# Surface rupture and slip variation induced by the 2010 El Mayor – Cucapah earthquake, Baja California, quantified using COSI-Corr analysis on pre- and post-earthquake LiDAR acquisitions

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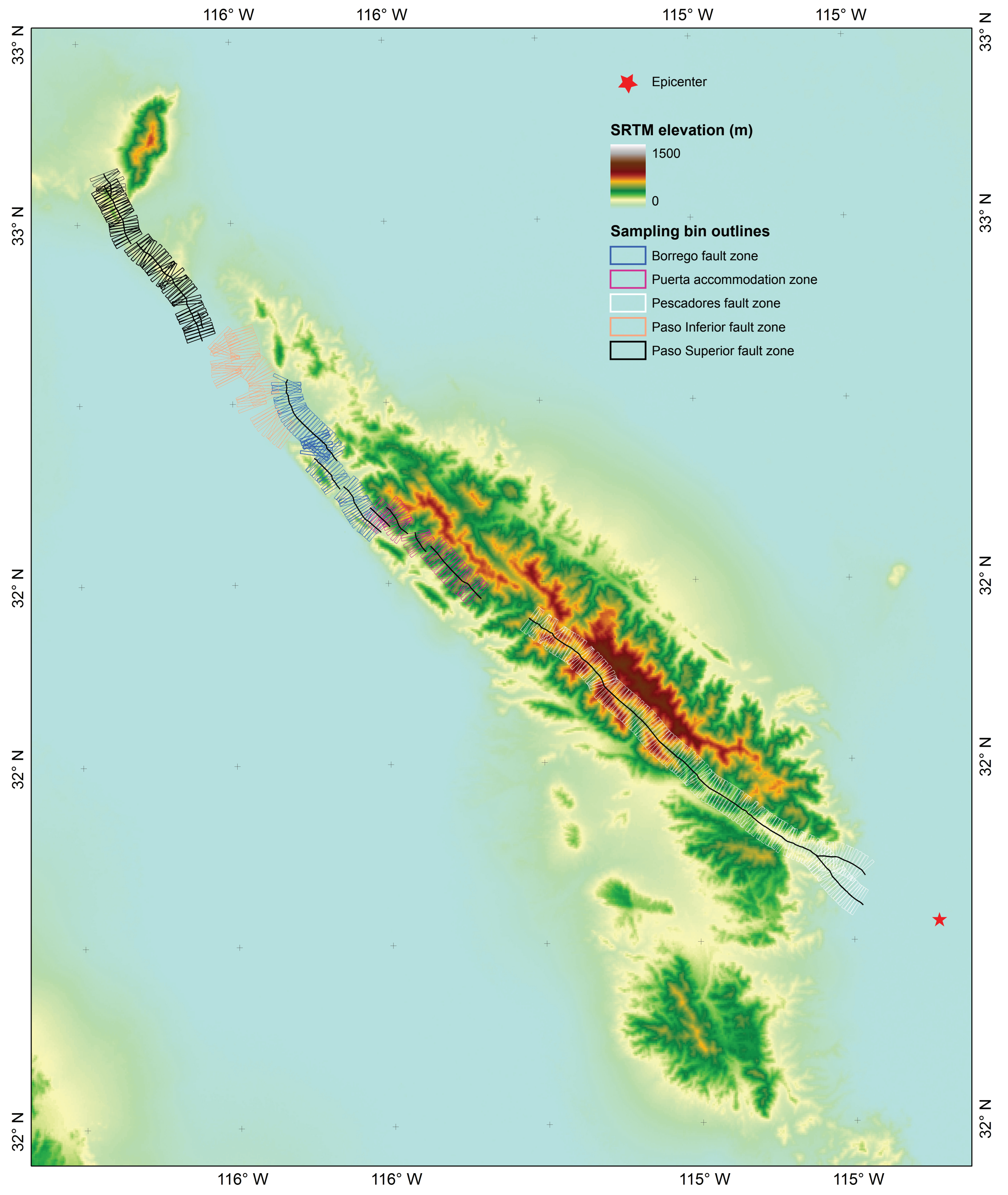
## Abstract:

Analysis of pre- and post-earthquake topographic data provides an opportunity to deliver the full 3D displacement field of the ground's surface. However, direct differencing of a pre- and post-earthquake digital topography model (DEM) generally leads to biased estimation of the vertical component of the deformation if the pre- and post-earthquake DEM exhibit horizontal mis-registration. We use the COSI-Corr sub-pixel correlation algorithm to estimate the relative horizontal offset between the pre- and post- 2010 El Mayor – Cucapah earthquake high resolution LiDAR acquisitions. Compensating for the horizontal offset between the two LiDAR acquisitions allows us to estimate unbiased measurements of the vertical component of the surface fault rupture. We also show the limitations of the available dataset, such as aircraft jitter artifacts, which impaired accurate measurements of the horizontal component of the surface deformation. This analysis shows an unprecedented view of the complete vertical slip component of the rupture induced by the Mw 7.2 2010 El Mayor – Cucapah earthquake, sampled at every 5 m, over a length of about 100 km, and with a vertical accuracy of a few centimeters. Variations in the vertical component of an oblique slip earthquake are presented, with breaks along multiple fault-strands showing opposite dip directions and diffuse boundaries. Vertical displacement profiles across the entire fault rupture and selective horizontal displacement profiles will be shown. With the availability of high precision pre- and post-earthquake data, COSI-Corr has the ability to accurately document the variability of 3D surface slip along strike of an earthquake rupture. Such data can be used to investigate the causes of this variability, and improve our understanding of its influence on the pattern of ground shaking.



## Data preparation:

Pre-earthquake LiDAR (with average point cloud density .013 points/m²) acquired in 2006 by INEGI was interpolated into a grid at 5m resolution by CICESE. Post-earthquake high resolution (9 to 18 returns/m²) LiDAR was collected by NCALM [Oskin et al., 2010] in mid-August, 2010 and was delivered via the OpenTopography website.

