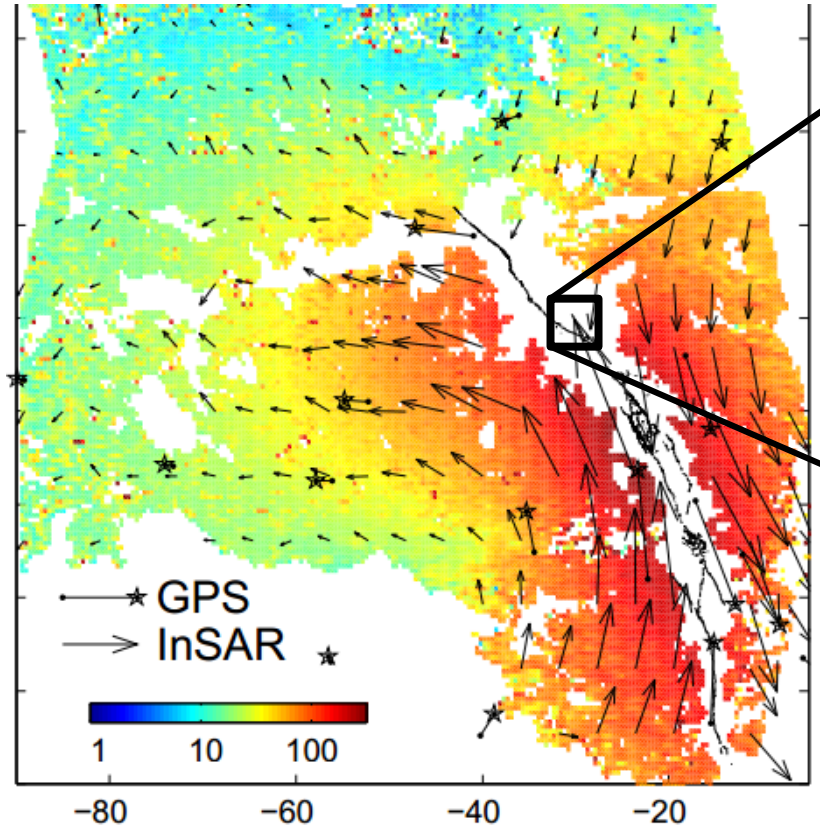
Quantifying Co-seismic Distributed Deformation Using Optical Image Correlation

Christopher Milliner

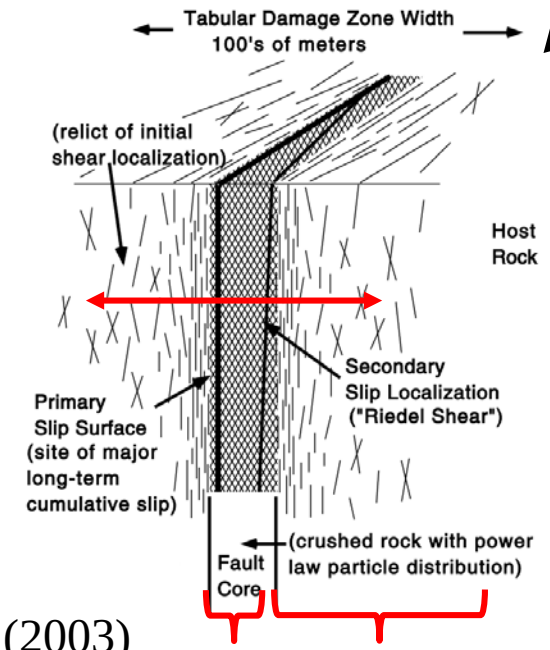
UC Berkeley

Dolan, J. Hollingsworth, J., Leprince, S., Ayoub, F., Sammis, C., Allam, A., Xu, X., Sandwell, D.

Challenges measuring near-field deformation



Fialko (2004)

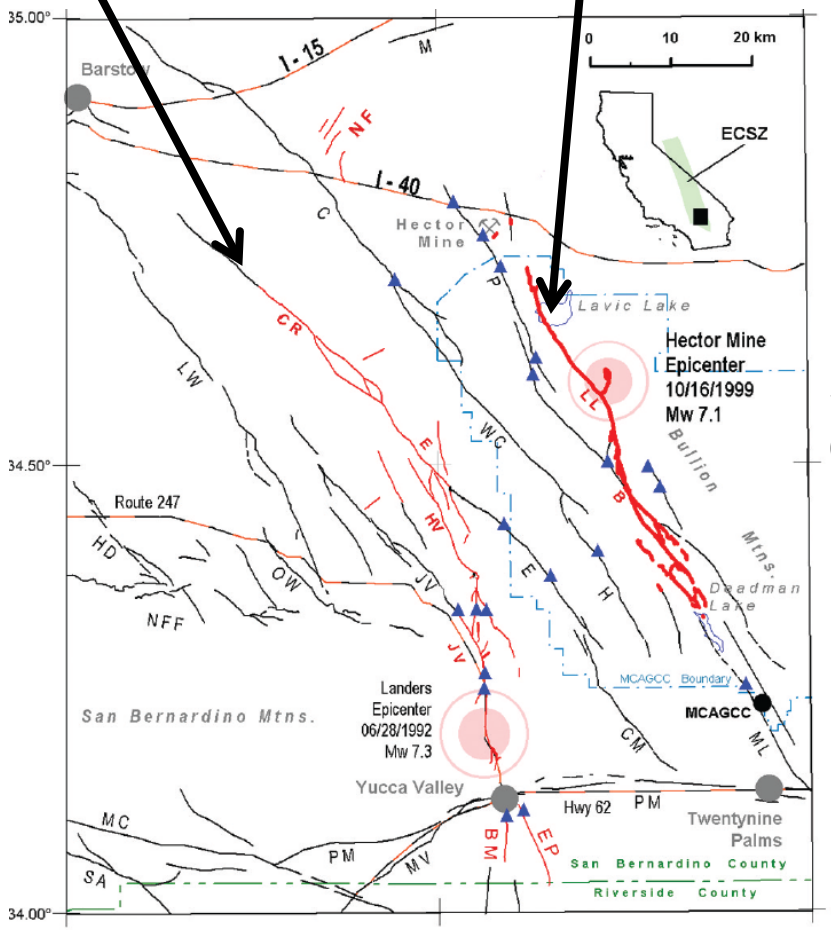


Ben-Zion & Sammis (2003)

Aim: Produce near-field data to better understand…

1992 M_w 7.3 Landers

1999 M_w 7.1 Hector Mine

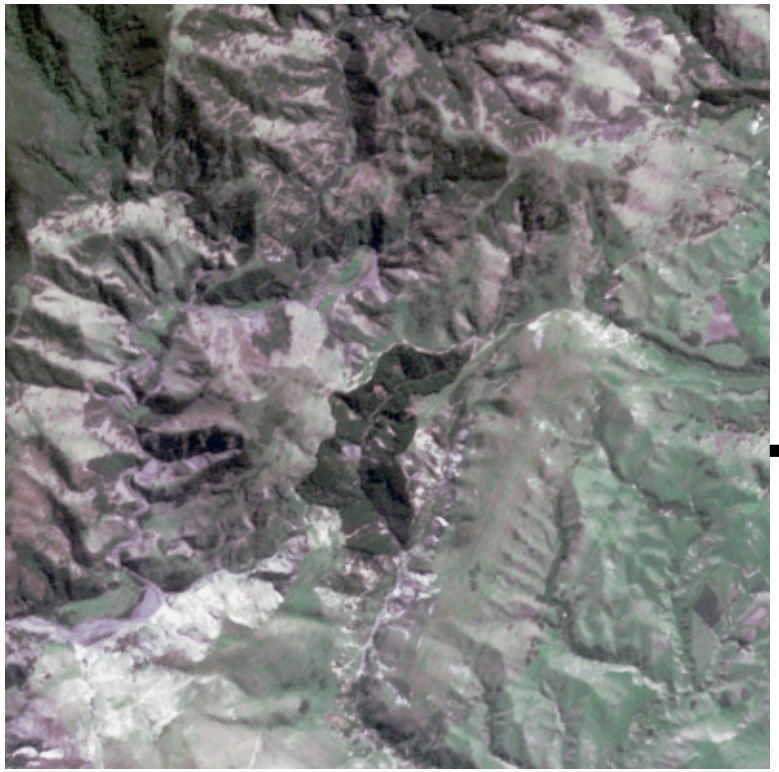


Structurally immature: 3-5 km cumulative displacement.

Treiman et al [2001]

Correlation method

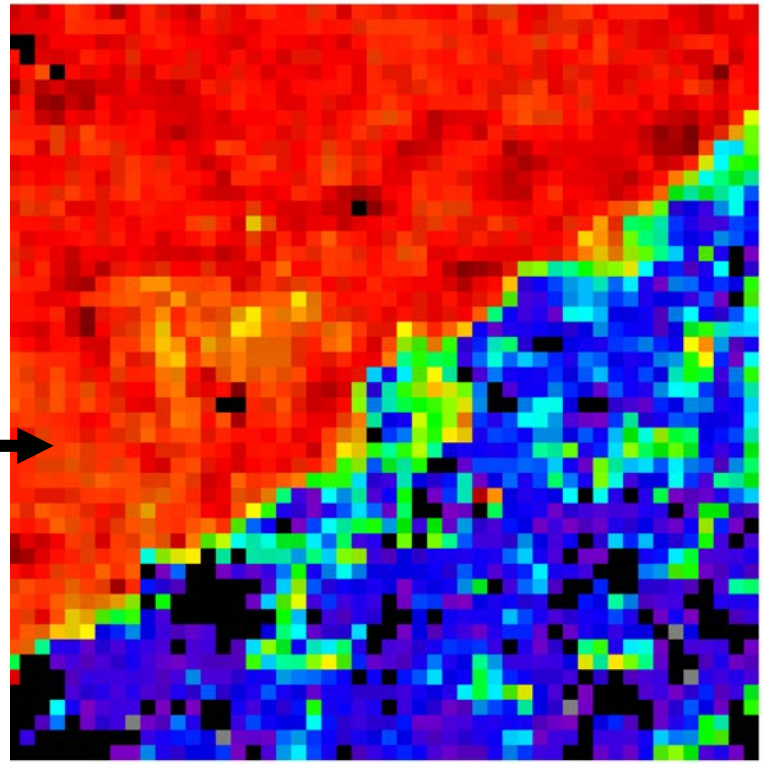
Before and After Images



Mw 7.8 Kaikoura, NZ

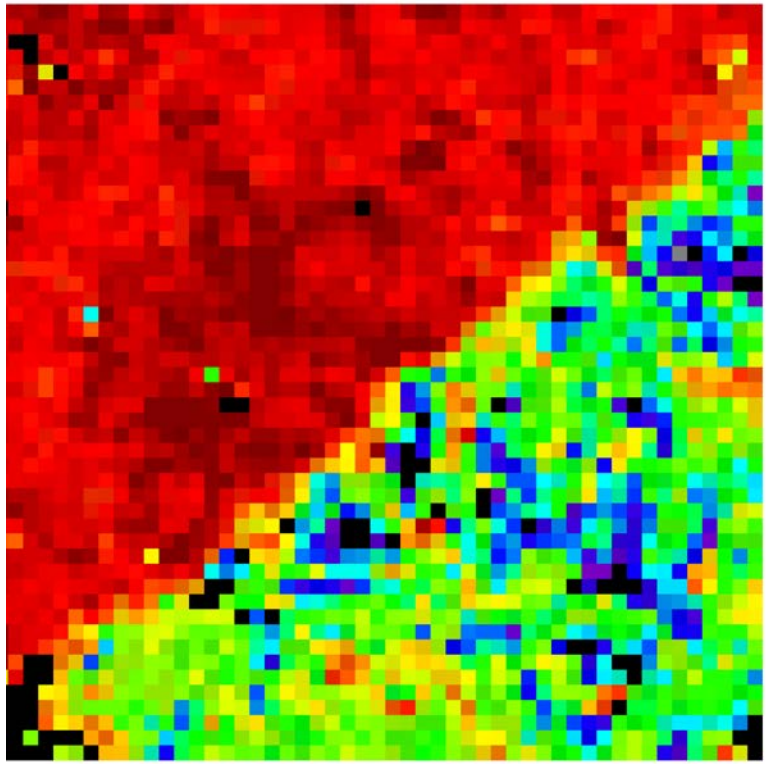
- Sentinel 2, 10 m resolution
- (~10 m offset)
- Kekerengu fault, NE of Clarence river.

