Magnitude – Area Scaling of SCR Earthquakes

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Summary

- Review of Existing Models
- Description of New Model
- Comparison of New and Existing Models

Existing Models

- Allman & Shearer, 2009
  Global, based on corner frequency
- Somerville et al., 1987
  TCR vs SCR based on source duration
- Somerville et al., 2001
  ENAM based on slip models
- Leonard, 2010
  Global, based on various data

Comparison of Methods

- Corner frequency: does not fully account for seismic wave propagation
- Duration, slip model: do account for seismic wave propagation
- Surface faulting, aftershocks: indirect "ground truth"

Allman & Shearer 2009

Table 1. Earthquake Classification According to Different Tectonic Regimes[a]

	Tectonic Regime	Number of Events	Median $\Delta\sigma$ (MPa)
SUB	subduction zone	481	2.98 ± 0.21
ORB	oceanic ridge boundary	23	2.82 ± 0.48
OTF	oceanic transform fault	115	6.03 ± 0.68
OCB	oceanic collision boundary	25	3.42 ± 0.56
CRB	continental ridge boundary	26	3.37 ± 0.47
CTF	continental transform fault	48	3.54 ± 0.64
CCB	continental collision boundary	81	2.63 ± 0.5
INTER	combined interplate	799	3.31 ± 0.18
INT	intraplate	61	5.95 ± 1.01

"Intraplate": > ~ 150 km from plate boundary so not directly comparable to SCR

Allman & Shearer 2009

"Intraplate": > ~ 150 km from plate boundary

TCR: CTF & CCB:	129 events:	30 bars
INT*:	61 events:	60 bars

* Proxy for SCR

Similar to Kanamori & Anderson,1975

Leonard 2010

- Self-consistent relations between L, W, D and Mo
- For all categories of earthquakes
- Data undocumented, based mainly on existing compilations of source parameters, areas mostly from aftershocks
- All relations have self-similar scaling of Mo with A
- $W = C1\ L\ \exp(\beta)$; $D = C2 \sqrt{A}$

New SCR Model Development

3 WAYS TO MEASURE RUPTURE AREA

•Source duration: Model teleseismic body waveforms and find the source duration that matches them

•Slip Model: Trim the slip model obtained from waveform inversion

•Surface Faulting/Aftershock Zone: One or both of these data types

New SCR Model Development

- Develop separate models for each of 3 data types
- Use the same value for seismic moment with each data type for the same event
- Assume self-similarity, i.e.:

  $\log10A = 2/3 \log10Mo + c1$

  $\log10A = Mw + c2$

Earthquake Source Data

- Source Duration (29) – mostly from older events already studied; not routinely evaluated (Harvard CMT assumes a reln.)
- Slip Model (8) – mostly from smaller eastern Canadian and larger Australian events
- Surface Fault / Aftershock (12) – from a wide variety of events

Events by Region

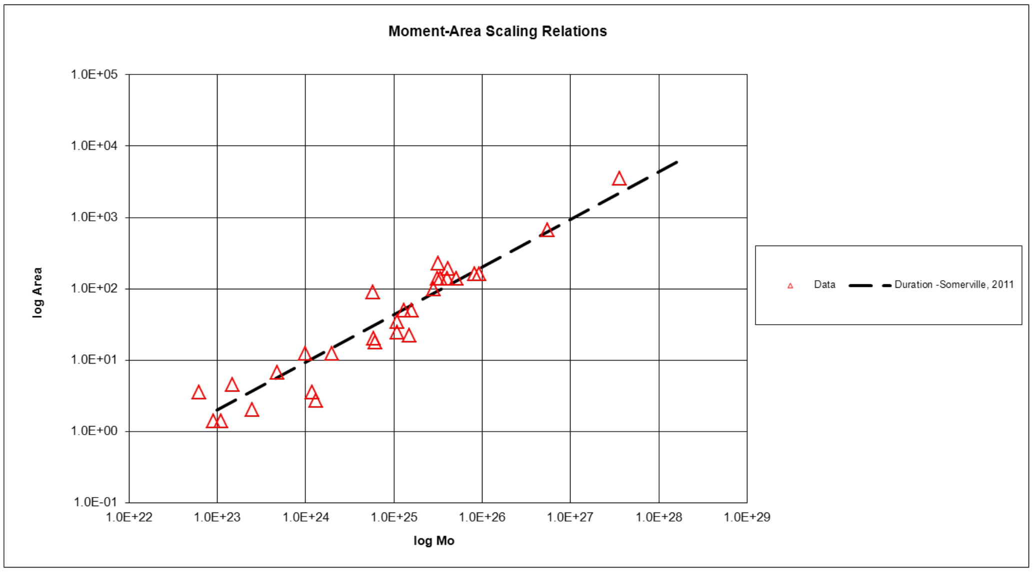
- Eastern Canada: 9 Mw 5.3 – 7.1
- Eastern U.S: 7 Mw 4.5 – 5.4
- Australia: 7 Mw 5.8 – 6.6
- India: 4 Mw 5.8 – 7.7
- Africa: 2 Mw 6.3 – 6.4
- Europe: 1 Mw 5.3

