UCERF3 Planning Meeting, December 1-2, 2009

Magnitude-Area Scaling of Strike-Slip Earthquakes

Paul Somerville, Robert Graves and
Seok Goo Song

URS Pasadena

Magnitude-Area Scaling of Strike-Slip Earthquakes

- Review of data and methods
- Different functional forms: SS, L, W, SSA
- The key issue – depth extent of slip
- Implications for strong ground motion simulation
- How to improve depth resolution of slip
- Include ground motion prediction tests in UCERF3 model testing?

Priority Science Objectives for SCEC3

- 1. Improve the unified structural representation and employ it to develop system-level models for earthquake forecasting and ground motion prediction
- **2. Develop an extended earthquake rupture forecast to drive physics-based SHA**
- 3. Define slip rate and earthquake history of southern San Andreas fault system for last 2000 years
- 4. Investigate implications of geodetic/geologic rate discrepancies
- 5. Develop a system-level deformation and stress-evolution model
- 6. Map seismicity and source parameters in relation to known faults
- 7. Develop a geodetic network processing system that will detect anomalous strain transients
- 8. Test of scientific prediction hypotheses against reference models to understand the physical basis of earthquake predictability
- 9. Determine the origin and evolution of on- and off-fault damage as a function of depth
- 10. Test hypotheses for dynamic fault weakening
- 11. Assess predictability of rupture extent and direction on major faults
- 12. Describe heterogeneities in the stress, strain, geometry, and material properties of fault zones and understand their origin and interactions by modeling ruptures and rupture sequences
- **13. Predict broadband ground motions for a comprehensive set of large scenario earthquakes**
- 14. Develop kinematic rupture representations consistent with dynamic rupture models
- 15. Investigate bounds on the upper limit of ground motion
- 16. Develop high-frequency simulation methods and investigate the upper frequency limit of deterministic ground motion predictions
- 17. Validate earthquake simulations and verify simulation methodologies
- 18. Collaborate with earthquake engineers to develop rupture-to-rafters simulation capability for physics based risk analysis
- 19. Prepare post-earthquake response

SCEC3 Priority Science Objectives

- 2. **Develop an extended earthquake rupture forecast to drive physics-based SHA**
- 1, 3-12. Itemization of 2.
- 13. **Predict broadband ground motions for a comprehensive set of large eq scenarios**
- 14-18. Itemization of 13.
- 19. Prepare post-earthquake response

Include ground motion prediction tests in UCERF3 model testing?

Data Types for Area Estimation

- Indirect measurements (aftershock zone; surface rupture length):

  Wells & Coppersmith (1994); Hanks & Bakun (2002); WGCEP(2002)

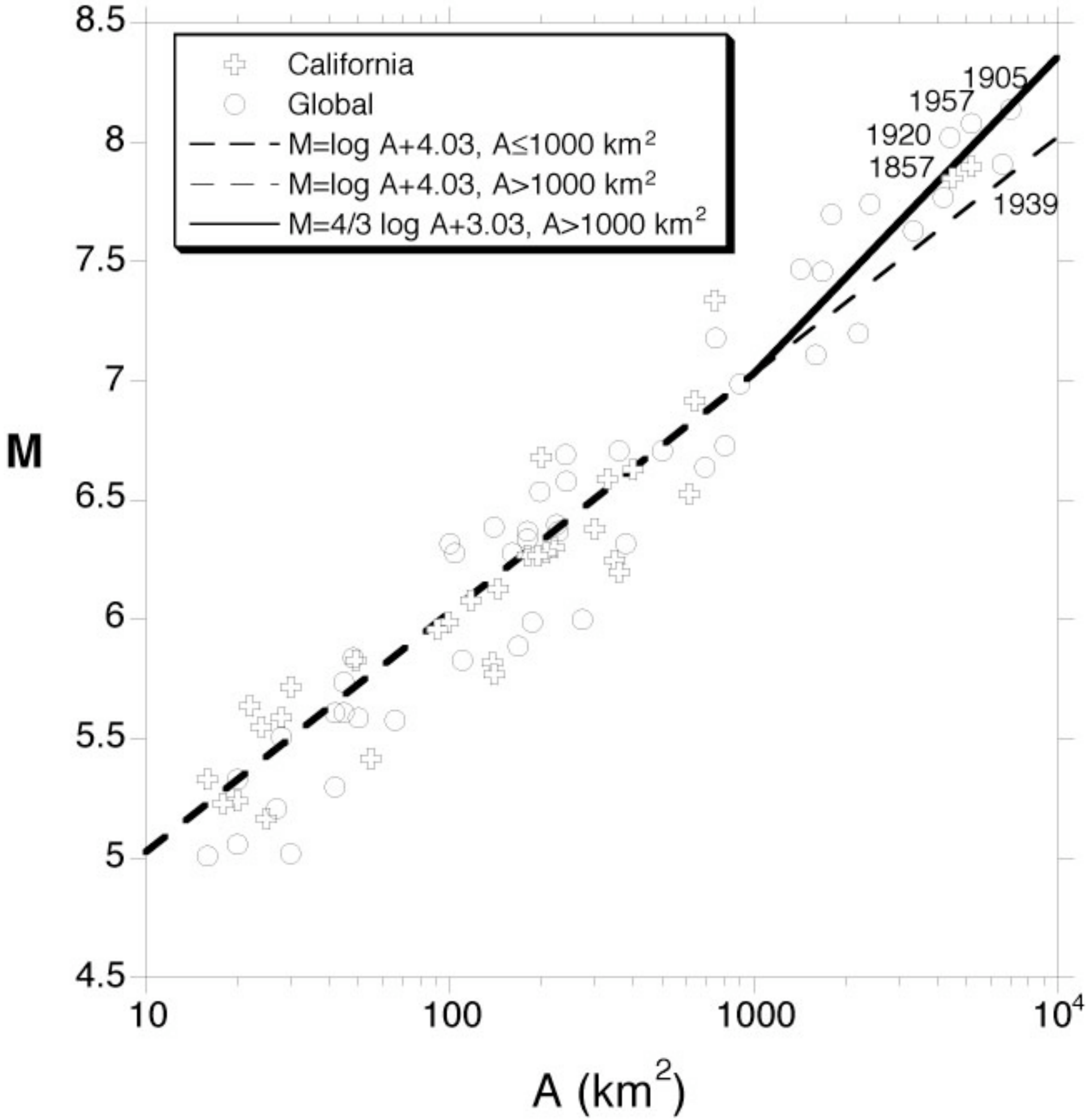
- Direct measurements from rupture models derived from seismic radiation:

  Somerville et al. (1999); Mai & Beroza (2000), Somerville (2006)

Comparison of Data used by WCGEP (2002) and Somerville (2006): 1999 Izmit Earthquake

