Inference of the 2004 Parkfield co-seismic slip distribution via joint inversion of GPS and aftershock data

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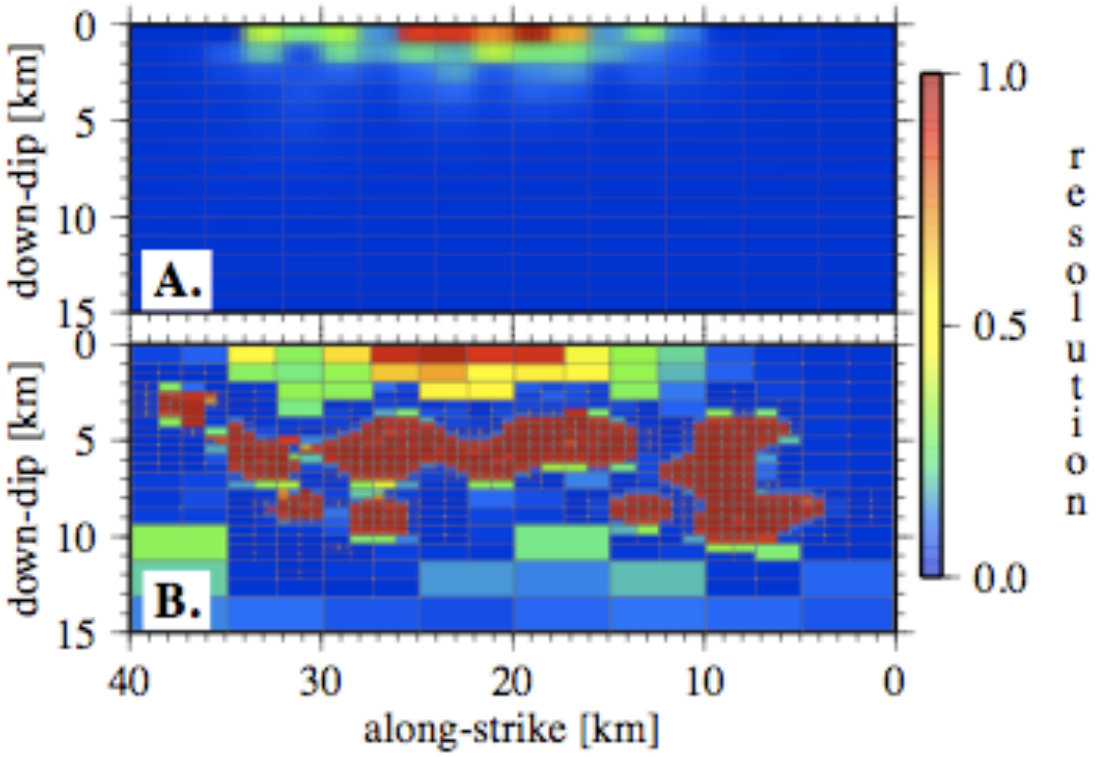
GPS-only (Johnson, 2006; Barbot et al., 2009; Page et al., 2009)

Joint GPS – aftershocks (this study)

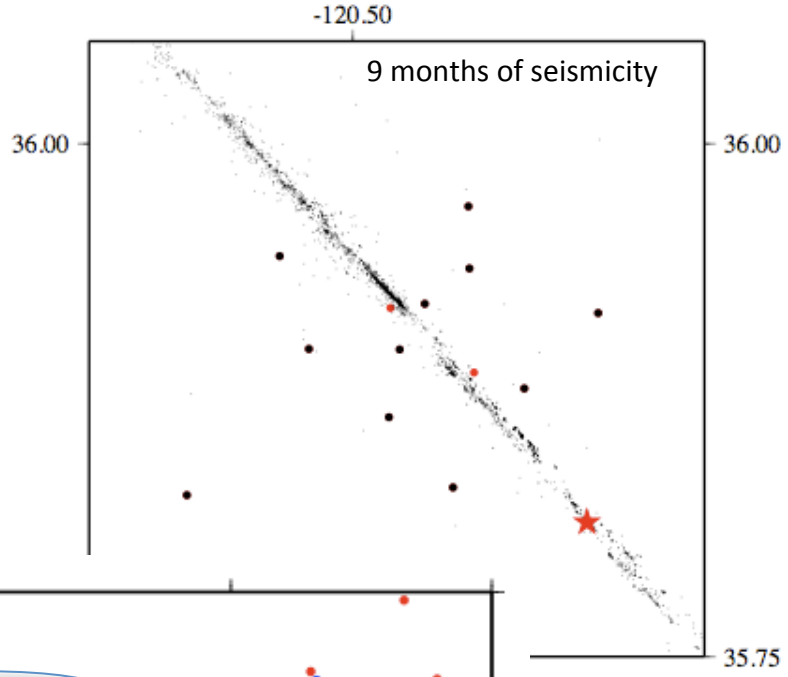


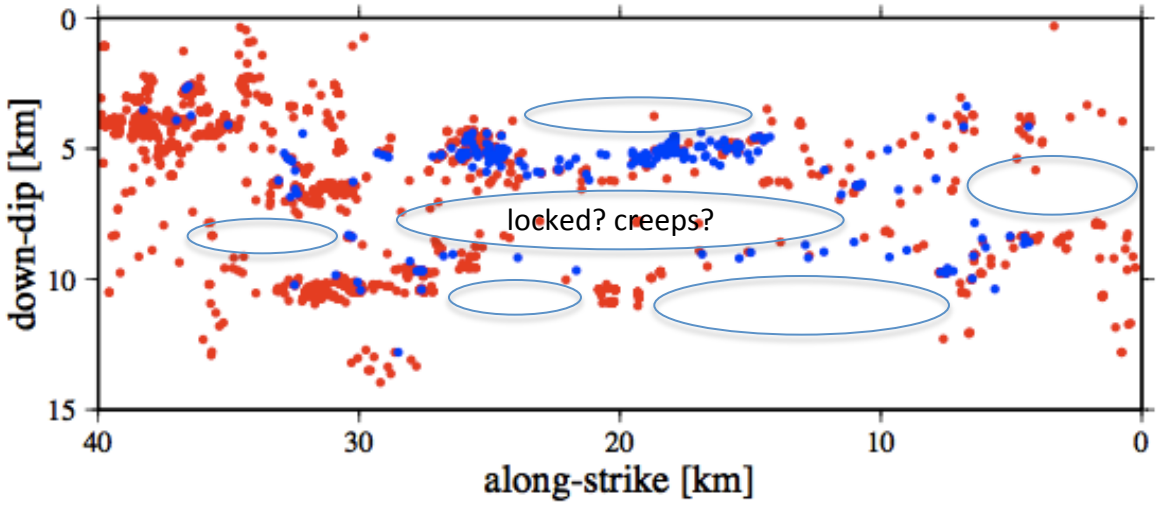
Introduction: Parkfield

- No off-fault aftershocks. Simple and well resolved fault plane – easy to model.

