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STATISTICAL SEISMOLOGY—Rogue earthquakes that are not ROGUE

http://mohoh.ess.ucla.edu/~kagan/Mirage.ppt
A Rogue Earthquake Off Sumatra

The magnitude ($M_w$) 8.6 earthquake of 11 April 2012 off the coast of Sumatra is one for the record books. It is far and away the largest strike-slip earthquake in the instrumental record. The $M_w$ 8.2 aftershock that occurred just over 2 hours later is also among the largest such earthquakes. Furthermore, the 11 April mainshock may be the largest intraplate earthquake ever recorded, although the location (see the figure) is consistent with the notion of a wide, diffuse plate boundary that bisects the Indo-Australian Plate near the Ninetyeast Ridge ($I$). The earthquakes are the latest in a series of large ($M_w$ 8) intraplate strike-slip earthquakes in oceanic lithosphere ($2$). What do these earthquakes reveal about earthquake physics, and how might they change earthquake hazard assessment?

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Figure 6. Plot of log aftershock zone length ($L$) against moment magnitude ($m$). Magnitude values are shifted in formulas shown in the plot ($m_r - m = 8.25$). Rupture length is determined using a 1-day aftershock pattern. Values of the correlation coefficient ($\rho$), coefficients for linear (dashed line) and quadratic (solid line) regression, standard ($\sigma$) and maximum ($\epsilon_{max}$) errors, and the total number ($n$) of aftershock sequences are shown in diagram. (a) All earthquakes, symbols are similar to Figure 2; (b) thrust earthquakes; (c) normal earthquakes; (d) strike-slip earthquakes.
Aftershocks vs moment, all earthquakes ($m_w > 7.0$, 1977–2012/04/13)

$\rho = 0.85, \quad L = 2.47 + 0.495 (m_w - 8.25)$

$\sigma = 0.131, \quad \epsilon_{\text{max}} = 0.464, \quad n = 181$

$L = 2.48 + 0.465 (m_w - 8.25) - 0.0314 (m_w - 8.25)^2$

$\sigma = 0.13, \quad \epsilon_{\text{max}} = 0.456$
Over the top. The 11 March tsunami overwhelmed a coastal seawall in Miyako City designed for lesser waves.
This map shows the estimated magnitude and long-term possibilities within 30 years of earthquakes on regions of offshore based on Jan.1, 2008.

**Graph:**

- **Title:** Subduction Zones (including orogens) of PB2002

- **Y-axis:** Number in catalog with magnitude > m
- **X-axis:** Moment magnitude, m

- **Line styles and labels:**
  - Black line: merged catalog, 1900-2002
  - Red dashed line: beta = 0.64, mc = 11
  - Yellow dashed line: beta = 0.64, mc = 9.58
  - Green dashed line: beta = 0.64, mc = 9.12

- **Events:**
  - 1963.10.13 Kuril Trench
  - 1906.01.31 Peru Trench
  - 1907.03.09 Atka Island
  - 1965.02.04 Amchitka Island
  - 1922.11.11 Chile
  - 1952.11.04 Kamchatka
  - 1964.03.28 Alaska
  - 1960.05.22 Chile

- **Inset:**
  - Log10 (Mc / 10 km)
  - Beta
  - Corner Magnitude

- **Scale ranges:**
  - X-axis: 7.0 to 10.0
  - Y-axis: 1 to 1000

- **Notations:**
  - mc: Moment Magnitude Cutoff
  - Beta: Statistical parameter in the frequency-magnitude distribution

Equations 12-14]. We calculate the maximum magnitude for the gamma distribution as

\[ m_{xg} = \frac{2}{3(1-\beta)} \left[ \log \dot{M} + \log \left( \frac{1-\beta}{\beta} \right) \right. \\
- \beta \log M_t - \log \alpha_t - \log \Gamma(2-\beta) \left. \right] - \frac{32}{3}, \tag{9} \]

where \( \Gamma \) is a gamma function, \( \alpha_t \) is the yearly number of events above the threshold level (\( \alpha = n/\Delta T \), where \( \Delta T \) is the time span of the Harvard catalog - 18.5 years), and \( \dot{M} \) is a geologic rate of deformation (Nm/yr). For the \( \beta \) range of 0.5-0.9, \( \log \Gamma(2-\beta) \) is almost constant, equal to \(-0.852 \approx -0.33 \) for different
GCMT, subduction zones, 1977–1995/6/30: Corner magnitude ($M_c$) distribution, BK2004

- FE #1, Alaska–Aleutian Arc
- FE #5, Mexico–Guatemala
- FE #6, Central America
- FE #7, Caribbean Loop
- FE #8, Andean S. America
- FE #12, Kermadec–Tonga–Samoa
- FE #13, Fiji Is
- FE #14, New Hebrides Is
- FE #15, Bismarck–Solomon Is
- FE #16, New Guinea
- FE #18, Guam–Japan
- FE #19, Japan–Kamchatka
- FE #20, Japan–Ryukyu Is
- FE #21, Taiwan
- FE #22, Philippines
- FE #23, Borneo–Celebes
- FE #24, Sunda Arc
- FE #46, Andaman Is–Sumatra

