Surface Rupture Data and Location Uncertainty in Fault Displacement Hazard Analysis

Mark D. Petersen and Rui Chen

USGS National Seismic Hazard Mapping Project
California Geological Survey

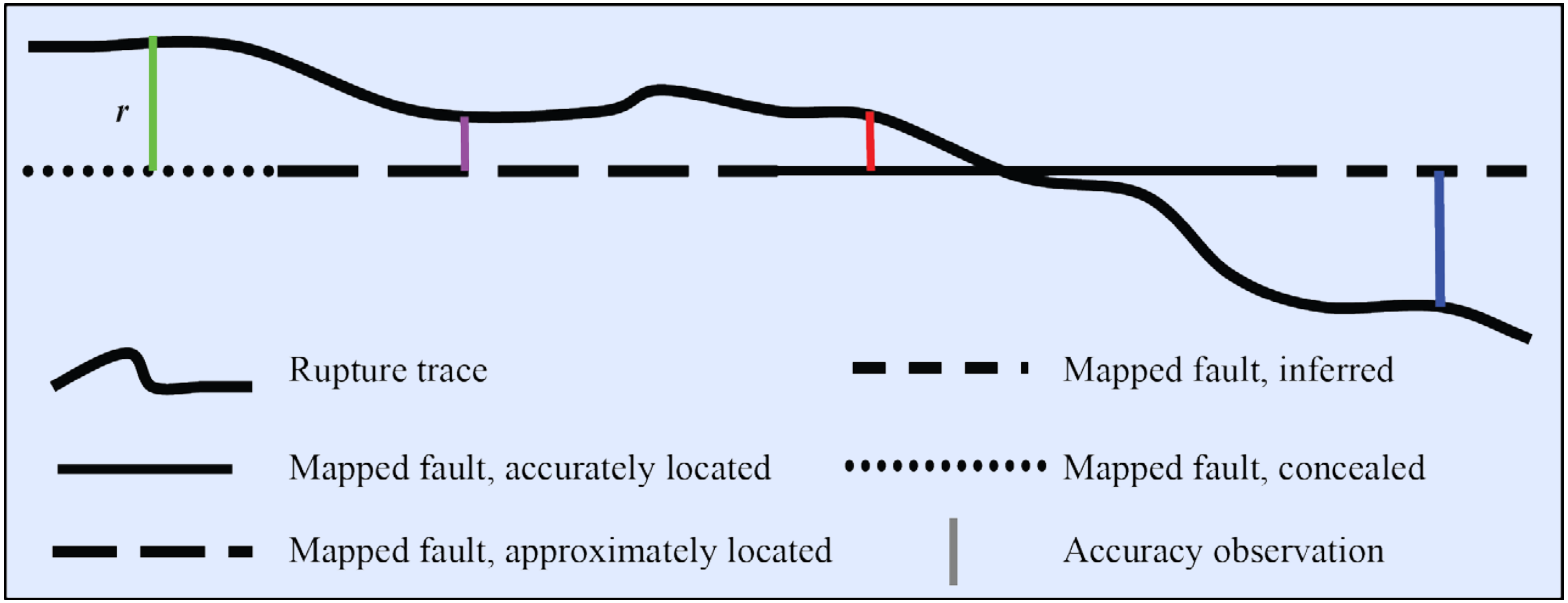
Objectives

- Review PFDHA methodology
- Compare fault displacement data
- Compare fault displacement hazard curves for different mechanisms
- Quantify mapping inaccuracy and natural variability in location of surface rupture from future earthquakes
- Show examples of PFDHA maps

Introduction: Fault rupture methods, data, & Applications

- Methods for fault displacement hazard and applications
  - Normal Faults: Youngs et al. (2003 Earthquake Spectra)
  - Strike-slip Faults: Petersen et al. (2011 BSSA)
  - Reverse Faults: Moss and Ross (2011 BSSA)
  - Extensional ground cracking: Thio
  - Others? (Hecker et al., 2013; Wells and Kulkarni, 2015; Thompson, 2016; etc.)
- Mapping Examples
  - Strike-slip fault: Chen and Petersen (2011 Earthquake Spectra)
- U.S. Standards for Nuclear Facilities – ANSI/ANS-2.30-2015 (Wong et al., 2015)
- IAEA and Japanese Method and Data (Takao et al., 2013)

Uncertainty in future surface rupture locations



- Epistemic uncertainty: associated with inaccuracy of mapped fault traces
- Aleatory variability: randomness as where future surface would occur
- Previously unmapped fault traces
- Regressions depend on:
  - Accuracy of mapped fault trace
  - Complexity of fault geometry
- Fault specific application using detailed fault trace (geologic assessment)

Normal faulting data compared to Strike-slip regressions

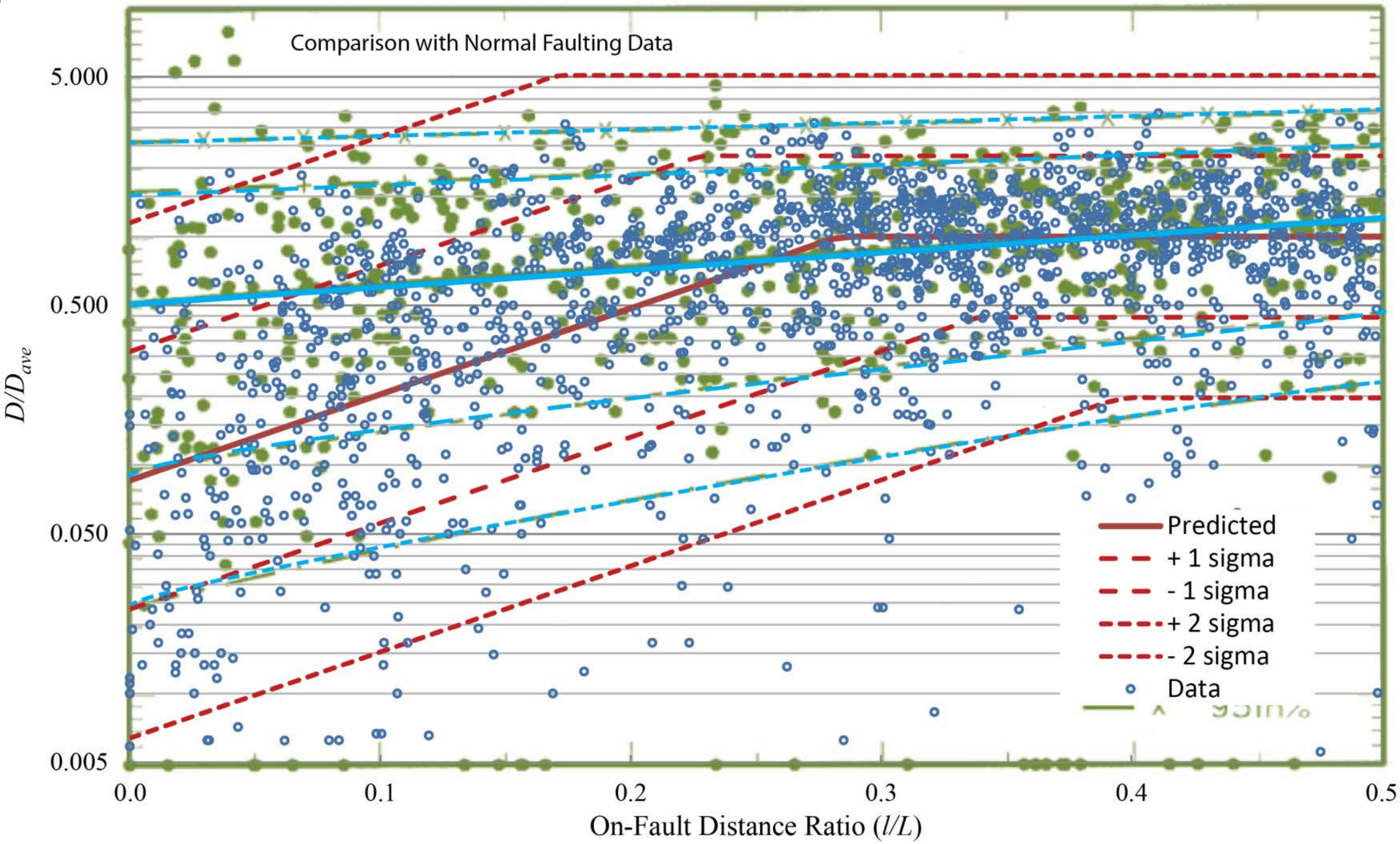


FIGURE 1. Comparison of normal (green circles) and strike-slip (blue circles) D/D_{ave} data for global normal faulting earthquakes. Normal fault displacement regressions are shown with blue lines and strike-slip with red lines (5th, 15th, 50th, 85th, and 95th percentiles from bottom to top) is from [2]. Normal faulting data are from [1].