AUTHOR	AREA		METHOD
	Untrimmed	Trimmed	
Delouis et al. (2002)	2550		Slip model inversion
Wright et al. (2001)	1700		INSAR
Yagi & Kikuchi (2000)	1050		Preliminary automated slip model inversion
AVERAGE - WGCEP	**1767**		
Bouchon et al. (2002)	2790	2790	Slip model inversion
Delouis et al. (2002)	3882	2700	Slip model inversion
Sekiguchi & Iwata (2002)	3285	2796	Slip model inversion
Thio et al (2004)	3040	2800	Slip model inversion
AVERAGE – Somerville	3249	**2772**	

Change in M-A Scaling at M 7: Hanks & Bakun, 2002



Different functional forms for M_o – A

Below transition:

- **SSim: D ~ L ~ W ~ $Mo^{1/3}$** (Mo = u D L W)

Above transition: **W saturates**

- **L: D ~ L - growing (large D, small A)** **Hanks & Bakun**
- **W: D ~ W - const (small D, large A)**
- **SSA: D ~ $Mo^{1/3}$ (intermediate between L and W;** **no change at transition)** **W&C; Somerville**

  e.g. W saturates and L compensates by growing faster

  e.g. W does not completely saturate

SSim = self-similar; SSA = self similar in area

Magnitude – Area Relations

$$M = \log(A) + k$$

A = **L**ength x **W**idth x **R** (seismic coupling factor)

- Wells and Coppersmith (W&C, 1994) widely used in hazard analysis
- Good agreement between W&C and kinematic rupture models derived from seismic waves
- Application of W&C to WG02 fault model overpredicts historical seismicity rate
- WG02 adopted 3 relations for large earthquakes:

$M = 3.98 + 1.02 \log(A)$ (W&C)

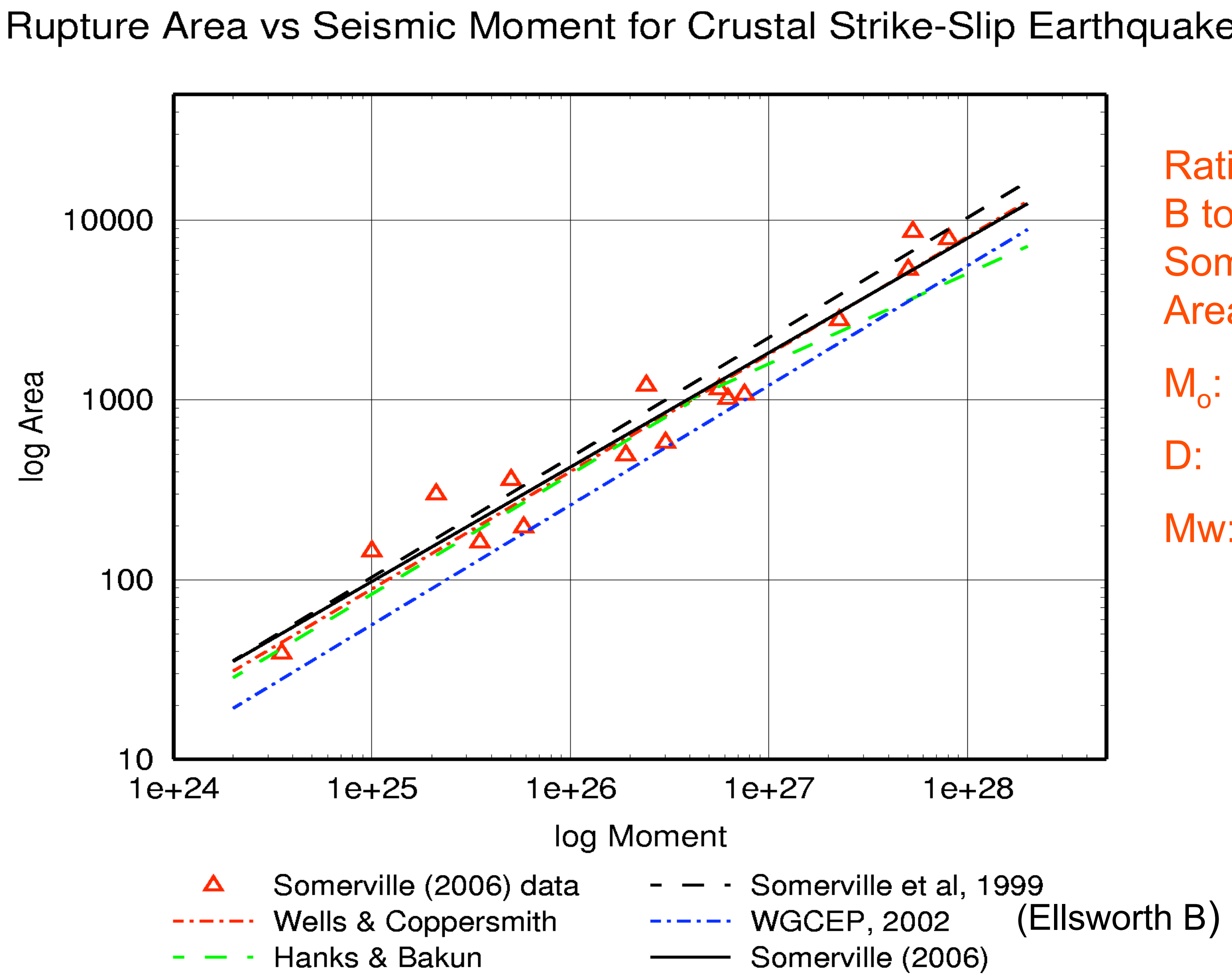
$M = 4.2 + \log(A)$ (Ellsworth)

$M = 3.03 + 4/3 \log(A)$ (Hanks & Bakun)

- WG07 eliminated W&C

Modified from Ellsworth

Moment – Area Scaling Relations



Ratio of Ellsworth B to W&C/ Somerville for fixed Area:

