Historical Great Earthquake Magnitudes: Too Big, Too Small, or Just Right

Susan Hough

US Geological Survey, Pasadena

Outline

- Too big
- Too small
- Just right

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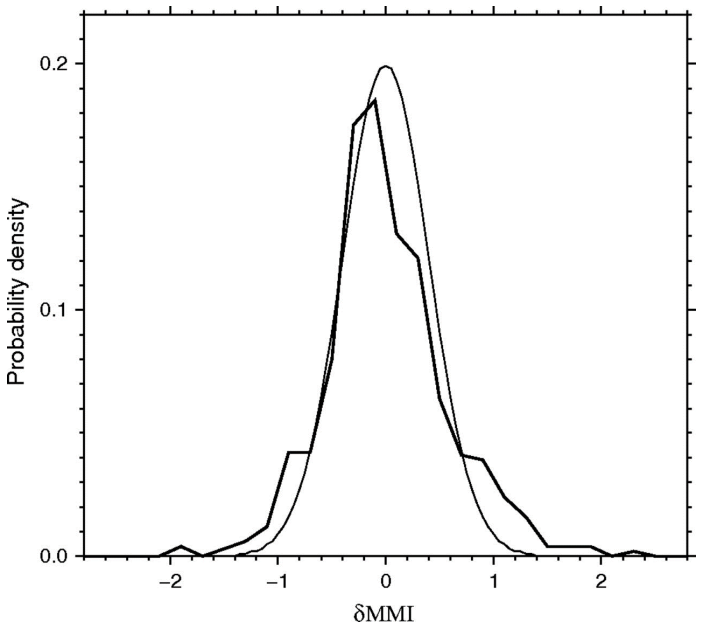
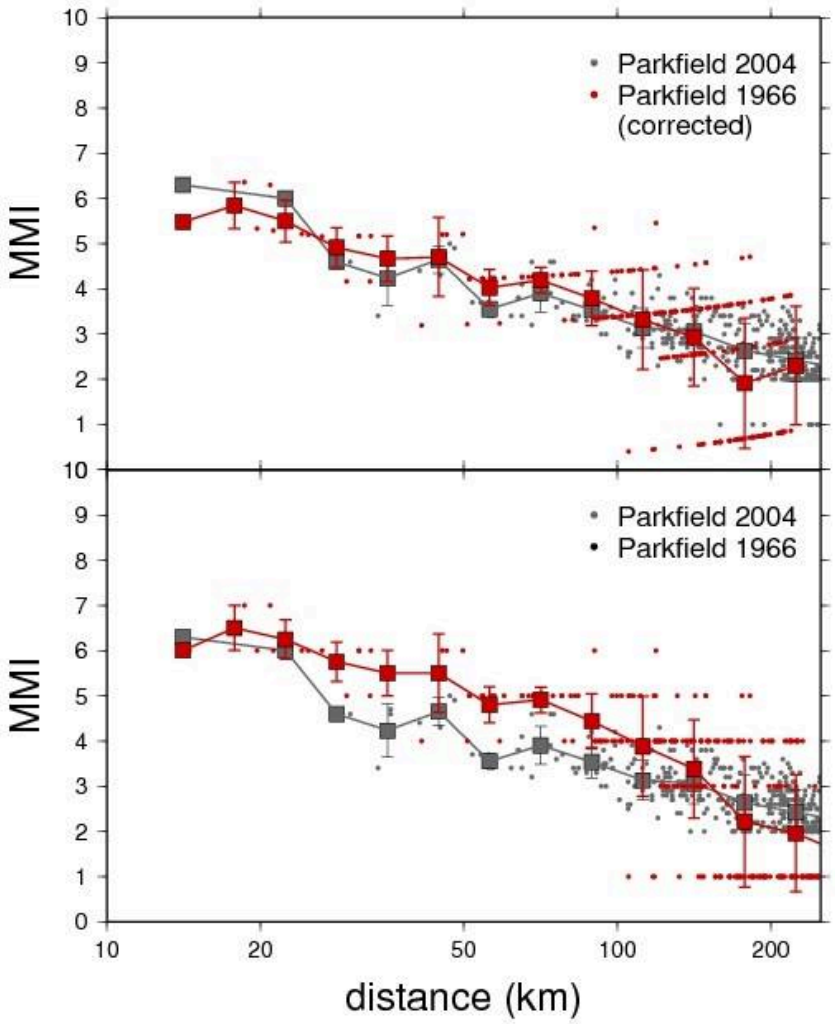
Overestimated Historical Earthquakes

"To assess damage reports from regions of vastly different population density, without taking this factor into account, may lead to grossly exaggerated intensity rating and a serious distortion of the hazard potential"
--Ambraseys et al., 1994

Reporting Bias

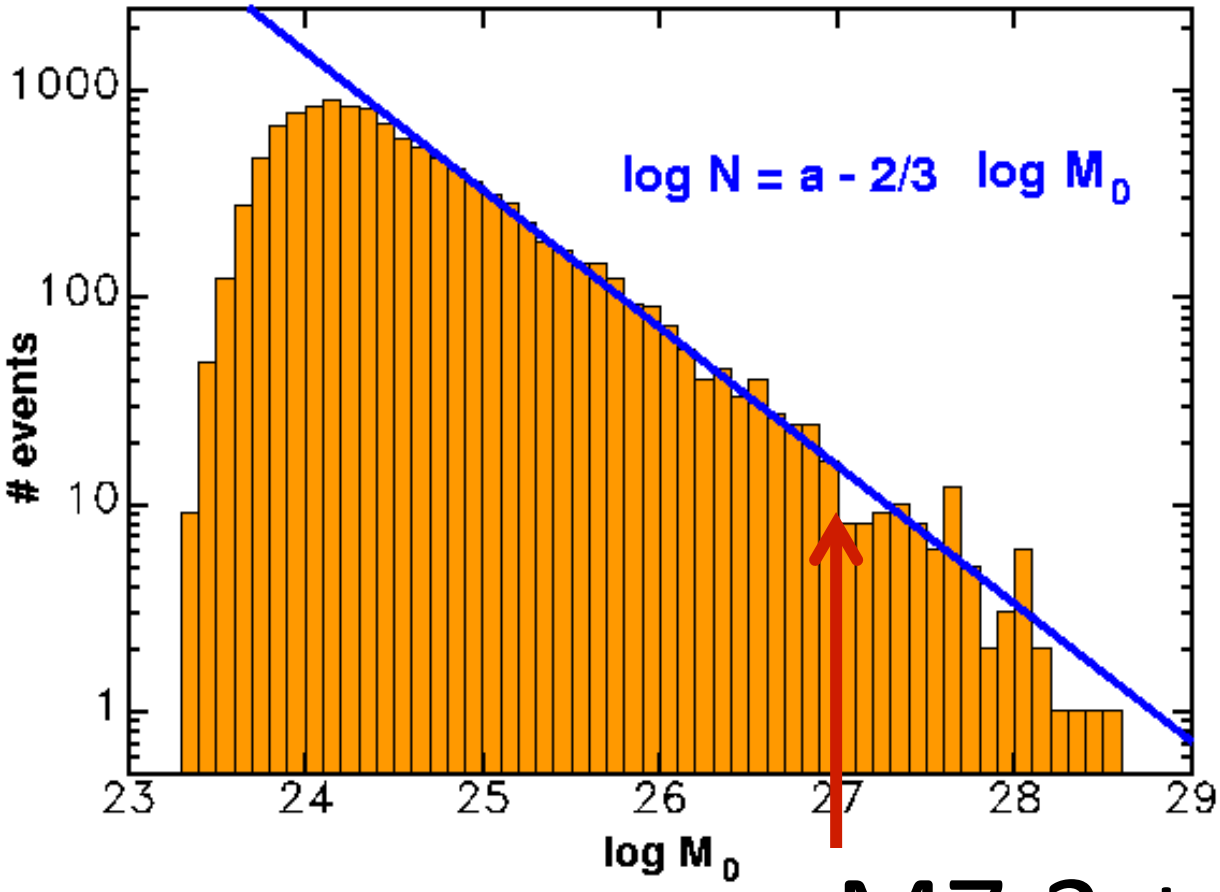


Intensity residuals: 20 cities with >20 ZIP codes reporting, 2011 Virginia earthquake.