East-west



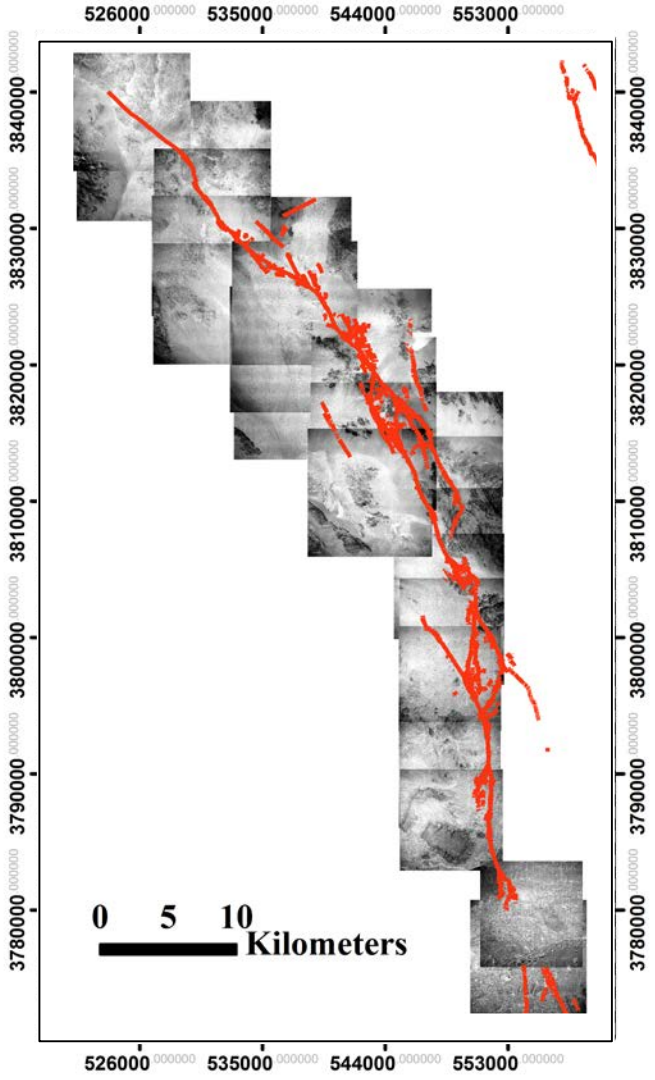
Only sensitive to horizontal motion

North-south



1/10 pixel size = limit of detectable motion → 10 cm of surface motion

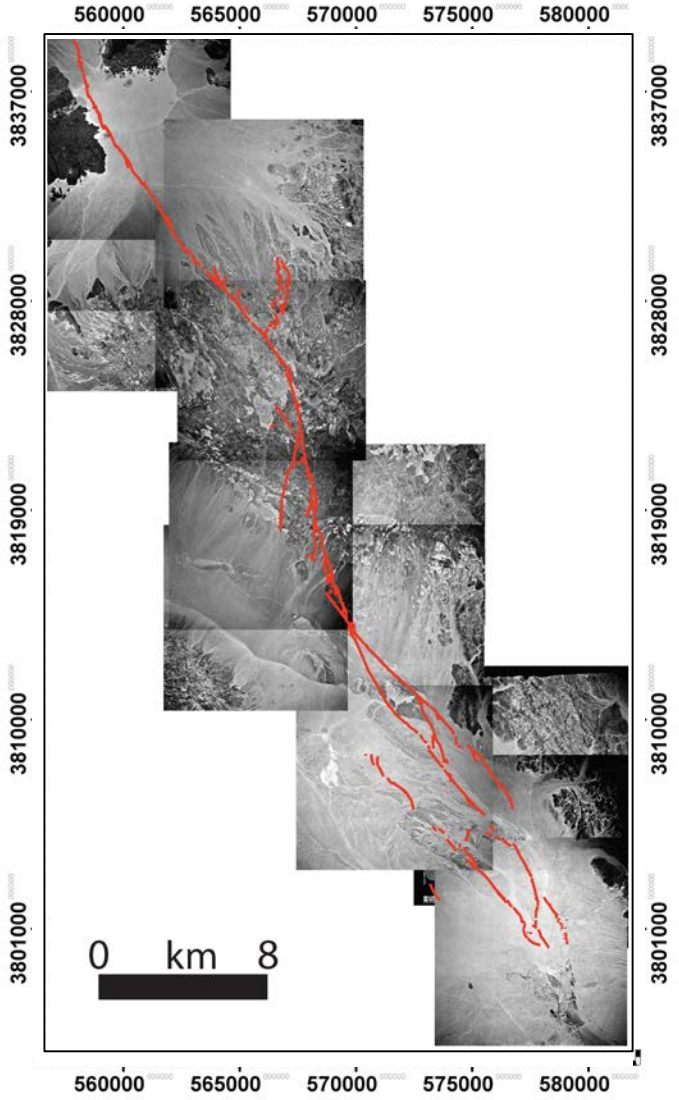
Landers



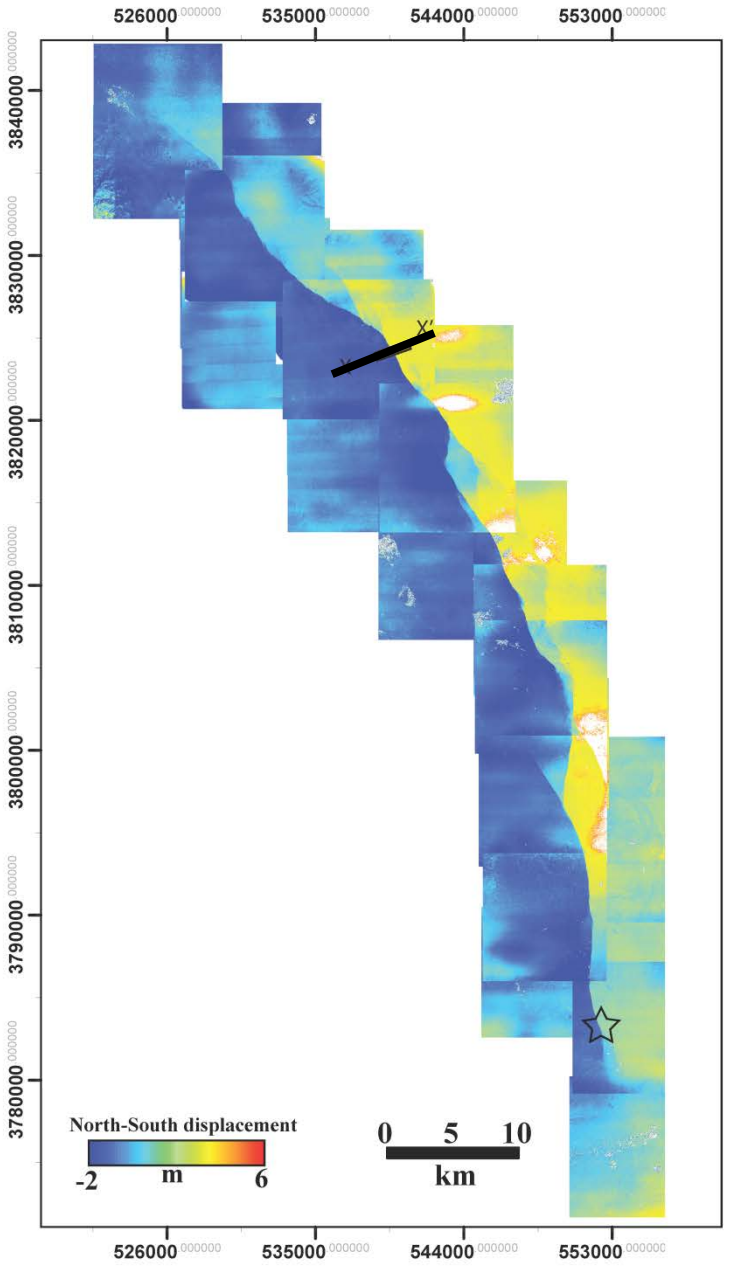
- 8 x 8 km footprint
- 1 m spatial resolution