M_o: 2

D: 2

Mw: 0.2

Key Issues

GENERAL AGREEMENT

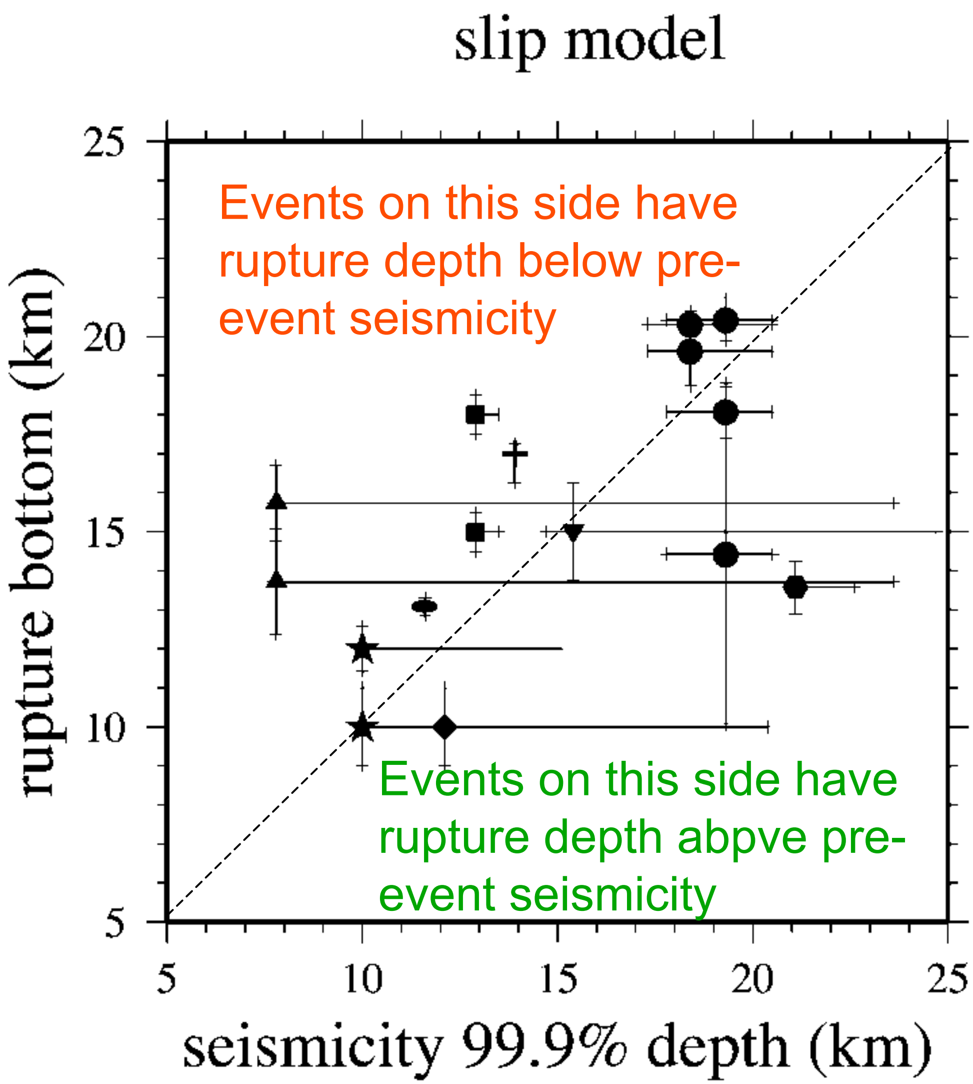
- The depth distribution of slip is poorly resolved in current earthquake rupture model inversions

  (Hence SCEC SIV Working Group)

DISAGREEMENT

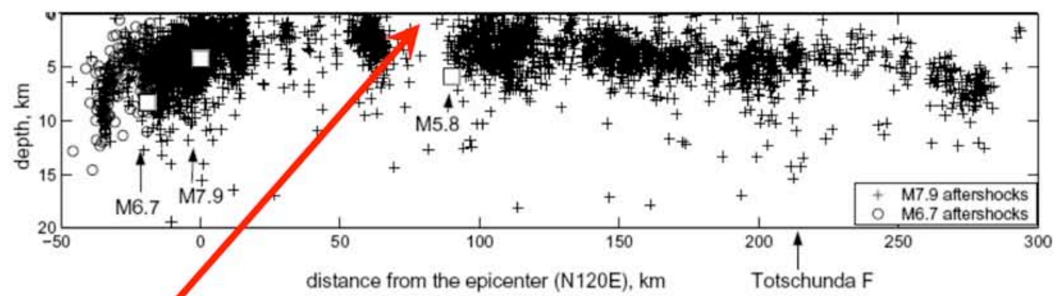
- The base of background seismicity delineates the base of the rupture zone of large earthquakes

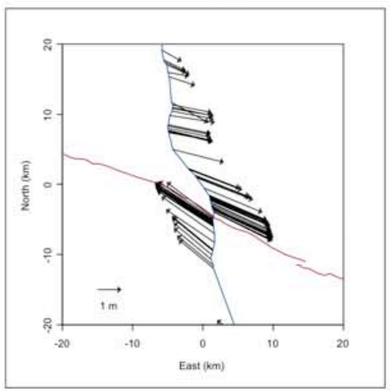
Maximum Depth of Pre-Event Seismicity vs. Bottom of Rupture in Large S. Cal Eqs



