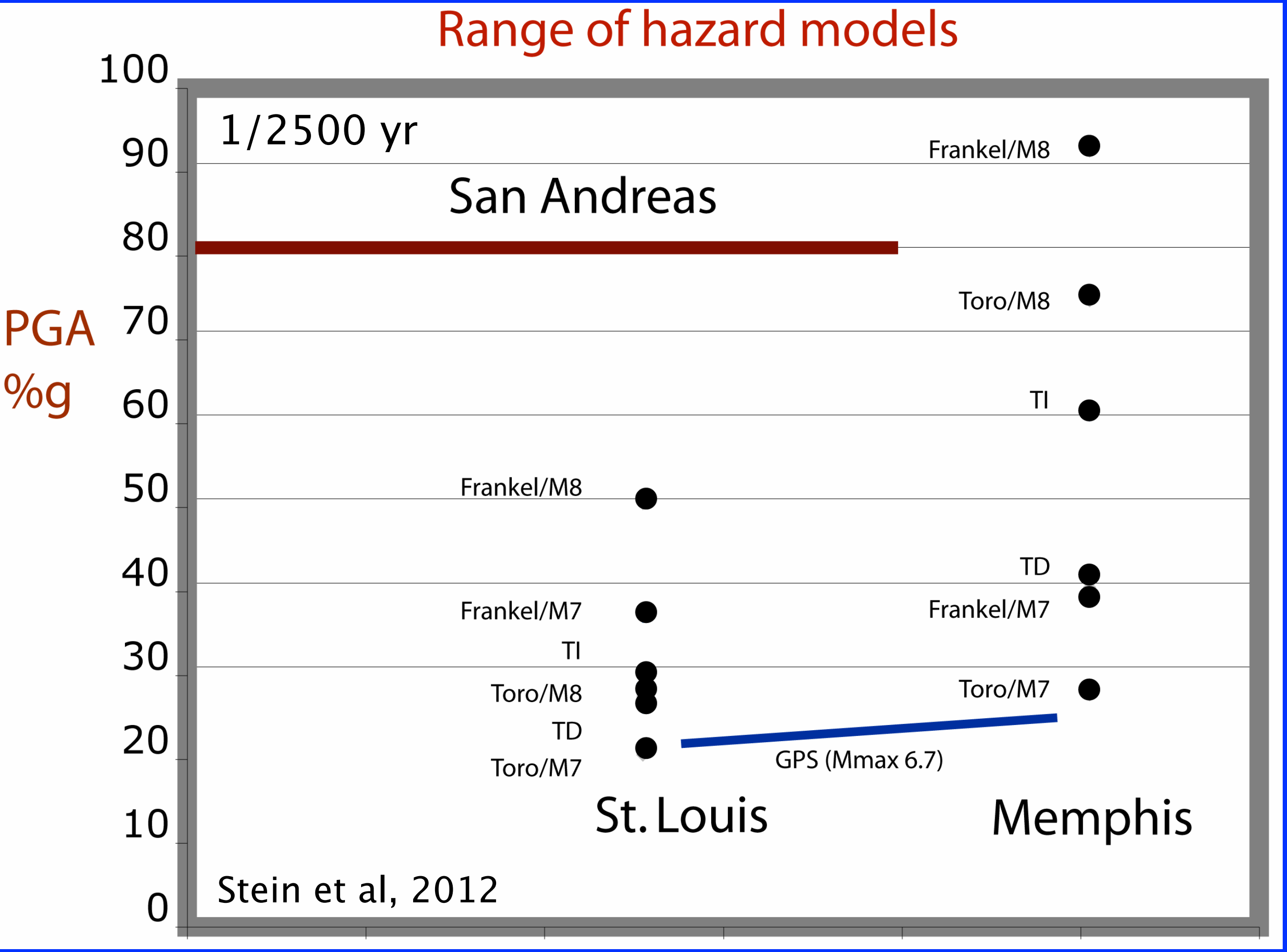
# *A GPS-based view of New Madrid earthquake hazard*