- National Aerial Photography Program, NAPP USGS

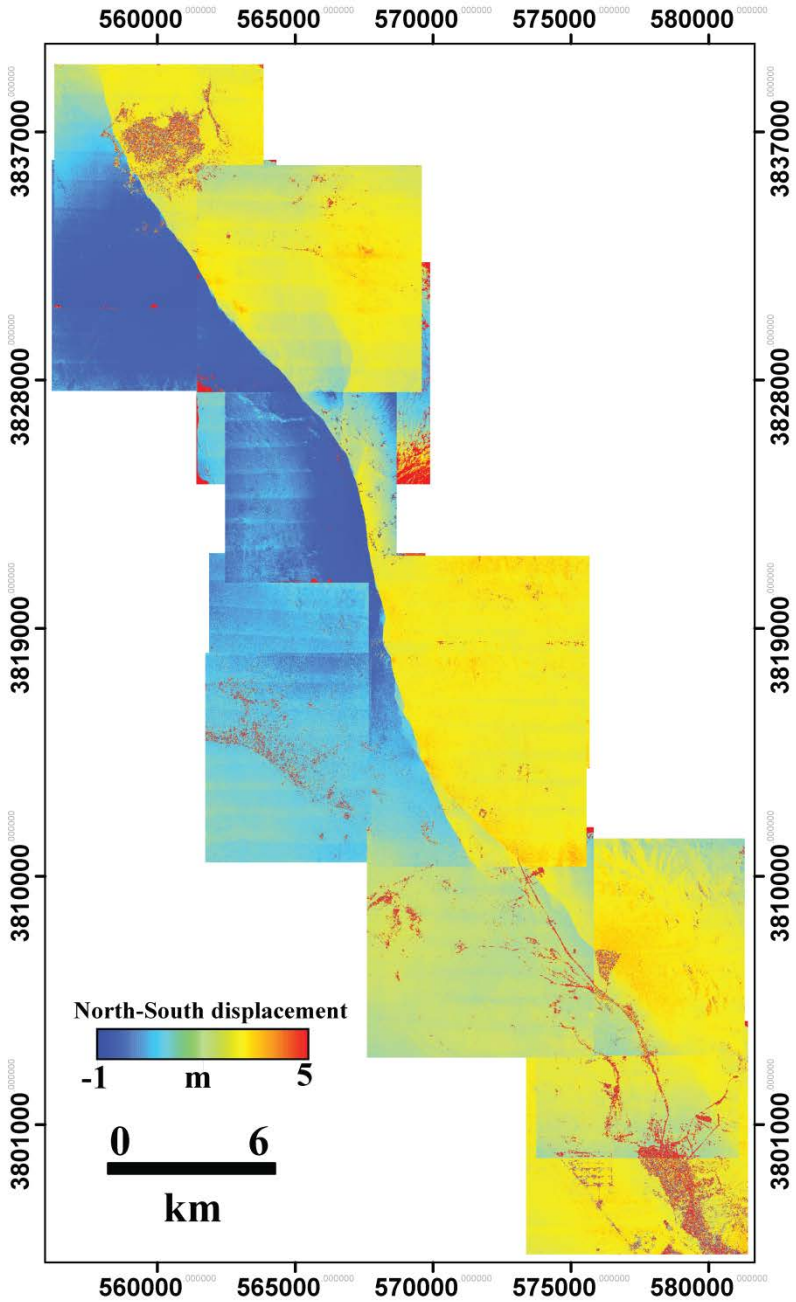
Hector Mine



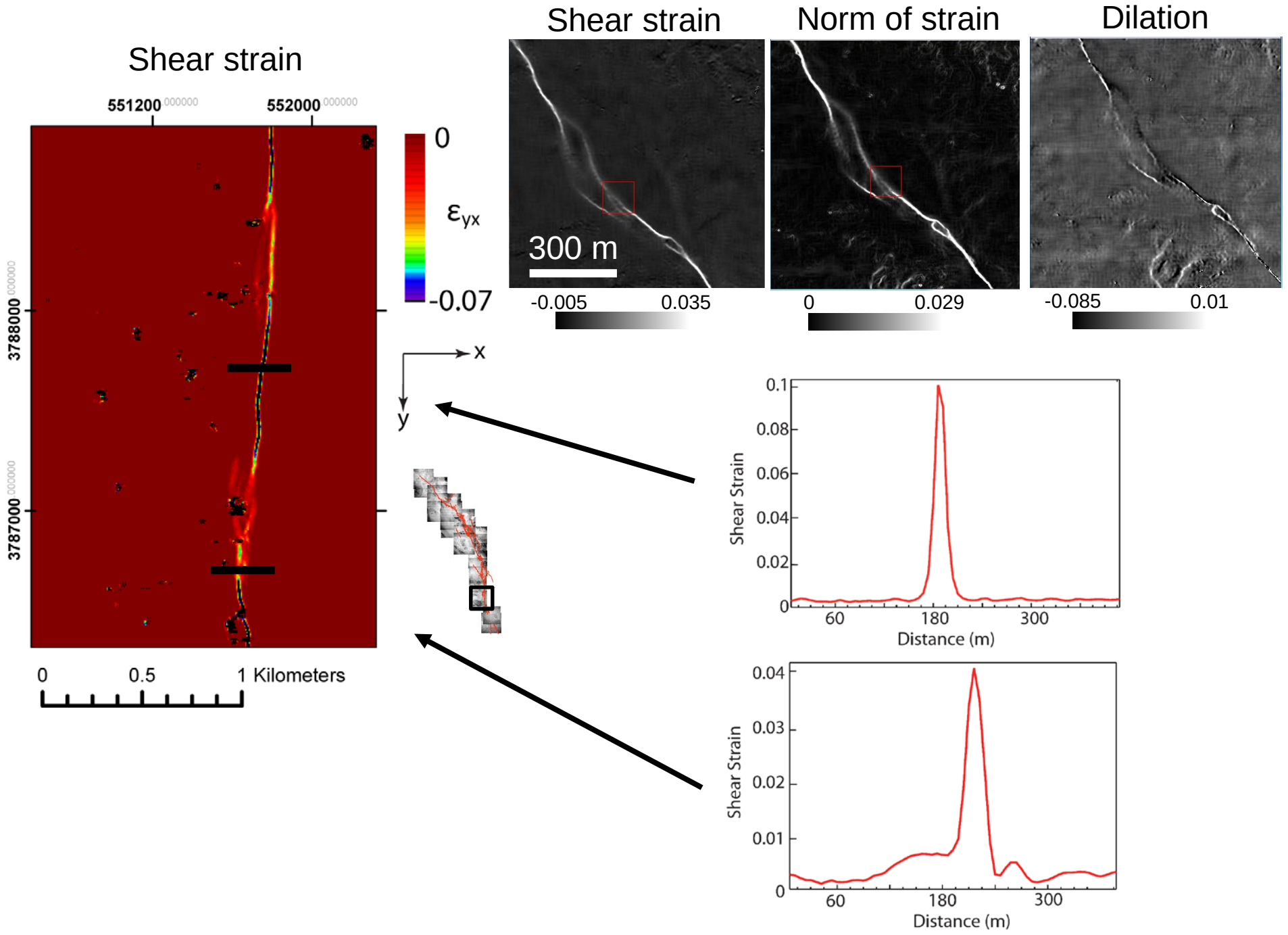
Landers



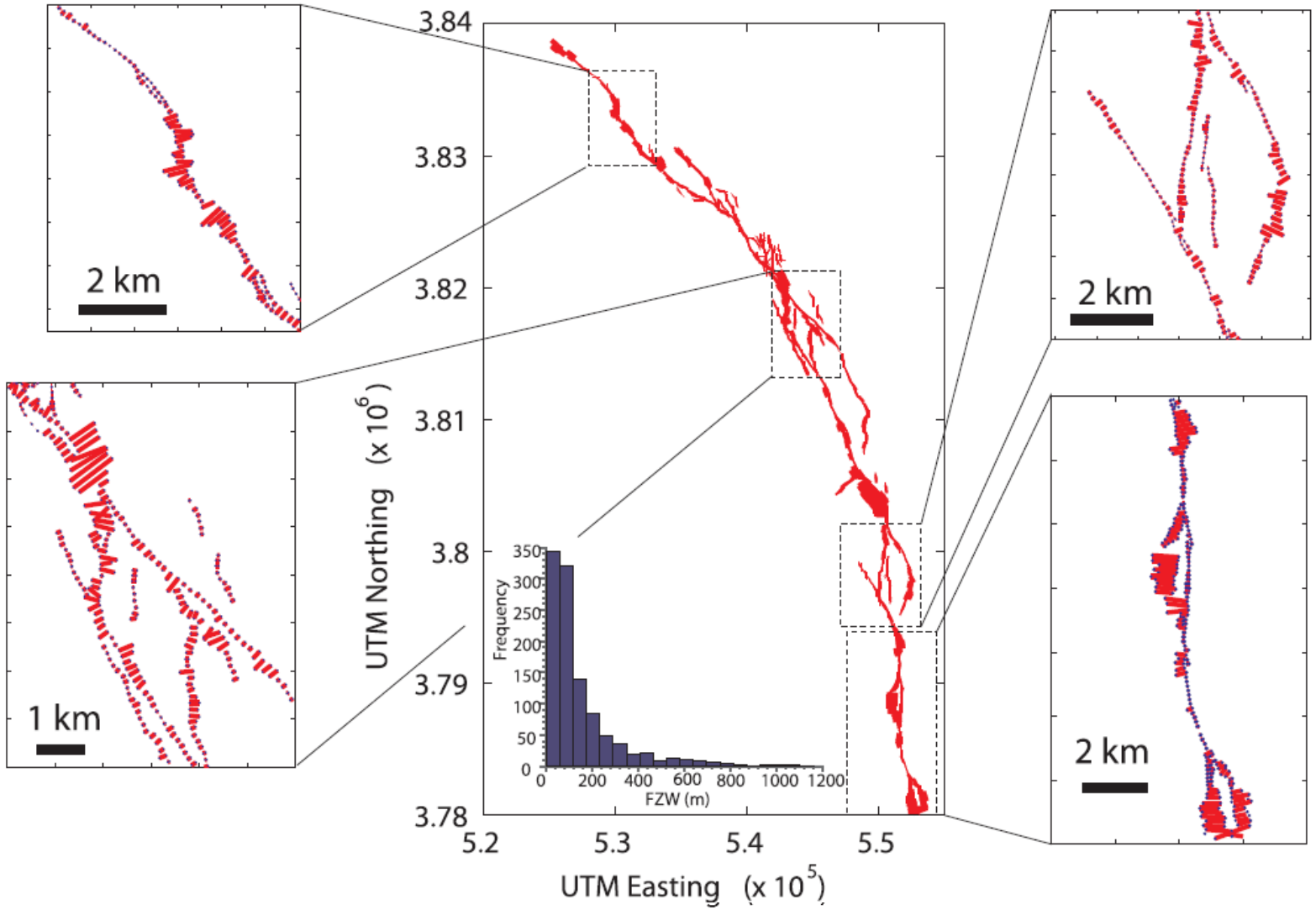
Hector Mine

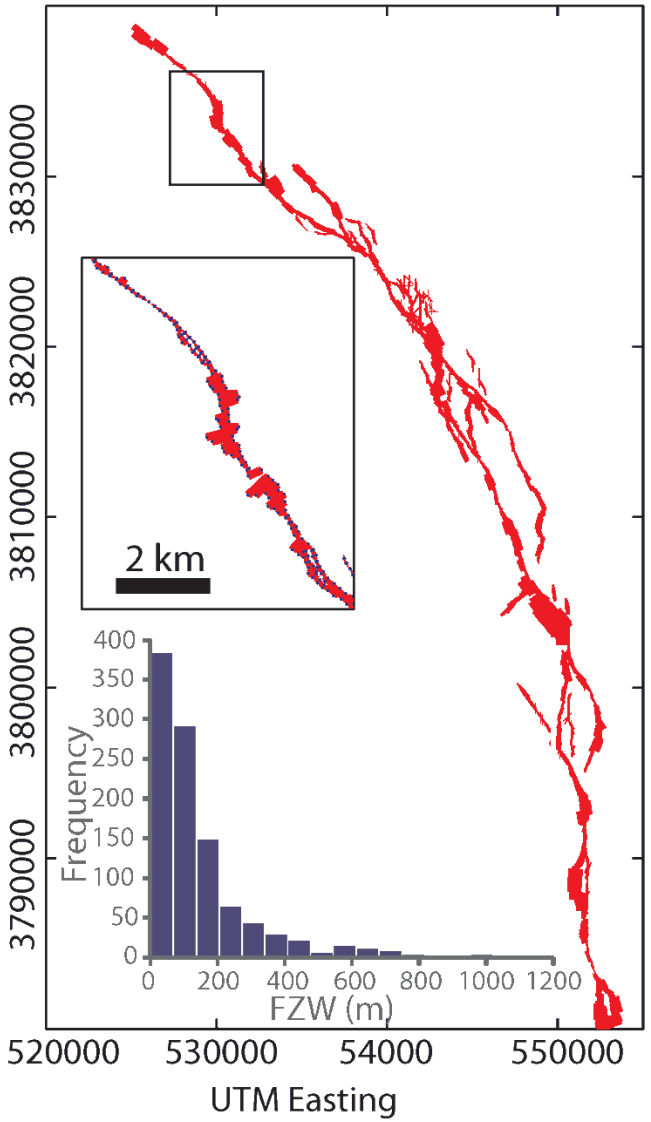


Milliner et al. (2016)

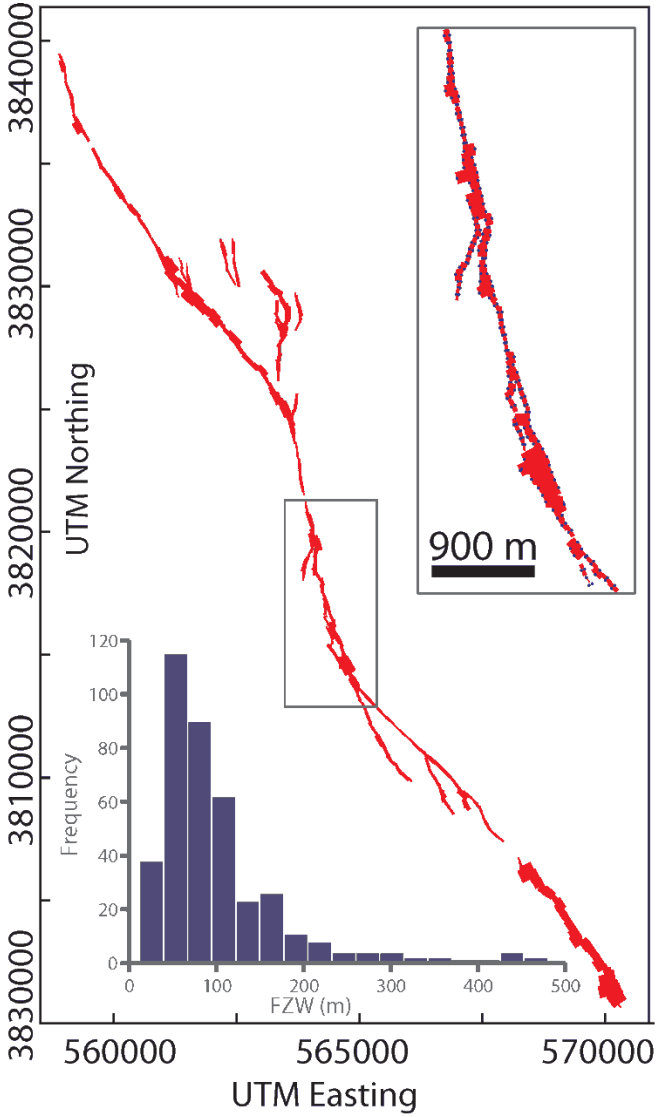

Shear strain
Shear strain
Norm of strain
Dilation
551200
552000
3788000
3787000
0
ε_{yx}
-0.07
x
y
300 m
-0.005
0.035
0
0.029
-0.085
0.01
0
0.5
1 Kilometers
Shear Strain
Distance (m)
Shear Strain
Distance (m)

