Analysis of Shallow Slip Deficit Using Sub-Pixel Image Correlation: Implications for Fault Slip Rates and Seismic Hazards

James Hollingsworth[1]*, James Dolan[1], Chris Milliner[1], Sebastien Leprince[2], Francois Ayoub[2], Jean-Philippe Avouac[2]

[1]Department of Earth Sciences, University of Southern California, Los Angeles, CA [2]Division of GPS, Caltech Pasadena, CA * **james.hollingsworth@usc.edu**

ABSTRACT

The pattern of surface displacement produced by an earthquake can be retrieved by sub-pixel correlation of optical satellite images, using the program COSI-Corr. This technique can provide robust measurements of displacement very close to fault ruptures, and is therefore a complementary tool to InSAR, which provides precise measurements of deformation in the far-field, but often de-correlates close to the fault. Inversions of InSAR data are commonly used to determine how slip varies on the fault plane during an earthquake. Previous inversion results for a number of large continental earthquakes suggest a deficit of slip occurs in the upper few kilometers of the crust. This 'missing' slip may occur later in the earthquake cycle, either in the post-seismic period as afterslip, or during the inter-seismic period as creep. Alternatively, this 'missing' slip could also be accommodated by distributed off-fault deformation not captured by InSAR. This latter point is significant, since any distributed off-fault deformation must be taken into account when calculating Quaternary fault slip-rates, that typically incorporate discrete offsets of geomorphic features measured over a narrow aperture.

The goal of this study is to use optical image correlation to better determine fault displacements close to faults so we can address the nature of distributed versus discrete coseismic deformation. Firstly, we show the surface deformation field for a number of large continental strike-slip earthquake. Secondly, we develop a tool that allows along-strike fault displacement profiles to be extracted from displacement maps. We quantify the difference between COSI-Corr-derived and field-derived fault displacement measurements; any difference is assumed to result primarily from distributed deformation, which can be difficult to measure in the field. By comparing the component of distributed, off-fault deformation with geological parameters, such as the fault structural maturity, we attempt to better constrain the parameters controlling fault slip in the upper crust. This approach allows us to potentially correct Quaternary fault slip rates determined for any fault based on its structural maturity, thus accounting for any distributed component of deformation that may occur throughout the seismic cycle. Consequently, our results have significant implications for probabilistic seismic hazard assessment, which rely heavily on geologically determined fault slip rates.

