2017 Annual Meeting Seismological Society of America 18–20 April • Denver, Colorado

Session: Scaling and Empirical Relationships of Moderate to Large Earthquakes:
Re-scaling or Re-thinking ?

Examination of Source Scaling Relations for Crustal Earthquakes in Japan

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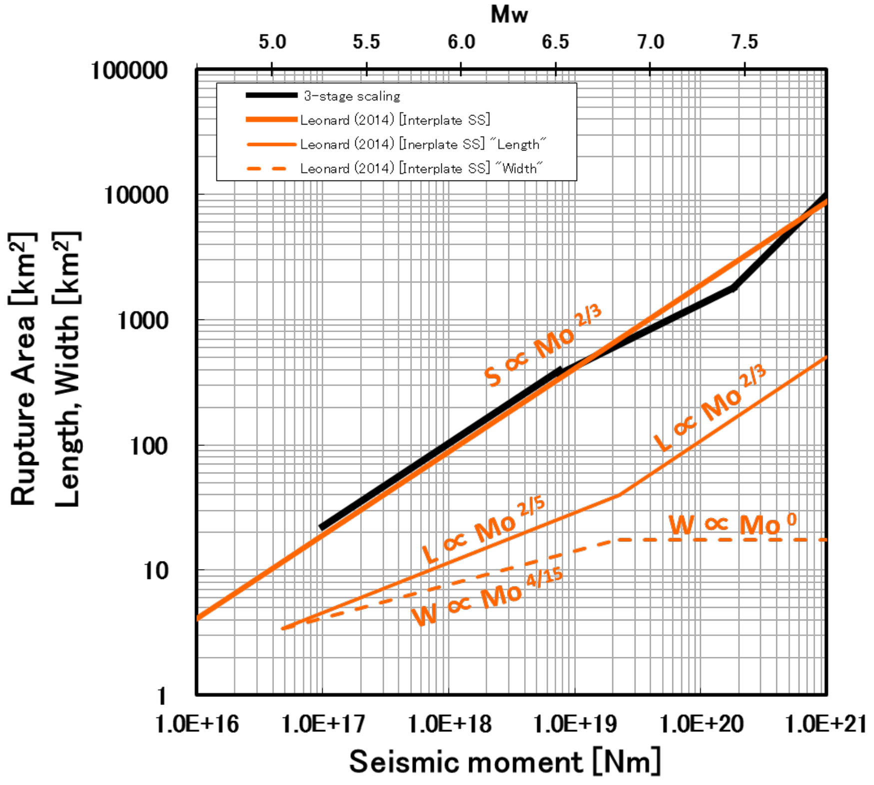
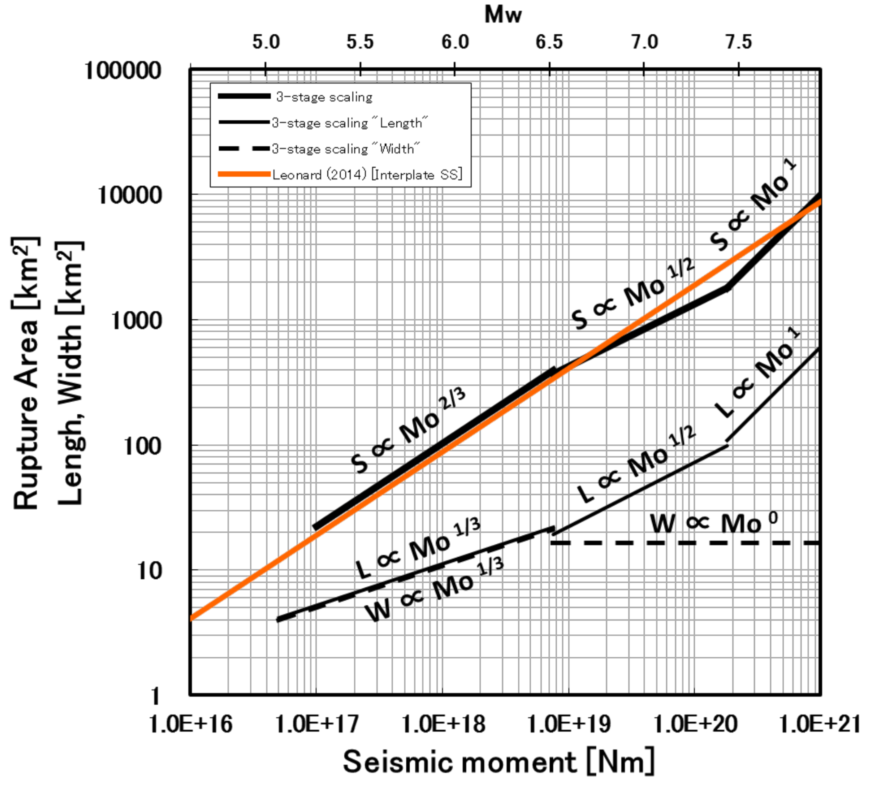
This study for the 2016 Kumamoto Eq. is partly published as Irikura et al. (2017, EPS).

Motivation: Source scaling and background physics

Leonard (2014)



HERP (2016) for SHA in Japan



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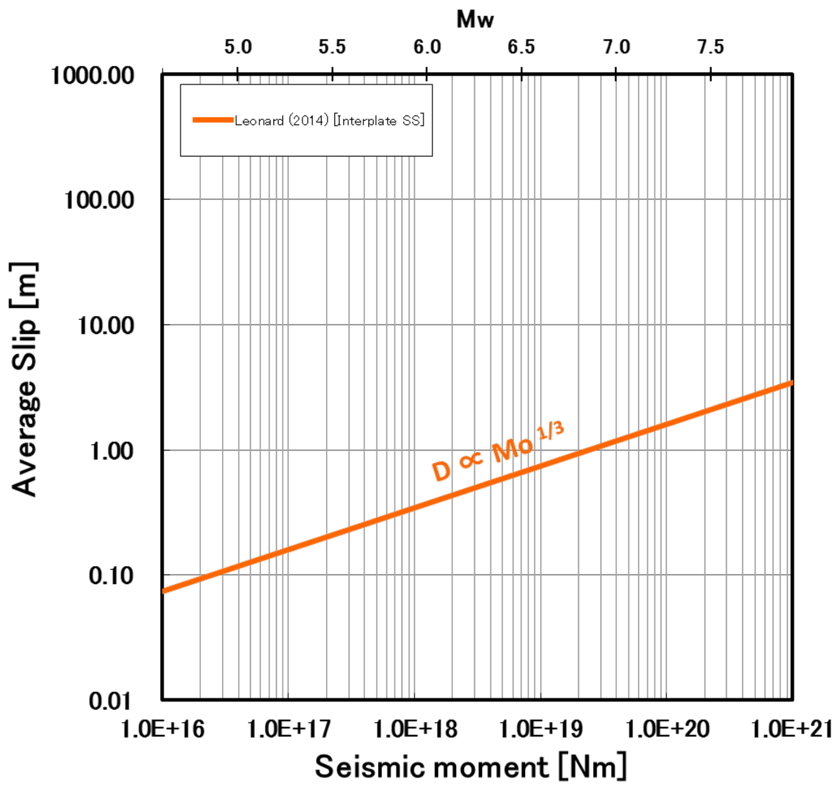
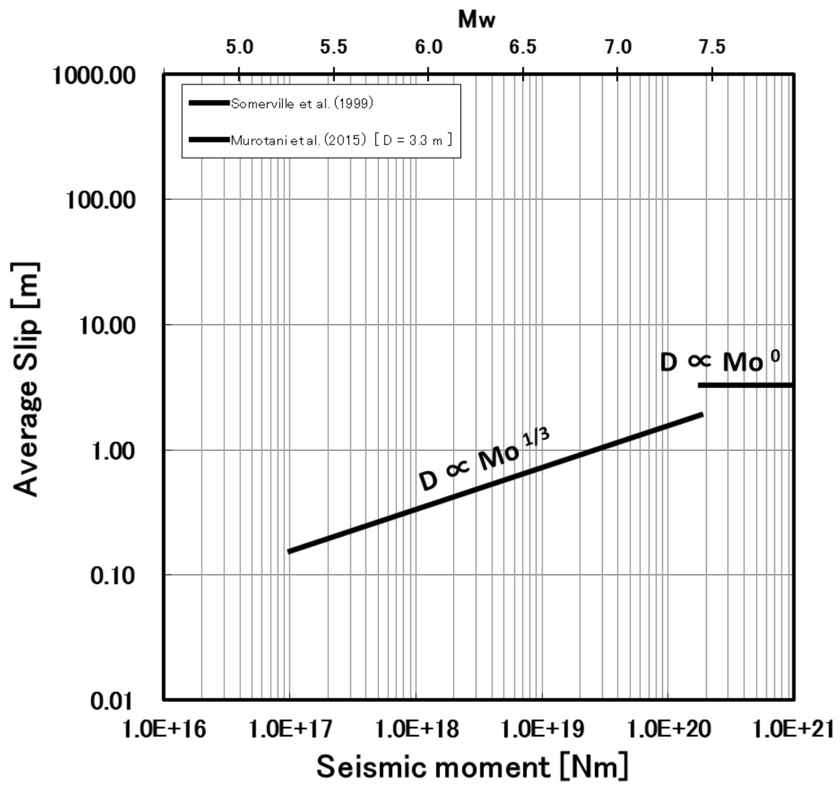
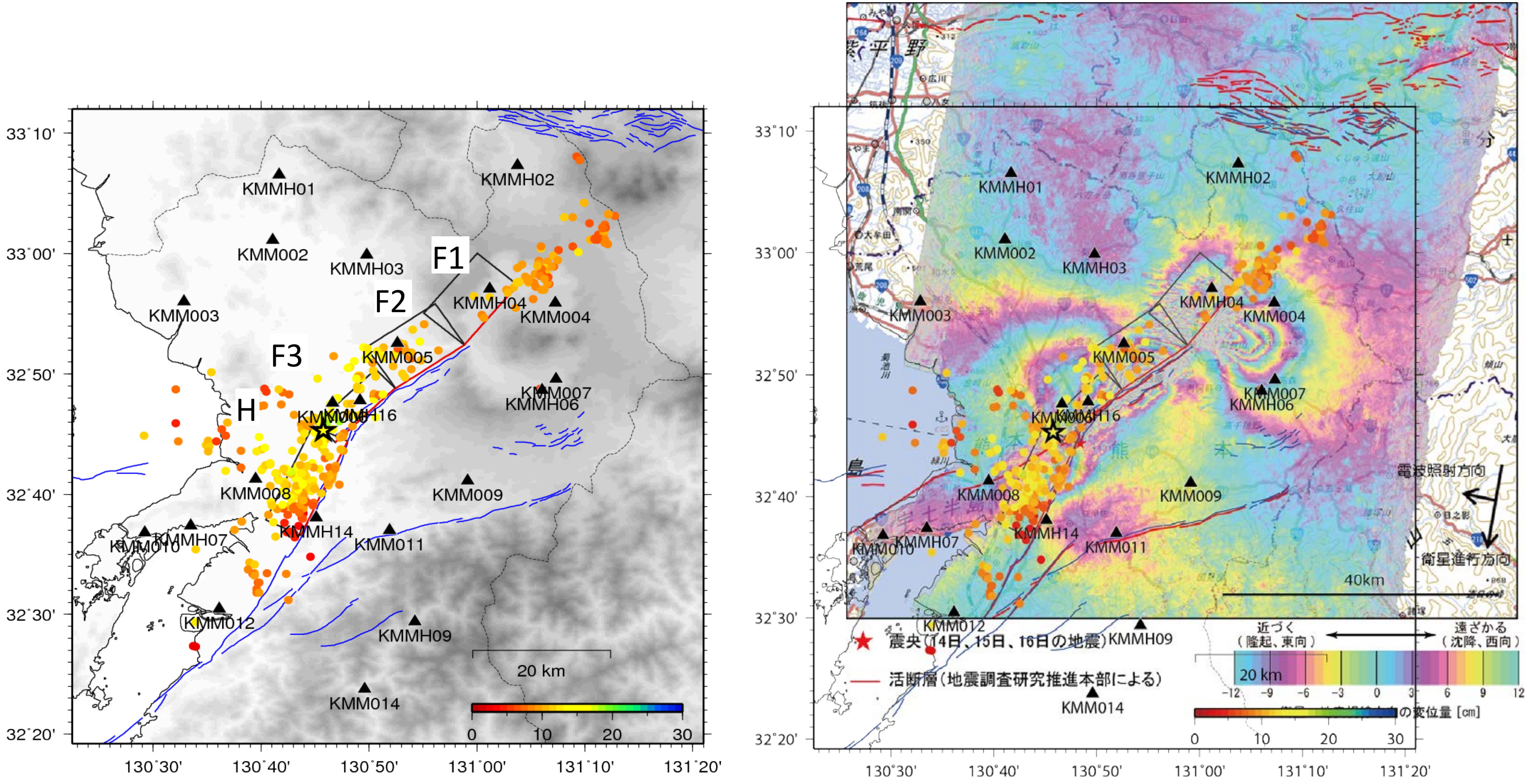


