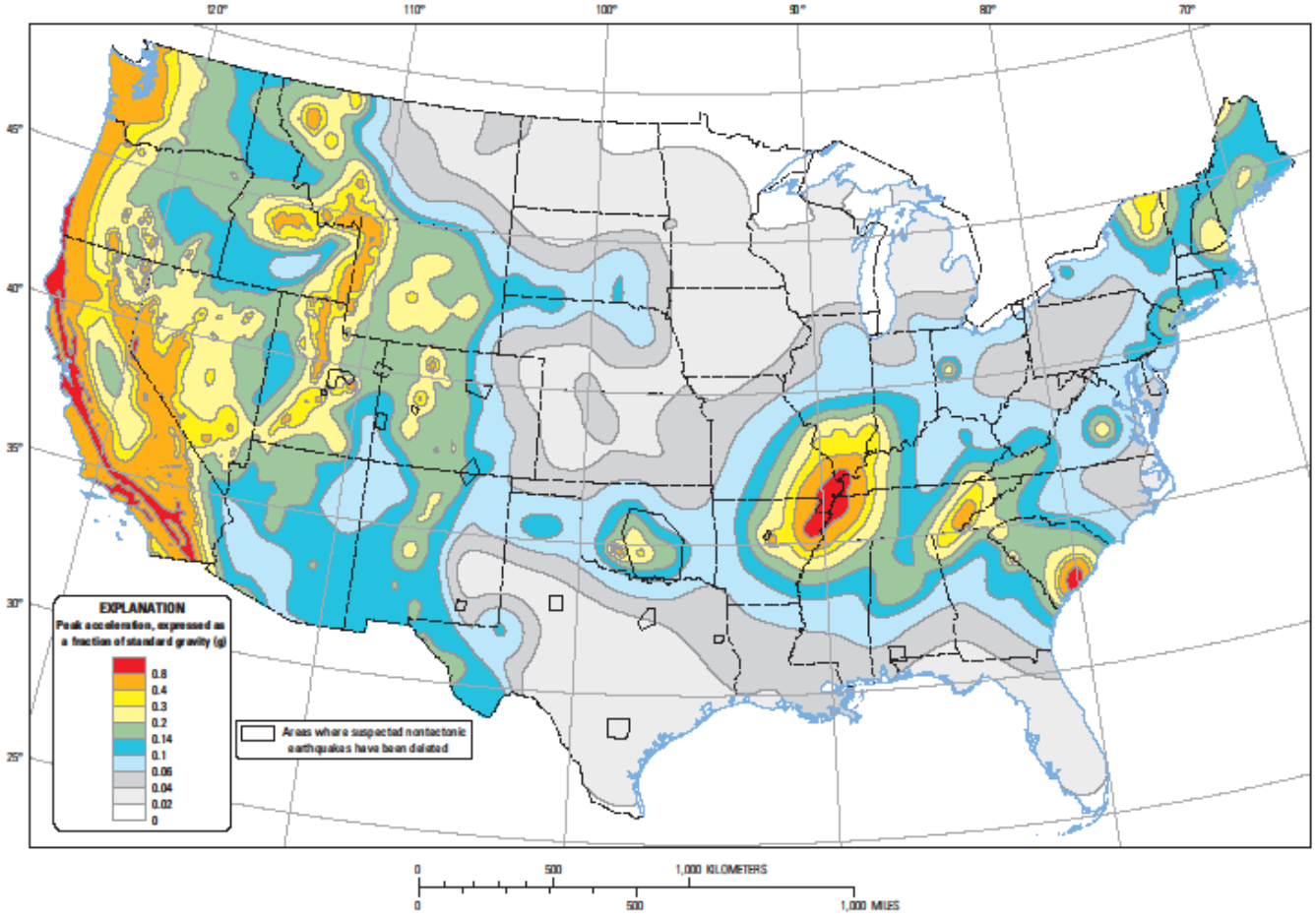
Incorporating Induced Seismicity into the U.S. National Seismic Hazard Models: Logic Tree and Straw Man Model



Two-percent probability of exceedance in 50 years map of peak ground acceleration

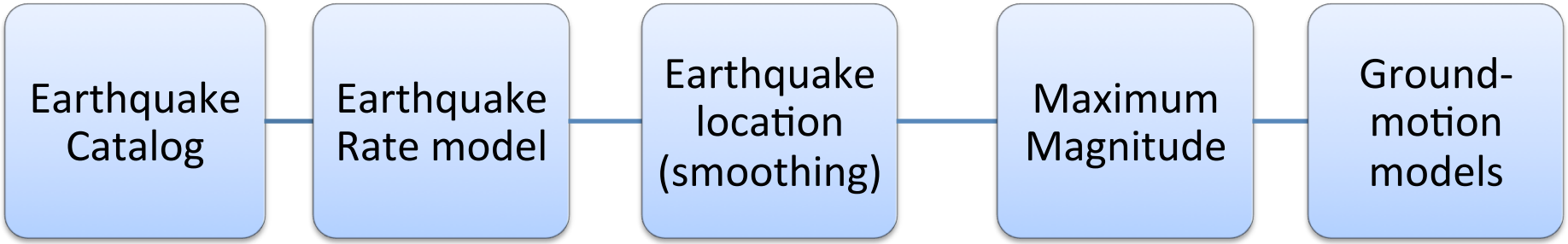
Hazard analysis

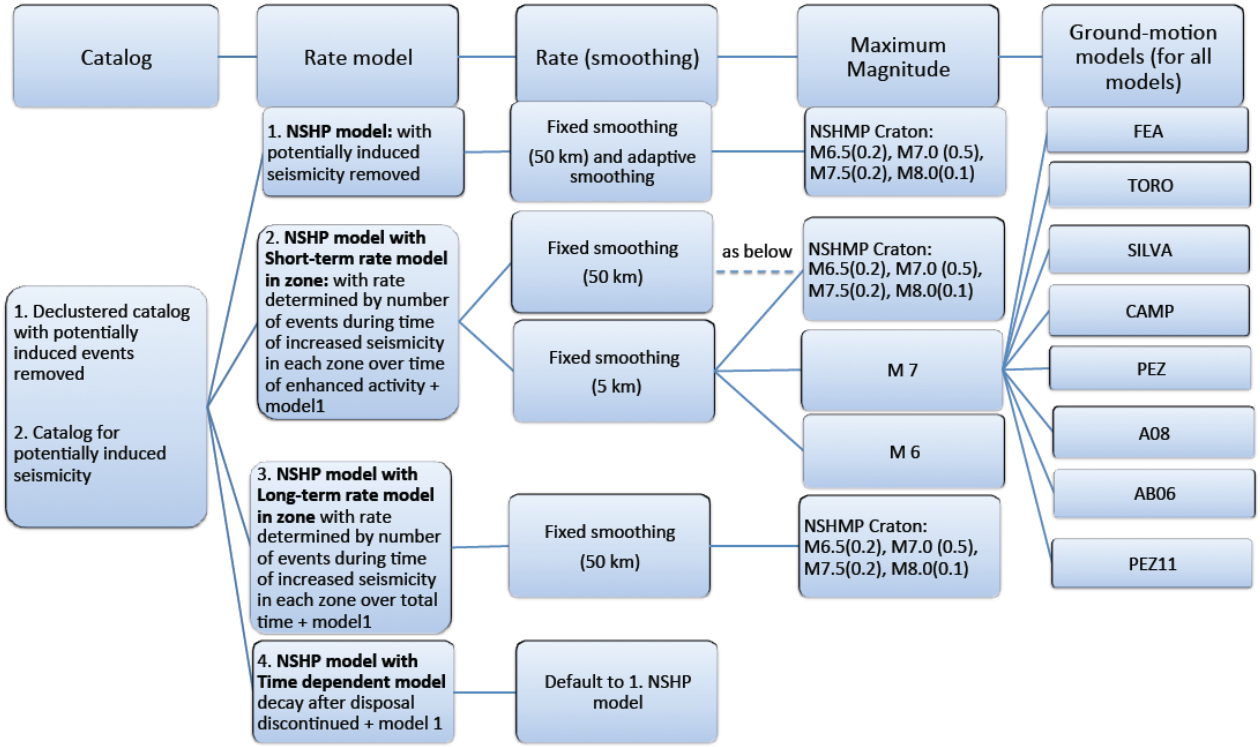
- Define logic tree
- Discuss each element of logic tree for Induced Seismicity
- Show influence of each element on the hazard
- Show straw man model for updated 2014 hazard maps
- Preliminary model due Dec 2014

What is a logic tree?

