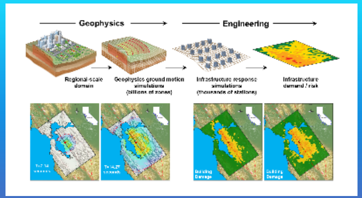

PEER International Pacific Rim Forum

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Earthquake Source Characterization for Broadband Ground Motion Simulation

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University of Tokyo

EARTHQUAKE RESEARCH INSTITUTE
THE UNIVERSITY OF TOKYO

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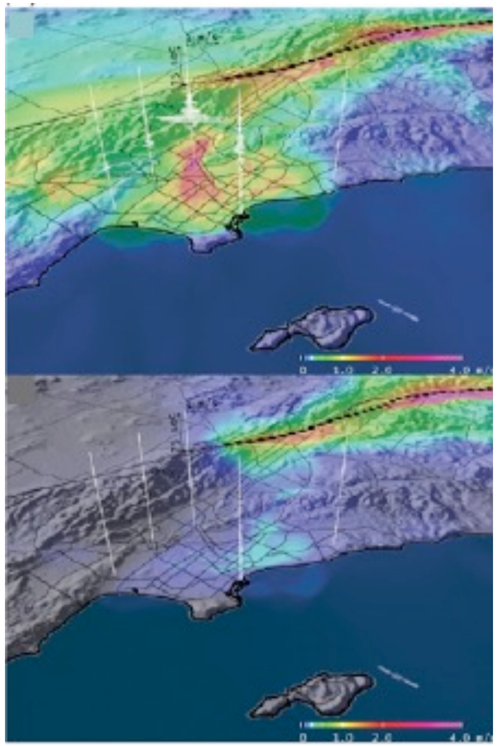
Scenario-based Seismic Hazard Analyses

Source Modeling
Velocity Structure Modeling

→

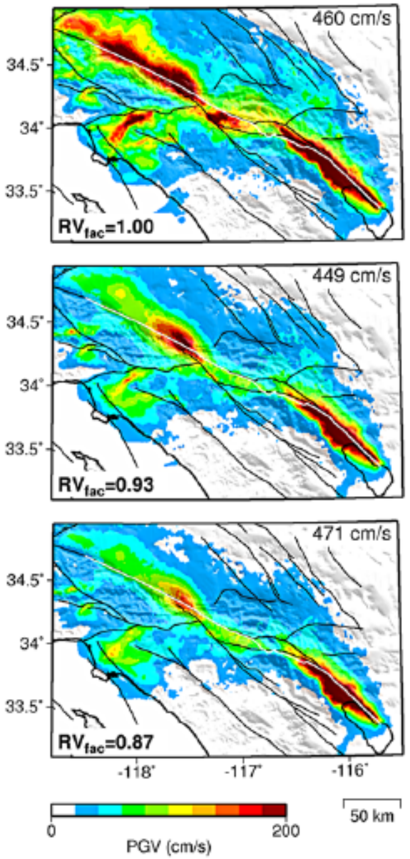
Ground Motion Simulation

Long-Period



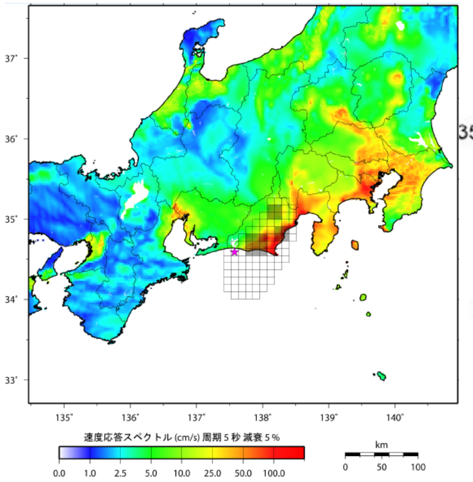
Olsen et al. (2006)

Broadband



Graves et al. (2008)

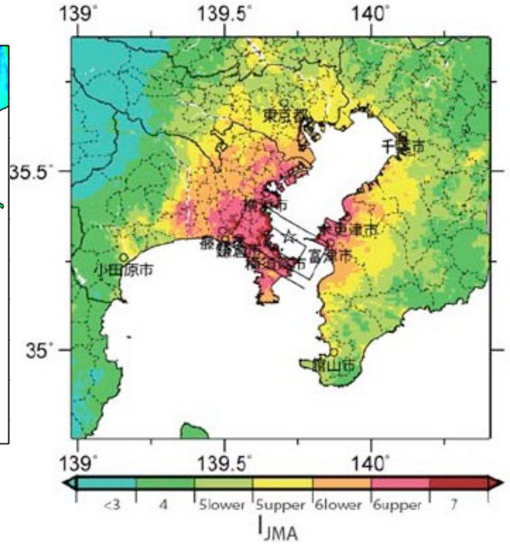
Long-Period



Earthq. Res. Comm. (2009)

Koketsu et al. (2010)

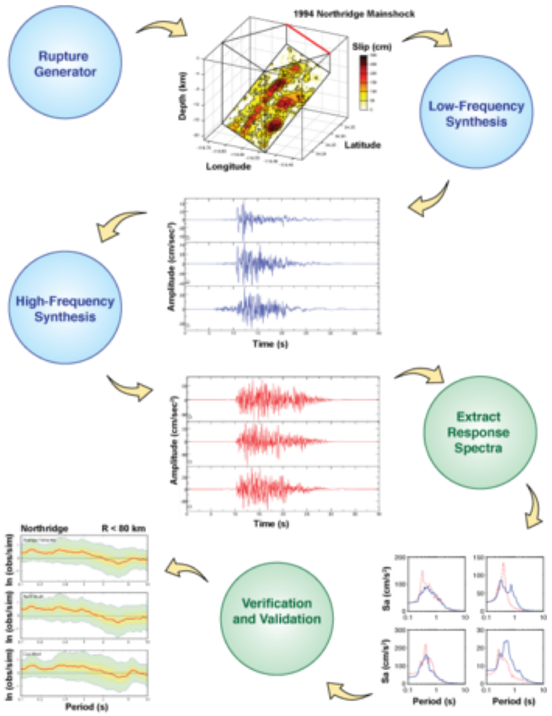
Broadband



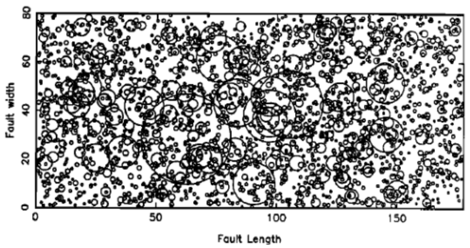
Earthq. Res. Comm. (2009)

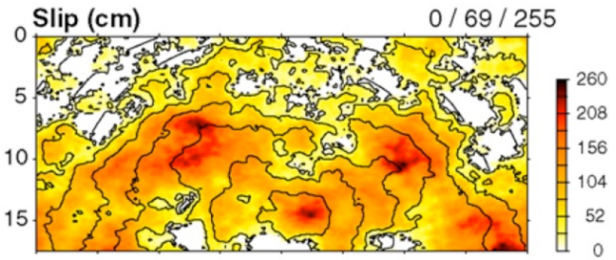
Fujiwara (2010)

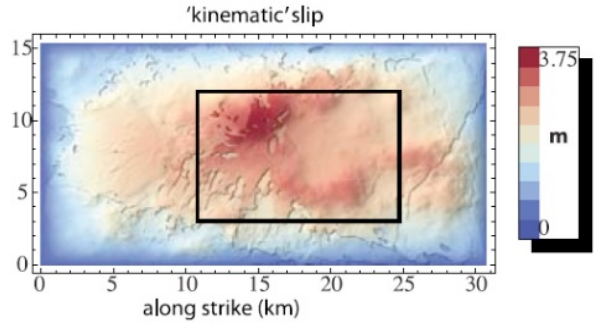
Broadband Source Modeling

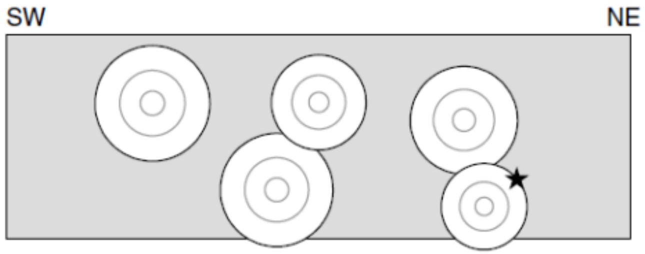


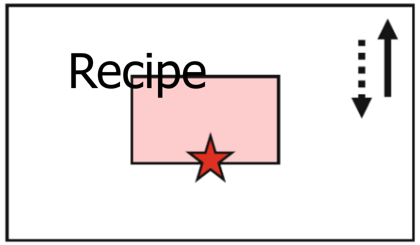
	SCEC Broadband Platform	Recipe
Source Model	**Heterogeneous and complex**	**Characterized source model (definitive & simpler)**
Velocity Model	Long-period: 3-D or 1-D Short-period: 1-D or scattering	Long-period: 3-D Short-period: 1-D with site response
Simulation	Hybrid method	Hybrid method & EGF method
Validation	Past earthquakes & GMPEs (5% pseudo-spectral acceleration)	Past earthquakes & GMPEs (ground motion, pulse, seismic intensity)



