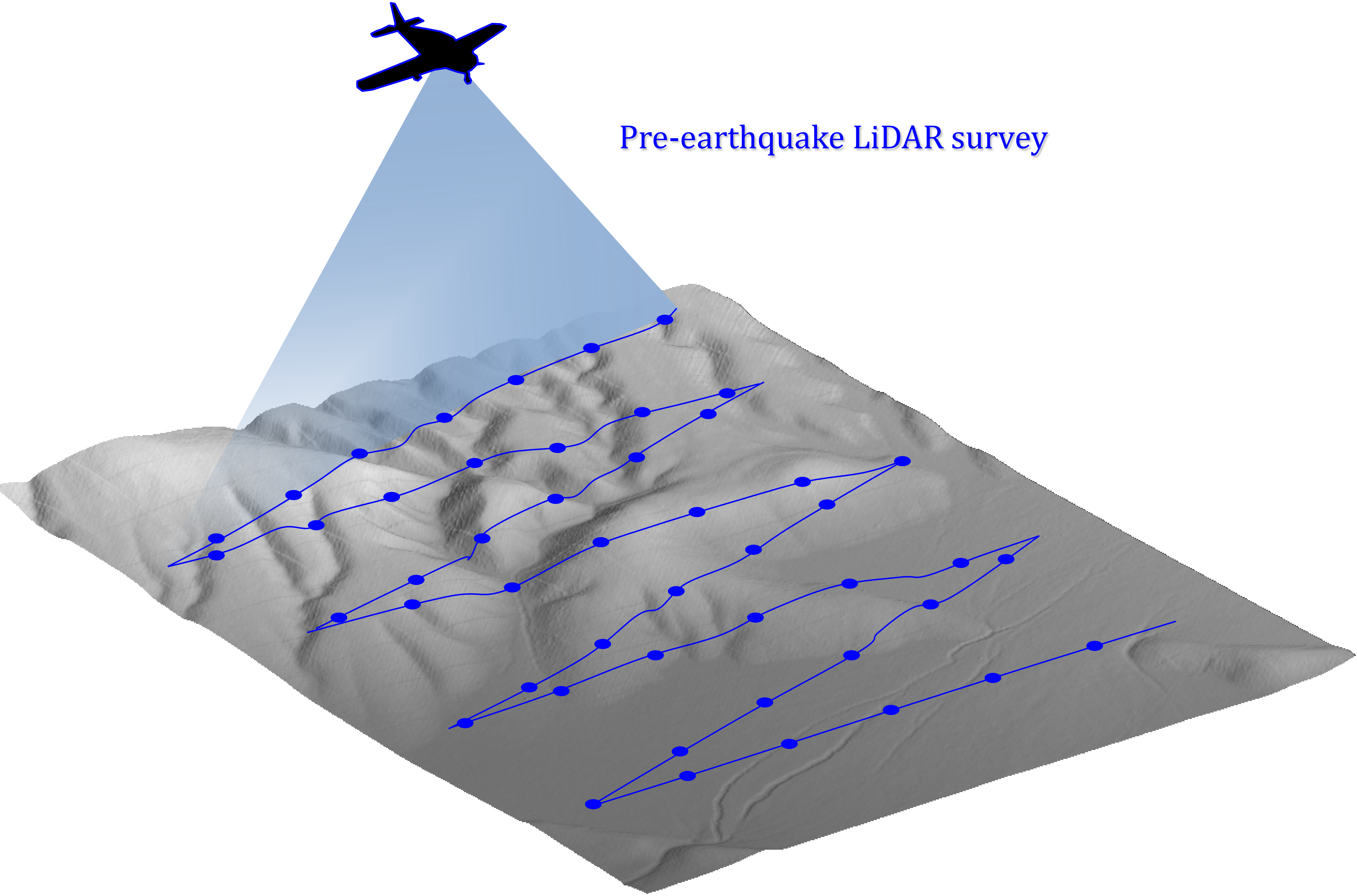
Thanks to: Ramon Arrowsmith, Srikanth Saripalli, Aravindhan Krishnan (ASU), Adrian Borsa (Scripps), Craig Glennie (Houston), Alejandro Hinojosa-Corona (CICESE), Tadashi Maruyama (AIST), Austin Elliott, Mike Oskin (UC Davis)

Aligning point clouds and topographic change detection

- Multi-temporal topography
- Earthquake examples:
    - aligning (registering) topography data with ICP
    - 2011 Fukushima earthquake (Japan)
- Other applications

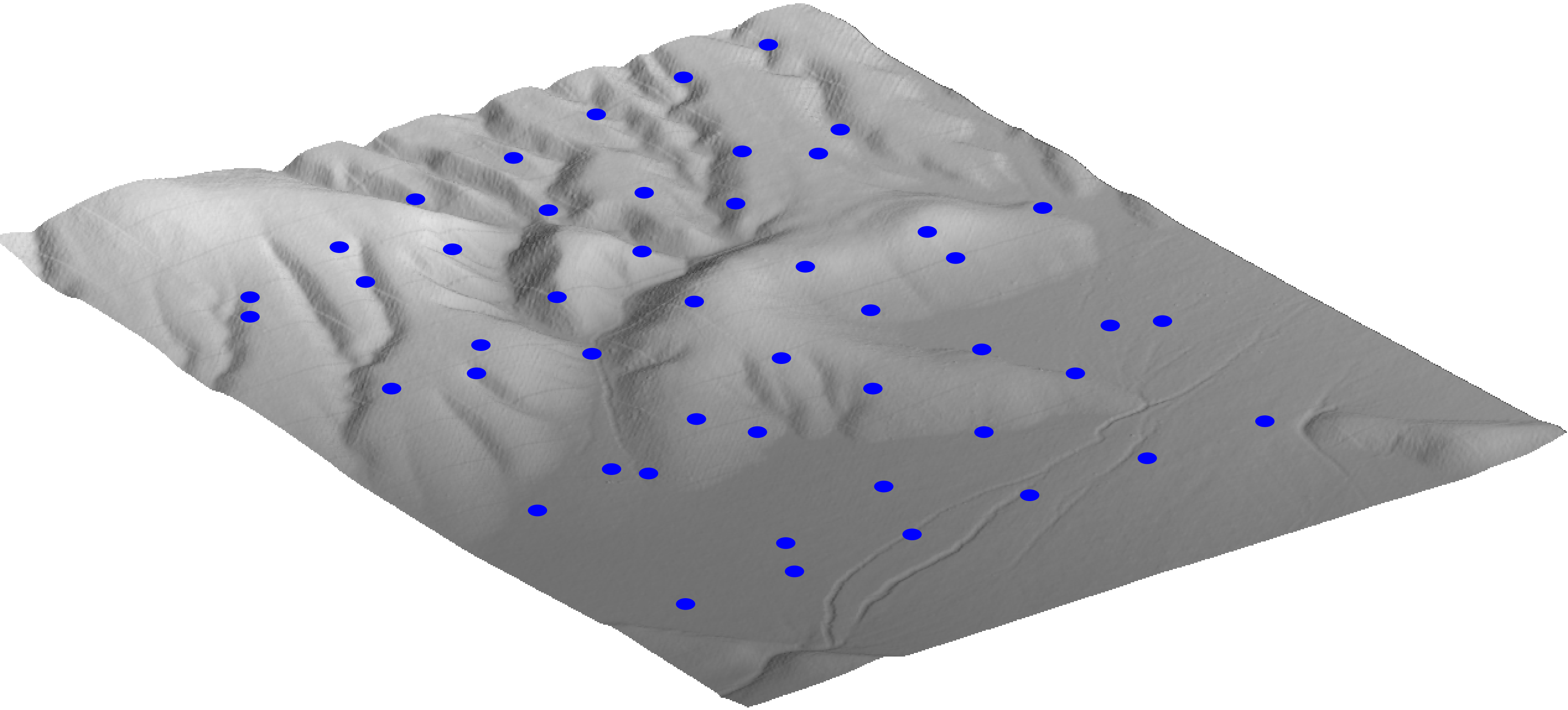


3-D earthquake deformation from repeat lidar

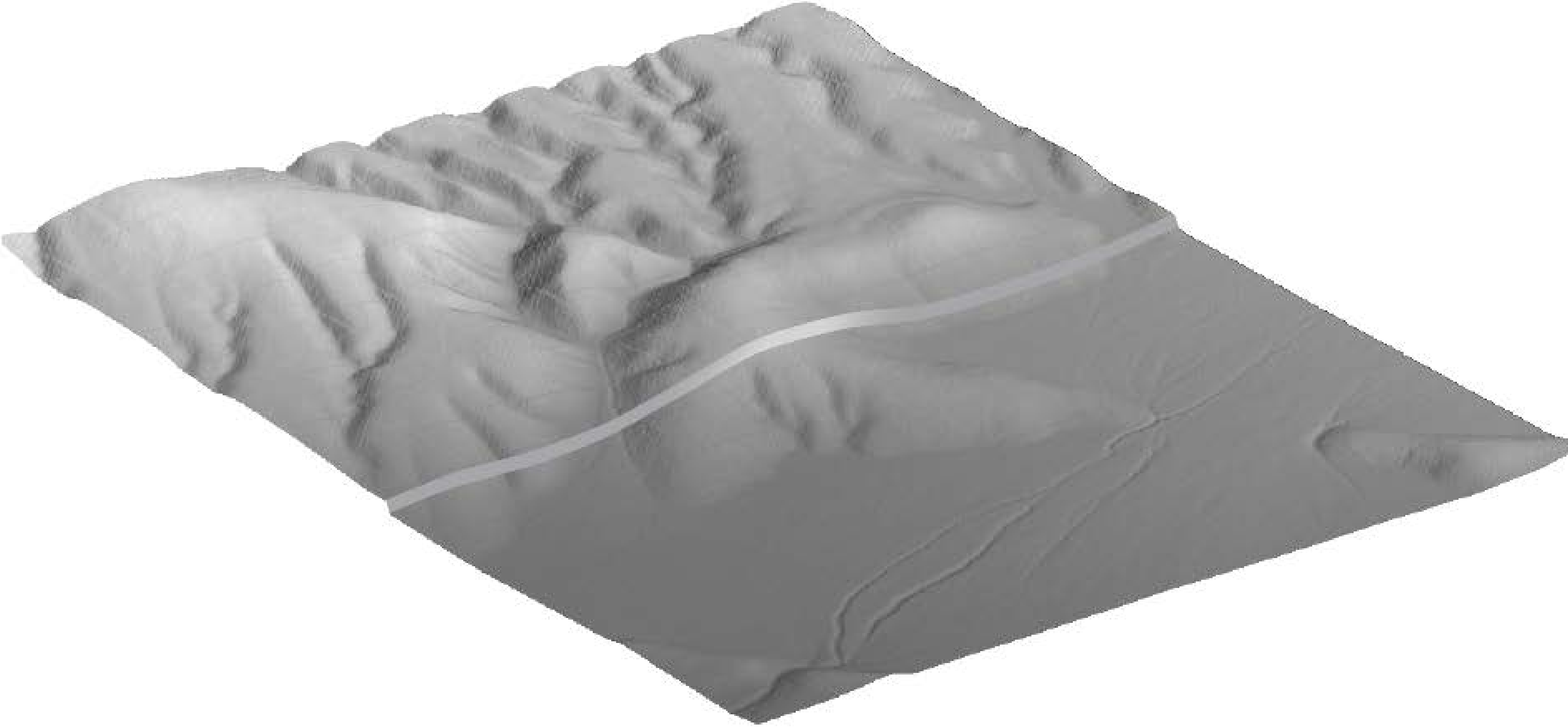


Pre-earthquake LiDAR survey

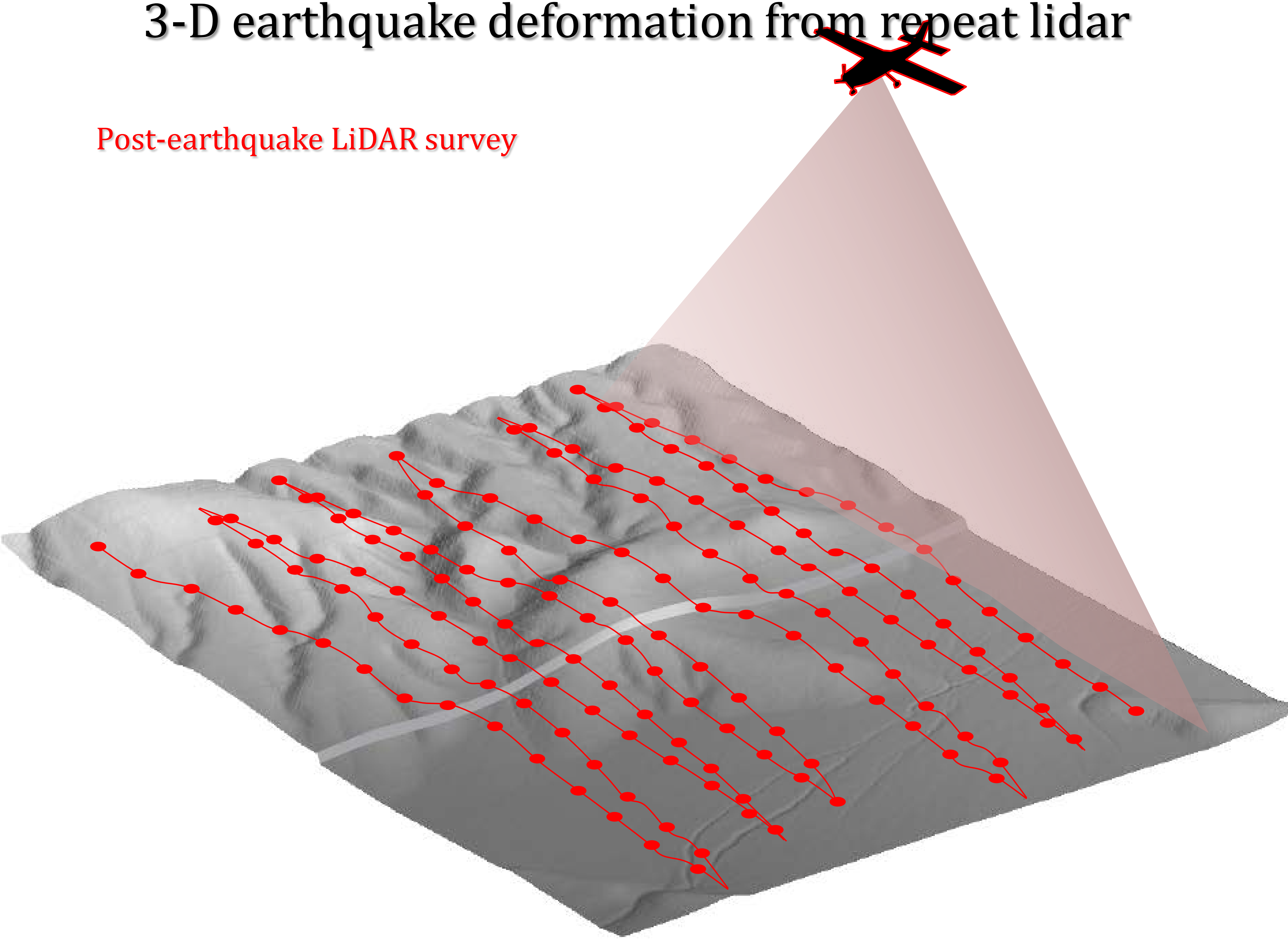
3-D earthquake deformation from repeat lidar



