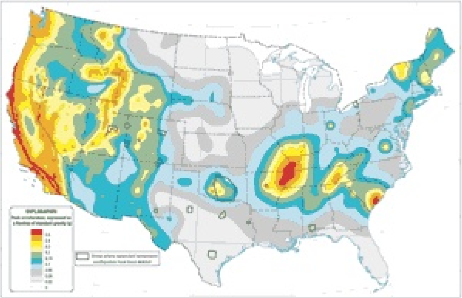
Utilization of Earthquake Geology Constraints in the USGS NSHM

Edward (Ned) Field

UNREST SCEC Workshop, June 2026

Seismic Hazard & Risk Analysis (e.g., NSHM)



e.g., Probability that shaking level will be exceeded

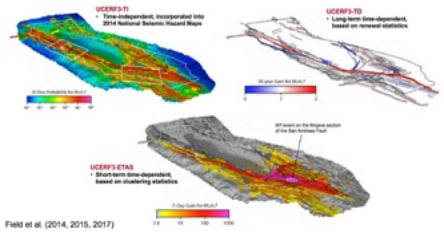
Two main model components:

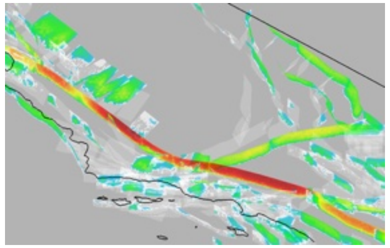
1) **Earthquake *Rupture* Forecast**

Gives the probability of all possible earthquake ruptures (or suite of stochastic event sets) for a region and over a specified timespan

Empirical (e.g., UCERFs)

Physics Based (e.g., MCQSim)





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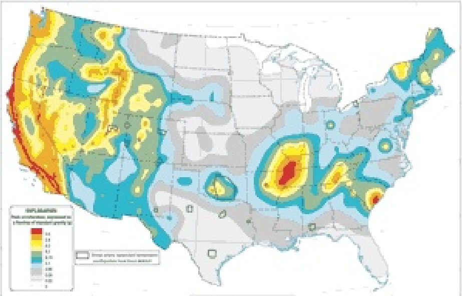

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Biggest game changers?

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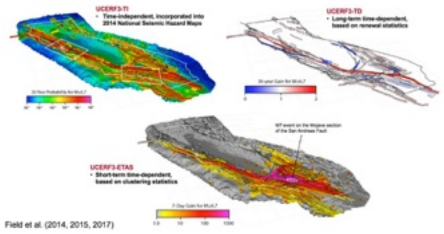

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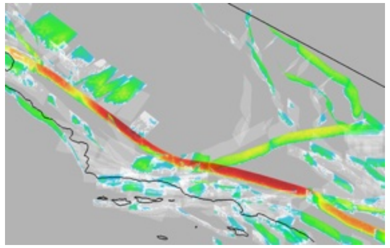
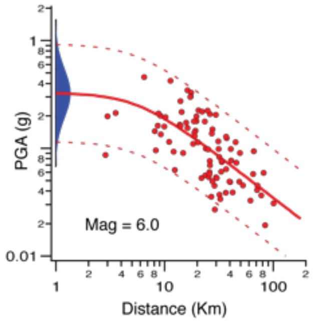


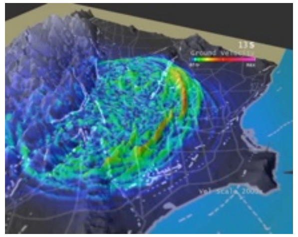
2) **Ground Motion Model**

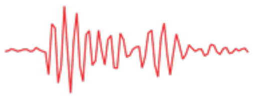
Non-ergodic models
(site, source, & path specific)

Empirical
"Attenuation Relationships"

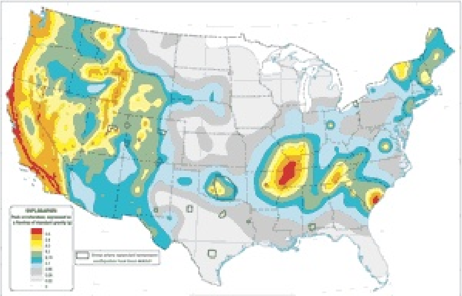


Physics-based
"Waveform Modeling"





Seismic Hazard & Risk Analysis (e.g., NSHM)



e.g., Probability that shaking level will be exceeded

Biggest game changers?

Two main model components:

1) **Earthquake *Rupture* Forecast**

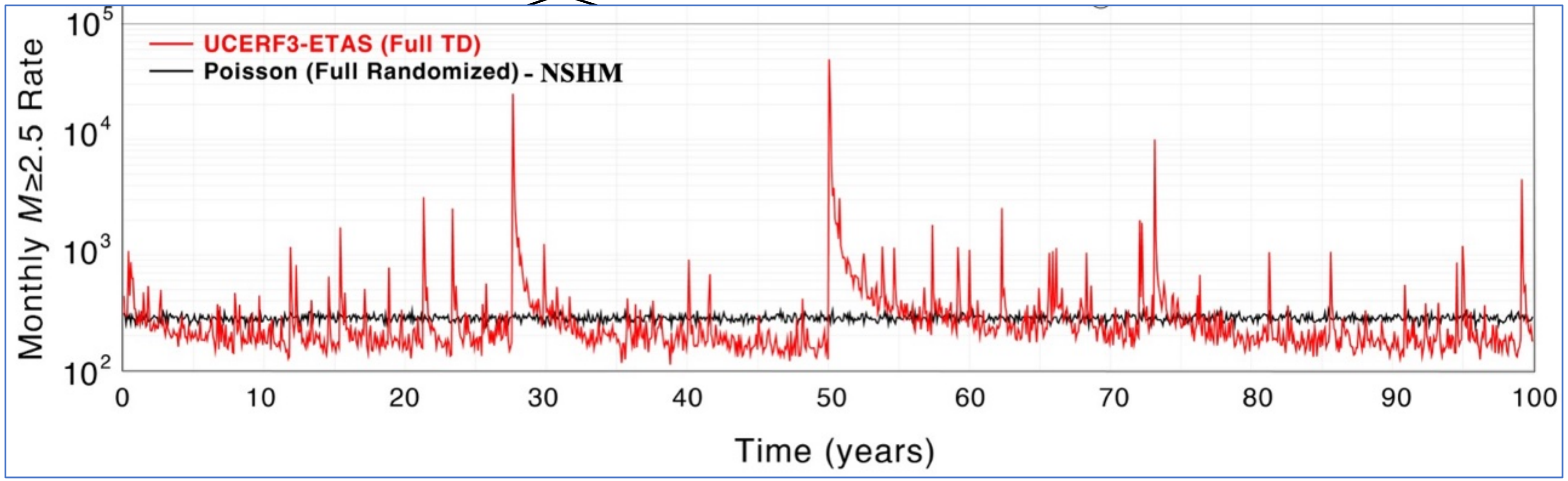
Full time dependence

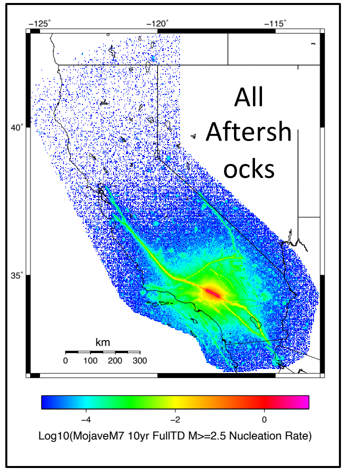
(spatiotemporal clustering)