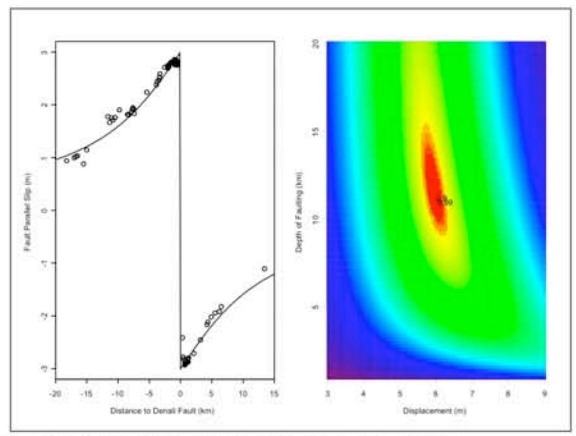
Nazareth & Haukkson

Rupture Depth from GPS – Denali Eq





Fault displacement vectors along the Trans-Alaskan Pipeline



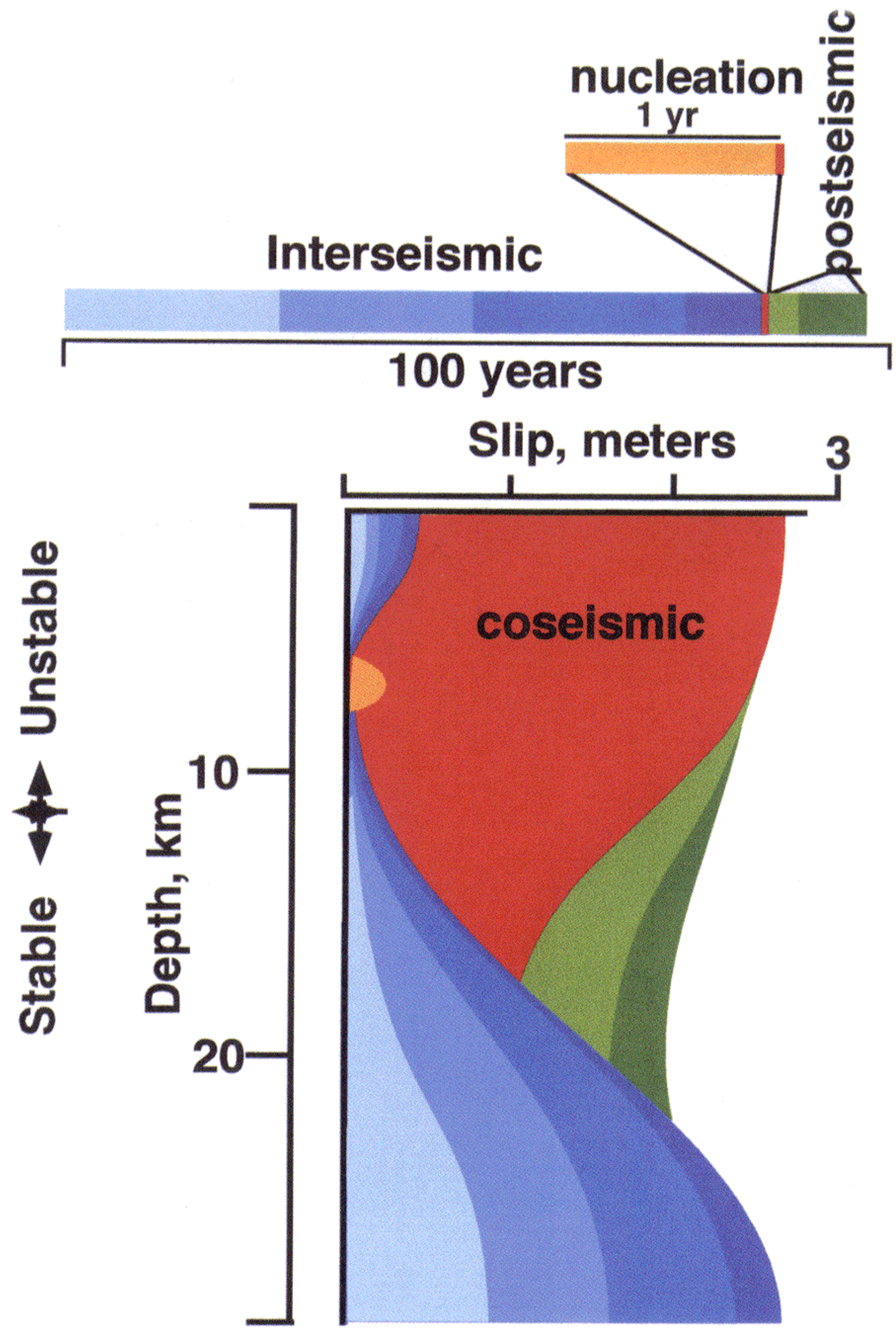
Best model: 5.95 m slip from 0 to 11.6 km