$\langle M_c \rangle = 7.69$  
$\langle M_c \rangle = 9.42$

Maximum registered earthquakes 1977–1995/6/30; $M_c \pm 1.96^*\sigma$
CENT, $M_t=6.5$; subduction zones, 1900–1976: Corner magnitude ($M_C$) distribution, BK2004

- FE #1, Alaska–Aleutian Arc
- FE #5, Mexico–Guatemala
- FE #6, Central America
- FE #7, Caribbean Loop
- FE #8, Andean S. America
- FE #12, Kermadec–Tonga–Samoa
- FE #13, Fiji Is
- FE #14, New Hebrides Is
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$\langle M_x \rangle = 8.17$
$\langle M_C \rangle = 9.55$

Maximum registered earthquakes 1900–1976; $M_C +/− 1.96^*\sigma$
End
Thank you
SUB: Subduction Zones (excluding orogens) of PB2002

- CMT catalog, Jan1977-Sep2002
- $\beta = 0.64$, $mc = 9.1$ (red line)
- $\beta = 0.64$, $mc = 8.2$ (yellow line)
- $\beta = 0.64$, $mc = 7.96$ (green line)

- Events:
  - 1977.06.22 Tonga Trench
  - 1979.12.12 Columbia Trench
  - 1996.02.17 New Guinea Trench
  - 1994.10.04 Kurile Trench
  - 1977.08.19 Java Trench
  - 2001.06.23 Peru Trench

Number in catalog with magnitude $m$ vs. Moment magnitude, $m$

**Figure 6.** Regional distribution of $m_{xzg}$ values in seismic zones. Solid lines are average $m_{xzg}$ for classes of zones, dashed line is the global $m_{xzg}$ average. Legend: star, $m_{xzg}$ estimate; circle, $m_{xzg} - 1.96\sigma_m$; cross, $m_{xzg} + 1.96\sigma_m$. 
\[ \rho = 0.8, \quad L = 2.47 + 0.473m_w, \quad \sigma = 0.122, \quad \varepsilon_{\text{max}} = 0.314, \quad n = 91 \]

\[ L = 2.45 + 0.401m_w - 0.0538m_w^2, \quad \sigma = 0.121, \quad \varepsilon_{\text{max}} = 0.311, \quad n = 91 \]
\[ \rho = 0.81, \quad L = 2.45 + 0.473m_w, \quad \sigma = 0.116, \quad \varepsilon_{\text{max}} = 0.302, \quad n = 64 \]

\[ L = 2.43 + 0.382m_w - 0.0666m_w^2, \quad \sigma = 0.116, \quad \varepsilon_{\text{max}} = 0.299, \quad n = 64 \]
\[ \rho = 0.96, \quad L = 2.44 + 0.524m_w, \quad \sigma = 0.069, \quad \varepsilon_{\text{max}} = 0.113, \quad n = 8 \]

\[ L = 2.42 + 0.345m_w - 0.157m_w^2, \quad \sigma = 0.0618, \quad \varepsilon_{\text{max}} = 0.103, \quad n = 8 \]
\( \rho = 0.75, \quad L = 2.52 + 0.457m_{\sigma}, \quad \sigma = 0.135, \quad \epsilon_{\text{max}} = 0.271, \quad n = 19 \)

\[ L = 2.58 + 0.686m_{\sigma} + 0.166m_{\sigma}^2, \quad \sigma = 0.134, \quad \epsilon_{\text{max}} = 0.296, \quad n = 19 \]
Aftershocks vs moment, all earthquakes ($m_w > 7.0$, 1977–2011/08/14)

\[ \rho = 0.83, \ L = 2.47 + 0.488 (m_w - 8.25) \]
\[ \sigma = 0.133, \ \varepsilon_{\text{max}} = 0.465, \ n = 172 \]
\[ L = 2.47 + 0.456 (m_w - 8.25) + -0.0342 (m_w - 8.25)^2 \]
\[ \sigma = 0.133, \ \varepsilon_{\text{max}} = 0.457 \]
GCMT catalog, subduction zones, 1977–2010/12/31: β distribution

<β> = 0.654

FE # 1, Alaska–Aleutian Arc
FE # 5, Mexico–Guatemala
FE # 6, Central America
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FE #13, Fiji Is
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FE #18, Guam–Japan
FE #19, Japan–Kamchatka
FE #20, Japan–Ryukyu Is
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FE #22, Philippines
FE #23, Borneo–Celebes
FE #24, Sunda Arc
FE #46, Andaman Is–Sumatra
GCMT, subduction zones, 1977–2010/12/31: Corner magnitude ($m_c$) distribution, BK2004

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FE # 19, Japan–Kamchatka
FE # 20, Japan–Ryukyu Is
FE # 21, Taiwan
FE # 22, Philippines
FE # 23, Borneo–Celebes
FE # 24, Sunda Arc
FE #46, Andaman Is–Sumatra

Maximum observed earthquakes 1977–1995/6/30–2010/12/31; $m_c +/− 1.96*σ$
This map shows the estimated magnitude and long-term possibilities within 30 years of earthquakes on regions of offshore based on Jan.1, 2008.