Mapping fault creep, frictional properties, and unrecognized active structures with dense geodetic data in the Imperial Valley, Southern California

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Eric O. Lindsey[1,2], Yuri Fialko[3]

[1]Earth Observatory of Singapore, Nanyang Technological University, [2]UC Berkeley, [3]Scripps Institution of Oceanography, UC San Diego

elindsey@ntu.edu.sg

Overview

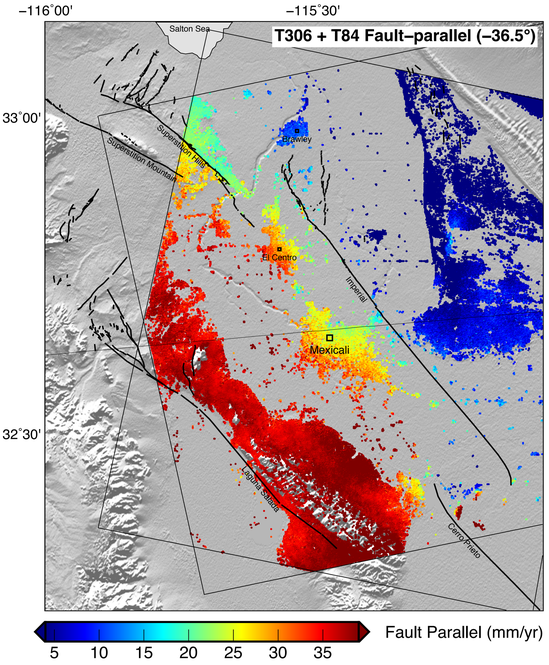
Imperial Fault modeling and friction:

- The Imperial fault in southern California is the only mapped continuous fault through the Imperial Valley, and has hosted several major earthquakes: 1940 (Mw7.0) and 1979 (Mw6.6).
- We find that it is creeping only north of the US-Mexico border, opposite to the pattern of 1940 coseismic slip.
- We show that co- and postseismic observations are critical for constraining frictional parameters, using a fully dynamic earthquake cycle model (Lapusta et al., 2000).

Unrecognized hazards:

- Geodetic data suggest unmapped **active structure(s)** west of the Imperial fault **slipping at 10 - 15 mm/yr.** This implies a lower rate of 25-30 mm/yr for the Imperial fault.
- A lower Imperial fault slip rate also agrees with the dynamic modeling, and with several independent lines of evidence.