*Seth Stein, Northwestern University*

**Uncertainties permit wide range (3X) of hazard models, some higher than for California**

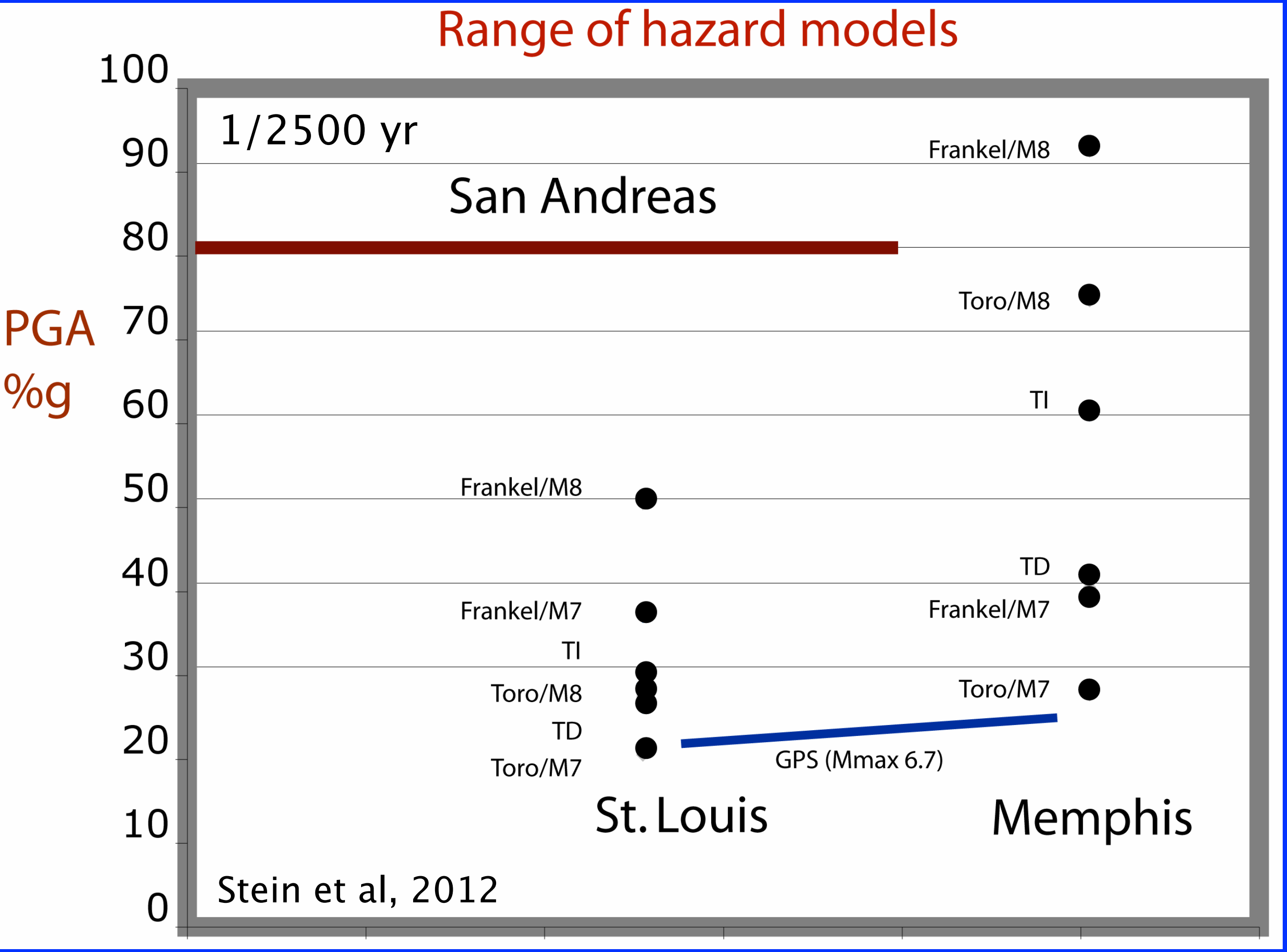
**GPS adds valuable constraint**



# GPS shows little or no deformation in past 20+ years, implying no large (M7) earthquake for long time (1000s of years)

**Hazard due to smaller regional (partly aftershock) seismicity (>M6 ~175 years in entire NMSZ)**

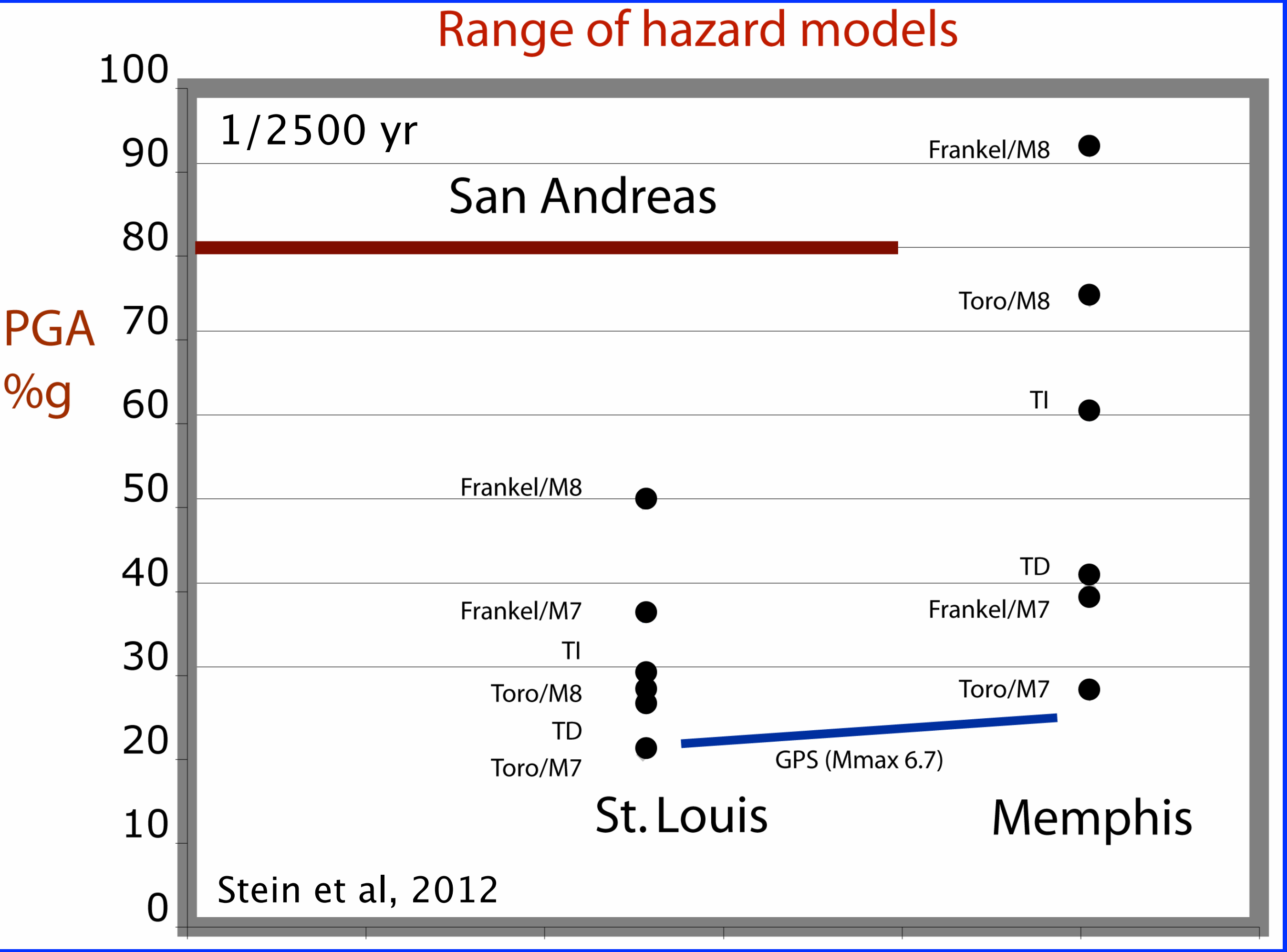
**Can be modeled as Mmax ~ 6.5**



# Although data will improve, whether hazard is California-level or much lower unlikely tobe resolved for many 100s of years

Hazard due to smaller regional (partly aftershock) seismicity (>M6 ~175 years in entire NMSZ)

Can be modeled as Mmax ~ 6.5

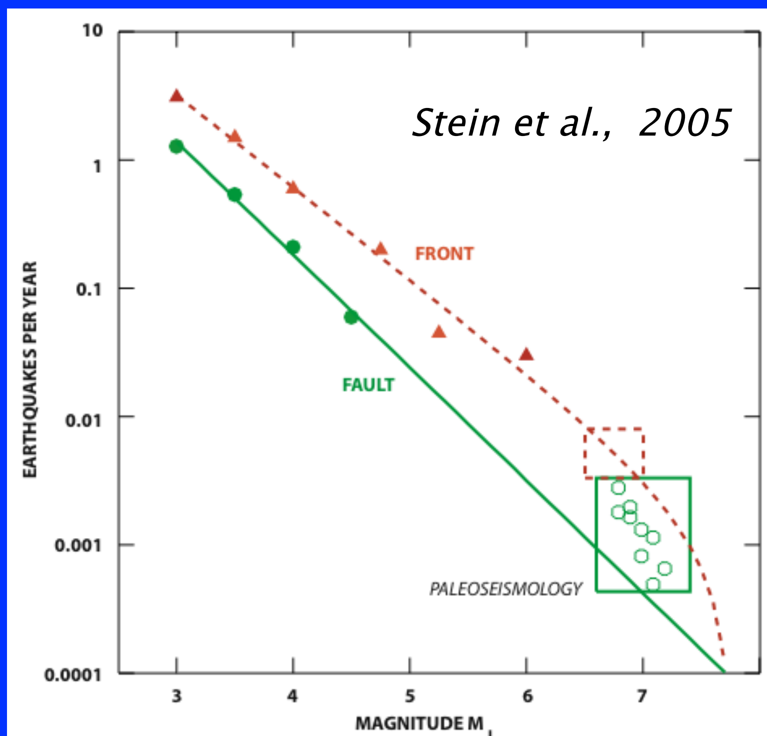


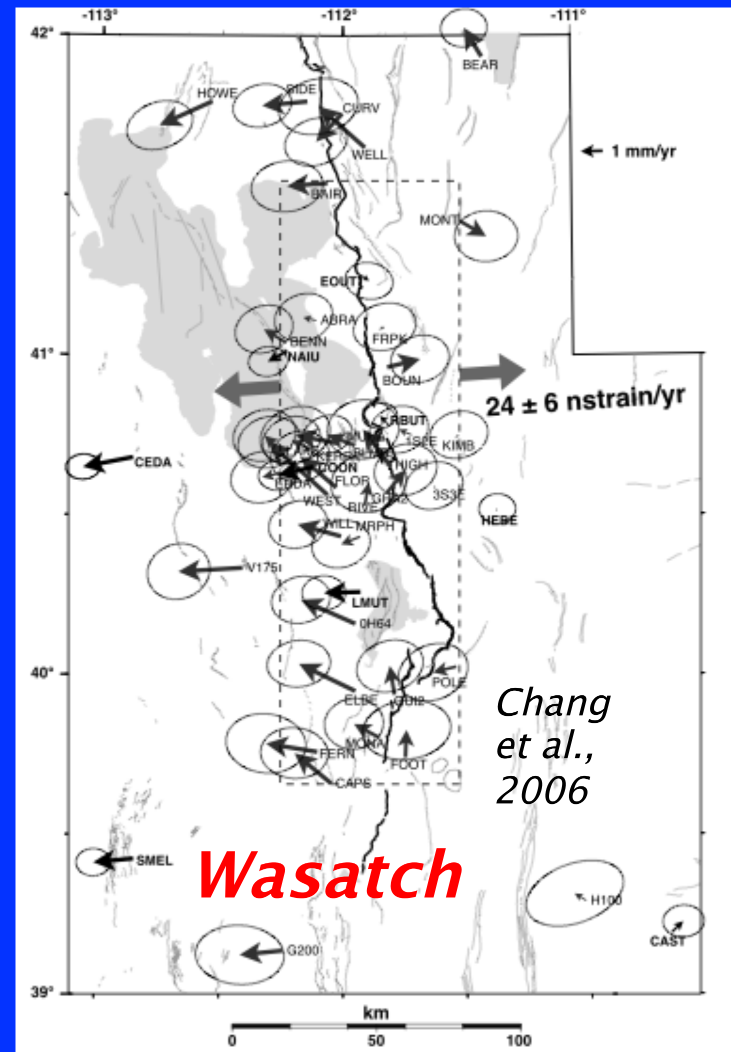
**Applying GPS in slowly deforming intraplate regions shows:**

***1) 1 mm/yr easily identified even with episodic data and consistent with rates inferred from seismicity, so if this were the case at New Madrid we'd see it***

*M 7 recurrence ~ 1000 yr from seismicity & paleoseismology*

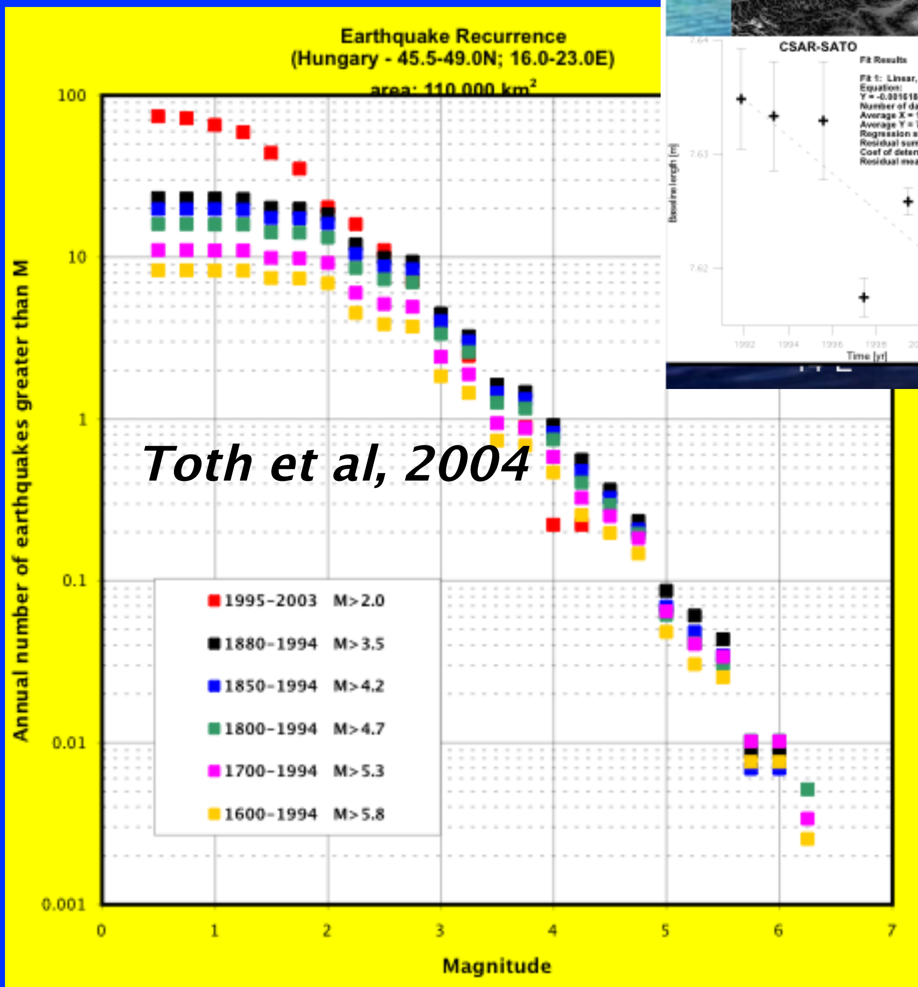
*GPS consistent - shows ~1-2 mm/yr extension*

