Catalogs and Gridded Rate Models

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NSHM Workshop
Mar 08, 2018
Newark, CA

Catalogs for hazard analysis: four steps

1) Reformat & combine pre-existing input catalogs

    Get uniform moment magnitudes

    Get parameters for computing unbiased seismicity rates

2) Delete duplicates, explosions, mining seismicity

3) Decluster (Gardner and Knopoff, 1974)

4) Flag induced earthquakes

Moment Magnitude Symbology

- With measured and converted moment magnitudes from many diverse sources, we don't try to reconcile the difference between **M** and M_w.
- We simply use the symbol M_w for non-specific moment magnitude. This seems to be consistent with other catalog work (*e.g.*, Grünthal and Wahlström, 2003).

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Step 1

Why uniform M_w?

- Ground motion models.
- We count earthquakes above specified magnitude thresholds to estimate seismicity rates. Input catalogs list disparate magnitudes/intensities, so we try to develop a uniform treatment.

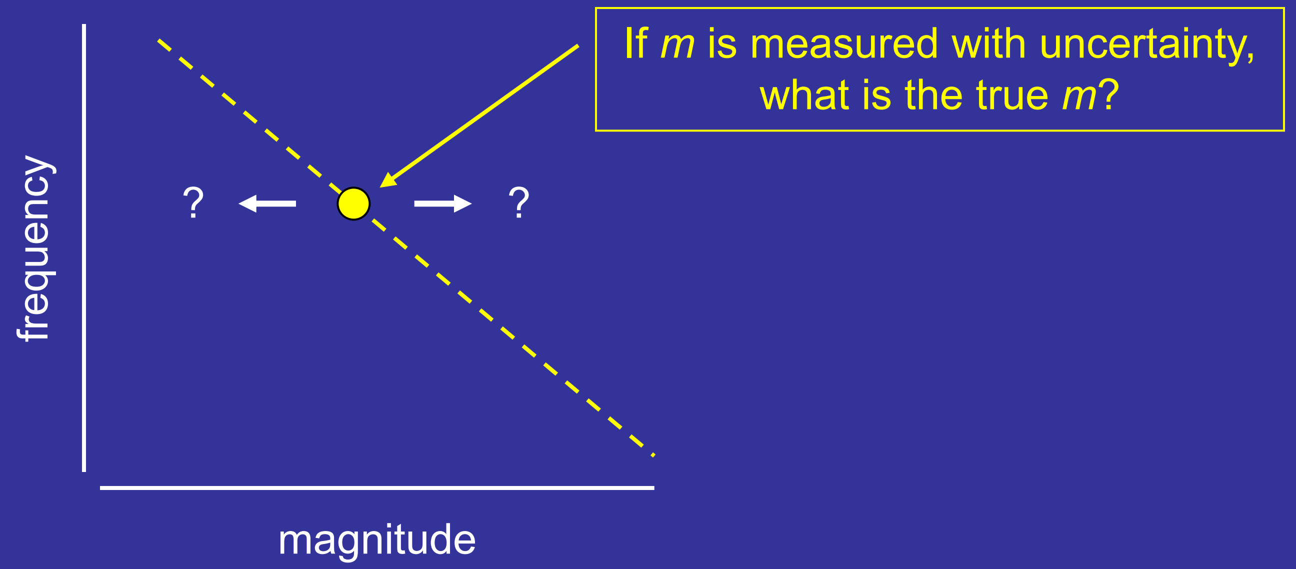
Step 1

Uniform M_w (continued...)

Also, computed seismicity rates may be biased if magnitudes:

a) follow an exponential frequency distribution, and

b) are measured or estimated with uncertainty



- Mags are adjusted by factors that depend on b-value (b) and magnitude uncertainty (σ_m)
- For b~1.0 & σ_m~0.1-0.3, rate adjustments ~2–25%

Step 1

Uniform M_w (continued...)

Recent work:

- CEUS-SSC (2012, SSHAC Level 3)
- Arabasz et al., Utah Working Group (2016)

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Step 1

Uniform M_w (continued...)

Categories of M_w

1) "Observed" or "measured" (SLU, GlobalCMT, ComCat)

2) Converted from another size measure

   Mostly CEUS (CEUS-SSC, 2012)

3) Set equal to m_L, m_b, etc.

   Mostly WUS (Felzer, 2007; Arabasz et al., 2016)

4) Original size measure is uncertain or complex

Step 1

Uniform M_w (continued...)