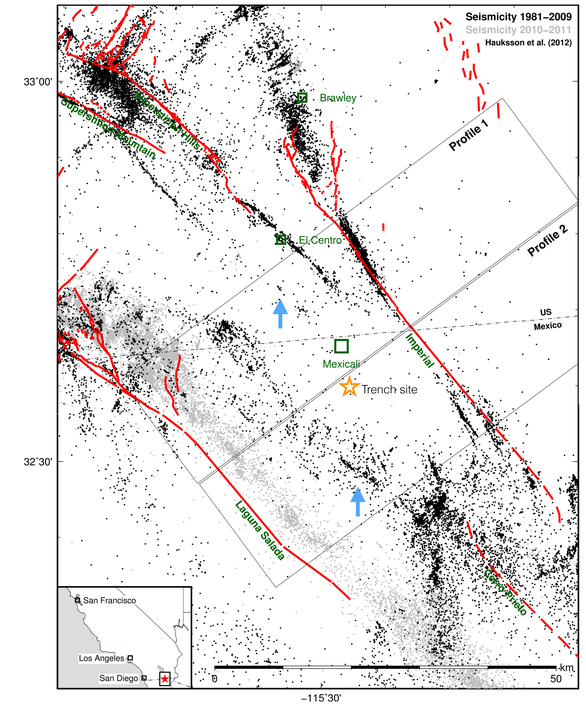
InSAR observations

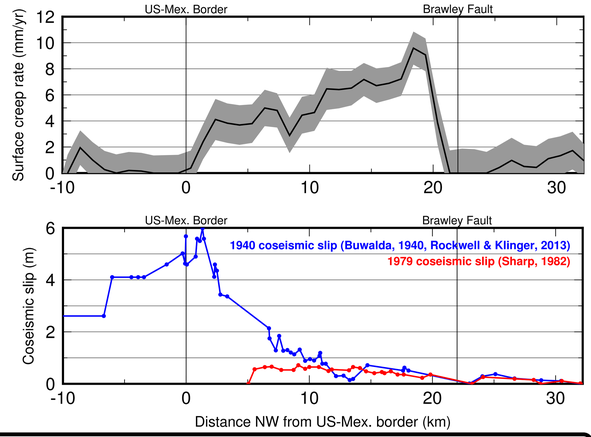


- We use data from Envisat (2003-2010): 149 acquisitions on four tracks (ascending tracks 77, 306, descending tracks 84, 356).
- Stable pixels identified by the StaMPS persistent-scatterers method (Hooper et al., 2004).
- Sum-Remove-Filter-Restore (SURF) method (Tong et al., 2013) used to combine the InSAR with GPS data, at a 70 km wavelength cutoff.
- Ascending/descending tracks combined to separate horizontal and vertical motion, provided the deformation rate and azimuth are constant (Lindsey et al., 2014).

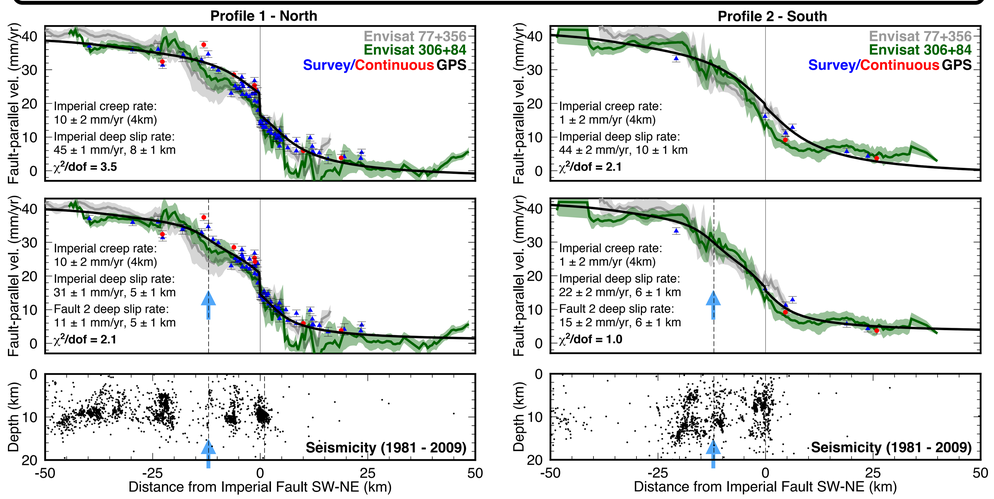
Creep rate along strike

- Combined InSAR and GPS observations are used to measure the fault creep rate every 2km along strike.
- Fit a line to data on each side of the fault and measure the offset.
- Creep rate increases northward from the U.S. - Mexico border; no creep observed south of the border.
- Surface creep rate is anticorrelated with coseismic slip during the Mw7.0 1940 earthquake (Rockwell & Klinger, 2013).





Strain asymmetry: unmapped hazards?

