Yan Y. Kagan

Dept. Earth and Space Sciences, UCLA, Los Angeles, CA 90095-1567, ykagan@ucla.edu, http://eq.ess.ucla.edu/~kagan/kagan.html

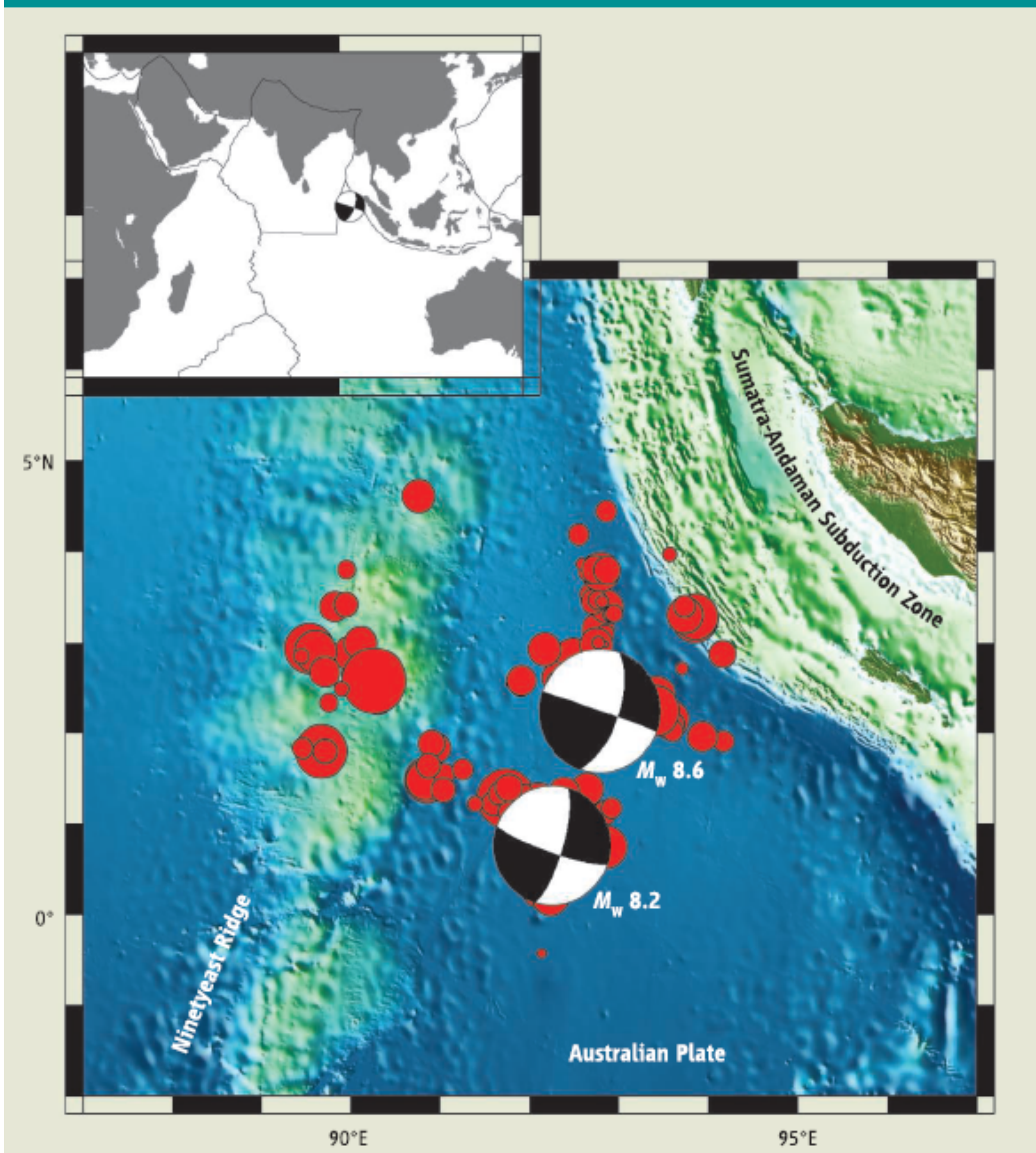
STATISTICAL SEISMOLOGY– Rogue earthquakes that are not ROGUE

http://moho.ess.ucla.edu/~kagan/Mirage.ppt

GEOPHYSICS

A Rogue Earthquake Off Sumatra

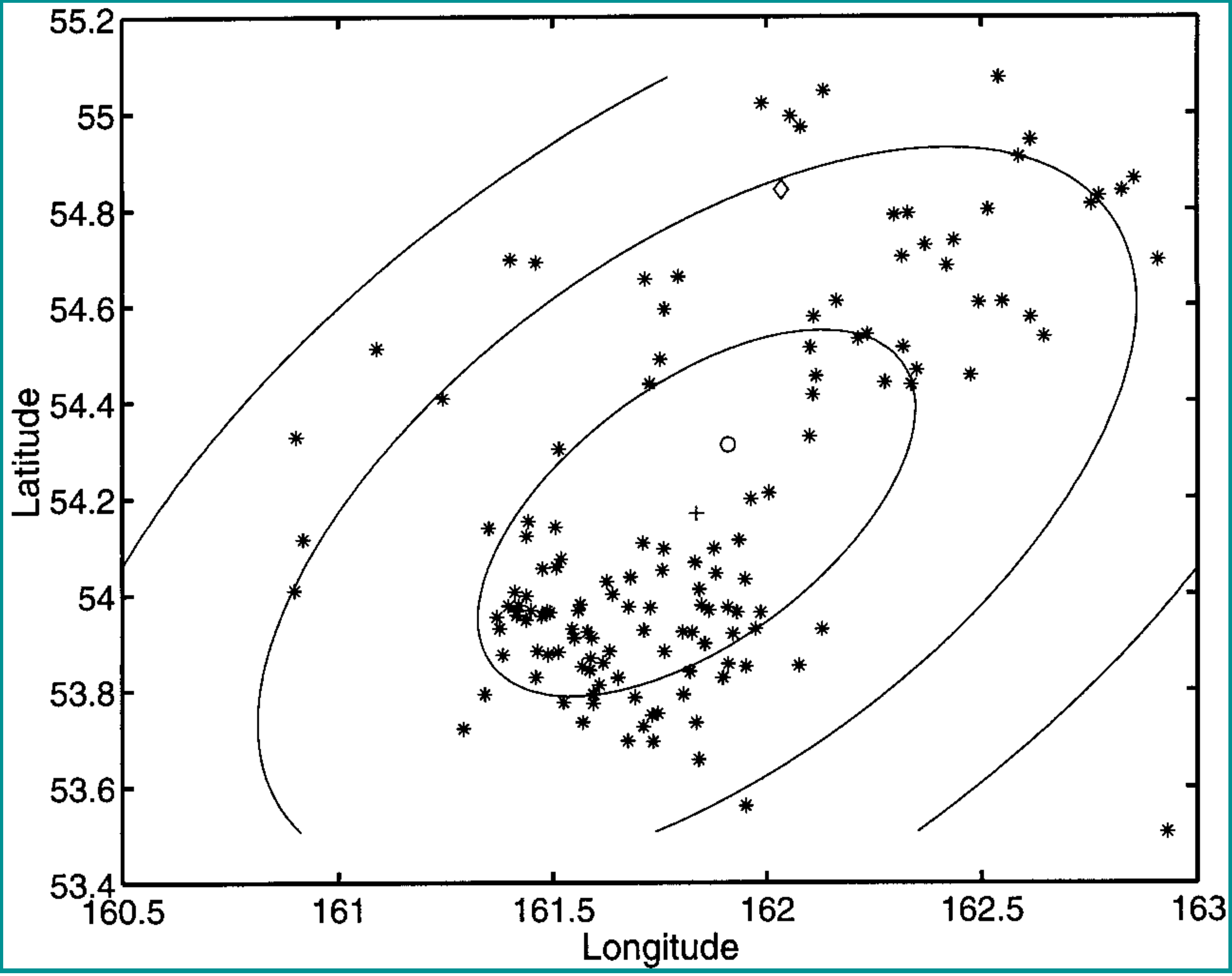
Jeffrey J. McGuire[1] and Gregory C. Beroza[2]



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 (*1*). 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?

Science, 336, 1118, 2012

Kagan, Y. Y., 2002. Aftershock zone scaling, Bull. Seismol. Soc. Amer., 92, 641-655.