Reverse faulting data compared to strike-slip regressions

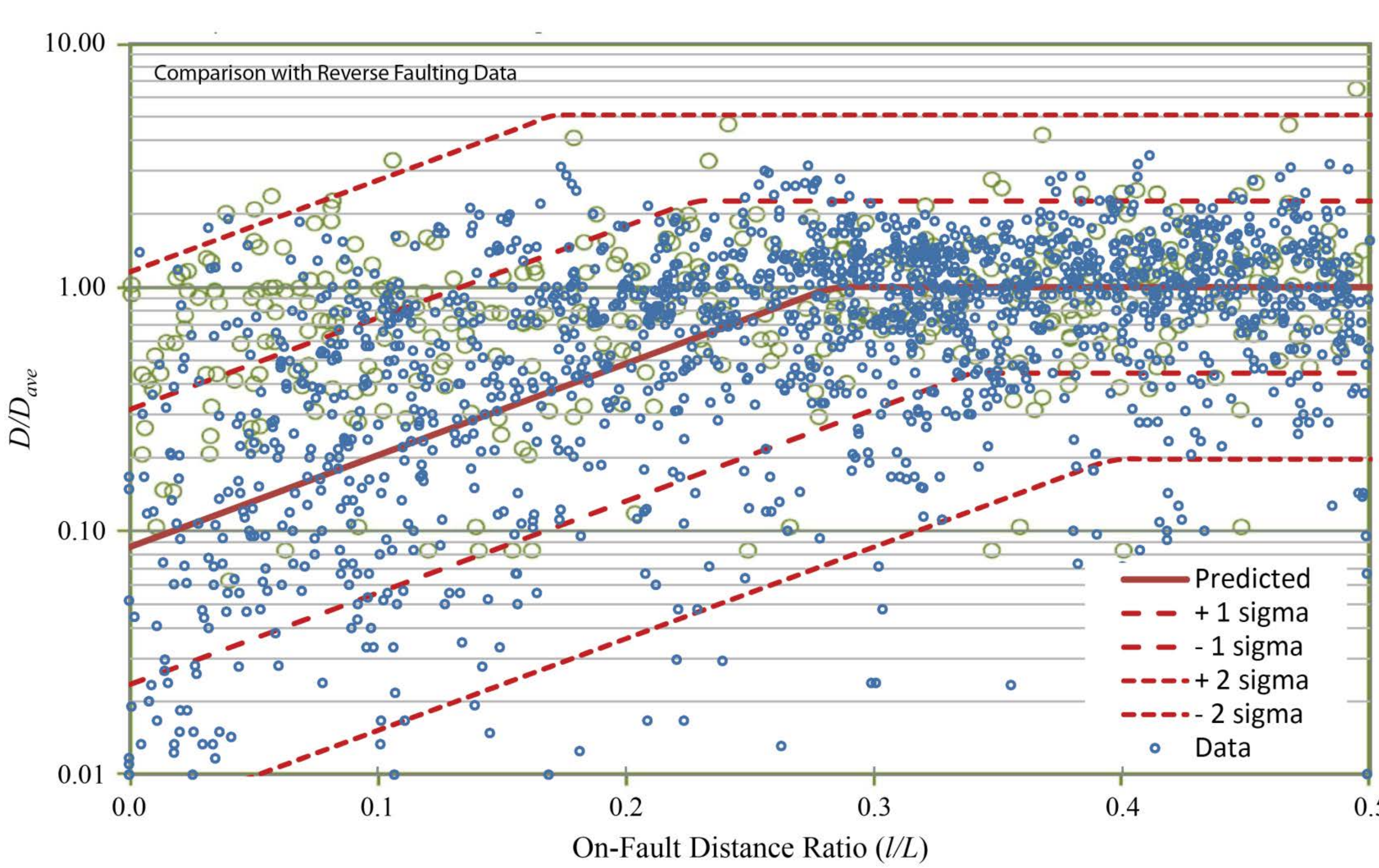


FIGURE 2. Comparison of reverse (green circles) and strike-slip (blue circles) D/D_{ave} data for global earthquakes. Strike-slip fault regressions are shown with red lines [2]. Reverse faulting data are from [3].

Japan faulting data and piecewise linear regression equations compared to strike-slip data and regressions

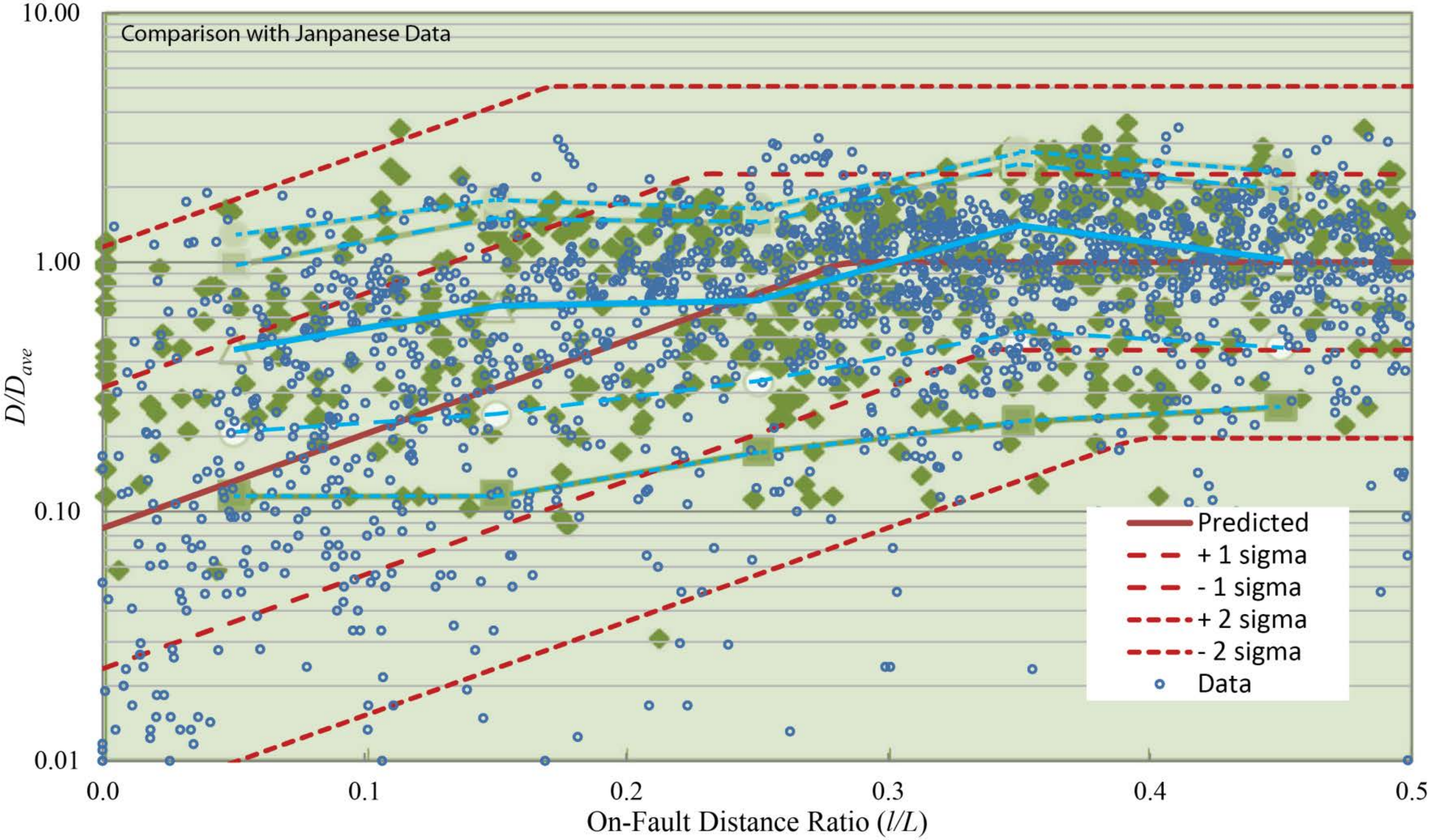


FIGURE 3. Comparison of Japanese all faulting type data (green diamonds) and strike-slip (blue circles) D/D_{ave} data for global earthquakes. Japanese data regressions are shown with blue lines (5th, 15th, 50th, 85th, and 95th percentiles from bottom to top) and strike-slip [2] with red lines. Japan data are from [4].