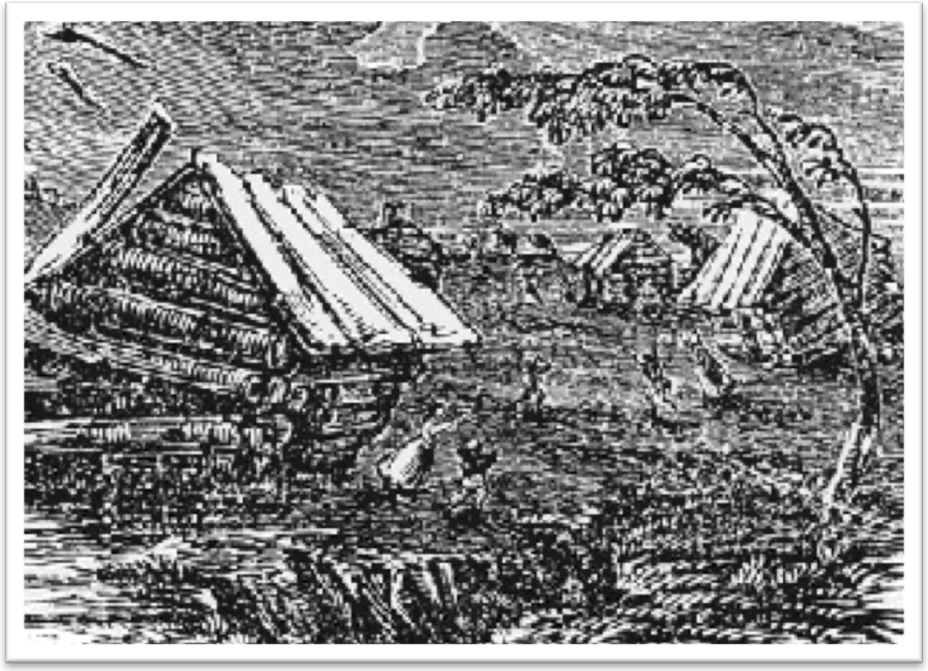
Hough, BEE 2013

Bayesian View

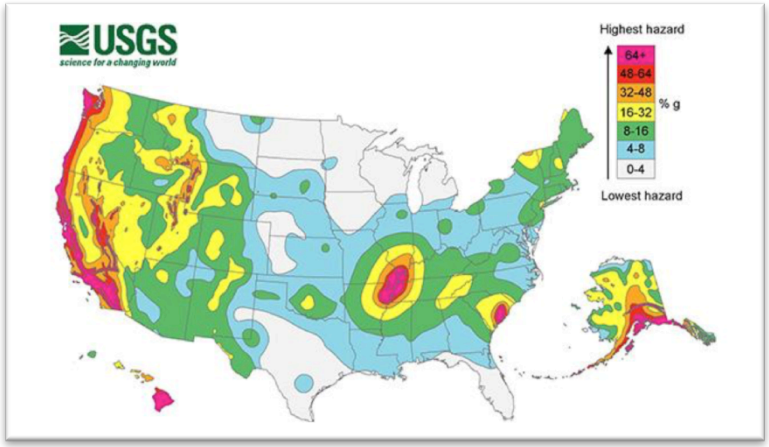


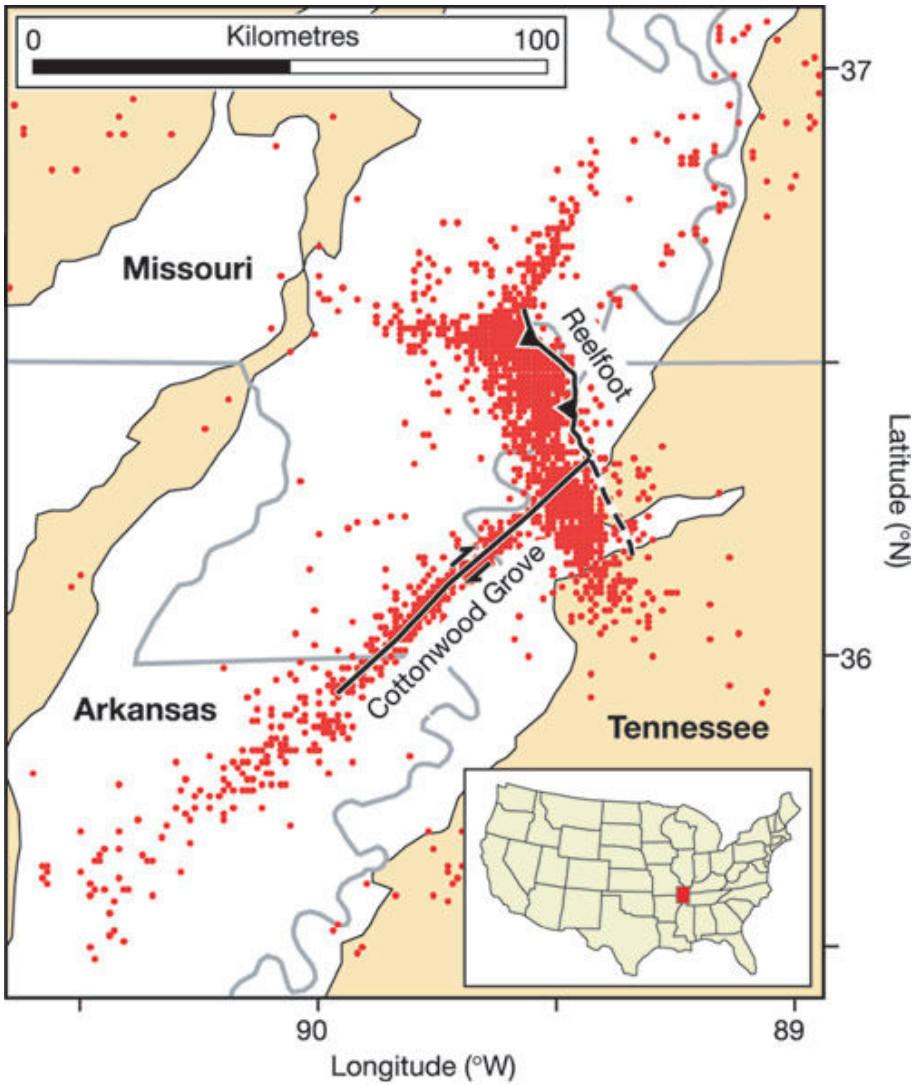
M7.3 ± 0.3

E.g, The 1811-1812 New Madrid Earthquakes

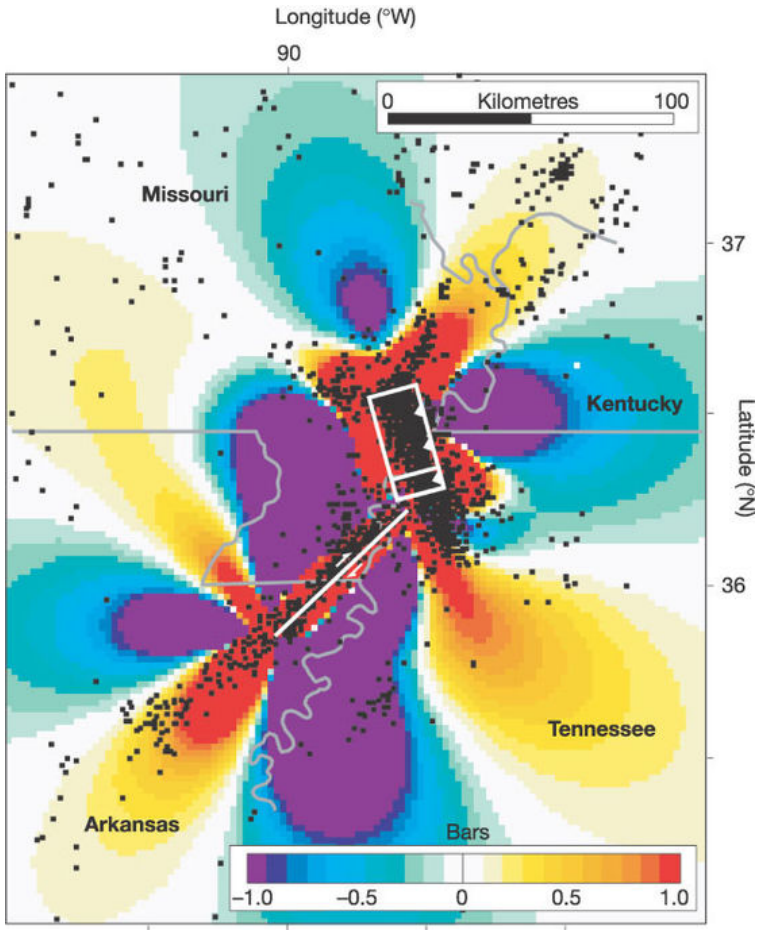


The New Madrid Seismic Zone





Aftershocks…or Not Aftershocks?



Mueller et al., 2004

REPORTS

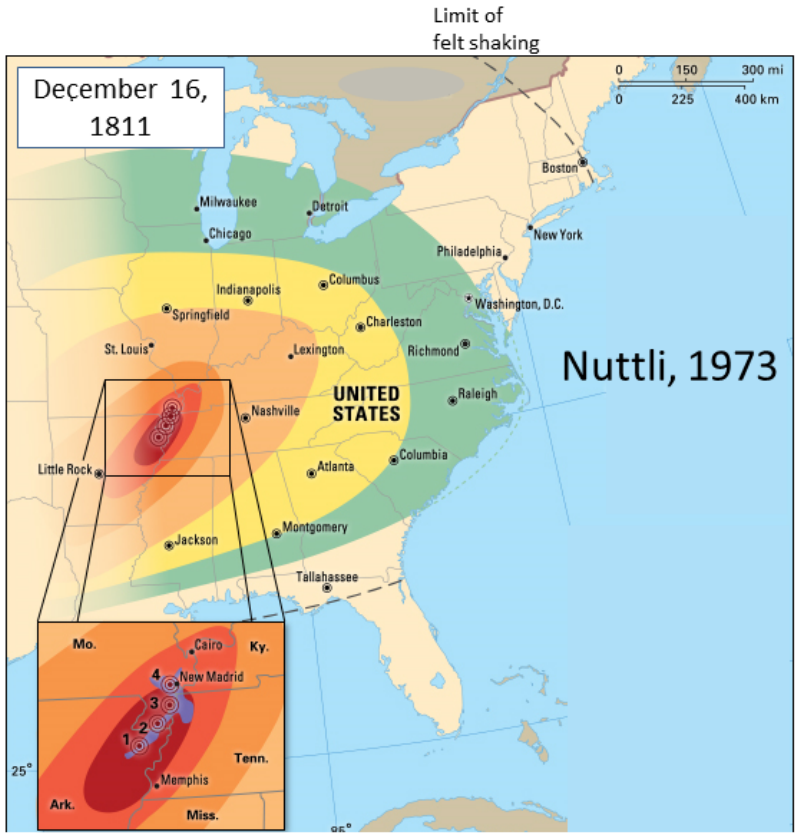
The New Madrid Seismic Zone: Not Dead Yet

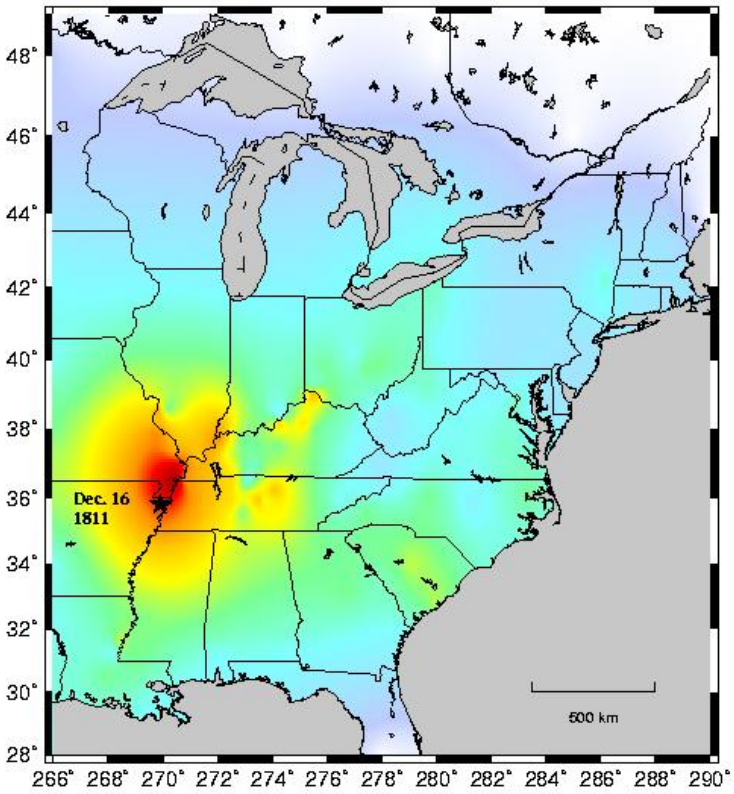
Morgan T. Page* and Susan E. Hough

The extent to which ongoing seismicity in intraplate regions represents long-lived aftershock activity is unclear. We examined historical and instrumental seismicity in the New Madrid central U.S. region to determine whether present-day seismicity is composed predominantly of aftershocks of the 1811–1812 earthquake sequence. High aftershock productivity is required both to match the observation of multiple mainshocks and to explain the modern level of activity as aftershocks; synthetic sequences consistent with these observations substantially overpredict the number of events of magnitude ≥ 6 that were observed in the past 200 years. Our results imply that ongoing background seismicity in the New Madrid region is driven by ongoing strain accrual processes and that, despite low deformation rates, seismic activity in the zone is not decaying with time.

Page and Hough, 2014

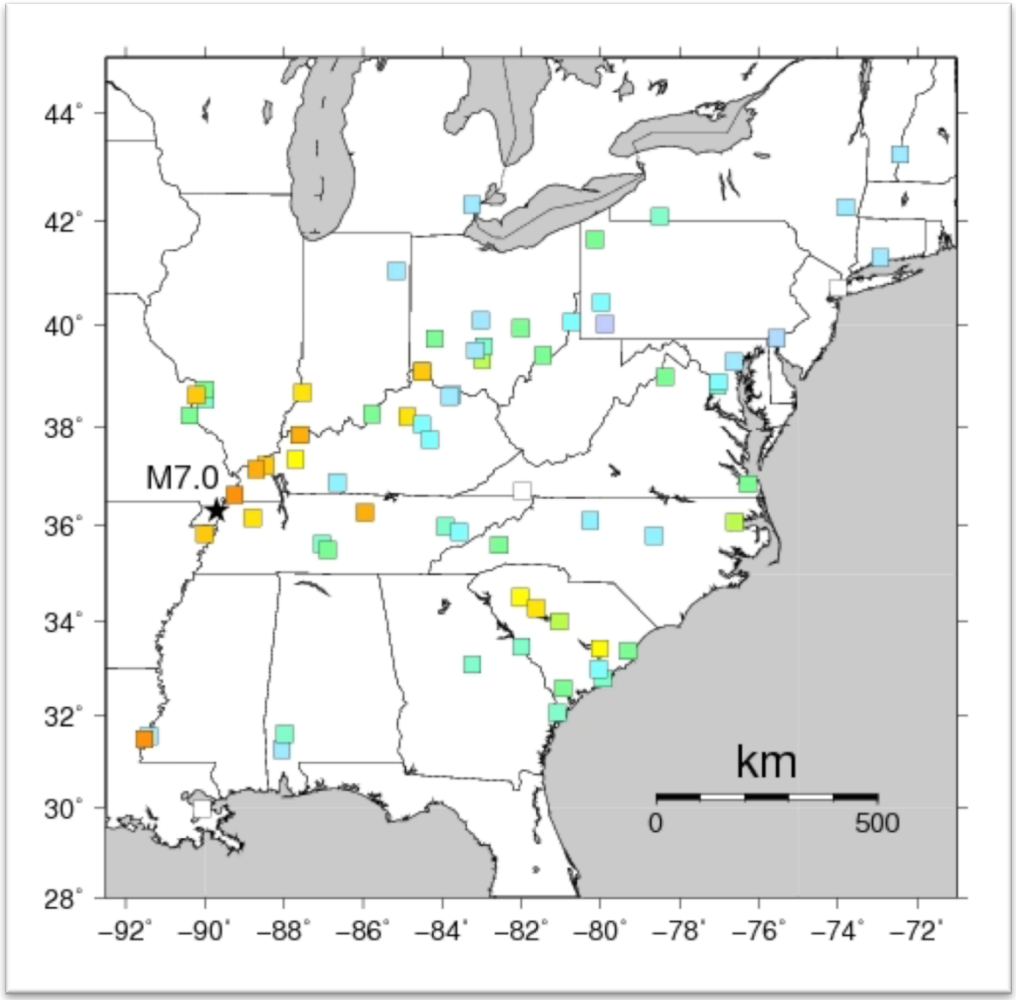
3. Interpretation of Accounts





PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	*16-31*	*31-60*	*60-116*	*>116*
INSTRUMENTAL INTENSITY	I	I-II	IV	V	VI	VII	VIII	IX	X+

Hough et al., 2000



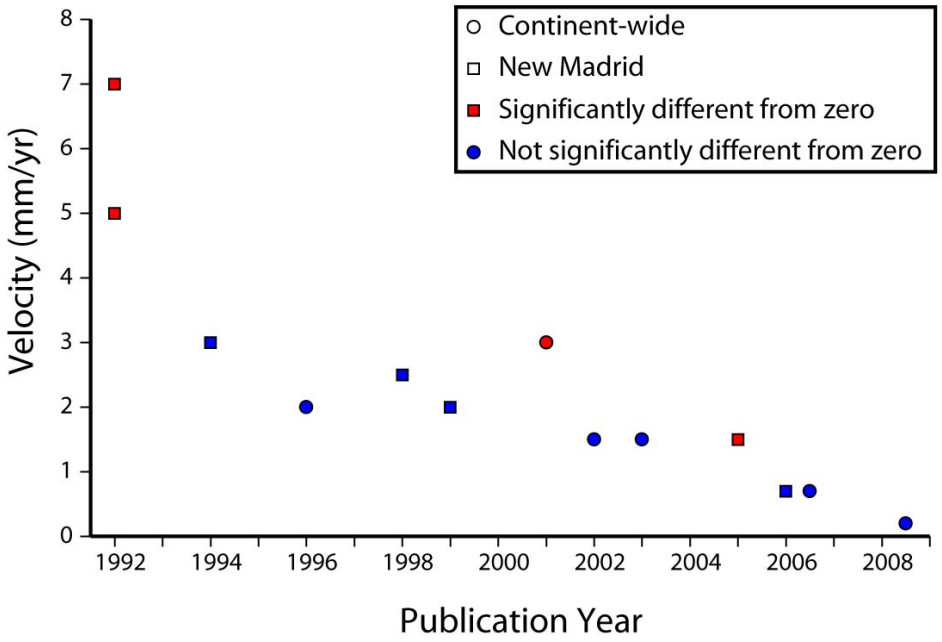
Hough and Page, 2011

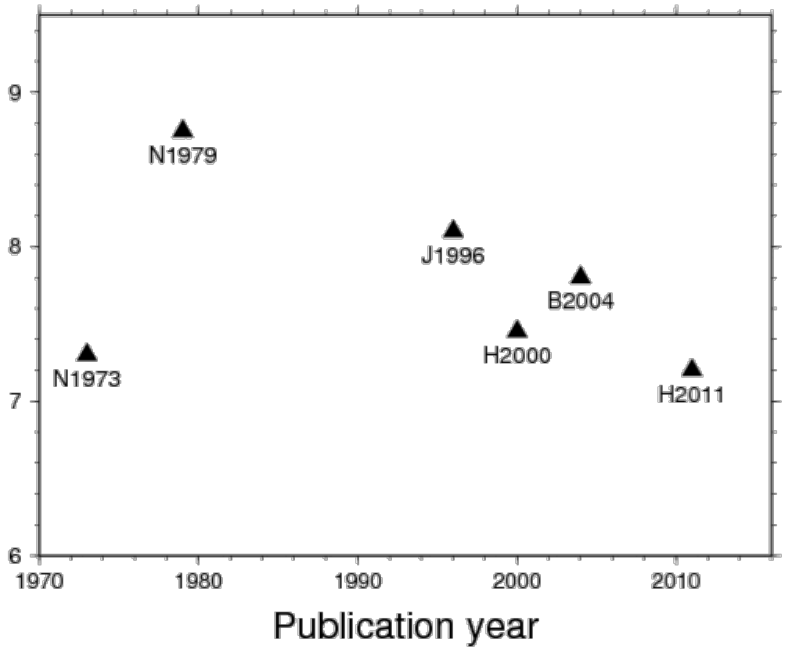
Magnitude Range

- 12/16/1811: 6.7 – 7.1 (**6.9**)
- 12/16/1811 (aftershock): 6.3 – 6.9 (**6.6**)
- 1/23/1812: 6.7-7.1* (**6.9***)
- 2/7/1812: 6.8-7.5 (**7.1**)