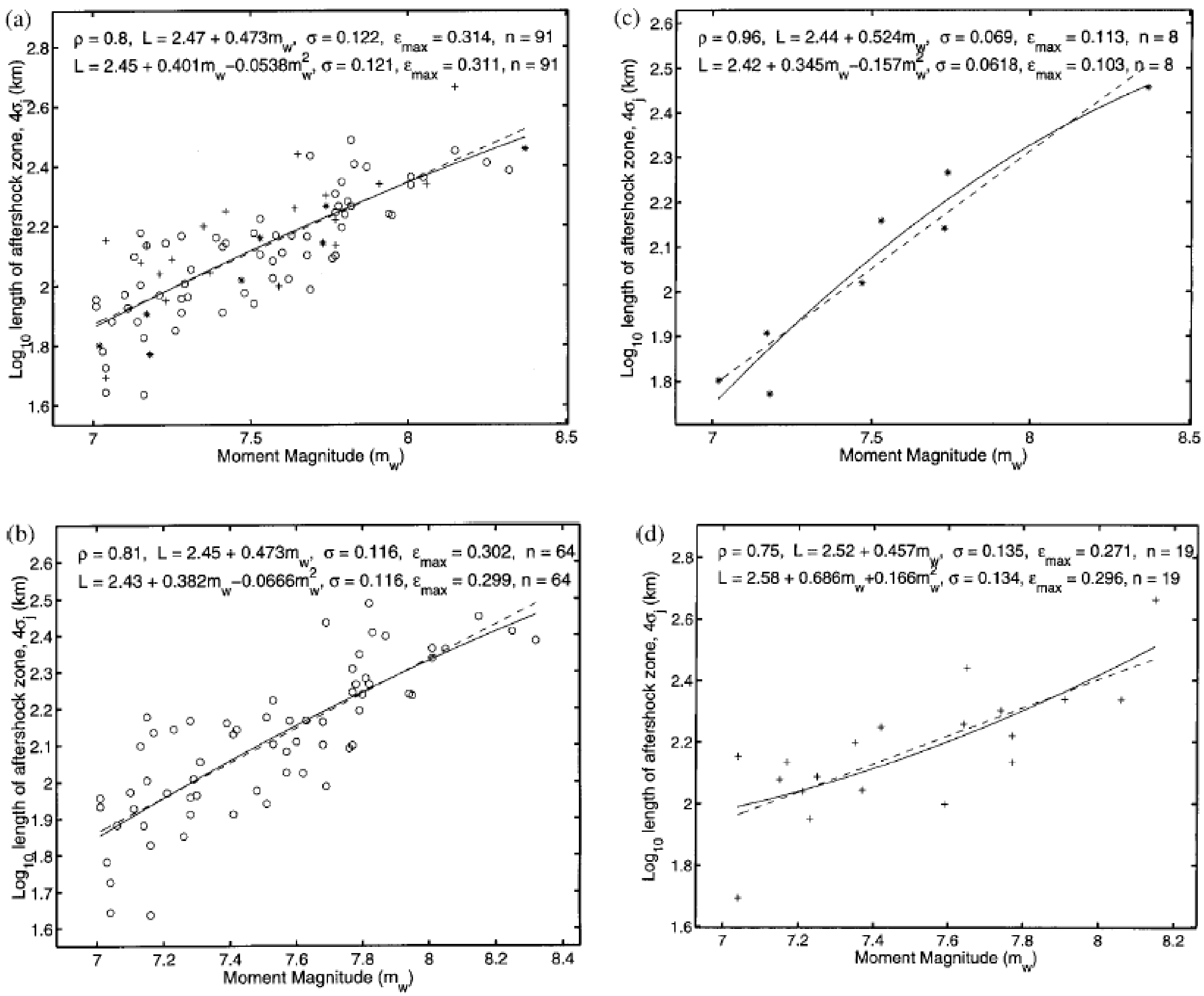
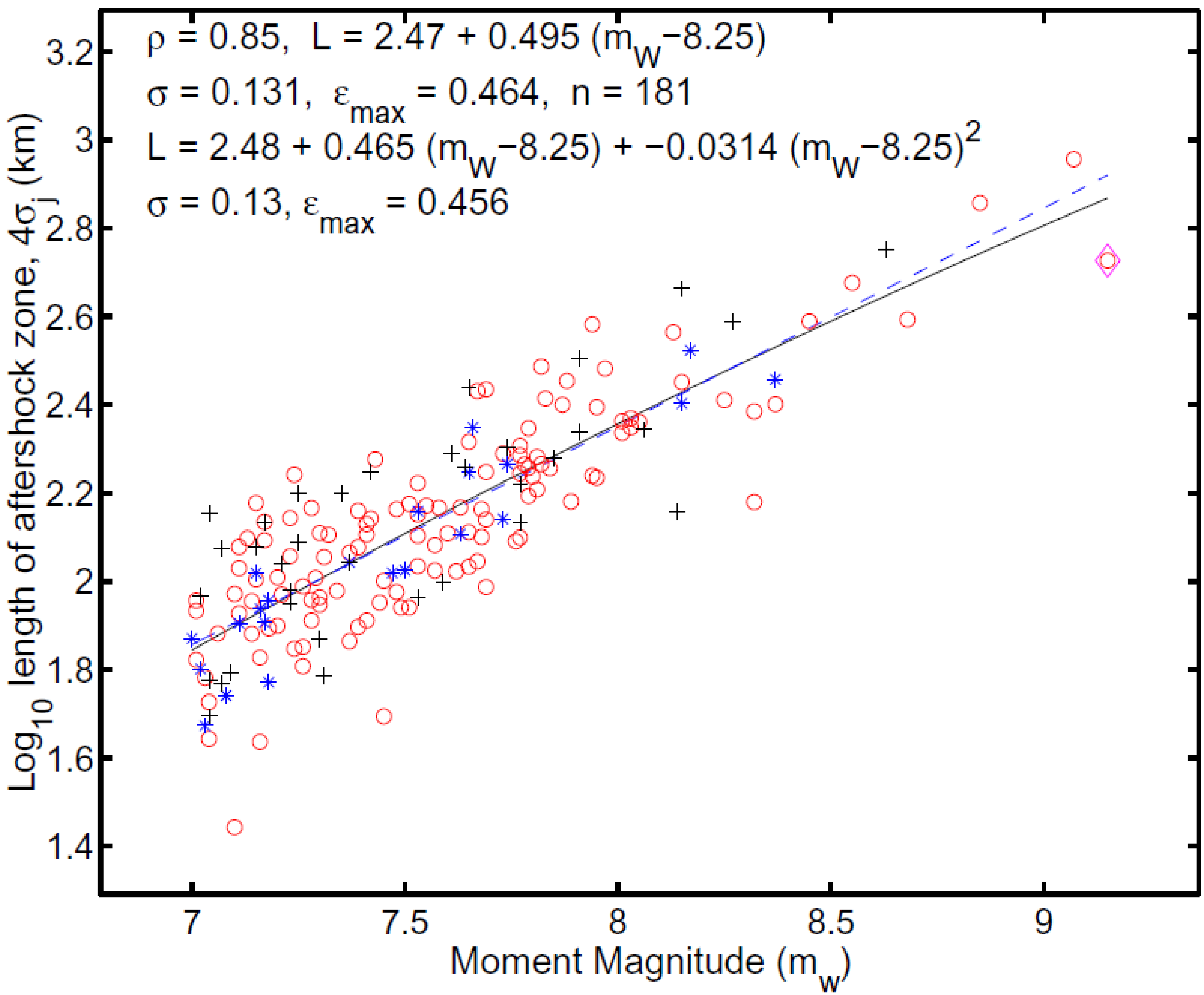


Figure 6. Plot of log aftershock zone length (L) against moment magnitude (m). Magnitude values are shifted in formulas shown in the plot ($m_r = m - 8.25$). Rupture length is determined using a 1-day aftershock pattern. Values of the correlation coefficient (ρ), coefficients for linear (dashed line) and quadratic (solid line) regression, standard (σ) and maximum (ε_{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.

Kagan, Y. Y., 2002. Aftershock zone scaling, Bull. Seismol. Soc. Amer., 92, 641-655.

Aftershocks vs moment, all earthquakes (m_w > 7.0, 1977−2012/04/13)

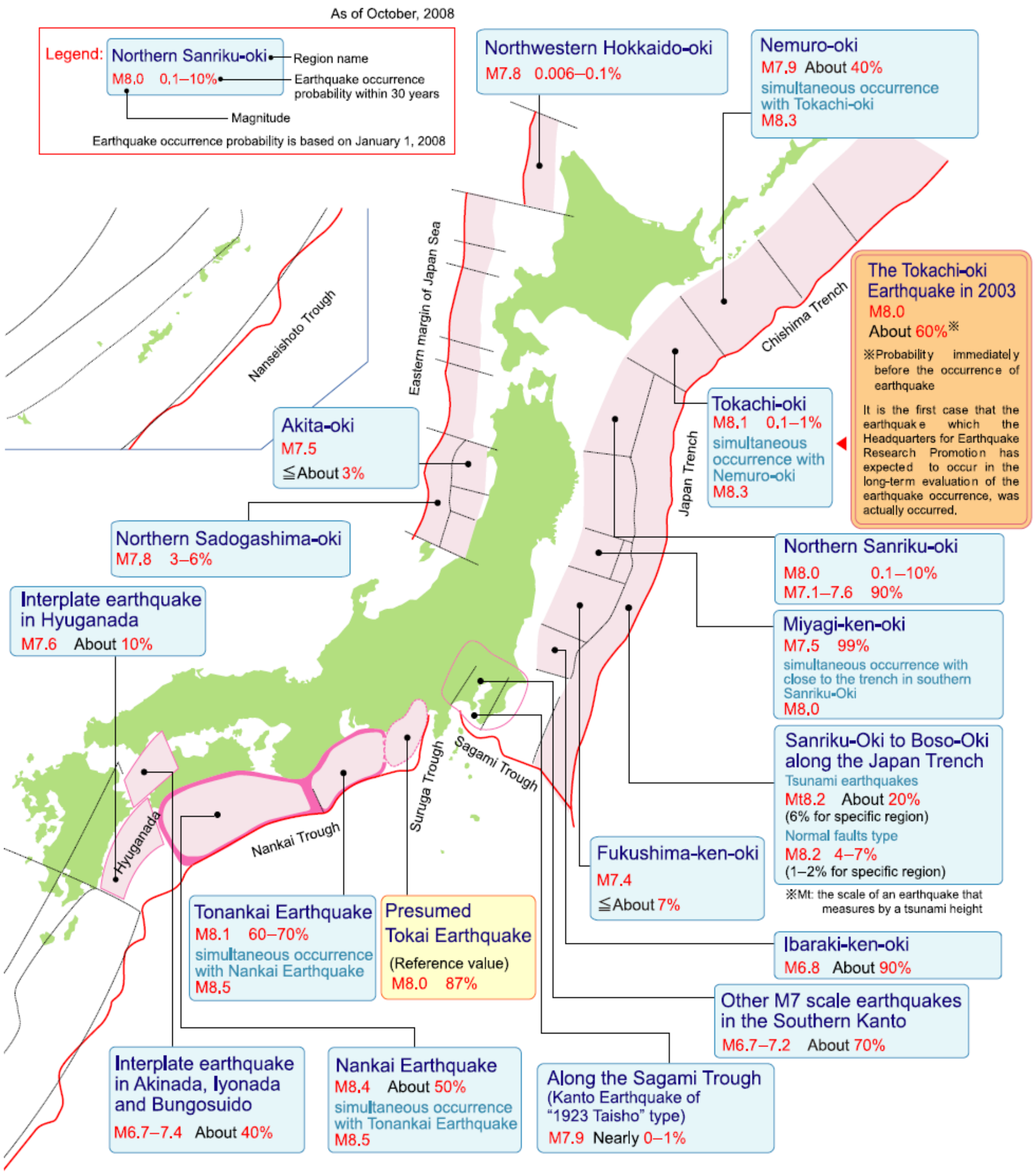


Tohoku M9 earthquake and tsunami

Over the top. The 11 March tsunami overwhelmed a coastal seawall in Miyako City designed for lesser waves.