INTRODUCTION

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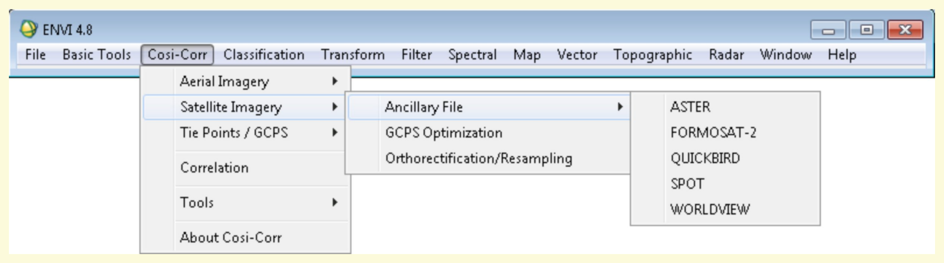
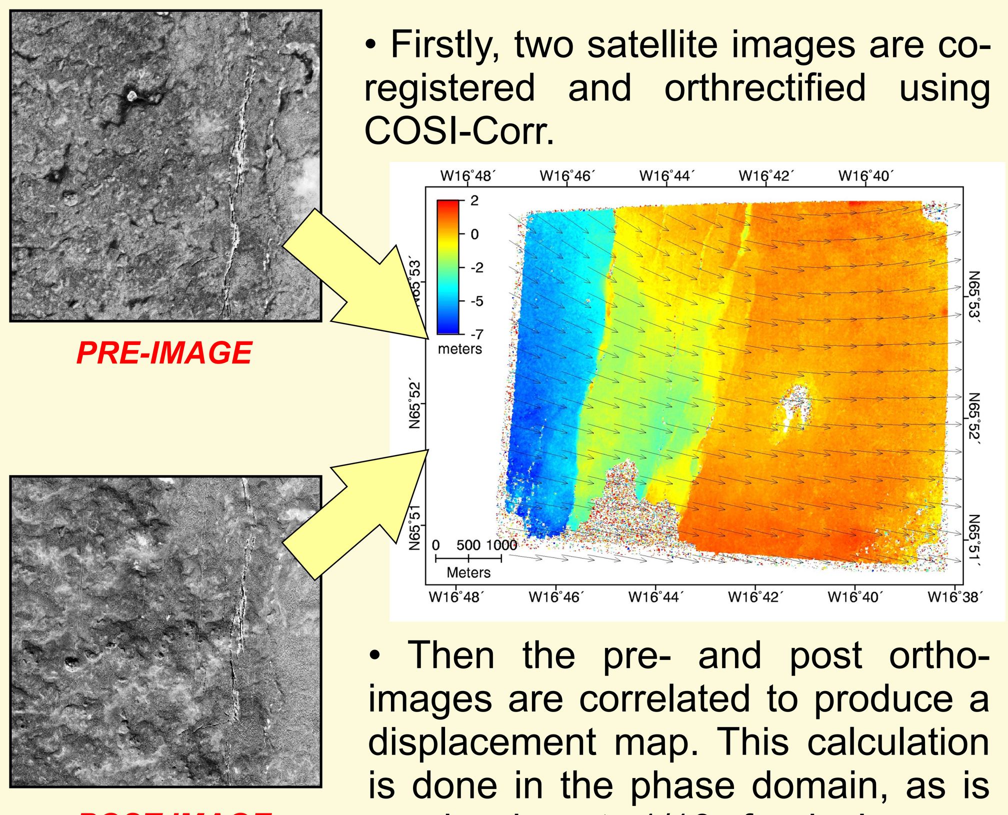
- Optical satellite images may be cross-correlated using the program COSI-Corr, yielding displacement maps of the Earth's surface



- Because optical image correlation does not de-correlate close to fault ruptures, where the ground deformation is typically greatest, this technique is useful in providing near-fault displacement measurements during large earthquakes.

- Using this technique, we examine a number of large continental strike-slip earthquakes, to retrieve the near-fault displacements. We then compare these with field measurements to better constrain the amount of off-fault distributed deformation which may be occurring.



- Firstly, two satellite images are co-registered and orthorectified using COSI-Corr.

- Then the pre- and post ortho-images are correlated to produce a displacement map. This calculation is done in the phase domain, as is precise down to 1/10 of a pixel.