- Defines the range of parameters/models applied in the maps (we don't simply use the estimate from one model but include alternative weighted models – that represent different views of how the earthquakes are generated and shake the ground)
- Example maximum magnitude: we can use the local observed maximum, the global observed in similar tectonic conditions maximum, the characteristics of known regional faults, or an estimate that is higher than what we have observed historically but is scientifically plausible (we may not have seen the maximum size earthquake yet- unknown unknowns).
- Applied with weights for each model (probabilities) that are determined based on expert opinion and data analysis.

Logic Tree for Induced Seismicity





Issues: Earthquake Catalog

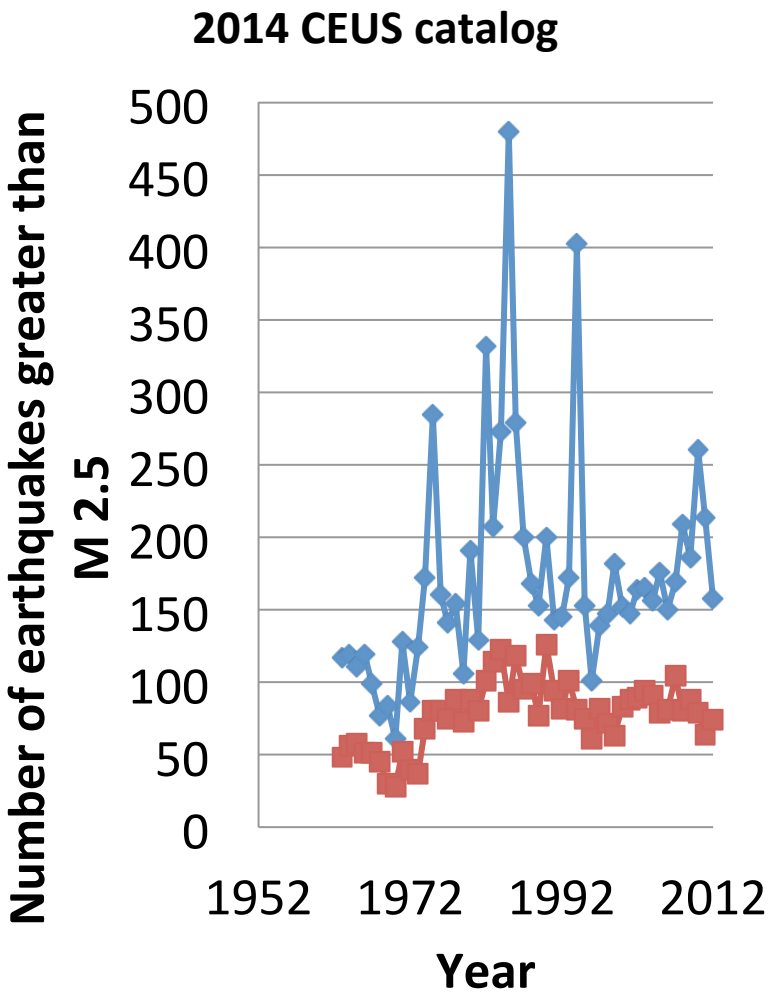
- What lower magnitude threshold should we use (Mw 2.7, lower)?
- Decluster model (after M5.7 Prague earthquake smaller earthquakes are not counted for about 290 days, 9 months, 47 km).
- Completeness time and magnitude uncertainty of earthquakes M 2.7 for the long-term rate