Total sequence Mw: 7 – 7.2

Hough and Page (2011)

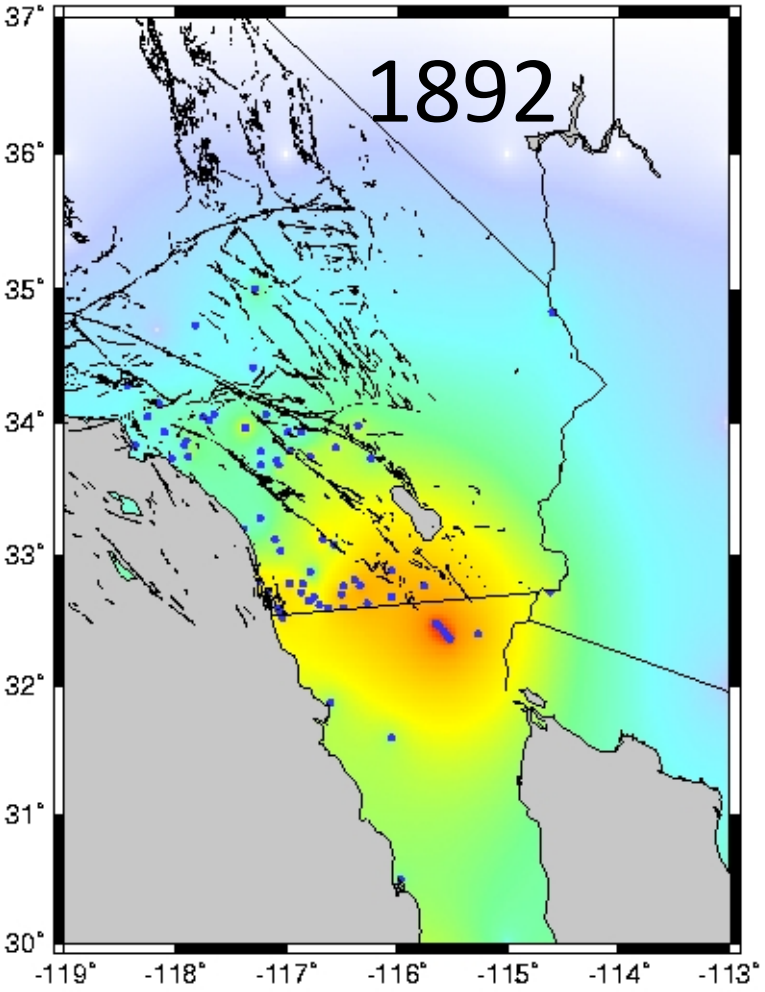


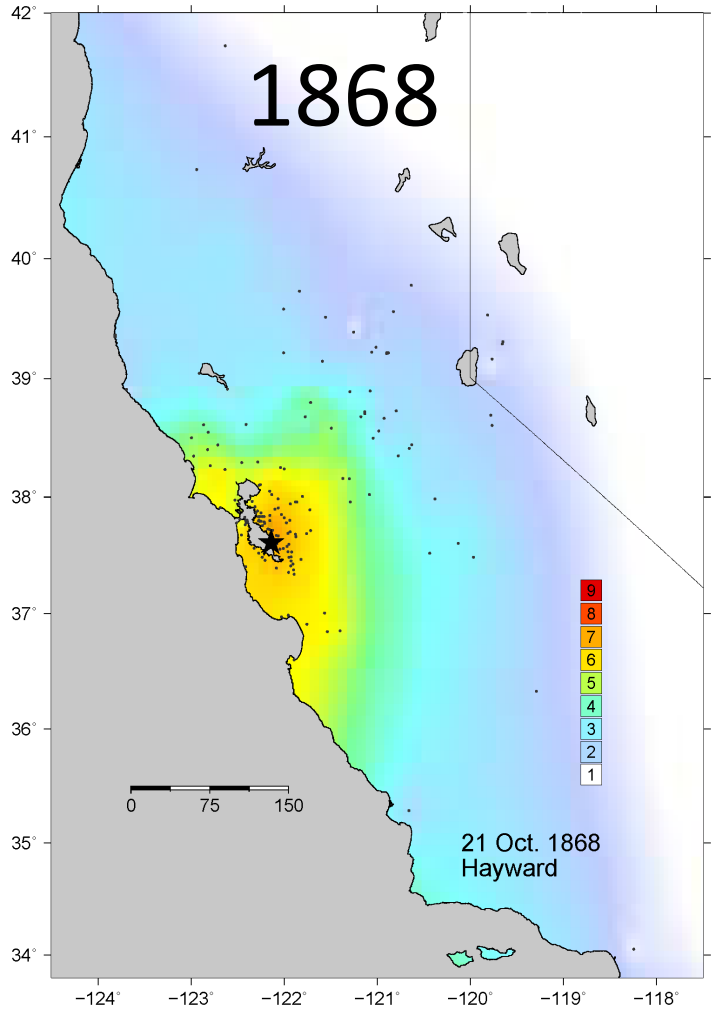


Calais and Stein, 2009

- Improved GPS data → lower strain rate
- Improved intensity analysis → lower magnitudes

Too Big…

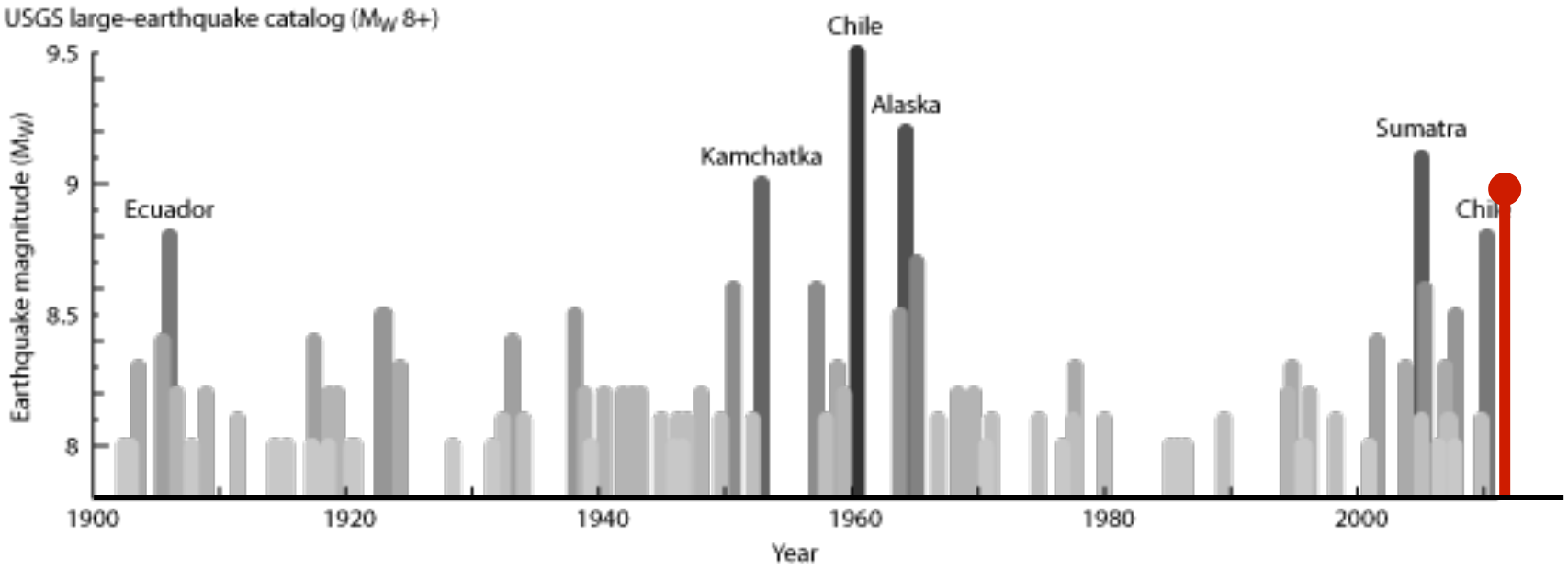




Hough and Martin, 2015

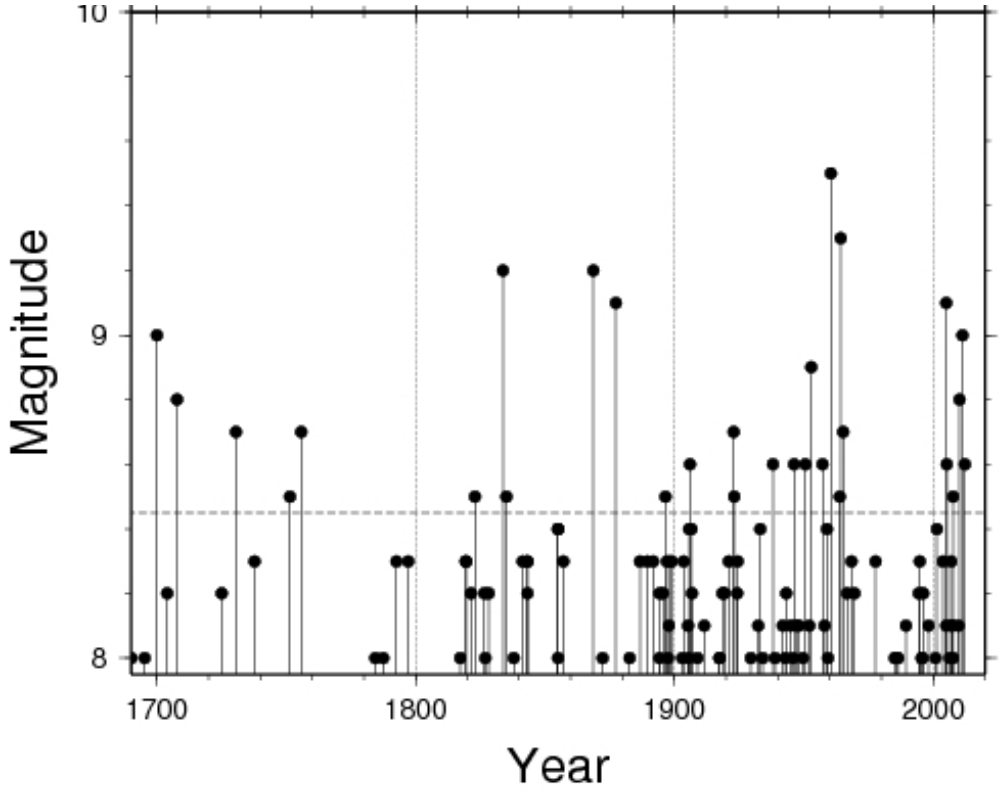
Outline

- Too big
- Too small
- Just right

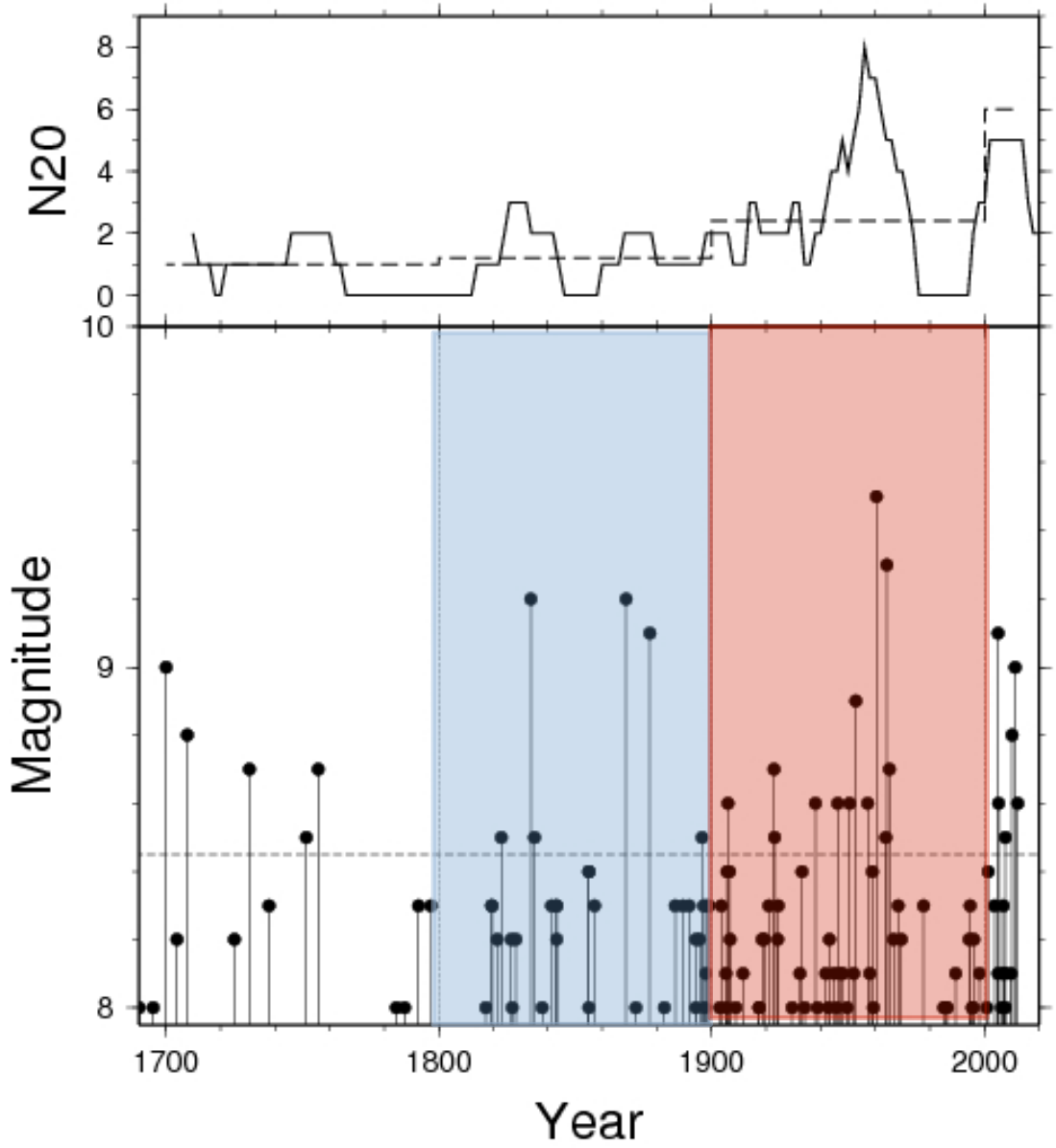

USGS large-earthquake catalog (M_W 8+)
Earthquake magnitude (M_W)
9.5
9
8.5
8
Ecuador
Kamchatka
Chile
Alaska
Sumatra
1900
1920
1940
1960
1980
2000
Year