Sources of σ_m estimates

- A few input catalogs list σ_m (per earthquake)
- Estimates for earthquake categories or eras
- Estimates from regression (for converted mags)

Ranges of σ_m

- Observed M_w: ~0.1–0.2
- M_w converted from instrumental magnitude: ~0.2–0.3
- M_w converted from macroseismic data: ~0.2–0.5+

Step 1

Uniform M_w (continued...)

Current NSHM practice:

1) Choose target (rate-uniform) M_w category for the catalog

Then, for each earthquake,

2) Identify one preferred size measure & get best M_w

3) Adjust best M_w to target M_w & compute corresponding counting factor N* (functions of b & σ_m)

4) Add σ_m, adjusted M_w, and N* to the catalog record

=> Count adjusted M_w by N* (rather than unity) to get unbiased rates

Step 1

NSHM Catalog Format

Fixed-length fields:

```
2.68  -71.100  42.400   0 1705 06 27  0  0  0.  0.500 2.68 1.940 NCE|i0,04.0WES
3.44  -89.530  36.460  10 2016 09 09 13 45 37.  0.100 3.42 1.027 SLU|wo,3.44
2.70  -99.828  36.648   3 2016 11 30 09 38 37.4 0.250 2.70 1.180 OGS|ml,OGS,2.4MLOGS
2.54  -77.623  37.876   9 2016 12 22 11 22 35.7 0.250 2.54 1.180 PDE|md,2.19md,se
```

M_w lon lat d y m d h m s σ_m M_w* N* comment

Step 2

Delete explosions and mining-related seismicity

- Search by event-type (limited)
- Published resources (limited)
  - Non-tectonic catalogs
  - Mask out mining zones

Step 2

Delete duplicates in time/distance windows

- Windows reflect era-dependence of catalog accuracy/completeness
- Windows are not meant to fix errors
- Time windows automatically expand if origin time is partially unknown

Era	Time Window	Distance Window
1990–present	10 s	20 km
1960–1989	20 s	50 km
1930–1959	60 s	100 km
1880–1929	10 m	250 km
pre–1880	30 m	500 km

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Step 2

A hierarchy based on our judgment is used to select a favorite from among duplicate entries

We prefer:

- Researched catalogs from special studies
- Original, single-institution catalogs
- Catalogs that list M_w