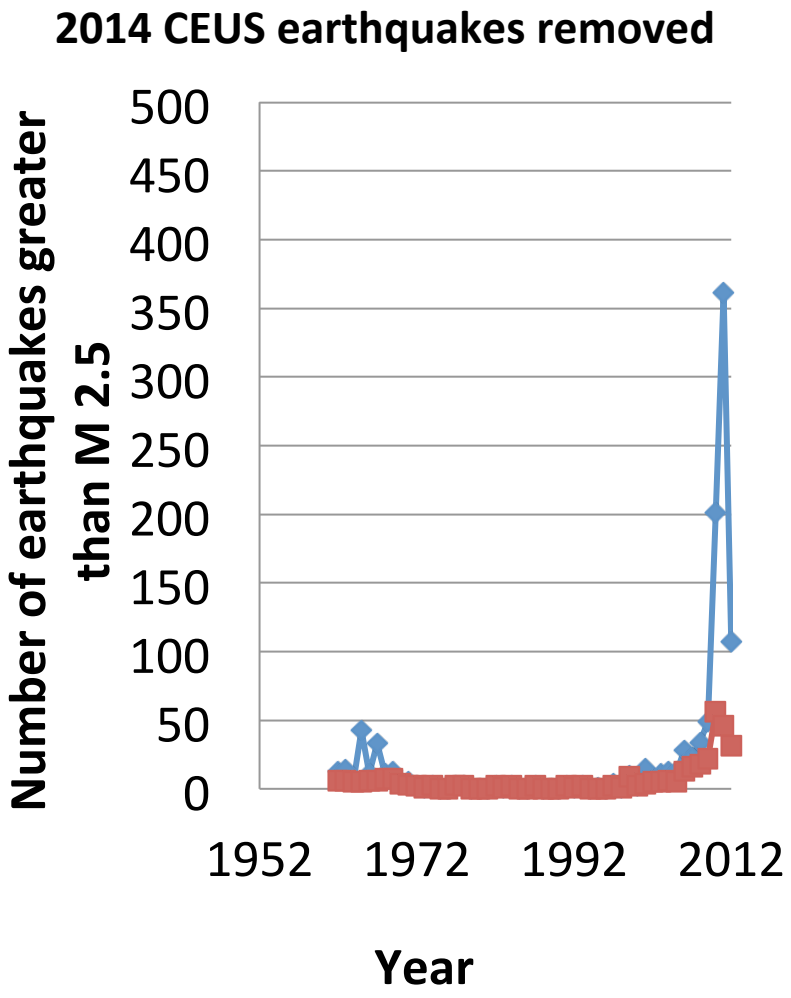
  time bracket is 1925 - 2012

  completeness shortens the bracket to 1960/1970/1980 to 2012

Earthquake Catalog

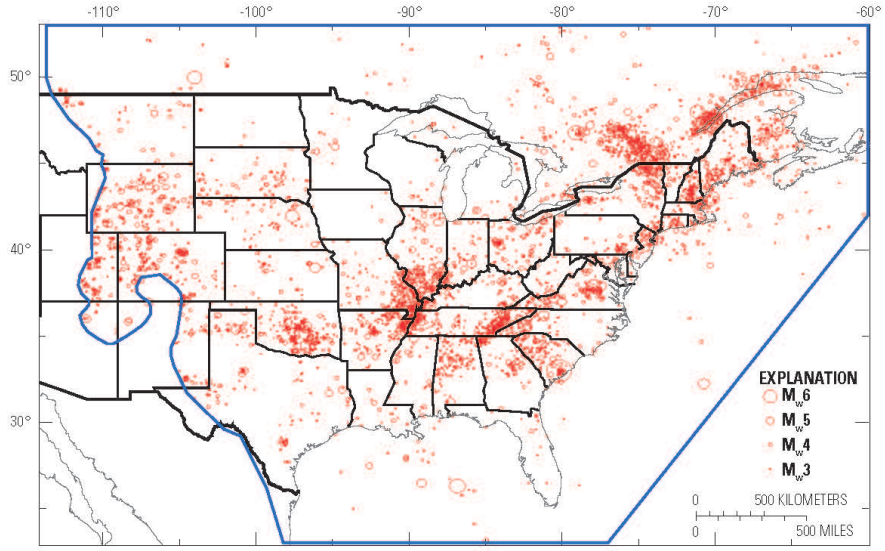
Left: Earthquake catalog considered for the 2014 National Seismic Hazard Models (NSHM).
Right: NSHM catalog of potentially induced earthquakes. The increase in the number of events over recent years is significant.
Both graphs shows the full NSHM (NSHM) catalog (blue), and the NSHM declustered catalog (red). Declustered catalog removes dependent earthquakes (i.e., aftershocks).



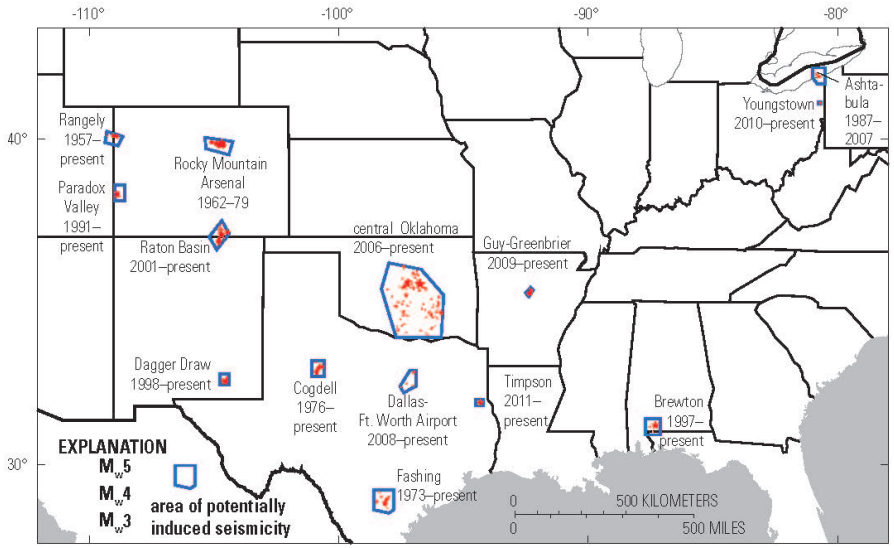


Seismicity in 14 Zones

2014 NSHM declustered catalog (1700 – 2012)



Areas of potentially induced seismicity (1957 – 2012). How to incorporate this seismicity into the NSHM in an appropriate way?

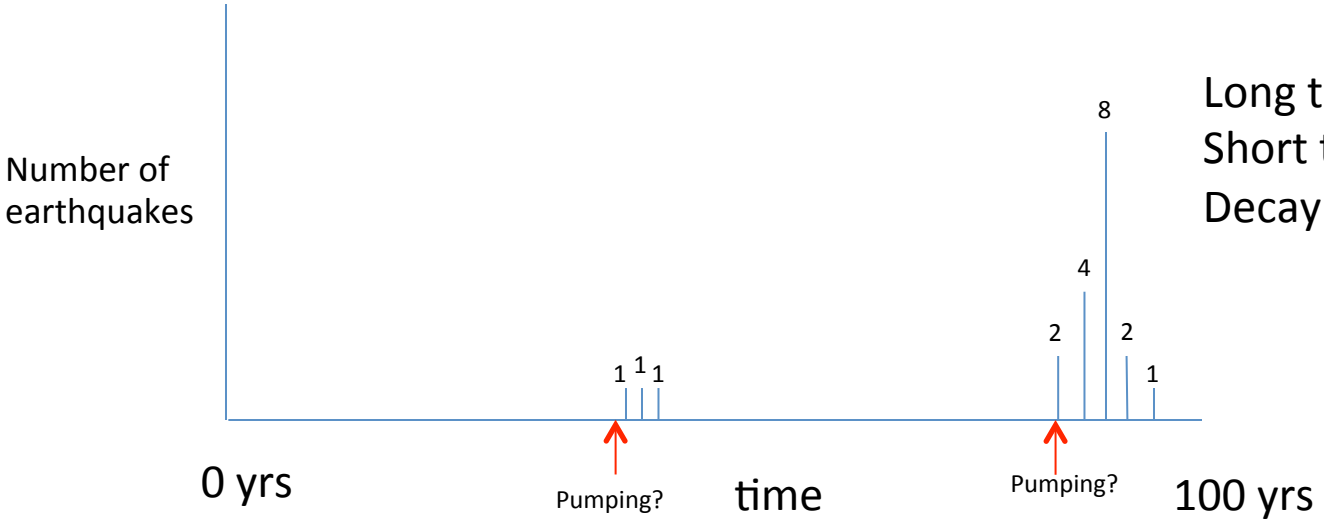


Issues: Rate models

How do we weight the different models?

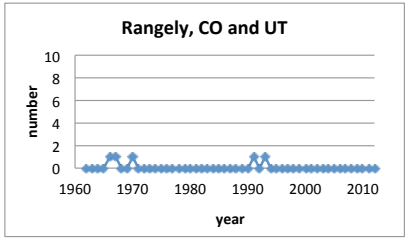
1. Long term rate model – assumes all earthquakes are equal
2. Short term rate model – assumes earthquake rates persist into future
3. Decay model – Not completed but assumes an Omori decay after pumping stops

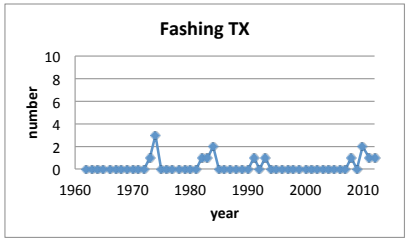
Should we consider other models?

