

# Determination of the Magnitude and Source Location of Paleoearthquakes from Paleoliquefaction Evidence

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Russell A. Green, PhD, PE

*Department of Civil and Environmental Engineering, Virginia Tech*



# Outline

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- Paleoliquefaction features in the central-eastern US
- Commonly used back-calculation procedure: empirical magnitude bound curves
- Back-calculated regional probabilistic magnitude bound curves

# Paleoliquefaction Features in the Central-Eastern US

Areas wherein paleoliquefaction features have been found in the Central Eastern US:

1. NMSZ and surrounding region
2. Marianna, AR region
3. St. Louis region
4. WVSZ and surrounding region
5. AR-LA-MS region
6. Charleston SZ
7. Atlantic Coast
8. Newburyport, MA and surrounding region
9. Charlevoix SZ and surrounding region
10. CVSZ

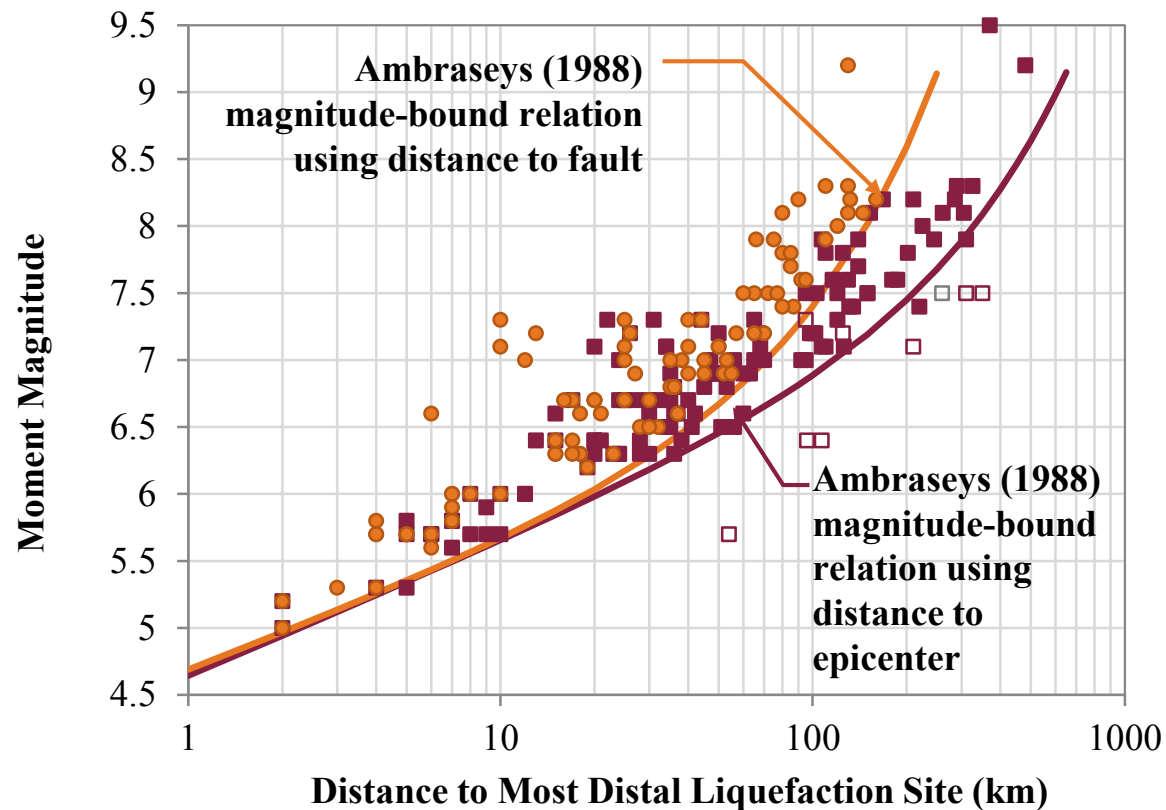


# Paleoliquefaction Features in the Central-Eastern US



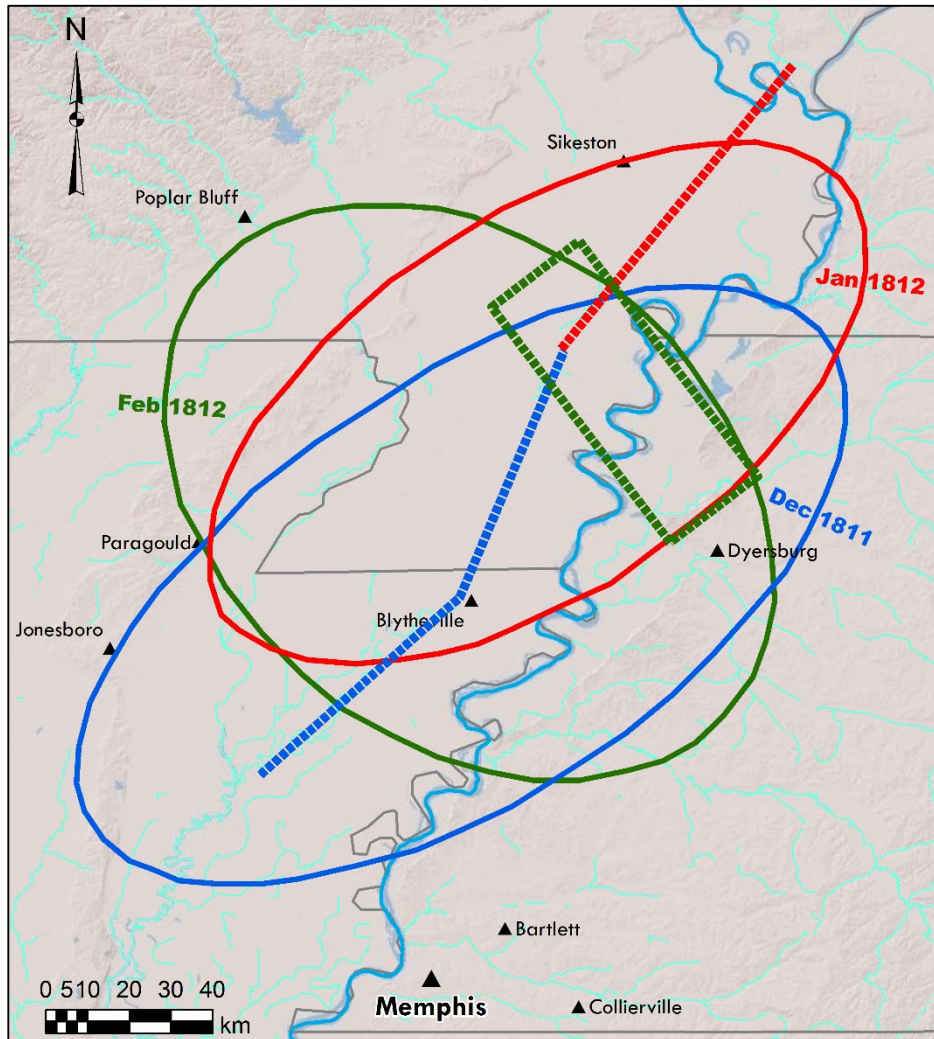
# Empirical Magnitude Bound Curves

## Worldwide Data

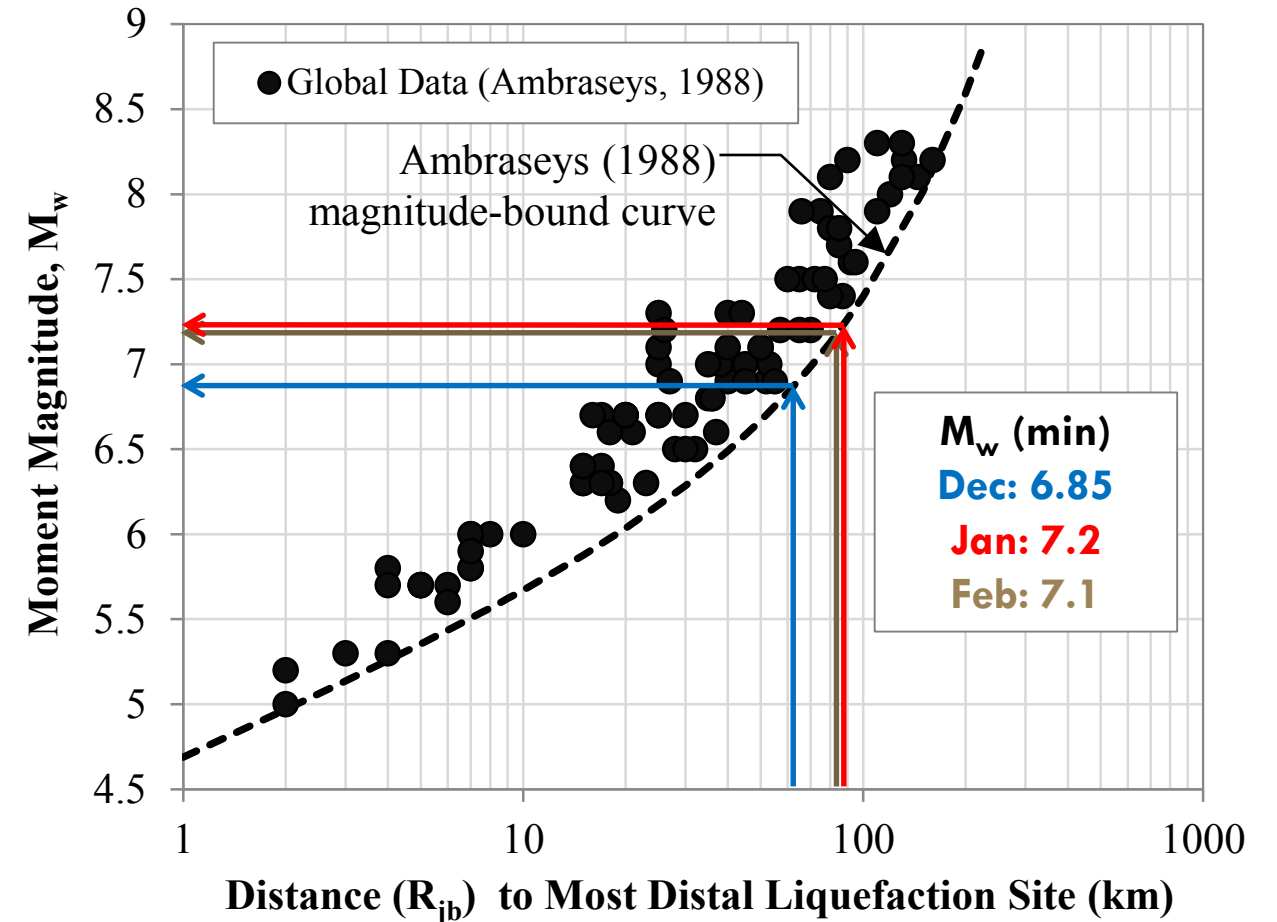


- Distance to most distal liquefaction feature for shallow/moderate depth earthquakes (focal depth < 50 km)
- Epicentral distance
- Distance to fault

