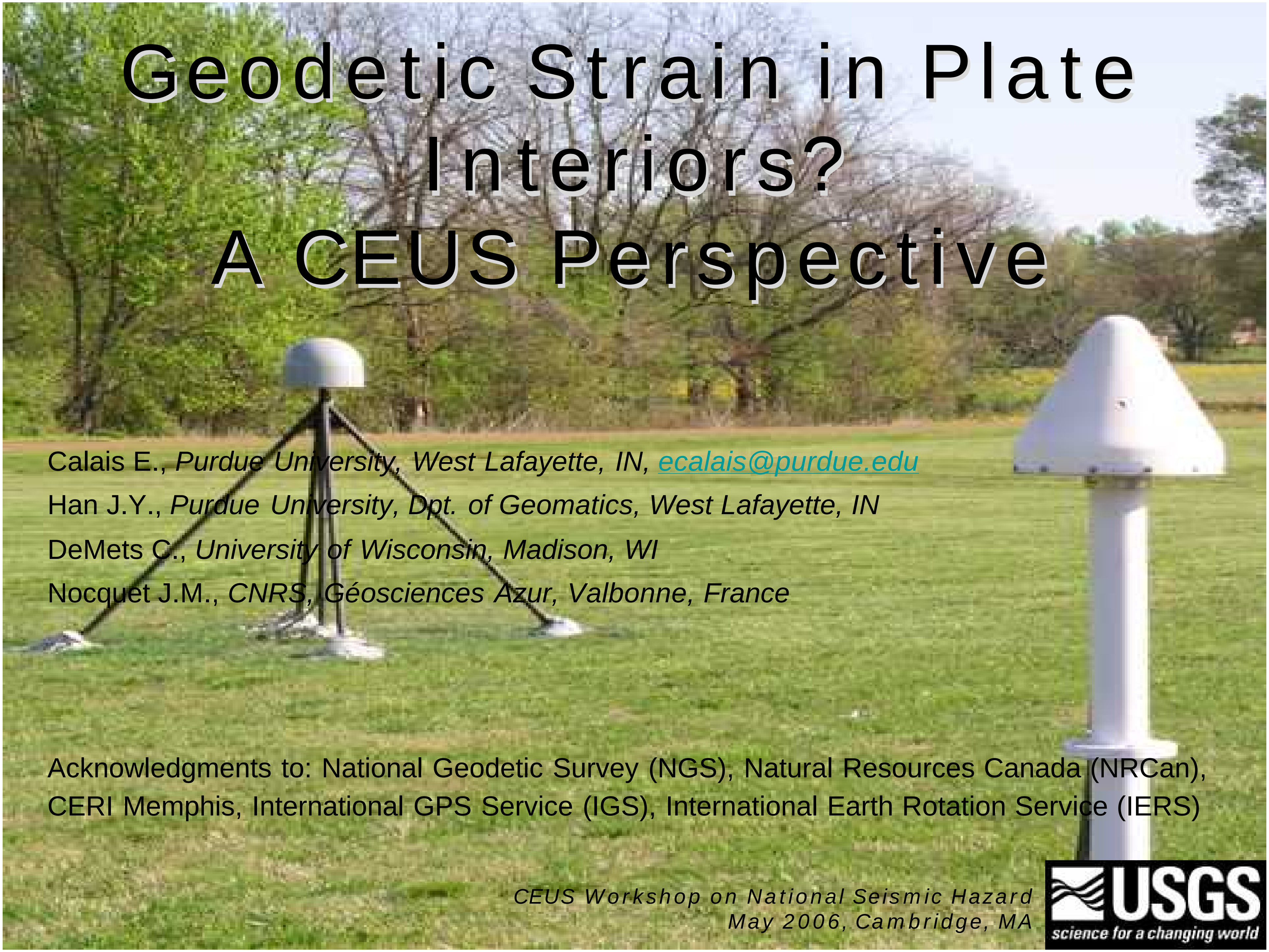


Geodetic Strain in Plate Interiors? A CEUS Perspective

Calais E., *Purdue University, West Lafayette, IN, ecalais@purdue.edu*

Han J.Y., *Purdue University, Dpt. of Geomatics, West Lafayette, IN*

DeMets C., *University of Wisconsin, Madison, WI*

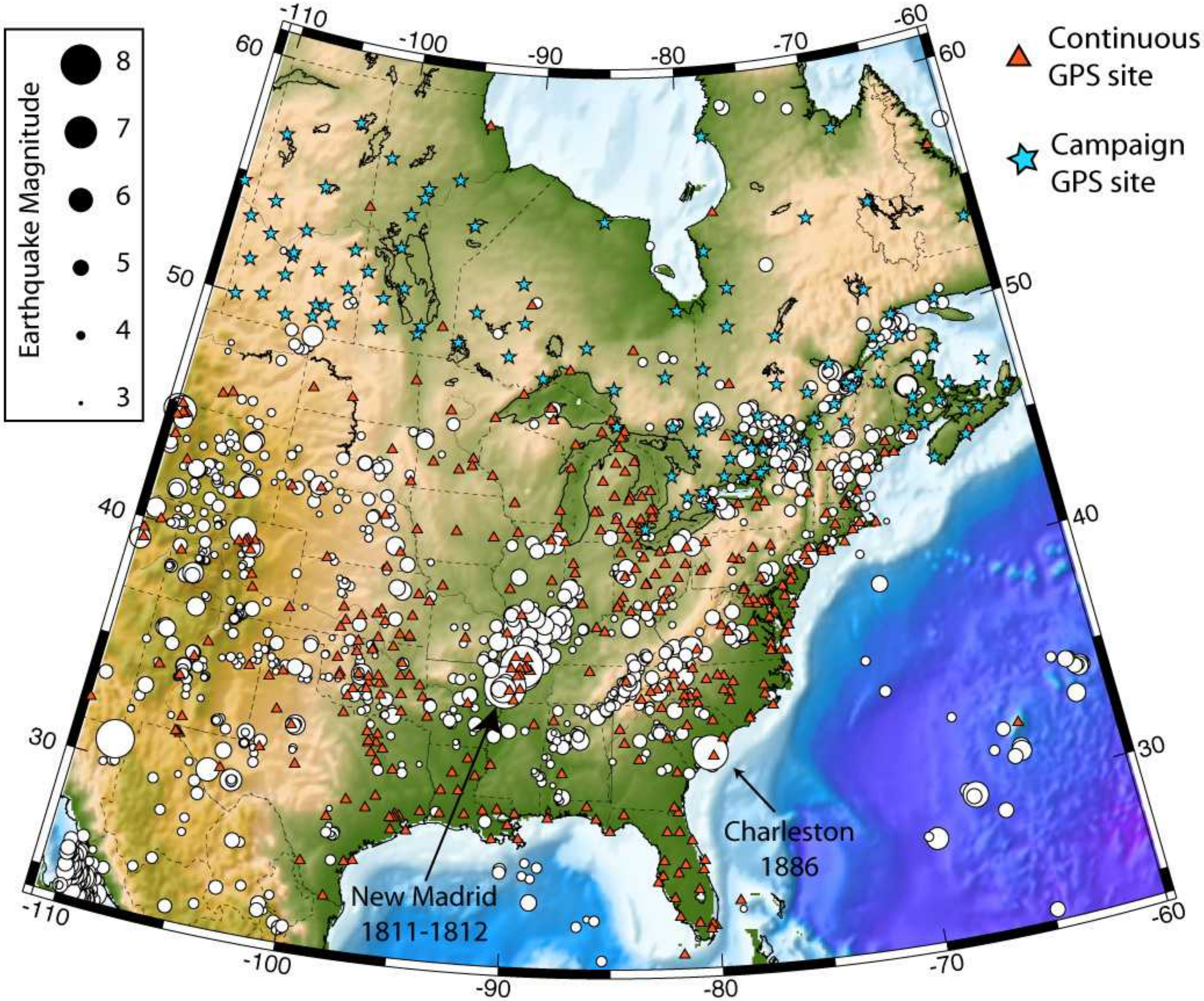
Nocquet J.M., *CNRS, Géosciences Azur, Valbonne, France*

Acknowledgments to: National Geodetic Survey (NGS), Natural Resources Canada (NRCan), CERI Memphis, International GPS Service (IGS), International Earth Rotation Service (IERS)