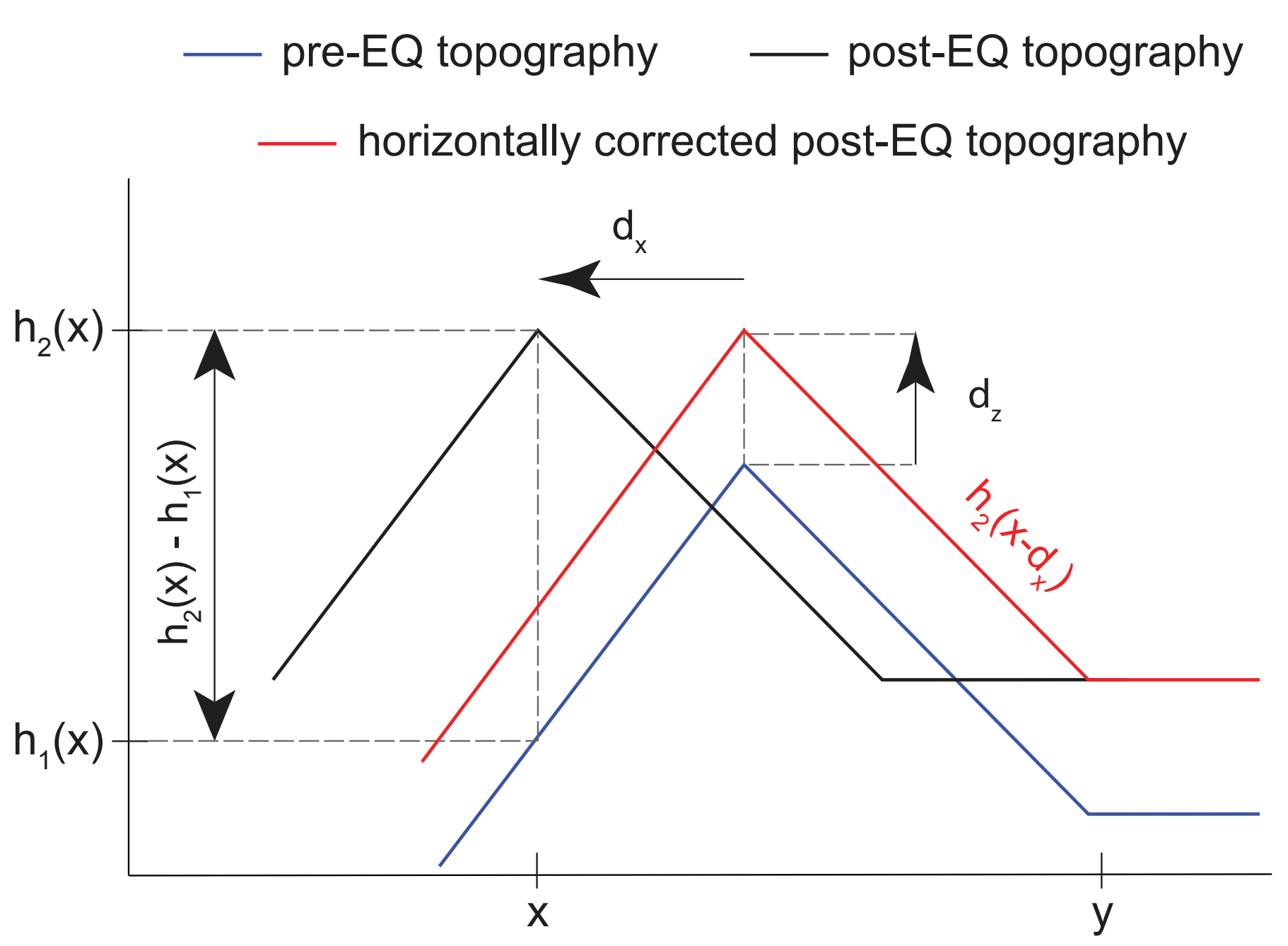
The post-earthquake point cloud was arranged into buffered tiles using the open library libLas (liblas.org), in combination with the free LASTool software . The ENVI plug-in "BCAL LIDAR Tools" was then used to grid, without edge effects, the post-earthquake point clouds on a 5m post-spacing grid aligned with the pre-earthquake 5m Lidar grid.

## Data Processing:

To measure a potential elevation difference between two elevation models, $h_1$ and $h_2$, they must be accurately registered horizontally. Consider that in addition to a potential elevation difference $d_z$ at ground location x, there also exists a horizontal mis-registration $d_x$ such that $h_2(x) = h_1(x+d_x) + d_z$. Then, the elevation difference between $h_2$ and $h_1$ will be proportionally biased, on the first order, by the local topography gradient:

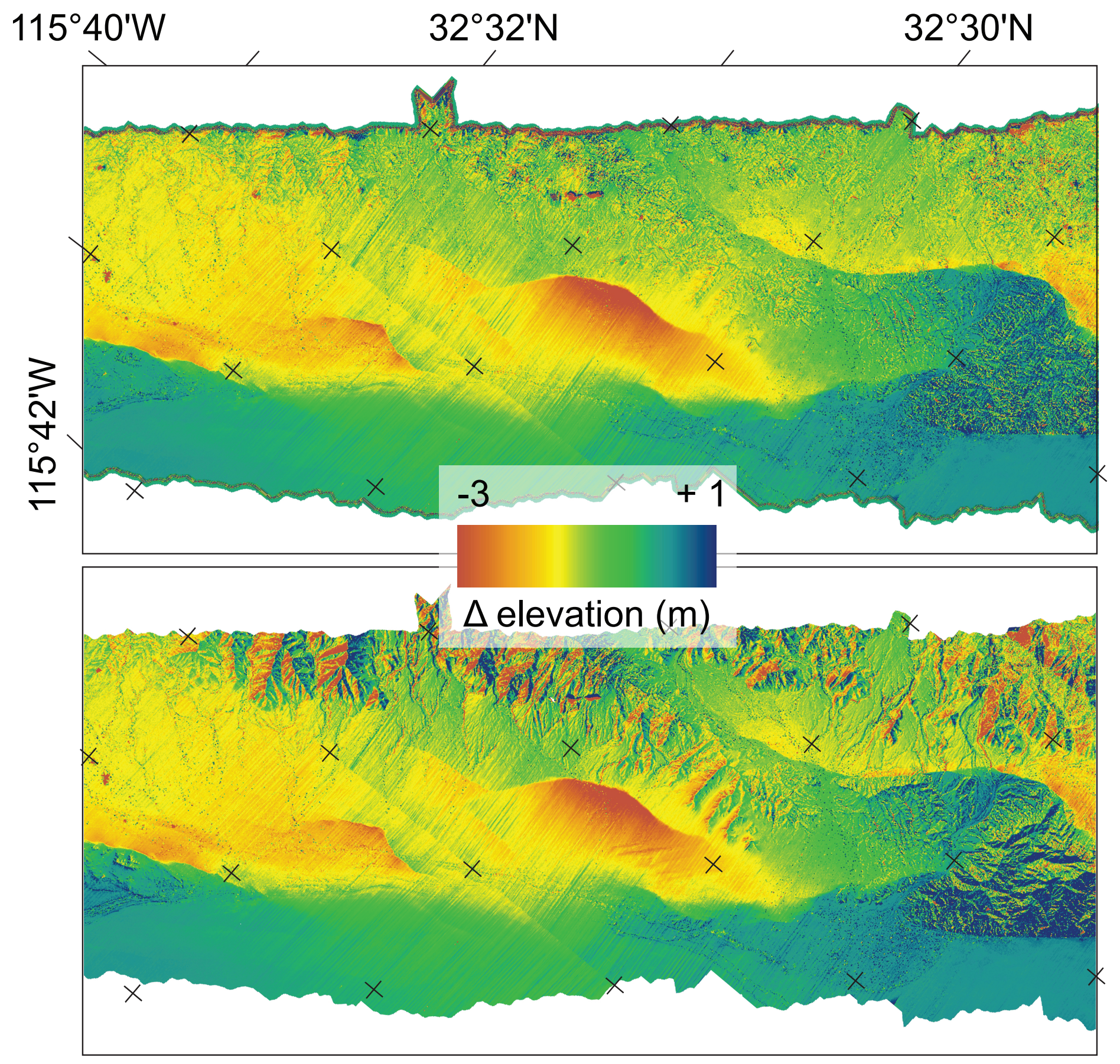
$$h_2(x) - h_1(x) = h_1'(x)d_x + d_z,$$

where $h_1'(x)$ is the derivative of $h_1$ at ground location x. In other words, elevation difference cannot be estimated by simple DEM differencing unless no horizontal mis-registration exists, or unless the topography is locally flat.



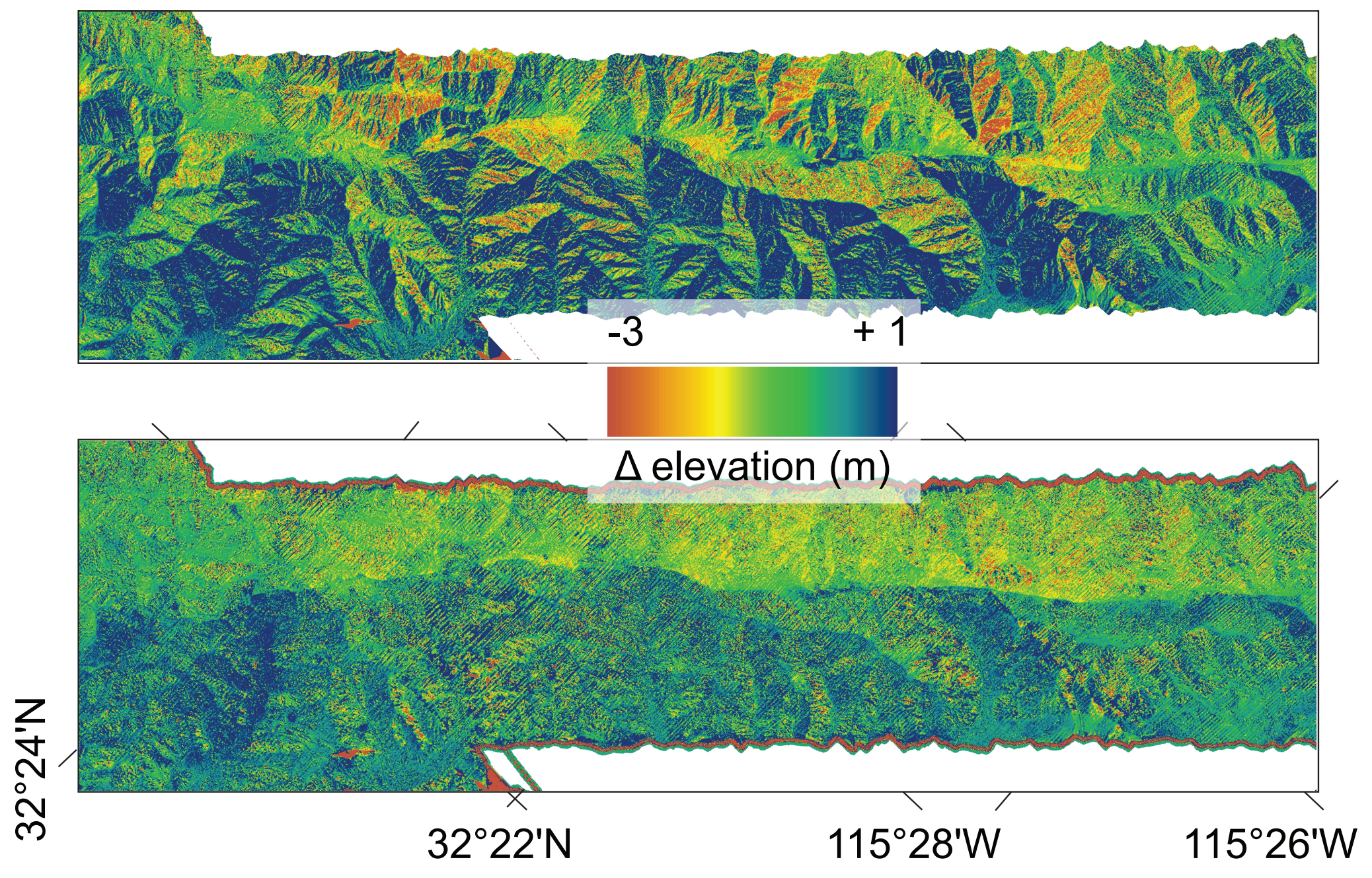
$$(1)\ h_2(x) - h_1(x) = h_1'(x)d_x + d_z \qquad (2)\ h_2(x - d_x) - h_1(x) - d_z$$