- Microseismicity occupies a small fraction of the fault plane

- The before and after spatial distributions are similar





Red = 5000 days before

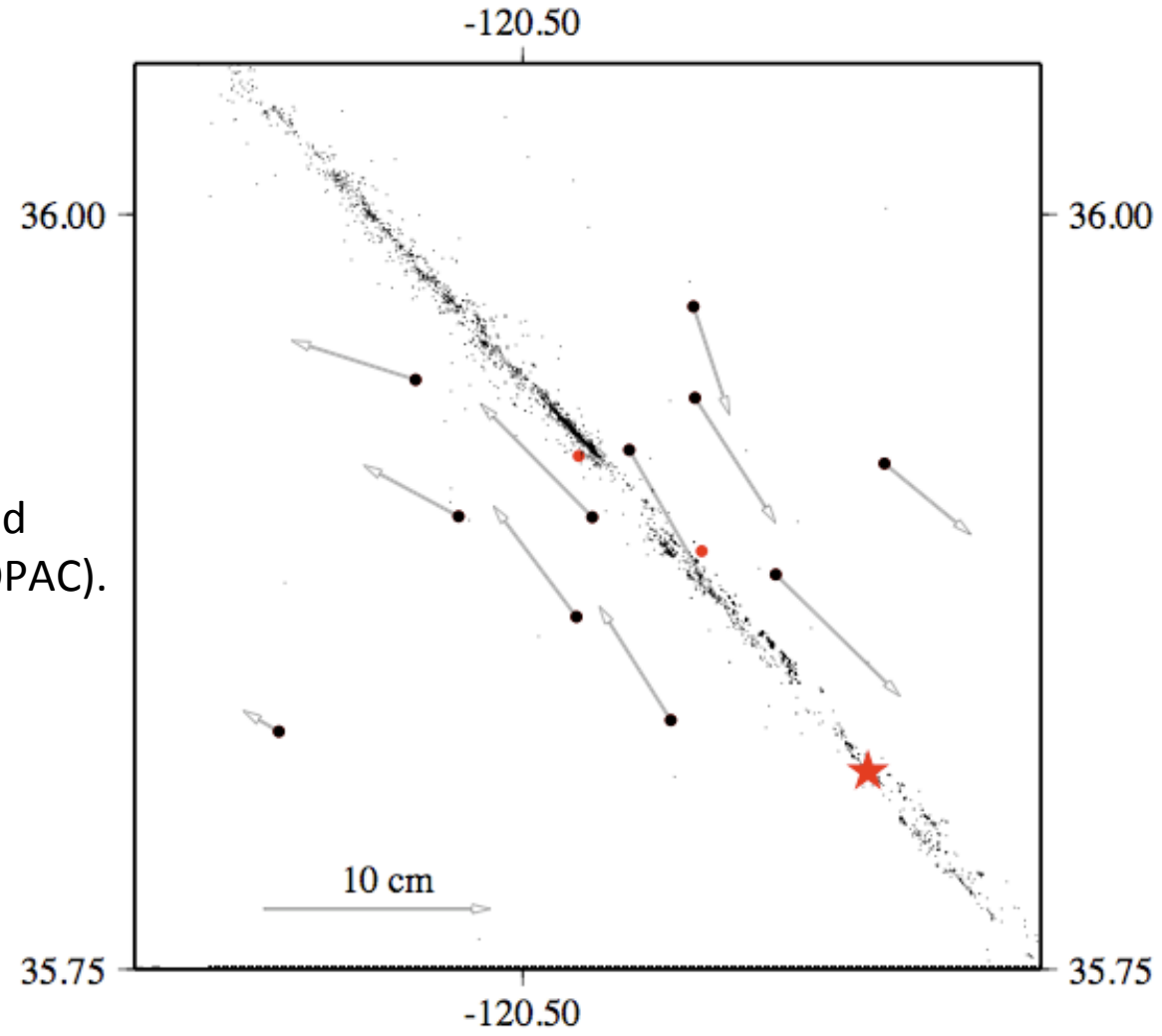
Blue = 1 day after

Aftershocks location are from Thurber et al. (2006)

Introduction: The GPS data

- Use 11 out of 13 stations.

- GPS co-seismic solution obtained by Scripps Orbit and Permanent Array Center (SOPAC).



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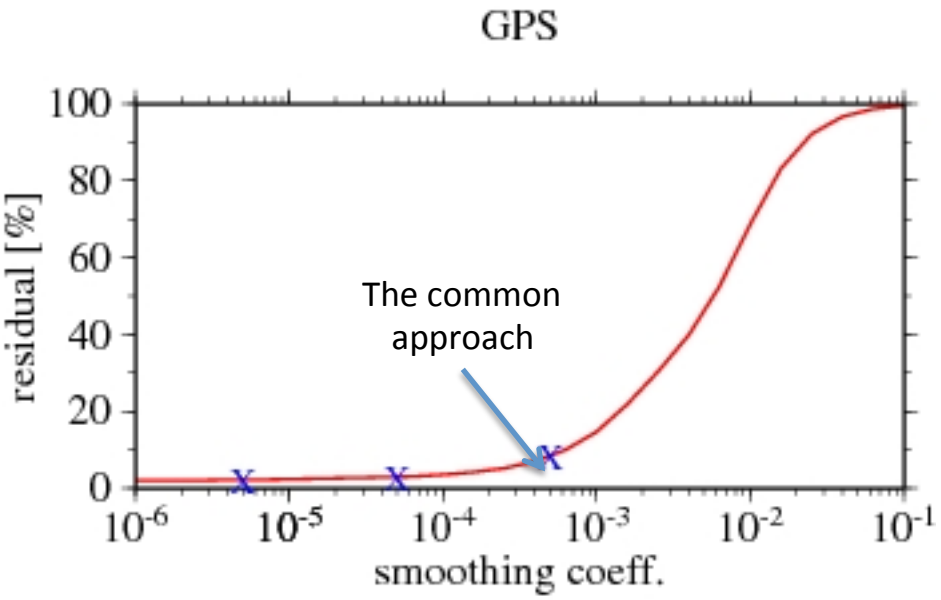
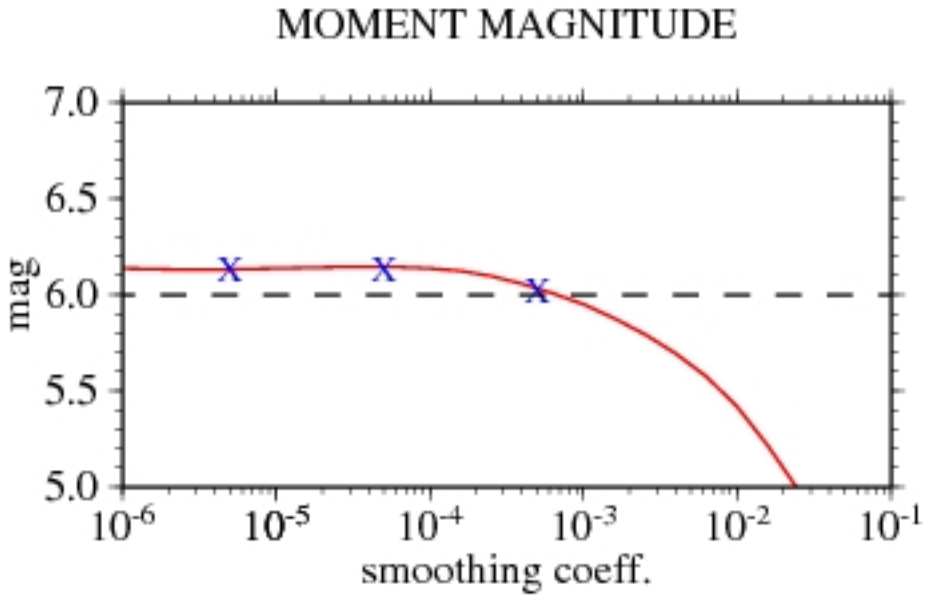
The shortcoming of GPS inversions: Inversion result

- Excellent fit to the data over a wide range of smoothness coeff.