1992 LANDERS

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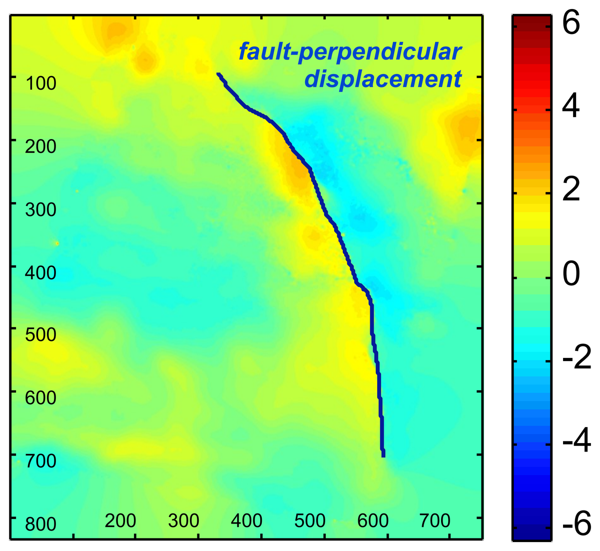
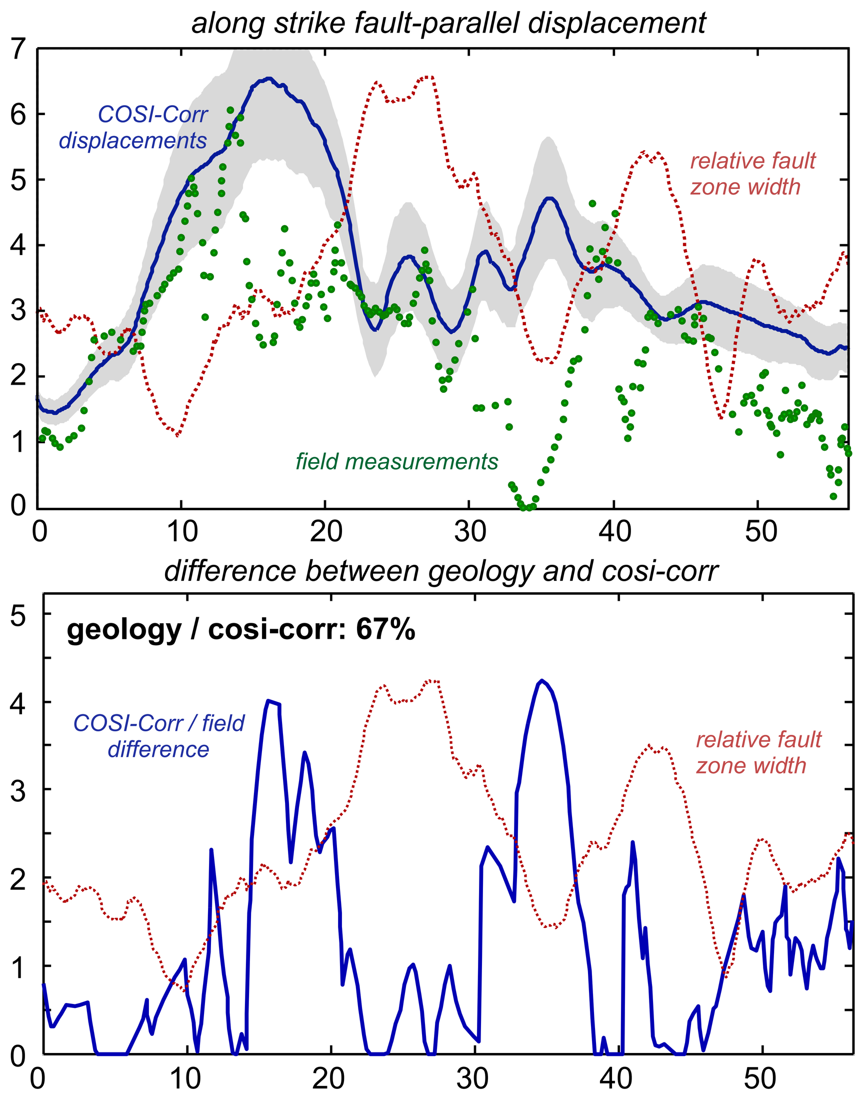
- 1992 Landers eq displacement



- We correlated pre- and post-earthquake SPOT 10 m satellite images to retrieve the displacement field (after Michel, et al., 1999).

- Using a new MATLAB tool for automatically extracting along strike displacements, we compare the SPOT correlation displacement field with field measurements.



- Our tool extracts both the along-strike displacement field and the width of the fault zone.

- The field measurements only account for 67% of the displacements determined by COSI-Corr.

- This suggests significant off-fault deformation is occurring.