Geodetc inversion: 11.6 km

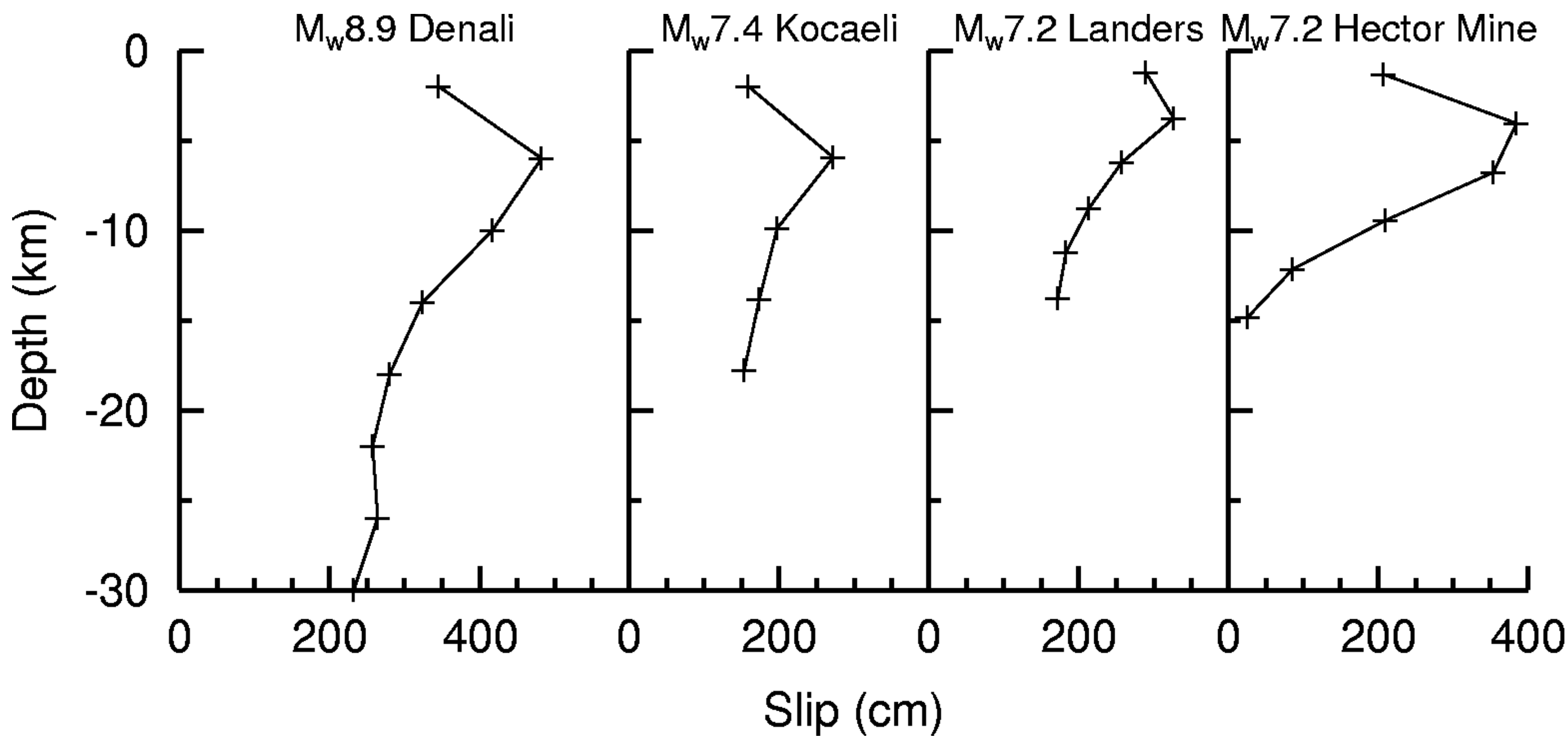
Rupture model inversions: 20 – 30 km

Ellsworth

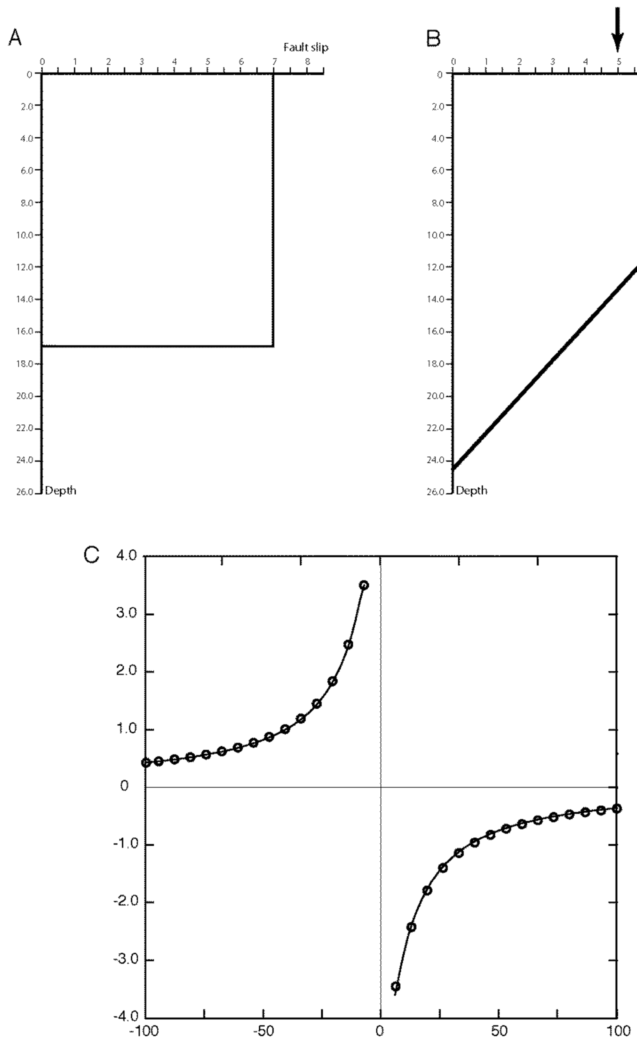
Coseismic zone may extend above and below the brittle seismogenic zone