HERP (2016) for SHA in Japan



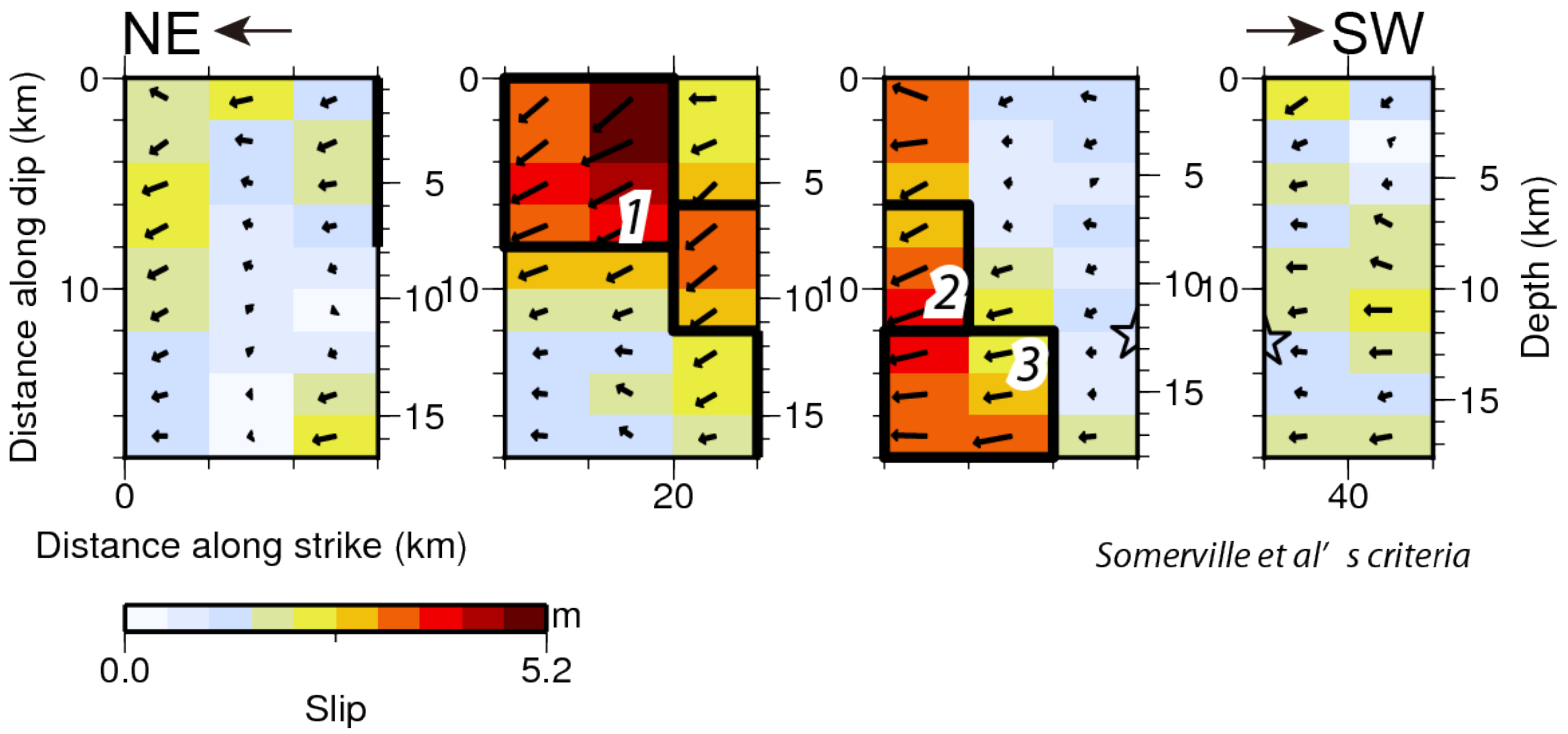
2016 Kumamoto earthquake (Mw 7.0)
Aftershock distribution, InSAR, and fault segment model



Triangle shows the seismic stations used in this study. Star shows the rupture starting point of the main shock. Aftershocks occurring within 48 h of the mainshock are plotted.

2016 Kumamoto earthquake
Slip distribution of strong motion waveform inversion (T = 2-20 s)

Total slip

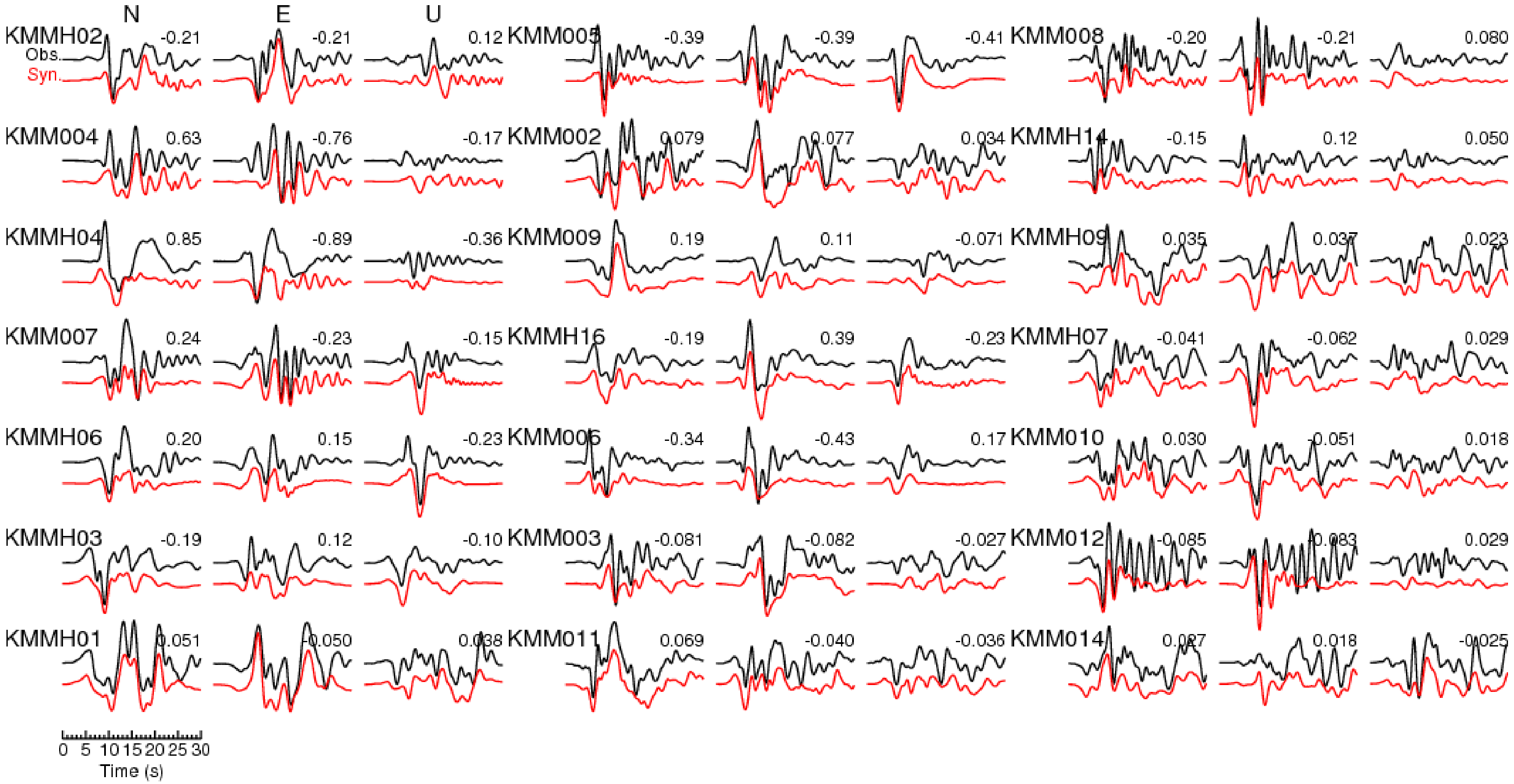


Averaged three slip inversions

M_0	4.42×10^{19} Nm
V_r	2.4 km/s
L	44 km
W	18 km
D	1.98 m
S	798 km^2

Yoshida et al. (2016)

Comparison of observed (black) and synthetic (red) velocity waveform from strong waveform inversion (T = 2-20 s)

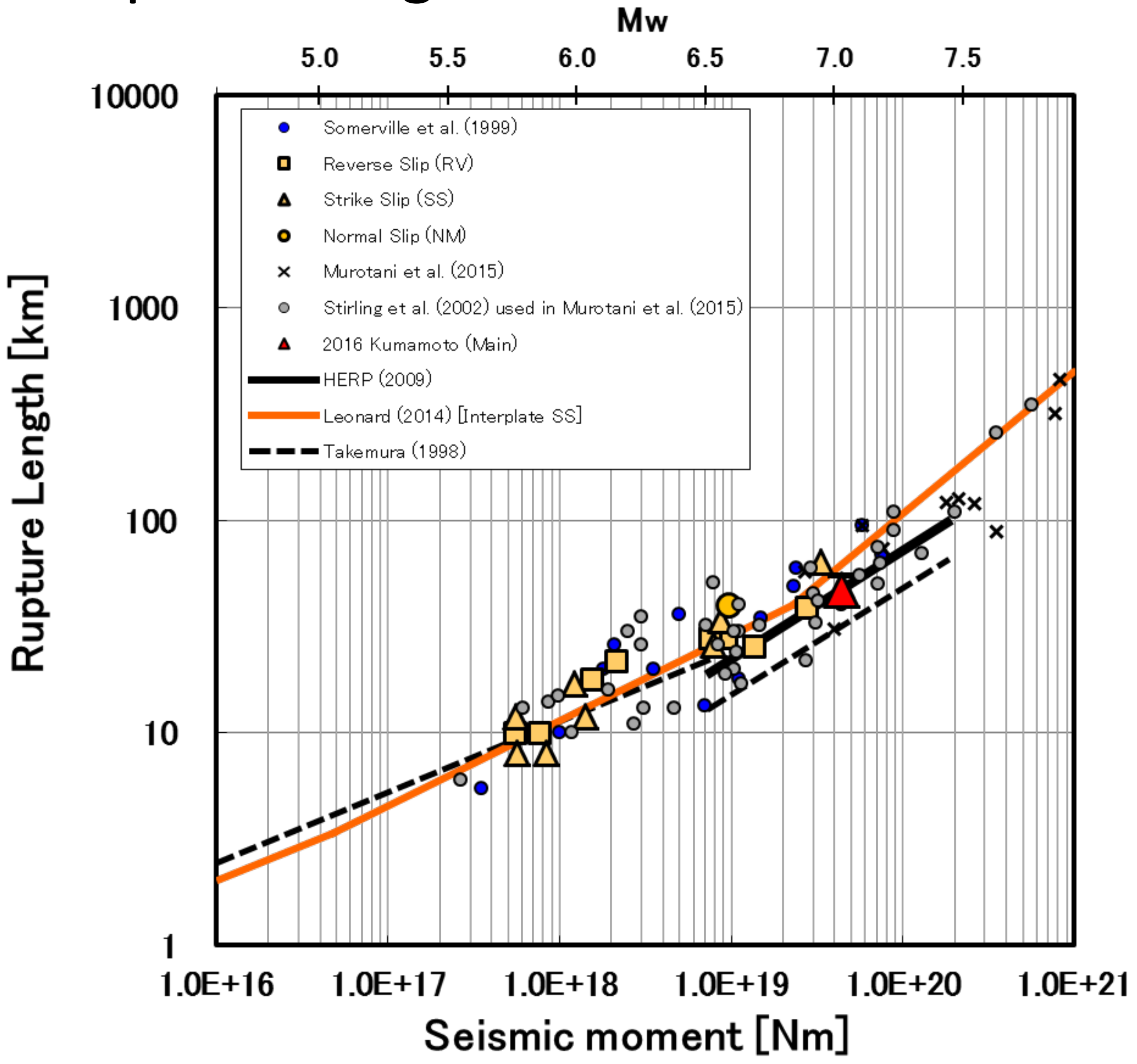


Yoshida et al. (2016)