3-D earthquake deformation from repeat lidar

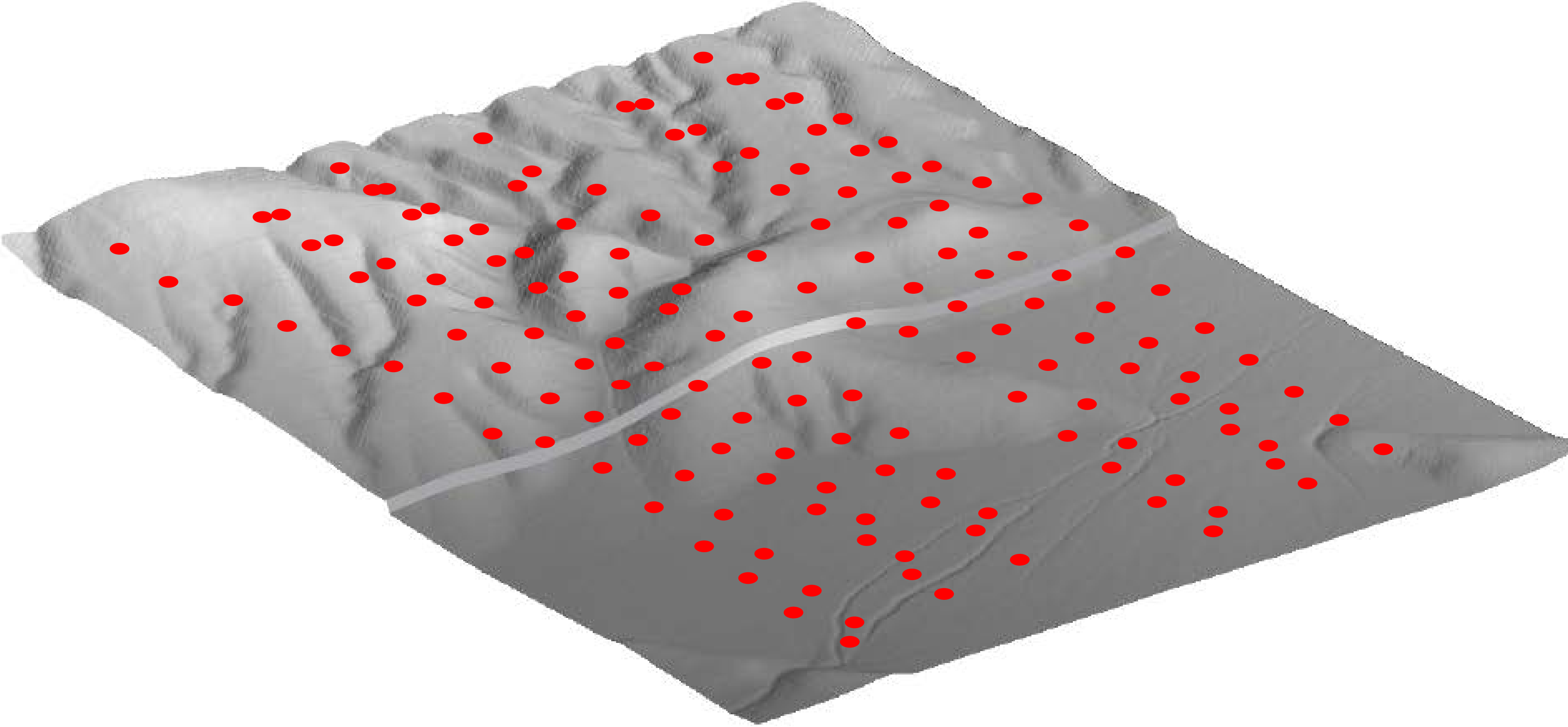


3-D earthquake deformation from repeat lidar



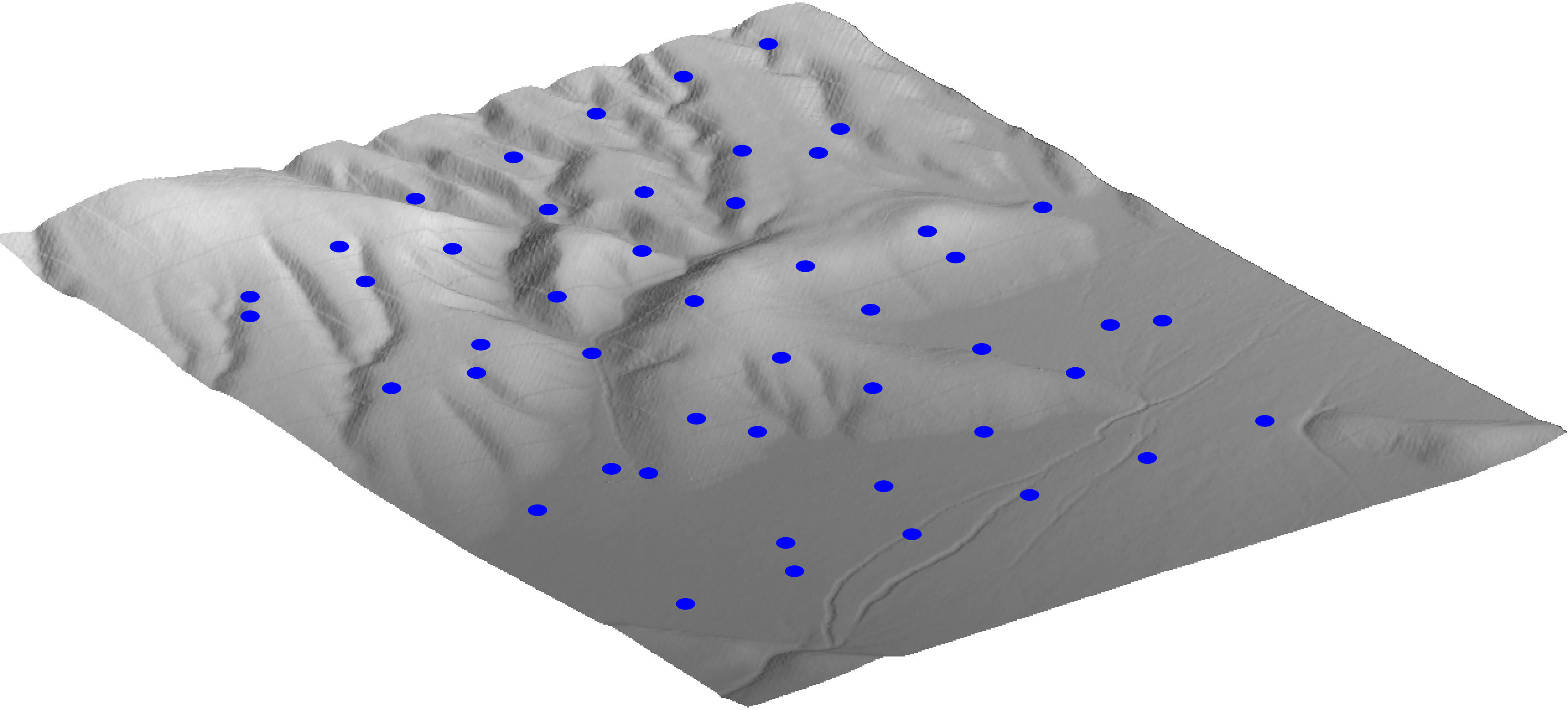
Post-earthquake LiDAR survey

3-D earthquake deformation from repeat lidar

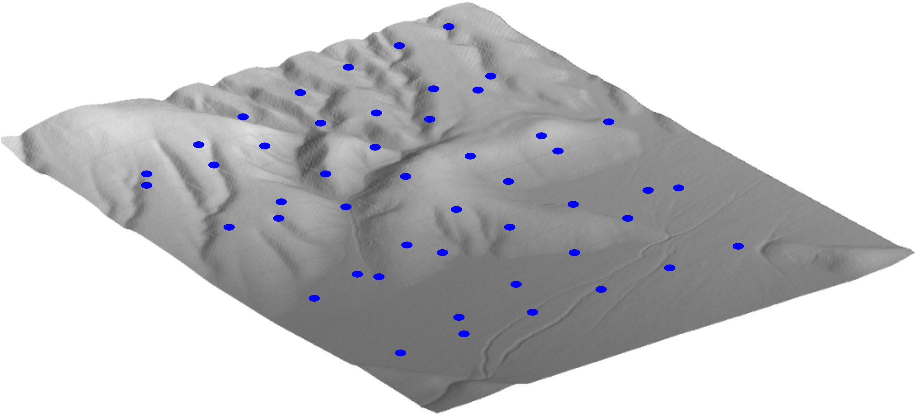

Post-earthquake point cloud

3-D earthquake deformation from repeat lidar

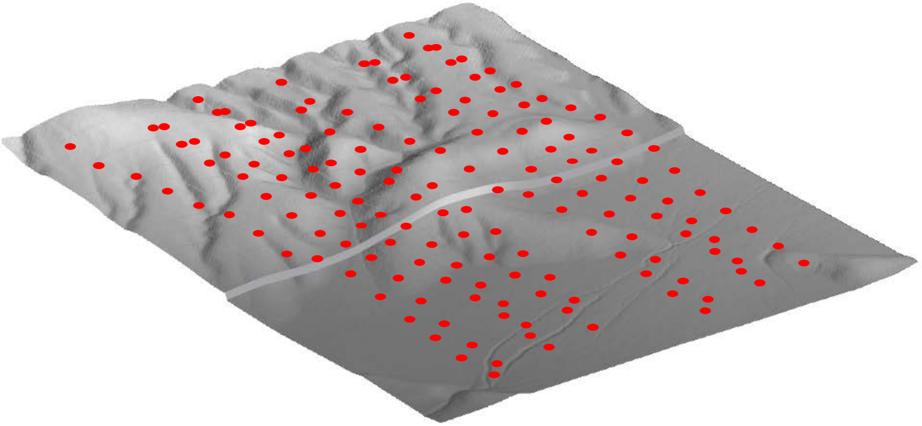
Pre-earthquake point cloud



3-D earthquake deformation from repeat lidar



Pre-earthquake point cloud



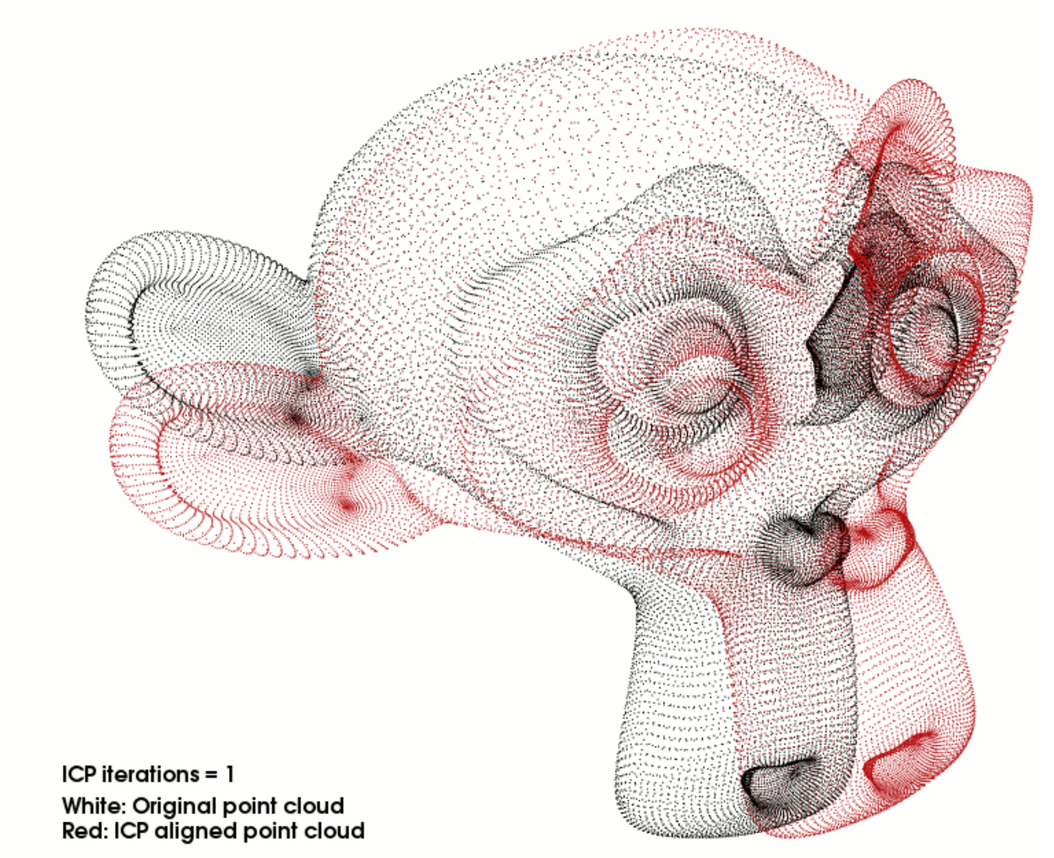
Post-earthquake point cloud

The Challenges of LiDAR differencing

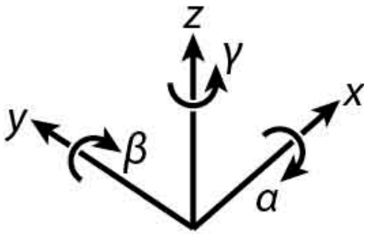
- Data are irregularly spaced (we can rasterize them, but lose information doing so)
- There can be large mismatches in point density (legacy datasets vs modern surveys)
- … and mismatches in data quality and metrics (third party vs research-grade)
- Treatment of vegetation returns in forested areas

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** [$\boldsymbol{t_x\, t_y\, t_z}$] and a **rotation** [$\boldsymbol{\alpha\, \beta\, \gamma}$]



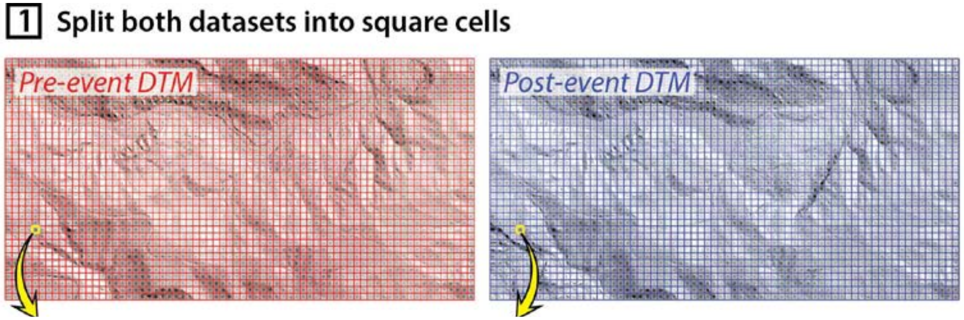
$$\boldsymbol{\Phi} = \begin{pmatrix} 1 & -\gamma & \beta & t_x \\ \gamma & 1 & -\alpha & t_y \\ -\beta & \alpha & 1 & t_z \\ 0 & 0 & 0 & 1 \end{pmatrix}$$



pointclouds.org/documentation/tutorials/interactive_icp.php

3-D earthquake deformation from repeat lidar

- 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]



- (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

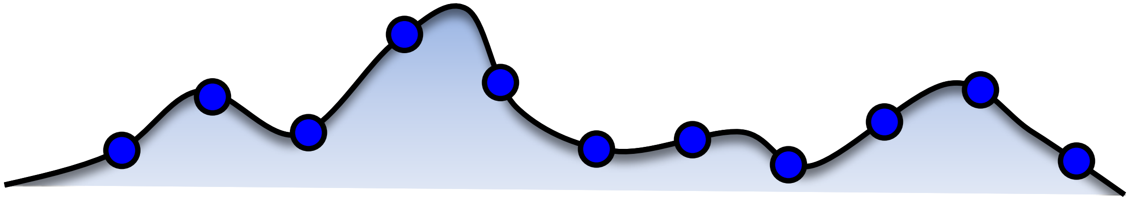
- (3) this is repeated for the next pair of cells

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

Iterative Closest Point algorithm (ICP)

Pre-earthquake cell

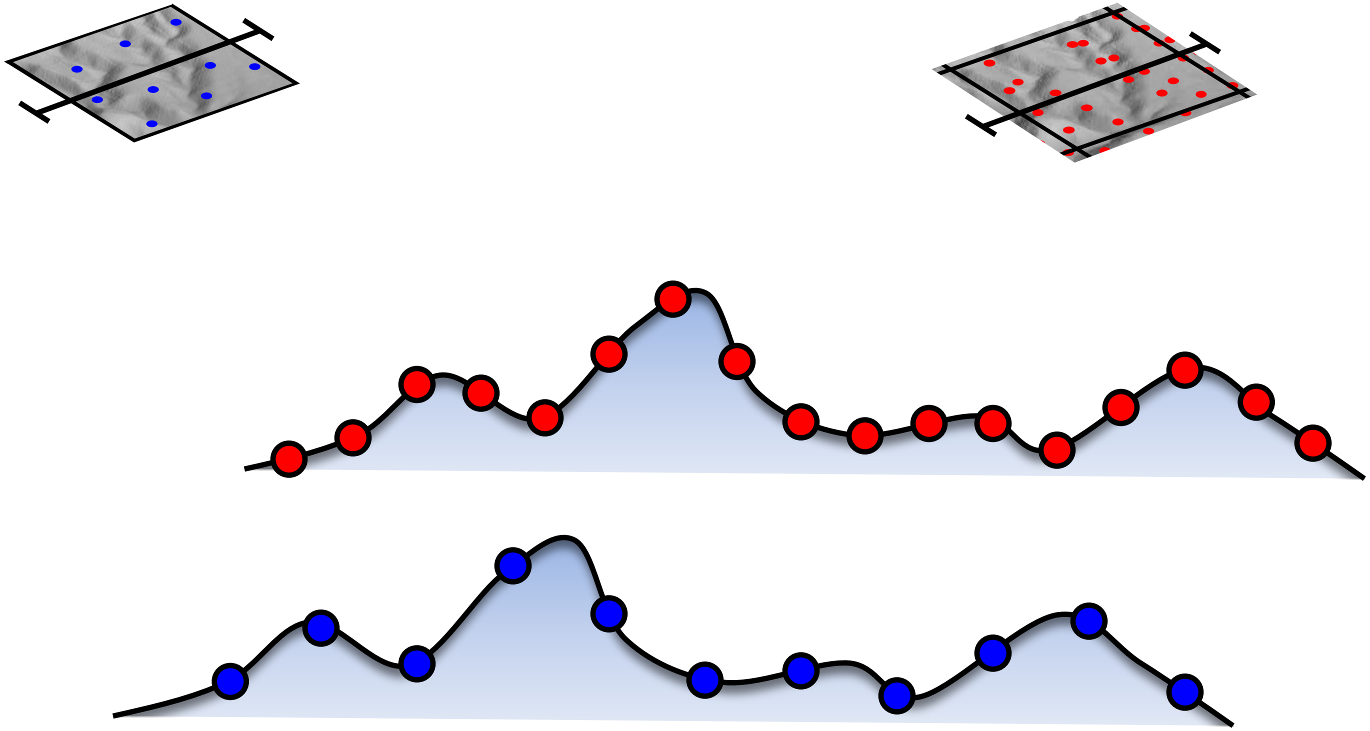
Post-earthquake cell



Iterative Closest Point algorithm (ICP)