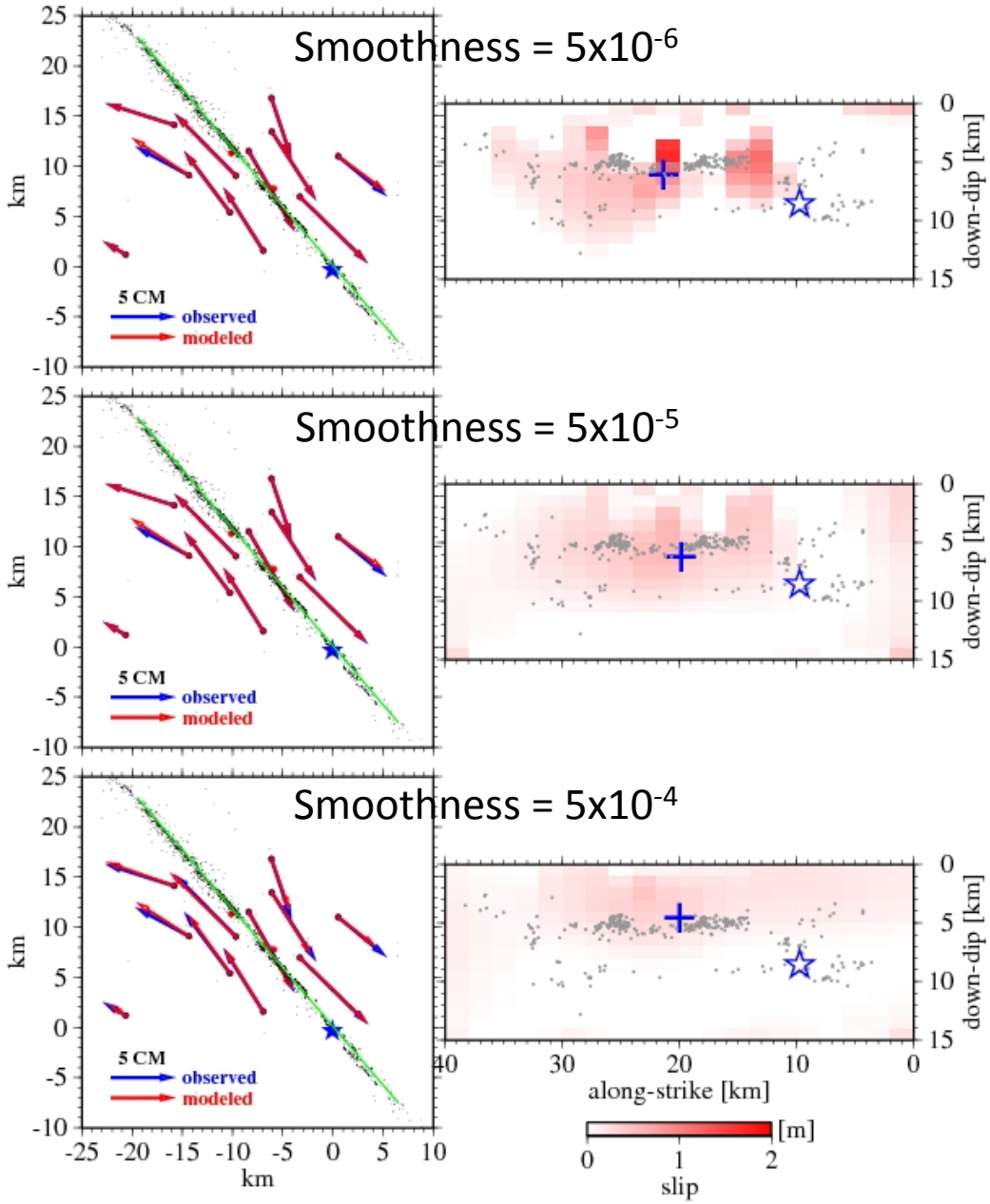


- The moment magnitude is well resolved.



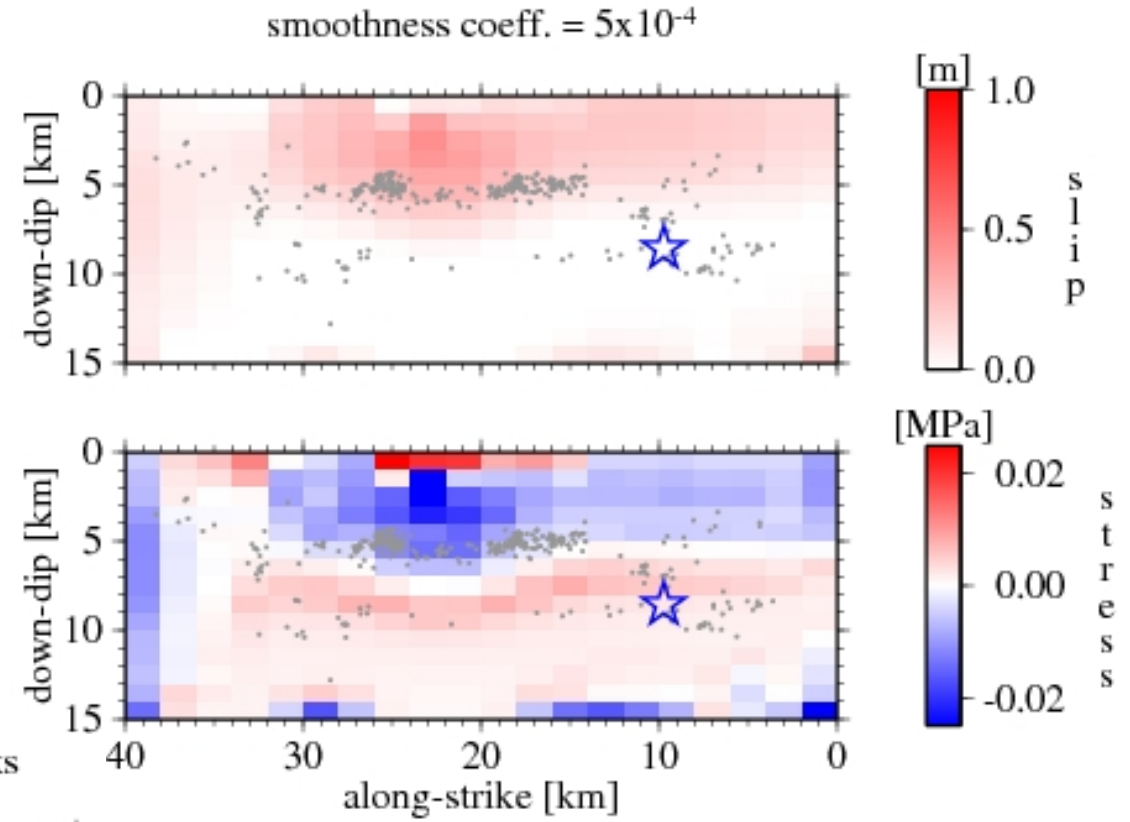
The shortcoming of GPS inversions: Inversion result

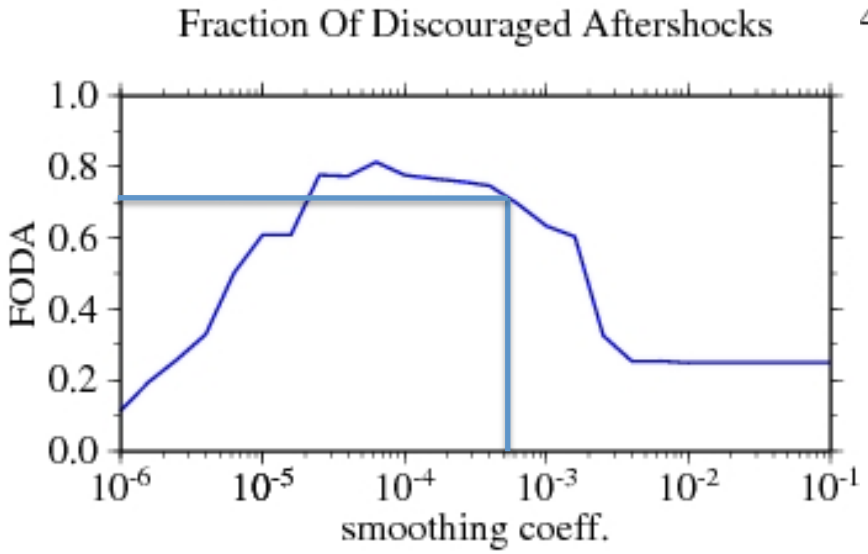
- Radically different slip distributions provide nearly identical fit to the data.
- Note also:
  - The moment centroid is the same for all solutions – a problem invariant?
  - Little or no slip near the hypocenter.



The joint GPS and aftershock data: Stress vs. aftershocks distribution in the models

Precise earthquake locations are from Thurber et al., 2006





- About 70% of the aftershocks are in areas that have experienced stress decrease – what does it mean???

