Physics-Based 3D Ground Motion Simulations

The SCEC/CME High-F and SEISM Projects

SCEC Site Effects Workshop
May 5, 2015

SCEC an NSF+USGS center

HPGeoC High Performance Geocomputing Laboratory

The Quake Group at Carnegie Mellon University

San Diego State University

ASEIS Analysis and Simulation of Earthquake Impacts
Center for Earthquake Research and Information
The University of Memphis

UW

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En-Jui Lee
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Fabio Silva
William Savran
Kyle Withers
Patrick Small
Naeem Khoshnevis
and more…

Physics-Based 3D Ground Motion Simulations

The SCEC/CME High-F and SEISM Projects

- The CME High-F and SEISM projects
- Background of 3D regional scale simulations
- Site effects in 3D, velocity models and geotechnical layers
- Venturing into nonlinear regional soil modeling in 3D
- Relevant recent advances and future directions

The Community Modeling Environment Group

A SCEC Special Projects Group

CME group objectives include:

- Develop structural models of California faults and geology,
- Develop and validate rupture physics models,
- Perform large-scale regional wave propagation simulations,
- Collaborate with engineers studying response to ground motions, and
- Integrate computational improvements into probabilistic seismic hazard.

CME funding (has included but not been limited to):

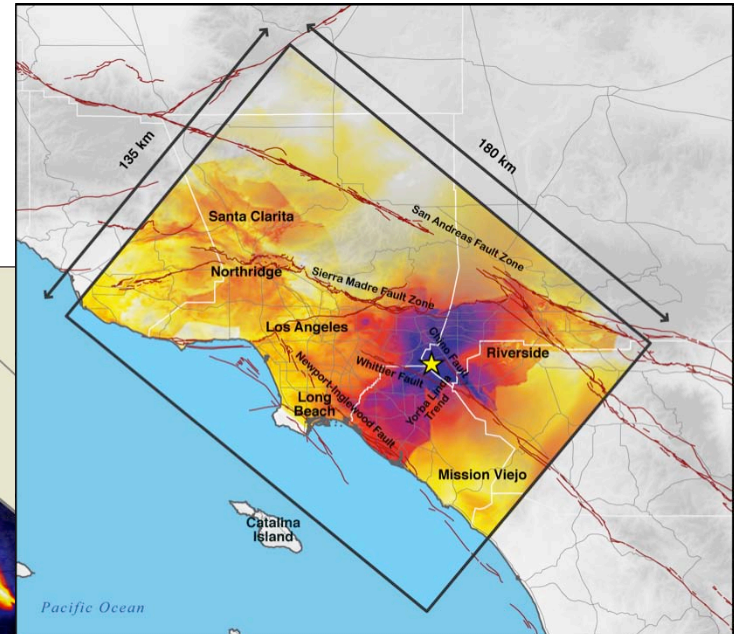
- Multi-PI NSF awards: PetaSHA (1, 2, and 3), Outward on the Spiral, SEISM (1 and 2), Geoinformatics (1 and 2); and other single-PI awards.
- Computational resources (NSF Track I and II, and DOE Incite) (computing time worth $)

For details: http://scec.usc.edu/scecpedia/CME

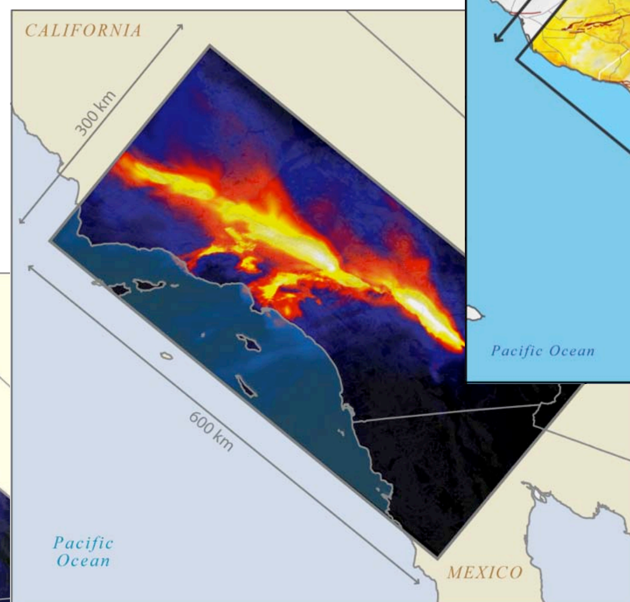
Physics-Based 3D Ground Motion Simulations

A Trajectory Toward Higher Frequencies and Lower Velocities

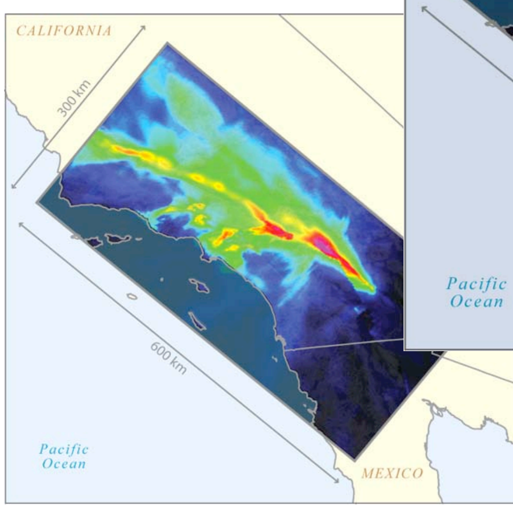
2009–2015
Chino Hills & La Habra
Simulation and Validation
2–4 Hz
200 m/s



2007–2008
ShakeOut
Simulation and Verification
0.5–1 Hz
500 m/s



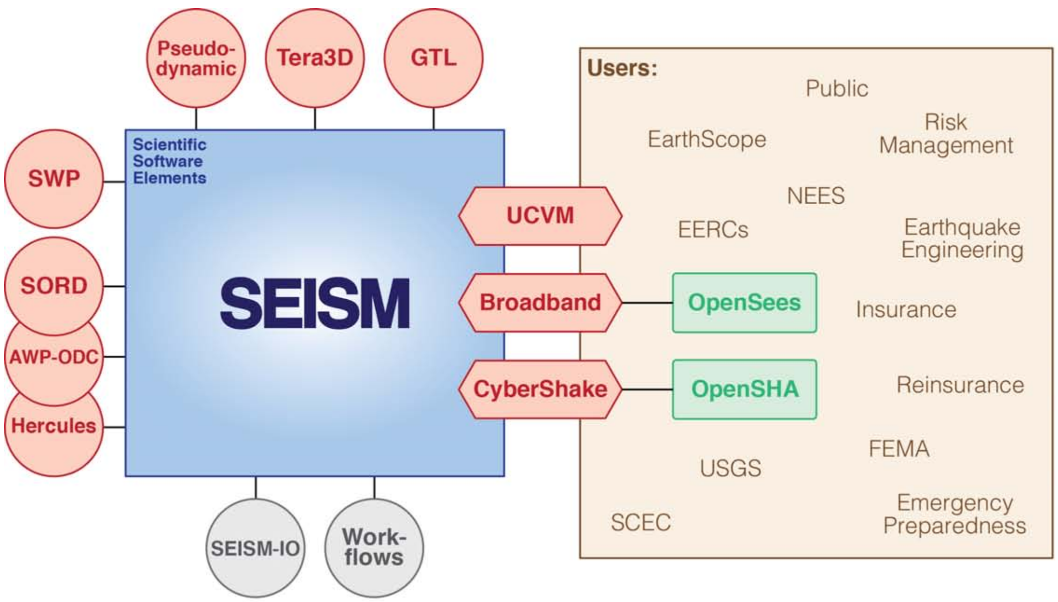
2005–2006
TeraShake
0.5–1 Hz
500 m/s

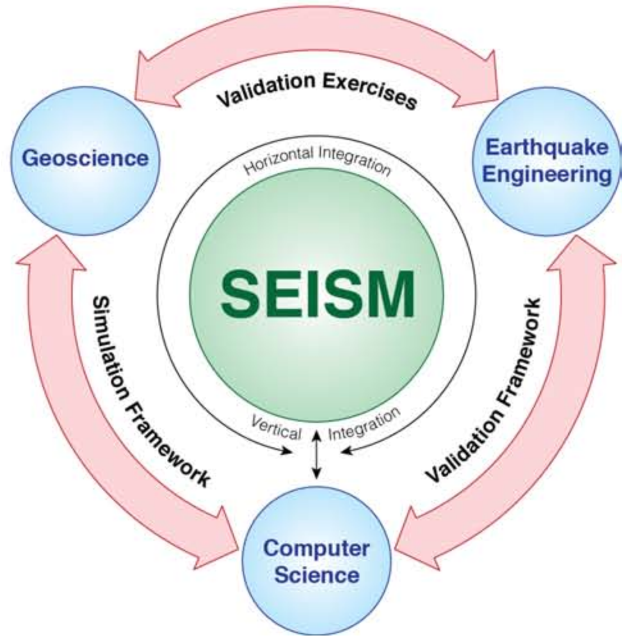


Olsen et al. (2008, 2009)
Bielak et al. (2010)
Olsen and Mayhew (2010)
Taborda and Bielak (2013, 2014)