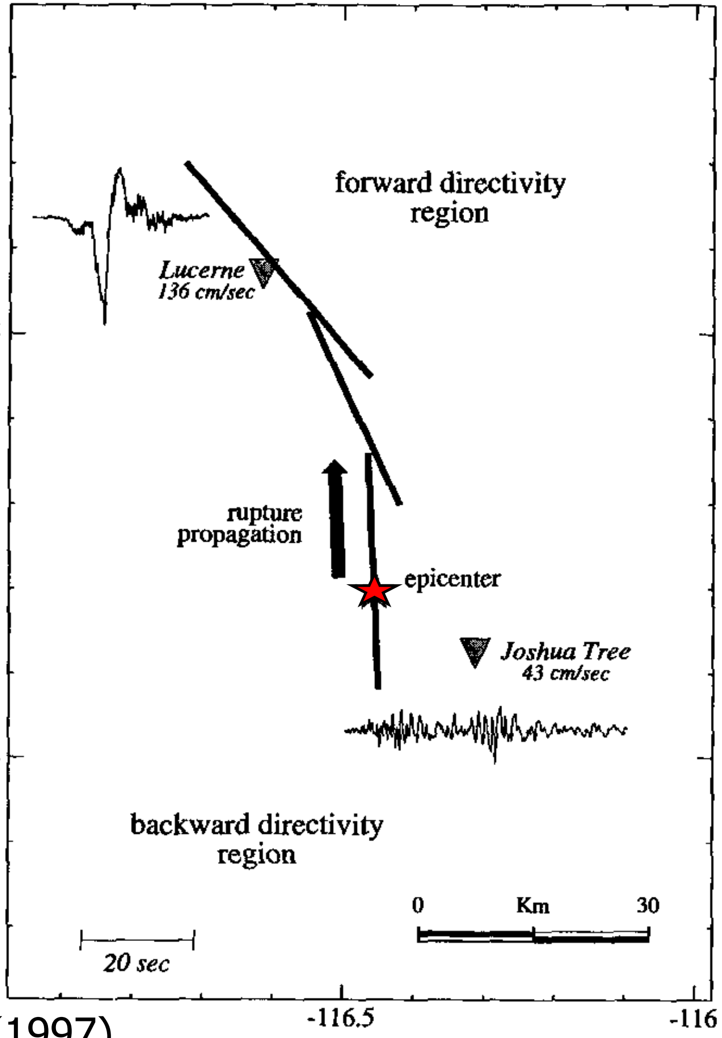




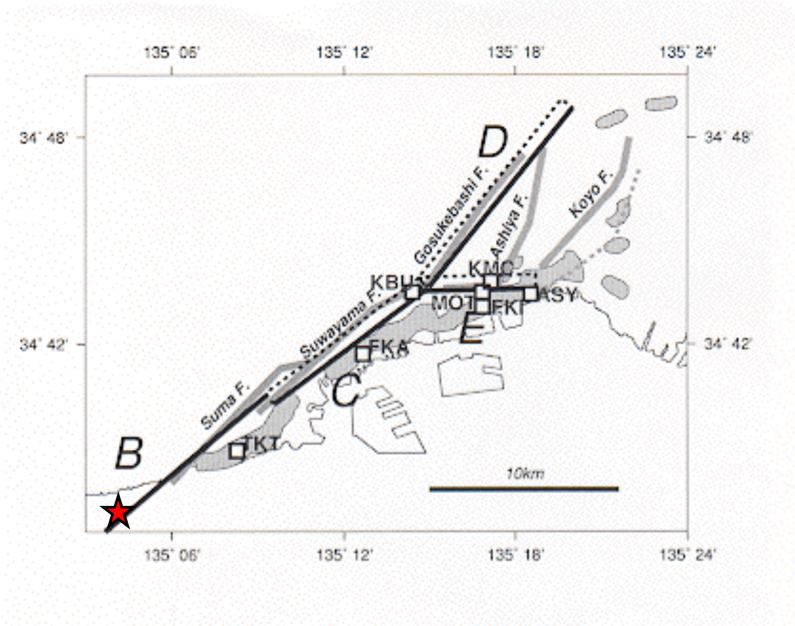


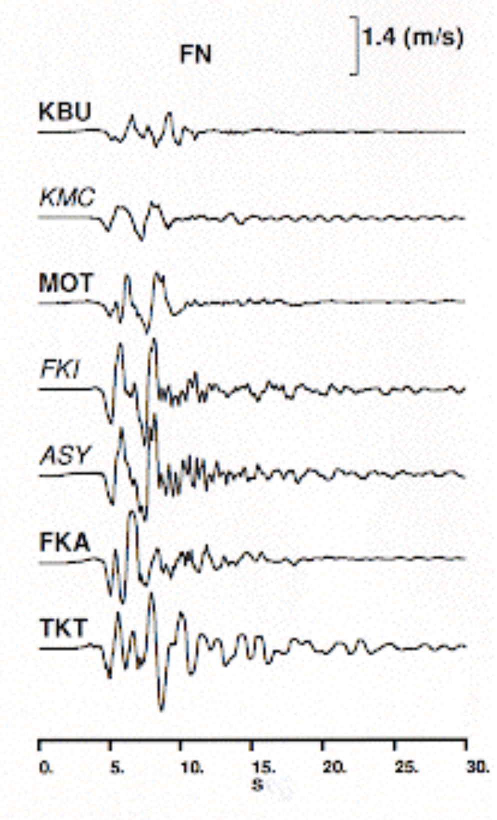


Rupture Directivity Pulse: Landers and Kobe



Somerville et al. (1997)





Irikura et al. (1998)

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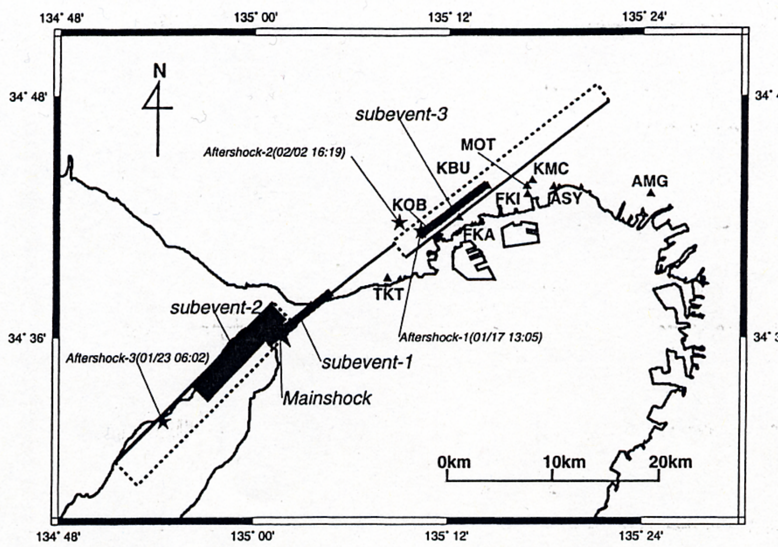
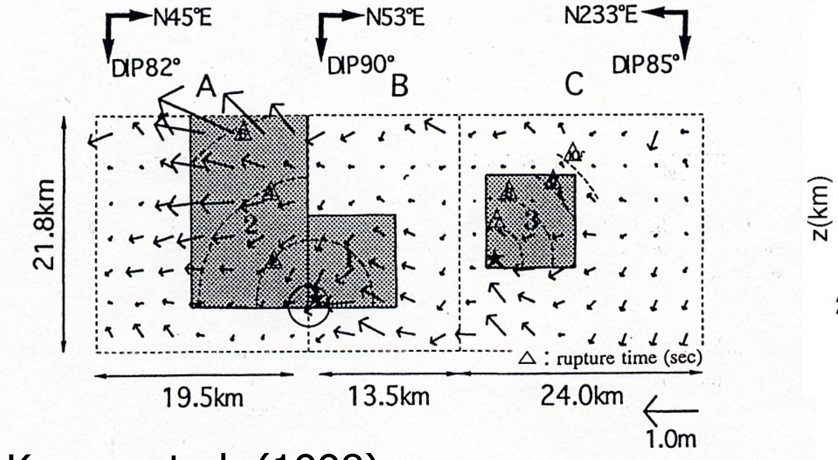
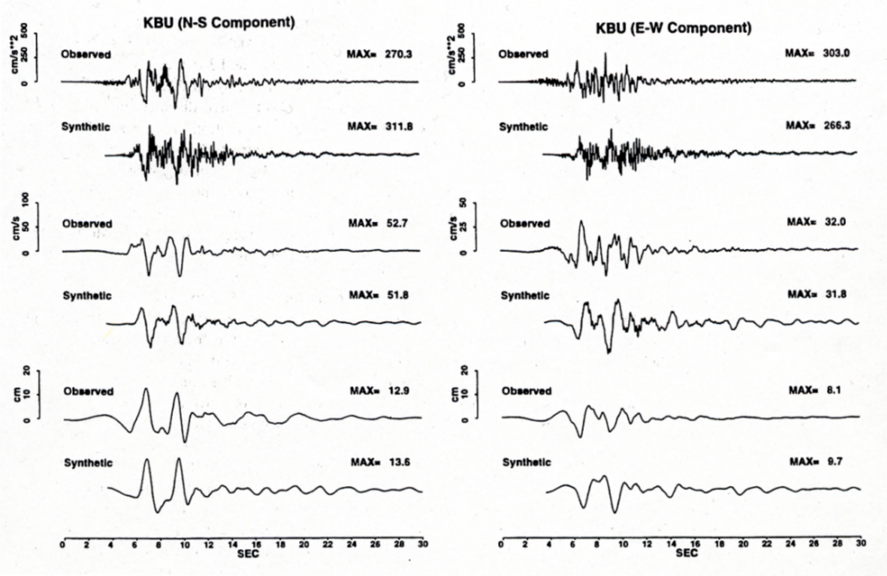
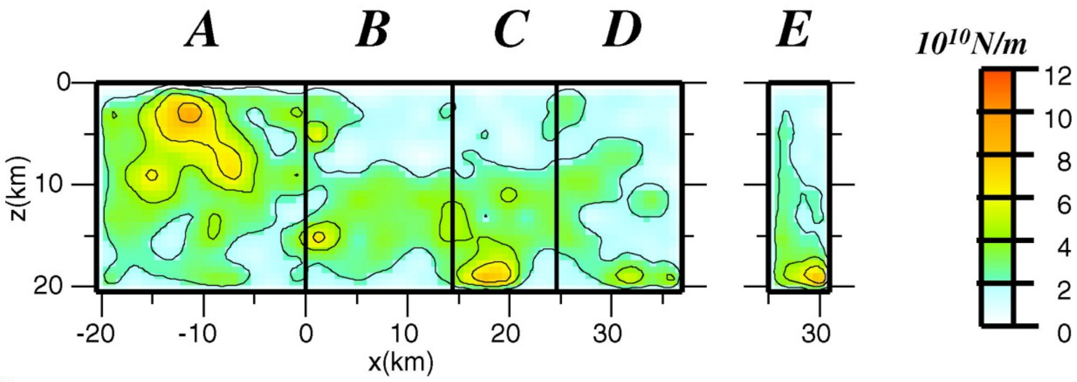
Rupture Directivity Pulse is dependent on Asperity Size





Kamae et al. (1998)

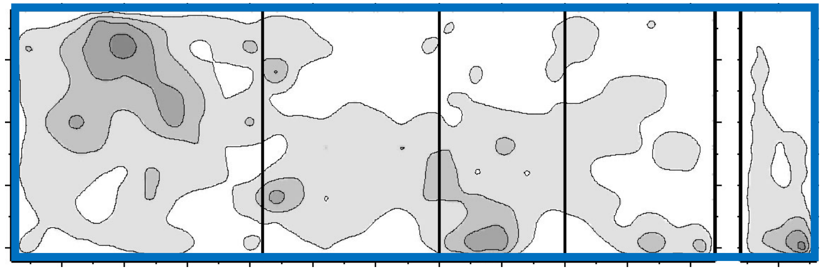


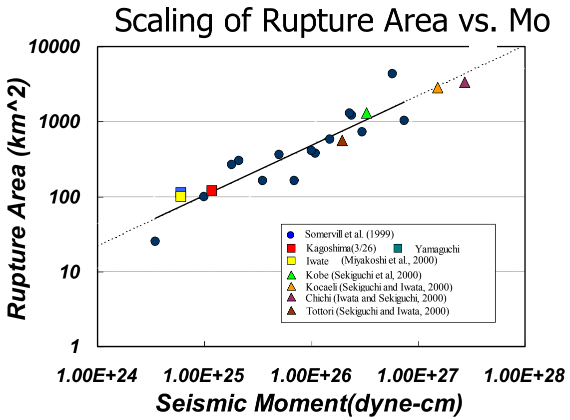


Sekiguchi et al. (2002)