The joint GPS and aftershock data: Constitutive stress – earthquake rate relation (based on Dieterich 1994)

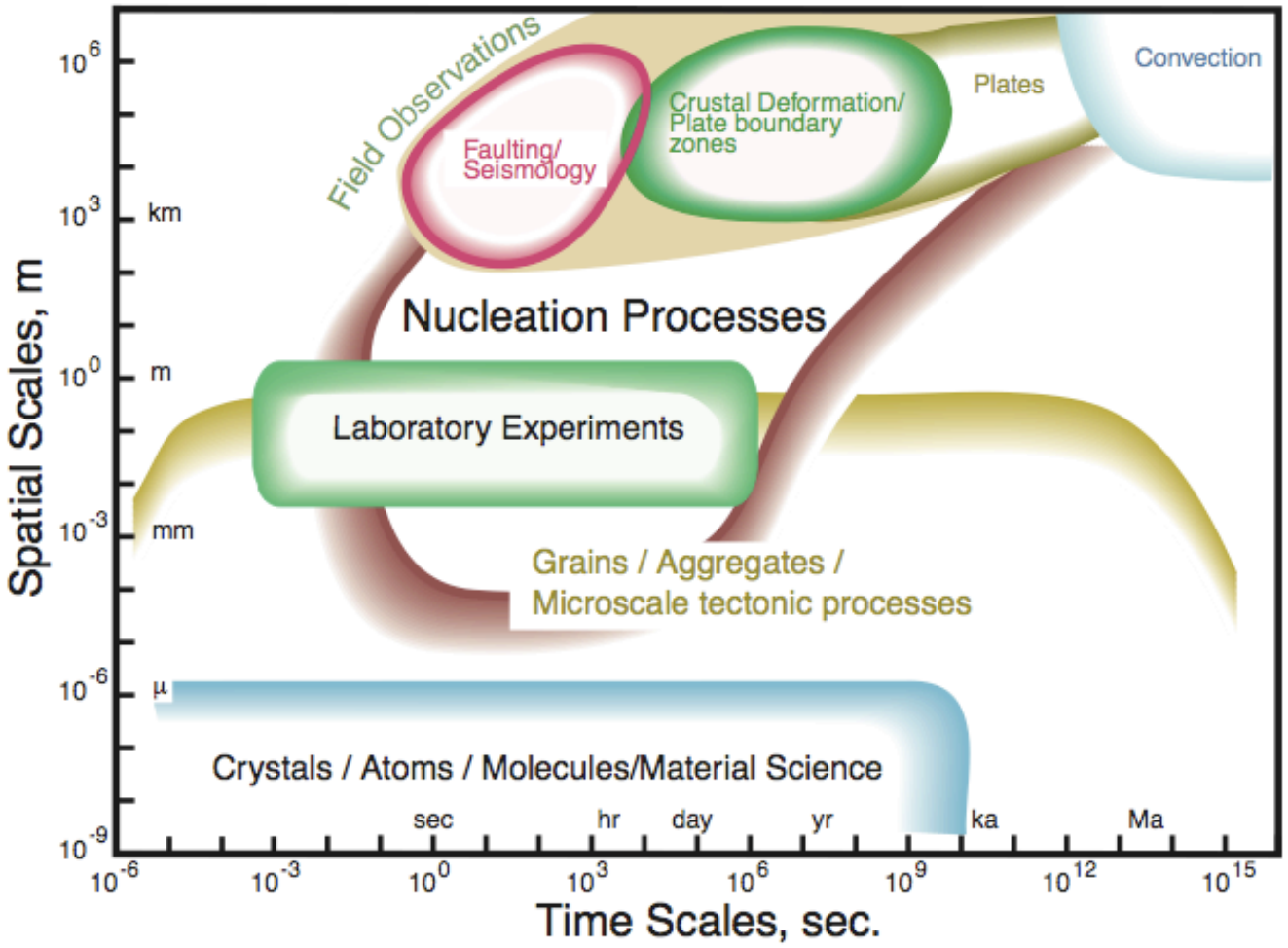
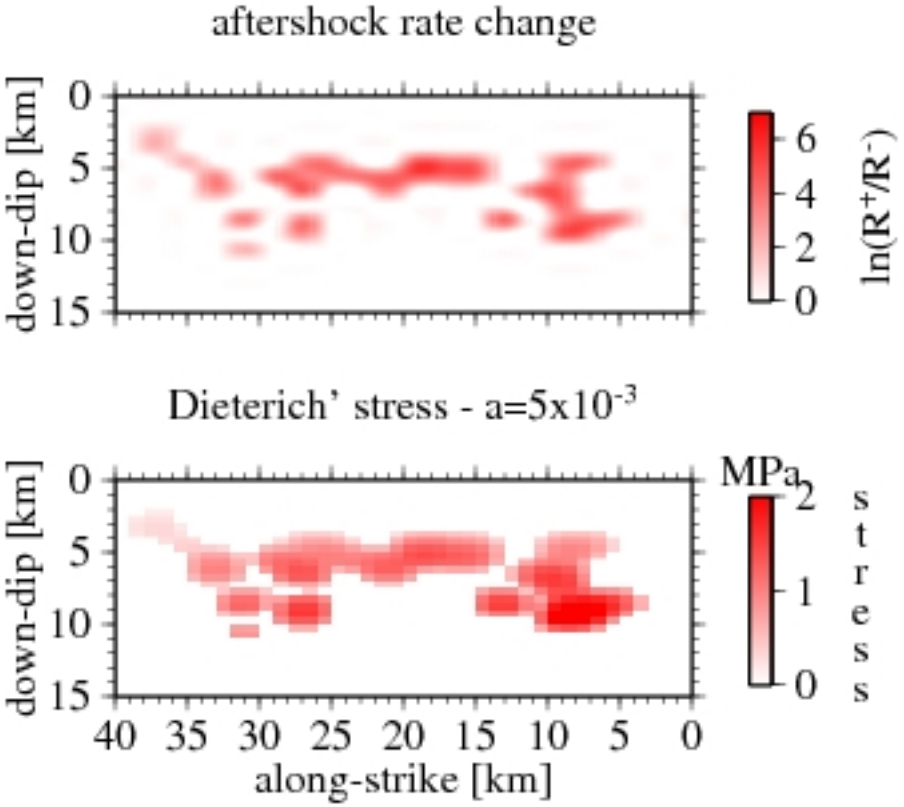


Figure from http://www.servogrid.org/EarthPredict/

The joint GPS and aftershock data: Constitutive stress – earthquake rate relation (based on Dieterich 1994)

$$\text{rate change} = \frac{n_{after} / \Delta t_{after}}{n_{before} / \Delta t_{before}}$$



$$\tau = a\sigma \ln(\text{rate change})$$

Δt_{before} = 20 years

Δt_{after} = 1 days or the time of the 10th aftershock

σ is lithostatic less hydrostatic

$a = 0.005$

The joint GPS and aftershock data: The set of equations

We solve for *u* via simultaneous solution of:

1. Ground displacement $$WGu = Wd$$

2. Smoothing $$\beta Au = 0$$

3. Stress distribution (inferred from aftershock distribution) $$\gamma_\beta Ku = \gamma_\beta \tau$$

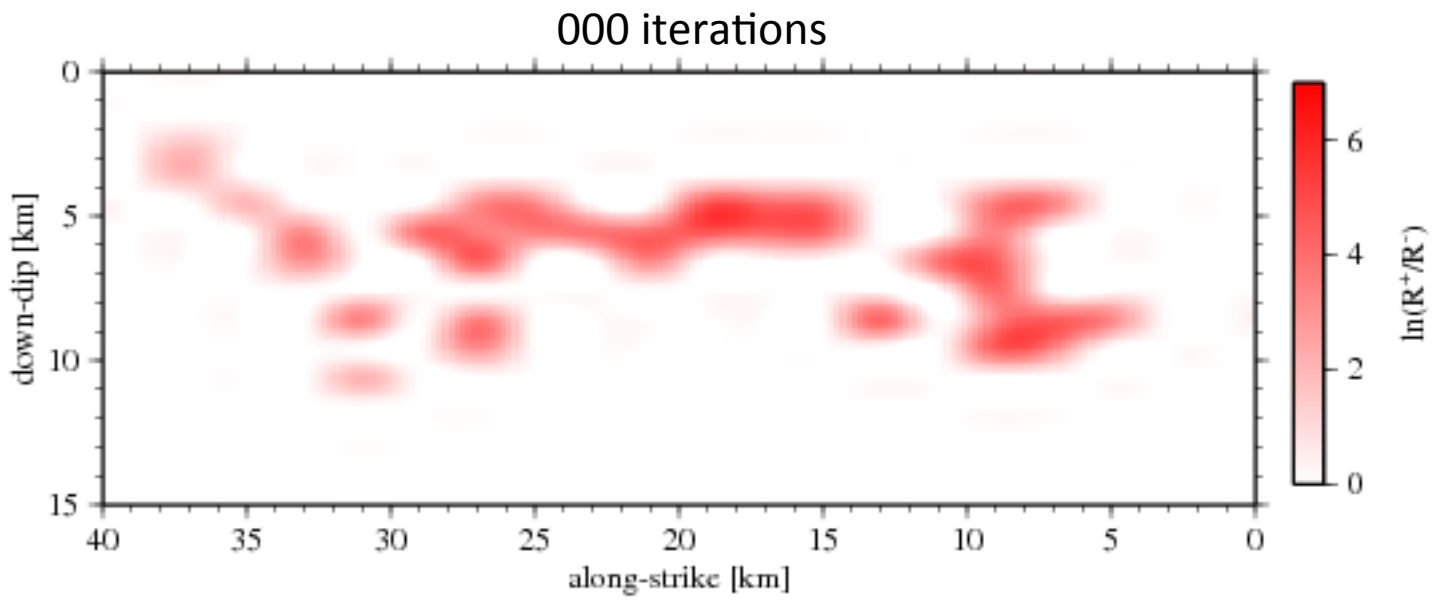
- γ is a s a relative weight ratio that accounts for the length difference of the two data vectors