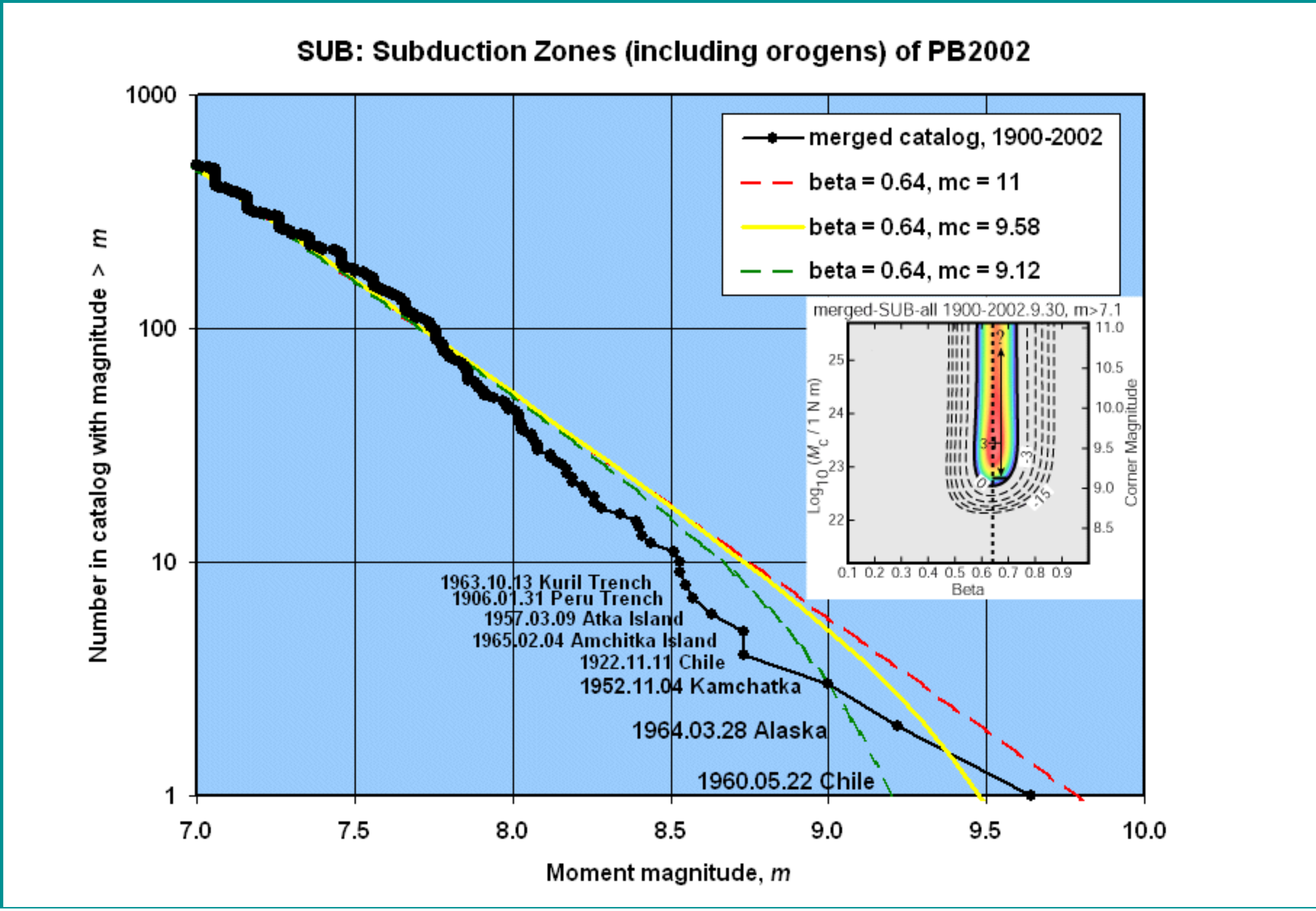
Evaluation of Major Subduction-zone Earthquakes

The Headquarters for Earthquake Research Promotion
地震調査研究推進本部



This map shows the estimated magnitude and long-term possibilities within 30 years of earthquakes on regions of offshore based on Jan.1, 2008.

Bird, P., and Y. Y. Kagan, BSSA, 94(6), 2380, 2004.

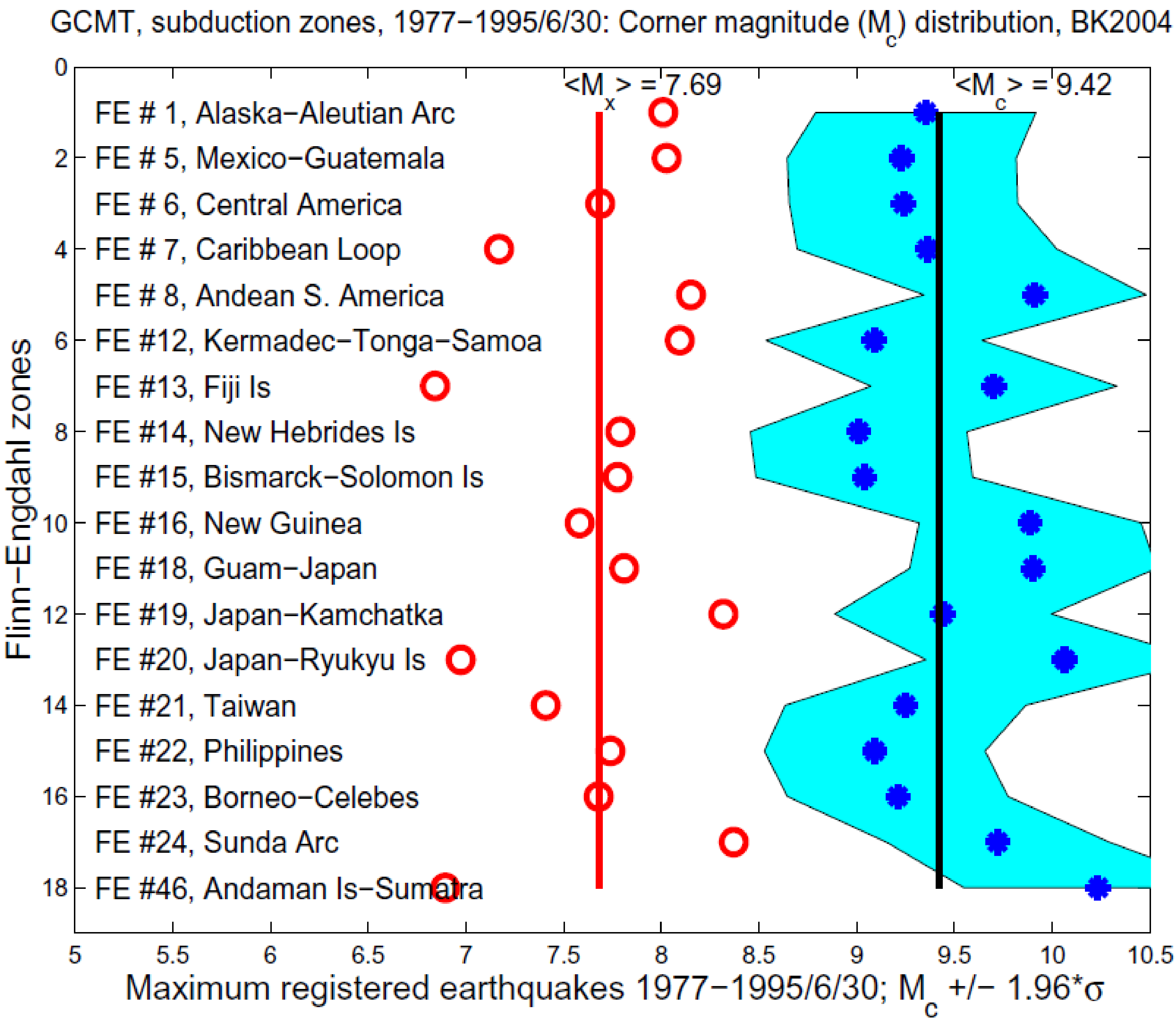


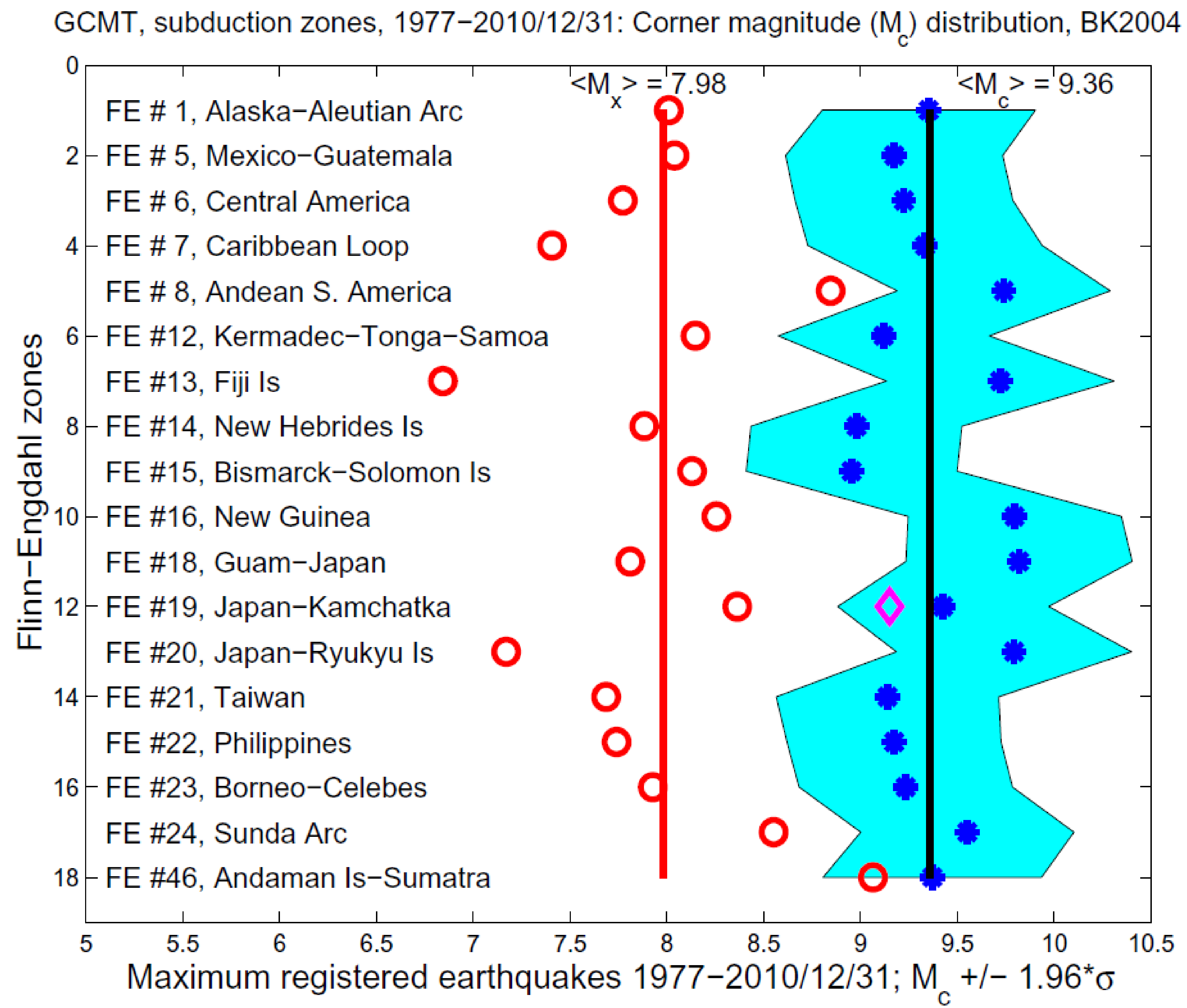
Kagan, Y. Y., 1997. Seismic moment-frequency relation for shallow earthquakes: Regional comparison, J. Geophys. Res., 102, 2835-2852.

equations 12–14]. We calculate the maximum magnitude for the gamma distribution as