TOTAL 30 Mw 5.3 – 7.7

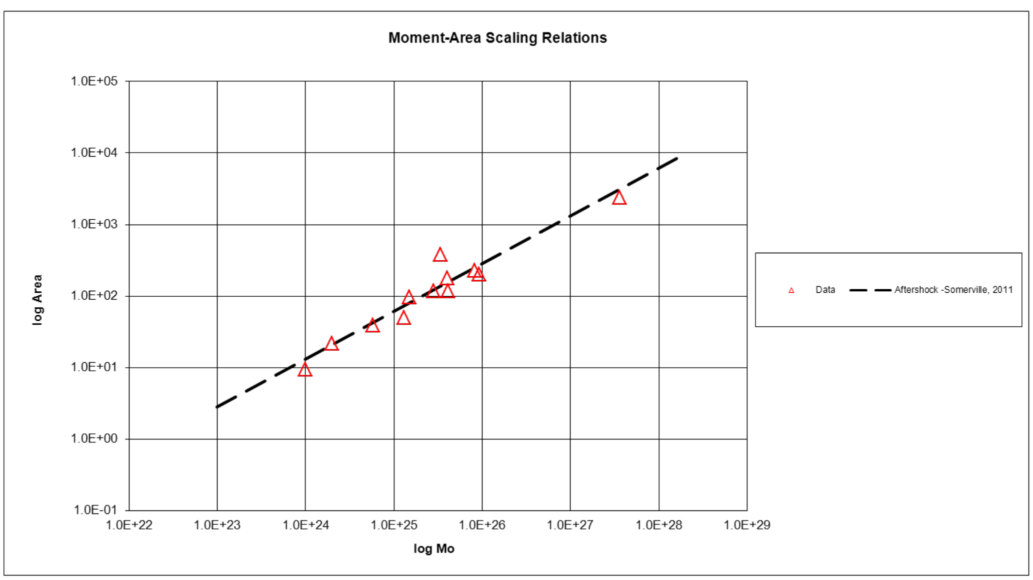
Earthquakes

Date	Location	Mw	H	Mo	Aftershock/Fault			Slip Model			Duration	
					L	W	A	L	W	A	Dur	A
1925.3.1	Charlevoix	6.29	10	3.1E25							5.0	140
1929.11.18	Gr. Banks#1	7.13	20	5.5E26							11.0	676
1935.11.1	Timiskaming	6.44	10	5.1E25							5.0	140
1939.10.19	Charlevoix	5.30	8	1.0E24							1.5	12.6
1940.12.20	Ossippee	5.35	10	1.2E24							0.8	3.6
1963.3.3	Missouri	4.66	15	1.1E23							0.5	1.40
1963.9.4	Baffin Bay	6.10	7	1.6E25							3.0	50
1965.10.21	Missouri	4.60	4	9.0E22							0.5	1.40
1967.12.10	Koyna	6.30	4.4	3.2+25							6.4	229
1968.10.14	Meckering	6.61	1	9.3E25	25	7	280				5.4	163
1986.3.30	Marryat Ck	5.81	1	5.8E24				13	3	39	4	89
1968.11.9	Illinois	5.38	25	1.3E24							0.7	2.73
1969.9.29	Ceres	6.37	11	4.0E25							5	140
1970.3.24	Lake McKay	5.99	12	1.1E25							2.5	35
1973.6.15	Maine	4.49	6	6.2E22							0.8	3.57
1979.6.2	Cadoux	6.08	6	1.5E25				16	6	96	2.0	22
1979.8.19	Quebec	4.75	6.5	1.5E23							0.9	4.52
1980.7.27	Kentucky	5.09	13.5	4.8E23							1.1	6.76
1982.1.9	Miramichi	5.50	7	2.0E24			17	5.4	4.0	22	1.5	12.6
1983.10.7	New York	4.90	7	2.5E23							0.6	2.01
1983.12.22	Guinea	6.32	13	3.4E25				24	17	378	5.0	140
1984.10.7	North Wales	5.30	20.7	1.0E24				3.0	3.2	9.6		
1988.1.22	Tennant Ck	6.26	2.7	2.8E25	12	16	192	13	9	117	4.2	99
“	“	6.38	3.0	4.1E25	16	10	160	13	9	117	5.9	195
“	“	6.58	4.2	8.2E25	18	12	216	19	12	228	5.4	163
1988.11.25	Saguenay	5.82	26	6.1E24			33				1.8	18
1989.12.25	Ungava	6.04	3	1.3E25			33	10	5	50	3.0	50
1993.9.30	Latur	5.99	6	1.1E25							2.1	24.6
1997.5.21	Jabalpur	5.81	35	5.9+24							1.9	20.2
2001.1.23	Bhuj	7.67	22	3.6E27	60	35	2100	60	40	2400	25	3495