2) **Ground Motion Model**

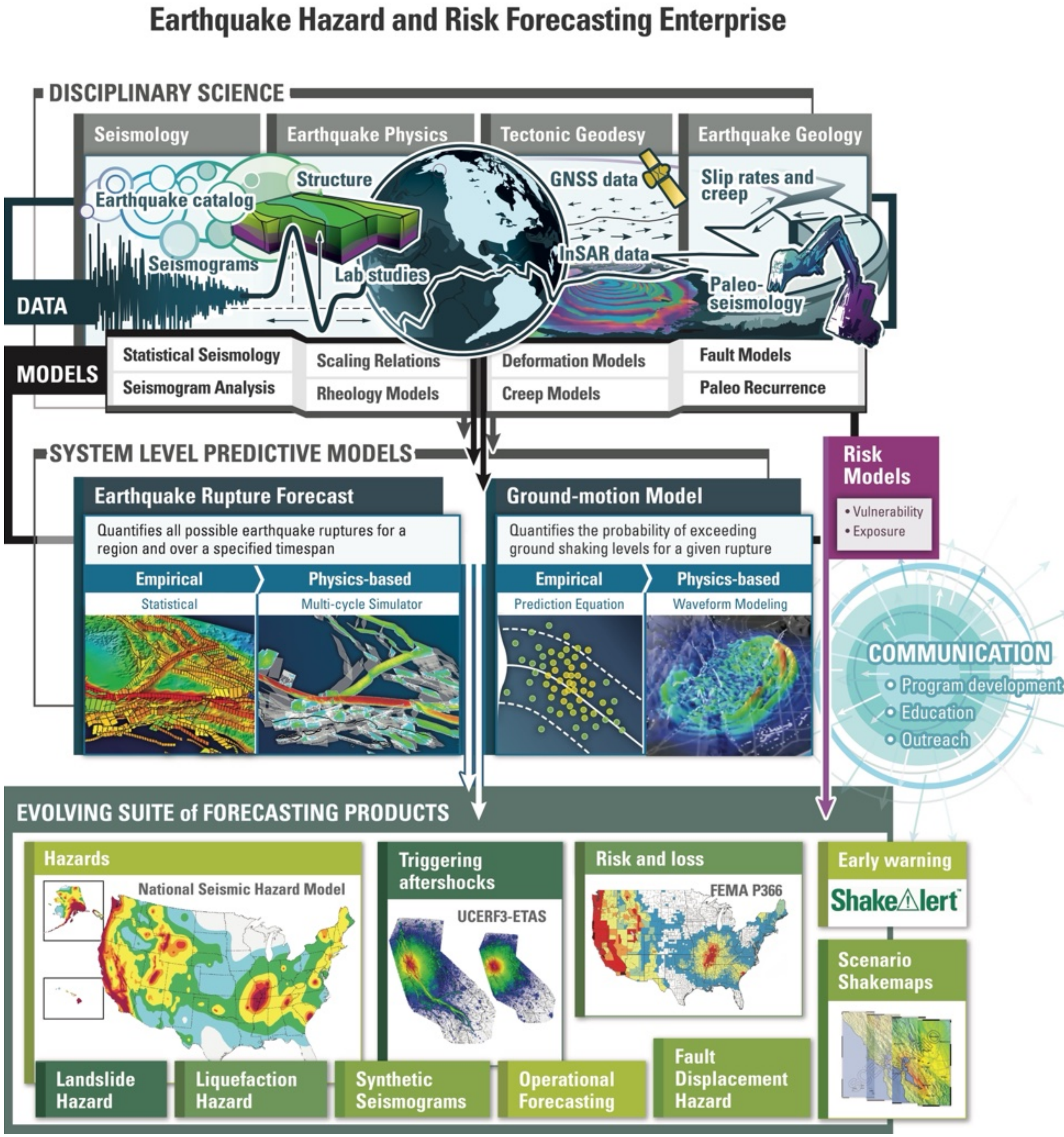
Non-ergodic models

(path specific)

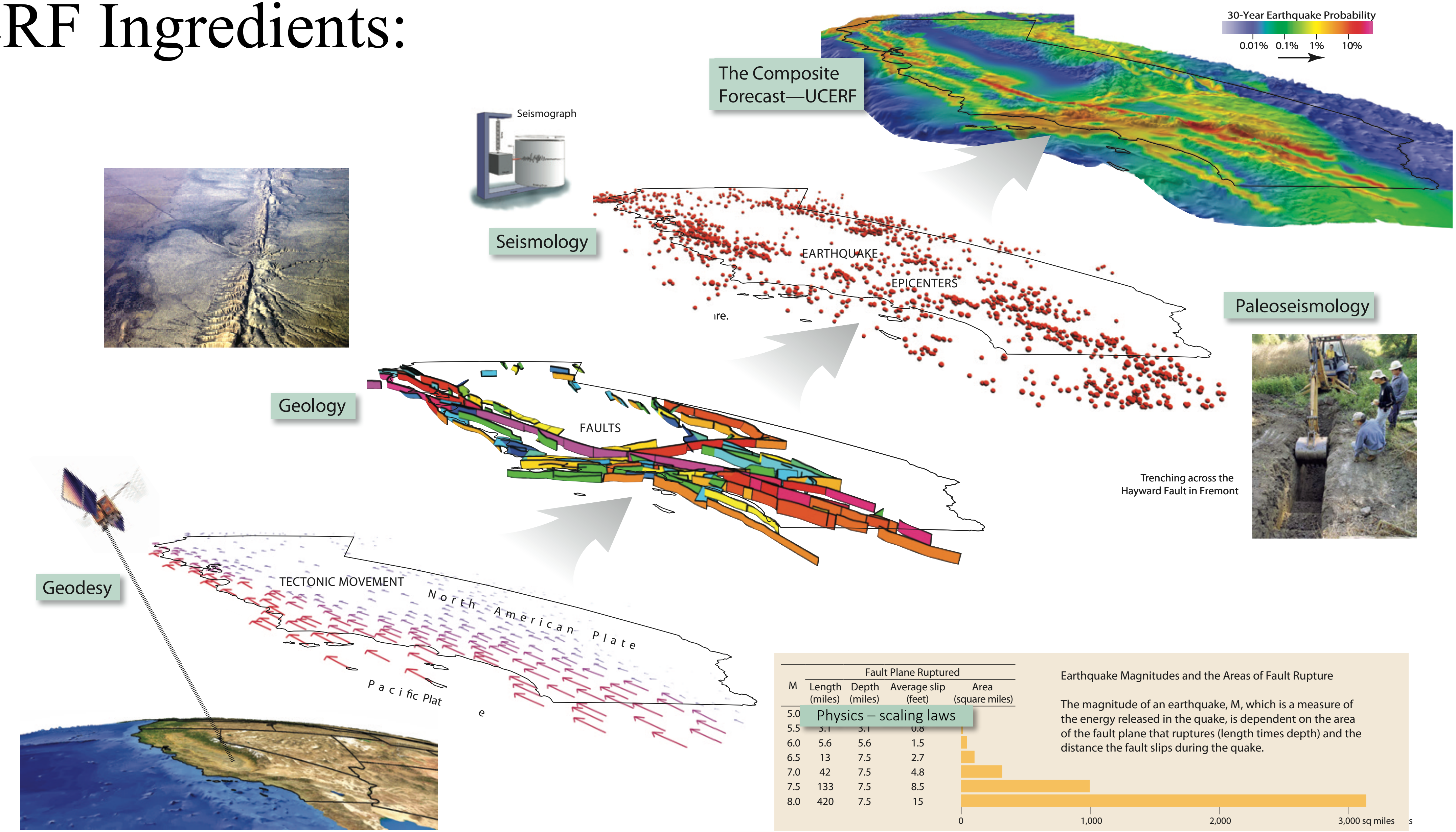




- **System level problem**
- **Assumptions, approximations, and uncertainties everywhere**
- **Epistemic uncertainties must be quantified & propagated**
- **We want state-of-art components to plug together → computational infrastructure is everything**
- ***We're in constant triage mode***



ERF Ingredients:



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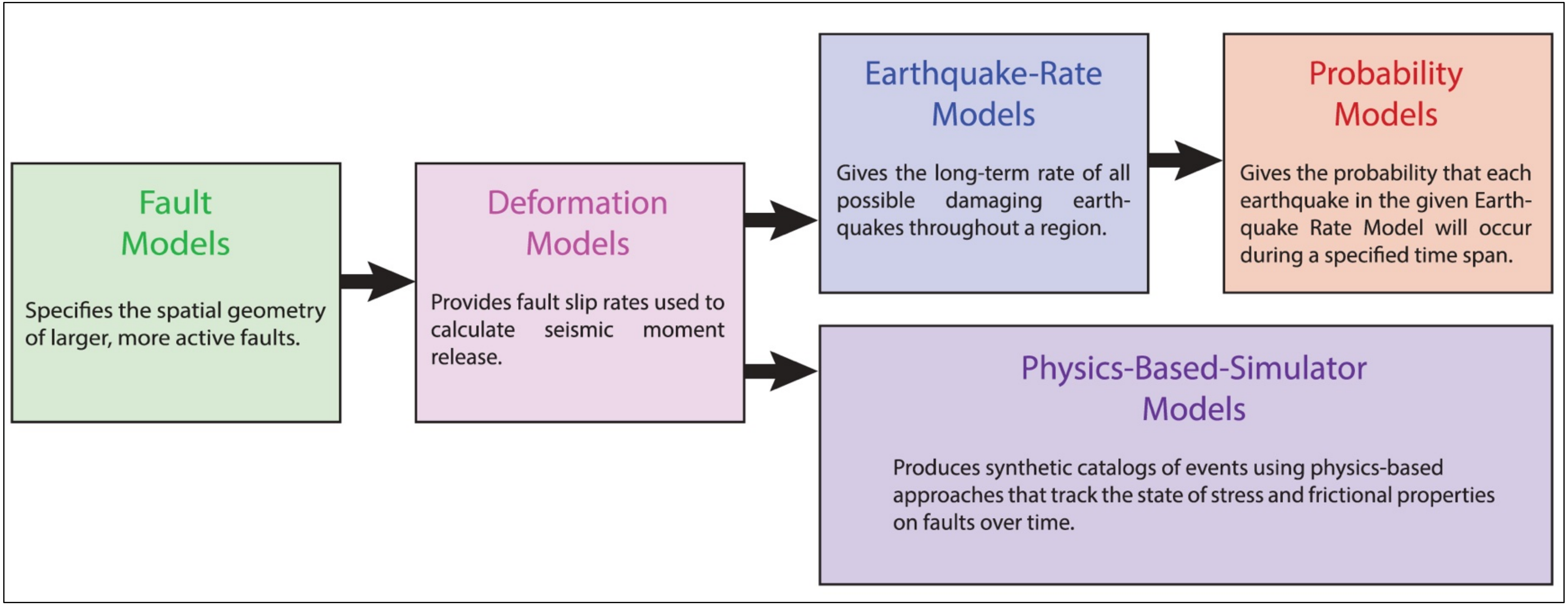

NSHM Earthquake Geology Constraints

- **Fault Traces** (& dips)
- **Surface creep**
- **Geologic slip rates** (for deformation models)
  - Inferred at sites (or between points on fault)
  - Categorical/generic value assignments
- **Recurrence Interval (RI) PDF at points**
  (Prob Density Func for supraseismogenic rups):
  - Mean RI
  - RI Coefficient of Variation
  - PDF shape (Lognormal, BPT, Weibull, other?)
- **Date of Last Event (DOLE)**

- **Surface slip distribution along strike**
  - For observed ruptures
  - Average over many ruptures
- **Paleo slip constraints at a location**
- **Paleo shaking constraints (“Paleoseismometry”)**:
  - Precariously balanced rocks
  - Tsunami deposits
  - Submarine turbidites
  - Liquefaction deposits
  - Lake (Lacustrine) paleoseismology

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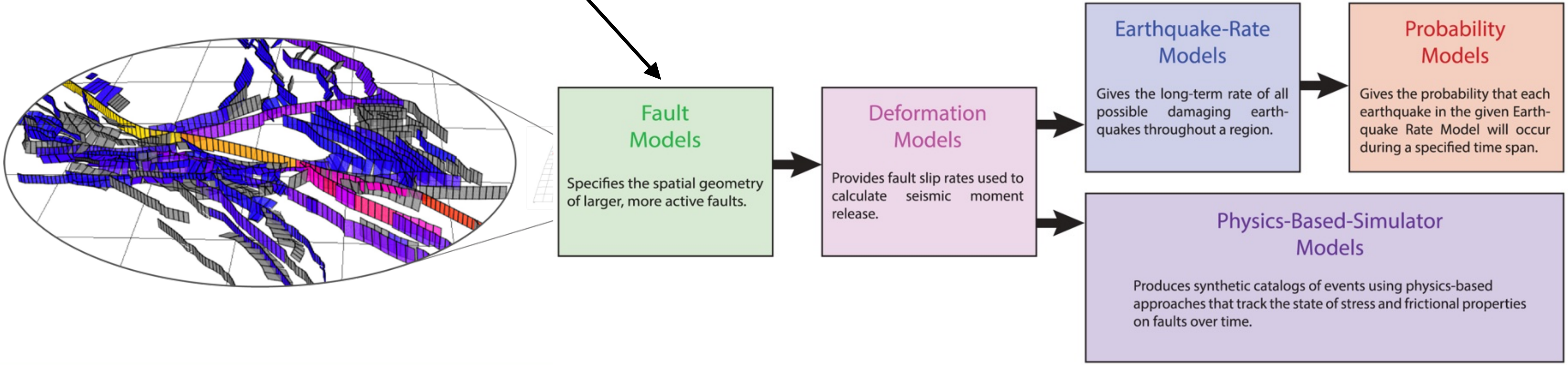

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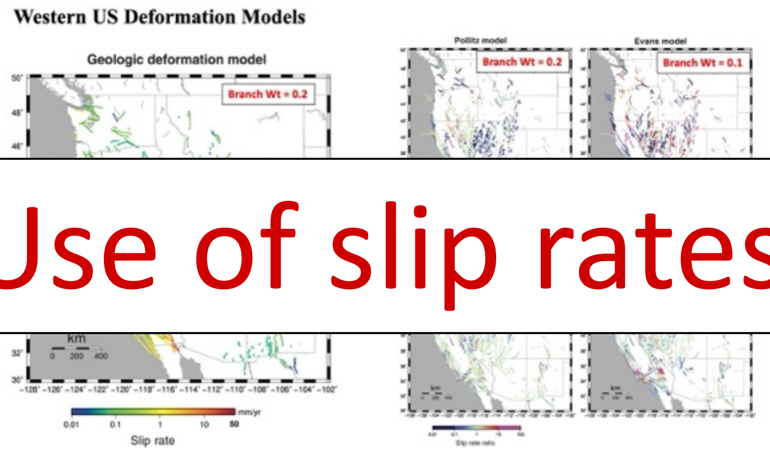
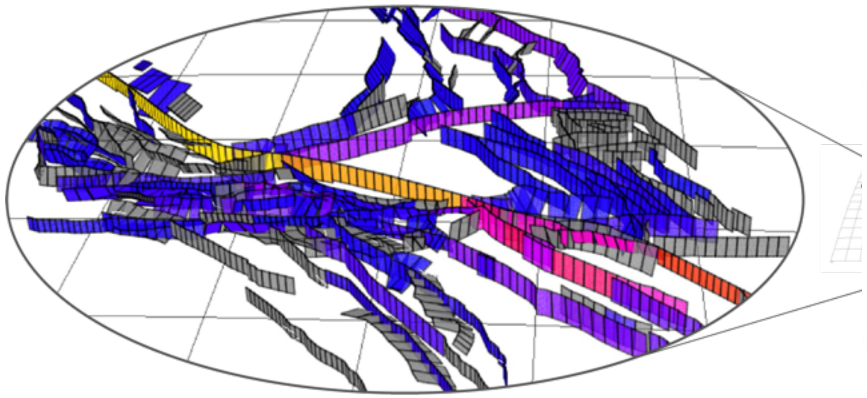


Use of slip rates?



Fault Models
Specifies the spatial geometry of larger, more active faults.

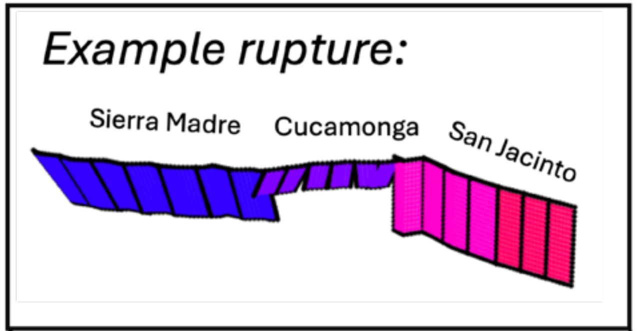
Deformation Models
Provides fault slip rates used to calculate seismic moment release.

Earthquake-Rate Models
Gives the long-term rate of all possible damaging earthquakes throughout a region.

Probability Models
Gives the probability that each earthquake in the given Earthquake Rate Model will occur during a specified time span.

Physics-Based-Simulator Models
Produces synthetic catalogs of events using physics-based approaches that track the state of stress and frictional properties on faults over time.

Inversion-based Fault-System Solution



$$\sum_{r=1}^{R} D_{sr} f_r = v_s$$

***Fault Slip Rates**:* v_s is the subsection slip rate and D_{sr} is the average slip on the s^{th} subsection in the r^{th} event.

$$\sum_{r=1}^{R} G_{sr} P_r^{paleo} f_r = f_s^{paleo}$$

***Paleoseismic Event Rates**:* f_s^{paleo} is a paleoseismically inferred event rate estimate, G_{sr} specifies whether the r^{th} rupture utilizes the s^{th} subsection (0 or 1), and P_r^{paleo} is the probability that the r^{th} rupture would be seen in a paleoseismic trench.