# Empirical Magnitude Bound Curve Procedure

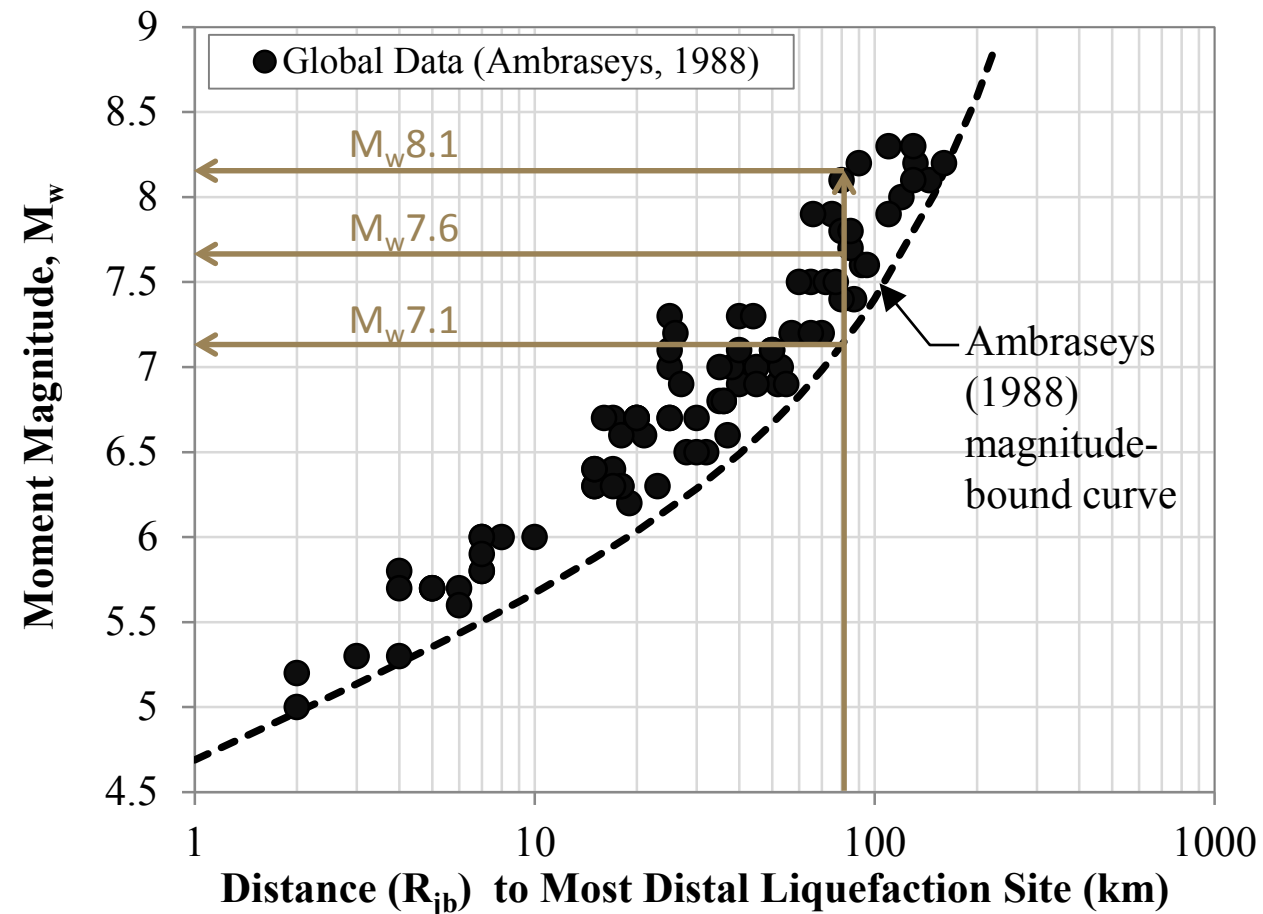


CEUS-SSC (2012) Preferred Rupture Scenario



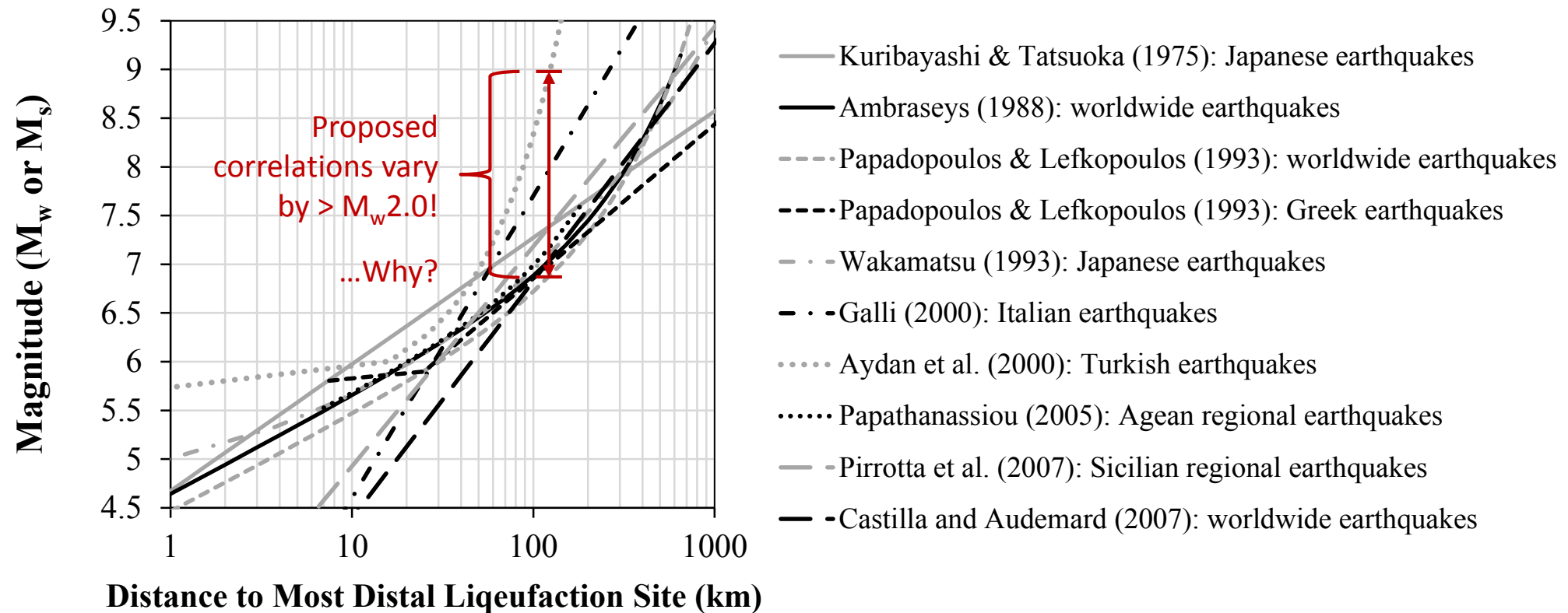
# Limitations of Empirical Magnitude Bound Curve Procedure

Magnitude of paleo-earthquake???



# Limitations of Empirical Magnitude Bound Curve Procedure

## Magnitude bound curves proposed in literature



# Back-Calculated Probabilistic Magnitude Bound Curves

- Back-calculate magnitude-bound curves using liquefaction triggering mechanics in conjunction with ground motion prediction equations.
- Using the total probability theorem to integrate over uncertainties, the probability that a site liquefies in an earthquake of magnitude (M) at site-to-source distance (R) is:

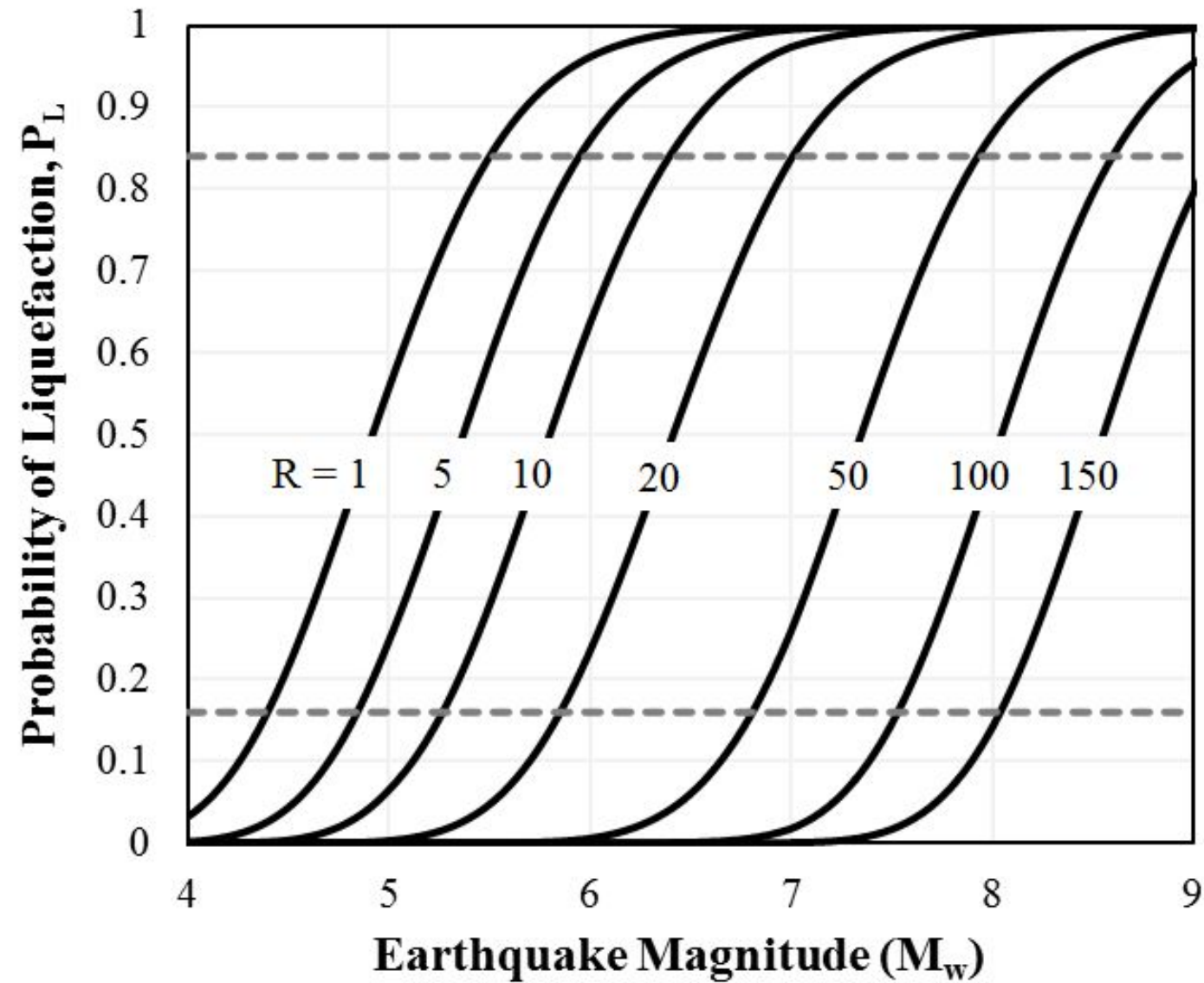
Using Stress-based liquefaction triggering mechanics:

$$P(\tau \geq \tau_t | \text{EQK: } M, R) = \int_{a_{\max}} \int_{r_d} P(\tau \geq \tau_t | a_{\max}, r_d) f(a_{\max} | M, R) f_{r_d}(r_d) \cdot dr_d \cdot da_{\max}$$

Using Strain-based liquefaction triggering mechanics:

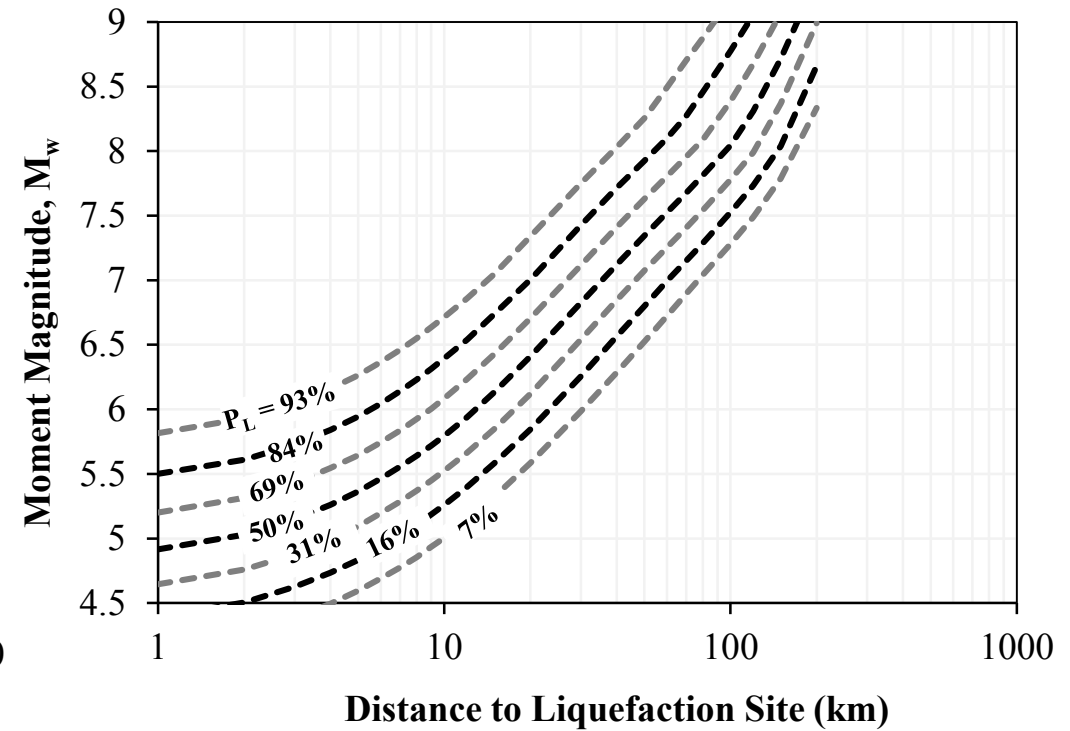
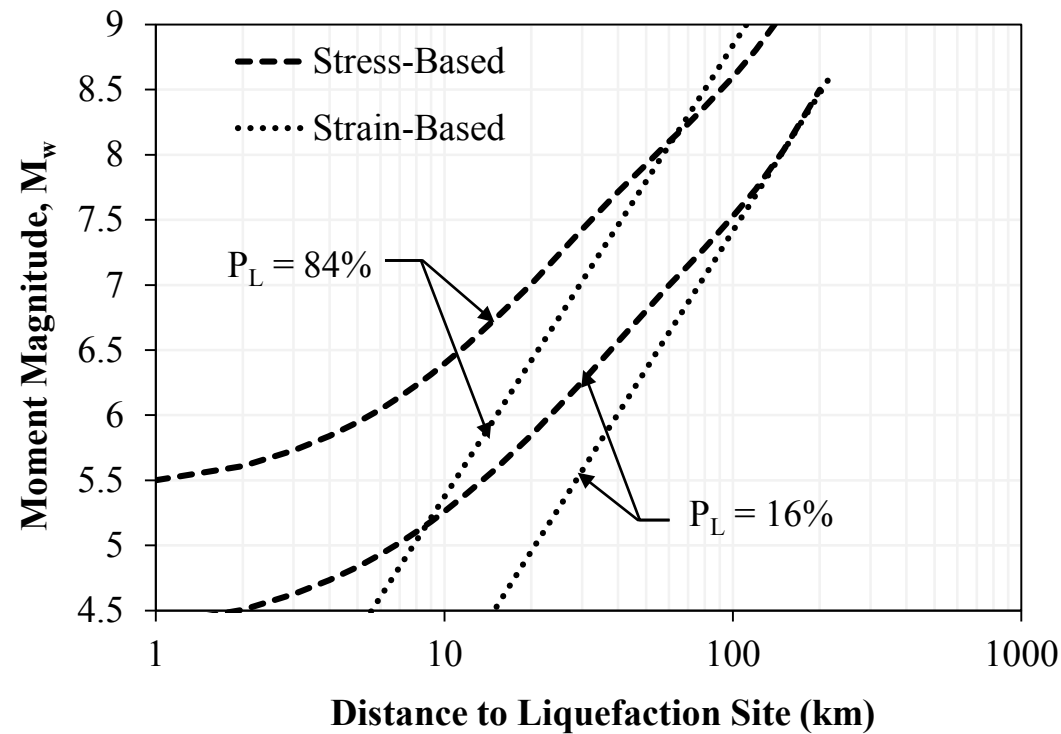
$$P(\gamma \geq \gamma_t | \text{EQK: } M, R) = \int_{a_{\max}} \int_{r_d} \int_{\frac{G}{G_{\max}}} P(\gamma \geq \gamma_t | a_{\max}, r_d, \frac{G}{G_{\max}}) f(a_{\max} | M, R) f_{r_d}(r_d) f_{\frac{G}{G_{\max}}}\left(\frac{G}{G_{\max}}\right) d\frac{G}{G_{\max}} \cdot dr_d \cdot da_{\max}$$

# Back-Calculated Probabilistic Magnitude Bound Curves



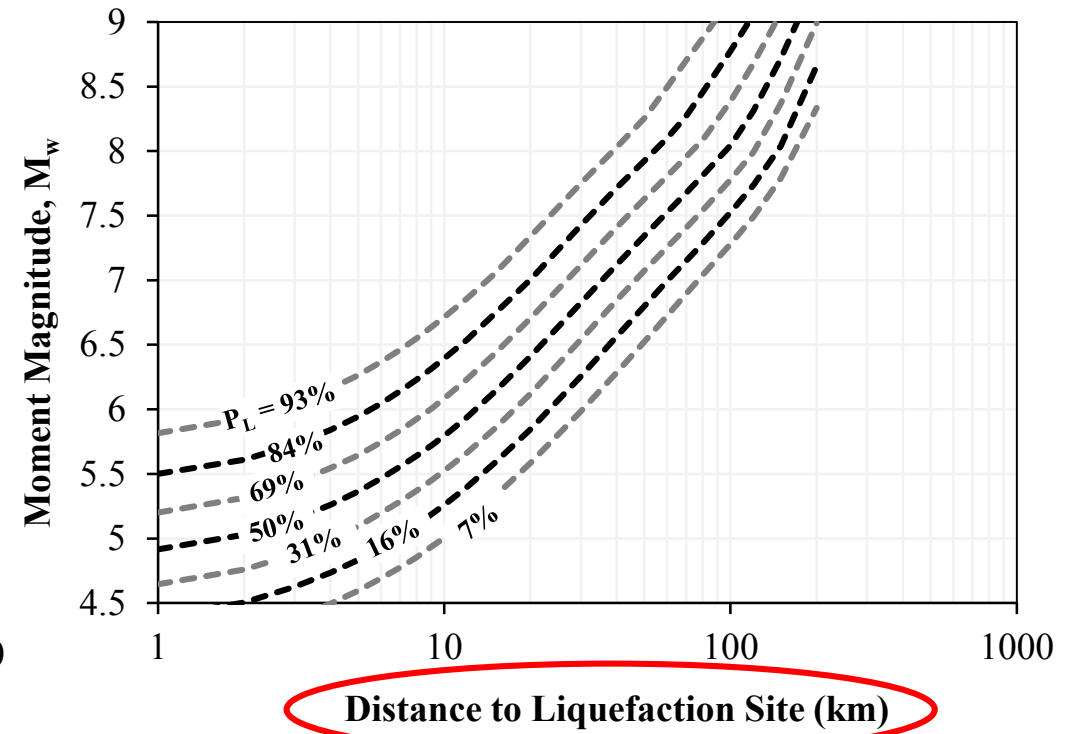
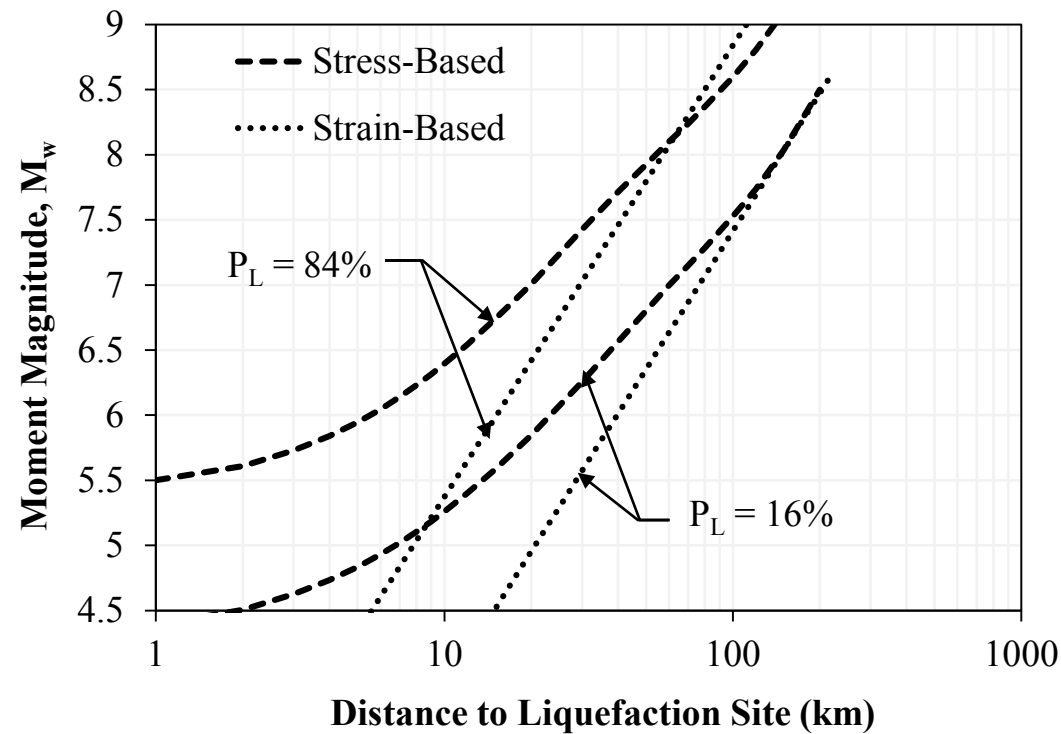
# Back-Calculated Probabilistic Magnitude Bound Curves

Combining results from the stress-based and strain-based frameworks...