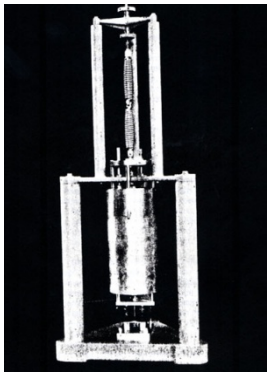
Historical Great Earthquakes

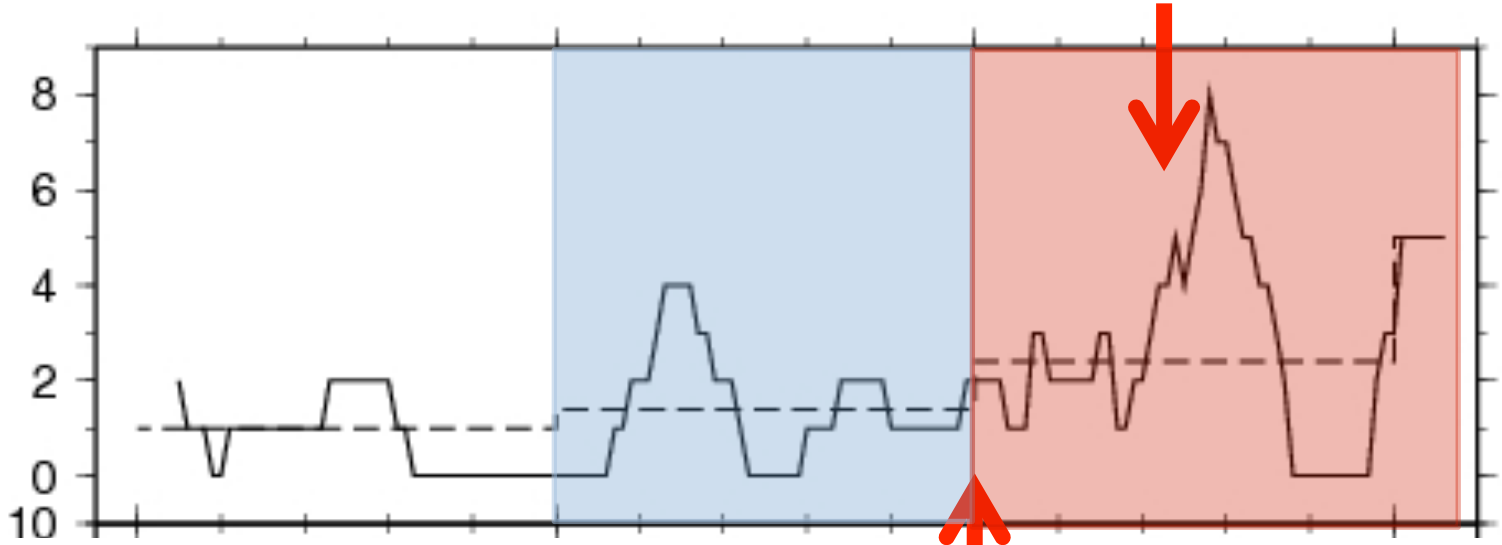
Catalogs: Centennial (1900+),
NGDC Significant Earthquakes (reviewed for M>8)