Evolution into the High-F and SEISM

Building Software to Support Physics-Based Ground Motion Simulations

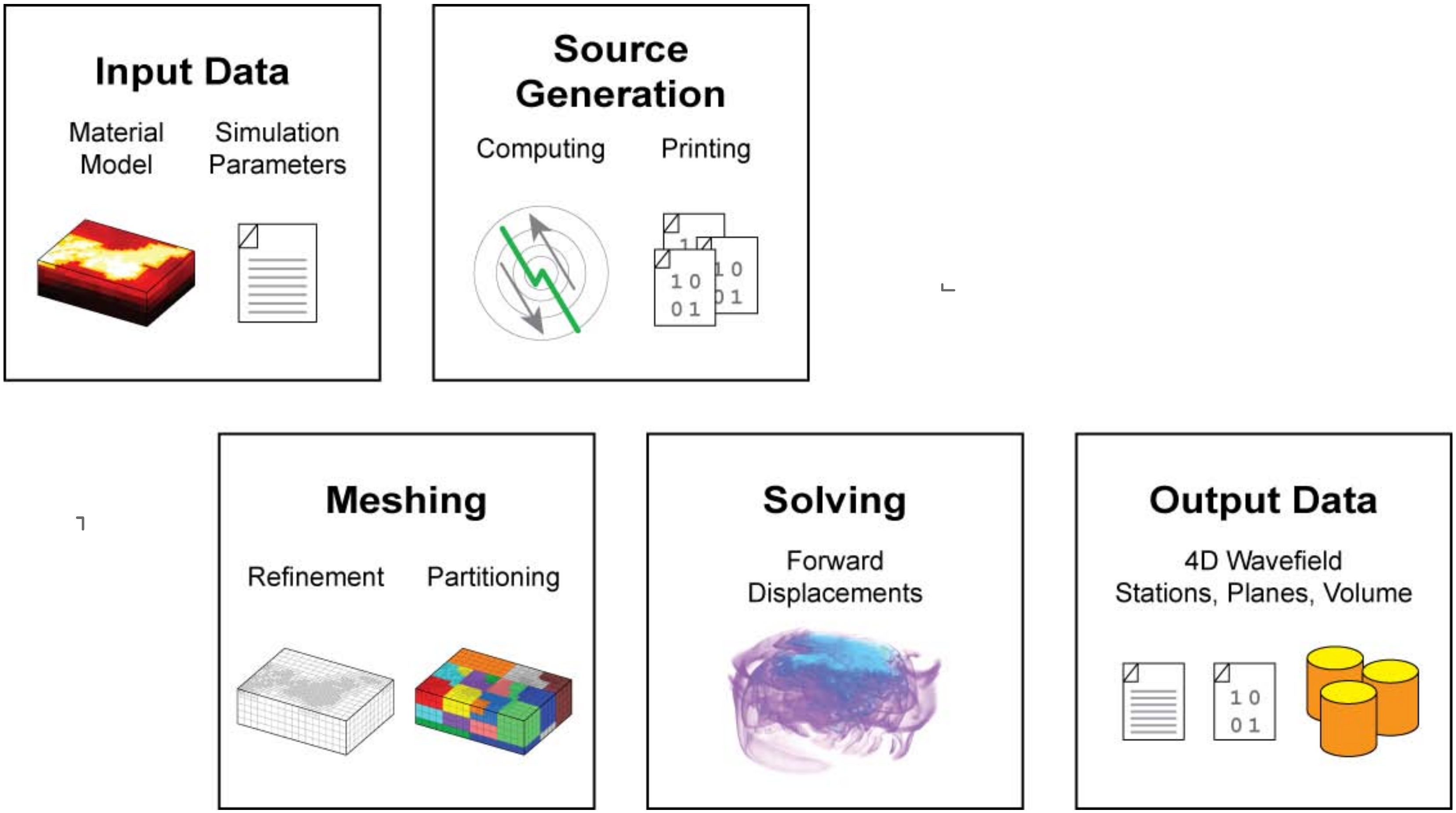




- AWP-ODC
- Hercules
- Broadband Platform
- CyberShake
- UCVM
- SEISM-IO

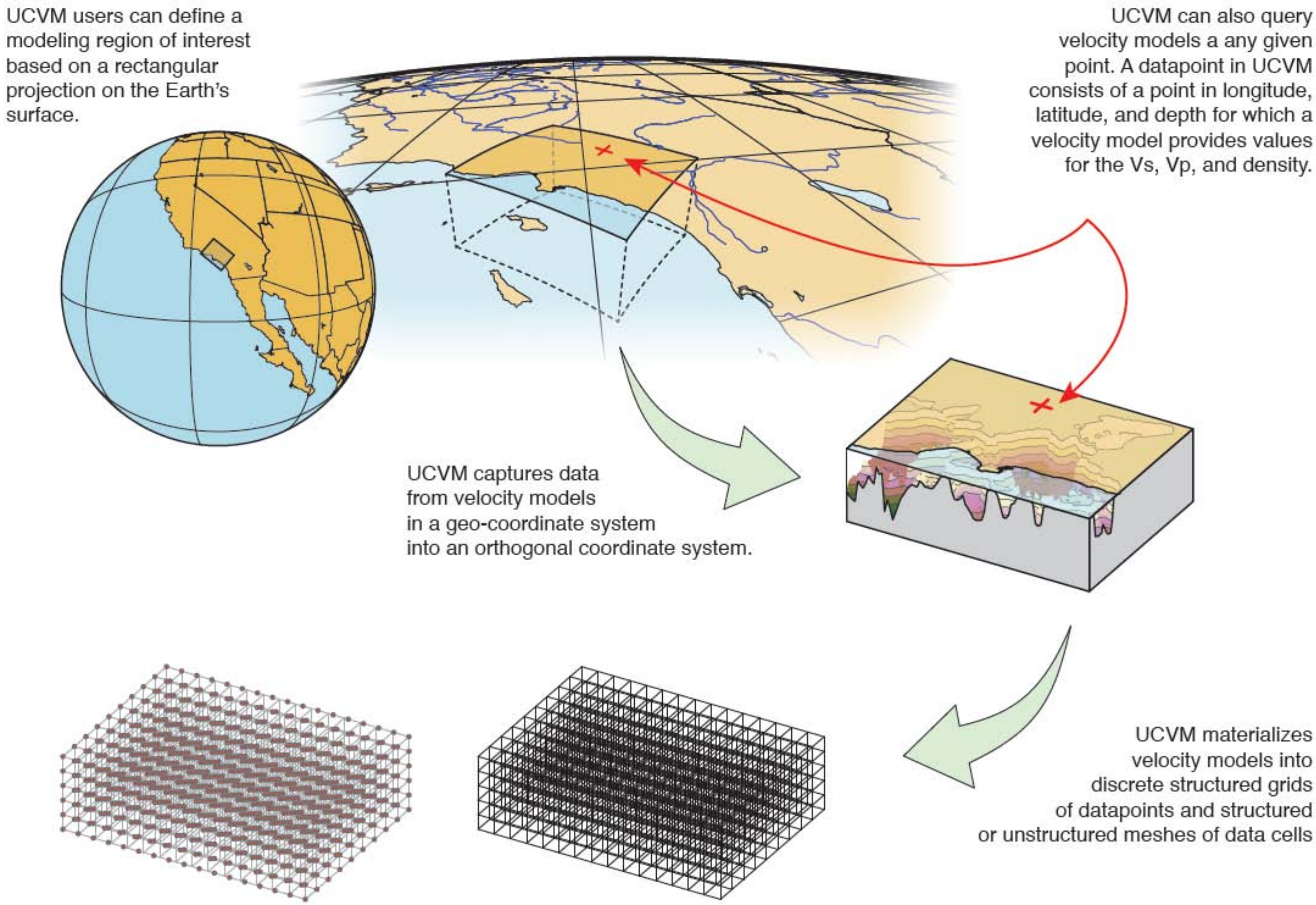
3D Regional Simulation Process

Velocity Models, Source Models, Wave Propagation Solver



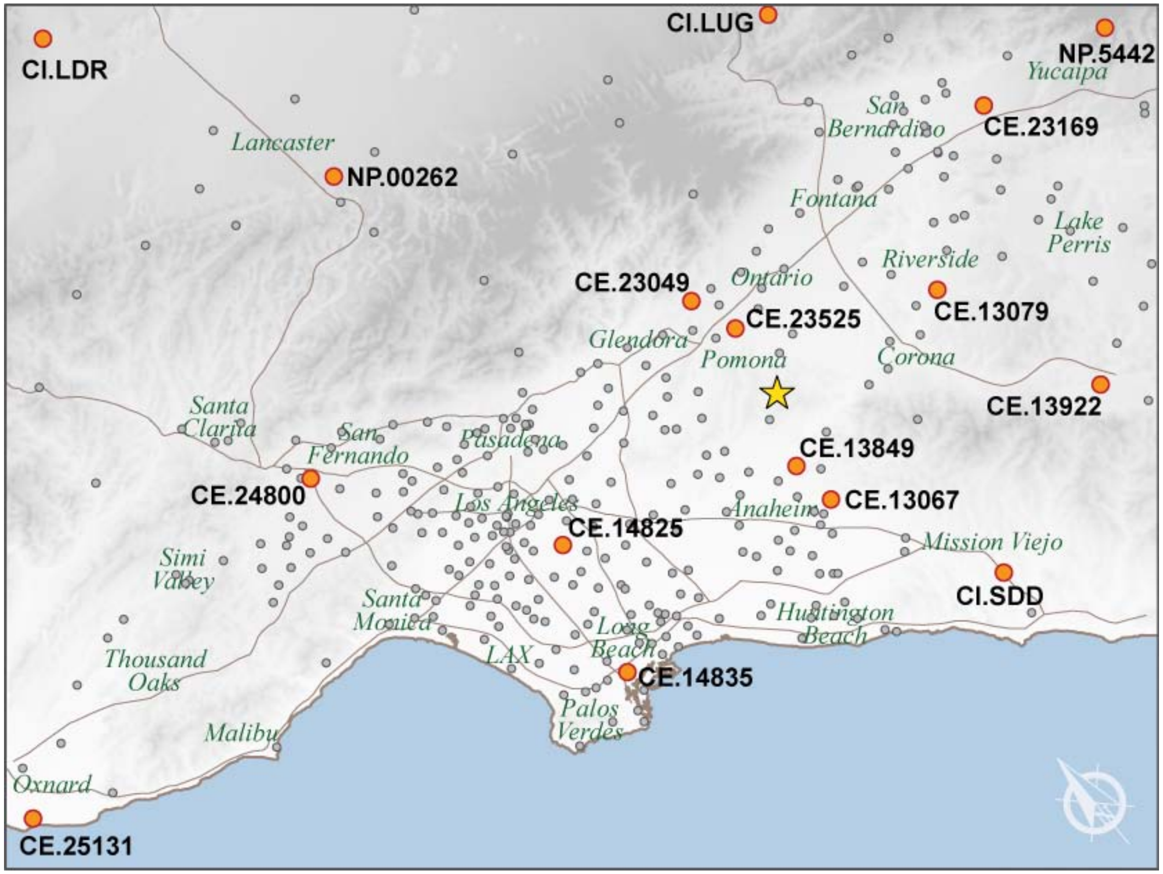
Seismic Community Velocity Models (CVMs): V_P, V_S, r

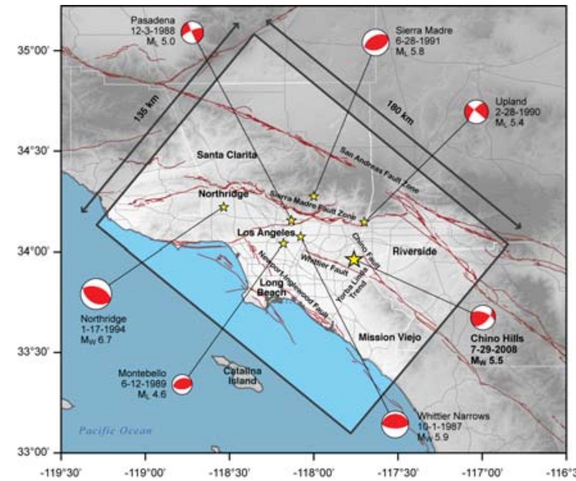