1999 HECTOR MINE

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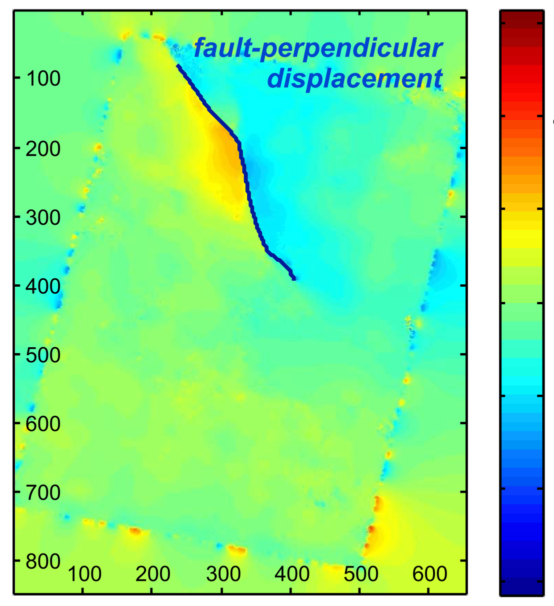
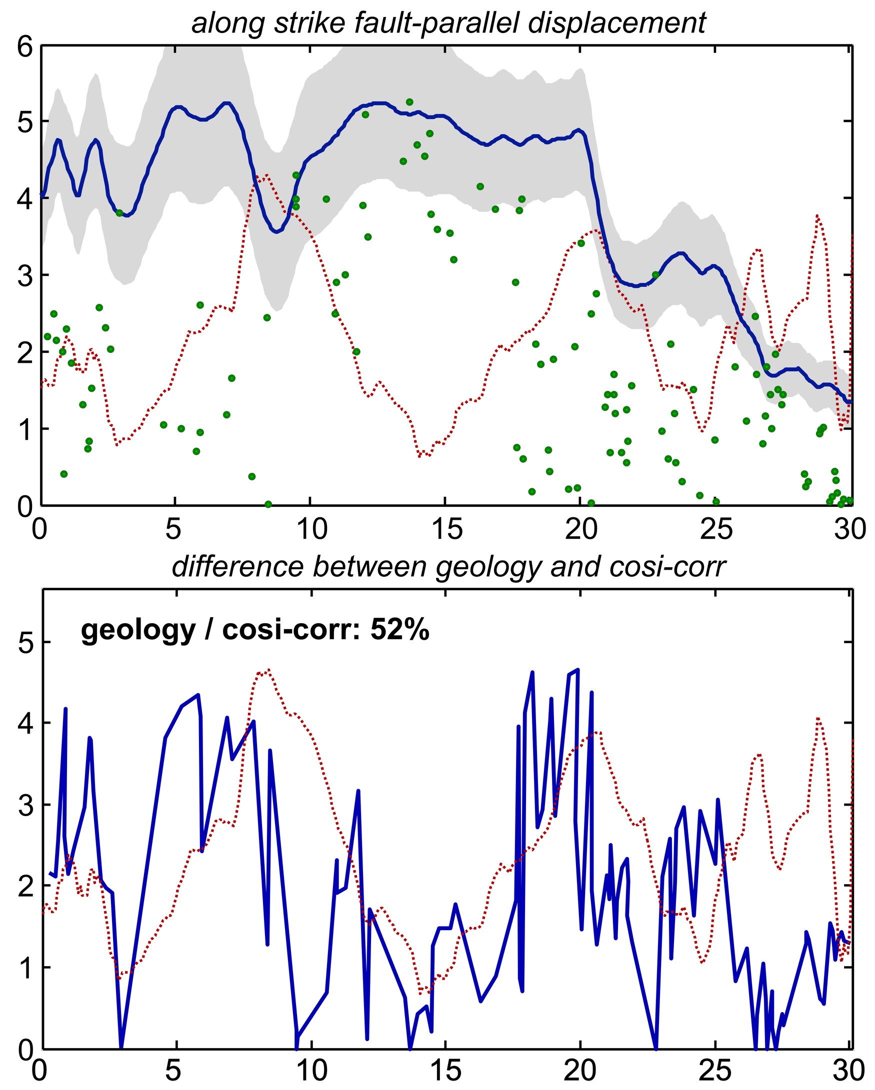
- 1999 Hector Mine eq displacement



- A similar analysis for the 1999 Hector Mine earthquake reveals a significant mismatch between field and COSI-Corr measurements.

- Almost half of the displacement may have occurred as diffuse off-fault deformation.



- The zones of significant mis-match correspond to the known secondary faults.

- The width of the fault zone is greatest where there is a large mismatch, further suggesting off-fault deformation is occurring in the sections.