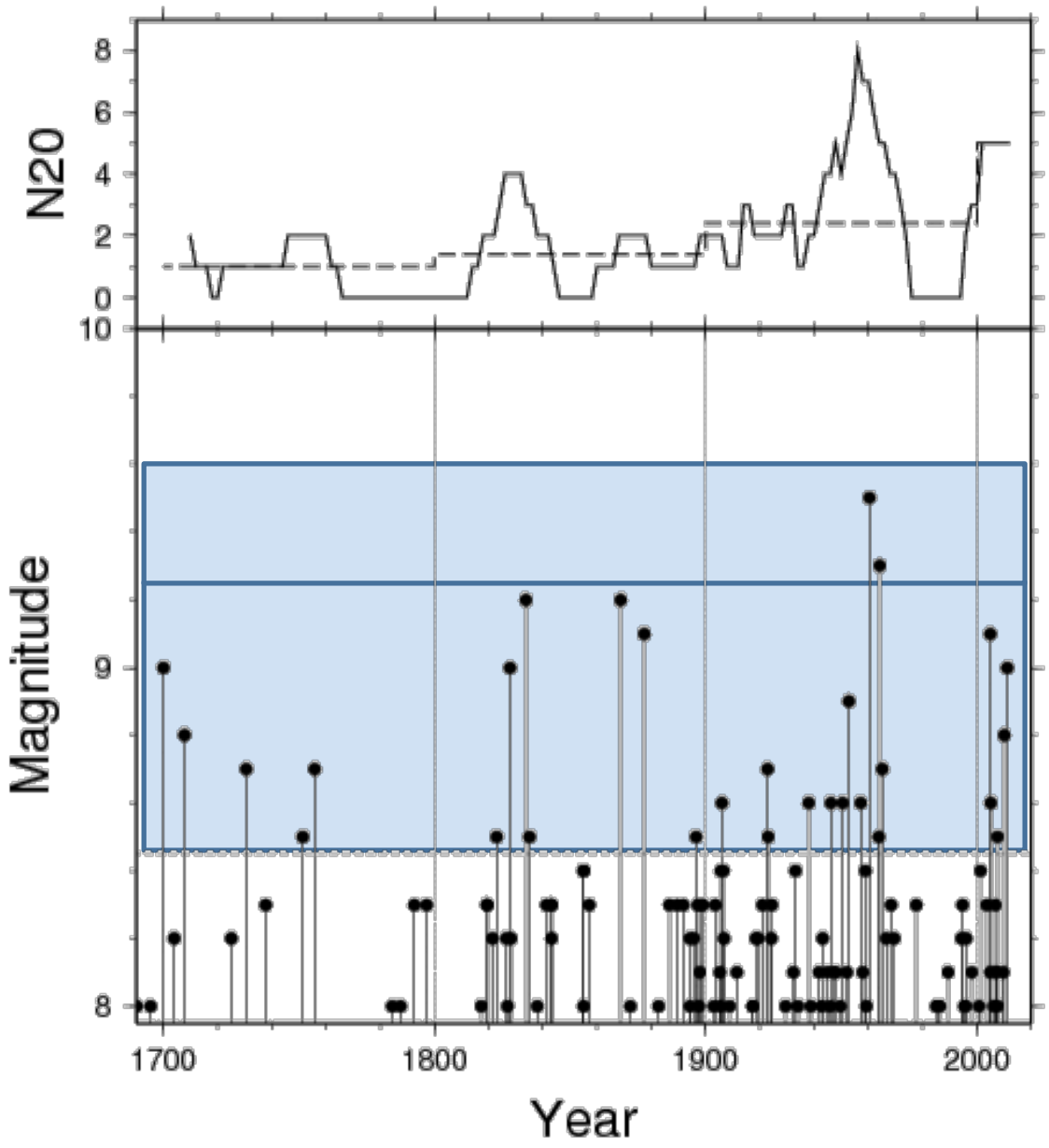


Hough, 2013


N20
8
6
4
2
0
10
9
8
Magnitude
1700
1800
1900
2000
Year




8
6
4
2
0
10


N20
8
6
4
2
0
10
9
8
Magnitude
1700
1800
1900
2000
Year

19^{th} Century *vs* 20^{th}-21^{st} Centuries

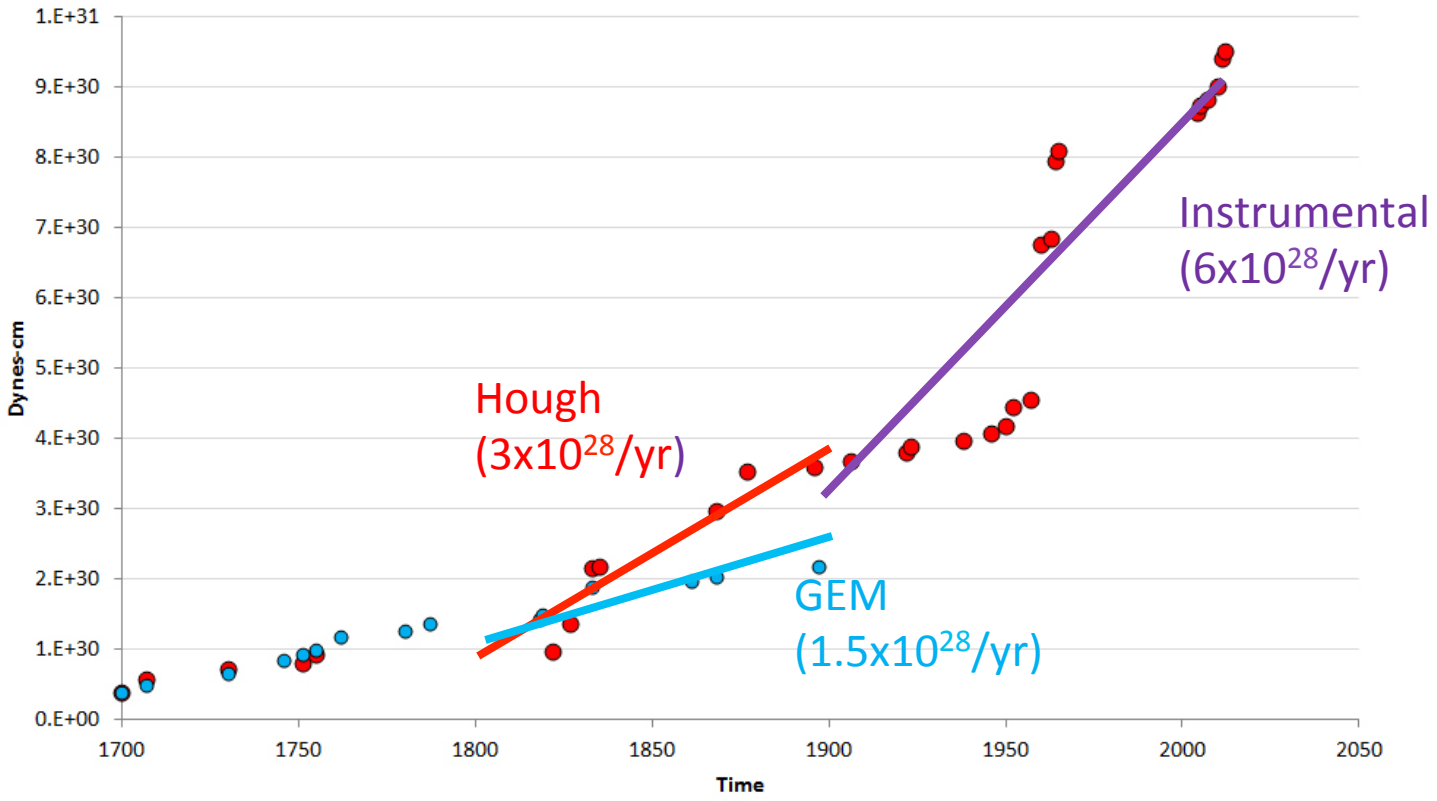
- **3** M≥9

  (1833, 1868, 1877)
- **3** 8.5≤M<9

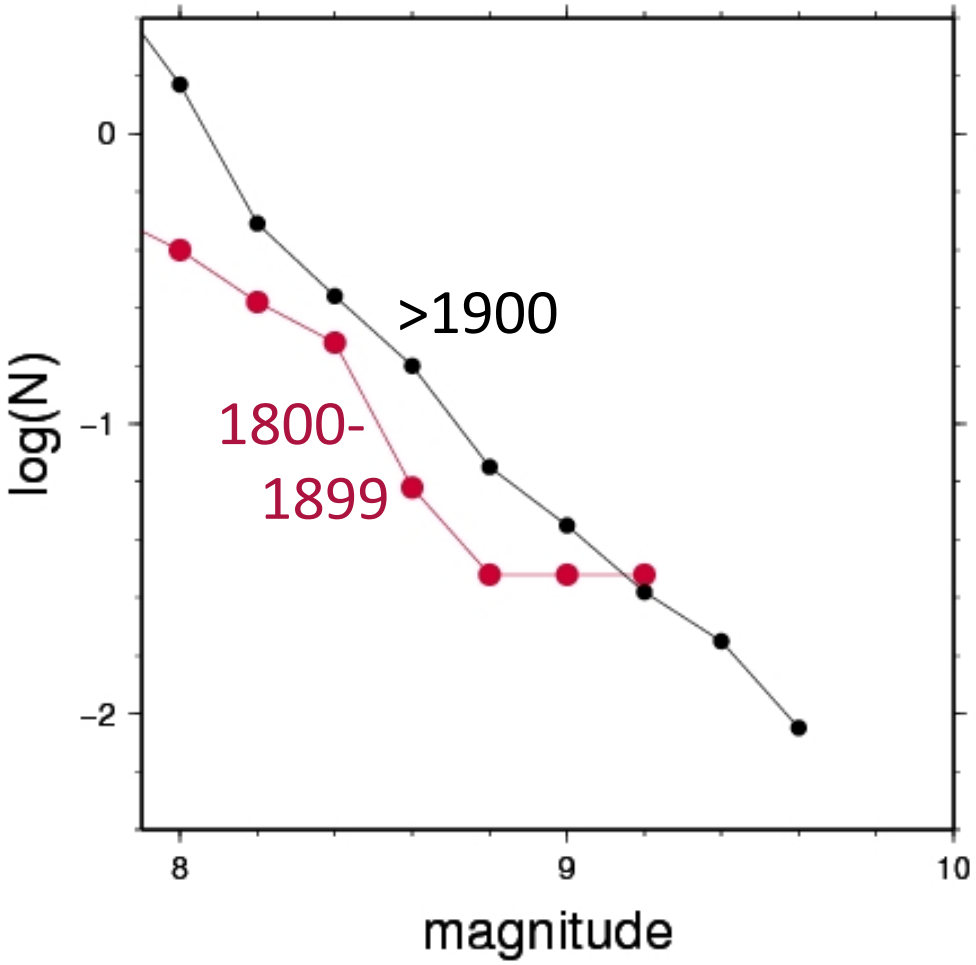
- **5** M>9

  (1952, 1960, 1964, 2004, 2011)
- **17** 8.5≤M<9

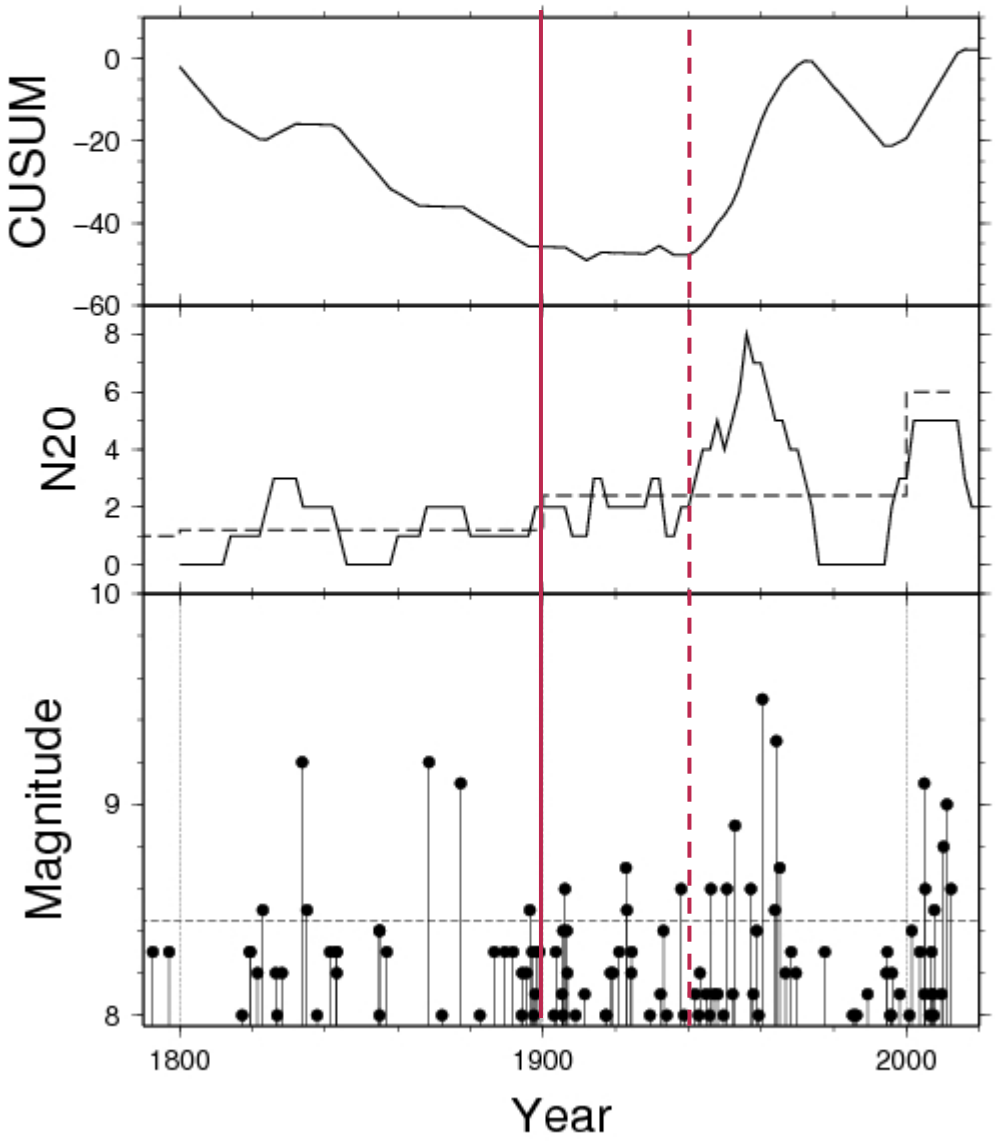
Moment Release



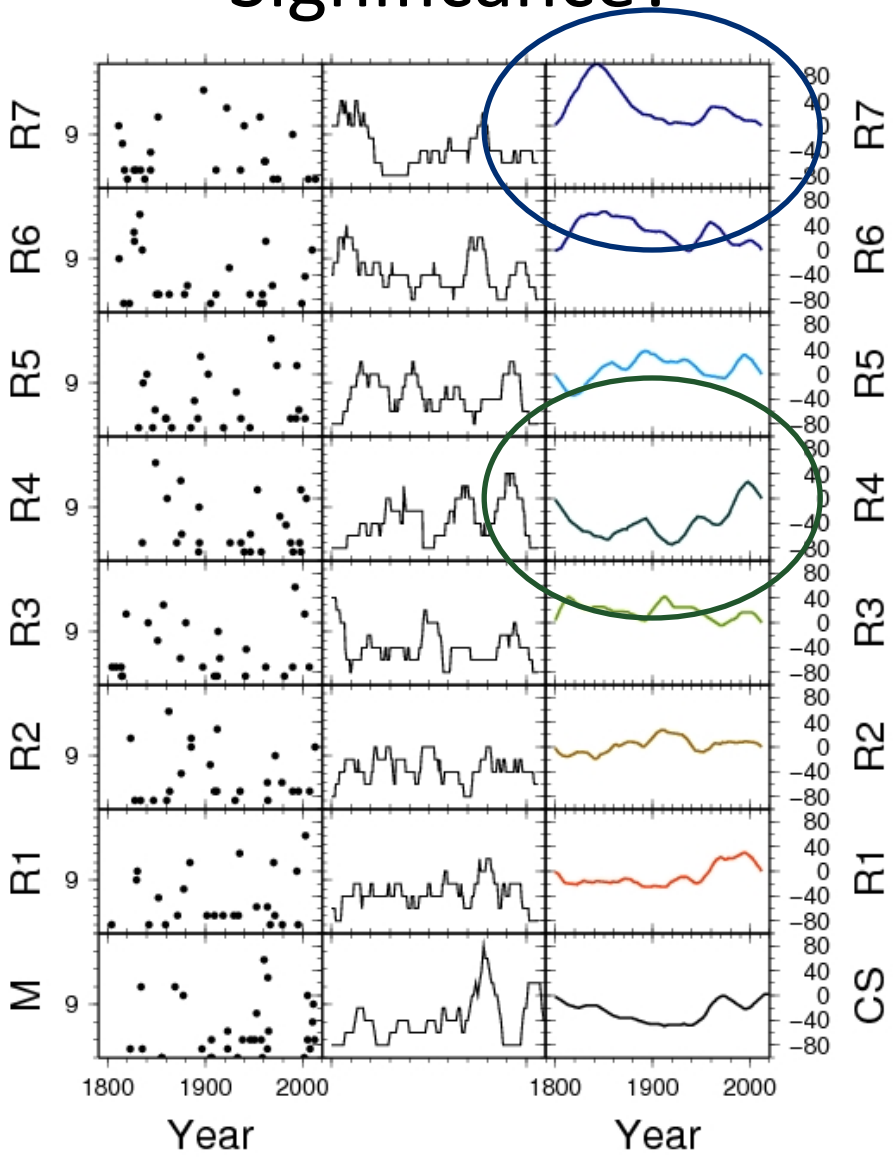
Magnitude Distribution



Change Point Analysis

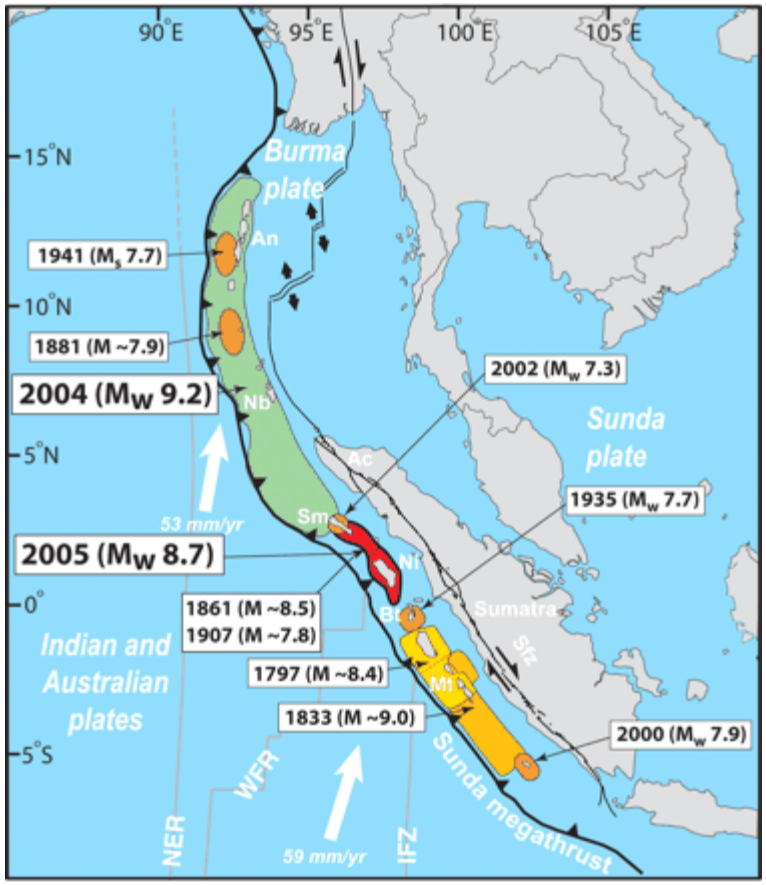


Change Point Analysis: Significance?



Missing Great Earthquakes

Missable Great Earthquakes

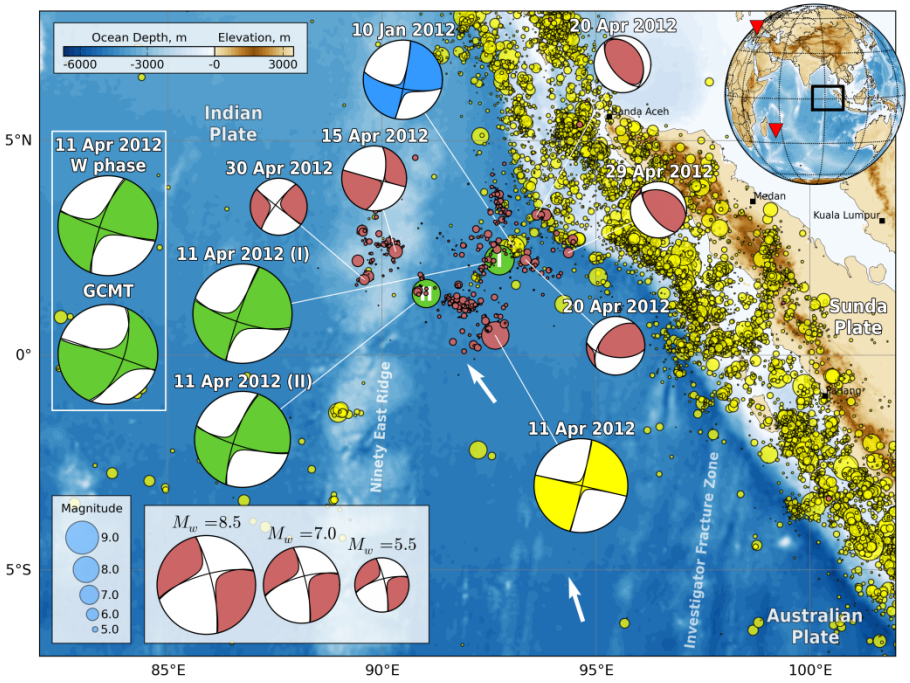


1. 2005 Nias (Mw8.7)

- 400-km rupture ("relatively short")
- 2.9-m max. uplift
- Max. displacement under land/shallow water
- Co-seismic raising of Nias/Simueleu islands

(Briggs et al., 2006)

Missable Great Earthquakes



2. 2012 Sumatra (Mw8.6)

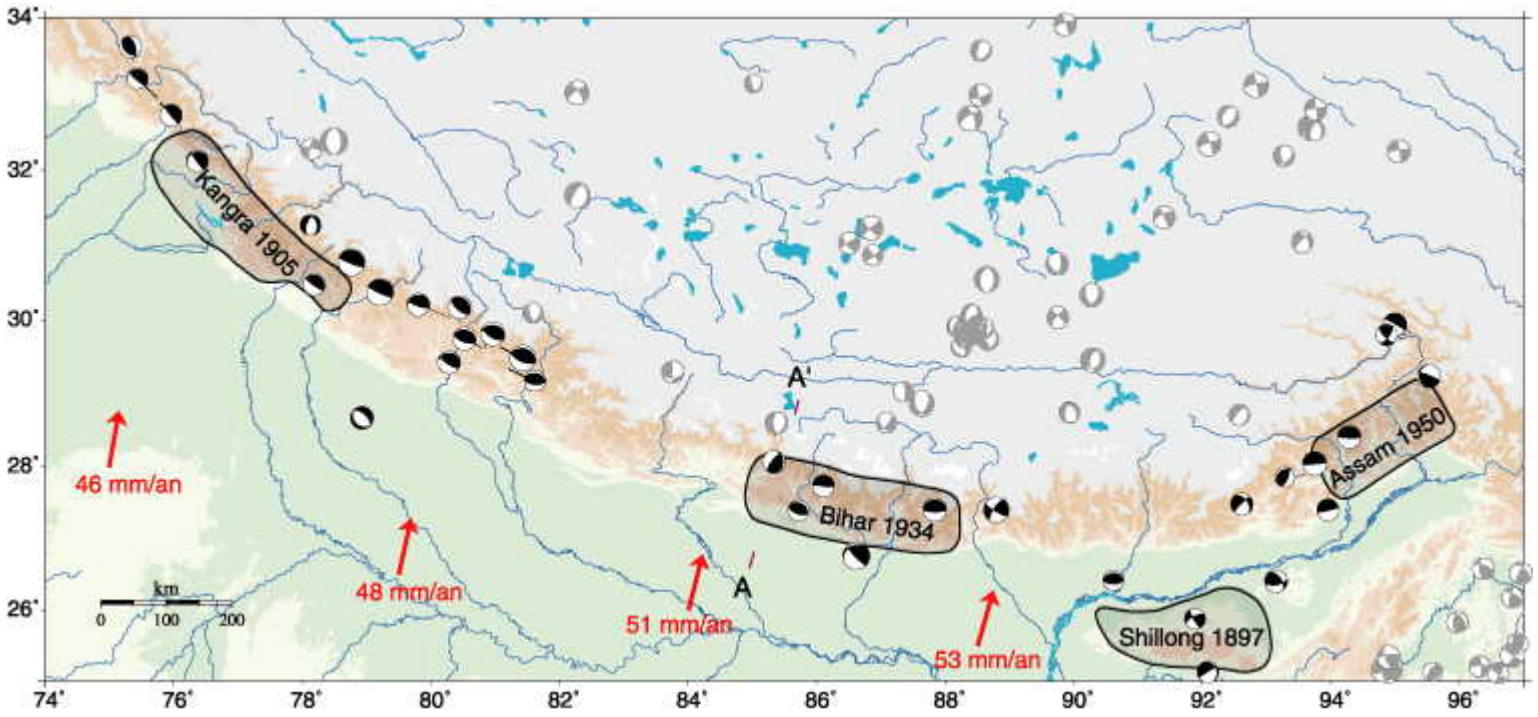
- Strike-slip
- Complex rupture process

  Duputel et al. (2012)