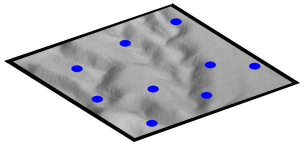
Pre-earthquake cell

Post-earthquake cell

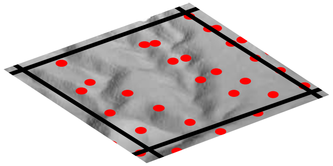


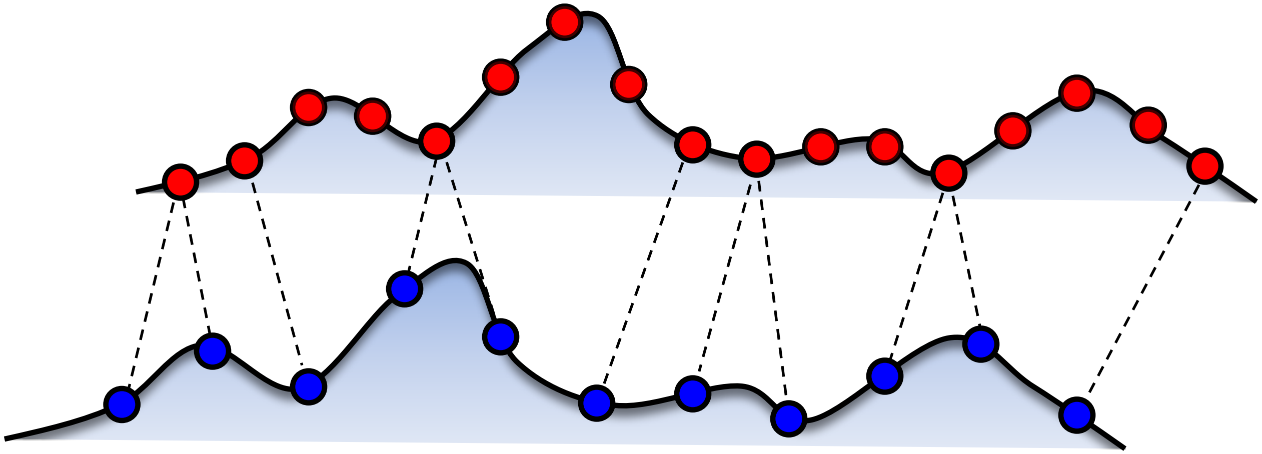
Iterative Closest Point algorithm (ICP)

Pre-earthquake cell



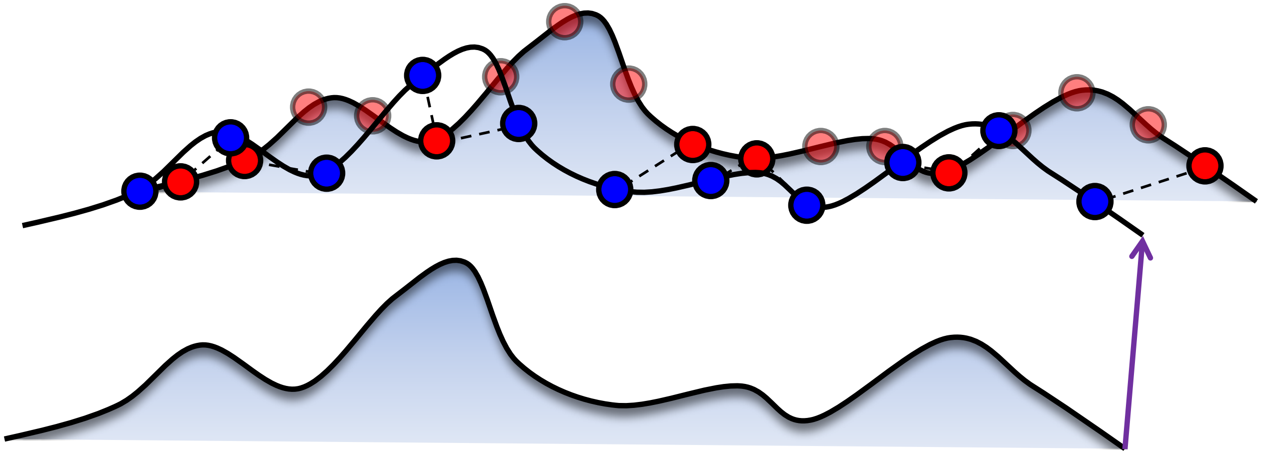
Post-earthquake cell





Find closest points

Iterative Closest Point algorithm (ICP)



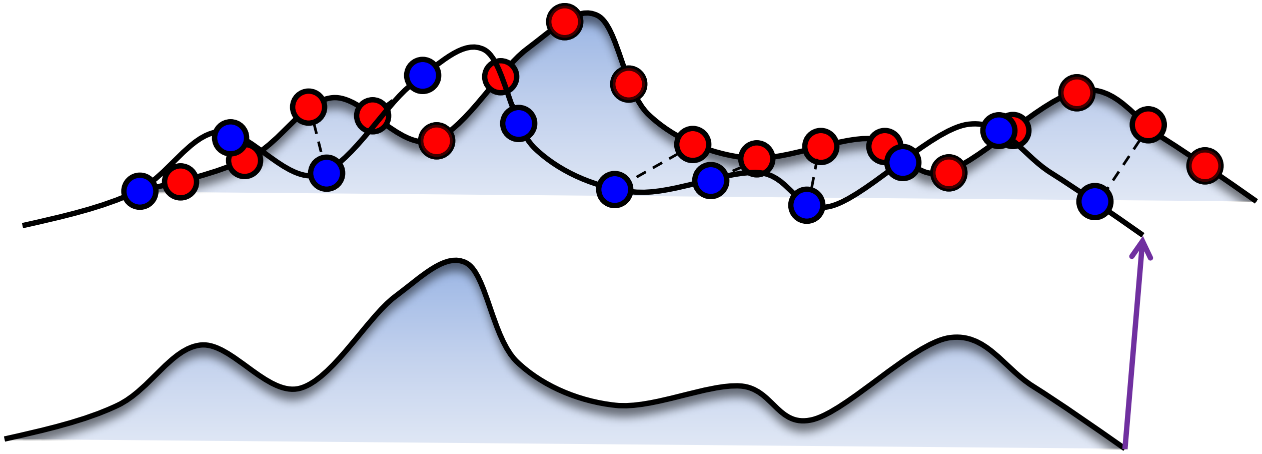
Iterate

Find closest points

Transform point cloud

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

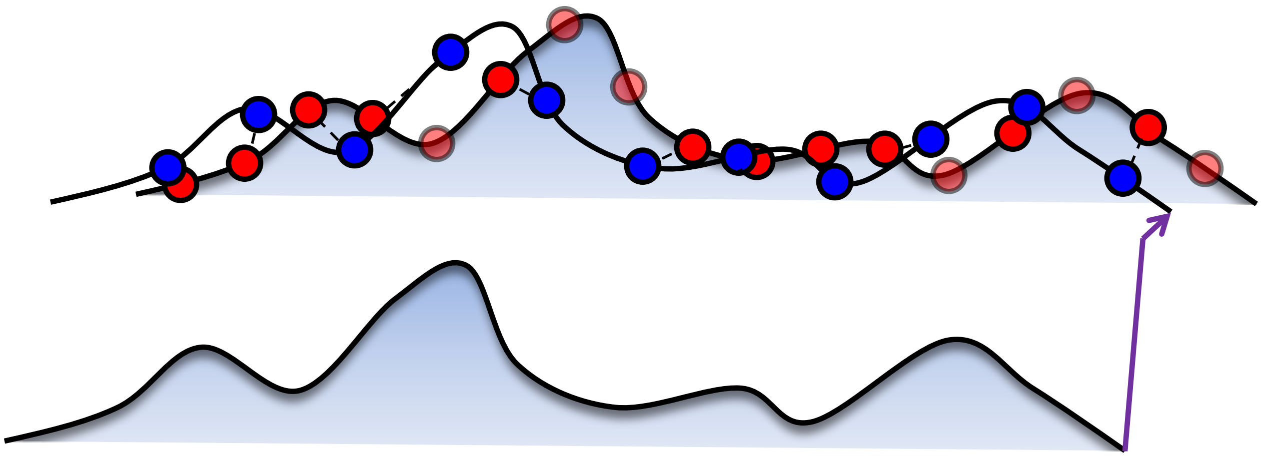
Iterative Closest Point algorithm (ICP)



Find closest points

Transform point cloud

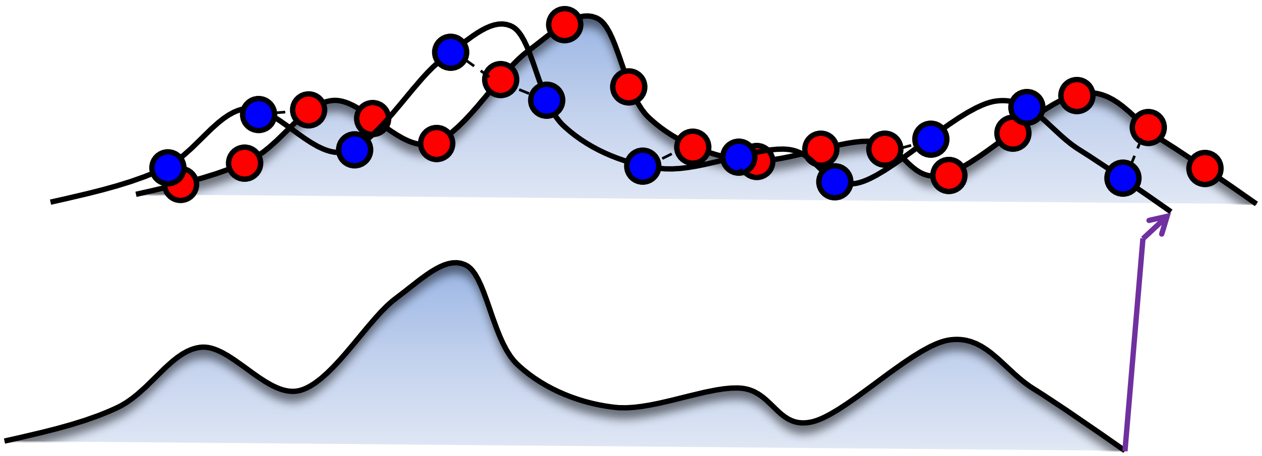
Iterative Closest Point algorithm (ICP)



Find closest points

Transform point cloud

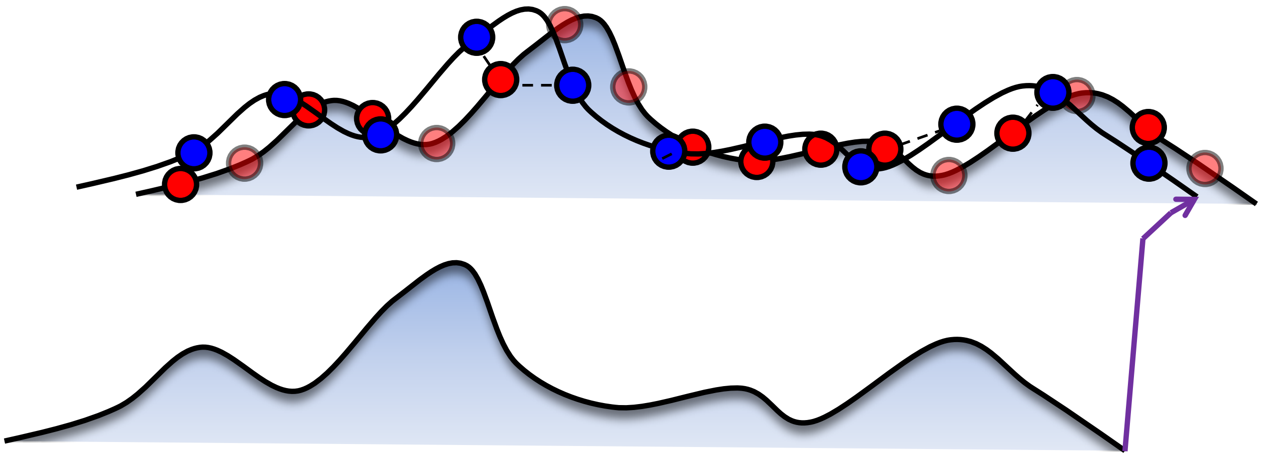
Iterative Closest Point algorithm (ICP)



Find closest points

Transform point cloud

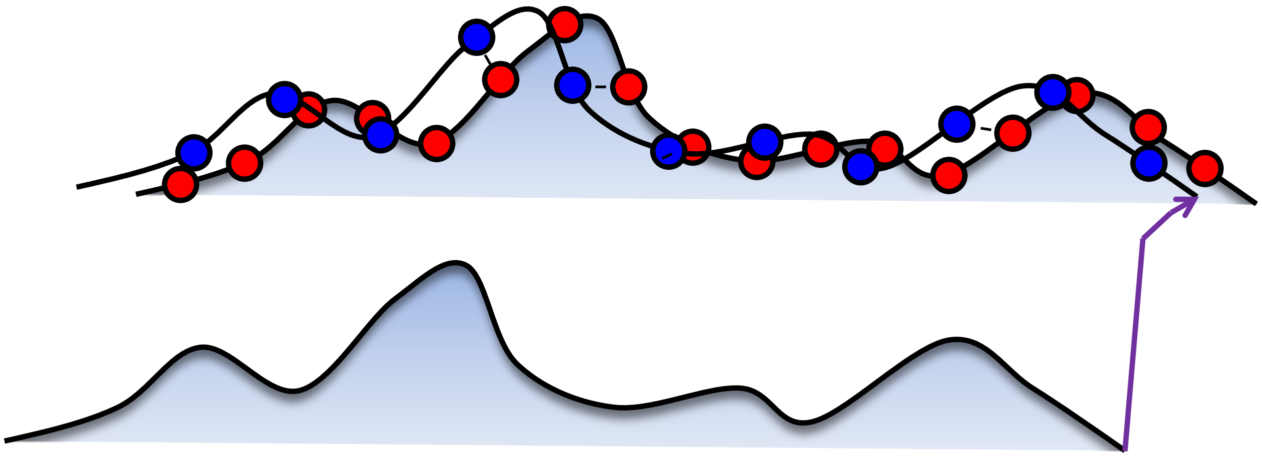
Iterative Closest Point algorithm (ICP)



Find closest points

Transform point cloud

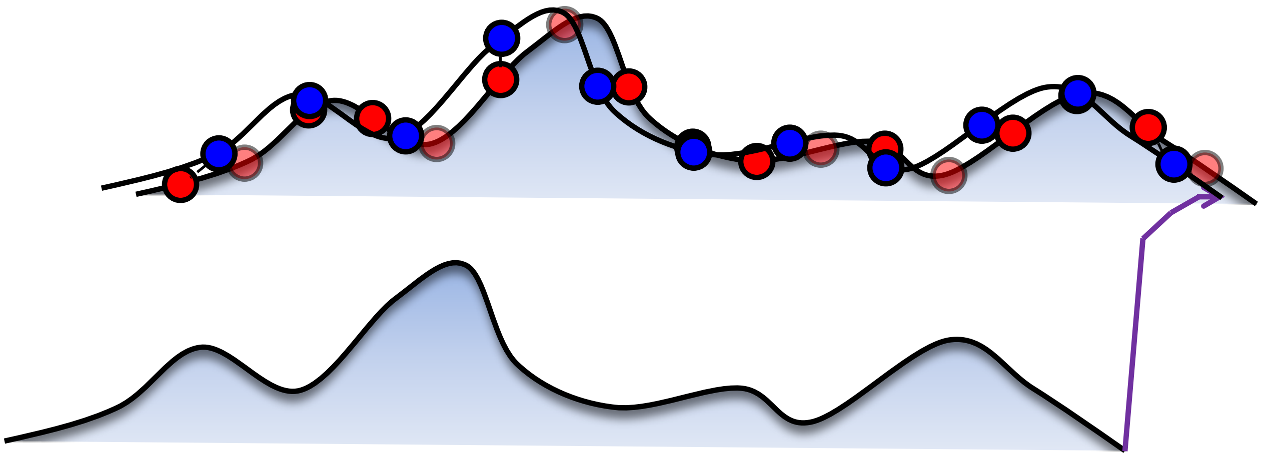
Iterative Closest Point algorithm (ICP)