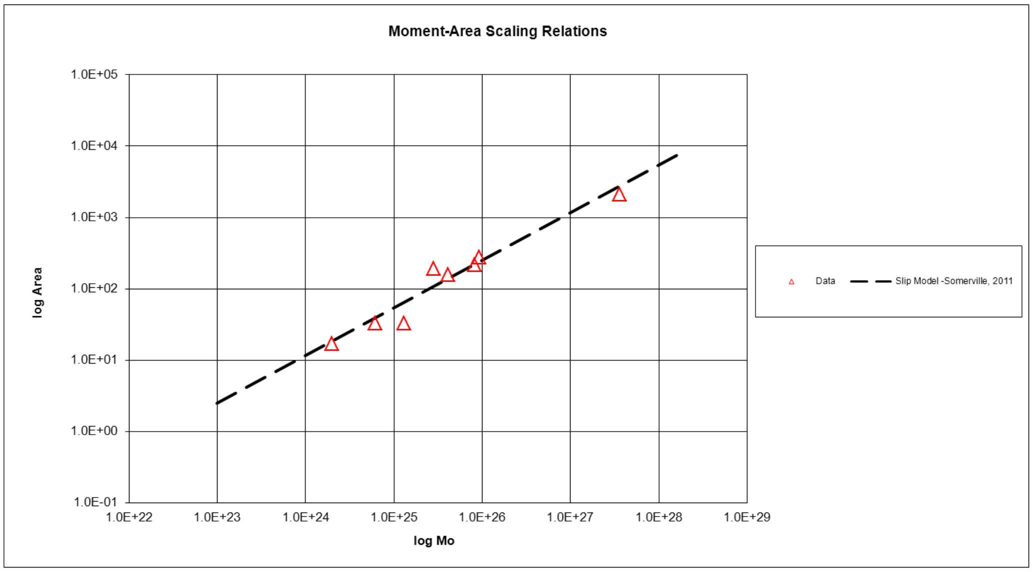
M – A from Source Duration



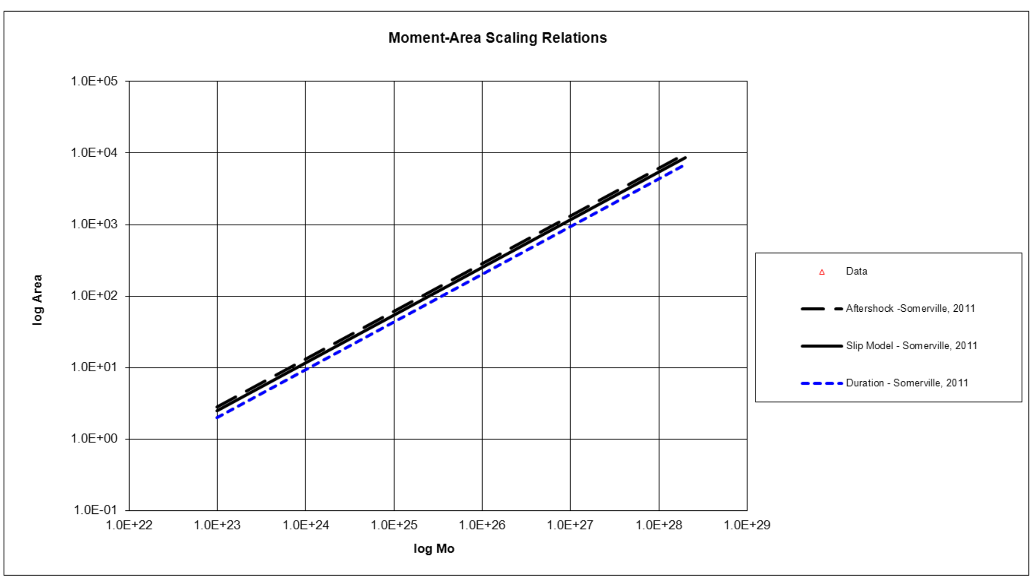
M - A from Aftershock Area



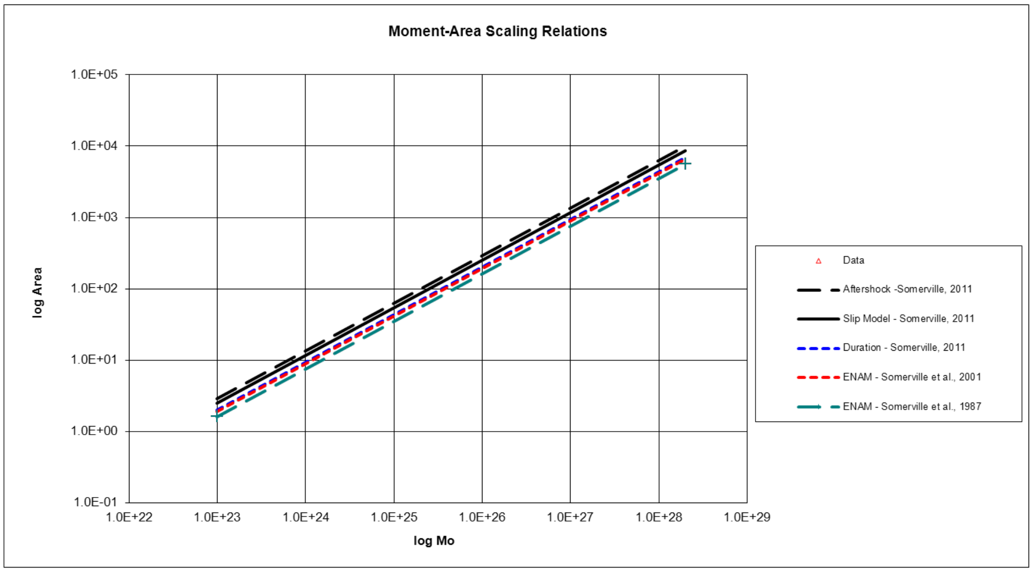