Fault Zone Width



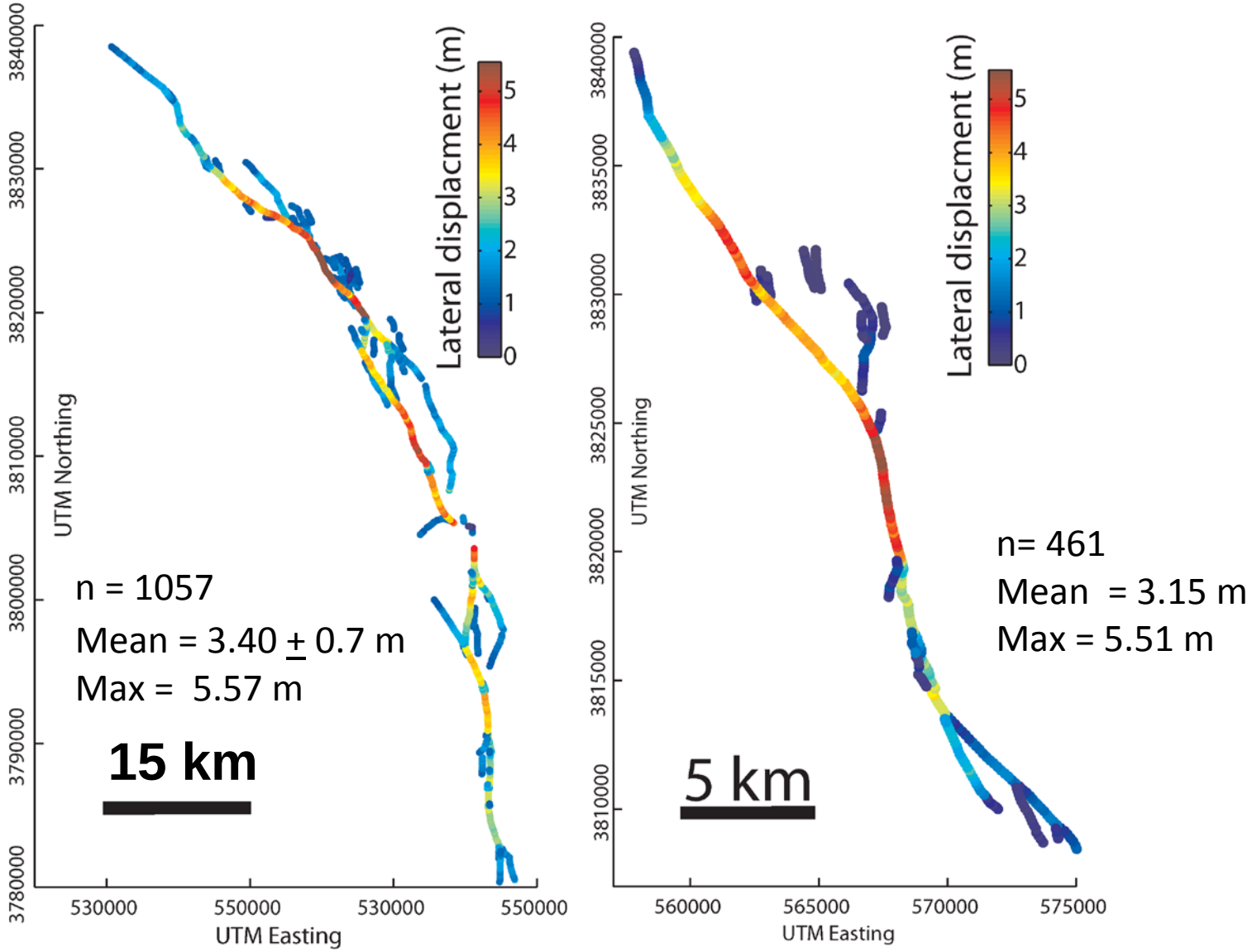


n = 1060
Mean = 156 m
Median = 96 m
Max = 1160 m



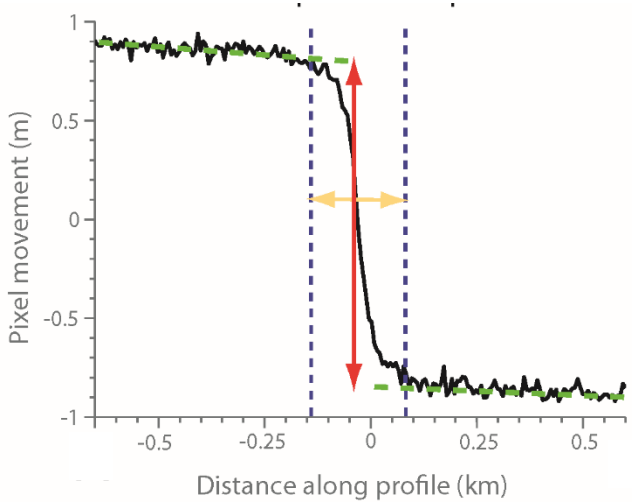
n = 443
Mean = 121 m
Median = 84 m
Max = 876 m

Fault Displacement



Estimating off-fault deformation

COSI-Corr displacement

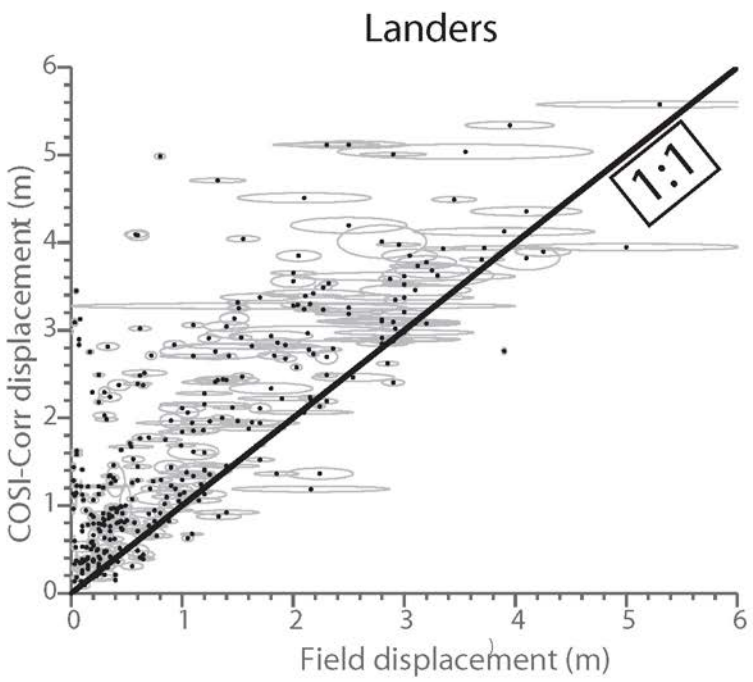


Field displacement

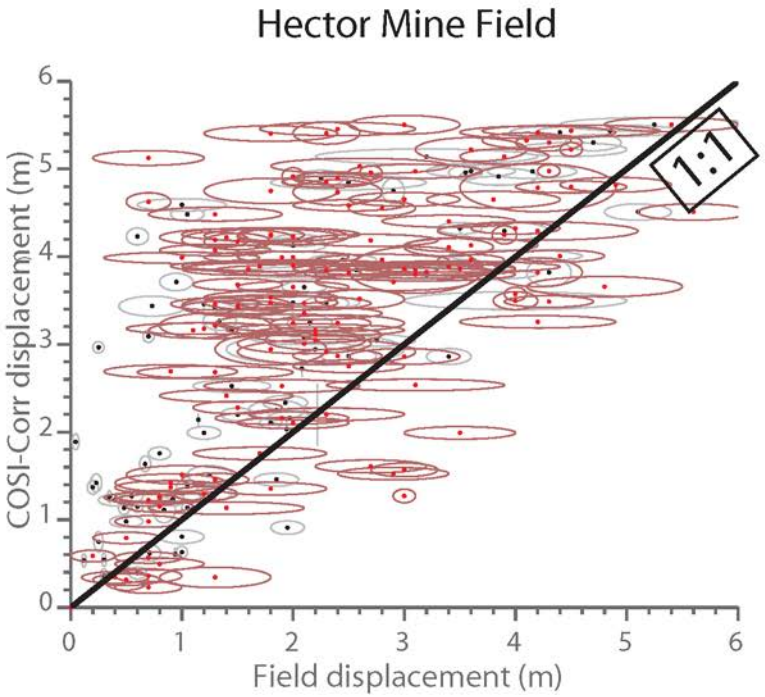
1-2 km in length

Are there systematic differences?

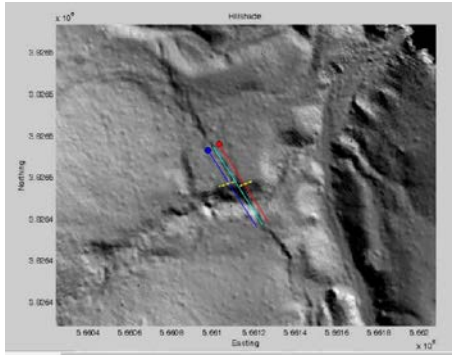
Distributed deformation



n = 280

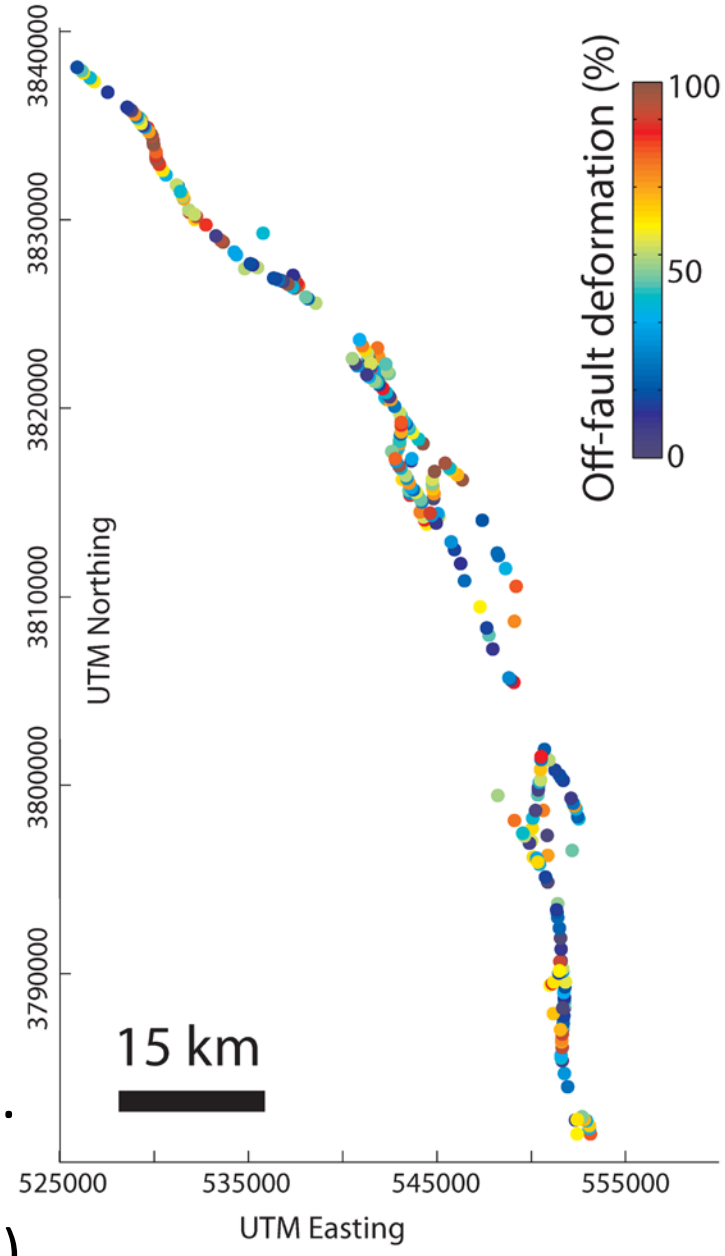


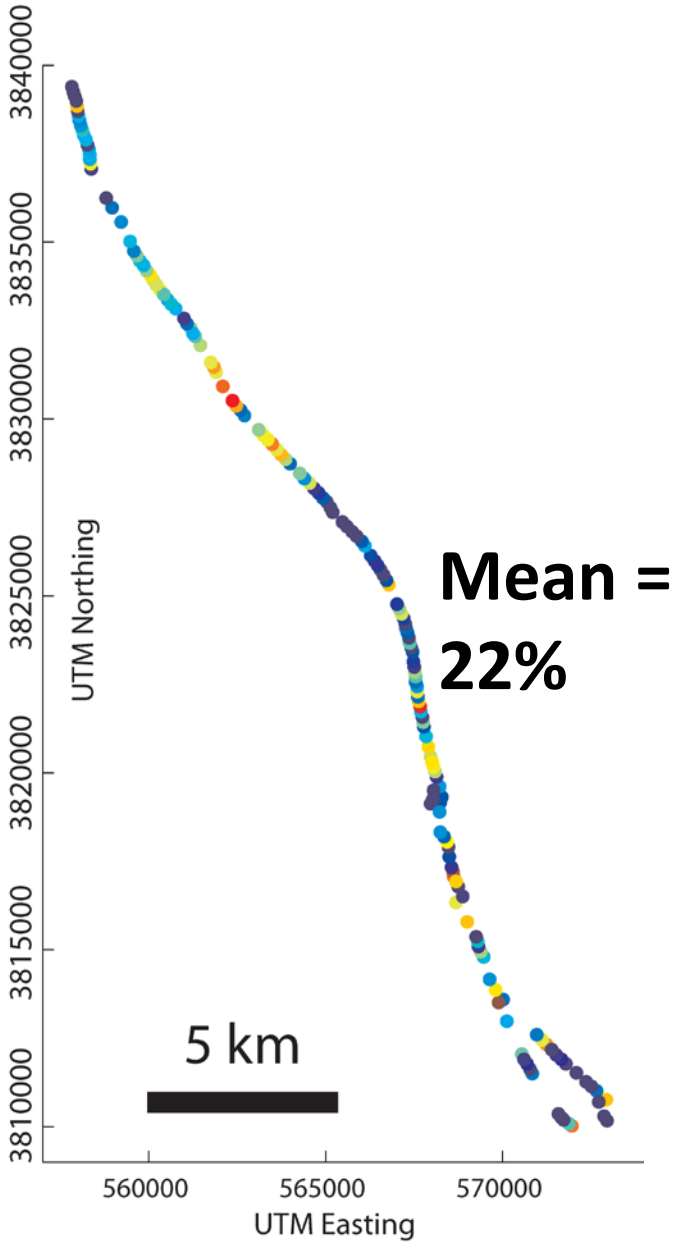
n = 220



Chen et al. (2015)

