Surface Rupture in Kinematic Ruptures Models for Hayward Fault Scenario Earthquakes

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Surface Rupture from Kinematic Rupture Models

Holistic approach to calculating surface slip

- Objective
  - Calculate surface slip from kinematic rupture models for large scenario earthquakes on the Hayward fault
  - Use Monte Carlo technique to turn assemble probability density function for surface slip from deterministic rupture models
- Constraints
  - Spectral content of radiated seismic waves match observations
  - Reduce coseismic slip in regions with aseismic creep
  - Explicitly include constraints on surface slip (in progress)
  - Include estimates of afterslip (in progress)

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Deterministic Kinematic Rupture Models

Complete description of spatial and temporal evolution of slip

- Spatial description of slip
  - Background slip distribution (if imposing rupture dimensions)
  - Spatial variation of slip (slip heterogeneity)
- Temporal evolution of slip
  - Hypocenter
  - Rupture speed
  - Slip time function

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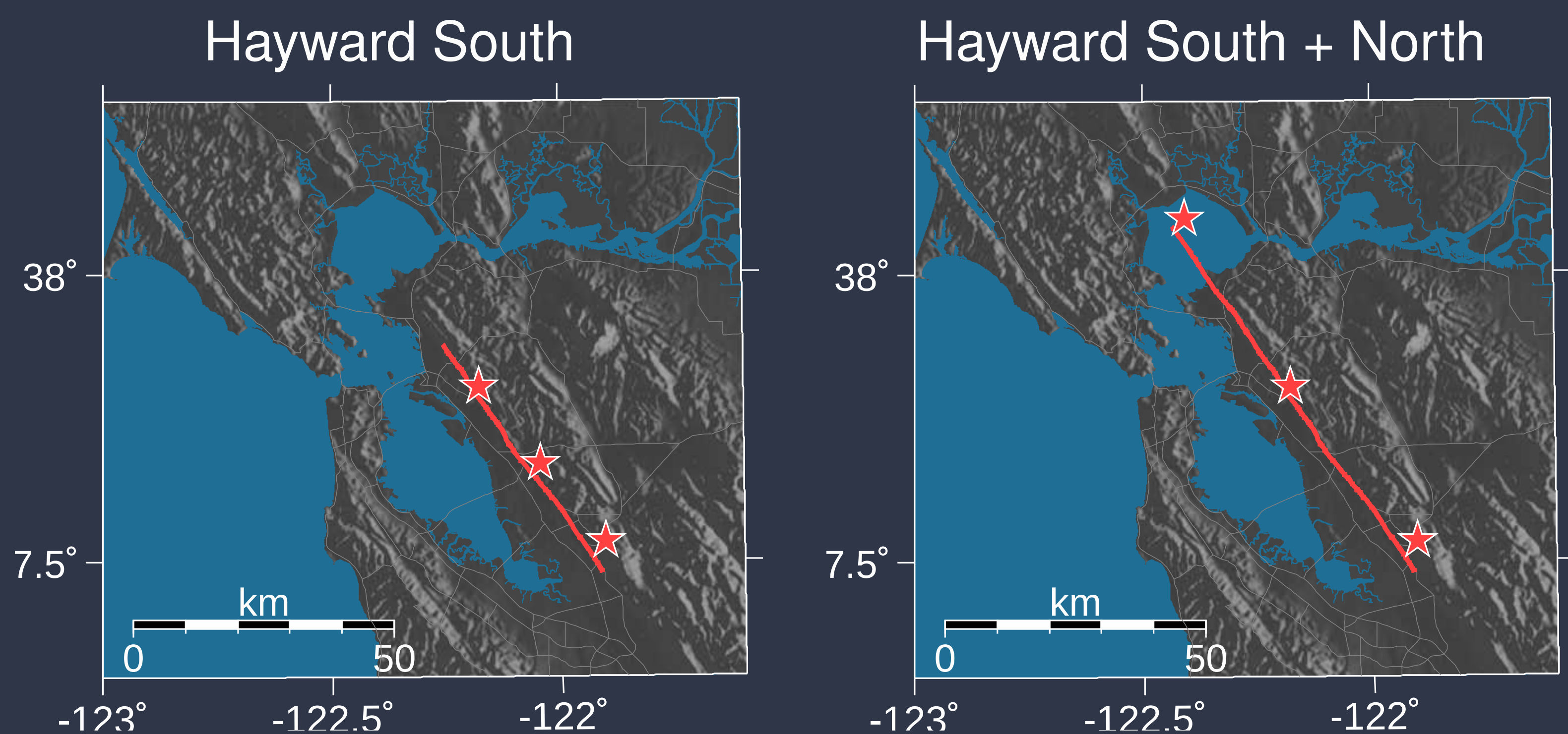
Rupture Lengths and Epicenters