CEUS Workshop on National Seismic Hazard
May 2006, Cambridge, MA

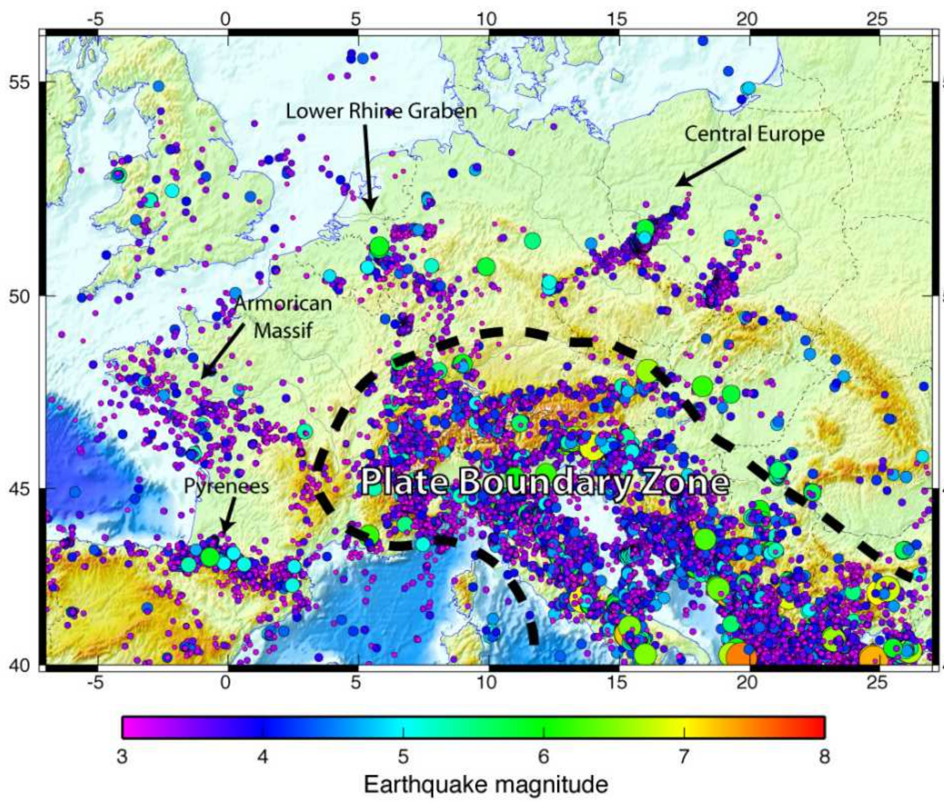
USGS
science for a changing world

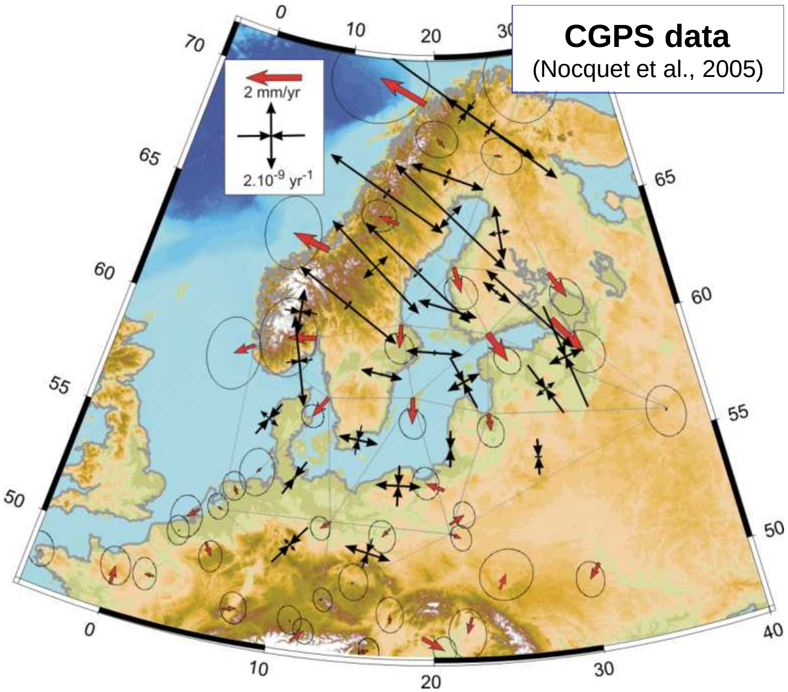
“Stable” North America?

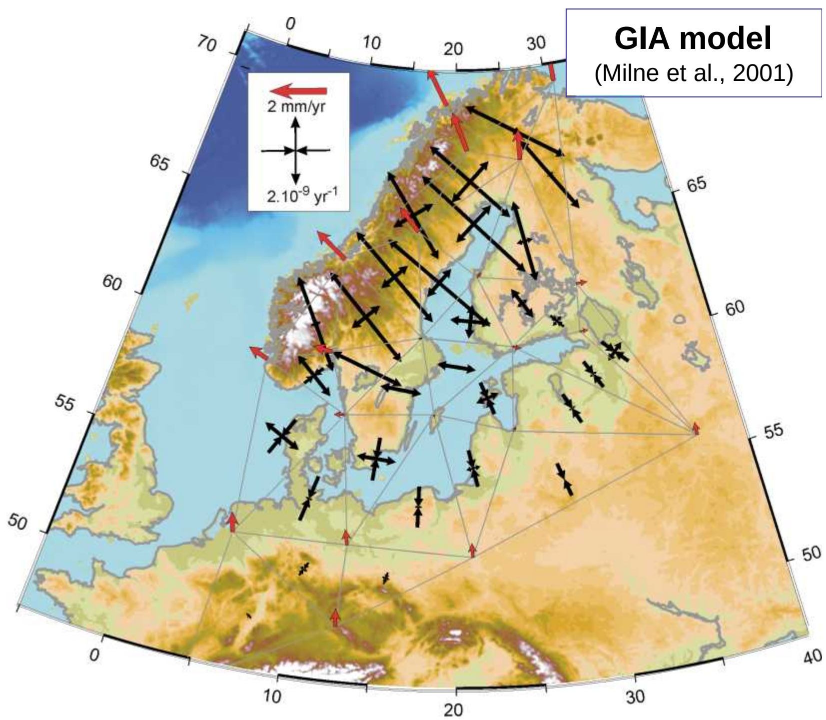


- CEUS is part of the stable part of the North American plate (NOAM)
- Large intraplate earthquakes in NOAM $\Rightarrow$ the plate deforms
  - $\rightarrow$ How fast?
  - $\rightarrow$ Where?
  - $\rightarrow$ Under what driving forces?
- Among other tools: GPS geodesy

Western Europe

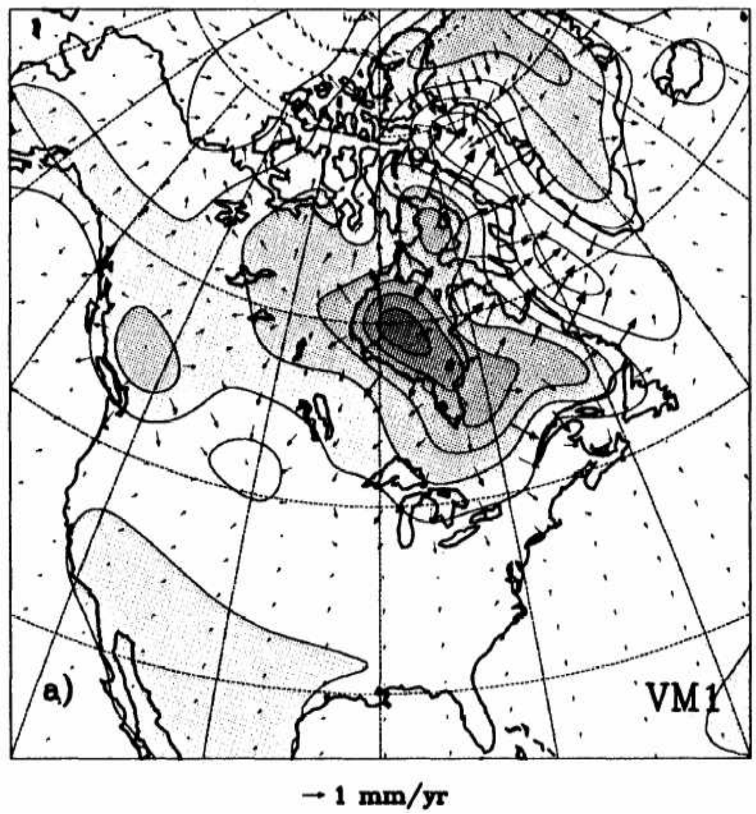




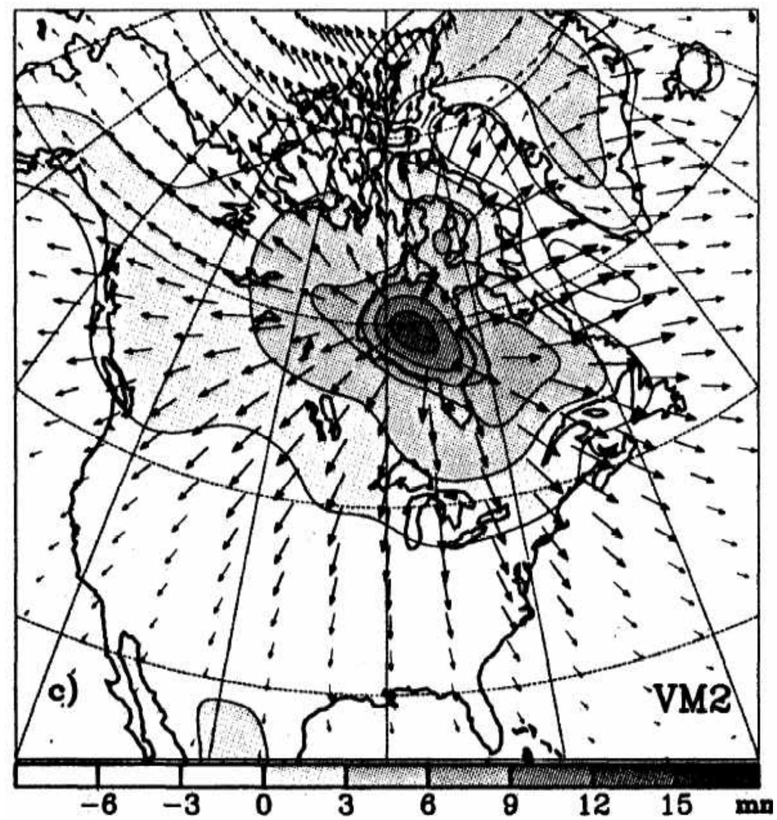


- Intraplate deformation results from Glacial Isostatic Adjustment (GIA) effects (radial shortening across forebulge ~10^{-9} /yr)
- South of ~52N (outside PBZ): Intraplate seismicity but no detectable intraplate strain, < 0.4 mm/yr