All other things being equal, compilation catalogs are lower preference

Step 3

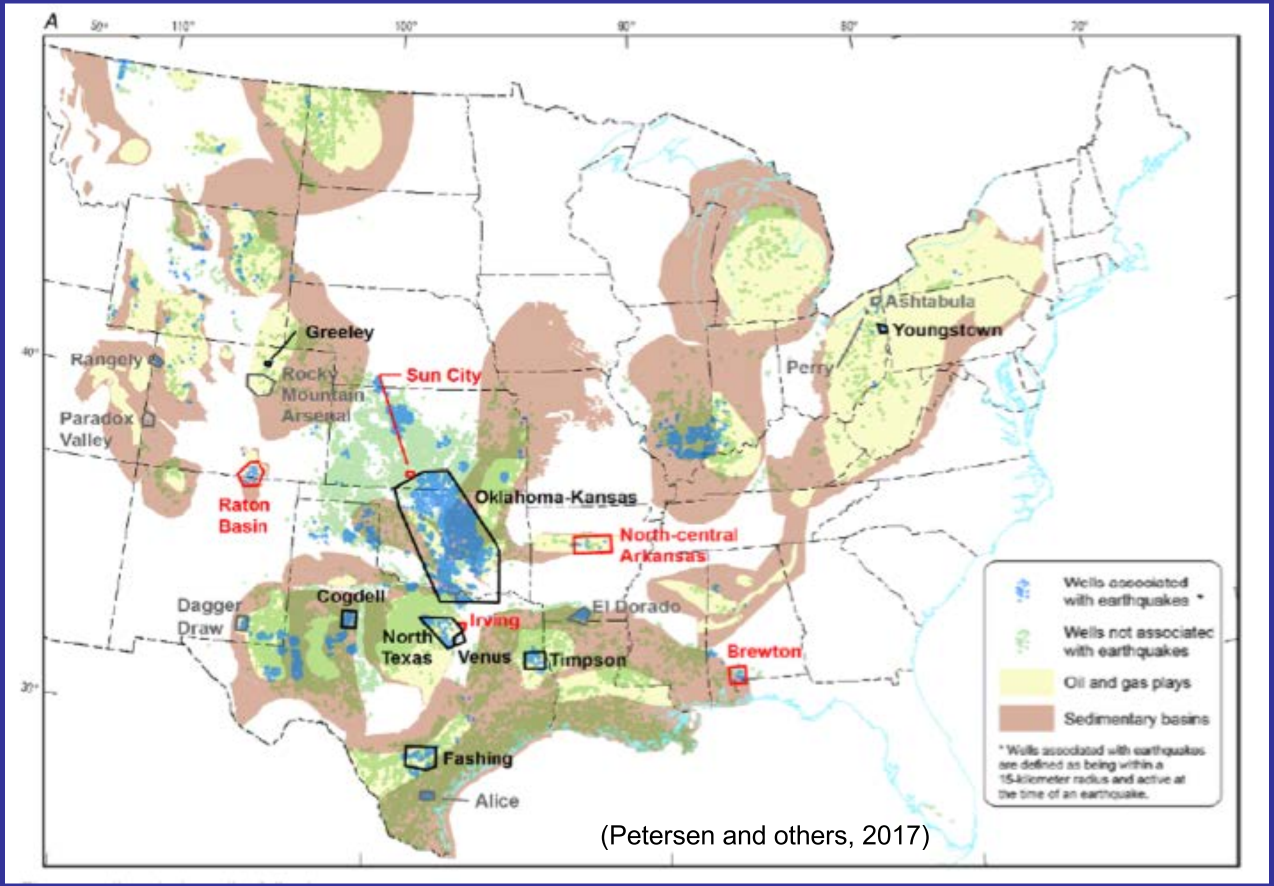
Decluster

- Most hazard codes assume statistically independent events
- Gardner & Knopoff (GK) (1974)
  - Each earthquake is considered a possible mainshock
  - Use magnitude-dependent radii & time windows to find fore/aftershocks
- GK74 is considered a bit old-fashioned, but...
  - Performed well in CEUS-SSC test (despite CA roots)
  - Advantage: no tuning parameters

Step 4

Induced earthquakes (IE) (CEUS)

- Increased seismicity in CEUS since 2008
- Timing and locations suggest links to underground fluid injection
- Use information from literature & local expertise to identify sequences



(Petersen and others, 2017)

- Parameterize with simple time windows and map polygons

CEUS Catalogs

- Mix: NSHM, M_{wo}, other M_w, NCEER91, USH/SRA, PDE, GSC, CEUS-SSC, OGS, etc.
- Use CEUS-SSC M_w conversions

(From CEUS-SSC, 2012)

Original Size Measure	Conversion Equation	σ_m[1]
Body-wave magnitude (m_b, m_{bLg}, M_N)	$M_{we} = m_b - 0.316 - 0.118Z_{NE} - 0.192Z_{1997GSC} + 0.280Z_{1982NE}$, where Z_{NE} = 1 for eqks in the northeast[2], and 0 otherwise; $Z_{1997GSC}$ = 1 for eqks after 1997 recorded by GSC, and 0 otherwise; Z_{1982NE} = 1 for eqks in the northeast[2] before 1982 recorded by other than GSC, and 0 otherwise	0.24
M_L from GSC	compute $m_b = M_L - 0.21$, and use m_b conversion	0.42
M_S	$M_{we} = 2.654 + 0.334M_S + 0.040M_S^2$	0.20
M_L, M_D, M_C in northeast (non-GSC)	$M_{we} = 0.633 + 0.806(M_L,M_D,M_C)$	0.27
M_L, M_D, M_C in midcontinent, east of -100°	$M_{we} = 0.869 + 0.762(M_L,M_D,M_C)$	0.25
M_L, M_D, M_C in midcontinent west of -100º	use m_b conversion	0.24
FA (felt area, km²)	$M_{we} = 1.41 + 0.218 \times \ln(FA) + 0.00087 \times (FA)^{0.5}$	0.22
I_0 (maximum intensity)	$M_{we} = 0.017 + 0.666 \times I_0$	0.50

WUS Catalogs

- Mix: NSHM, M_{wo}, UCERF, USH/SRA, PDE, GSC, etc.
- $M_w = m_L, m_b, m_D$, etc.
- Two Step-1 catalogs to facilitate integration of California seismicity:
  - ✓ UCERF zone: prefer UCERF catalog
  - ✓ Rest of WUS: don't use UCERF catalog
- No induced earthquakes (so far)