To estimate the relative horizontal offsets between the pre- and the post-earthquake LiDAR DEMs, we used the sub-pixel phase correlation algorithm provided in COSI-Corr [Leprince et al, 2007]. The post-earthquake DEM was then warped onto the pre-earthquake DEM according to the relative horizontal offset field measured, producing $h_2(x - dx)$.

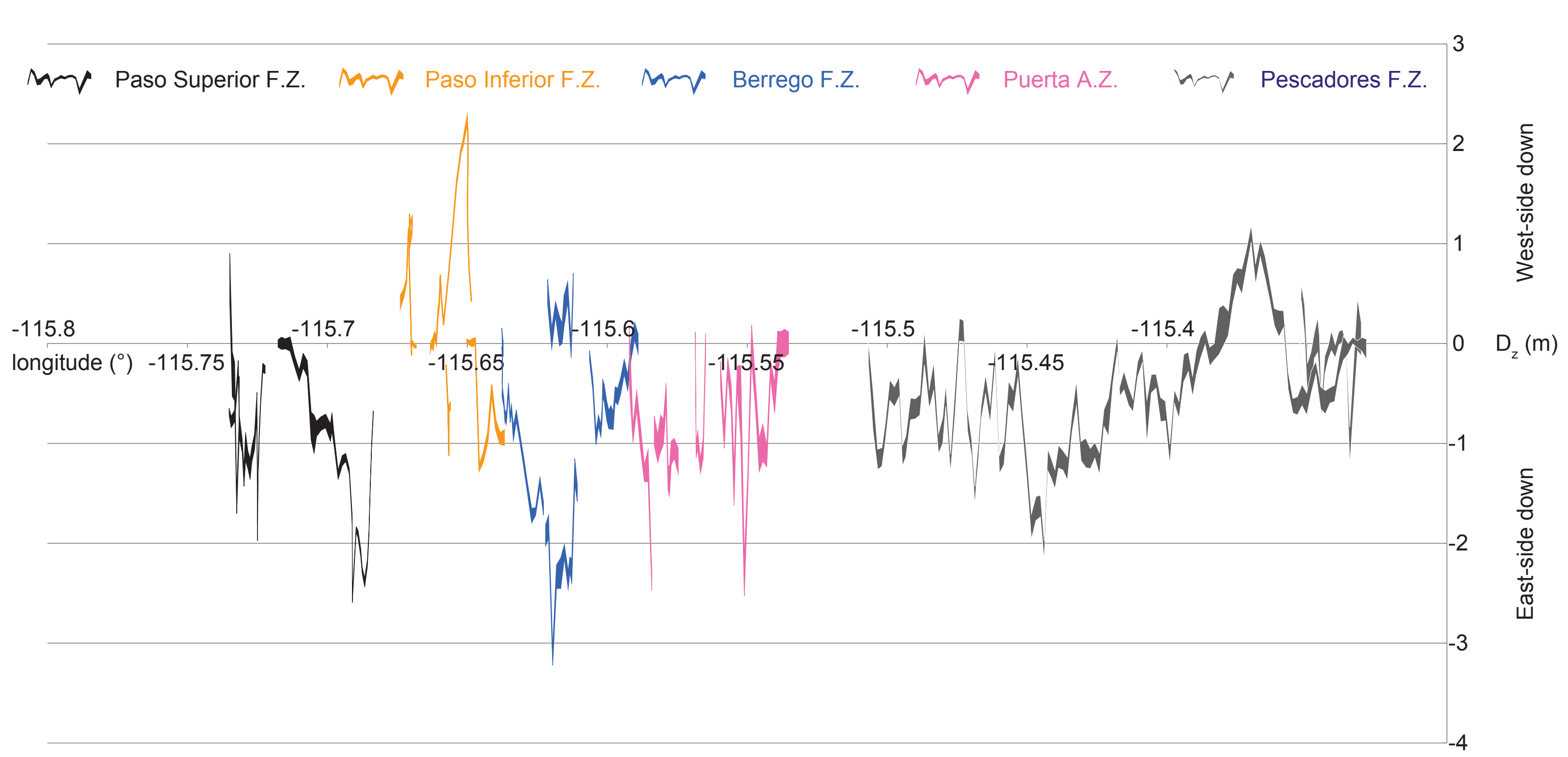


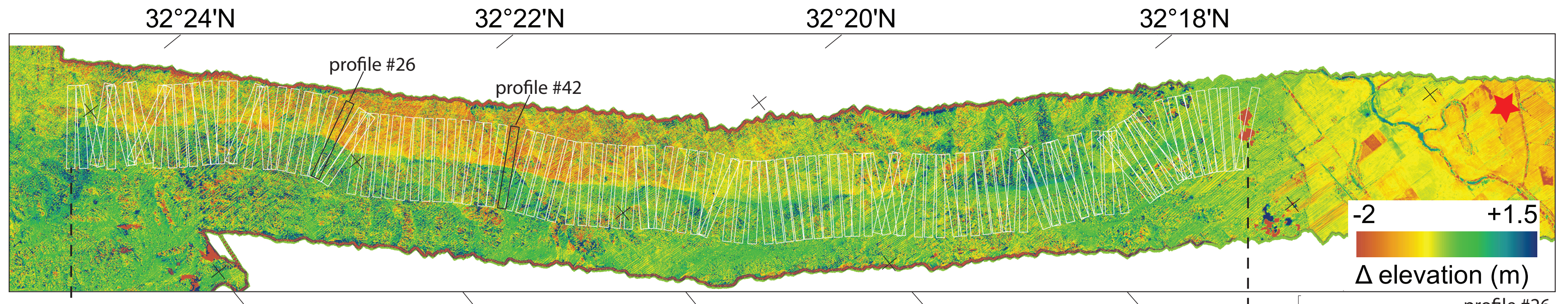