M – A from Slip Models



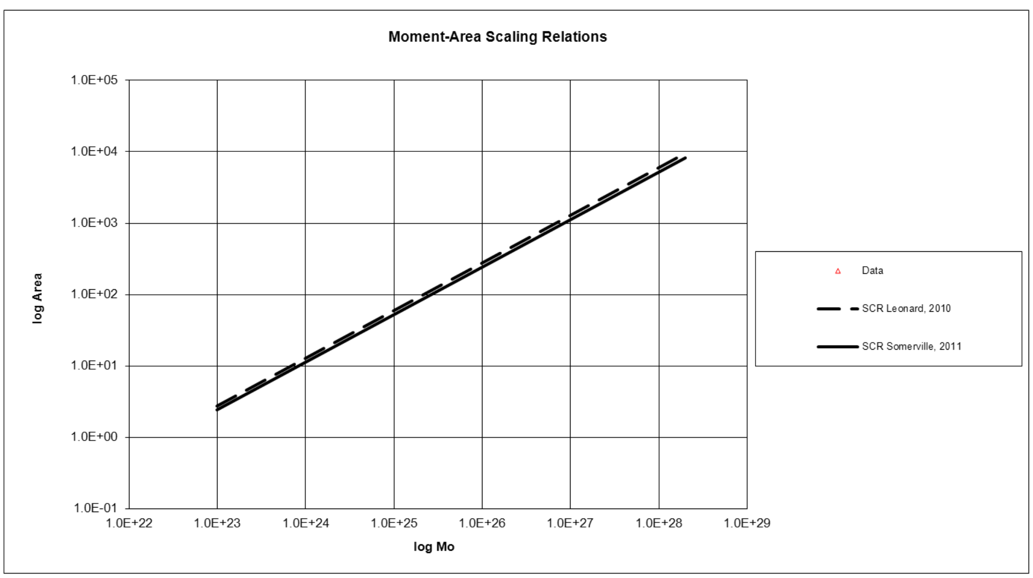
Comparison of 3 New Models



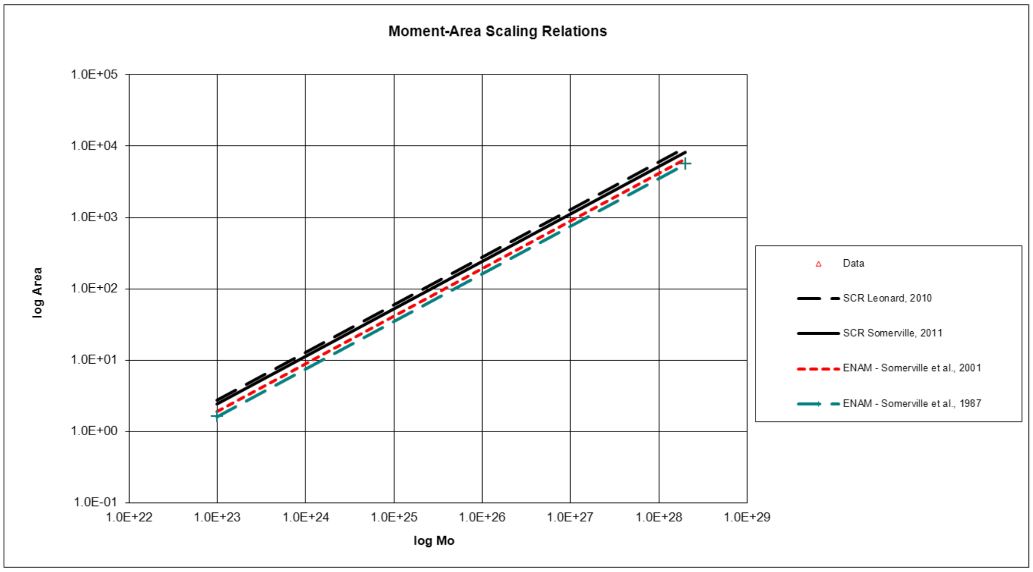
Comparison of 3 New Models with Previous Somerville Models