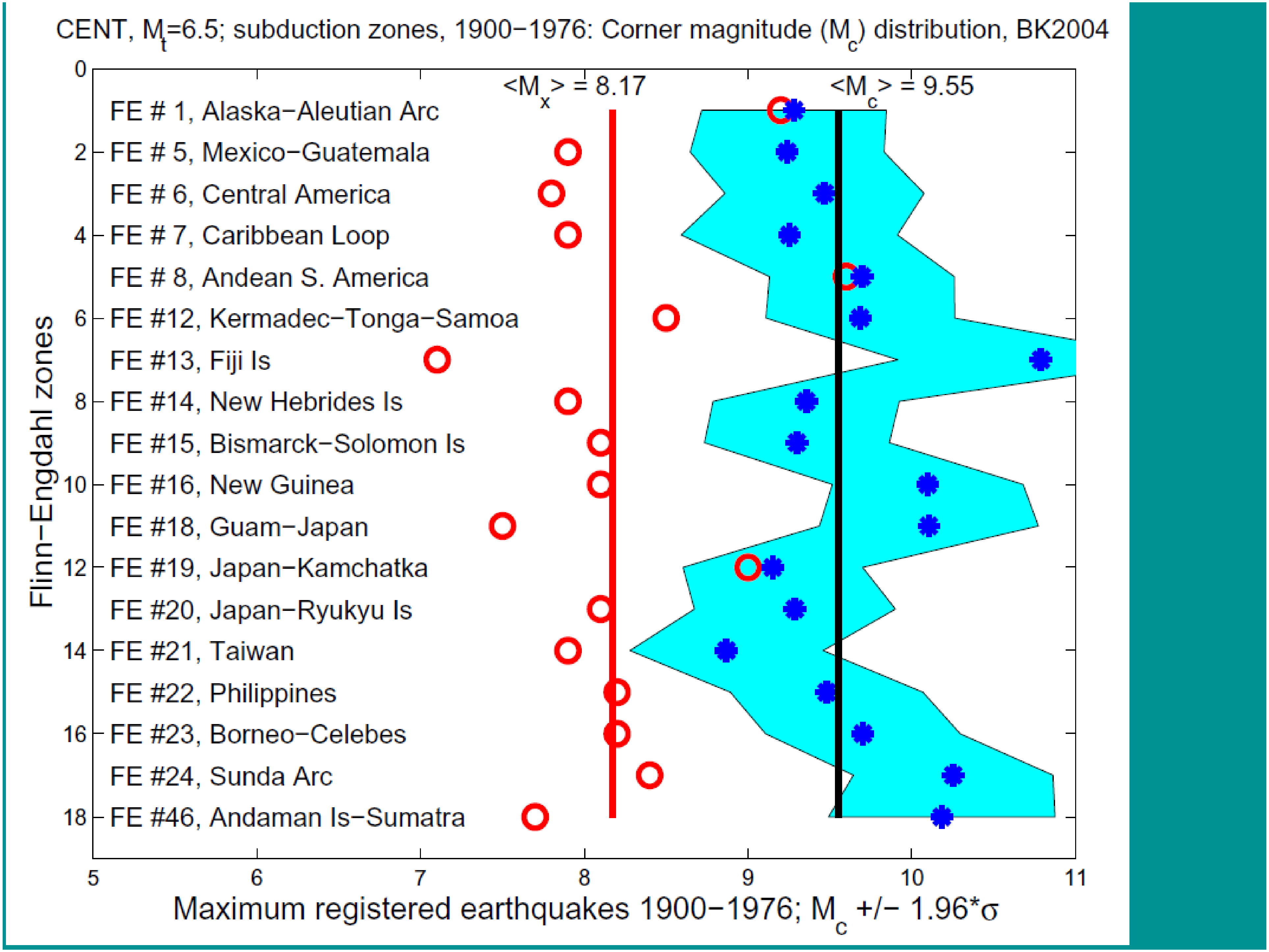
$$m_{xg} = \frac{2}{3(1-\beta)}\left[\lg \dot{M} + \lg\left(\frac{1-\beta}{\beta}\right) - \beta \lg M_t - \lg \alpha_t - \lg \Gamma(2-\beta)\right] - \frac{32}{3}, \qquad (9)$$

where Γ is a gamma function, α_t is the yearly number of events above the threshold level ($\alpha = n/\Delta T$, where ΔT is the time span of the Harvard catalog – 18.5 years), and $\dot{M}$ is a geologic rate of deformation (N m/yr). For the β range of 0.5–0.9, $\lg\Gamma(2-\beta)$ is almost


GCMT, subduction zones, 1977−1995/6/30: Corner magnitude (M_c) distribution, BK2004
<M_x> = 7.69
<M_c> = 9.42
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
Flinn−Engdahl zones
0
2
4
6
8
10
12
14
16
18
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
Maximum registered earthquakes 1977−1995/6/30; M_c +/− 1.96*σ



GCMT, subduction zones, 1977−2010/12/31: Corner magnitude (M_c) distribution, BK2004
$<M_x> = 7.98$
$<M_c> = 9.36$
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
Flinn−Engdahl zones
0
2
4
6
8
10
12
14
16
18
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
Maximum registered earthquakes 1977−2010/12/31; M_c +/− 1.96*σ

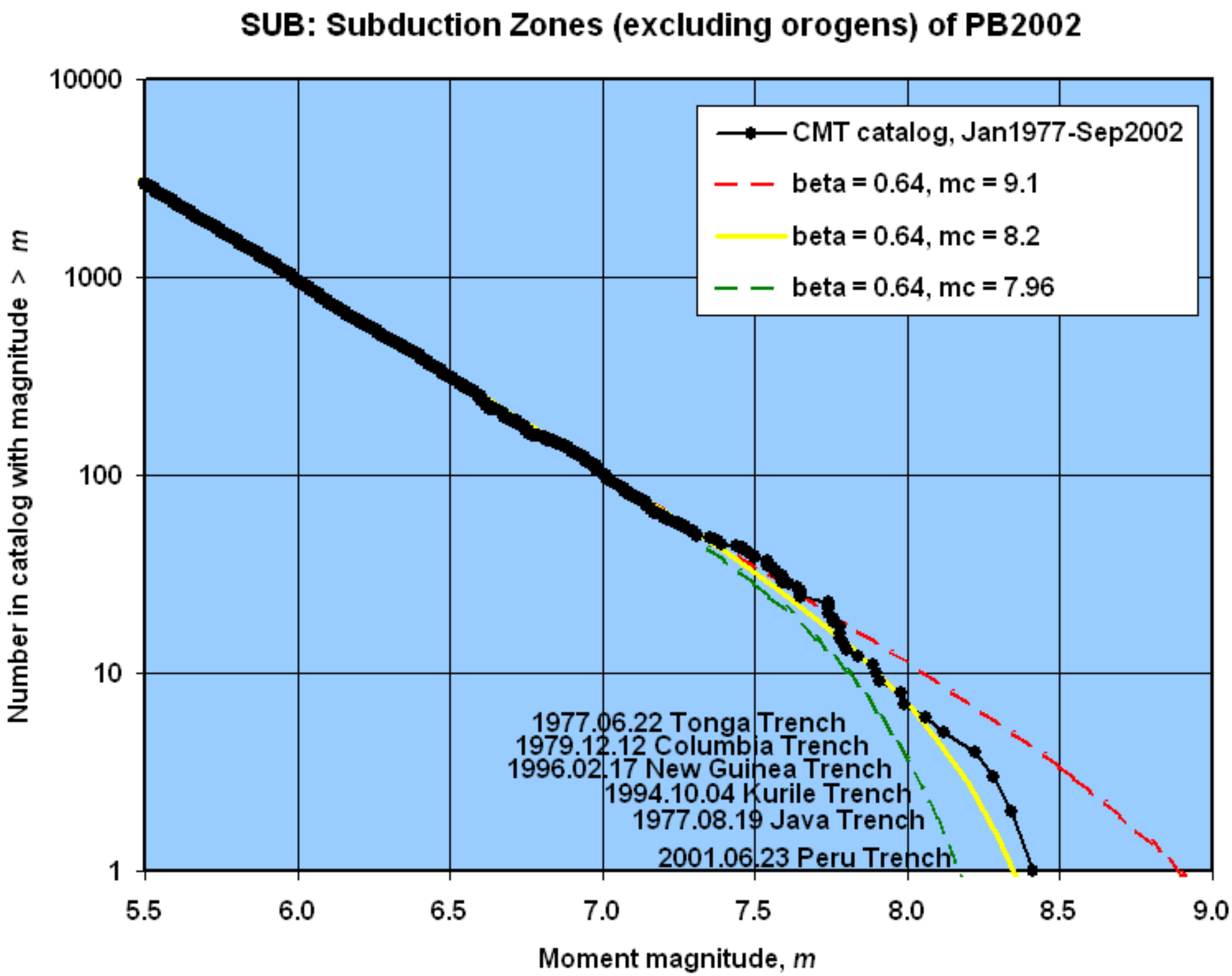


CENT, M_t=6.5; subduction zones, 1900−1976: Corner magnitude (M_c) distribution, BK2004
$\langle M_x \rangle = 8.17$
$\langle M_c \rangle = 9.55$
FE # 1, Alaska−Aleutian Arc
FE # 5, Mexico−Guatemala
FE # 6, Central America
FE # 7, Caribbean Loop
FE # 8, Andean S. America
FE #12, Kermadec−Tonga−Samoa
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
Flinn−Engdahl zones
0
2
4
6
8
10
12
14
16
18
5
6
7
8
9
10
11
Maximum registered earthquakes 1900−1976; M_c +/− 1.96*σ

End

Thank you

Bird, P., and Y. Y. Kagan, BSSA, 94(6), 2380, 2004.



Kagan, Y. Y., 1997. Seismic moment-frequency relation for shallow earthquakes: Regional comparison, J. Geophys. Res., 102, 2835-2852.