We often impose a rupture length and epicenter in scenarios



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Background Slip Distribution

Imposed rupture dimensions control basic parameters

- Calculate Mw using magnitude-area relation (Hanks and Bakun)

$$M_{\mathrm{w}} = \begin{cases} 3.98 + \log A & \text{if } A < 468\mathrm{km}^2 \\ 3.09 + 4/3 \log A & \text{if } A \geq 468\mathrm{km}^2 \end{cases}$$

- Calculate average slip from rupture area and magnitude

$$D_{avg} = \frac{M_o}{A\mu}$$

- Taper slip along buried edges of rupture

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Example of Background Slip Distribution

Hayward South + North, Mw 7.05

(NW) San Pablo Bay

San Jose (SE)

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Spatial Variation in Slip

Wavenumber spectra characterized by source inversions

- Somerville *et al.*, 1999

$$P(k_x, k_y) = \frac{1}{1 + \left(a_x^2 k_x^2 + a_y^2 k_y^2\right)^2}$$

$$\log a_x = -1.72 + 1/2 M_\mathrm{w}$$

$$\log a_y = -1.93 + 1/2 M_\mathrm{w}$$

- Mai and Beroza, 2002

$$P(k_x, k_y) = \frac{a_x a_y}{(1 + a_x^2 k_x^2 + a_y^2 k_y^2)^{H+1}}, H \approx 0.75$$