Comparison of Leonard (2010) and Somerville (2011) Models



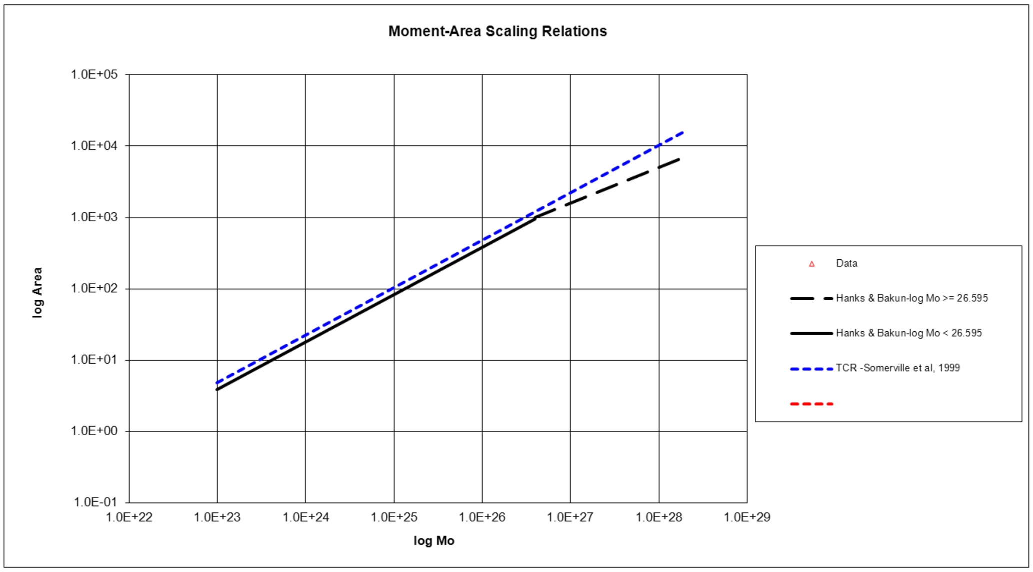
Comparison of Old and New SCR Models



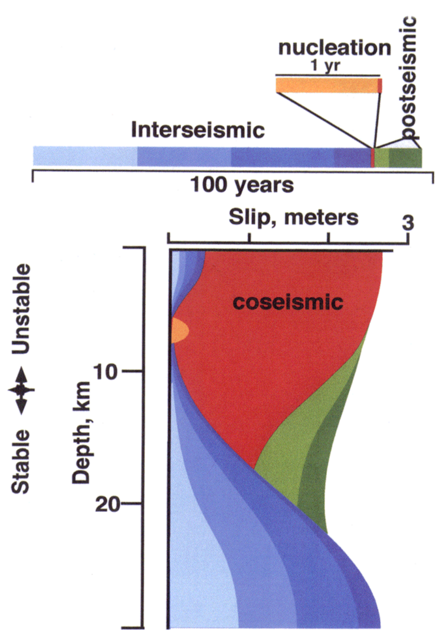
Width Saturation in TCR

- Width scaling saturates in some manner as the seismogenic zone extends from the brittle zone into the ductile zones above and below it
- M-A scaling of TCR earthquakes is subject to controversy for Mw > 7 (Hanks & Bakun, 2002)
- Below Mw 7.0, there is general agreement that the scaling is self similar