(left) Borrego Fault elevation change with and without correction for horizontal offset. Note that flat topography areas stay unchanged.

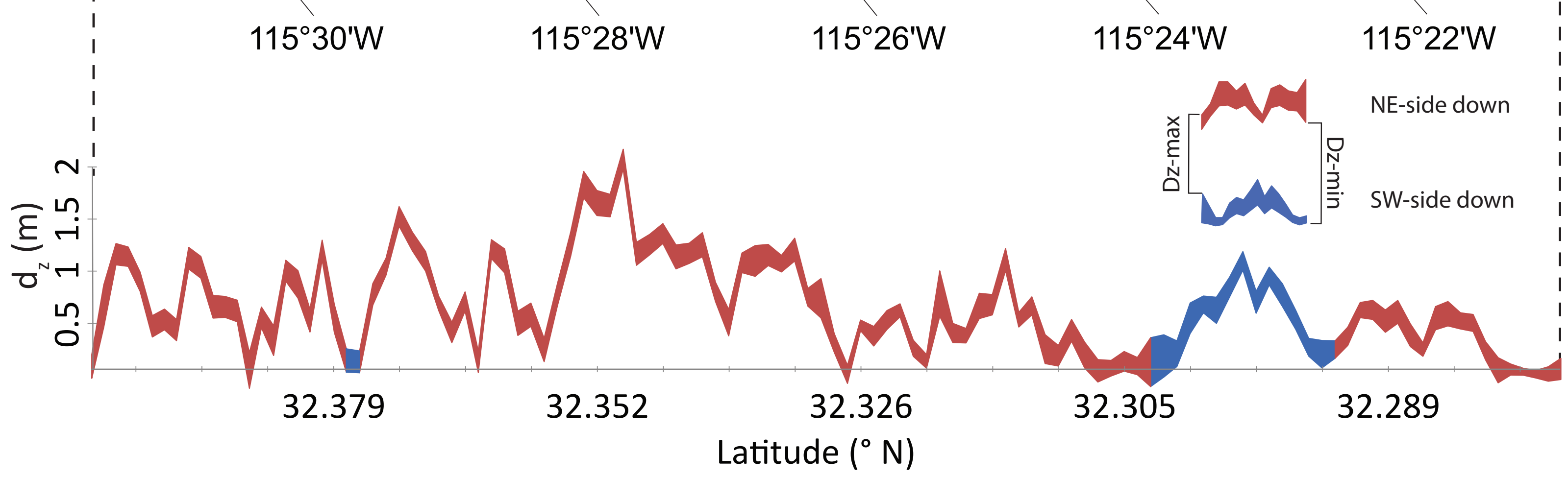
(below) Northern section of the Pescadores Fault elevation change with and without correction for horizontal offset.



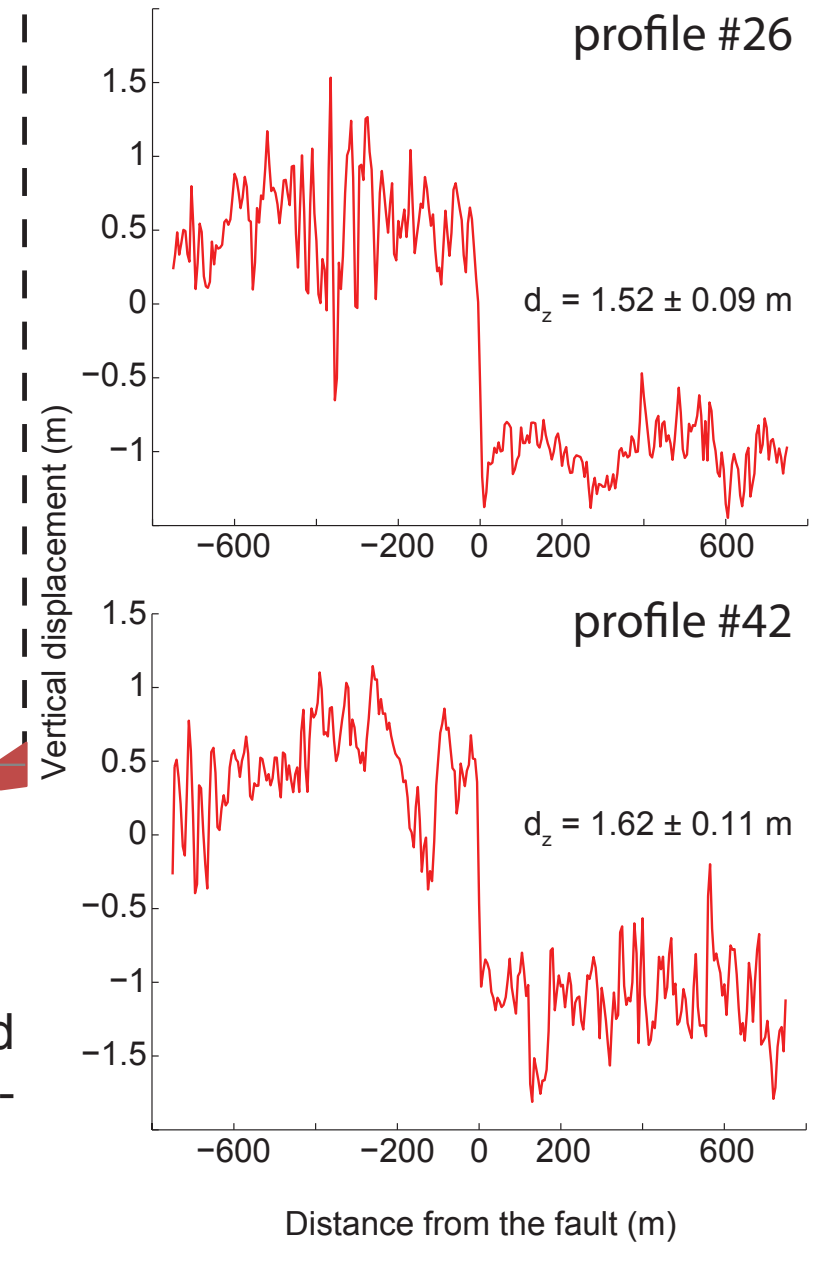
Vertical slip ($D_z$) distribution along faults with surface rupture NW of the El Mayor - Cucapah earthquake epicenter.