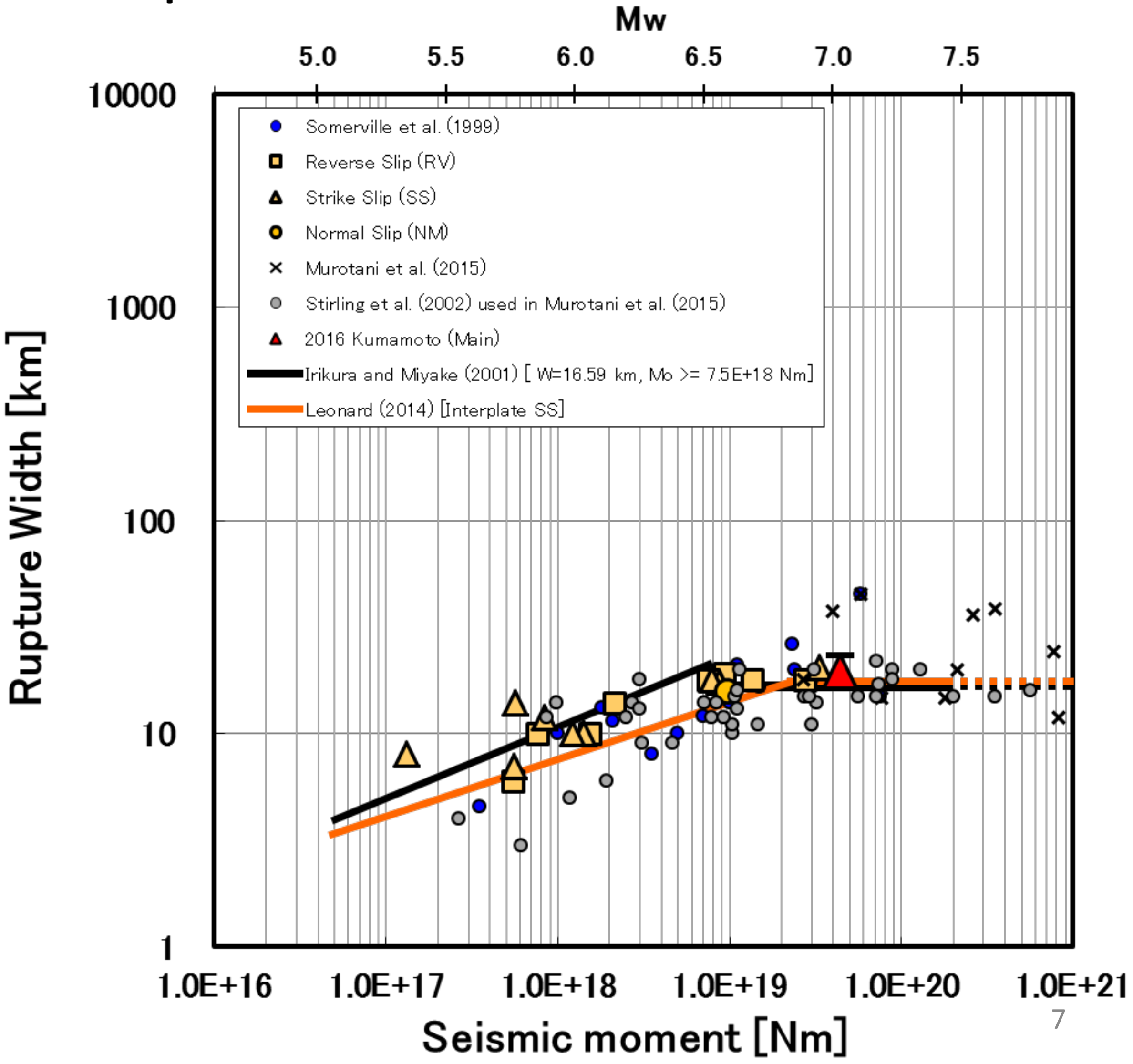
Comparison of scaling relationships between Japan one and other countries

Red star: 2016 Kumamoto

Rupture Length vs. Seismic Moment



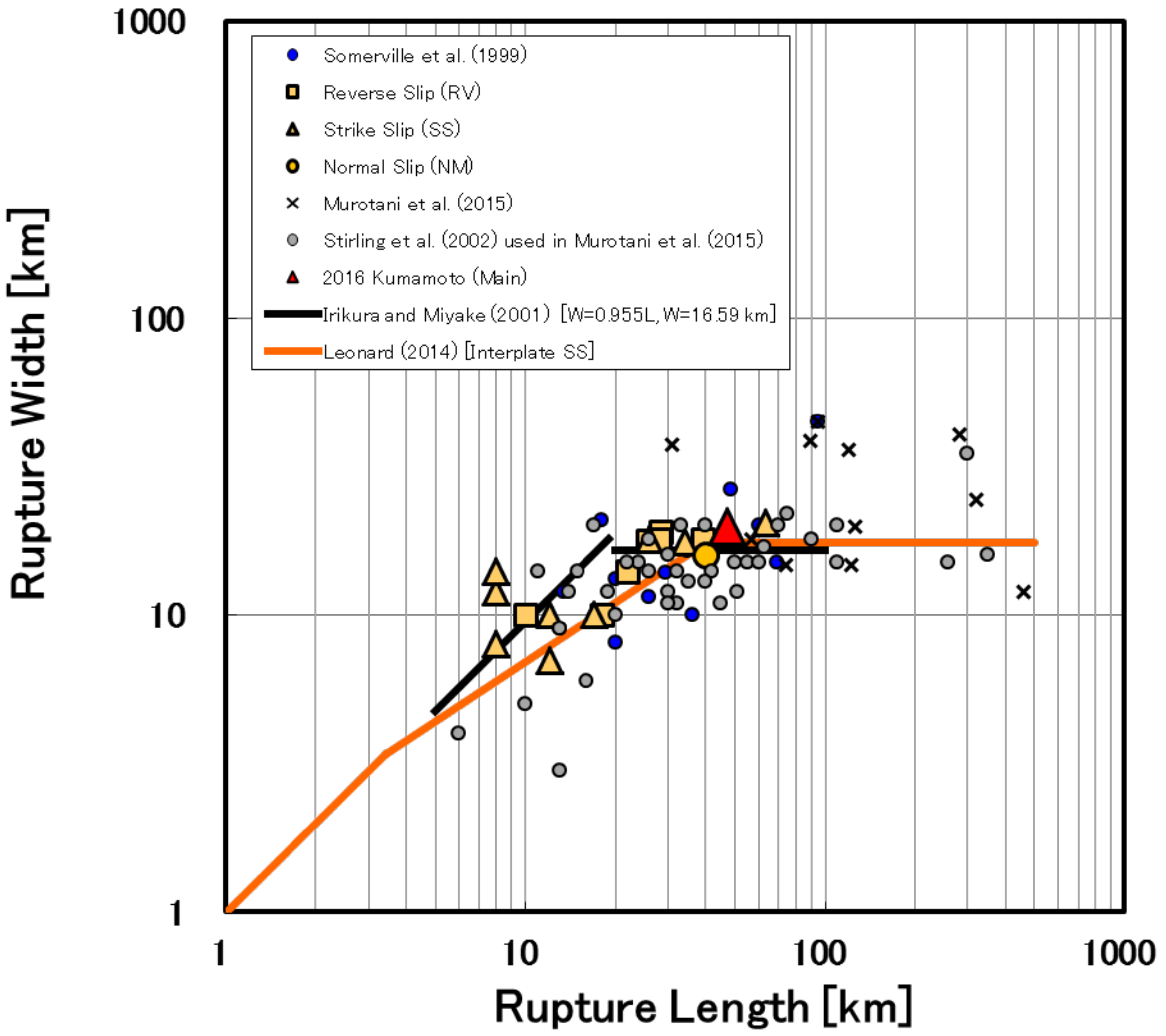
Rupture Width vs. Seismic Moment



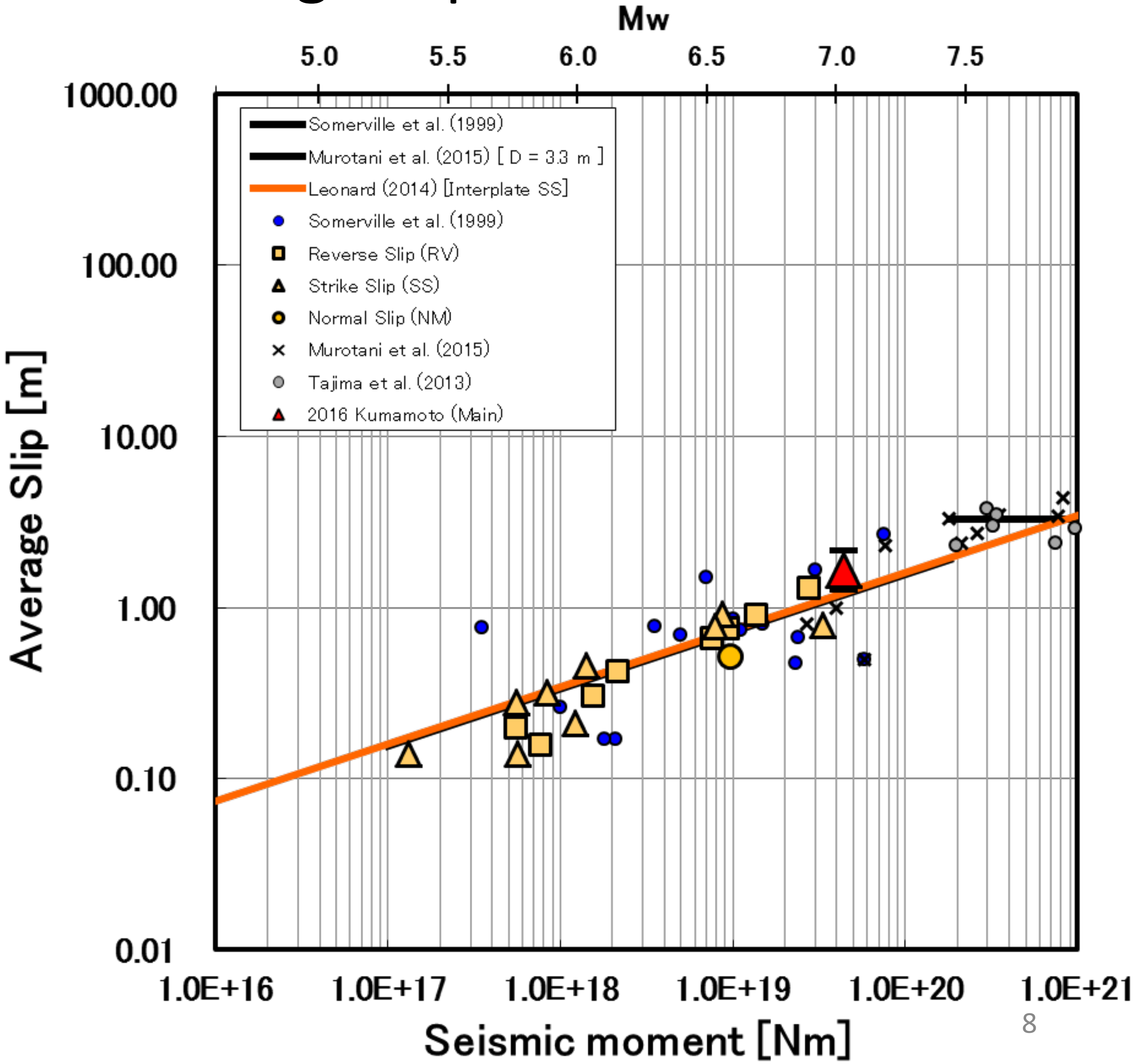
Comparison of scaling relationships between Japan one and other countries