GIA in North America

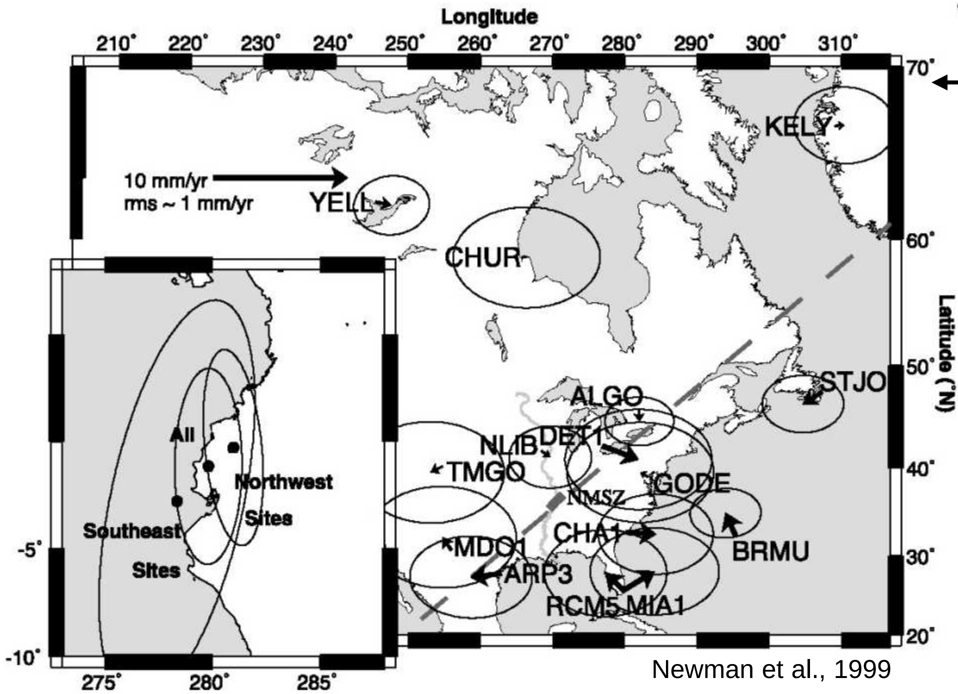


Peltier, GRL, 1998



- NOAM interior deforms under GIA
- Current GIA models are uncertain (ice history + mantle viscosity)
- Some predictions are testable with GPS
- Link between GIA and seismicity in NOAM has long been proposed (e.g., Stein et al., 1979, 1989; Hasegawa and Basham, 1989; Balz and Zoback, 2001; Wu and Johnston, 2000; Mazzotti et al., 2005)

Tectonic Strain in the CEUS?



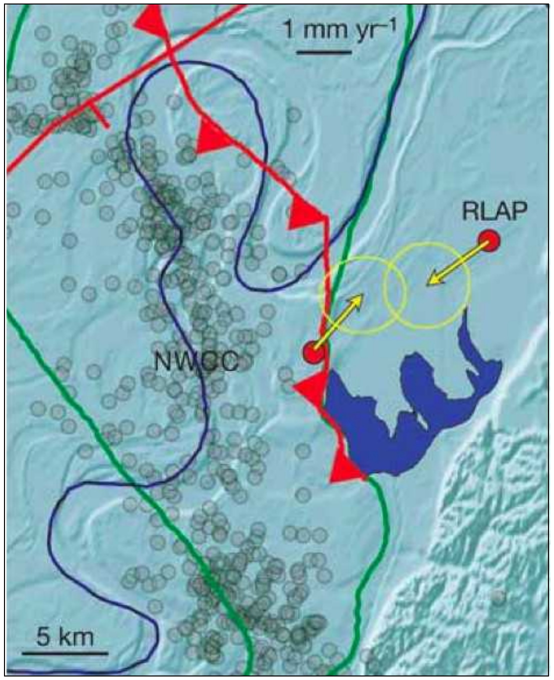
Newman et al., 1999

Continental scale:

- Less than 2 mm/yr (Argus and Gordon, 1996; Dixon et al., 1996; Kogan et al., 2000)
- Significant deviations in south Central US, ~2 mm/yr? (Gan and Prescott, 2001)
- Less than 1.5 mm/yr (Sella et al., 2002; Marquez-Azua and DeMets, 2003)

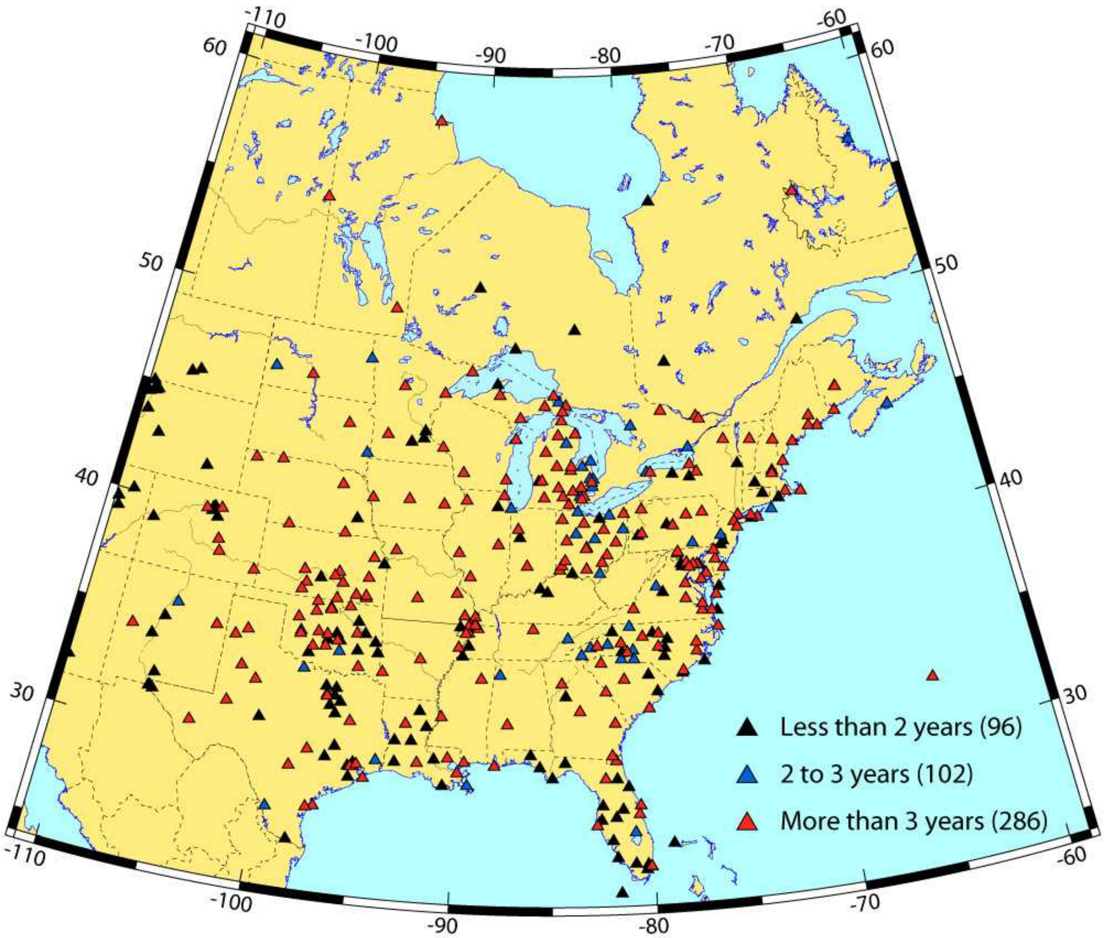
Regional scale, New Madrid Seismic Zone:

- 5-7 mm/yr in southern NMSZ (Liu et al., 1992)
- Less than ~3 mm/yr in northern NMSZ (Snay et al., 1994)
- Less than 2.5 mm/yr (Weber et al., 1998; Newman et al., 1999)
- Significant deviations (~1.5 mm/yr) across Reelfoot fault, with *"rates of strain comparable to active plate boundaries"* (Smalley et al., 2005)