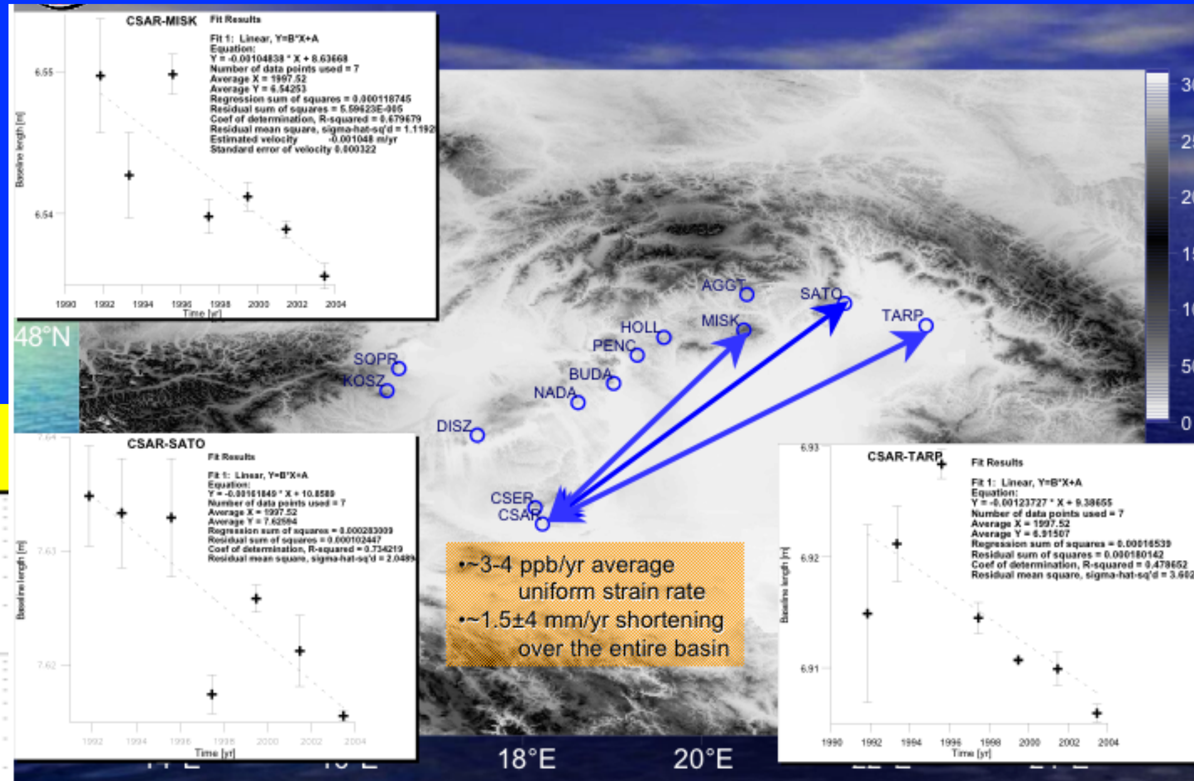


# Hungary

# Pannonian Basin Intracontinental Eurasia




*Episodic sites in soft sediment*

*GPS shows ~1-2 mm/yr shortening (Grenerczy et al., 2000)*

*Consistent with M 7 expected ~ 1000 yr from seismicity*

**2) Experience shows it's wise to wait before placing great credence in a marginal apparent motion because**

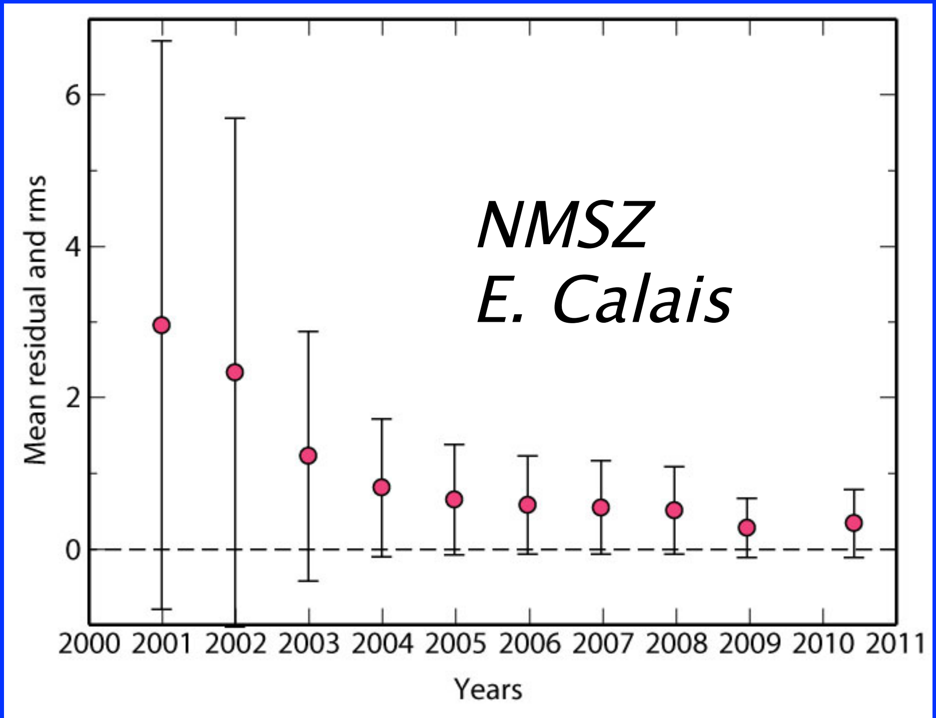
- precision improves with longer observations as 1/T

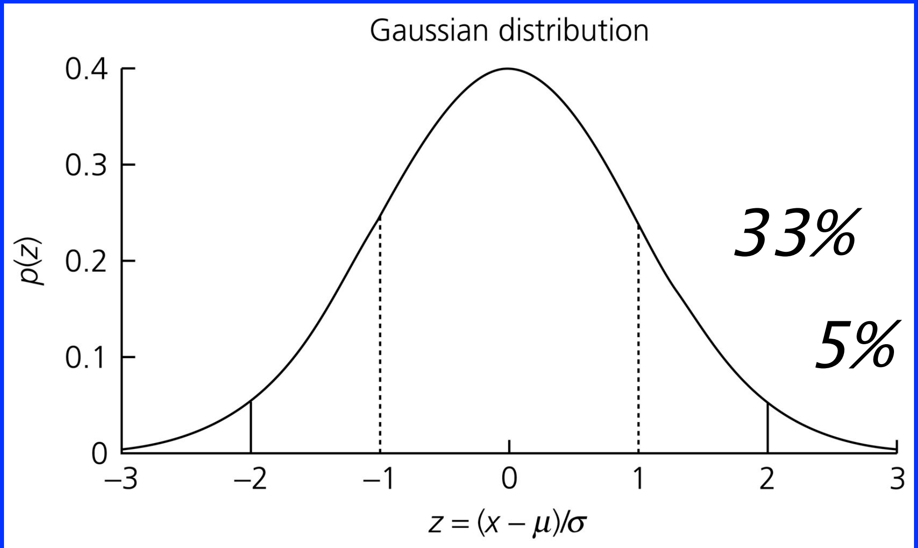
Rate v of motion of site that started at $x_1$ and reaches $x_2$ in time T is $v = (x_1 - x_2)/T$

For position uncertainty $\sigma$,
rate uncertainty is $\sigma_v = 2^{1/2} \sigma / T$

- If there is no real motion, 33% of sites appear to move faster than $1\sigma$ limit, 5% faster than $2\sigma$

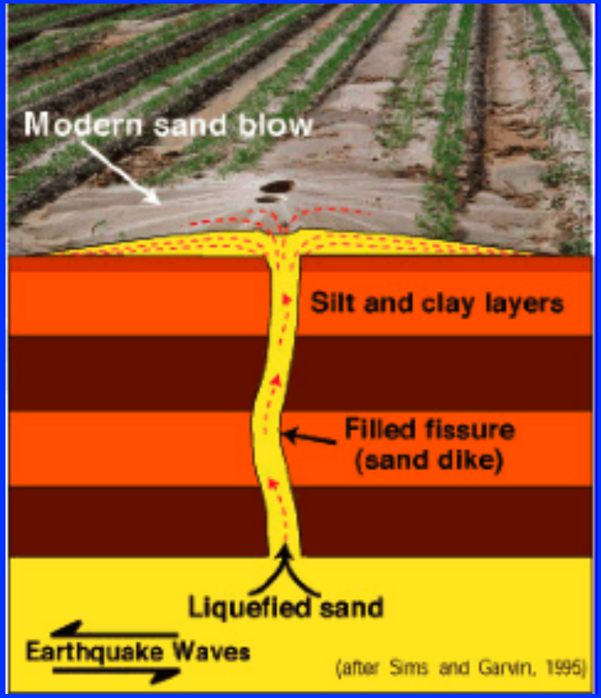
Thus it's wise to wait to see if signal climbs out of noise or drops into it



New Madrid 1991: because paleoseismology showed large events in 900 & 1450 AD, like those of 1811-12

GPS studies started, expecting to find strain accumulating consistent with large (~M7) events ~500 years apart




Initial result found expected strain accumulation…

# 1992: Combining GPS & old triangulation found rapid strain accumulation similar to that on San Andreas, implying large upcoming earthquakes

## Rapid Intraplate Strain Accumulation in the New Madrid Seismic Zone

Lanbo Liu, Mark D. Zoback, Paul Segall*

Remeasurement of a triangulation network in the southern part of the New Madrid seismic zone with the Global Positioning System has revealed rapid crustal strain accumulation since the 1950s.

strain rates must be relatively rapid if paleoseismic evidence indicating the occurrence of damaging earthquakes every 500 to 1000 years (2, 3) represents repeated slip on the same faults (4).