Red star: 2016 Kumamoto

Rupture Length vs. Rupture Width

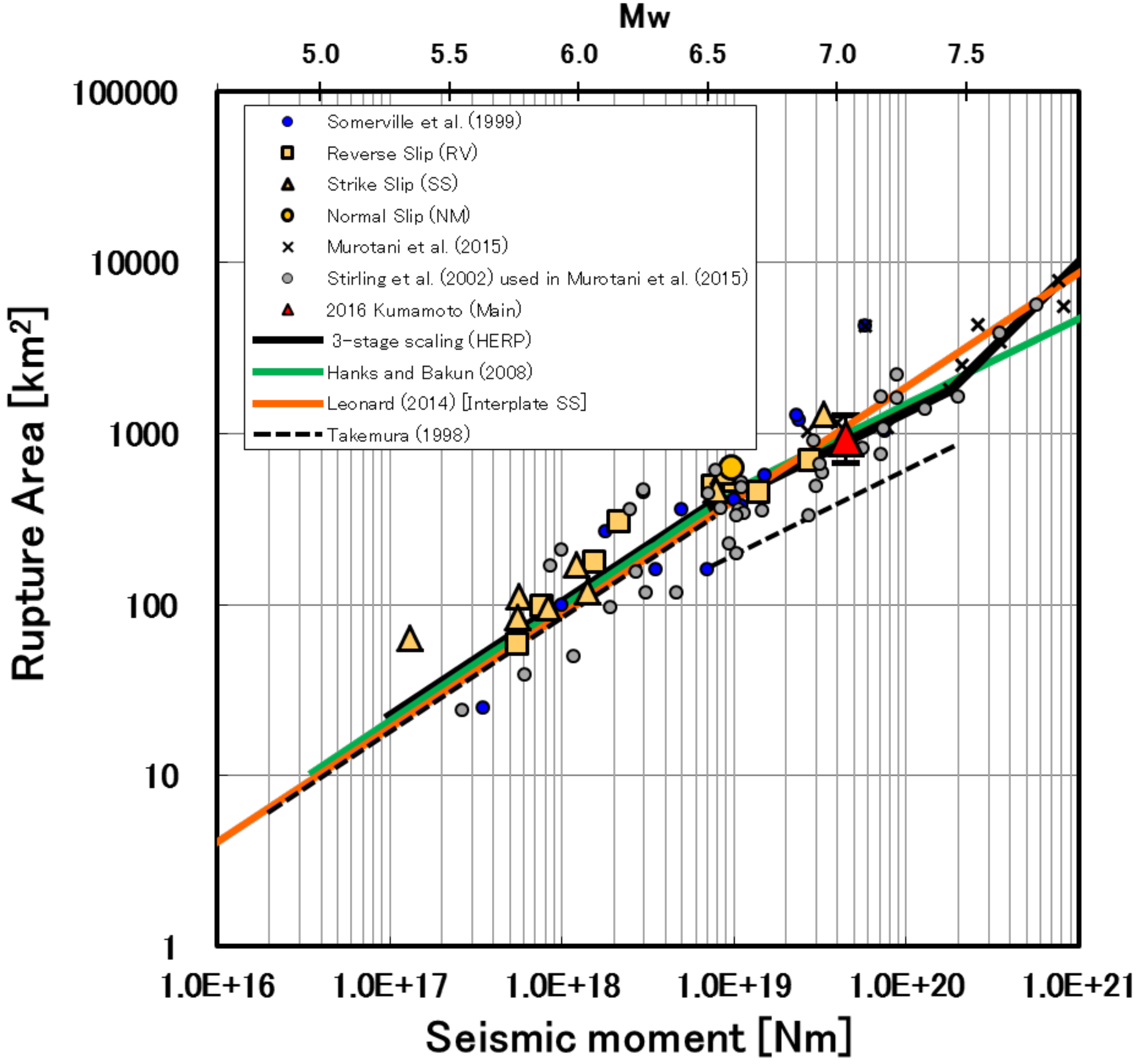


Average Slip vs. Seismic Moment



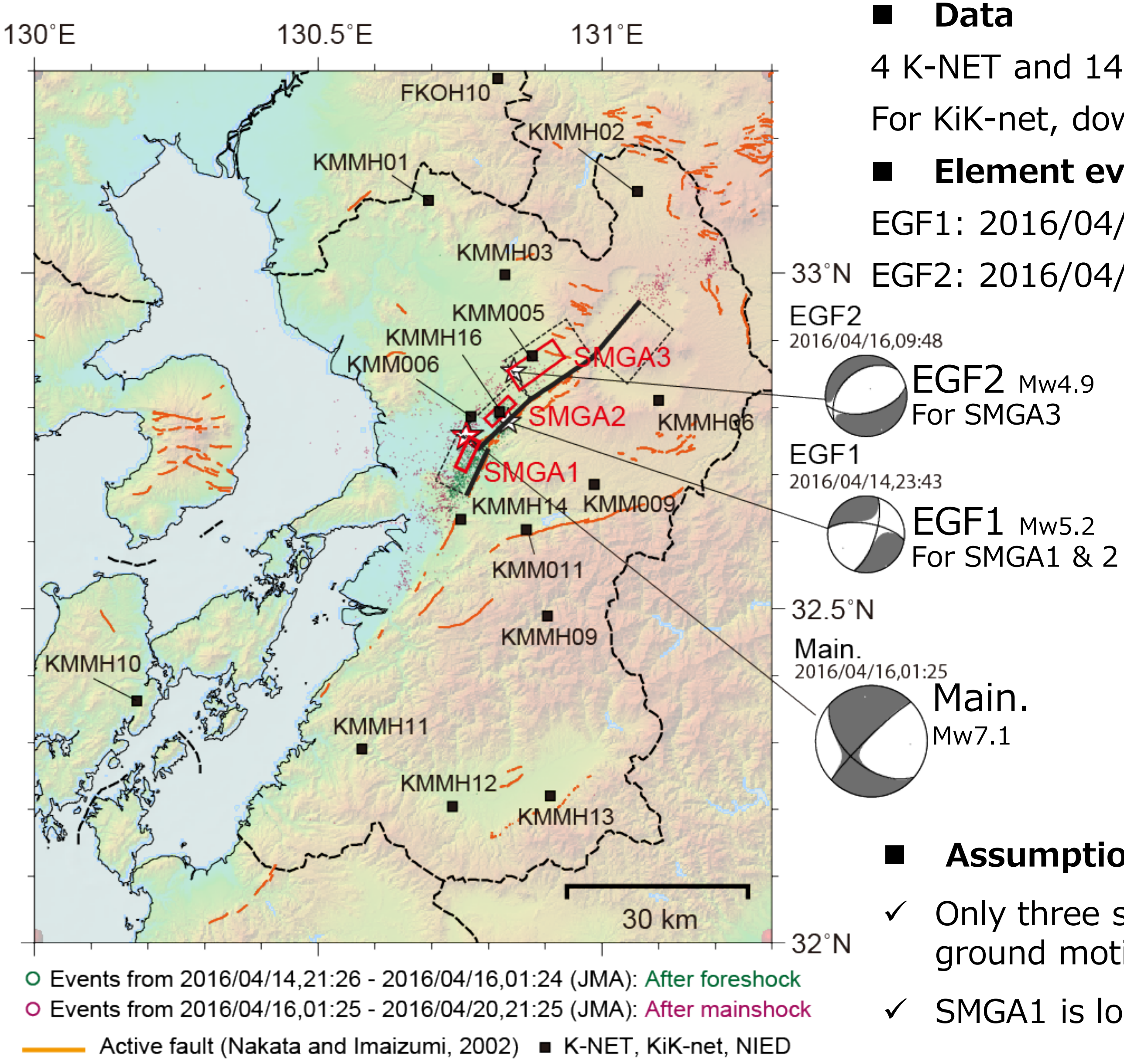
Comparison of scaling relationships between Japan and other countries

Rupture Area vs. Seismic Moment



Red star:
2016 Kumamoto

SMGA broadband source model for the 2016 Kumamoto Eq.



- **Data**

4 K-NET and 14 KiK-net stations

For KiK-net, downhole data were used.

- **Element event (EGF event)**

EGF1: 2016/04/14,23:43 M_w 5.2 for SMGA1&2

EGF2: 2016/04/16,09:48 M_w 4.9 for SMGA3

- **Fault geometry**

Yoshida et al. (2016): 4 seg.

- **Modelling parameters**

Area S,

Rise time T_r,

Stress drop $\Delta\sigma$,

Rupture velocity V_r,

Rupture startling point of SMGA

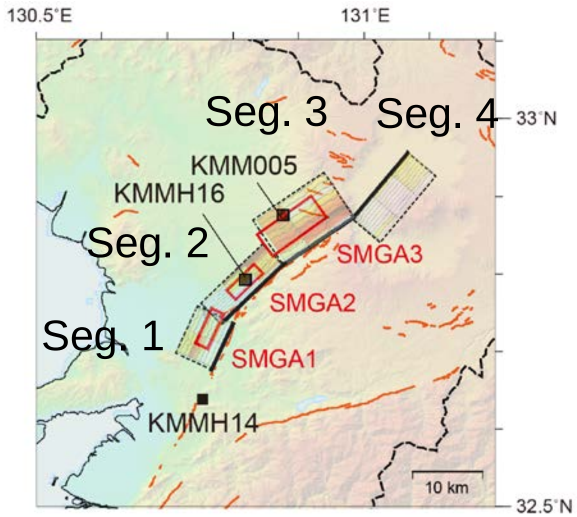
Location of SMGA

- **Assumptions**

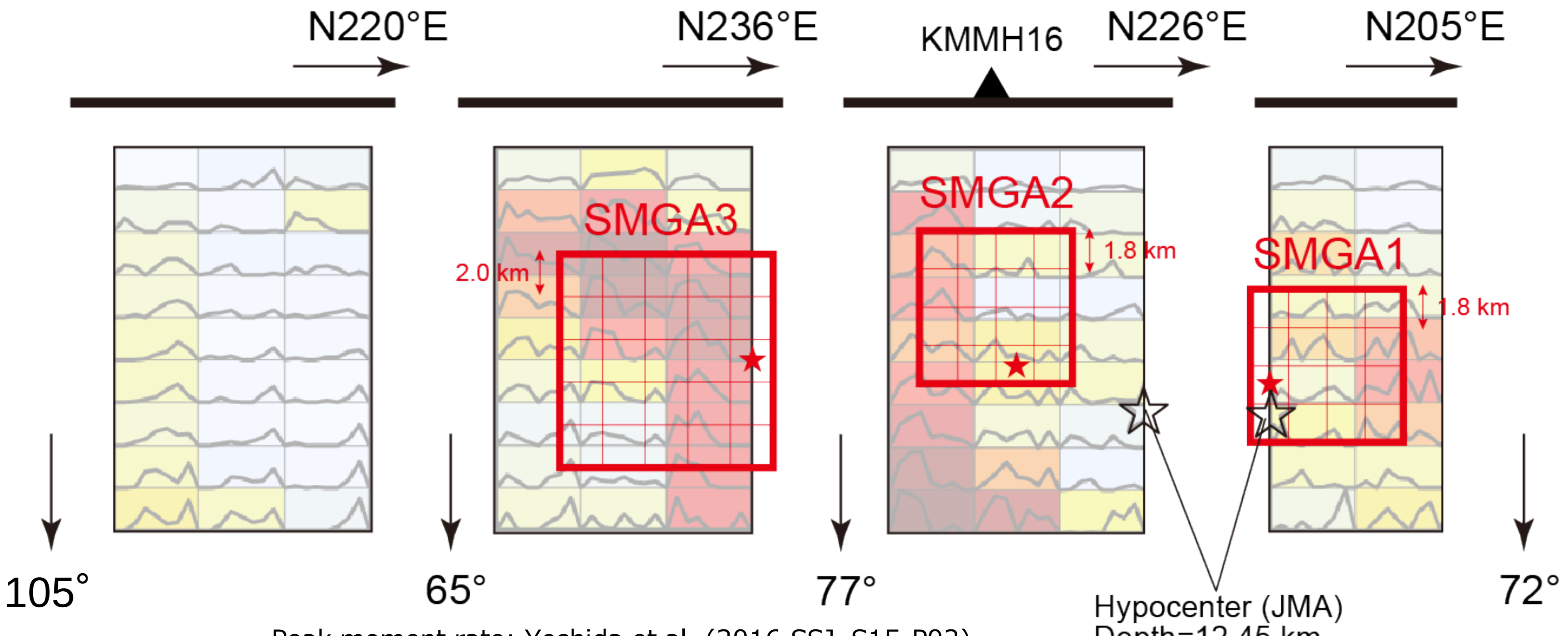
✓ Only three squared SMGA generate strong ground motions without background area

✓ SMGA1 is located including hypocenter.

SMGA broadband source model for the 2016 Kumamoto Eq.