Missable Great Earthquakes

3. 1950 Assam (Mw8.6)

- Continental convergence zone

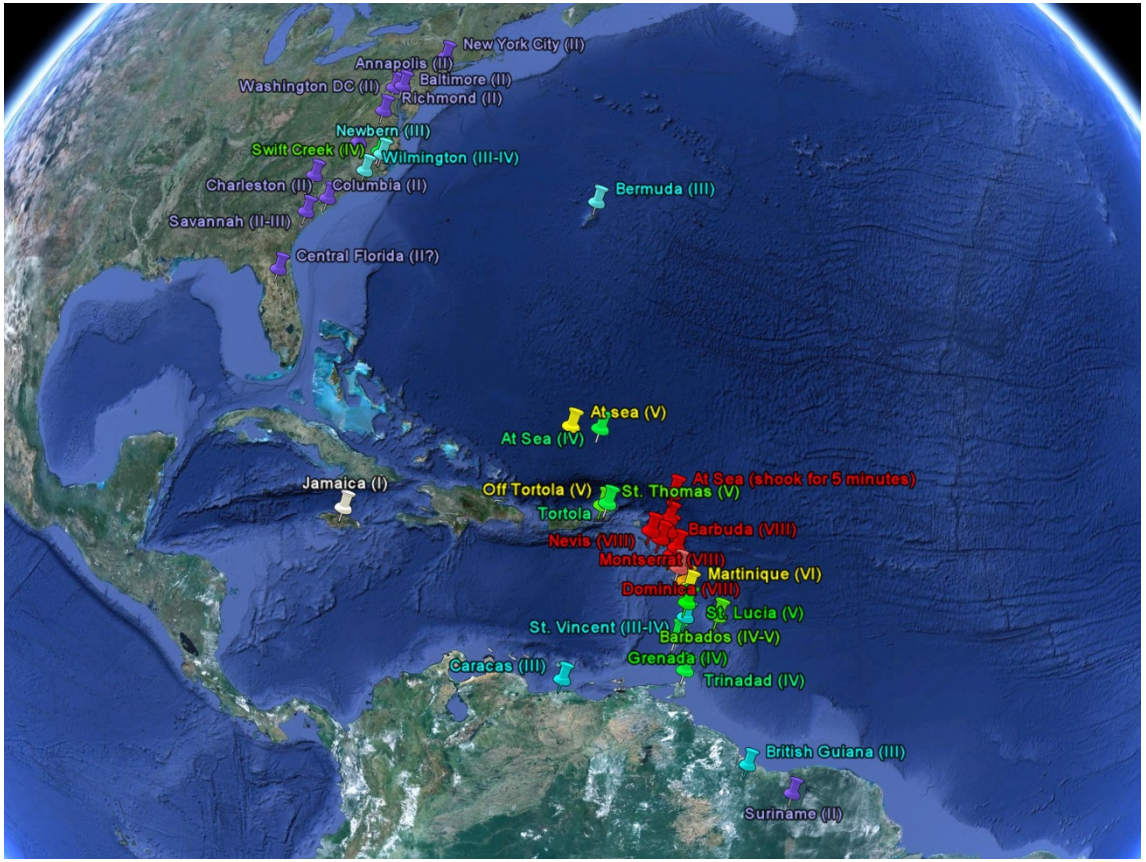


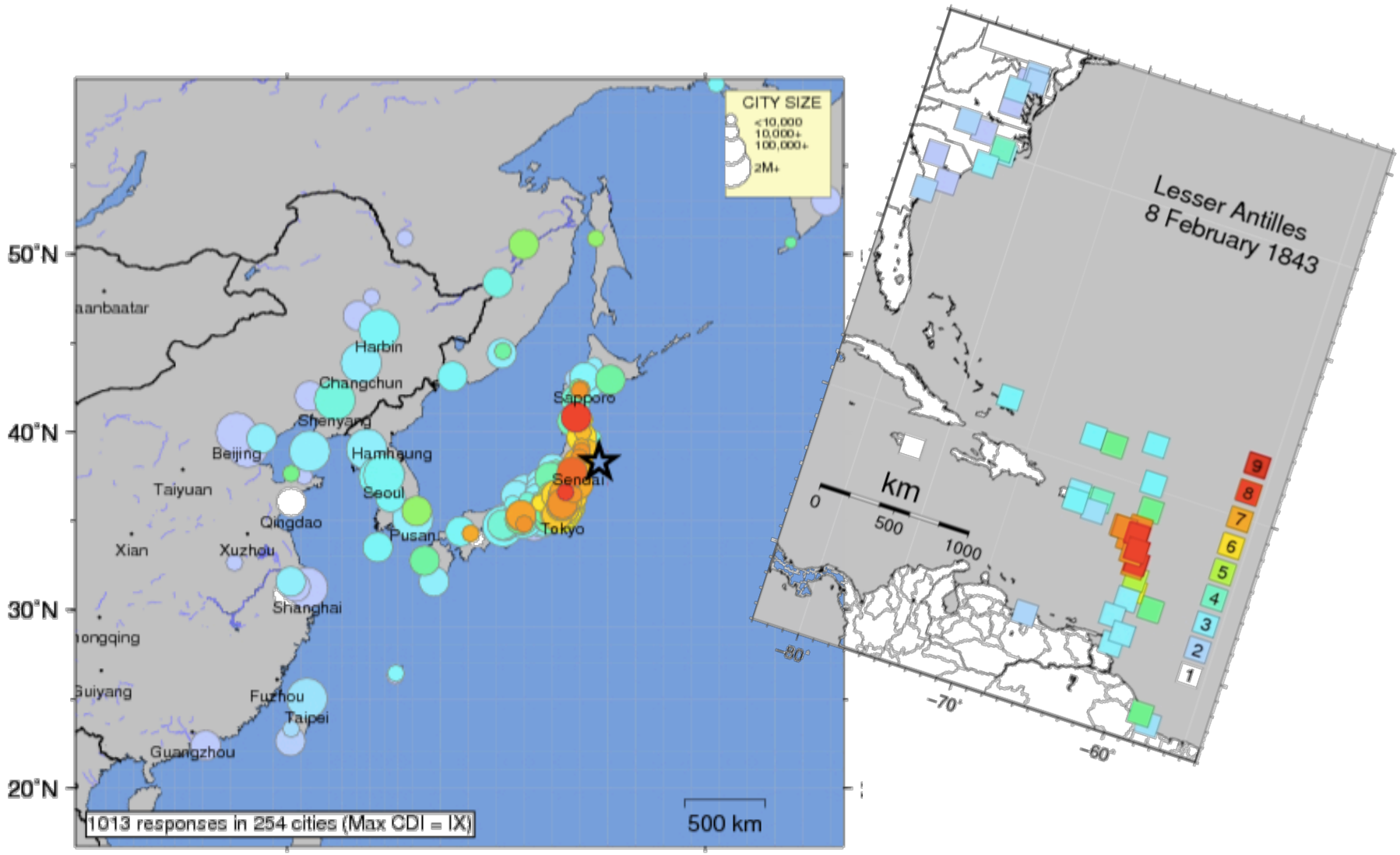
Missing Great Earthquakes

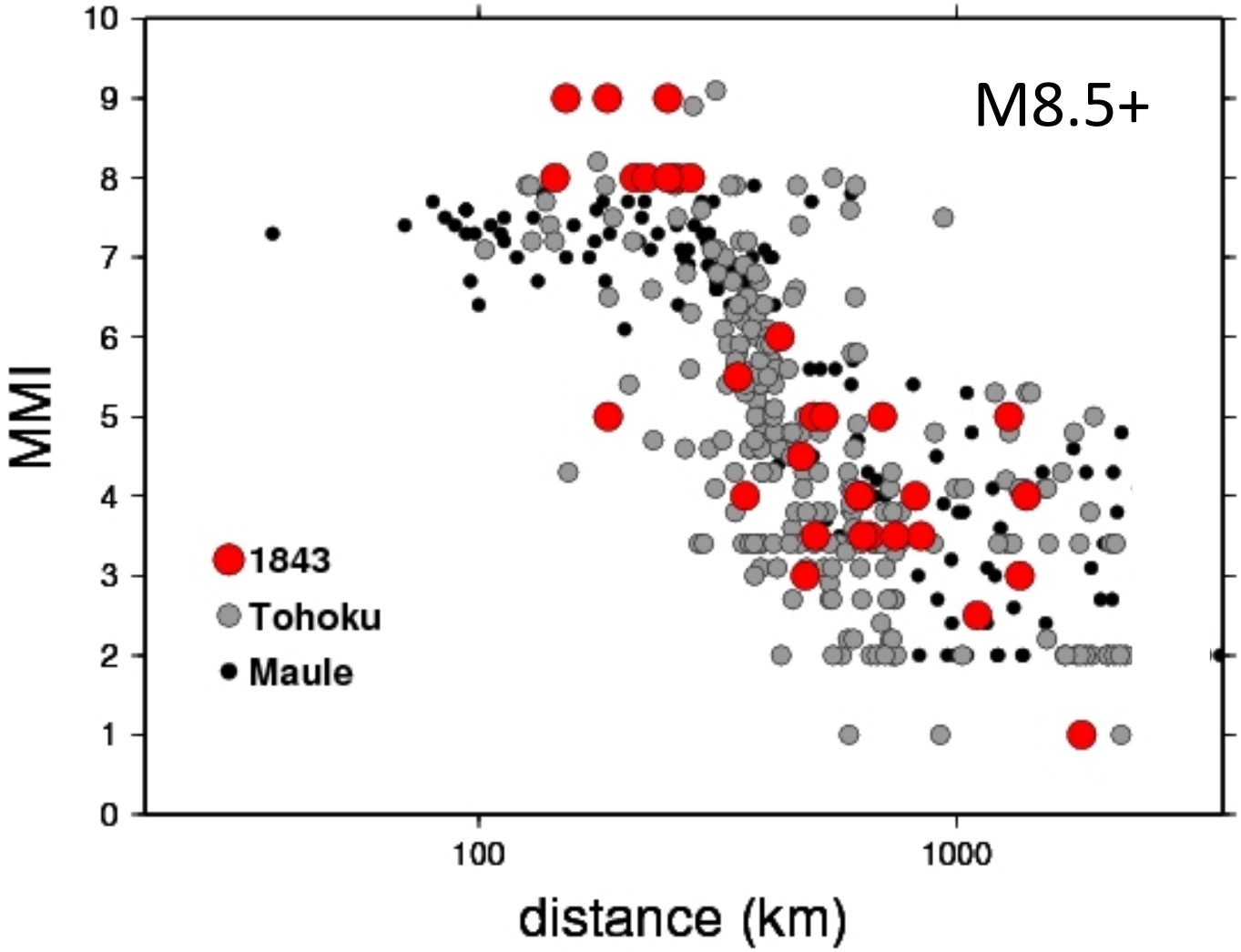
1. 1843 Antilles (Mw8.5+)

- McCann and Sykes, 1984: M8-8.5
- M8.3 (NEIC)
- 1988: M7.5-8.0 (Bernard and Lambert, 1988)
- 1992: Ms>8 (Shepherd, 1992)
- 2011: M8.5 (Feuillet et al.: near-field accounts)
- 2012: M7.8 (tenBrink et al.: near-field accounts)

Missing Great Earthquakes

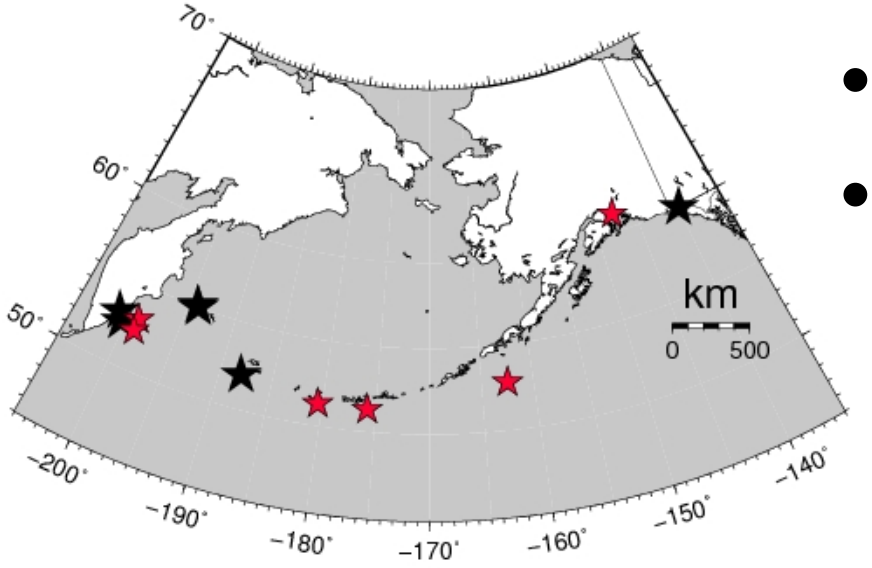



CITY SIZE
<10,000
10,000+
100,000+
2M+
50°N
40°N
30°N
20°N
Harbin
Changchun
Shenyang
Beijing
Hamhaung
Taiyuan
Seoul
Qingdao
Pusan
Xian
Xuzhou
Shanghai
Fuzhou
Taipei
Guangzhou
Sapporo
Sendai
Tokyo
1013 responses in 254 cities (Max CDI = IX)
500 km
Lesser Antilles
8 February 1843
km
0
500
1000
-80°
-70°
-60°
9
8
7
6
5
4
3
2
1


M8.5+
MMI
distance (km)
1843
Tohoku
Maule
10
9
8
7
6
5
4
3
2
1
0
100
1000

Missing Great Earthquakes

2. 1841 Kamchatka (Mw8.5+)