Source Characterization

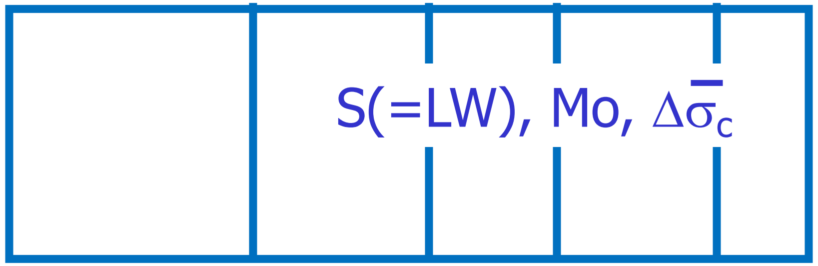
Based on heterogeneous slip by waveform inversion…

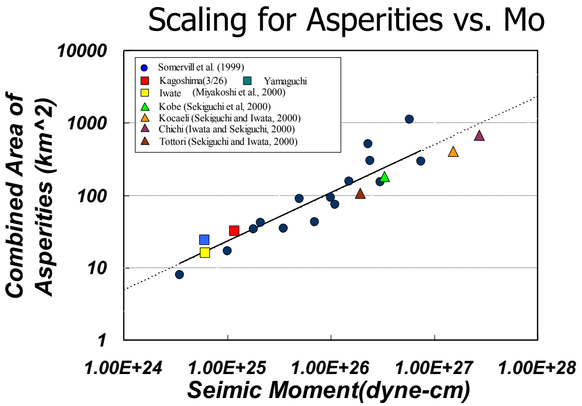




Outer Fault Parameters

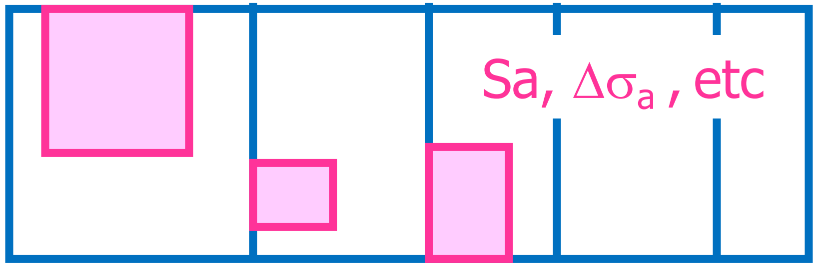
$\Delta\sigma_c$ ~ 2.3 MPa (Eshelby crack)



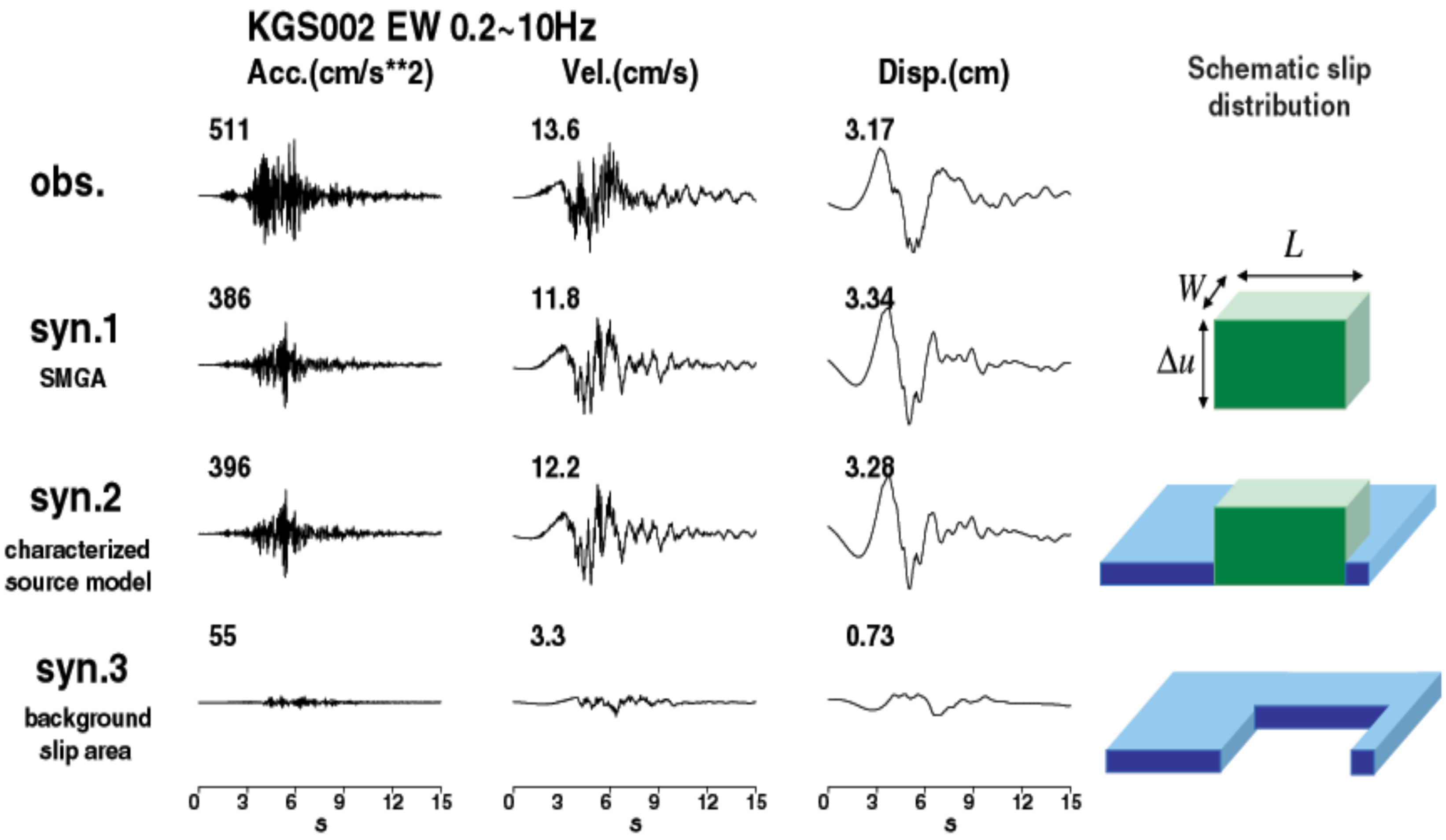


Inner Fault Parameters:

size (22%) and stress drop of asperities $\Delta\sigma_a$ ~ 10.5 Ma



Characterized Source Model for Broadband Ground Motion



Miyake et al. (2003)

Recipe for Strong Ground Motion Prediction

Outer Fault Parameters

Irikura and Miyake (2001, 2011)

- **Rupture area S** is given.
- **Seismic moment Mo** from the empirical relation of **Mo-S**.
- **Average static stress-drop** $\Delta\sigma_c$ from appropriate physical model (e.g., circular crack model, tectonic loading model, etc.)

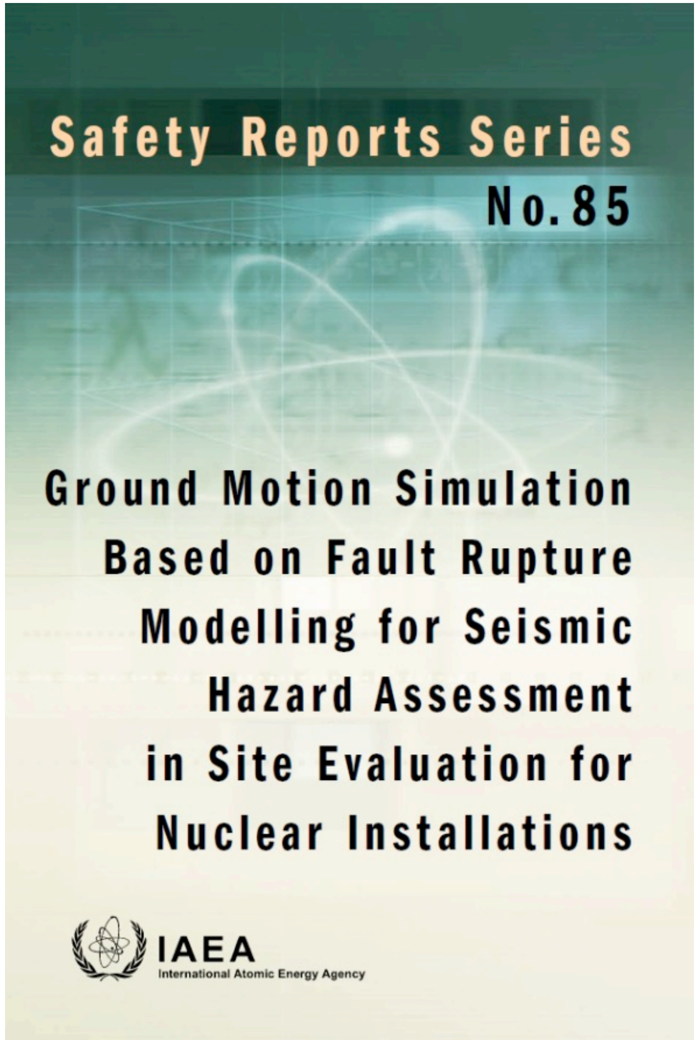
Inner Fault Parameters

- **Combined area of asperities Sa** from the empirical relations of **S-Sa** or **Mo-Ao**.
- **Stress drop** on asperities $\Delta\sigma_a$ based on the multiple asperity model.
- **Number** of asperities from fault segments.
- **Average slip** of asperities **Da** from **dynamic simulations**.
- **Effective stress** for asperities σ_a and background area σ_b are given.
- **Slip velocity time function** given as Kostrov-like function.

Extra Fault Parameters

- Rupture nucleation and termination are related to **fault geometry**.

Recipe on IAEA Safety Report Series No. 85



IAEA (2015)

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Concept of the Recipe

The first concept of the recipe is that anybody can reproduce the same source definitively.

The second concept is easy to simulate damaging rupture directivity pulses that enhance response spectra seen in the 1992 Landers, 1994 Northridge, and 1995 Kobe earthquakes.

The third concept is the characterized source calibrated by empirical Green's functions including realistic complexity of velocity structure and site response.

Random realization is possible by changing the rupture starting points, location of asperities, and rupture velocity to assess simulated ground motion variability.