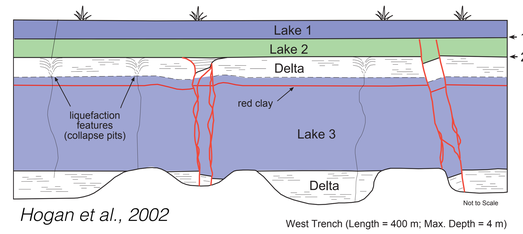


Strain Asymmetry:

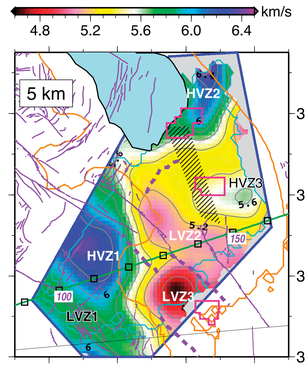
- Geodetic asymmetry across the Imperial fault is better explained by dislocation models including a second fault.
- The second fault location coincides with microseismicity extending south of the San Jacinto fault zone, and the inferred slip rate matches that of the San Jacinto fault zone.
- The models do not rule out the presence of more than one unmapped active fault in the western Imperial valley.

Additional evidence for unmapped active faults:

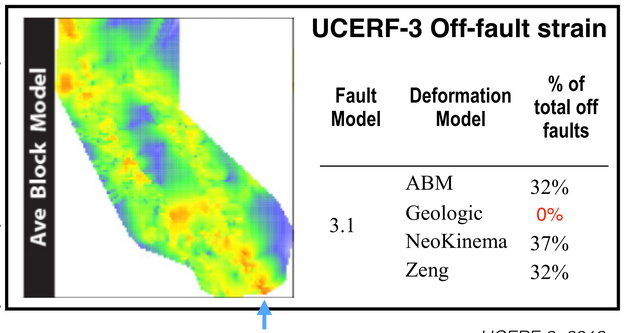
- Paleoseismic trenching found an active structure with several large events (orange star; Hogan et al., 2002).
- UCERF-3 models require significant "off-fault" strain in the Imperial valley.
- SSIP-imaged low velocity zone also suggests trans-tension in the western part of the valley.



Hogan et al., 2002



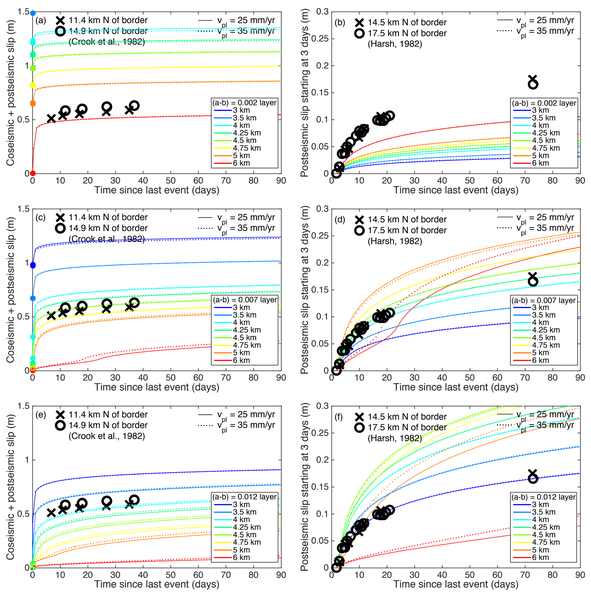
Persaud et al., 2016



Fault Model	Deformation Model	% of total off faults
3.1	ABM	32%
	Geologic	0%
	NeoKinema	37%
	Zeng	32%