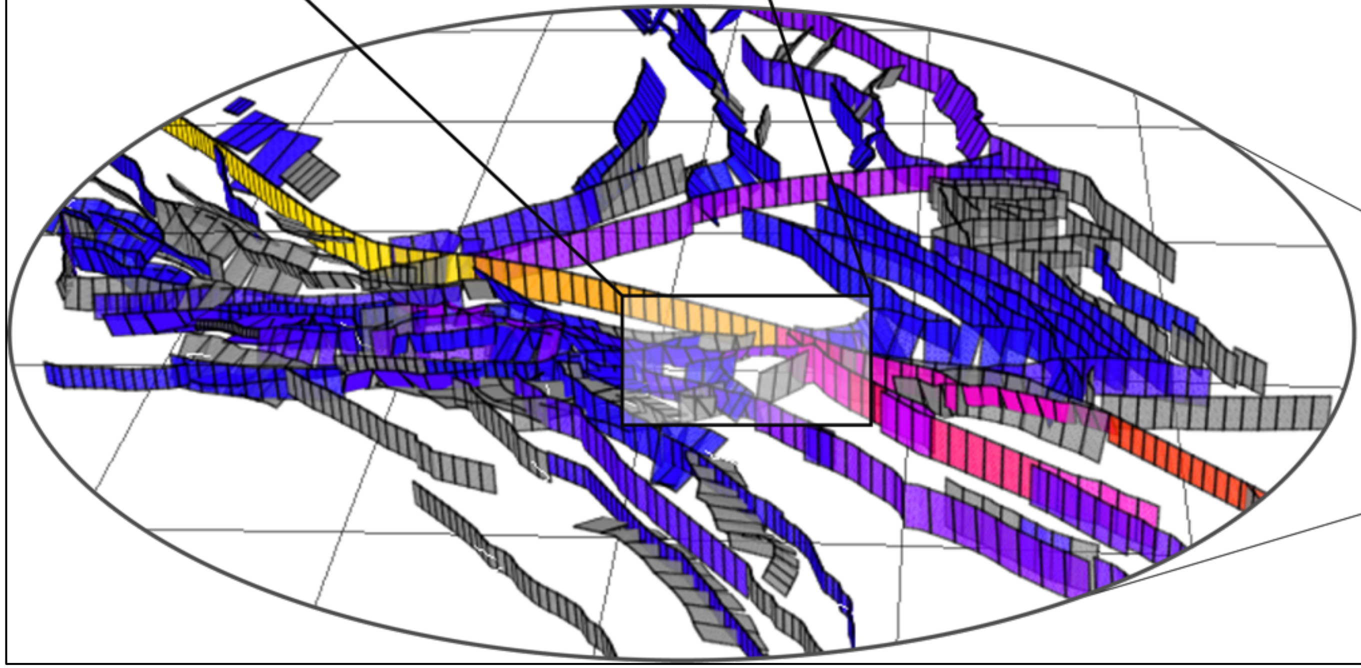
$$\sum_{r=1}^{R} M_{gr}^{m} f_r = R_g^m$$

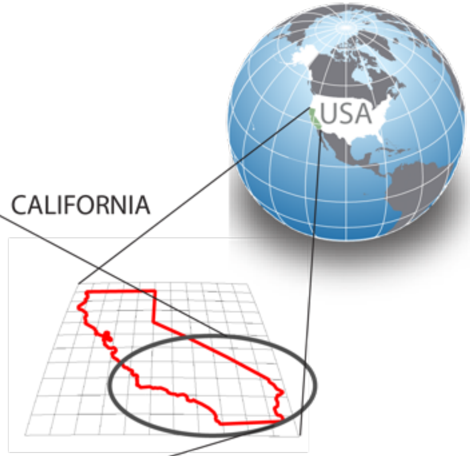
***Magnitude Frequency Distribution**:* This forces a group (g) of ruptures (e.g., those in a geographic region or those at a point on a fault) to have a specified total MFD. R_g^m represents the nucleation rate for the m^{th} magnitude bin for the g^{th} rupture group. Matrix M_{gr}^m indicates whether the r^{th} rupture is both part of the g^{th} group and falls in the m^{th} magnitude bin (0 or 1).

$$R_{s\acute{s}} \leq F_{s\acute{s}} Min(R_s, R_{\acute{s}})$$

***Fault Segmentation**:* This limits the extent to which neighboring fault sections (s and $\acute{s}$) can rupture together. Specifically, this limits the co-rupture rate ($R_{s\acute{s}}$) to be less than a specified fraction ($F_{s\acute{s}}$) of the lowest rupture rate on either subsection (R_s and $R_{\acute{s}}$). A fault-jump distance version of this is applied by replacing $F_{s\acute{s}}$ with $Min(1, e^{-(d_{s\acute{s}}-\delta)/d_o})$, where $d_{s\acute{s}}$ is jump distance, d_o is a decay parameter, and δ is an offset parameter (no penalty is applied up to this distance).

* f_r represents the frequency or rate of the rth rupture (what we are solving for).





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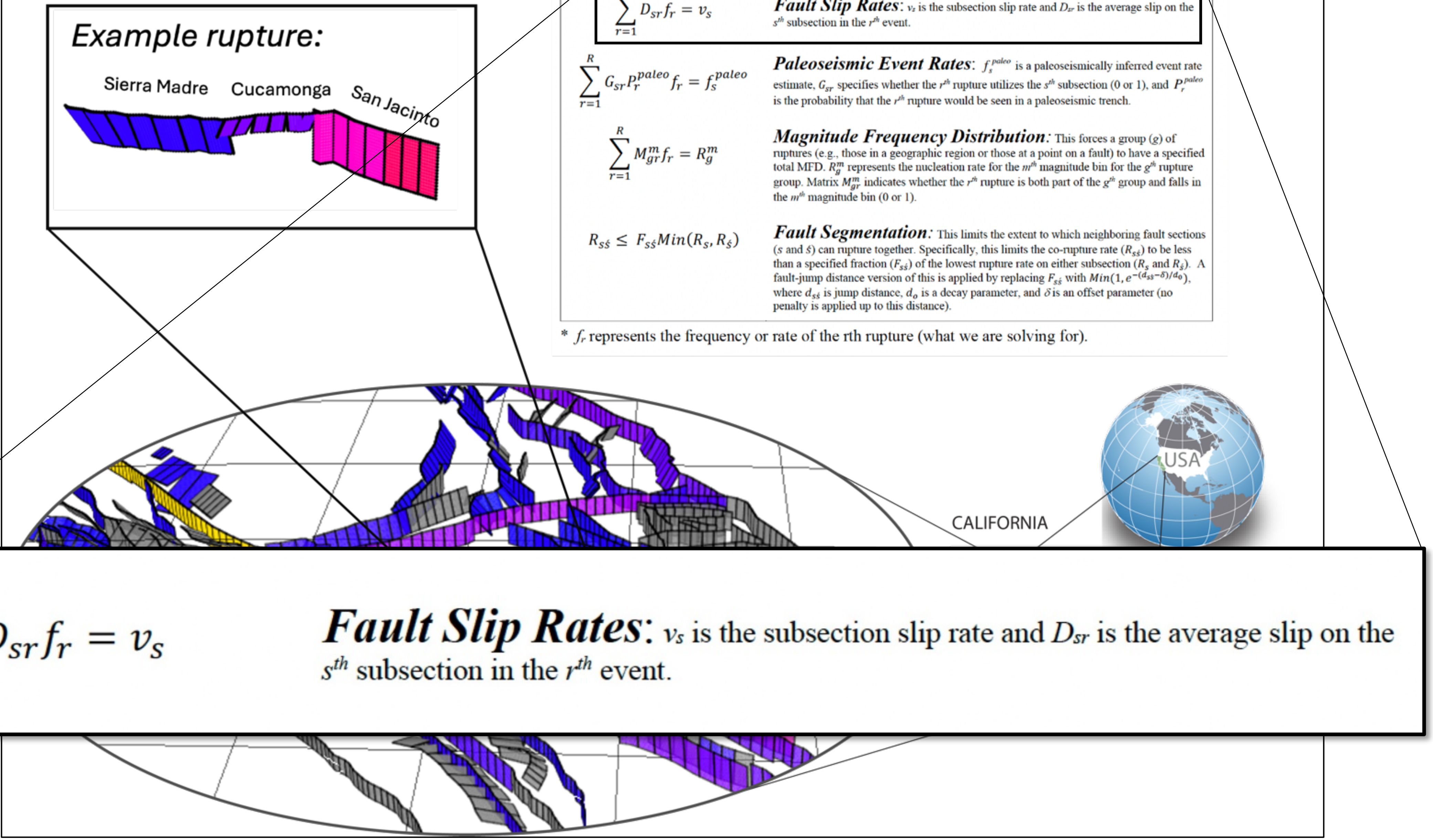