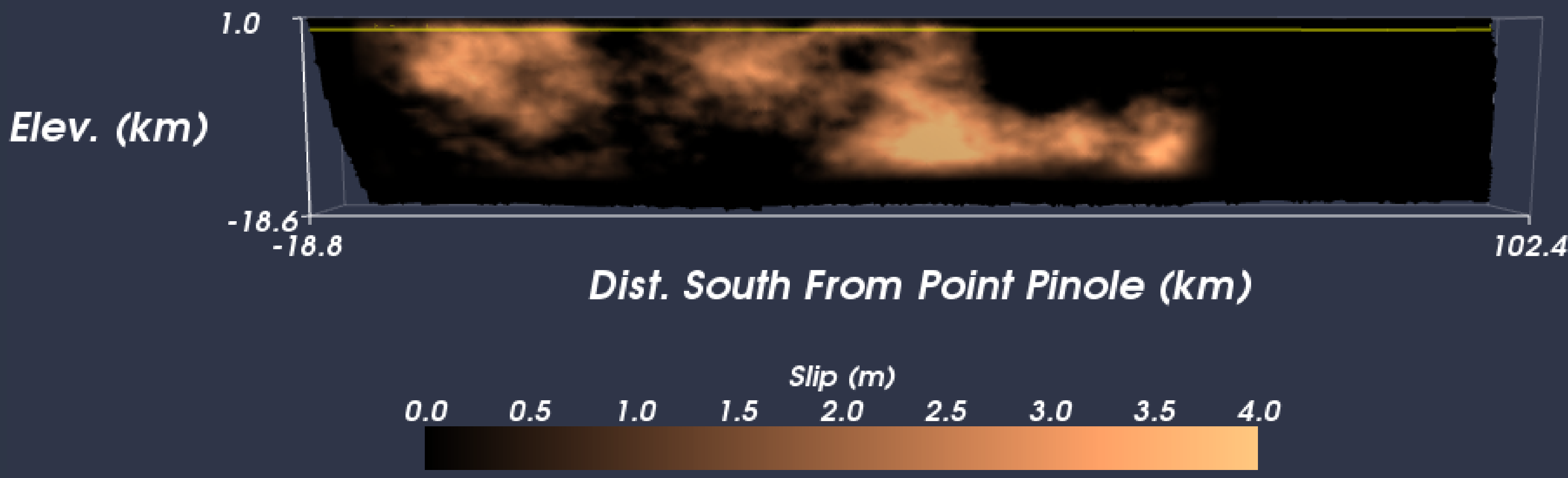
$$\log a_x = -2.5 + 1/2 M_\mathrm{w}$$

$$\log a_y = -1.5 + 1/3 M_\mathrm{w}$$

Blending Background and Spatial Variation

Select wavenumber for cross-over using NGA GMPEs

(NW) San Pablo Bay San Jose (SE)



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Accounting for Creep: Slip-predictable Approach

Reduce background slip according to creep

- Use model from Funning et al. (2007) to define rate and distribution of creep
- Assume no afterslip (for the moment)
- Locked patches

Slip = Elapsed time * Slip rate

- Creeping patches

Slip = Elapsed time * (Slip rate - Creep rate)

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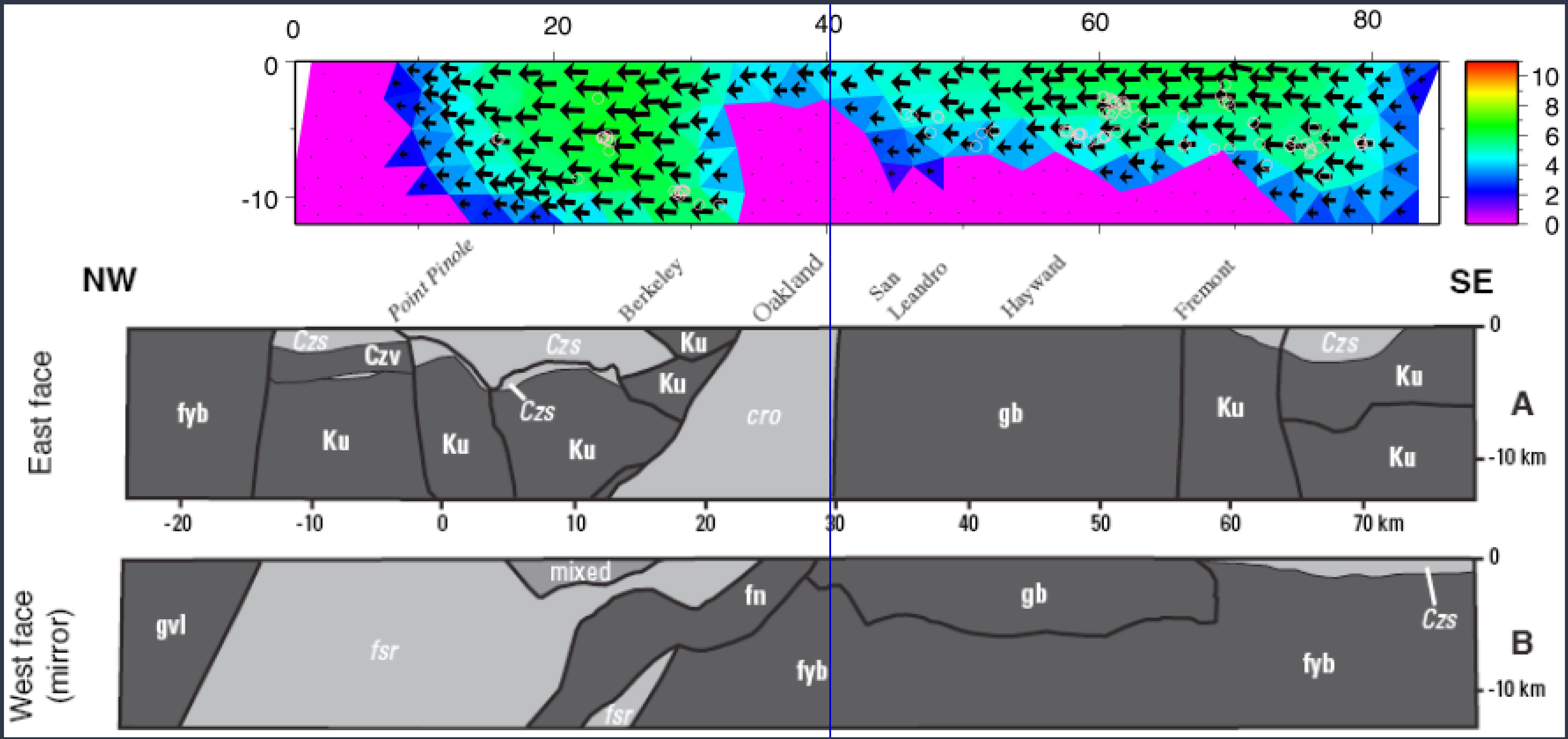
Creep on Hayward Fault: Funning et al. Model