Alternative Models of TCR M-A



The brittle (seismogenic) zone is bounded above and below by ductile zones



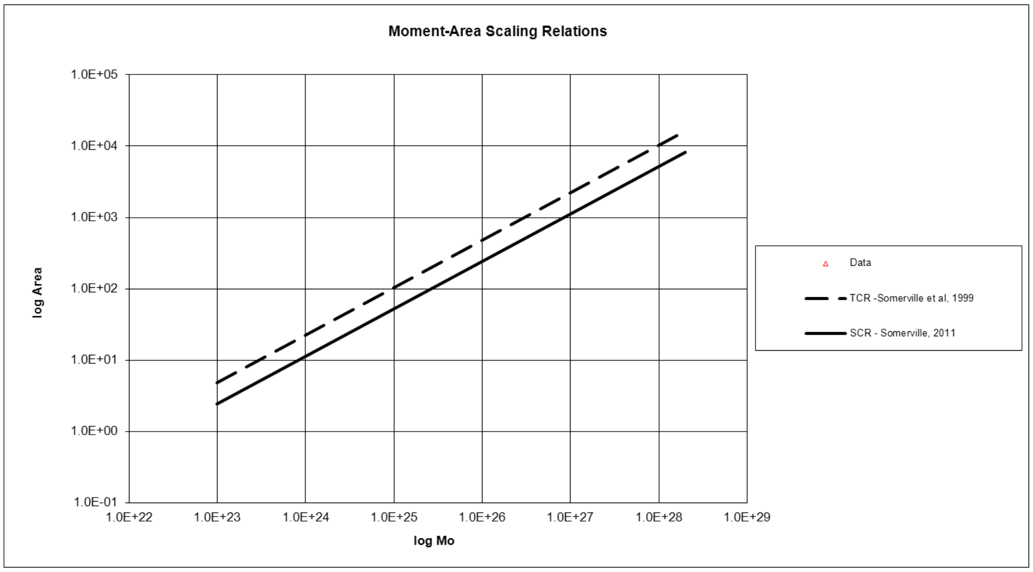
Width Saturation in SCR

- SCR earthquakes have rupture dimensions that are about half those of TCR earthquakes
- The TCR crust is also generally thicker than the SCR crust and the shallow ductile zone is very thin or absent
- This suggests that the saturation of width, if it occurs at all in SCR crust, is at Mw that could be much larger than 7.0