SCEC Broadband Platform v19.4.0

method	source module	wave propagation module (long-period + short-period)	references
GP	k-squared	1D FK + 1D EXSIM	Graves and Pitarka (2010)
SDSU	k-squared	1D FK + 1D scattering	Mai et al. (2010)
UCSB	dynamic	1D FK	Schmedes et al. (2010)
CSM	random	1D R/T matrix	Zeng et al. (1994)
EXSIM	Random	1D EXSIM	Motazedian and Atkinson (2005)
SONG	pseudo-dynamic	1D FK + 1D EXSIM	Song (2016)
Recipe (original)	characterized	3D FDM+1D stochastic	Morikawa et al. (2011) Iwaki et al. (2016)
Irikura Recipe 1	characterized	1D FK + 1D EXSIM	Pitarka et al. (2017)
Irikura Recipe 2	characterized	1D FK + 1D stochastic	Iwaki et al. (2016)

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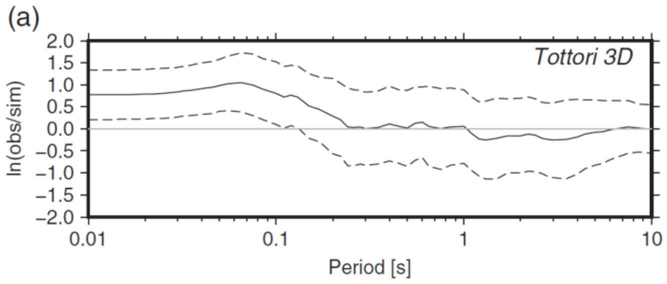
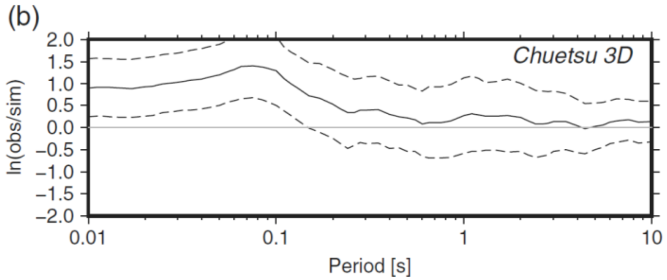
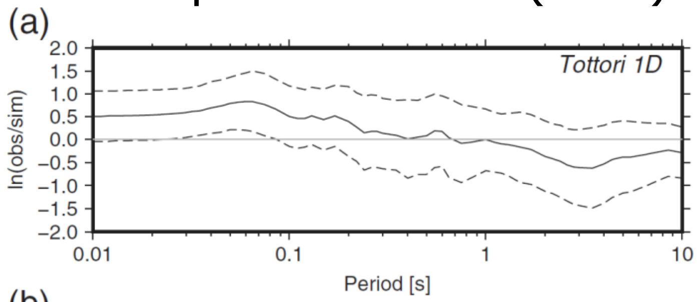
Performance of the Recipe: 1-D & 3-D velocity

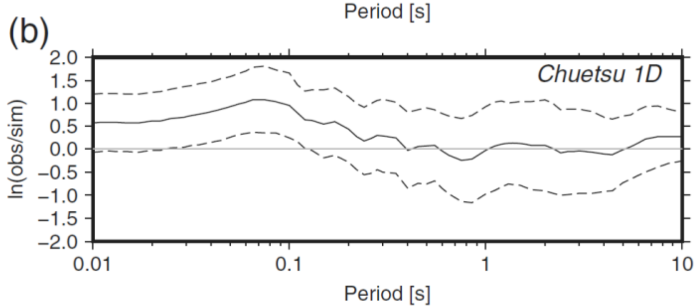
3D recipe: Iwaki et al. (2016)



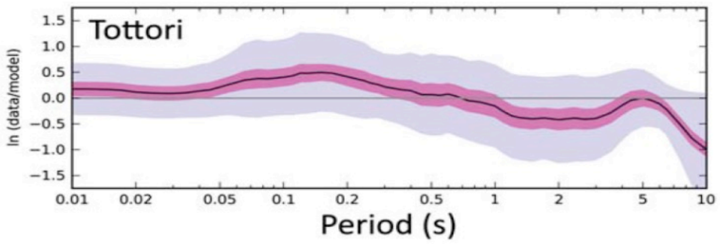


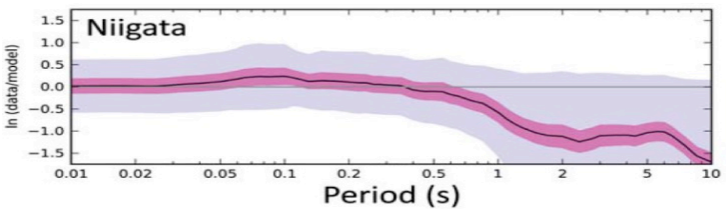
1D recipe: Iwaki et al. (2016)

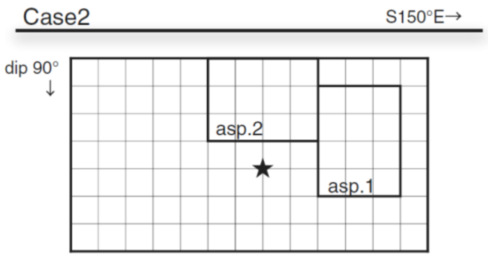


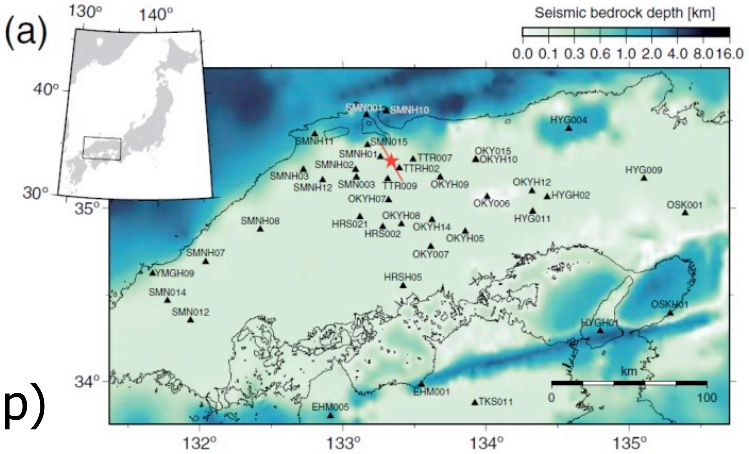


SDSU: Olsen and Takedatsu (2015)

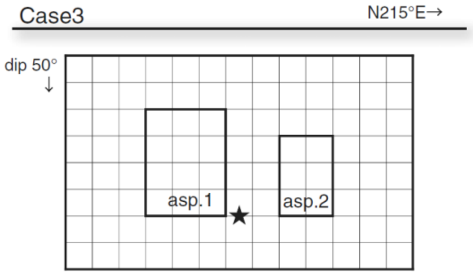


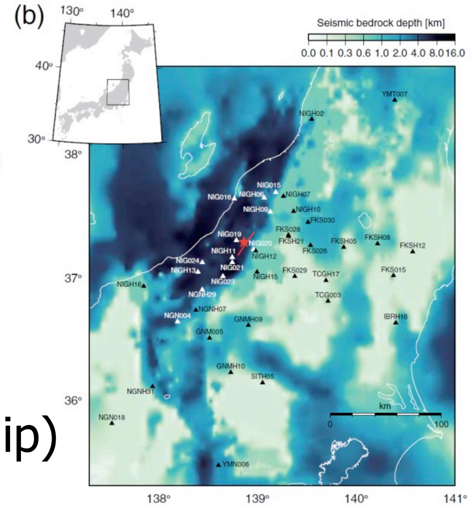






Mw6.6 Tottori (strike slip)





Mw6.6 Chuetsu (dip slip)

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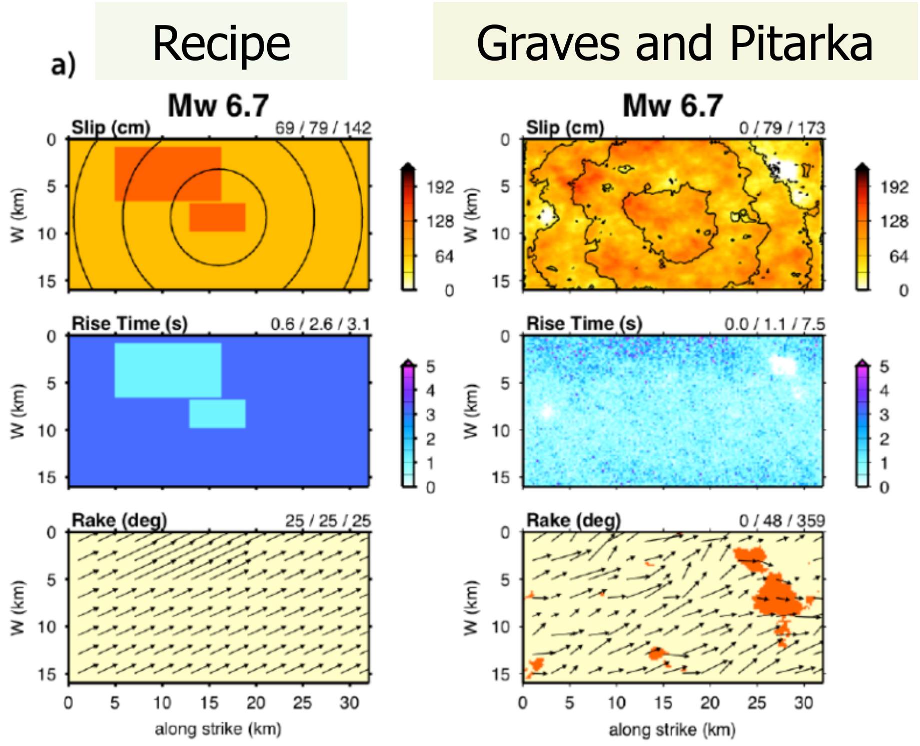
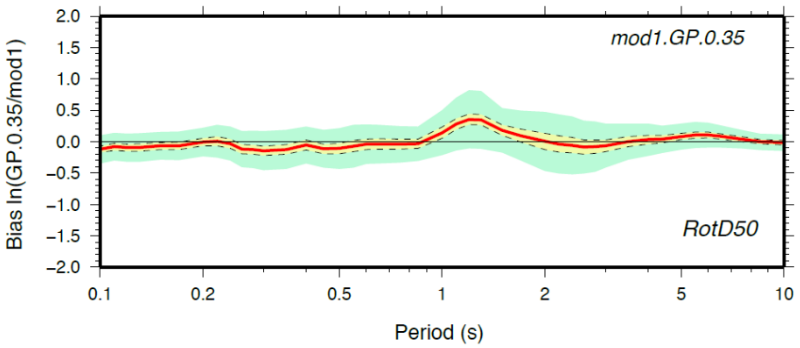
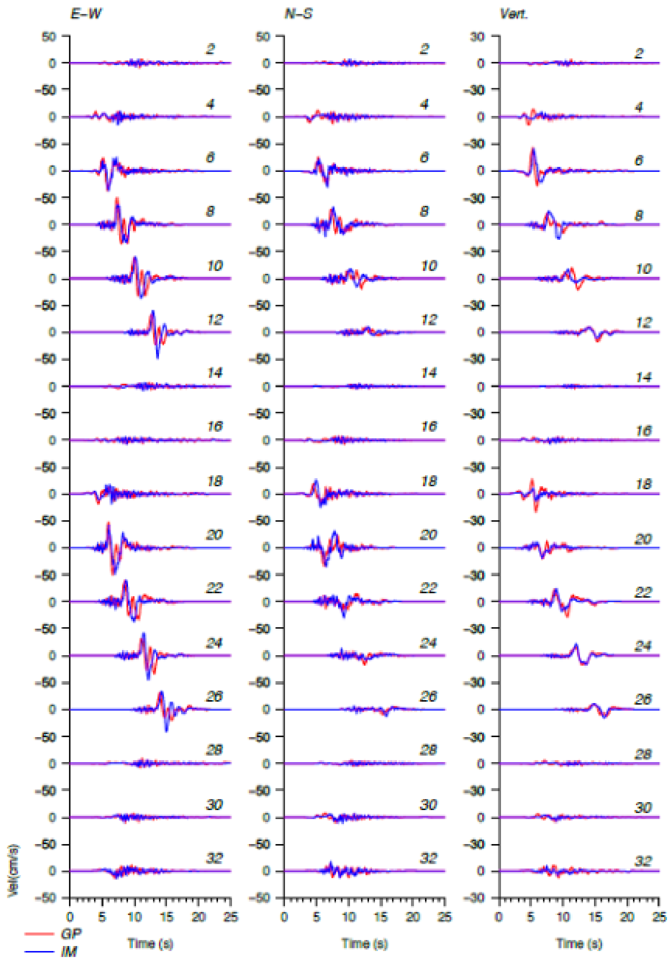
Pitarka et al. (2017)