The measured shear strain rates are quite large, roughly one-third of the average strain rate in the San Andreas fault system (22) and about two orders of magnitude higher than estimated plate-wide average strain rates.

*Science*, *1992*

## Greeted with skepticism because triangulation method had also found in "Long Island and New York Connecticut areas, the strain rates are surprisingly large, roughly equivalent to rates observed near the San Andreas Fault"

**Evidence for lower crustal ductile strain localization in southern New York**


**Mark D. Zoback*, William H. Prescott & Scot W. Krueger***

US Geological Survey, Menlo Park, California 94025, USA



NATURE VOL. 317 24 OCTOBER 1985

# 1999: GPS alone shows little or no motion ( 0 +/- 2 mm/yr)

## 2 Centuries Later, Good News for Quake Area, Maybe

*The New York Times Science, Tuesday, April 27, 1999. By Sandra Blakeslee*

Midwesterners who worry about earthquakes got some good news last week: their risk of catastrophe may have been vastly overstated.

New measurements taken around New Madrid, MO - the epicenter of devastating earthquakes in 1811 and 1812 - show that the ground there is scarcely moving. According to many scientists, this means that it will take 2,500 to 10,000 years before another very large earthquake could occur in the region, although smaller, less damaging earthquakes are possible.

"The motions are small to zero," said Dr. Seth Stein, a professor of geological sciences at Northwestern University in Evanston, Ill., who made the new measurements. Earlier evidence showing rapid regional ground motion, a geologic sign that large quakes are probable, "was based on honest scientific errors," Dr. Stein said.

# Slow Deformation and Lower Seismic Hazard at the New Madrid Seismic Zone

Andrew Newman,[1] Seth Stein,[1*] John Weber,[2] Joseph Engeln,[3] Ailin Mao,[4] Timothy Dixon[4]

Global Positioning System (GPS) measurements across the New Madrid seismic zone (NMSZ) in the central United States show little, if any, motion. These data are consistent with platewide continuous GPS data away from the NMSZ, which show no motion within uncertainties. Both these data and the frequency-magnitude relation for seismicity imply that had the largest shocks in the series of earthquakes that occurred in 1811 and 1812 been magnitude 8, their recurrence interval should well exceed 2500 years, longer than has been assumed. Alternatively, the largest 1811 and 1812 earthquakes and those in the paleoseismic record may have been much smaller than typically assumed. Hence, the hazard posed by great earthquakes in the NMSZ appears to be overestimated.

*Science*, April 1999

It is also possible that 1811–1812–style earthquakes may never recur. If more accurate future surveys continue to find essentially no interseismic slip, we may be near the end of a seismic sequence. It has been suggested that because topography in the New Madrid region is quite subdued, the NMSZ is a feature no older than a few million years and perhaps as young as several thousand years (*21*). Therefore, New Madrid seismicity might be a transient feature, the present locus of intraplate strain release that migrates with time between fossil weak zones.

Although much remains to be learned about this intriguing example of intraplate tectonics, the present GPS data imply that 1811–1812–size earthquakes are either much smaller or far less frequent than previously assumed. In either case, it seems that the hazard from great earthquakes in the New Madrid zone has been significantly overestimated. Hence, predicted ground motions used in building design there, such as the National Seismic Hazard Maps (*22*) that presently show the seismic hazard there exceeding that in California, should be reduced.

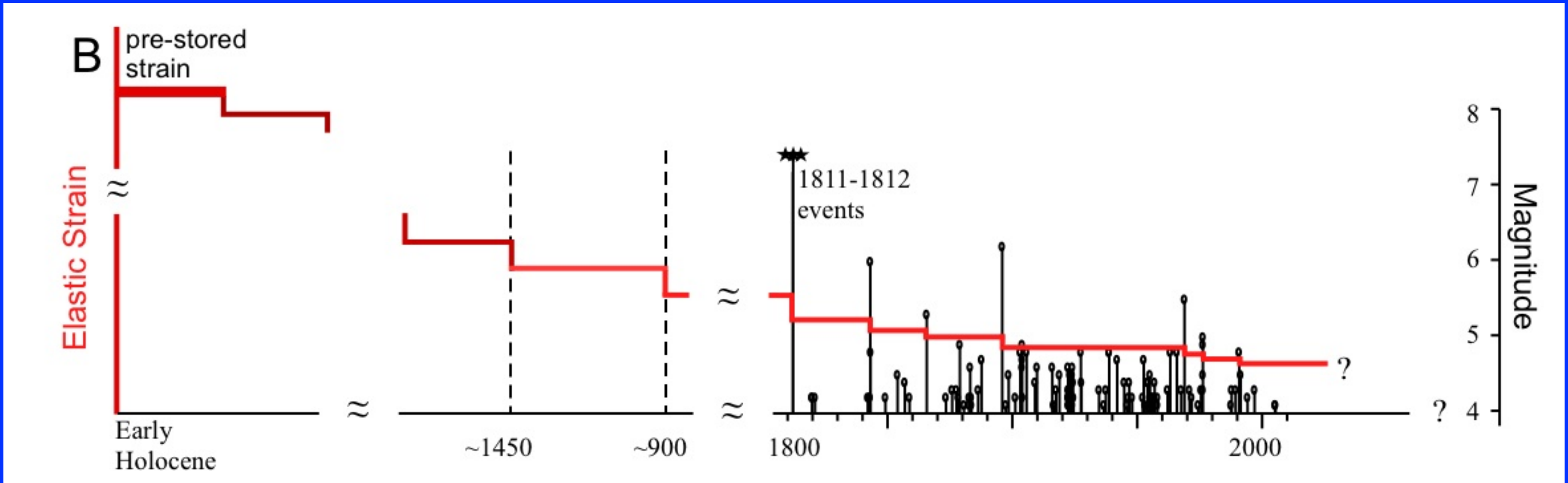
GPS show little or no motion

Seismicity transient & migrates

"If more accurate surveys continue to find essentially no slip, we may be near the end of a seismic sequence"

Either way, hazard overestimated

# Since NMSZ isn't being loaded, large events must use up stored elastic strain until sequence ends

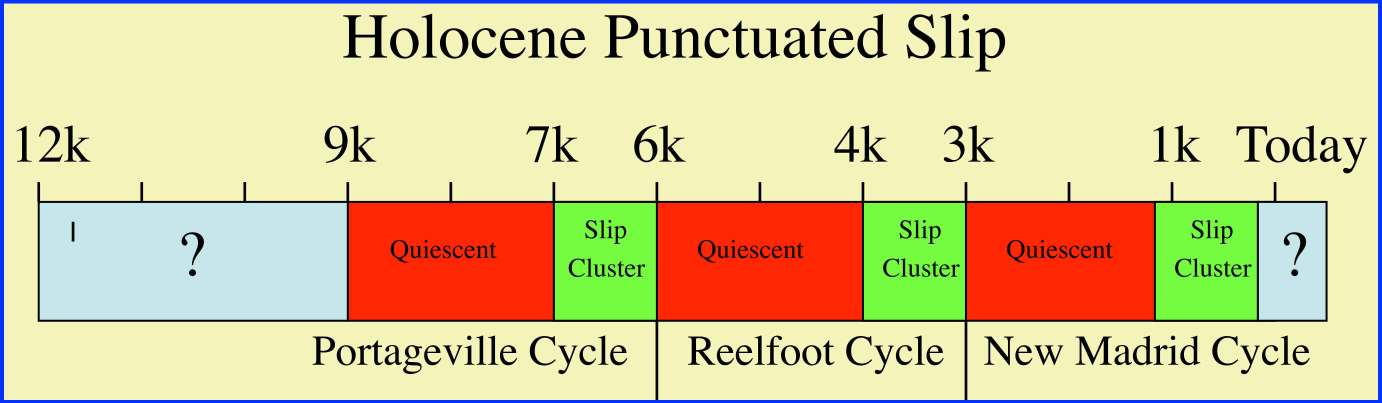



*Liu & Stein, 2012*

# Earthquake cluster in past 2000 years is transient unrepresentative of long term NMSZ behavior

Lack of significant fault topography, jagged fault, seismic reflection, and other geological data also imply that recent pulse of activity is only a few thousand years old

## Recent cluster likely ended




New Madrid earthquake history inferred from Mississippi river channels

Holbrook et al., 2006

# 2004: Stanford group retracts high strain claim, agrees rate “not significantly greater than zero”

**INTRAPLATE STRAIN ACCUMULATION IN THE NEW MADRID SEISMIC ZONE**

Mark H. Murray, Mark D. Zoback (Stanford University), Paul Segall (Stanford University)

High strain rates ($\sim$100 nanostrain/yr) were reported within a network spanning the southern NMSZ based on a 1991 GPS survey and triangulation data collected in the 1950's (*Liu et al.*, 1992). We present new strain rate estimates within this southern NMSZ network from GPS surveys conducted in 1993 and 1997 that show the recent deformation rates are not significantly greater than zero.

http://seismo.berkeley.edu/annual_report/ar02_03/node34.html

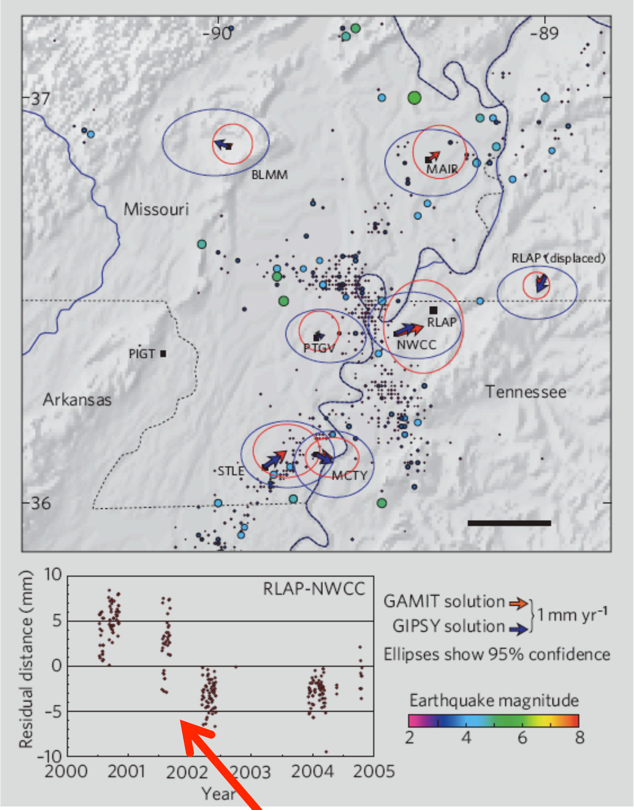
# 2005: Strains as high as at plate boundaries ($10^{-7}$/ yr) reported again, based on one site pair