Find closest points

Transform point cloud

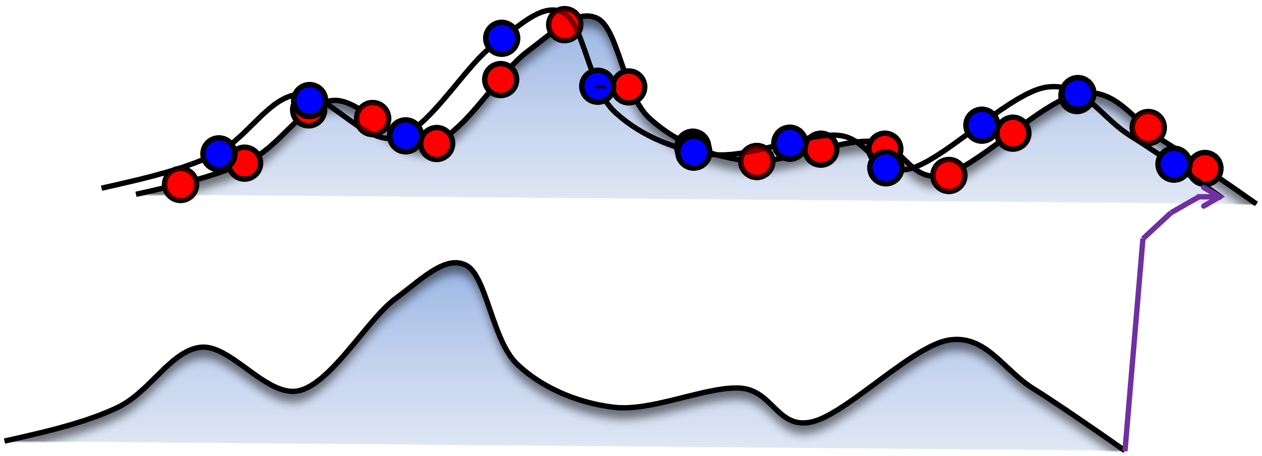
Iterative Closest Point algorithm (ICP)



Find closest points

Transform point cloud

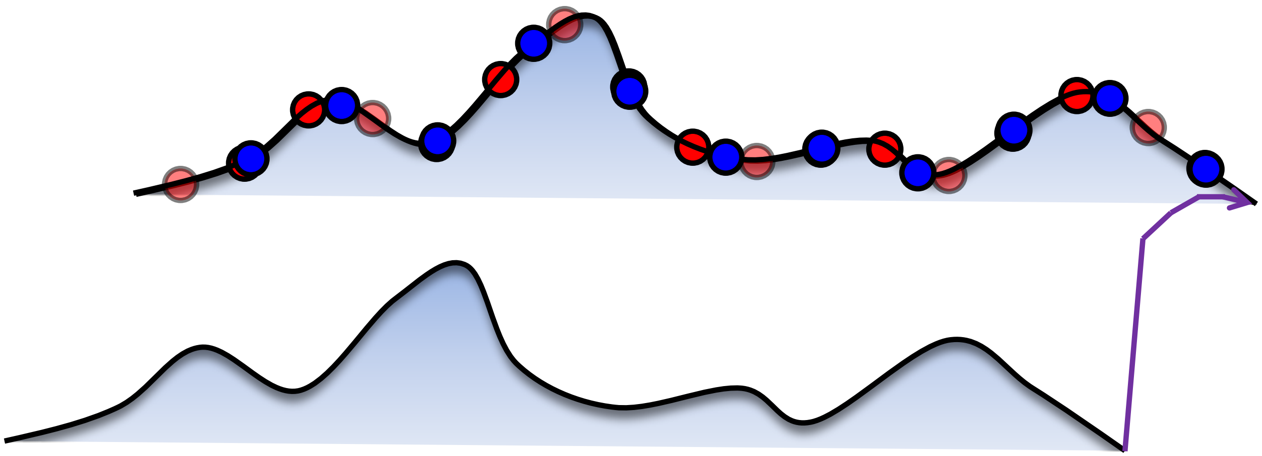
Iterative Closest Point algorithm (ICP)



Find closest points

Transform point cloud

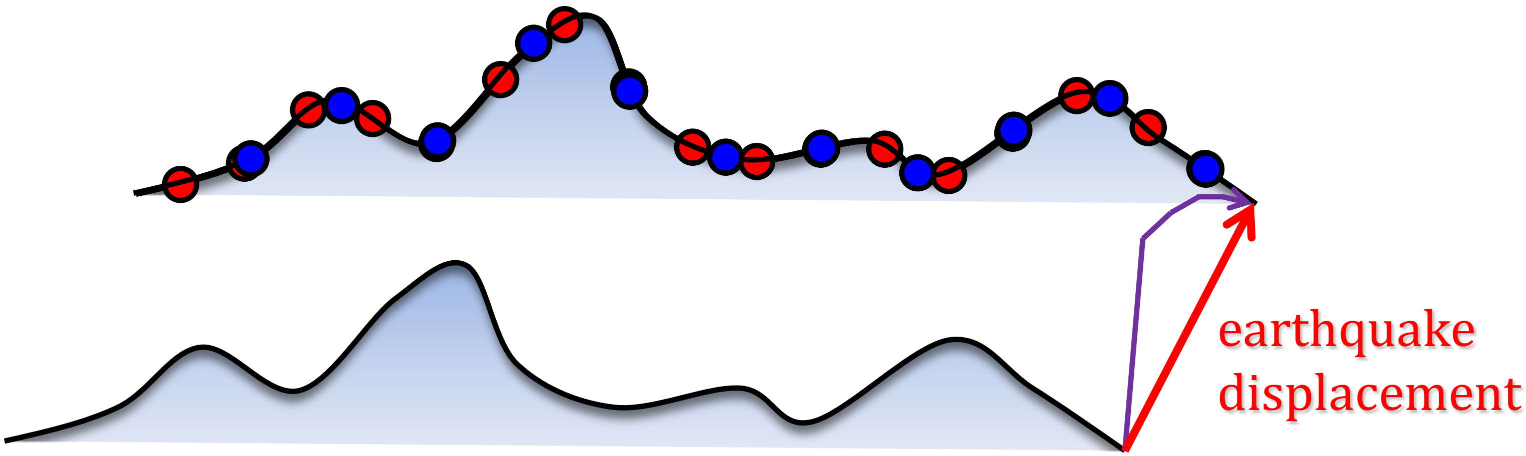
Iterative Closest Point algorithm (ICP)



Find closest points

Transform point cloud

Iterative Closest Point algorithm (ICP)



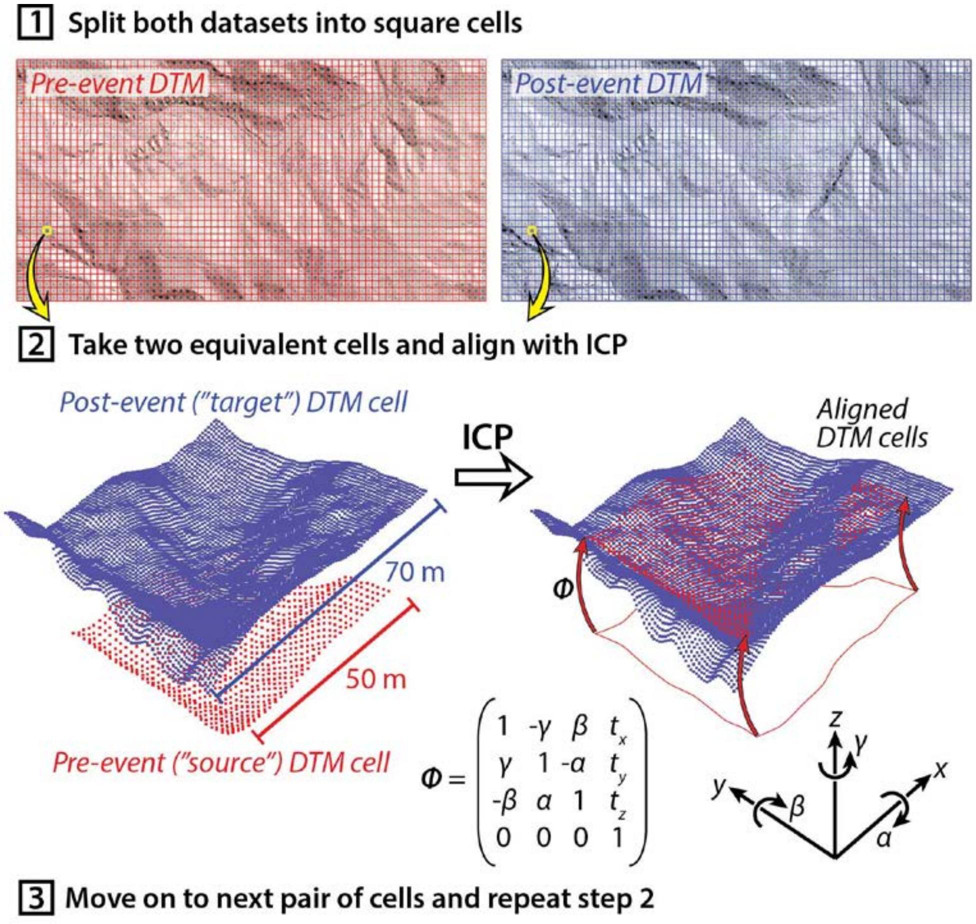
Find closest points

Transform point cloud

3-D earthquake deformation from repeat LiDAR point clouds

Caveats

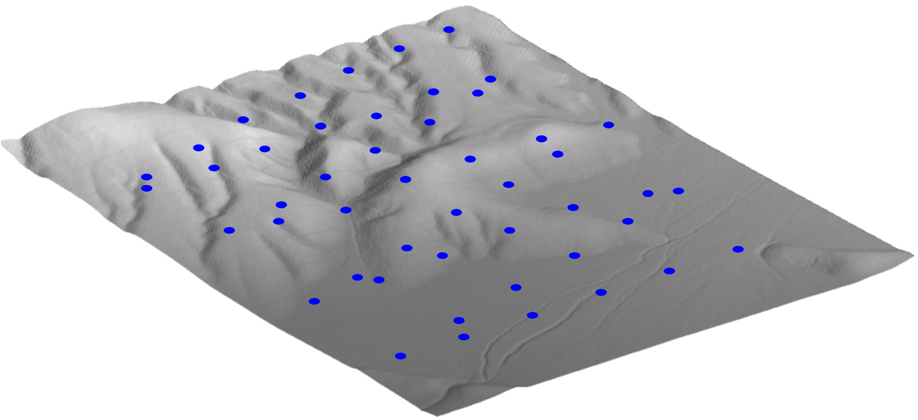
- ICP will not work if there are large changes to the shape of the cell, e.g. through landsliding
- ICP will generate spurious results in areas that are very planar



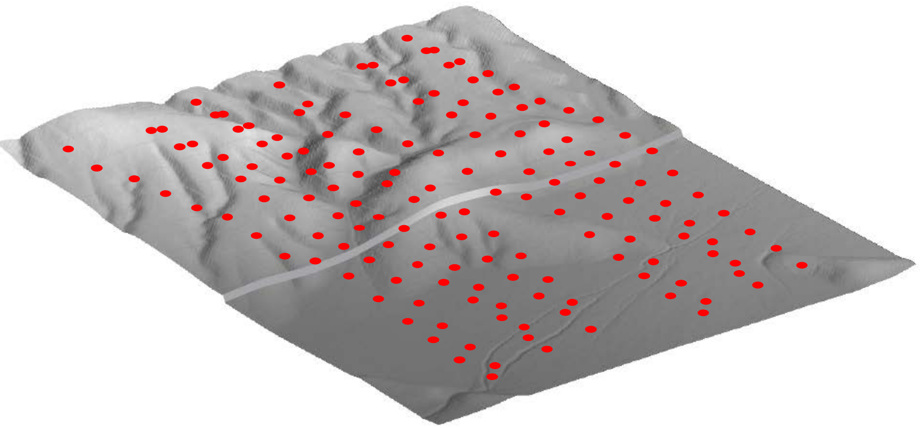
$$\Phi = \begin{pmatrix} 1 & -\gamma & \beta & t_x \\ \gamma & 1 & -\alpha & t_y \\ -\beta & \alpha & 1 & t_z \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

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

Pre-earthquake point cloud



Post-earthquake point cloud



The **Iterative Closest Point** algorithm: a method for registering (aligning) two sets of points

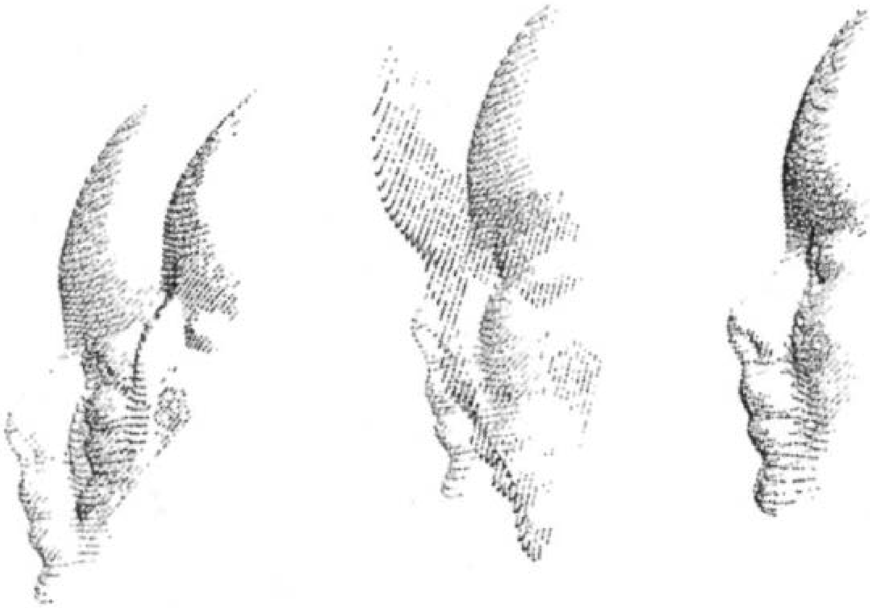


Fig. 4. Iterative point-based registration of phantom face range data

3-D earthquake deformation from repeat LiDAR point clouds

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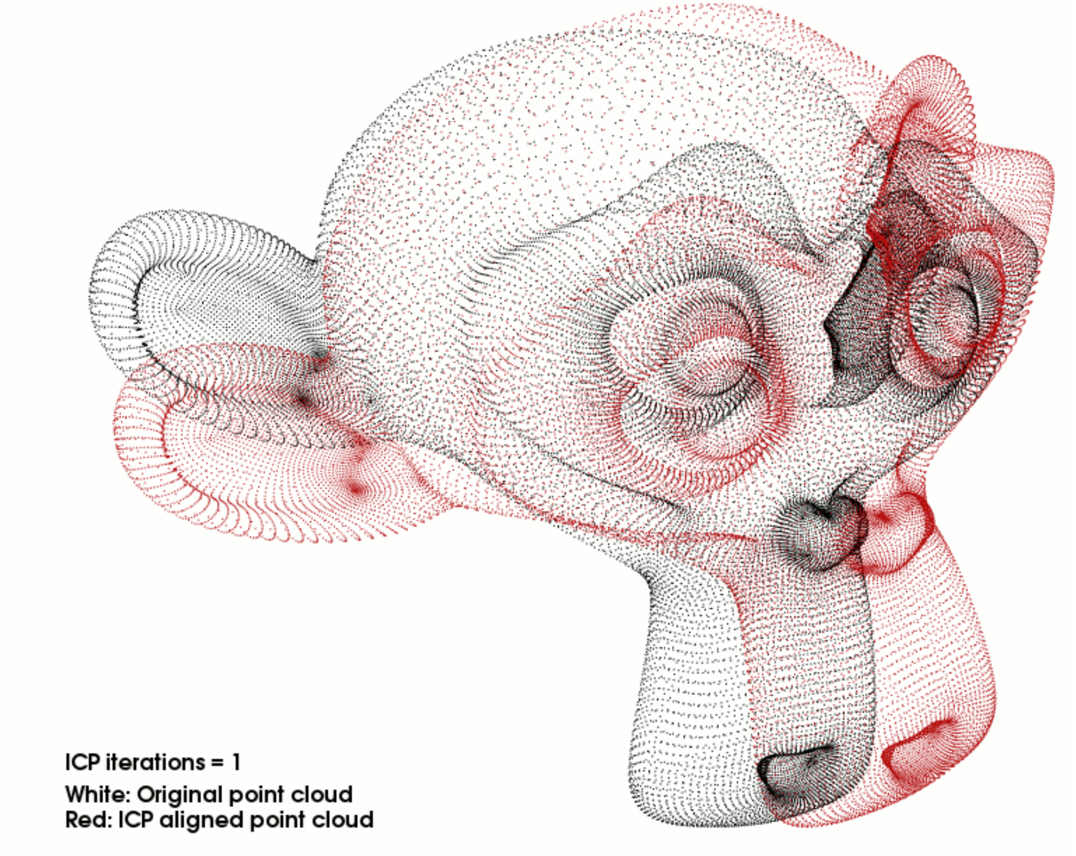
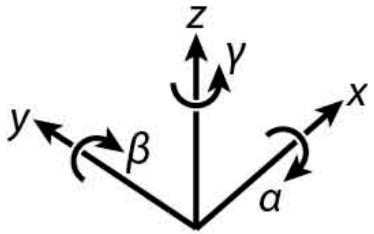
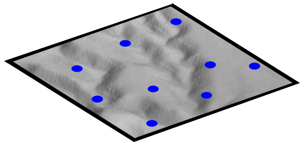


pointclouds.org/documentation/tutorials/interactive_icp.php

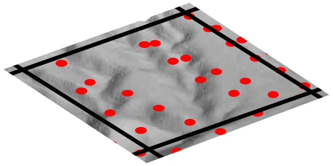
$$\Phi = \begin{pmatrix} 1 & -\gamma & \beta & t_x \\ \gamma & 1 & -\alpha & t_y \\ -\beta & \alpha & 1 & t_z \\ 0 & 0 & 0 & 1 \end{pmatrix}$$