CEUS background sources

- M_w catalog; delete IE for building code maps
- Seven completeness zones (based on CEUS-SSC)
- b = 1.0
- Four gridded rate models:

  1) Model 1: count M_w2.7+ (~m_b3+)

  2) Model 2: count M_w3.7+ (~m_b4+)

  3) Model 3: count M_w4.7+ (~m_b5+)

  4) Model 4: floors (“adaptive”) for four sub-regions

  Uniform rates for Eastern Tennessee & New Madrid
- Smoothing: 2-D gaussian fixed & nearest-neighbor
- Logic trees for Models 1–4 & smoothing alternatives

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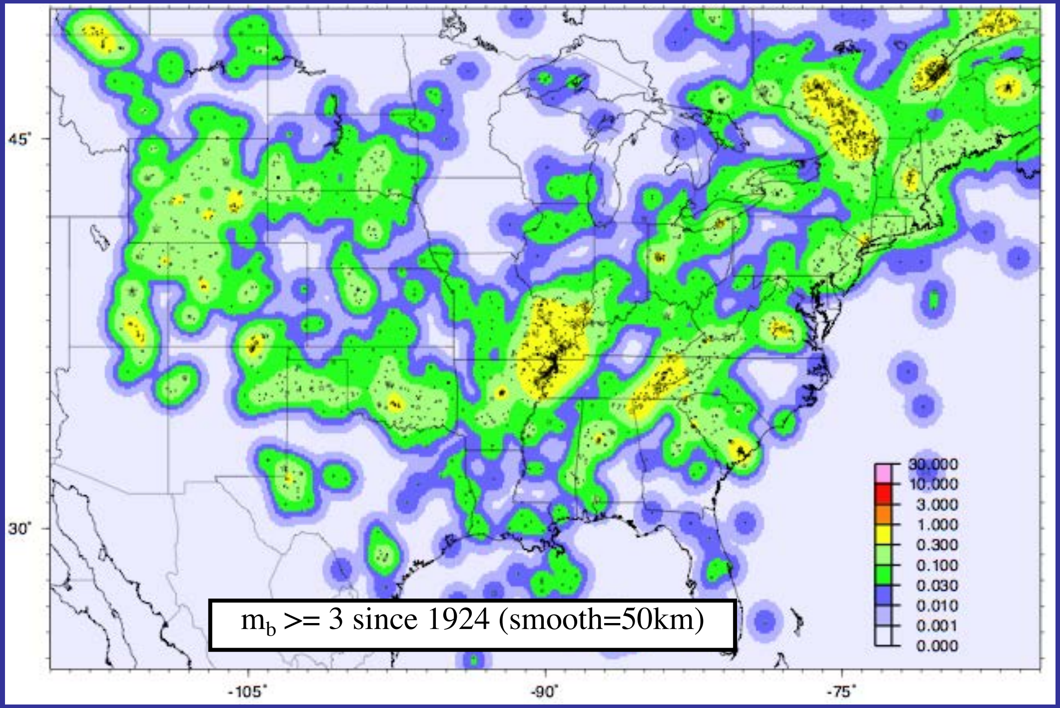
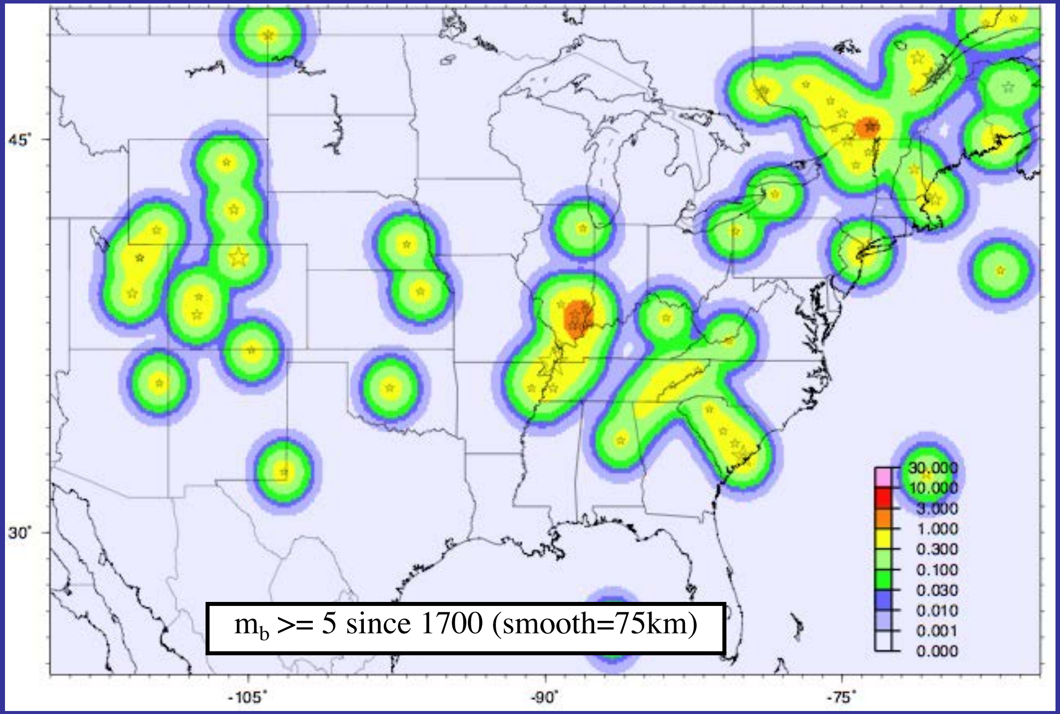