1995 SAKHALIN

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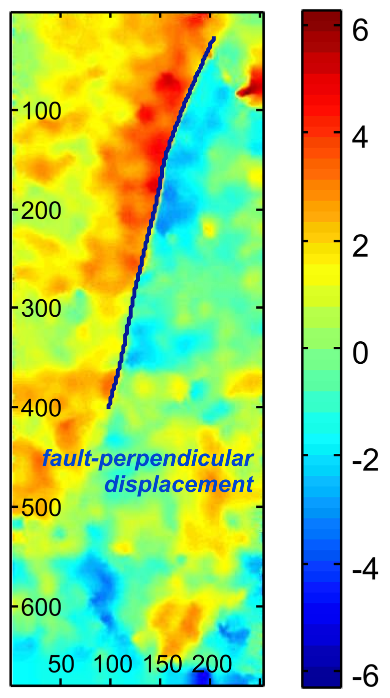
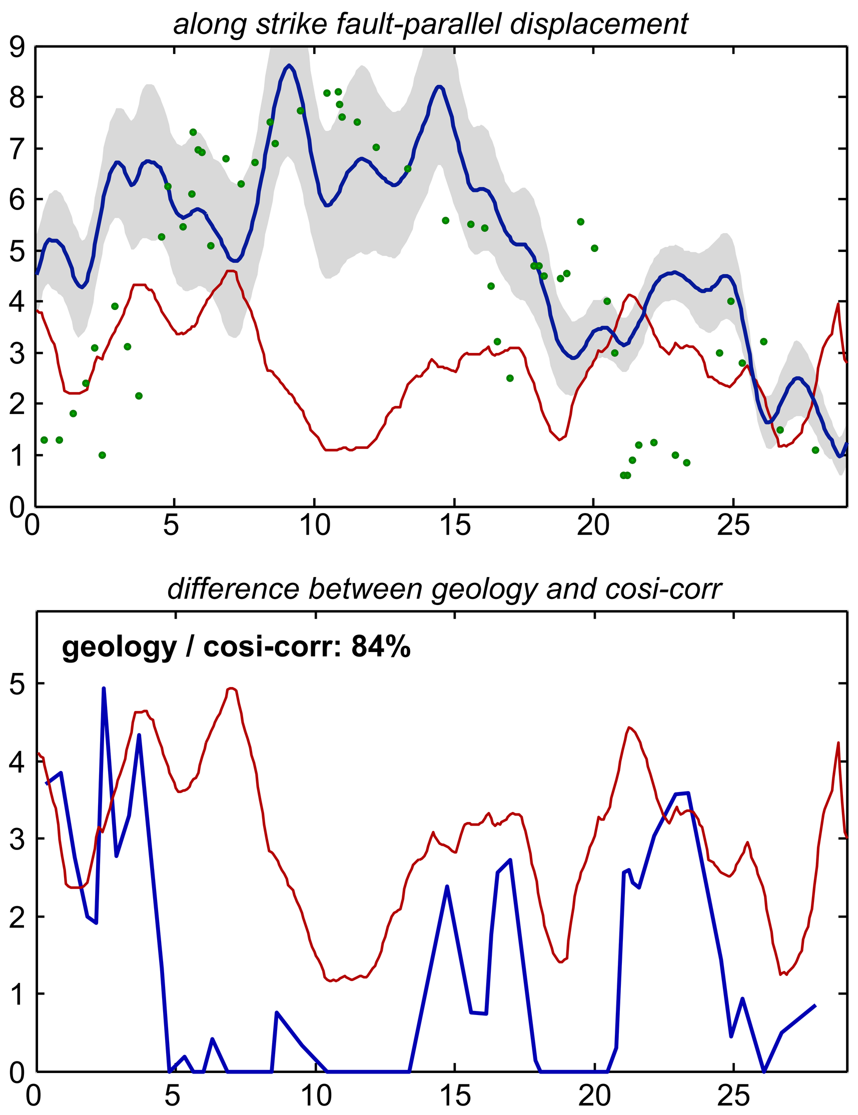
- 1995 Sakhalin earthquake



- We correlate a SPOT 10 m image with WorldView satellite images from the 1995 Sakhalin earthquake.

- The field-measurements account for 84% of the COSI-Corr displacement field, which implies off-fault deformation is occurring., But less than for Landers and Hector Mine.