Smalley et al., 2005

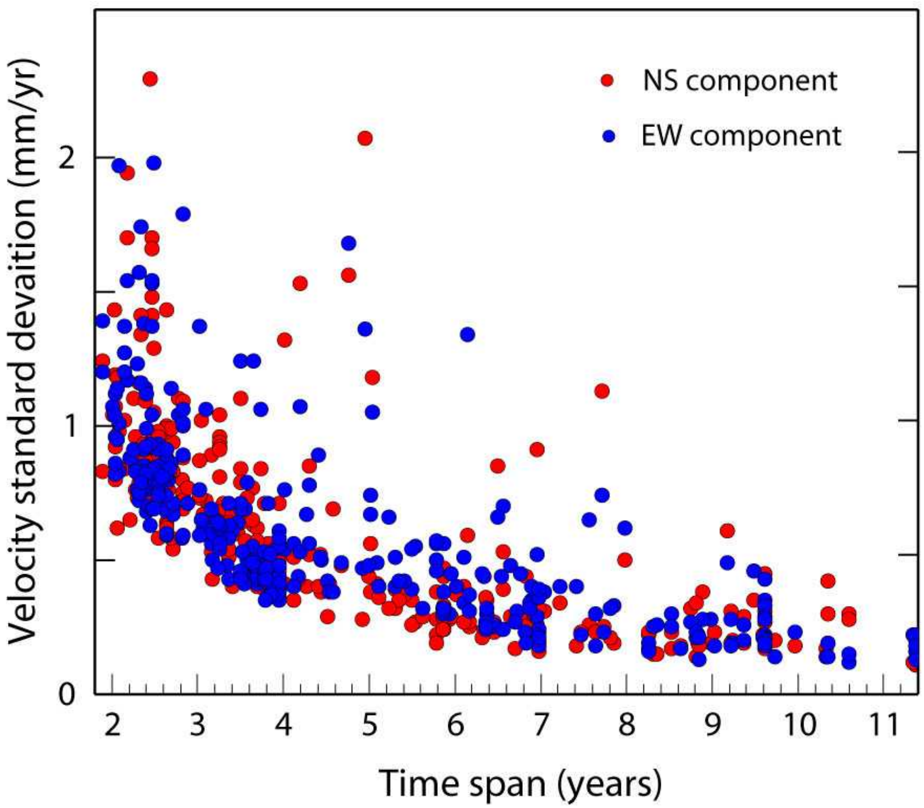
600 Continous GPS stations in Stable North America



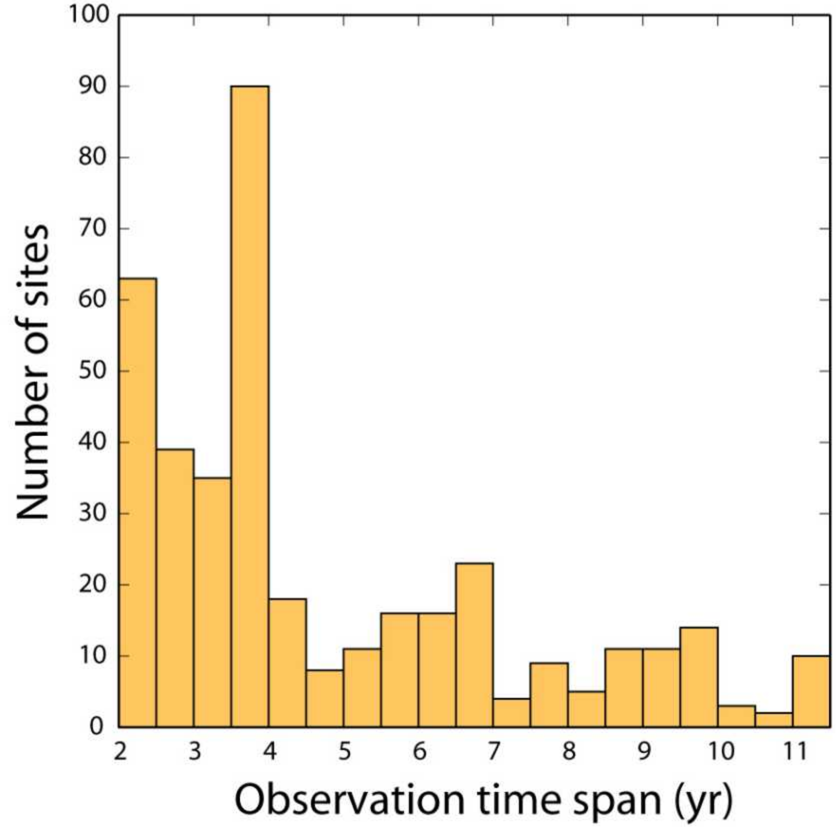
563 continuous GPS sites: most are "CORS" stations + IGS + NRCan + local networks (*e.g.*, GAMA)

- Pros:
  - Larger number of sites
  - High density of sites in some areas
  - Minimal cost…
- Cons:
  - Density varies geographically
  - Monument quality
- Data processing:
  - Combine 3 independent solutions
  - "Randomize" systematic biases in individual solutions
  - Redundancy => outlier detection
  - Rescaling of covariance associated with each individual solution => final uncertainty reflects:
    - Variance in original solution
    - Level of agreement between solutions

Precision



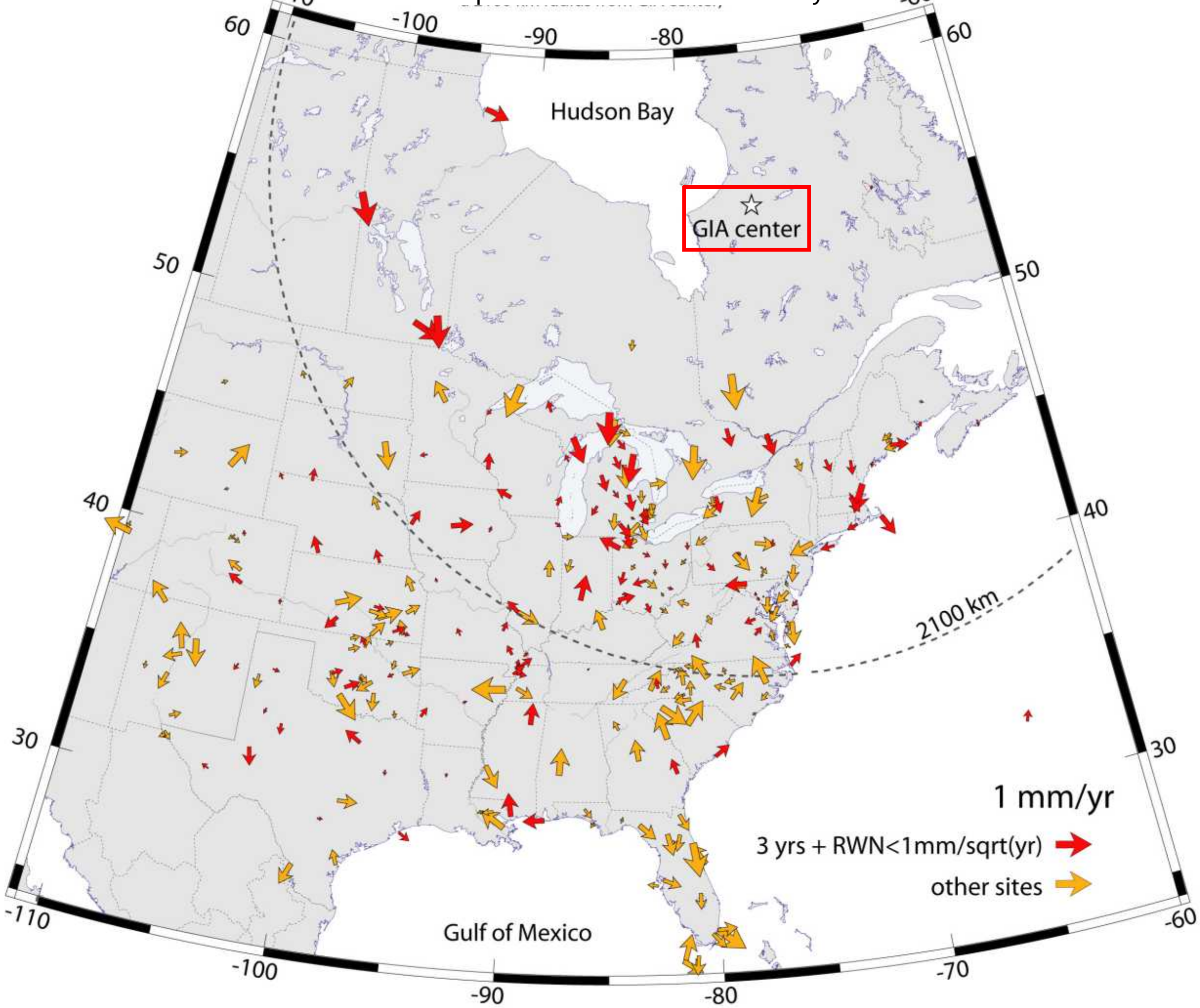
Precision: 0.5 mm/yr after 2.5 to 3 years