# Back-Calculated Probabilistic Magnitude Bound Curves

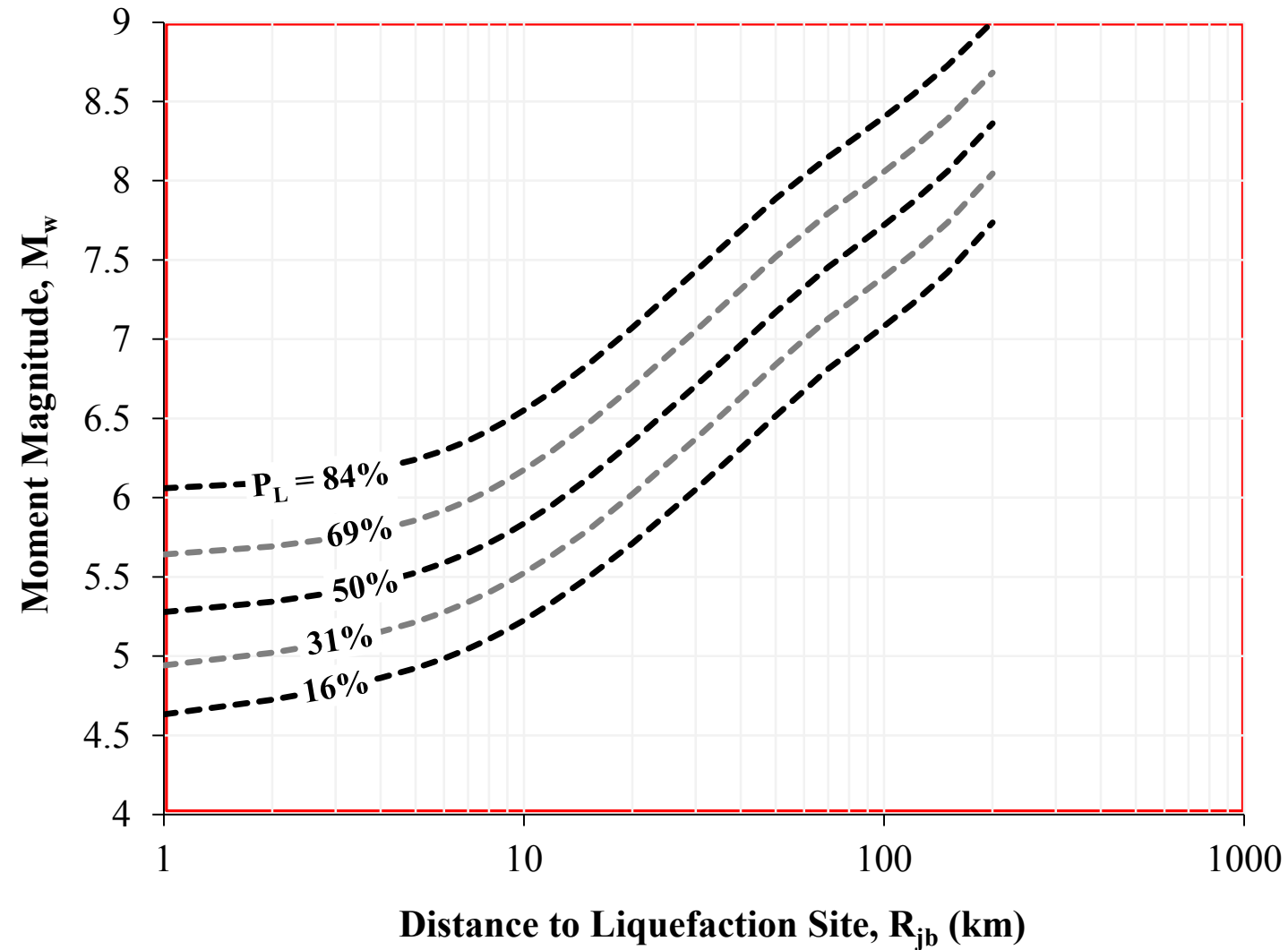
Combining results from the stress-based and strain-based frameworks...



Can use all paleo-features, not just the most distal features

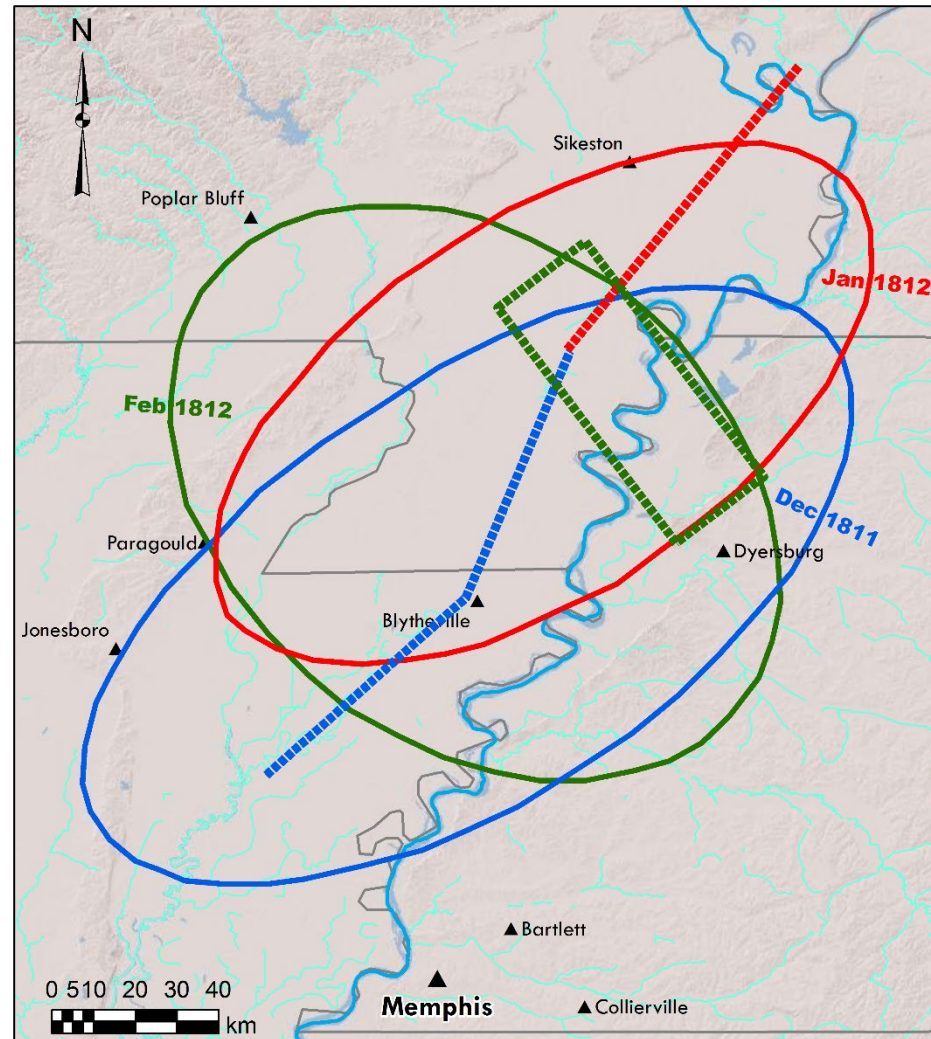
# Back-Calculated Probabilistic Magnitude Bound Curves

Application to the 1811-1812 New Madrid Earthquakes



# Back-Calculated Probabilistic Magnitude Bound Curves

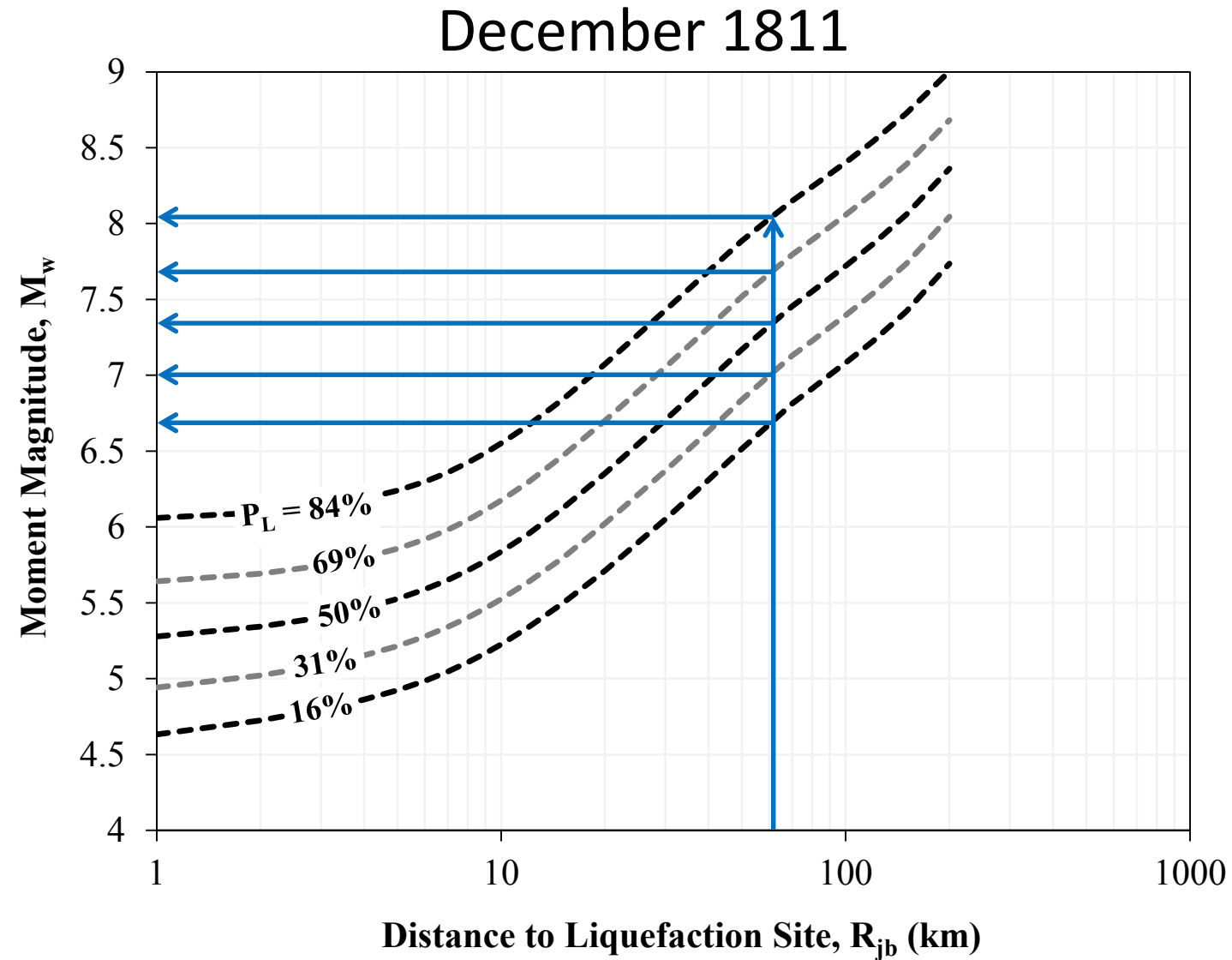
Application to the 1811-1812 New Madrid Earthquakes