Slip Depth Profiles from Rupture Model Inversions

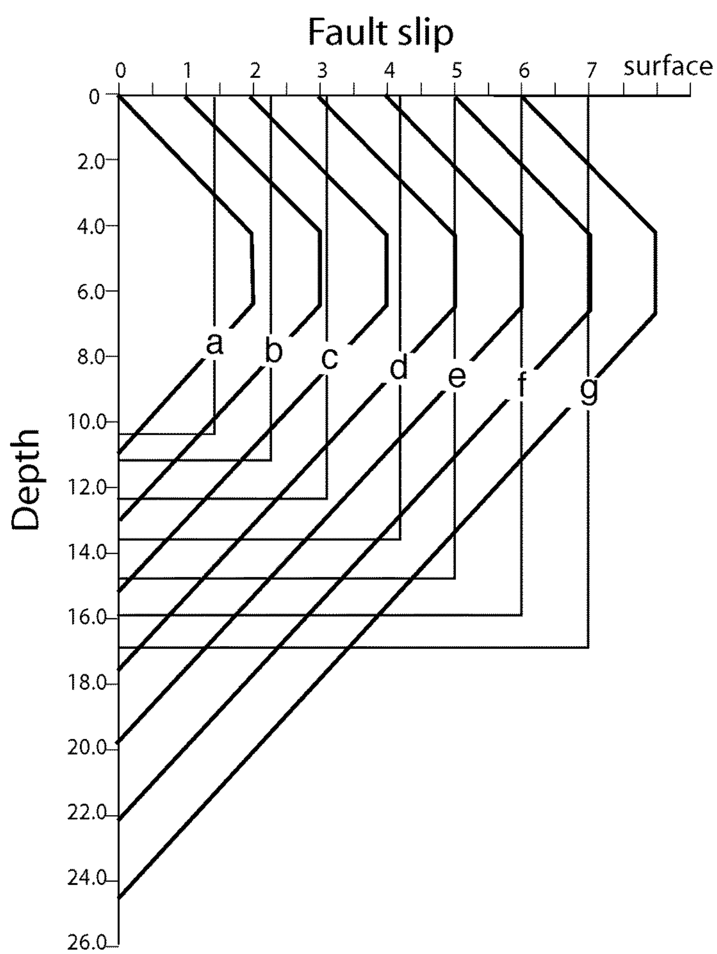


Ambiguity in Depth Distribution of Slip from Geodetic Data



King & Wesnousky

Equivalent Box and Taper Models

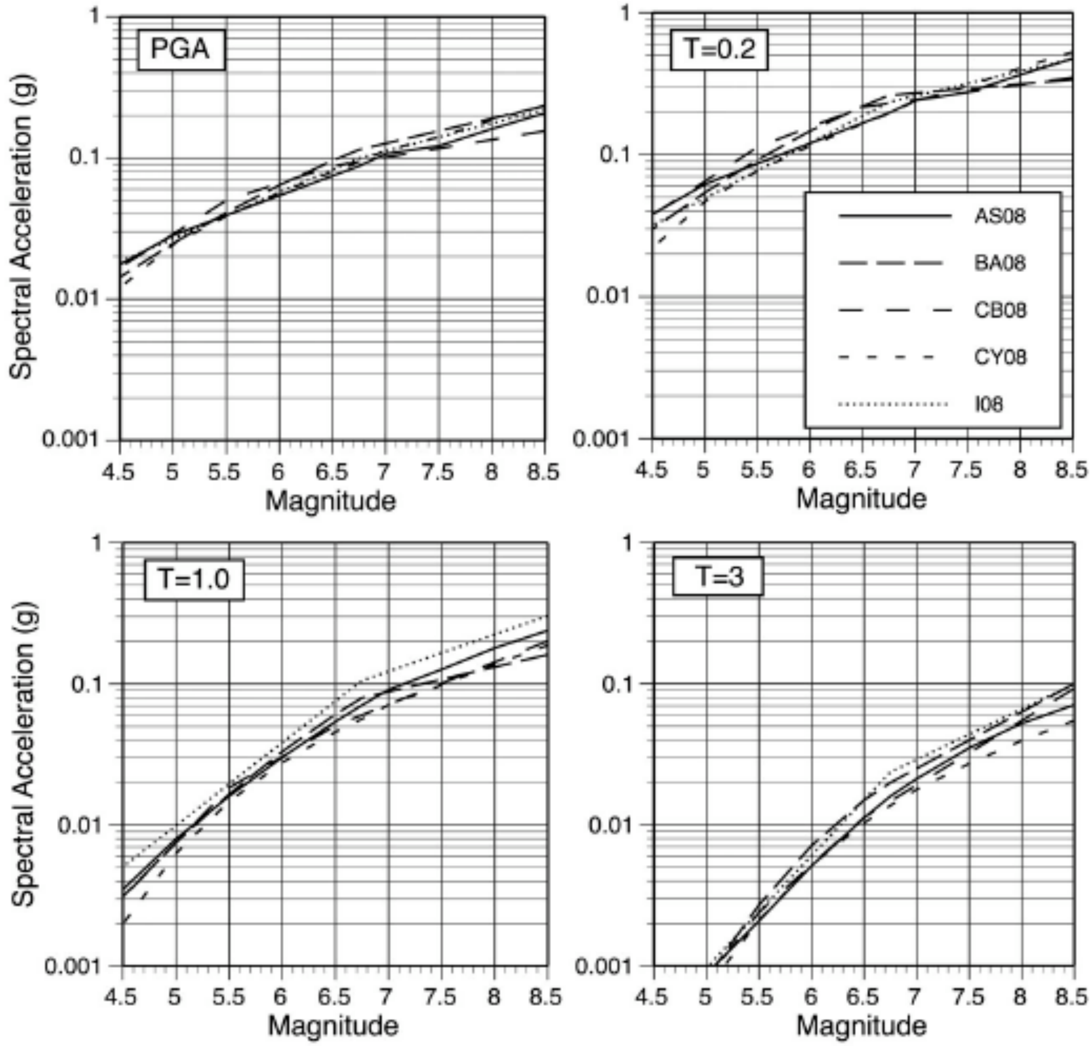


King & Wesnousky

Implications for Strong Motion Simulation

- SSA models produce ground motion simulations that are compatible with recorded long period strong ground motion amplitudes
- L models do not – they predict ground motions that are much too large, especially at long periods
- Graves et al. resorted to using SSA-like models, not L models, in Cybershake in order to match recorded ground motions and prediction models

Observed Change in Magnitude Scaling of Ground Motion Amplitudes



Reduction in observed ground motions for M > 7

L model predicts the opposite trend due to increased slip scaling above M7

Conjecture:

M<7: mainly brittle

M>7: brittle, plus ductile behavior at the top and bottom edges of the rupture zone, with low slip velocity and rupture velocity giving weak ground motions

Improved Resolution of Depth of Slip in Rupture Model Inversions

- Smoothing for regularization is non-physical, degrades the resolution of the inverted model, and introduces bias e.g. in depth extent
- Instead use physically guided regularization e.g. based on spatial autocorrelation of slip
- This can be done using a Bayesian approach e.g. with the spatial autocorrelation of fault slip as a prior distribution

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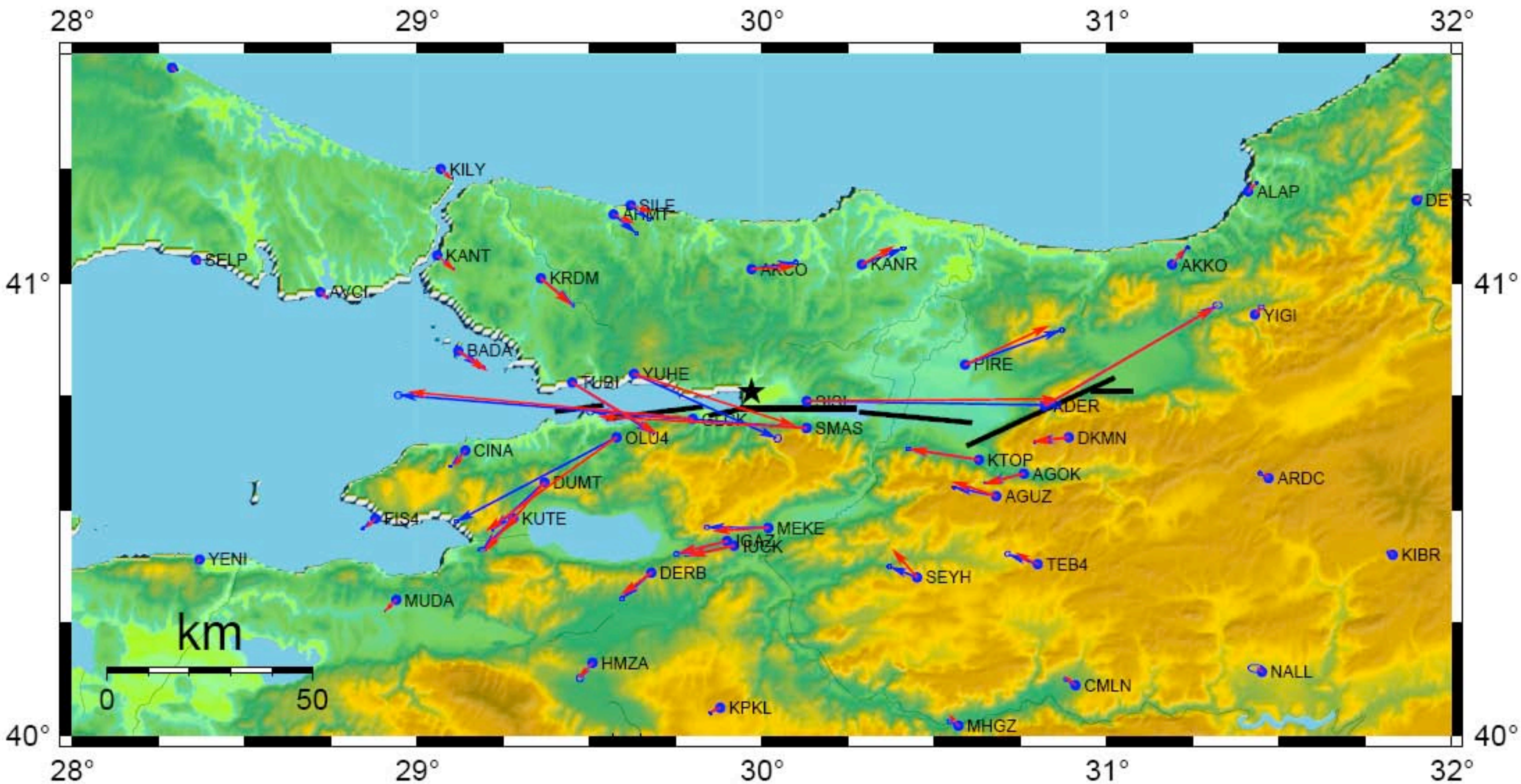
1999 Izmit, Turkey, Earthquake