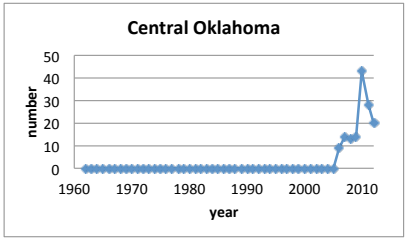


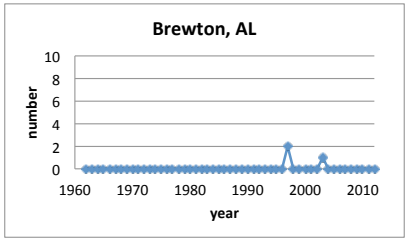
Long term:(3+17)/100 = 0.2
Short term:(17)/10=1.7
Decay: ? 1/10 = 1.0

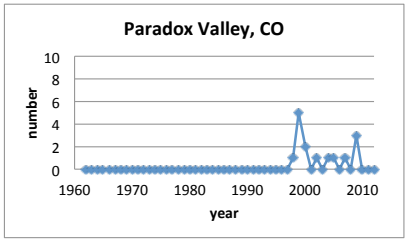
Rates for 14 Areas of Potentially Induced Seismicity

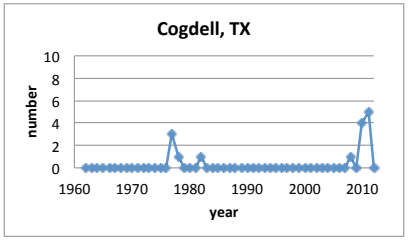


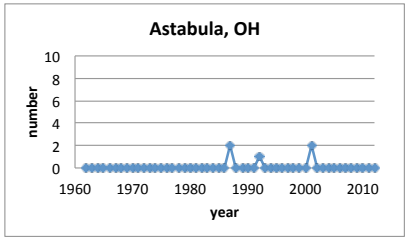


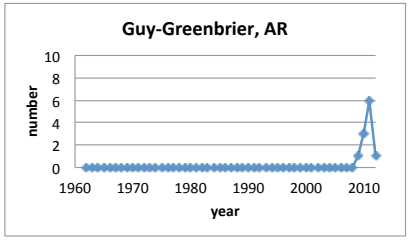


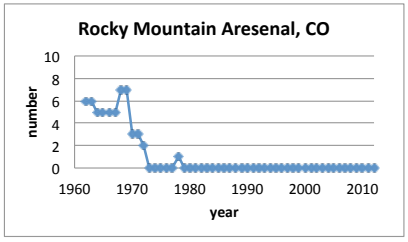


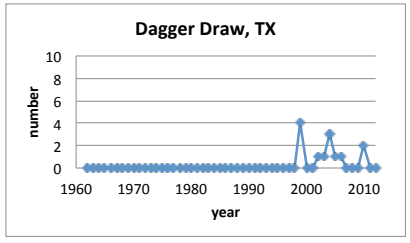


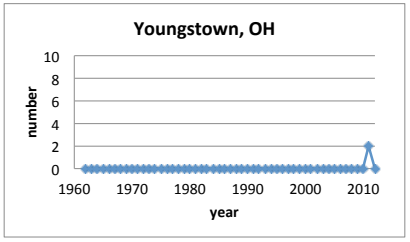


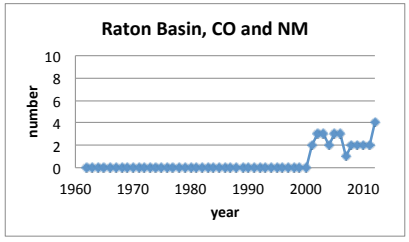


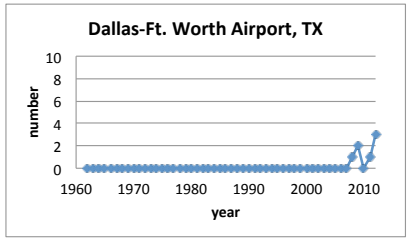


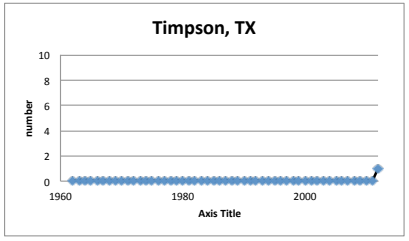












Rate Models

Seismic hazard increases by including potentially induced seismicity

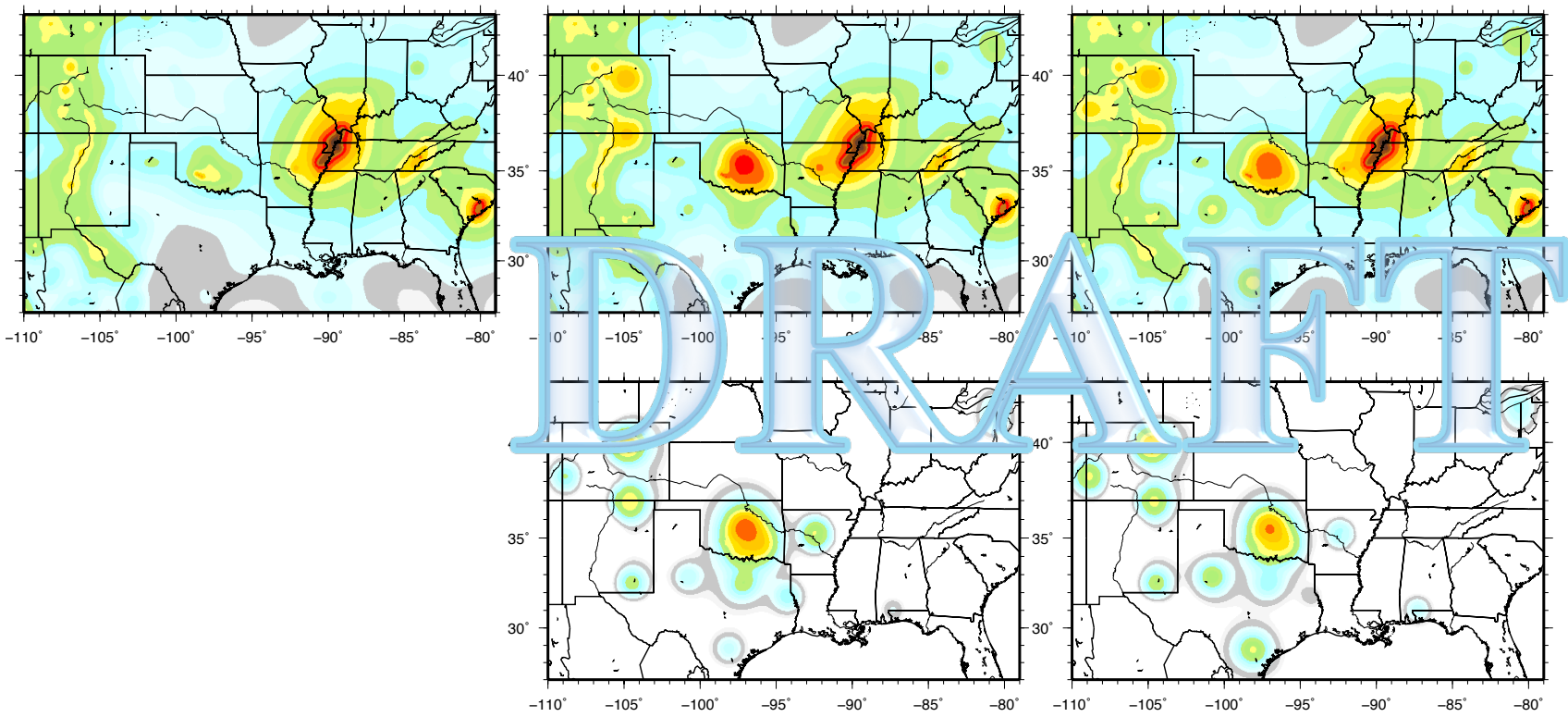
Short-term

Long-term

2014 NSHP (suspected induced events removed)

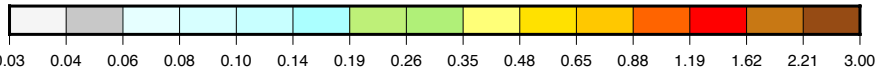
Ind. added: Short–term, 50 km R, CEUS Mmax