Age distribution of sites: Most are young < 4 years

Residual velocities

Error ellipses omitted for sake of clarity

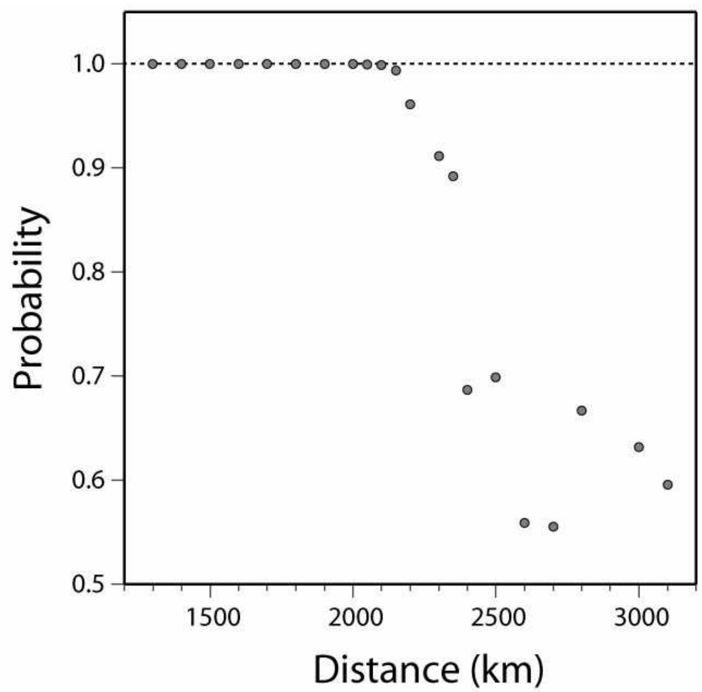


Small (WRMS = 0.8 mm/yr), most not significant at a 95% confidence level

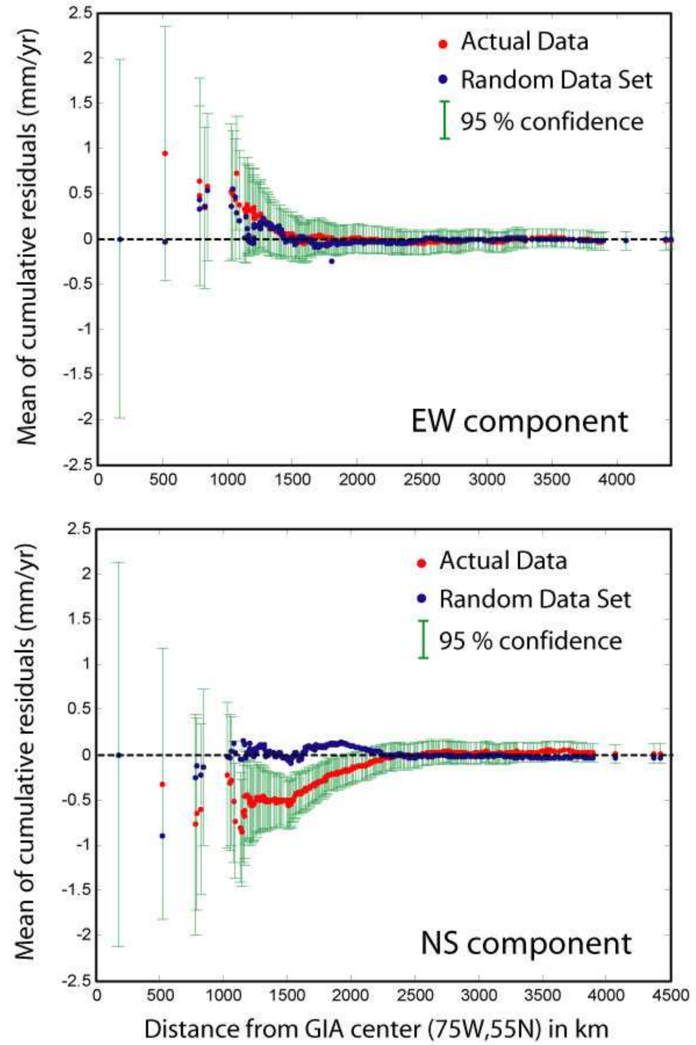
⇒ **Random pattern? Or hidden strain signal?**

Random residuals?

Probability (from F-test) that a 2-plate model fits the data better than a single plate model. Distance = from GIA center, boundary between 2 subsets tested

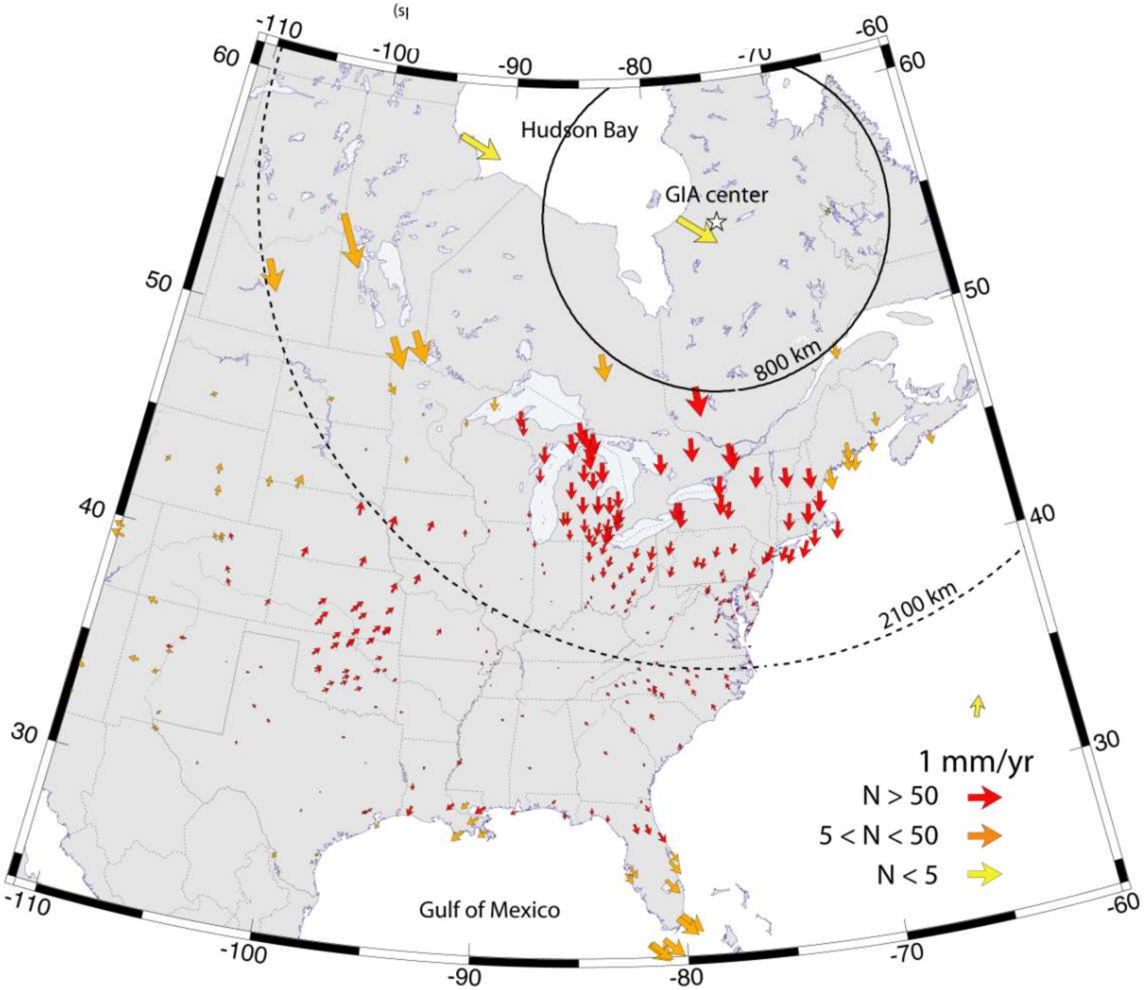


Significant deviation from random distribution for NS component for distances > 2100 km from GIA center



Comparison between actual residual and simulated random data set (with same mean and variance as actual data)

Random residuals?