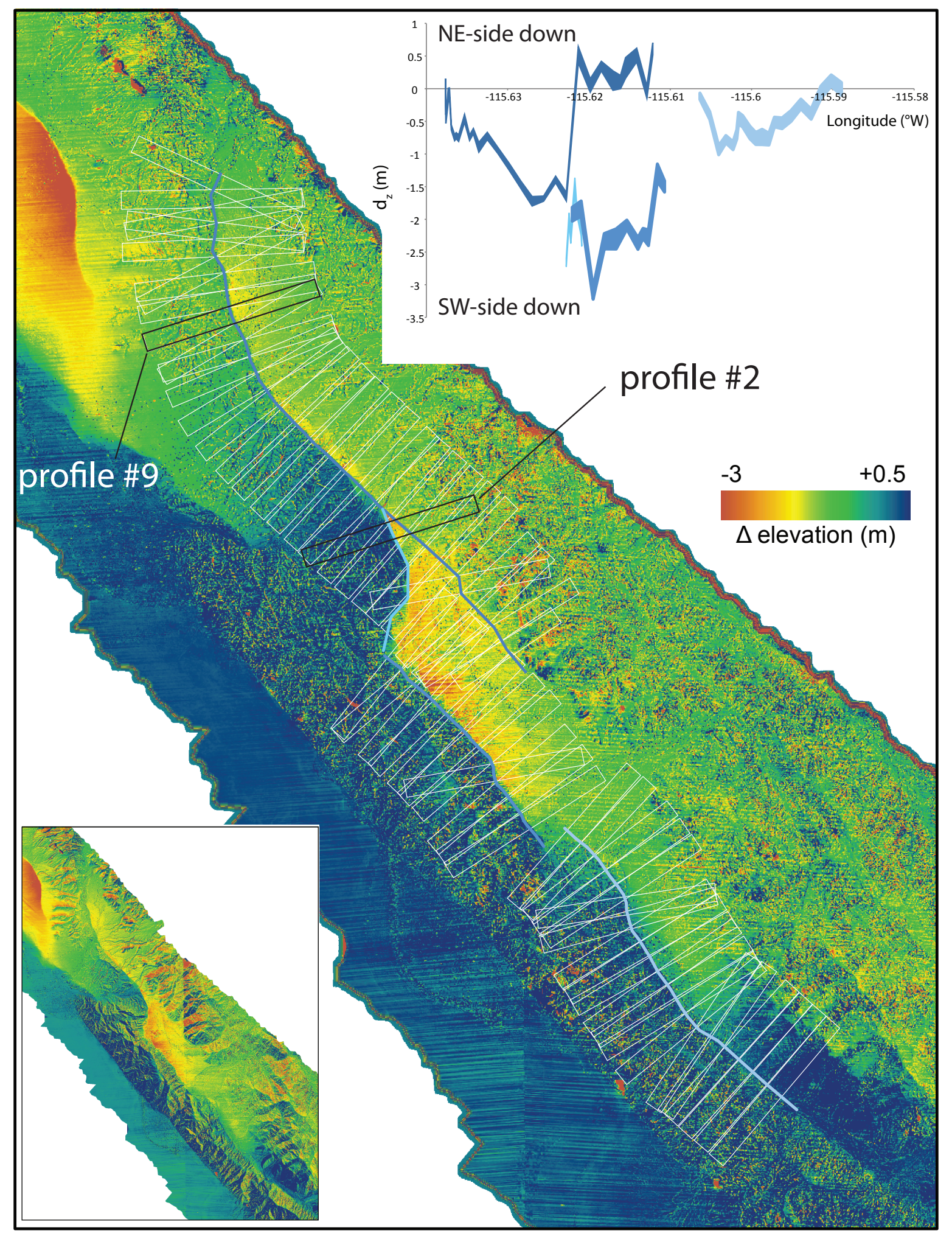




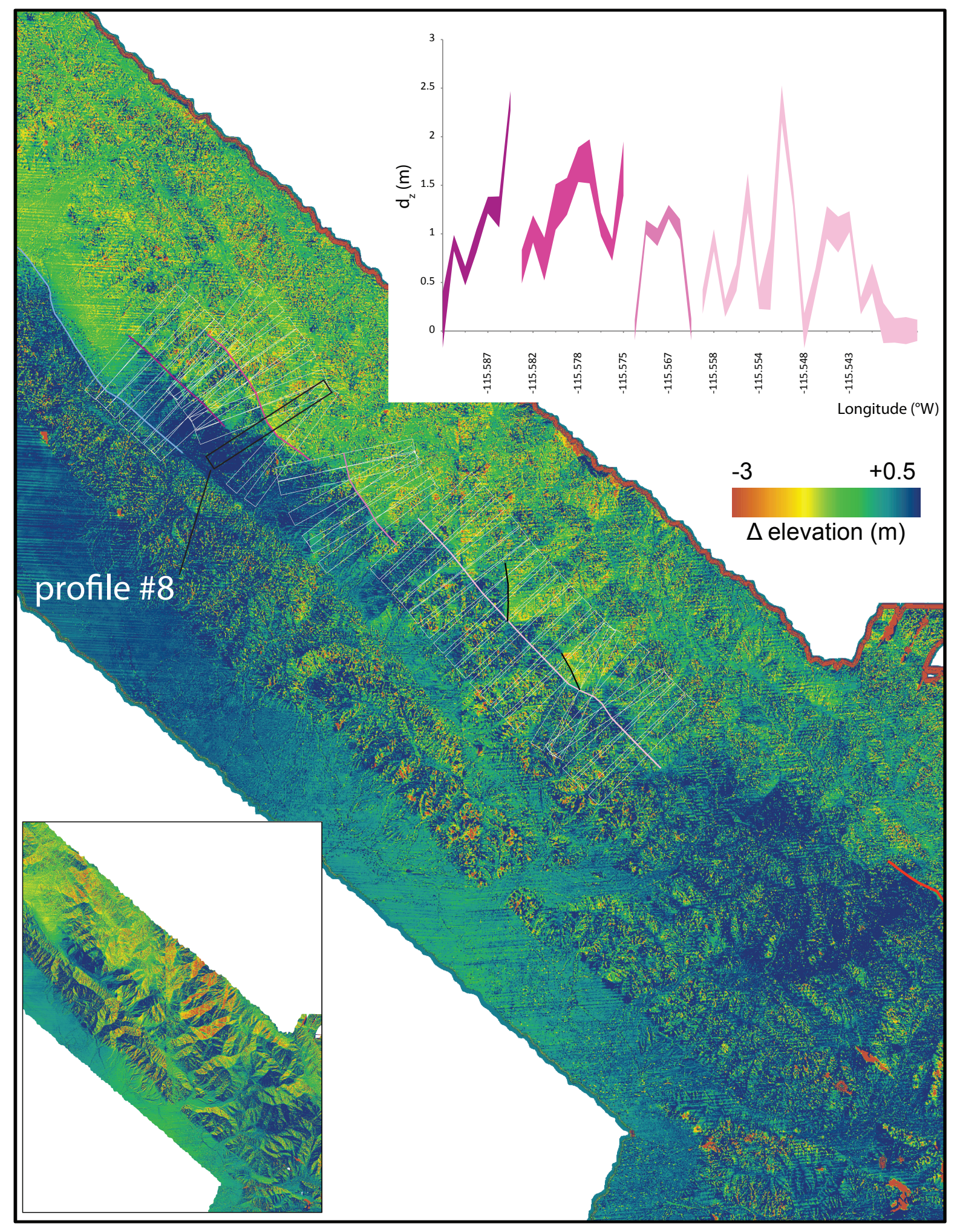
Horizontally corrected elevation change (Dz-min and Dz-max) distribution along the Pescadores Fault. Vertical displacements are plotted against latitude of the center of corresponding sampling bin 150 m wide and 1.5 km long. Epicenter of the mainshock is ~4.5 km to the southeast.