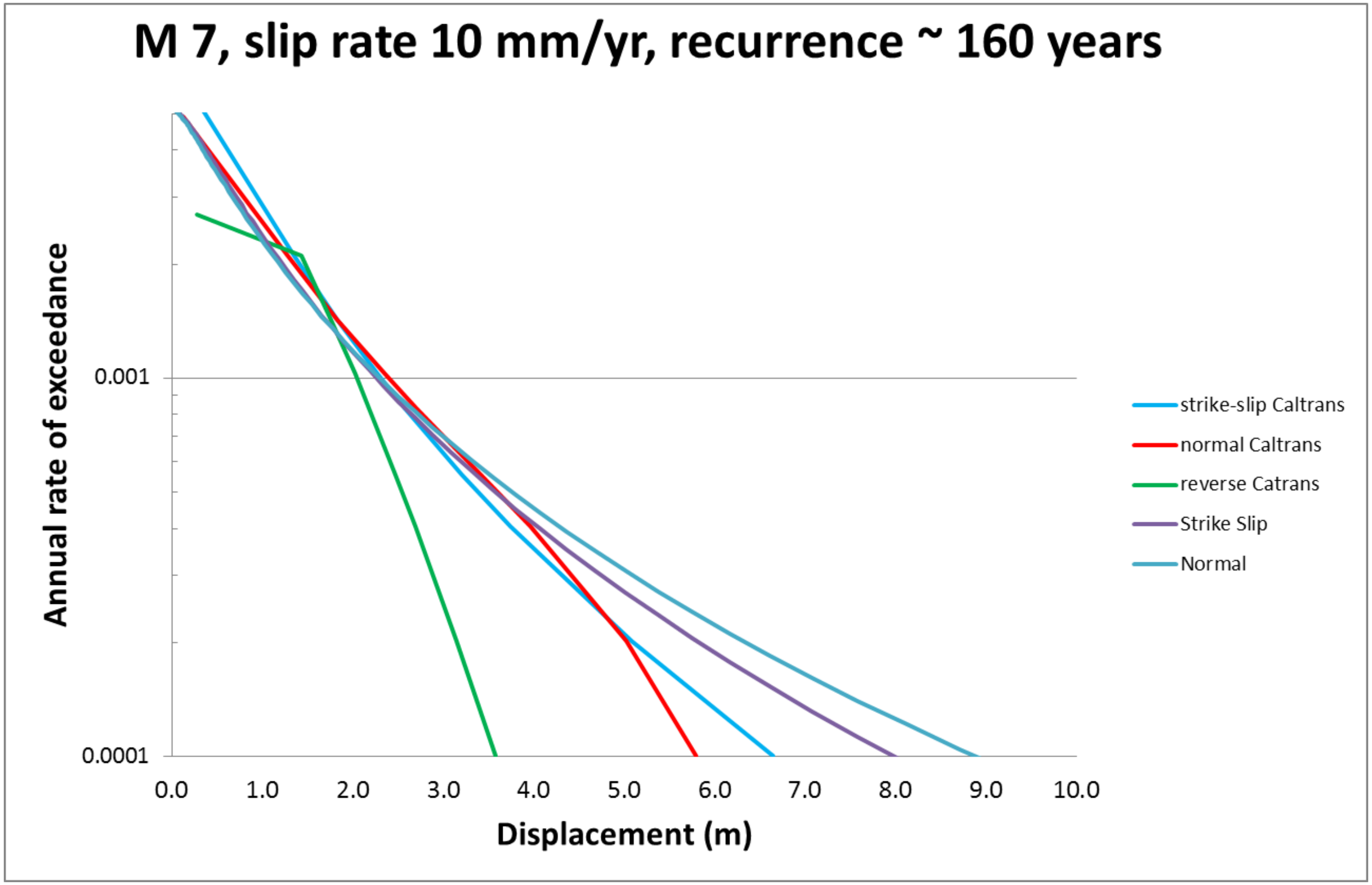
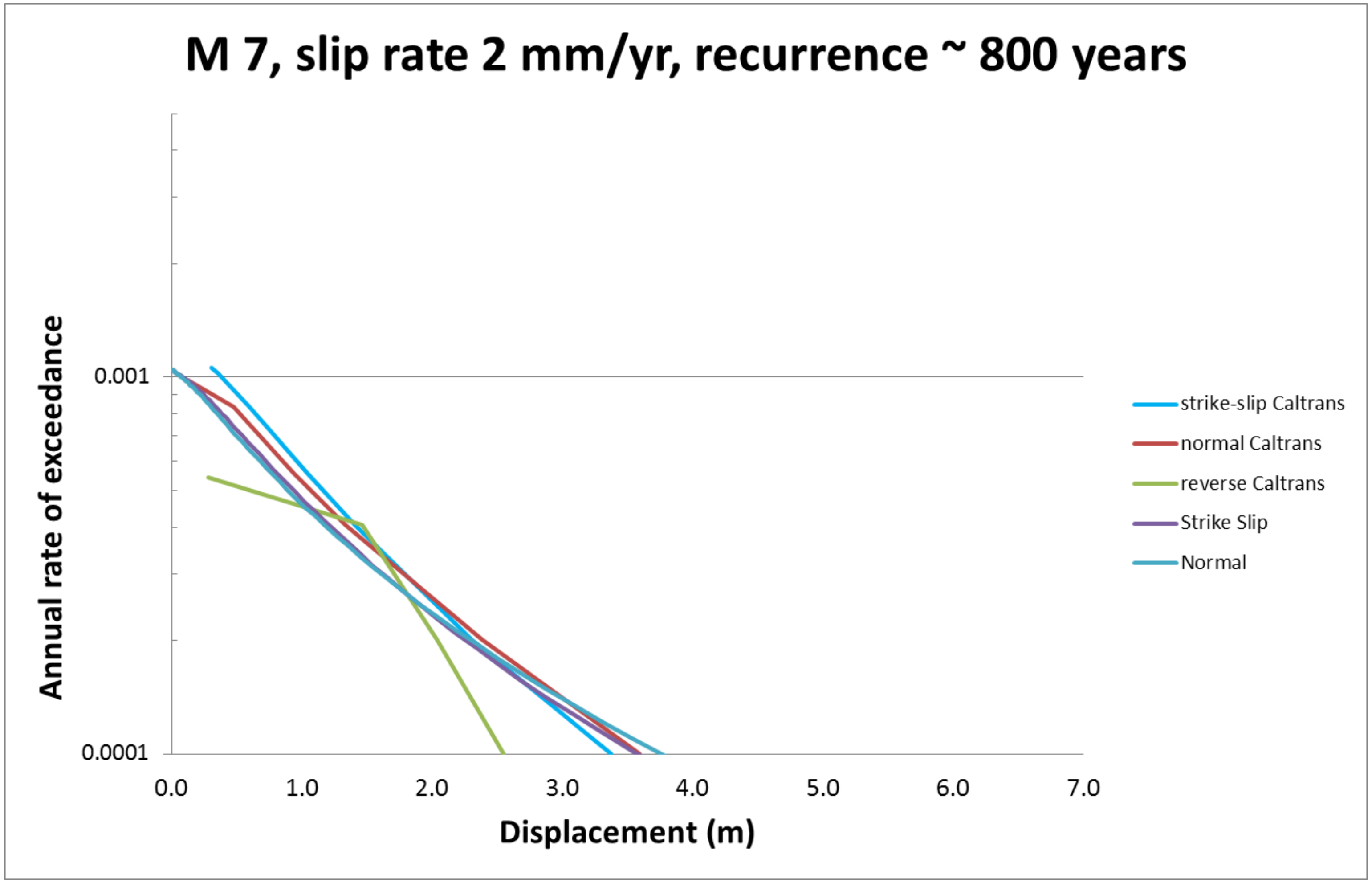
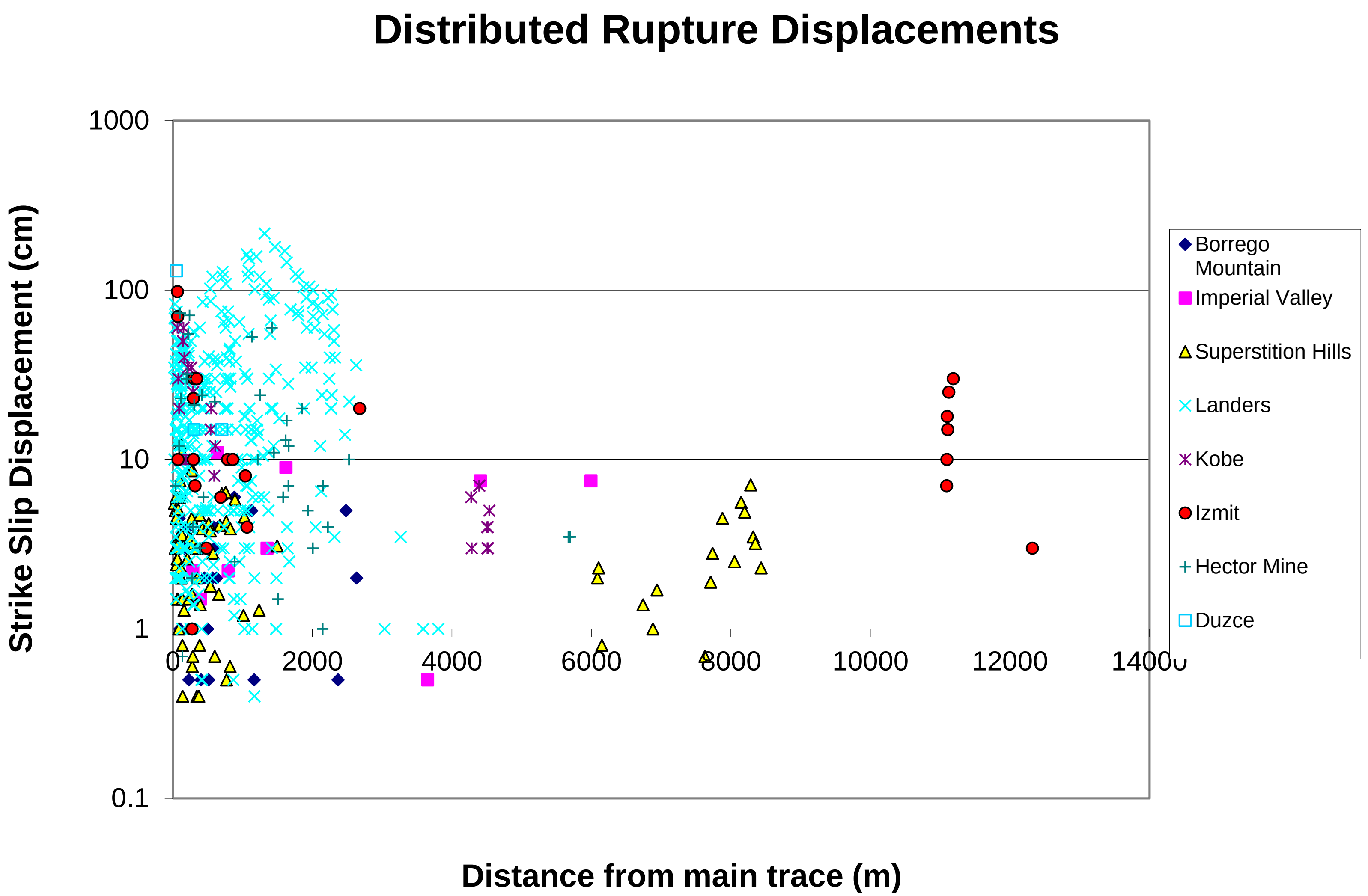