**CEUS-SSC (2012) Preferred Rupture Scenario**

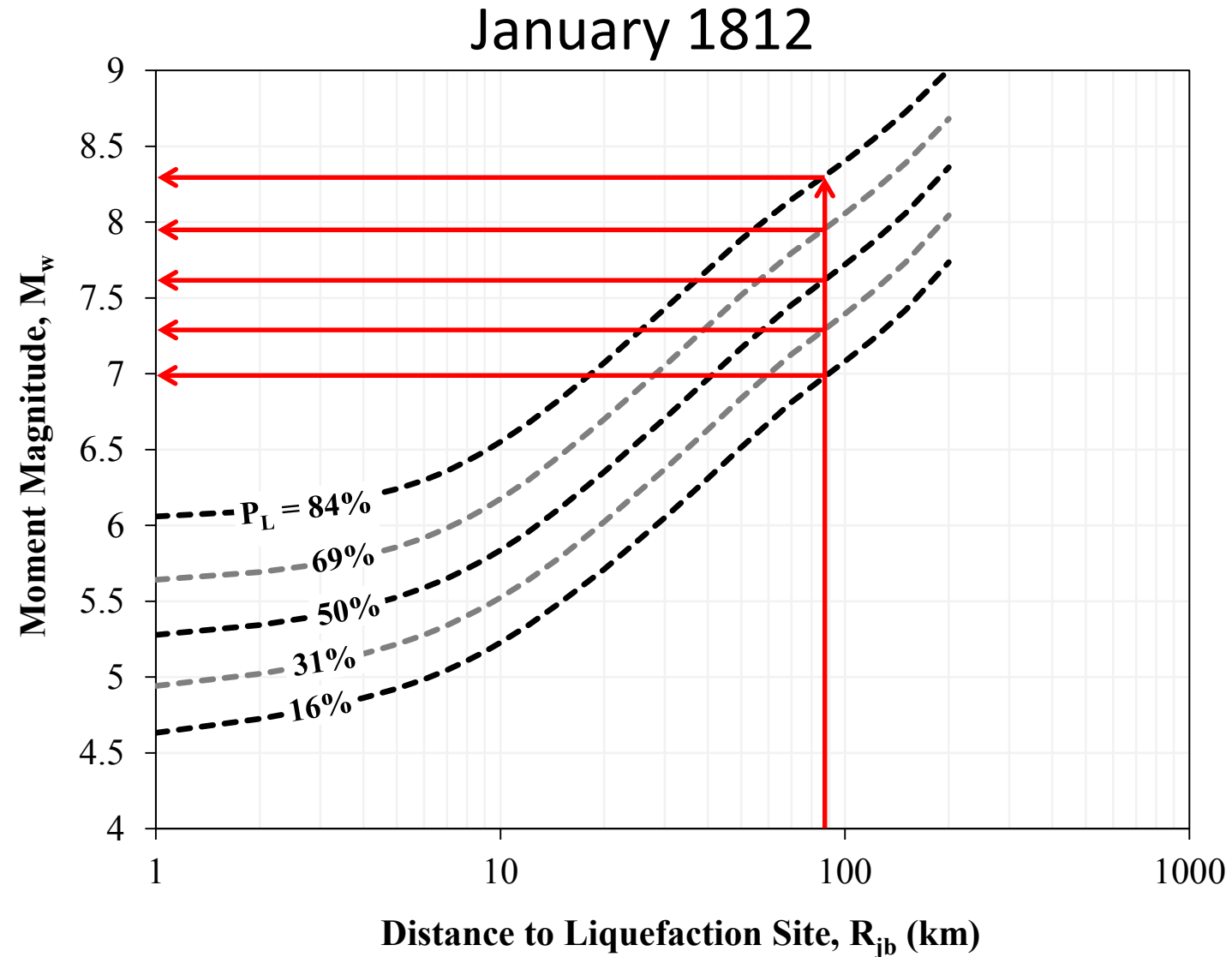
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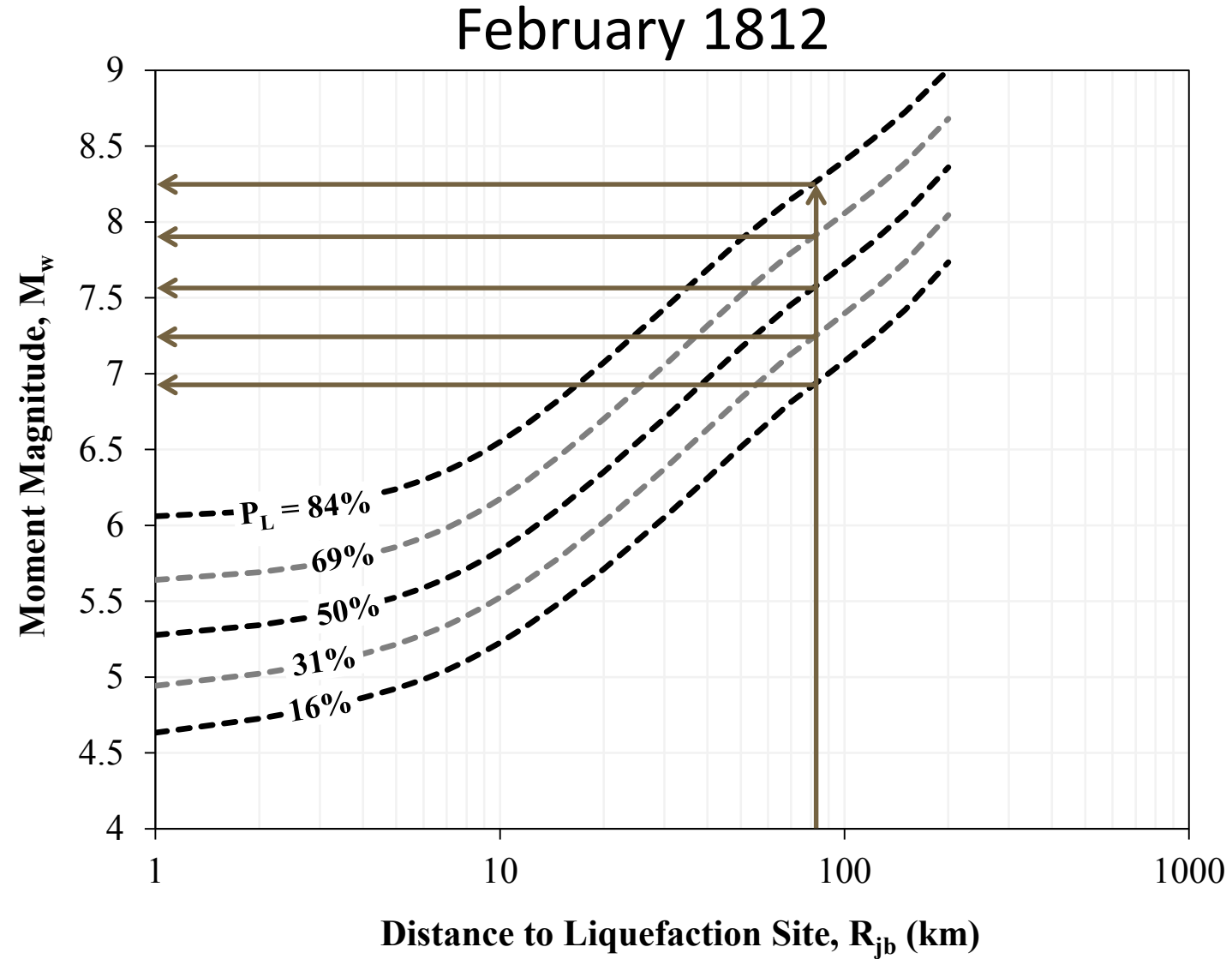
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Application to the 1811-1812 New Madrid Earthquakes



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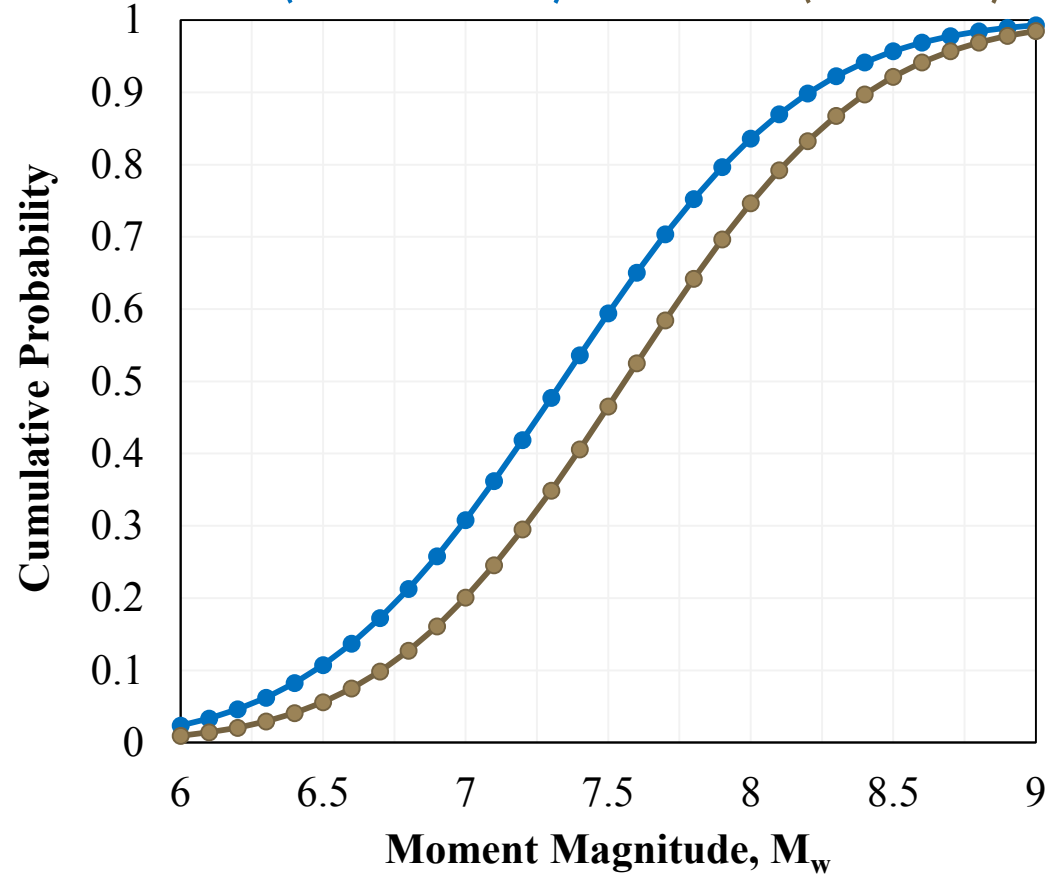
Application to the 1811-1812 New Madrid Earthquakes



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Application to the 1811-1812 New Madrid Earthquakes

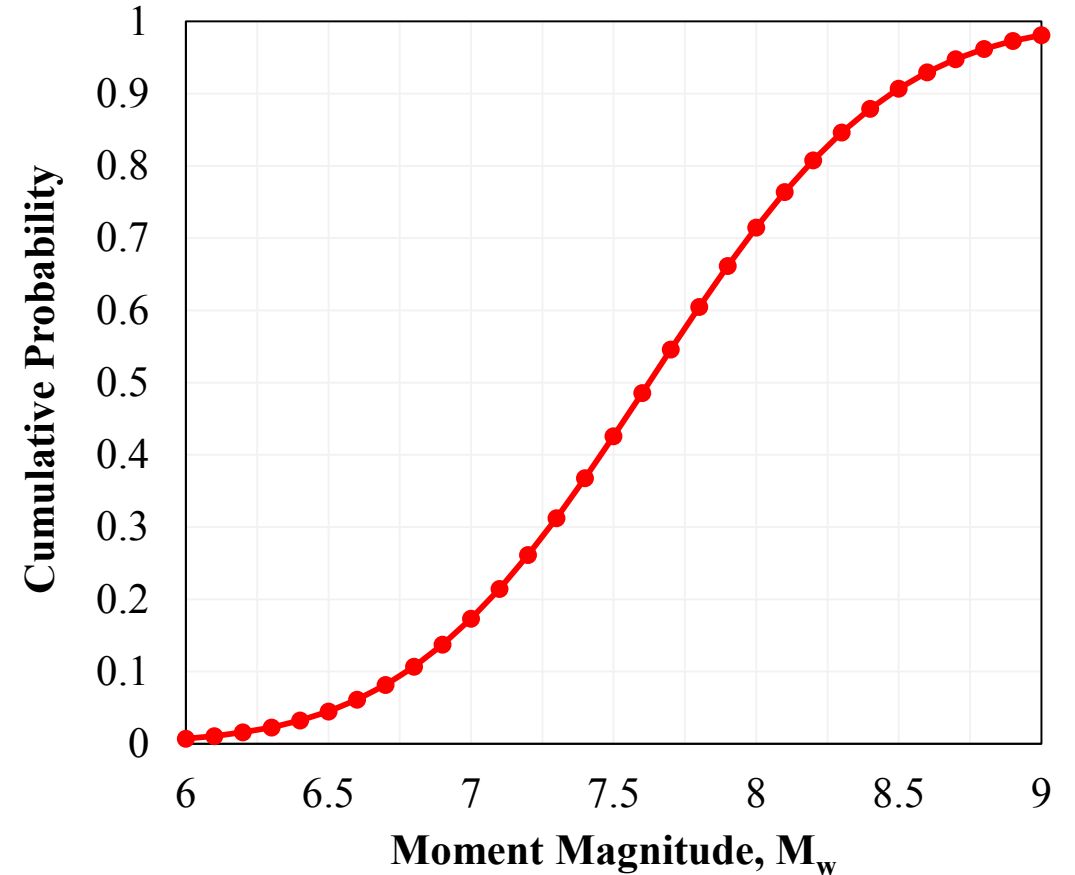
Southern (Cottonwood) & Central (Reelfoot) Faults