Ind. added: Long–term M2.7, 50 km R, CEUS Mmax



Difference: Short–term model and 2014 NSHP

Difference: Long–term model and 2014 NSHP



5 Hz, 2% probability of exceedance in 50 years (2012 and previous); Difference (bottom maps)

Issues: Smoothing

Smoothing uses the location of past earthquakes to predict the spatial distribution of future earthquakes

- What is the appropriate smoothing parameter for induced seismicity?
  - 5 km (what is the distance applied in adaptive smoothing models for tightly clustered events?)
  - 50 km applied in USGS hazard maps

Smoothing (Short-term rate)

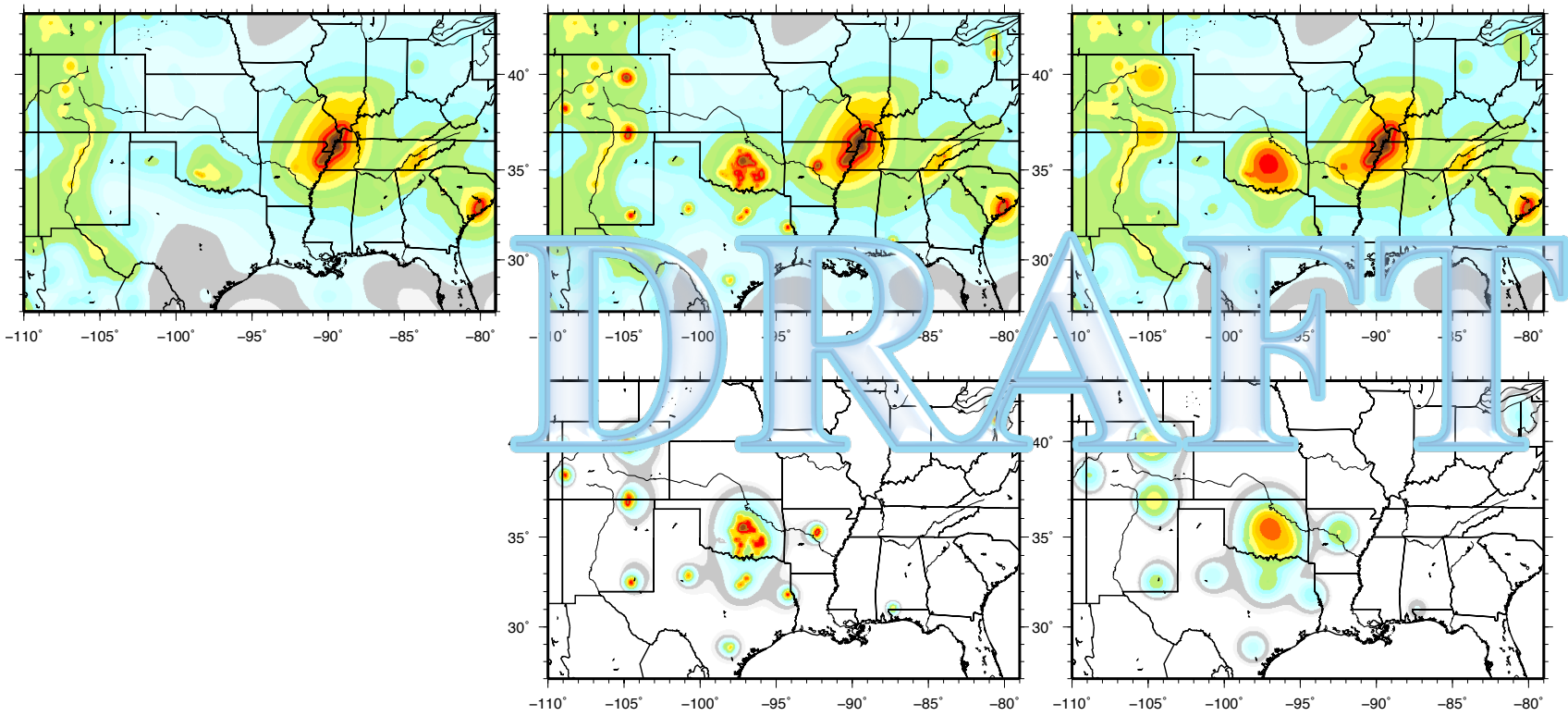
5 km

50 km

2014 NSHP (suspected induced events removed)

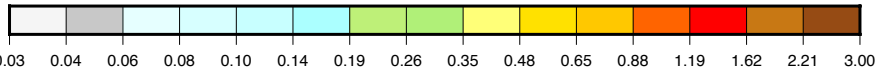
Ind. added: 5 km R, CEUS Mmax (high)

Ind. added: 50 km R, CEUS Mmax (low)