FIGURE 4. Hazard curves for M 7 displacements for M 7 earthquake on a very active fault with recurrence of about 160 years.



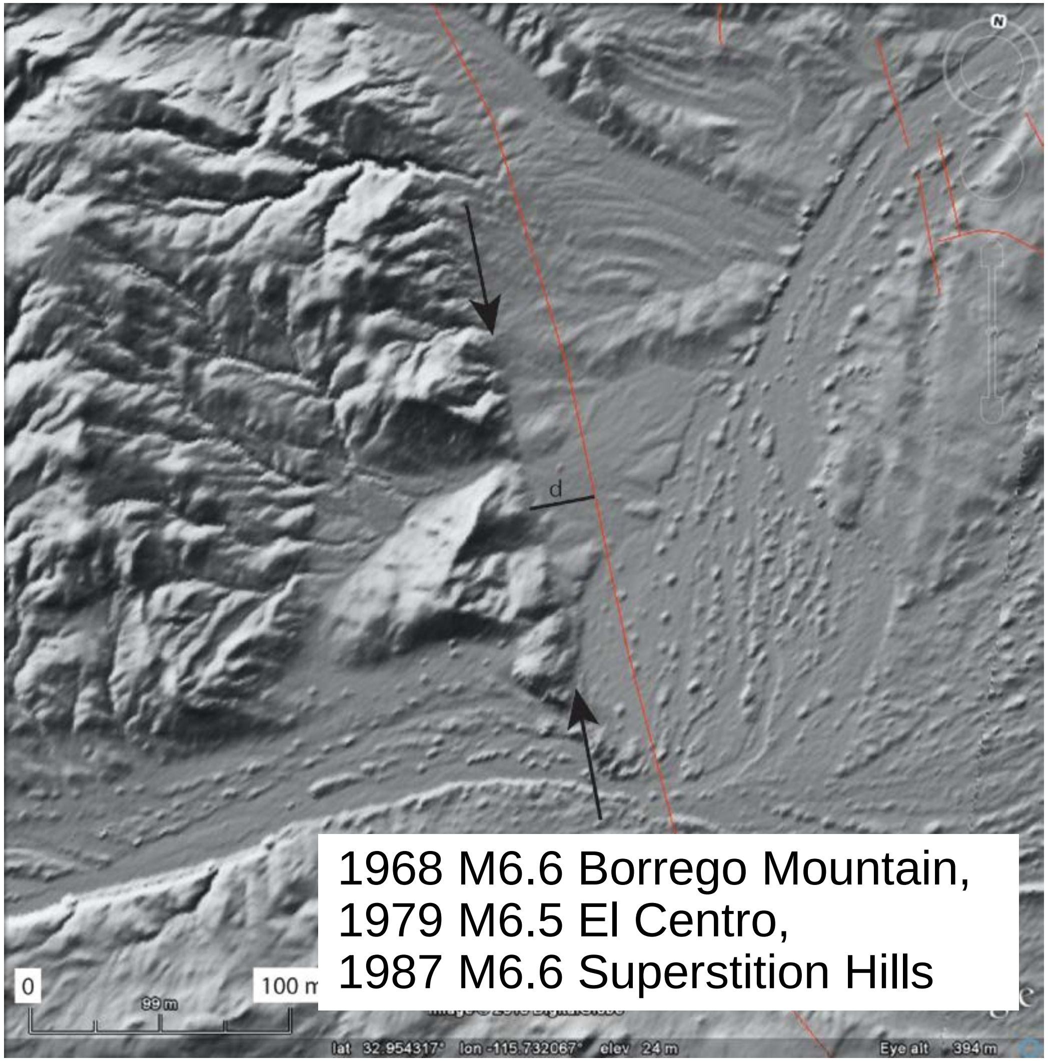
M 7, slip rate 2 mm/yr, recurrence ~ 800 years
Annual rate of exceedance
0.001
0.0001
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
Displacement (m)
strike-slip Caltrans
normal Caltrans
reverse Caltrans
Strike Slip
Normal