From physical crustal models to discrete models for simulation



Validation of Historic Event Simulations

The 2008 Chino Hills earthquake (Vs_{min} = 200 m/s, f_{max} = 4 Hz)



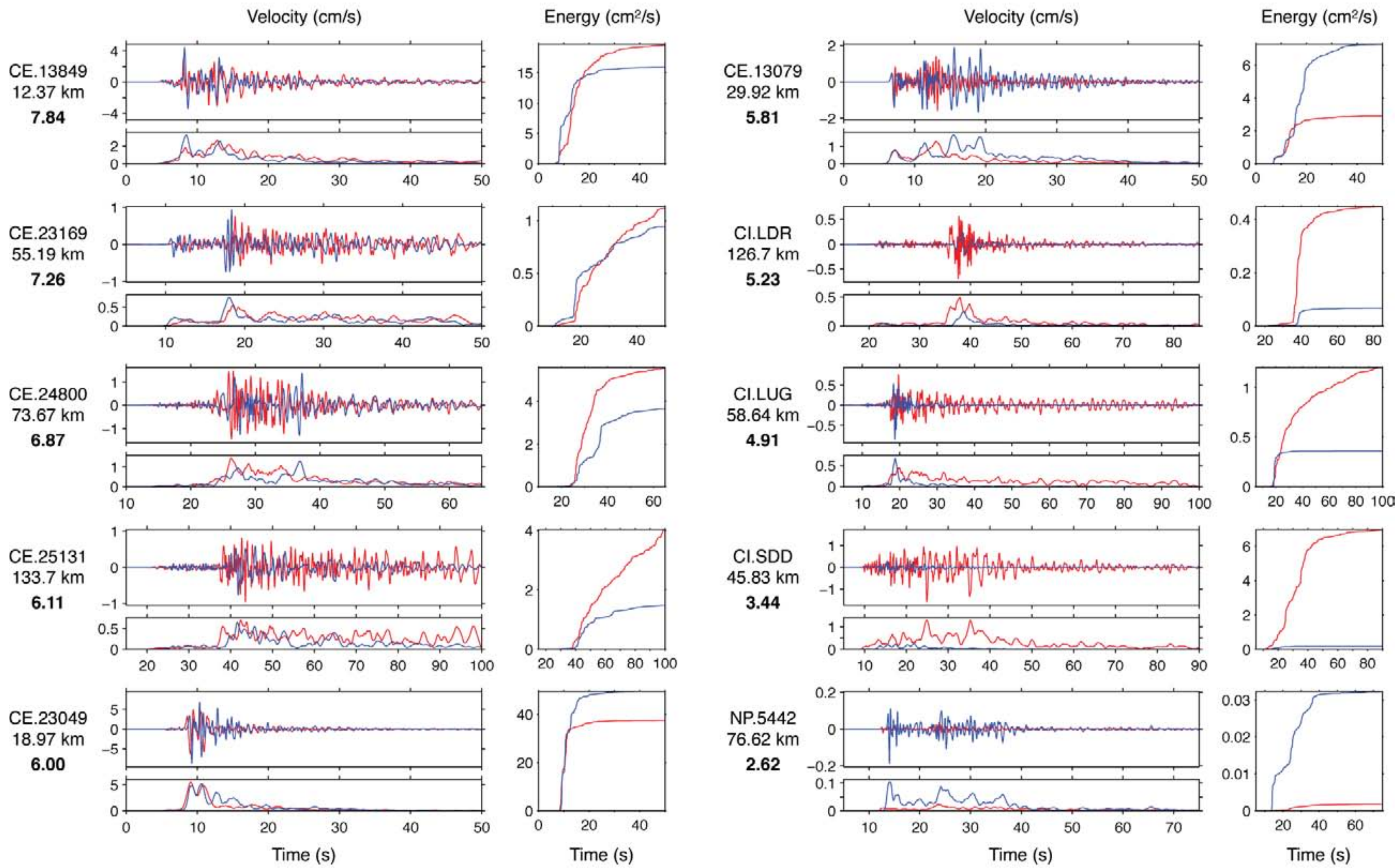


- Largest earthquake in the L.A. region since the 1994 Northridge earthquake.
- No significant damages, no fatalities.
- Excellent opportunity for testing assumptions and methodologies.
- Recorded in over 450 strong motion station from different seismic networks. 336 surface stations within simulation domain.