Recipe vs. Graves and Pitarka (GP) for Mw 6.7 Scenario EQ







0.1-10 Hz velocity

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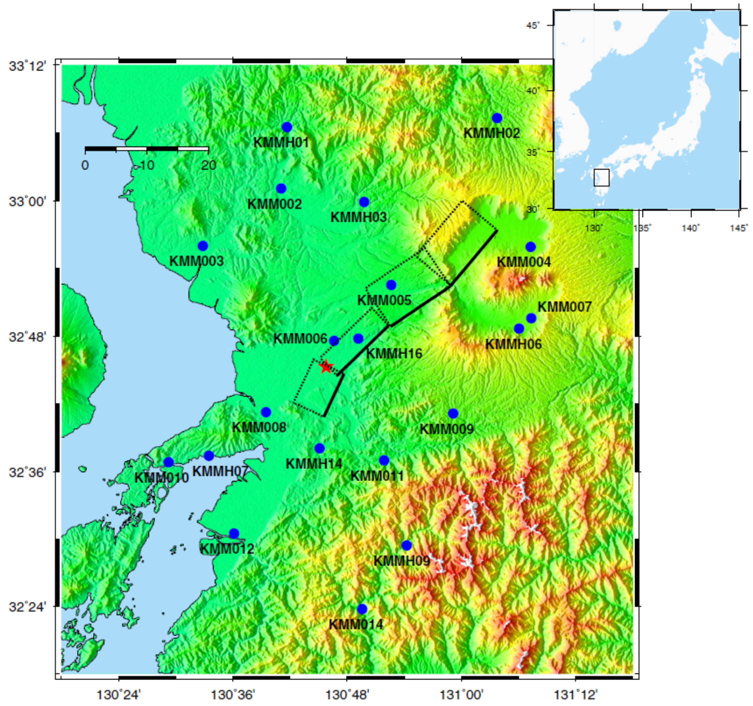
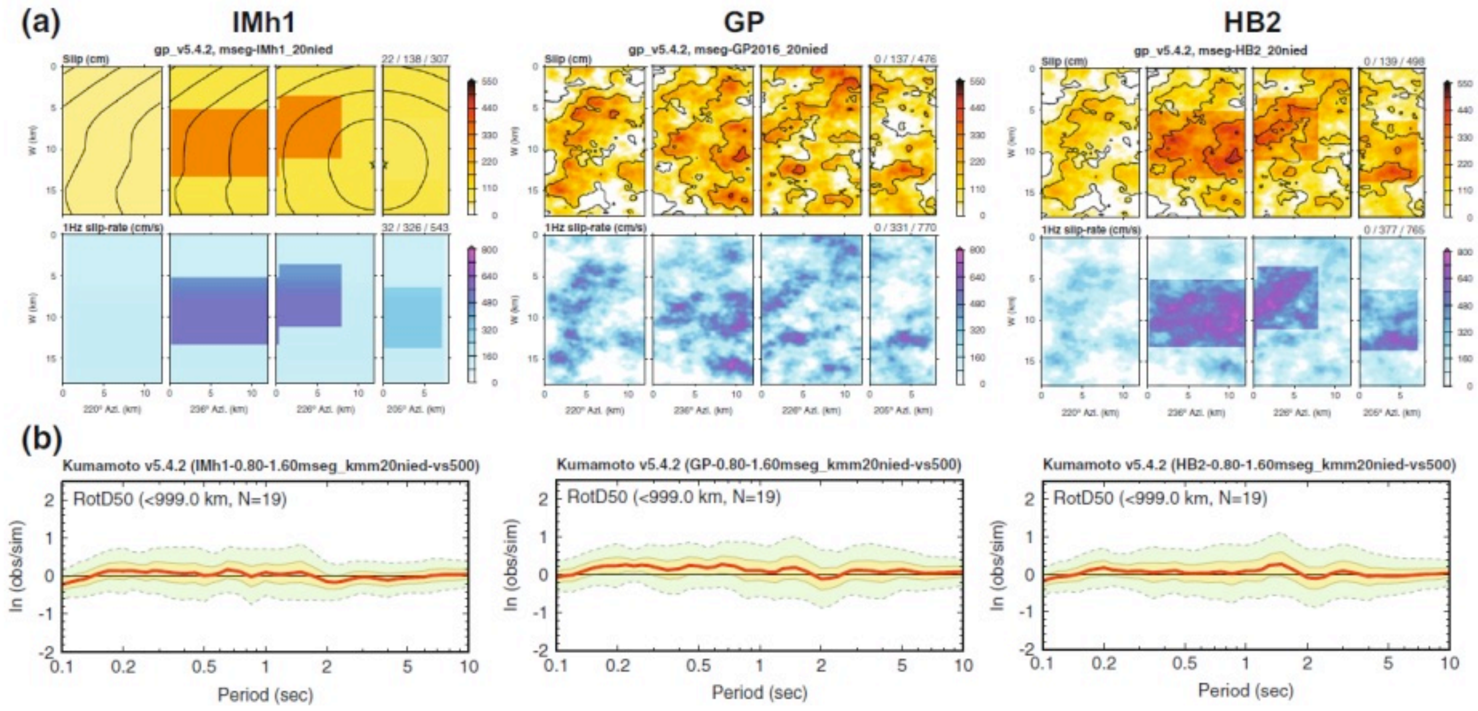
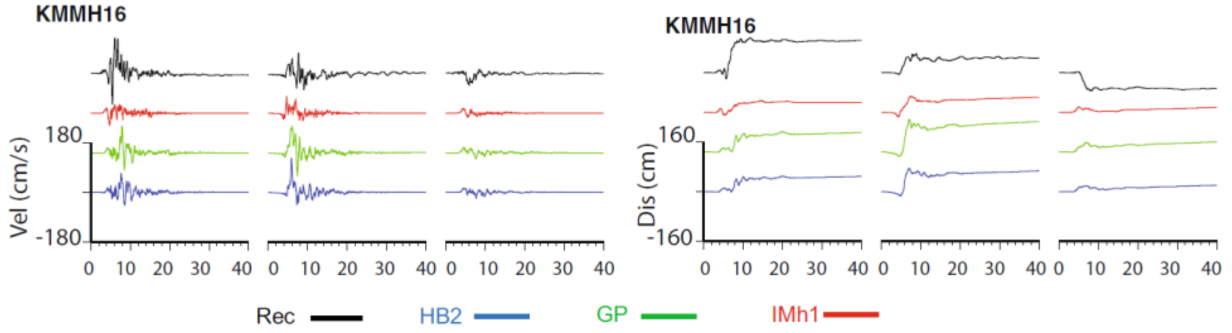
Pitarka et al. (2020)

Recipe, Graves and Pitarka (GP) & hybrid for Mw 7.0 Kumamoto EQ





1D velocity model is adjusted.



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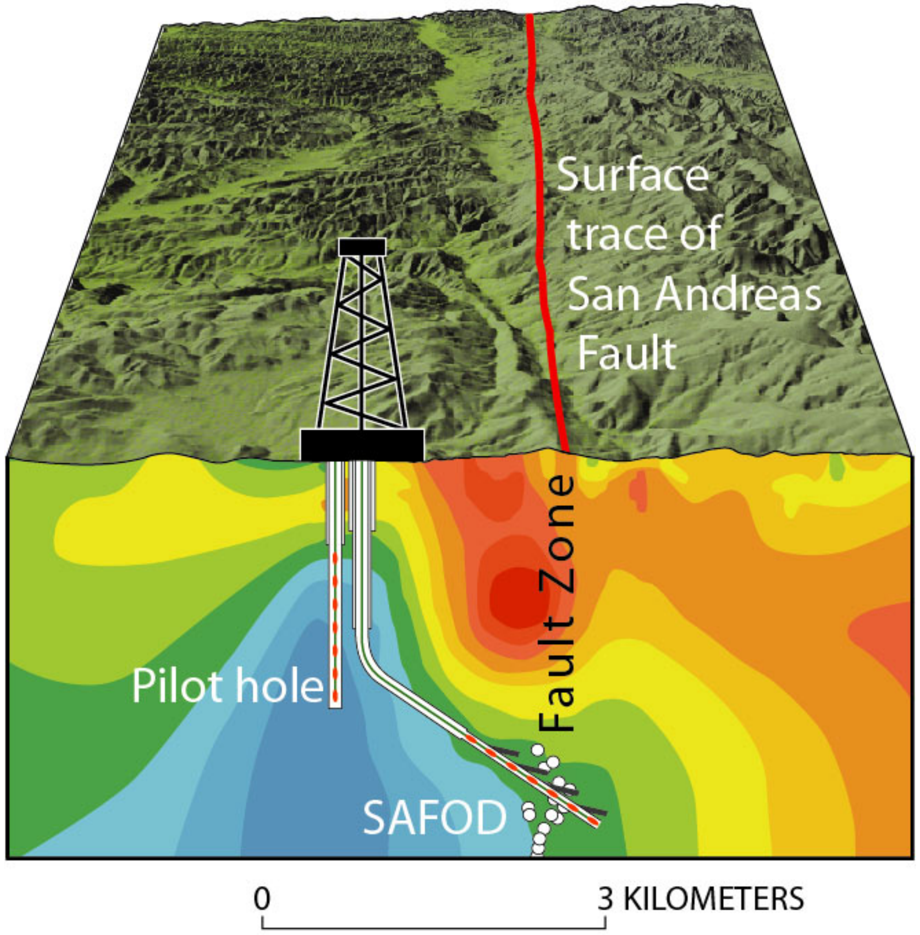
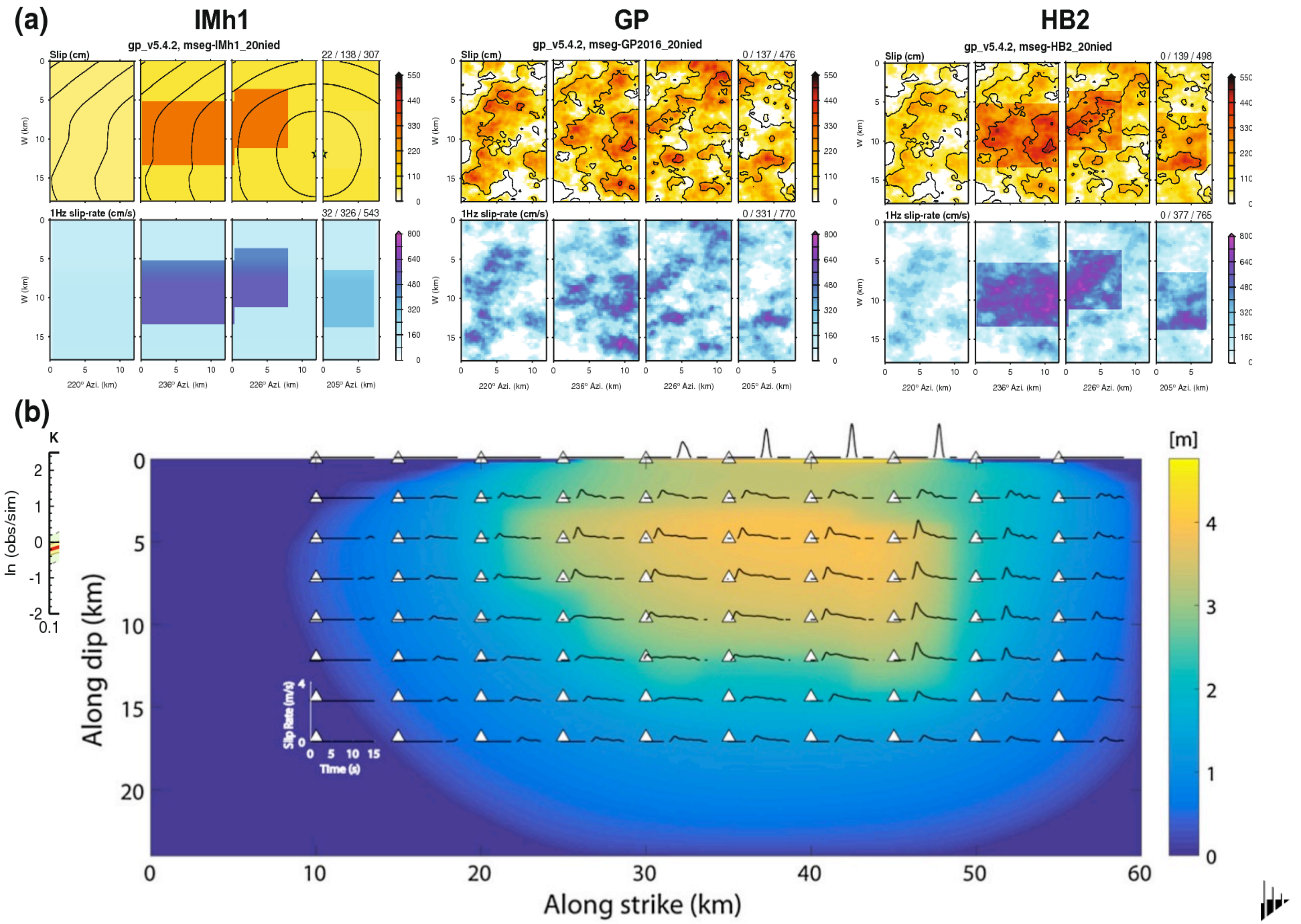
Kinematic: Pitarka et al. (2020)
Dynamic: Dalguer et al. (2020)