UCERF-3, 2013

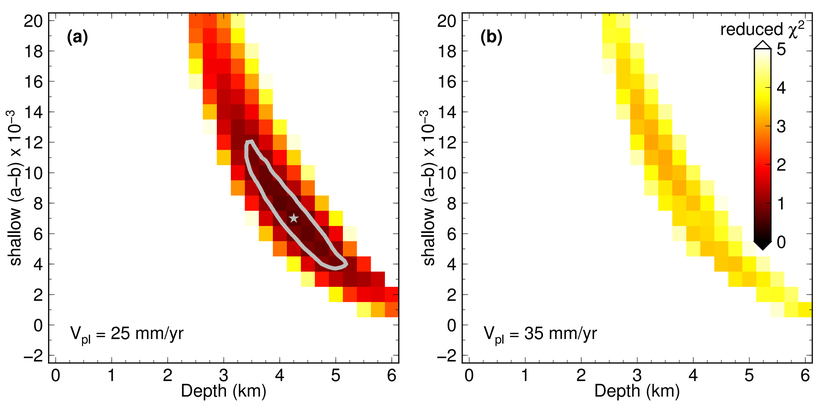
Model: rate-and-state friction



- Earthquake cycle models have been used to model shallow creep (Kaneko et al., 2013); it was found that more data in addition to interseismic creep rates are needed to obtain a good constraint on key parameters.
- We use rate- and state- dependent friction with aging law; fully dynamic, antiplane deformation (Lapusta et al., 2000):

$$\tau(z,t) = \sigma(z)\left[f_o + a(z)\ln\frac{V(z,t)}{V_o} + b(z)\ln\frac{V_o\theta(z,t)}{L}\right] \qquad \frac{d\theta(z,t)}{dt} = 1 - \frac{V(z,t)\theta(z,t)}{L}$$

- Grid search and compare to inter-, co- and postseismic data: good fit exists only for V_plate < 30 mm/yr.



Summary

- A combination of interseismic, coseismic and postseismic observations are required to constrain key frictional parameters controlling fault creep, such as the **shallow value of (a-b) and the depth of creep.**
- To obtain a good fit to all data, earthquake cycle models require a **lower Imperial fault slip rate** (20 - 30 mm/yr).
- The additional relative plate motion (10-15 mm/yr) could be taken up by one or several **blind fault structures** to the west.
- Extra fault(s) are also supported by the presence of a **geodetic strain asymmetry** across the valley, microseismic lineaments, and paleoseismic trenching.
- This hypothesis is tectonically simpler, and explains several unusual features of the Imperial valley, including a seismically imaged low velocity zone in the west, and mis-modeled off-fault strain in the UCERF-3 models.

References

This work: **Lindsey, E. O., and Y. Fialko (2016), Geodetic constraints on frictional properties and earthquake hazard in the Imperial Valley, southern California, J. Geophys. Res. Solid Earth, 121, doi: 10.1002/2015JB012516.**

Crook, C. N., Mason, R. G. and Wood, P. R., in USGS Professional Paper 1254, 1982.

Crowell, B.W., Y. Bock, D. T. Sandwell and Y. Fialko, J. Geophys. Res., 118, 5030-5039, doi:10.1002/jgrb.50347, 2013.

Harsh, P. W., in USGS Professional Paper 1254, 1982.

Hogan, P. J. Lindvall, S. C., Magistrale, H., and Rockwell, T. K., SCEC Annual meeting poster, 2002.

Hooper, A., H. Zebker, P. Segall, and B. Kampes, Geophys. Res. Lett., 31(23), doi:10.1029/2004GL021737, 2004.

Kaneko, Y., Y. Fialko, D. T. Sandwell, X. Tong, and M. Furuya, J. Geophys. Res., 118, 316-331, doi: 10.1029/2012JB009661, 2013.

Lapusta, N., Rice, J. R., Ben-Zion, Y. and Zheng, G., J. Geophys. Res. 105(B10), 2000.

Persaud, P., Ma, Y., Stock, J. M., Hole, J. A., Fuis, G. S., & Han, L., Geology, 44(9), G38033.1. doi: 10.1130/G38033.1, 2016.

Rockwell, T. K., and Y. Klinger, Bull. Seism. Soc. Am., 102, 629-640, doi: 10.1785/0120120192, 2013.

Thomas, A. P. and T. K. Rockwell, J. Geophys. Res., 101(B3), 5987-5997, doi:10.1029/95JB01547, 1996.

Tong, X., D. T. Sandwell, and B. Smith-Konter, J. Geophys. Res., 118, doi: 10.1029/2012JB009442, 2013.

UCERF-3, USGS Open-File Report 2013-1165, 2013.