Mean = 46 ± 10%



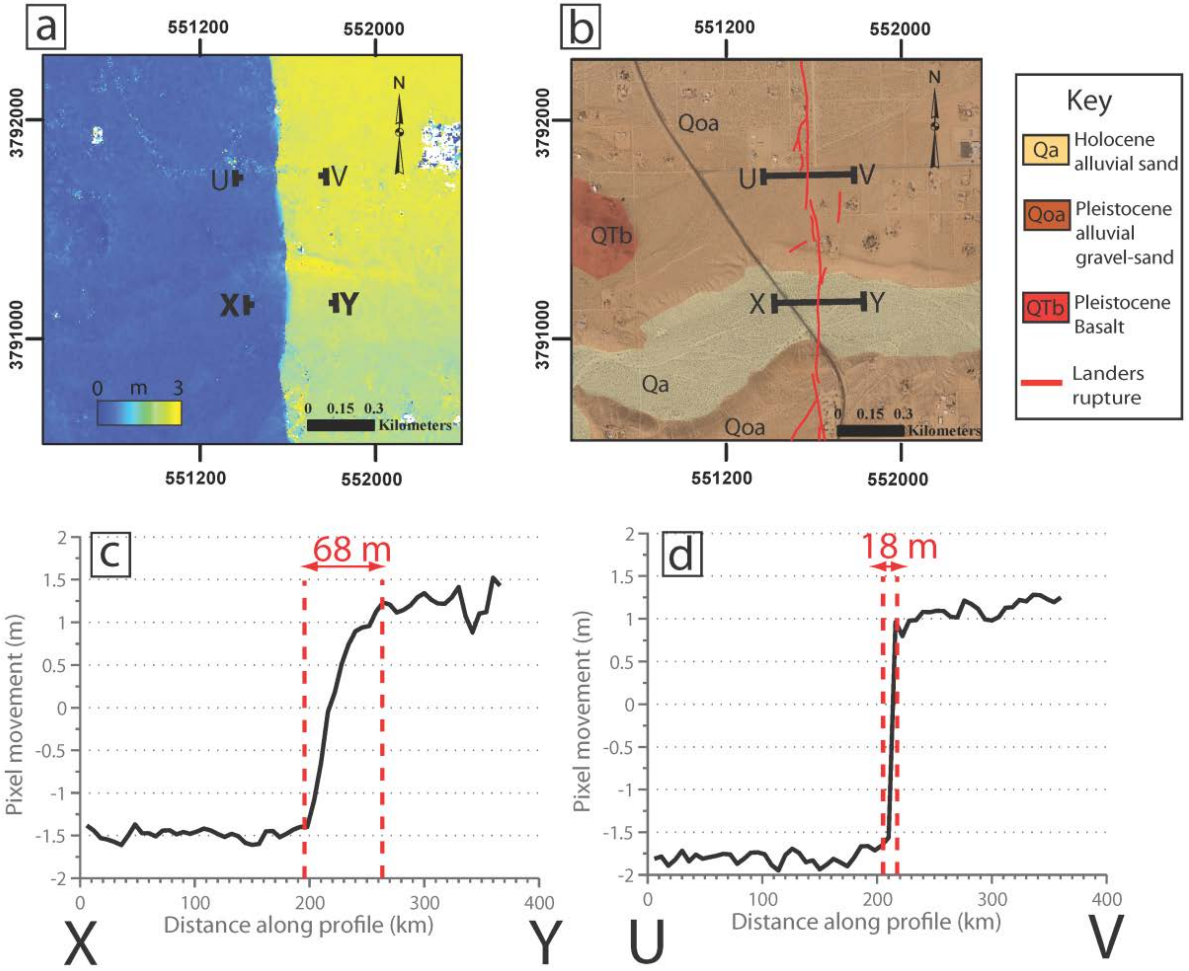


Mean = 39 ± 22%

Estimates consistent with prior work:

- 47% Harper Lake fault Shelef & Oskin (2009).
- 40% Izmit (Rockwell et al. 2002).
- 40% Treiman et al. (2002)

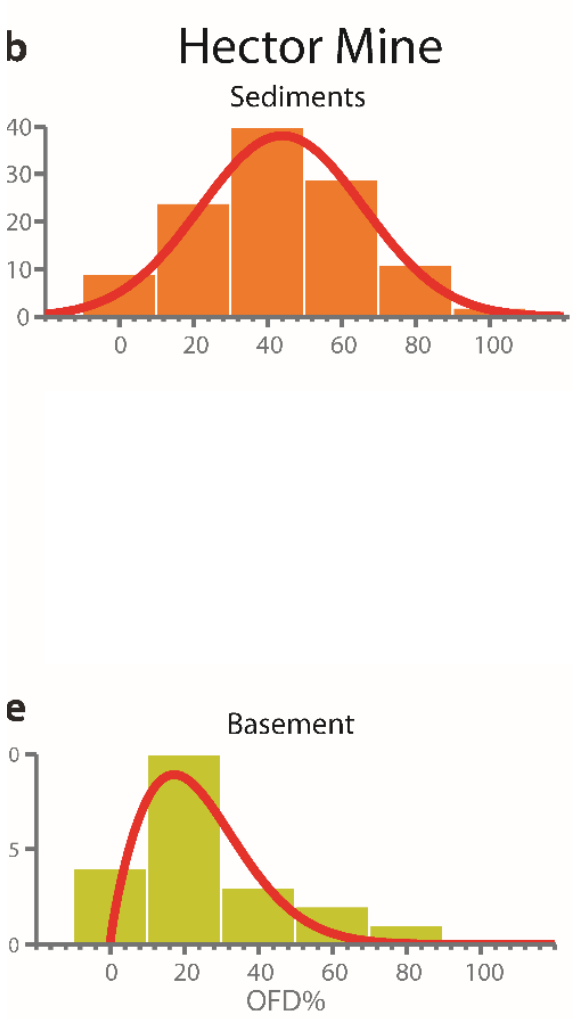
Does the magnitude and width of distributed strain systematically vary according to some physical property?

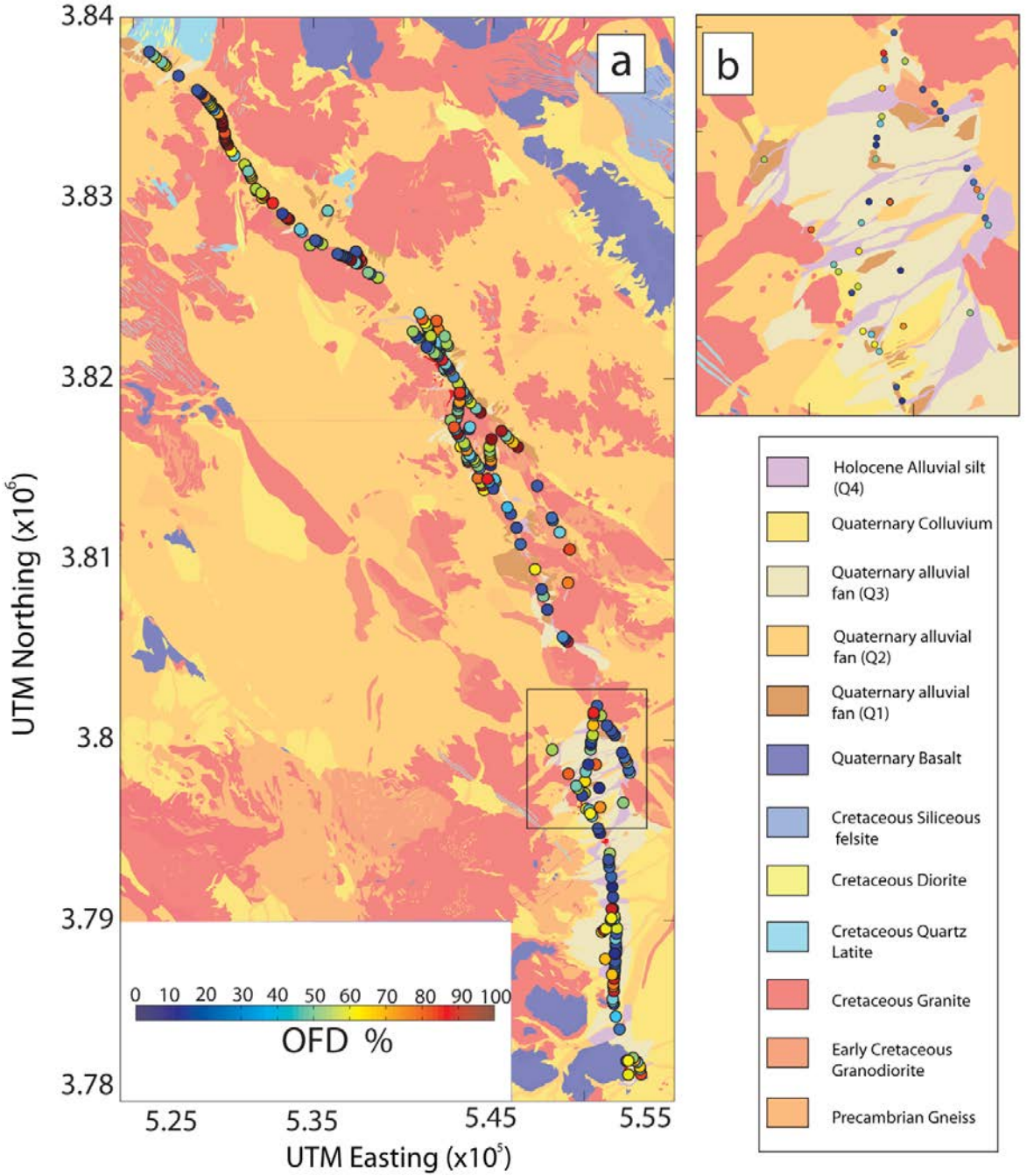


Come up with robust empirical scaling relations, that relate width of OFD with **x, y** or **z?**

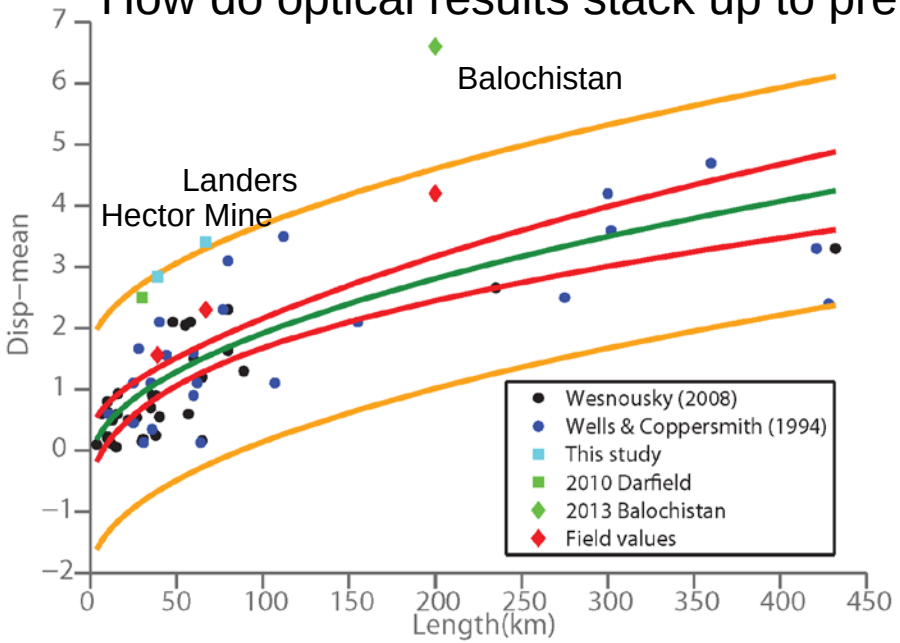
Estimate expected OFD along a rupture has use for microzonation and perhaps steps towards correcting geologic slip rates.