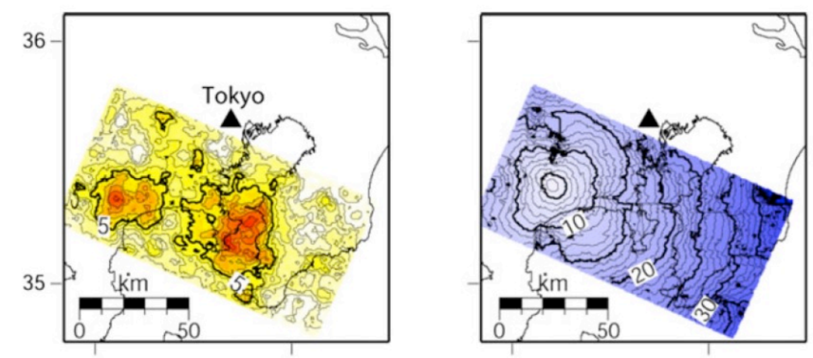
Shallow slip modeling needs deep borehole observations



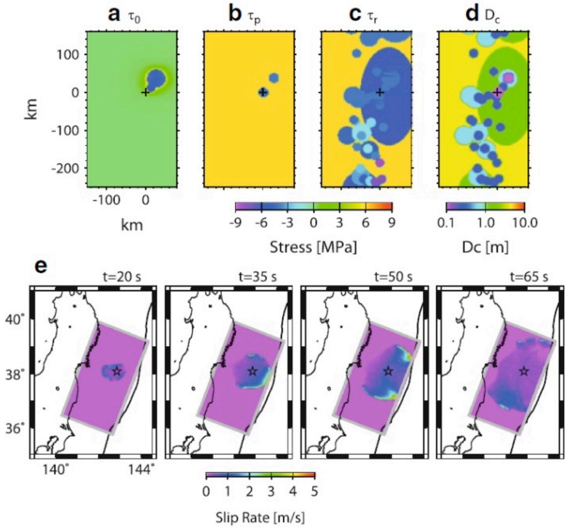


Variation of megathrust source modeling

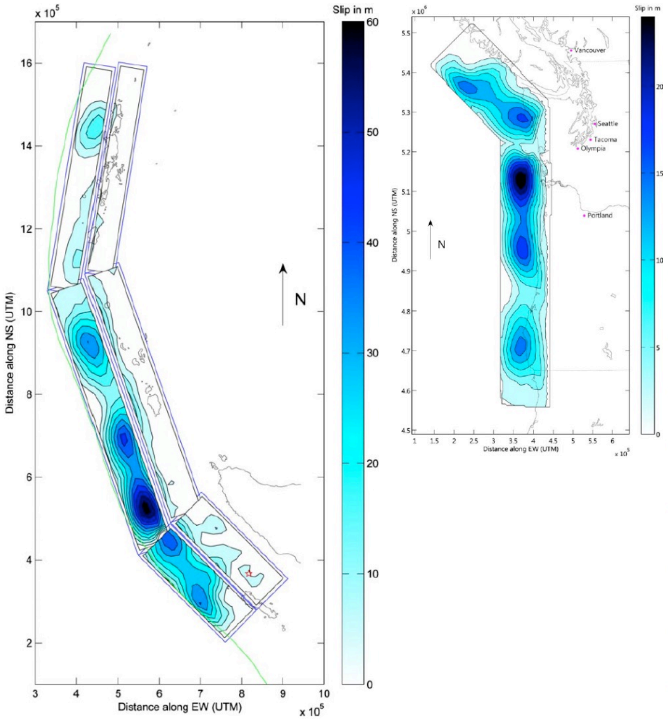
1923 Kanto (Sekiguchi and Yoshimi, 2011)



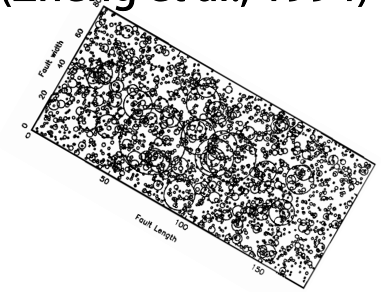
2011 Tohoku
(Aochi and Ide, 2014)



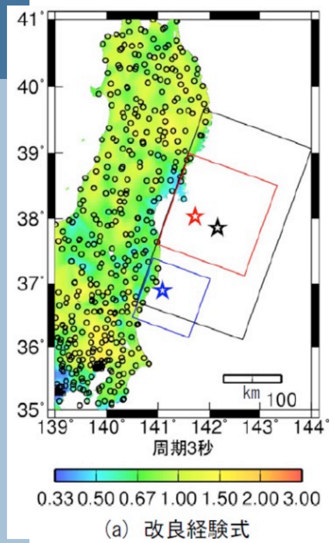
2004 Sumatra applied to
M9 Casncadia (Olsen et al., 2008)



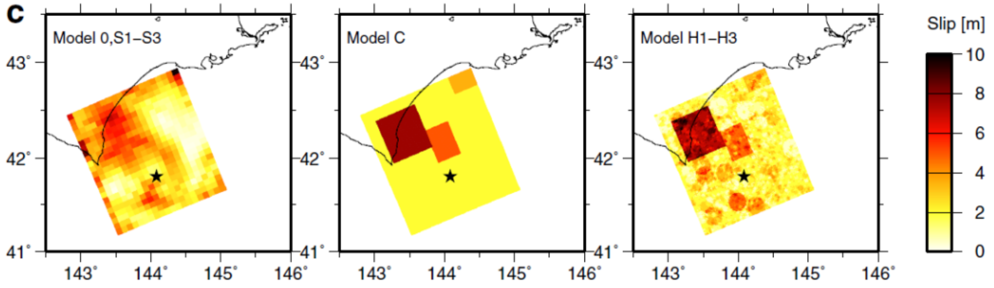
1985 Mexico
(Zheng et al., 1994)



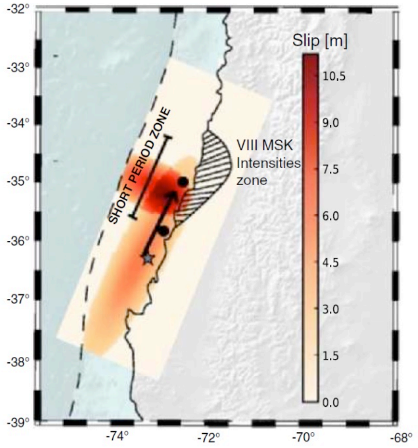
2011 Tohoku (Satoh et al., 2014)