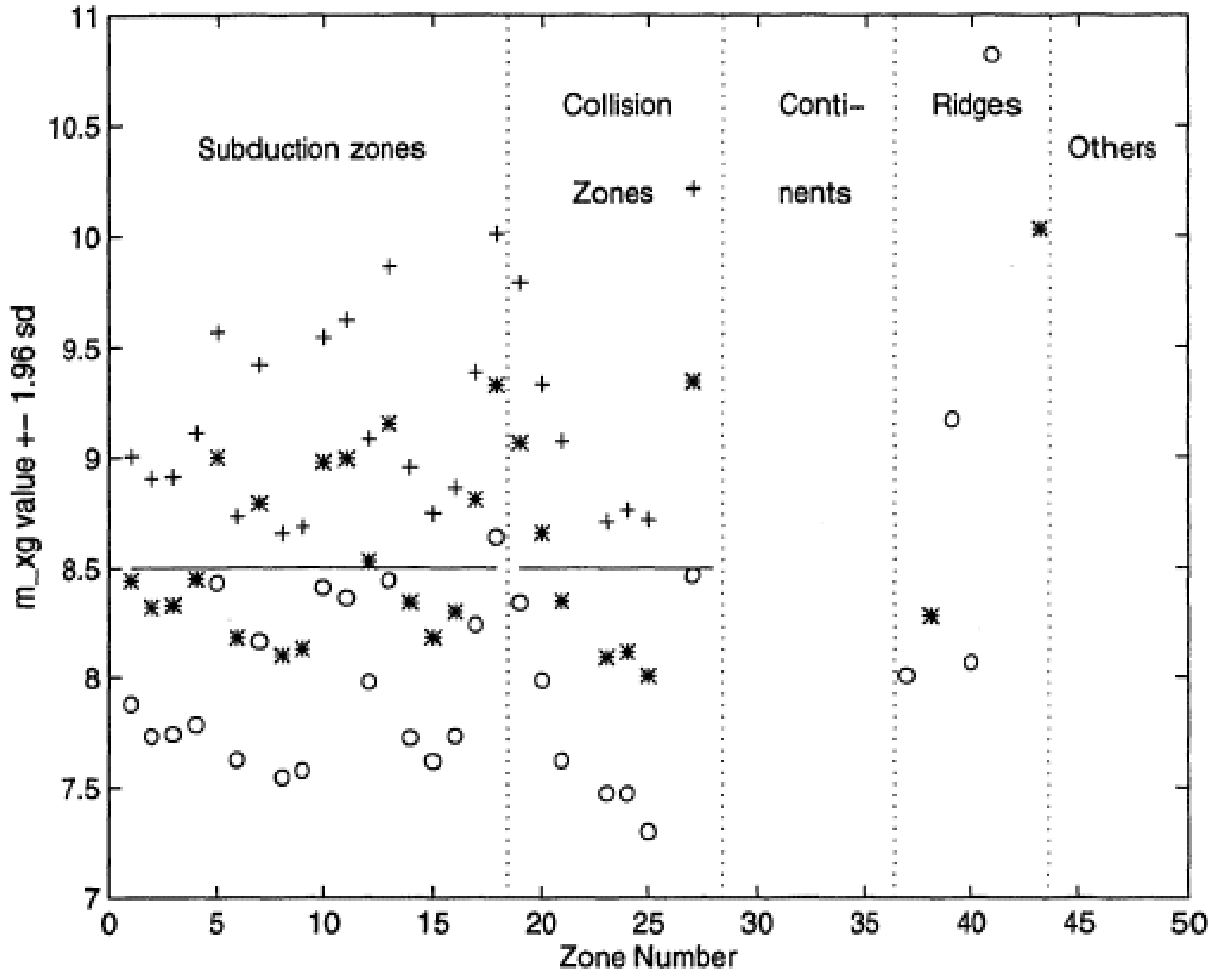
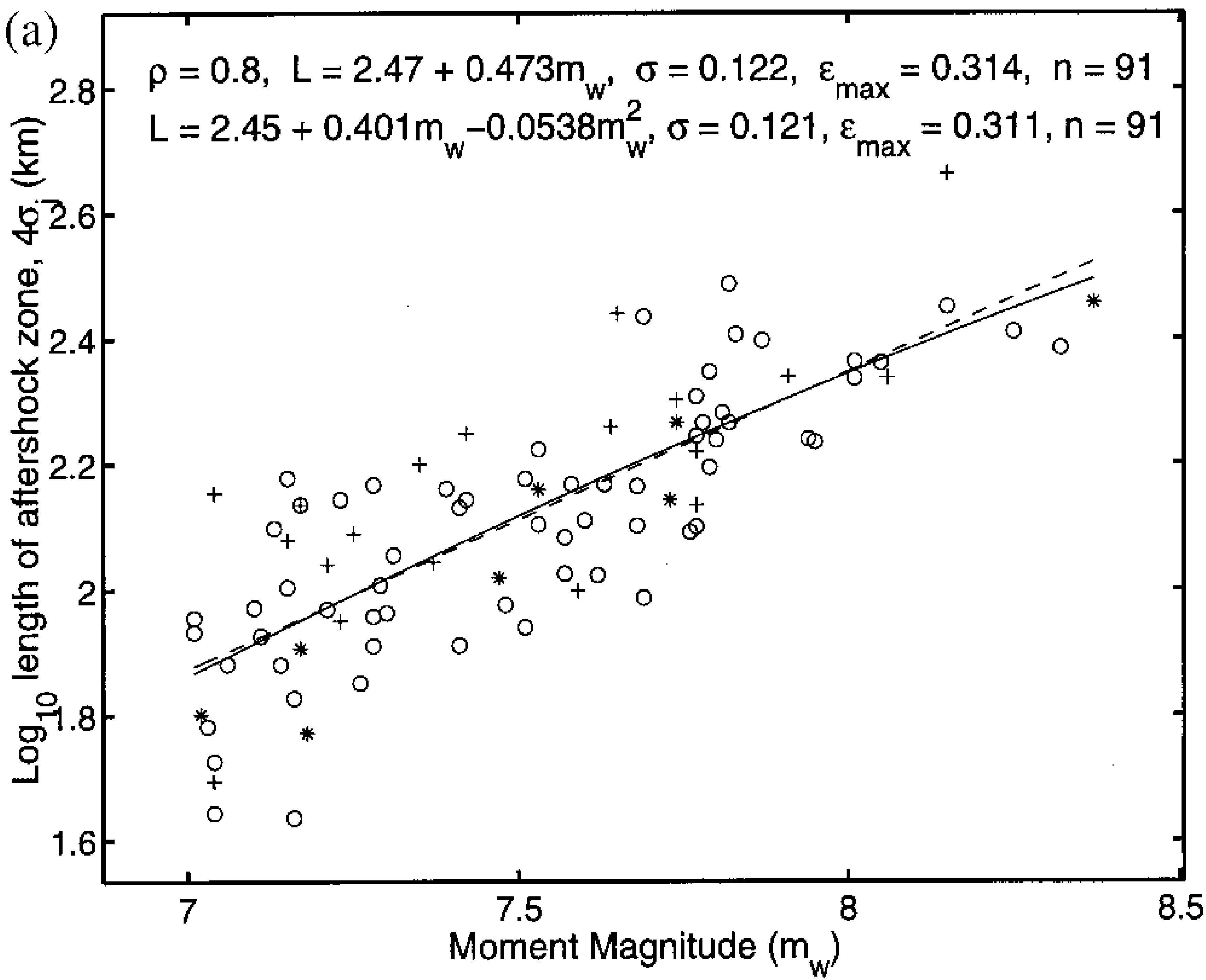
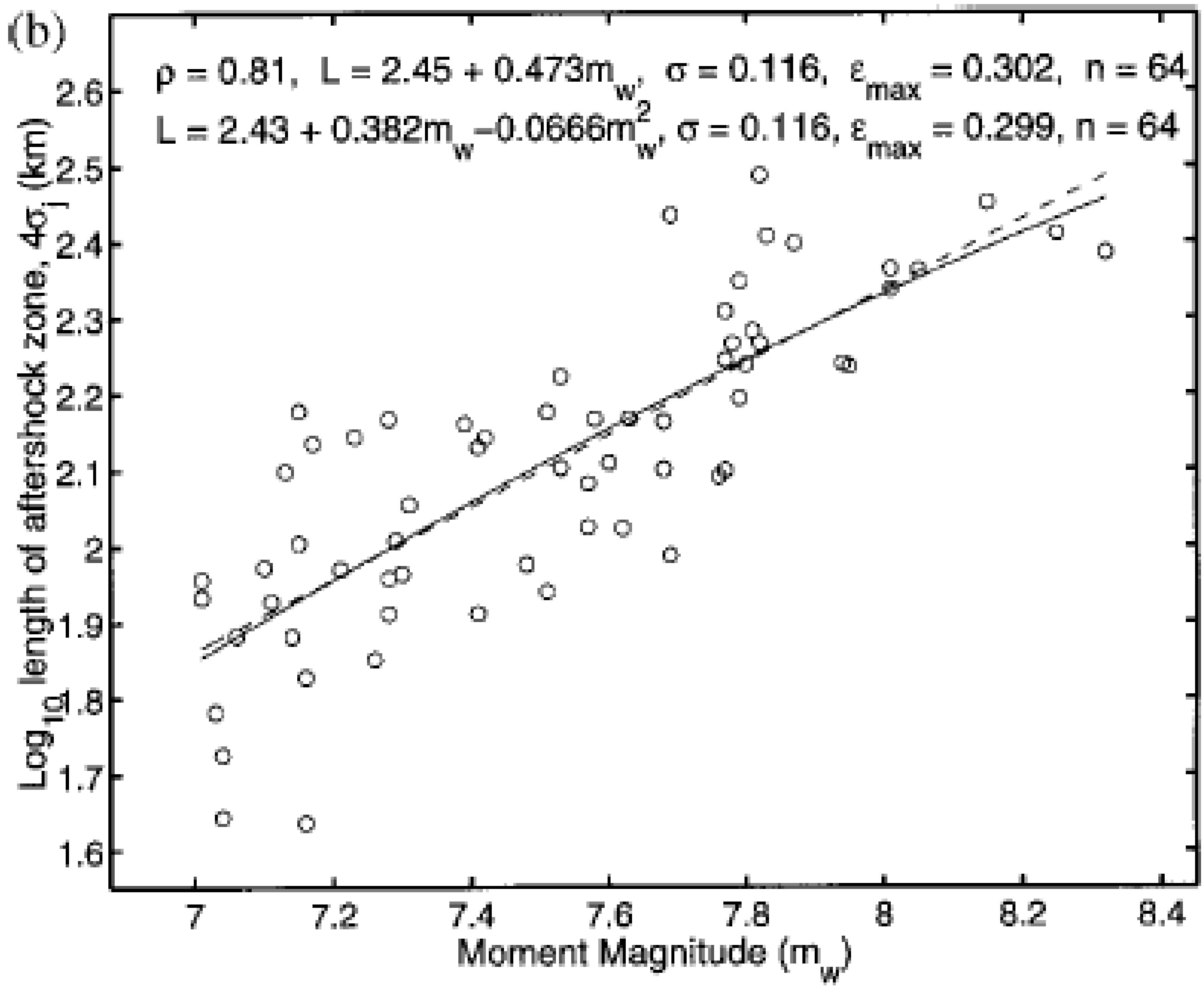
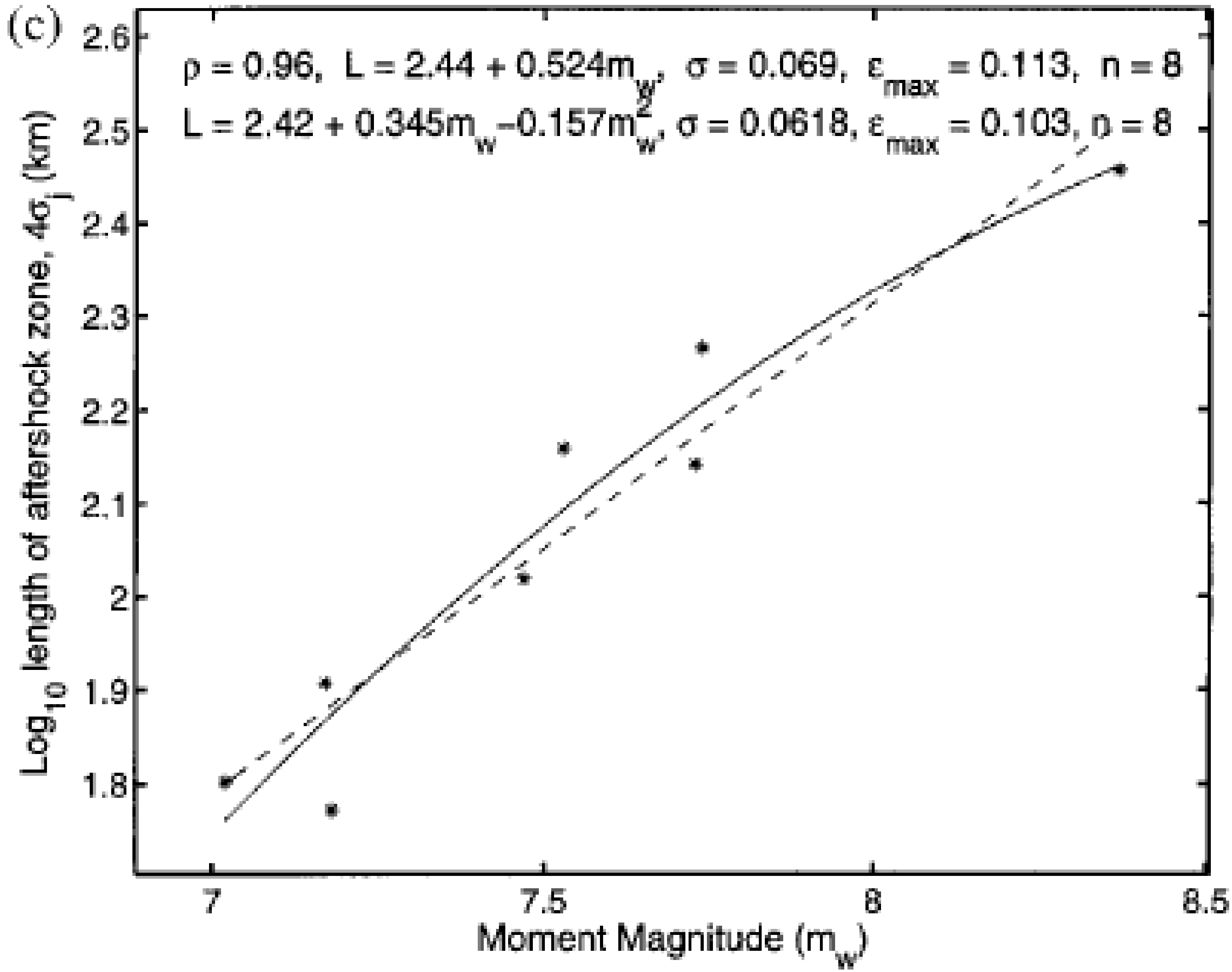