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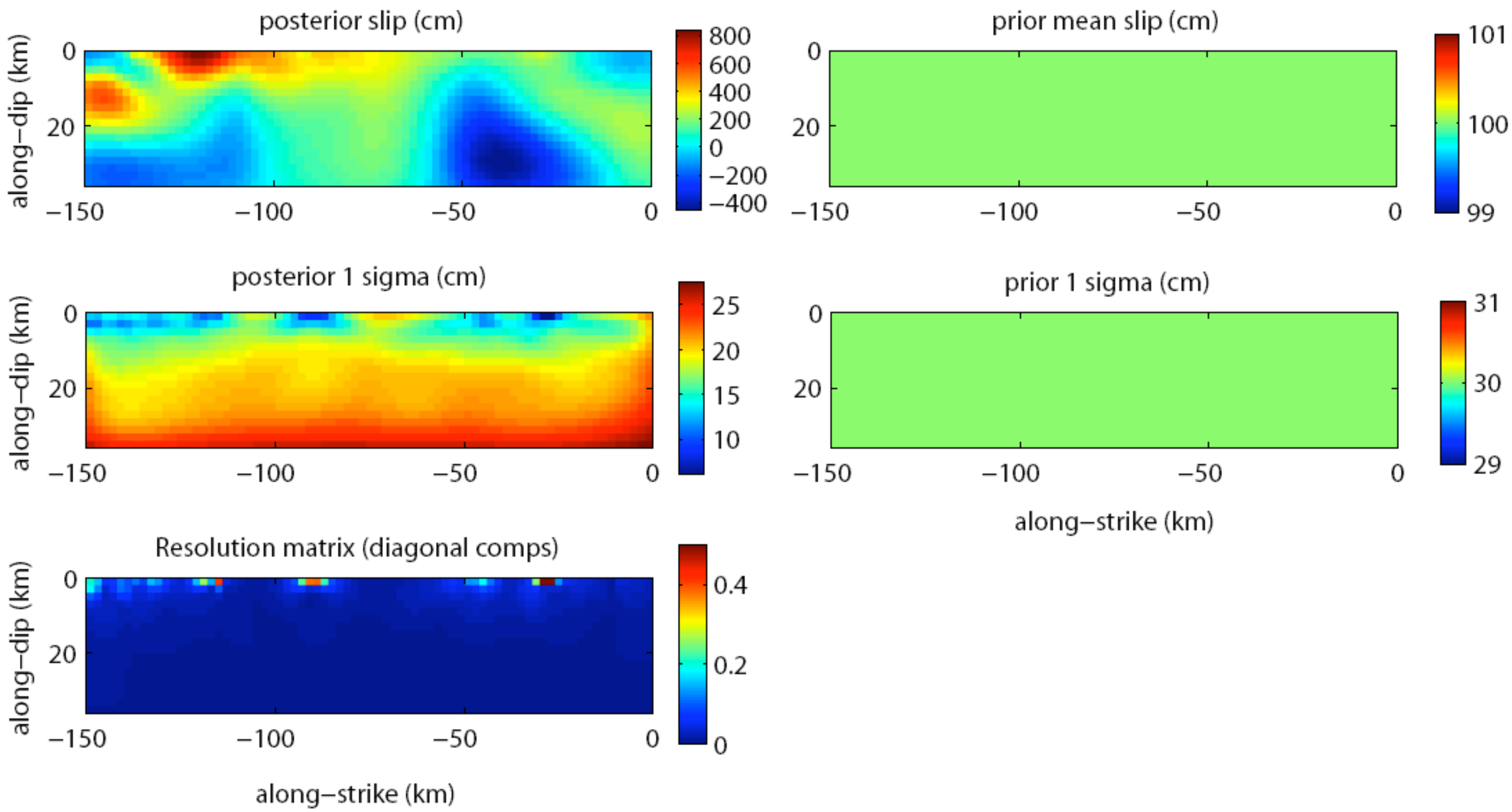
1999 Izmit, Turkey earthquake



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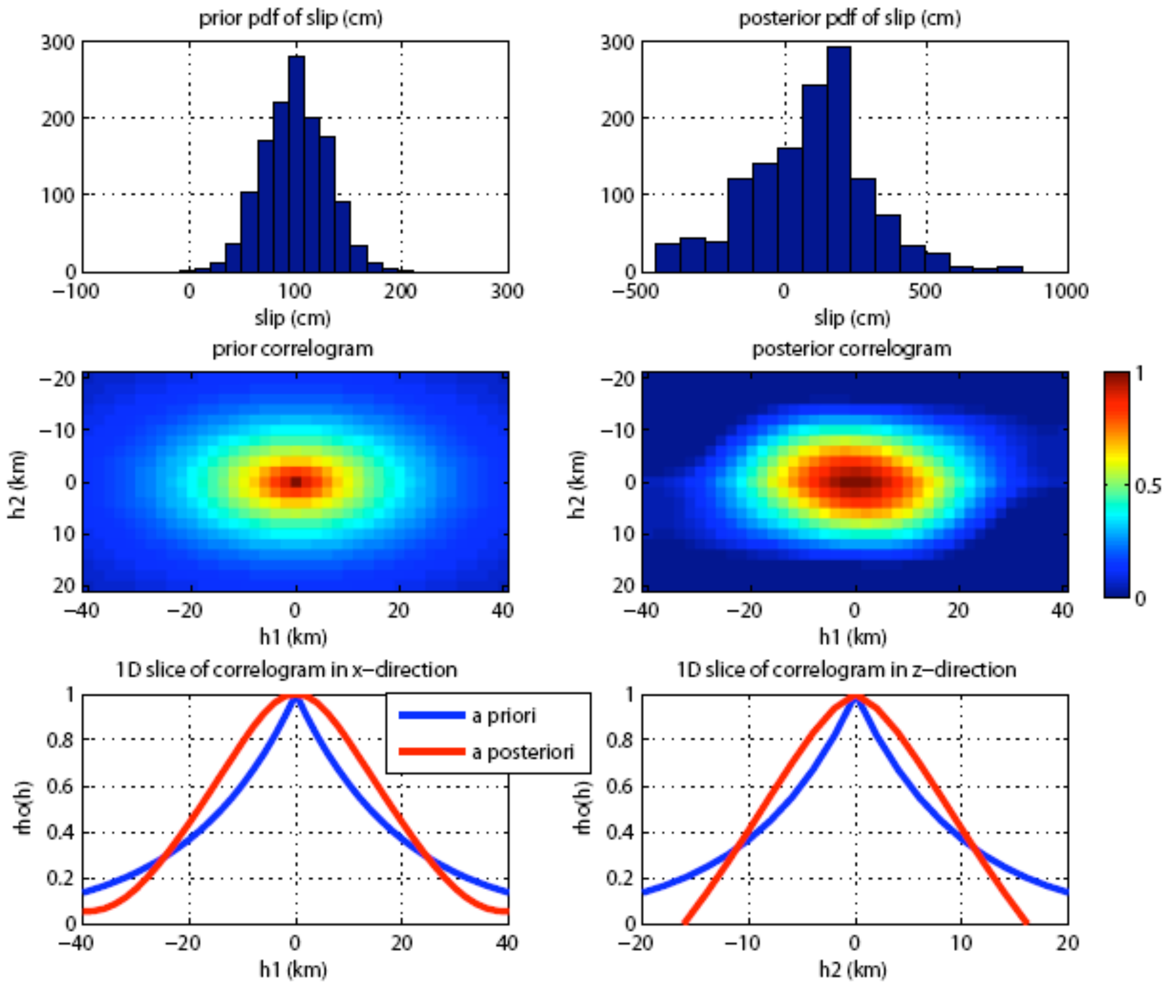
Izmit: Spatial Autocorrelation of Slip Exponential prior -> Gaussian posterior