Dec 1811    Feb 1812

Median  $M_w$     7.35    7.55

Northern Fault



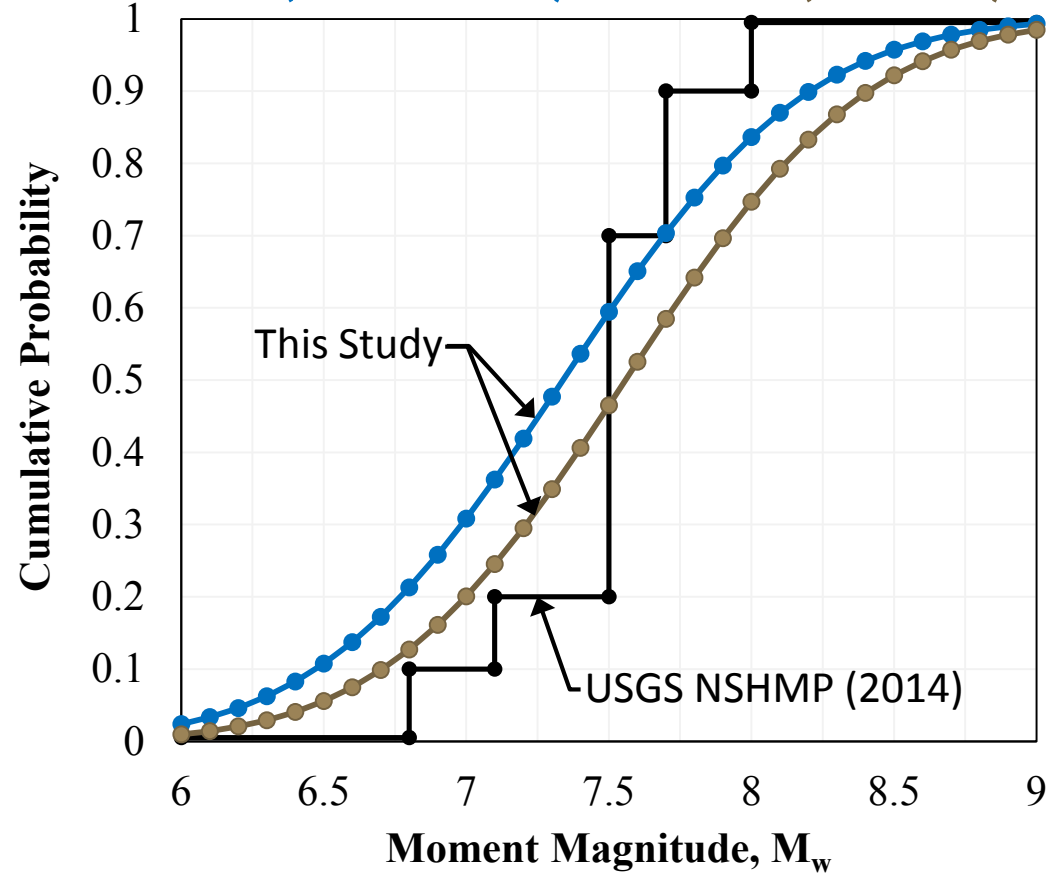
Jan 1812

Median  $M_w$     7.62

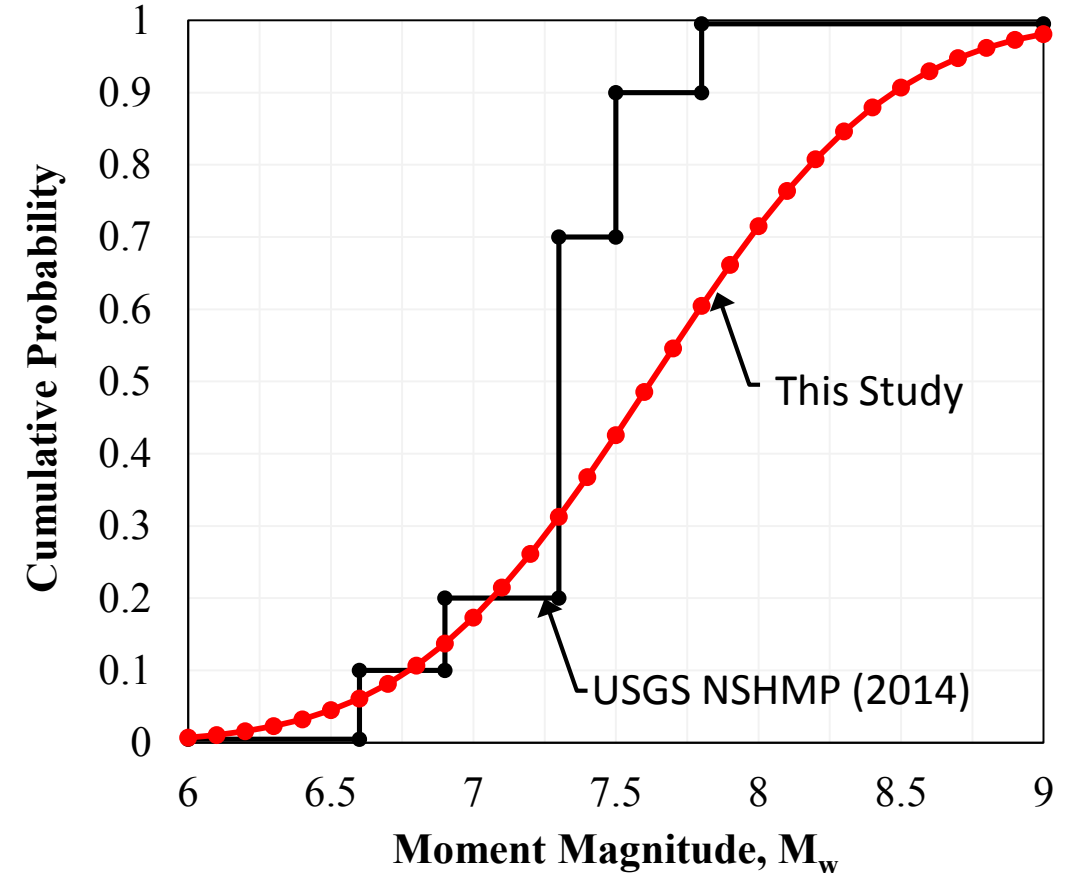
# Back-Calculated Probabilistic Magnitude Bound Curves

## Application to the 1811-1812 New Madrid Earthquakes

Southern (Cottonwood) & Central (Reelfoot) Faults



Northern Fault



	Dec 1811	Feb 1812
Median $M_w$ (This Study)	7.35	7.55
Median $M_w$ (USGS, 2014)	7.5	7.5

	Jan 1812
Median $M_w$ (This Study)	7.62
Median $M_w$ (USGS, 2014)	7.3

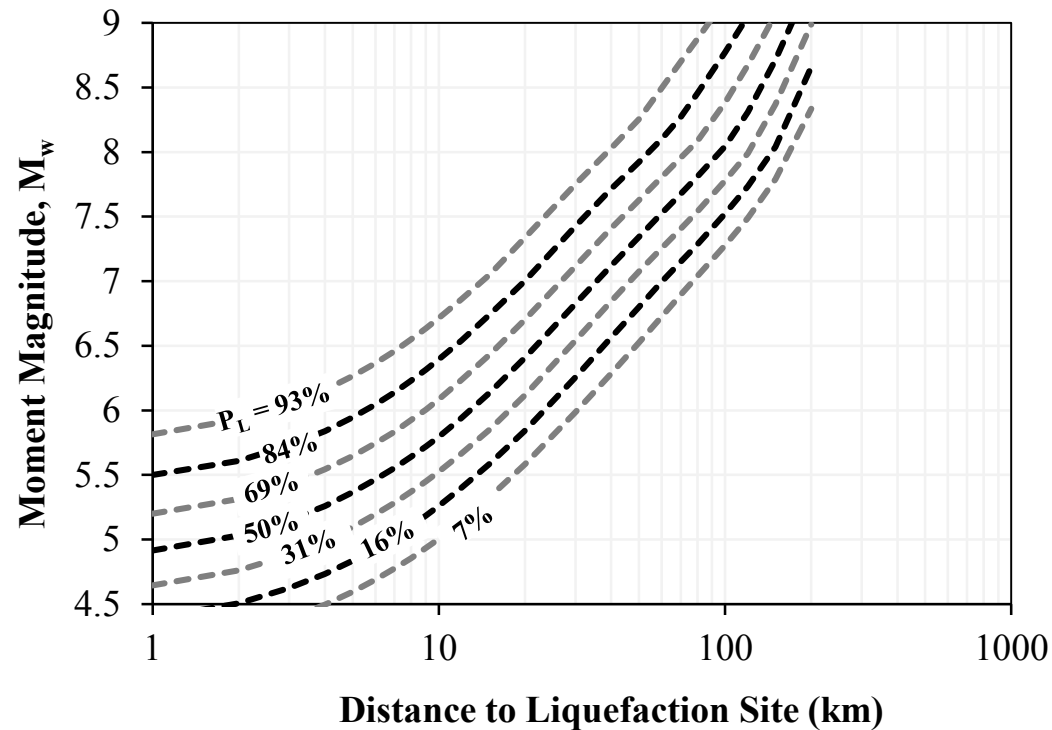
# Back-Calculated Probabilistic Magnitude Bound Curves

## Future Work

- Expand framework to account for epistemic uncertainties in analysis inputs ( $z_{\text{crit}}$ ,  $z_{\text{gwt}}$ ,  $q_{\text{c1Ncs}}$ , etc.)
- Expand framework for determining source location