2003 Tokachi-oki (Iwaki et al., 2016)



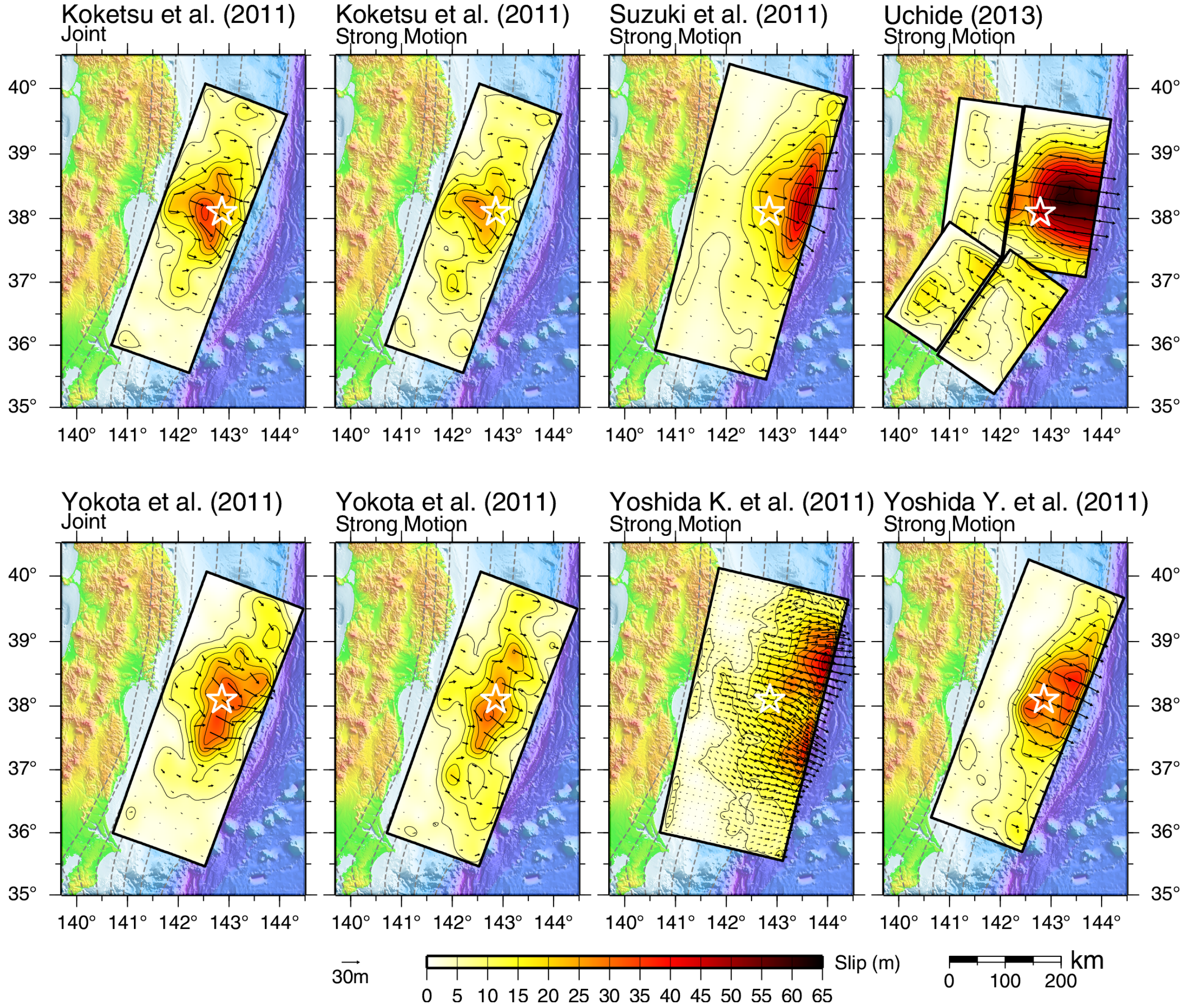
2009 Maule
(Ruiz et al., 2012)



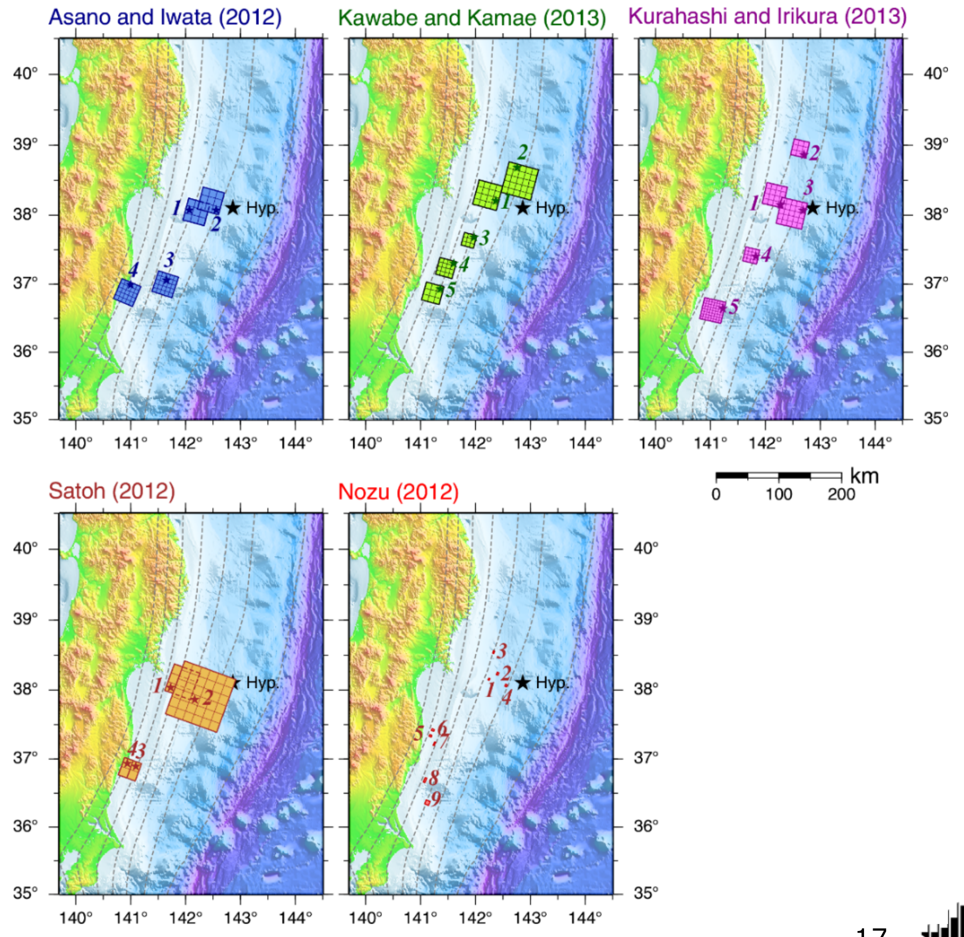
Miyake et al. (2016)

M9-class long-period source & M8-class short-period source: 2011 Tohoku

Slip inversion: T > 10 s



Broadband modeling: T = 0.1-10 s



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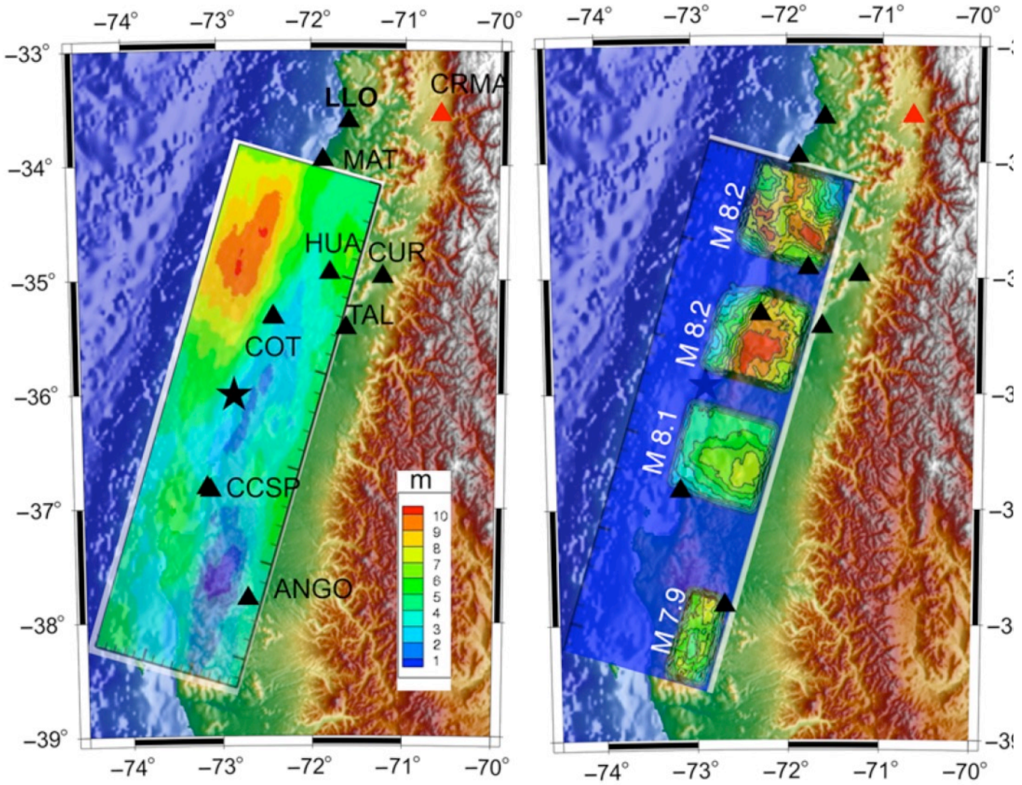
M9-class long-period source & M8-class short-period source: 2010 Maule

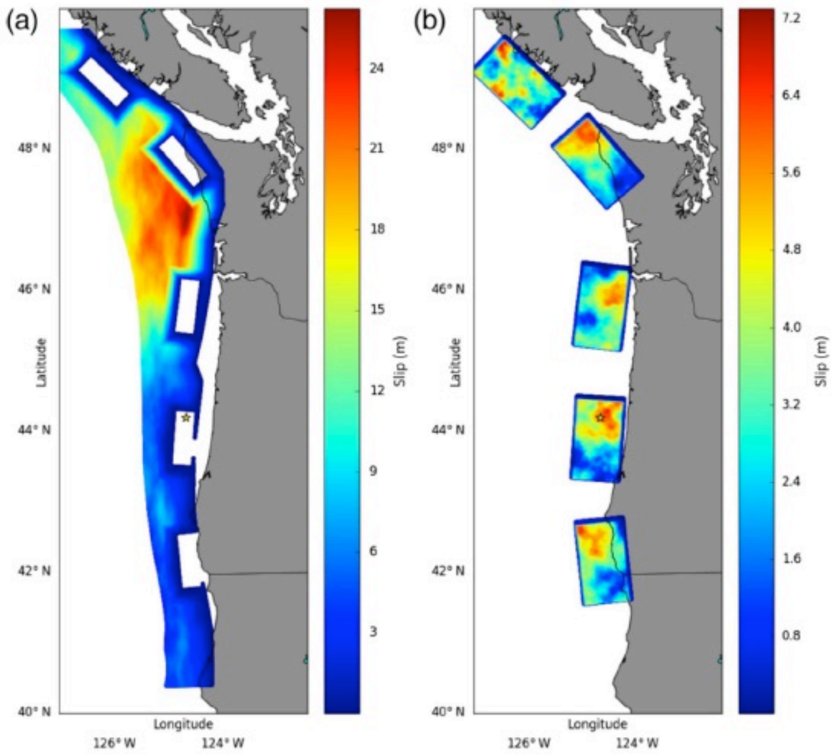
Frankel (2017)
Frankel et al. (2018)
Wirth et al. (2018)