Residual velocities are not random: GIA-like pattern

- Calculate weighted average of horizontal velocities as a function of inter-site distance using variable taper (800 km on the figure)

$$v = \frac{\sum_{i=1}^{N} w_i v_i}{\sum_{i=1}^{N} w_i}$$

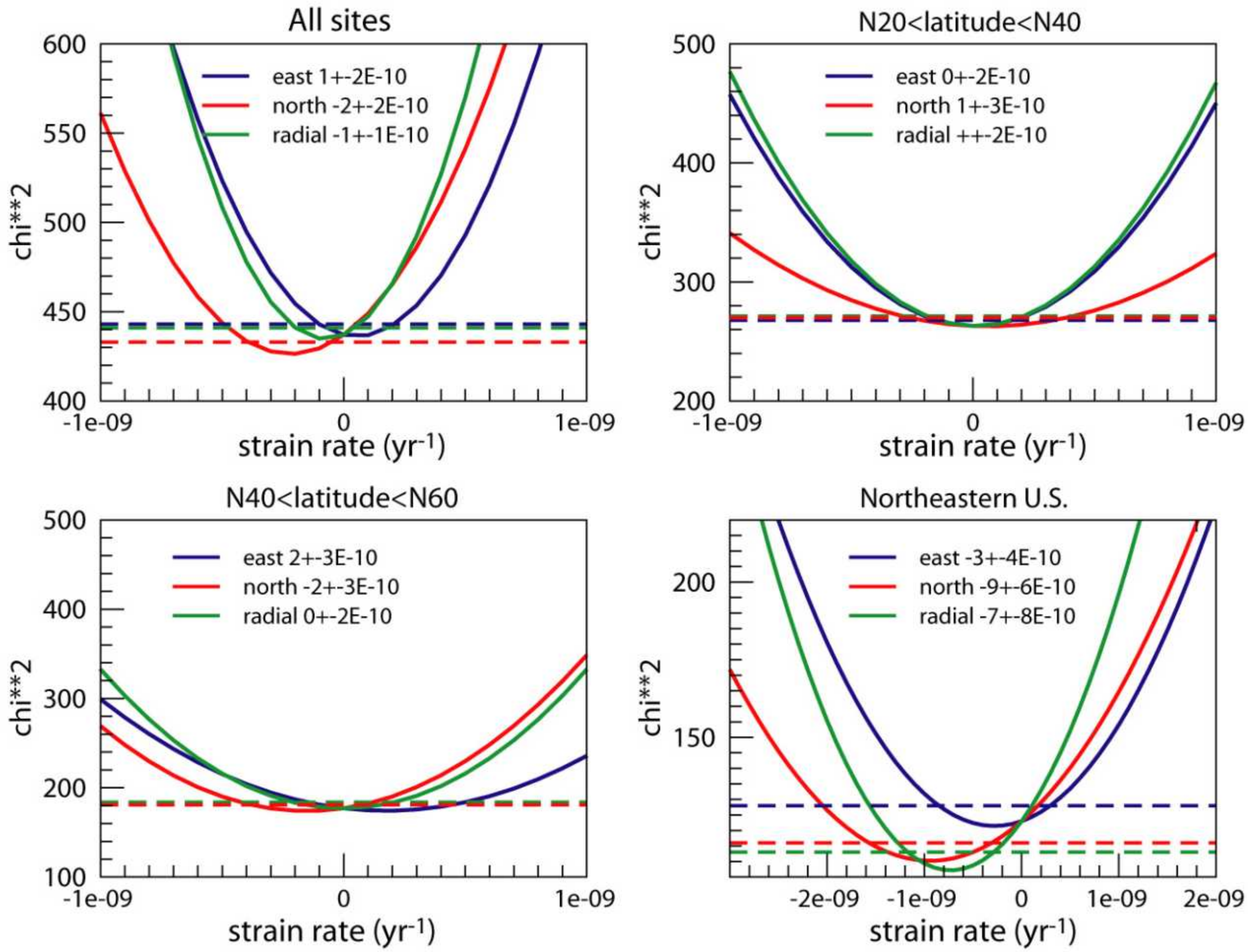
$$w_i = \frac{1}{\sigma_i^2} \times \frac{1}{1 + \left(d/d_S\right)^2}$$

- Spatially random velocities cancel out
- Spatially correlated velocities are enhanced

Intraplate strain?

Dashed lines = 95% confidence

Negative strain rate = compression, positive = extension

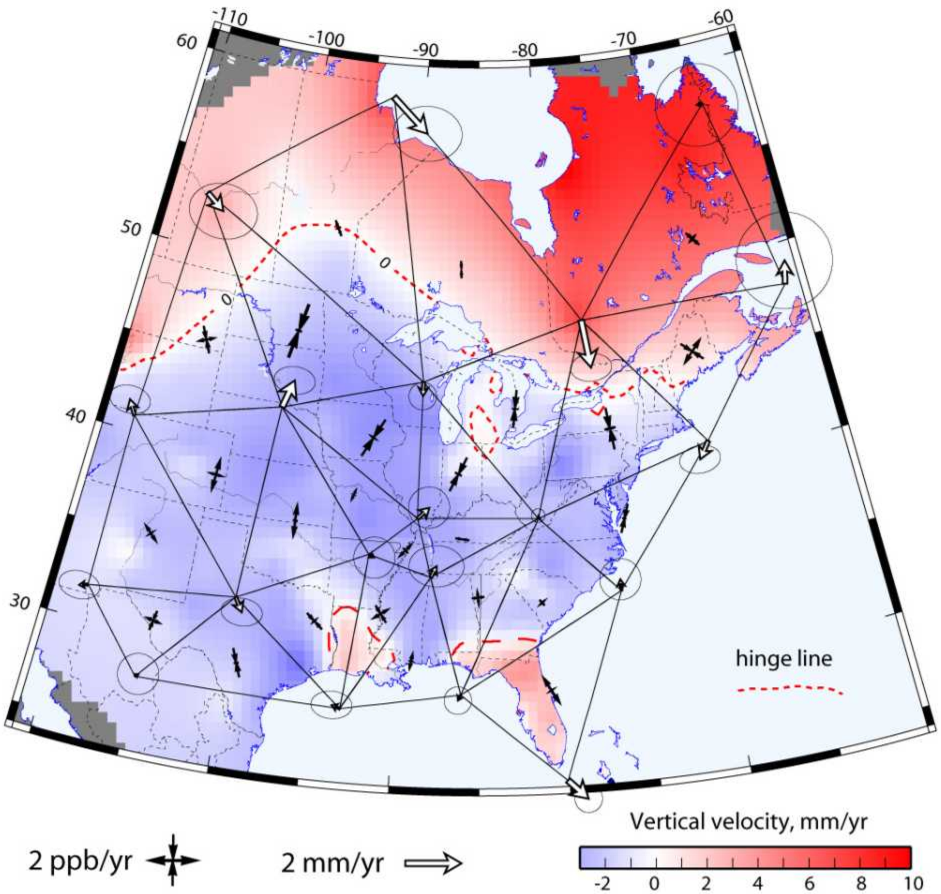


Allowing for (uniform) strain improves the fit but not for north or south subsets separately

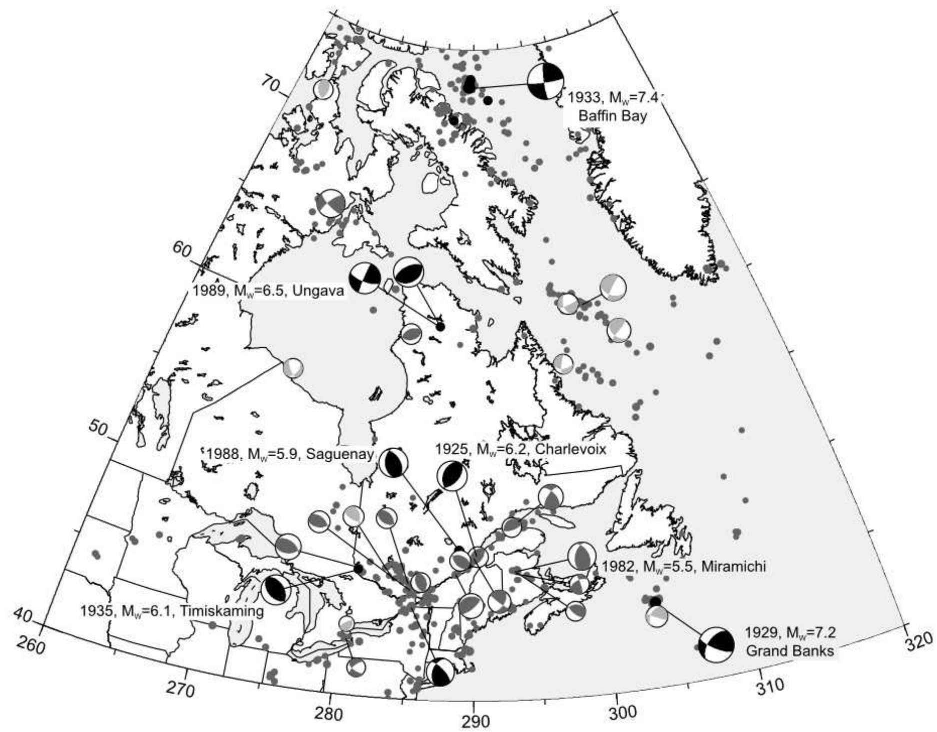
Strain localized around GIA uplift (incl. northeastern U.S.): NS or radial shortening at ~10^{-9} /yr

South of 40N: less than $2x10^{-10}$ /yr (or less than 0.6 mm/yr)