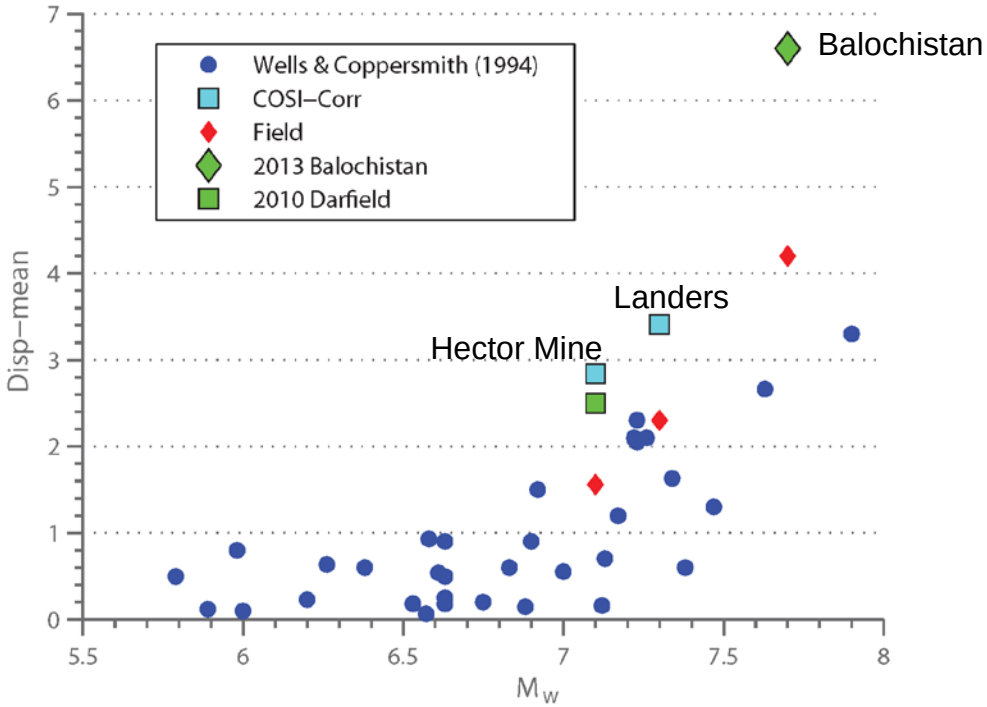
Near-surface materials





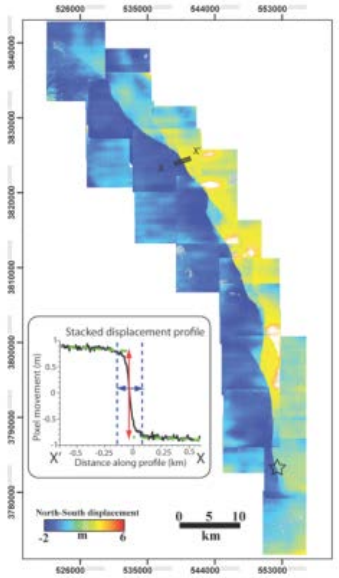
How do optical results stack up to previous measurements?

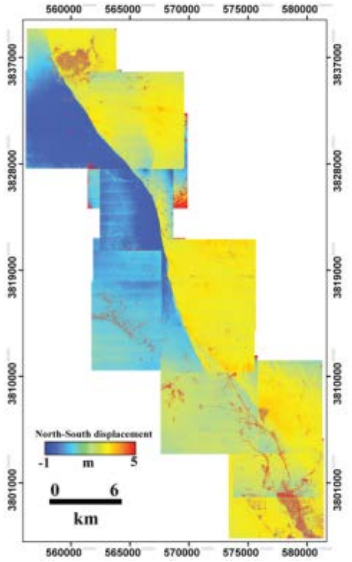


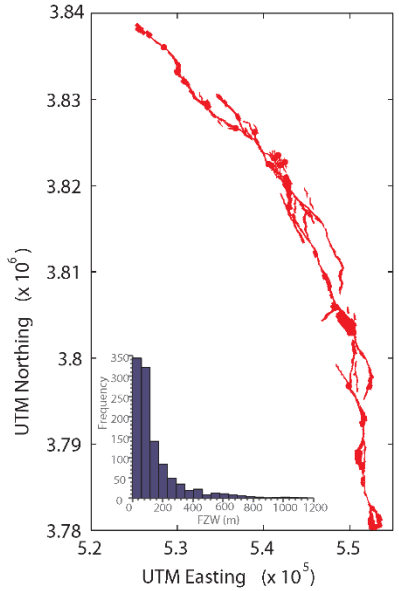


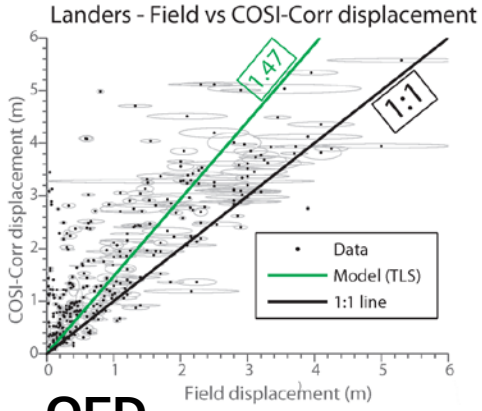
For hazard should we separate mature from immature faults? Degree of maturity closer to a continuum…

Conclusions





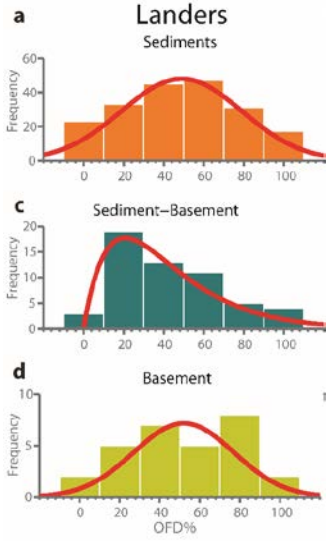


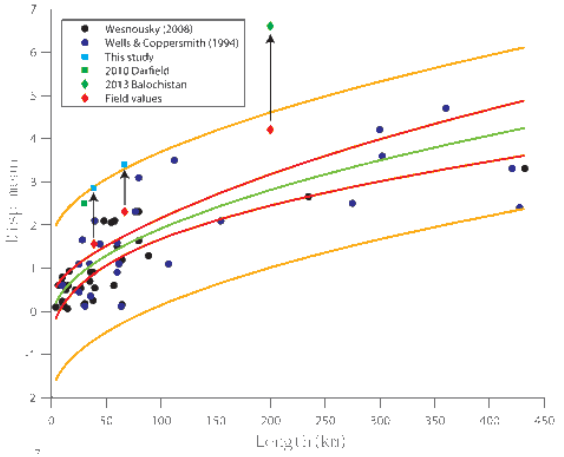


OFD

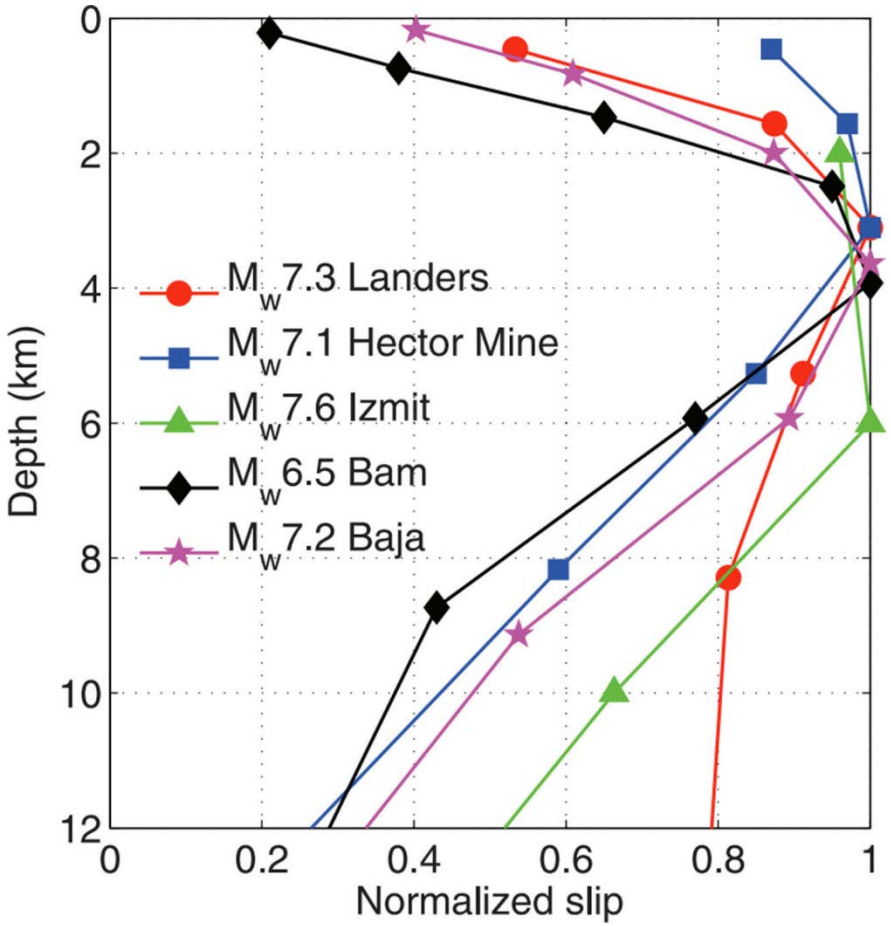
Landers: 46 ± 10%

Hector Mine: 39 ± 10 %

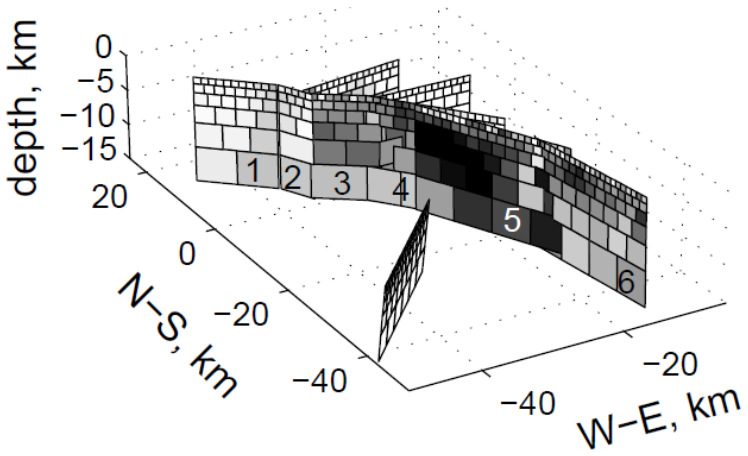




The shallow slip deficit



Fialko et al. (2005)

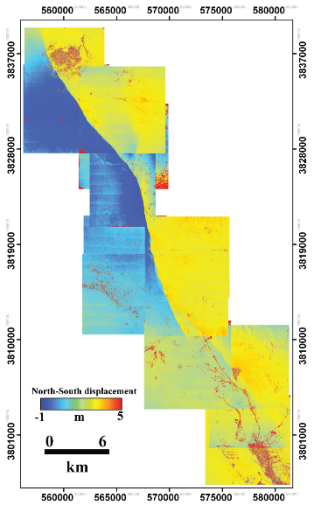


Fialko (2004)

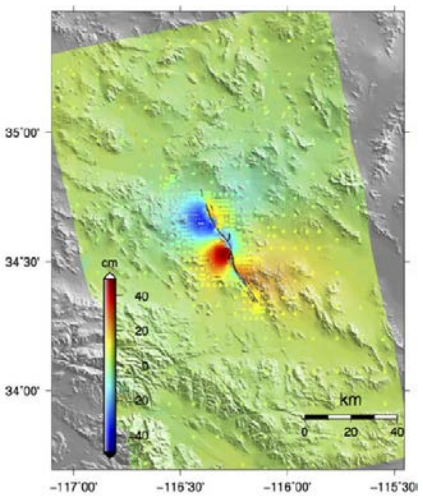
How could these new, near-field constraints alter estimates of slip at depth?