Taborda and Bielak (2013, 2014)

Validation: Time Series

The 2008 Chino Hills earthquake (Vs_{min} = 200 m/s, f_{max} = 4 Hz)

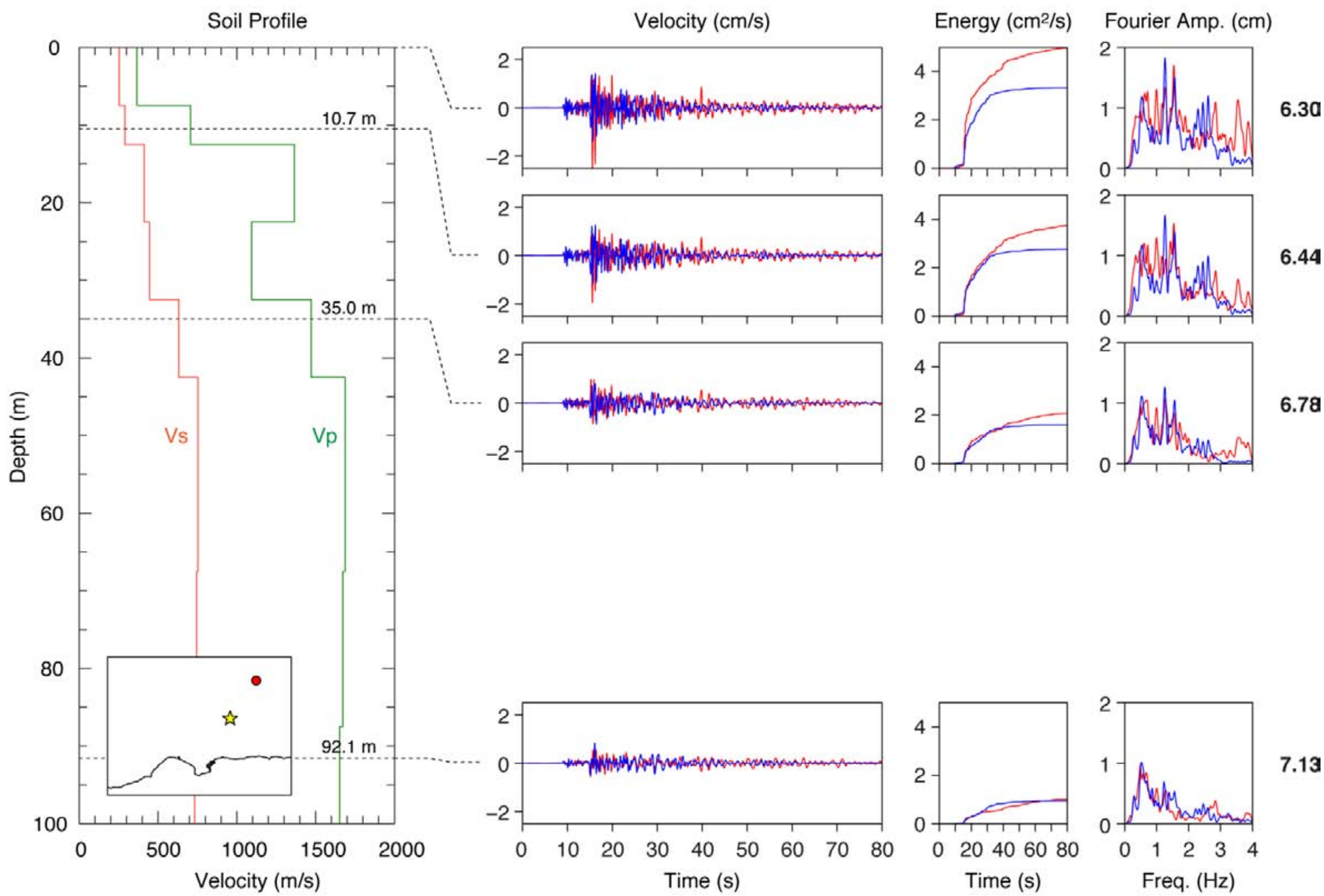


Data
Synthetics

Taborda and Bielak (2013, 2014)

Evidence of Site Effects Relevance

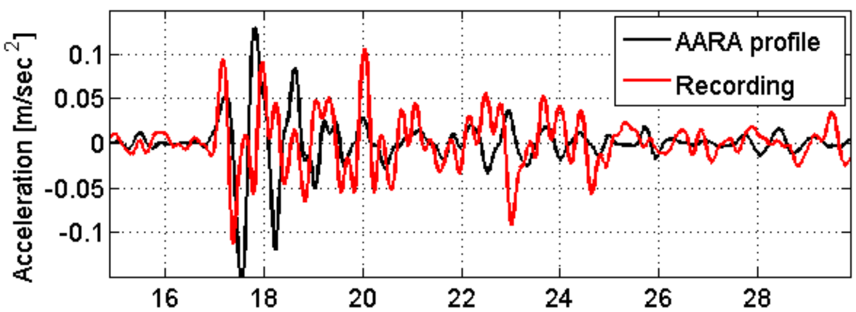
Goodness-of-fit decay in the upper 100 m

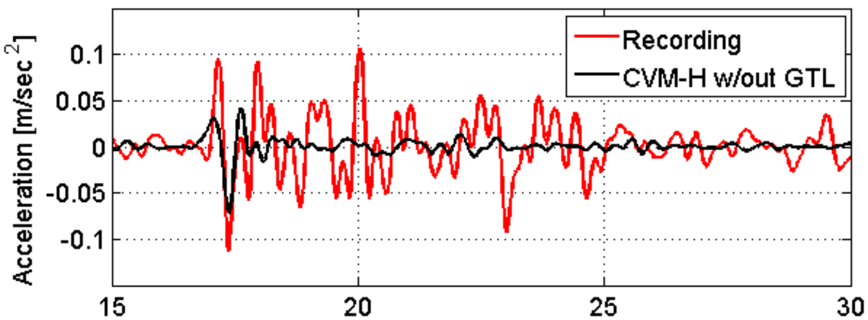


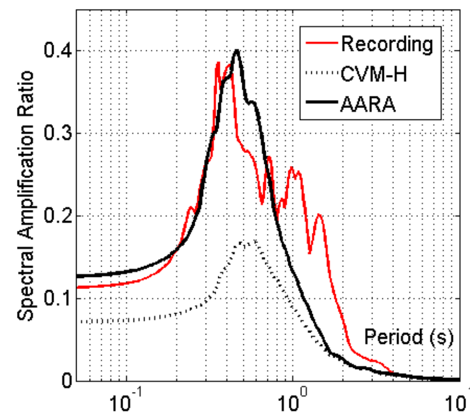
Taborda and Bielak (2013, 2014)