$$\gamma_{\beta=0} \approx \left\| Wd^{\text{obs}} \right\| / \left\| \tau^{\text{obs}} \right\|$$

- Equations 1, 2 and 3 are solved for *u*, using the NNLS algorithm.

The joint GPS and aftershock data: The grid

The fault plane is discretized non-uniformly using a quadtree algorithm (Budiman et al., 2007):



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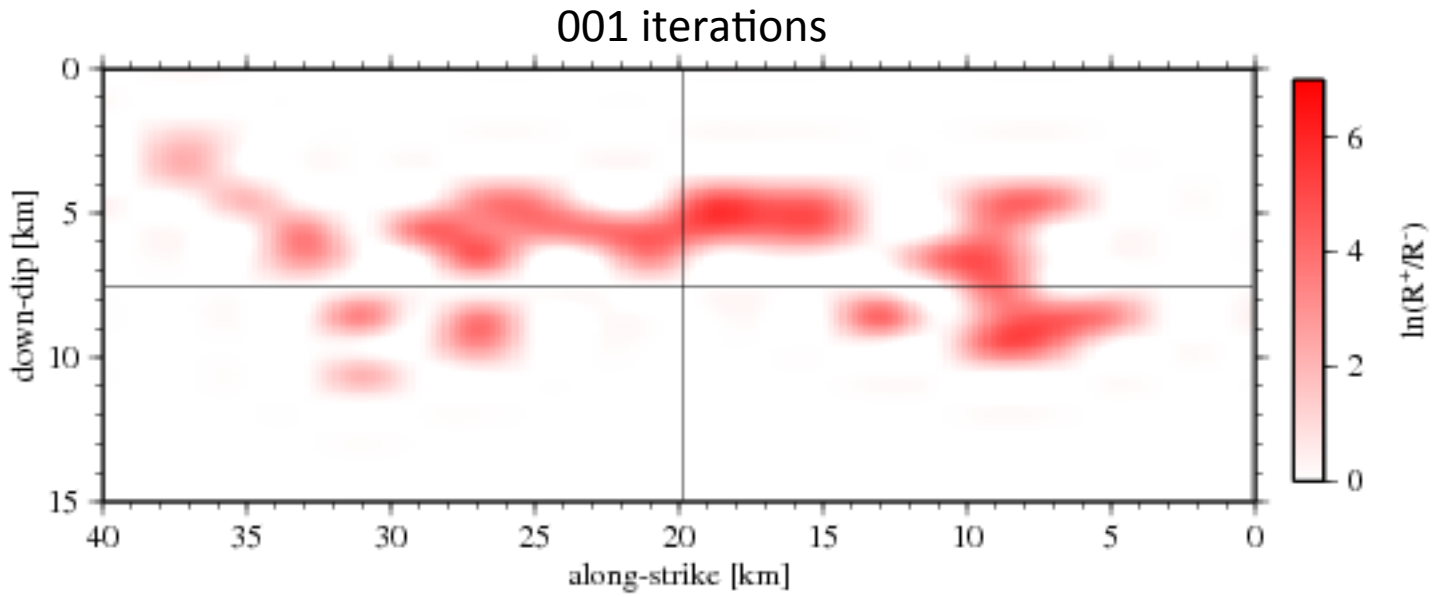

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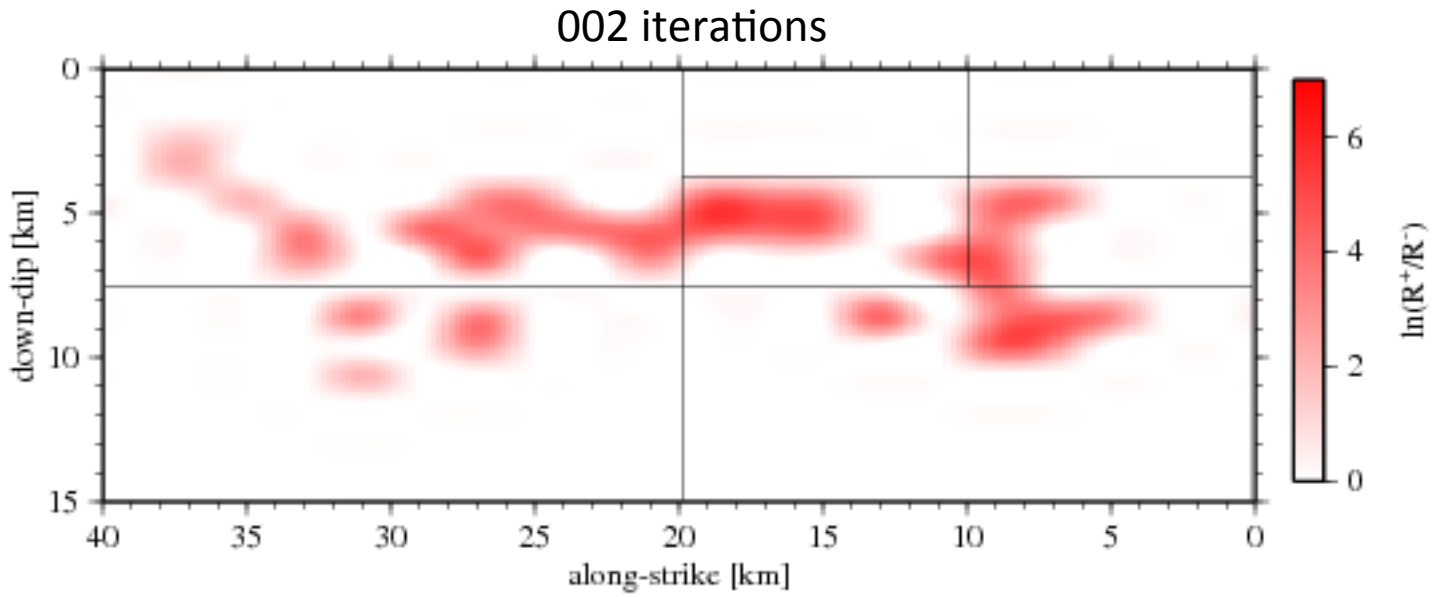