CEUS rate grids (10^{ai}), 2008 NSHM

Top: m_b3+ with 50km smoothing (Model 1)

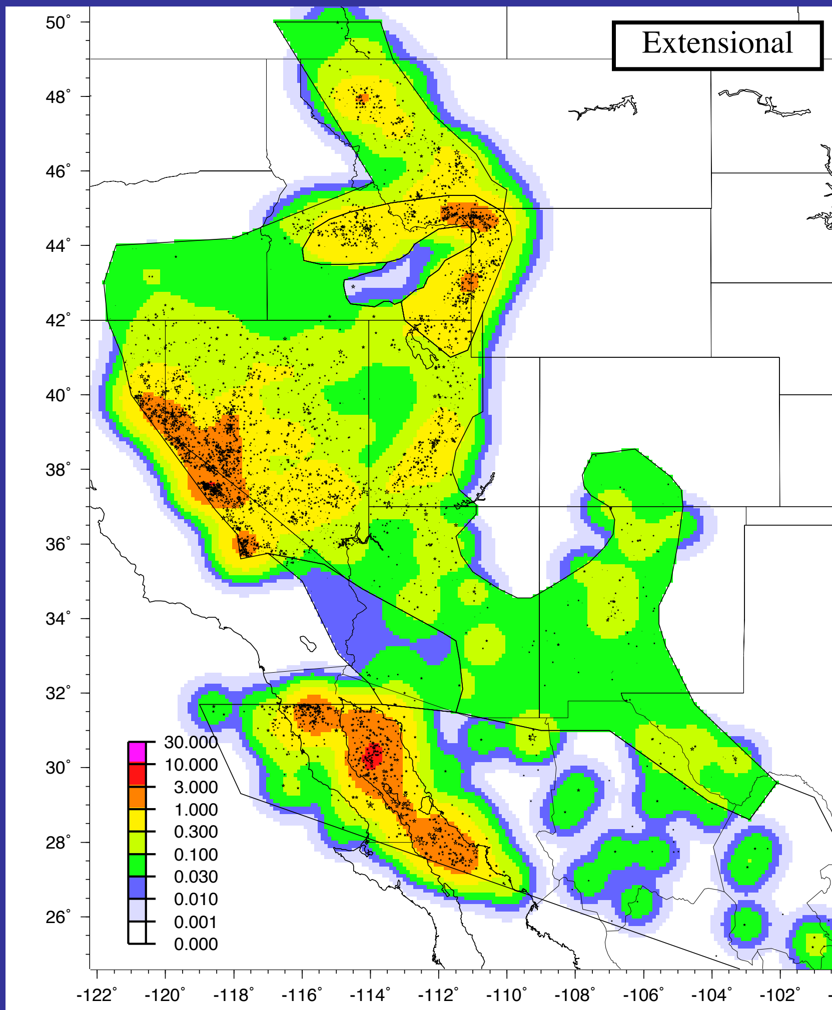
Bottom: m_b5+ with 75km smoothing (Model 3)