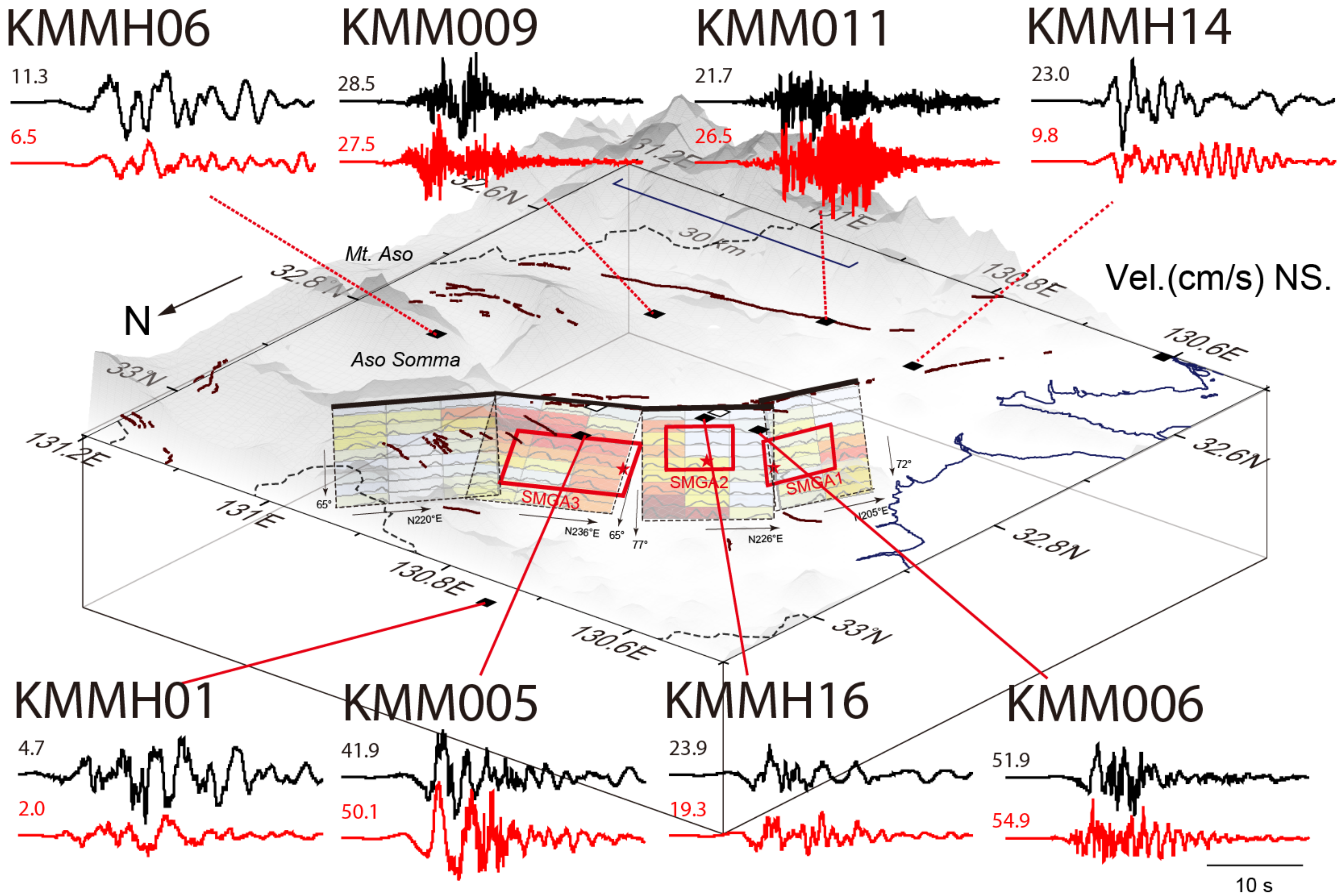


	SMGA1	SMGA2	SMGA3
Area (km^2)	51.8	51.8	100.0
M_0 (Nm)	2.08×10^{18}	2.08×10^{18}	5.49×10^{18}
Rise time (s)	0.6	0.6	0.6
$\Delta\sigma$ (MPa)	13.6	13.6	13.4
V_r (m/s)	2.8	2.8	2.8

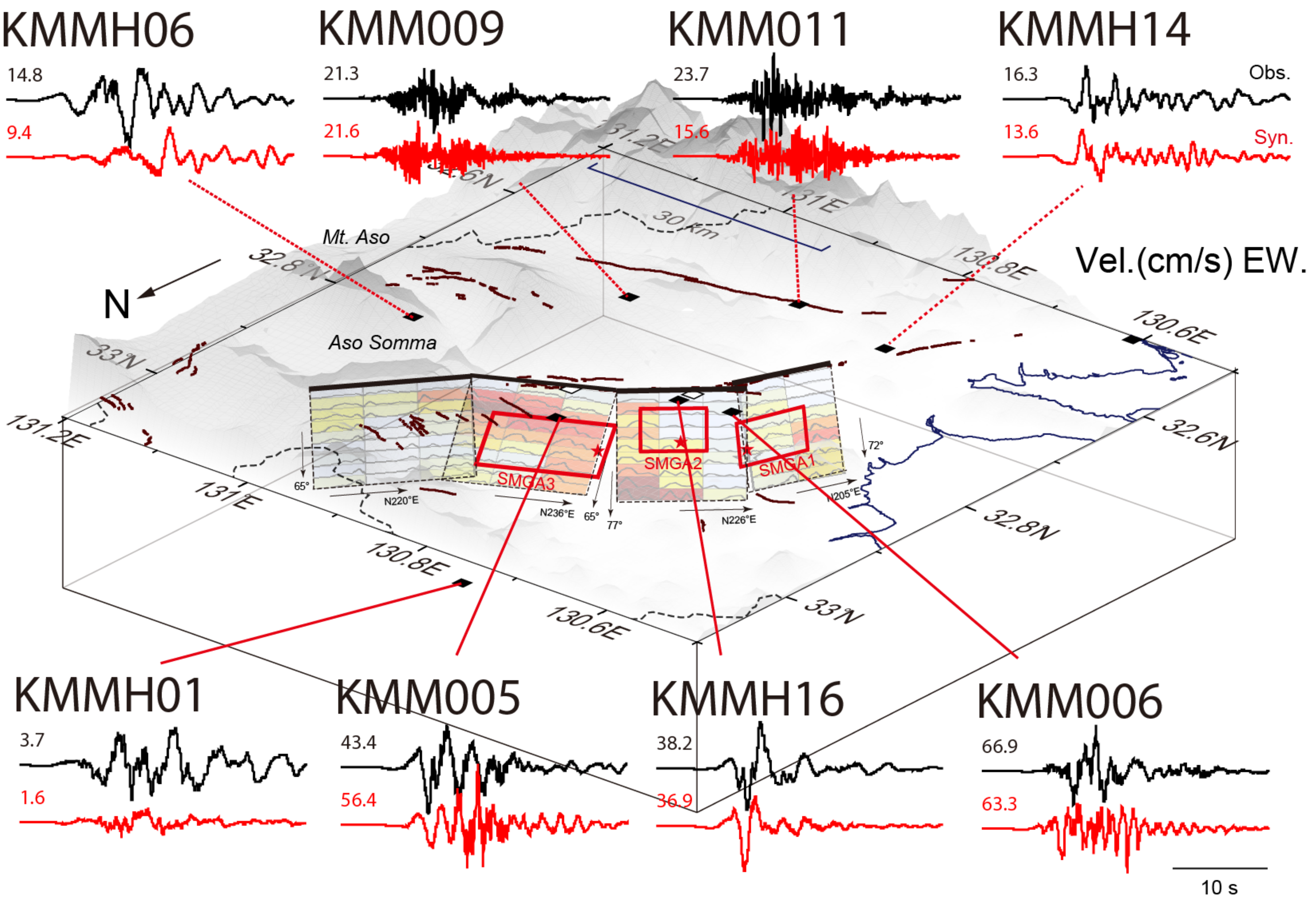


Peak moment rate: Yoshida et al. (2016,SSJ_S15-P02)

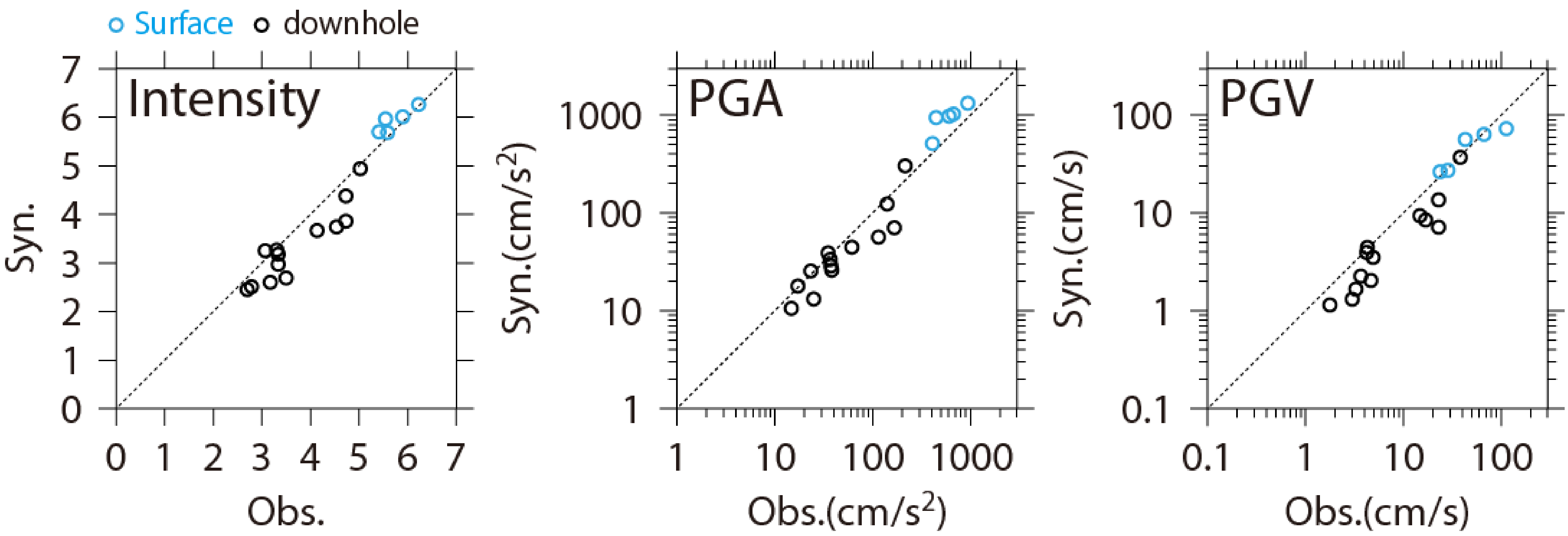
Velocity waveforms (NS component: 0.2-10 Hz) **Obs.** vs. **Syn.**



Velocity waveforms (EW component: 0.2-10 Hz) **Obs.** vs. **Syn.**



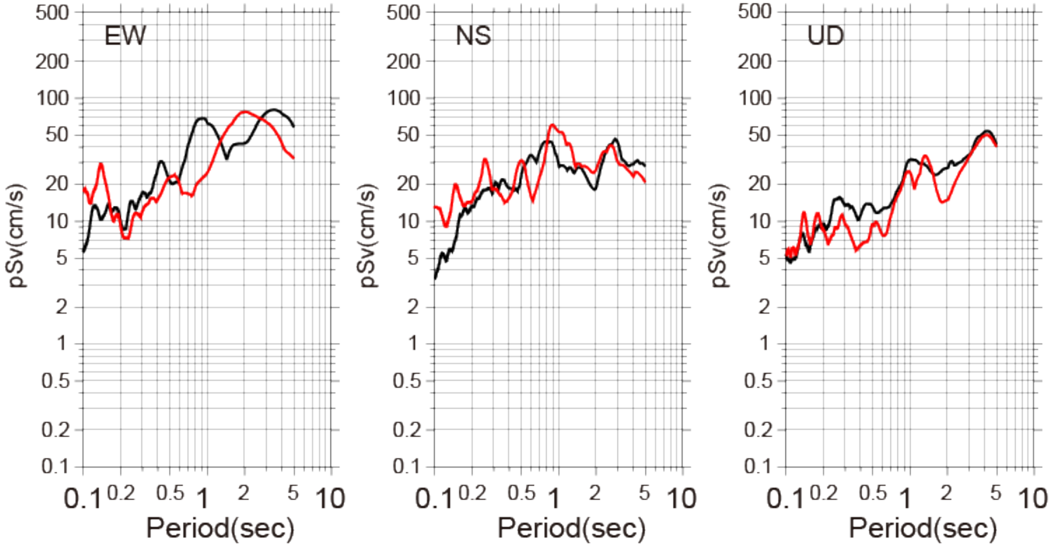
Comparison between observed and synthetic ones of intensity (JMA scale), PGA, and PGV



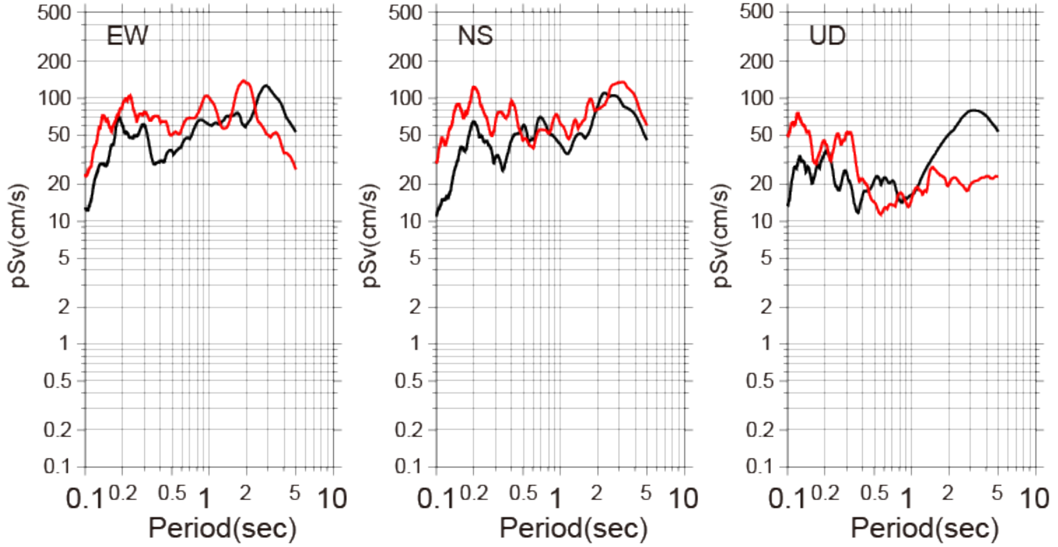
- The synthetic ground motions explain well the characteristics of observed ground motion in the broadband frequency range.
- PGA for the station using the surface records could be relatively overestimated due to the non-linear site effect during the mainshock.