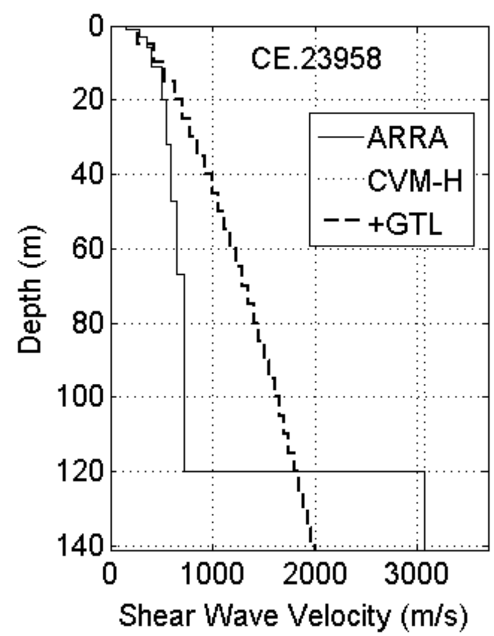
Alternative A: Better GTL Profiles

Combination of regional 3D simulation with local 1D propagation





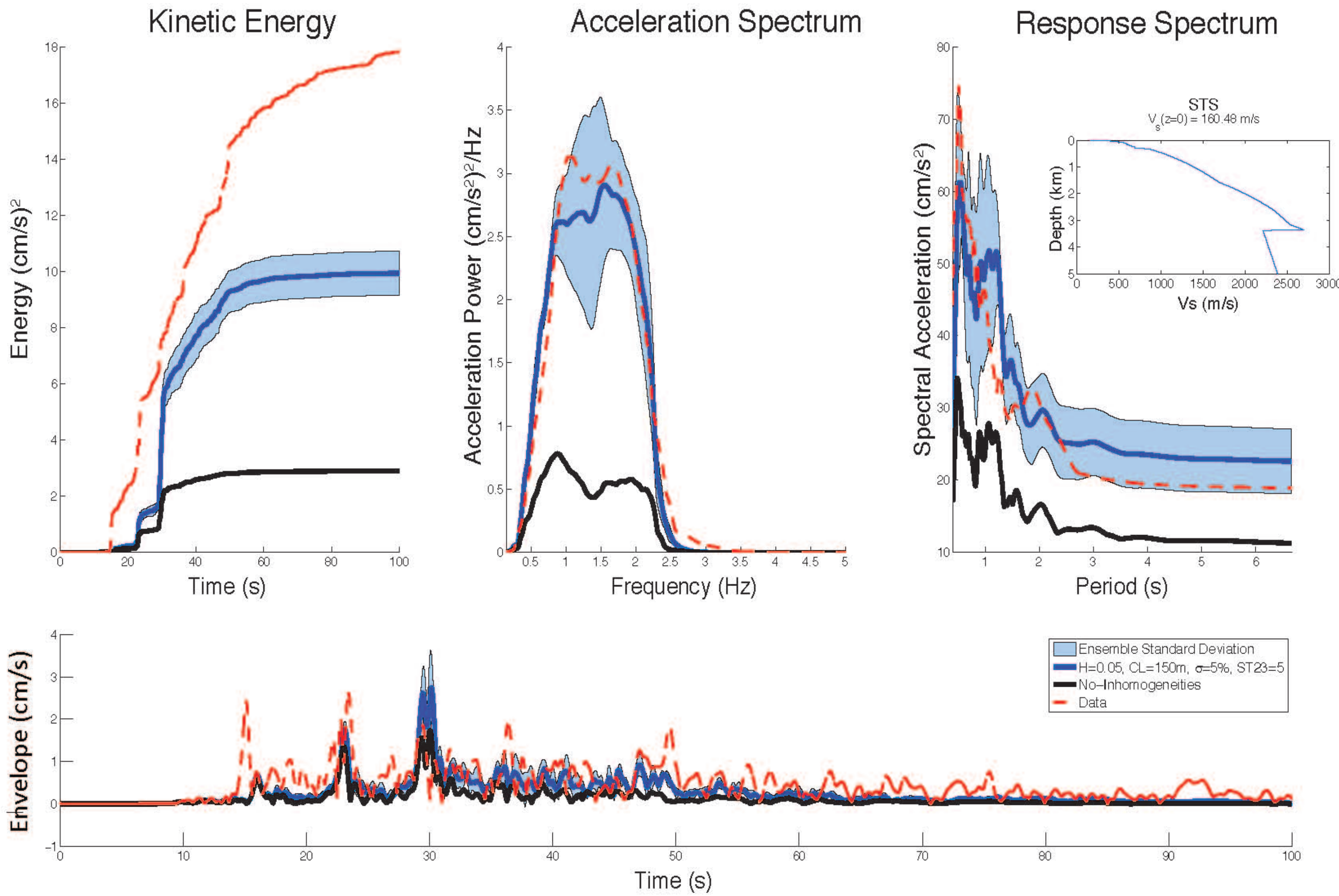




Courtesy of D. Asimaki

Alternative B: Small Scale Heterogeneities

Combination of regional 3D simulation with local 1D propagation

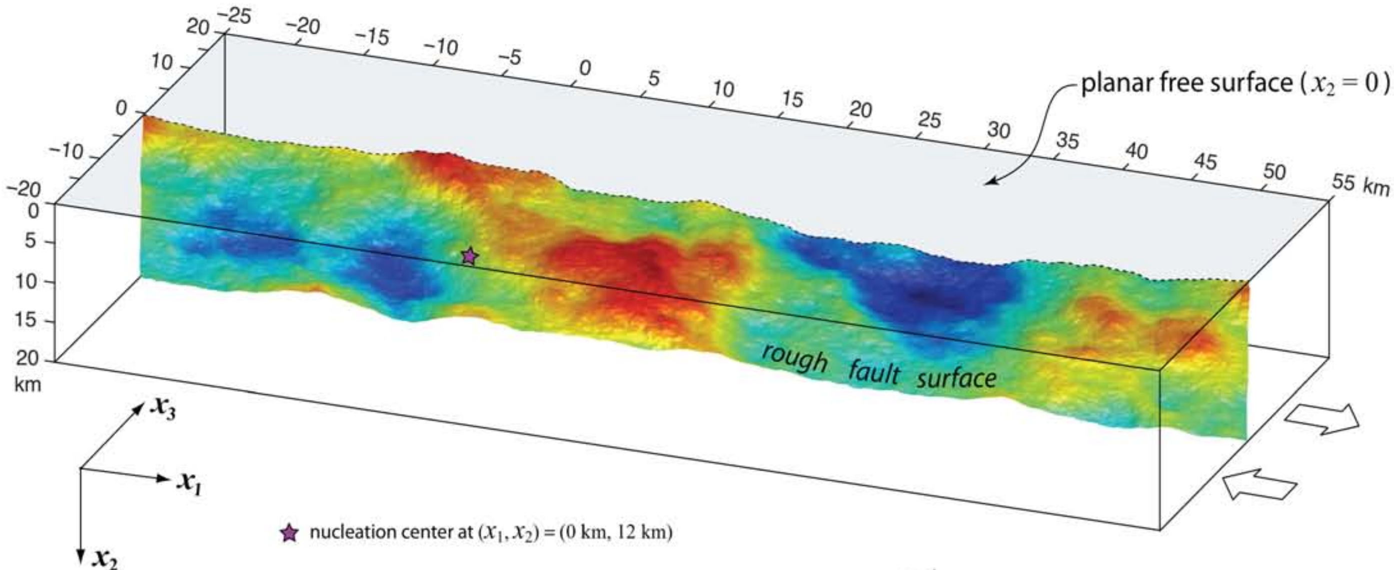


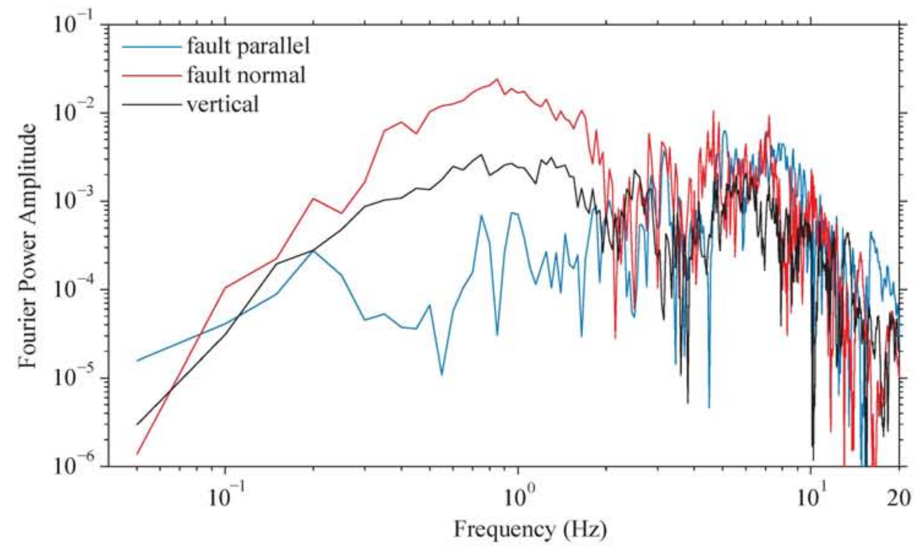
STS Station
North-South (dist. 51.5 km)

Olsen (2014)
Savran and Olsen (2014)