Difference: high model and 2014 NSHP

Difference: low model and 2014 NSHP

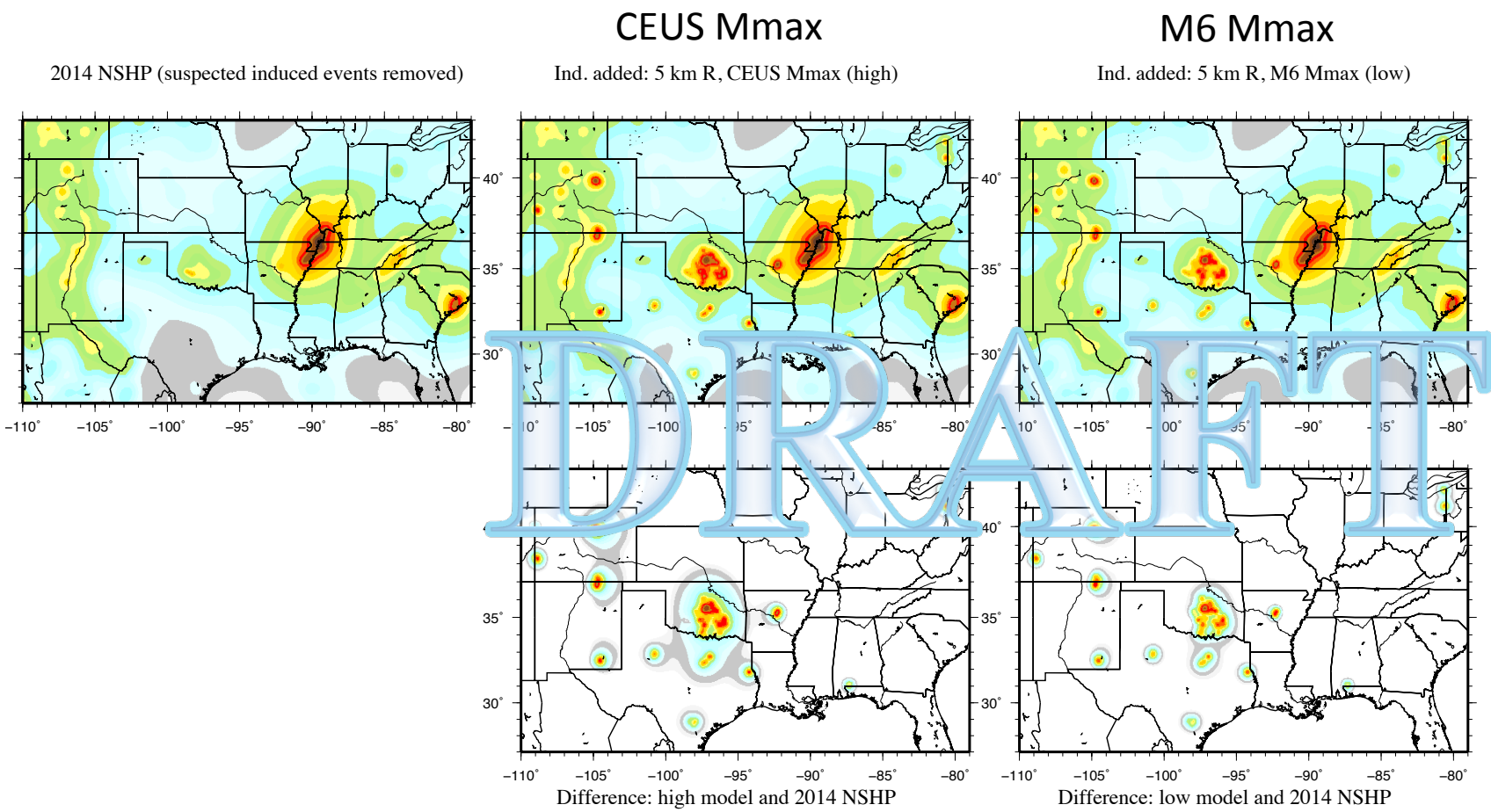


5 Hz, 2% probability of exceedance in 50 years (2012 and previous); Difference (bottom maps)

Issues: Maximum magnitude

- What is the maximum size earthquake that can be induced?
  - M 6 (similar to Prague earthquake)
  - M 7 (similar to reservoir induced earthquakes)
  - M 7.0 with range up to M 8 and down to M 6.5 (applied in the National Seismic Hazard Maps)

Maximum Magnitude (Short-term rate)



Issues: Earthquake source and ground shaking

- Are the ground motions generated by an induced event different from natural earthquakes?
  - Lower stress drop?
  - Shallower depth

Ground Motion Models (Short-term rate)

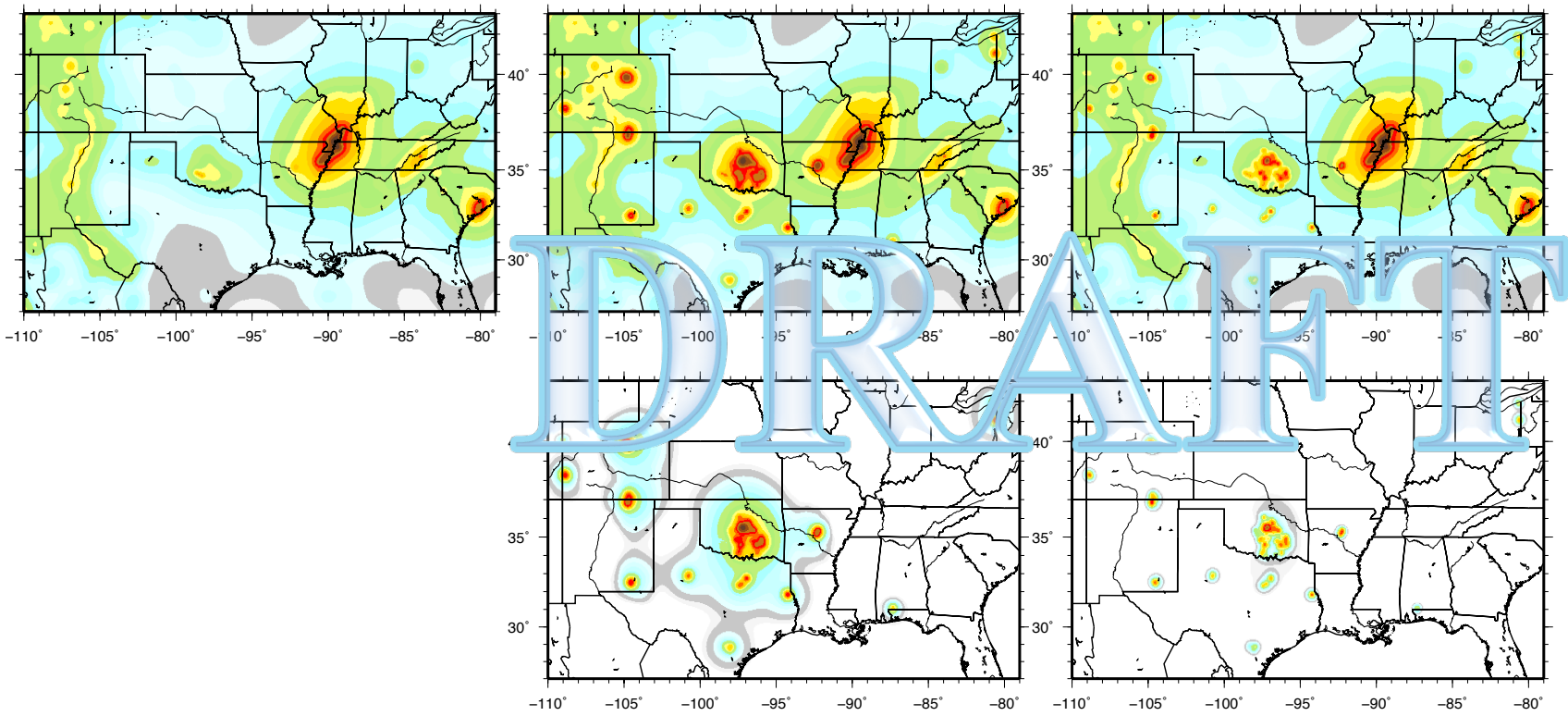
FEA

AB06’

2014 NSHP (suspected induced events removed)

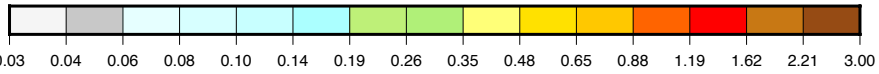
Ind. added: FEA GMM, 5km R, CEUS Mmax (high)

Ind. added: AB06’ GMM, 5km R, CEUS Mmax (low)