Pseudo Velocity Response Spectra (h=0.05) **Obs.** vs. **Syn.**

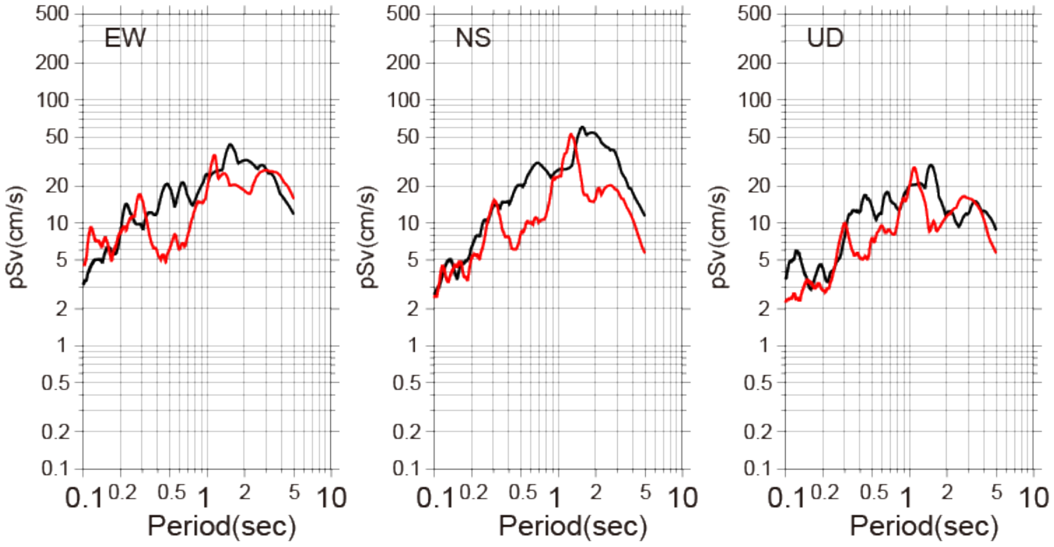
KMMH16 MASHIKI: Downhole



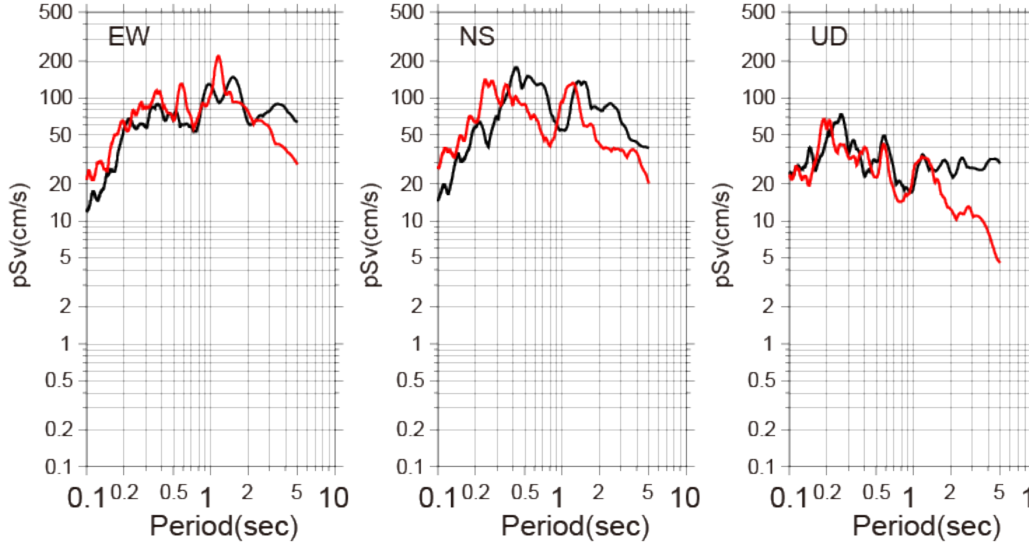
KMM005 OHDU: Surface



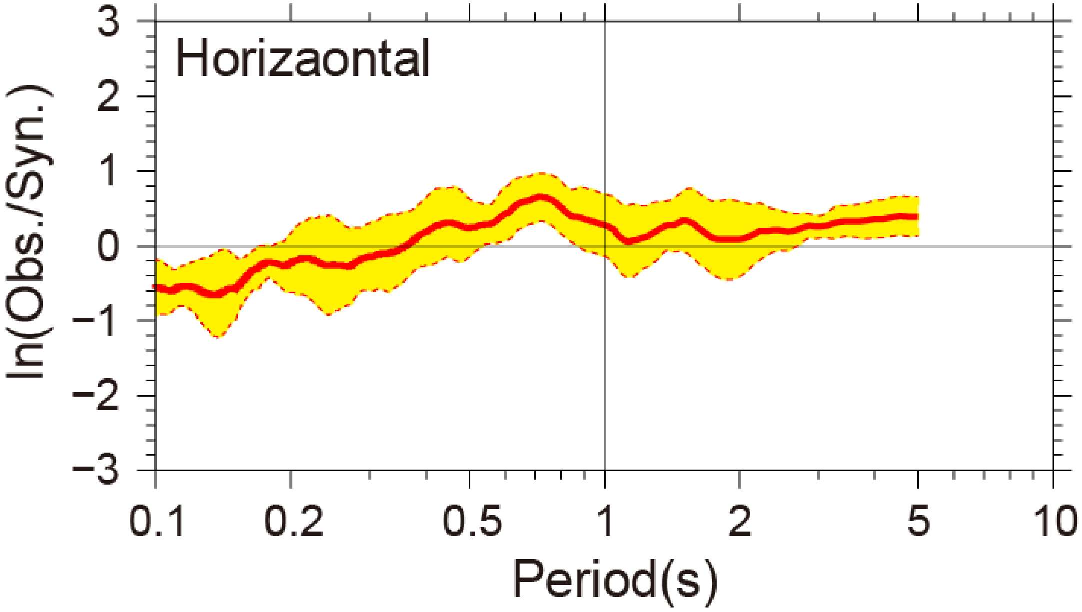
KMMH14 TOYONO: Downhole

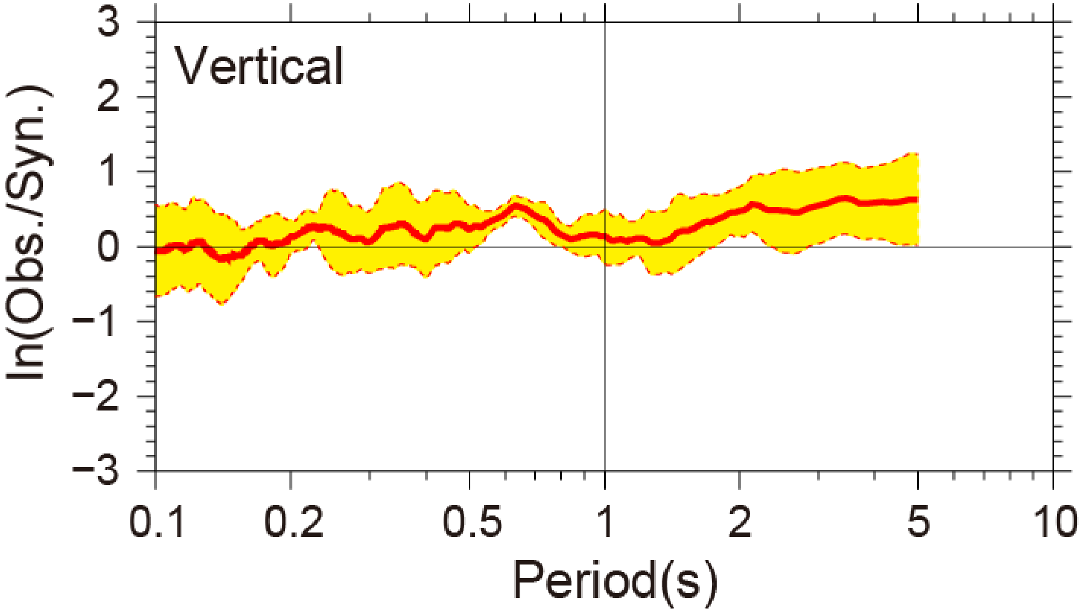


KMM006 KUMAMOTO: Surface



Bias Plots for horizontal and vertical components





- ■ For short period range (<0.3 s), synthetic ground motions are larger than the observations.
- ✓ It is likely caused by the non-linear site effect during the mainshock for some stations using the surface records.

