Magnitude Uncertainty

&

Implications for Hazard

C. Mueller, USGS

NSHMP Workshop, Memphis, Feb 2012

Why it matters — Case 1

- Example: With magnitude uncertainty and an underlying exponential distribution, an *observed* mag-5 eqk is more likely to be *true* 4.9 than 5.1.
- => *observed* eqk rates are biased high
- So, decrease *a* ("agrid") by a factor that depends on *b* and σ (Tinti & Mulargia, 1985; Felzer, 2008):

$$a^* = a - constant \times b^2 \sigma^2$$

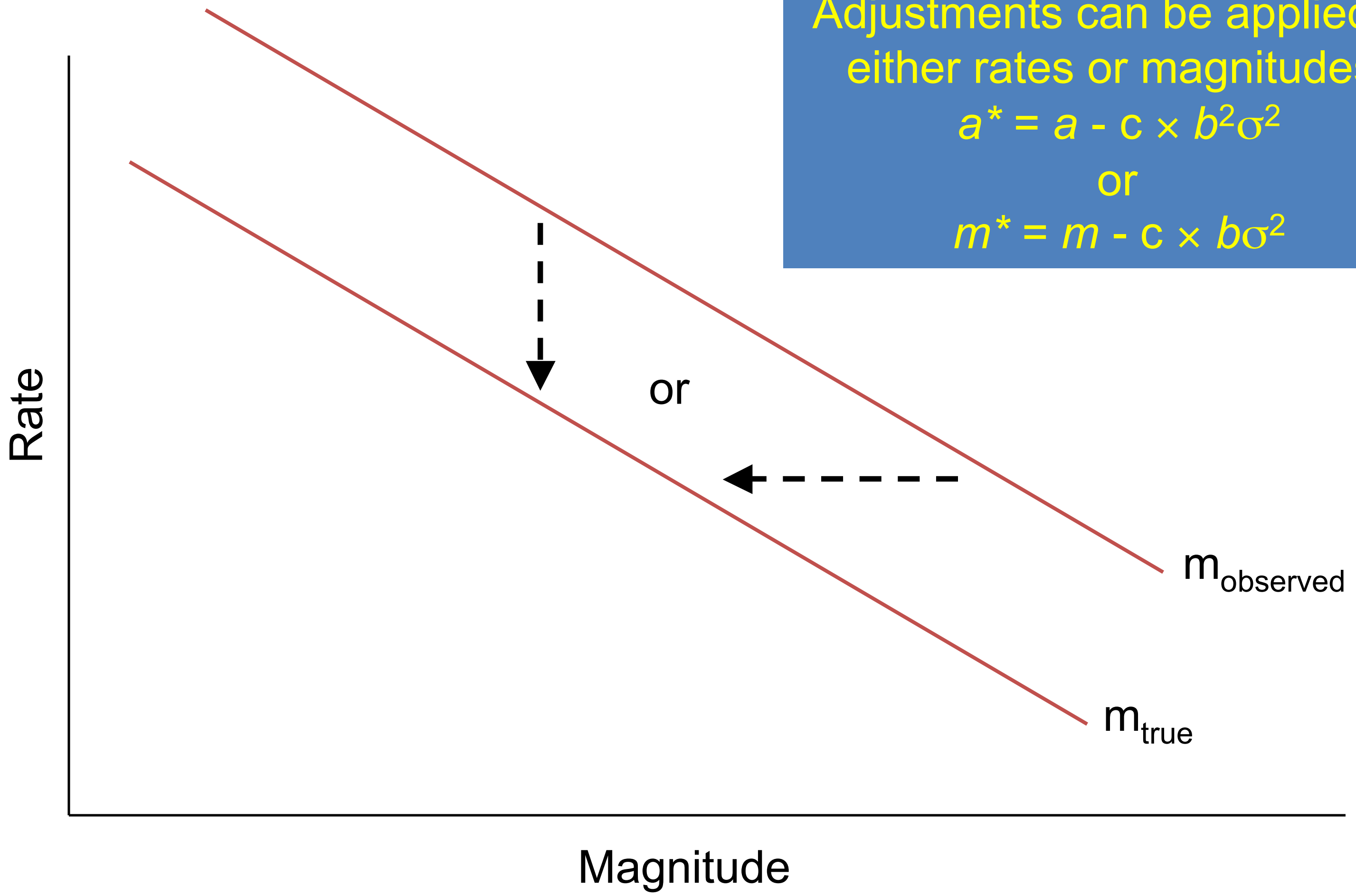
- For realistic *b* & σ, rates decrease ~ 2-15%

Adjustments can be applied to either rates or magnitudes:

$$a^* = a - c \times b^2\sigma^2$$

or

$$m^* = m - c \times b\sigma^2$$



Why it matters — Case 2

- Example: Convert I_e to m, and consider the rate of eqks with $m >$ some m_t. Simple conversion only counts eqks with $I_e >$ corresponding I_t. But with uncertainty smaller eqks contribute $m > m_t$, and with an exponential distribution these outnumber larger eqks which do the opposite.
- => *converted* eqk rates are biased low
- So, increase *a* ("agrid") by the same factor (Veneziano & VanDyck, 1986; McGuire, 2004):

$$a^* = a + constant \times b^2\sigma^2$$

Simulation Example (McGuire, 2004)

What is the rate of earthquakes with m > 4.6?