Petersen et al. Fault rupture hazard model

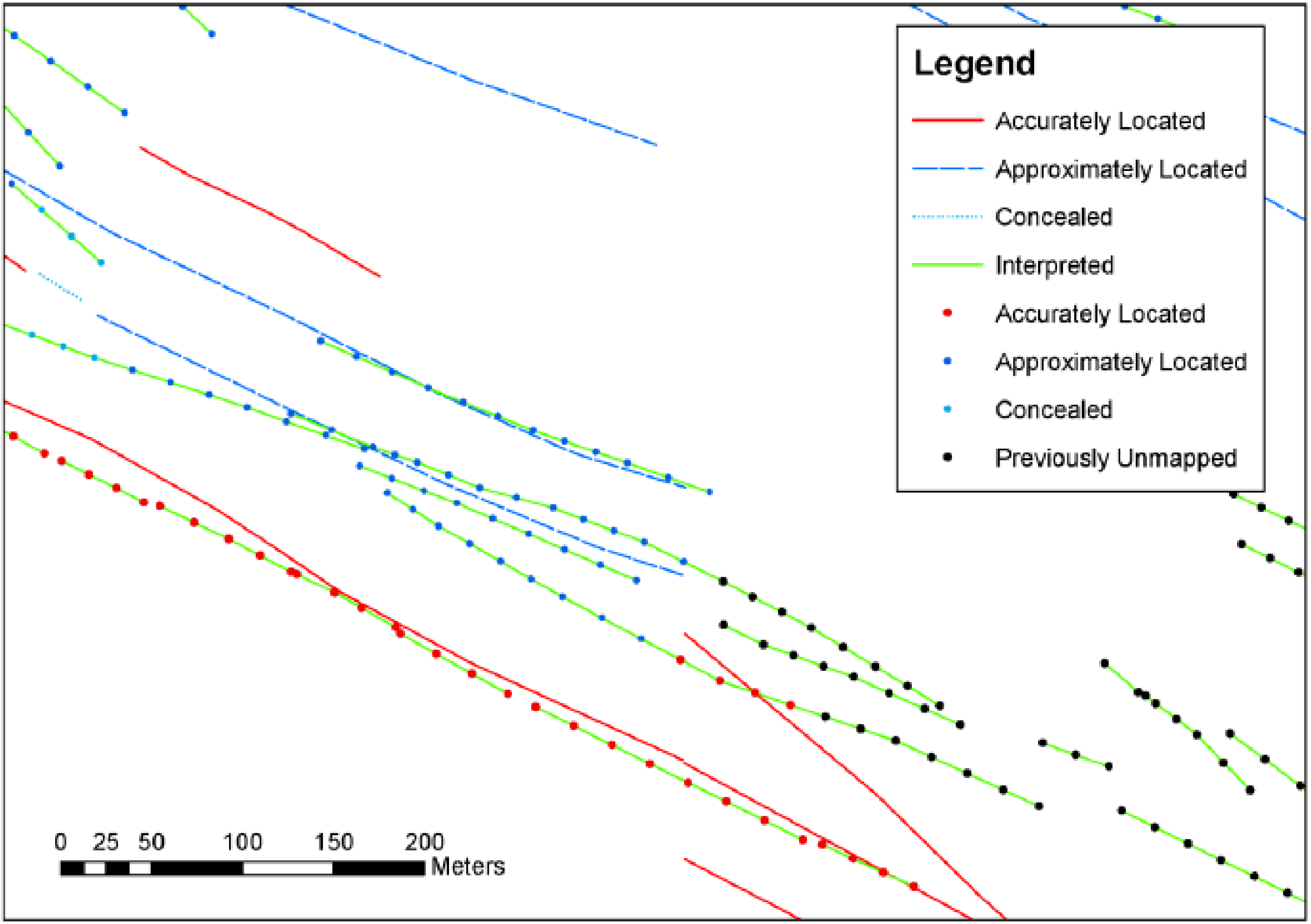


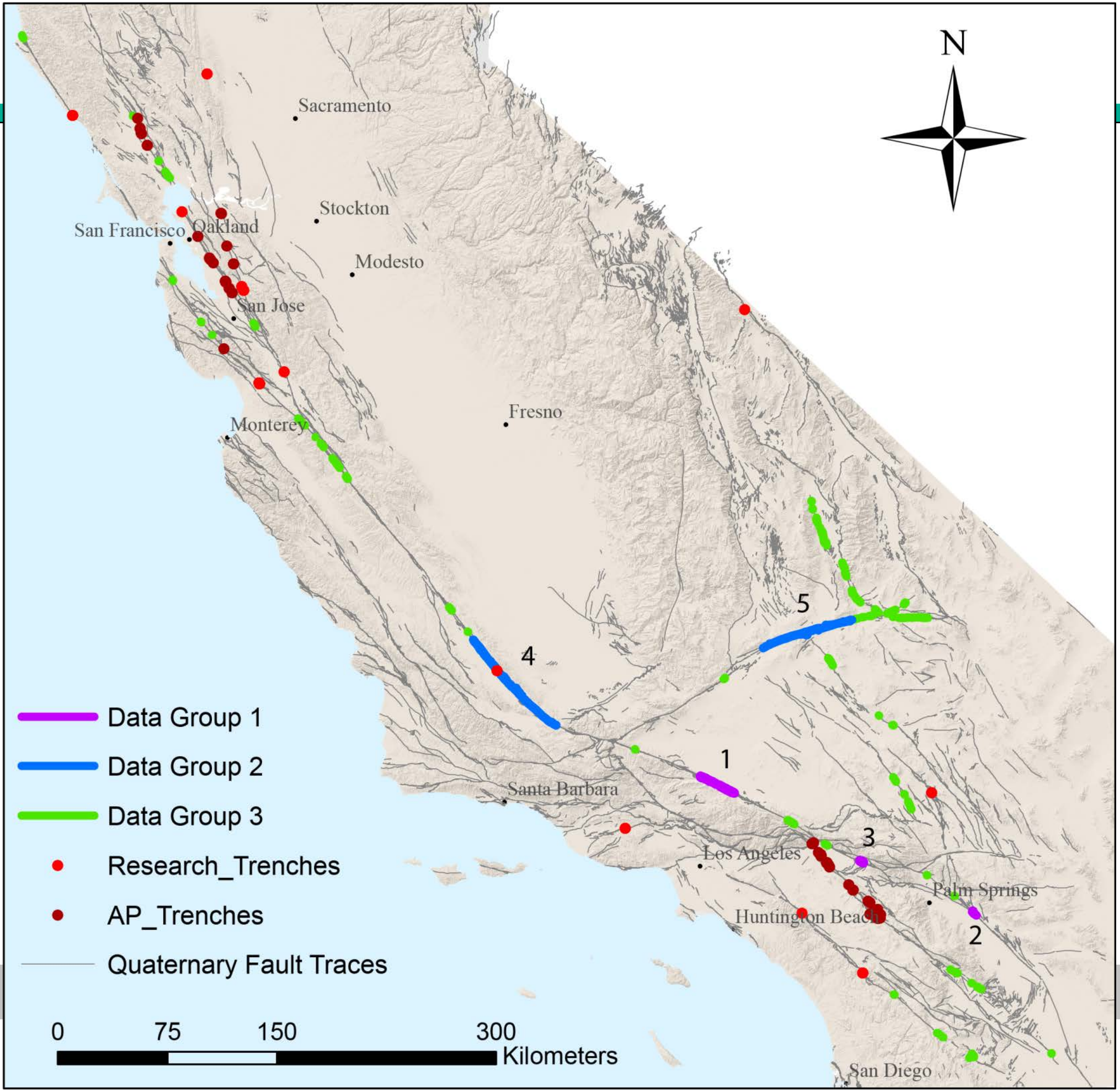
Quantifying Total Location Uncertainty

- Total uncertainty is mostly from mapping inaccuracy (epistemic)
- Fault map used in PFDHA
  - AP fault traces in CA
- Traces of actual surface ruptures
  - Historical surface rupturing earthquakes (Petersen et al., 2011 BSSA)
  - Imagery-based interpretation, e.g. High resolution LiDAR DEM and MASTER (this study)