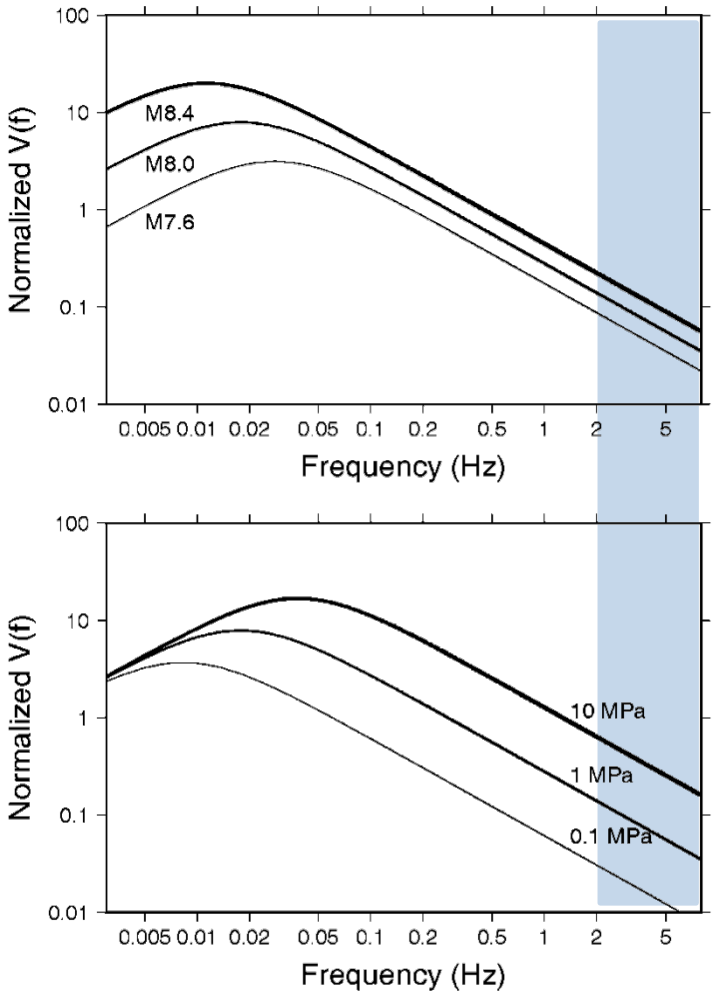


- Mt9.0
- 4.6-m tsunami, Hilo (Abe, 1979)

Outline

- Too big
- Too small
- Just right

Stress Drop Ambiguity



10 MPa M7.6 ← → 0.1 MPa M8.4

Tsunami Magnitudes

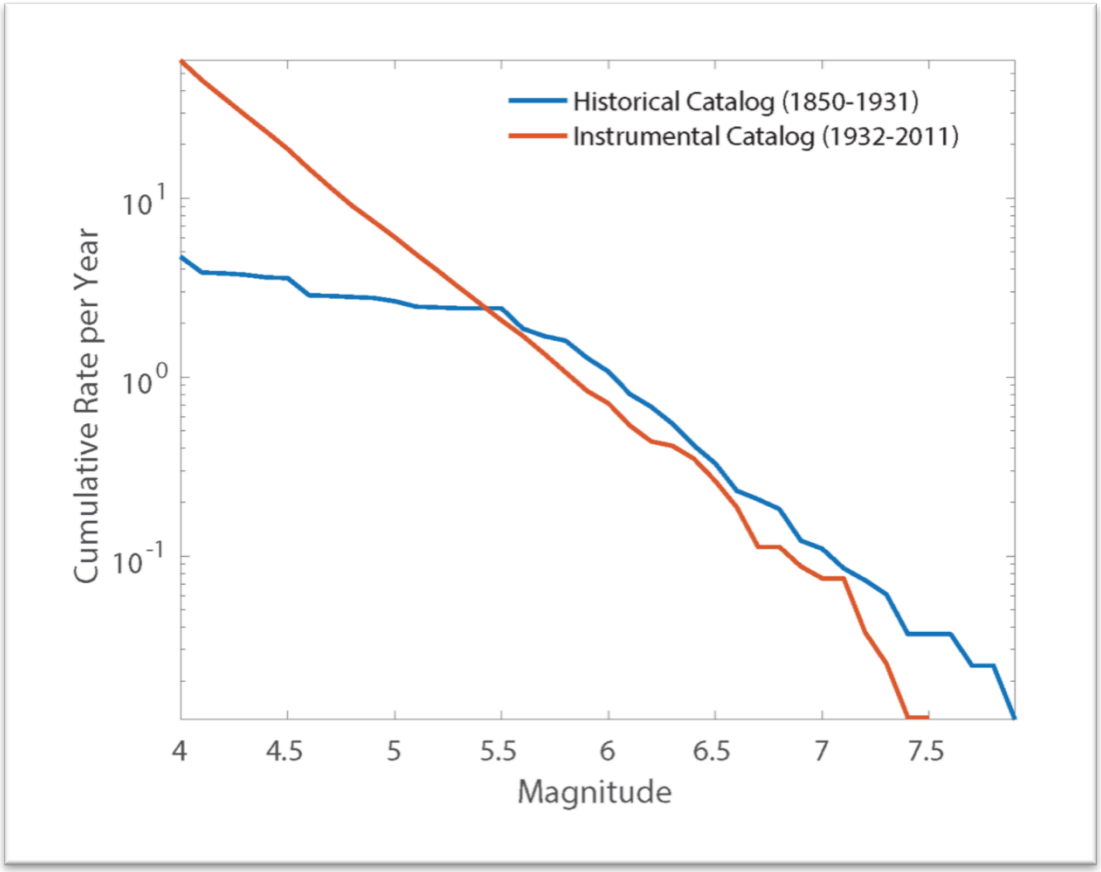
TABLE 4. Great Tsunamigenic Earthquakes

Date	Region	M_t	Local Height
May 22, 1960	Chile	9.4	25 m at Isla Mocha
April 1, 1946	Aleutian	9.3	30 m at Unimak Is.
Nov. 7, 1837	Chile	9¼	(6 m at Hilo, Hawaii)
March 28, 1964	Alaska	9.1	30 m, Valdes Inlet
May 17, 1841	Kamchatka	9	(4.6 m, Hilo, Hawaii)
Aug. 13, 1868	Chile	9.0	14 m, Arica
May 10, 1877	Chile	9.0	21 m, Mejillones
Nov. 4, 1952	Kamchatka	9.0	18 m, Paramushir Is.
March 9, 1957	Aleutian	9.0	12 m, Unimak Is.
Feb. 3, 1923	Kamchatka	8.8	8 m, Kolgir Bay
Jan. 31, 1906	Ecuador	8.7	(3.6 m, Hilo, Hawaii)
Sept. 7, 1918	Kurile	8.7	12 m, Urup Is.
Nov. 11, 1922	Chile	8.7	9 m, Chanaral
June 15, 1896	Japan	8.6	24 m, Yoshihama
Feb. 4, 1965	Aleutian	8.6	10 m, Semya Is.

M_t = 8.6 or over.

What Magnitudes are “Just Right” in California?

Is California in an Earthquake Drought?

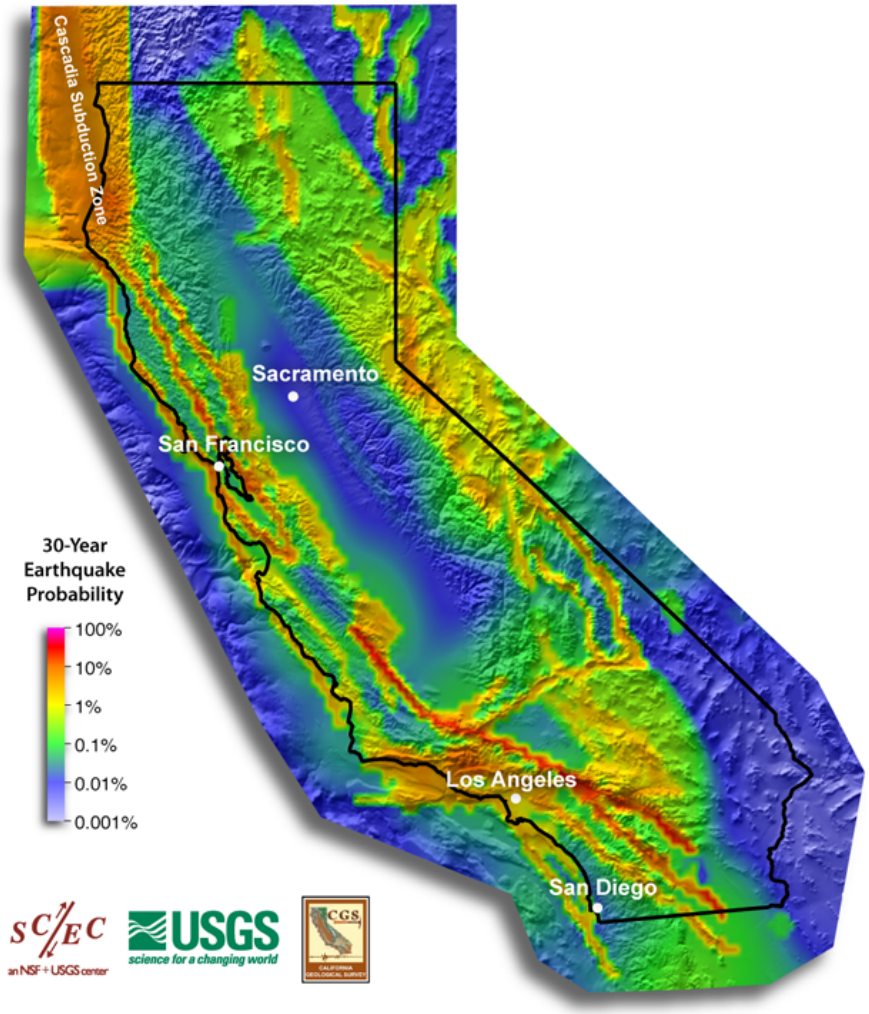


Hough and Page, in review

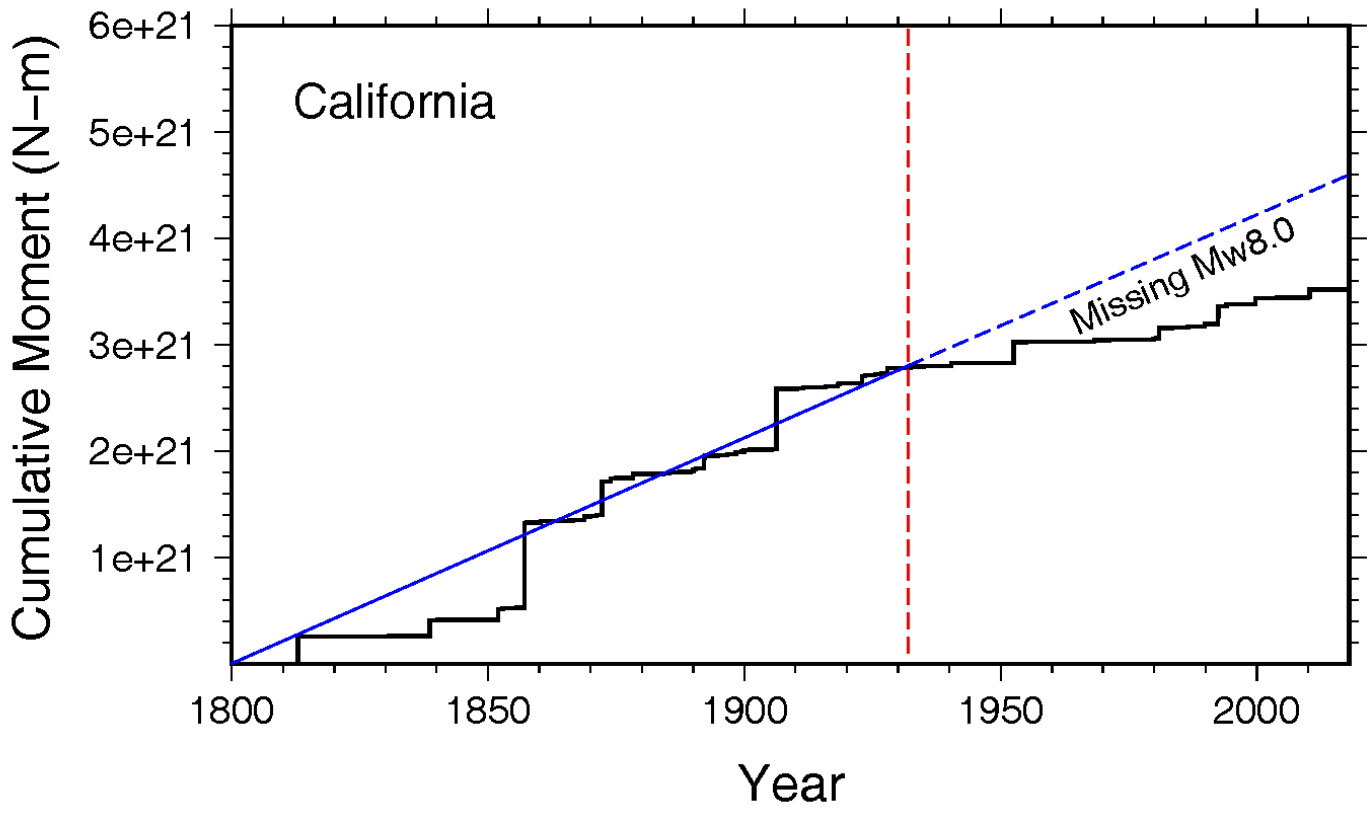
Ten Largest Historical Earthquakes in Contiguous United States (CEUS-SSC + UCERF3)

- 1857 Fort Tejon (7.9)
- 1906 San Francisco (7.8)
- 1812 New Madrid (7.8)
- 1811 New Madrid (7.6)
- 1812 New Madrid (7.5)
- 1872 Owens Valley (7.6)
- 1952 Kern County (7.5)
- 1812 San Andreas (7.5)
- 1838 San Andreas (7.4)
- Tie:
  - 1980 Eureka (7.3)
  - 1892 Laguna Salada (7.3)
  - 1852 Western Nevada (7.3)