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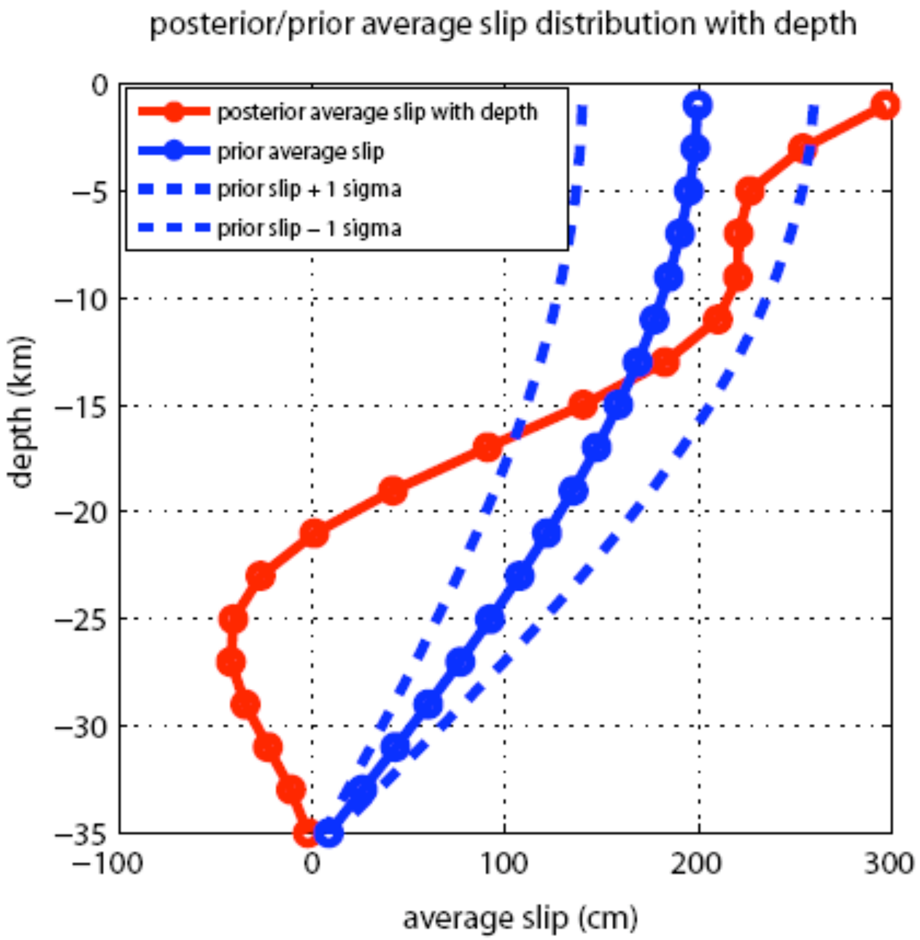
Izmit Eq: Inversion of Depth Profile of Slip using GPS Data



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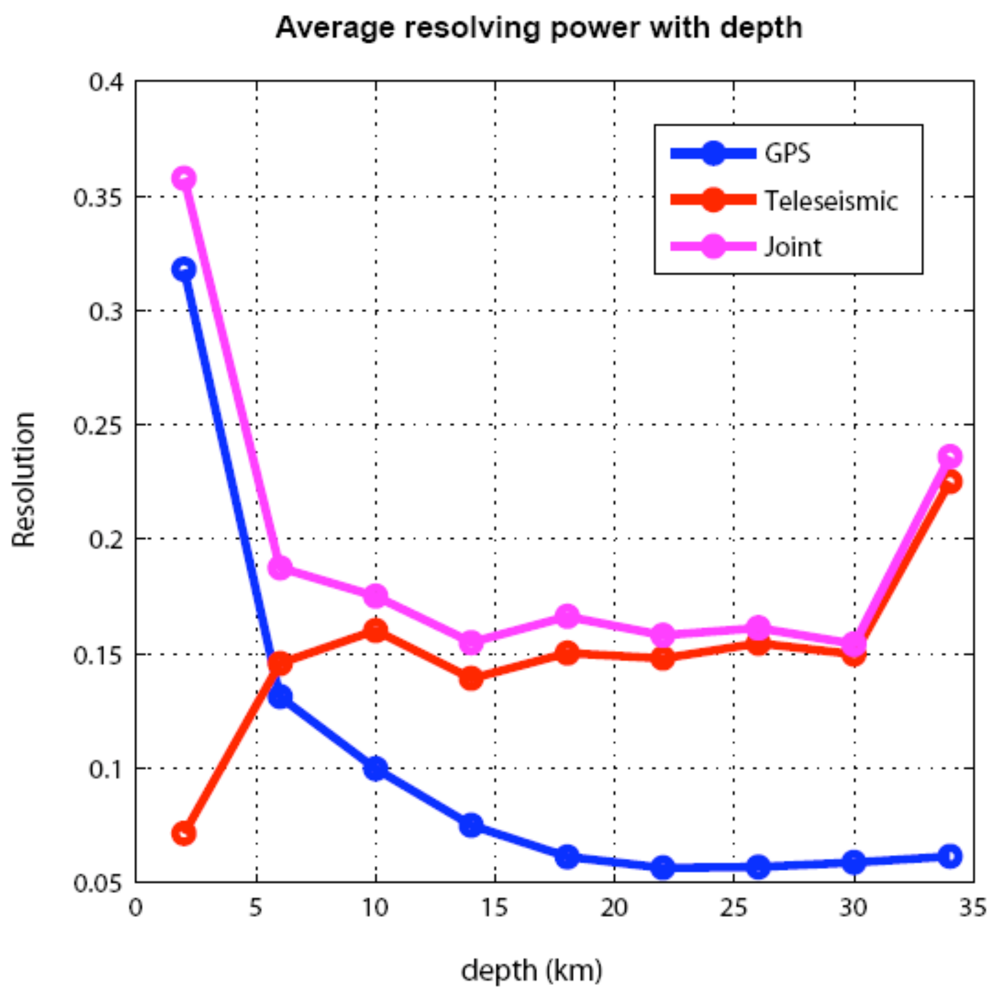
Izmit Eq: Resolving Power of GPS and Teleseismic Data



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Magnitude-Area Scaling of Strike-Slip Earthquakes

- The key issue – depth distribution of slip
- Current WG Magnitude – Area relations are incompatible with strong ground motion data when used for simulation e.g. Cybershake
- Improve depth resolution of slip using physically guided regularization e.g. based on spatial autocorrelation of slip instead of smoothing
- This can be done using a Bayesian approach e.g. with the autocorrelation of slip as a prior distribution

Include Ground Motion Prediction Tests in UCERF3 Model Testing

- **Task 21) Model Testing:** Outline a clear strategy for testing both model predictions and embedded assumptions; coordination through CSEP seems appropriate.
- If GMPE's are used with UCERF, M-A relations may not be a big issue
- If physics-based ground motion simulations are used with UCERF, M-A relations are a big issue