Comparison of fault traces for total uncertainty




N
Sacramento
Stockton
San Francisco
Oakland
Modesto
San Jose
Fresno
Monterey
Santa Barbara
Los Angeles
Palm Springs
Huntington Beach
San Diego
1
2
3
4
5
Data Group 1
Data Group 2
Data Group 3
Research_Trenches
AP_Trenches
Quaternary Fault Traces
0
75
150
300
Kilometers

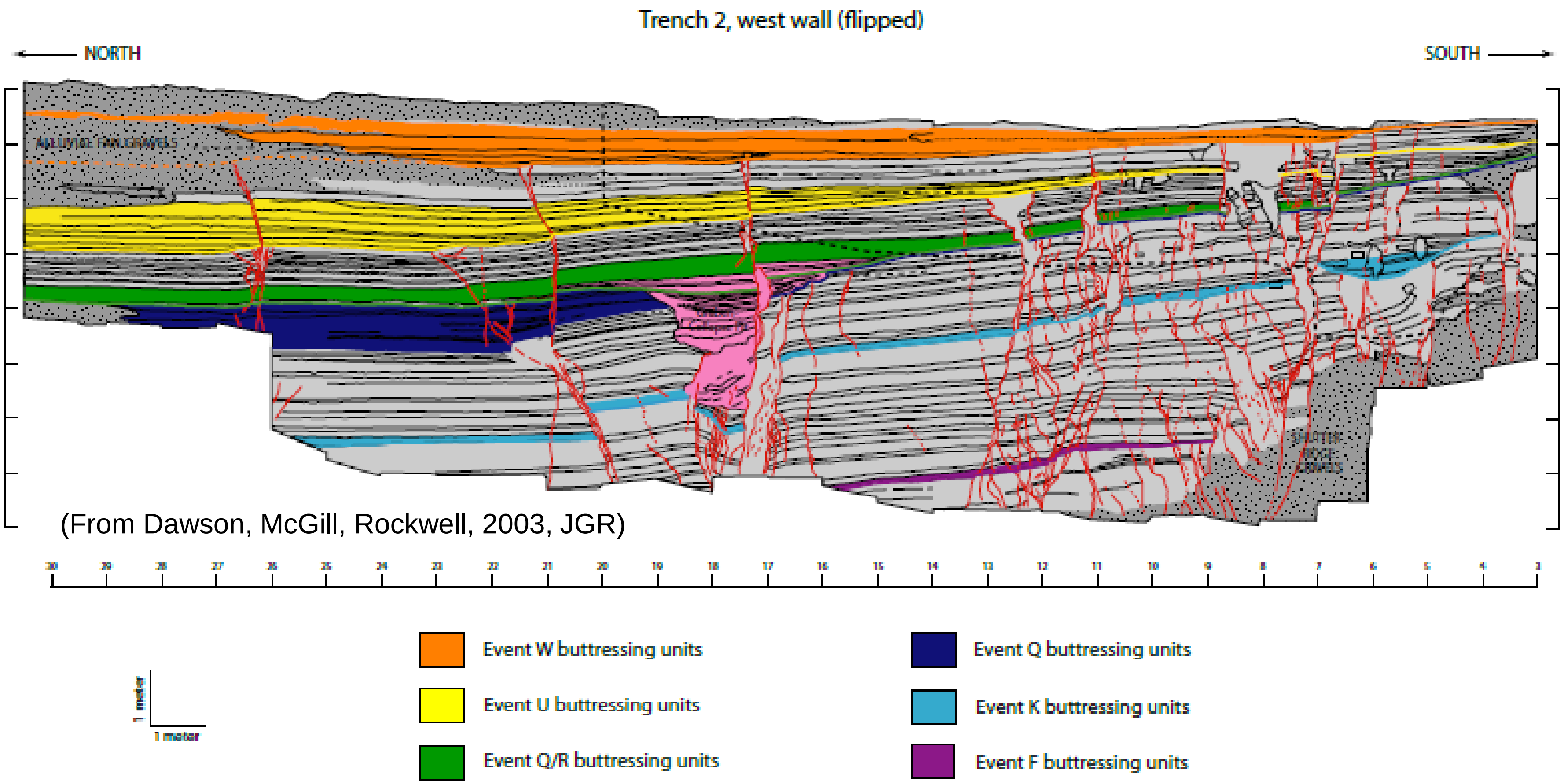
Summary Statistics of Total Location Uncertainty

Type of Mapped Trace	Mean (m)	σ (m)	COV
Accurate	17.7 (18.5)	13.9 (19.5)	0.8 (1.1)
Approximate	25.8 (25.2)	25.0 (35.9)	1.0 (1.4)
Concealed	33.9 (39.4)	27.3 (52.4)	0.8 (1.3)
Inferred	29.8 (45.1)	33.9 (57.0)	1.1 (1.3)
All	21.6 (30.6)	20.5 (43.1)	0.9 (1.4)
Unmapped	190.4	221.8	1.2

Data in parentheses are from Petersen et al. (2011, BSSA) based on historical surface ruptures

Aleatory Variability of Surface Rupture

El Paso Peaks, Garlock Fault



(From Dawson, McGill, Rockwell, 2003, JGR)

Data for Quantifying Aleatory Location Variability

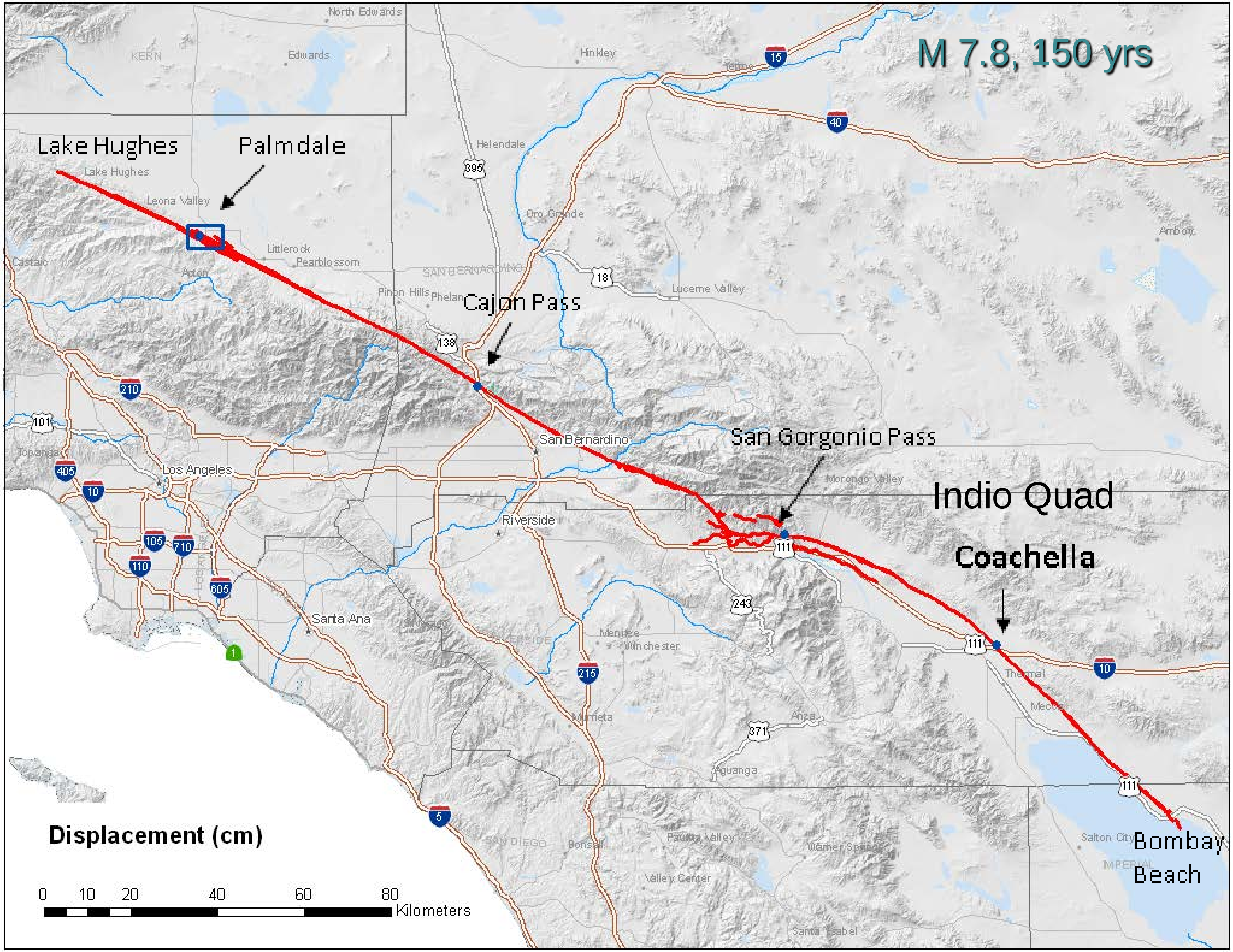
- Available Data (163 trenches)
  - Trenches for paleoseismic research
  - Trenches for development investigations to comply with AP Act
- Compilation of paleoseismic data
  - Attributes: Fault Name, Site Name, Site Latitude, Site Longitude, Mapped Trace Category (from the AP Zone map), Trench Number, and Comments
  - Data fields: trench length, maximum width of faulting, event, event zone width, and MRE trace to event distance
- Need more data