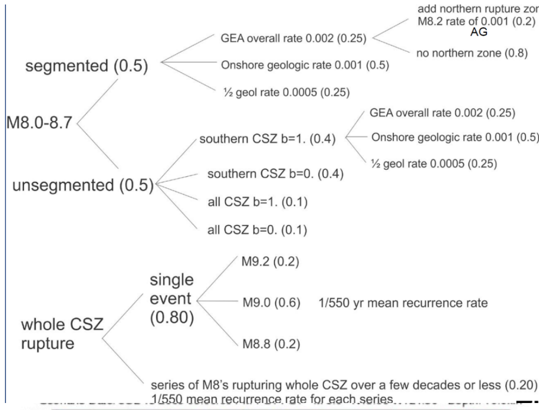
Slip inversion: T > 10 s

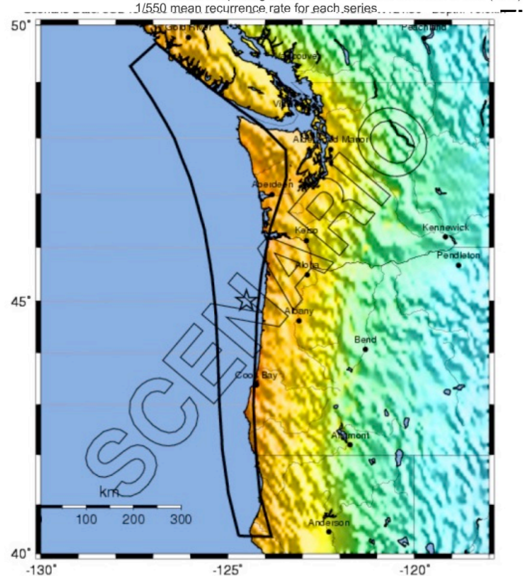
subevent modeling: T = 0.1-10 s

Application to Cascadia
By USGS



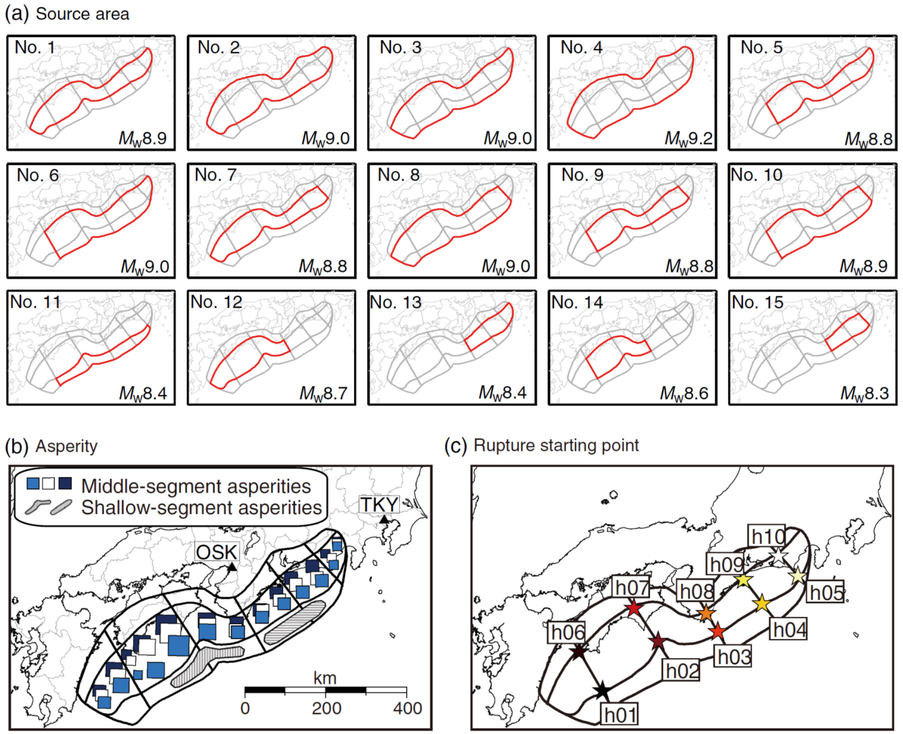


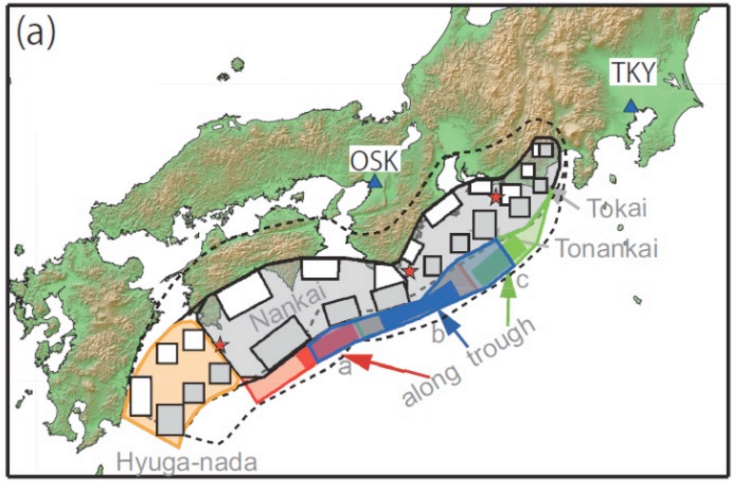


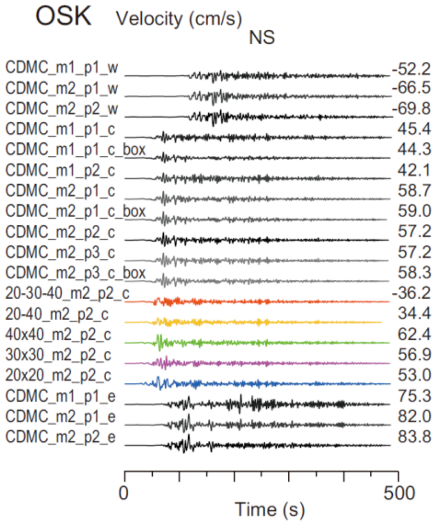


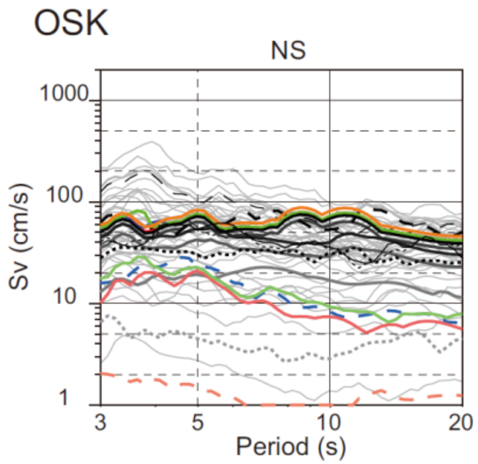
Maeda et al. (2013; 2015)

Uncertainty of megathrust source modeling

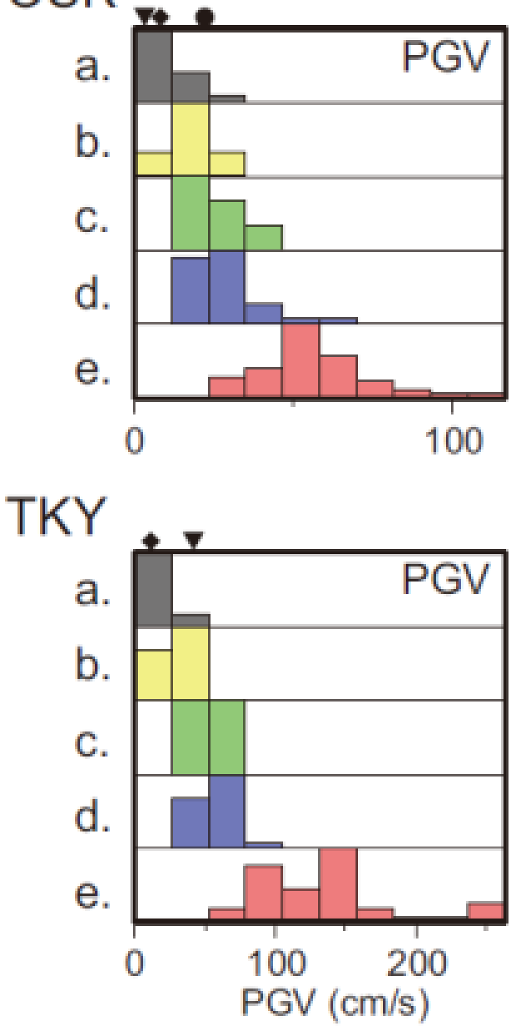








e. max class



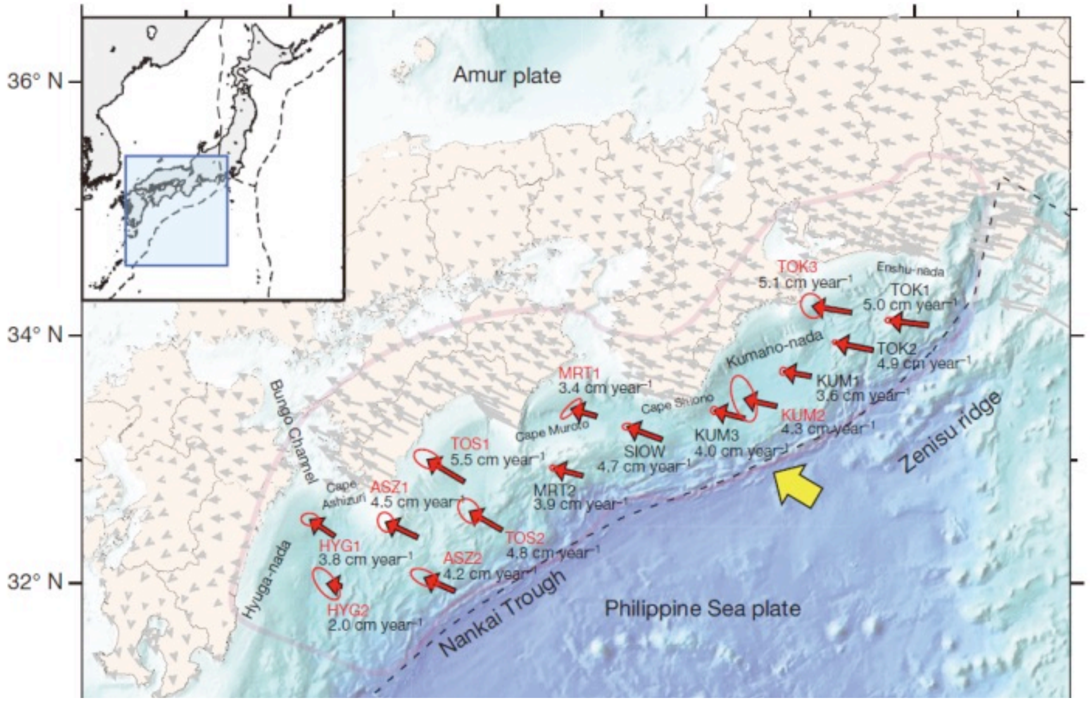
Offshore observation may constrain sources

Seismic observation (NIED)

The picture can't be displayed.

Aoi et al. (2020)

Geodetic observation
(Japan Coast Guard)



Yokota et al. (2016)

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Conclusions

- Broadband source modeling for crustal earthquakes is well summarized on the SCEC Broadband Platform.
- Validation for 1-D and 3-D velocity model shows a reasonable performance.
- A recipe for predicting strong ground motions targets to reproduce ground motion pulses that are important to earthquake engineering.
- Shallow source modeling needs deep borehole observations to capture slip velocity.
- M9-class long-period source & M8-class short-period source may constrain more by offshore observations.

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