Shallow slip deficit ? Not really

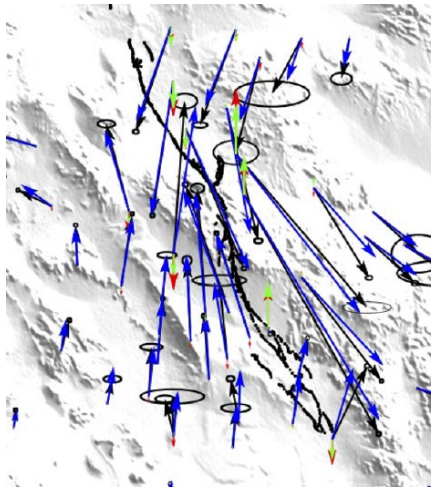
Optical



InSAR + AZO



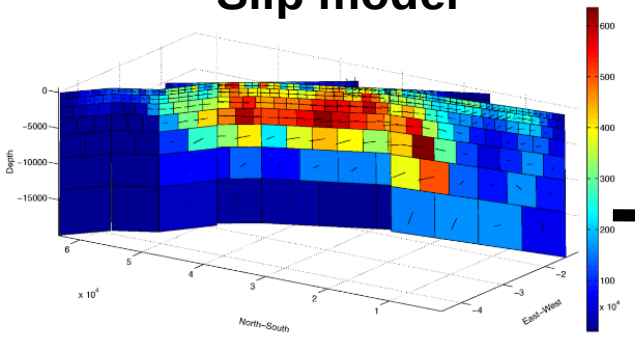
GPS



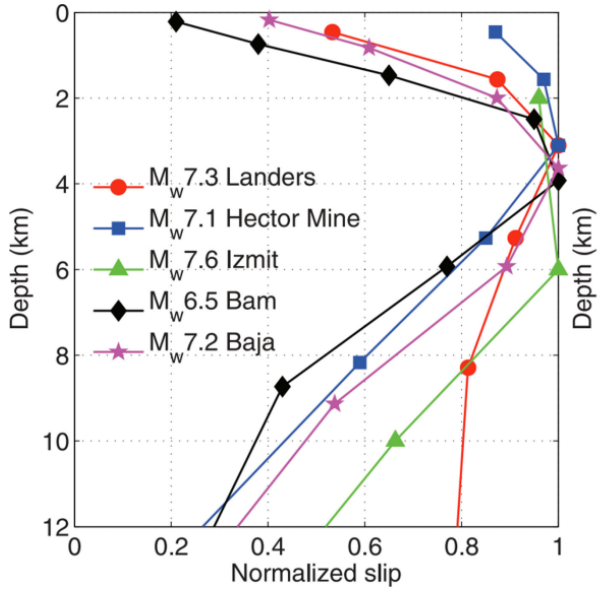
Implications for:

- Dynamic rupture simulations
- Generating synthetic strong ground motions

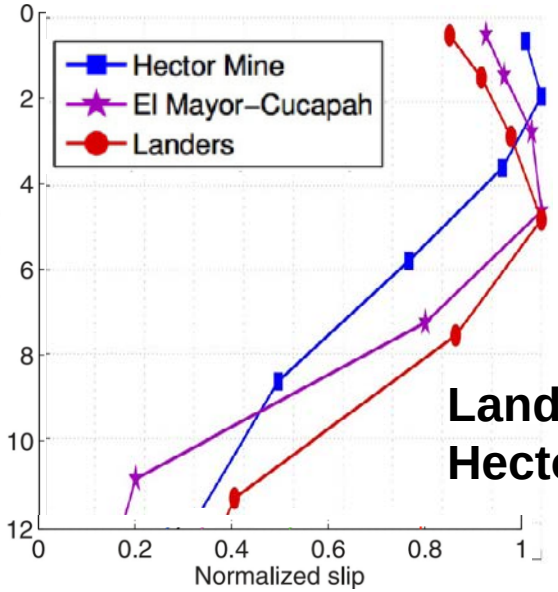
Slip model



Xu et al. (2016)



Fialko et al. (2005)



Landers: 46%→18%
Hector Mine: 17%→3%

Xu et al. (2016)

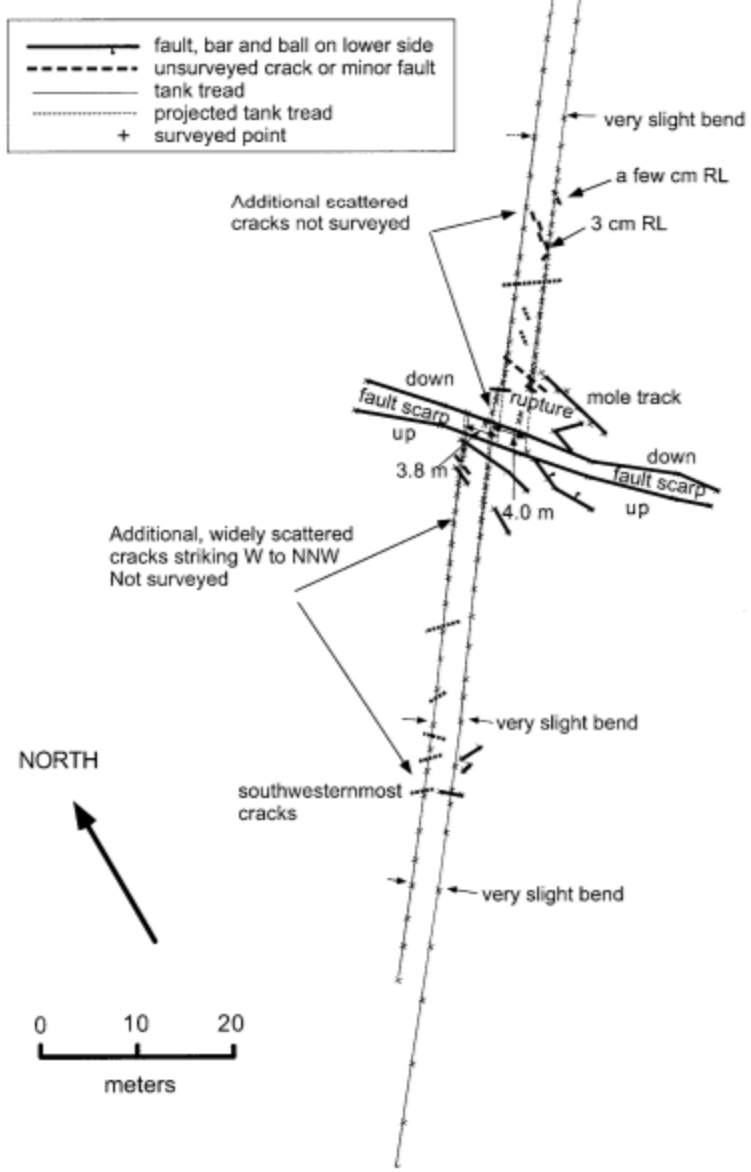


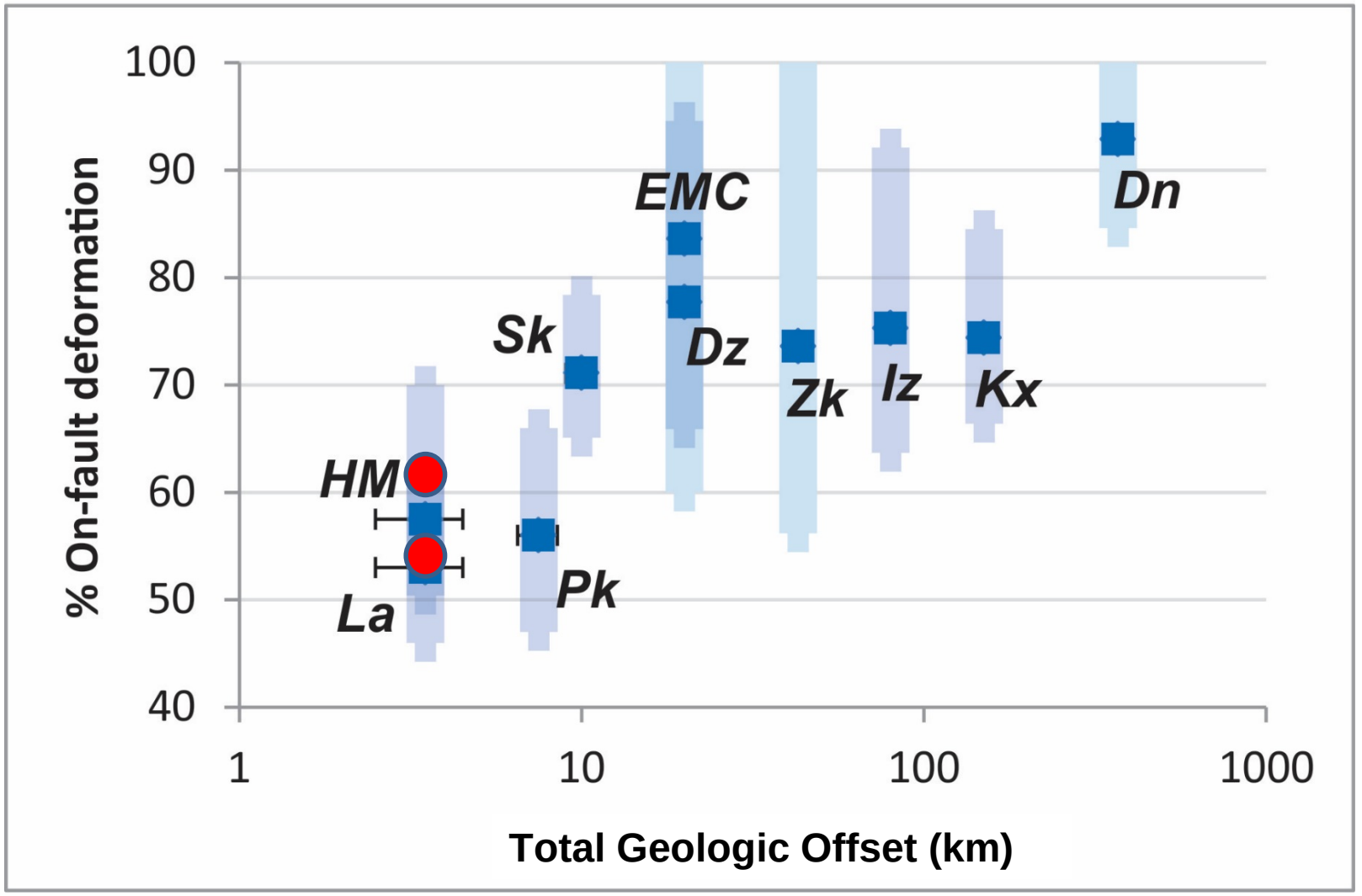
Figure 13. Map of survey along a tank track north of the Bullion Mountains. This track was very fresh and well defined, and it crossed the fracture zone at a 78° angle. About 40% of the total offset occurred as right-lateral warping within 7–10 m of the fault scarp. Site is at locality E, near kilometer 11 (Fig. 2b).

measurement (using a tape measure) of 3.5 ± 0.2 m for this same tank track (S. Lindvall, 1999 personal comm.).