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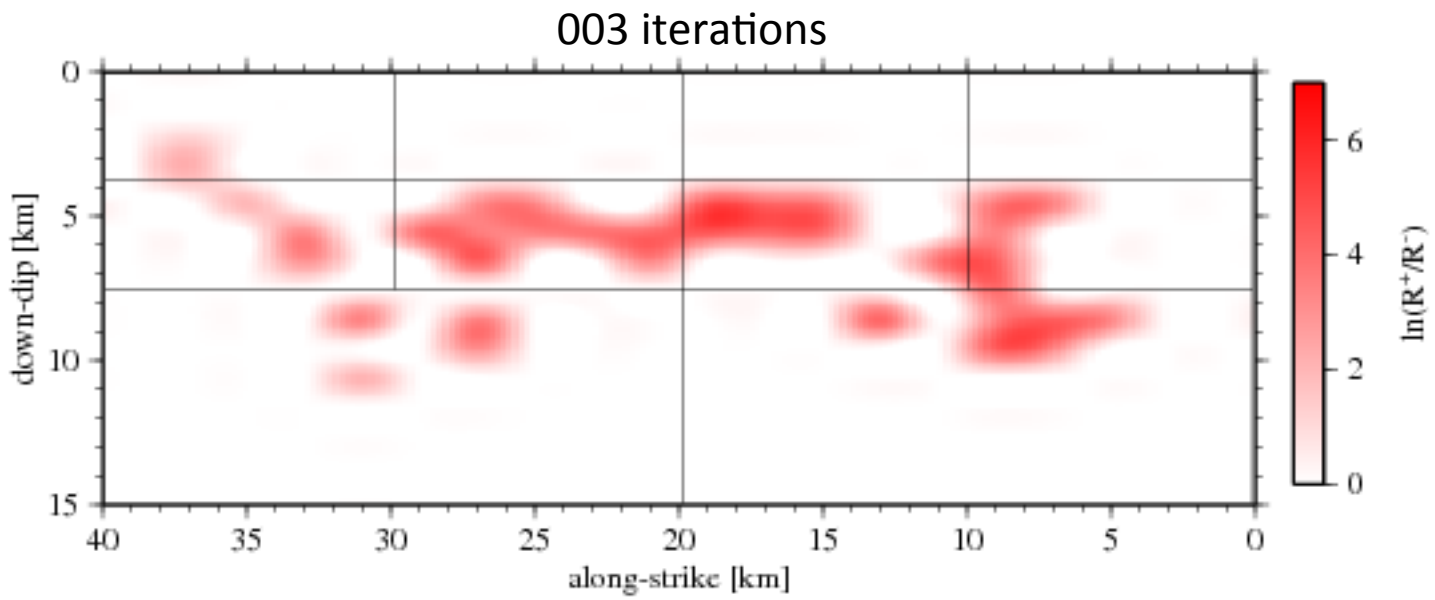

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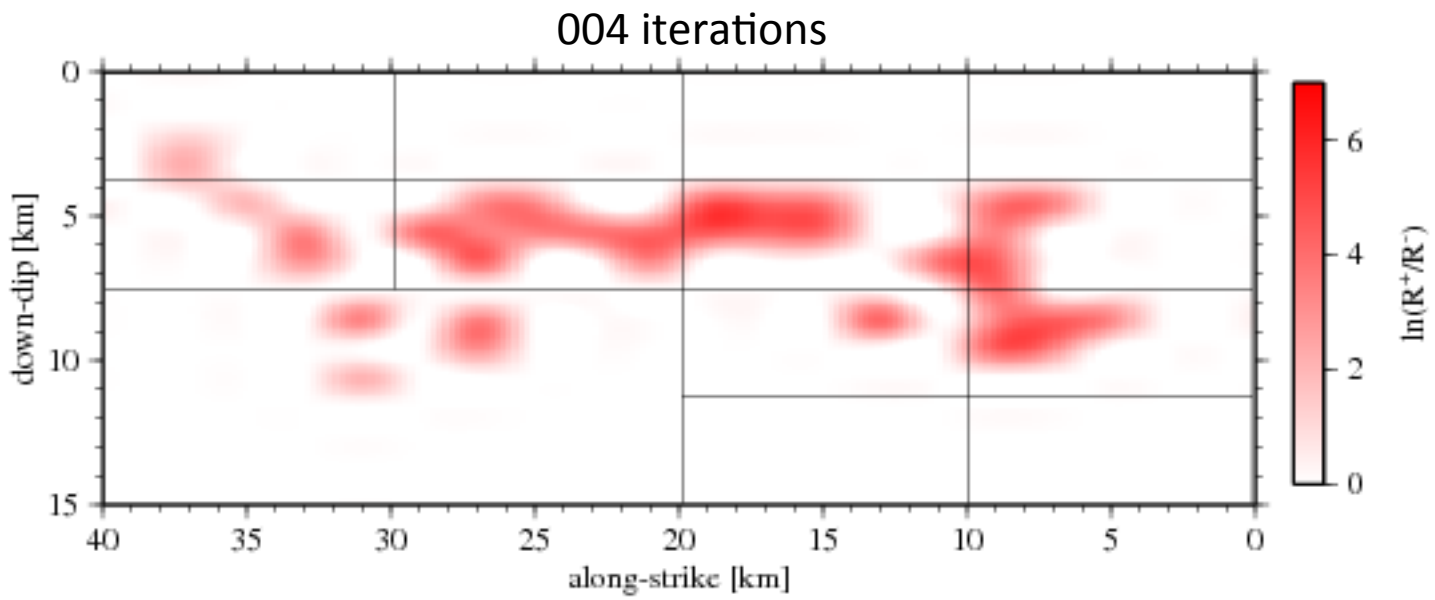

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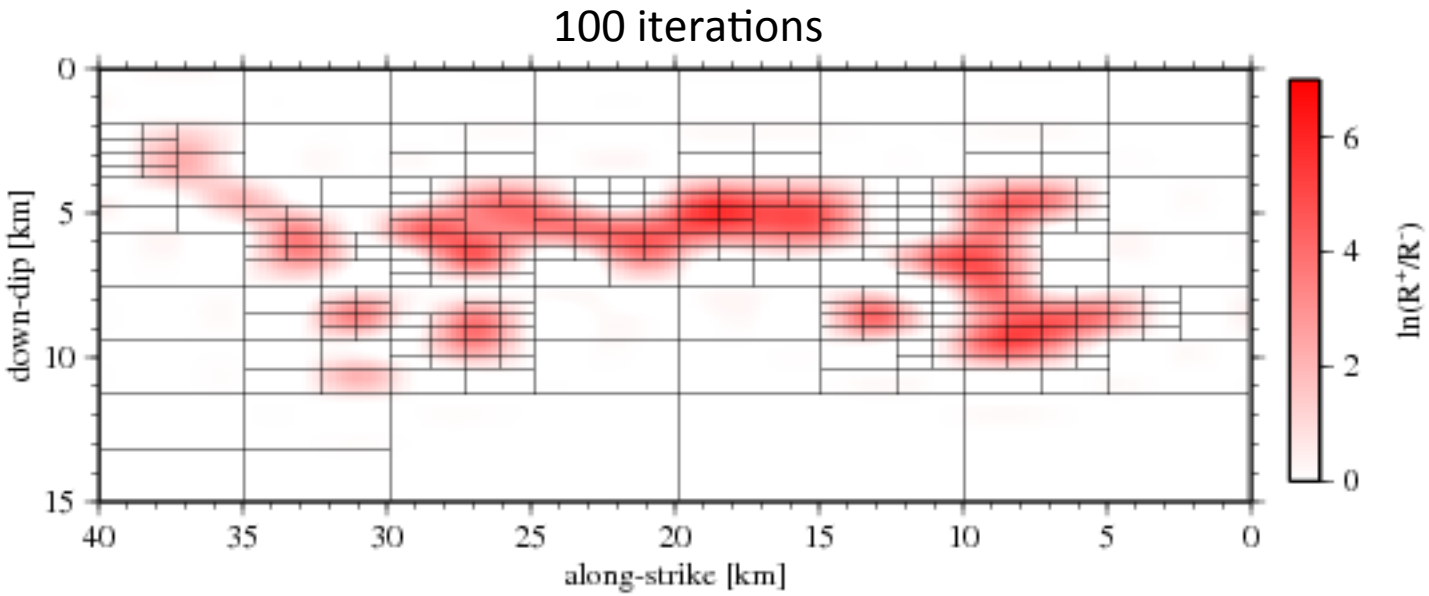