Rough Fault Dynamic Rupture Models

Improving the source's geometrical complexity

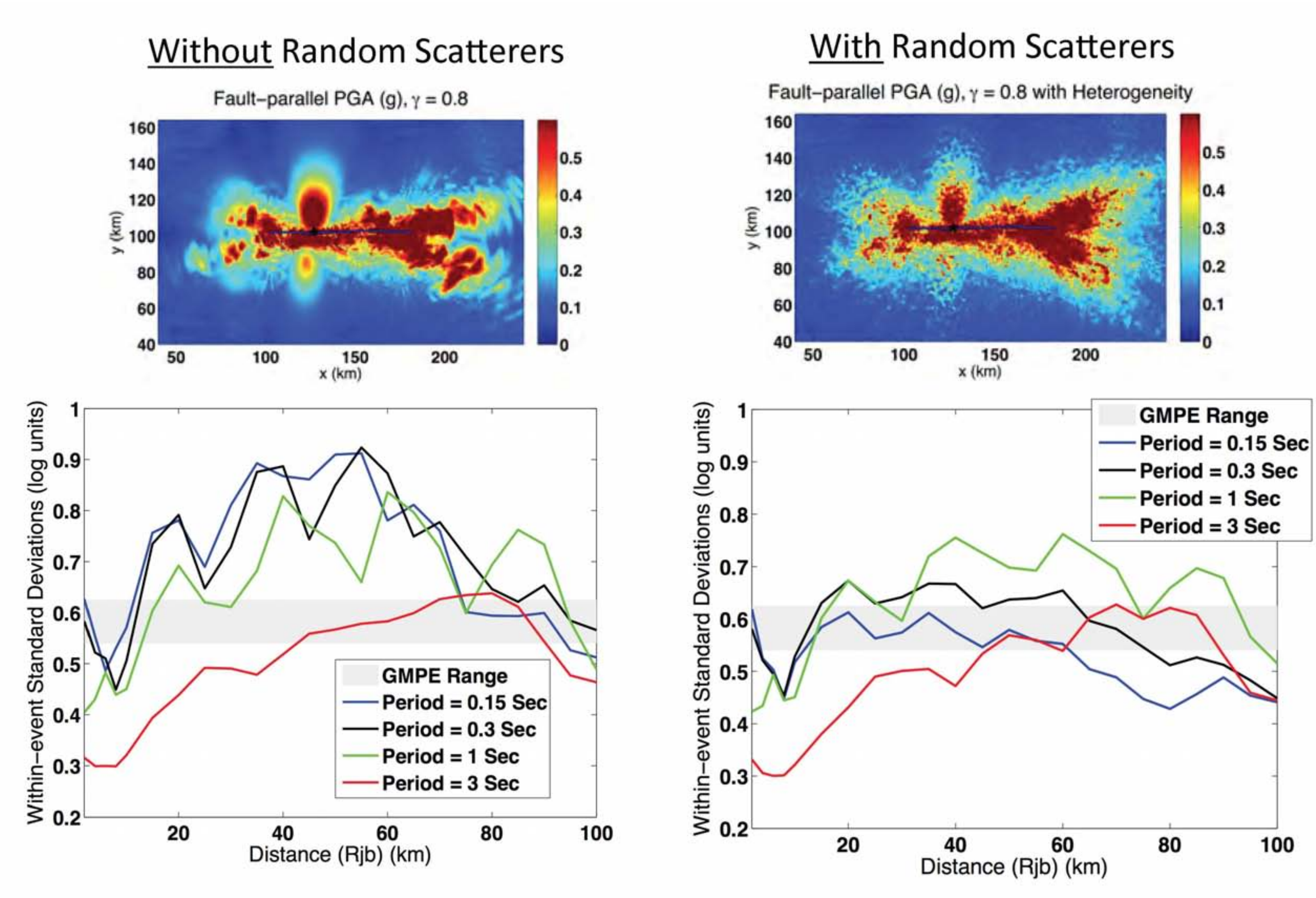




Shi and Day (2013)

Small Scale Heterogeneities

Representing observed variability in medium properties

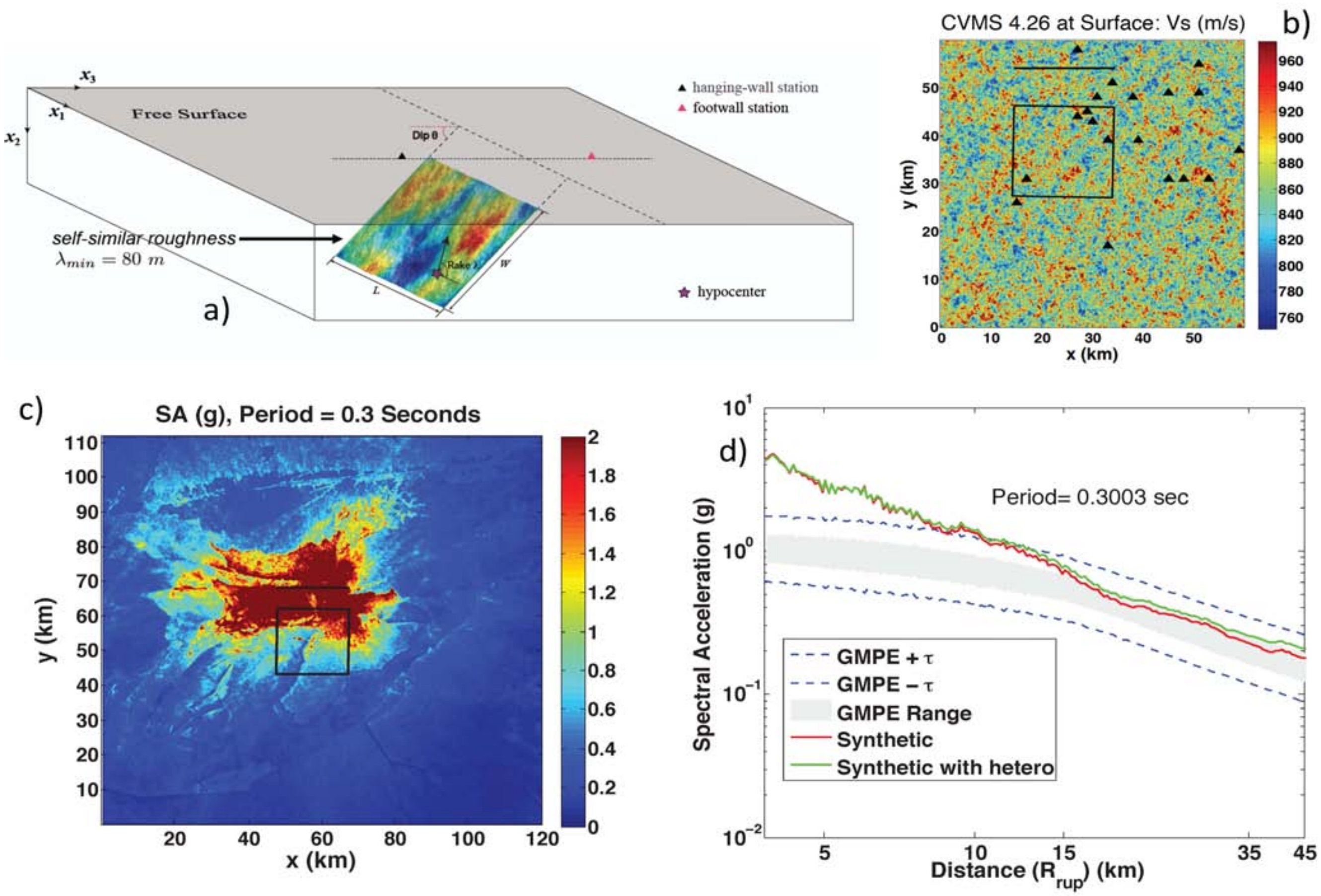


Withers et al. (2015)

Evolution into the High-F and SEISM

Building Software to Support Physics-Based Ground Motion Simulations

0-8 Hz 3D Simulation of the M_w6.7 Northridge, CA, Earthquake

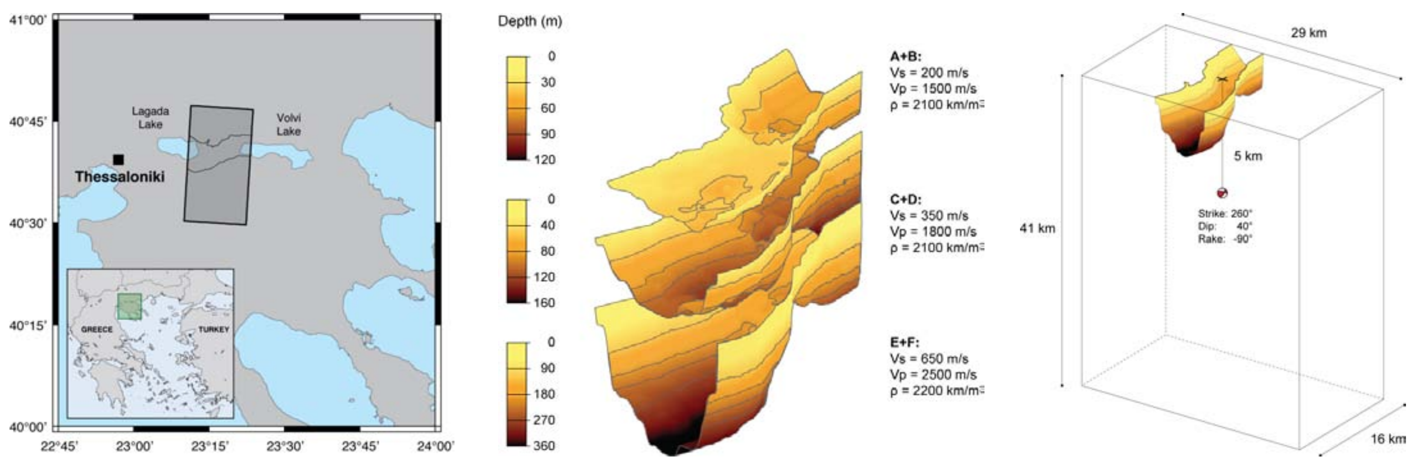


Withers et al. (2015)

