Catalogs and Gridded Rate Models

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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).
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.
Also, computed seismicity rates may be biased if magnitudes:

- a) follow an exponential frequency distribution, and
- b) are measured or estimated with uncertainty

If $m$ is measured with uncertainty, what is the true $m$?

- Mags are adjusted by factors that depend on $b$-value ($b$) and magnitude uncertainty ($\sigma_m$)
- For $b\sim1.0$ & $\sigma_m\sim0.1-0.3$, rate adjustments $\sim2-25\%$
Uniform $M_w$ (continued...)

Recent work:

• CEUS-SSC (2012, SSHAC Level 3)
• Arabasz et al., Utah Working Group (2016)
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
Uniform $M_w$ (continued...)

Sources of $\sigma_m$ estimates

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

Ranges of $\sigma_m$

- Observed $M_w$: $\sim 0.1–0.2$
- $M_w$ converted from instrumental magnitude: $\sim 0.2–0.3$
- $M_w$ converted from macroseismic data: $\sim 0.2–0.5+$
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 $b$ & $\sigma_m$)

4) Add $\sigma_m$, adjusted $M_w$, and $N^*$ to the catalog record

=>$\text{Count adjusted } M_w \text{ by } N^* \text{ (rather than unity) to get unbiased rates}$
### NSHM Catalog Format

**Fixed-length fields:**

<table>
<thead>
<tr>
<th>Mw</th>
<th>lon</th>
<th>lat</th>
<th>d</th>
<th>y</th>
<th>m</th>
<th>d</th>
<th>h</th>
<th>m</th>
<th>s</th>
<th>σm</th>
<th>Mw*</th>
<th>N*</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.68</td>
<td>-71.100</td>
<td>42.400</td>
<td>0</td>
<td>1705</td>
<td>06</td>
<td>27</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.500</td>
<td>2.68</td>
<td>1.940</td>
<td>NCEli0,04.0WES</td>
</tr>
<tr>
<td>3.44</td>
<td>-89.530</td>
<td>36.460</td>
<td>10</td>
<td>2016</td>
<td>09</td>
<td>09</td>
<td>13</td>
<td>45</td>
<td>37</td>
<td>0.100</td>
<td>3.42</td>
<td>1.027</td>
<td>SLUlw0,3.44</td>
</tr>
<tr>
<td>2.70</td>
<td>-99.828</td>
<td>36.648</td>
<td>3</td>
<td>2016</td>
<td>11</td>
<td>30</td>
<td>09</td>
<td>38</td>
<td>37.4</td>
<td>0.250</td>
<td>2.70</td>
<td>1.180</td>
<td>OGSml,OGS,2.4MLOGS</td>
</tr>
<tr>
<td>2.54</td>
<td>-77.623</td>
<td>37.876</td>
<td>9</td>
<td>2016</td>
<td>12</td>
<td>22</td>
<td>11</td>
<td>22</td>
<td>35.7</td>
<td>0.250</td>
<td>2.54</td>
<td>1.180</td>
<td>PDEmd,2.19md,se</td>
</tr>
</tbody>
</table>
Delete explosions and mining-related seismicity

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

<table>
<thead>
<tr>
<th>Era</th>
<th>Time Window</th>
<th>Distance Window</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990–present</td>
<td>10 s</td>
<td>20 km</td>
</tr>
<tr>
<td>1960–1989</td>
<td>20 s</td>
<td>50 km</td>
</tr>
<tr>
<td>1930–1959</td>
<td>60 s</td>
<td>100 km</td>
</tr>
<tr>
<td>1880–1929</td>
<td>10 m</td>
<td>250 km</td>
</tr>
<tr>
<td>pre–1880</td>
<td>30 m</td>
<td>500 km</td>
</tr>
</tbody>
</table>
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.
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
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

- Parameterize with simple time windows and map polygons

(Petersen and others, 2017)
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)

<table>
<thead>
<tr>
<th>Original Size Measure</th>
<th>Conversion Equation</th>
<th>$\sigma_m^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body-wave magnitude ($m_b$, $m_{bLg}$, $M_N$)</td>
<td>$M_{wc} = m_b - 0.316 - 0.118Z_{NE} - 0.192Z_{1997GSC} + 0.280Z_{1982NE}$, 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</td>
<td>0.24</td>
</tr>
<tr>
<td>$M_L$ from GSC compute $m_b = M_L - 0.21$, and use $m_b$ conversion</td>
<td>$M_{wc} = 2.654 + 0.334M_s + 0.040M_s^2$</td>
<td>0.42</td>
</tr>
<tr>
<td>$M_s$</td>
<td>$M_{wc} = 0.633 + 0.806(M_L, M_D, M_C)$</td>
<td>0.27</td>
</tr>
<tr>
<td>$M_L, M_D, M_C$ in northeast (non-GSC)</td>
<td>$M_{wc} = 0.869 + 0.762(M_L, M_D, M_C)$</td>
<td>0.25</td>
</tr>
<tr>
<td>$M_L, M_D, M_C$ in midcontinent, east of -100°</td>
<td>$M_{wc} = 0.633 + 0.806(M_L, M_D, M_C)$</td>
<td>0.27</td>
</tr>
<tr>
<td>$M_L, M_D, M_C$ in midcontinent west of -100° use $m_b$ conversion</td>
<td>$M_{wc} = 0.869 + 0.762(M_L, M_D, M_C)$</td>
<td>0.25</td>
</tr>
<tr>
<td>FA (felt area, km$^2$)</td>
<td>$M_{wc} = 1.41 + 0.218 \times \ln(FA) + 0.00087 \times (FA)^{0.5}$</td>
<td>0.22</td>
</tr>
<tr>
<td>$I_0$ (maximum intensity)</td>
<td>$M_{wc} = 0.017 + 0.666 \times I_0$</td>
<td>0.50</td>
</tr>
</tbody>
</table>
WUS Catalogs

- Mix: NSHM, M_w, 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 $M_w 2.7+ (~m_b 3+)$
  2) Model 2: count $M_w 3.7+ (~m_b 4+)$
  3) Model 3: count $M_w 4.7+ (~m_b 5+)$
  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
CEUS rate grids (10^ai), 2008 NSHM

Top: \( m_b \geq 3 \) since 1924 (smooth=50km) (Model 1)

Bottom: \( m_b \geq 5 \) since 1700 (smooth=75km) (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: $M_w 4^+, 5^+, 6^+$
  - Extensional & non-extensional sub-regions
  - Floors ("adaptive") for five sub-regions
- Smoothing: 2-D gaussian fixed & nearest neighbor
WUS rate grids ($10^{ei}$), 2014 NSHM

$M_w 4+$, $5+$, $6+$ 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-$M_w$ 5 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 $M_w$s 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?