Pre-earthquake point cloud



Post-earthquake point cloud



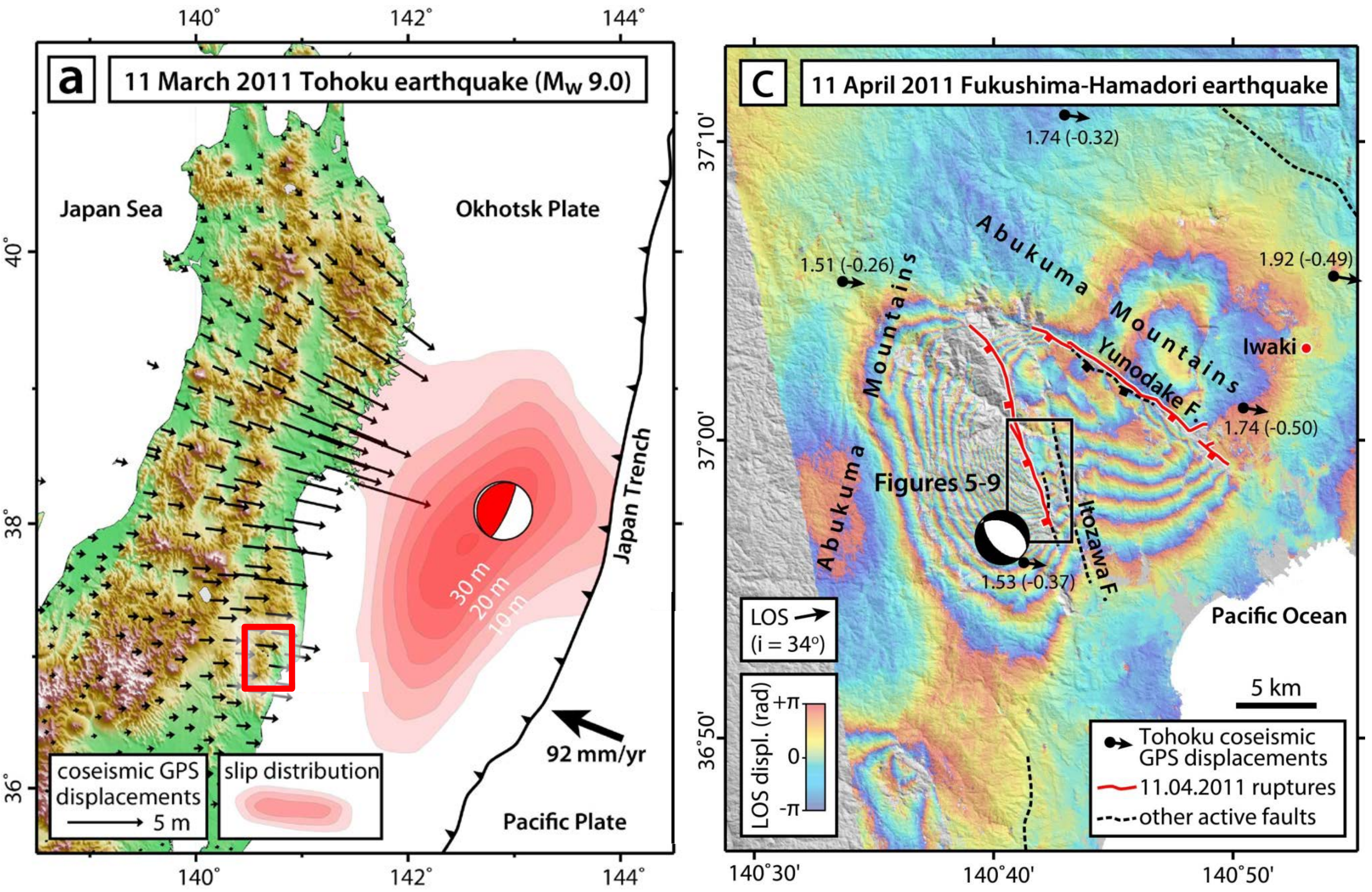
The **Iterative Closest Point** algorithm: a method for registering (aligning) two sets of points

- the two point clouds are first split into square "windows", 50 m in diameter
- ICP is run separately on each pair of windows. (An additional "fringe" of 5 m is included in the post-event window in order to capture the coseismic displacement)
- ICP finds the displacement and rotation that best aligns the pre-event and post-event point clouds.
- This alignment corresponds to the local coseismic displacement for that window.

see Nissen et al. (2012), Geophys. Res. Lett. and Nissen et al. (2014) EPSL for details

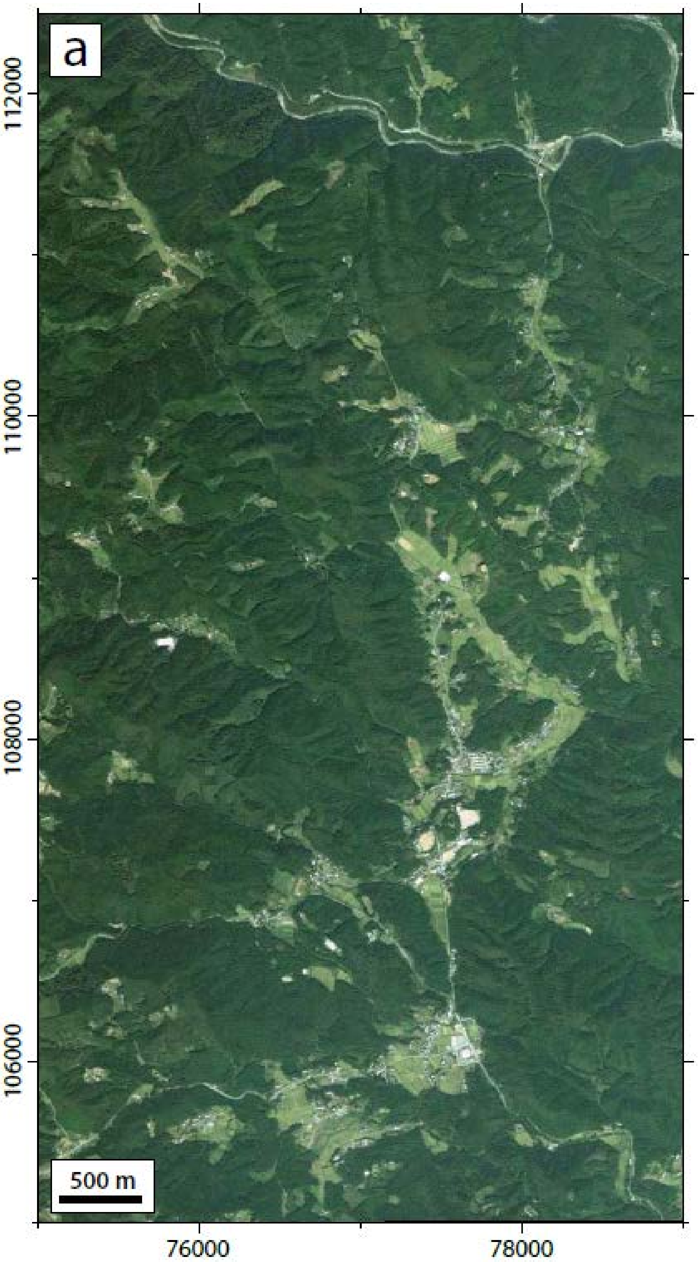
Imagery based methods are more mature and quite effective (mostly 2D)!

11 April 2011 Fukushima-Hamadori earthquake

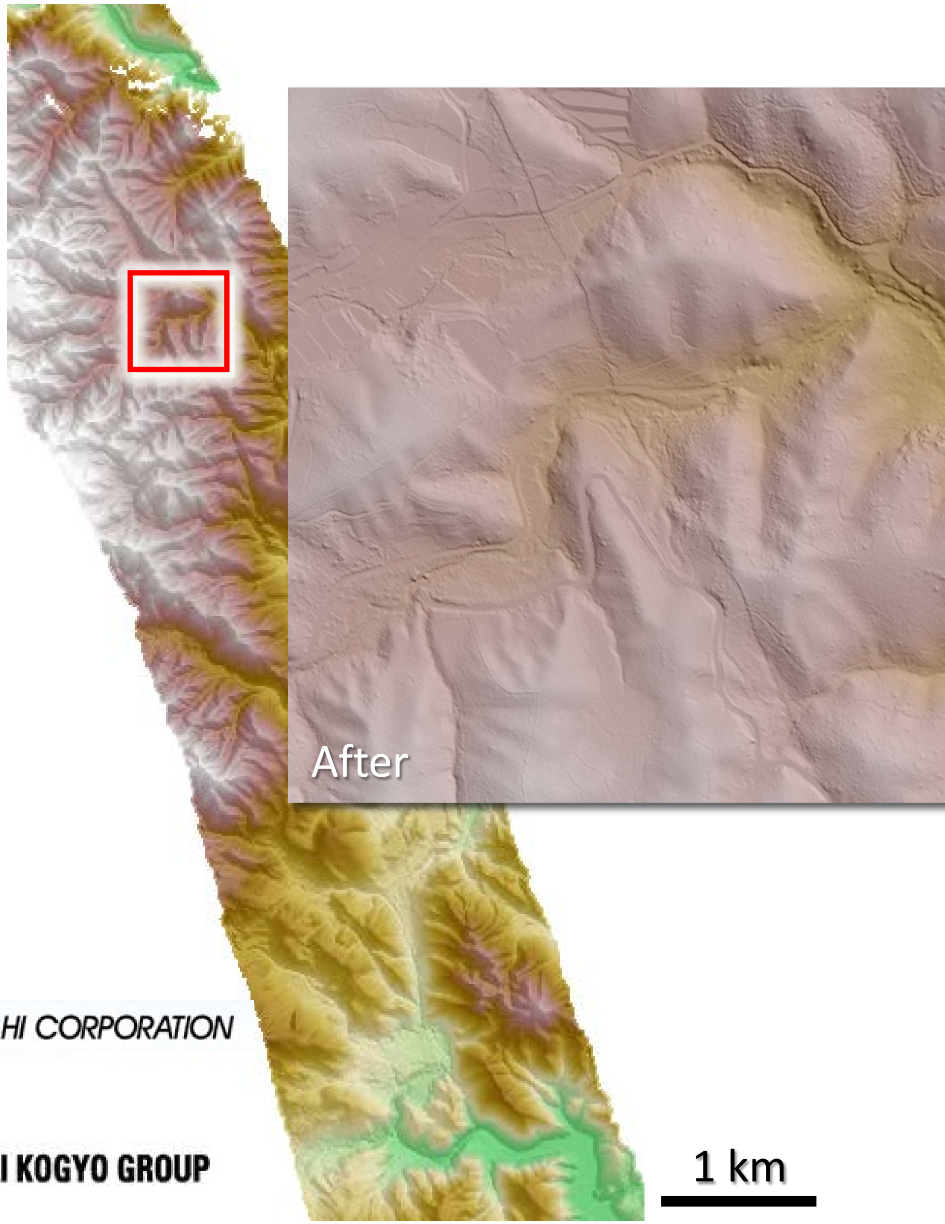


Nissen et al. (2014), *Earth Planet. Sci. Lett.*

11 April 2011 Fukushima-Hamadori earthquake



Tadashi Maruyama (AIST)