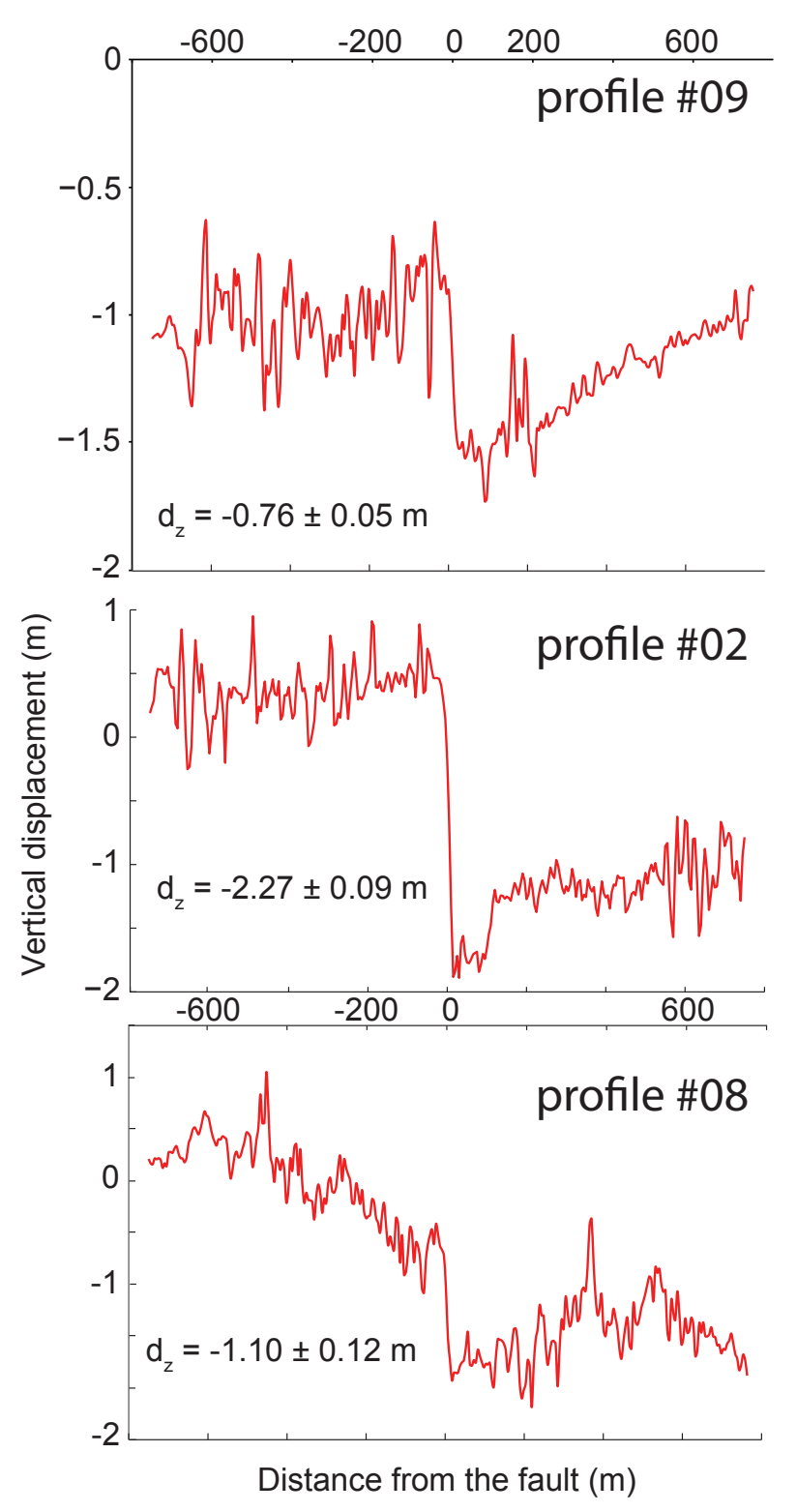


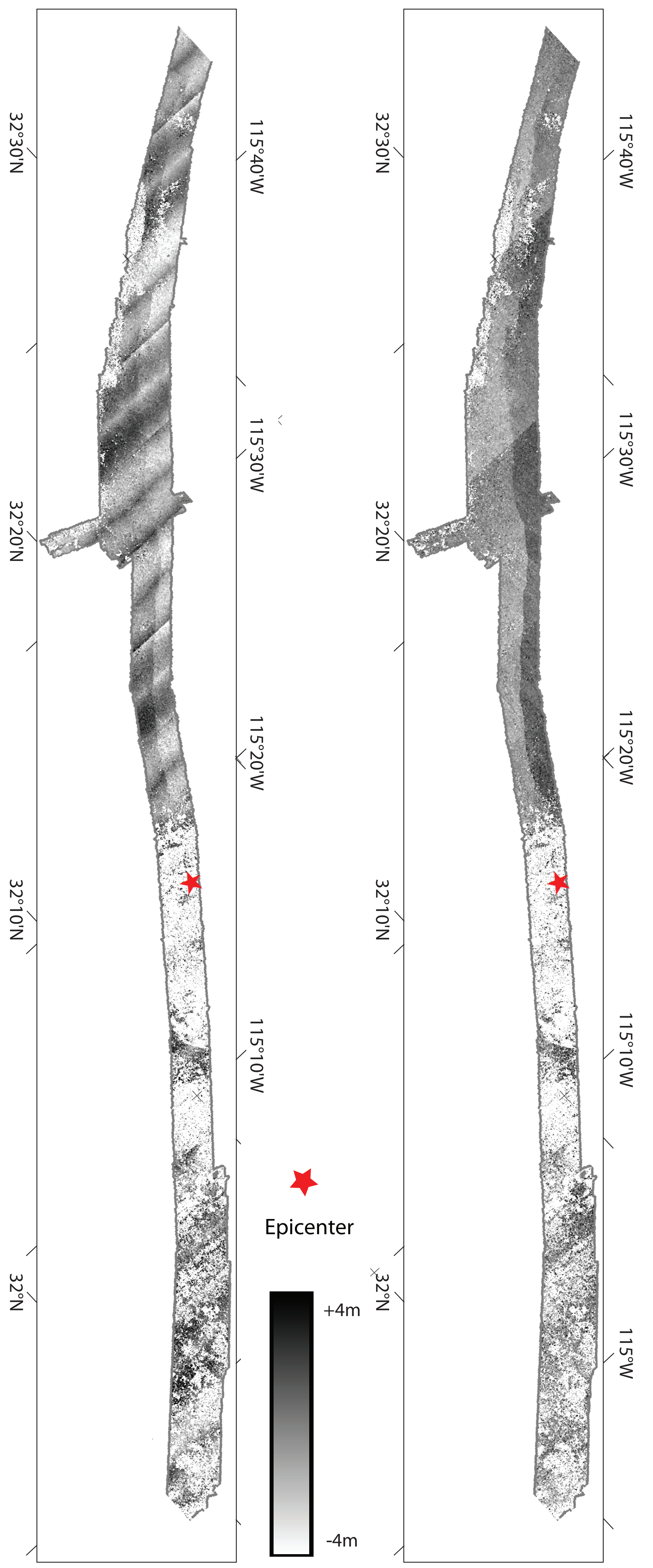
Unbiased vertical change and slip distribution along the Borrego Fault zone. Inset shows uncorrected results.



Unbiased vertical change and slip distribution along the Puerta Accommodation zone. Inset shows uncorrected results.







East-West (left) and North-South (right) components of the displacement. In addition to the horizontal fault rupture offsets, the horizontal component of the displacement field shows clear uncorrected aircraft jitter artifacts, which also contribute in biasing the elevation offset measurement

## Conclusions:

- We successfully used COSI-Corr to recover 3D deformation from high-resolution pre- and post-earthquake LiDAR acquisitions for the first time.

- Aircraft jitter is the largest limitation in recovering the horizontal component of the deformation.

- We densely mapped the full extent of the vertical slip distribution associated with the El Mayor - Cucapah earthquake.

- Unlike field measurements, COSI-Corr has the ability to measure distributed slip away from the main rupture.

- Dense coverage of unbiased slip distribution can be used to investigate the causes of slip variability, and improve our understanding of its influence on the pattern of ground shaking.

## References:

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