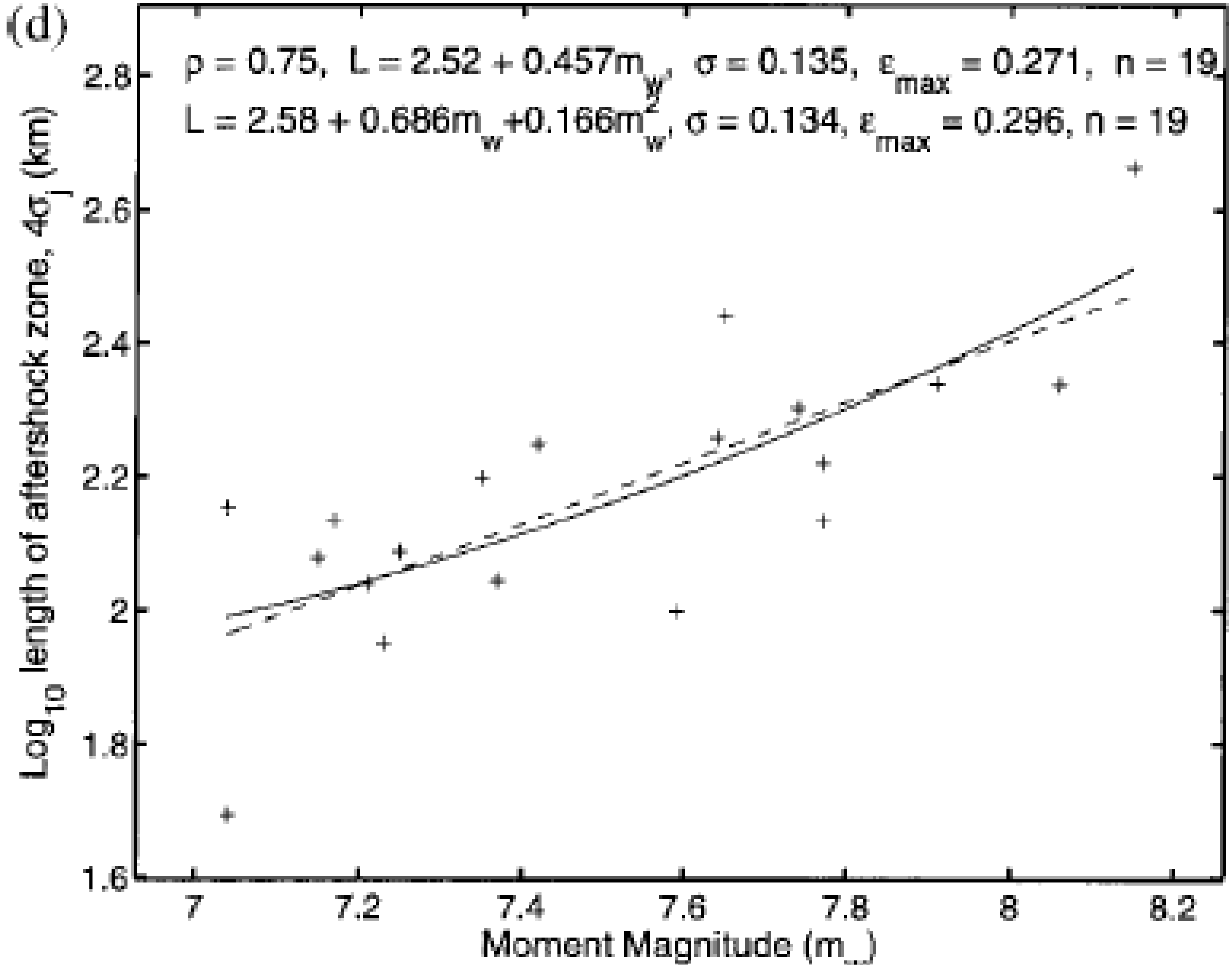
Figure 6. Regional distribution of m_{xg} values in seismic zones. Solid lines are average m_{xg} for classes of zones, dashed line is the global m_{xg} average. Legend: star, m_{xg} estimate; circle, $m_{xg} - 1.96\sigma_m$; cross, $m_{xg} + 1.96\sigma_m$.


(a)
ρ = 0.8, L = 2.47 + 0.473m_w, σ = 0.122, ε_max = 0.314, n = 91
L = 2.45 + 0.401m_w − 0.0538m_w^2, σ = 0.121, ε_max = 0.311, n = 91
Log10 length of aftershock zone, 4σ_l (km)
2.8
2.6
2.4
2.2
2
1.8
1.6
7
7.5
8
8.5
Moment Magnitude (m_w)

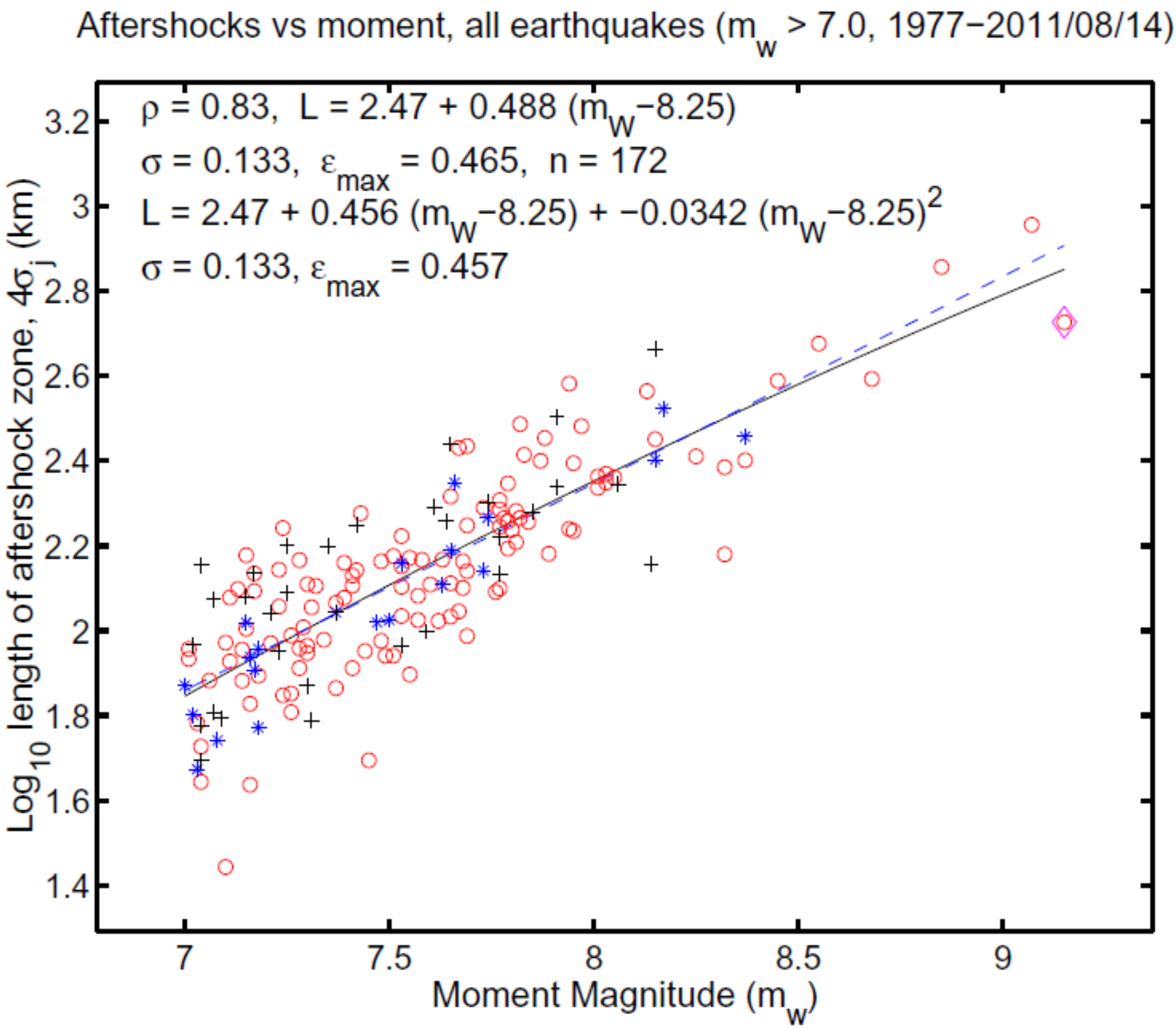


(b)
ρ = 0.81, L = 2.45 + 0.473m_w, σ = 0.116, ε_max = 0.302, n = 64
L = 2.43 + 0.382m_w −0.0666m_w^2, σ = 0.116, ε_max = 0.299, n = 64
Log10 length of aftershock zone, 4σ_l (km)
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
7
7.2
7.4
7.6
7.8
8
8.2
8.4
Moment Magnitude (m_w)