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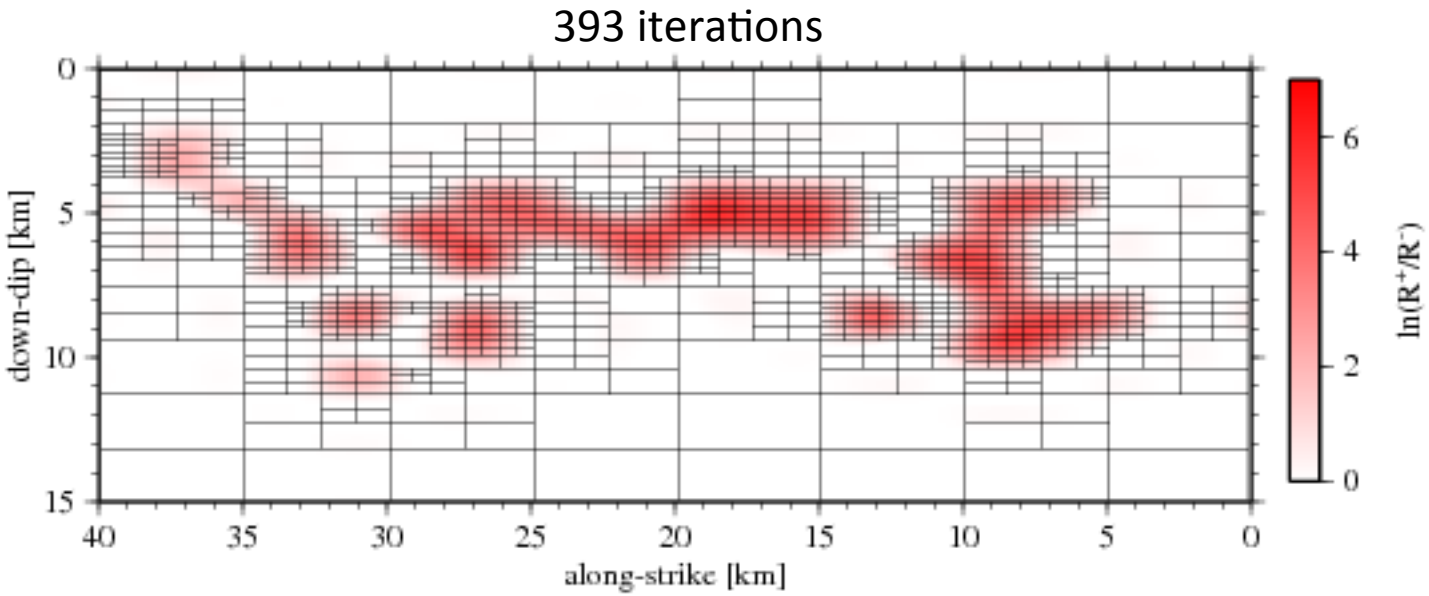

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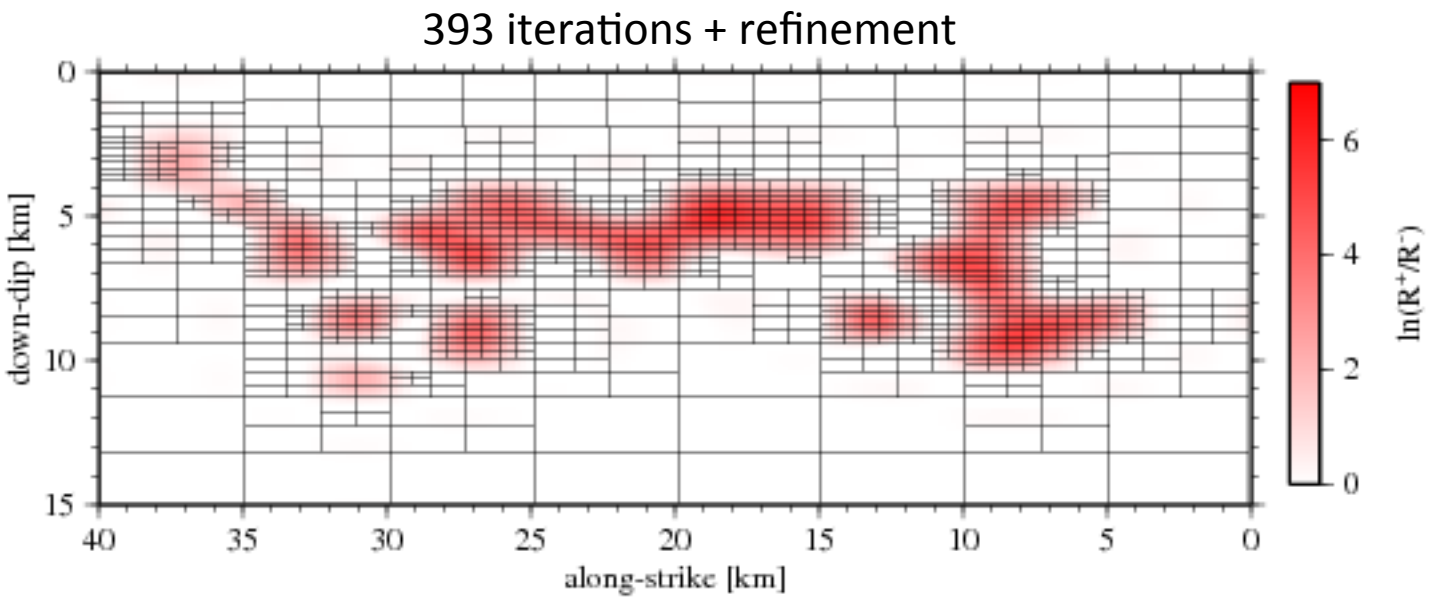
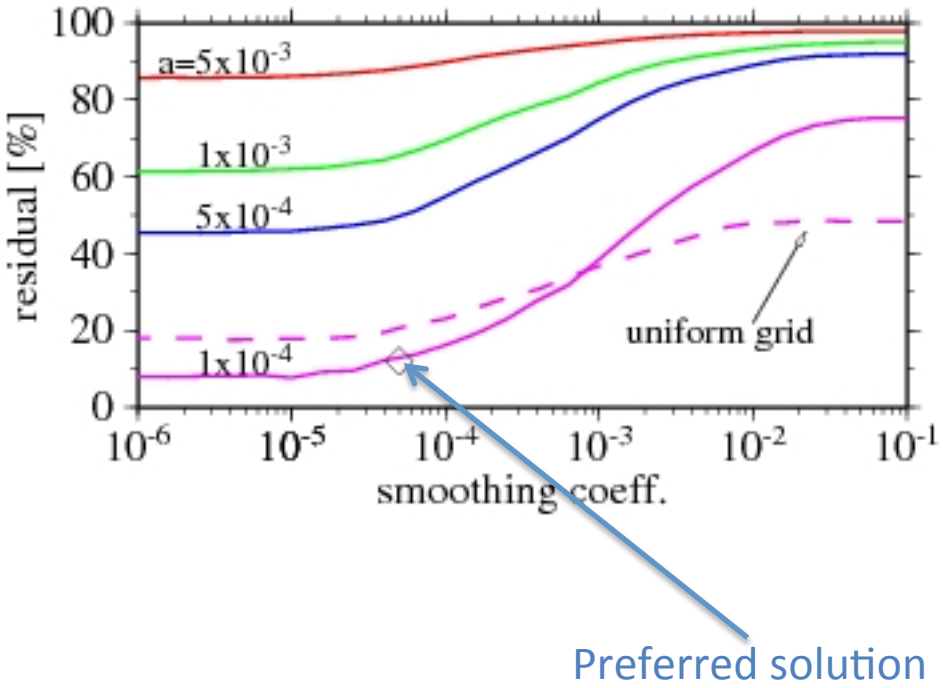