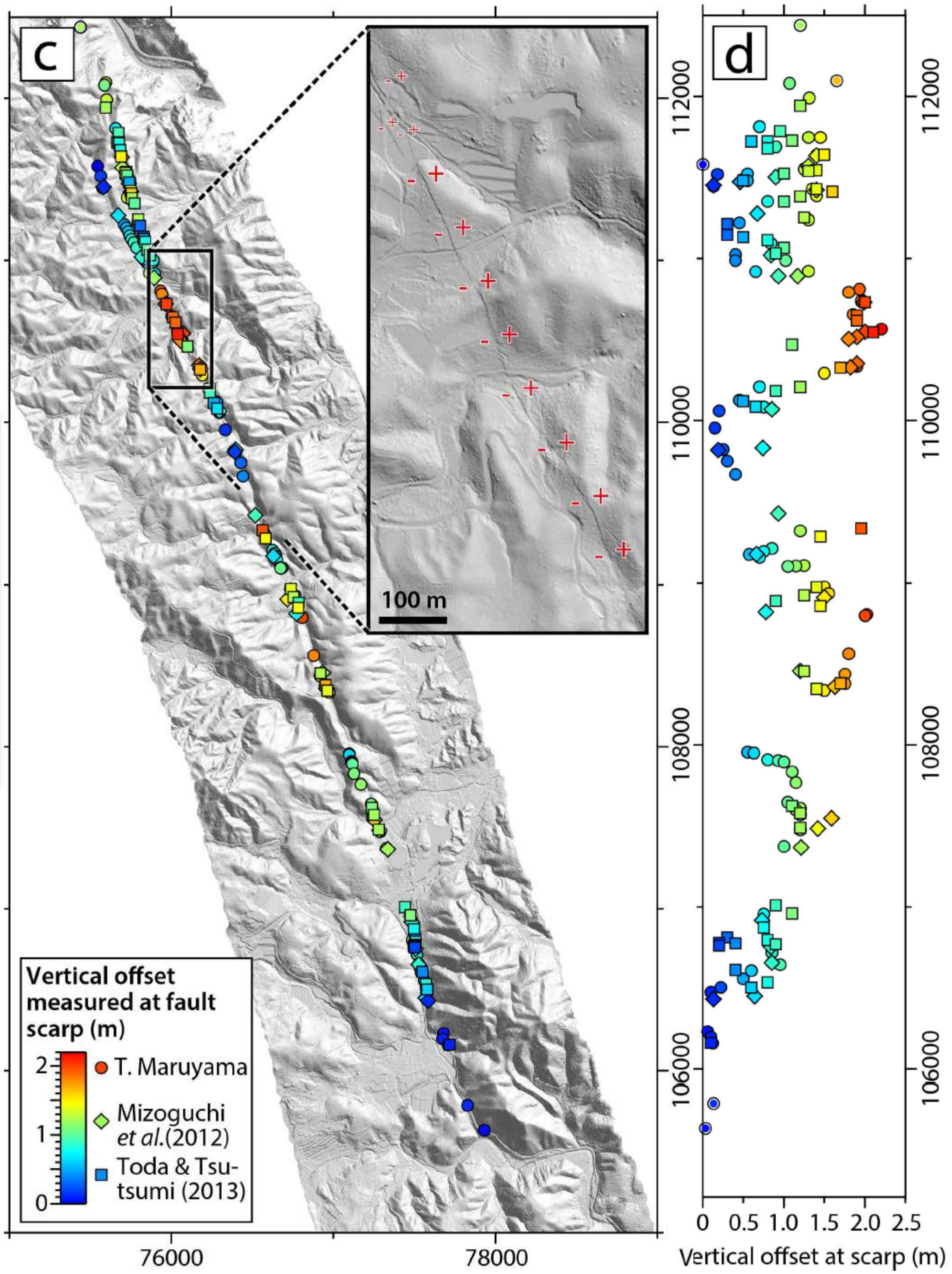
AERO ASAHI CORPORATION

KOKUSAI KOGYO GROUP

2011 post-event 1 m DEM

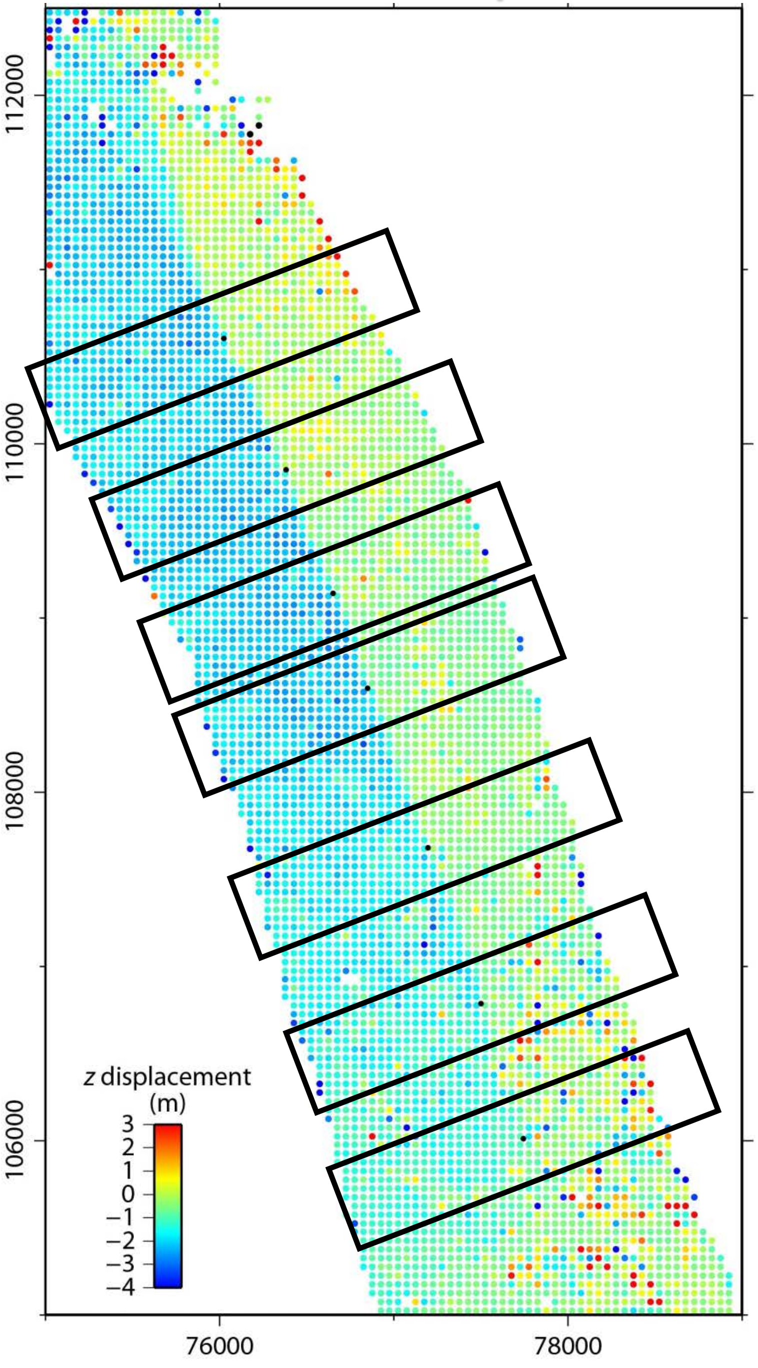
AERO ASAHI CORPORATION

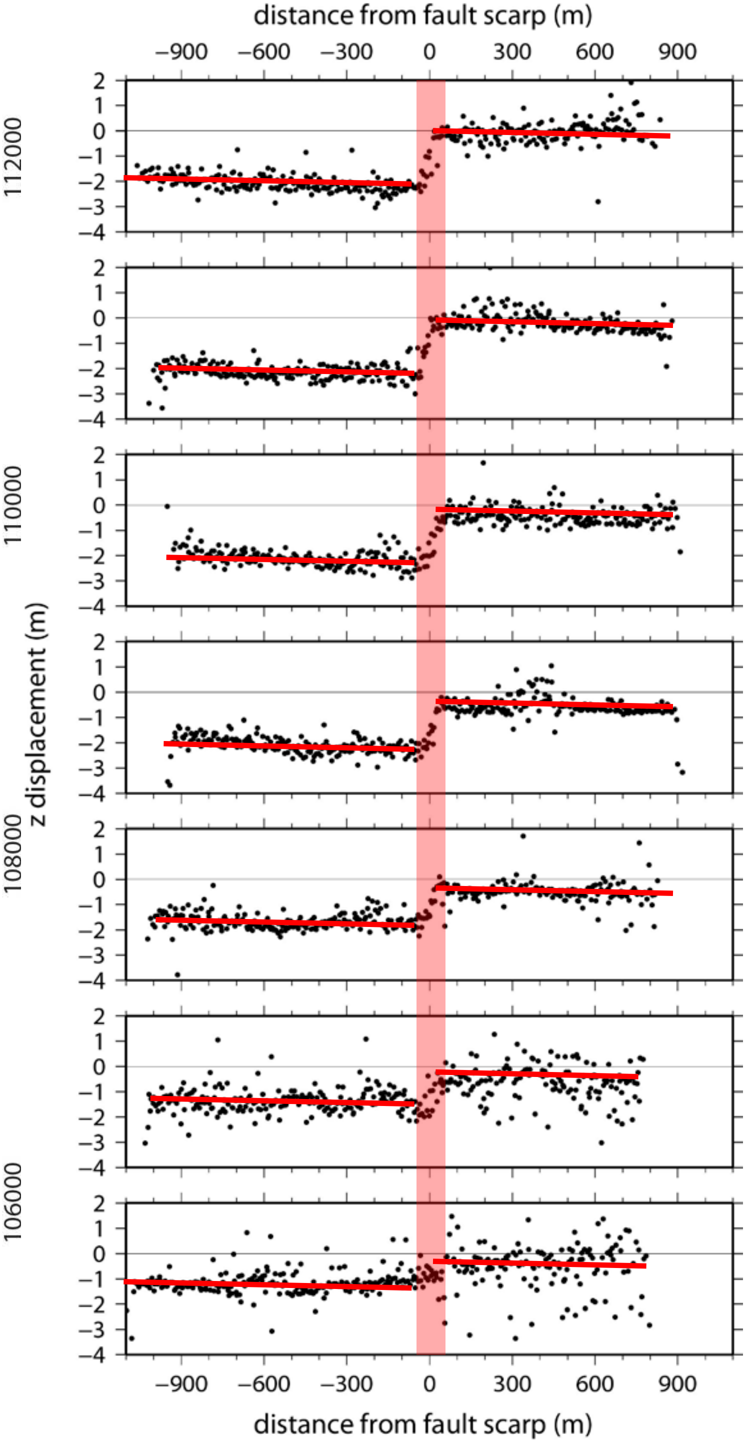
11 April 2011 Fukushima-Hamadori earthquake



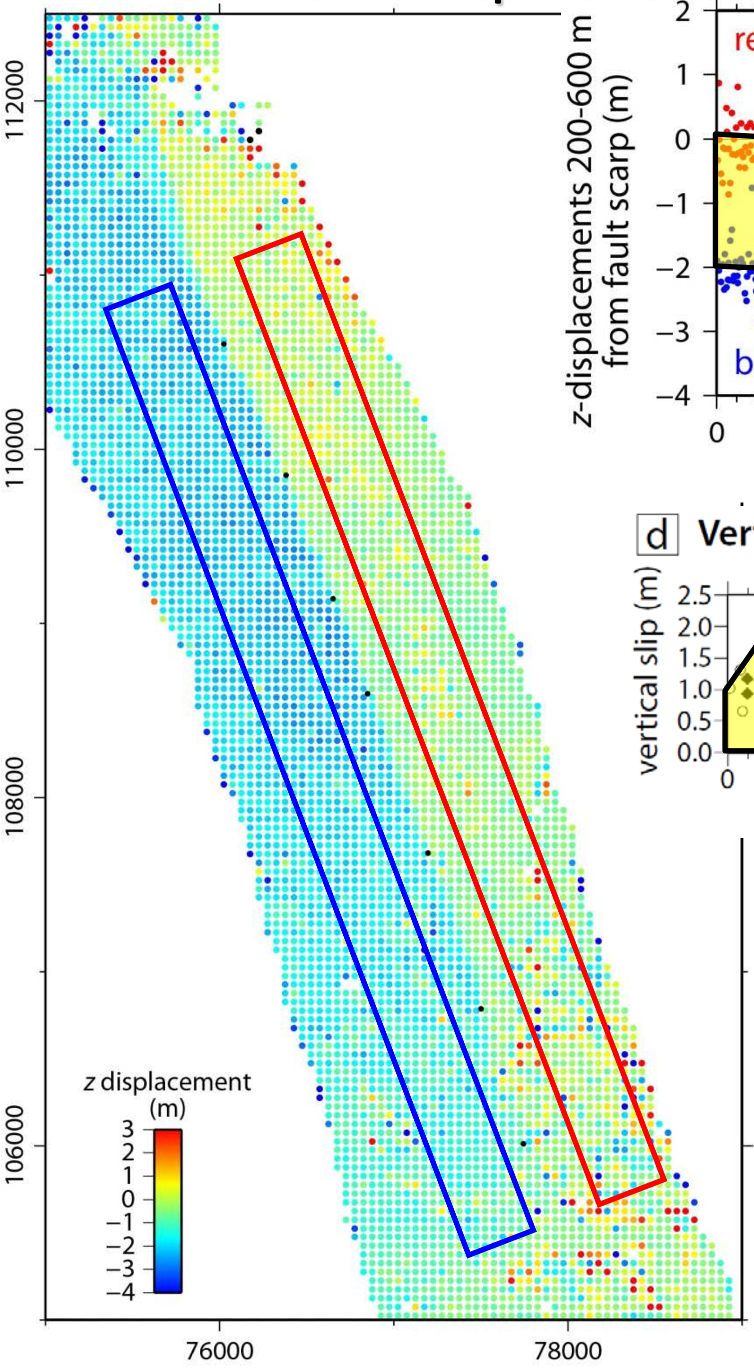
Photos from Toda & Tsutsumi (2013), *BSSA*