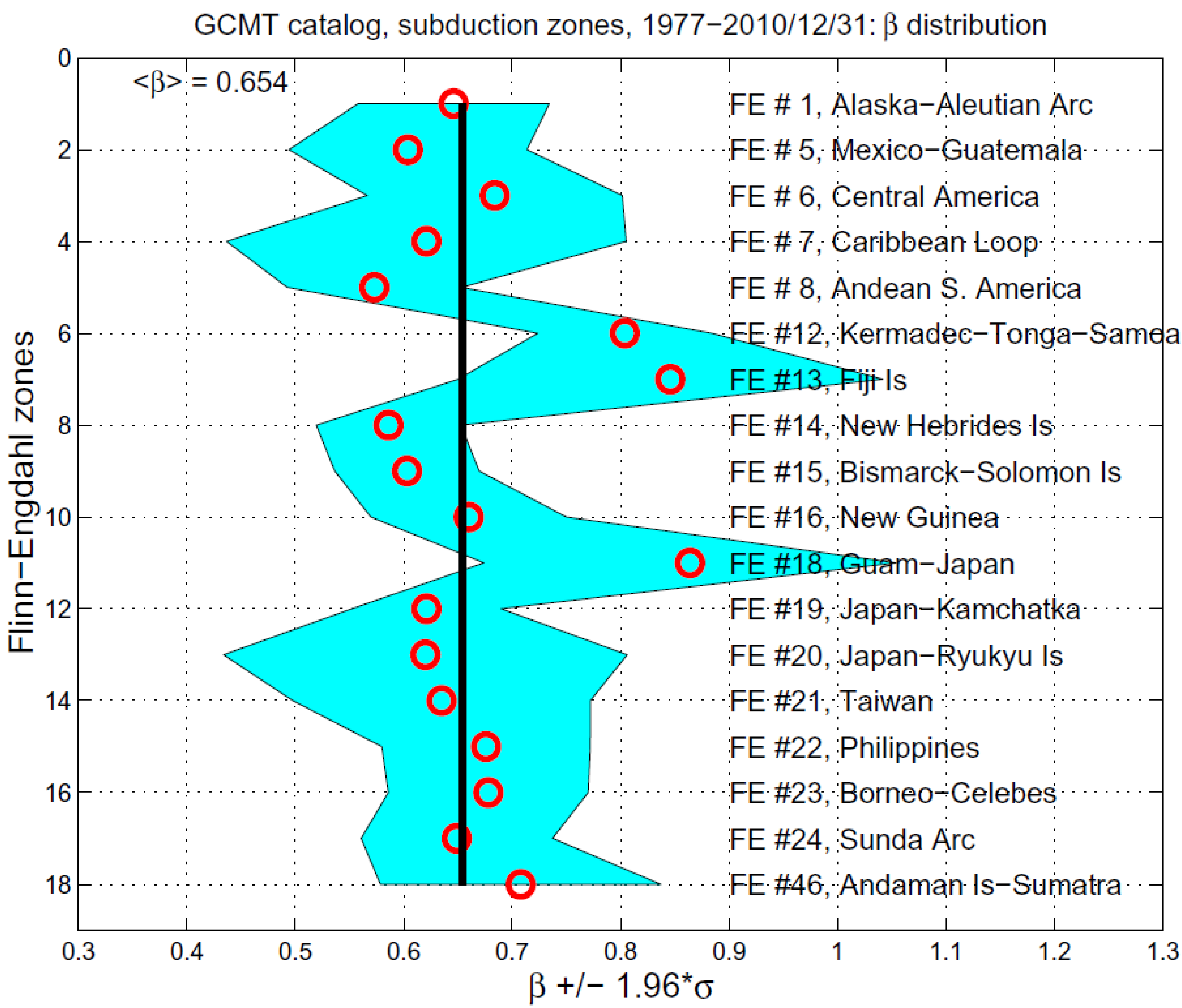

(c)
ρ = 0.96, L = 2.44 + 0.524m_w, σ = 0.069, ε_max = 0.113, n = 8
L = 2.42 + 0.345m_w − 0.157m_w^2, σ = 0.0618, ε_max = 0.103, n = 8
Log10 length of aftershock zone, 4σ_j (km)
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
7
7.5
8
8.5
Moment Magnitude (m_w)

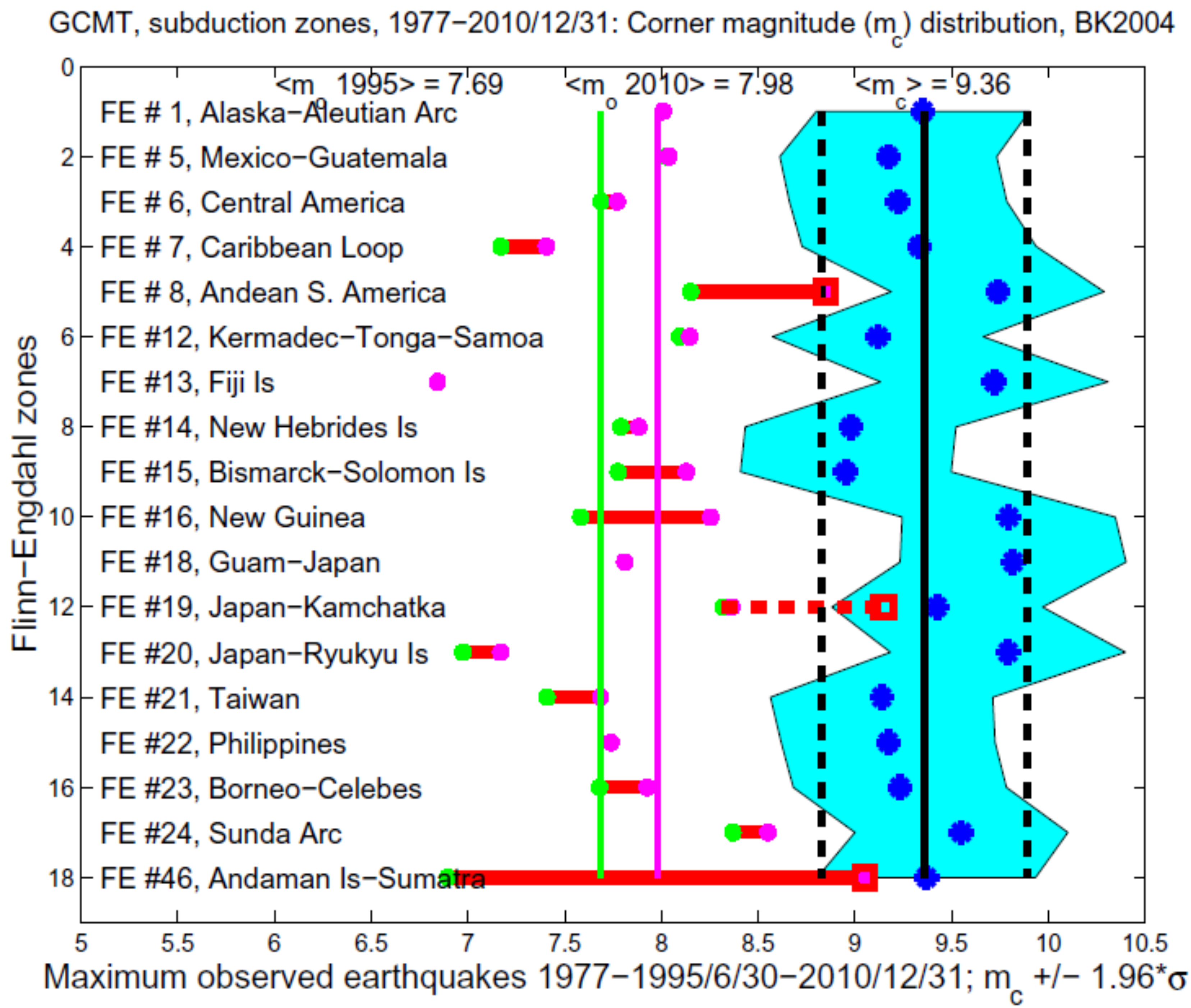


(d)
ρ = 0.75, L = 2.52 + 0.457m_w, σ = 0.135, ε_max = 0.271, n = 19
L = 2.58 + 0.686m_w + 0.166m_w^2, σ = 0.134, ε_max = 0.296, n = 19
Log10 length of aftershock zone, 4σ_j (km)
2.8
2.6
2.4
2.2
2
1.8
1.6
7
7.2
7.4
7.6
7.8
8
8.2
Moment Magnitude (m_w)