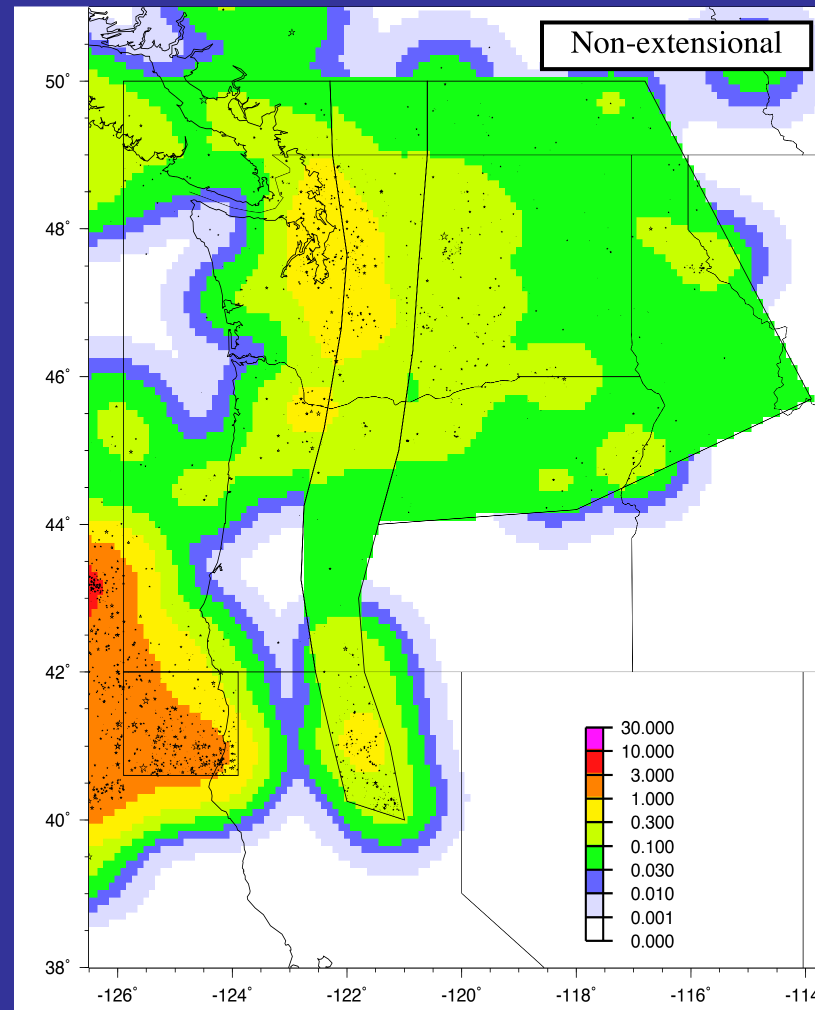
WUS background sources

- M_w catalog
- Distinct completeness for coastal California and rest of WUS
- b = 0.8
- Gridded rate models:
  – Weichert with three completeness levels: M_w4+, 5+, 6+
  – Extensional & non-extensional sub-regions
  – Floors (“adaptive”) for five sub-regions
- Smoothing: 2-D gaussian fixed & nearest neighbor

WUS rate grids (10^{ai}), 2014 NSHM

M_w4+, 5+, 6+ with 50km smoothing





Issues

CEUS: Change minimum mag for rates from $M_w 2.7$ to $M_w 3.0$?

Advantage:

1) Less sensitivity to M_w conversions for small earthquakes
2) Less sensitivity to man-made seismicity
3) Less sensitivity to declustering
4) Simpler completeness models & better rate estimates

Disadvantage:

1) Lose some hazard
2) $M_w 3 \approx m_b 3.3$; step "backward" from $m_b 3$?