# Back-Calculated Probabilistic Magnitude Bound Curves

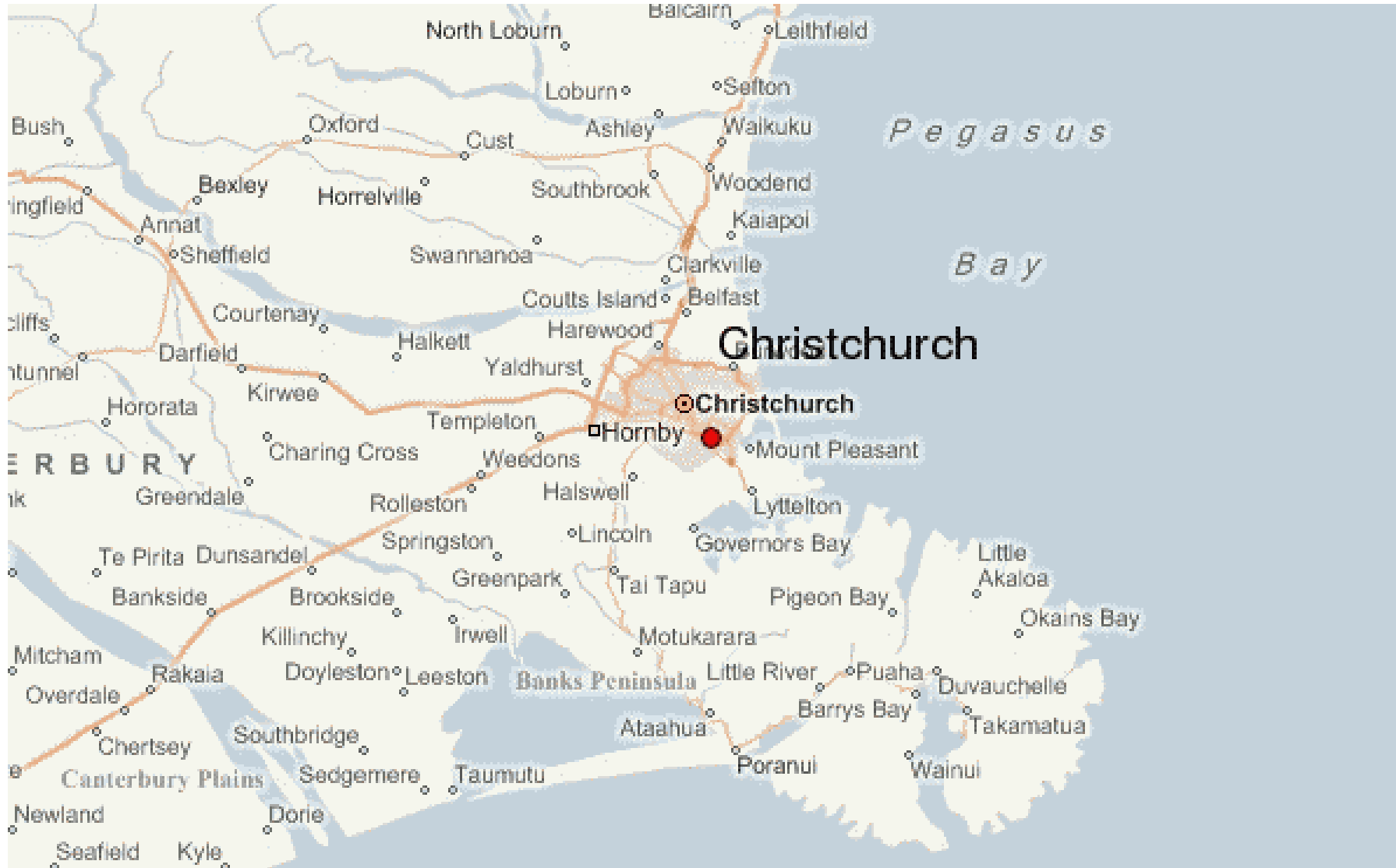
Expand framework to account for epistemic uncertainty in analysis input parameters



Back-calculated probabilistic magnitude bound curves for given values of  $q_{c1Ncs}$ ,  $z_{gwt}$ ,  $z_{crit}$ , etc. Calculate curves for combinations of ranges of all values. Use logic tree approach for accounting for epistemic uncertainty in these parameters.

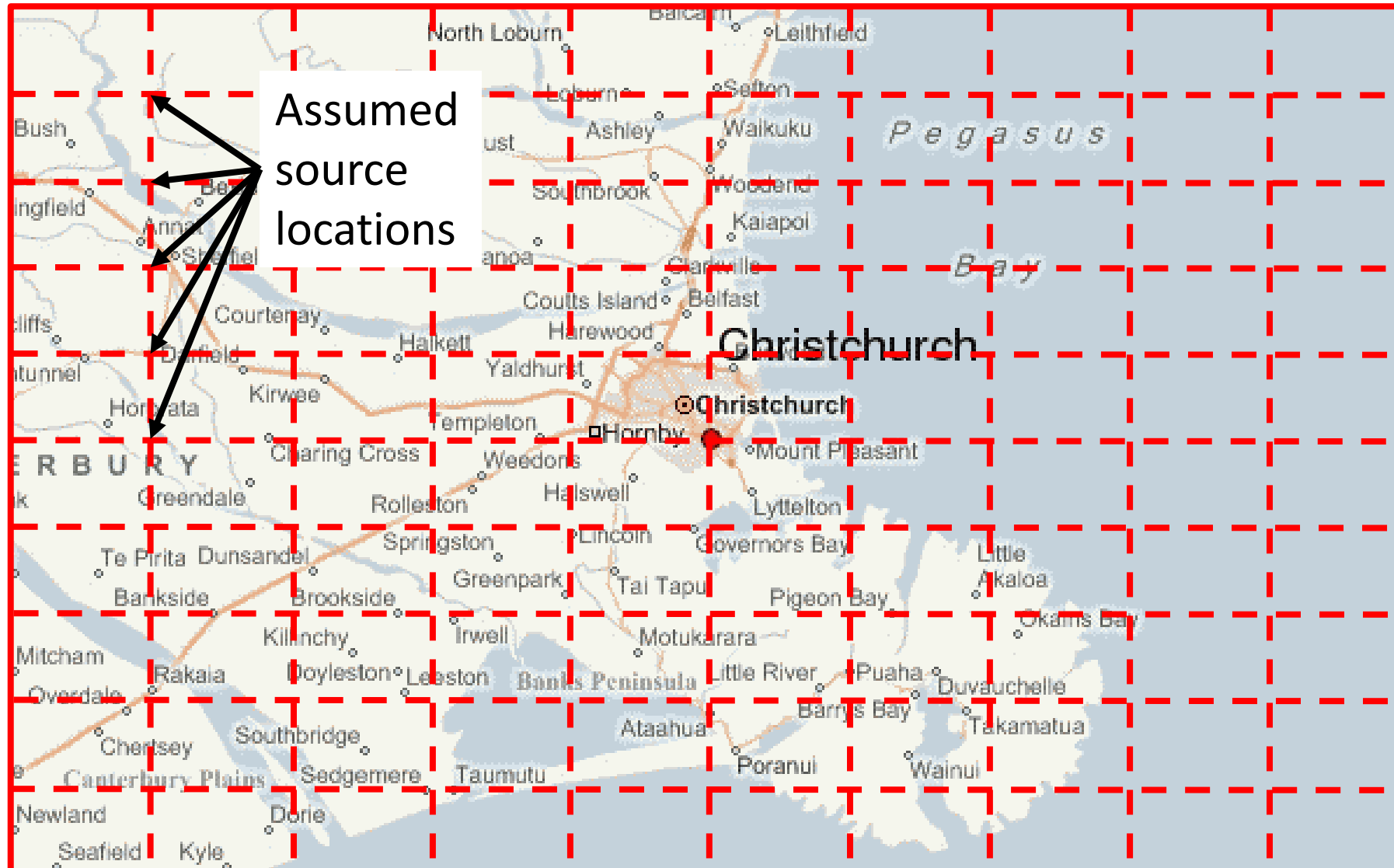
# Back-Calculated Probabilistic Magnitude Bound Curves

Expand framework for determining source location



# Back-Calculated Probabilistic Magnitude Bound Curves

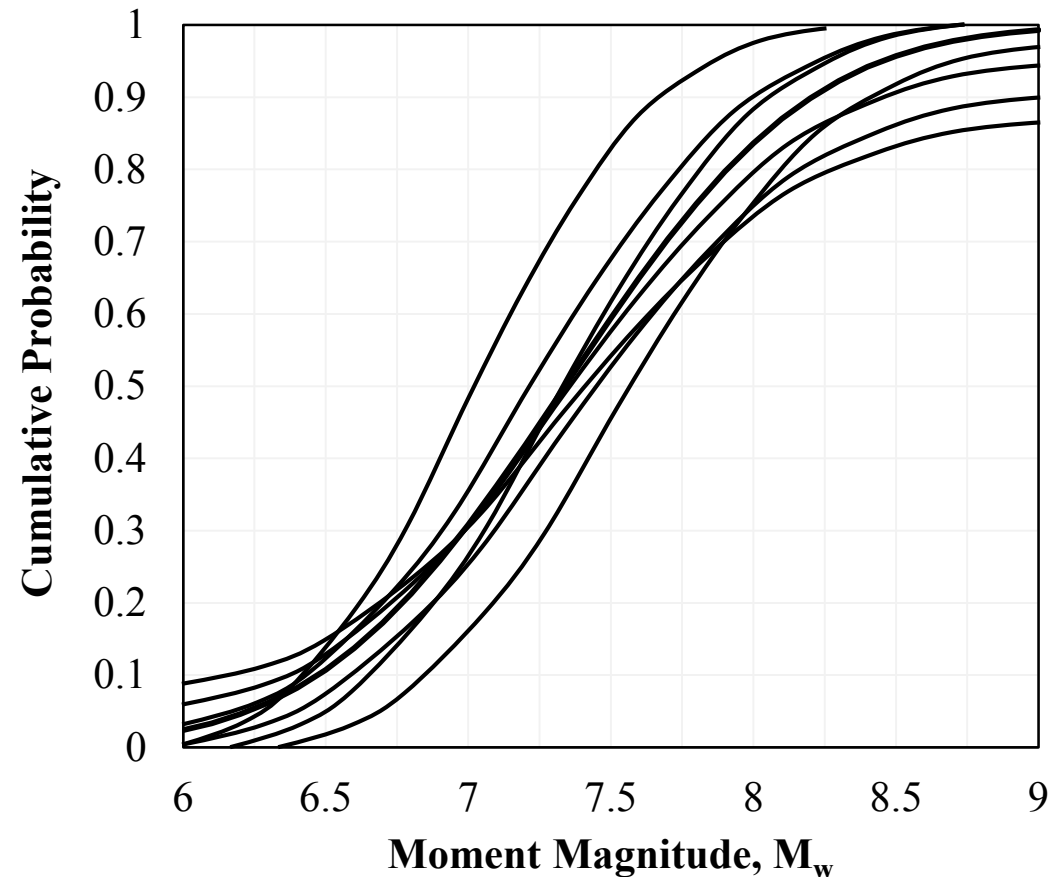
Expand framework for determining source location



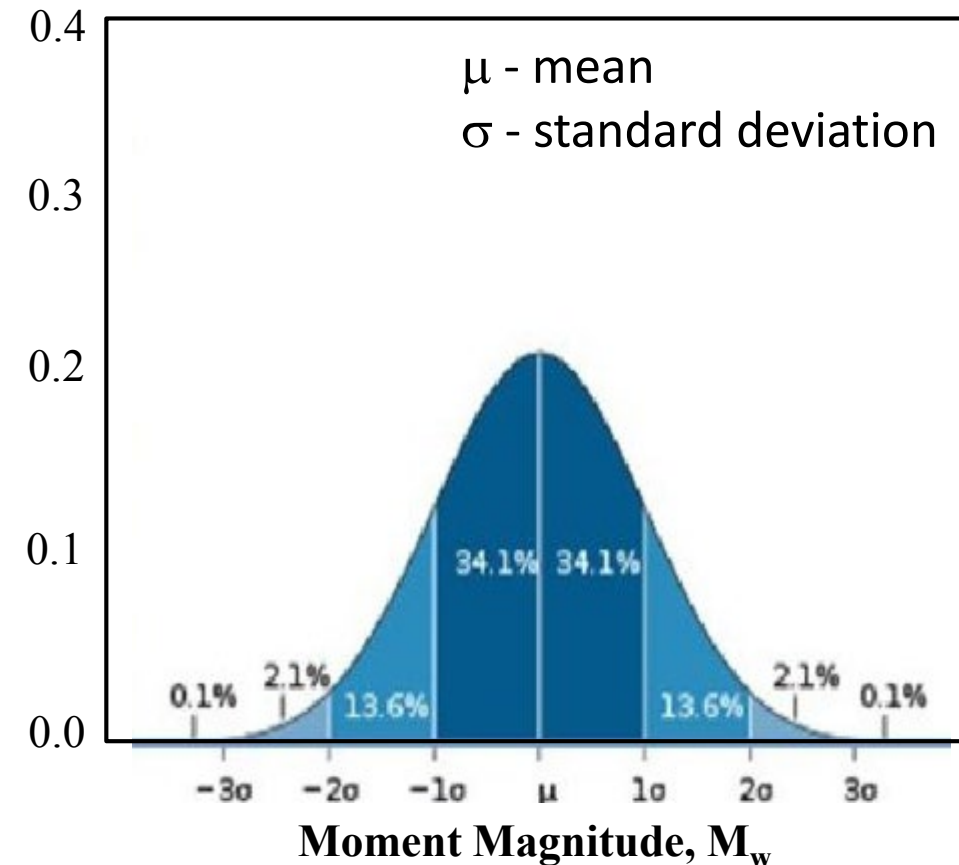
# Back-Calculated Probabilistic Magnitude Bound Curves