Interpolated strain rates and vertical velocities



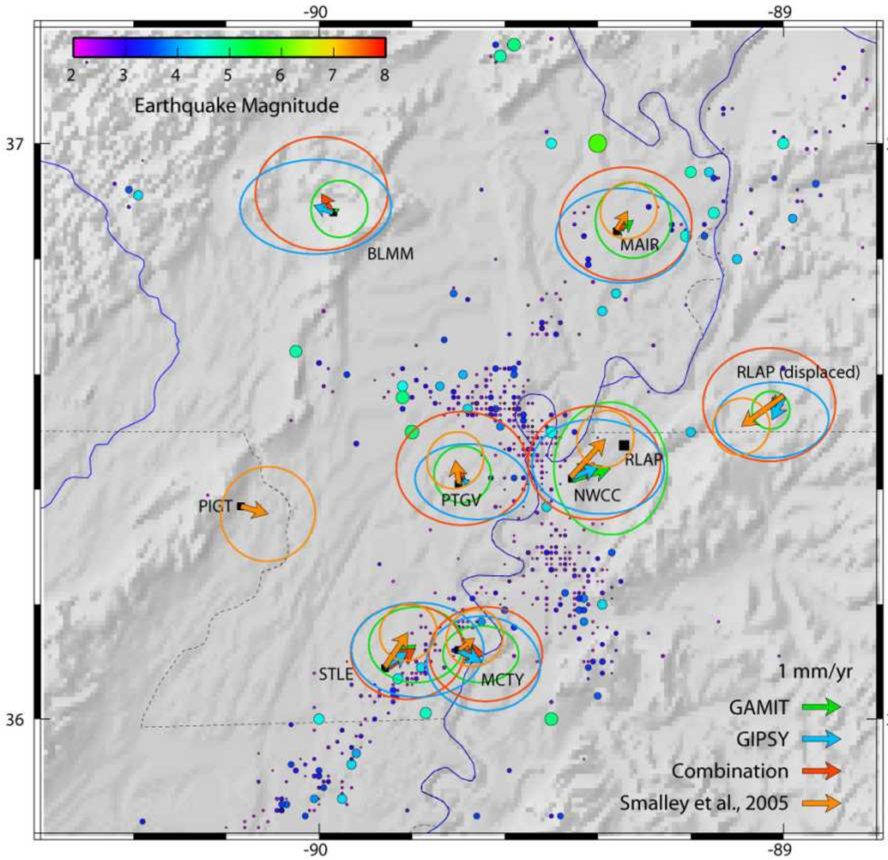
Compilation of focal mechanisms in the NE US and Eastern Canada, from Mazzottti and Adams (2005)

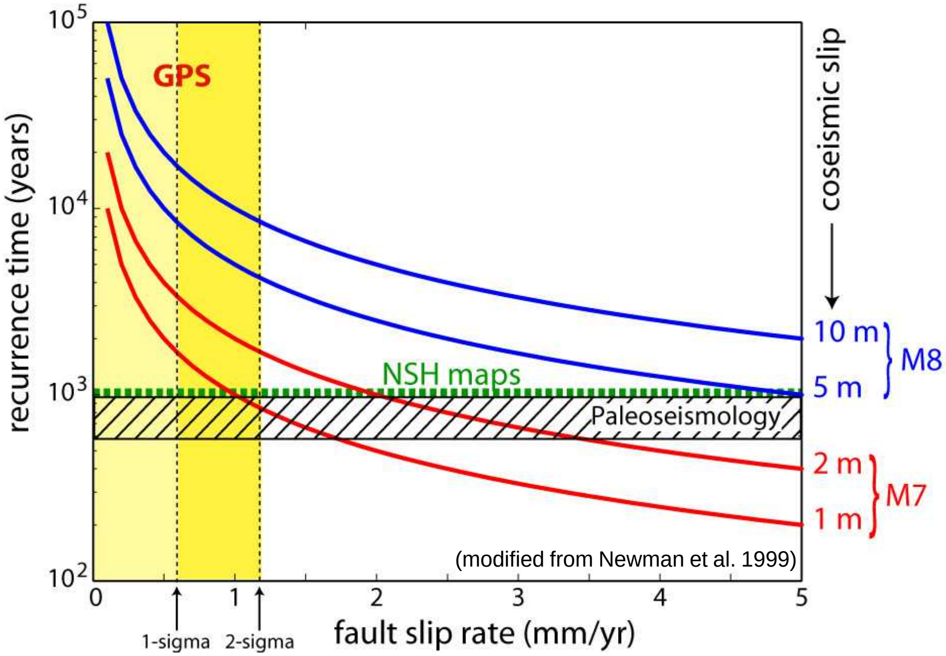


- Compressional strain localizes around GIA uplift area (~10^{-9} yr^{-1}), consistent with GIA effect
- Observed NS to NW-SE shortening consistent with earthquake focal mechanisms in St Lawrence valley (Québec)

Local strain?