1999 IZMIT

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- 1999 Izmit earthquake.

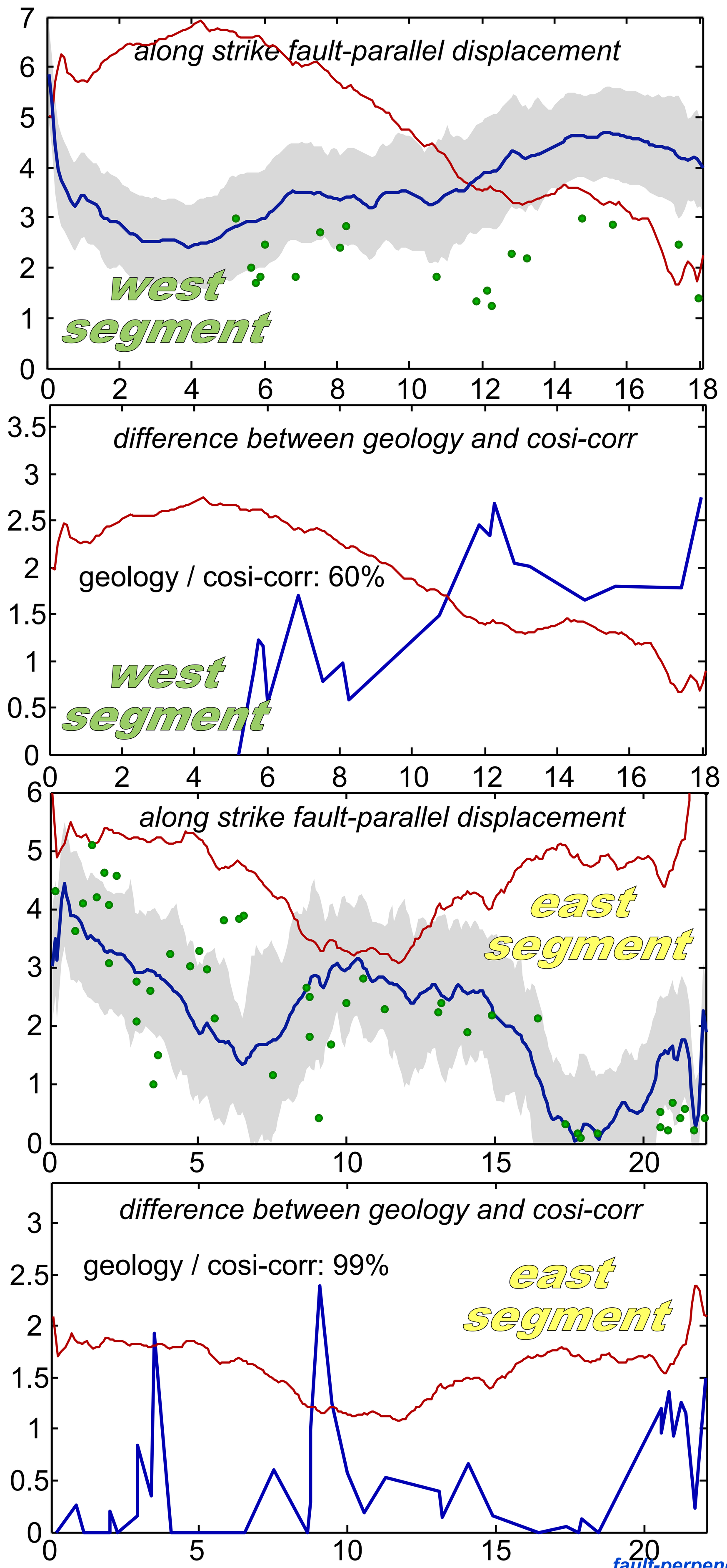
- We correlate 10 m SPOT satellite images from before and after the Izmit earthquake (Michel, et al., 2002).