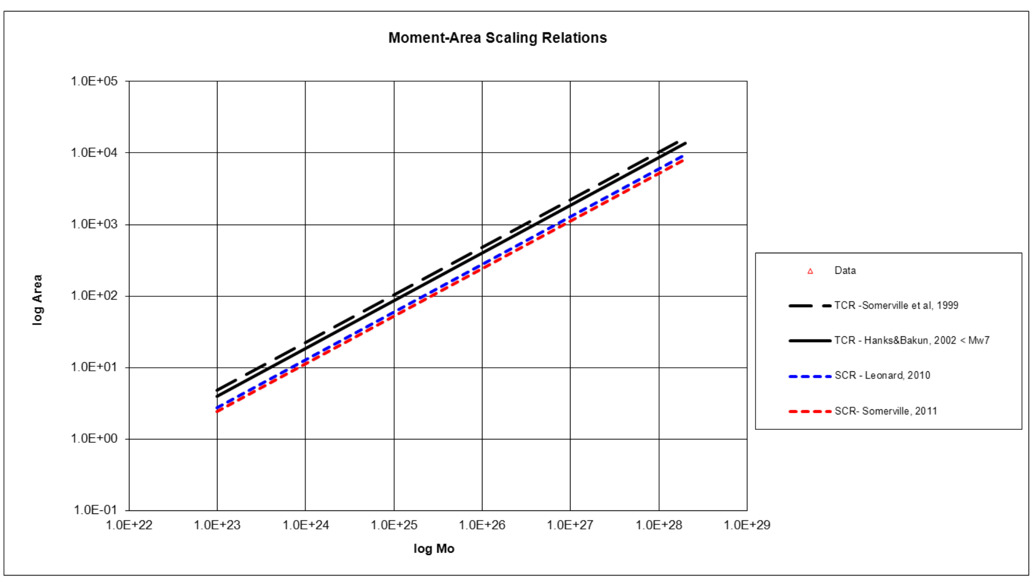
Assumption of Self-Similar Scaling of M-A

- Below Mw 7.0, there is general agreement that the scaling is self similar
- In this study we have assumed self-similarity in M-A scaling for all magnitudes
- This is consistent with all of the scaling relations of Leonard (2010), which embody width saturation anyway

Comparison of TCR and SCR Models - Somerville



Comparison of SCR and TCR Models – Various Authors



Stress Drop

- Self-similar relations between seismic moment and rupture area can be viewed as lines of constant stress drop, assuming:
- Stress drop is defined as the static stress drop of a circular crack embedded in an elastic medium; this gives values like Brune stress drops
- Stress drop values for other fault geometries and for surface faulting earthquakes may differ

Comparison of Models

Log10 A = 2/3 Log10Mo + intercept

Model Region	Reference	Slope	Intercept	Stress Drop
TCR	Somerville et al., 1999	2/3	-14.65	23.4
TCR, Mw < 7.0	Hanks & Bakun, 2002	2/3	-14.74	31.9
TCR, dip slip	Leonard, 2010	2/3	-14.70	27.8
ENAM	Somerville et al., 1987	2/3	-15.12	118.4
SCR	Somerville et al., 1987	2/3	-15.03	86.8
ENAM	Somerville et al., 2001	2/3	-15.05	93.0
SCR	Leonard, 2010	2/3	-14.89	53.5
SCR – Avg of Methods	Somerville, 2011	2/3	-14.946	64.8
SCR - Aftershock	Somerville, 2011	2/3	-14.876	51.0
SCR - Duration	Somerville, 2011	2/3	-15.028	86.2
SCR – Slip Model	Somerville, 2011	2/3	-14.934	62.3

Conclusions

- The results of this study and of Leonard (2010) are compatible
- All three methods of estimating rupture area (duration, slip model, aftershocks) in this study give fairly similar results
- All three methods are subject to systematic bias

Conclusions – SCR M-A

- SCR earthquakes have rupture dimensions that are about half those of TCR earthquakes
- The above conclusion is not very subject to systematic bias
- A representative SCR M-A relation is:

  Log10 A = 2/3 log Mo – 14.95

  Log 10 A = Mw + 4.25

  (static stress drop ~ 65 bars)

Conclusions – TCR M-A

- M-A scaling of TCR earthquakes is subject to controversy for Mw > 7 (Hanks & Bakun, 2002)
- Below Mw 7.0, there is general agreement that the scaling is self similar
- A representative TCR M-A relation is:

  Log10 A = 2/3 log Mo – 14.65

  Log 10 A = Mw + 3.95

  (static stress drop ~ 25 bars)

Comparison with Allman & Shearer

	SCR/INT*	TCR
This Study (area ratio = 2)	65 bars	25 bars
Allman & Shearer* (stress drop ratio = 2)	60 bars	30 bars

*"Intraplate": > ~ 150 km from plate boundary, so INT is an imperfect proxy for TCR