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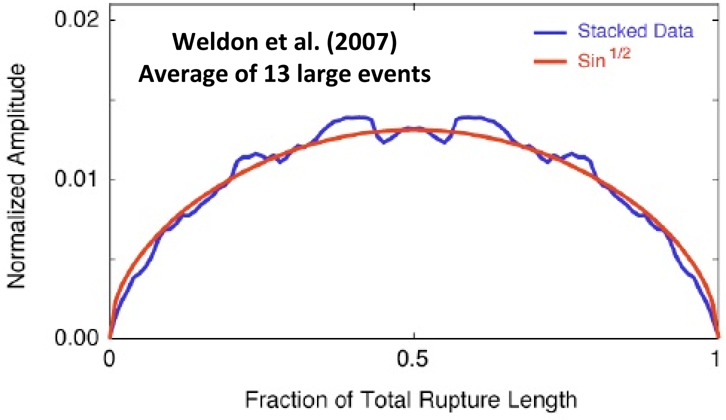

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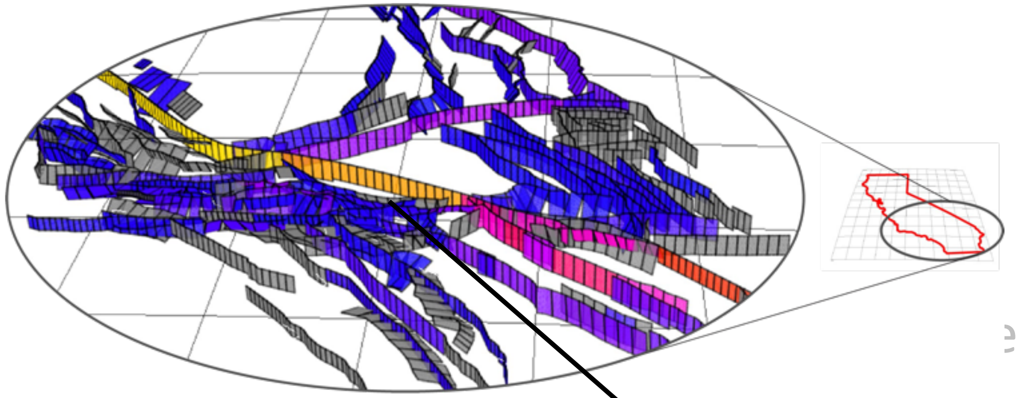

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(Prob Density Func for supraseismogenic rups):

- **Mean RI (1/rate)**
- RI Coefficient of Variation
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Recurrence Interval
(supra-seismogenic rutures)

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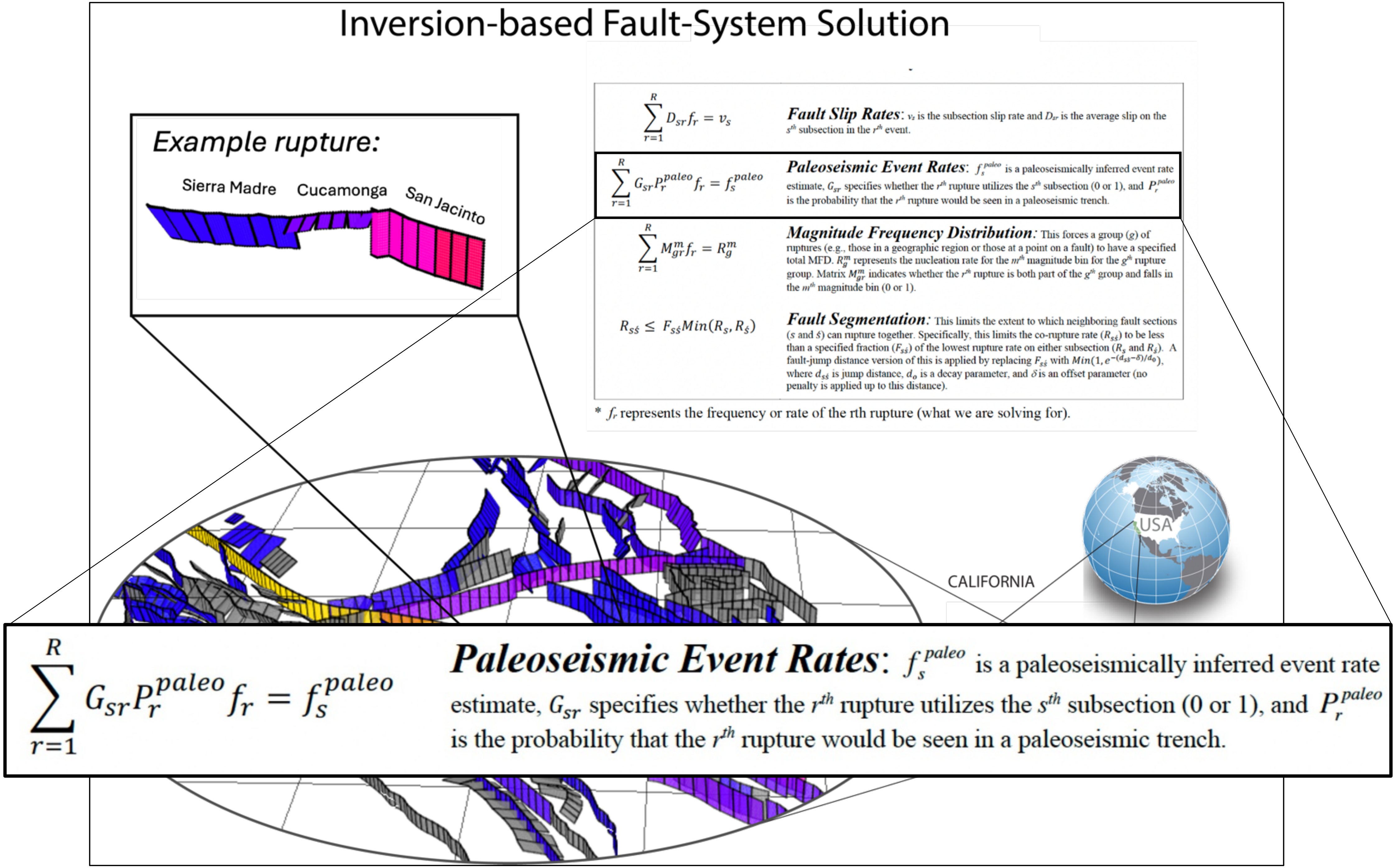
Inversion-based Fault-System Solution
Example rupture:
Sierra Madre
Cucamonga
San Jacinto
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CALIFORNIA
USA
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Inversion-based Fault-System Solution

whether the r^{th} rupture utilizes the s^{th} subsection

$1/meanRI$ on subsection s

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Inversion-based Fault-System Solution

Note:

To date, a single, generic model has been applied to all paleo sites

Ave Slip (D_r, meters)	Mag (approximate)	Probability of Detection ("Dist" is fractional distances from end of rupture)		
		Dist = 0.05	Dist = 0.25	Dist = 0.5
0.08	5.5	0.01	0.02	0.02
0.16	6.0	0.06	0.11	0.14
0.88	6.5	0.53	0.62	0.64
2.04	7.0	0.80	0.82	0.83
3.20	7.5	0.95	0.96	0.97
4.36	8.0	0.98	0.99	0.99

Weldon & Biasi, UCERF3 Appendix I

Probability of the r^{th} rupture being seen at the paleo site

1/*meanRI* on subsection *s*

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Inversion-based Fault-System Solution

Shouldn't this be customized for each paleo site?