1) Designate eqks by epicentral intensity (convenient to use decimal values)
2) Convert: $m_c = 1.3 + 0.6I_e$ (G-R, from global data) with $\sigma_m = 0.6$

MMI	I_e	n	m_c	n [m_c>4.6] "deterministic"				
III	2.6-3.4	699	2.9-3.3	0				
IV	3.6-4.4	211	3.5-3.9	0				
V	4.6-5.4	63	4.1-4.5	0				
VI	5.6-6.4	19	4.7-5.1	19				
VII	6.6-7.4	6	5.3-5.7	6				
VIII	7.6-8.4	2	5.9-6.3	2				
total		1000		27				

What is the rate of earthquakes with $m > 4.6$?

1) Designate eqks by epicentral intensity (convenient to use decimal values)
2) Convert: $m_c = 1.3 + 0.6I_e$ (G-R, from global data) with $\sigma_m = 0.6$

MMI	I_e	n	m_c	n [m_c>4.6] "deterministic"	prob [m>4.6]	n [m>4.6] "exact"		
III	2.6-3.4	699	2.9-3.3	0	0.006	4		
IV	3.6-4.4	211	3.5-3.9	0	0.06	13		
V	4.6-5.4	63	4.1-4.5	0	0.29	18		
VI	5.6-6.4	19	4.7-5.1	19	0.63	12		
VII	6.6-7.4	6	5.3-5.7	6	0.83	5		
VIII	7.6-8.4	2	5.9-6.3	2	0.99	2		
total		1000		27		54		

What is the rate of earthquakes with m > 4.6?

1) Designate eqks by epicentral intensity (convenient to use decimal values)
2) Convert: $m_c = 1.3 + 0.6 I_e$ (G-R, from global data) with $\sigma_m = 0.6$

MMI	I_e	n	m_c	n [m_c>4.6] "deterministic"	prob [m>4.6]	n [m>4.6] "exact"	m*	n [m*>4.6] "approx"
III	2.6-3.4	699	2.9-3.3	0	0.006	4	3.2-3.7	0
IV	3.6-4.4	211	3.5-3.9	0	0.06	13	3.8-4.3	0
V	4.6-5.4	63	4.1-4.5	0	0.29	18	4.4-4.9	29
VI	5.6-6.4	19	4.7-5.1	19	0.63	12	5.0-5.5	19
VII	6.6-7.4	6	5.3-5.7	6	0.83	5	5.6-6.1	6
VIII	7.6-8.4	2	5.9-6.3	2	0.99	2	6.2-6.7	2
total		1000		27		54		56

Rounding

- From ~1900–1940 it was observatory practice in California to round magnitudes to the nearest 1/2 or 1/4 magnitude unit
- “Unround” to adjust rates
- CEUS-SSC: The effect on rates of rounding to 0.1 mag units can be ignored
- Was rounding ever used in CENA?

USGS hazard model

Faults

↓

Ground-motions

&

Hazard

←

Historical Seismicity

1) Declustered catalog: $m_b \geq 3$

2) Completeness

3) b = 0.95

4) 10^a grids (Weichert):

   1. $m_b \geq 3$ since 1924 (smooth 50km)
   2. $m_b \geq 4$ since 1850 (smooth 75km)
   3. $m_b \geq 5$ since 1700 (smooth 75km)
   4. Background "floor" (adaptive)

   Adjust rates for magnitude uncertainty

Mmax = 7.0 craton, 7.5 margin

Uncertainty for "observed" M_w

Time Period	σ [M|M_{obs}]
1920–1959	0.30
1960–1975	0.15
1975–1984	0.125
1985–present	0.10

From CEUS-SSC (Chapter 3), citing Johnston (1996) and Harvard M_w catalog

USGS science for a changing world

Table 3.3-1
Conversion Relationships Used–Develop Uniform Moment Magnitudes E[M]

Size Measure	Conversion Relationship	$\sigma[\mathbf{M}\|\mathbf{X}]$
Body-wave magnitude (m_b, m_{bLg}, $m_{Lg(f)}$, M_N)	$E[\mathbf{M}] = m_b - 0.316 - 0.118Z_{NE} - 0.192Z_{1997GSC} + 0.280Z_{1982NE}$ Z_{NE} = 1 for earthquakes located in the Northeast (northeast of the dashed line on Figure 3.3-16, including GSC data), and 0 otherwise $Z_{1997GSC}$ = 1 for earthquakes occurring after 1997 recorded by GSC, and 0 otherwise Z_{1982NE} = 1 for earthquakes occurring in the Northeast before 1982 recorded by other than GSC, and 0 otherwise	0.24
M_L reported by GSC	Compute $m_b = M_L - 0.21$ and use m_b conversion	0.42
M_S	$E[\mathbf{M}] = 2.654 + 0.334M_S + 0.040M_S^2$	0.20
M_C, M_D, M_L in northeastern United States (other than GSC)	$E[\mathbf{M}] = 0.633 + 0.806(M_C\ M_D \text{ or } M_L)$	0.27
M_C, M_D, M_L in midcontinent United States east of longitude 100°W	$E[\mathbf{M}] = 0.869 + 0.762\ (M_C, M_D, \text{or } M_L)$	0.25
M_C, M_D, M_L in midcontinent United States west of longitude 100°W	Use m_b conversion	0.24
Ln(FA) (in km^2)	$E[\mathbf{M}] = 1.41 + 0.218 \times \ln(FA) + 0.00087\sqrt{FA}$	0.22
I_0	for $I_0 <= VI$ $E[\mathbf{M}] = 0.017 + 0.666I_0$ for $I_0 > VI$ $E[\mathbf{M}] = 4.008 + 3.411 \times \sqrt{2}Erf^{-1}\left[(I_0 - 6)/6.5\right]$	0.50

Conversion equations & sigmas

CEUS-SSC Tbl 3.3-1