## Space geodetic evidence for rapid strain rates in the New Madrid seismic zone of central USA

R. Smalley Jr[1,2], M. A. Ellis[1,2], J. Paul[1] & R. B. Van Arsdale[2]

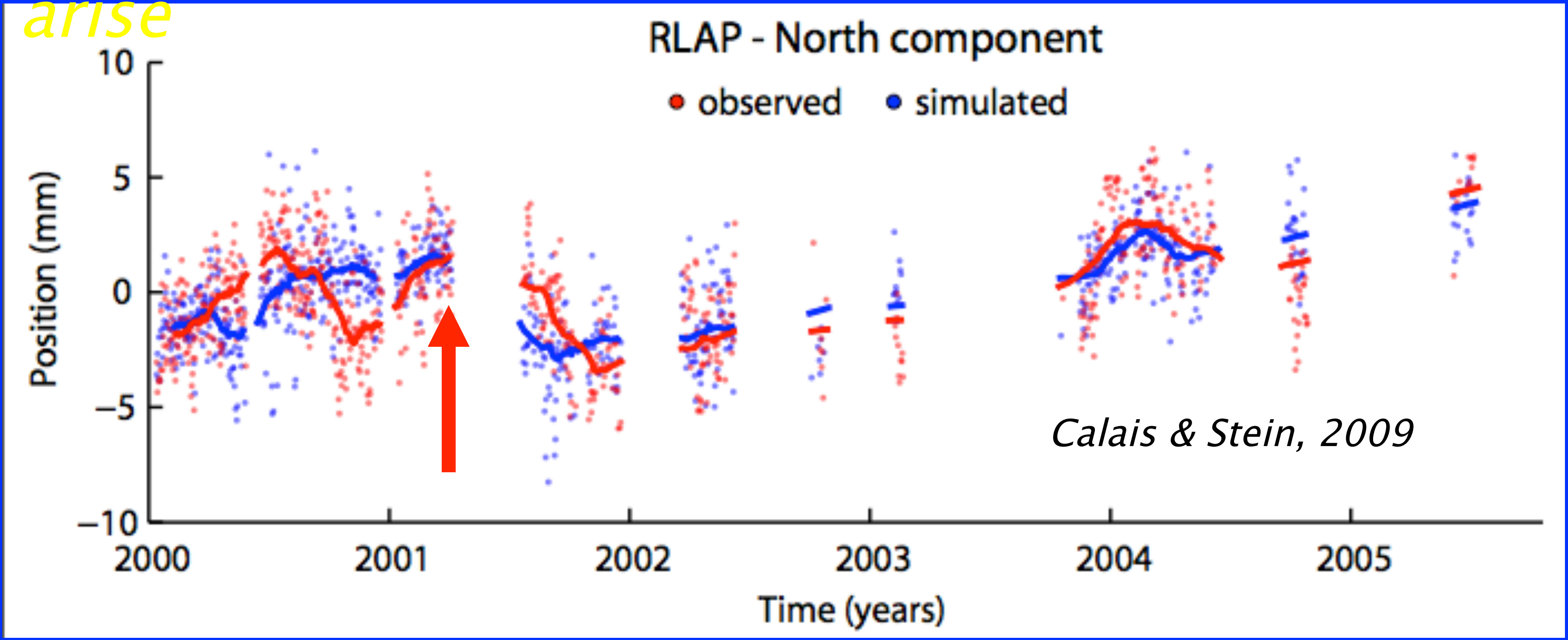
1. Center for Earthquake Research and Information,
2. Department of Earth Sciences, The University of Memphis

In the winter of 1811–1812, near the town of New Madrid in the central United States and more than 2,000 km from the nearest plate boundary, three earthquakes within three months shook the entire eastern half of the country and liquefied the ground over distances far greater than any historic earthquake in North America[1,2]. The origin and modern significance of these earthquakes, however, is highly contentious[3]. Geological evidence demonstrates that liquefaction due to strong ground shaking, similar in scale to that generated by the New Madrid earthquakes, has occurred at least three and possibly four times in the past 2,000 years (refs 4–6), consistent with recurrence statistics derived from regional seismicity[7]. Here we show direct evidence for rapid strain rates in the area determined from a continuously operated global positioning system (GPS) network. Rates of strain are of the order of $10^{-7}$ per year, comparable in magnitude to those across active plate boundaries, and are consistent with known active faults within the region. These results have significant implications for the definition of seismic hazard and for processes that drive intraplate seismicity.

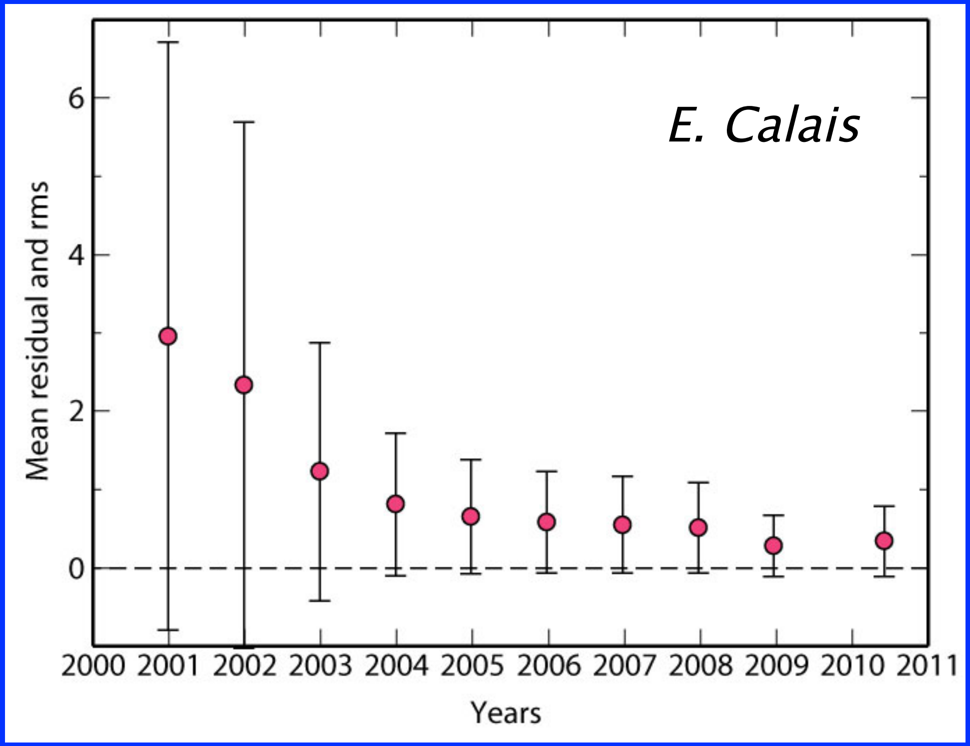



Appears due to artifact of "tear" in data (Calais et al., 2005)

# *Noise modeling shows how apparent motions arise*

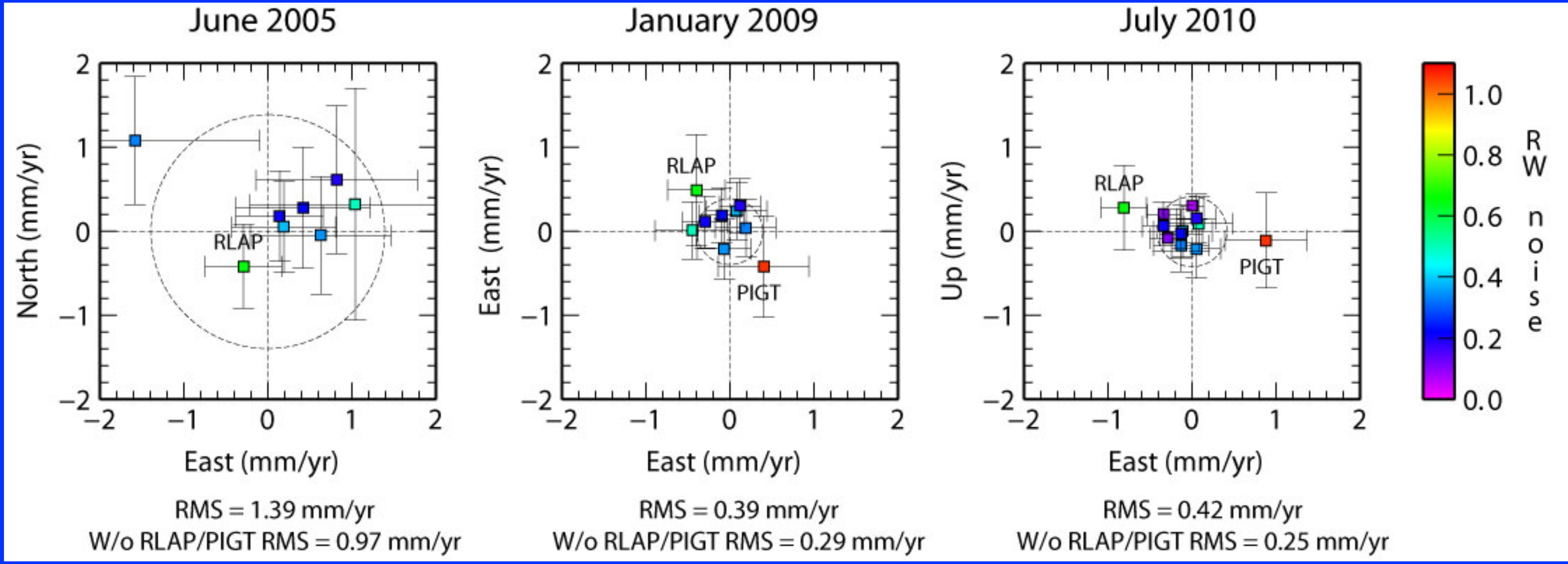



*Colored noise and loading effects in the simulated positions leads to apparent non-zero long-term velocities. Simulated time series contain fluctuations comparable to those observed in the data, in particular at site RLAP where the apparent motion in 2001 was previously interpreted as a tectonic effect. Hence even the largest apparent site velocities are both statistically insignificant and can be fully explained as non-tectonic artifacts. Therefore, GPS observations in the NMSZ do not require tectonic site motions different from zero.*