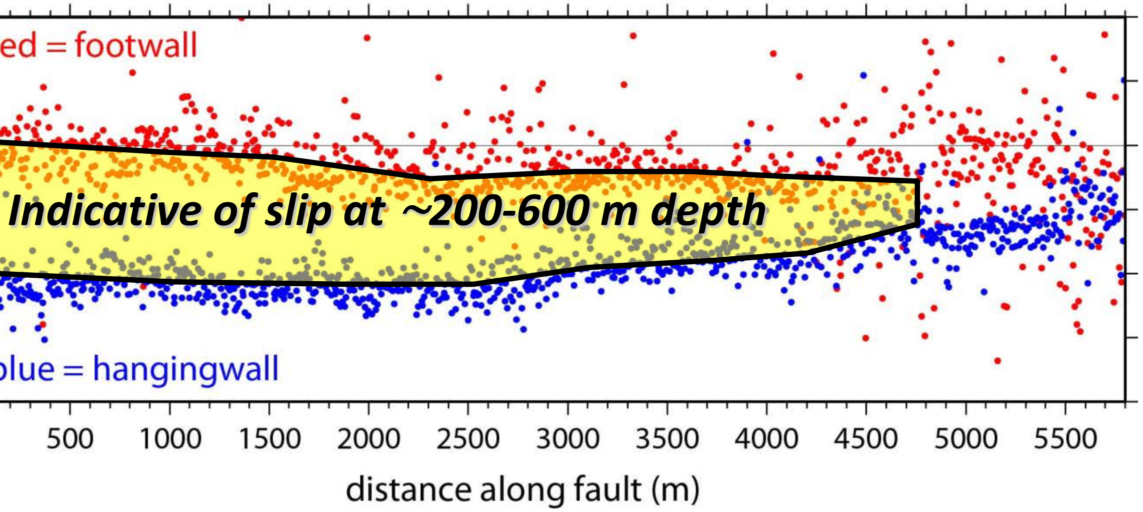
2005-2011 vertical displacements



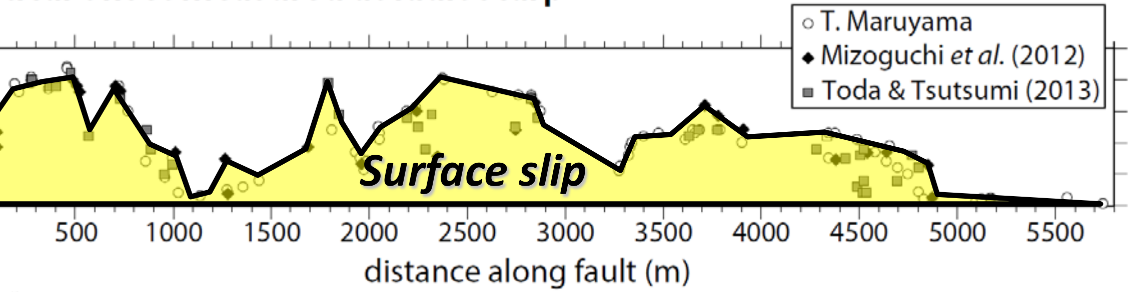


2005-2011 vertical displacements



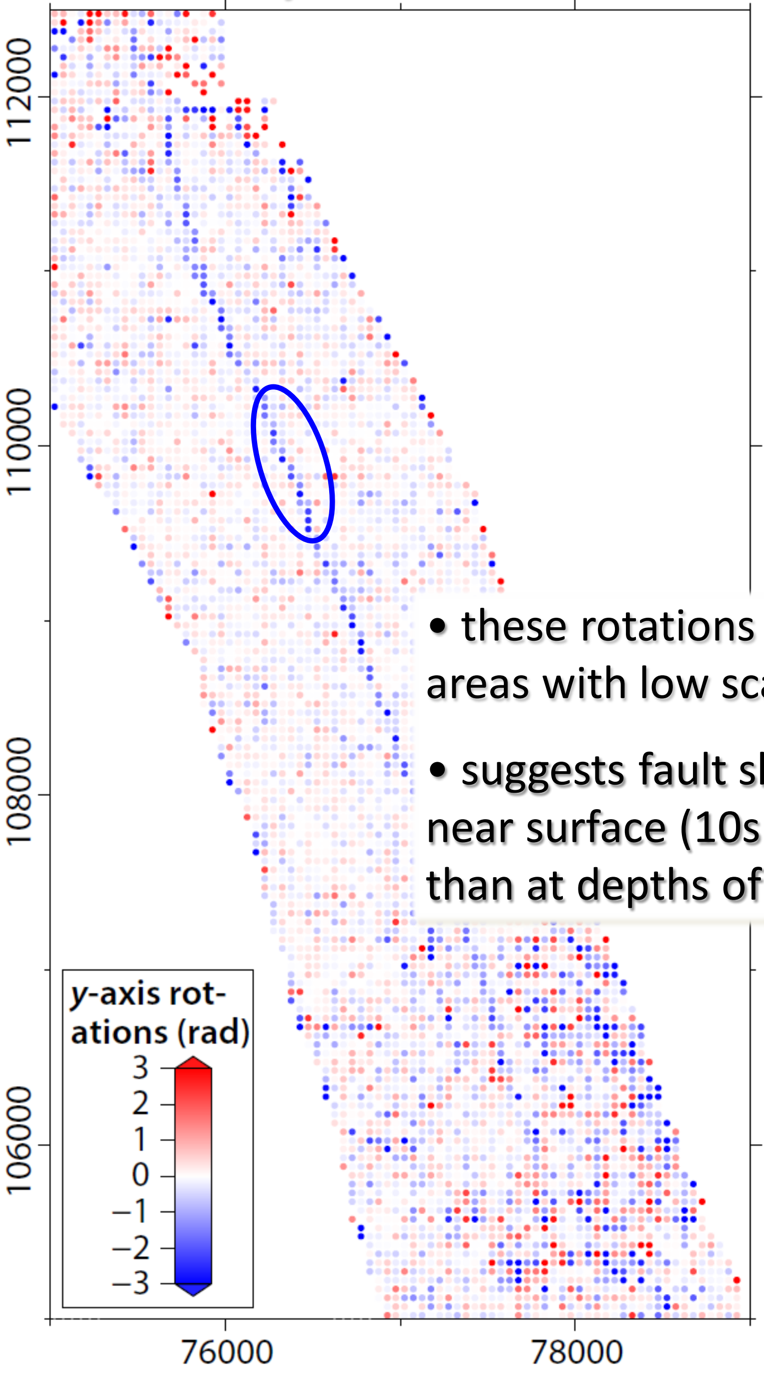


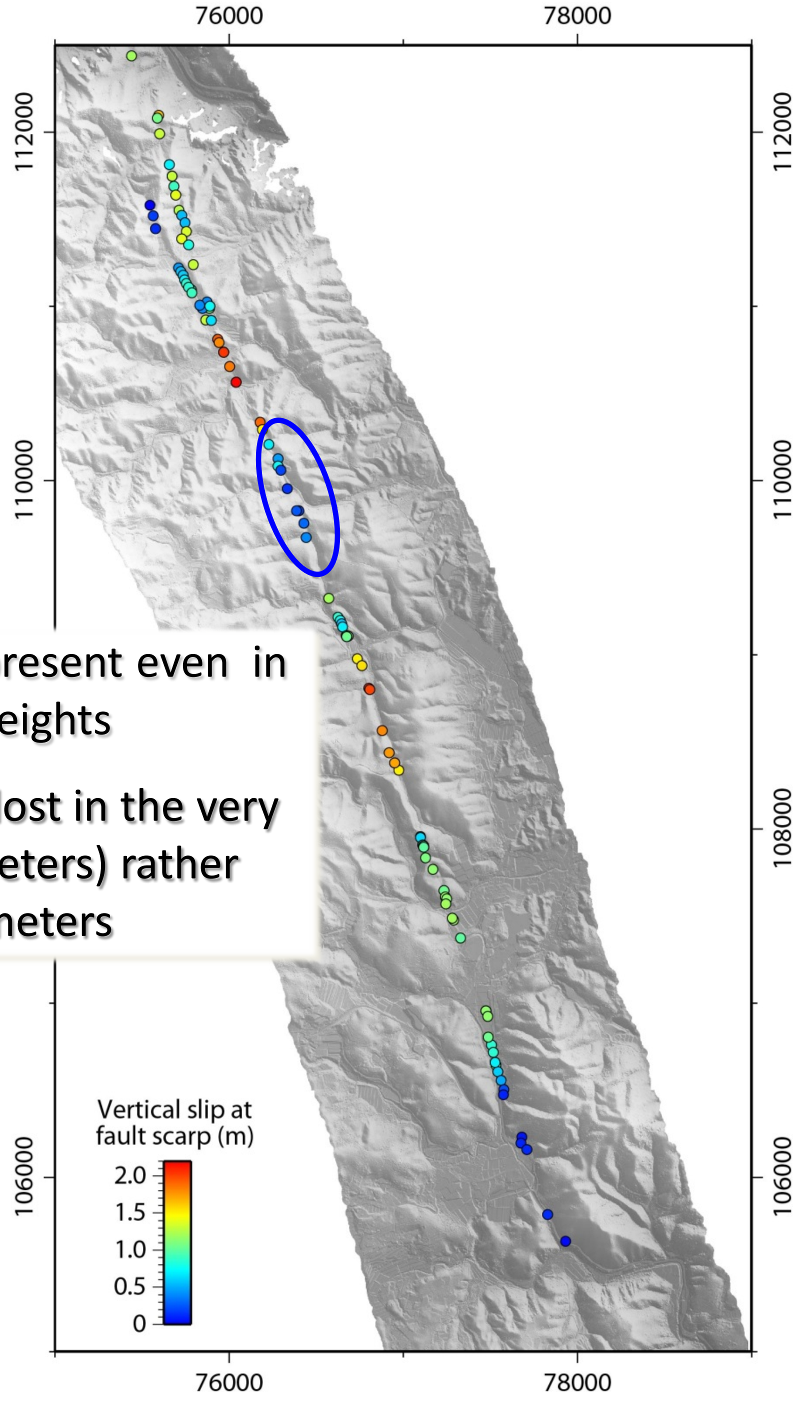
d Vertical offset measured at fault scarp



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

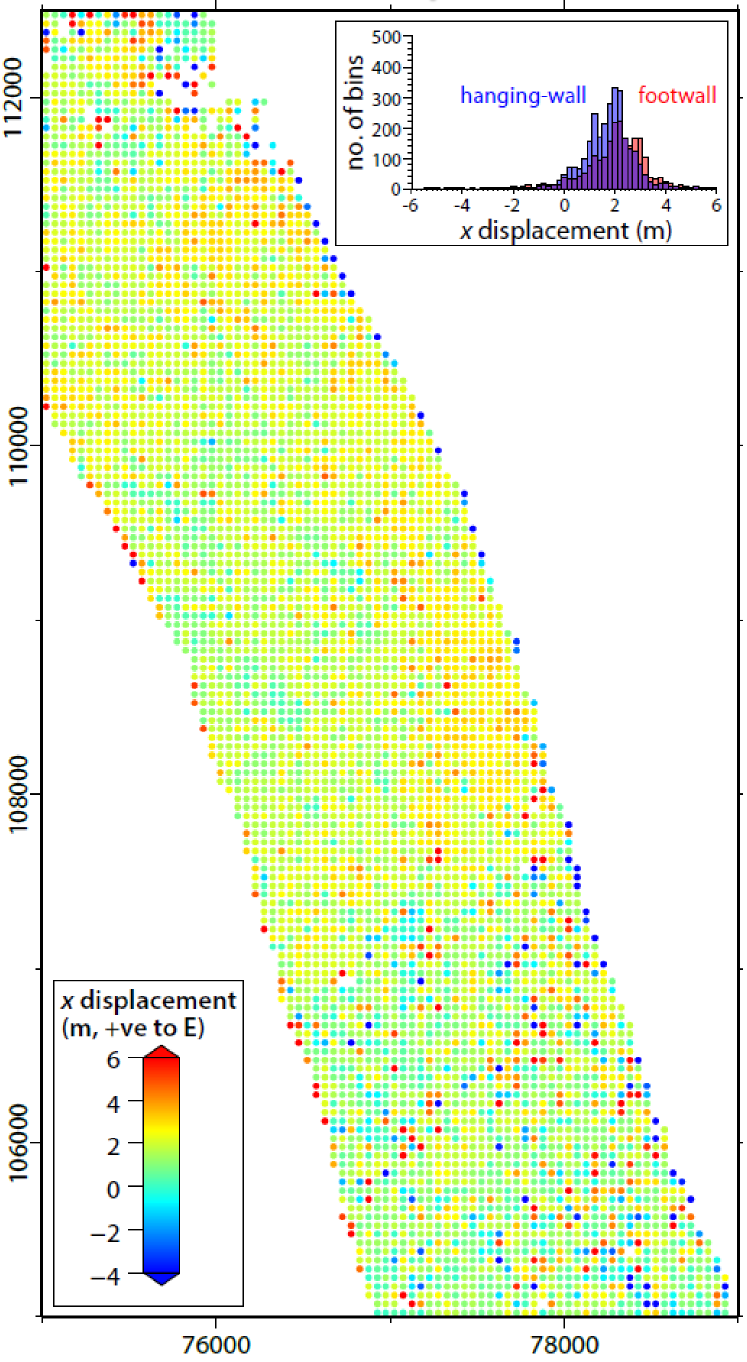
2005-2011 *y*-axis rotations

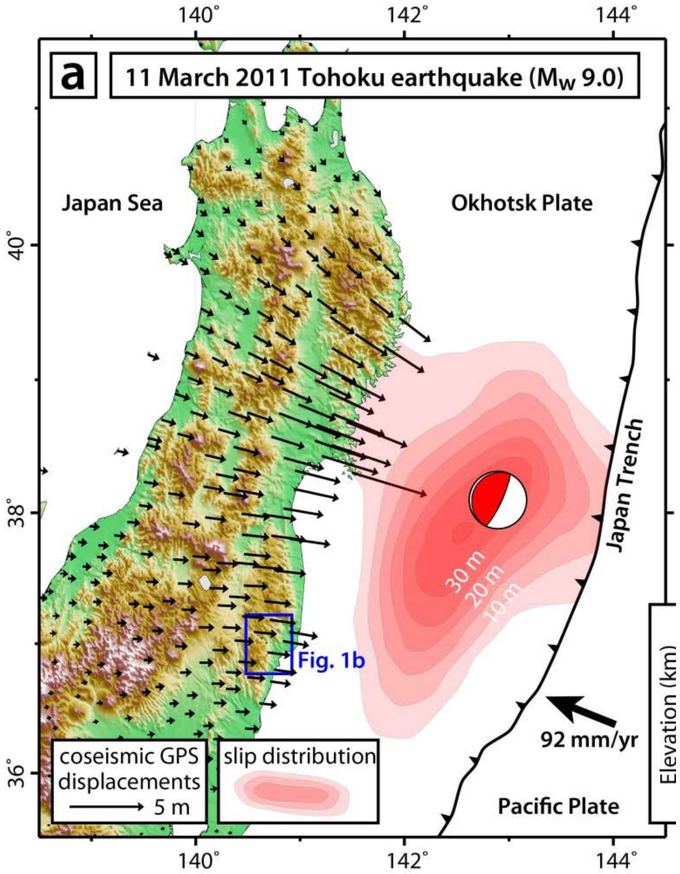




- these rotations are present even in areas with low scarp heights
- suggests fault slip is lost in the very near surface (10s of meters) rather than at depths of kilometers