WRMS: Gamit = 0.6 mm/yr | Gipsy = 0.6 mm/yr | Combination = 0.6 mm/yr



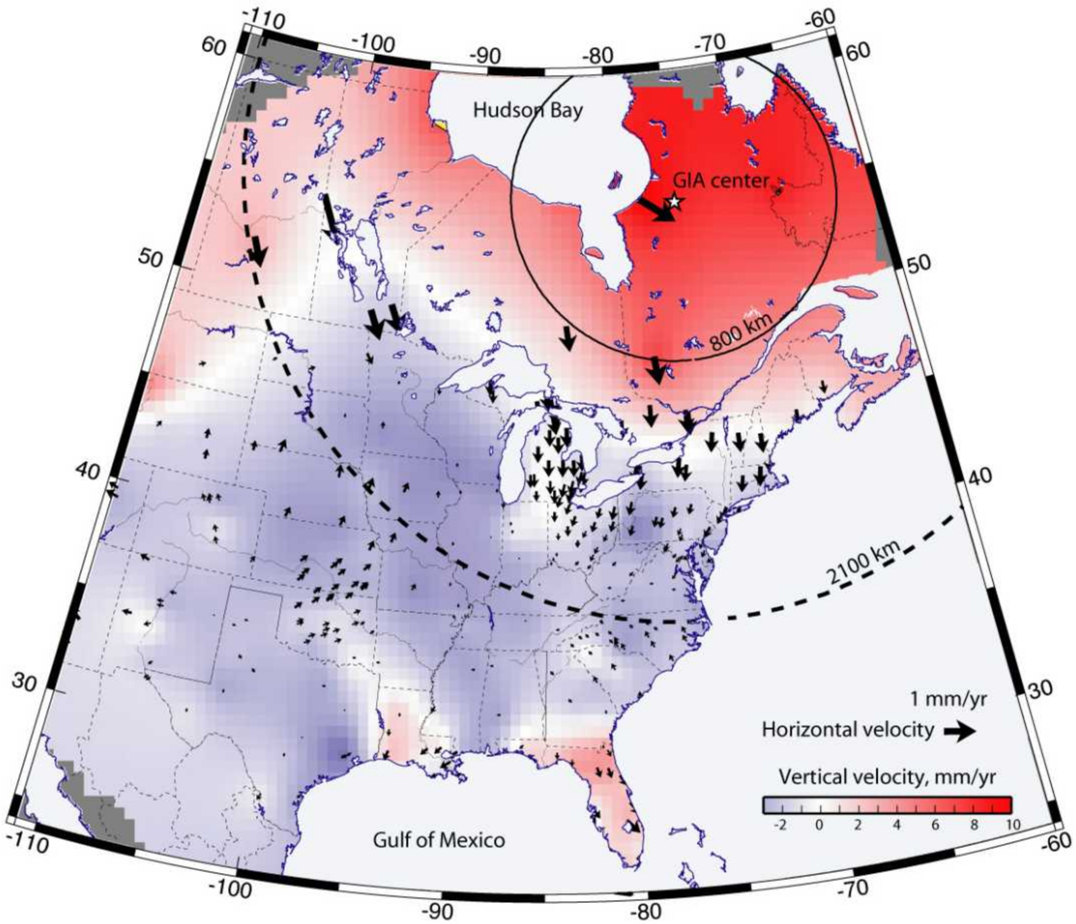


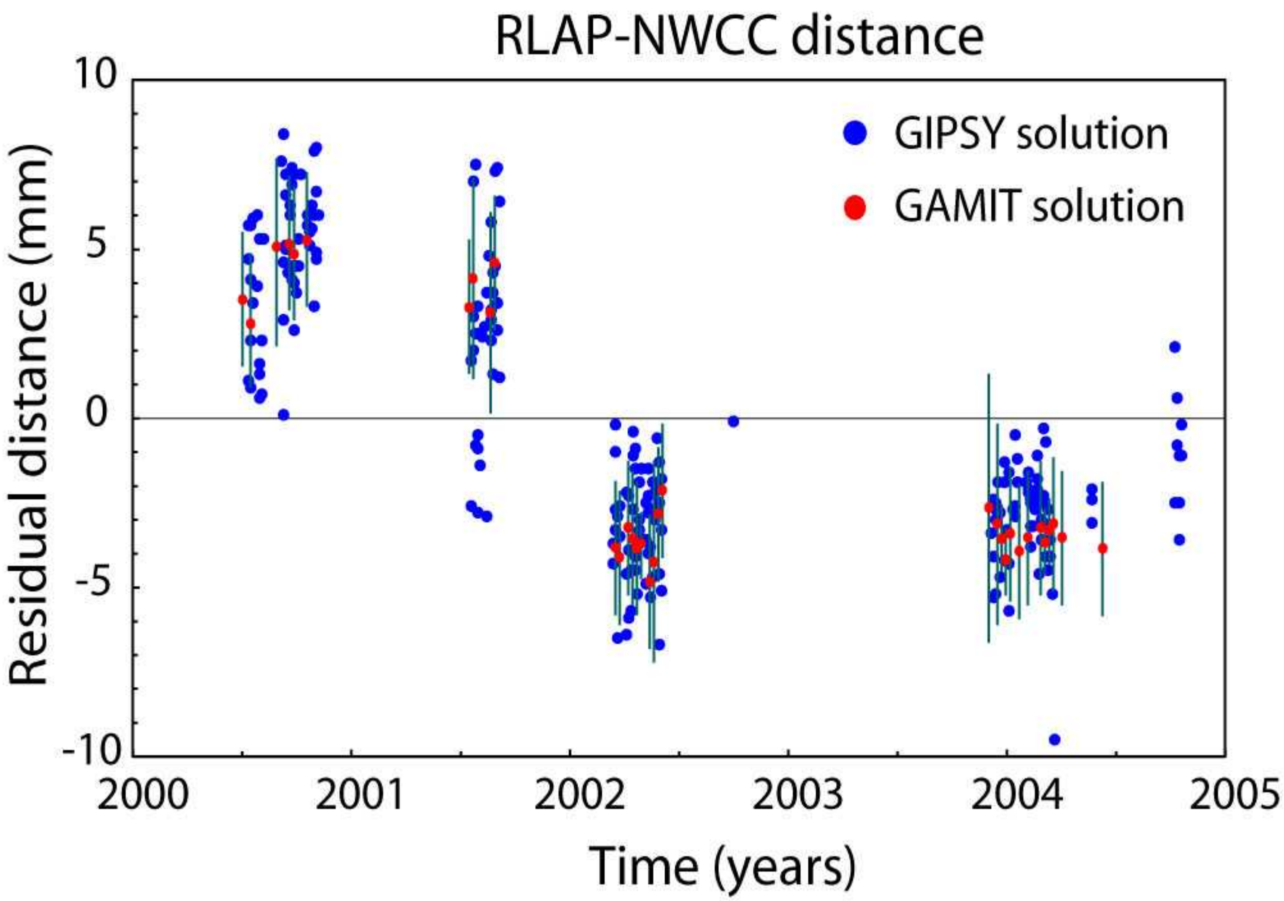
(NSH = National Seismic Hazard)

- GPS: surface deformation < 0.6 mm/yr (or 1.2 mm/yr at 95% confidence).
- Paleoseismology: 600-1000 years repeat time of “large” events.
- GPS and paleoseismology are consistent if characteristic earthquakes in NMSZ are low M7.

Conclusions

- First-order strain signal in NOAM (and CEUS) is likely to result from Glacial Isostatic Adjustment
- We now have much tighter bounds on intraplate strain in the CEUS:
  - No significant deviation from rigidity resolvable at the 0.6 mm/yr level
  - EW strain < 2×10^{-10} yr^{-1}
  - No areas of localized strain found <u>yet</u>
- Better understanding of GIA is required to understand the relationship between surface strain and earthquakes in the CEUS
  - GIA stresses and earthquakes
  - GIA signal may mask other, more subtle, strain signals
- Time works for us:
  - Improvements in GPS data processing
  - New data, more older sites





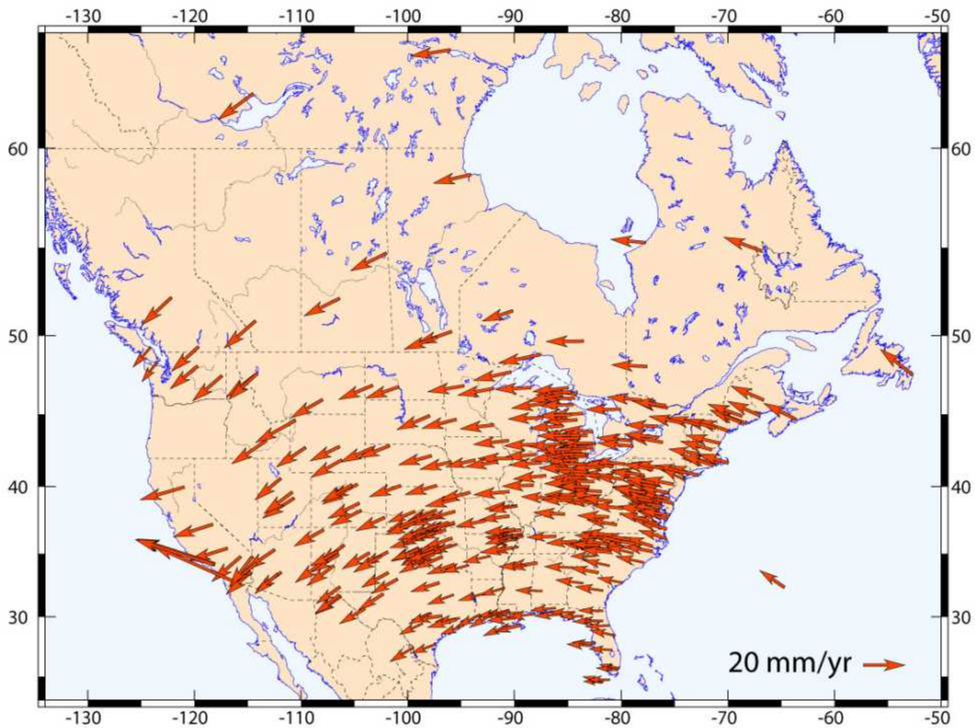
- Shortening across the Reelfoot fault?
  - 1.1 +- 1.2 mm/yr (95% confidence)
  - Jump in time series in winter 2001-2002?

⇒ No convincing evidence for shortening

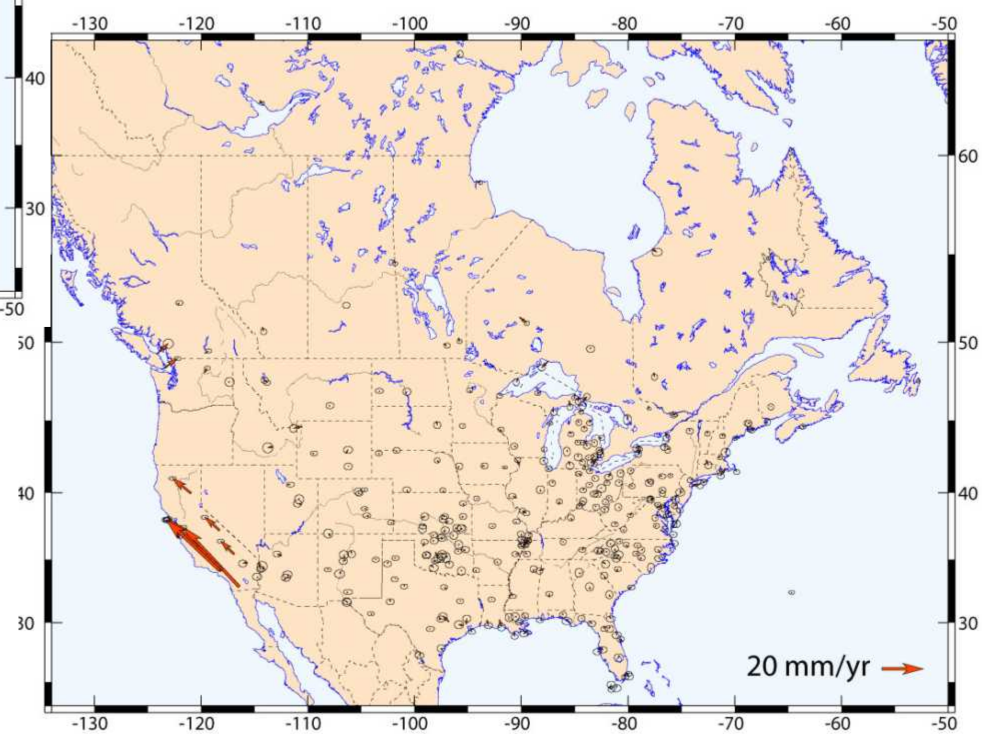
- Strain rate:
  - 1 mm/yr over 10 km => 10^{-7}/yr
  - San Andreas:
    - 10 mm/yr over 10 km => 10^{-6}/yr
    - 30 mm/yr over 200 km => ~10^{-7}/yr

⇒ If strain, then 10 times less than active plate boundary

Rigid rotation of North America



1. Velocities w.r.t. ITRF2000 - global reference frame
2. Estimate angular rotation of “rigid” North America



3. Subtract rigid model $\Rightarrow$ residual velocities
4. Deviation from rigidity = WRMS of scatter of residuals about zero