Continuous GPS measurements find little or no detectable deformation with progressively higher precision, showing sites move as part of stable North America to better than 0.2 mm/yr (strain rate < $10^{-9}$ /yr)

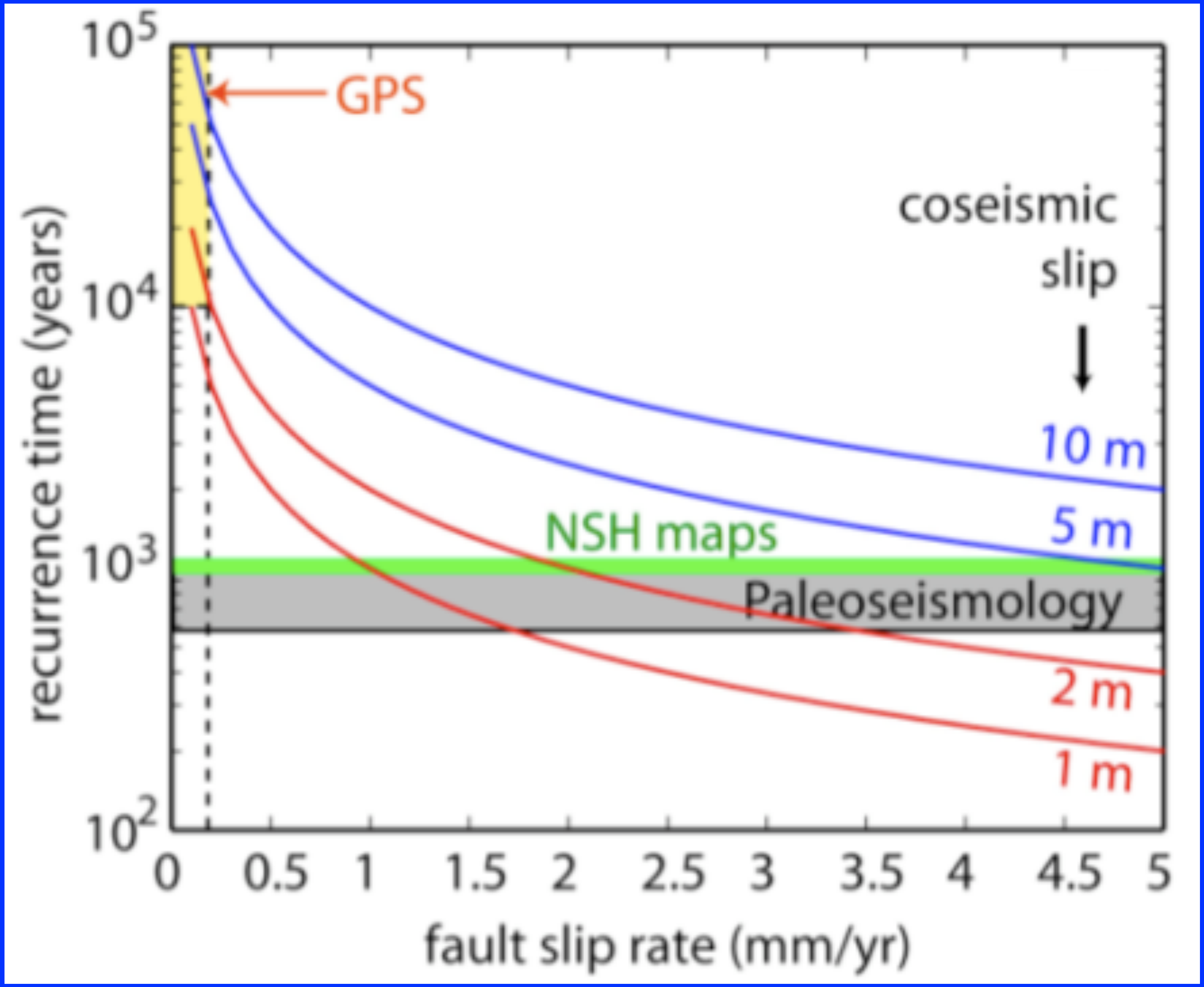
Sites with largest errors have largest apparent motion



Long time needed to store up slip for future large earthquake

For steady motion, M 7 at least 10,000 years away M 8 100,000

Because recent earthquakes correspond to strain release at a rate equivalent to a slip of at least 1-2 mm/yr over the past ~2,000 years, *deformation varies with time*




*Calais & Stein, 2009*

# Plate Boundary Earthquakes

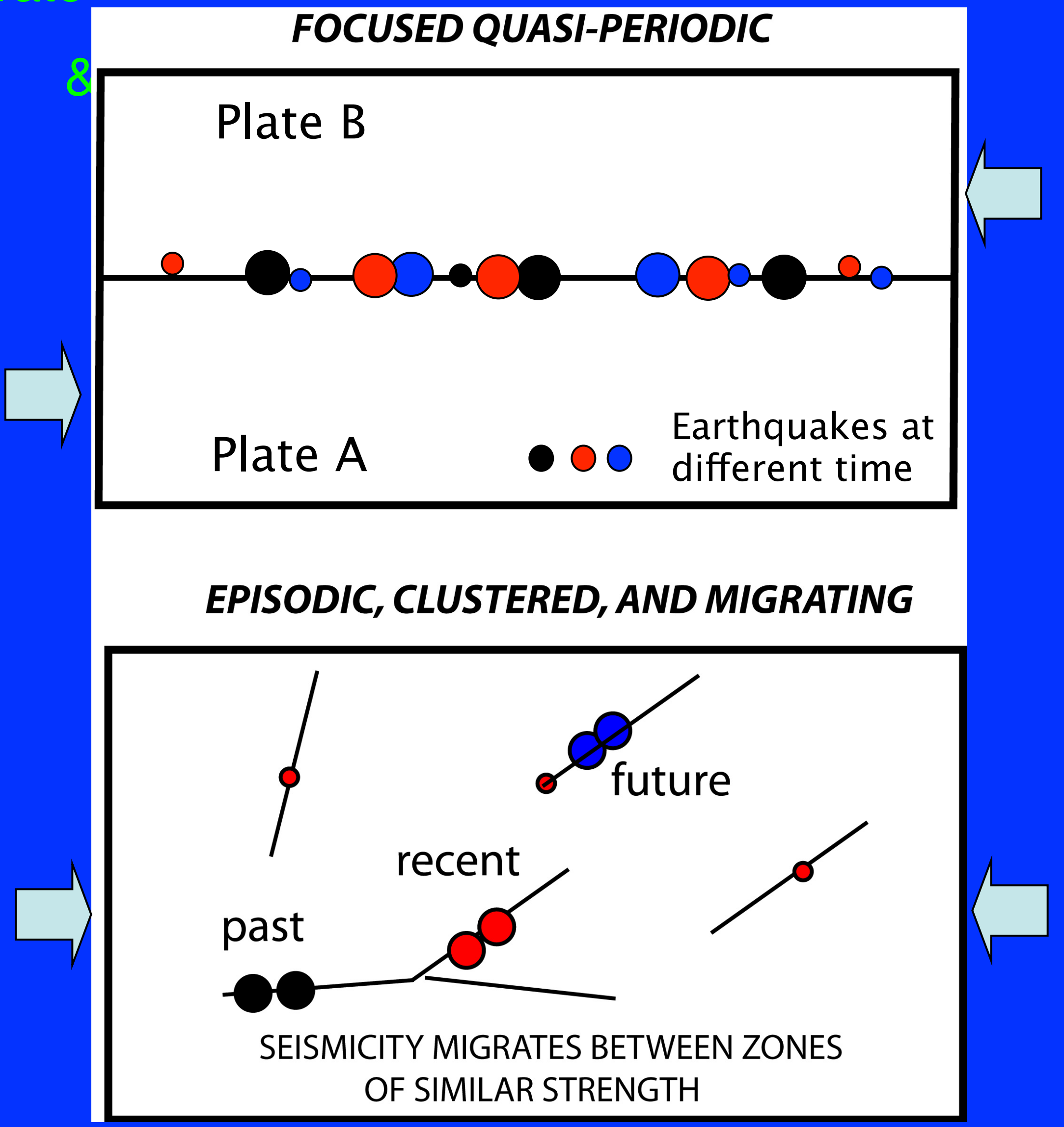
- Fault loaded rapidly at constant rate
- Earthquakes spatially focused & temporally quasi-periodic