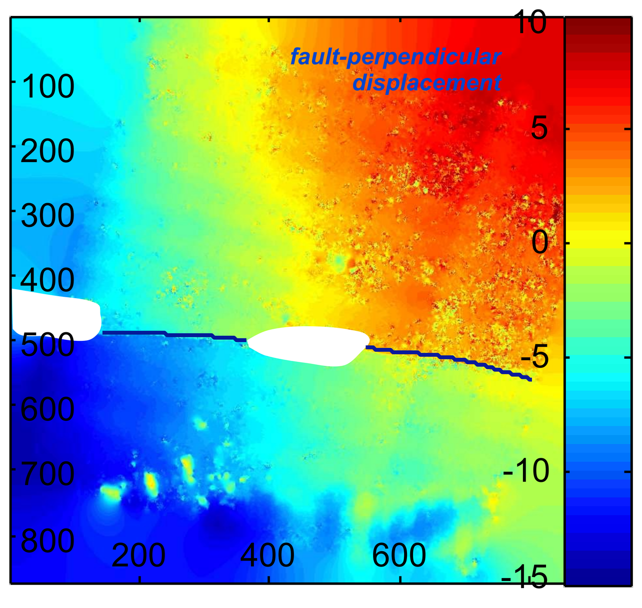
- We calculate the mis-match between the field measurements for two segments of the fault either side of Lake Sapanca.

- For the western Izmit-Sapanca Lake segment, the field measurements account for 60% of the COSI-Corr measurements.

- For the eastern Sapanca-Akyazi segment, we get a similar amount of displacement between field and COSI-Corr.

- The large difference between these two segments suggest they behaved differently during the earthquake, with more off-fault deformation occurring to the west.





1999 DUZCE

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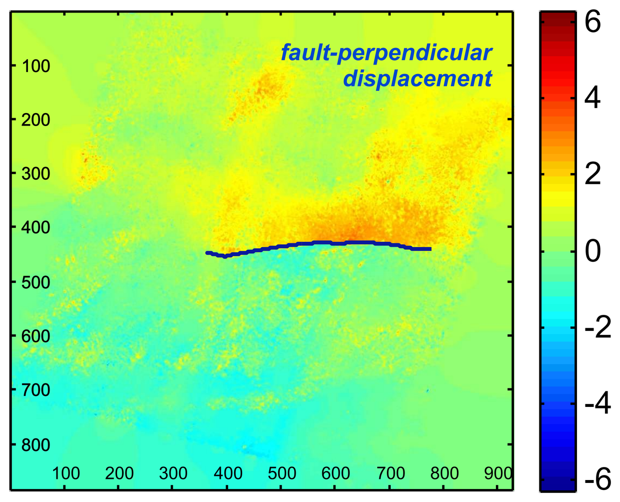
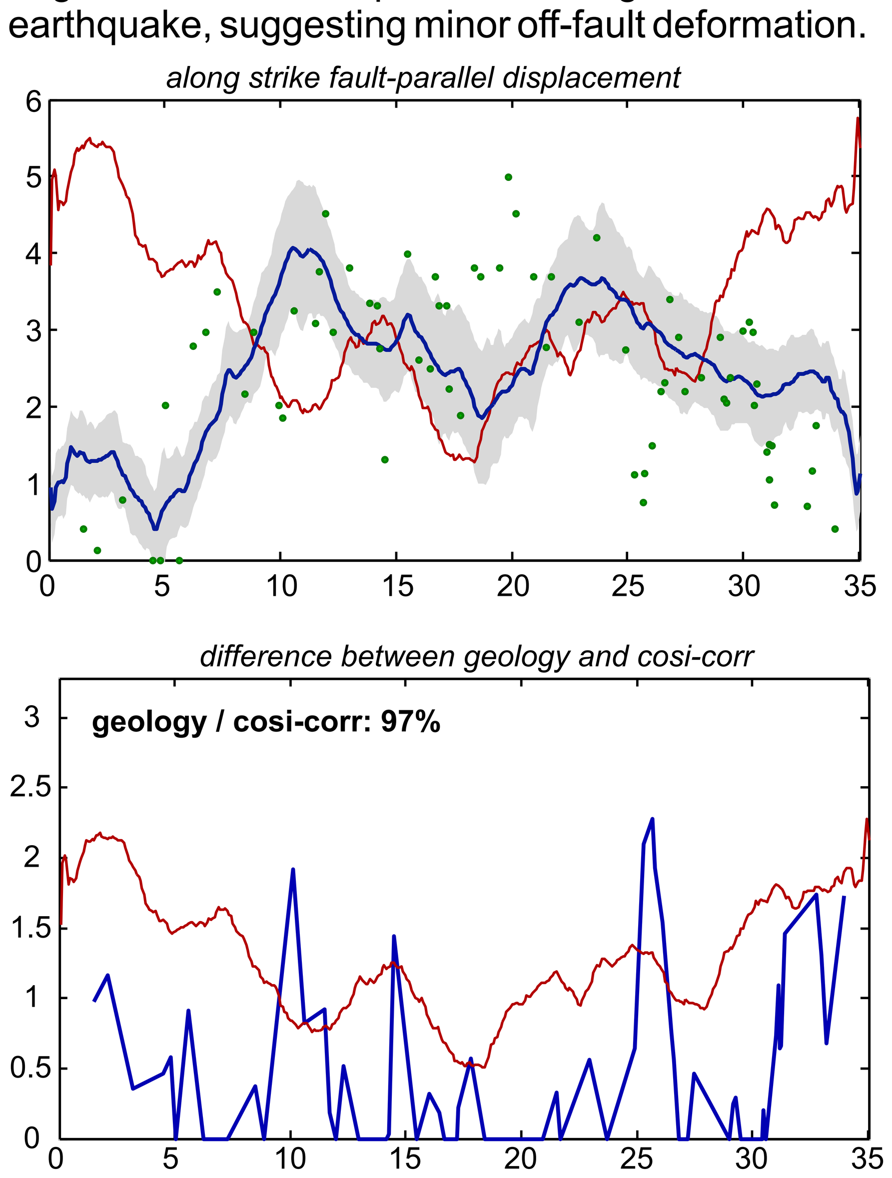
- 1999 Duzce eq