Rate and distribution of creep constrained by geodetic data



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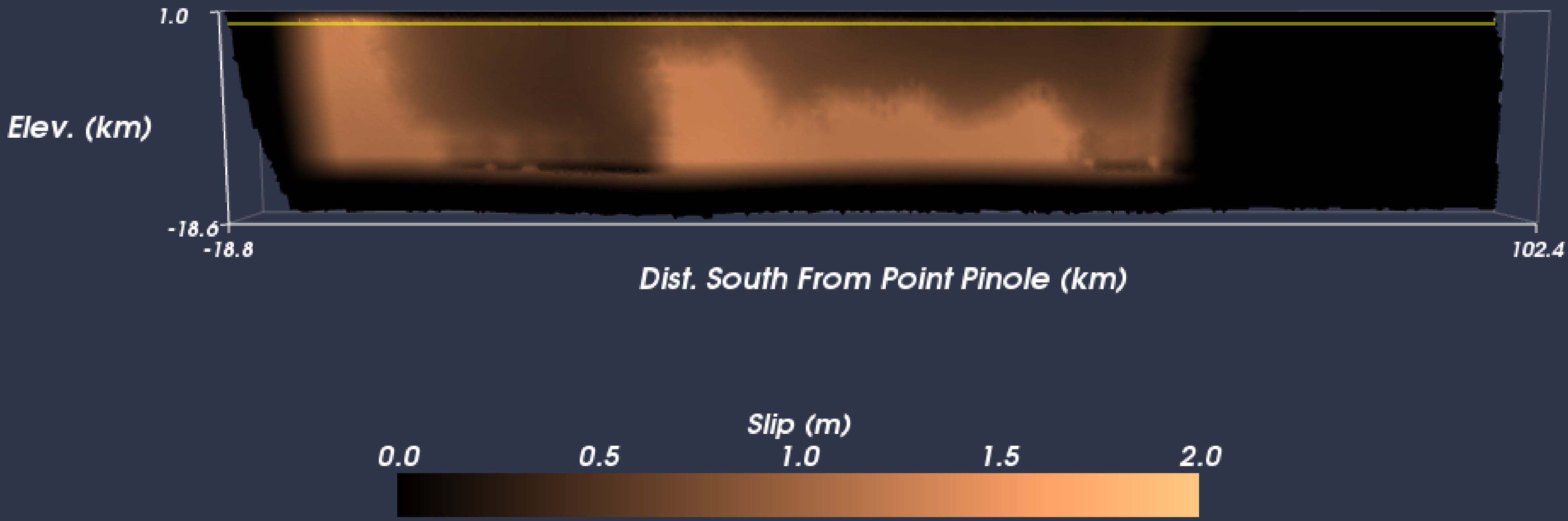
Slip-predictable Approach: Background Slip