$R_i = \ln(O_i / S_i)$

$\text{Bias} = (1/N) \sum R_i$

$\sigma = [(1/N) \sum (R_i - \text{Bias})^2]^{1/2}$

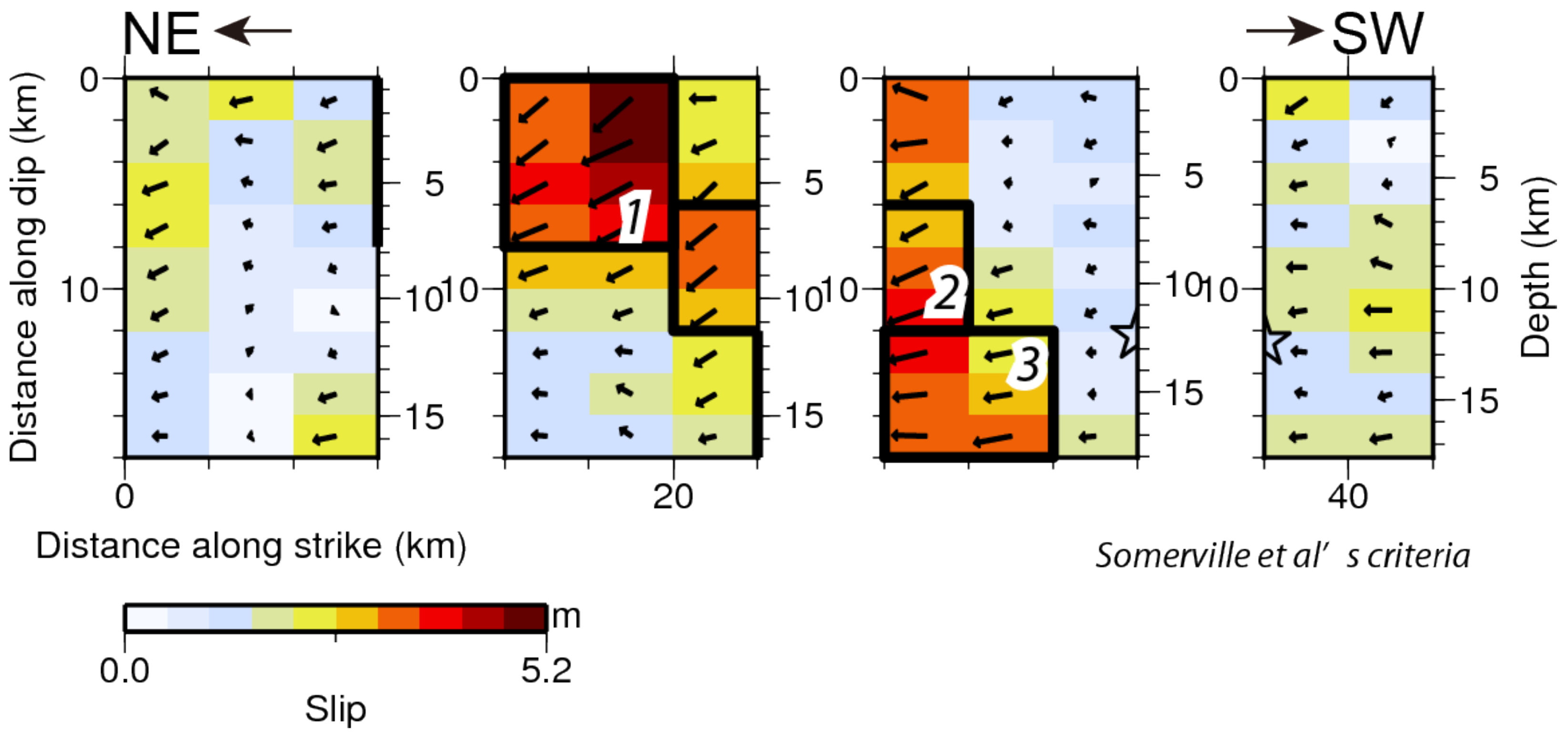
N = 10 sites, R<40 km

Mean bias

± Standard error

2016 Kumamoto earthquake
Slip distribution of strong motion waveform inversion (T = 2-20 s)

Total slip



Averaged three slip inversions

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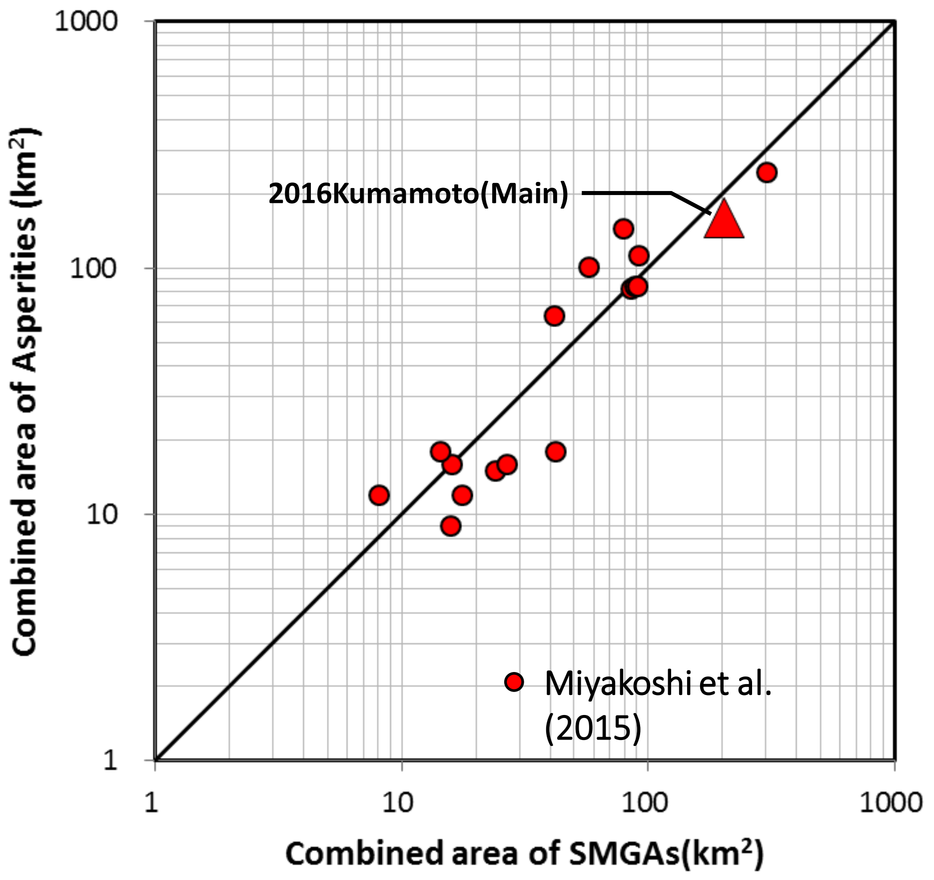
Yoshida et al. (2016)

Comparison between combined area of asperities from the slip distribution and that of SMGAs from strong motion simulation

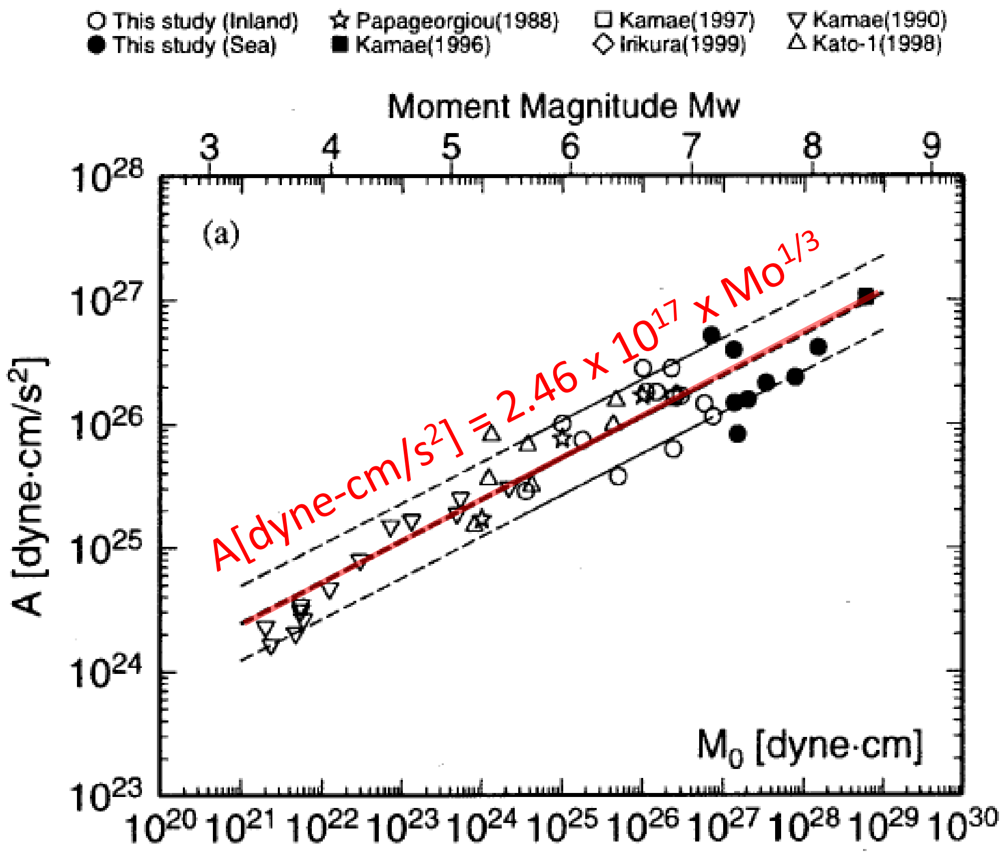


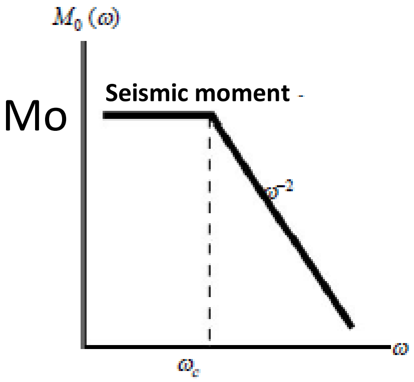
Acceleration level versus Seismic Moment

Dan et al. (2001)

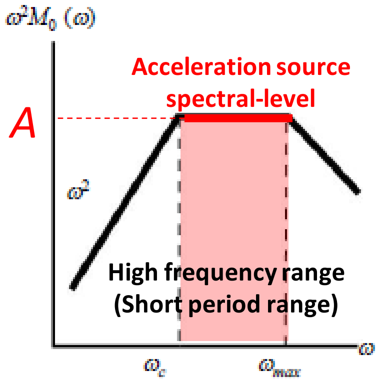
Empirical relation of the Acceleration level (or "Short period level")