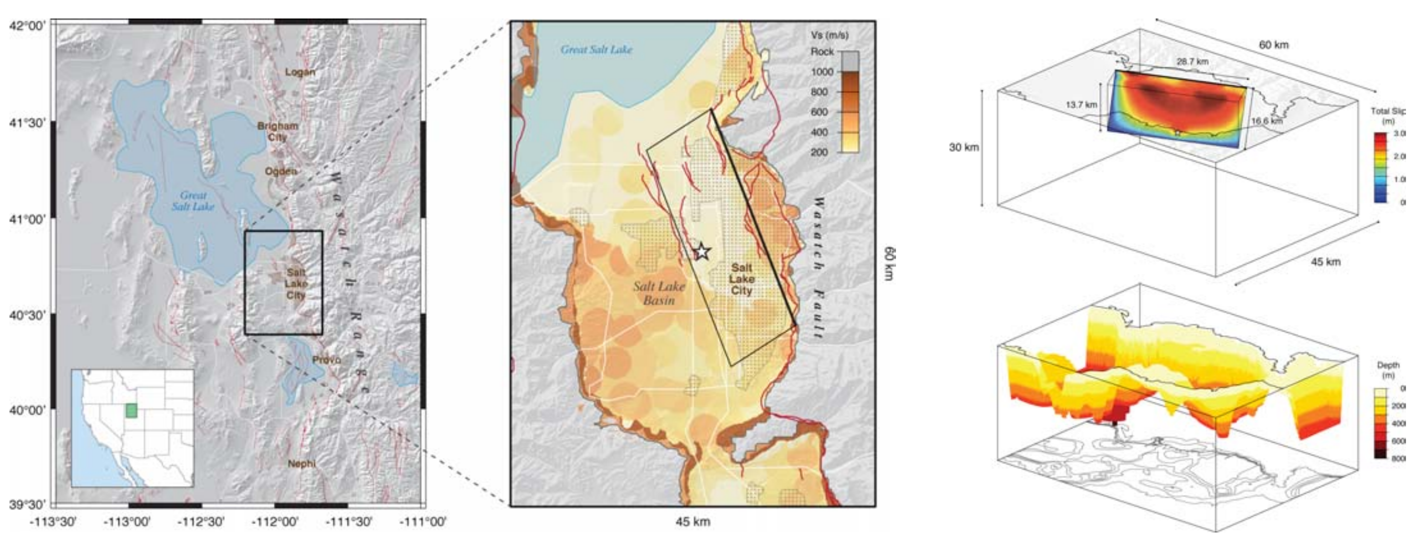
From Linear to Nonlinear Site Effects

Simulations using DP constitutive material model: Euroseistest and Salt Lake City

2008–2010
E-2VP Project
point source
200 m/s, 4 Hz



2009–2011
Utah GSWG
extended source
200 m/s, 1 Hz



Taborda et al. (2012)

From Linear to Nonlinear Site Effects

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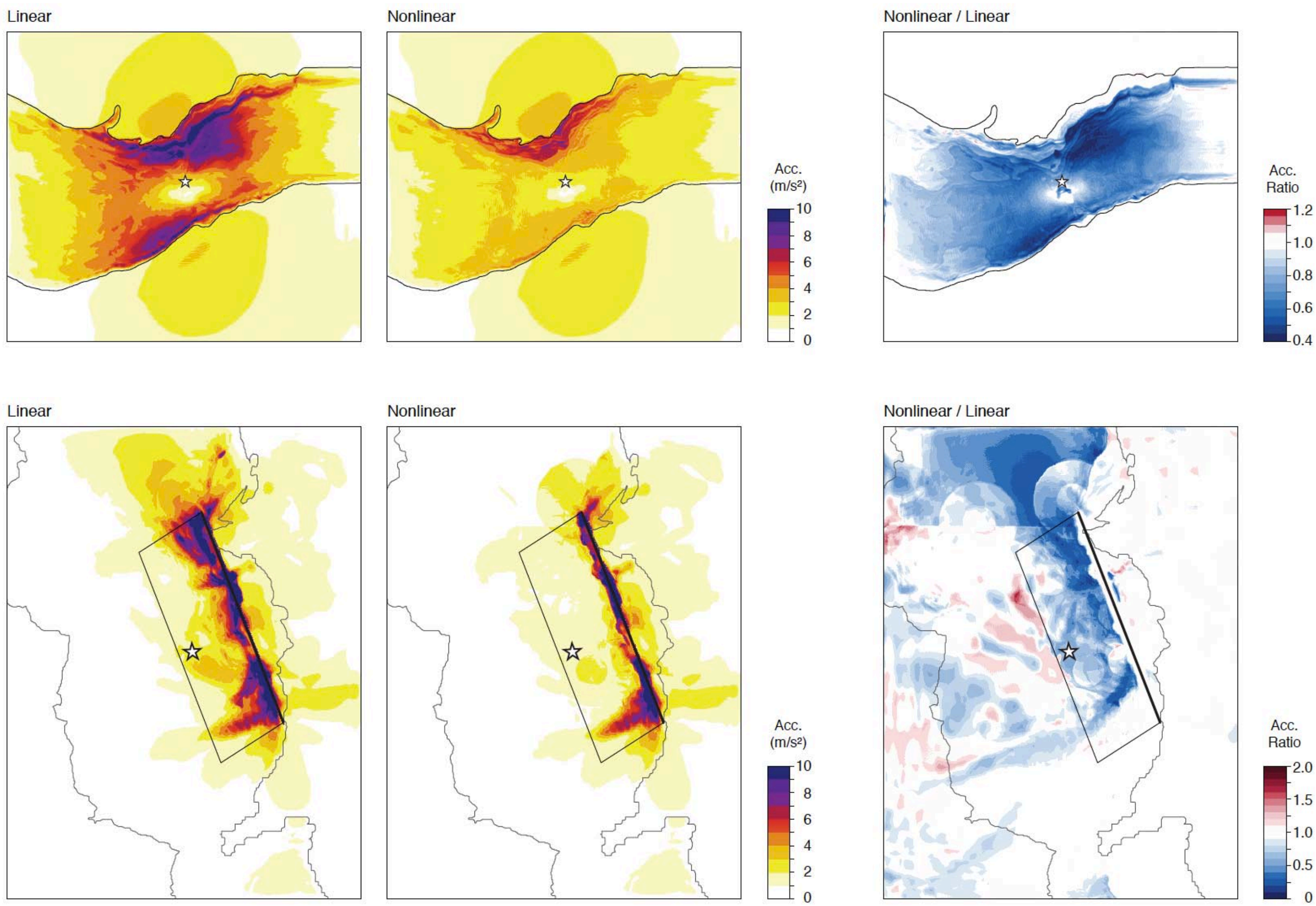

Taborda et al. (2012)