(NW) San Pablo Bay San Jose (SE)



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Accounting for Creep: Slip-gradient Approach

Impose gradient in slip in creeping areas

- Impose vertical gradient in background slip in creeping areas delineated by Funning et al. (2007)
- Compute Mw using Hanks and Bakun (2002) magnitude-area relation using effective rupture area (following WG02)

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Accounting for Creep: Slip-gradient Approach

Impose gradient in slip in creeping areas

- Impose vertical gradient in background slip in creeping areas delineated by Funning et al. (2007)
- Compute Mw using Hanks and Bakun (2002) magnitude-area relation using effective rupture area (following WG02)
- Features
  - Slip more likely to reach surface in larger events
  - More of the creeping areas rupture coseismically in larger events
  - Assume no afterslip (for the moment)

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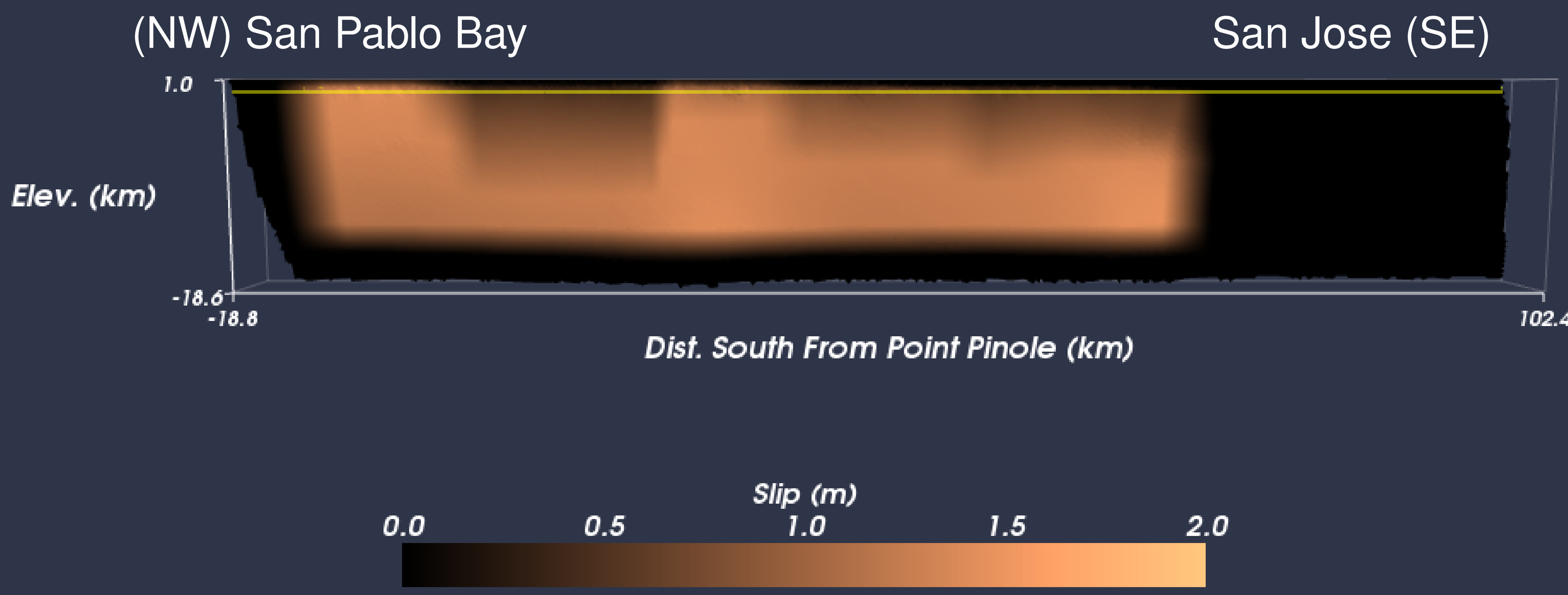
Slip-gradient Approach: Background Slip