Acceleration level (A [Nm/s^2]): Acceleration source spectral-level



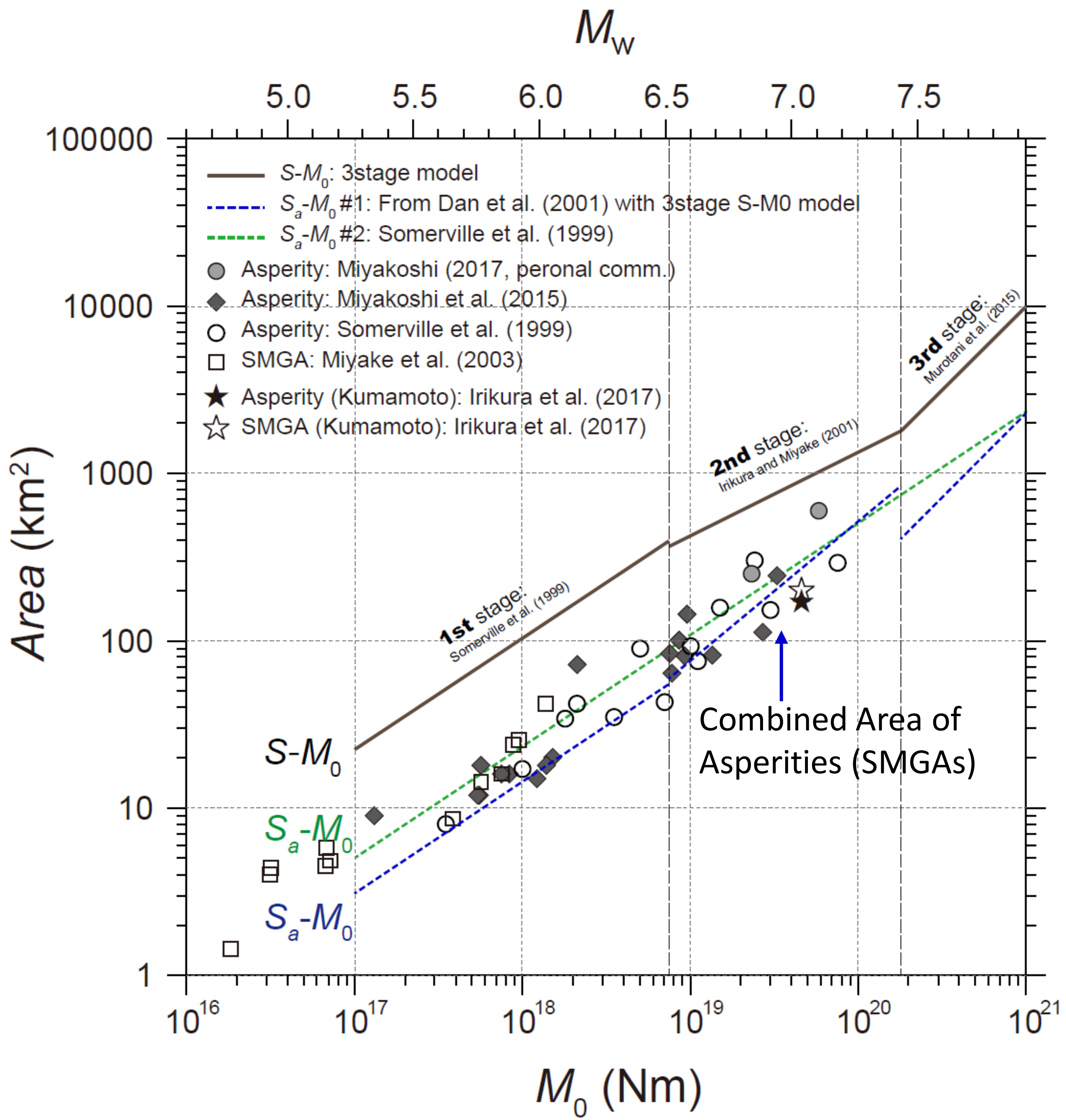


Source spectrum

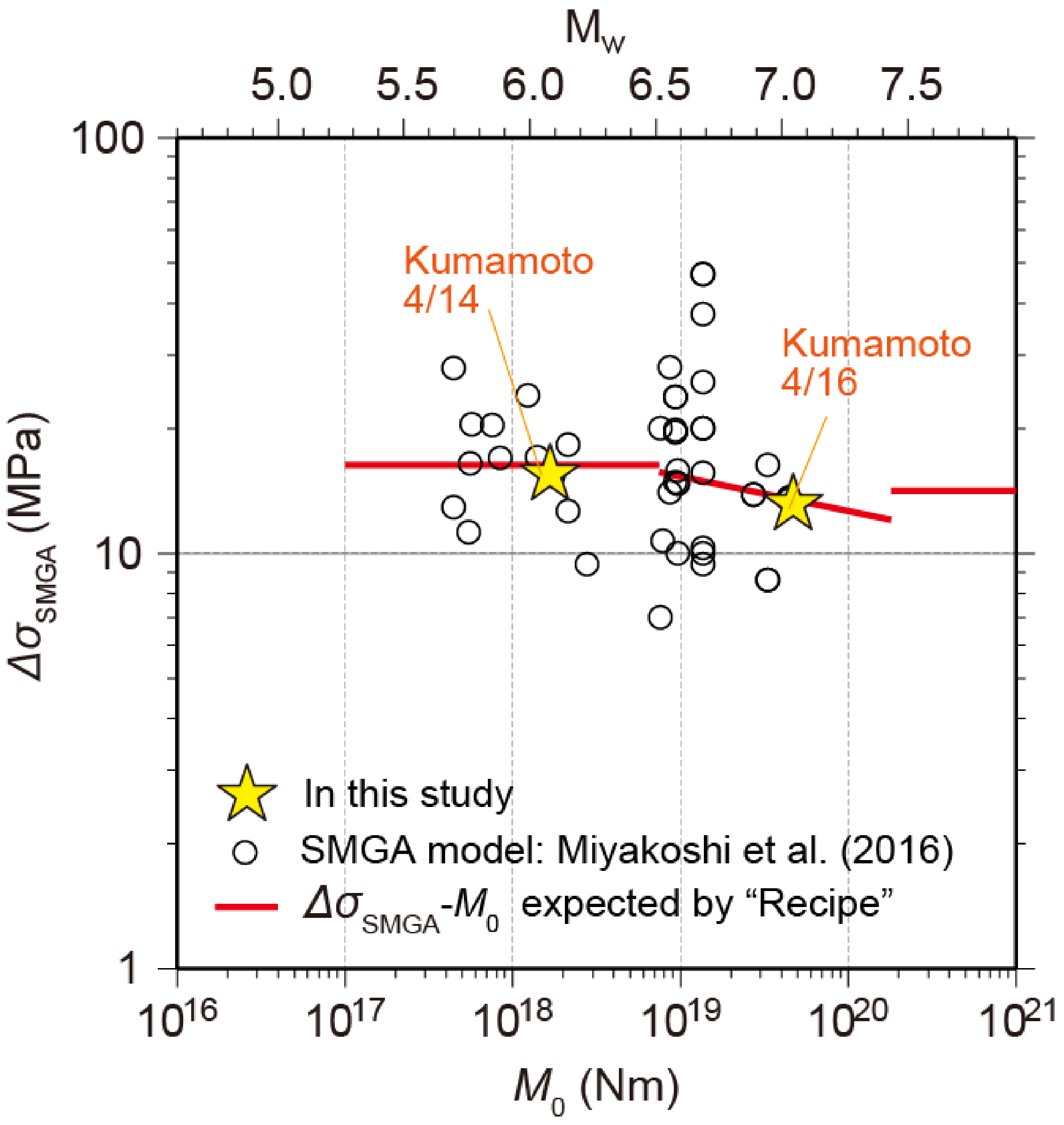


Acceleration source spectrum

Combined Area of Asperities (SMGA) vs. Seismic Moment



Stress drop on the SMGA versus seismic moment



Stress drop on SMGA is estimated from the average stress drop in the rupture area ($\Delta\sigma$) and the inverse ratio of SMGA over the rupture area (1/ (Sa/S)).

SMGA: $Sa = \pi \cdot r^2$

Rupture area $S = \pi \cdot R^2$

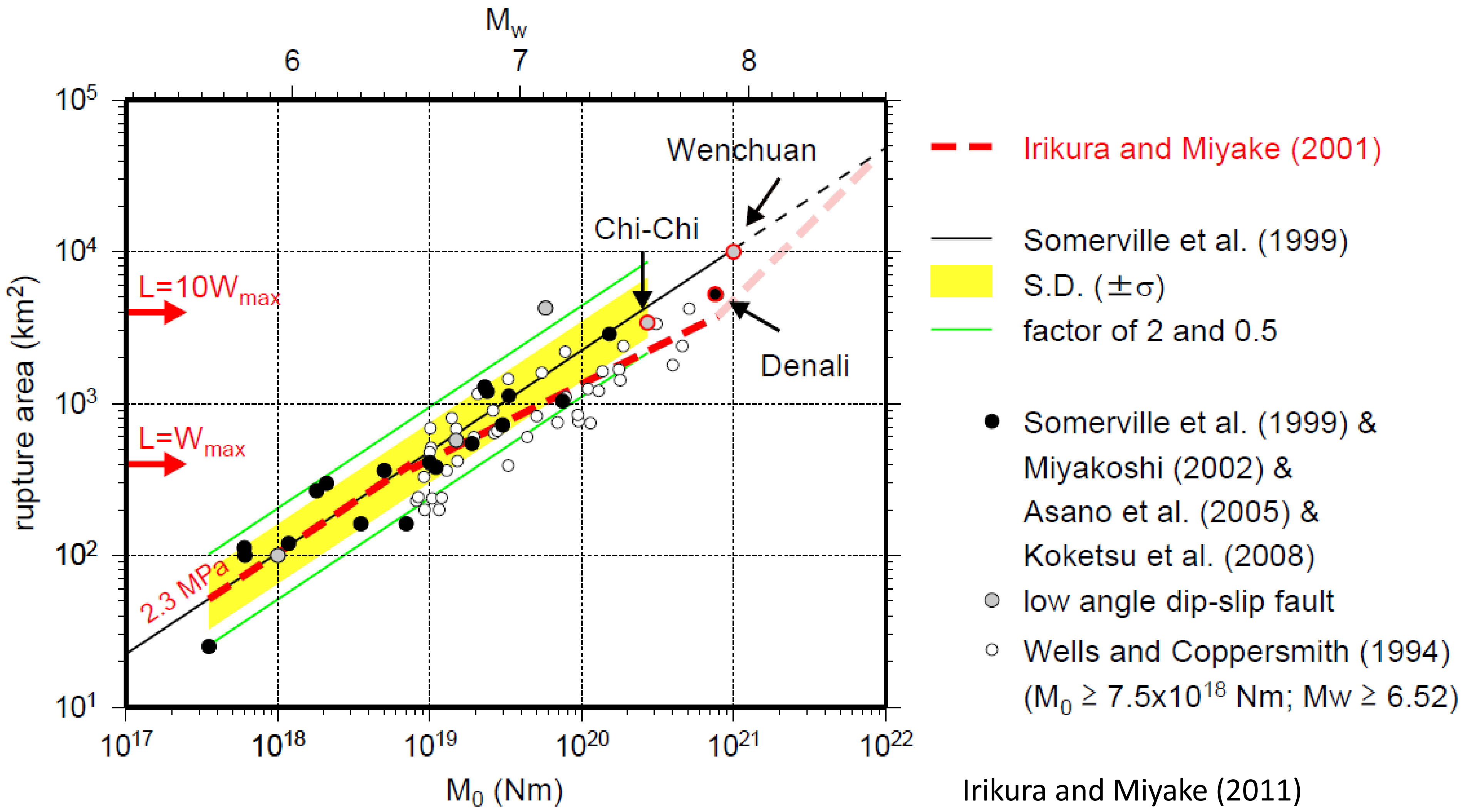
$\Delta\sigma_a = S / Sa \cdot \Delta\sigma$ (Madariaga, 1979)

■ Red lines indicate the relationship between $\Delta\sigma_{SMGA}$ and M_0 expected by "Recipe" for inland crustal earthquakes.

Summary

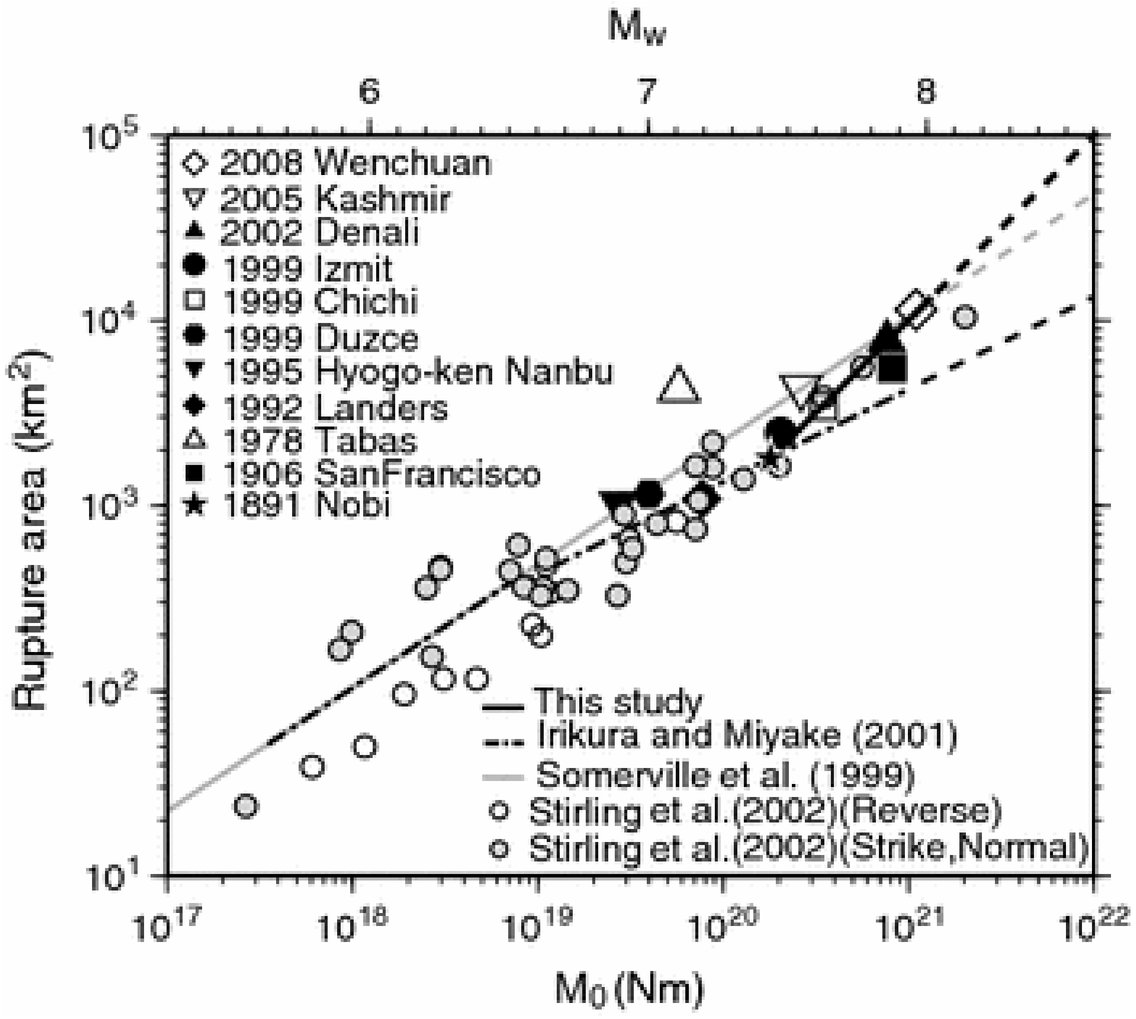
1. The rupture area and asperity area were determined based on slip distributions obtained from waveform inversion of the 2016 Kumamoto earthquake observations (Mw 7.0). The relationship between the rupture area and the seismic moment for this earthquake follows the second-stage scaling within one standard deviation of a three-stage scaling for crustal earthquakes in Japan.
2. The ground motions of this earthquake are well simulated using a characterized broadband source model consisting of strong motion generation areas (SMGAs) based on the EGF method.
3. Scaling relation of rupture area to seismic moment seems to be universal for most crustal earthquakes, indicating less regional variations of stress drop. On the contrary, scaling relations of rupture length and width to seismic moment show regional variations.

Scaling Relationship for Crustal Earthquakes in Japan
Rupture Area vs. Seismic Moment (Irikura and Miyake, 2001; 2011)



Irikura and Miyake (2011)

Extended scaling relationship
Rupture Area vs. Seismic Moment (Murotani et al. (2015)



Crack model
Mw < 6.5

L-model (D ∝ L)
6.5 ≤ Mw ≤ 7.4

W-model (D ∝ W)
Mw > 7.4

Background of this study
W ~ 18 km for L-model
L > 100 km for W-model

Murotani et al. (2015)