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- **Surface creep**
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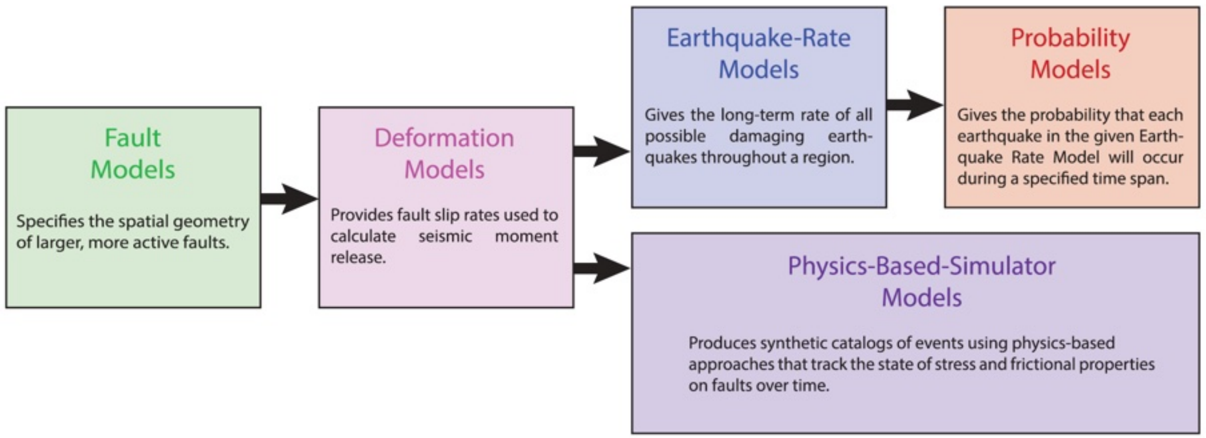
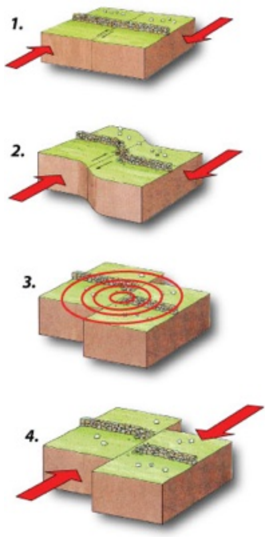


- **Recurrence Interval (RI) PDF at points**
  (Prob Density Func for supraseismogenic rups):
  - Mean RI
  - **RI Coefficient of Variation**
  - **PDF shape (~~Lognormal, BPT, Weibull~~, other?)**

- **Date of Last Event (DOLE)**

Potentially useful for computing **elastic-rebound-motivated** probabilities



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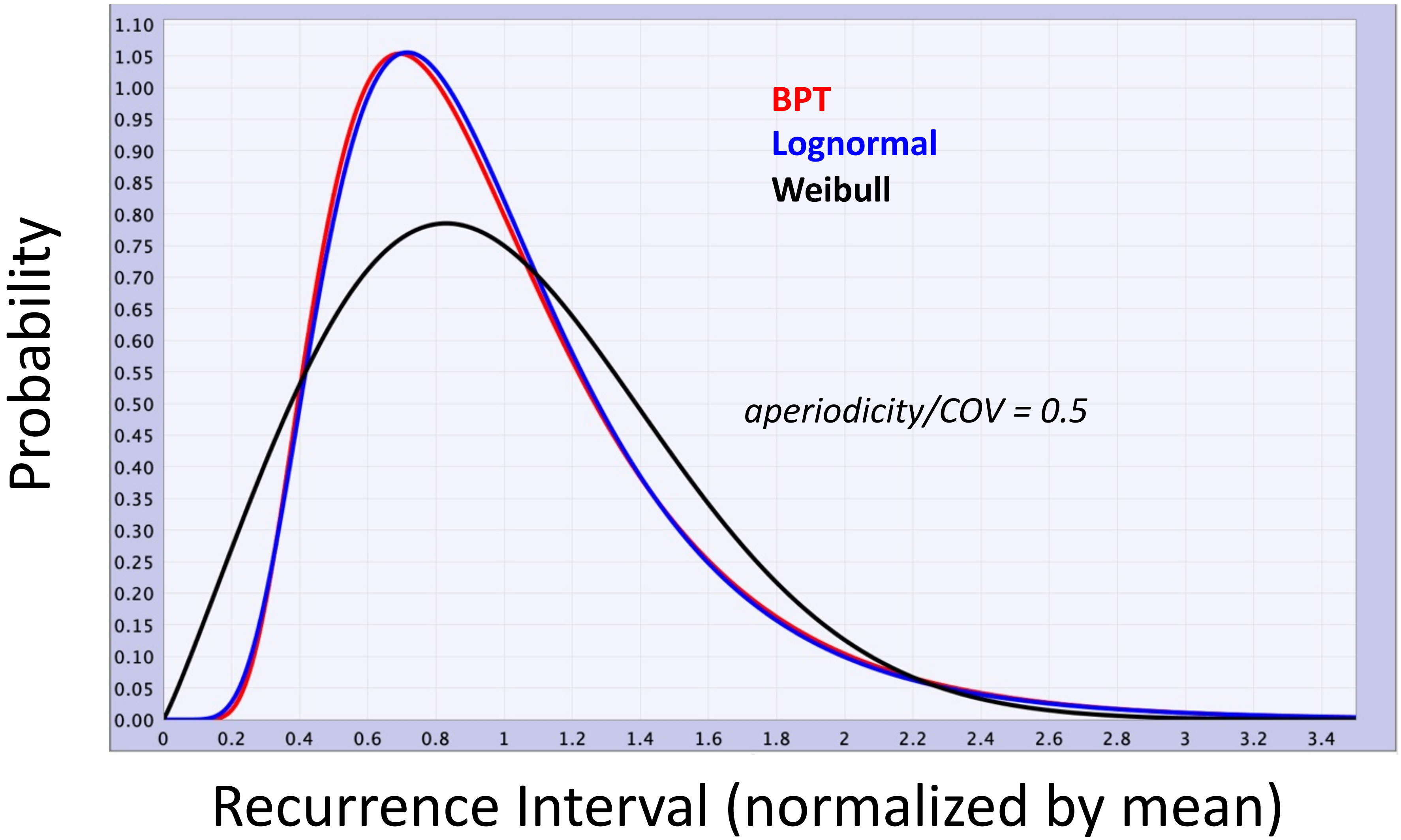
Not yet clear how to apply these given there is no good reason to assume RIs at a point on a fault follow any of the classic renewal models (once strict segmentation has been relaxed).

There is no good reason to presume that recurrence intervals at a point on a fault conform to any classic renewal models...



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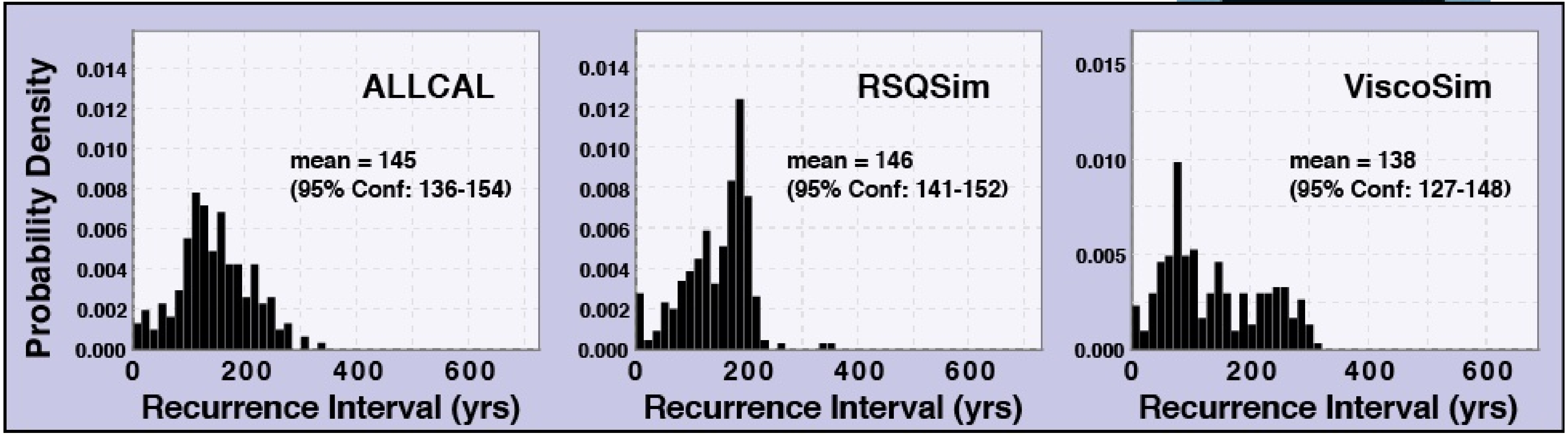
Physics-based earthquake simulators

Shapes are different, esp. at short recurrent (7% in first bin)