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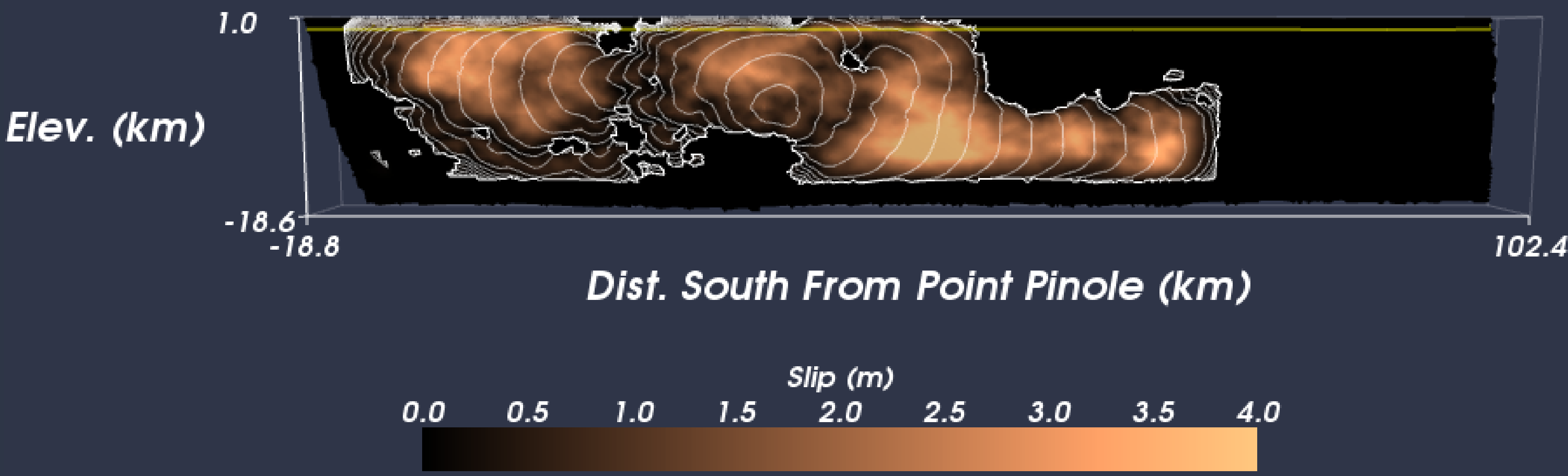
Hayward South + North Rupture Model

Slip distribution with 1 s rupture time contours

(NW) San Pablo Bay

San Jose (SE)



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Constraining Surface Slip

Wells and Coppersmith, 1994

- Maximum slip (strike-slip)

$$\log D_{max} = -7.03 + 1.03 M_{\mathrm{w}}$$

- Average slip (strike-slip)

$$\log D_{avg} = -6.32 + 0.90 M_{\mathrm{w}}$$

- Empirical relation for coseismic slip without creep or afterslip

Surface Slip: Accounting for creep and afterslip

- Effect of creep on coseismic rupture
  - Reduced magnitude for given rupture area (WG02 effective area)
  - Use reduced magnitude in slip/magnitude relation
- Incorporating afterslip (some assumptions)
  - Afterslip releases stress concentrations following rupture
  - Near-surface slip driven by greater slip at depth