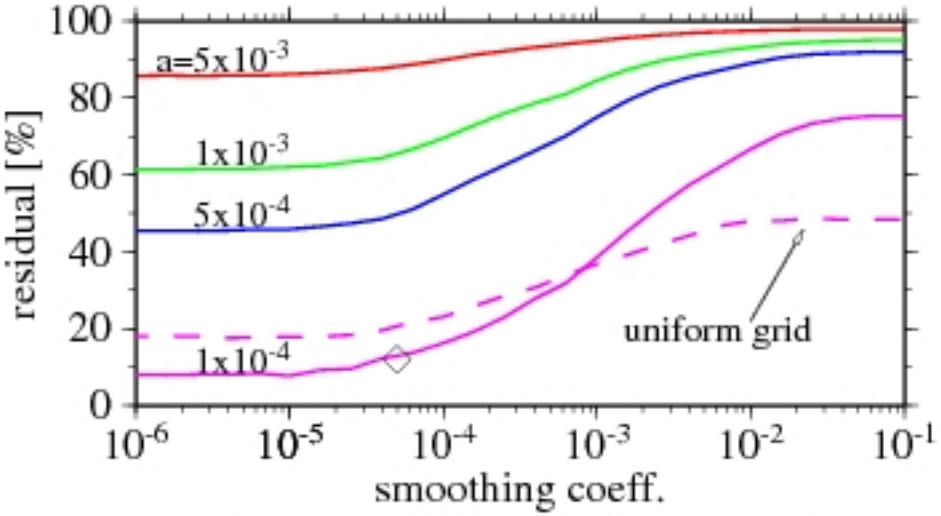
The joint GPS and aftershock data: Inversion result

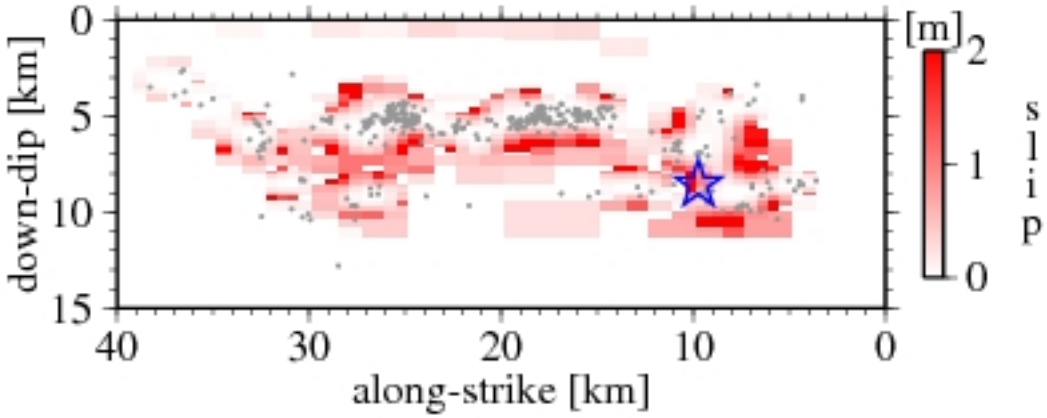


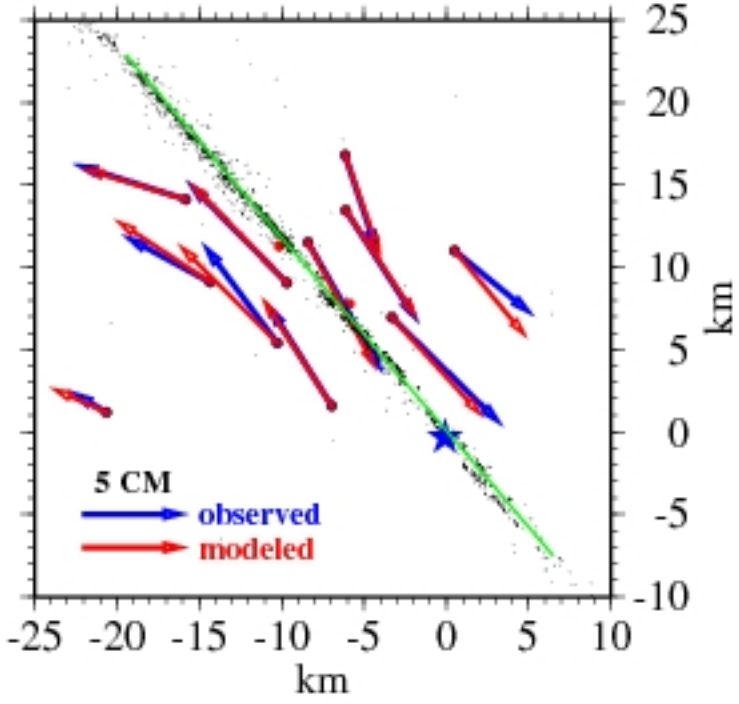
•Our joint inversion provides an upper bound on the frictional properties of fault patches that have experienced aftershock activity.

•We find that satisfying fit to both aftershocks and GPS data sets can only be obtained for a constitutive friction parameter that is more than an order of magnitude lower than the laboratory values.

The joint GPS and aftershock data: Inversion result







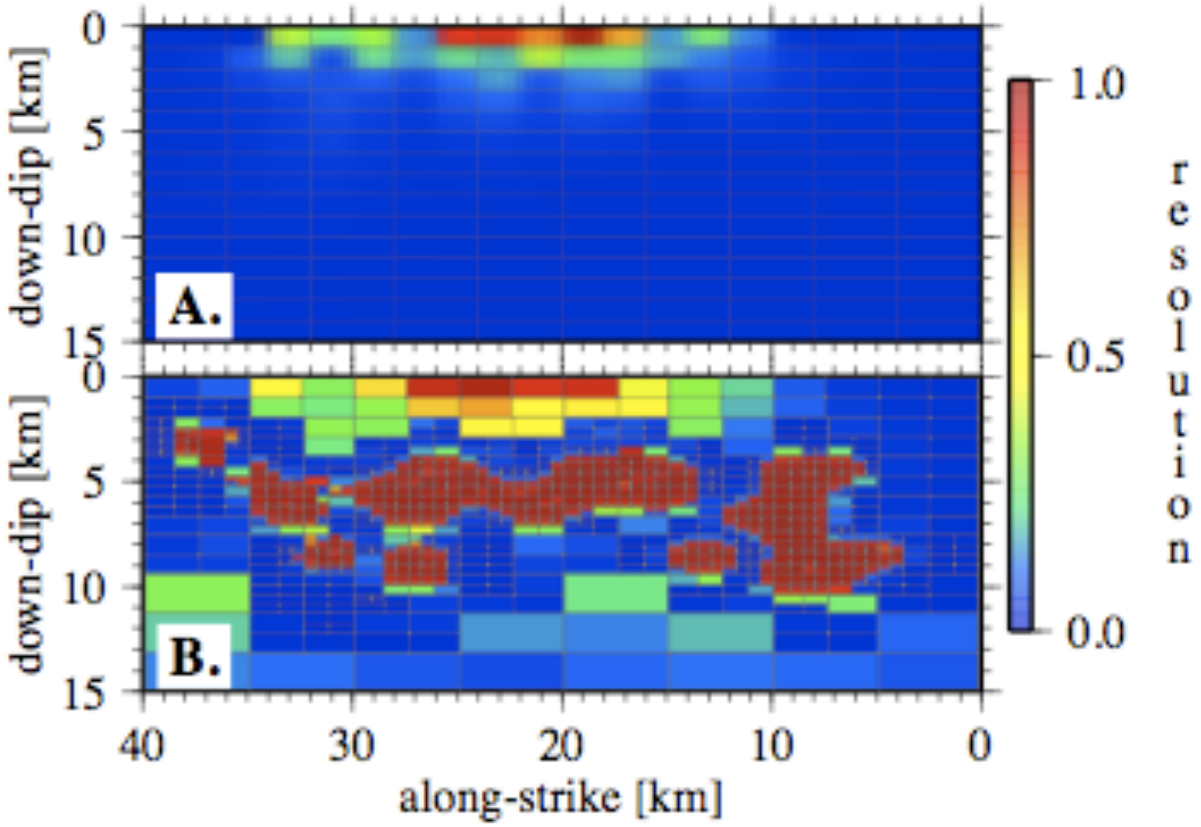
- A consequence of the irregular aftershock distribution is that the slip distribution is extremely non-smooth, with the aftershock zones acting as barriers.

- The preferred model shows significant slip near the hypocenter.

The joint GPS and aftershock data: Inversion result

GPS-only

Joint GPS - aftershocks



Conclusions:

- It is possible to find a slip model that satisfies both geodetic and aftershock datasets.

- Use of aftershock data enhances the resolution.

- Experimentally obtained *a* values cannot explain aftershock distribution – more than 1 order of magnitude smaller values can.

THANK YOU!