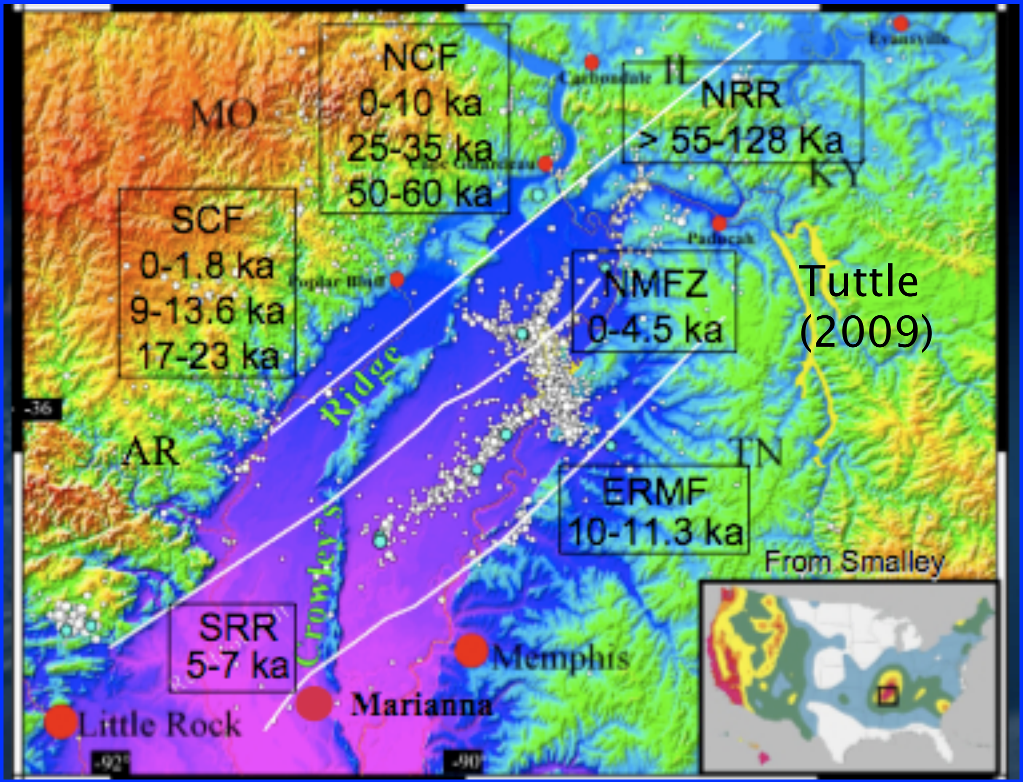
*Past is good predictor*

# Intraplate Earthquakes

- Tectonic loading collectively accommodated by a complex system of interacting faults
- Loading rate on a given fault is slow & may not be constant
- Earthquakes can cluster on a fault for a while then shift

*Past can be poor predictor*





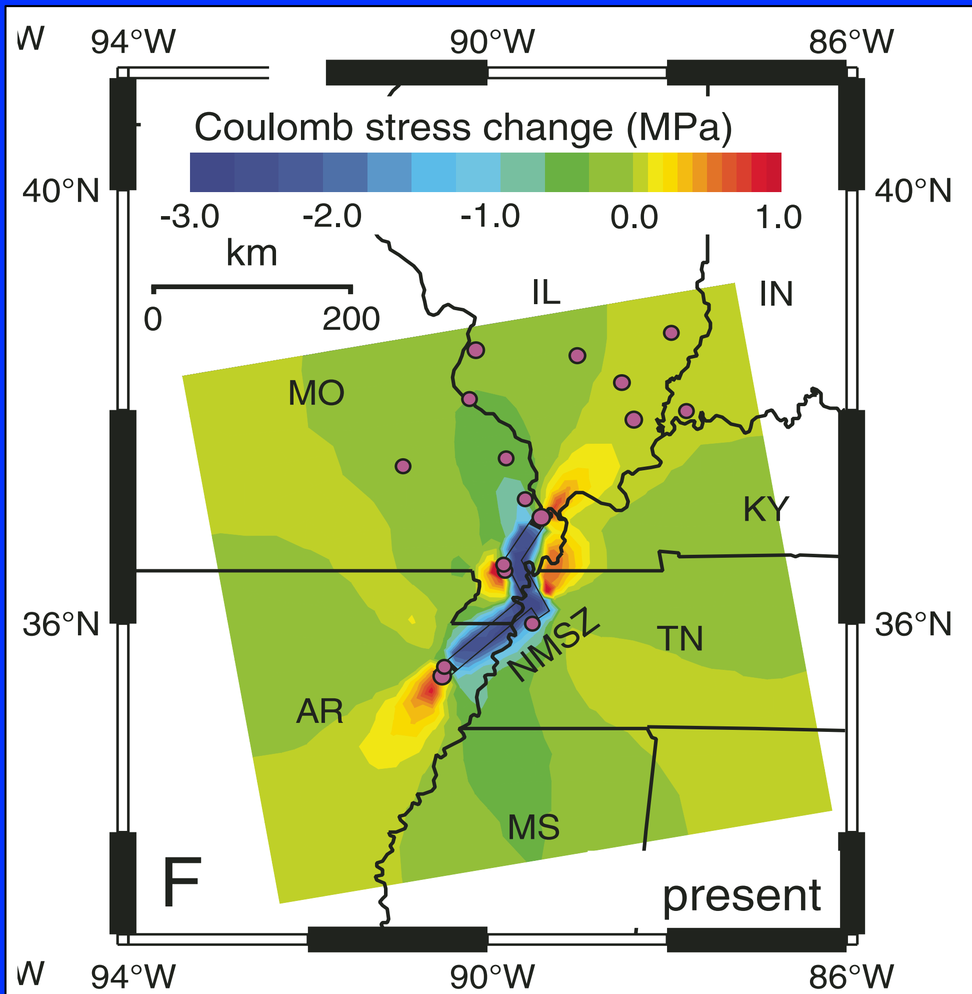


Faults active in past show little present seismicity

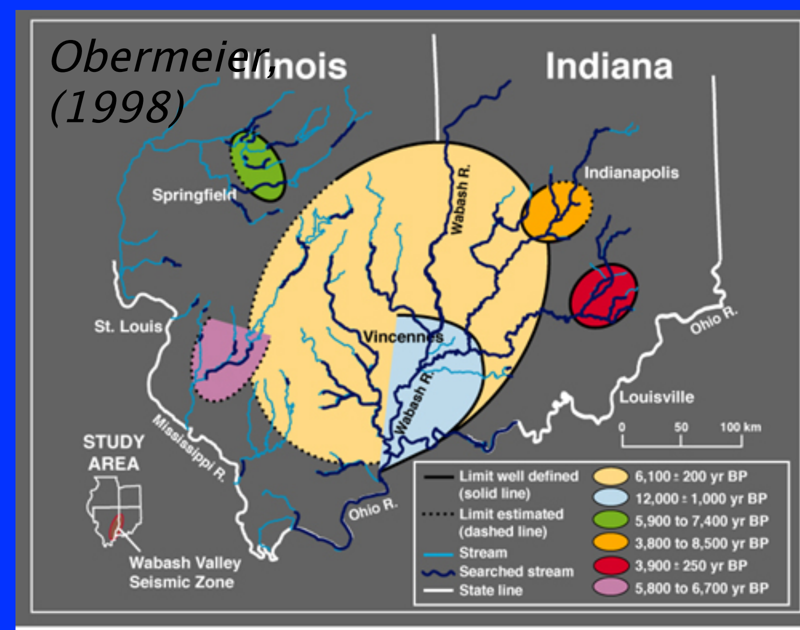
Seismicity migrates among faults due to fault interactions (stress transfer)