Difference: high model and 2014 NSHP

Difference: low model and 2014 NSHP



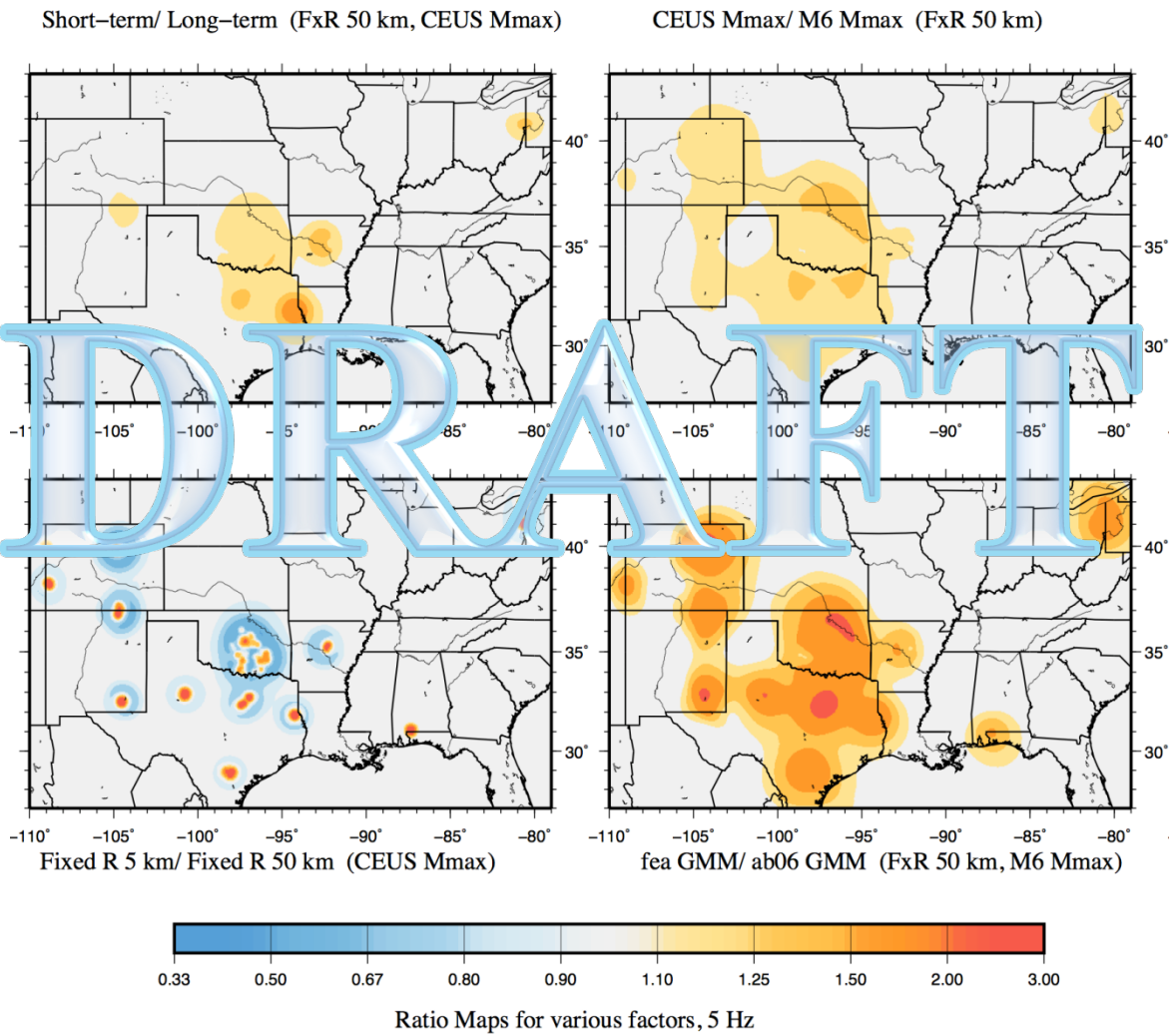
5 Hz, 2% probability of exceedance in 50 years (2012 and previous); Difference (bottom maps)

Ratio Maps

Shows changes upon inclusion of induced events

Rate model

Rate (smoothing)



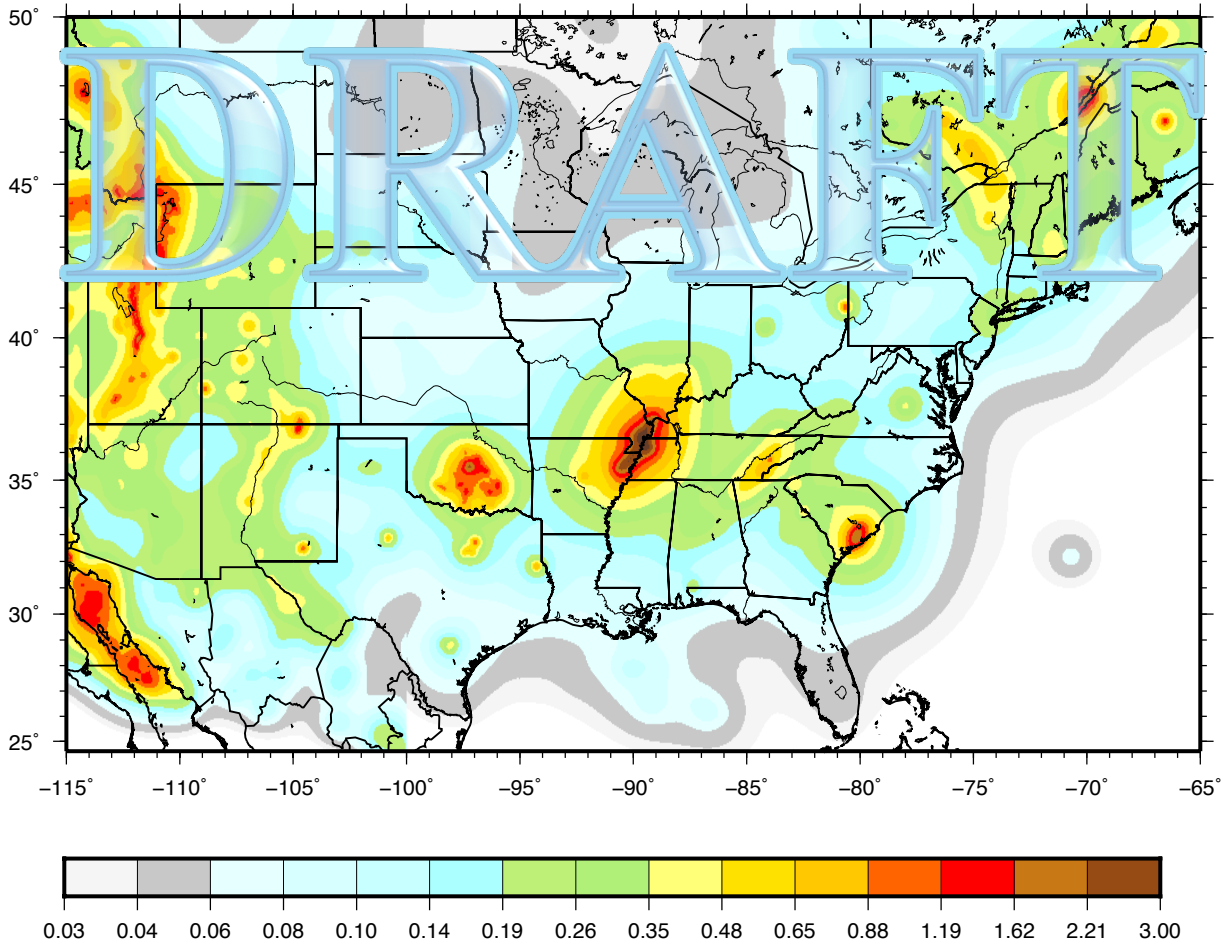
Mmax

Ground-motion model

Straw Man

- Catalog: Declustered
- Rate model: Short-term with three areas turned off
  - Rocky Mountain Arsenal, CO
  - Guy-Greenbrier, AR
  - Ashtabula, OH
- Rate (smoothing): 5 km (50%) and 50 km (50%)
- Maximum Magnitude: M6 (50%) and CEUS (50%)
- All Ground-motion models, same weights as the 2014 NSHM