Summary Statistics of Location Variability Data

Representation	Mean (m)	σ (m)	COV	Number of Data Points
Upper Bound	17.4	32.3	1.85	125
Rough Estimate	10.0	10.1	1.01	52
Event zone width	2.8	2.6	0.93	49

- <u>Upper bound:</u> inferred from *zone half width* from trenches with one identified event
- <u>Rough Estimate:</u> inferred by combining three data fields from trenches with more than one identified event (*zone half width, distance from MRE to prior event, trench length divided by number of events*)
- Mean of epistemic uncertainty for accurately mapped traces falls between the upper bound and rough estimate from trench data

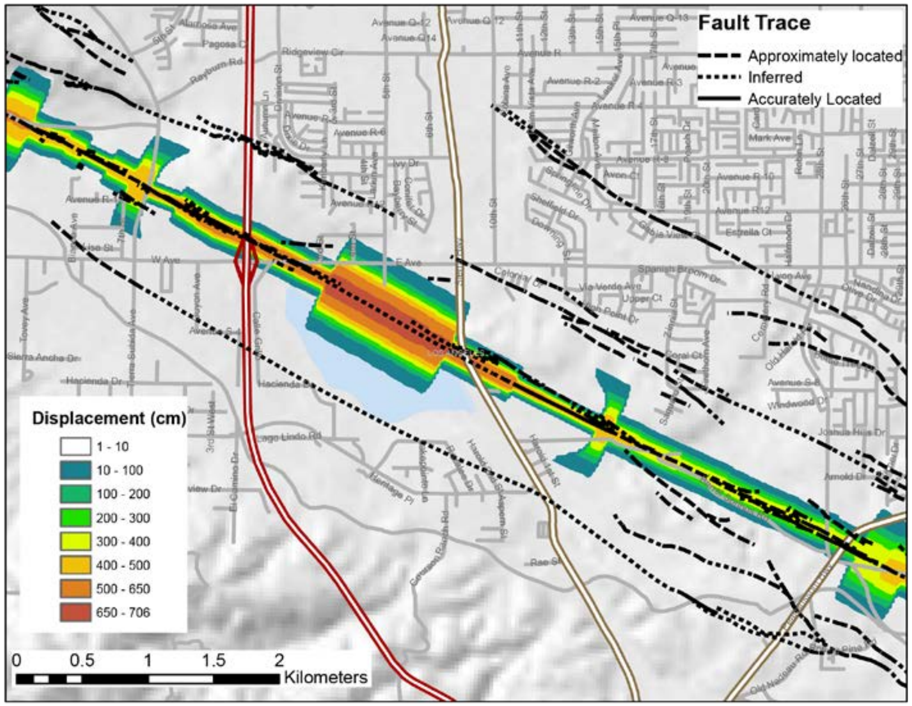
Example Mapping Application – ShakeOut Scenario



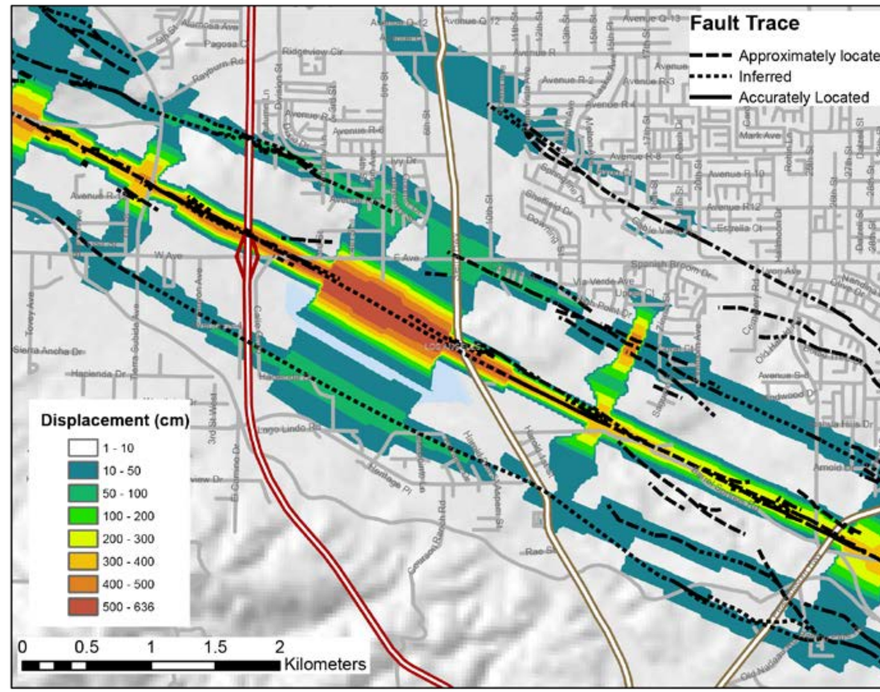
Example of mapping fault zones: partitioned slip