2005-2011 E-W displacements

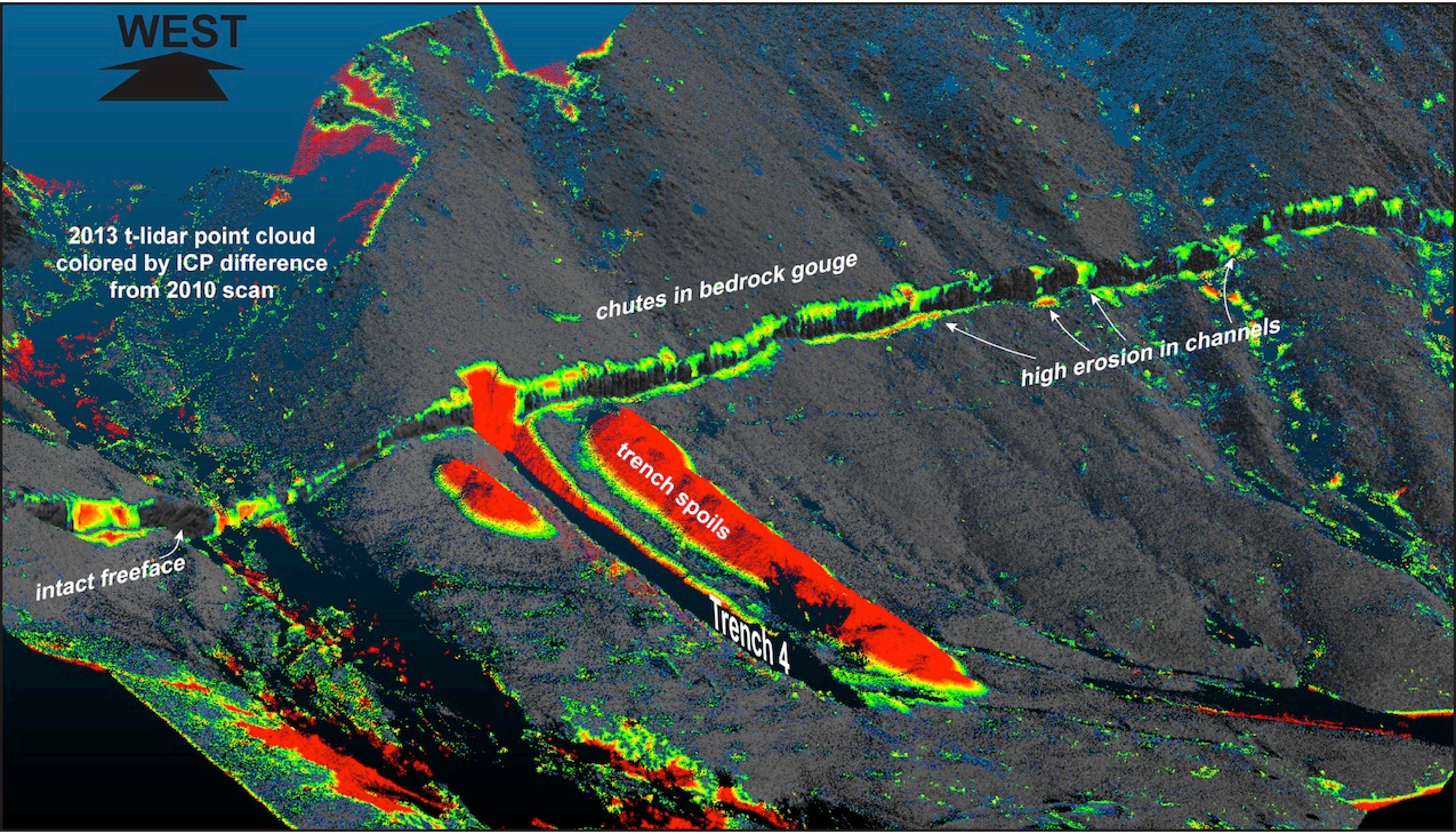




Degradation of the 2010 El Mayor-Cucapah earthquake scarp

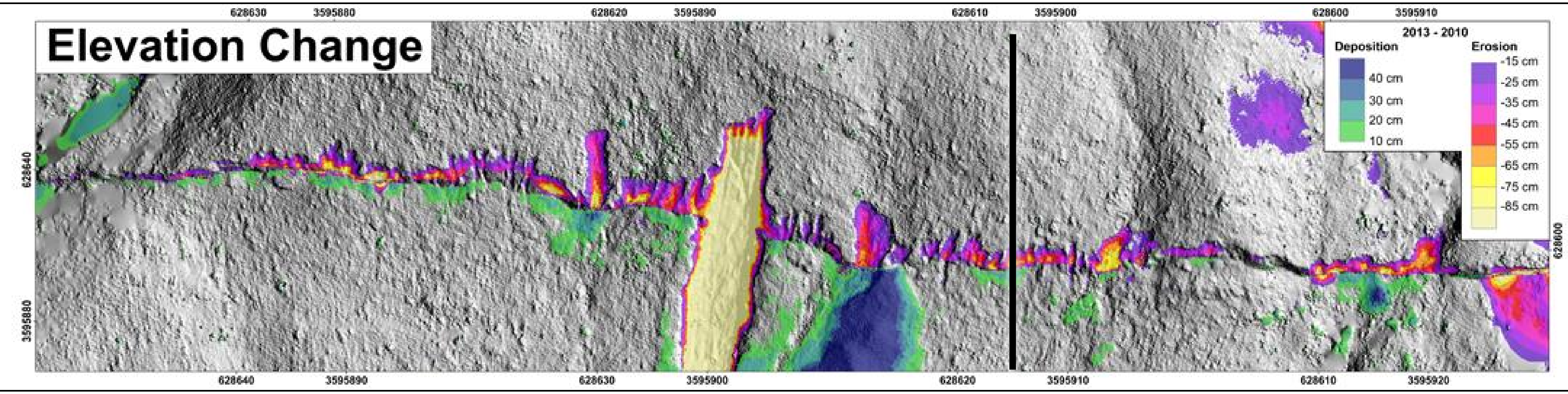
Austin Elliott, UC Davis/Oxford

Degradation of the 2010 El Mayor-Cucapah earthquake scarp

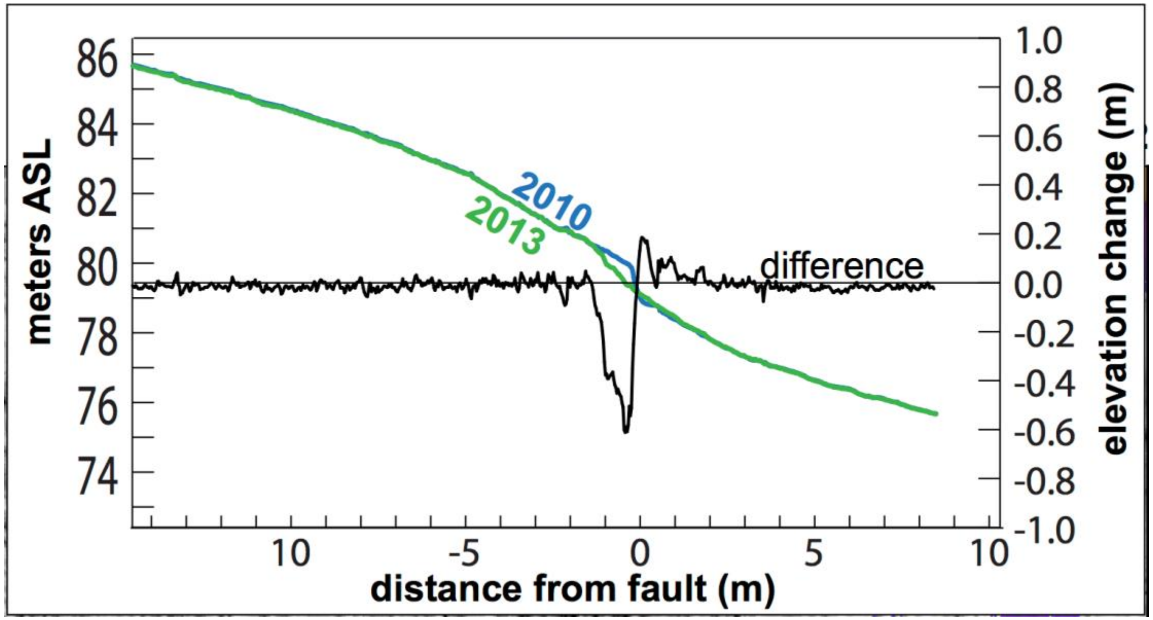


Austin Elliott, UC Davis/Oxford

Degradation of the 2010 El Mayor-Cucapah earthquake scarp

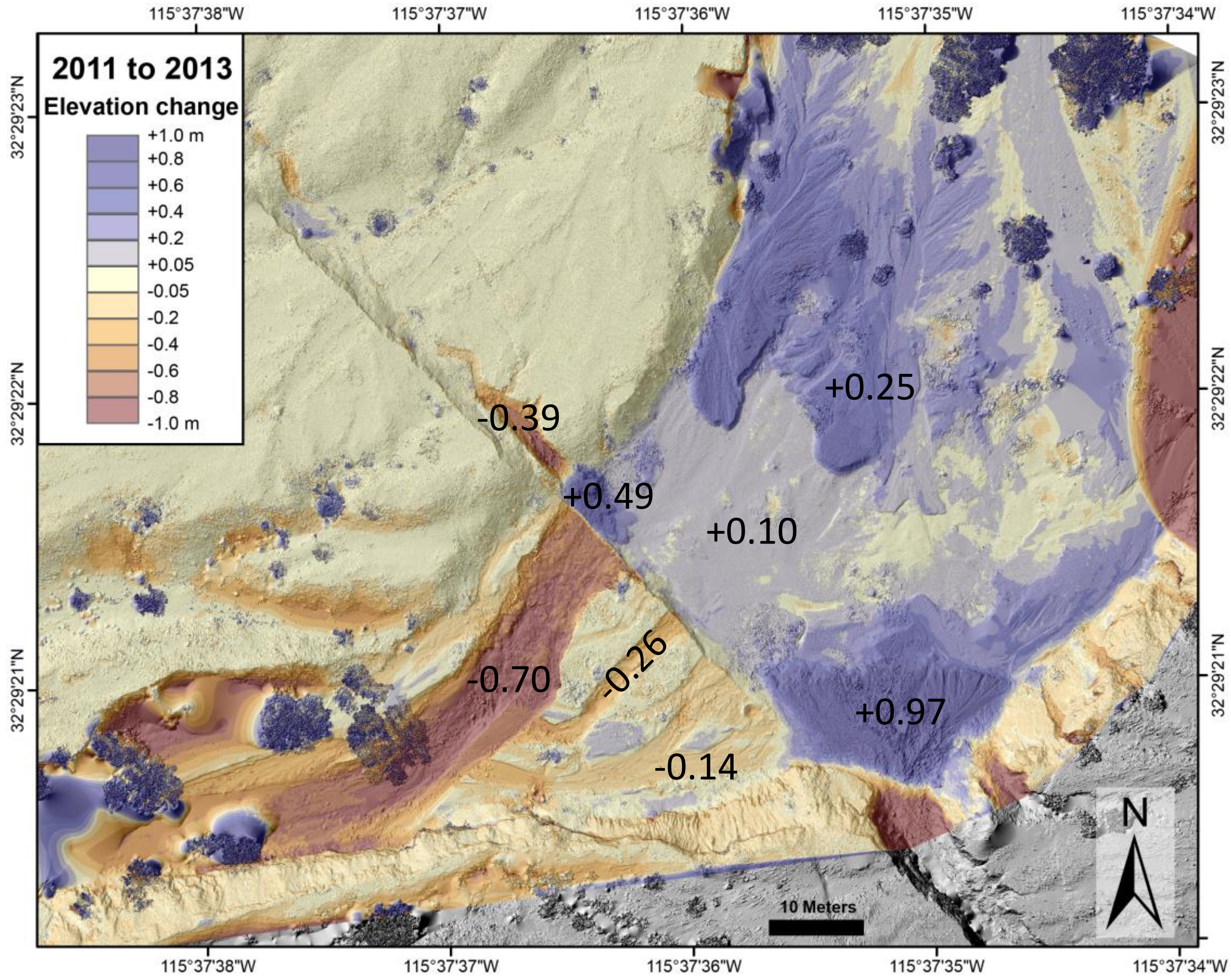


10 m



Austin Elliott, UC Davis/Oxford

Degradation of the 2010 El Mayor-Cucapah earthquake scarp



Austin Elliott, UC Davis/Oxford

Aligning point clouds and topographic change detection

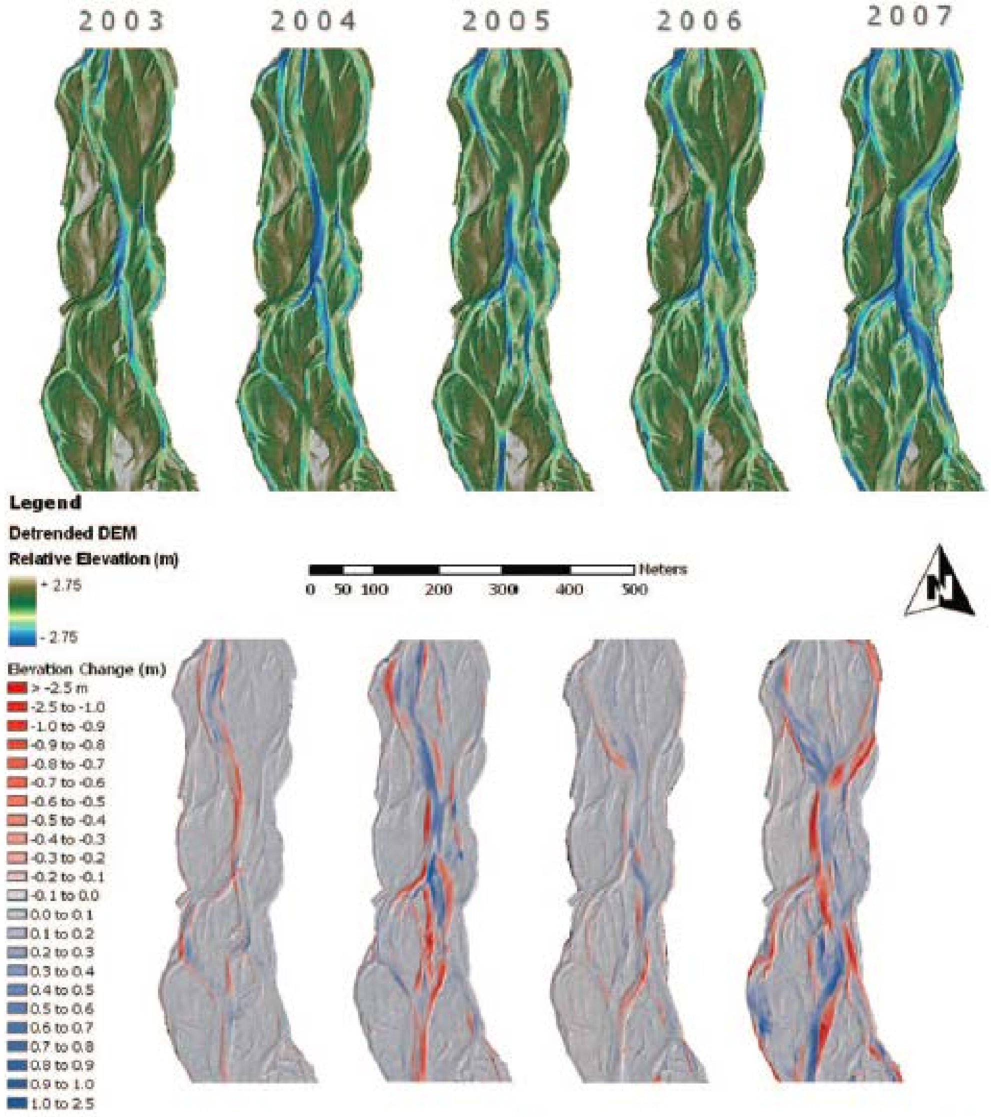


Figure 2. Detrended DEMs and DoD for 2003 to 2007. Note that the hillshades from the more recent year in the DoD are shown behind the DoD for context. This figure is available in colour online at www.interscience.wiley.com/journal/espl

RTK dGPS surveys tied to base stations occupying the same known point.

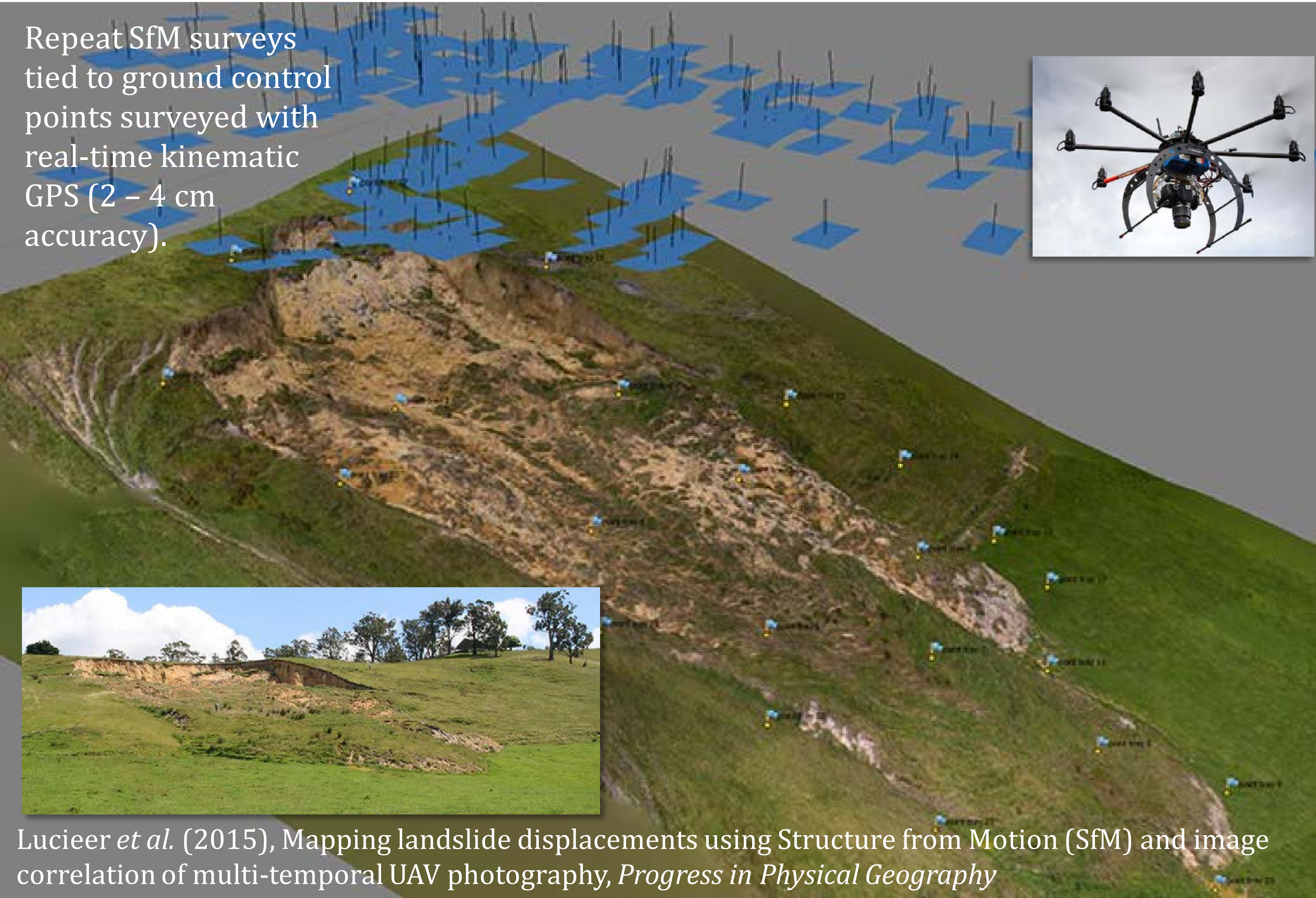
Point clouds are in exactly the same reference frame from the start.

DEMs are generated and pixel values subtracted: "DEM of Difference" of DOD

Wheaton *et al.* (2010), Accounting for uncertainty in DEMs from repeat topographic surveys: improved sediment budgets, *Earth Surface Processes and Landforms*

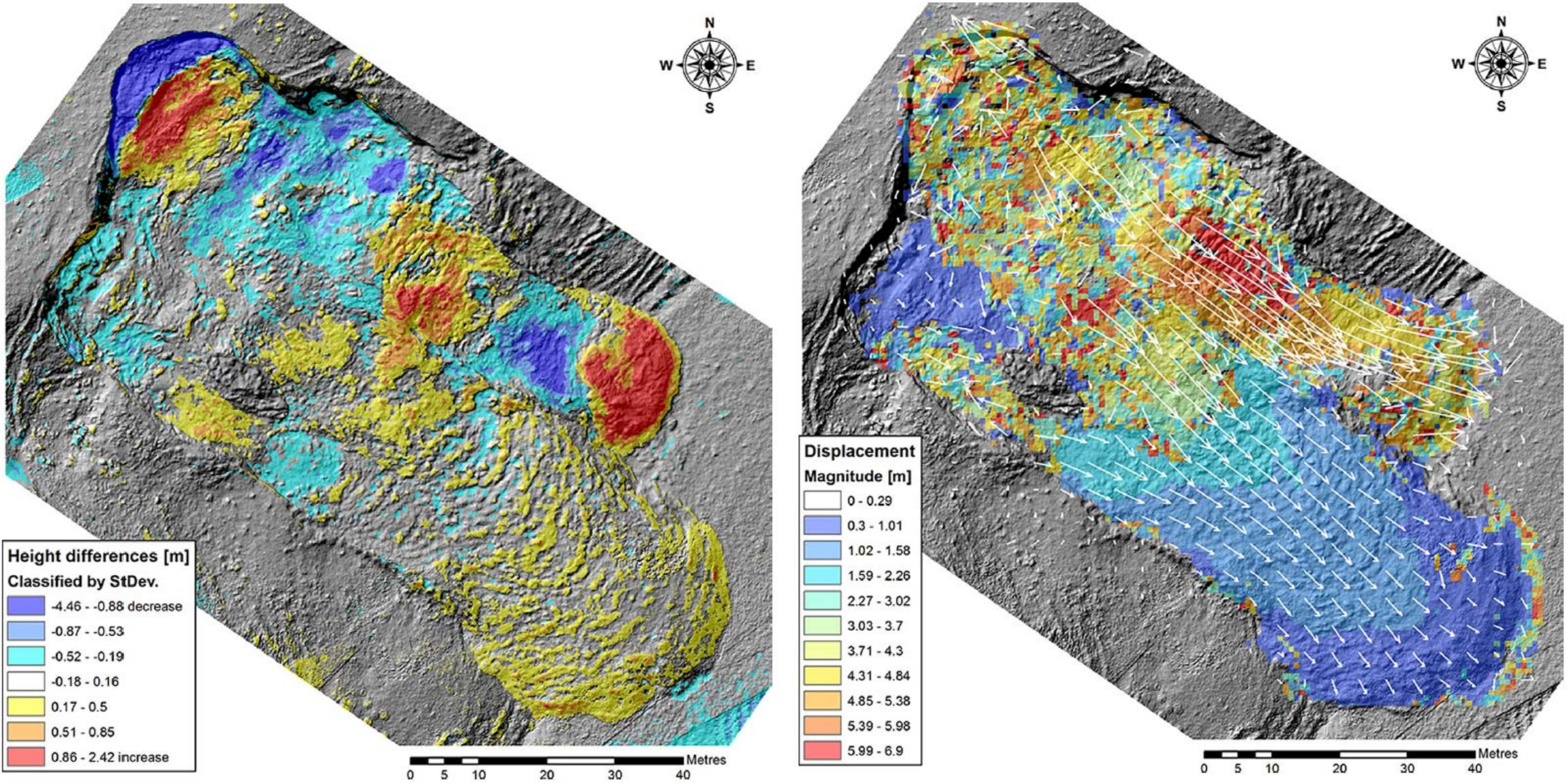
Aligning point clouds and topographic change detection

Repeat SfM surveys tied to ground control points surveyed with real-time kinematic GPS (2 – 4 cm accuracy).



Lucieer *et al.* (2015), Mapping landslide displacements using Structure from Motion (SfM) and image correlation of multi-temporal UAV photography, *Progress in Physical Geography*

Aligning point clouds and topographic change detection



- DEM of Difference (left) and horizontal displacement field from pixel cross-correlation (right)

- Caltech COSI-Corr package: Co-registration of optically-sensed images and correlation http://www.tectonics.caltech.edu/slip_history/spot_coseis/index.html

Lucieer *et al.* (2015), Mapping landslide displacements using Structure from Motion (SfM) and image correlation of multi-temporal UAV photography, *Progress in Physical Geography*