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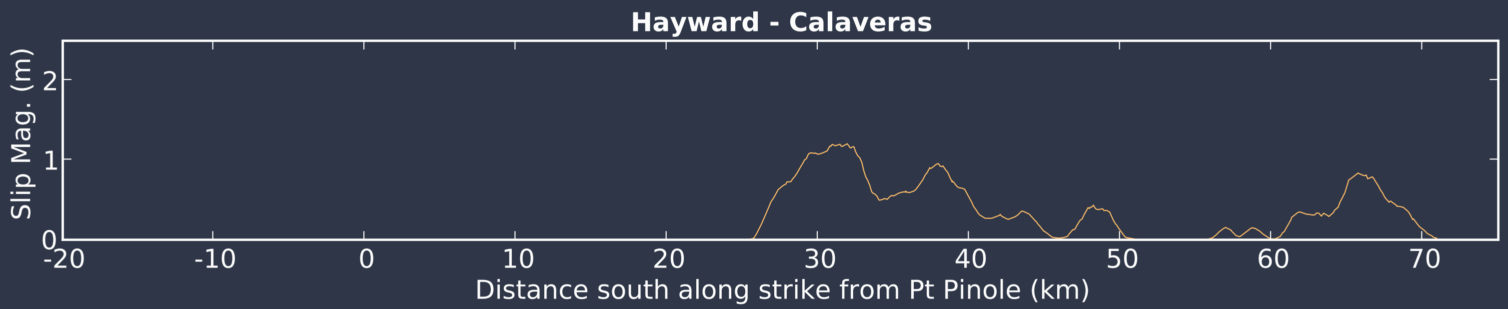
Coseismic Slip from Scenario Rupture Models

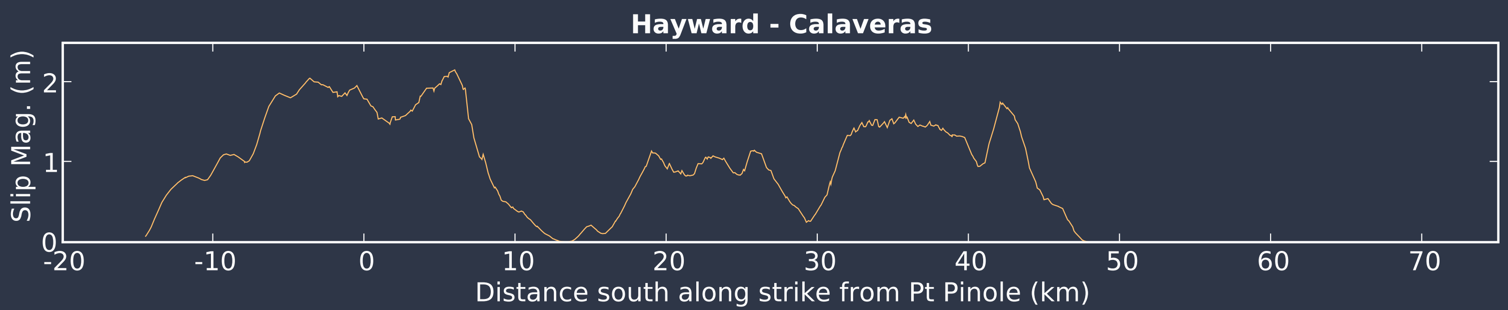
Fine-tune stochastic parameters and blending for better match

W&C, 1994	Max. Slip. (m)	Avg. Slip (m)
Mw 6.76	0.86	0.58
Mw 7.05	1.7	1.1

Hayward South, Mw 6.76



Hayward South + North, Mw 7.05



Probabilistic Estimation of Surface Offset

Use Monte Carlo approach to calculate probability density function

- Vary magnitude and rupture end points
  - Gutenberg-Richter frequency-magnitude relation
  - Characteristic events
  - Selection of particular scenarios (this study)
- Random seed for stochastic variation of slip
- Vary slip-gradient in accounting for creep
- Hypocenter, slip time function, rupture speed (temporal evolution only)

Long-Term Research Issues

Incorporate more physics into rupture models

Spontaneous dynamic rupture models include fault constitutive behavior (but are currently poorly constrained)

- Do fault constitutive model parameters vary in the near surface?
  - Stable sliding at shallow depths instead of unstable sliding
  - Variation in friction (cohesion and overburden pressure)
- Does coseismic slip decrease at shallow depths?
- Does surface slip have the same spatial variation as deep slip?
- Is surface coseismic slip slower/faster than slip at depth?
- How does creep affect slip?
  - Does effect of creep vary with earthquake magnitude?
  - Correlation of afterslip with creep?

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