- Pre- and post-eq SPOT 10 m images were correlated for the Duzce earthquake (Konca, et al., 2010)

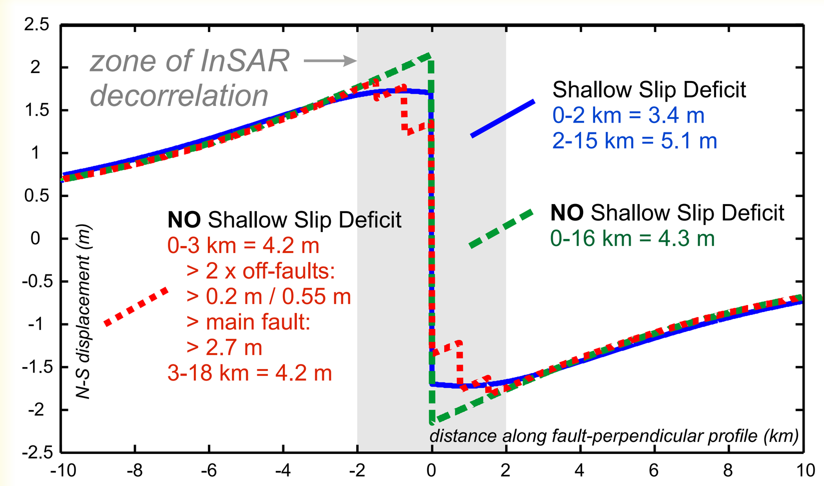
- There is only a very minor mis-match between the field and COSI-Corr measurements for the fault segment which ruptured during the Duzce earthquake, suggesting minor off-fault deformation.



DISCUSSION & CONCLUSIONS

- We find evidence for significant off-fault deformation in the 1992 Landers and 1999 Hector Mine earthquakes, and the western segment of the 1999 Izmit earthquake.. Only a moderate amount of off-fault deformation occurs in the 1995 Sakhalin earthquake, while virtually no off-fault deformation occurs on the eastern segment of the 1999 Izmit earthquake and 1999 Duzce earthquake.

- Inclusion of off-fault deformation in inversions of fault slip may account for the discrepancy of slip in the shallow crust (Fialko, et al., 2005).



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