Preliminary Straw Man Model



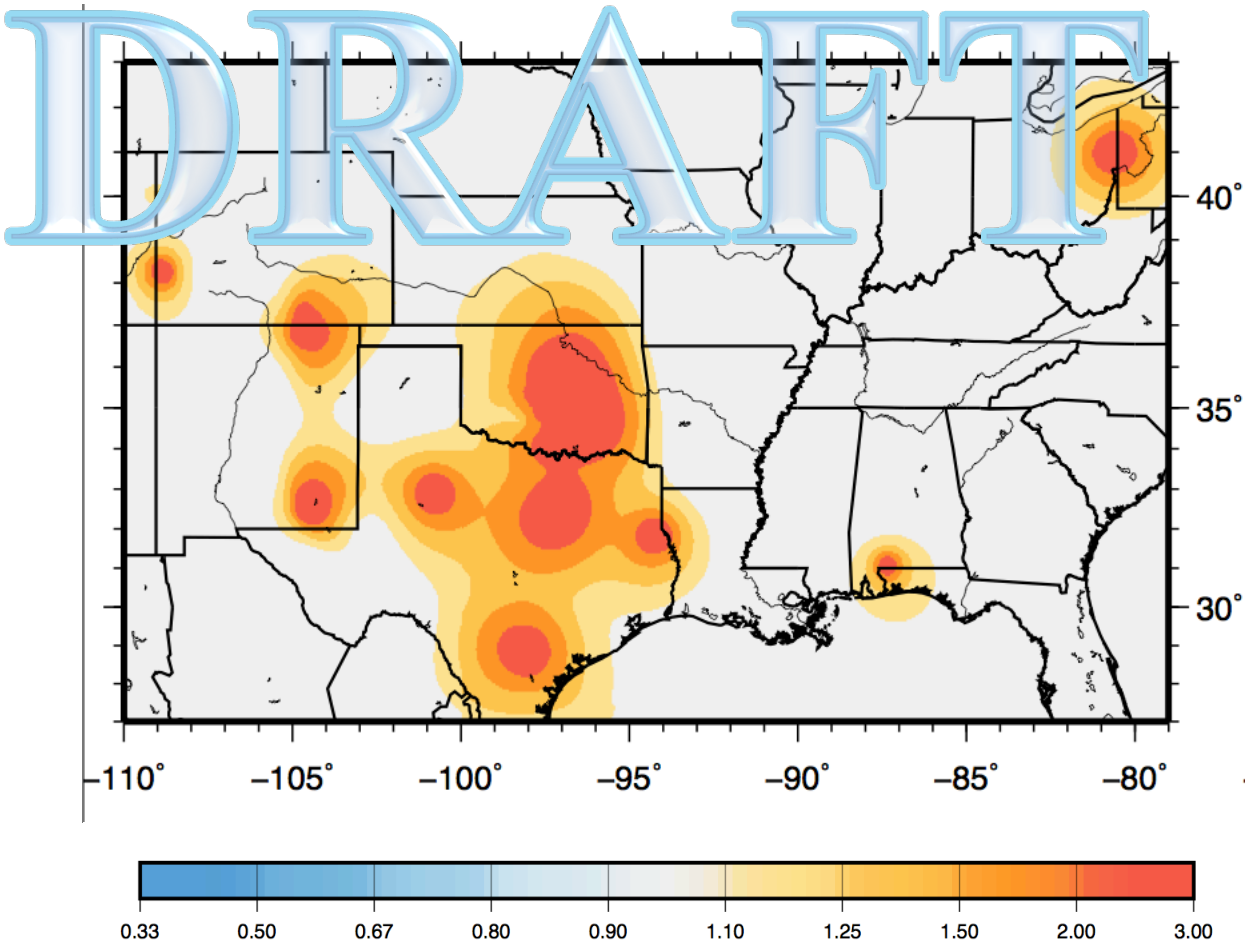
Straw man: series–specific rates for non–tectonic events; 5 Hz; 2% in 50 yr

Fixed R 5 km (50%) & 50 km (50%); Mmax M6 (50%), CEUS (50%); 2014 NSHM CEUS GMM

Zero weight given to: Rocky Mt. Arsenal, CO; Guy–Greenbrier, AR; Ashtabula, OH

Preliminary Ratio Map

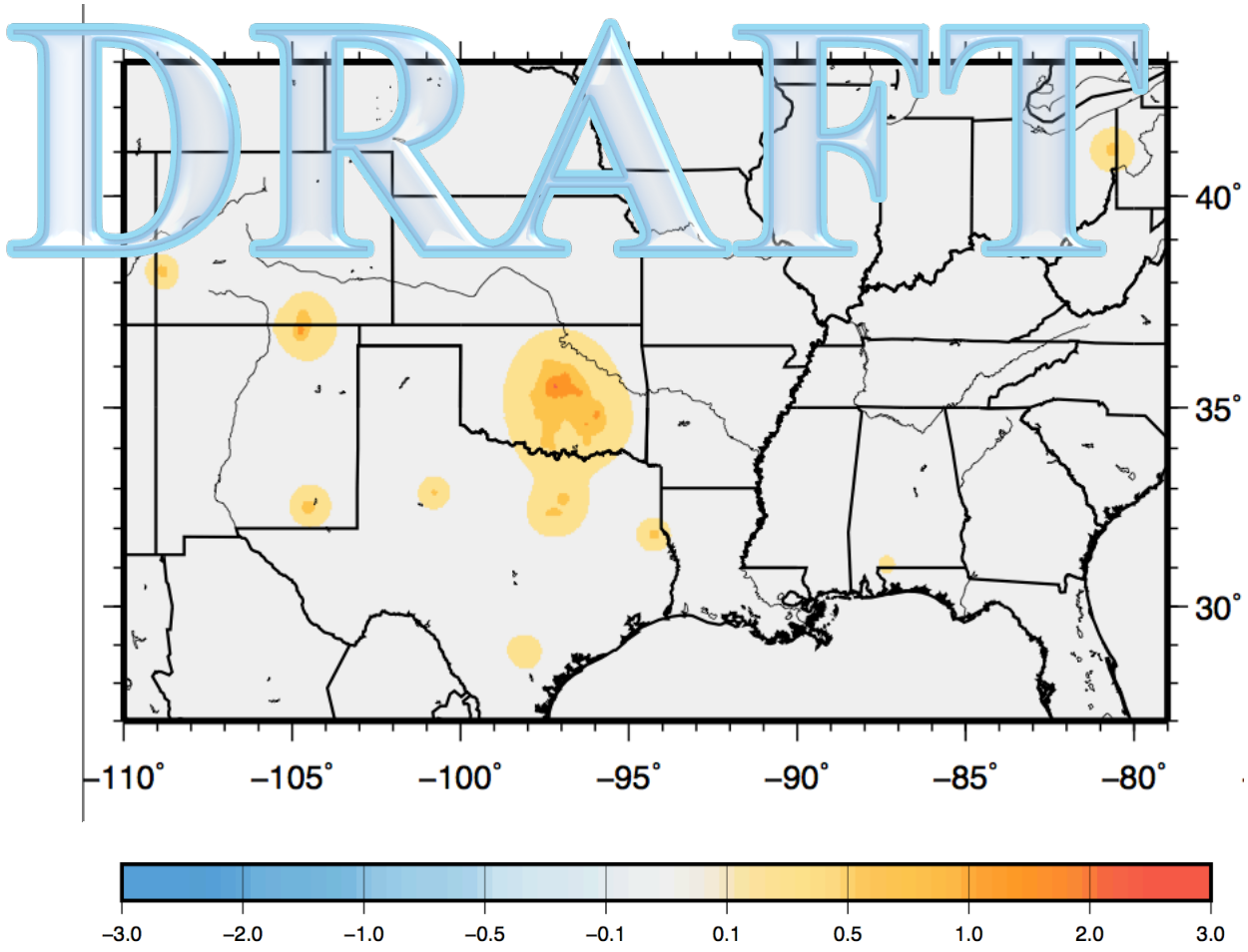
Straw man divided by 2014 NSHM (suspected induced events removed)



Change in 5 Hz spectral acceleration for 2% in 50 years

Preliminary Difference Map

Straw man minus the 2014 NSHM (suspected induced events removed)



Change in 5 Hz spectral acceleration for 2% in 50 years

Discussion of Logic Tree

- Catalog (lower magnitude threshold, start dates, completeness, …)
- Rate model (long-term, short-term, decay)
- Smoothing Model (5 km vs 50 km)
- Maximum magnitude (M 6, M7, or M7 for natural earthquakes- extends up to M8)
- Earthquake ground shaking models (8 different models)
- How should we modify the straw man model?