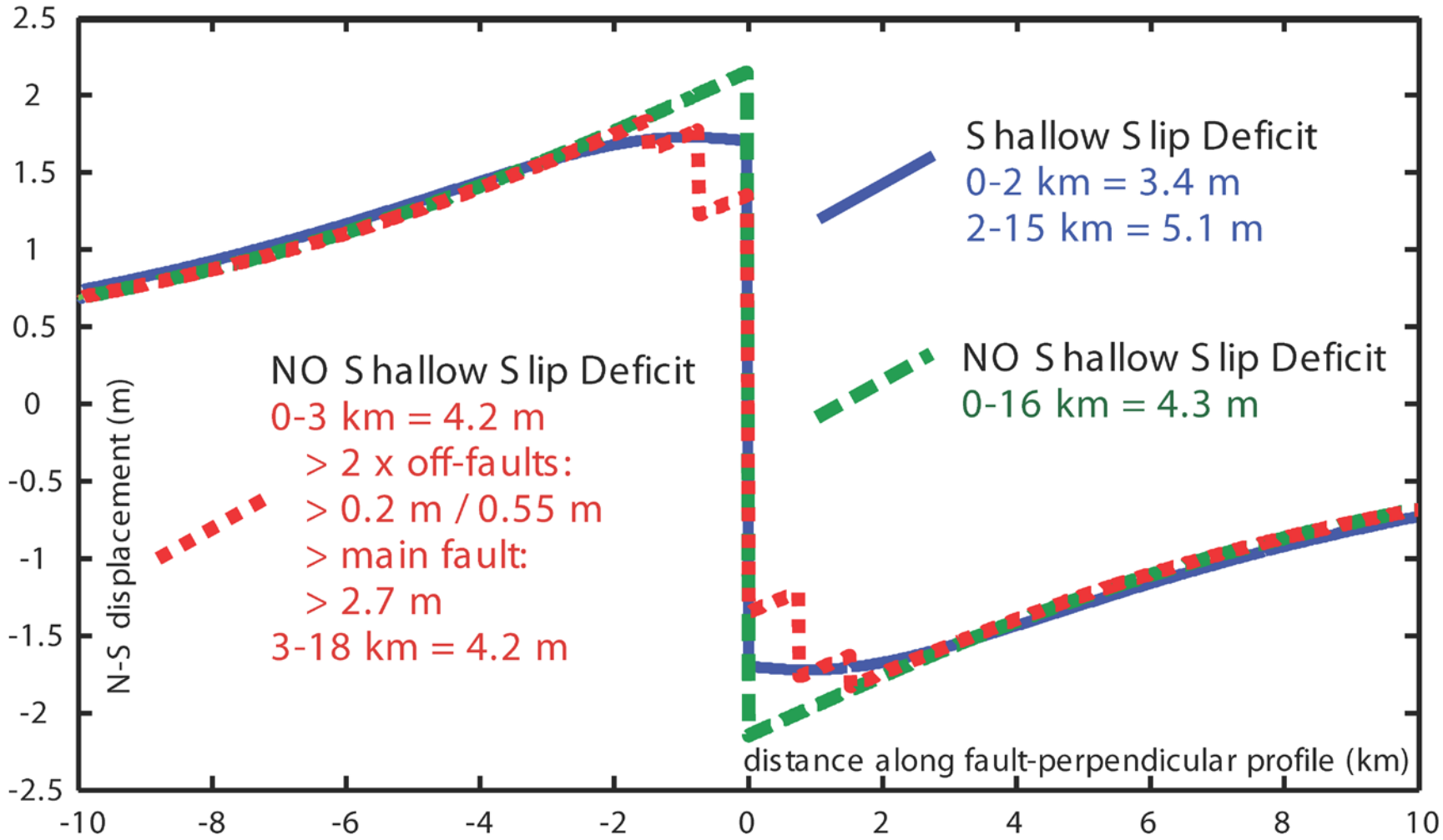
The fact that this track could be assumed to have been straight prior to the earthquake allowed the distributed shear to be included in both the taped and surveyed measurements. Thus, the two measurement techniques yield offset values that essentially agree, within the reported errors. If this feature had been a stream channel or some other nonlinear geomorphic feature, then the right-lateral offset would probably have been measured as 2.1 m for one track and 2.4 m for the other, based on the brittle offsets on visible fractures. Thus, about 40% of the total right-lateral deformation at this location occurred as distributed shear at the surface. This is similar to the maximum amount of distributed shear observed along the 1999 earthquake ruptures in Turkey (Rockwell *et al.*, 2002). Along many portions of the 1999 Hector Mine earthquake rupture, cultural features of sufficient linearity were lacking, and the measured offsets may under-

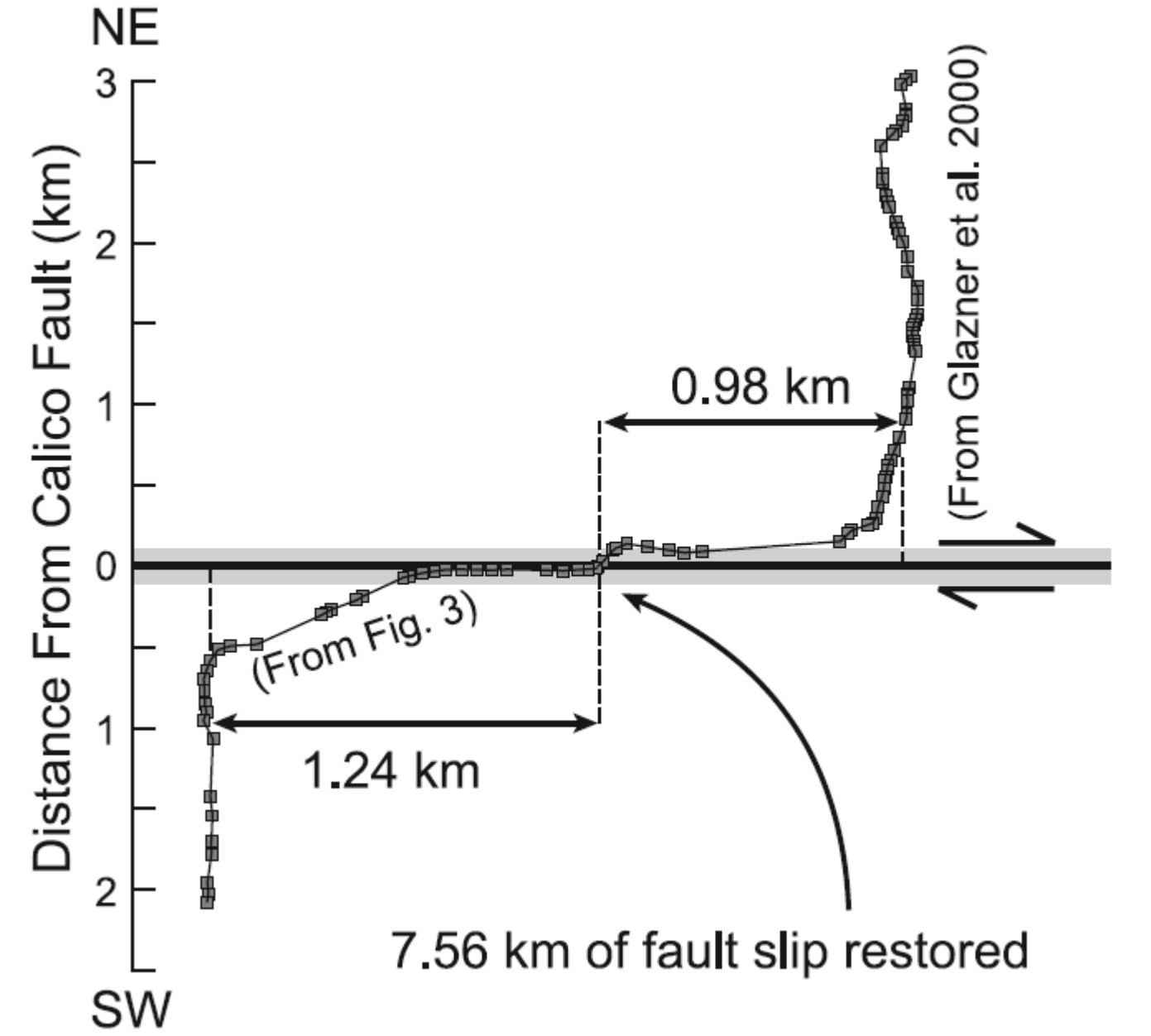
Treiman et al. (2002)

Immature faults may have up to 50% co-seismic deformation occurring OFF-FAULT

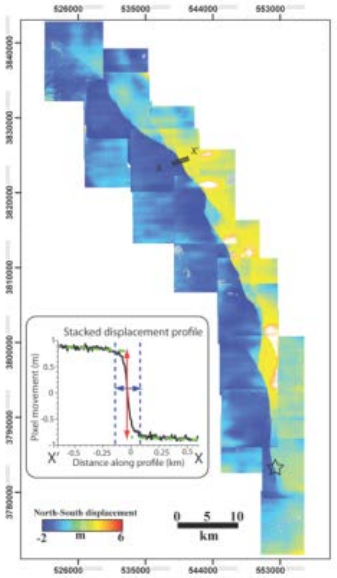


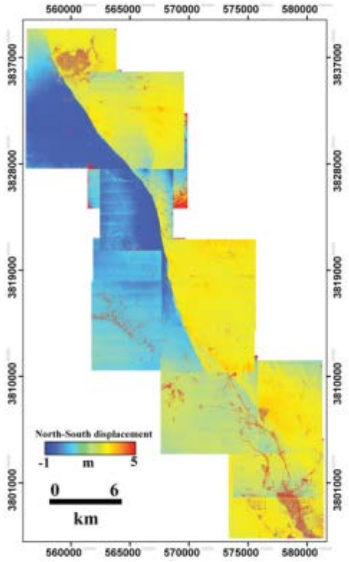
Hollingsworth et al. (in prep)

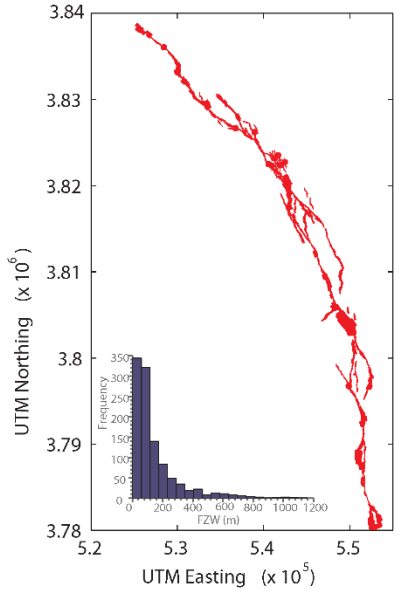

2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-10
-8
-6
-4
-2
0
2
4
6
8
10
N-S displacement (m)
distance along fault-perpendicular profile (km)
Shallow Slip Deficit
0-2 km = 3.4 m
2-15 km = 5.1 m
NO Shallow Slip Deficit
0-16 km = 4.3 m
NO Shallow Slip Deficit
0-3 km = 4.2 m
> 2 x off-faults:
> 0.2 m / 0.55 m
> main fault:
> 2.7 m
3-18 km = 4.2 m

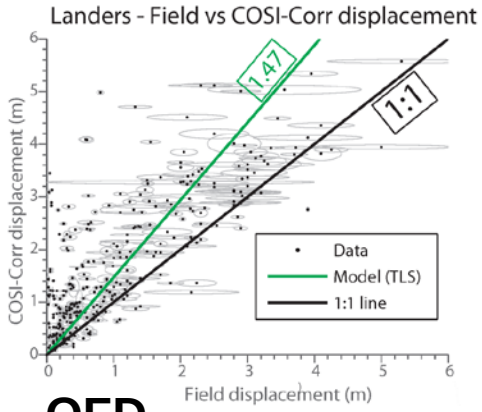

NE
SW
Distance From Calico Fault (km)
3
2
1
0
1
2
0.98 km
(From Glazner et al. 2000)
(From Fig. 3)
1.24 km
7.56 km of fault slip restored

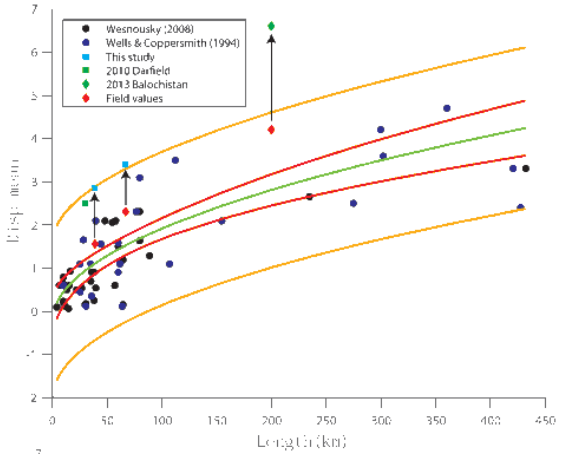
Conclusions

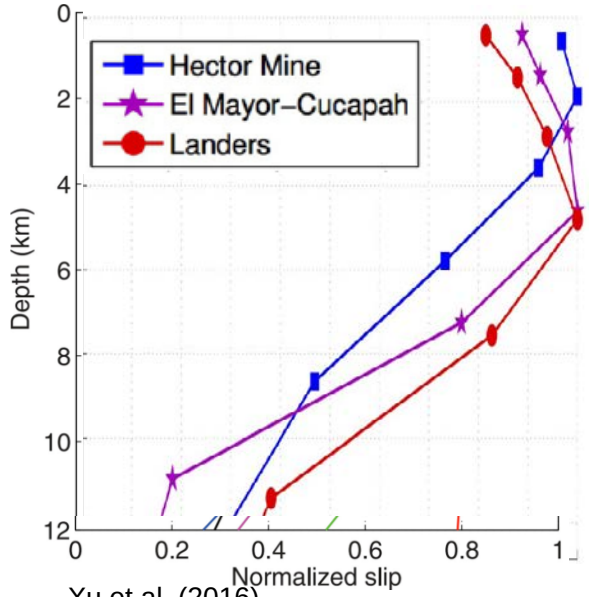












OFD

Landers: 46 ± 10%

Hector Mine: 39 ± 10 %

Xu et al. (2016)