From Linear to Nonlinear Site Effects

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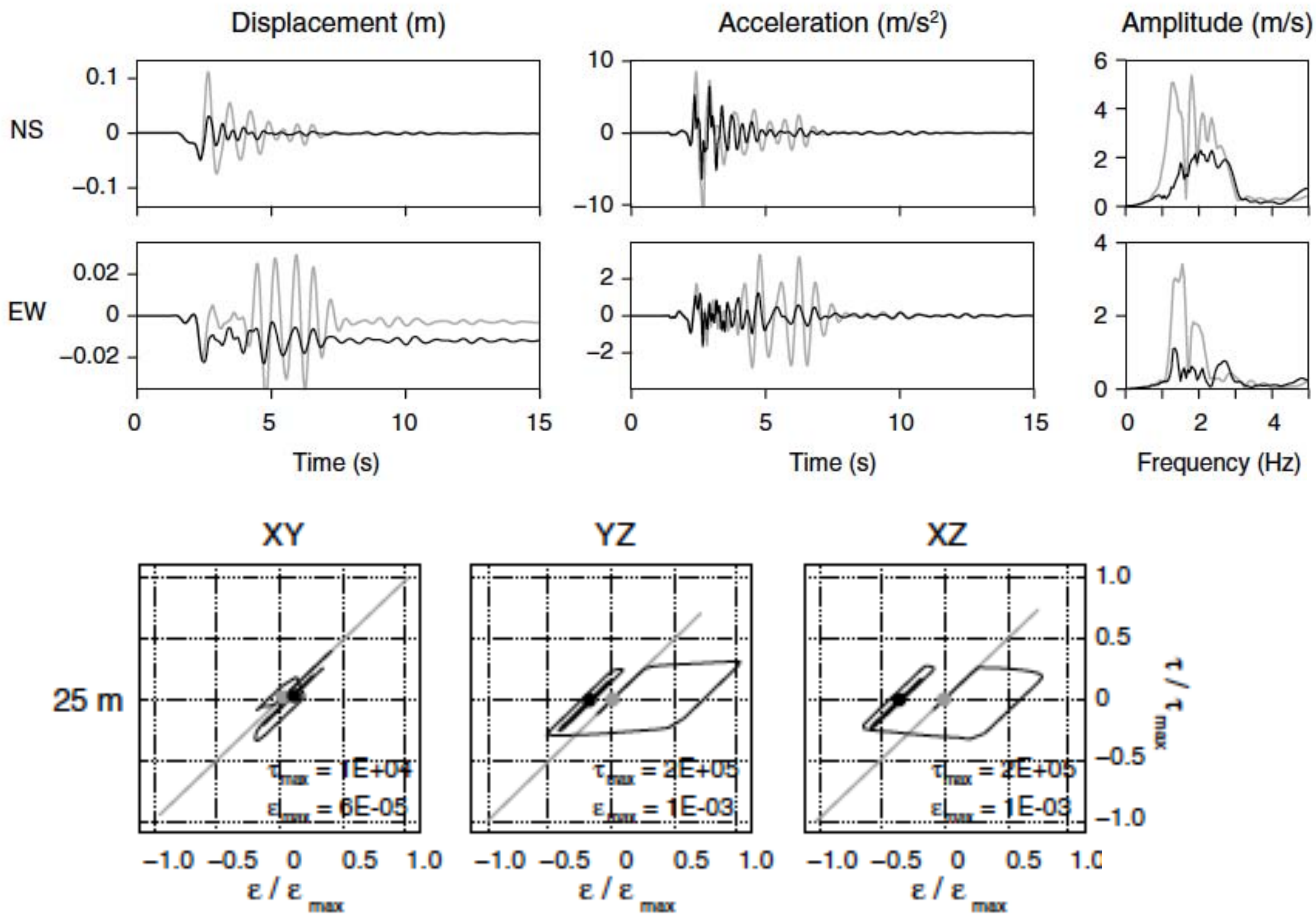
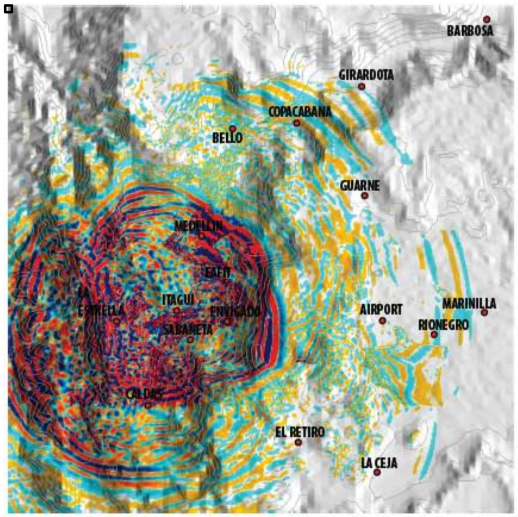


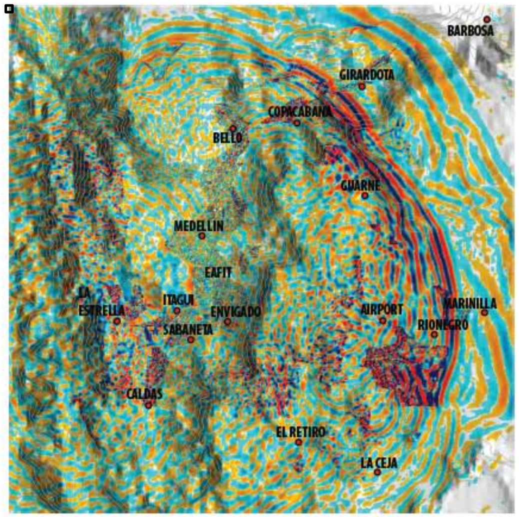
Taborda et al. (2012)

Surface Topography

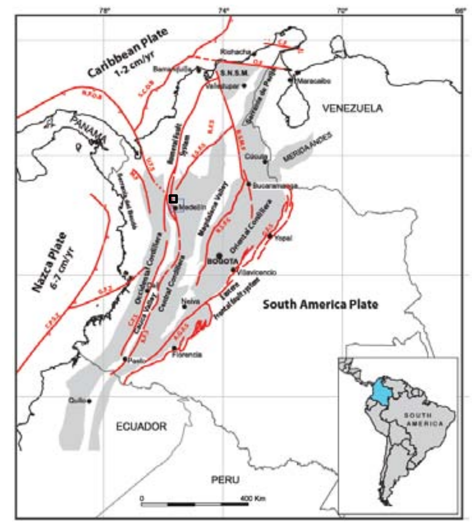
With Topography



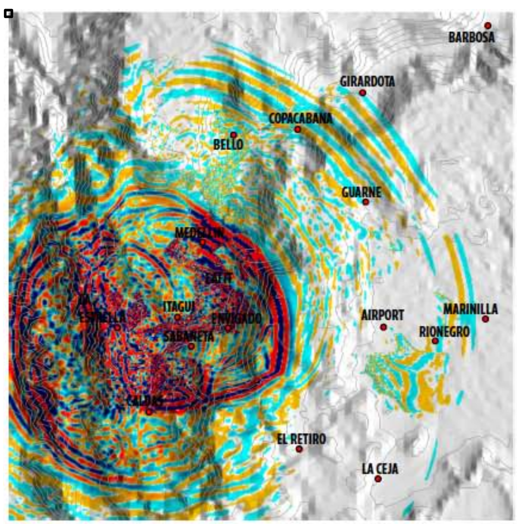
(b) IVM-AbV; 7.5s



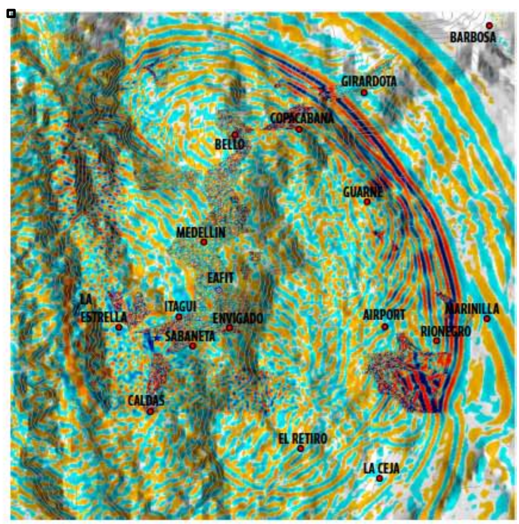
(c) IVM-AbV; 14s



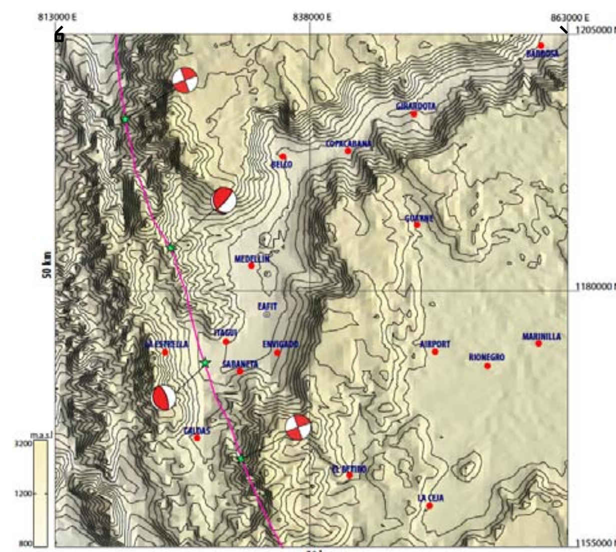
Without



(e) SQD; 7.5s



(f) SQD; 14s



Restrepo and Bielak (2014)