RSQSim is the gold standard due to realistic aftershocks

Pitman Canyon supra-seismogenic RIs



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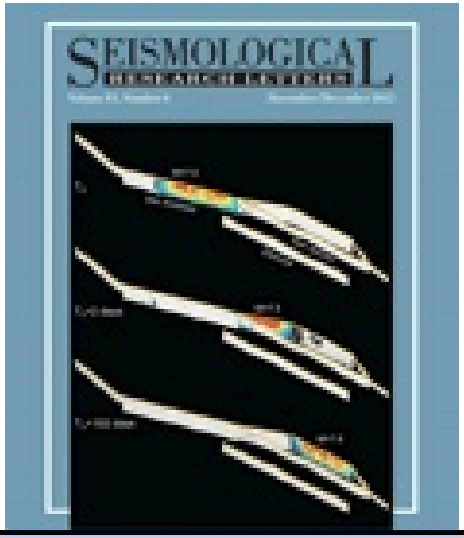
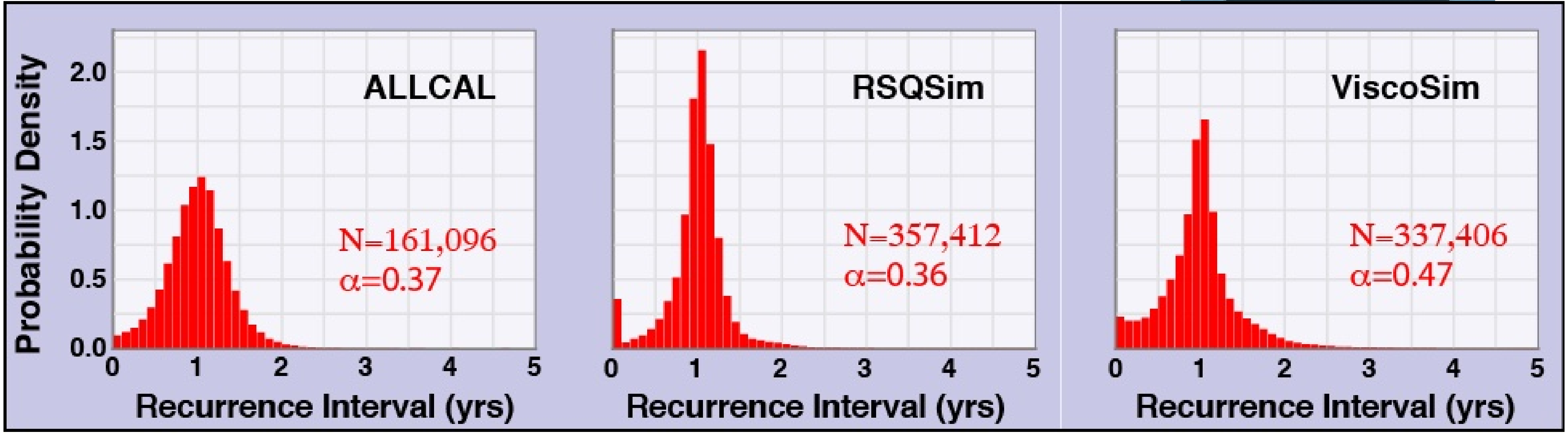


Normalized RIs averaged over **all fault surface locations** (cells)



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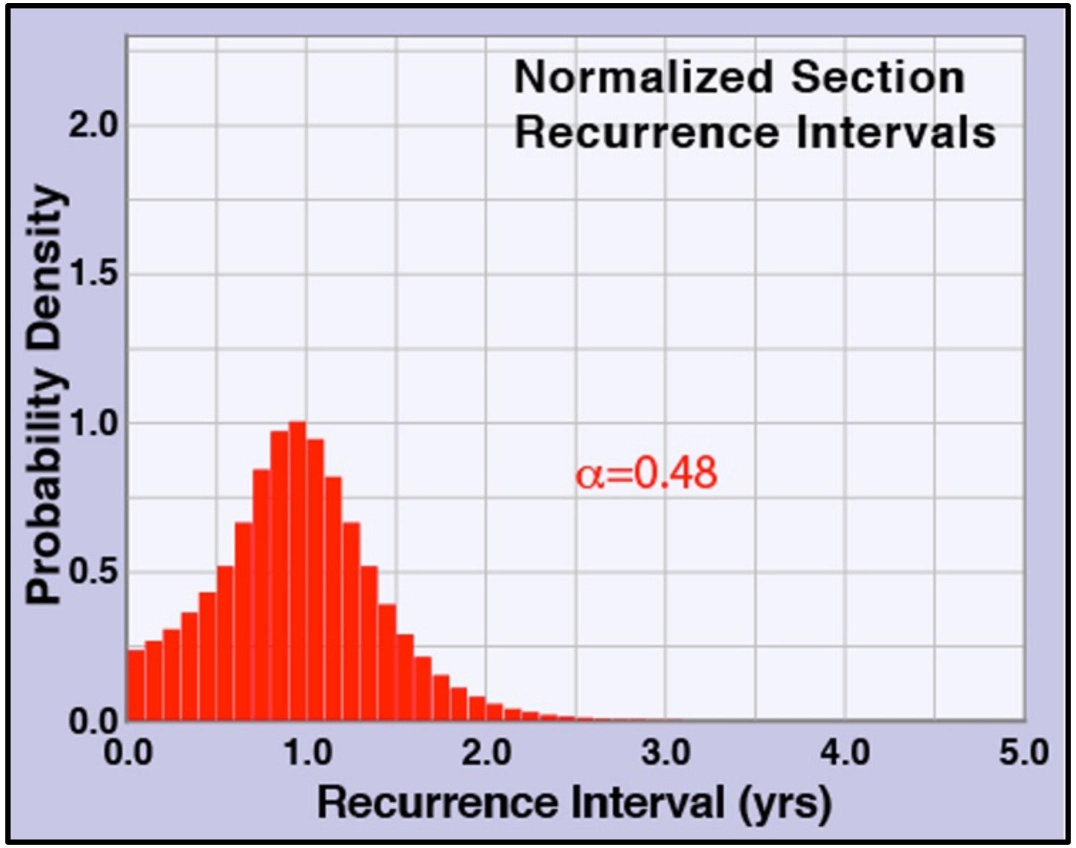
UCERF3-TD and forthcoming nationwide model make no such assumption:

Based on Monte Carlo Simulations:



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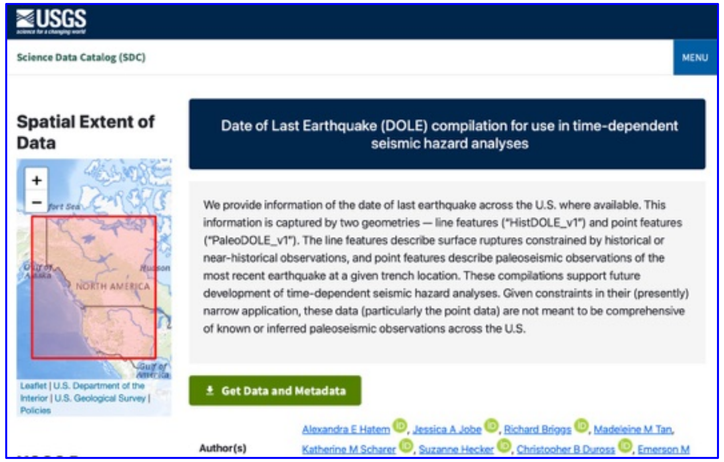
  - **PDF shape (~~Lognormal, BPT, Weibull~~, other?)**
- **Date of Last Event (DOLE)**

Not yet clear how to apply these given there is no good reason to assume RIs at a point on a fault follow any of the classic renewal models (once strict segmentation has been relaxed).

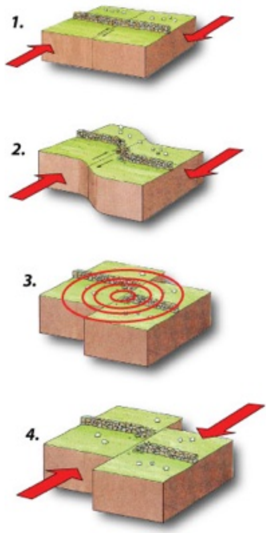
Even if we knew the exact PDF at each point on all faults, it's not clear how to map these back into the probability for each rupture.