Meers fault, Oklahoma
Active 1000 years ago, dead now

# *Eventually may get stress transfer from NMSZ to Wabash & NE Arkansas, which had large events 6 Ky ago*




Wabash: M~7 6 Kybp

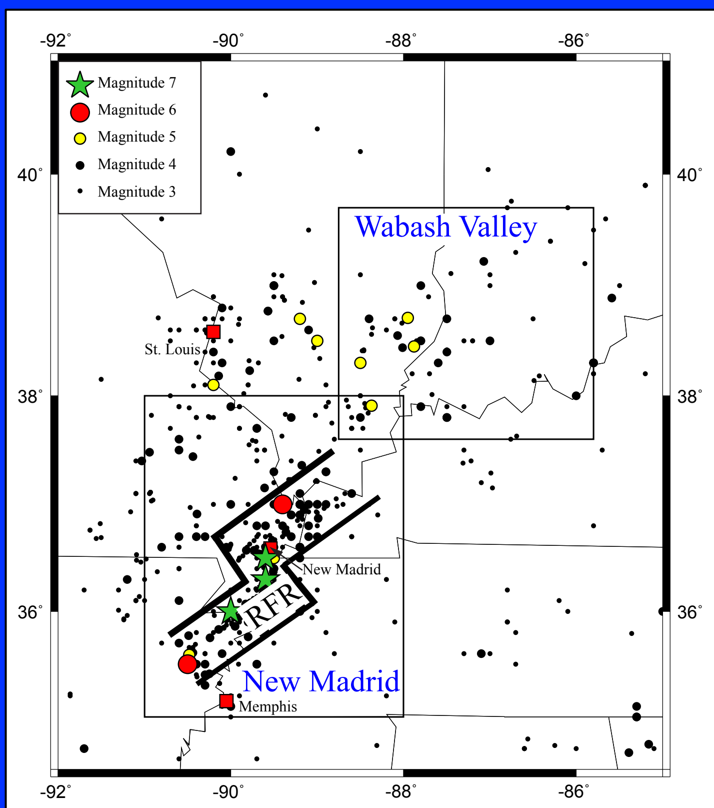


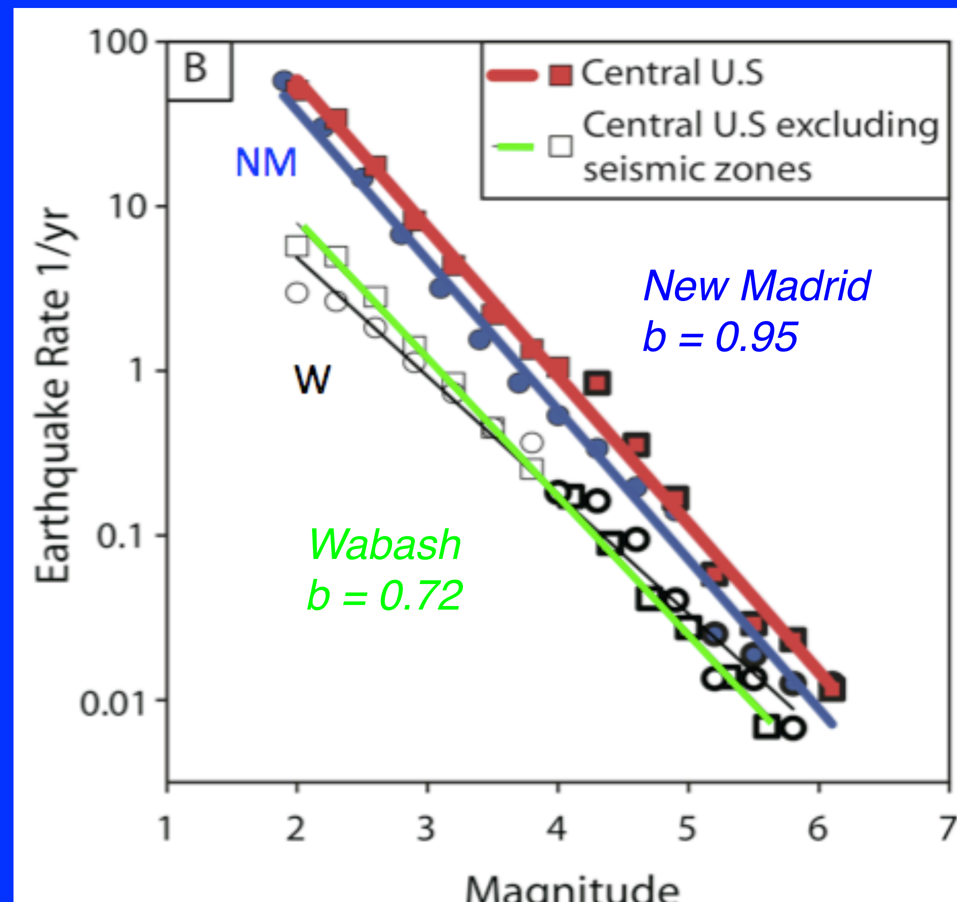

EXTENT OF LIQUEFACTION FOR LARGER PREHISTORIC EARTHQUAKES

*Li et al., 2007*

# Are we seeing stress transfer already?

Transfer might explain why Wabash has lower b-value (higher stress), but NMSZ having many aftershocks seems likelier since Wabash value is typical of central US and New Madrid is high



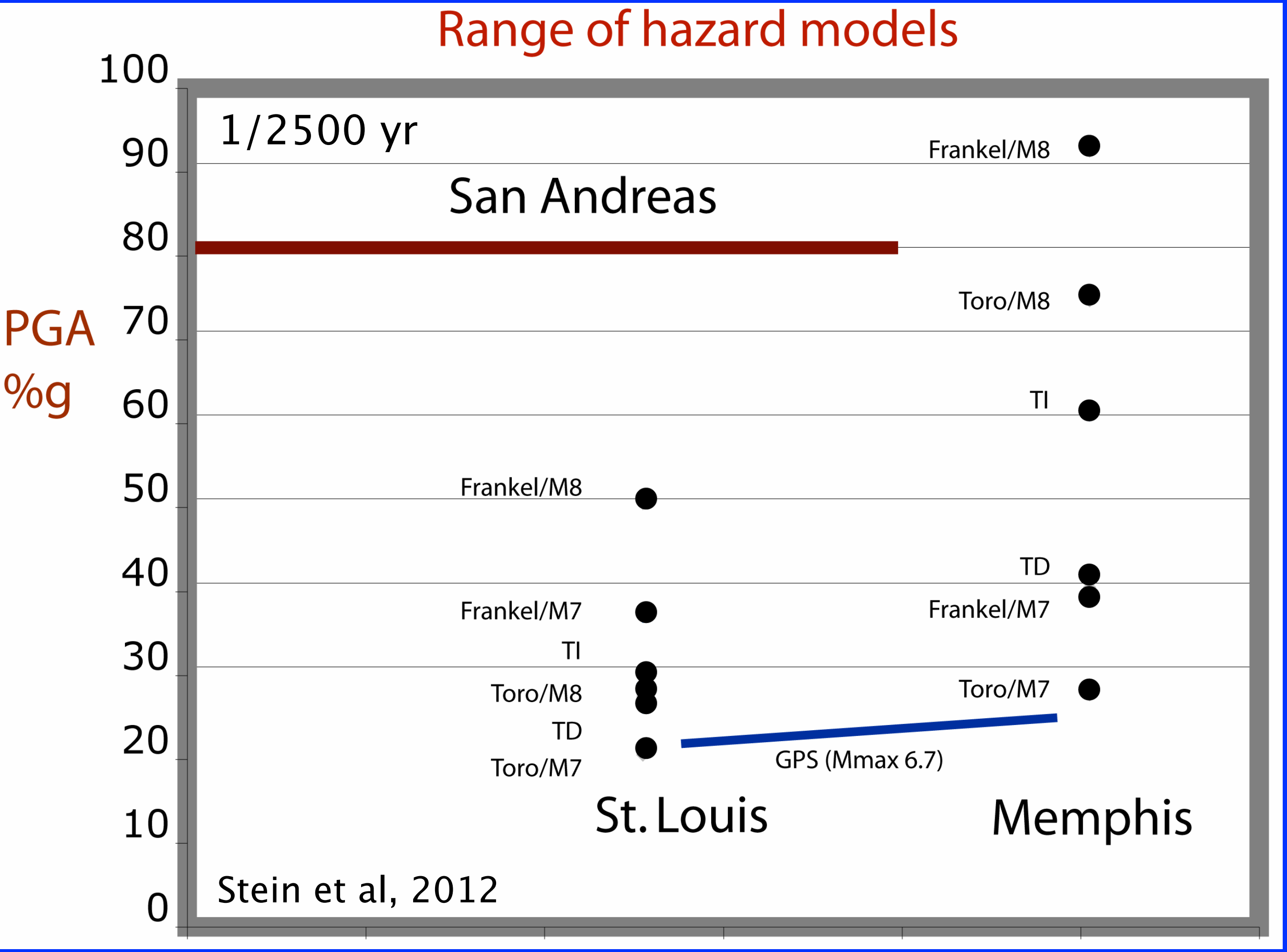




*Merino, Stein, Liu & Okal 2010*

# Summary: GPS shows little or no deformation, implying no large (M7) earthquake for long time (1000s of years)

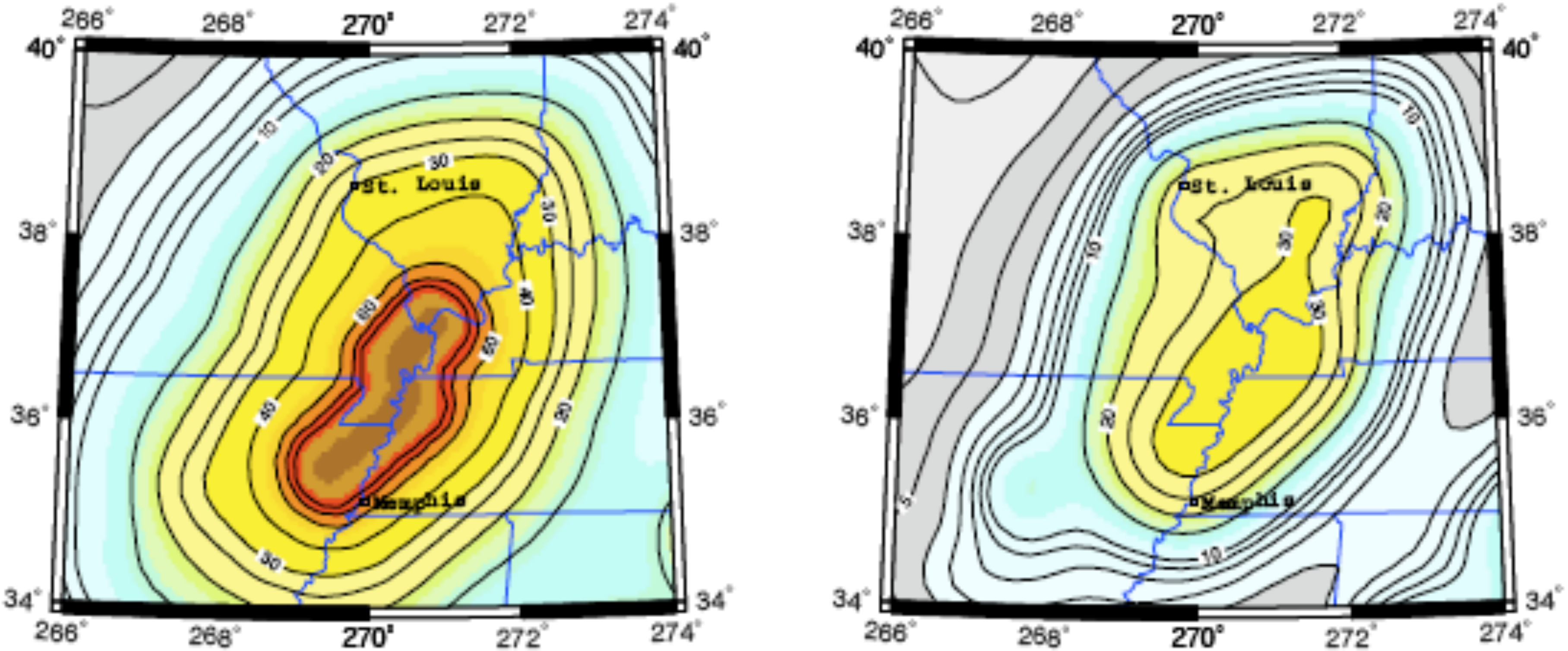
**Hazard due to smaller regional (partly aftershock) seismicity (>M6 ~175 years in entire NMSZ)**

**Can be modeled as Mmax ~ 6.5**



*NSHM Mmax 7.7*

*GPS: Mmax 6.7*




1/2500 year (2% in 50 year)