Expand framework for determining source location

Cumulative probability distributions for each paleoliquefaction feature for a given event and assumed source location



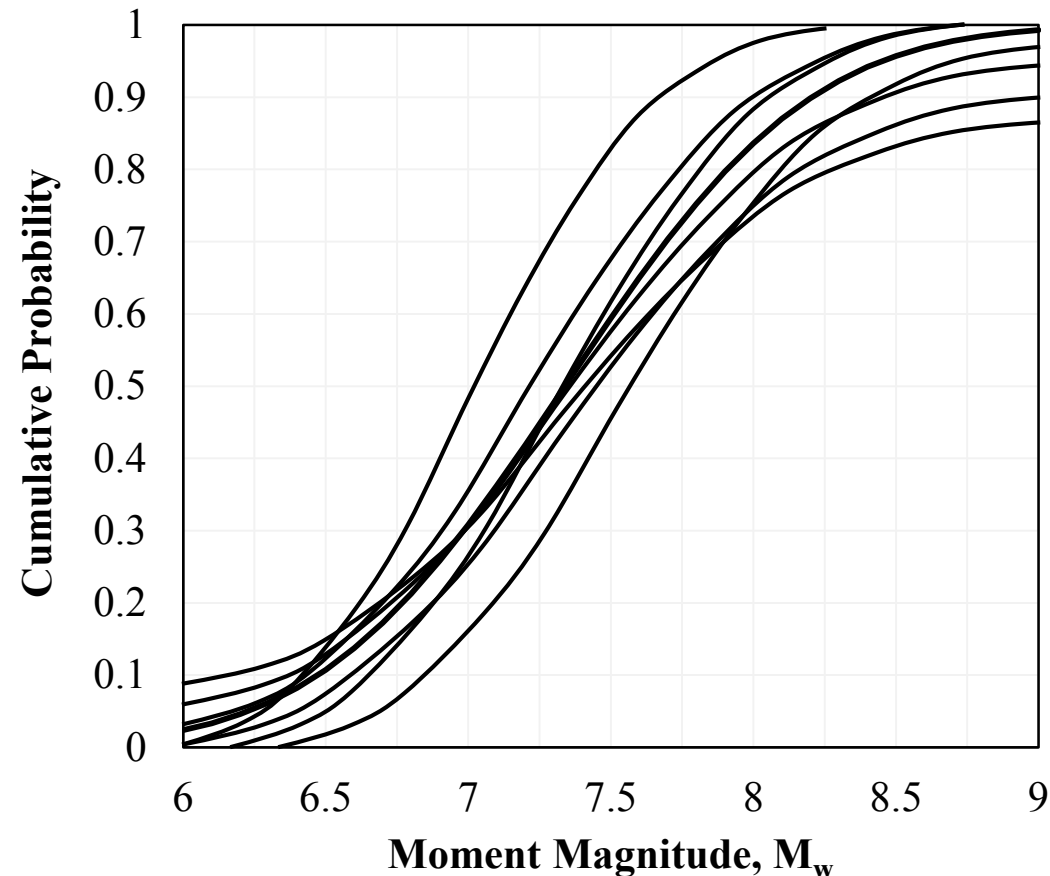
Combined probability distribution for paleo-magnitude for the event for assumed source location



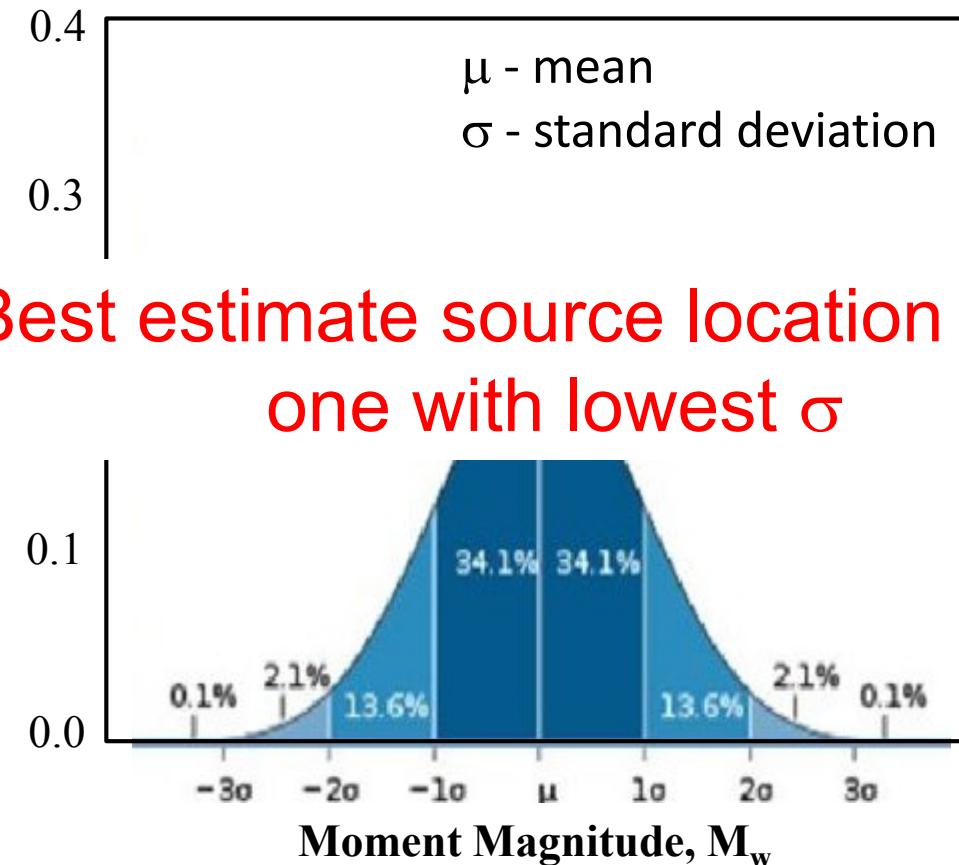
# Back-Calculated Probabilistic Magnitude Bound Curves

Expand framework for determining source location

Cumulative probability distributions for each paleoliquefaction feature for a given event and assumed source location



Combined probability distribution for paleo-magnitude for the event for assumed source location



**Best estimate source location is the one with lowest  $\sigma$**

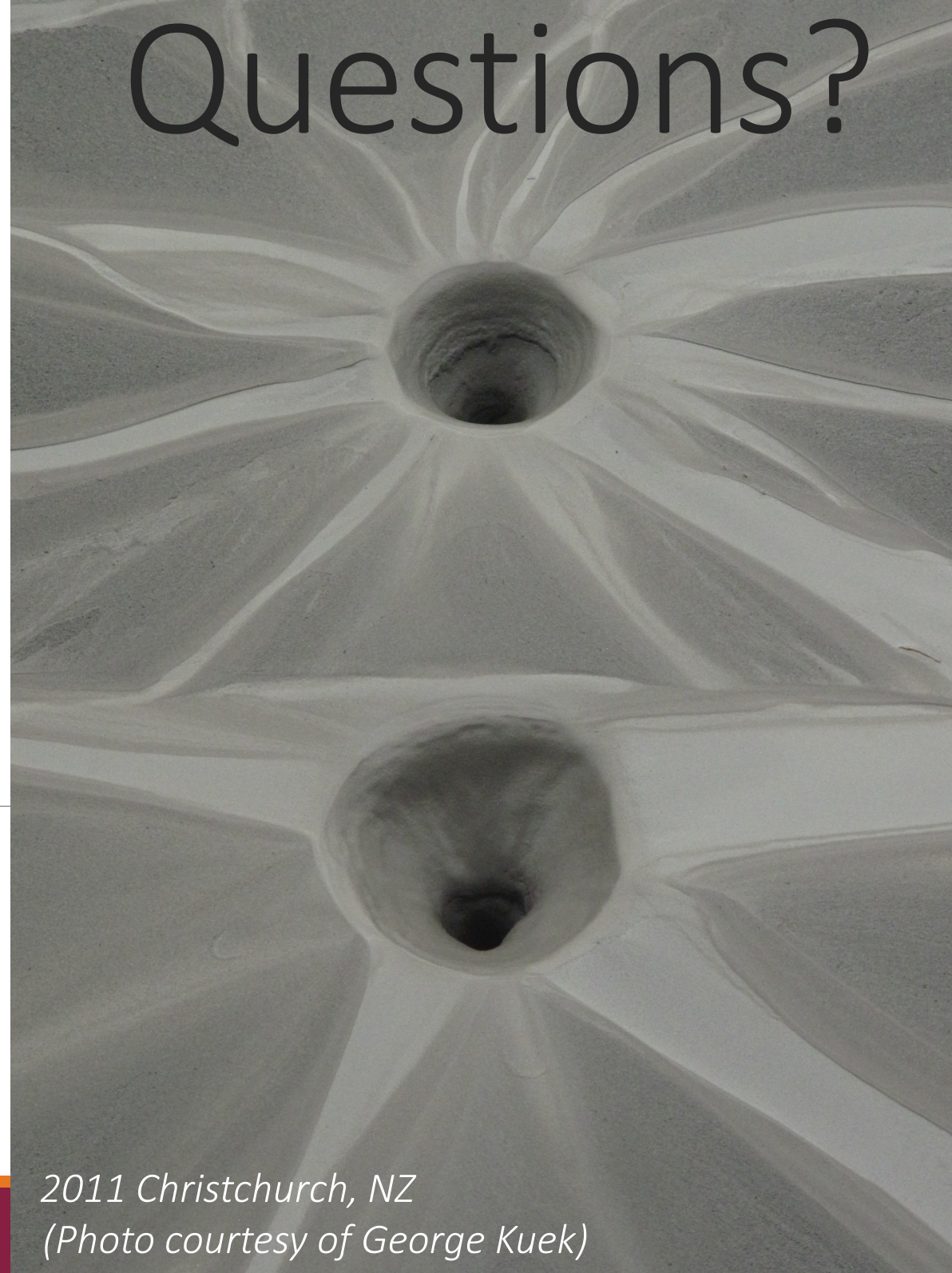
# Conclusions

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Commonly used procedures for estimated paleo-magnitudes have limitations

Newly proposed procedures are very promising for determining both the magnitude and location of paleoearthquakes and associated uncertainties

# Questions?



*2011 Christchurch, NZ  
(Photo courtesy of George Kuek)*

# References

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