California and Environs

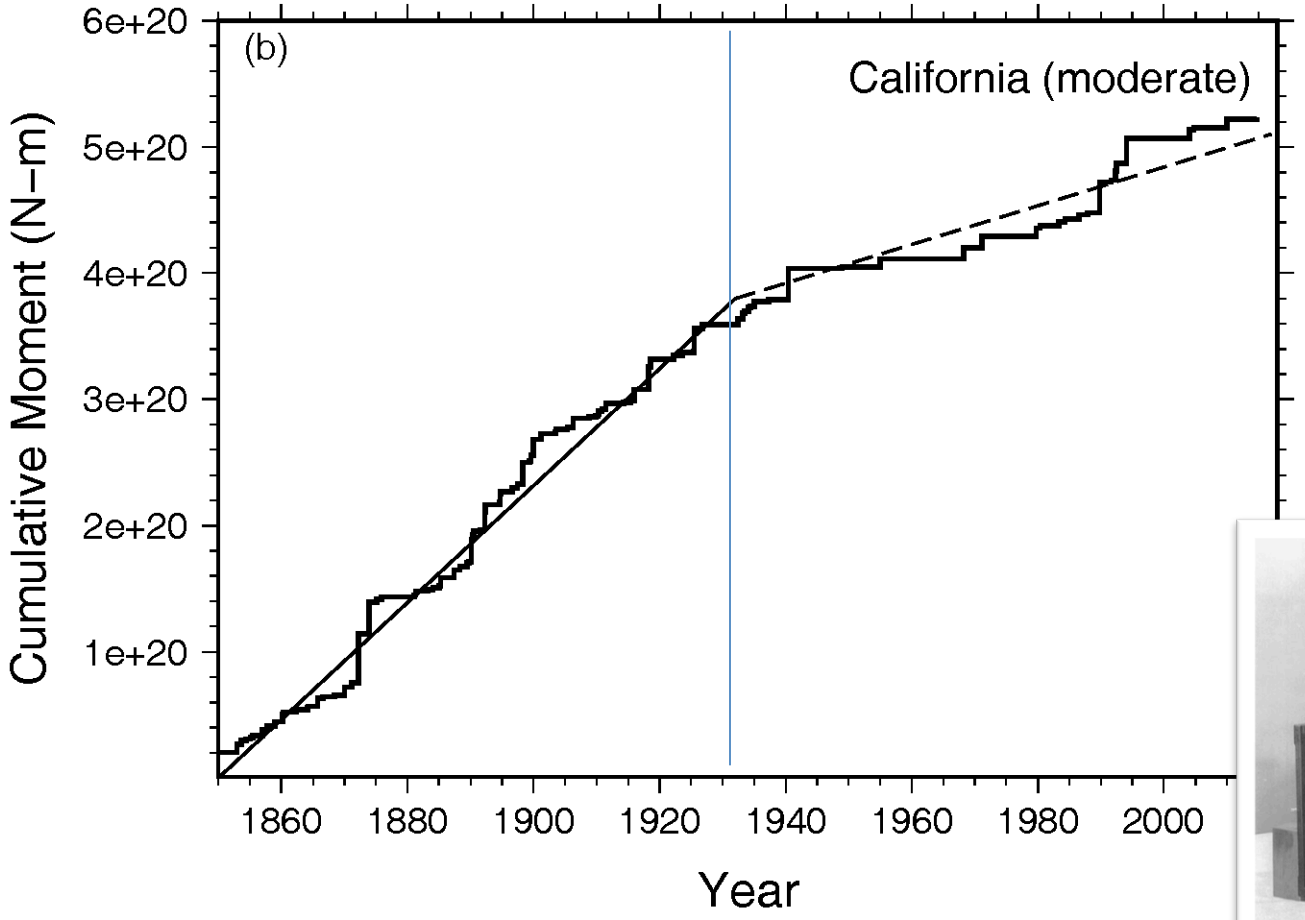


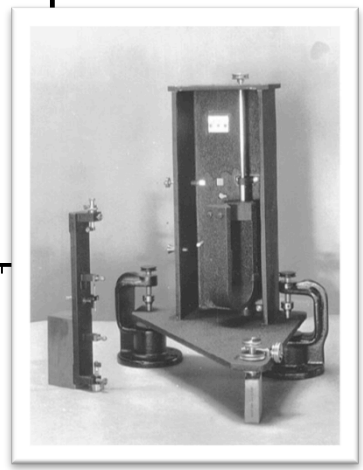
California Moment Release Since 1800



1. Missing moment = two 1906's, or one M8

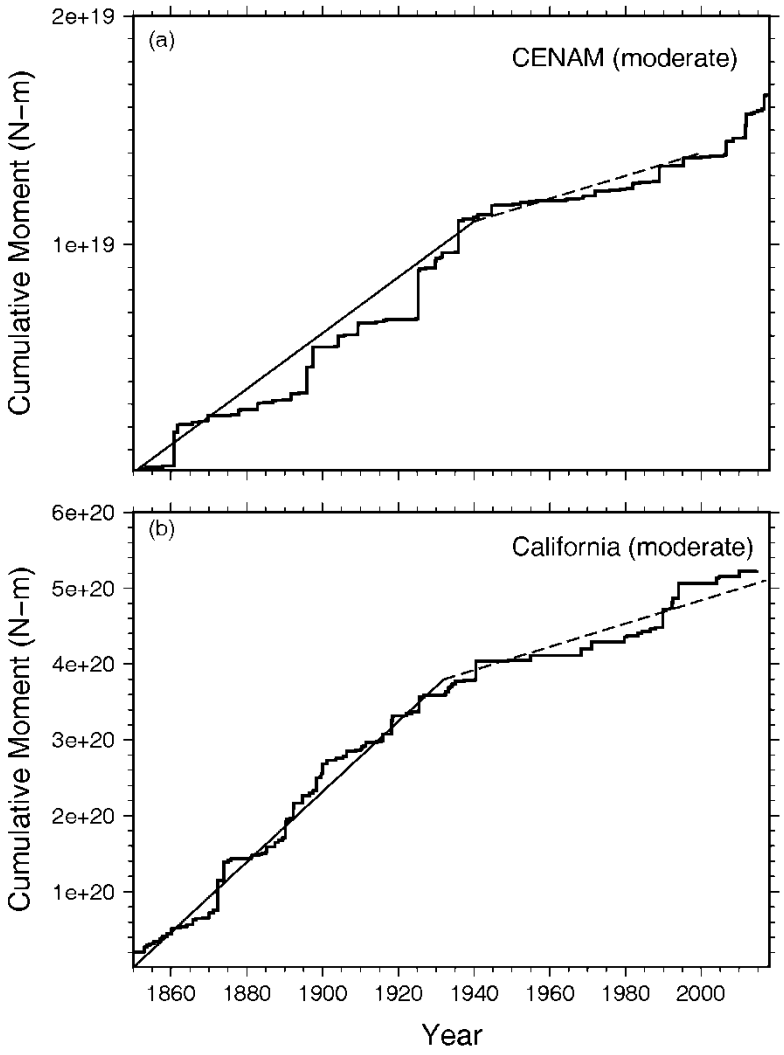
Moderate ($6 \leq M_w < 7$) Events

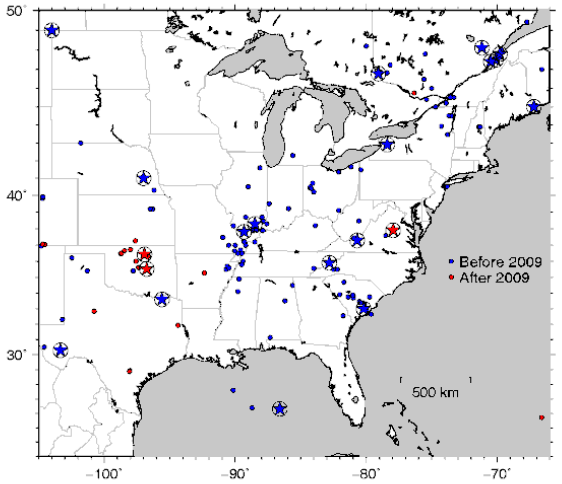




2. Instrumental network → lower rate (X2)

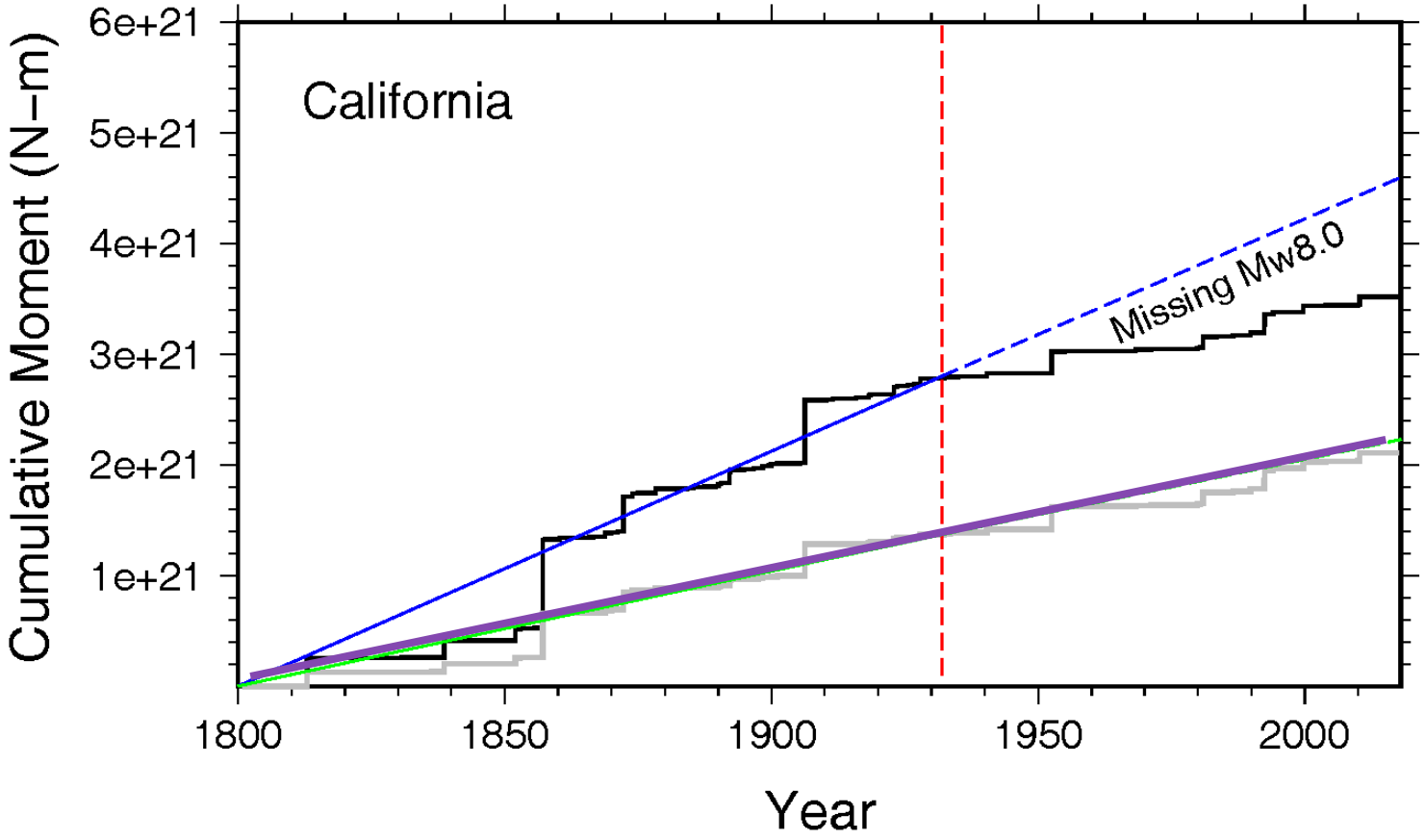
Central-Eastern North America



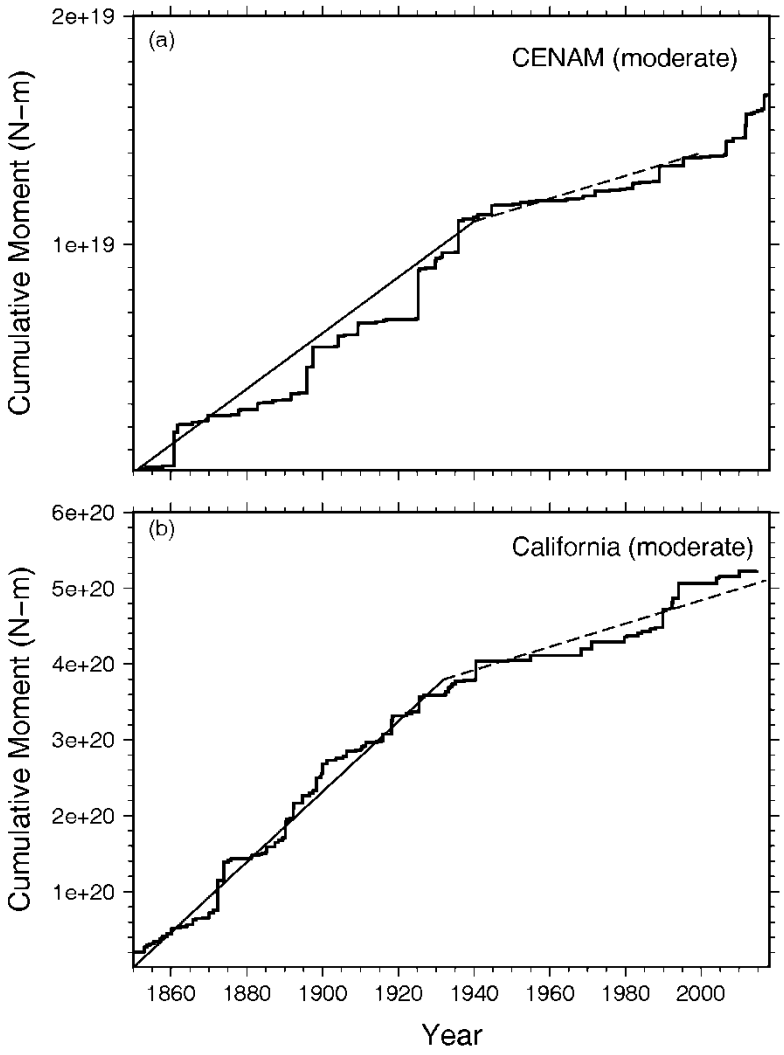


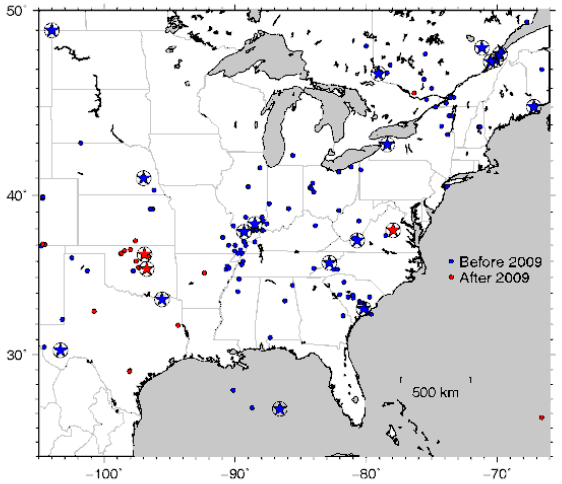
In fact…

Subtract 0.2 units from *all* < 1932 CA earthquakes…



Central-Eastern North America





Conclusions

- Many (most?) historical earthquake magnitudes overestimated;
- Stress drop variability → irreducible uncertainty

  (but you can't have your cake and eat it too);
- Some great historical earthquake magnitudes underestimated;
- Consideration of rates → magnitude of systematic bias;
- Maybe no earthquake drought in California?
- In central U.S., drought → largest New Madrid mainshock