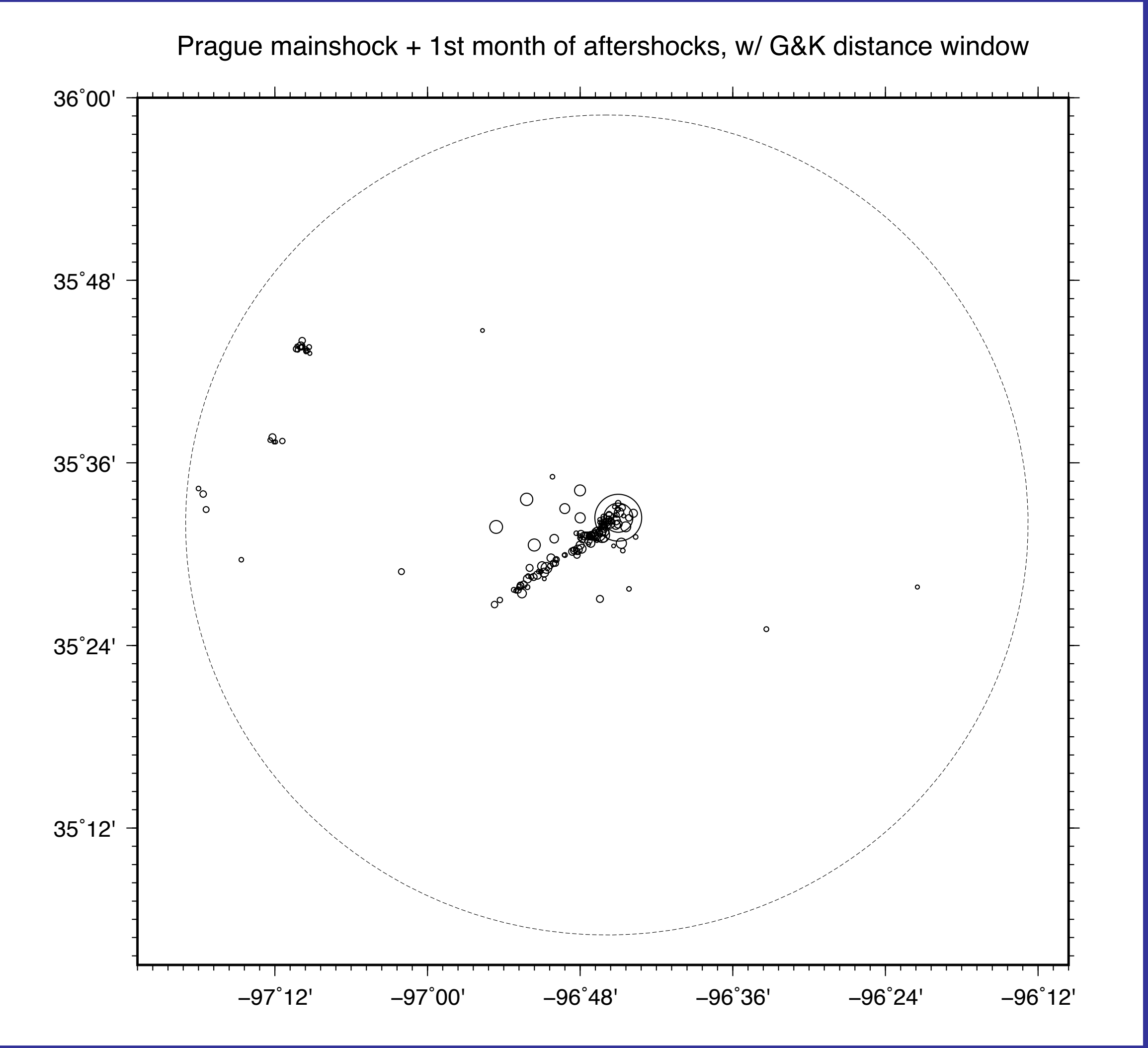
Different mag min for eastern CEUS (m_{bLg}) and western CEUS (m_L)?

Logic tree...?

CEUS: Declustering in Oklahoma?

With hazard models based on 1-year catalogs, and ~1-year GK windows for mid-M_w5 eqks, we see some unreasonable declustering behavior in Oklahoma

Prague: Adjust windows? Just Oklahoma? All CEUS? Use a different declustering methodology?



CEUS: Mag conversions for small earthquakes?

Empirical conversions are developed from observed M_w data, which doesn't exist for small earthquakes.

Is there a better way to estimate M_w for small events?

Other Issues

CEUS & WUS: Better treatment of mining seismicity?

CEUS & WUS: Better duplicate checking?

WUS: Induced earthquakes?

CEUS & WUS: Use PDE M_ws with high preference?

CEUS & WUS: b-value zonation?

CEUS & WUS: Update or maintain floor/zone rates?

CEUS: Change floor weight in Rocky Mtn zone?

CEUS & WUS: Better M_w estimates for old earthquakes?