NSHM Earthquake Geology Constraints

- **Fault Traces** (& dips)
- **Surface creep**
- **Geologic slip rates** (for deformation models)
  - Inferred at sites (or between points on fault)
  - Categorical/generic value assignments
- **Recurrence Interval (RI) PDF at points** (Prob Density Func for supraseismogenic rups):
  - Mean RI
  - RI Coefficient of Variation
  - PDF shape (~~Lognormal, BPT, Weibull~~, other?)
- **Date of Last Event (DOLE)**



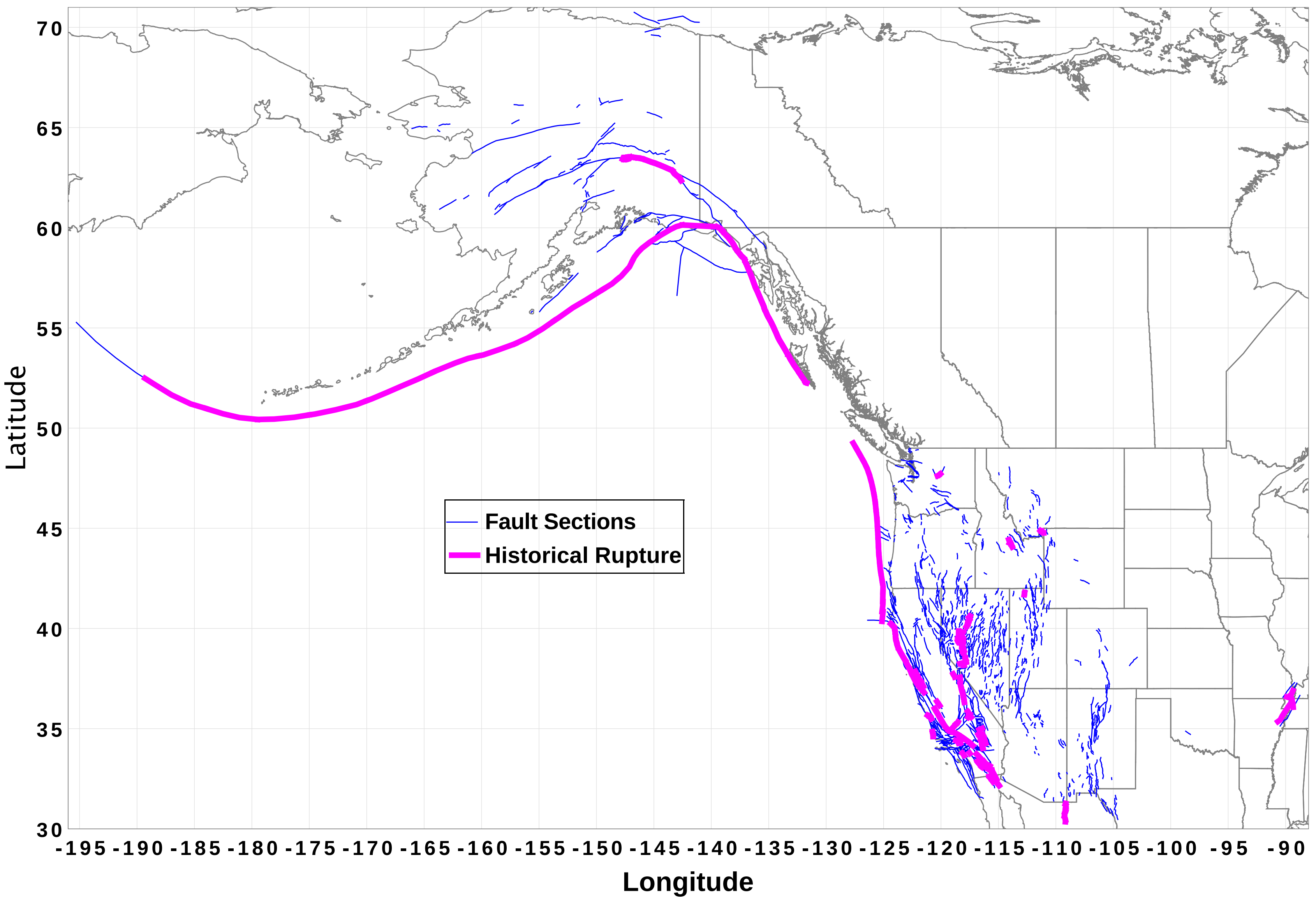
(Hatem et al., 2024)



Date of last event (DOLE) Database

(Hatem et al., 2024)

Historic Ruptures

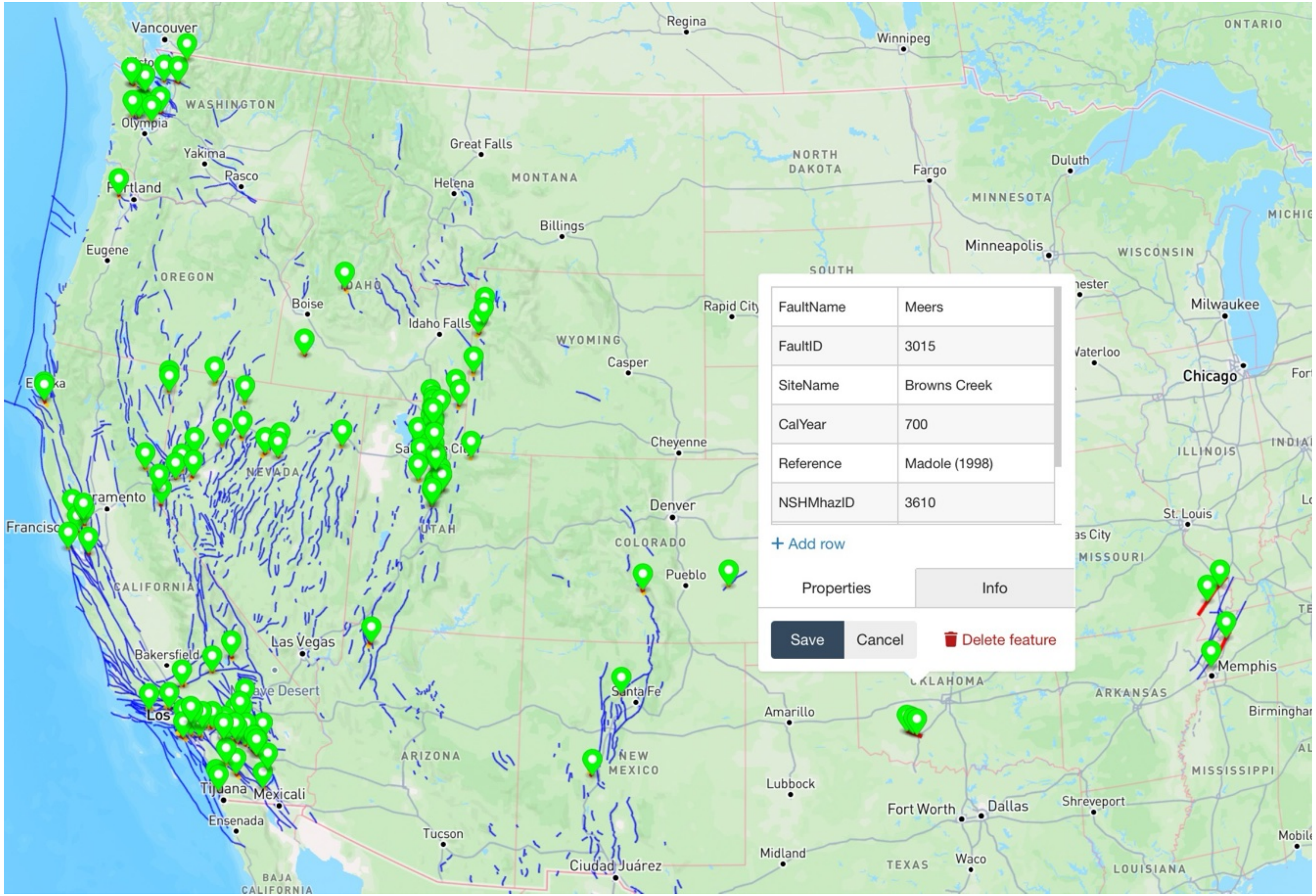


Date of last event (DOLE) Database

(Hatem et al., 2024)

Paleoseismic DOLE sites (plus 2 in AK)

These are experimental due to possibility of a missed more recent event



NSHM Earthquake Geology Constraints

- **Topic of current Powell Center project** **(to operationalize use of such constraints)**

- A test of hazard estimates (shaking probability)

- If discrepancy seen, first suspect is ergodic GMM assumption

els)

ult)

er?)

- Surface slip distribution along strike
  - For observed ruptures
  - Average over many ruptures
- **Paleo slip constraints at a location**
- **Paleo shaking constraints (“Paleoseismometry”)**:
  - Precariously balanced rocks
  - Tsunami deposits
  - Submarine turbidites
  - Liquefaction deposits
  - Lake (Lacustrine) paleoseismology

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