ShakeOut Scenario
M 7.8, 150 yr

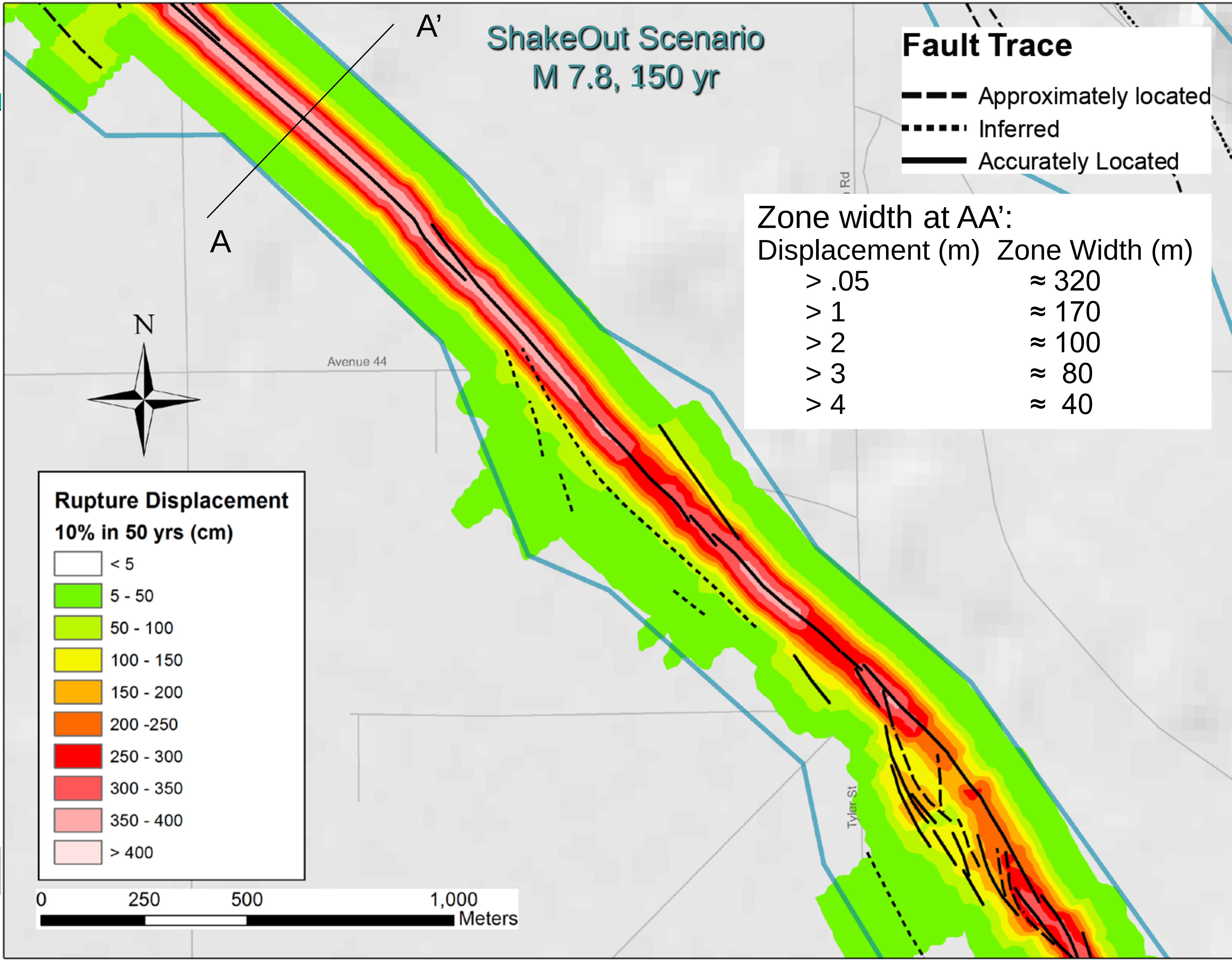
No Partition of Probabilistic Displacement
(10% in 50 years)

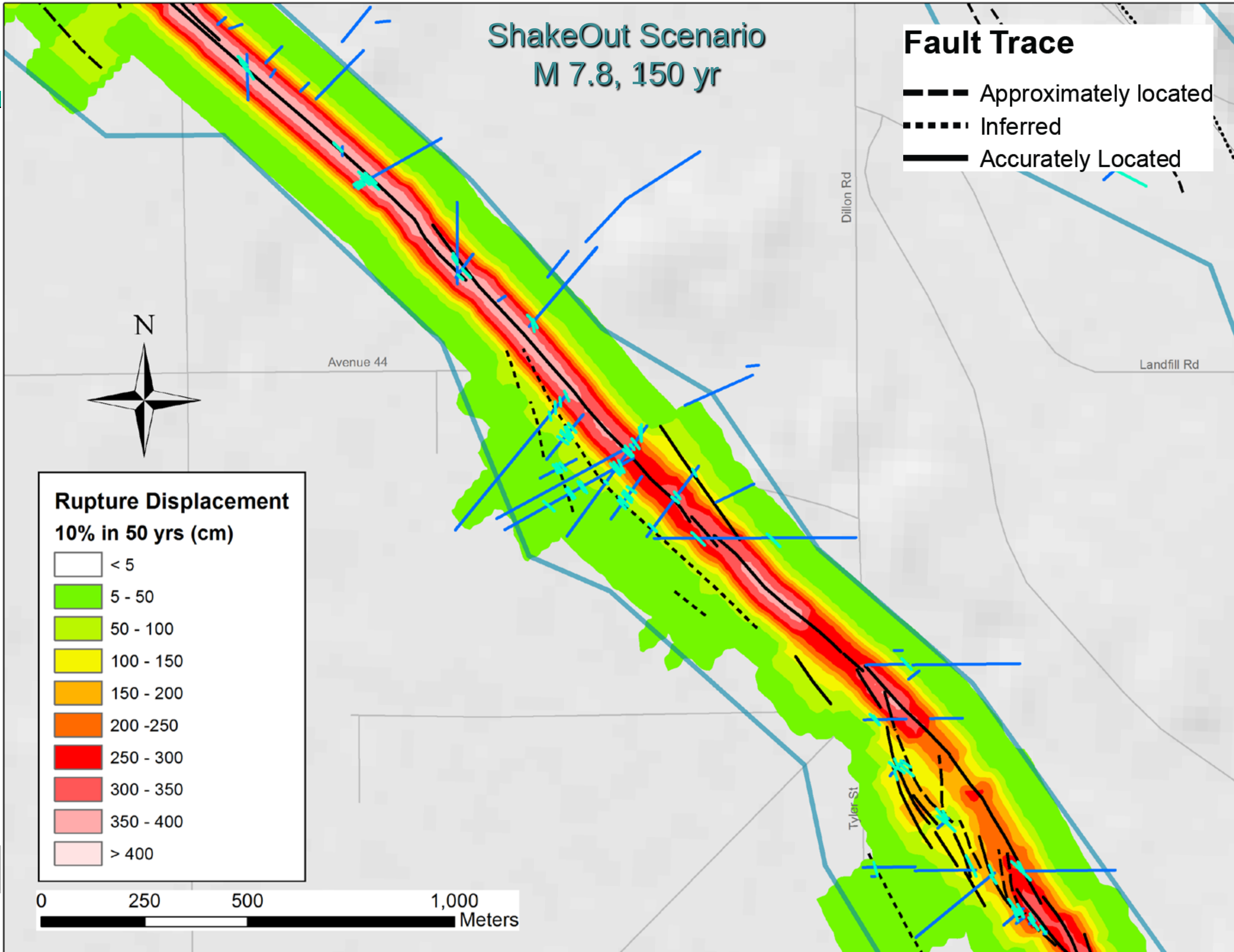


Partitioned Probabilistic Displacement
(10% in 50 years)



(Chen and Petersen, 2011, EQS)


ShakeOut Scenario
M 7.8, 150 yr
A'
A
Fault Trace
Approximately located
Inferred
Accurately Located
Zone width at AA':
Displacement (m) Zone Width (m)
> .05 ≈ 320
> 1 ≈ 170
> 2 ≈ 100
> 3 ≈ 80
> 4 ≈ 40
N
Avenue 44
Tyler St
Rd
Rupture Displacement
10% in 50 yrs (cm)
< 5
5 - 50
50 - 100
100 - 150
150 - 200
200 -250
250 - 300
300 - 350
350 - 400
> 400
0 250 500 1,000
Meters


ShakeOut Scenario
M 7.8, 150 yr
Fault Trace
Approximately located
Inferred
Accurately Located
Dillon Rd
N
Avenue 44
Landfill Rd
Tyler St
Rupture Displacement
10% in 50 yrs (cm)
< 5
5 - 50
50 - 100
100 - 150
150 - 200
200 -250
250 - 300
300 - 350
350 - 400
> 400
0
250
500
1,000
Meters

Conclusions

Improvements needed:

- How do we account for hazards from low slip rate faults or from multi-stranded faults?
- Need to look at global paleoseismic data and more LiDAR data (especially for site specific)
- More data are need, can dynamic rupture simulation provides useful data?
- How do we define aleatory variability in rupture location so that we can treat two kinds of uncertainties separately?
- How do we treat those previously unmapped faults (site specific studies)?
- Are displacement maps useful, why?
- How do we account for triggered earthquakes
- Simulate uplift for fault rupture and displacement hazard (Thio)