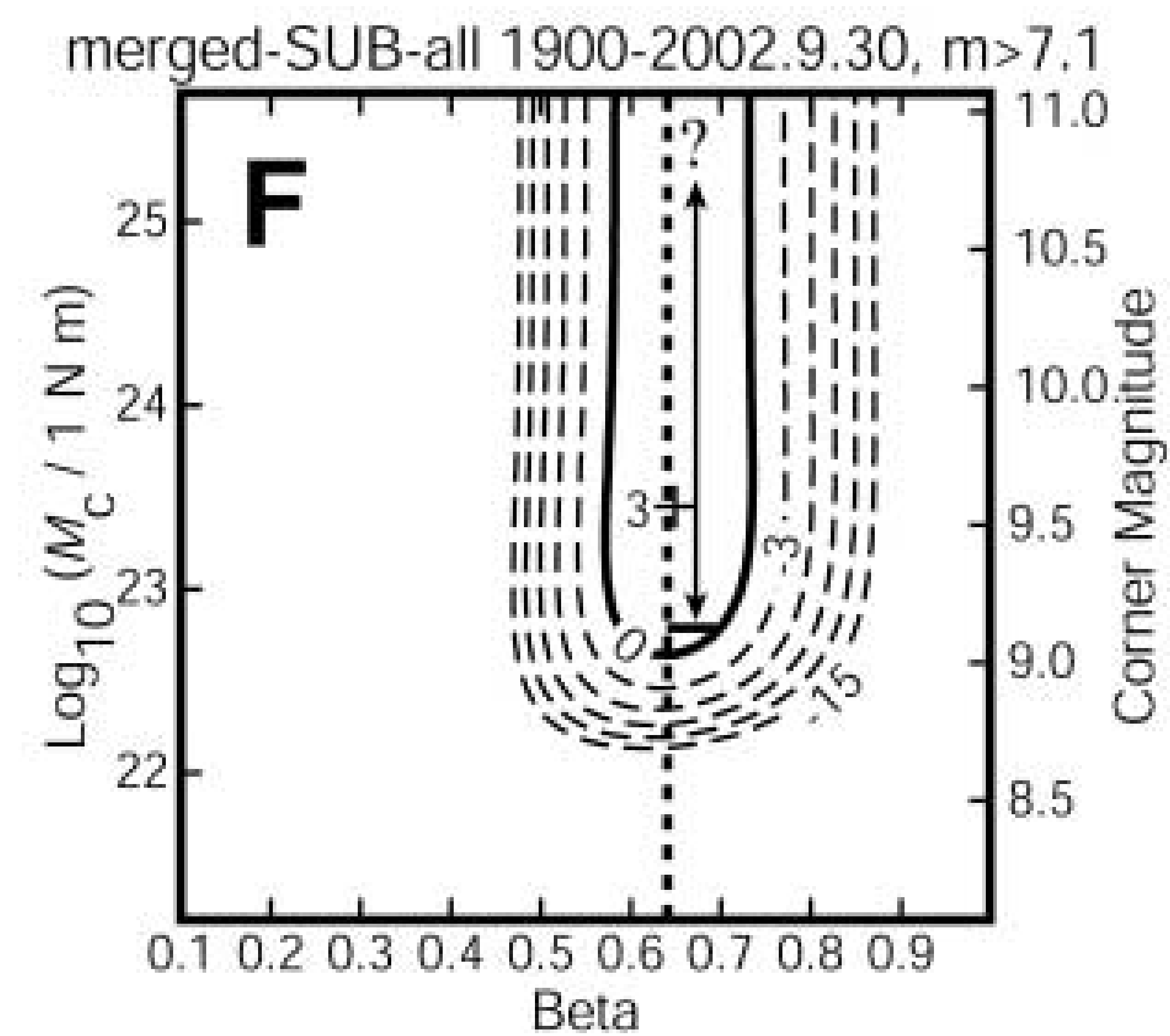


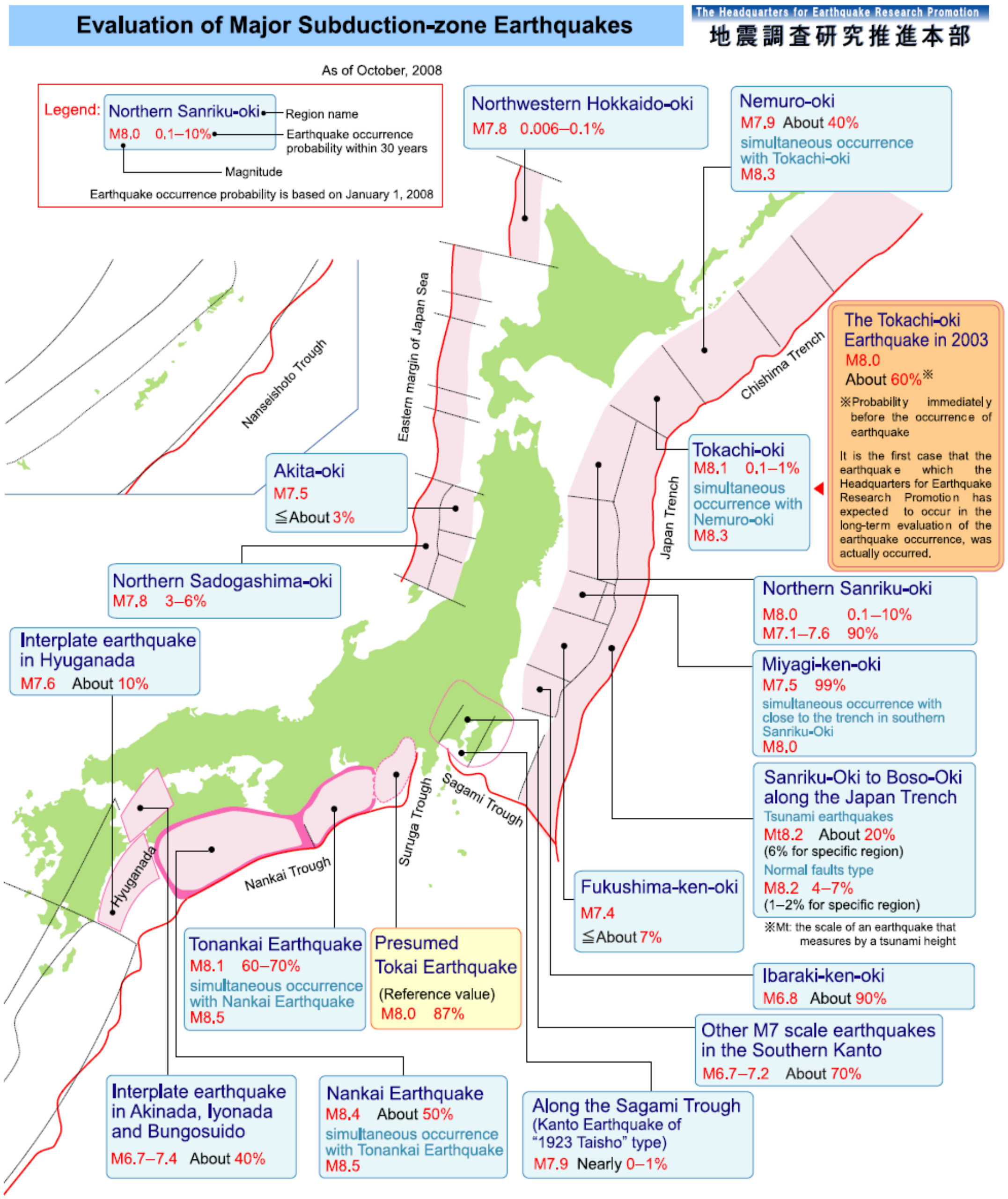
Aftershocks vs moment, all earthquakes (m_w > 7.0, 1977−2011/08/14)
ρ = 0.83, L = 2.47 + 0.488 (m_W−8.25)
σ = 0.133, ε_max = 0.465, n = 172
L = 2.47 + 0.456 (m_W−8.25) + −0.0342 (m_W−8.25)^2
σ = 0.133, ε_max = 0.457
Log_10 length of aftershock zone, 4σ_j (km)
Moment Magnitude (m_w)
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
7
7.5
8
8.5
9

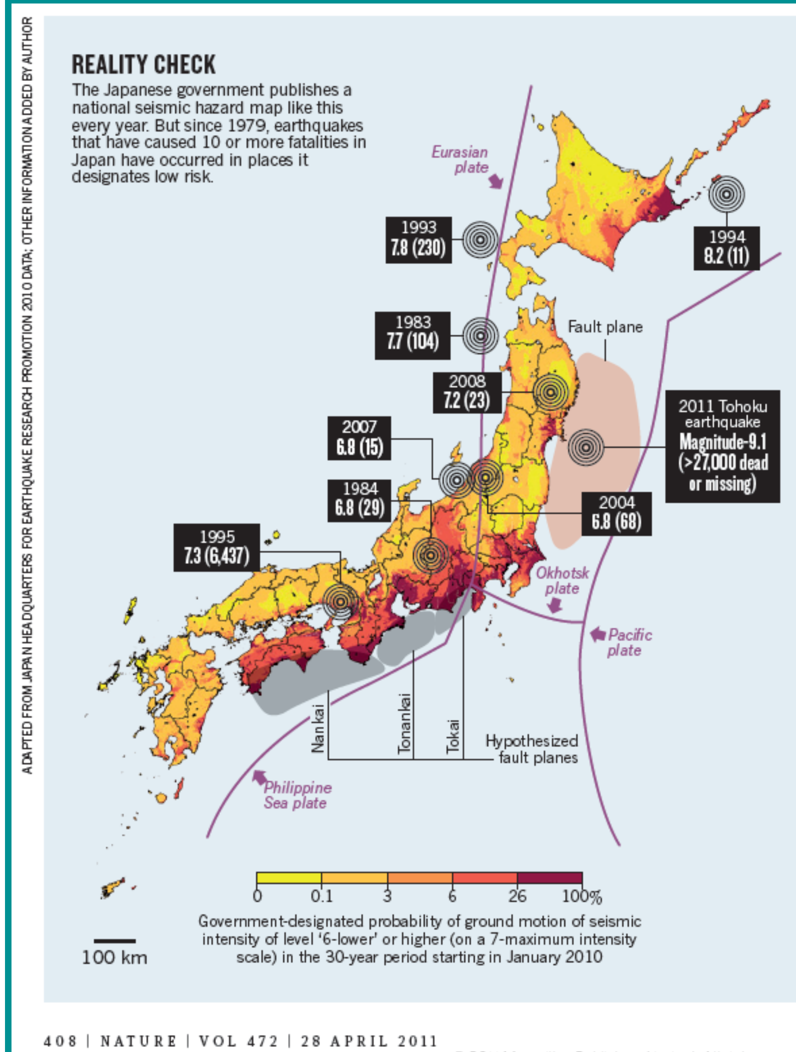

GCMT catalog, subduction zones, 1977−2010/12/31: β distribution
<β> = 0.654
FE # 1, Alaska−Aleutian Arc
FE # 5, Mexico−Guatemala
FE # 6, Central America
FE # 7, Caribbean Loop
FE # 8, Andean S. America
FE #12, Kermadec−Tonga−Samoa
FE #13, Fiji Is
FE #14, New Hebrides Is
FE #15, Bismarck−Solomon Is
FE #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
Flinn−Engdahl zones
β +/− 1.96*σ
0
2
4
6
8
10
12
14
16
18
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3


GCMT, subduction zones, 1977−2010/12/31: Corner magnitude (m_c) distribution, BK2004
<m_o 1995> = 7.69
<m_o 2010> = 7.98
<m_c> = 9.36
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
Flinn−Engdahl zones
0
2
4
6
8
10
12
14
16
18
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
Maximum observed earthquakes 1977−1995/6/30−2010/12/31; m_c +/− 1.96*σ

Bird, P., and Y. Y. Kagan, BSSA, 94(6), 2380, 2004.







This map shows the estimated magnitude and long-term possibilities within 30 years of earthquakes on regions of offshore based on Jan.1, 2008.